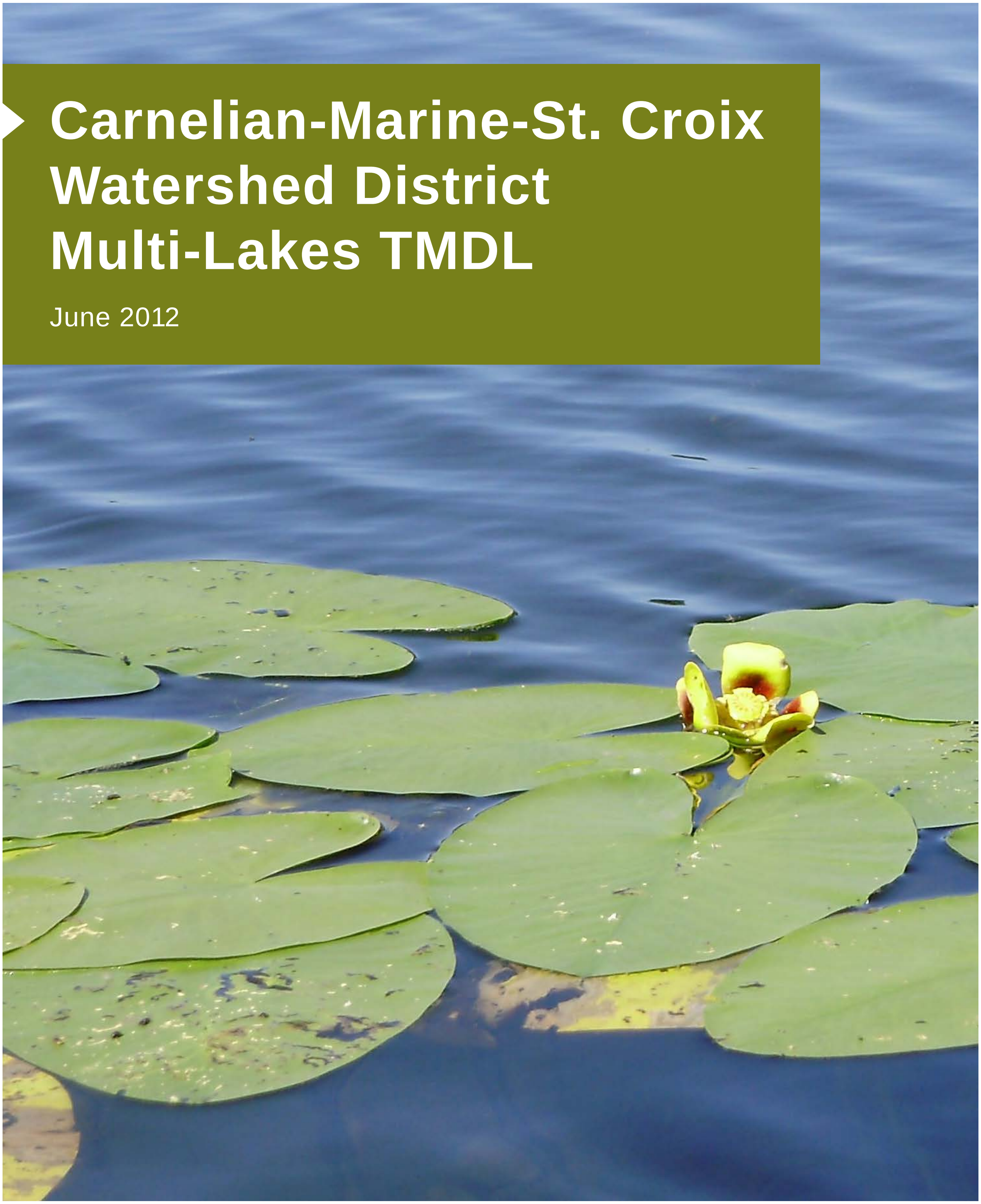
Carnelian-Marine-St. Croix Watershed District Multi-Lakes TMDL

June 2012



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CMSCWD Multi-Lakes TMDL

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Summary Table

EPA/MPCA Required Elements	Summary	TMDL Page #
Location	Carnelian-Marine Saint Croix Watershed District (CMSCWD) in the St. Croix River Basin in Washington County, MN	12

EPA/MPCA Required Elements	Summary				TMDL Page #
303(d) Listing Information	Describe the water body as it is identified on the State/Tribe's 303(d) list:				12
	Lake Name	**Lake ID**	**Year Listed**	**Target Start/Completion**	
	East Boot	82-0034-00	2004	2011/2015	
	Fish	82-0064-00	2004	2011/2015	
	Goose	82-0059-00	2002	2011/2015	
	Hay	82-0065-00	2002	2011/2015	
	Jellum's	82-0052-02	2004	2011/2015	
	Long	82-0068-00	2004	2011/2015	
	Loon	82-0015-02	2004	2011/2015	
	Louise	82-0025-00	2004	2011/2015	
	Mud (Main Lake)	82-0026-02	2010	2008/2012	
	South Twin	82-0019-00	2006	2012/2016	

EPA/MPCA Required Elements	Summary			TMDL Page #
Applicable Water Quality Standards/ Numeric Targets	Class 2B waters, MN Eutrophication Standards, MN Rule 7050.0222 Subp. 4 North Central Hardwood Forests Ecoregion			22
	Parameter	**General**	**Shallow Lakes**	
	TP (µg/l)	TP < 40	TP < 60	
	Chlorophyll-*a* (µg/l)	Chl < 14	Chl < 20	
	Secchi transparency (m)	SD > 1.4	SD > 1.0	
	Applicable Lakes	East Boot, Goose	Fish, Hay, Jellum's, Long, Loon, Louise, Mud, South Twin	

EPA/MPCA Required Elements	Lake	Loading Capacity (lb TP/day)	TMDL Page #
Loading Capacity (expressed as daily load)	East Boot	0.51	64
	Fish	0.41	81
	Goose	0.69	98
	Hay	0.28	111
	Jellum's	0.48	126
	Long	0.30	138
	Loon	0.69	155
	Louise	0.49	167
	Mud	0.42	178
	South Twin	0.26	195
	Critical condition: in summer when TP concentrations peak and clarity is typically at its worst		198

EPA/MPCA Required Elements	Source	Permit #	TMDL Lakes	WLA (lb TP/day)	TMDL Page #
Wasteload Allocation	MS4 stormwater, City of Stillwater	MNR040000	South Twin	0.0082	195
	Construction stormwater	MNR100001	all	Various	all
	Industrial stormwater	MNR50000 (no current permits)	all	Various	all

	Reserve Capacity (and related discussion)	NA	--	--	44

<table>
<tr><td rowspan="12">Load Allocation</td><td colspan="2">The load allocation is based on the following sources of phosphorus that do not require NPDES permit coverage, as applicable to each lake:
· Watershed runoff
· Loading from upstream waters
· Runoff from feedlots not requiring NPDES permit coverage
· Atmospheric deposition
· Subsurface sewage treatment systems (SSTS)
· Groundwater
· Internal loading</td><td rowspan="2"></td></tr>
<tr><td>Lake</td><td>LA (lb TP/day)</td></tr>
<tr><td>East Boot</td><td>0.46</td><td>64</td></tr>
<tr><td>Fish</td><td>0.37</td><td>81</td></tr>
<tr><td>Goose</td><td>0.62</td><td>98</td></tr>
<tr><td>Hay</td><td>0.25</td><td>111</td></tr>
<tr><td>Jellum's</td><td>0.43</td><td>126</td></tr>
<tr><td>Long</td><td>0.27</td><td>138</td></tr>
<tr><td>Loon</td><td>0.62</td><td>155</td></tr>
<tr><td>Louise</td><td>0.44</td><td>167</td></tr>
<tr><td>Mud</td><td>0.38</td><td>178</td></tr>
<tr><td>South Twin</td><td>0.23</td><td>195</td></tr>
<tr><td>Margin of Safety</td><td colspan="2">Explicit MOS: 10% of loading capacity</td><td>42</td></tr>
<tr><td>Seasonal Variation</td><td colspan="2">Seasonal variation: Critical conditions in these lakes occur in the summer, 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 Sept).</td><td>197</td></tr>
<tr><td>Reasonable Assurance</td><td colspan="2">Summarize Reasonable Assurance
Active local partners and agencies (CMSCWD, WCD)
NPDES permit compliance</td><td>222</td></tr>
<tr><td>Monitoring</td><td colspan="2">Monitoring Plan included? yes</td><td>199</td></tr>
<tr><td>Implementation</td><td colspan="2">1. Implementation Strategy included? yes
2. Cost estimate included? yes</td><td>200</td></tr>
<tr><td>Public Participation</td><td colspan="2">1. Public Comment period
2. Comments received?
3. Public meetings were held on December 9, 2008; September 22, 2009; and March 16, 2011</td><td>223</td></tr>
</table>

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AU	animal unit
BMP	best management practice
chl	chlorophyll-*a*
CMSCWD	Carnelian-Marine-Saint Croix Watershed District
CMWD	Carnelian-Marine Watershed District
MPCA	Minnesota Pollution Control Agency
MWMO	Marine Watershed Management Organization
DNR	Department of Natural Resources
LA	load allocation
MOS	margin of safety
SSTS	subsurface sewage treatment system
TMDL	total maximum daily load
TP	total phosphorus
WCD	Washington Conservation District
WLA	wasteload allocation

EXECUTIVE SUMMARY

The federal Clean Water Act requires that states identify water bodies that do not meet water quality standards and that the states develop plans to restore these impaired waters. The restoration plans include an assessment of what pollutant is causing the impairment and how much of that pollutant the water body can handle and still meet water quality standards. This assessment is known as a total maximum daily load study, or TMDL.

A common type of lake impairment affects the lake's ability to support aquatic recreation, which includes swimming, boating, and simply aesthetic enjoyment. This aquatic recreation impairment is due to excessive nutrients, most commonly phosphorus. While phosphorus is a nutrient that is needed for plant growth, excessive inputs can lead to high amounts of algae. This algae can impair recreational activities through unsightly algae blooms, which at times can include toxic forms of algae and unpleasant odors.

Ten lakes within the Carnelian-Marine-St. Croix Watershed District (CMSCWD) are on this list of impaired waters: East Boot, Fish, Goose, Hay, Jellum's, Long, Loon, Louise, Mud, and South Twin (see Table 1 for impairment listing information). This TMDL report addresses these impairments and includes an evaluation of the ecological health of each lake, an assessment of the phosphorus sources to each lake, and guidelines on how to restore the aquatic recreational use of each lake. Summaries of these lake evaluations can be found on the CMSCWD's website (http://cmscwd.org/).

The numeric goals for each lake are based on the State of Minnesota's eutrophication standards for lakes (Table 3). 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. All lakes in this study except for East Boot and Goose are shallow.

Multiple sources of information were used to evaluate the ecological health of each lake:

- In-lake water quality data, including phosphorus concentrations, chlorophyll concentrations, and Secchi transparency
- Sediment phosphorus concentrations
- Fisheries surveys
- Plant surveys
- Algae composition and relative abundance
- Zooplankton composition and relative abundance (zooplankton are tiny invertebrates that live in the water column of lakes; they feed on algae and serve as a food source for certain types of fish)

The following phosphorus sources were evaluated for each lake: watershed runoff, feedlots, subsurface sewage treatment systems (SSTS), loading from upstream lakes, atmospheric deposition, and internal loading. The phosphorus source inventory was then used to develop a lake response model for each lake, and these models were used to determine the phosphorus reductions needed for the lakes to meet water quality standards.

The following discussion presents the analyses and results on a lake-by-lake basis.

East Boot Lake

East Boot Lake is located in May Township, and the dominant land uses in the watershed are agriculture and undeveloped. The lake does not meet lake water quality standards for TP or chlorophyll-*a*, but is meeting the standard for Secchi transparency.

The following summarizes the in-lake assessment:

- Black bullhead are present in the lake, which could lead to high internal loading rates due to their habit of foraging in bottom sediments.
- Curly-leaf pondweed was abundant throughout much of the lake in June 2008. Curly-leaf pondweed dies back in June and July and releases phosphorus into the water column.
- The phytoplankton community is dominated by blue-green algae, and in the spring there is a high proportion of algal species that indicate eutrophic conditions.
- The zooplankton community is dominated by smaller species such as rotifers and copepods, with very few larger species of cladocera that are more effective at controlling algae.
- In late summer, TP and chlorophyll concentrations increase at the same time that large zooplankton decrease in abundance and less edible zooplankton increase in abundance, suggesting an effect of high planktivory on the plankton community.
- Portions of the lake stratify during the growing season and a high concentration of phosphorus builds up in the hypolimnion.

Phosphorus sources to the lake are dominated by feedlots, watershed runoff, internal loading, and atmospheric deposition. A 14% reduction in phosphorus loads to the lake is needed to restore the aquatic recreation use of East Boot Lake (Table EX - 1). To meet the TMDL, taking into account the MOS, total loading to the lake needs to be reduced by 27 lb/yr, or 14% (Table 91). Private practices in the agricultural land uses in the watershed will be the primary mechanism for reducing watershed loads; education will also play a role. Fish management and curly-leaf pondweed management are the main strategies to reduce internal loading in East Boot Lake. To improve the chances of success of in-lake management, reductions in watershed loading should first be completed. While East Boot Lake is not classified as a shallow lake according the MPCA’s definition, 50% of the lake is less than 15 feet deep, and many shallow lake management practices apply.

Table EX - 1. East Boot Lake Phosphorus Reduction Summary

Phosphorus Source	Existing Annual TP Load (lb/yr)	Implementation Scenario Annual TP Load (lb/yr)	Load Reduction Needed (lb/yr)	Reduction
Watershed	47	24	23	49%
Atmospheric Deposition	12	12	0	0%
Internal	134	130	4	3.0%
Total	**193**	**166**	**27**	**14%**

Fish Lake

Fish Lake is a landlocked shallow lake located in the City of Scandia, and the dominant land uses in the watershed are agriculture and undeveloped. The lake does not meet any of the three lake water quality standards.

The following summarizes the in-lake assessment:

- The lake is used as a walleye rearing pond by the DNR. During a 2008 harvest, the only species observed were walleye and golden shiners.
- The lake is a shallow lake with a diverse community of native macrophytes.
- There is an overall dominance of blue-green algae; at times the potentially toxic *Microcystis* dominates the phytoplankton community.
- The dominance of major groups of zooplankton cycles throughout the season. The early dominance of copepods and cladocera followed by a decrease in their numbers and an increase in smaller rotifers is indicative of planktivory and a low grazing capacity.
- The lake is hypereutrophic, with TP and chlorophyll-*a* consistently not meeting standards. The data suggest a trend in improving water clarity. Despite the trend in increasing clarity, the data suggest that the lake is still in the turbid phase often seen in shallow lakes.

Phosphorus sources to the lake are dominated by watershed runoff and internal loading. A 33% reduction in phosphorus loads to the lake is needed to restore the aquatic recreation use of Fish Lake (Table EX - 2). Private projects in the watershed will be the primary mechanism for reducing watershed loads; education will also play a role. Fish management is the main strategy to reduce internal loading in Fish Lake. To improve the chances of success of fisheries management, reductions in watershed loading should first be completed.

Table EX - 2. Fish Lake Phosphorus Reduction Summary

Phosphorus Source	Existing Annual TP Load (lb/yr)	Implementation Scenario Annual TP Load (lb/yr)	Load Reduction Needed (lb/yr)	Percent Reduction
Watershed	76	38	38	50%
Atmospheric Deposition	17	17	0	0%
Internal	113	82	31	27%
Total	**206**	**137**	**69**	**33%**

Goose Lake

Goose Lake is a landlocked lake located in the City of Scandia, and the dominant land uses in the watershed are undeveloped, agriculture, and single family residential. The lake does not meet lake water quality standards for TP or chlorophyll-*a*, but is meeting the standard for Secchi transparency.

The following summarizes the in-lake assessment:

- Goose Lake is managed by the DNR as a fishery for bluegill and northern pike; a winter aeration system is used to prevent winter kill. There is a high potential of internal loading due to benthivorous fish (black bullhead and potentially bluegill under certain conditions).
- Curly-leaf pondweed was present in the lake in June 2008. While not abundant, its presence in the lake indicates the potential for increased internal loading during curly-leaf pondweed die-back if the plant becomes more abundant.
- The algal community is dominated by blue-green algae, including both *Anabaena* and *Microcystis*, which has the potential to form the toxin microcystin. An Anabaena bloom occurred in June and a green algae (*Chlamydomonas*) bloom occurred later in the season.
- The zooplankton community is dominated by copepods in the spring, followed by dominance by a hard-shelled rotifer in the summer. Cladocera are present, although not in large numbers. This community composition suggests strong predation by planktivores, leading to low grazing potential in the lake.
- Portions of the lake stratify during the growing season and a high concentration of phosphorus builds up in the hypolimnion.

Phosphorus sources to the lake are dominated by watershed runoff, septic systems, internal loading, and atmospheric deposition. A 34% reduction in phosphorus loads to the lake is needed to restore the aquatic recreation use of Goose Lake (Table EX - 3). Private projects in the watershed (including a potential ravine stabilization) will be the primary mechanism for reducing watershed loads; public projects, new development standards, and education will also play a role. Fish and curly-leaf pondweed management are the main strategies to reduce internal loading in Goose Lake. To improve the chances of success of in-lake management, reductions in watershed loading should first be completed.

Table EX - 3. Goose Lake Phosphorus Reduction Summary

Phosphorus Source	Existing Annual TP Load (lb/yr)	Implementation Scenario Annual TP Load (lb/yr)	Load Reduction Needed (lb/yr)	Reduction
Watershed	152	77	75	50%
Atmospheric Deposition	23	23	0	0%
Internal	171	129	42	25%
Total	**346**	**229**	**117**	**34%**

Hay Lake

Hay Lake is a shallow lake located in the City of Scandia, and the dominant land uses in the watershed are undeveloped, agriculture, and single family residential. The lake does not meet lake water quality standards for TP or chlorophyll-*a*, but is meeting the standard for Secchi transparency.

The following summarizes the in-lake assessment:

- The lake is a very shallow lake (mean depth under four feet) with a diverse community of submergent and floating leaf macrophytes, with no areas of open water.
- The predominance of two algal species that are indicative of high nutrients represents a high potential for algal blooms.
- The zooplankton community is dominated by rotifers, with fewer numbers of copepods and cladocera, indicating a low grazing capacity.
- Hay Lake has high transparency but has poor chlorophyll-*a* and TP concentration, which could be indicating that blue-green algae may be problematic. (Blue-green algae contain chlorophyll, but their relatively large size does not affect transparency in the same way that smaller sized algae does.)

Phosphorus sources to the lake are dominated by watershed runoff, septic systems, internal loading, and atmospheric deposition. A 34% reduction in phosphorus loads to the lake is needed to restore the aquatic recreation use of Hay Lake (Table EX - 4). Private projects in the watershed will be the primary mechanism for reducing watershed loads; education will also play a role. Fish management is the main strategy to reduce internal loading in Hay Lake. To improve the chances of success of in-lake management, reductions in watershed loading should first be completed.

Table EX - 4. Hay Lake Phosphorus Reduction Summary

Phosphorus Source	Existing Annual TP Load (lb/yr)	Implementation Scenario Annual TP Load (lb/yr)	Load Reduction Needed (lb/yr)	Percent Reduction
Watershed	63	32	31	49%
Atmospheric Deposition	11	11	0	0%
Internal	63	48	15	24%
Total	**137**	**91**	**46**	**34%**

Jellum's Bay

Jellum's Bay is a shallow lake located in the City of Scandia and is considered to be a bay of Big Marine Lake. The dominant land uses in the watershed are undeveloped and agriculture. The lake does not meet lake water quality standards for TP or chlorophyll-*a*, but is meeting the standard for Secchi transparency.

The following summarizes the in-lake assessment:

- The lake is used as a walleye rearing pond by the DNR. During a 2008 harvest, large populations of bluegill and green sunfish were observed.
- The lake is a shallow lake with a diverse community of native macrophytes.
- The zooplankton community is dominated by rotifers, leading to a low grazing capacity by zooplankton.
- The abundant bryozoan population likely impacts the transparency of the lake through its filter-feeding action.

Phosphorus sources to the lake are dominated by watershed runoff and internal loading. A 29% reduction in phosphorus loads to the lake is needed to restore the aquatic recreation use of Jellum's Bay (Table EX - 5). Education is the main strategy for reducing watershed loads, and fish management is the main strategy to reduce internal loading in Jellum's Bay. To improve the chances of success of in-lake management, reductions in watershed loading should first be completed.

Table EX - 5. Jellum's Bay Phosphorus Reduction Summary

Phosphorus Source	Existing Annual TP Load (lb/yr)	Implementation Scenario Annual TP Load (lb/yr)	Load Reduction Needed (lb/yr)	Reduction
Watershed	81	71*	10	13%
Atmospheric Deposition	17	17	0	0%
Internal	124	69	55	44%
Total	**222**	**157**	**65**	**29%**

*If Long Lake achieves water quality standards, it would account for a 5 lb/yr TP reduction, and an additional 5 lb/yr reduction from the watershed would be desirable to help stabilize the lake in the clearwater phase.

Long Lake

Long Lake is a shallow lake located in the City of Scandia, and the dominant land uses in the watershed are undeveloped and agriculture. The lake does not meet lake water quality standards for TP or chlorophyll-*a*, but is meeting the standard for Secchi transparency.

The following summarizes the in-lake assessment:

- The lake is used as a walleye rearing pond by the DNR. During a 2008 harvest, large populations of green sunfish were observed.
- Long Lake is a shallow lake with a diverse population of macrophytes and good water transparency. The lake appears to be in the clearwater, macrophyte-dominated phase often seen in shallow lakes. This clearwater phase is advantageous for water quality.
- The phytoplankton and zooplankton communities within the lake are well-balanced.
- The lake's water quality has been improving during recent years.

Phosphorus sources to the lake are dominated by watershed runoff and internal loading. A 25% reduction in phosphorus loads to the lake is needed to restore the aquatic recreation use of Long Lake (Table EX - 6). Private projects in the watershed will be the primary mechanism for reducing watershed loads; education will also play a role. Minor in-lake practices will be necessary to meet the TMDL.

Table EX - 6. Long Lake Phosphorus Reduction Summary

Phosphorus Source	Existing Annual TP Load (lb/yr)	Implementation Scenario Annual TP Load (lb/yr)	Load Reduction Needed (lb/yr)	Percent Reduction
Watershed	52	26	26	50%
Atmospheric Deposition	11	11	0	0%
Internal	71	63	8	11%
Total	**134**	**100**	**34**	**25%**

Loon Lake

Loon Lake is a shallow lake located in Stillwater Township, and the dominant land uses in the watershed are agriculture and park, recreation, or preserve. The lake does not meet any of the three lake water quality standards.

The following summarizes the in-lake assessment:

- The most recent fisheries information from 1984, combined with anecdotal information, indicates a high population of black bullhead. The lake likely experiences winterkills.
- Loon Lake is a shallow lake with a low density and diversity of macrophytes.
- The phytoplankton community is dominated by blue-green algae.
- The patterns of cycling zooplankton suggest that planktivory by fish is driving zooplankton dynamics and therefore the grazing capacity of the lake.
- All three water quality parameters are not meeting the standards. The lake is hypereutrophic and is in the turbid, phytoplankton-dominated phase seen in poor quality shallow lakes.

Phosphorus sources to the lake are dominated by watershed runoff and internal loading. A 32% reduction in phosphorus loads to the lake is needed to restore the aquatic recreation use of Loon Lake (Table EX - 7). Education and private projects in the watershed will be the primary mechanisms for reducing watershed loads, and sediment disturbance management and fish management are the main strategies to reduce internal loading in Loon Lake. To improve the chances of success of in-lake management, reductions in watershed loading should first be completed.

Table EX - 7. Loon Lake Phosphorus Reduction Summary

Phosphorus Source	Existing Annual TP Load (lb/yr)	Implementation Scenario Annual TP Load (lb/yr)	Load Reduction Needed (lb/yr)	Reduction
Watershed	107	54	53	50%
Atmospheric Deposition	14	14	0	0%
Internal	210	156	54	26%
Total	**331**	**224**	**107**	**32%**

Lake Louise

Lake Louise is a landlocked, shallow lake located in Stillwater and May Townships, and the dominant land uses in the watershed are agriculture and undeveloped. The lake does not meet lake water quality standards for TP or chlorophyll-*a*, but is meeting the standard for Secchi transparency.

The following summarizes the in-lake assessment:

- The lake is used as a walleye rearing pond by the DNR. During a 2008 harvest, large populations of bluegill were observed. There have not been any fish surveys completed.
- Curly-leaf pondweed is abundant in the lake and likely contributes to internal phosphorus loading.
- The phytoplankton community is dominated by blue-green algae, with a high potential for algal blooms.
- The zooplankton community is dominated by cladocera, large zooplankton that have a high grazing capacity.

Phosphorus sources to the lake are dominated by watershed runoff and internal loading. A 26% reduction in phosphorus loads to the lake is needed to restore the aquatic recreation use of Lake Louise (Table EX - 8). Private projects in the watershed will be the primary mechanism for reducing watershed loads; public projects and education will also play a role. Curly-leaf pondweed management is the main strategy to reduce internal loading in Lake Louise. To improve the chances of success of in-lake management, reductions in watershed loading should first be completed.

Table EX - 8. Lake Louise Phosphorus Reduction Summary

Phosphorus Source	Existing Annual TP Load (lb/yr)	Implementation Scenario Annual TP Load (lb/yr)	Load Reduction Needed (lb/yr)	Percent Reduction
Watershed	51	26	25	49%
Atmospheric Deposition	12	12	0	0%
Internal	158	125	33	21%
Total	**221**	**163**	**58**	**26%**

Mud Lake

Mud Lake (ID 82-0026-02) is located in May Township and is a shallow lake bordered by pasture land on the west and south, and by forested areas to the northeast. The lake does not meet lake water quality standards for TP, chlorophyll-*a*, or Secchi transparency.

The following summarizes the in-lake assessment:

- The lake is used as a walleye and musky rearing pond by the DNR. The fish kill in 2001 prior to stocking may have lead to water quality improvements.
- Water quality declines throughout the growing season; internal loading likely leads to these changes.

- Phytoplankton and zooplankton data are not available.
- The Secchi transparency standard was met in 2004; the standards were not met in any other years of water quality data collection.

Phosphorus sources to the lake are dominated by watershed runoff, septic systems, and internal loading. A 17% reduction in phosphorus loads to the lake is needed to restore the aquatic recreation use of Mud Lake (Table EX - 9). Private projects in the watershed will be the primary mechanism for reducing watershed loads; education will also play a role. Vegetation enhancement and cattle exclusion are the main strategies to reduce internal loading in Mud Lake. To improve the chances of success of in-lake management, reductions in watershed loading should first be completed.

Table EX - 9. Mud Lake Phosphorus Reduction Summary

Phosphorus Source	Existing Annual TP Load (lb/yr)	Implementation Scenario Annual TP Load (lb/yr)	Load Reduction Needed (lb/yr)	Reduction
Watershed	27	14	13	48%
Atmospheric Deposition	16	16	0	0%
Internal	127	111	16	13%
Total	**170**	**141**	**29**	**17%**

South Twin Lake

South Twin Lake is a shallow lake located in the City of Stillwater, and the dominant land uses in the watershed are agriculture and undeveloped. The lake does not meet lake water quality standards for TP or chlorophyll-*a*, but is meeting the standard for Secchi transparency.

The following summarizes the in-lake assessment:

- The are no fisheries data for the lake.
- Curly-leaf pondweed is abundant in the lake and likely contributes to internal phosphorus loading.
- The phytoplankton community is dominated by blue-green algae, with a high potential for algal blooms.
- The zooplankton community is dominated by cladocera, large zooplankton that have a high grazing capacity.
- Lake water quality met all three standards in 2003 and 2004 but has worsened in recent years.

Phosphorus sources to the lake are dominated by watershed runoff, internal loading, and atmospheric deposition. A 19% reduction in phosphorus loads to the lake is needed to restore the aquatic recreation use of South Twin Lake (Table EX - 10). Public and private projects in the watershed will be the primary mechanism for reducing watershed loads; education will also play a role. Curly-leaf pondweed management is the main strategy to reduce internal loading in South Twin Lake. To improve the chances of success of in-lake management, reductions in watershed loading should first be completed.

Table EX - 10. South Twin Lake Phosphorus Reduction Summary

Phosphorus Source	Existing Annual TP Load (lb/yr)	Implementation Scenario Annual TP Load (lb/yr)	Load Reduction Needed (lb/yr)	Reduction
Watershed	22	11	11	50%
Atmospheric Deposition	15	15	0	0%
Internal	73	63	10	14%
Total	**110**	**89**	**21**	**19%**

TMDL Summary

The following table (Table EX - 11) summarizes the TMDL and the load reduction goals for all lakes.

Table EX - 11. Summary of Loading Goals

Lake	Phosphorus Source	Existing Annual TP Load (lb/yr)	Implementation Scenario Annual TP Load (lb/yr)	Percent Reduction
East Boot	Watershed	47	24	49%
	Atmospheric Deposition	12	12	0%
	Internal	134	130	3.0%
	Total	**193**	**166**	**14%**
Fish	Watershed	76	38	50%
	Atmospheric Deposition	17	17	0%
	Internal	113	82	27%
	Total	**206**	**137**	**33%**
Goose	Watershed	152	77	50%
	Atmospheric Deposition	23	23	0%
	Internal	171	129	25%
	Total	**346**	**229**	**34%**
Hay	Watershed	63	32	49%
	Atmospheric Deposition	11	11	0%
	Internal	63	48	24%
	Total	**137**	**91**	**34%**
Jellum’s	Watershed	81	71	13%
	Atmospheric Deposition	17	17	0%
	Internal	124	69	44%
	Total	**222**	**157**	**29%**
Long	Watershed	52	26	50%
	Atmospheric Deposition	11	11	0%
	Internal	71	63	11%
	Total	**134**	**100**	**25%**
Loon	Watershed	107	54	50%
	Atmospheric Deposition	14	14	0%
	Internal	210	156	26%
	Total	**331**	**224**	**32%**
Louise	Watershed	51	26	49%
	Atmospheric Deposition	12	12	0%
	Internal	158	125	21%
	Total	**221**	**163**	**26%**
Mud	Watershed	27	14	48%
	Atmospheric Deposition	16	16	0%
	Internal	127	111	13%
	Total	**170**	**141**	**17%**
South Twin	Watershed	22	11	50%
	Atmospheric Deposition	15	15	0%
	Internal	73	63	14%
	Total	**110**	**89**	**19%**

1 BACKGROUND

1.1 303(d) Listings

This TMDL addresses ten lake impairments within the Carnelian-Marine-St. Croix Watershed District (CMSCWD). The ten lakes are listed on the 2010 EPA's 303d list of impaired waters due to excess nutrients: East Boot, Fish, Goose, Hay, Jellum's, Long (in Scandia), Loon, Louise, Mud, and South Twin (Table 1). The following applies to all of the impaired lakes in this project:

Impaired Use: Aquatic recreation
Pollutant or Stressor: Nutrient/eutrophication biological indicators
Hydrologic Unit Code: 0703000

Table 1. Impaired Waters Listings

Lake Name	Lake ID	Year Listed	Target Start/Completion	CALM Category*
East Boot	82-0034-00	2004	2011/2015	5C
Fish	82-0064-00	2004	2011/2015	5C
Goose	82-0059-00	2002	2011/2015	5C
Hay	82-0065-00	2002	2011/2015	5C
Jellum's	82-0052-02	2004	2011/2015	5C
Long	82-0068-00	2004	2011/2015	5C
Loon	82-0015-02	2004	2011/2015	5C
Louise	82-0025-00	2004	2011/2015	5C
Mud (Main Lake)	82-0026-02	2010	2008/2012	5C
South Twin	82-0019-00	2006	2012/2016	5C

5C: Impaired by one pollutant and no TMDL study plan is approved by EPA

The MPCA's projected schedule for TMDL completions, as indicated on the 303(d) impaired waters list, implicitly reflects Minnesota's priority ranking of this TMDL. Ranking criteria for scheduling TMDL projects include, but are not limited to: impairment impacts on public health and aquatic life; public value of the impaired water resource; likelihood of completing the TMDL in an expedient manner, including a strong base of existing data and restorability of the waterbody; technical capability and willingness locally to assist with the TMDL; and appropriate sequencing of TMDLs within a watershed or basin.

The water quality evaluation for the lakes was completed using data from 1999 through 2008 for all lakes except for Mud Lake, and 2010 for Mud Lake. Practices implemented after 2008 (2010 for Mud Lake) will be considered to be part of the TMDL implementation activities and can be applied to load reduction goals.

1.2 Lake and Watershed Descriptions

The CMSCWD is located in northern Washington County (Figure 1). The majority of the watershed ultimately drains to the St. Croix River. The portion of the watershed that does not drain to the St. Croix River is landlocked. The overall watershed is approximately 81.4 square miles (52,100 acres) in size.

The CMSCWD is within the watershed of Lake St. Croix and Lake Pepin, which are both on the 303(d) waters list for an aquatic life use impairment due to excessive nutrients. Four of the lakes in the CMSCWD Multi-Lakes TMDL are landlocked (East Boot, Fish, Goose, and Louise), and therefore practices implemented in those watersheds will not address the Lake St. Croix or Lake Pepin TMDLs. The following lakes in this study are not landlocked, and therefore practices implemented to address these lake TMDLs will also reduce nutrients delivered to downstream water bodies, thus making progress towards meeting the Lake St. Croix and Lake Pepin nutrient loading goals: Hay (intermittent), Jellum's, Long, Loon (intermittent), Mud, and South Twin.

1.2.1 Population

Population is expected to increase throughout the Carnelian-Marine-St. Croix Watershed (Table 2).

Table 2. Current population and population forecasts for Cities and Townships in CMSCWD

County	City or Township	Population				% Change 2000 to 2030
		2000	2010	2020	2030	
Washington	Grant	4,026	4,400	4,450	4,500	12%
Washington	Hugo	6,363	19,100	29,000	40,000	529%
Washington	Marine on St. Croix	602	760	880	1,000	66%
Washington	May Township	2,928	3,200	3,600	4,000	37%
Washington	Scandia	3,692	4,370	5,000	5,400	46%
Washington	Stillwater	15,323	19,100	21,300	19,900	30%
Washington	Stillwater Township	2,553	2,690	2,940	3,350	31%

Source: Metropolitan Council 2030 Regional Development Framework Population Forecasts (January 9, 2008)

1.2.2 Related Plans and Studies

A Paleolimnological Investigation of Trophic Change in Lakes of the Carnelian-Marine Watershed District

In 2001, the Carnelian-Marine Watershed District completed a paleolimnological investigation (CMWD 2001b) of trophic changes in four lakes in the watershed: Big Carnelian Lake, Big Marine Lake, East Boot Lake, and Loon Lake. The purpose of the investigation was to establish the baseline trophic conditions existing in the lake prior to European settlement in the mid-1800s. Sediment cores of 1-2 meters in length were collected from deep areas of each lake and dated using ^{210}Pb methods. Water column total phosphorus concentrations were quantitatively reconstructed from fossil diatom assemblages using diatom-based transfer function developed from a set of 55 Minnesota lakes. The results of the investigations for East Boot Lake and Loon Lake are discussed in the Existing Studies, Monitoring and Management section for each lake.

The Influence of Ground Water on the Quality of Lakes in the Carnelian-Marine Watershed District

In 2001, the Carnelian-Marine Watershed District (CMWD 2001a) completed a study to determine the source, magnitude, and quality of groundwater inputs to lakes in the district. The study investigated three major factors to identify groundwater inputs: 1) the distribution of bedrock and glacially-derived sediments within the watershed, 2) the shape and direction of the water table, and 3) direct detection of groundwater flow in the shoreline zone. Together, these three factors were used to explain the relationship of the lakes to the groundwater system and determine the relative importance of groundwater in each lake. This investigation primarily focused on four lakes: Big Marine Lake, Big Carnelian Lake, Square Lake, and Little Carnelian Lake. More detailed lake-groundwater interaction investigations were conducted in the following report.

Integrating Groundwater and Surface Water Management – Northern Washington County

In 2003, Washington County completed a study (Washington County 2003) to determine how surface water bodies interact with groundwater in northern Washington County. Lake and groundwater interaction of forty seven lakes throughout northern Washington County was determined. Extensive hydrologic monitoring was completed as part of the study. Data collected and analyzed included lake and groundwater levels, precipitation, stream flow, surface and groundwater chemistry, surficial geology, direct groundwater measurements, and an inventory of natural resources. The groundwater function, defined as the character of interaction between the lake and the surrounding groundwater, was determined for the lakes. Quaternary water table mapping developed in the study depicts a water table sloping to the east discharging on a regional scale to the St. Croix River. Results from this study were used to determine the role of groundwater as a phosphorus source to the impaired lakes in this TMDL study.

Lower St. Croix River Spring Creek Stewardship Plan.

The Lower St. Croix River Spring Creek Stewardship Plan (MWMO 2003) was completed in 2003. The primary reasons for undertaking this project were to describe and evaluate spring creeks and associated groundwater-dependent resources, and, based on this increased understanding of these unique resources, to define stewardship strategies towards their long-term protection. The Stewardship Plan is a companion to *Integrating Groundwater and Surface Water Management in Northern Washington County* (Washington County 2003), which evaluated groundwater-surface water interaction and prescribed management recommendations for groundwater resources. The Stewardship Plan assessed twenty of the major creeks that flow into the St. Croix River from the northern boundary of the City of Stillwater to the northern boundary of Washington County along the Minnesota side of the river. Each of the twenty streams was evaluated seasonally for two years. Parameters assessed include hydrology, geomorphology, water quality and chemistry, macroinvertebrates, fisheries, and riparian plant communities. Groundwater discharge areas supporting groundwater dependent plant communities were identified, evaluated and mapped. Using this data, streams were classified into one of four Stream Comparison Domains:

1. Surface water-fed streams
2. Groundwater-fed streams with large watersheds
3. Groundwater-fed streams with small watersheds
4. Groundwater-fed streams, urban land uses

Results of two years of monitoring and data collection show that the spring creeks and associated groundwater-dependent natural resources are among the most diverse and unique ecosystems in the Twin Cities region. Over half the streams evaluated contain self-sustaining populations of brook trout and several contain new or undocumented (for Minnesota) taxa of macroinvertebrates.

Carnelian-Marine-St. Croix Watershed District 2010 Watershed Management Plan

The CMSCWD 2010 Watershed Management Plan (CMSCWD 2010) was developed to guide management of the District's water resources through the year 2020. The document includes assessment of the lakes, streams, and wetlands of the District and an implementation program based on objectives, policies, and resource management plans. Individual resource management plans for lakes and streams are included as well as a wetland management plan. Water resources identified in the implementation plan for undergoing management or study are based on a prioritization system that extends through the 10-year period of the plan. Each of the impaired lakes are undergoing *Impaired Watershed Management* per the implementation plan. This TMDL study will inform the extent of management activities necessary.

1.2.3 Topography and Land Use

The CMSCWD landscape is characterized generally from west to east by hilly topography associated with the St. Croix Moraine and till deposits, a large outwash plain with very sandy soils, and bluffs and terraces associated with the historic St. Croix River. Due to the rolling nature of the topography, there are numerous landlocked depressions. The CMSCWD impaired lake watersheds are shown in Figure 2. Figure 3 and Figure 4 illustrate the 2005 and projected 2030 generalized land use, respectively. The land use in each individual impaired lake watershed is presented in the individual lake TMDL report sections.

Figure 1. Carnelian-Marine-St. Croix Watershed District Location Map

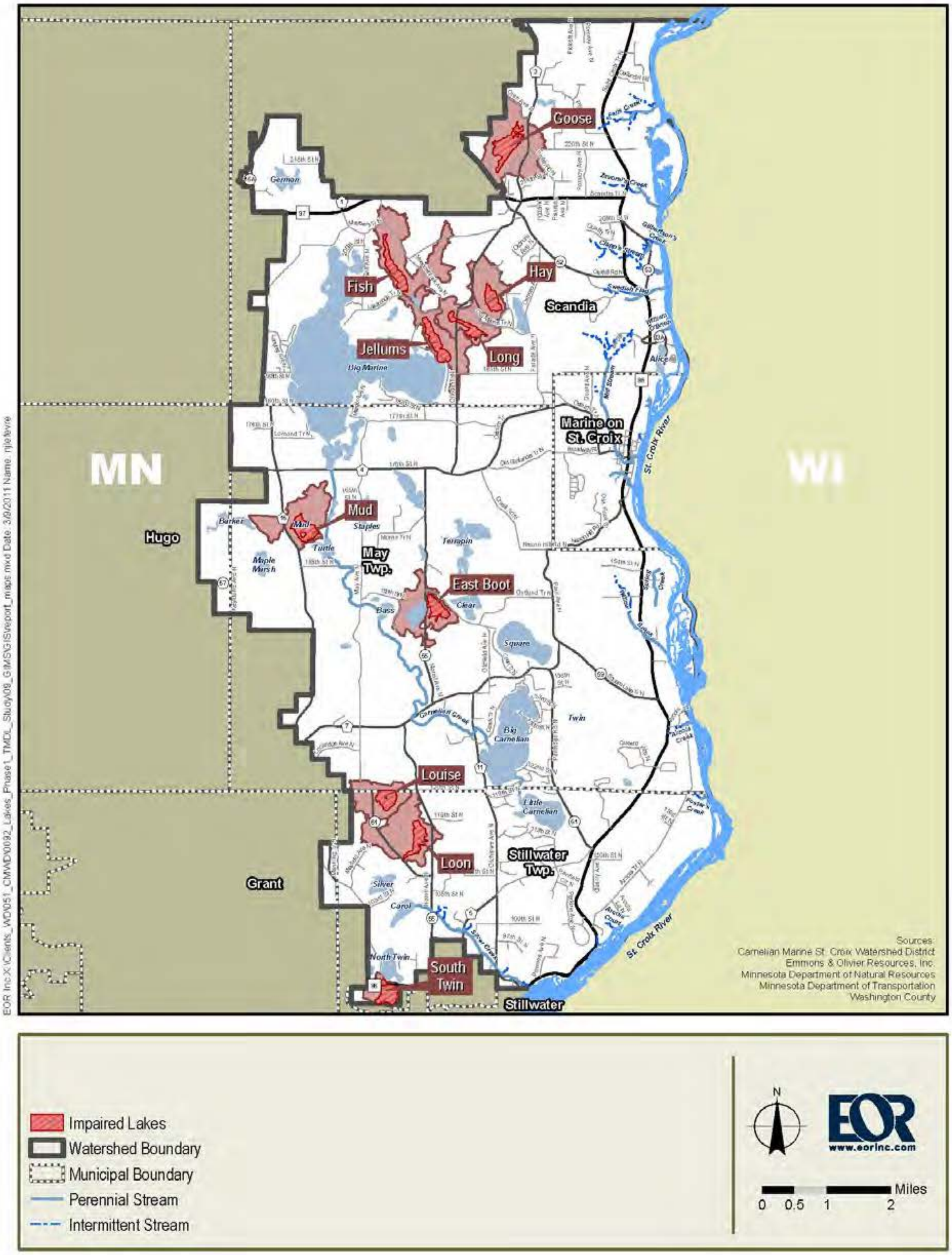

Figure 2. Impaired Lakes Watershed Boundaries

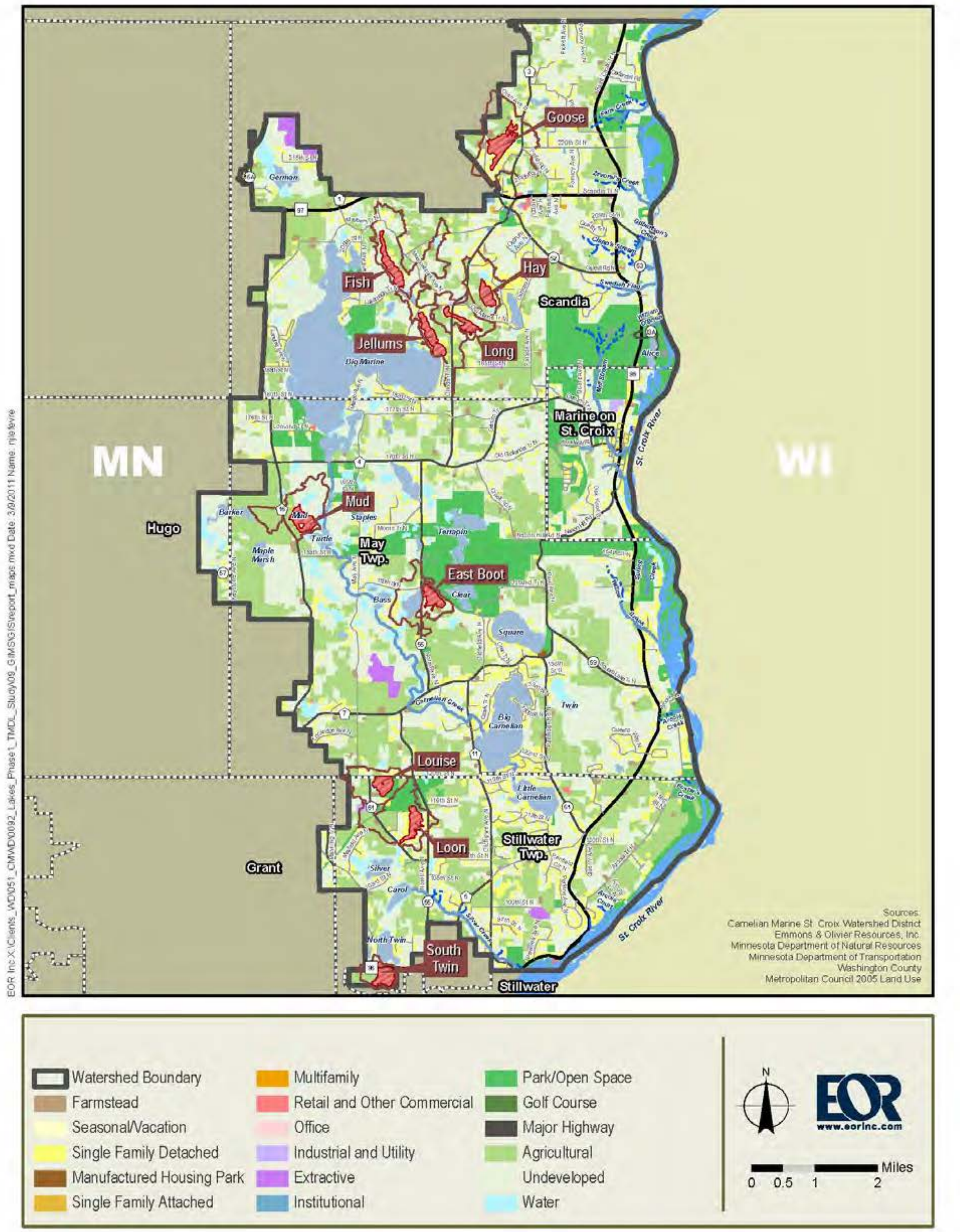

Figure 3. 2005 Land Use
(2005 Generalized Land Use for the Twin Cities Metropolitan Area, Metropolitan Council)

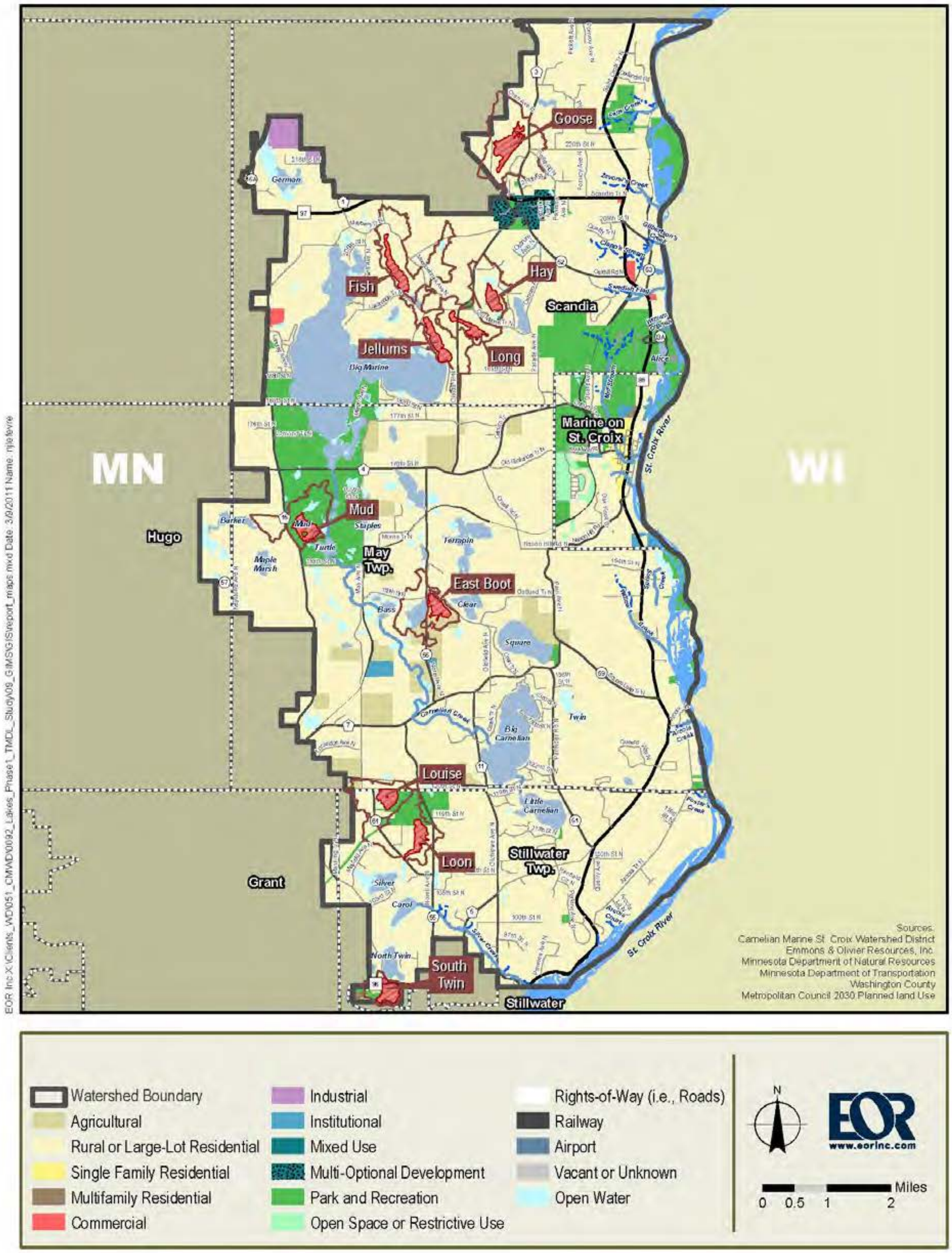

Figure 4. 2030 Land Use
(Planned Regional Land Use for the Twin Cities Metropolitan Area, Metropolitan Council)

2 WATER QUALITY STANDARDS

2.1 Designated Uses

The listed lakes are all classified as Class 2B, 3C, 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 that support or may support fish, other aquatic life, bathing, boating, or other recreational purposes and for which quality control is or may be necessary to protect aquatic or terrestrial life or their habitats or the public health, safety, or welfare.

2.2 Pollutant of Concern

2.2.1 Phosphorus

Total phosphorus is often the limiting factor controlling primary production in freshwater lakes. It is the nutrient of focus for this TMDL, and is 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-*a* 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.

2.2.2 Role of Phosphorus in Shallow Lakes

Eight of the ten lakes in this study are classified by the MPCA as shallow lakes. 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.

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 5): 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. Since lakes in the clear state typically have lower phosphorus concentrations, there is a reduced phosphorus load to downstream water resources.

Nutrient reduction in a shallow lake does not lead to a linear improvement in water quality (indicated by turbidity in Figure 5). 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 5 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.

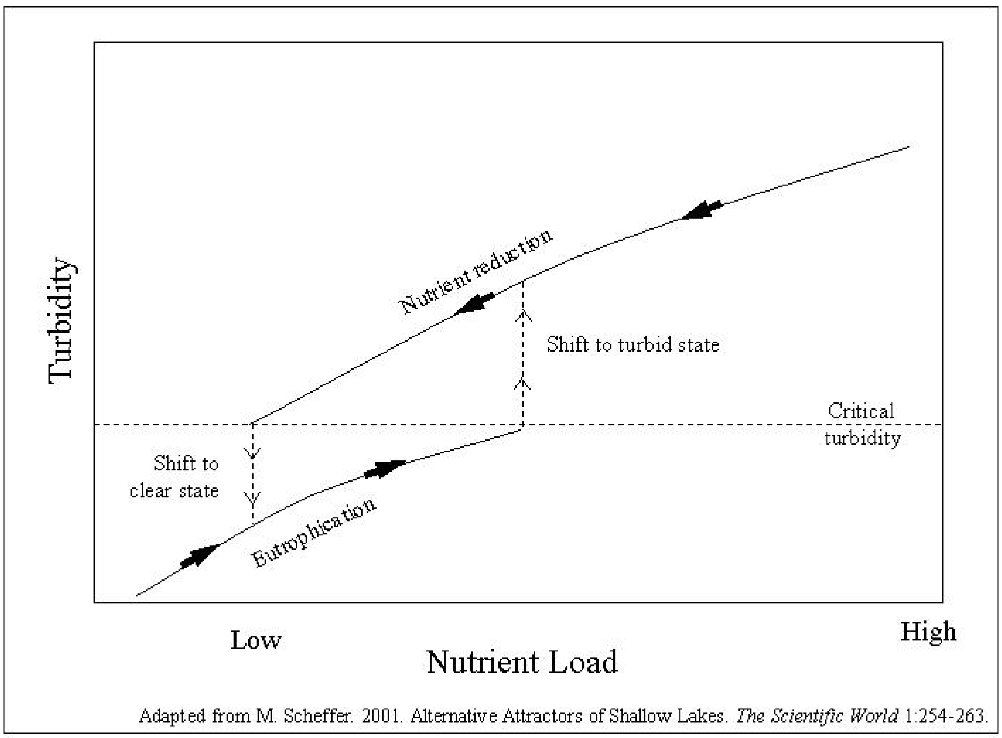

Figure 5. Alternative Stable States in Shallow Lakes.

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, water skiing, 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.

2.3 Water Quality Standards

Water quality standards are established to protect the designated uses of the state's waters. Minnesota's Rule 7050 includes eutrophication standards for lakes (Table 3). Eutrophication standards were developed for lakes and reservoirs, and for shallow lakes in particular. Standards provide for higher phosphorus concentrations, higher chlorophyll concentrations, and poorer transparency in shallow lakes, due to higher rates of internal loading in shallow lakes and different ecological characteristics.

In developing the lake nutrient standards for Minnesota lakes (Minn. Rule 7050), the MPCA evaluated data from a large cross-section of lakes within each of the state's ecoregions (Heiskary and Wilson 2005). Clear relationships were established between the causal factor total phosphorus and the response variables chlorophyll-*a* and Secchi transparency. Based on these relationships it is expected that by meeting the phosphorus target in each lake, the chlorophyll-*a* and Secchi standards will likewise be met.

Standards are applied based on the ecoregion in which the lake is located; all of the lakes in this study are within the North Central Hardwood Forest ecoregion.

Table 3. MN Eutrophication Standards

Parameter	North Central Hardwood Forest Ecoregion	
	Eutrophication Standard, Lakes and Reservoirs	**Eutrophication Standard, Shallow Lakes**
TP (µg/l)	TP < 40	TP < 60
Chlorophyll-*a* (µg/l)	chl < 14	chl < 20
Secchi transparency (m)	SD > 1.4	SD > 1.0
Lakes to which standards apply	East Boot, Goose	Fish, Hay, Jellum's, Long, Loon, Louise, Mud, South Twin

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 feet) covers at least

80% of the lake's surface area. Fish, Hay, Jellum's, Long, Loon, Louise, Mud, and South Twin Lakes are shallow according to this definition.

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 transparency (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 it 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 Determination of Impairment* (MPCA 2009).

2.4 TMDL Numeric Goals

The numeric water quality goal for this TMDL is the average growing season total phosphorus concentration in the lakes. The state standard is 40 µg/L for lakes and 60 µg/L for shallow lakes.

3 METHODS

3.1 Phosphorus Source Assessment

A phosphorus source assessment was conducted for each of the lakes included in this study. Sources of phosphorus can be either external or internal. Examples of external sources include watershed runoff, point sources, and atmospheric deposition. Internal sources of phosphorus can be released from sediments or can be a result of biological processes in the lake. Sediment phosphorus can be a result of phosphorus within the lake sediments that is either released due to anoxic conditions or due to suspension caused by wind mixing or benthic fish. The presence of curly-leaf pondweed can also contribute to internal sources of phosphorus.

This section provides a description of the potential sources of phosphorus to each of the lakes in the TMDL study area. In 2004, the MPCA conducted a study on the phosphorus sources contributing to the ten major basins within Minnesota. The final report, *Detailed Assessment of Phosphorus Sources to Minnesota Watersheds* (MPCA 2004), identified both point and non-point sources and quantified the loading for each of the basins. For this report, an inventory was done on all of the potential individual phosphorus sources within the TMDL area, and total phosphorus (TP) loads were quantified based heavily on the methods and guidance within the 2004 MPCA report. Ultimately, a phosphorus budget was developed for each of the TMDL lakes in this study.

Results of the watershed phosphorus budget are reported as a GIS shapefile to make possible the future use of the data for implementation planning. The GIS shapefile *PhosLoad_2011LakesTMDL.shp* identifies phosphorus loading to each lake throughout its direct watershed (the area excluding upstream lakes and their watersheds); it includes direct watershed runoff based on land cover and land use and runoff from feedlots (see *Direct Watershed Runoff* and *Runoff from Feedlots Not Requiring NPDES Permit Coverage*, respectively, in *Section 3.1.2 Sources of Phosphorus Not Requiring NPDES Permit Coverage*, which begins on page 27). Phosphorus loads from feedlots as reported in this TMDL study were distributed evenly across the feedlot area; feedlot areas were identified using 2009 aerial photography. See *Section 17.1 Approach to Determining Watershed Management Strategies* for more guidance on using the tool during implementation planning.

3.1.1 Sources of Phosphorus Requiring NPDES Permit Coverage

The regulated sources of phosphorus within the study area are point sources, those originating from a single, identifiable source in the watershed. Point sources are regulated through the National Pollutant Discharge Elimination System (NPDES) and State Disposal System (SDS) permits. Point sources include the following:

- Municipal and industrial wastewater treatment systems
- Regulated stormwater
- Feedlots requiring NPDES permit coverage

Municipal and Industrial Wastewater Treatment Systems

For any discharge of municipal or industrial wastewater to a surface water, ground surface or subsurface, an NPDES/SDS permit is required and administered by the MPCA. There are no NPDES permitted facilities within the TMDL lakes' watersheds.

Regulated Stormwater

Watershed runoff is generated during precipitation events. Certain types of watershed runoff are permitted under the National Pollutant Discharge Elimination System (NPDES)/State Disposal System (SDS) program including regulated Municipal Separate Storm Sewers (MS4), construction stormwater, and industrial stormwater. While there is some regulated watershed runoff in the watersheds, the majority of watershed runoff in the project area is not regulated through NPDES permits.

Phosphorus loads from direct watershed runoff were estimated using the Simple Method; this approach is described in *Section 3.1.2: Sources of Phosphorus Not Requiring NPDES Permit Coverage, Direct Watershed Runoff*.

The following is a description of the types of regulated watershed runoff in the project area.

MS4

The boundaries of one regulated MS4 (City of Stillwater) and one MS4 that will likely be regulated in the near future (City of Scandia) overlap with the watersheds draining to the CMSCWD impaired waters (Table 4).

MS4s are defined by the Minnesota Pollution Control Agency (MPCA) as conveyance systems owned or operated by an entity such as a state, city, town, county, district, or other public body having jurisdiction over disposal of stormwater or other wastes. A conveyance system includes ditches, roads, storm sewers, stormwater ponds, etc. Certain MS4 discharges are regulated by NPDES/SDS permits administered by the MPCA.

MS4s outside of urbanized areas with a population of at least 5,000 and discharging or having the potential to discharge to impaired waters are required to obtain an NPDES stormwater permit. The City of Stillwater is a regulated MS4 community that falls into this category. The MPCA designates communities as regulated MS4s as populations hit the threshold of 5,000 and updated information is available from the U.S. Census Bureau. The City of Scandia is projected to have a population of at least 5,000 by the year 2030 (Metropolitan Council 2030 Regional Development Framework - Revised Forecasts as of December 31, 2009). All existing and future regulated MS4s are provided an individual WLA. Future point sources may be included in a WLA. 40 C.F.R. § 130.2(h) states that a WLA is "the portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution."

Within the Cities of Stillwater and Scandia, 2030 land use data (Regional Planned Land Use for the Twin Cities Metropolitan Area, Metropolitan Council) were used to approximate the areas that are (or will be) regulated by the MS4 permit. Regulated land uses are considered to be those having stormwater conveyances owned by the MS4. Only those land uses that are regulated under the MS4 permit were considered to be part of regulated watershed runoff:

- Land uses used to approximate areas regulated under the MS4 permit: single family residential, multi-family residential, and community park and recreation.
- Land uses used to approximate areas not regulated under the MS4 permit: rural and low density residential. All residential densities at or lower than 1 unit per 2.5 acres were considered as low density and not regulated under the MS4 permit.

The only lake watershed that contains areas within either Stillwater or Scandia, and also contains land uses that are or will be regulated by an MS4 permit is South Twin Lake, which contains portions of the City of Stillwater that are regulated by the MS4 permit. The remaining portions of those cities that are located within the TMDL watersheds are not regulated by the MS4 permit. Therefore the City of Stillwater is the only municipality that will receive a WLA for regulated MS4 runoff (see Section 3.3.2).

Table 4. Municipal Separate Storm Sewers (MS4)

Permittee	NPDES Permit Number	MS4 Preferred ID	Lake
City of Stillwater	MNR040000	MS400259	South Twin

Construction
Construction sites can contribute substantial amounts of sediment and phosphorus to watershed runoff. The NPDES/SDS Construction Stormwater Permit administered by the MPCA 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 pollution 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.

Industrial
The NPDES/SDS Industrial Stormwater Multi-Sector General Permit re-issued in April 2010 applies to facilities with Standard Industrial Classification Codes in 29 categories of industrial activity with the potential for significant materials and activities to be 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 permit identifies a phosphorus benchmark monitoring value for facilities within certain sectors that are known to be phosphorus sources.

There are no facilities with an industrial stormwater permit in any of the lakes' watersheds.

Feedlots Requiring NPDES Permit Coverage

Animal waste containing phosphorus can be transported in watershed runoff to surface waters. The primary goal of the state feedlot program is to ensure that surface waters are not contaminated by the runoff from feedlots, manure storage or stockpiles, and cropland with improperly applied manure. Feedlots that either (a) have a capacity of 1,000 animal units or more, or (b) meet or exceed the EPA's Concentrated Animal Feeding Operation (CAFO) threshold, are required to apply for coverage under an NPDES/SDS permit for livestock production from the MPCA. The permit requires that the feedlots have zero discharge to surface water and therefore should not be a contributing phosphorus source. There are no feedlots requiring NPDES permit coverage within the study area.

3.1.2 Sources of Phosphorus Not Requiring NPDES Permit Coverage

The following are the sources of phosphorus not requiring NPDES permit coverage that were evaluated:

- Direct Watershed runoff
- Loading from upstream waters
- Runoff from feedlots not requiring NPDES permit coverage
- Atmospheric deposition
- Subsurface sewage treatment systems (SSTS)
- Groundwater
- Internal loading

<u>Direct Watershed Runoff</u>

The Simple Method (Schueler 1987) was used to calculate direct watershed runoff and associated TP loads. The Simple Method uses an equation that relates watershed pollutant load to watershed drainage area, rainfall depth, percent impervious cover, and event mean runoff pollutant concentration (EMC) based on land use and land cover. A lake loading analysis evaluated watershed runoff and associated TP loads from upstream waters (see *Loading from Upstream Waters*).

Watershed Drainage Area

Impaired watershed areas were derived based on two-foot contour data completed by the CMSCWD in 2008, satellite imagery, a detailed stormsewer structure inventory, and anecdotal information available from the CMSCWD. Many of the watershed boundaries were field verified. The Simple Method calculates annual runoff as a product of annual runoff volume and a runoff coefficient (based on impervious surface). All subwatershed areas characterized in the Simple Method model contribute to the downstream water body based upon the effects of land cover and impervious surfaces on the transformation of rainfall to runoff. The model does not account for the topography of the watershed. Therefore, subwatersheds that are physically landlocked during average annual precipitation would (under typical land cover and impervious surface conditions) contribute phosphorus to the downstream water body if modeled using the Simple Method. This scenario would result in an overestimate of phosphorus loading. Due to the rolling, landlocked nature of the landscape in the CMSCWD, pollutant loading would be grossly overestimated using this approach. Therefore, the impaired lake watersheds are defined by those areas that contribute to the downstream water body under conditions of average annual precipitation. Of the areas that only contribute runoff under above-average precipitation conditions (which were not incorporated into the watershed loading estimates), none of them are regulated through an NPDES (including MS4) permit.

In determining the watershed drainage area of Mud Lake, a more in depth investigation was undertaken in order to evaluate the hydrologic connectivity between Big Marine Lake, Mud Lake and Turtle Lake. The Big Marine Lake, Mud Lake, and Turtle Lake drainages are connected through a wetland complex north of Mud Lake. Big Marine Lake discharges south to the wetland complex between the three lakes. The primary flow path for the Big Marine Lake outflow is toward Turtle Lake where drainage continues southward through Carnelian Creek. An operable weir at the Turtle Lake outlet and a fixed weir at the Big Marine Lake outlet control the flow through the system. The Turtle Lake weir is operated by the Carnelian Marine-St. Croix Watershed District under a permit from the Minnesota Department of Natural Resources. When water is flowing over Big Marine Lake outlet weir, the Turtle Lake weir is lowered to ease the passage of flows downstream. When there is no outflow from Big Marine Lake, the Turtle Lake weir is raised to maintain water levels in the Turtle Lake system.

Mud Lake interacts with this system through the wetland complex connecting Big Marine Lake and Turtle Lake. Levies constructed as part of District's Outlet to the St. Croix River (completed in 1985) eliminated a direct connection to the south between Mud Lake and Turtle Lake. Mud Lake discharges to the north, through wetlands and into the wetland complex connecting Big Marine Lake and Turtle Lake (which includes the CMSCWD outlet channel). Flow from Big Marine Lake and Turtle Lake would only be expected to enter Mud Lake under reverse flow conditions, if floodwaters were to back up through the wetland complex and into Mud Lake. Therefore, Mud Lake watershed was defined as having no loading from either Big Marine or Turtle Lakes.

Climate

A gridded surface was developed in a Geographic Information System (GIS) based on the MN Hydrology Guide (SCS 1992) to determine the annual precipitation and evaporation by watershed.

Watershed Runoff Volume

The annual depth of runoff for the analysis was initially evaluated using similar methodology as the annual precipitation method. The MN Hydrology Guide indicated average annual runoff depths ranging from six to eight inches.

As part of the calibration process, monitored flow data from Carnelian Creek were provided from two average runoff years (as determined by Washington Conservation District staff): 2002 and 2004. Using FLUX to separate baseflow from storm flow, the average runoff depth over the 1,200+ acre drainage area was calculated to be 3.94 inches. Because the monitored data are expected to be more accurate than a statewide compilation of data, the 3.94 inches of runoff was used for the Simple Method calculation.

Land Use, Land Cover and EMCs

Land cover data were obtained from the 2008 Minnesota Land Cover Classification System (MLCCS). For land cover categories that have associated impervious area (MLCCS series below

20,000), the land cover data were combined (intersected in a spatial database) with the 2005 land use data (2005 Generalized Land Use for the Twin Cities Metropolitan Area, Metropolitan Council). For land cover categories that do not have associated impervious areas (MLCCS series at or above 20,000) and are therefore all natural communities, land use data were not combined with the land cover data. Land use and land cover may have changed in the watershed since the data that the models are based on were collected. To maintain consistency with the data sources, these recent changes were not incorporated into the models.

The resulting database provided the basis for assigning Simple Method parameters. Each land cover/land use category was assigned an event mean concentration (EMC), which serves to estimate the phosphorus concentration in watershed runoff. For impervious areas (MLCCS series below 20,000), EMCs were based on land use. For pervious areas (MLCCS series at or above 20,000), EMCs were based on land cover. The EMCs were generated based on values in the literature and other similar studies (MCWD Lakes TMDL, Pope County 8 Lakes TMDL).

The EMCs ranged from 0.01 mg/L for certain wetlands and all open water surfaces to 0.46 mg/L for residential and farmstead land uses (Table 5). EMCs for different land uses inherently include management practices that occur in the land use. In other words, land use practices and/or BMPs implemented within the study areas of the referenced literature are assumed to be comparable to those within the TMDL study area. For example, the EMC for cultivated crops includes some average amount of runoff from fertilizers and manure applied within the area defined by the land use. It is assumed that runoff from feedlots is not accounted for in the direct watershed runoff numbers.

Table 5. TP Event Mean Concentration (EMC) Values by Land Cover and Land Use

Land Cover (applied to pervious surfaces)	Phosphorus (mg/L)
Cropland	0.32
Exposed Earth	0.46
Forest/Shrub/Grassland	0.04
Open Water	0.01
Wetlands	0.01-0.04*
Land Use (applied to impervious surfaces)**	**Phosphorus (mg/L)**
Commercial	0.28
Farmsteads	0.46
Industrial	0.28
Institutional	0.28
Multi-Family Residential	0.32
Park and Recreation	0.40
Single Family Residential	0.46
Vacant/Agricultural	0.32

*Vary based on wetland type.
**Land use categories are from 2005 Generalized Land Use database. These land use EMCs only apply to areas identified by land cover (MLCCS) data as containing impervious surfaces.

Each land cover/land use combination is also assigned an estimated impervious percentage, which is used to estimate runoff depth from a precipitation event. The impervious percentages assigned to the land cover/land use combination are based on the NRCS (Natural Resources Conservation Service) curve number methodology using GIS-based NRCS curve numbers. The impervious values were adjusted such that the runoff depth from the one-year storm using the NRCS method generated the same volume of runoff using the Simple Method runoff calculation.

Direct Watershed Runoff under Future (2030) Conditions
An additional analysis was conducted to identify phosphorus loading under future conditions. Future loading from direct watershed runoff was estimated using the same method as for existing watershed runoff (see *Direct Watershed Runoff* for further discussion), but 2030 land use data (Regional Planned Land Use for the Twin Cities Metropolitan Area, Metropolitan Council) were used in place of 2005 land use data. Metropolitan Council categorizes land use differently in the 2005 and the 2030 databases. This can result in slightly different modeled phosphorus loading, even though land use does not actually change.

<u>Loading from Upstream Waters</u>

Lakes and streams upstream of impaired waters were evaluated in each watershed to determine if there were sufficient data to determine a TP load from that resource. Upstream lakes only occurred in the East Boot Lake (West Boot Lake as the upstream lake) and Jellum's Bay (Long Lake as the upstream lake) watersheds. Annual average TP loads were calculated for the West Boot Lake and Long Lake watersheds, which were determined from in-lake phosphorus concentration data and average annual runoff values. The average annual runoff values were derived using the same gridded surface discussed under *Direct Watershed Runoff*. The watershed area being modeled using the Simple Method, described above, was then modified to eliminate the upstream lake and that lake's watershed area. Table 6 summarizes the upstream lake loading calculations.

Table 6. Summary of phosphorus loading from upstream waters

Receiving Water	Upstream Lake	Averaging Period	TP (µg/L)	Runoff Depth (in/yr)	Drainage Area (acres)*	Runoff Volume (AF/yr)	TP Load (lb/yr)
East Boot Lake	West Boot Lake	2000-2007	20	3.94	229	75.2	4.1
Jellum's Bay	Long Lake	2000-2008	81	3.94	259	84.9	19

*Calculations are from lake outlet; includes lake area and drainage area

Runoff from Feedlots Not Requiring NPDES Permit Coverage

Runoff during precipitation and snow melt can carry phosphorus from uncovered feedlots to nearby surface waters. For the purpose of this study, non-permitted feedlots are defined as being all registered feedlots without an NPDES/SDS permit that house under 1,000 animal units. While these feedlots do not fall under NPDES regulation, other regulations still apply. There are two non-permitted feedlots within the study area (Figure 6); one is located within the Fish Lake subwatershed and the other is located within the East Boot Lake subwatershed.

The protocol outlined in Appendix D of the Detailed Assessment of Phosphorus Sources to Minnesota Watersheds (MPCA 2004) for calculating the TP loading to surface waters from open lot non-permitted feedlots was evaluated and refined for this study area. Using feedlot data provided by the MPCA, the total number of animal units of dairy cattle and goats were estimated for all non-permitted feedlots with open lots in each of the lake's watersheds. The number of animal units was multiplied by the annual manure phosphorus generated by each type of livestock to calculate the TP generated by livestock in all open lot non-permitted feedlots (MWPS 2004).

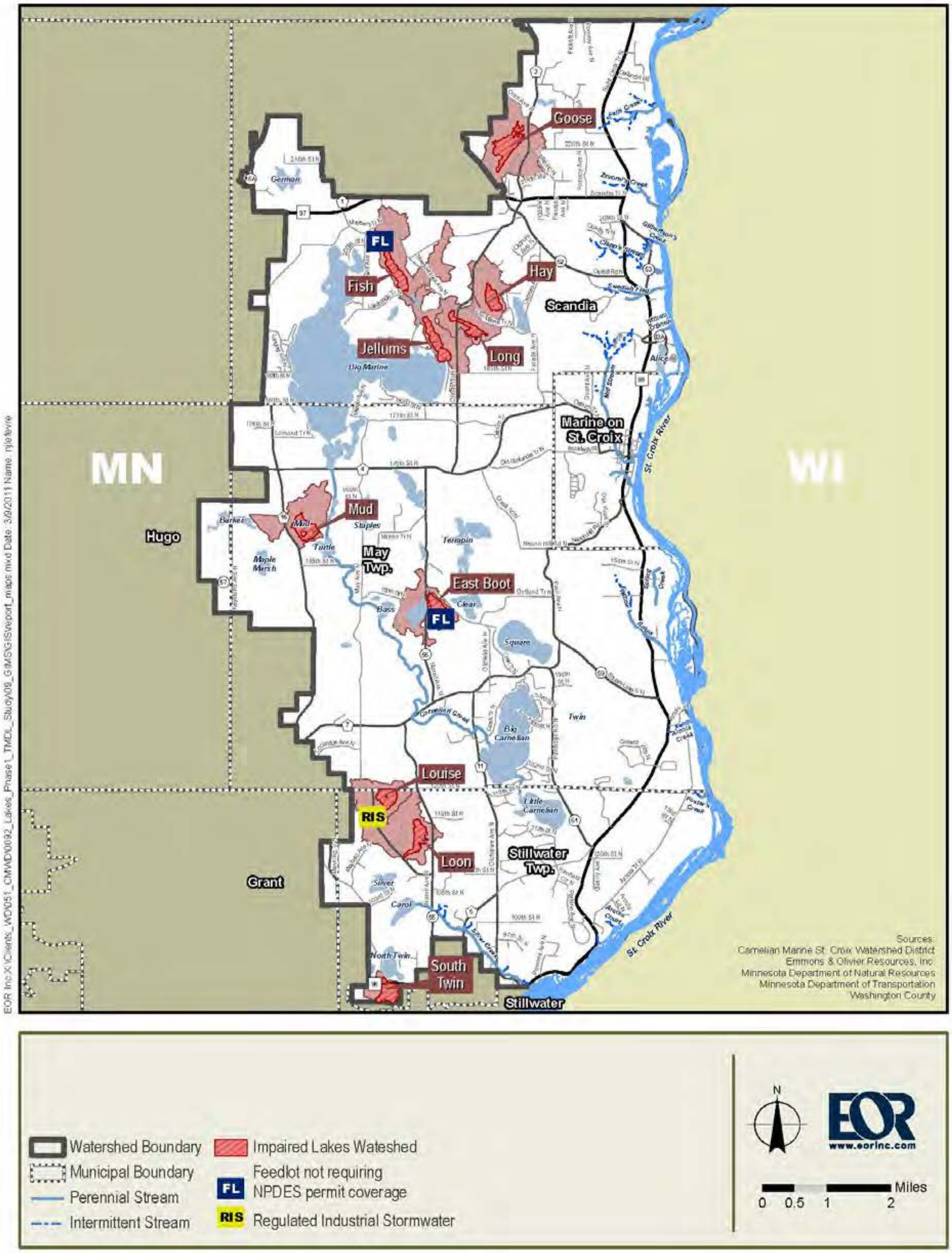

Figure 6. Feedlots and Regulated Industrial Stormwater Sites

Atmospheric Deposition

Atmospheric deposition represents the phosphorus that is bound to particulates in the atmosphere and is deposited directly onto surface waters as the particulates settle out of the atmosphere. Average phosphorus atmospheric deposition loading rates were calculated for the St. Croix River Basin (MPCA 2004). The report determined that atmospheric deposition equaled 0.27 lb/ac of TP per year. This rate was applied to each lake's surface area to determine the total pounds per year of atmospheric phosphorus deposition to each of the TMDL lakes.

Subsurface Sewage Treatment Systems

Phosphorus loads attributed to subsurface sewage treatment systems (SSTS) adjacent to each of the lakes were calculated using data provided by Washington County and the MPCA's Detailed Assessment of Phosphorus Sources to Minnesota Watersheds (MPCA 2004). Total loading is based upon the number of houses within 500 feet of the lake, if the SSTS system is conforming or failing, the number of people using the system, and an average value for phosphorus production per person per year.

Washington County provided data on installed septic systems in the lake's watersheds. Conforming versus failing systems were calculated based upon an estimate that 11.4% of SSTS are failing within the St. Croix River Basin (MPCA 2004). The Washington County capita per residence value is derived from the 2000 Census. Values for phosphorus production per capita per year and the percentage of phosphorus passing through the SSTS for both conforming and non-conforming systems are derived from the MPCA's Detailed Assessment of Phosphorus Sources to Minnesota Watersheds (MPCA 2004).

Groundwater

Phosphorus loading attributed to groundwater to the lakes in this study is assumed to be negligible. The report *Integrating Groundwater and Surface Water Management – Northern Washington County* (Washington County 2003) includes an evaluation of the interaction between surface water and groundwater in the study area. The study classified the groundwater function of 47 lakes in northern Washington County. Eight of the ten lakes in this TMDL were classified in the endeavor. To determine the groundwater function of a lake, or the character of interaction between the lake and the surrounding groundwater, the investigation analyzed various criteria. The groundwater function of each lake was determined based on the following:

- Correlation of lake water level to groundwater level fluctuations
- Correlation of lake water level to precipitation trends
- Surficial geology based on geomorphic region
- In-lake chemistry analysis
- Watershed area to water surface area ratio
- Water quality based on Trophic State Index
- Comparison to nearby groundwater levels
- Direct measurement of groundwater inflows and outflows
- Surface water inflow and outflow

The degree of groundwater interaction was characterized as high or low connectivity. Lakes were then classified as groundwater recharge (lake loses water to groundwater), groundwater discharge (lake gains water from groundwater), or flow-through (both recharge and discharge occur in different areas). Of the lakes in this TMDL study, Long and Hay Lakes were not included in the analysis. However, the lake response models for these lakes did not suggest that there was a phosphorus load that was unaccounted for in the phosphorus budget. East Boot Lake was classified as having a high groundwater connectivity as a groundwater flow-through lake. The remaining lakes were classified as precipitation-driven lakes.

East Boot Lake was characterized as a groundwater flow-through lake, meaning that groundwater is both entering and exiting the lake. TP concentrations in the groundwater are similar to the in-lake TP concentrations; therefore the impact of groundwater phosphorus loading on the lake was assumed to be negligible. TP concentrations in nearby Quaternary wells are approximately 40 to 60 µg/L, and the average in-lake concentration is 44 µg/L. Additionally, the lake response model did not suggest that there was a phosphorus load that was unaccounted for in the phosphorus budget.

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.
- Physical disturbance by boats.
- 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.

Internal loading due to the anoxic release from the sediments of each lake was estimated in this study. Internal loading due to physical disturbance and decaying curly-leaf pondweed is difficult to estimate reliably and was therefore not included in the lake phosphorus analyses. In lakes where internal loading due to these sources is believed to be substantial, the internal load estimates presented here are likely an underestimate of the actual internal load.

The internal phosphorus loading to the lake was estimated based on the expected release rate (RR) of phosphorus from the lakebed sediment, the lake anoxic factor (AF), and the lake area. Lake sediment samples were taken and tested for concentration of total phosphorus (TP) and bicarbonate dithionite extractable phosphorus (BD-P), which analyzes iron-bound phosphorus. Phosphorus release rates were calculated using two different equations relating the sediment concentrations to release rate. Given the potential error and uncertainty in the estimates, multiple equations were used in order to increase confidence and arrive at a reasonable range of internal loading values.

Both equations are statistical regression equations; developed using measured release rate and sediment concentration data from different sets of lakes (Nürnberg 1988; Nürnberg 1996). The approach assumes that if a regression equation adequately characterizes the relationship between release rate and sediment phosphorus concentration data in the study set of lakes, then it is reasonable to apply the same equation to other lakes for which the sediment phosphorus concentration is known.

In general, this is appropriate if the lakes under consideration are similar in nature to the lakes in the studies from which the equations were developed, and if the sediment phosphorus concentrations are within the range of the observed values. In this particular study, the measured phosphorus concentrations were generally lower than the concentrations in the study sets used to derive the equations. However, they are applicable to some extent, and given that they are the best feasible methods currently available, these equations were used to arrive at the estimated range for internal phosphorus loading.

3.2 Lake Assessments

The methods used for each lake's impairment assessment are presented below. The impairment assessments include a description of the lake; summary of relevant water quality data; information on the lake biology including fisheries, macrophytes, and plankton communities; and lake sediment data.

Mud Lake was added to the impaired waters list in the middle of this project and was subsequently added to the project. Several differences existed in the approach to the impairment assessment for Mud Lake; these differences are detailed in the following methods descriptions for the lake assessments.

3.2.1 Lake Descriptions

The lake descriptions include data summarized from the DNR Lake Finder database and best available bathymetry data either provided by the DNR or collected by the CMSCWD. In all cases, a GIS grid was developed based on bathymetry data. Some of the bathymetry data were decades old; the data were therefore adjusted as necessary based on the current water level in the lake (estimated from 2008 aerial photography). Mud Lake bathymetric data were collected in 2010.

3.2.2 Water Quality Data

Water Chemistry

The water quality data used to calculate the growing season means (June through September) were from 1999 through 2008; these means were used to evaluate compliance with water quality standards. (Data for Mud Lake were from 2001 through 2010.) If data were available from before 1999, the data were graphed in the water quality graphs, but were not used to calculate the growing season means. Data were obtained from the MPCA Environmental Data Access database.

Fisheries

The fisheries management data were obtained from the DNR.

Macrophytes

Macrophyte data were collected during 2008 and 2010 as part of this TMDL study. The macrophyte data provide information on the presence and extent of macrophytes in the lakes in the spring and fall seasons. Phosphorus release from decaying curly-leaf pondweed (*Potamogeton crispus*) in the spring can cause high levels of internal nutrient loading to lakes, and therefore this macrophyte is mapped in areal extent when identified. The fall macrophyte survey was used to identify exotic macrophytes that may have been present in the lakes.

Plankton

Plankton data were collected during 2008 as part of this TMDL study.

Phytoplankton

The impact of eutrophication on algae concentrations is often evaluated through direct measurements of nutrients, water clarity (Secchi transparency), and the concentration of chlorophyll-*a*. It is also important, however, to know which algae compose a bloom. A single lake may have several algal blooms over the summer, each composed of different species. In some cases, the species may be toxic while other blooms are simply a nuisance. Algal species composition is also important for understanding how nutrients impact the food chain. For example, toxins produced by the blue-green algae Microcystis are passed up the food chain and impair the growth, reproduction, and survival of pike (Karjalainen et al. 2005). These toxins can also sicken or kill pets and humans (Stewart et al. 2006).

The algal community composition was measured monthly for five months from May to September 2008 in each of the study lakes except for Mud Lake. Integrated samples were counted on a Palmer cell, a unit used to sort and count algae. The first 300 cells were counted. This allows quantitative assessment of community composition, but does not provide absolute densities. The latter requires much greater sampling effort and more difficult laboratory methods that increase expense. Since chlorophyll-*a* concentrations quantify algal production, the community composition method is a very efficient way of assessing the lake-specific mechanisms connecting nutrients to water quality and lake biota.

Two important groups, the green algae and blue-green algae (also known as cyanobacteria), are the most common algal groups in this study. Green algae can form nuisance blooms and can cause anoxic conditions when they decompose. They do not, however, produce toxins that can directly harm other biota. Changes in green algae species dominance are important both because different green algae indicate different nutrient conditions and different species have different effects on the food chain (Reynolds 2006).

Blue-green algae can also form nuisance blooms. Some species of blue green algae are capable of producing toxins that harm wildlife, pets, and humans, making them an important group to track. These organisms are most often phosphorus limited, since they are capable of using atmospheric nitrogen, so they tend to become very common in conditions of anthropogenic eutrophication. In the lake analyses, the relative proportion of blue-green and green algae are analyzed along with species composition as it changes over the sampling period.

Zooplankton

Zooplankton are small animals (from microscopic up to about 1 cm in these lakes). Most zooplankton filter feed on algae, so the number and kind of zooplankton heavily influence the algal response to nutrient inputs (Cottingham et al. 2004).

There are three main groups of zooplankton: the rotifers, copepods, and cladocerans. Rotifers are generally very small sac-like organisms with bristling wheel-like mouths. They are very tolerant of fish presence but are subject to being eaten by other plankton. Rotifers graze on algae; although found in large numbers, their small size limits the impact they have on most pelagic (open water) algae.

Copepods are small crustaceans, from microscopic to about 1 cm long in the study lakes. Most copepods are size selective omnivores, eating algae as well as predating other zooplankton. Larger copepods like *Diaptomus* are very easy prey for fish. Cladocerans, or water fleas, are small crustaceans that filter feed algae at very high rates. They also tend to be favorite fish-food for planktivorous fish.

Changes in the relative proportions of these three main groups can show a lot about what is going on in a lake. Dominance by rotifers shows high planktivory and low grazing potential. Dominance by cladocerans shows high grazing potential and low predation by planktivorous fish. Individual species of zooplankton also have specific nutrient tolerances and requirements, making them useful indicator species of water quality.

Plankton Sampling Methods

Zooplankton were sampled (in all lakes except for Mud Lake) monthly from May to September, 2008 with a standard Wisconsin plankton tow net (mesh size 54 µm). Vertical tows were taken at or near the deepest area of the lake, rinsed into a 250 mL vial, and preserved in 80% ethanol. Zooplankton were identified to species (genus when not possible) at the Saint Croix Research Laboratory of the Science Museum of Minnesota using an Olympus BX50F4 Microscope.

Algae samples were collected using a two meter tube to take an integrated column of water from the top two meters at the deepest point of each lake (similar to the zooplankton protocol). The sample was mixed vigorously in a bucket. 30-50 ml were then removed and brought to 85% ETOH (ethyl alcohol preservative).

Analyses

Taking the zooplankton and algal analyses together is a way of ‘looking under the hood’ of a lake at the causal mechanisms that link nutrients, water quality, and the food web. This can sometimes be very complex, and it is not easy to answer all questions with a rapid assessment. However, even a basic analysis of changes in the planktonic community over time is a very important way of understanding the sources and pathways of impairments. Some plankton species are also indicators of different water quality and biological factors due to specific tolerances. Taken together with the water quality data the plankton community analyses shed light on what exactly is happening within the impaired lakes. Eventually, plankton analysis may also be useful for assessing the success of different management options.

Two different levels of analyses were completed with the plankton data. For five of the lakes (East Boot, Fish, Goose, Loon, and South Twin), analyses of changes over the season and examination of trends in individual species or functional groups were completed. This level of analysis offers an understanding of the mechanisms that lead to the observed plankton communities and related water quality in each of the lakes.

For the remaining four lakes (Hay, Jellum’s, Long, and Louise), a more basic level of analysis was performed by combining all sampling events from spring to fall into one analysis. This is a useful way of comparing the baseline differences between lakes and understanding the basic system within a lake. Algal diversity was measured using Genera of algae, not species. Algal species are very difficult (and costly) to identify, while Genera are much easier and often more reliable. This measurement is an adequate way of expressing the relative proportions of different major functional groups. Zooplankton diversity is represented as species richness (number of species) because most organisms were identifiable to species level, and the few left as Genera are unlikely to represent more than one species.

Sediment

Sediment samples were collected using a WaterMark Universal Core Head Sampler. The samples were taken from the deepest spot in the lake and several samples (approximately three) were composited. The top 5 to 10 cm of sediment was sampled. Sediment samples were analyzed for percent organic matter, iron adsorbed phosphorus (BD-P, or bicarbonate dithionite extractable phosphorus), labile phosphorus, total phosphorus, and percent solids. Sediment sampling results were used to calculate the internal load of phosphorus to the lake.

3.3 TMDL Derivation

This section presents the overall approach to estimating the components of the TMDL. The phosphorus sources were first identified and estimated in the phosphorus source assessment (Section 3.1). The loading capacity (TMDL) of each lake was then estimated (Section 3.3.1) using an in-lake phosphorus response model and was divided among wasteload allocations (WLAs) and load allocations (LAs).

- Loading capacity (=TMDL): the total amount of pollutant that the water body can assimilate and still maintain water quality standards.
- Wasteload allocations (WLAs): the pollutant load that is allocated to point sources, including regulated municipal stormwater, regulated construction stormwater, and regulated industrial stormwater, all covered under NPDES permits. A source can receive a WLA for a current or future permitted pollutant source.
- Load allocations (LA): the pollutant load that is allocated to sources not requiring NPDES permit coverage, including non-regulated watershed runoff, atmospheric deposition, and internal loading.

3.3.1 Loading Capacity: Lake Response Model

The modeling software Bathtub (Version 6.1) was selected to link phosphorus loads with in-lake water quality. A publicly available model, Bathtub was developed by William W. Walker for the U.S. Army Corps of Engineers (Walker 1999). It has been used successfully in many lake studies in Minnesota and throughout the United States. Bathtub is a steady-state annual or seasonal model that predicts a lake's summer (June through September) mean surface water quality. Bathtub's time-scales are appropriate because watershed phosphorus loads are determined on an annual or seasonal basis, and the summer season is critical for lake use and ecological health. Bathtub has built-in statistical calculations that account for data variability and provide a means for estimating confidence in model predictions. The heart of Bathtub is a mass-balance phosphorus model that accounts for water and phosphorus inputs from tributaries, watershed runoff, the atmosphere, sources internal to the lake, and (if appropriate) groundwater; and outputs through the lake outlet, groundwater (if appropriate), water loss via evaporation, and phosphorus sedimentation and retention in the lake sediments.

Long-term averages were used as input data to the models, due to the lack of detailed annual loading and water balance data for each of the lakes. The outputs from the phosphorus source assessment (Section 3.1) were used as inputs to the Bathtub lake models. The models were calibrated to existing water quality data, and then were used to determine the phosphorus reductions needed to meet each lake's phosphorus standard. Since the Bathtub model does not explicitly account for internal loading, the independent internal load estimate was added to the phosphorus budget after the Bathtub model was completed. The phosphorus reduction needed to meet the phosphorus standard, calculated from the Bathtub model, was subtracted from the total existing phosphorus load to determine each lake's loading capacity. The loading capacity of each lake is the TMDL; the TMDL is then split into wasteload allocations (WLAs), load allocations (LAs), and a margin of safety (MOS).

The TMDL (or loading capacity) 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 (and, therefore, the TMDL goals) were established with this seasonal variability in mind. The annual loads were converted to daily loads by dividing the annual loads by 365.

Appendix B Supporting Data for Bathtub Models contains for all lakes Bathtub modeling case data (inputs), diagnostics (results), and segment balances (water and phosphorus budgets) for both the calibrated (benchmark/existing) models and the TMDL scenarios including a 5% MOS as described in *Margin of Safety* in Section 3.3.2.

System Representation in Model

In typical applications of Bathtub, lake and reservoir systems are represented by a set of segments and tributaries. Segments are the basins (lakes, reservoirs, etc.) or portions of basins for which water quality parameters are being estimated, and tributaries are the defined inputs of flow and pollutant loading to a particular segment. For this study, the direct drainage area for each lake (i.e., segment) and loading from upstream water bodies were lumped as a single tributary input. Only two lakes have loading from upstream lakes (West Boot Lake flows into East Boot Lake, and the Long Lake watershed flows into Jellum's Bay).

Under normal use, internal loading is not represented explicitly in Bathtub. An average rate of internal loading is implicit in Bathtub since the model is based on empirical data. The model provides an option to include an additional load identified as an internal load if circumstances warrant, but it is generally not recommended. In the lake models, adjustments to internal loading were not necessary for model calibration. The internal loading estimates calculated from the lake sediment data were therefore not directly entered into the model, but were used as an independent estimate of internal loading and to represent internal loading in the overall lake nutrient balance. See discussion titled *Internal Loading* under Section 3.1.2 for more details.

Model Input

The input required to run the Bathtub model includes lake geometry information, climate data, and water quality and flow data for runoff contributing to the lake. Observed lake water quality data is also entered into the Bathtub program in order to facilitate model verification and calibration. Table 7 lists the key input values used in the simulations.

Table 7. Bathtub model input data

Lake	Surface Area (acres)	Lake Fetch (ft)	Av Depth (ft)	Observed Lake Quality (surface growing season mean)			Contributing Area[1]			Precip (in)	Evap (in)
				TP (µg/L)	Chl-a (µg/L)	Secchi (m)	Wtrshed Load (lb/yr)	Flow (ac-ft/yr)	TP (µg/L)		
East Boot	45.7	727	14.8	43.9	24.2	2.2	47	99	176	30.1	35.3
Fish	63.3	1354	3.9	112.7	69.2	0.8	76	140	199	30.0	35.1
Goose	85	1294	11	63.5	42.7	1.7	152	170	330	30.0	35.0
Hay	41.4	759	3.8	92.1	41.4	1.1	63	70	330	30.0	35.1
Jellum's	64	1215	5.9	97.3	52.4	1.0	81	181	165	30.1	35.1
Long	39.8	1097	4.4	81.2	42.8	1.1	52	72	269	30.1	35.1
Loon	52.8	862	5.6	135.8	109.3	0.5	107	129	306	30.1	35.4
Louise	46.1	524	4.0	119.9	51.7	1.0	50	72	257	30.1	35.4
Mud	60.3	2000	5.0	79.0	33.6	0.7	27	104	96	30.1	35.3
South Twin	55.9	684	5.3	72.8	38.9	1.1	22	27	296	30.2	35.5

[1] Contributing area includes direct watershed runoff, SSTS, and, for East Boot and Jellum's Bay, upstream lake loading.

Precipitation and Evaporation
See discussion titled *Direct Watershed Runoff* under Section 3.1.2 for estimates of annual precipitation and evaporation rates, which were based on data from the MN Hydrology Guide.

Atmospheric Deposition
Average phosphorus atmospheric deposition loading rates were estimated to be 0.27 lb/ac-yr for the St. Croix River Basin (MPCA 2004), applied over each lake's surface area. See discussion titled *Atmospheric Deposition* in Section 3.1.2 for more details.

Segment Data: Lake Morphometry and Observed Water Quality
Lake morphometry data were gathered from the DNR, collected by the CMSCWD, or were data collected for this study. Data sources are provided in the individual lake TMDL chapters. Observed water quality averages are from the lake assessments (Section 3.2) and are ten-year (1999-2008) growing season (June through September) means of total phosphorus, chlorophyll-*a*, and Secchi transparency.

The Mud Lake model used growing season means from 2010. Mud Lake data was scarce for TP (2000, 2001, and 2010 only) and chlorophyll-*a* (2001 and 2010 only). 2000 and 2001 data showed much poorer water quality in comparison to 2010 data, and more complete Secchi transparency data (2000, 2001, 2004-2007, and 2010) illustrate a downward trend. Land management practices within the previous 10 years (e.g. rotational grazing and reseeding) may have contributed to the improved water quality.

Since the water quality evaluation for the lakes was completed using data from 1999 through 2008 for all lakes except for Mud Lake, and 2010 for Mud Lake, practices implemented after 2008 (2010 for Mud Lake) will be considered to be part of the TMDL implementation activities and can be applied to load reduction goals.

Tributary Data: Flow Rate and Phosphorus Concentration
All of the watershed sources (Section 3.1) were combined into a single tributary input for each lake. Watershed phosphorus sources include direct watershed runoff, loading from upstream waters, runoff from feedlots, and subsurface sewage treatment systems.

Chlorophyll-Secchi Coefficient
Among the empirical model parameters is the non-algal turbidity, a term that reflects turbidity due to the presence of color and inorganic solids in the water column. This parameter uses the chlorophyll-Secchi coefficient, which is the ratio of the inverse of Secchi transparency (the inverse being proportional to the light extinction coefficient) to the chlorophyll-*a* concentration. The default coefficient in Bathtub is 0.025 m^2/mg, which was calibrated to United States Army Corps of Engineers reservoir data. A value of 0.015 m^2/mg has been found to be more representative of Minnesota lakes and was used in this study.

<u>Selection of Equations</u>

Bathtub allows choice among several different mass balance phosphorus models. For deep lakes in Minnesota, the option of the Canfield-Bachmann lake formulation (Canfield and Bachmann 1981) has proven to be appropriate in most cases. For each lake in this study, all phosphorus models were tested to determine which equation delivered a result closest to the observed concentration. In all cases, the Canfield Bachmann lake formulation provided the best fit to the data, and in order to perform a uniform analysis it was selected as the standard equation for the study. For other parameters, the default model selections (chlorophyll-*a* model based on phosphorus, light, and flushing; transparency model based on chlorophyll-*a* and turbidity) were used.

Model Calibration

In the calibration process, it is first necessary to check that the lake behaves like the lakes in the dataset used to develop the regression equation, and that calibration coefficients will not have to be adjusted to an unrealistic degree. Before calibration coefficients were adjusted to calibrate the model, it was verified that the predictions made by the uncalibrated model were sufficiently close to the observed concentrations to warrant using the normal calibration process.

In the case of the Canfield Bachmann lakes equation, the 95% confidence interval corresponds to 31 to 288% of the calculated total phosphorus value (Canfield and Bachmann 1981). This would suggest that calibration coefficients in the range of 0.31 to 2.88 could be considered reasonable. Even if this is further restricted to a range of 0.5 to 2 (as suggested for other phosphorus retention equations in Bathtub), the Canfield Bachmann lakes equation delivers results sufficiently close to observed values for all lakes.

For all lake models, calibration coefficients were then modified so that the predicted values of phosphorus, chlorophyll-*a*, and Secchi transparency matched the observed values. Matches were made to the nearest whole number for phosphorus and chlorophyll-*a* concentrations (µg/L), and to the nearest tenth of a meter for Secchi transparencies.

Estimated Phosphorus Load Reduction Requirements

With calibrated existing conditions models completed for all the lakes, reductions in phosphorus loading could be simulated in order to estimate the effects on lake water quality. Specifically, the goal of the analysis was to identify the reduction in phosphorus loading required in order to meet the water quality TMDL goal for total phosphorus. Using the calibrated existing conditions model as a starting point, the phosphorus concentrations associated with tributaries were reduced until the model indicated that the phosphorus water quality goal was met.

With this process, a series of models were developed that included a level of phosphorus loading consistent with the lake water quality TMDL goal. Actual load values are calculated within the Bathtub software, so loads from the TMDL goal models could be compared to the loads from the existing conditions models to determine the amount of load reduction required.

3.3.2 TMDL Allocations

Margin of Safety

A 10% explicit margin of safety (MOS) was accounted for in the TMDL for each lake. This MOS is sufficient to account for uncertainties in predicting loads to the lakes and predicting how lakes respond to changes in phosphorus loading. This explicit MOS is considered to be appropriate based on the generally good agreement between the water quality models' predicted and observed values. Since the models reasonably reflect the conditions in the lakes and their watersheds, the 10% MOS is considered to be adequate to address the uncertainty in the TMDL, based upon the data available.

Wasteload Allocations

Regulated MS4 Stormwater

The only regulated MS4 stormwater (or future regulated stormwater, see Section 3.1.1) is in the South Twin Lake watershed within the City of Stillwater. The City of Stillwater is therefore the only municipality that will receive a WLA for regulated MS4 runoff.

An area-weighted WLA was assigned using 2030 land use data (Regional Planned Land Use for the Twin Cities Metropolitan Area, Metropolitan Council) to determine the proportion of the watershed load (excluding internal and atmospheric sources) that originates in the municipal areas that are regulated (or will be regulated) by the municipality's MS4 permit. See Section 3.1.1 for a description of regulated (versus non-regulated) municipal areas.

If additional portions of MS4 communities come under permit coverage in the future due to urban expansion and increased population densities, a portion of the LA will be shifted to the WLA. In the case of a load transfer, the LA will be converted to a load per unit area (e.g. lb/acre) and the resulting WLA will be based on areal proportion. The MPCA will make these allocation shifts.

MS4 permits for state (Mn/DOT) and county road authorities apply to roads within the U.S. Census Bureau Urban Area. The watersheds are not within the U.S. Census Bureau Urban Area. Therefore, no roads are currently under permit coverage and no WLA is assigned to the corresponding road authorities. If, in the future, the U.S. Census Bureau Urban Area extends into the watershed and these roads come under permit coverage, one of the following will occur:

- If the road under question falls under an area currently covered by a WLA, a portion of the WLA will be shifted from the municipality or township in which the roads occur. In the case of a load transfer, the WLA will be converted to a load per unit area (e.g. lb/acre) and the resulting WLA for the roads will be based on their areal proportion. This would result in no change in the overall WLA for the impaired receiving water.
- If the road under question falls under an area currently covered by the LA, a portion of the LA will be shifted to the WLA. In the case of a load transfer, the LA will be converted to a load per unit area (e.g. lb/acre) and the resulting WLA for the roads will be based on their areal proportion.

These WLA and LA shifts will be made by the MPCA.

A percent reduction goal for phosphorus loading was provided for the City of Stillwater in the South Twin Lake TMDL, and was equal to the percent reduction provided for unregulated watershed runoff. See *Section 16.2: Watershed vs. In-Lake Load Reduction* for information on how the watershed loading goals and internal loading goals were developed.

Regulated Construction Stormwater
The construction stormwater wasteload allocations were calculated based on the estimated area of Washington County under permitted construction activity over six years (November 2004 to November 2010). Project areas of permits were summed up within the county and presented as an annual average percent of total county area that has been issued a construction stormwater permit, which was 0.58%. This percentage was multiplied by the total TMDL (loading capacity) minus the MOS to determine the construction stormwater WLA.

The existing load from regulated construction stormwater was assumed to be the same as the WLA, and a 0% reduction of loads from regulated construction stormwater is assumed in the load reduction goals.

Regulated Industrial Stormwater
There are no facilities with an industrial stormwater permit in any of the lakes' watersheds. A small portion of the TMDL for each lake was set aside for future regulated industrial stormwater sources, especially in anticipation of new applicants with the recent re-issuance of the permit. The additional industrial stormwater WLA is equal to the amount allocated for regulated construction stormwater [0.58% of the total TMDL (loading capacity) minus the MOS].

The existing load from regulated industrial stormwater was assumed to be the same as the WLA, and a 0% reduction of loads from regulated industrial stormwater is assumed in the load reduction goals.

Load Allocations

One load allocation was set for each lake. The load allocation includes all sources of phosphorus that do not require NPDES permit coverage, including watershed runoff, internal loading, atmospheric deposition, and any other identified loads as described in Section 3.1. The WLAs for stormwater were first calculated; the WLAs and the MOS were then subtracted from the loading capacity (TMDL) to generate the LA for each lake.

Percent reduction goals for phosphorus loading were provided for unregulated watershed runoff and for internal loading. See *Section 16.2: Watershed vs. In-Lake Load Reduction* for information on how the watershed loading goals and internal loading goals were developed. Additional information on the watershed and internal loading goals is included in the implementation approaches for each lake in Section 17.3.

Reserve Capacity

Because future land use is already factored into the WLA estimate and no new traditional permitted point sources are planned in the watershed, no portion of the allowable loading was explicitly set aside as reserve capacity.

3.4 Summary of Model Applications

This section provides a summary of how the models that were applied to each lake in this TMDL study interact. Details are provided throughout the *Methods* section. The Simple Method was used to estimate existing phosphorus loading to lakes based on land use and land cover data. The Simple Method is based, in part, on volume of runoff, which is applied to the model as an annual depth of runoff over the entire watershed. FLUX was used in the conversion of stream monitoring data to identify an annual depth of runoff for the study area. Phosphorus loading from the Simple Method (using land cover and land use) was combined with phosphorus loading from all other estimated external sources: feedlots (those not requiring NPDES permit coverage), atmospheric deposition, SSTS, and upstream lake loading. Ultimately, external phosphorus loading served as input to the Bathtub model, which estimates in-lake water quality. The Bathtub models were calibrated to existing in-lake water quality data (10-year growing season means) and were then used to identify the phosphorus load reductions needed to meet the TMDL water quality goal for total phosphorus.

4 EAST BOOT LAKE TMDL

4.1 Physical Characteristics

East Boot Lake (ID 82-0034) is a lake located in May Township. East Boot Lake is divided from West Boot Lake by Norrell Ave; a culvert beneath the road connects the two lakes. The culvert acts as an equalizer pipe, although flow is typically from West Boot Lake to East Boot Lake. The East and West Boot Lake watershed is landlocked. Table 8 summarizes the lake's characteristics and Figure 7 illustrates the available bathymetry. The bathymetric data do not illustrate the current condition of the lake, which has a higher water level and which was taken into account when quantifying lake characteristics.

Table 8. East Boot Lake Characteristics

Characteristic	Value	Source
Lake total surface area (ac)	45.7	2008 MLCCS revised based on 2008 aerial photos
Percent lake littoral surface area	56	Calculated based on revised DNR bathymetry data
Lake volume (ac-ft)	676	Calculated (mean depth x surface area)
Mean depth (ft)	14.8	Calculated based on revised DNR bathymetry data
Maximum depth (ft)	25	Based on revised DNR bathymetry data
Drainage area (acres)	300.7	CMSCWD
Watershed area:lake area	6.6	Calculated

Figure 7. East Boot Lake Bathymetry
Contour units are feet.

4.2 Land Use

At present, the dominant land uses in the East Boot Lake watershed are agriculture and undeveloped land (Table 9). The watershed also contains a large area of parkland, Wilder Forest, which is located immediately north and east of the lake. No major land use changes are projected between now and 2030 (Table 10); changes are assumed to be the result of Metropolitan Council's re-categorization of 2030 land use as compared to 2005 land use.

Table 9. East Boot Lake Watershed Land Use, 2005
(2005 Generalized Land Use for the Twin Cities Metropolitan Area)

Land Use	Direct Drainage		Entire Drainage (including West Boot watershed and lake)	
	Total Acres	% of Watershed	Total Acres	% of Watershed
Agricultural	14.3	20.0%	77.8	25.9%
Farmstead	3.4	4.7%	3.4	1.1%
Industrial and Utility	-	-	-	-
Institutional	-	-	-	-
Park, Recreation, or Preserve	12.4	17.3%	21.4	7.1%
Retail and Other Commercial	-	-	-	-
Seasonal/Vacation	-	-	-	-
Single Family Detached	-	-	17.2	5.7%
Undeveloped	39.3	54.9%	114.5	38.1%
Water	2.2	3.1%	66.4	22.1%
Total	**71.7**	**100.0%**	**300.7**	**100.0%**

Table 10. East Boot Lake Watershed Land Use, 2030
(Regional Planned Land Use for the Twin Cities Metropolitan Area)

Land Use	Direct Drainage		Entire Drainage (including West Boot watershed and lake)	
	Total Acres	% of Watershed	Total Acres	% of Watershed
Agricultural	55.2	77.0%	92.5	30.8%
Airport	-	-	-	-
Commercial	-	-	-	-
Industrial	-	-	-	-
Institutional	-	-	-	-
Mixed Use	-	-	-	-
Multifamily Residential	-	-	-	-
Multi-Optional Development	-	-	-	-
Open Space or Restrictive Use	-	-	-	-
Park and Recreation	-	-	-	-
Railway (inc. LRT)	-	-	-	-
Rights-of-Way (i.e., Roads)	-	-	-	-
Rural or Large-Lot Residential	14.3	19.9%	141.8	47.2%
Single Family Residential	-	-	-	-
Vacant or No Data	-	-	-	-
Water	2.2	3.1%	66.4	22.1%
Total	**71.7**	**100.0%**	**300.7**	**100.1%***

* Total percent does not equal 100.0 due to rounding.

4.3 Existing Studies, Monitoring, and Management

Based on an Aerial Lakeshore Analysis (CMWD 1999), the major influence on the lake is non-point source runoff from agricultural fields and dairy operation adjacent to the lake followed by non-point source pollution from County Road #55. The District has been working for the last 10-yrs with the landowner, Department of Agriculture and Washington Conservation District to address the feedlot and manure management concerns and restore the quality of the lake.

In 2000 a phosphorus sensitivity analysis for several lakes in the Carnelian-Marine Watershed District was completed (CMWD 2000). The study noted that East Boot Lake has a relatively high nutrient load from a feedlot on the south end of the lake.

In 2001 the Carnelian-Marine Watershed District completed a paleolimnological investigation of trophic changes in East Boot Lake (CMWD 2001b). The purpose of the investigation was to establish the baseline trophic conditions existing in the lake prior to European settlement in the mid-1800s. The diatom-inferred total phosphorus (TP) values for East Boot Lake indicate that changes in nutrient inputs to the lake coincided with peaks in agricultural activity. Inferred TP increases around 1930 and drops by the 1950s, coinciding with the regional peak in farming activity around 1930 and improvements in farming practices between 1930 and the 1950s. The investigation found that, prior to 1902, the inferred TP concentrations in the lake ranged from 18.5 to 21 μg/L. TP concentrations doubled between 1902 and 1928 to 42 μg/L and started to decline around 1953. Since 1959, inferred TP values range from 22 to 31 μg/L, with values over 30 μg/L occurring after 1995.

The East Boot Lake Watershed Management Plan was written as part of the Carnelian-Marine-St. Croix Watershed District's 2010 Watershed Management Plan. Management, monitoring, and implementation activities are expected to be driven by an implementation plan developed based on this TMDL study. In addition, installed best management practices undergo ongoing monitoring. Potential future projects include roadside revegetation, purple loosestrife control and collection, and a water quality diagnostic and feasibility study.

4.4 Lake Uses

East Boot Lake does not have a public access..

4.5 Biological Characteristics

4.5.1 Fish

DNR management of East Boot Lake is limited to netting surveys and monitoring winter oxygen levels. The lake is not stocked by the DNR.

A 2003 fish survey showed black crappie as the most abundant fish species in the lake. The lake also had a population of black bullhead, largemouth bass, northern pike, pumpkinseed sunfish, and yellow bullhead. While the black bullhead were on average large (size averaged more than 12 inches and weight of one pound), the survey concluded that the population size of black bullhead had decreased since previous surveys and the numbers were comparable to the numbers of bullhead found in similar lakes.

4.5.2 Macrophytes

Macrophyte surveys were completed for East Boot Lake in June and August of 2008. Curly-leaf pondweed was observed throughout the lake in the June survey. Curly-leaf pondweed was not observed during the August survey (Figure 8). A diversity of other macrophyte species was present in the lake during both surveys (Table 11).

Table 11. Plant Species Observed During 2008 East Boot Lake Macrophyte Surveys

Scientific Name	Common Name	June	August
Ceratophyllum demersum	Coontail	ü	ü
Elodea canadensis	Elodea	ü	ü
Nymphaea odorata	White water-lily	ü	ü
Potamogeton amplifolius	Large-leaved pondweed	ü	ü
Potamogeton crispus	Curly-leaf pondweed	ü	
Potamogeton foliosus	Leafy pondweed	ü	
Potamogeton robbinsii	Fern-leaved pondweed	ü	ü
Potamogeton zosteriformis	Flat-stemmed pondweed	ü	

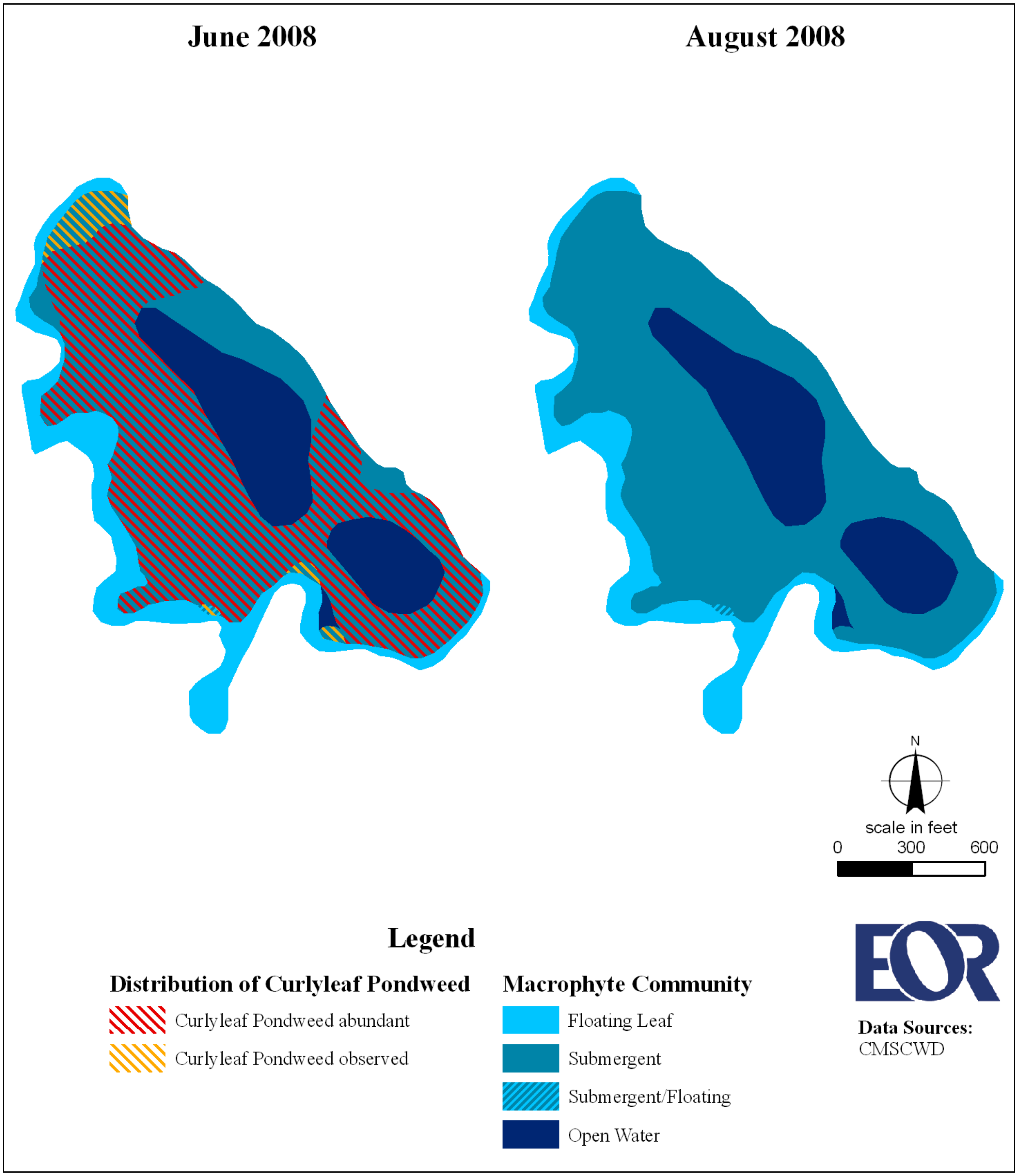

Figure 8. Distribution of Macrophyte Communities in East Boot Lake

4.5.3 Plankton Community

Phytoplankton

The algal community of East Boot Lake in 2008 was dominated by blue-green algae, followed by a mix of other algal types (Figure 9). Over the season, there is a roughly even mix of algae in spring followed by increased dominance of blue-green algae (Figure 10). September samples show a return to a more balanced mix of algal types. The proportion of algal indicators of eutrophy was extremely high in spring, with 40% of algal community composed of eutrophic-specialized algae.

The most common blue-green algae is *Anabaena limneticus* but *Microcystis* is also a consistently strong blue-green component of the algal community (Figure 11). These two species increased in abundance dramatically in August as total phosphorus increased and water clarity decreased (Figure 12). The rest of the community was a highly variable and patchy mix of algal species with no clear patterns over time.

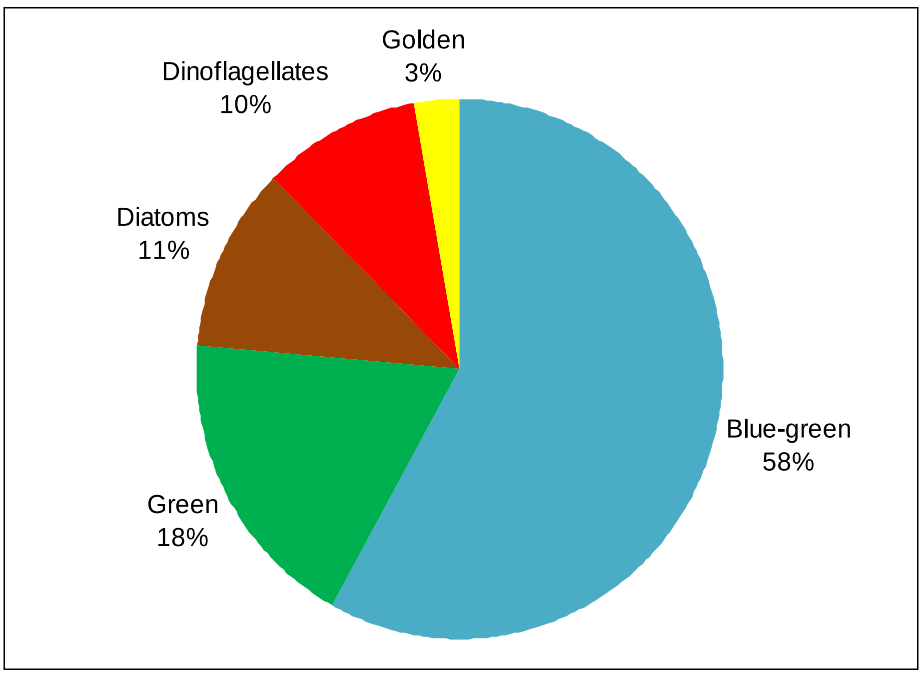

Figure 9. Total algal composition of major groups (%) in East Boot Lake over 5 monthly sampling periods, 2008

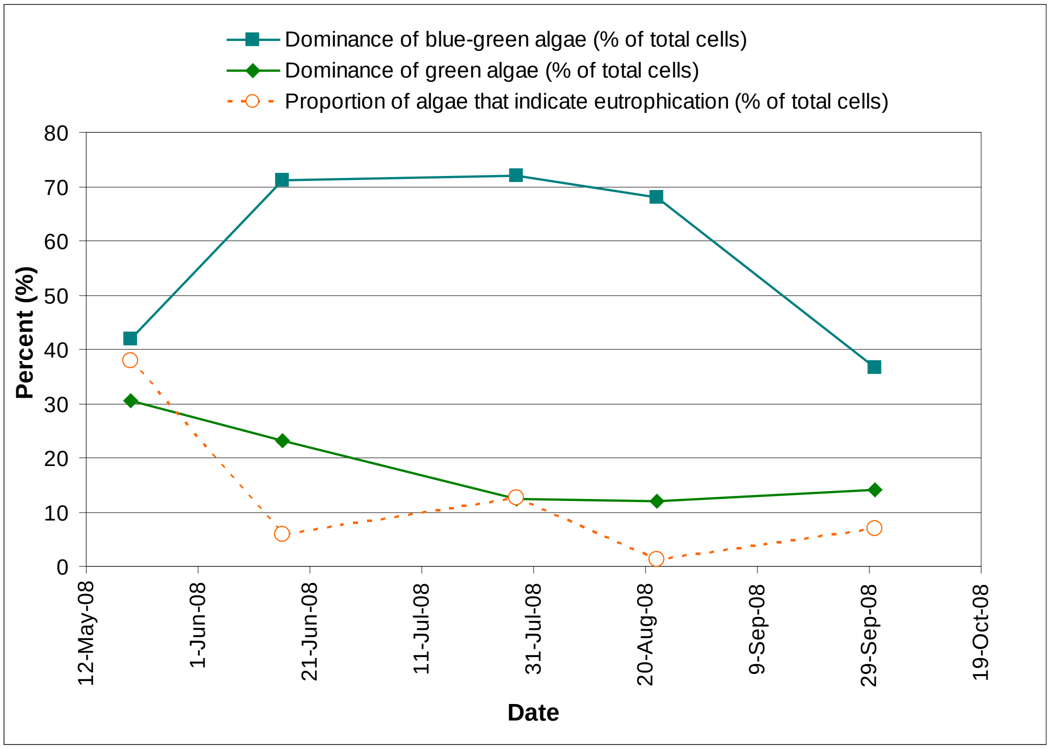

Figure 10. Dominance of major algal groups and indicator species in East Boot Lake over five monthly sampling periods in 2008 (% of cells/300 counted)

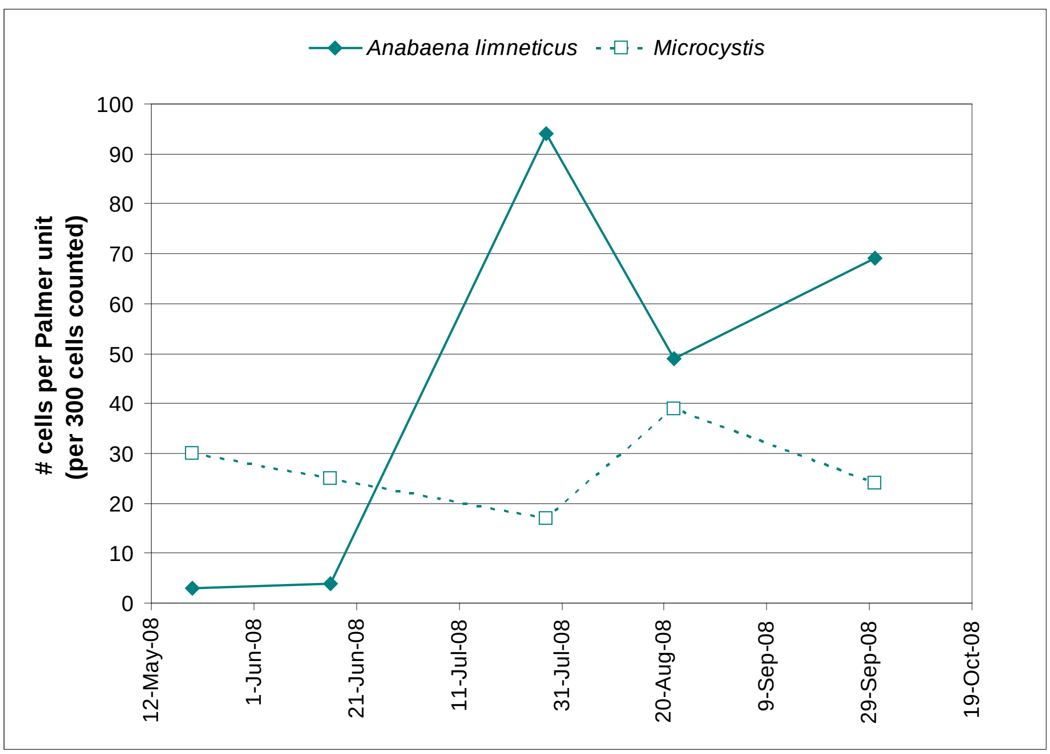

Figure 11. Dominance of the most abundant algal taxa in East Boot Lake over five monthly sampling periods in 2008

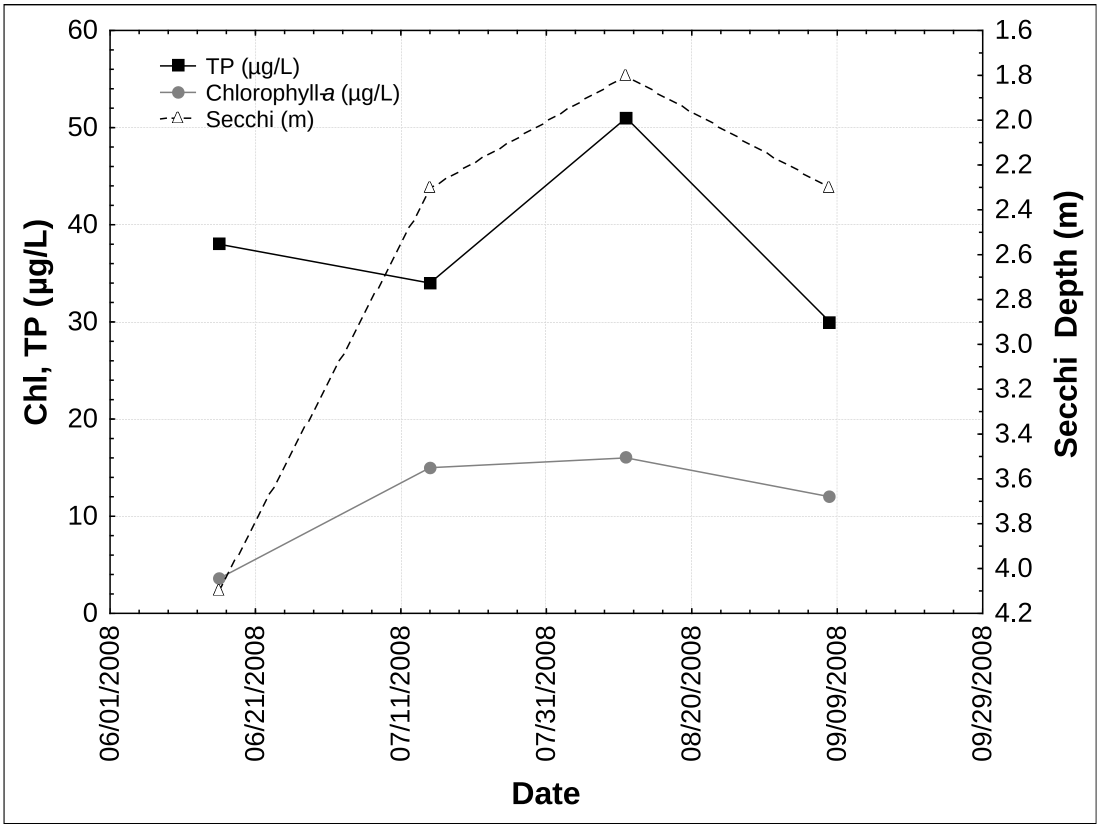

Figure 12. Chlorophyll-*a* concentrations (as a proxy for algal density), total phosphorus, and Secchi transparency for East Boot Lake over five monthly sampling periods, 2008

<u>Zooplankton</u>

The zooplankton community of East Boot Lake in 2008 was co-dominated overall by copepods and rotifers (Figure 13). Cladocerans and copepods were the dominant zooplankton in spring, which is somewhat unusual because rotifers are most often the dominant plankton during and just after ice. Over the summer of 2008, rotifers increased in dominance (Figure 14). Cladocerans become very rare in the community while copepods increased (in part due to consistent numbers during the decrease in cladocerans).

Patterns of the contribution of the most common species to community composition show that cladoceran and copepod species are consistently a minor component of the community while rotifers increase in dominance over the year (Figure 15). Observations of zooplankton densities confirmed that the dominance of copepods was due to a mix of species that individually never became very abundant but increased in importance as cladoceran numbers decreased. Rotifer populations increased in abundance and diversity over the summer, primarily due to large populations of *Keratella cochlearis*, a small loricate (hard 'shelled') rotifer.

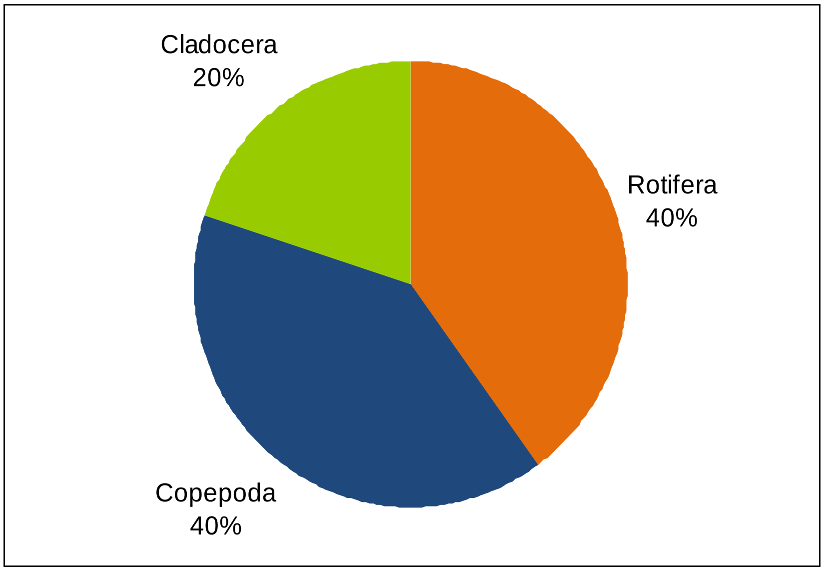

Figure 13. Total zooplankton composition of major groups (%) in East Boot Lake over 5 monthly sampling periods, 2008

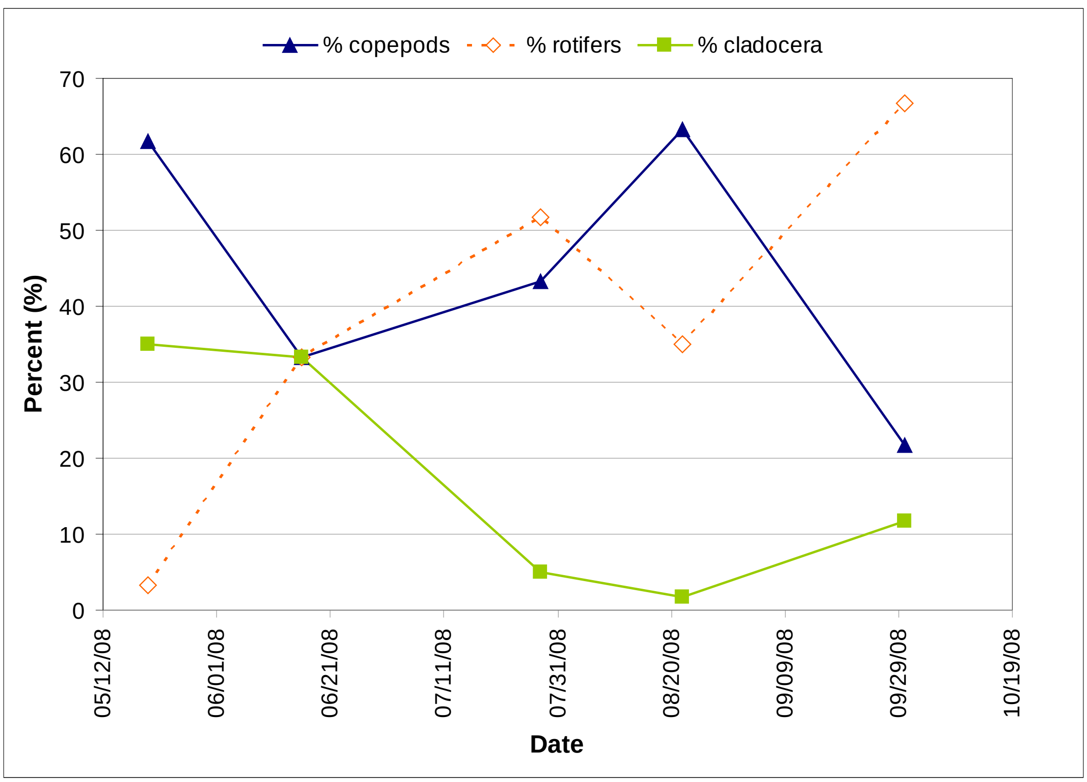

Figure 14. Dominance of major zooplankton groups and indicator species in East Boot Lake over five monthly sampling periods in 2008 (as % of individuals counted)

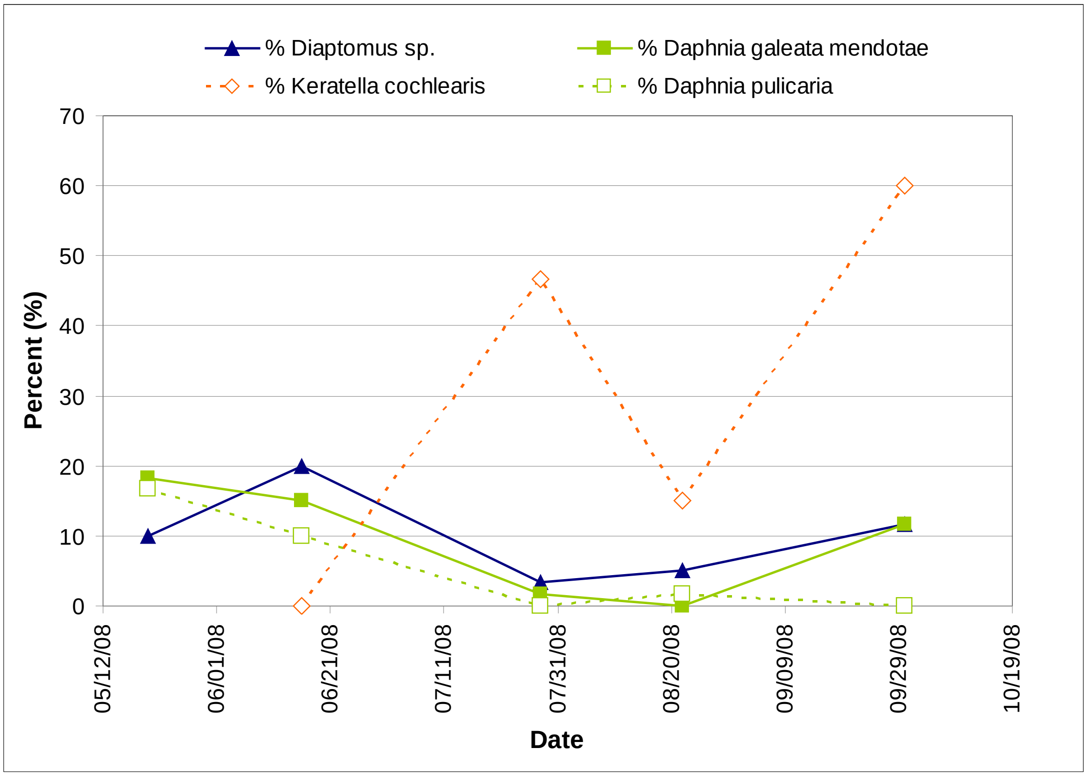

Figure 15. Dominance of the most abundant zooplankton taxa in East Boot Lake over five monthly sampling periods in 2008 (as % of individuals counted)

Discussion

The dominance of blue-green algae in East Boot Lake indicates a potential for algal blooms with potential toxic microcystins. The blue-green community is dominated by *Anabaena limneticus*, an indicator of high phosphorus. This species does not produce toxins but can form nuisance blooms. *Microcystis* is a significant component of the community over the entire growing season.

The high proportion of eutrophic indicator species in the algal community indicates that a very significant amount of nutrients are present in the lake over winter, with high cycling at turnover.

The overall zooplankton community composition, particularly the absence or low numbers of larger cladocerans, indicates low grazing potential and high planktivory by fish. Larger copepods and the few cladocerans present are highest in spring, crashing to very low numbers or completely absent in mid and late summer, recovering only in September. The rotifers are dominated by *Keratella cochlearis*, a small hard-shelled species that is very tolerant to fish predation. The increased dominance of rotifers over the summer also indicates that a predation impact is suppressing the zooplankton community's ability to mediate algal blooms. The presence at very low densities of the large copepod *Diaptomus* and two species of large cladoceran *Daphnia* indicate the potential for zooplankton grazing to be improved.

4.6 Water Quality

Monitoring data are available from 2000 through 2008. The lake is not meeting lake water quality standards for TP or chlorophyll-*a*, but is meeting the standard for Secchi transparency (Table 12).

Table 12. East Boot Lake, Surface Water Quality Means (2000-2008) and Standards

Parameter	Growing Season Mean (June – September)	Lake Standard
TP (µg/L)	44	40
Chlor-*a* (µg/L)	24	14
Secchi transparency (m)	2.2	1.4

The annual mean TP concentration has fluctuated above and below the standard (Figure 16). There is a trend in water quality improvement suggested by the annual mean chlorophyll-*a* (Figure 17) and Secchi transparency data (Figure 18).

The seasonal pattern of TP concentrations in East Boot Lake (Figure 19), along with the observed dense population of curly-leaf pondweed, suggests that the senescence of curly-leaf pondweed in early summer likely contributes to the high in-lake TP concentrations seen in July. This is also true for the observed seasonal increase in chlorophyll-*a* (Figure 20) and decrease in Secchi transparency (Figure 21).

There is a strong relationship between chlorophyll-*a* and Secchi transparency (Figure 22); relationships between the other parameters are not as strong.

In 2008 the lake stratified in May and became more strongly stratified as the growing season progressed (Figure 23). The hypolimnion became progressively more enriched with phosphorus throughout the growing season (Figure 24).

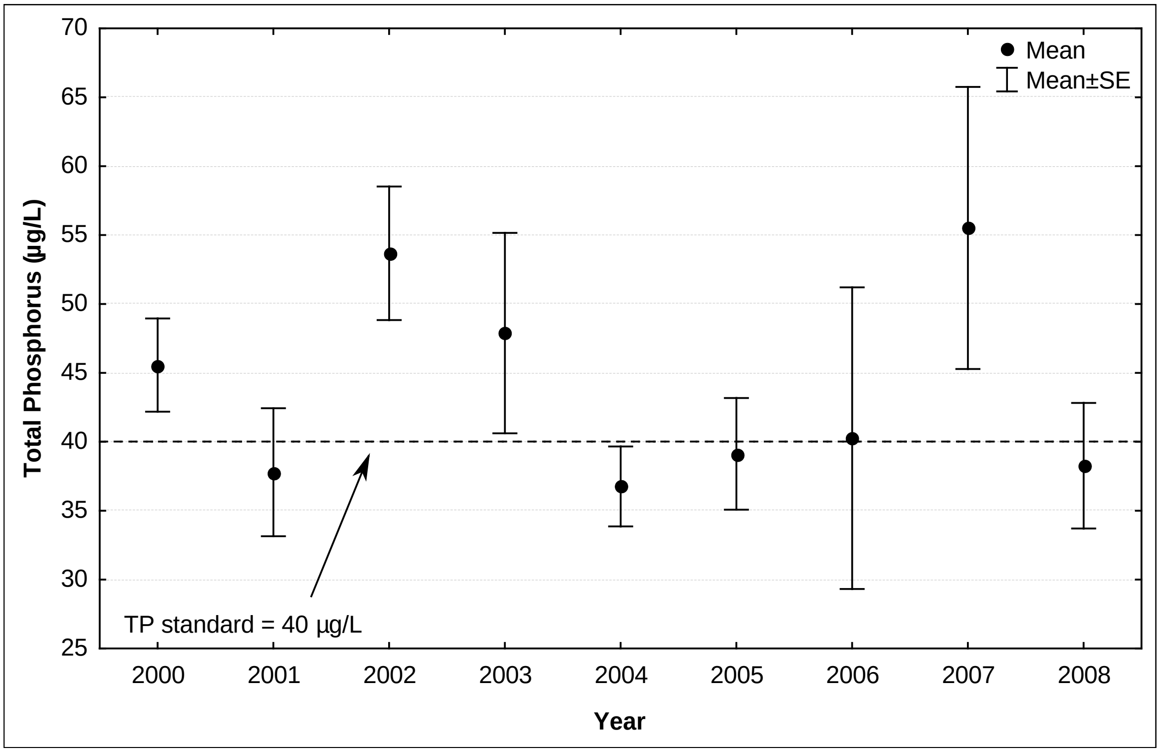

Figure 16. East Boot Lake, Growing Season Means Total Phosphorus

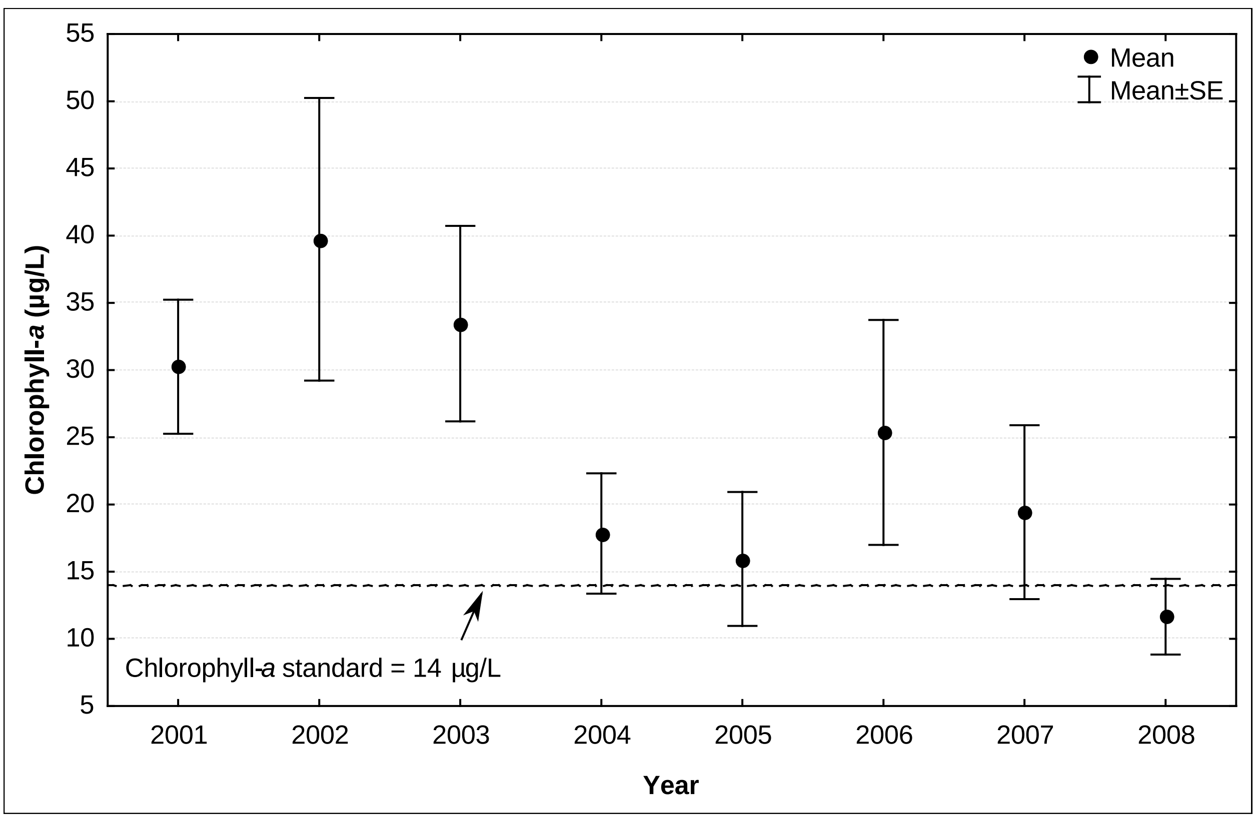

Figure 17. East Boot Lake Growing Season Means Chlorophyll-*a*

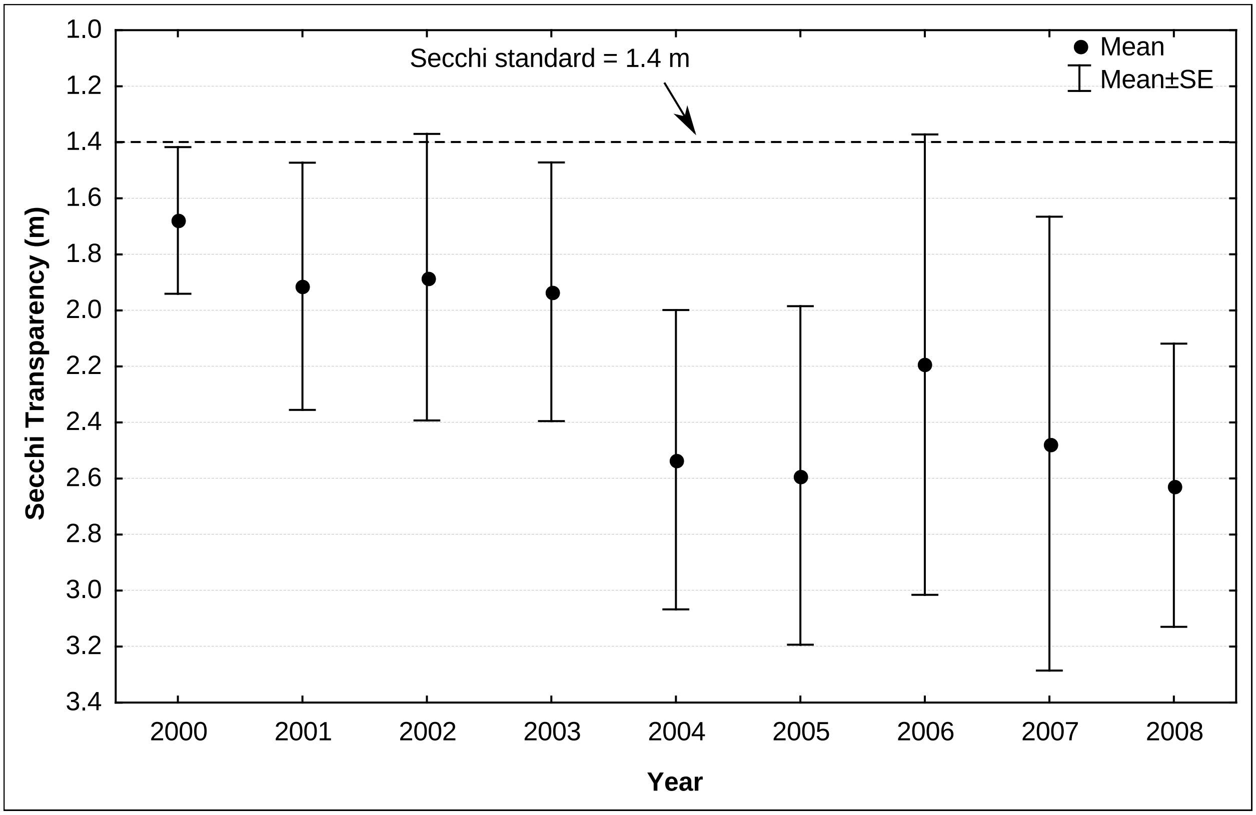

Figure 18. East Boot Lake, Growing Season Means Secchi Transparency

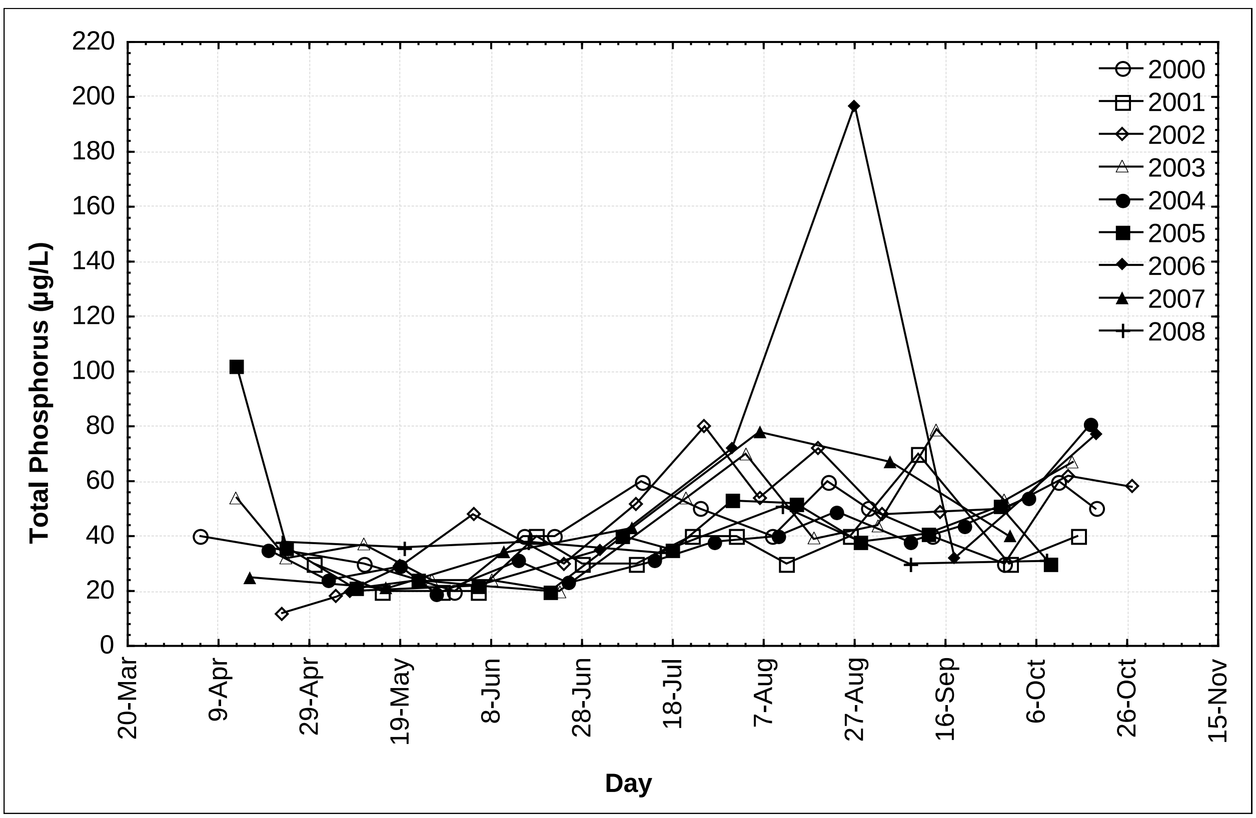

Figure 19. East Boot Lake Seasonal Total Phosphorus Patterns

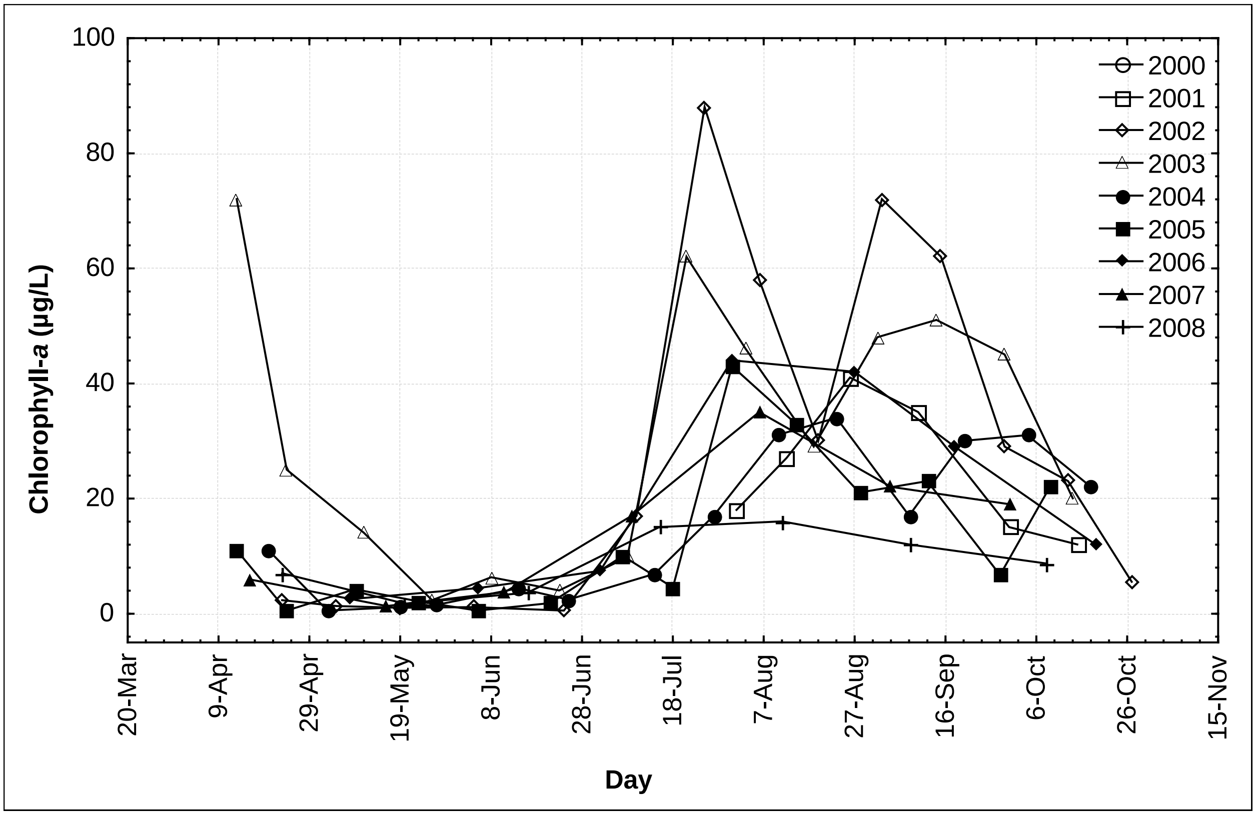

Figure 20. East Boot Lake Seasonal Chlorophyll-*a* Patterns

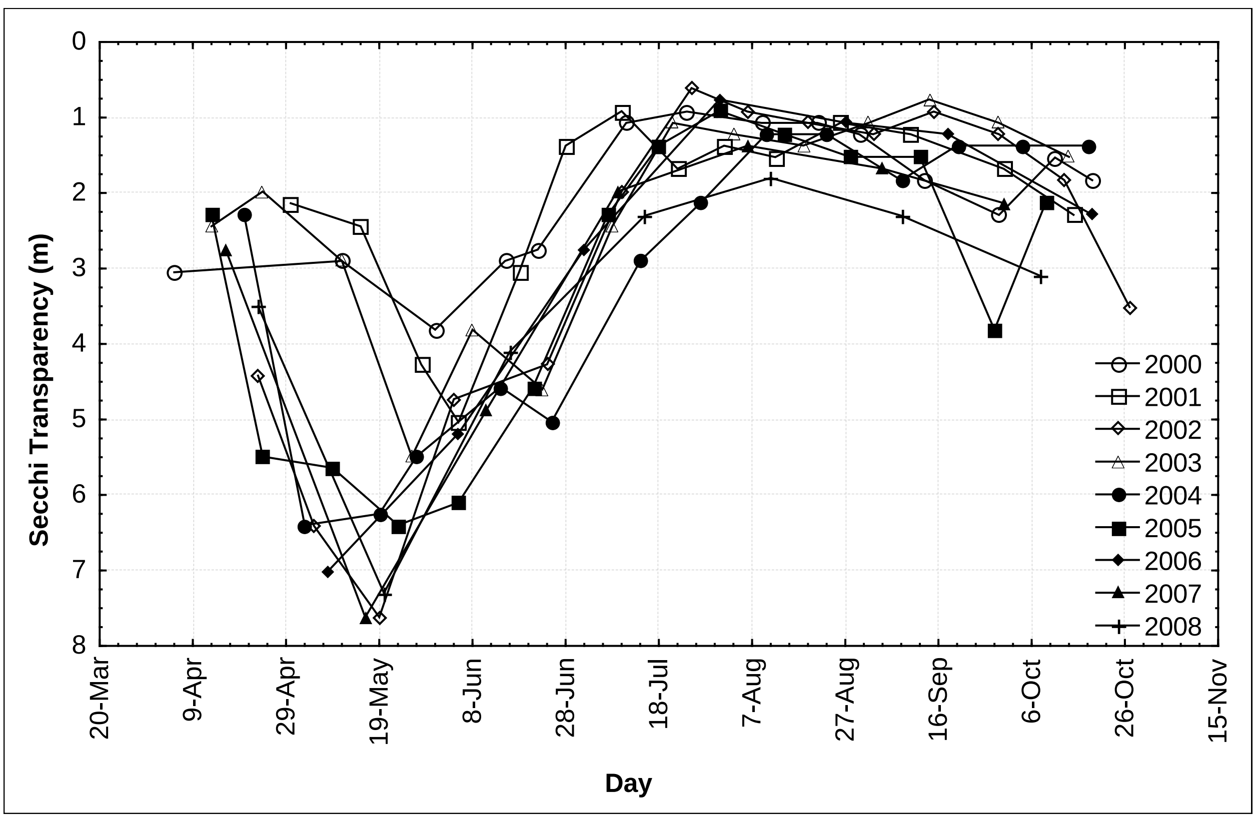

Figure 21. East Boot Lake Secchi Transparency Patterns

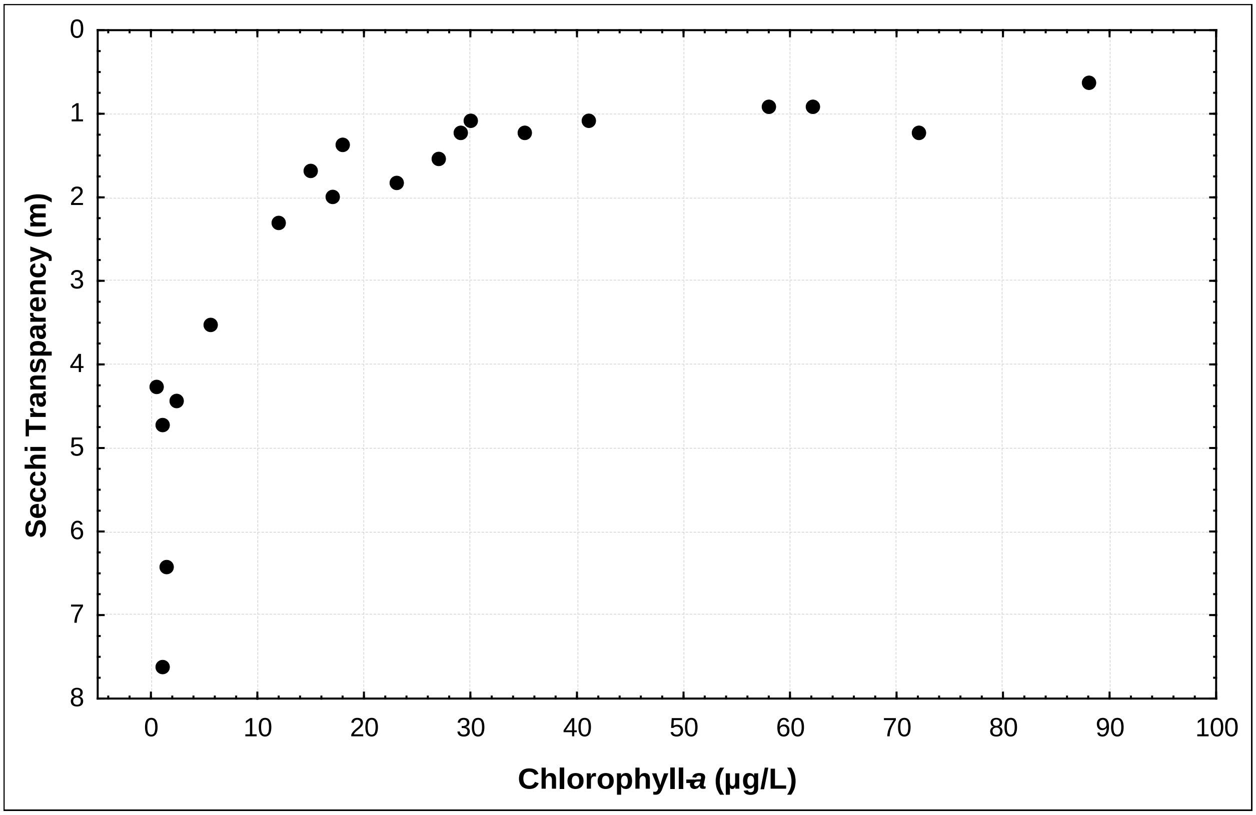

Figure 22. Relationship of Secchi Transparency and Chlorophyll-*a* in East Boot Lake

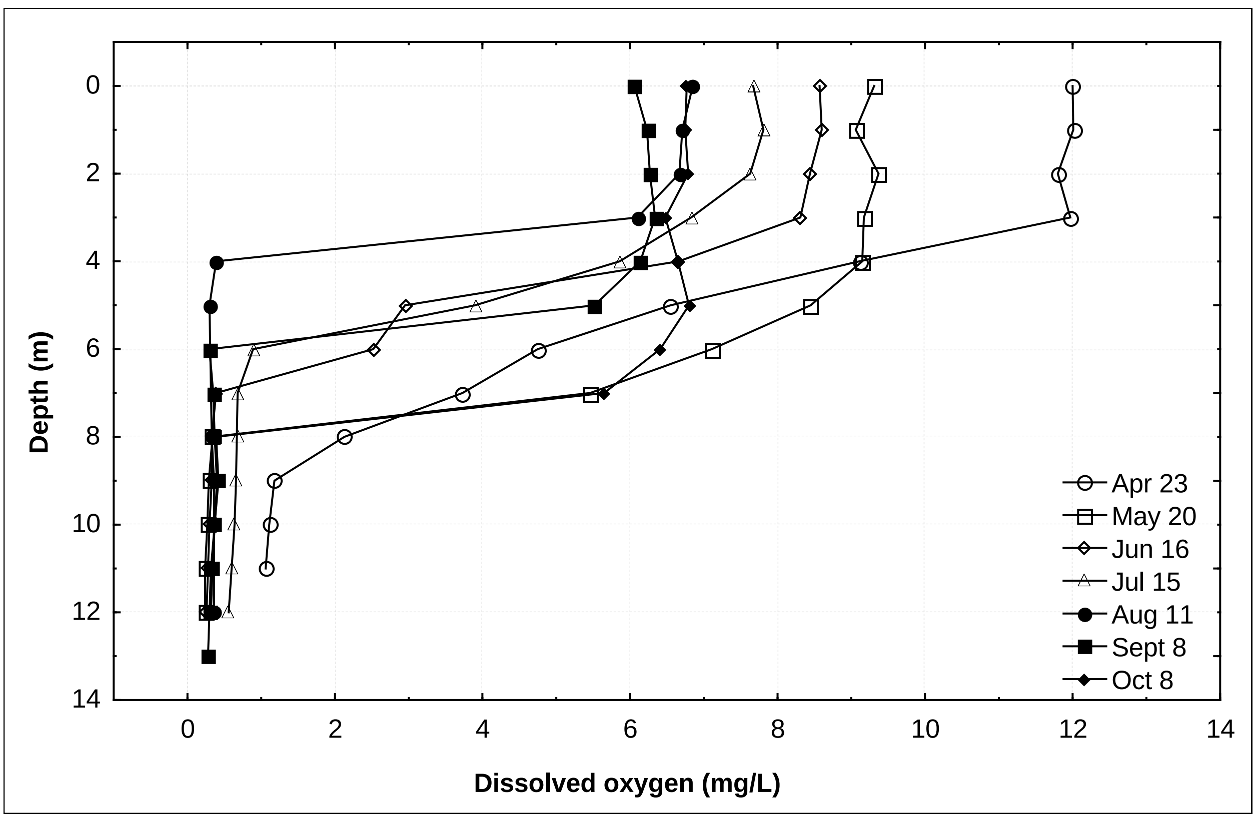

Figure 23. East Boot Lake Dissolved Oxygen, 2008

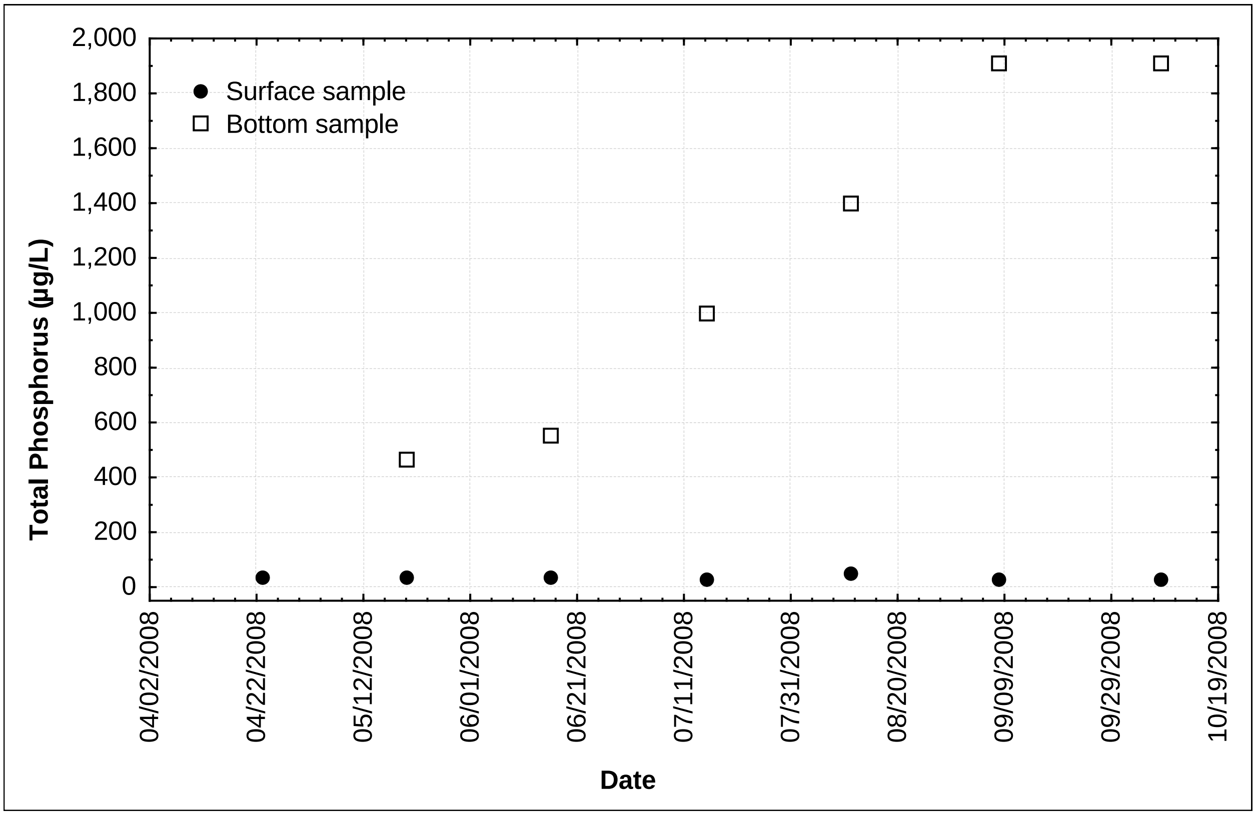

Figure 24. East Boot Lake Surface and Bottom Total Phosphorus Samples, 2008

4.7 In-Lake Impairment Assessment Summary

- Black bullhead are present in the lake, which could lead to high internal loading rates due to their habit of foraging in bottom sediments.
- Curly-leaf pondweed was abundant throughout much of the lake in June 2008. Curly-leaf pondweed dies back in June and July and releases phosphorus into the water column.
- The phytoplankton community is dominated by blue-green algae, and in the spring there is a high proportion of algal species that indicate eutrophic conditions..
- The zooplankton community is dominated by smaller species such as rotifers and copepods, with very few larger species of cladocera that are more effective at controlling algae.
- In late summer, TP and chlorophyll concentrations increase at the same time that large zooplankton decrease in abundance and less edible zooplankton increase in abundance, suggesting an effect of high planktivory on the plankton community.
- Portions of the lake stratify during the growing season and a high concentration of phosphorus builds up in the hypolimnion.

4.8 Phosphorus Source Inventory

4.8.1 Watershed Phosphorus Sources

The contributing watershed to East Boot Lake includes watershed runoff coming from the direct drainage to the lake and drainage from West Boot Lake. It is estimated that East Boot Lake receives 47 pounds of phosphorus annually from watershed runoff (Table 13). Approximately 9% of the phosphorus is coming from West Boot Lake. Within the East Boot Lake watershed there is one registered feedlot (not regulated by an NPDES permit), housing approximately 80 animal units. The feedlot is the largest contributor of watershed phosphorus to the lake.

The 2030 phosphorus load from direct watershed runoff is estimated to be 11 lb/yr, the same as under existing conditions. No major land use changes are projected between now and 2030 (see Section 4.2).

Table 13. East Boot Lake Watershed Phosphorus Source Summary, Existing Loads

Phosphorus Source	Annual TP Load (lb/yr)	Percent of Watershed TP Load	Area (ac)	Average Areal TP Load (lb/ac-yr)[1]	Average TP Concentra-tion (µg/L)[2]
Feedlots not Requiring NPDES Permit Coverage	31	66%	n/a	n/a	n/a
Direct Watershed Runoff	11	23%	72	0.15	171
SSTS	1	2%	n/a	n/a	n/a
Upstream Lake Loading (West Boot Lake)[3]	4	9%	229	0.017	20
Total	**47**	**100%**			

[1] Annual TP load (lb/yr) divided by drainage area (ac)
[2] Annual TP load (lb/yr) divided by average annual volume of runoff [3.94 (average annual depth of runoff in inches) * drainage area (ac) * conversion factor]
[3] Calculations are from lake outlet; includes lake area and drainage area

4.8.2 Atmospheric Phosphorus Sources

Atmospheric deposition is estimated to be 12 lb/yr (see *Atmospheric Deposition* in Section 3.1.2 for more information).

4.8.3 Internal Phosphorus Sources

Internal loading accounts for an additional 16 to 253 lb/yr (134 lb/yr average) of phosphorus loading to the lake, representing 21% to 81%, respectively, of the total loading to the lake.

4.8.4 Phosphorus Load Summary

The total phosphorus load to East Boot Lake is 193 lb/yr (Table 14).

Table 14. East Boot Lake Phosphorus Source Summary, Existing Loads

Phosphorus Source	Phosphorus Load (lb/yr)
Watershed	47
Atmospheric	12
Internal	134
Total	**193**

4.9 TMDL Loading Capacity and Allocations

The phosphorus loading capacity of East Boot Lake is 185 lb/yr, to be split among allocations according to Table 15. To meet the TMDL, the total load to the lake needs to be reduced by 8 lb/yr.

Watershed scale pollutant load modeling was conducted and analyzed on an annual basis to establish this TMDL at a level necessary to attain and maintain applicable water quality standards. Daily wasteload allocations were derived from this analysis.

Table 15. East Boot Lake Existing Loads, TMDL Allocations, and Reductions Needed

Load Component	TP Existing	TP TMDL Allocation		TP Reduction	
	lb/yr	lb/yr	lb/day	lb/yr	%
WLA					
Construction stormwater (permit #MNR100001)	0.14	0.14	0.00038	0	0%
Industrial stormwater (permit # MNR50000)	0.14	0.14	0.00038	0	0%
Total WLA	**0.28**	**0.28**	**0.00076**	**0**	**0%**
LA*					
Watershed	47	24	0.066	23	49%
Atmospheric	12	12	0.033	0	0%
Internal	134	130	0.36	4.0	3.0%
Total LA	**193**	**166**	**0.46**	**27**	**14%**
MOS	**--**	**19**	**0.052**	**--**	**--**
Total	***193***	***185***	***0.51***	***27*****	***14%***

*LA components are broken down for guidance in implementation planning; the LA should be considered categorical.

**27 lb/yr reduction takes into account MOS; 8 lb/yr reduction (=27-MOS) needed to reach total loading capacity

5 FISH LAKE TMDL

5.1 Physical Characteristics

Fish Lake (ID 82-0064) is a shallow lake located in the City of Scandia, MN. The lake does not outlet under normal conditions, and therefore is considered landlocked for this study. Table 16 summarizes the lake's characteristics. Figure 25 illustrates the bathymetry of the lake.

Table 16. Fish Lake Characteristics

Characteristic	Value	Source
Lake total surface area (ac)	63.3	2008 MLCCS revised based on 2008 aerial photos
Percent lake littoral surface area	100	Calculated based on 2008 WCD bathymetry data
Lake volume (ac-ft)	247	Calculated (mean depth x surface area)
Mean depth (ft)	3.9	Calculated based on 2008 WCD bathymetry data
Maximum depth (ft)	7	Based on 2008 WCD bathymetry data
Drainage area (acres)	426.7	CMSCWD
Watershed area:lake area	6.7	Calculated

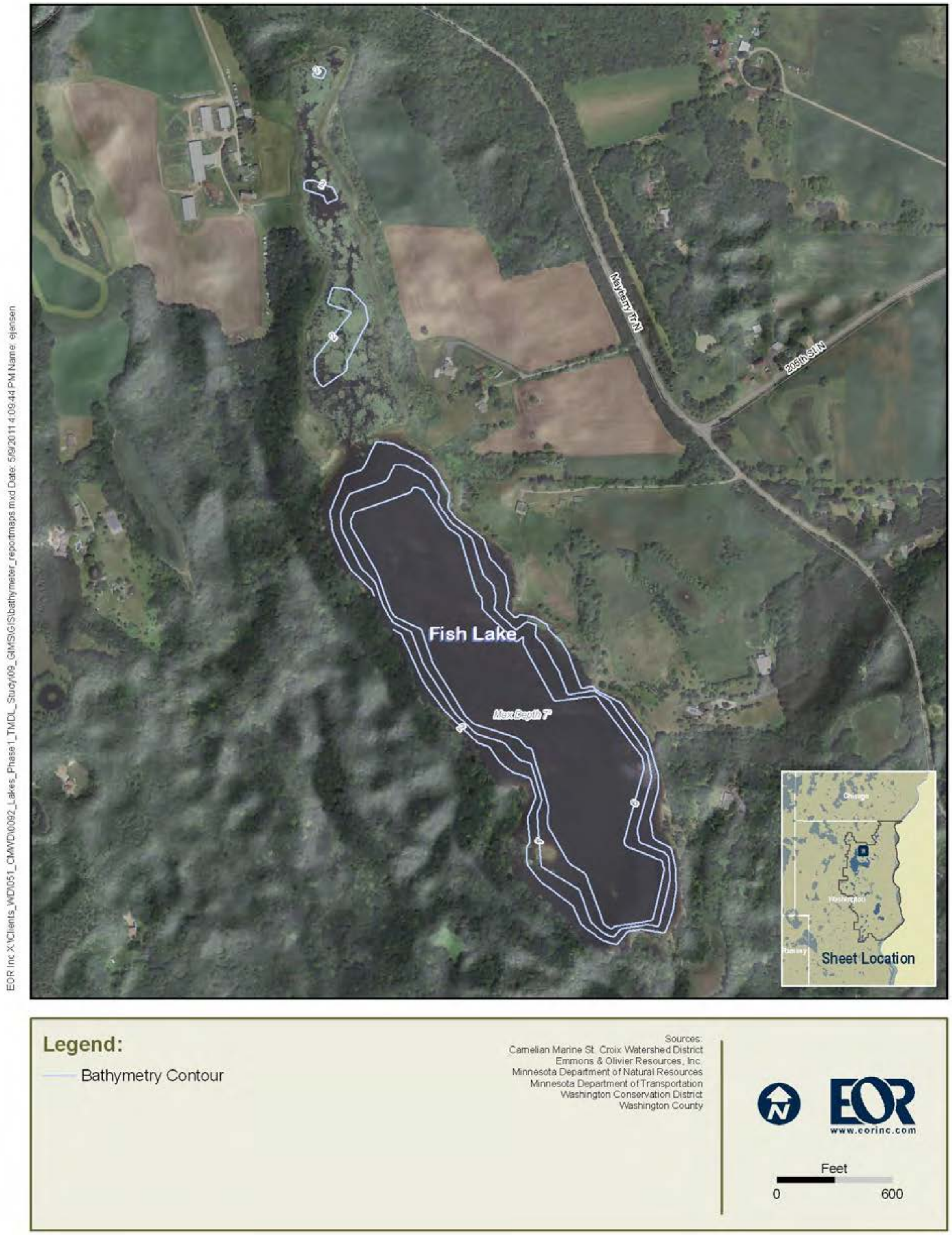

Figure 25. Fish Lake Bathymetry
Contour units are feet.

5.2 Land Use

At present, the Fish Lake watershed is dominated by undeveloped land (Table 17). Agriculture is the second most dominant land use. Farmsteads and single family residential land uses are found throughout the watershed. No major land use changes are projected between now and 2030 (Table 18); changes are assumed to be the result of Metropolitan Council's re-categorization of 2030 land use as compared to 2005 land use.

Table 17. Fish Lake Watershed Land Use, 2005
(2005 Generalized Land Use for the Twin Cities Metropolitan Area)

Land Use	Total Acres	% of Watershed
Agricultural	114.6	26.8%
Farmstead	7.0	1.6%
Industrial and Utility	-	-
Institutional	-	-
Park, Recreation, or Preserve	-	-
Retail and Other Commercial	-	-
Seasonal/Vacation	-	-
Single Family Detached	30.1	7.0%
Undeveloped	263.7	61.8%
Water	11.5	2.7%
Total	**426.7**	**100.0%**

Table 18. Fish Lake Watershed Land Use, 2030
(Regional Planned Land Use for the Twin Cities Metropolitan Area)

Land Use	Total Acres	% of Watershed
Agricultural	-	-
Airport	-	-
Commercial	-	-
Industrial	-	-
Institutional	-	-
Mixed Use	-	-
Multifamily Residential	-	-
Multi-Optional Development	-	-
Open Space or Restrictive Use	-	-
Park and Recreation	-	-
Railway (inc. LRT)	-	-
Rights-of-Way (i.e., Roads)	-	-
Rural or Large-Lot Residential	415.3	97.3%
Single Family Residential	-	-
Vacant or No Data	-	-
Water	11.5	2.7%
Total	**426.8***	**100.0%**

* 2030 total acres do not match 2005 total acres due to rounding.

5.3 Existing Studies, Monitoring, and Management

Based on an Aerial Lakeshore Analysis study (CMWD 1999), the greatest influence on the lake is non-point source runoff from agricultural fields adjacent to the lake followed by a single potentially failing septic system.

In 2000 a phosphorus sensitivity analysis for several lakes in the Carnelian-Marine Watershed District was completed (CMWD 2000). The study noted that the water quality of Fish Lake exceeded the ecoregion goal of 40µg/L of total phosphorus and suggested that the lake be passively maintained.

The Fish Lake Watershed Management Plan was written as part of the Carnelian-Marine-St. Croix Watershed District's 2010 Watershed Management Plan. Management, monitoring and implementation activities are expected to be driven by an implementation plan developed based on this TMDL study.

5.4 Lake Uses

Fish Lake is used by the DNR for rearing walleye.

5.5 Biological Characteristics

5.5.1 Fisheries

Fish Lake is currently managed as a walleye rearing pond by the DNR. A fish toxin was applied in 2003 to eliminate the existing fish, and the lake was first stocked in 2004. In May of 2008 the lake was stocked with 336,000 walleye fry. A harvest was completed in early October 2008 removing 852 pounds of walleye fingerlings, yearlings, and adults. Golden shiners were the only other fish species observed.

5.5.2 Macrophytes

Macrophyte surveys were completed for Fish Lake in June and August of 2008. Curly-leaf pondweed was not observed during either survey (Figure 26). The distribution of macrophyte communities remained essentially the same between the June and August survey. A diversity of macrophyte species was present in the lake during both surveys (Table 19).

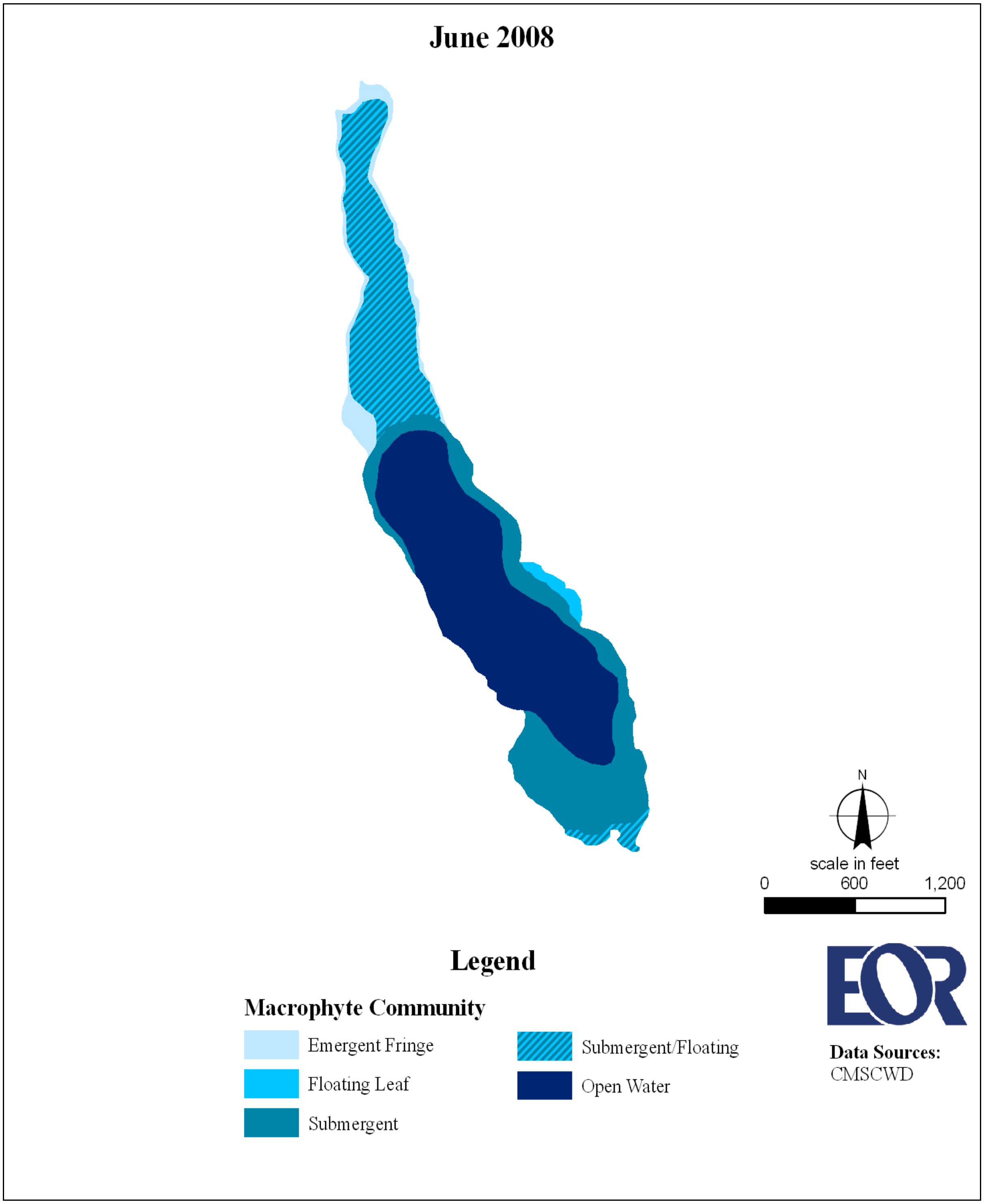

Figure 26. Distribution of Macrophyte Communities in Fish Lake

Table 19. Plant Species Observed During 2008 Fish Lake Macrophyte Surveys

Scientific Name	Common Name	June	August
Ceratophyllum demersum	Coontail	ü	ü
Elodea canadensis	Elodea	ü	ü
Nuphar lutea	Yellow water-lily	ü	ü
Nymphaea odorata	White water-lily	ü	ü
Potamogeton foliosus	Leafy pondweed	ü	
Vallisneria americana	Wild Celery	ü	

5.5.3 Plankton Community

Phytoplankton

The phytoplankton community in Fish Lake during the growing season of 2008 was dominated by blue-green algae (Figure 27). Over the course of the 2008 summer, green algae and blue-green co-dominated in early spring, followed by an apparent rise in blue-green algae to almost complete dominance (90% of algal cells) by late August (Figure 28). Algal data are missing from the July sampling period due to loss during shipping or at the laboratory. Algal indicators of high eutrophication are relatively high in spring, decrease in July and August, and increase again in the fall to represent over 20% of algal cells (Figure 28).

The species that compose these major groups also change over time. Spring shows a fairly even community dominance followed by a spike in the dominance of the blue-green *Microcystis* species (Figure 29). *Anabaena*, also a blue-green algae, replaces *Microcystis* in dominance followed by the increasing proportion of the green algae *Chlamydomonas* in September (Figure 29).

Algal blooms follow a fairly tight response to nutrient inputs, shown by chlorophyll-*a* concentrations tracking nutrient concentrations (Figure 30). The June chlorophyll peak corresponds to the *Microcystis* bloom while the September chlorophyll peak results from a bloom of *Chlamydomonas*.

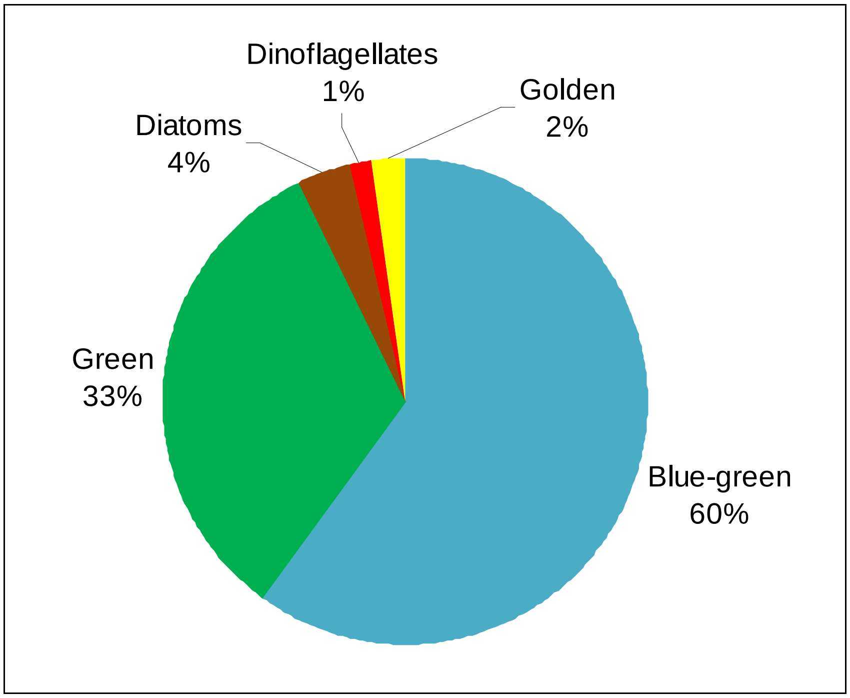

Figure 27. Total algal composition of major groups (%) in Fish Lake over 4 monthly sampling periods, 2008

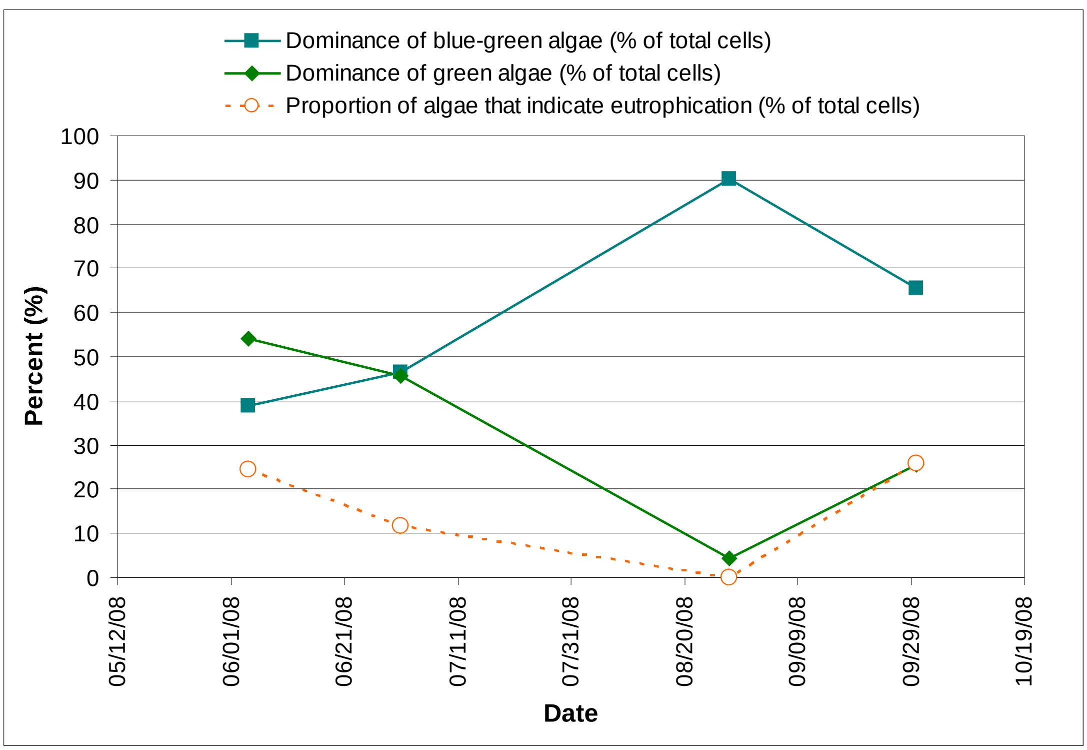

Figure 28. Dominance of major algal groups and indicator species in Fish Lake over four monthly sampling periods in 2008 (% of cells/300 counted)

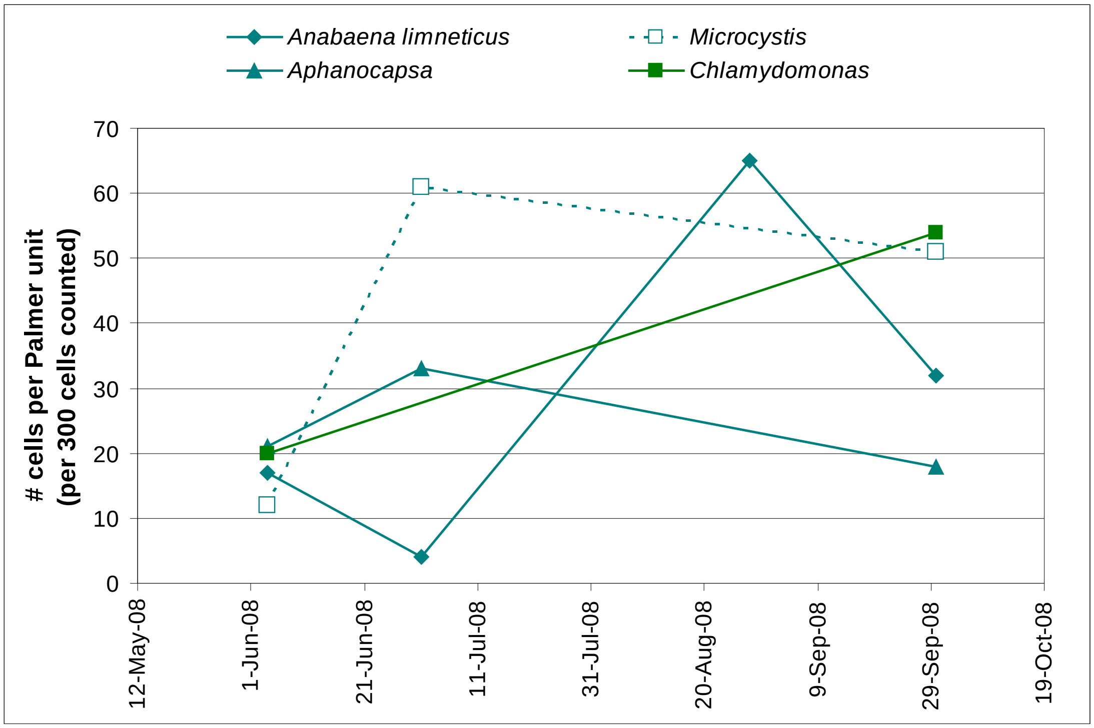

Figure 29. Dominance of the most abundant algal taxa in Fish Lake over four monthly sampling periods in 2008

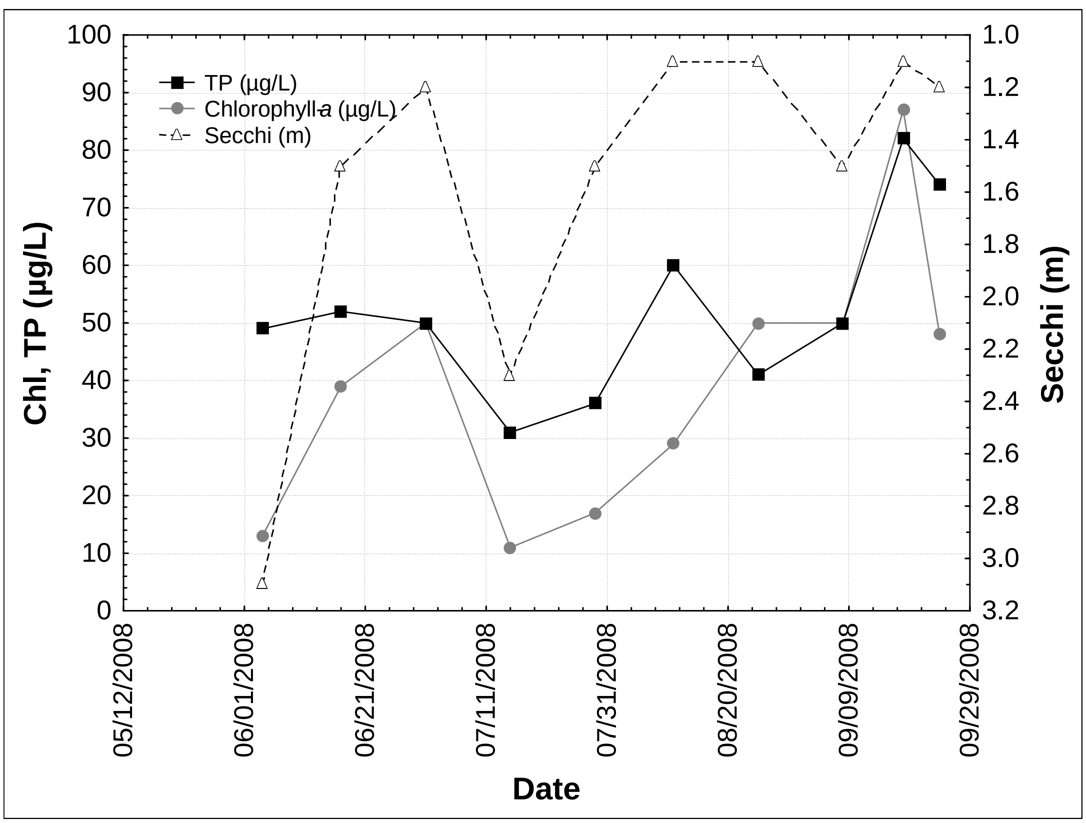

Figure 30. Chlorophyll-*a* concentrations (as a proxy for algal density), total phosphorus, and Secchi transparency for Fish Lake, 2008

Zooplankton

The three main zooplankton groups were relatively balanced over the summer of 2008 (Figure 31). The overall zooplankton composition, however, masks the extreme variation in composition over time (Figure 32). Cladocerans and copepods (in particular several genera of small cyclopoid copepods) are dominant in spring followed by a sudden crash and the dominance of rotifers. This relationship reversed in mid-summer but repeats in late summer and early fall. Species composition also changes over time (Figure 33). The cladoceran *Bosmina* is dominant in spring, and appears to recover again in mid-summer. The other major cladoceran in Fish Lake is *Daphnia*, which is only present in small numbers with a peak in August. The large copepod genus *Diaptomus* is present in spring but quickly disappears by July. The first period of rotifer dominance is due to the small *Keratella* species while the second period of rotifer dominance in September is due to large *Asplanchna* species.

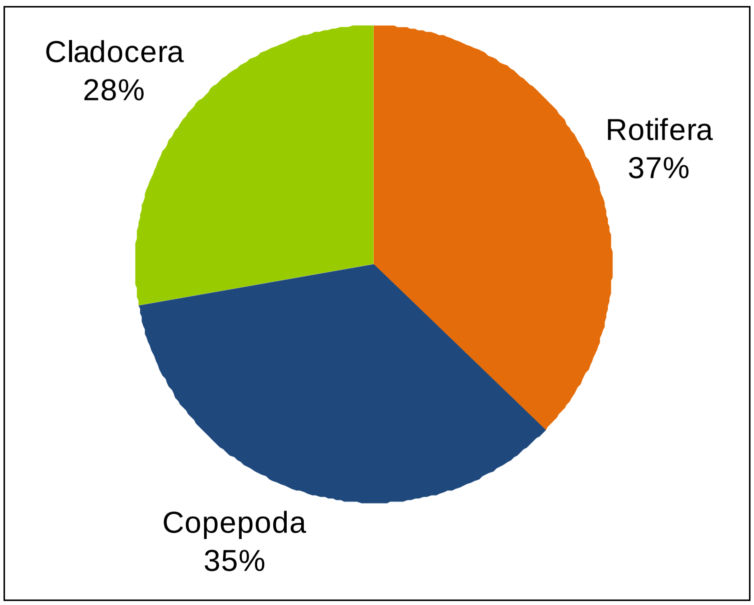

Figure 31. Total zooplankton composition of major groups (%) in Fish Lake over 5 monthly sampling periods, 2008

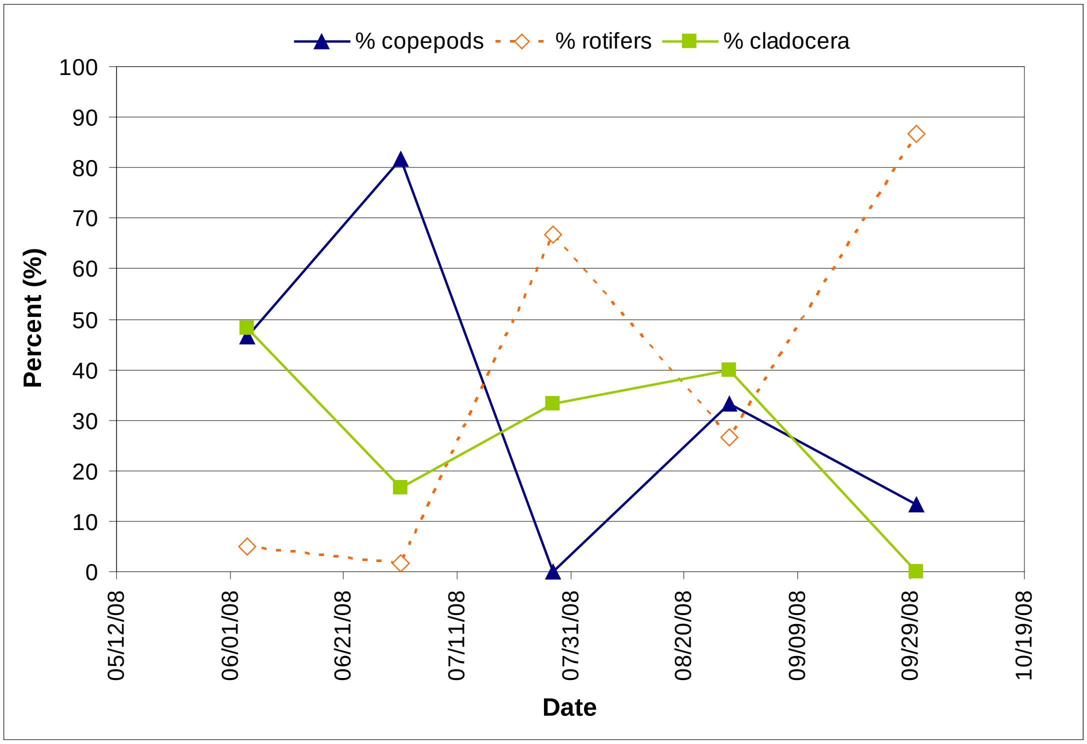

Figure 32. Dominance of major zooplankton groups and indicator species in Fish Lake over five monthly sampling periods in 2008 (as % of individuals counted)

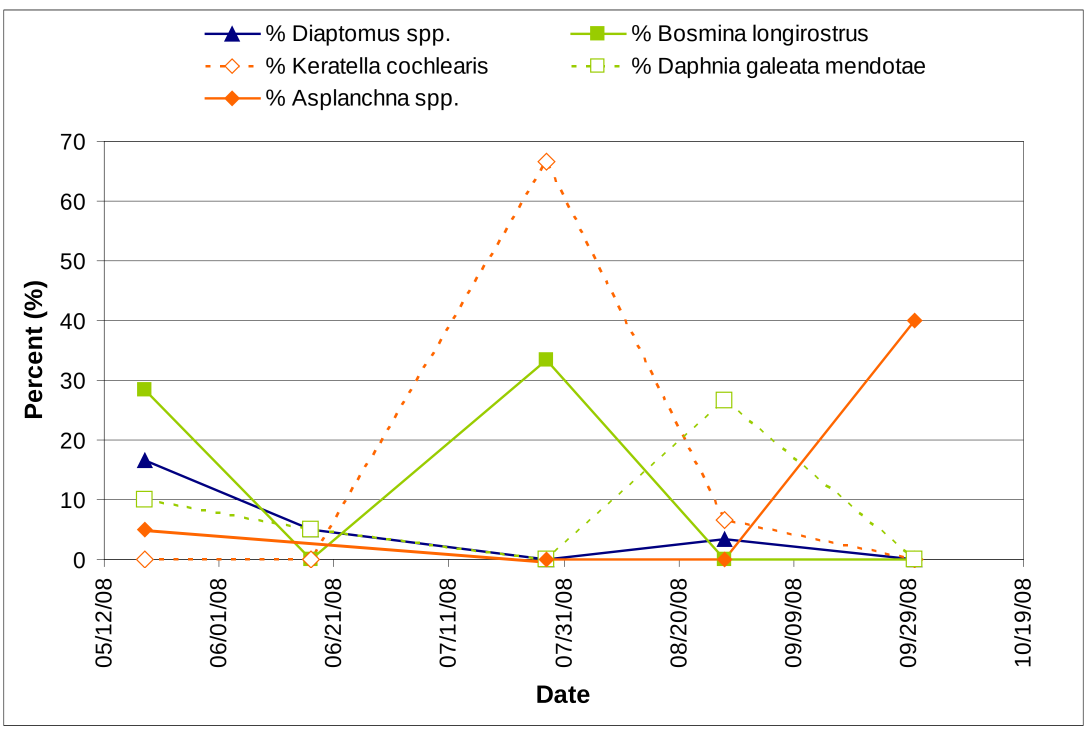

Figure 33. Dominance of the most abundant zooplankton taxa in Fish Lake over five monthly sampling periods in 2008 (as % of individuals counted)

Discussion

Overall the algal phenology shows a typical response to high nutrients, with a variety of blue-greens and the green algae *Chlamydomonas* shifting in dominance over the different blooms. Indicators of eutrophy are a relatively high proportion of the algal community and there is potential for toxic and nuisance blooms. Algae in Fish Lake bloom three times over the summer, the largest bloom occurring in September (Figure 30). These blooms are composed of different algae. The blue-green *Microcystis* is dominant particularly in the June bloom. This genus is capable of producing toxins as well as nuisance odors. The blue-greens *Aphanocapsa* (dominant in June and potentially in the mid-summer bloom) and *Anabaena* (dominant in the August bloom) are a nuisance but do not produce toxins. *Aphanocapsa* is an indicator of eutrophication. *Chlamydomonas* increases in dominance after the August bloom and is also an indicator of eutrophication. Other indicators of eutrophication decrease after spring but increase in dominance by September, with data unavailable for mid-summer.

The zooplankton community cycled over the summer of 2008, with spring dominance of cladocerans and copepods quickly crashing to be replaced by small, loricate (shelled) rotifers. This is indicative of planktivory and reduces the grazing capacity of the zooplankton community. This is particularly evident in the early presence followed by the total absence of large species like *Diaptomus* and *Daphnia*, which are common fish food. A late-summer recovery by *Daphnia* shows the potential for better grazer representation in the zooplankton community.

The first period of rotifer dominance was due to *Keratella*, and the second period of rotifer dominance (in September) is primarily due to large numbers of *Asplanchna*, a large, sac-like rotifer. Some authors consider this group an indicator of eutrophication but this is not universal. The data suggest that the *Keratella* over-grazed algae in their size range (they are much smaller than *Asplanchna*), which was followed by the dominance of the larger *Asplanchna*.

The September algal bloom (composed of both blue-green and green algae) led to the highest chlorophyll-*a* concentrations observed in 2008, and it corresponds to a period when cladocera were absent, also suggesting a lack of grazing capacity in the lake.

5.6 Water Quality

TP and Secchi transparency monitoring data are available from 2000-2008. Chlorophyll-*a* data are available from 2001-2008. A summary of the data indicates that the lake is not meeting any of the lake water quality standards (Table 20).

Table 20. Fish Lake, Surface Water Quality Means and Standards, 2000-2008

Parameter	Growing Season Mean (June – September)	Shallow Lake Standard
TP (µg/L)	112	60
Chlor-*a* (µg/L)	69	20
Secchi transparency (m)	0.8	1.0

Figure 34 to Figure 36 show the mean growing season total phosphorus (TP), chlorophyll-*a*, and Secchi transparency data from Fish Lake. While TP and chlorophyll-*a* fluctuate up and down, there is a trend in Secchi transparency of improving water clarity.

Figure 37 shows the seasonal chlorophyll-*a* patterns. Water quality generally declines in July and August, and starts improving again in the fall. TP and Secchi transparency patterns are similar.

There are relatively strong relationships between TP, chlorophyll-*a*, and Secchi transparency (TP vs. chlorophyll-*a* shown in Figure 38). Dissolved oxygen data suggests that the lake does not seasonally stratify (Figure 39).

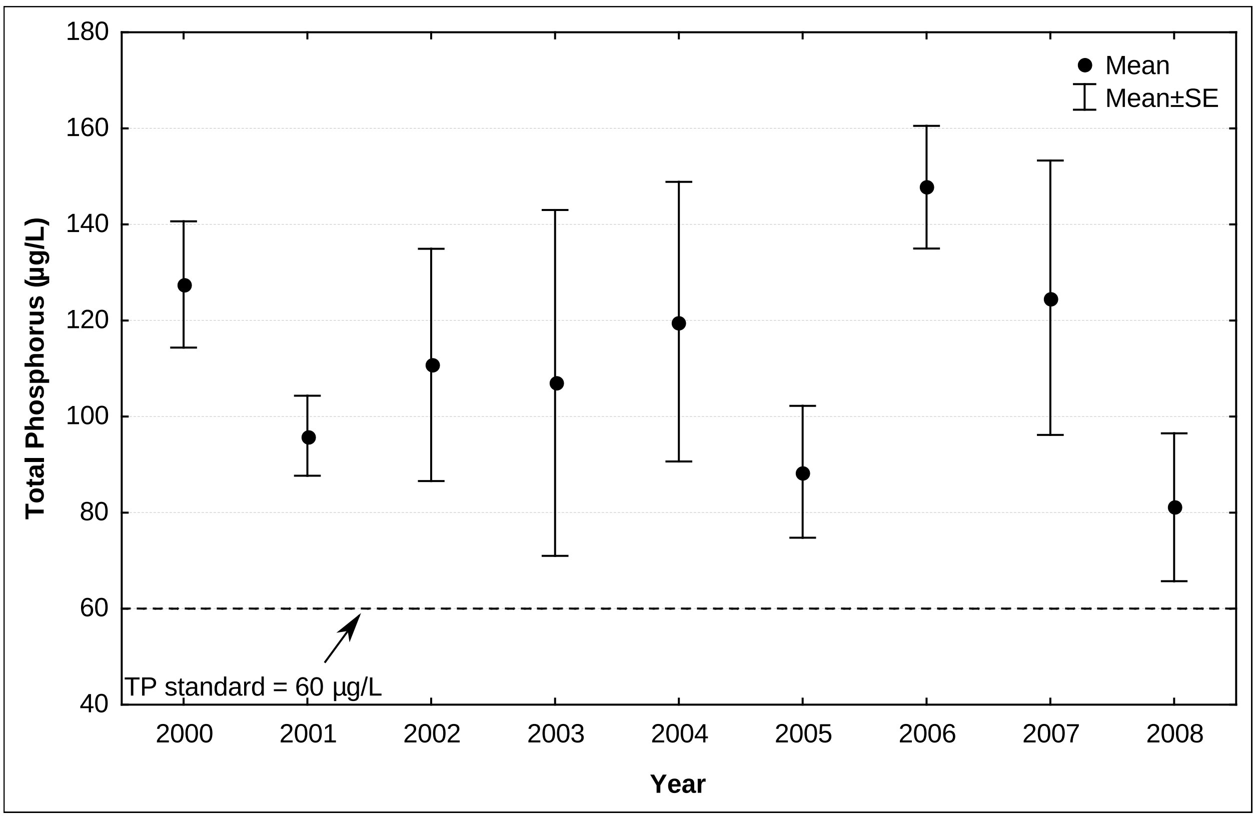

Figure 34. Fish Lake, Growing Season Means Total Phosphorus

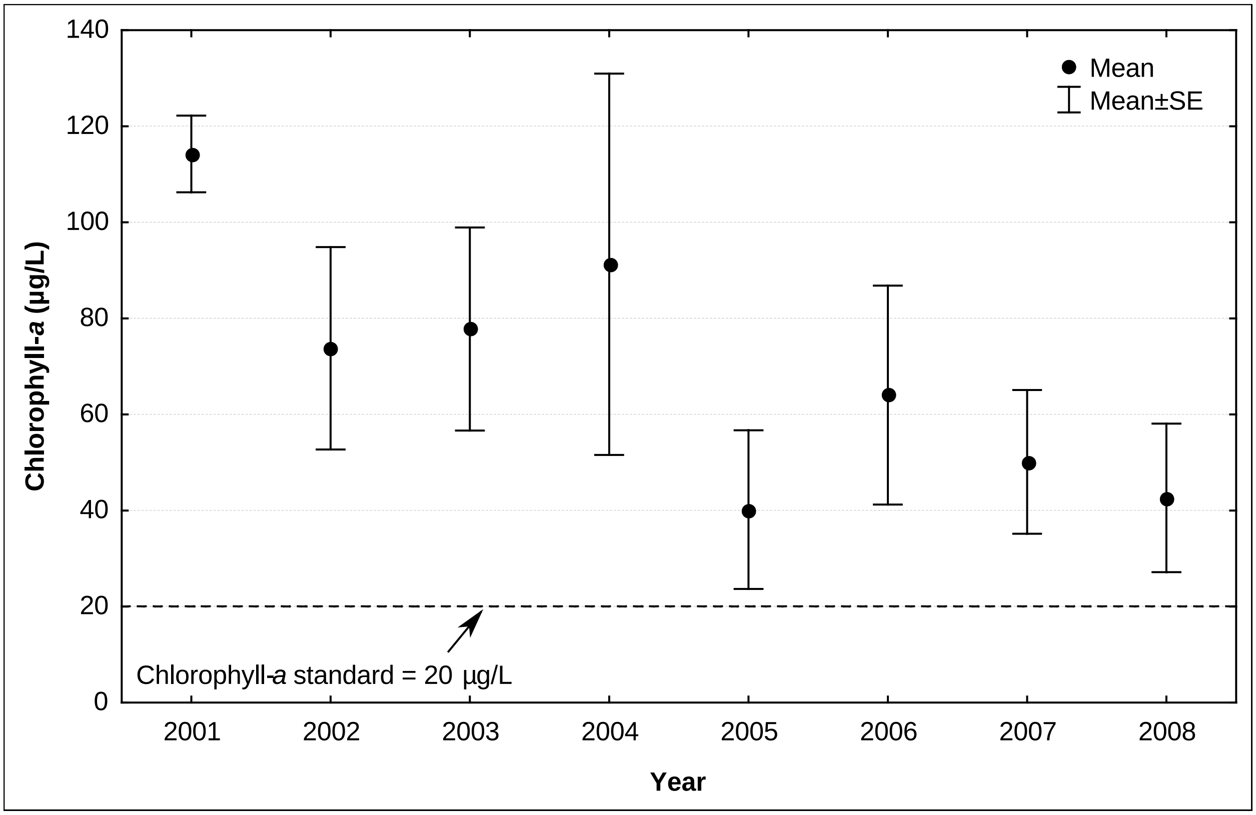

Figure 35. Fish Lake, Growing Season Means Chlorophyll-*a*

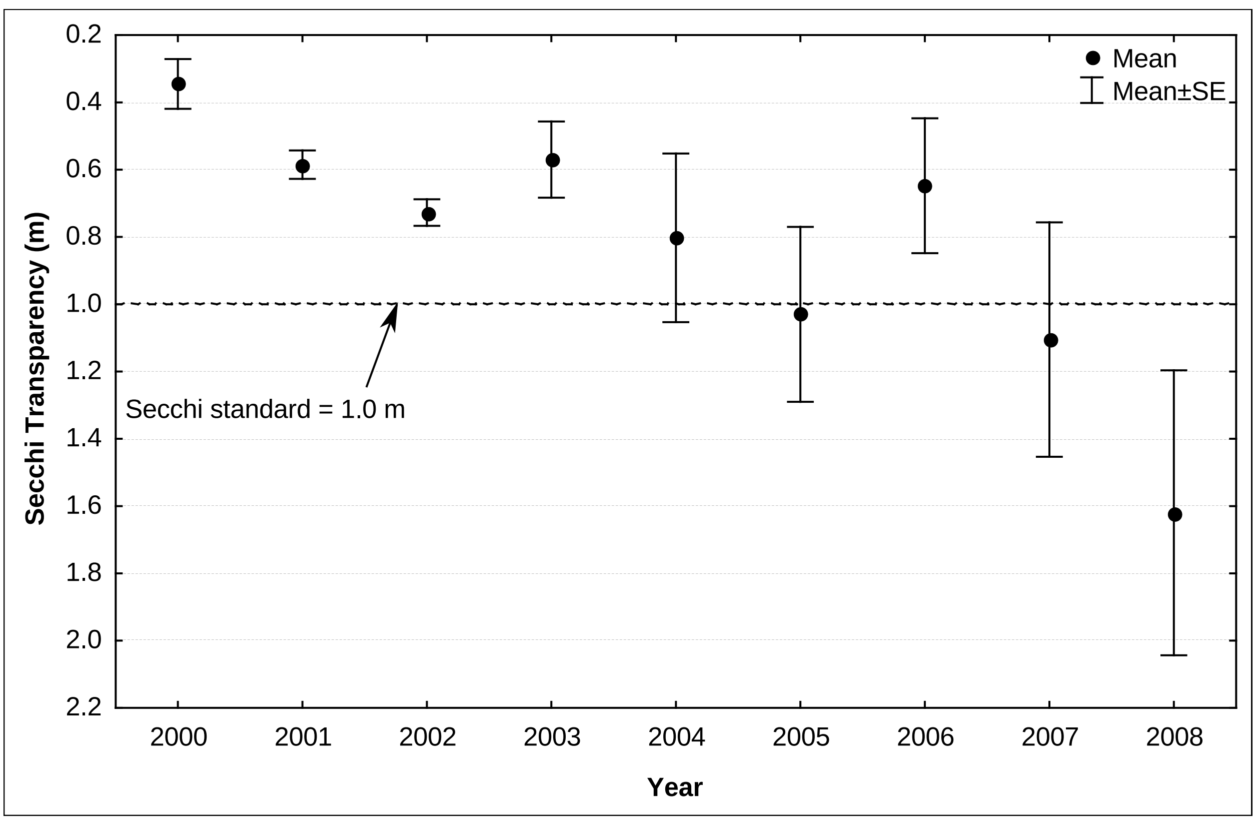

Figure 36. Fish Lake Growing Season Means Secchi Transparency, 2000-2008

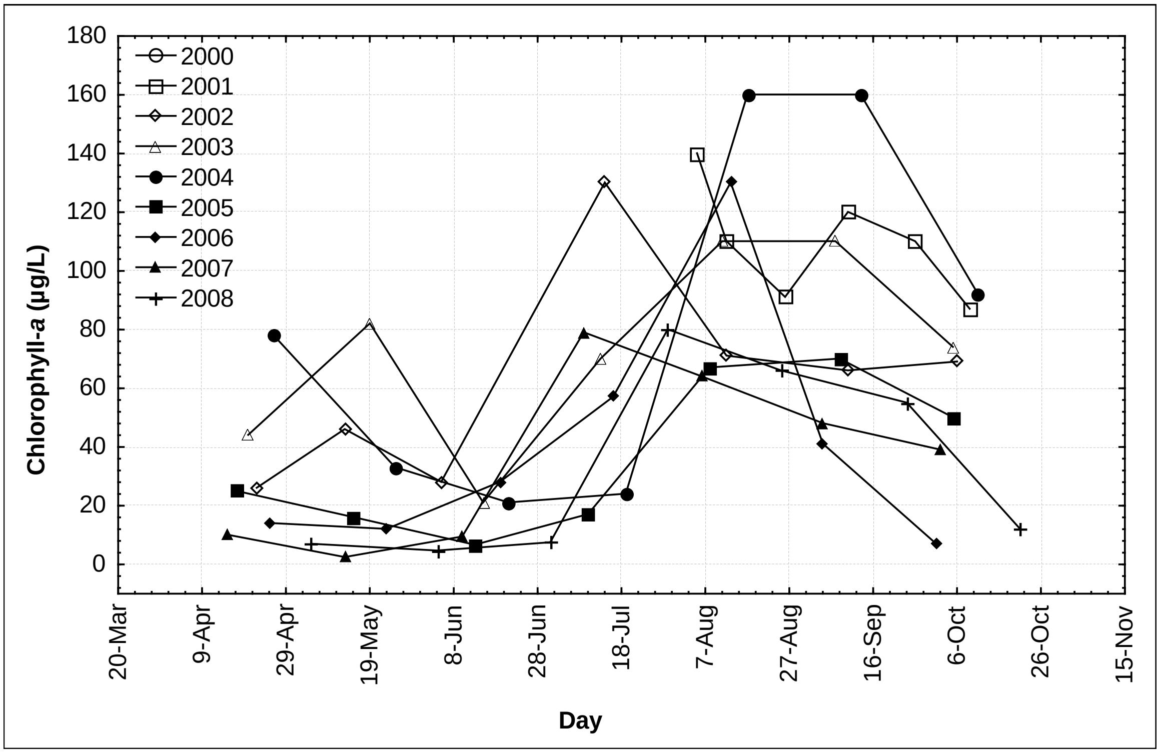

Figure 37. Fish Lake Seasonal Chlorophyll-*a* Patterns

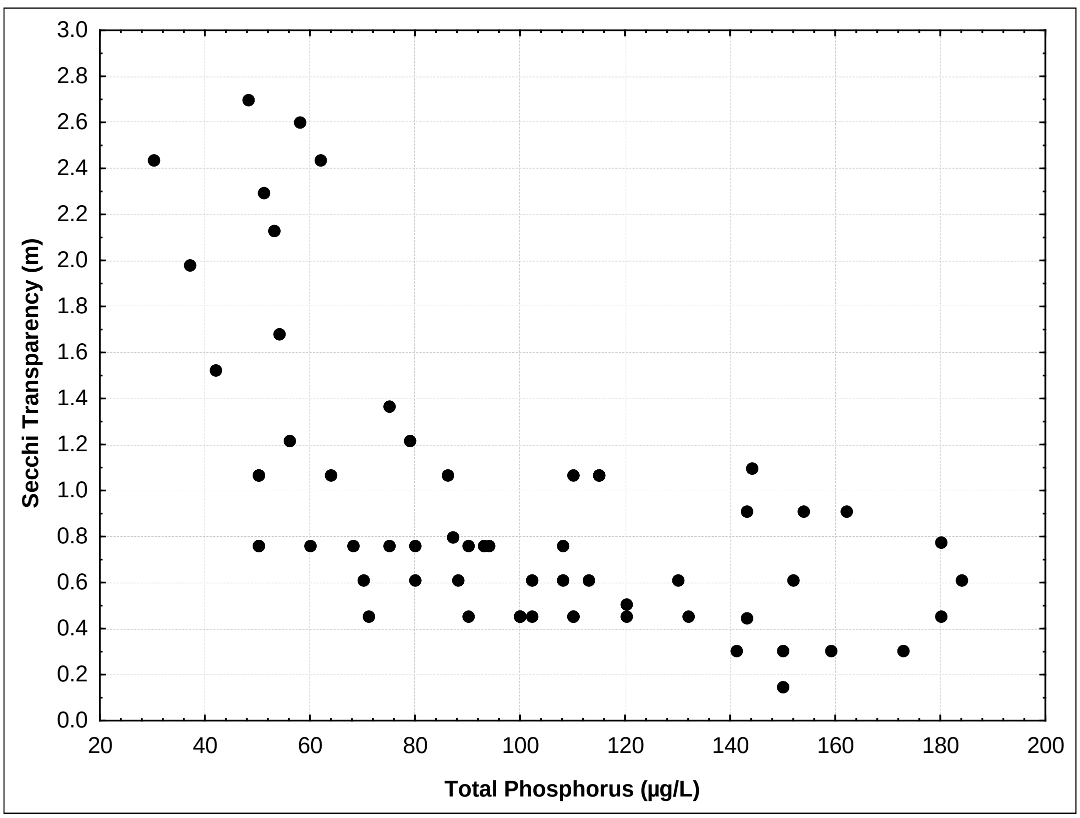

Figure 38. Relationship of Secchi Transparency to Total Phosphorus in Fish Lake

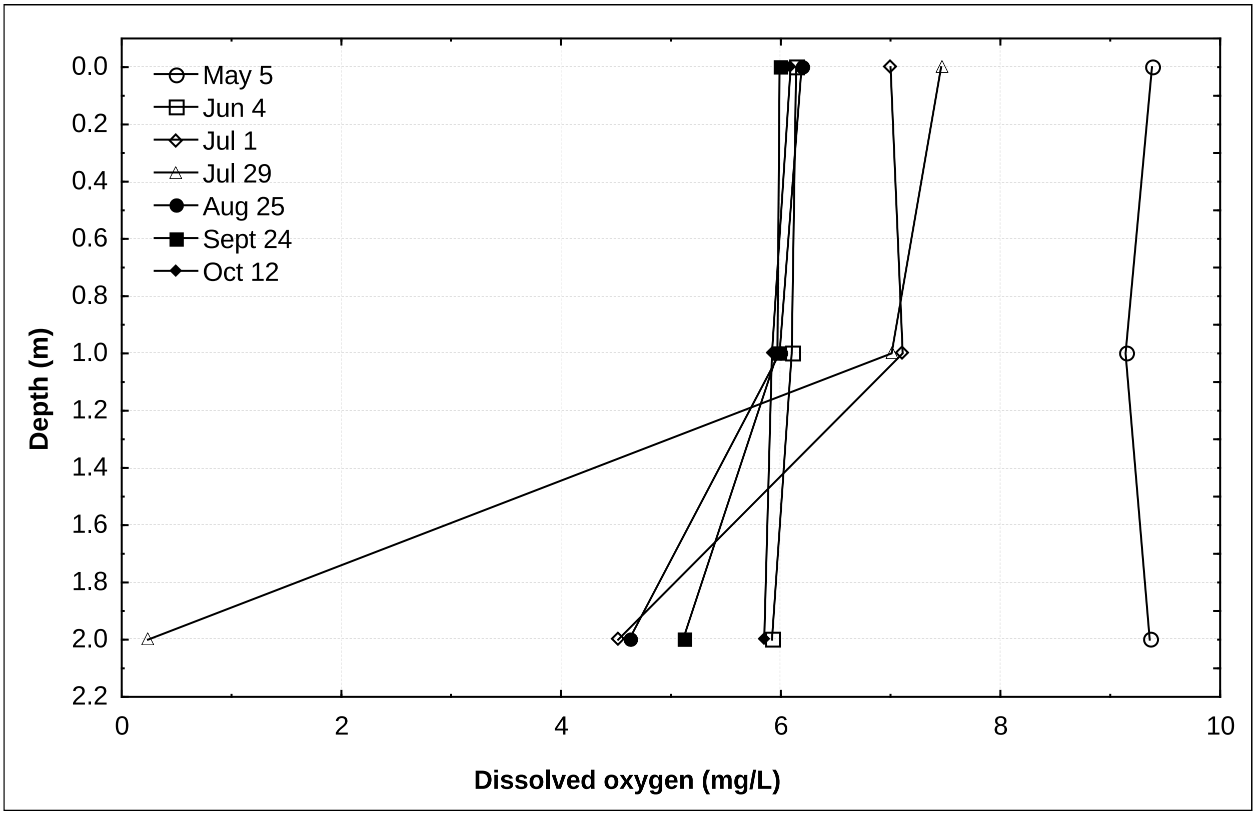

Figure 39. Fish Lake Dissolved Oxygen, 2008

5.7 In-Lake Impairment Assessment Summary

- The lake is used as a walleye rearing pond by the DNR. During a 2008 harvest, the only species observed were walleye and golden shiners.
- The lake is a shallow lake with a diverse community of native macrophytes.
- There is an overall dominance of blue-green algae; at times the potentially toxic *Microcystis* dominates the phytoplankton community.
- The dominance of major groups of zooplankton cycles throughout the season. The early dominance of copepods and cladocera followed by a decrease in their numbers and an increase in smaller rotifers is indicative of planktivory and a low grazing capacity.
- The lake is hypereutrophic, with TP and chlorophyll-*a* consistently not meeting standards. The data suggest a trend in improving water clarity. Despite the trend in increasing clarity, the data suggest that the lake is still in the turbid phase often seen in shallow lakes.

5.8 Phosphorus Source Inventory

5.8.1 Watershed Phosphorus Sources

It is estimated the Fish Lake receives 76 pounds of phosphorus annually from watershed runoff (Table 21). The largest watershed source of phosphorus is from direct watershed runoff from the contributing watershed (427 acres). One feedlot not requiring NPDES permit coverage exists within the watershed and contributes only 2 pounds of phosphorus annually to the lake.

The 2030 phosphorus load from direct watershed runoff is estimated to be 66 lb/yr, a minor change from 68 lb/yr under existing conditions. No major land use changes are projected between now and 2030 (see Section 5.2). The change in future loading is assumed to be the result of Metropolitan Council's re-categorization of 2030 land use as compared to 2005 land use (see *Direct Watershed Runoff: Direct Watershed Runoff under Future (2030) Conditions* in Section 3.1.2 for further discussion).

Table 21. Fish Lake Watershed Phosphorus Source Summary, Existing Loads

Phosphorus Source	Annual TP Load (lb/yr)	Percent of Watershed TP Load	Area (ac)	Average Areal TP Load (lb/ac-yr)[1]	Average TP Concentra-tion (µg/L)[2]
Feedlots not Requiring NPDES Permit Coverage	2	3%	n/a	n/a	n/a
Direct Watershed Runoff	68	89%	427	0.16	178
SSTS	6	8%	n/a	n/a	n/a
Total	**76**	**100%**			

[1] Annual TP load (lb/yr) divided by drainage area (ac)
[2] Annual TP load (lb/yr) divided by average annual volume of runoff [3.94 (average annual depth of runoff in inches) * drainage area (ac) * conversion factor]

5.8.2 Atmospheric Phosphorus Sources

Atmospheric deposition is estimated to be 17 lb/yr (see *Atmospheric Deposition* in Section 3.1.2 for more information).

5.8.3 Internal Phosphorus Sources

Internal loading accounts for an additional 22 to 204 lb/yr (113 lb/yr average) of phosphorus loading to the lake, representing 19% to 69%, respectively, of the total loading to the lake.

5.8.4 Phosphorus Load Summary

The total phosphorus load to Fish Lake is 206 lb/yr (Table 14).

Table 22. Fish Lake Phosphorus Source Summary, Existing Loads

Phosphorus Source	Phosphorus Load (lb/yr)
Watershed	76
Atmospheric	17
Internal	113
Total	**206**

5.9 TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Fish Lake is 152 lb/yr, to be split among allocations according to Table 23. To meet the TMDL, the total load to the lake needs to be reduced by 69 lb/yr.

Watershed scale pollutant load modeling was conducted and analyzed on an annual basis to establish this TMDL at a level necessary to attain and maintain applicable water quality standards. Daily wasteload allocations were derived from this analysis.

Table 23. Fish Lake Existing Loads, TMDL Allocations, and Reductions Needed

Load Component	TP Existing	TP TMDL Allocation		TP Reduction	
	lb/yr	lb/yr	lb/day	lb/yr	%
WLA					
Construction stormwater (permit #MNR100001)	0.22	0.22	0.00060	0	0%
Industrial stormwater (permit # MNR50000)	0.22	0.22	0.00060	0	0%
Total WLA	**0.44**	**0.44**	**0.0012**	**0**	**0%**
LA*					
Watershed	76	38	0.10	38	50%
Atmospheric	17	17	0.047	0	0%
Internal	113	82	0.22	31	27%
Total LA	***206***	***137***	**0.37**	***69***	**33%**
MOS	**--**	**15**	**0.04**	**--**	**--**
Total	***206***	***152***	***0.41***	***69****	***33%***

*LA components are broken down for guidance in implementation planning; the LA should be considered categorical.
**69 lb/yr reduction takes into account MOS; 54 lb/yr reduction (=69-MOS) needed to reach total loading capacity

6 GOOSE LAKE TMDL

6.1 Physical Characteristics

Goose Lake (ID 82-0059) is a lake located in the City of Scandia. Goose Lake is essentially landlocked, with a historic overflow to the northeast of the lake. Table 24 summarizes the lake's characteristics and Figure 40 illustrates the lake's bathymetry.

Table 24. Goose Lake Characteristics

Characteristic	Value	Source
Lake total surface area (ac)	85	2008 MLCCS revised based on 2008 aerial photos
Percent lake littoral surface area	61	Calculated based on DNR lake bathymetry data
Lake volume (ac-ft)	935	Calculated (mean depth x surface area)
Mean depth (ft)	11	Calculated based on DNR lake bathymetry data
Maximum depth (ft)	25	Based on DNR lake bathymetry data
Drainage area (acres)	516.9	CMSCWD
Watershed area:lake area	6.1	Calculated

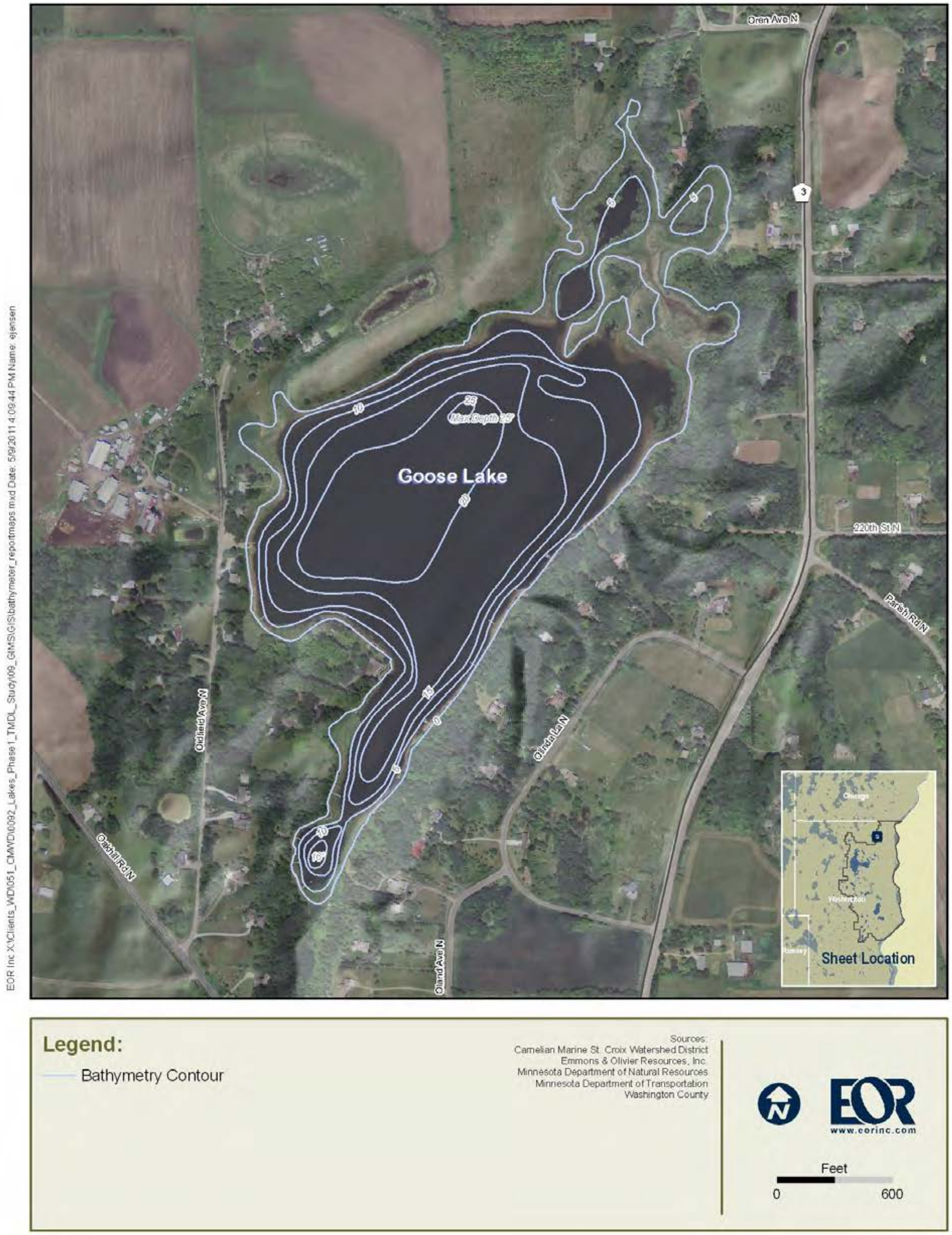

Figure 40. Goose Lake Bathymetry
Contour units are feet.

6.2 Land Use

Land use within the Goose Lake watershed is currently dominated by undeveloped, single family residential, and agricultural land uses (Table 25). Park land uses are also found in the watershed. No major land use changes are projected between now and 2030 (Table 26); changes are assumed to be the result of Metropolitan Council's re-categorization of 2030 land use as compared to 2005 land use.

Table 25. Goose Lake Watershed Land Use, 2005
(2005 Generalized Land Use for the Twin Cities Metropolitan Area)

Land Use	Total Acres	% of Watershed
Agricultural	161.3	31.2%
Farmstead	18.4	3.6%
Industrial and Utility	-	-
Institutional	-	-
Park, Recreation, or Preserve	2.7	0.5%
Retail and Other Commercial	-	-
Seasonal/Vacation	-	-
Single Family Detached	94.6	18.3%
Undeveloped	232.7	45.0%
Water	7.2	1.4%
Total	**516.9**	**100.0%**

Table 26. Goose Lake Watershed Land Use, 2030
(Regional Planned Generalized Land Use for the Twin Cities Metropolitan Area)

Land Use	Total Acres	% of Watershed
Agricultural	-	-
Airport	-	-
Commercial	-	-
Industrial	-	-
Institutional	-	-
Mixed Use	-	-
Multifamily Residential	-	-
Multi-Optional Development	-	-
Open Space or Restrictive Use	-	-
Park and Recreation	-	-
Railway (inc. LRT)	-	-
Rights-of-Way (i.e., Roads)	-	-
Rural or Large-Lot Residential	509.7	98.6%
Single Family Residential	-	-
Vacant or No Data	-	-
Water	7.2	1.4%
Total	**516.9**	**100.0%**

6.3 Existing Studies, Monitoring, and Management

The Town of New Scandia (now the City of Scandia) developed a management plan for Goose Lake in 2005 initiated by the Goose Lake Association in response to concerns regarding water quality, water levels, and lake use. The plan includes issues regarding the lake, lake goals and objectives, and a comprehensive management plan to achieve the goals. The plan suggests that internal loading is a significant factor in water quality of Goose Lake.

The Goose Lake Watershed Management Plan was written as part of the Carnelian-Marine-St. Croix Watershed District's 2010 Watershed Management Plan. Management, monitoring, and implementation activities are expected to be driven by an implementation plan developed based on this TMDL study. Educational programming is currently encouraging voluntary native landscaping in the nearshore area around the lake for water quality, habitat, and aesthetics. A potential future project is the development of a lake vegetation management plan.

6.4 Lake Uses

Goose Lake has a city-maintained concrete public access on Oldfield Avenue, but limited locations for shore-fishing by the public. The lake is managed by the DNR as a fishery for bluegills and northern pike.

6.5 Biological Characteristics

6.5.1 Fish

Goose Lake is managed as a fishery for bluegills and northern pike. The DNR has stocked the lake with northern pike, walleye, and largemouth bass in the past. An aeration system was installed in 1996-1997 to prevent winter kill; DNR owns the aerator and the City of Scandia operates it. Stocking of bass to control the bluegill population started after the aerator was installed.

The DNR conducted a fishery survey on Goose Lake in 2005. In the survey, bluegill and black bullhead were the most abundant fish species observed. 40% of the bluegill were under 5 inches long, with the remainder under 8 inches long, indicating the potential that the population is stunted due to high densities and low food resources. Under these conditions, the fish can be benthivorous, foraging in the bottom sediments similar to black bullhead. This action can increase internal loading through physical disturbance of the bottom sediments. Black crappie, largemouth bass, northern pike, pumpkinseed sunfish, and yellow perch were also observed in the survey. Anecdotal evidence from more recent years suggests that black bullhead and bluegill are not overabundant on the lake anymore.

6.5.2 Macrophyte Community

Macrophyte surveys were completed for Goose Lake in June and August of 2008. Curly-leaf pondweed was observed in the June survey in scattered patches in shallow water near the shore of the lake (Figure 41). Curly-leaf pondweed was not observed in the August survey. The distribution of macrophyte community types remained essentially the same between the June and

August survey, with the majority of the lake lacking macrophyte vegetation. The macrophyte species observed in Goose Lake are listed in Table 27.

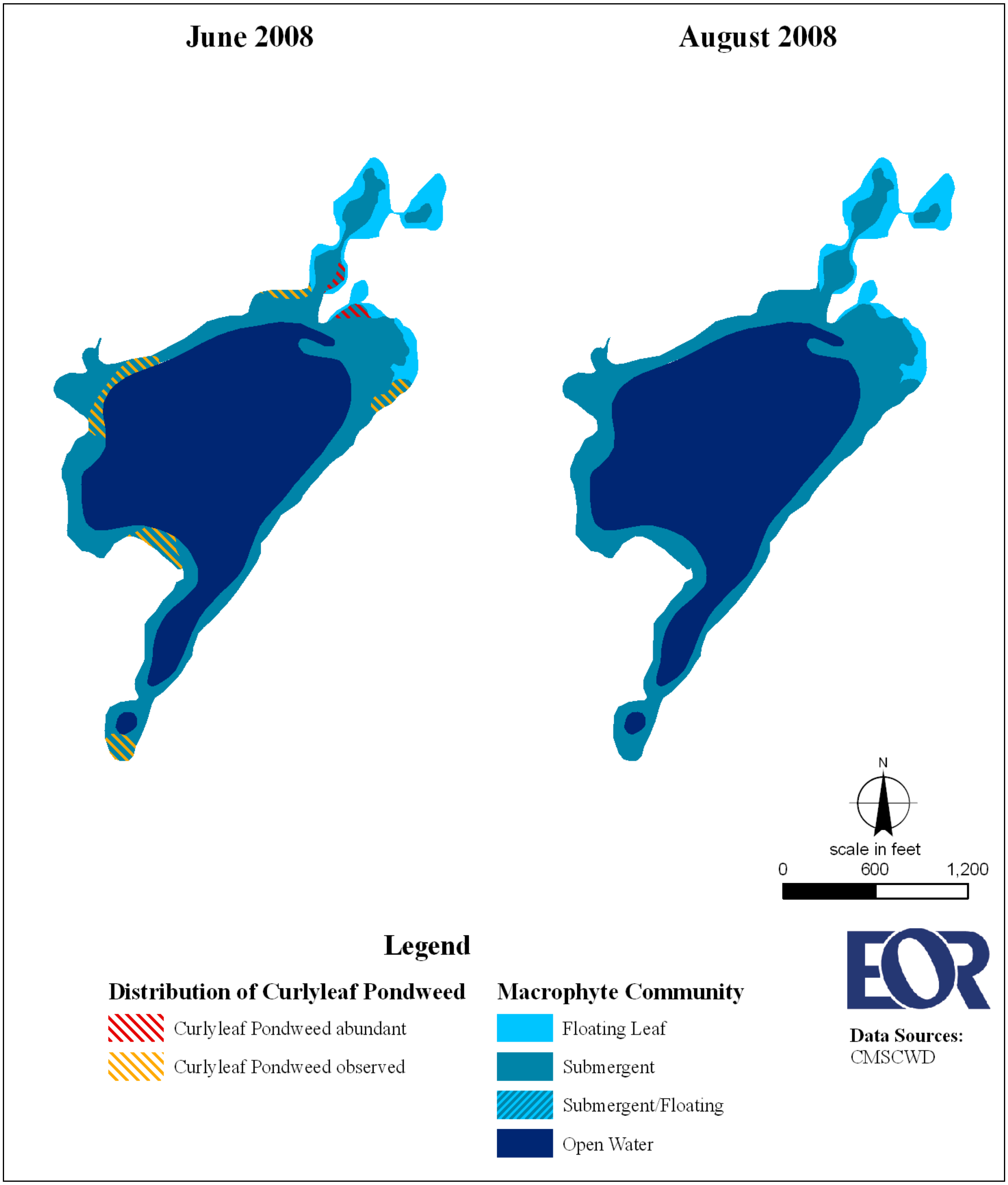

Figure 41 Distribution of Macrophyte Communities in Goose Lake

Table 27. Plant Species Observed During 2008 Goose Lake Macrophyte Surveys

Scientific Name	Common Name	June	August
Ceratophyllum demersum	Coontail	ü	ü
Elodea canadensis	Elodea	ü	ü
Nymphaea odorata	White water-lily	ü	ü
Potamogeton crispus	Curly-leaf pondweed	ü	
Potamogeton foliosus	Leafy pondweed	ü	

6.5.3 Plankton Community

Phytoplankton

Blue-green algae were the dominant algal group in Goose Lake over a 5-month sampling period (2008), followed by green algae (Figure 42). Blue-green algae become dominant in early summer, followed by a slow decline in proportional representation as green algae become more common (Figure 43). The most common blue-green genera is *Anabaena sphaeroides*, which can have negative impacts on aquatic fauna and produces nuisance blooms. Also present as a consistent component of the community is *Microcystis*, a blue-green algae that can produce the toxin microcystin.

Chlorophyll-*a* concentrations show two major algal blooms (Figure 45). The first bloom, which occurred in June, was due to the blue-green algae *Anabaena sphaeroides*. The second bloom started in August with another spike in September and was primarily due to increases in the green algae *Chlamydomonas* (Figure 44).

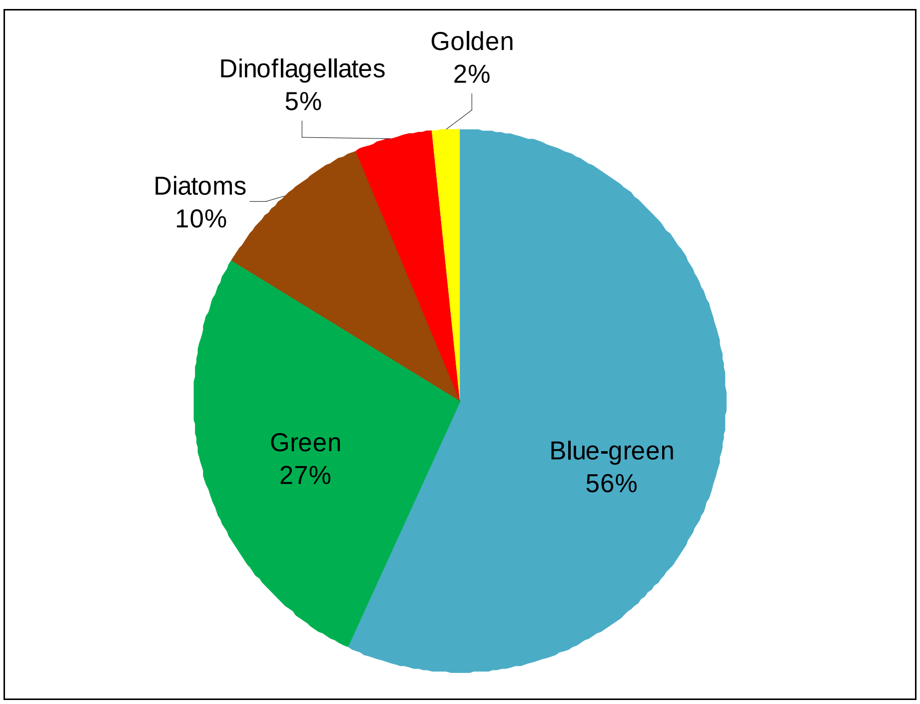

Figure 42. Total algal composition of major groups (%) in Goose Lake over 5 monthly sampling periods, 2008

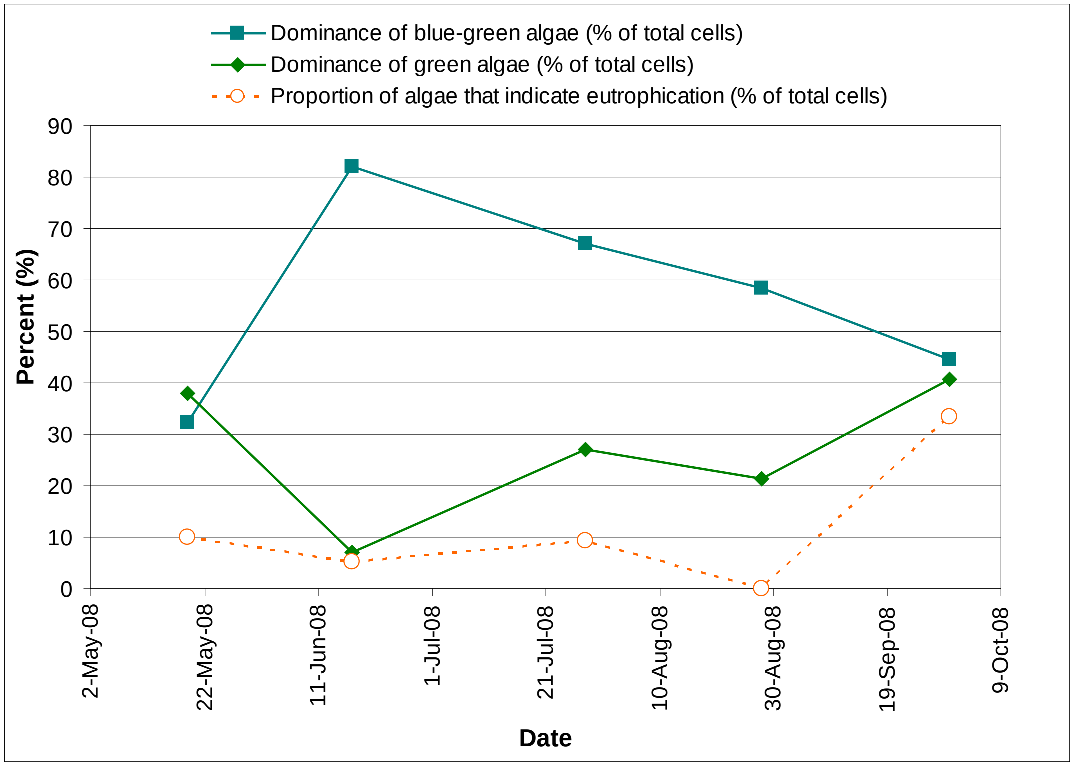

Figure 43. Dominance of major algal groups and indicator species in Goose Lake over five monthly sampling periods in 2008 (% of cells/300 counted)

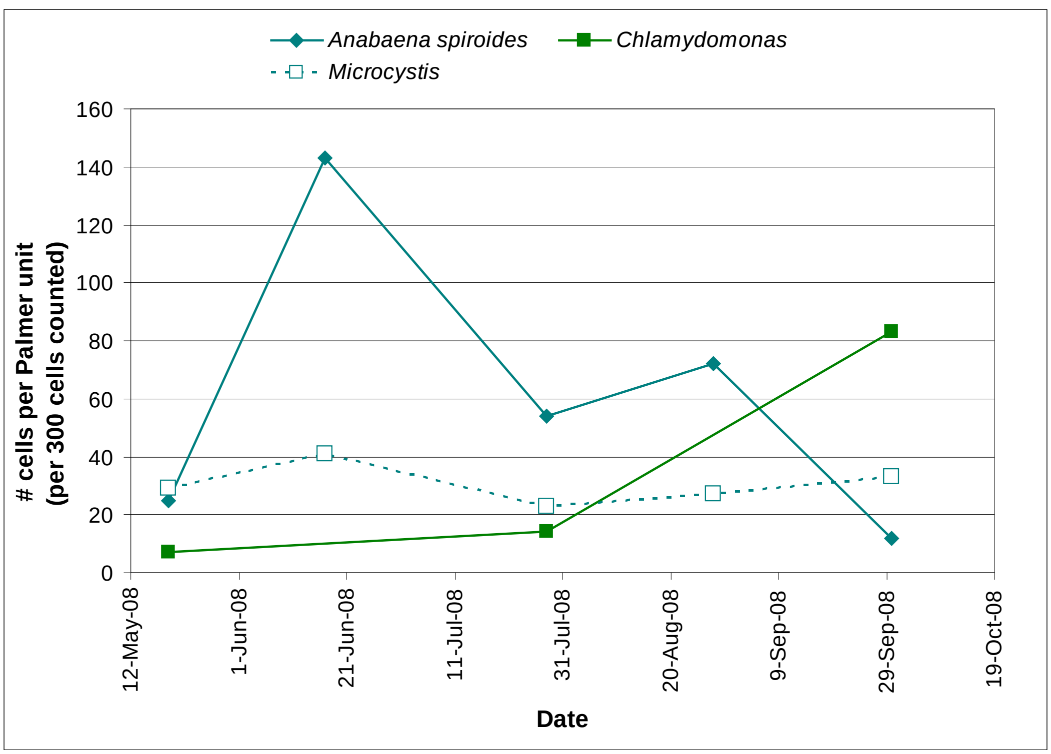

Figure 44. Dominance of the most abundant algal taxa in Goose Lake over five monthly sampling periods in 2008

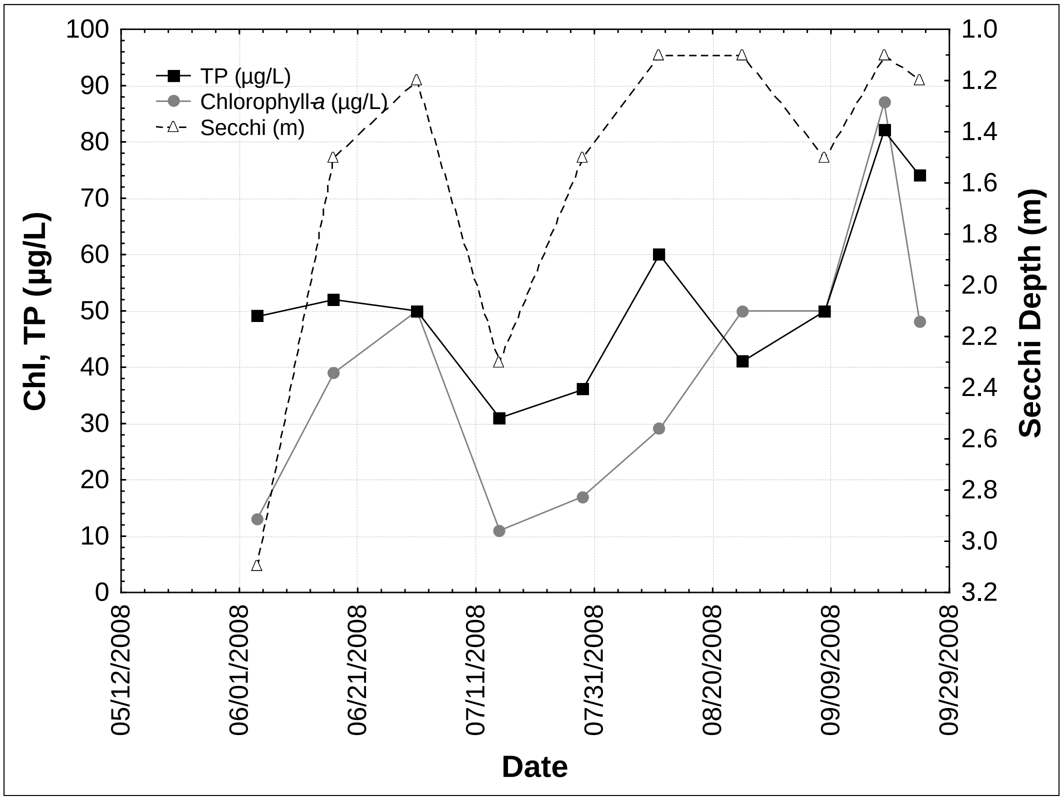

Figure 45. Chlorophyll-*a* concentrations (as a proxy for algal density), total phosphorus, and Secchi transparency for Goose Lake, 2008

Zooplankton

The zooplankton community in Goose Lake over five monthly sampling periods in 2008 was dominated by rotifers, followed by copepods (Figure 46). This relationship changes strongly over time (Figure 47). Copepods are the dominant group (primarily the genus *Diaptomus*) in spring but sharply decline in mid-summer when rotifers become the dominant zooplankton group (Figure 48). Cladocerans never become a major component of the zooplankton community, but are represented by the large *Daphnia galeata mendotae*. The most common rotifer is *Keratella cochlearis*, a small rotifer with a hard shell or lorica.

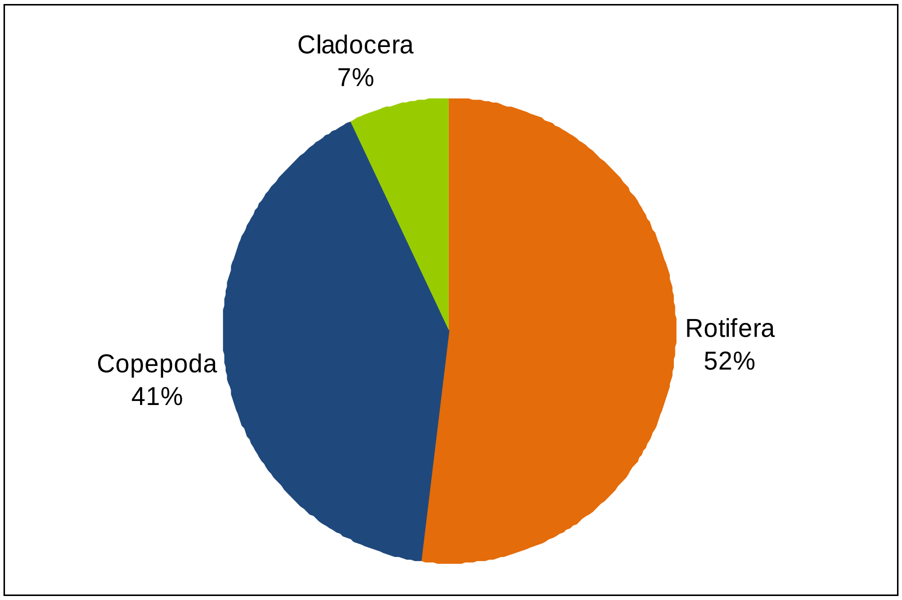

Figure 46. Total zooplankton composition of major groups (%) in Goose Lake over 5 monthly sampling periods, 2008

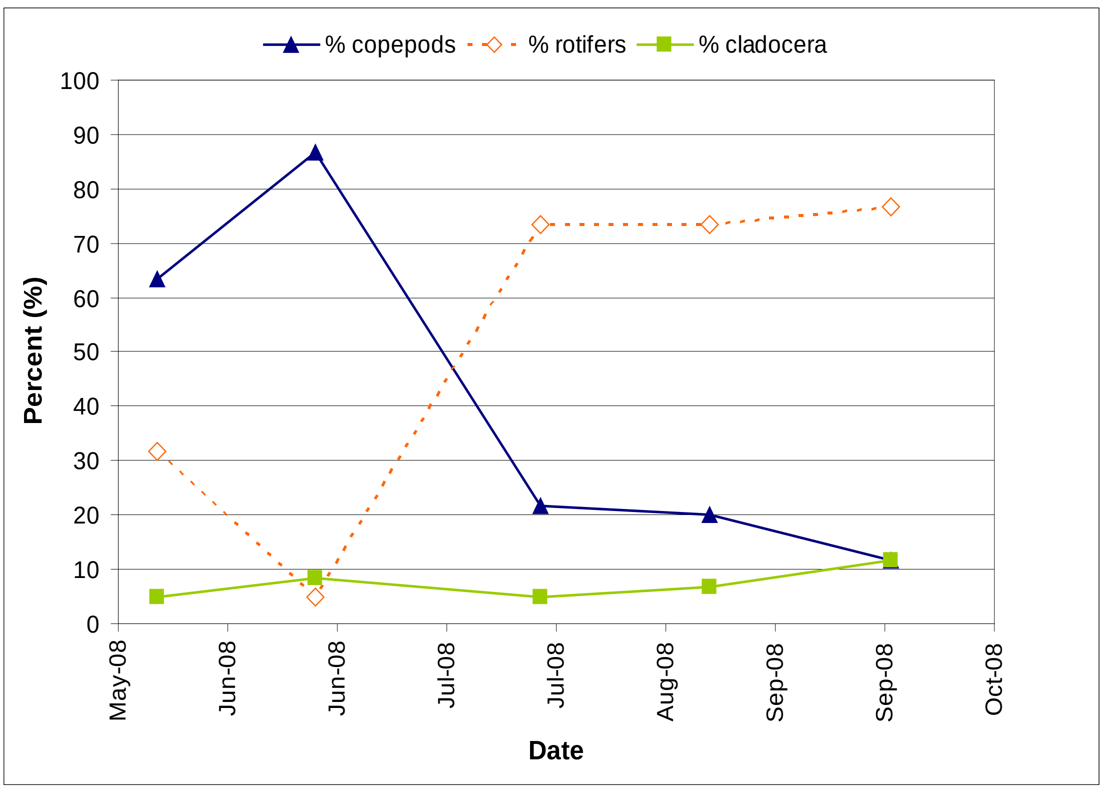

Figure 47. Dominance of major zooplankton groups and indicator species in Goose Lake over five monthly sampling periods in 2008 (as % of individuals counted)

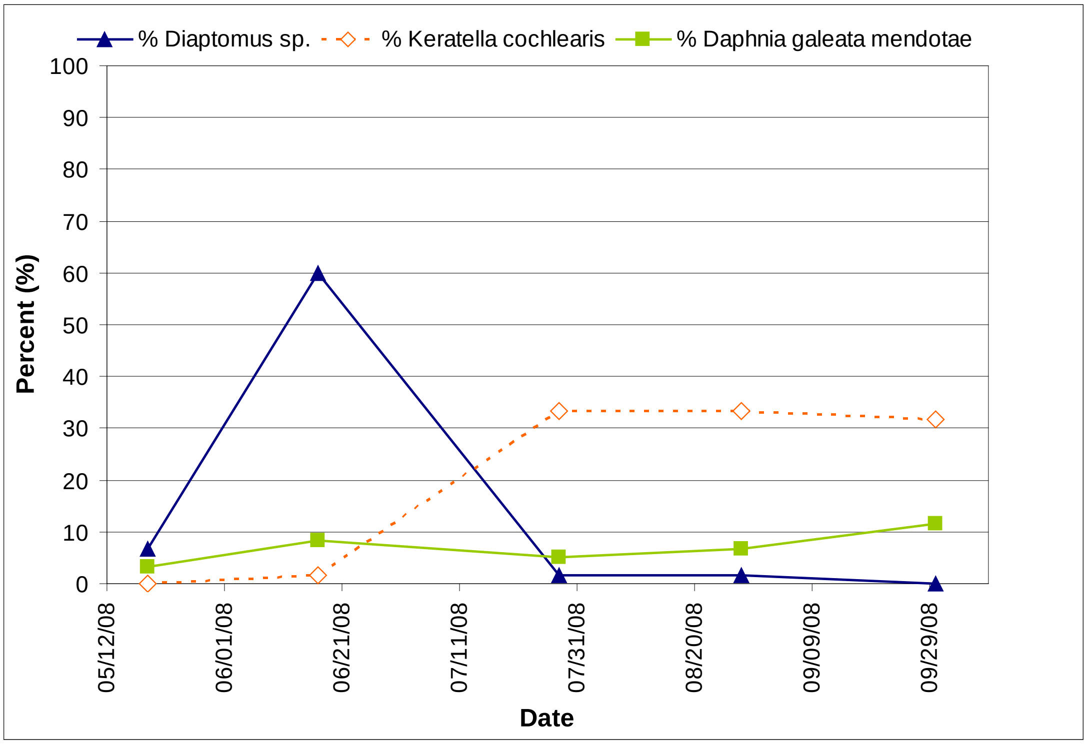

Figure 48. Dominance of the most abundant zooplankton taxa in Goose Lake over five monthly sampling periods in 2008 (as % of individuals counted)

Discussion

Two algal blooms occurred in Goose Lake in 2008 but were composed of different algal groups. The first was primarily a blue-green algae bloom, the second a green algae bloom. There is a clear relationship between the blooms and changes in phosphorus concentrations. Toxin producing blue-green algae species are sufficiently dominant in this lake to warrant caution, particularly if the lake is used by children or pets (Stewart et al. 2006). The algal blooms also impact water clarity (Figure 45).

The zooplankton community shows a strong dominance by the genus *Diaptomus*, a voracious omnivore that is large enough to be prey for fish even if they are not normally planktivorous. These copepods decreased dramatically by July 2008 and were replaced by very small, hard shelled rotifers. This shift in zooplankton community composition could be due to predation by planktivorous fish. Over the sampling period, cladocerans were poorly represented in the zooplankton community.

Overall, the rapid decline of *Diaptomus* in July as well as the lack of larger cladocerans indicates a very poor grazing capacity. Zooplankton grazers are a fundamental mechanism for controlling or mediating algal responses to nutrient pulses (Cottingham et al. 2004). Importantly, the alga *Chlamydomonas* is a favorite food of most zooplankton, particularly cladocerans and larger copepods. The fact that the late summer bloom was *Chlamydomonas* emphasizes the lack of grazing capacity due to rotifer dominance of the zooplankton community.

6.6 Water Quality

Monitoring data are available from 1994 through 2008. The lake is meeting the lake standard for Secchi transparency, but not meeting the lake standard for total phosphorus or chlorophyll-*a* (Table 28).

Table 28. Goose Lake, Surface Water Quality Means (1999-2008) and Standards

Parameter	Growing Season Mean (June – September)	Lake Standard
TP (µg/L)	64	40
Chlor-*a* (µg/L)	43	14
Secchi transparency (m)	1.7	1.4

Figure 49 through Figure 51 show the mean growing season total phosphorus (TP), chlorophyll-*a* and Secchi transparency data from Goose Lake. TP and chlorophyll-*a* means are consistently above the standard, whereas Secchi transparency means fluctuate above and below the standard.

Chlorophyll-*a* generally peaks in June and then again in August or September (Figure 52). Seasonal patterns for TP and Secchi transparency are less clear. There is a strong relationship between chlorophyll-*a* and Secchi transparency (Figure 53); relationships between the other parameters are not as strong.

In 2008, the lake was stratified (Figure 54) and TP concentrations in the bottom waters were higher than in the surface waters (Figure 55), suggesting internal loading of phosphorus from the sediments.

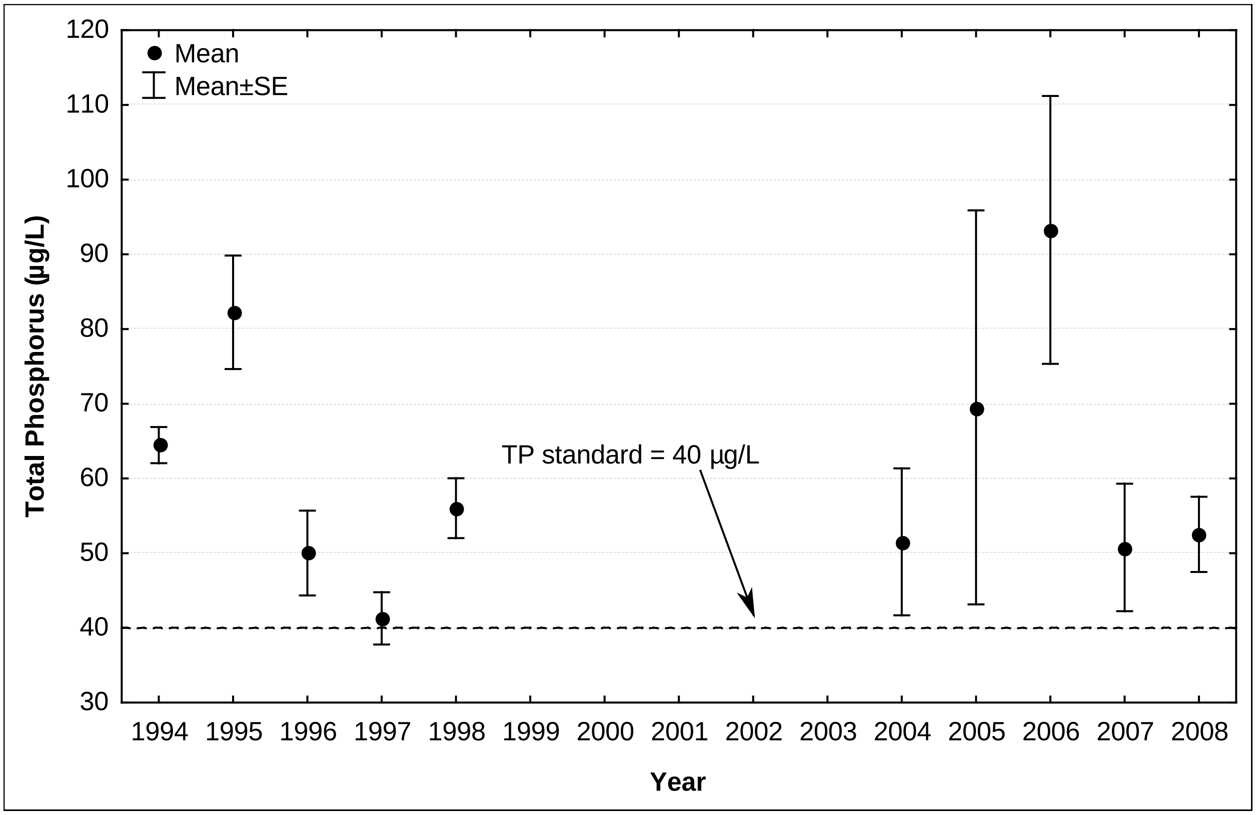

Figure 49. Goose Lake, Growing Season Means Total Phosphorus

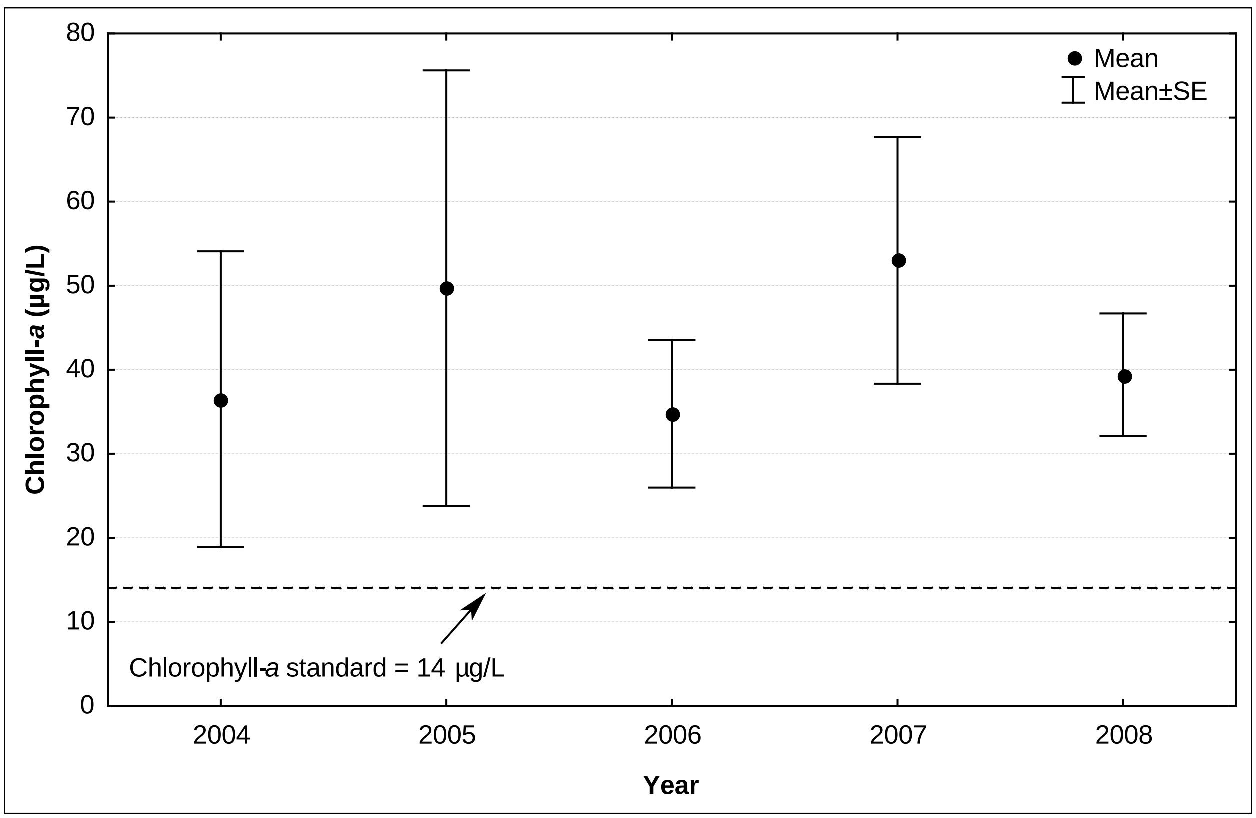

Figure 50. Goose Lake Growing Season Means Chlorophyll-*a*

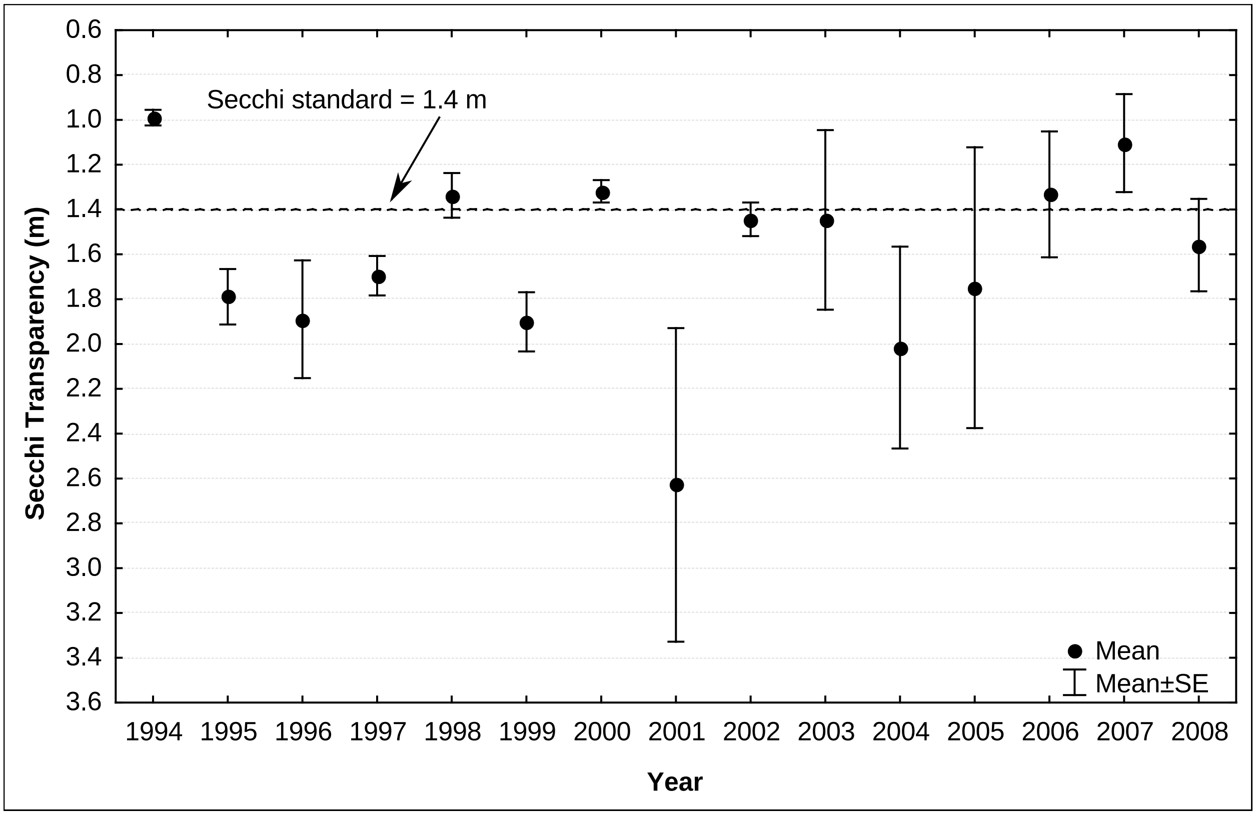

Figure 51. Goose Lake Growing Season Means Secchi Transparency

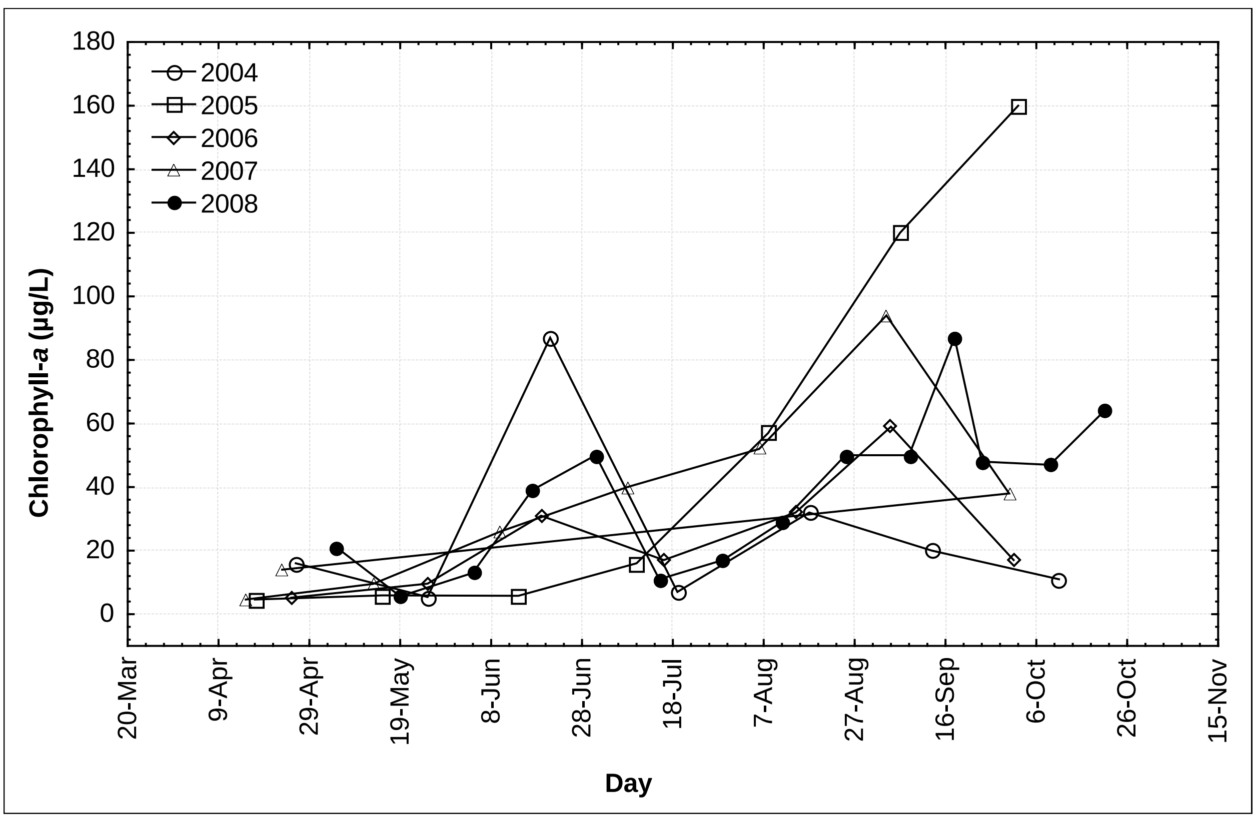

Figure 52. Goose Lake Seasonal Chlorophyll-*a* Patterns

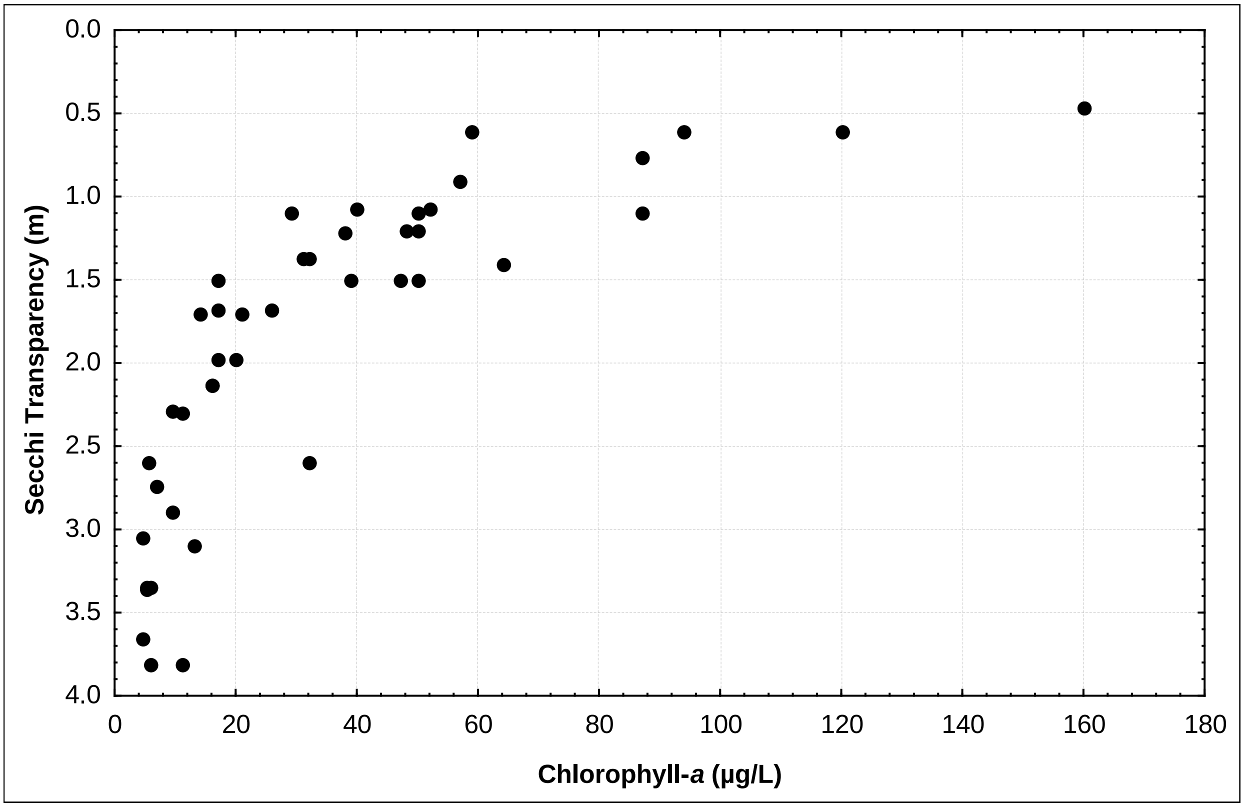

Figure 53. Relationship of Secchi Transparency to Chlorophyll-*a* in Goose Lake

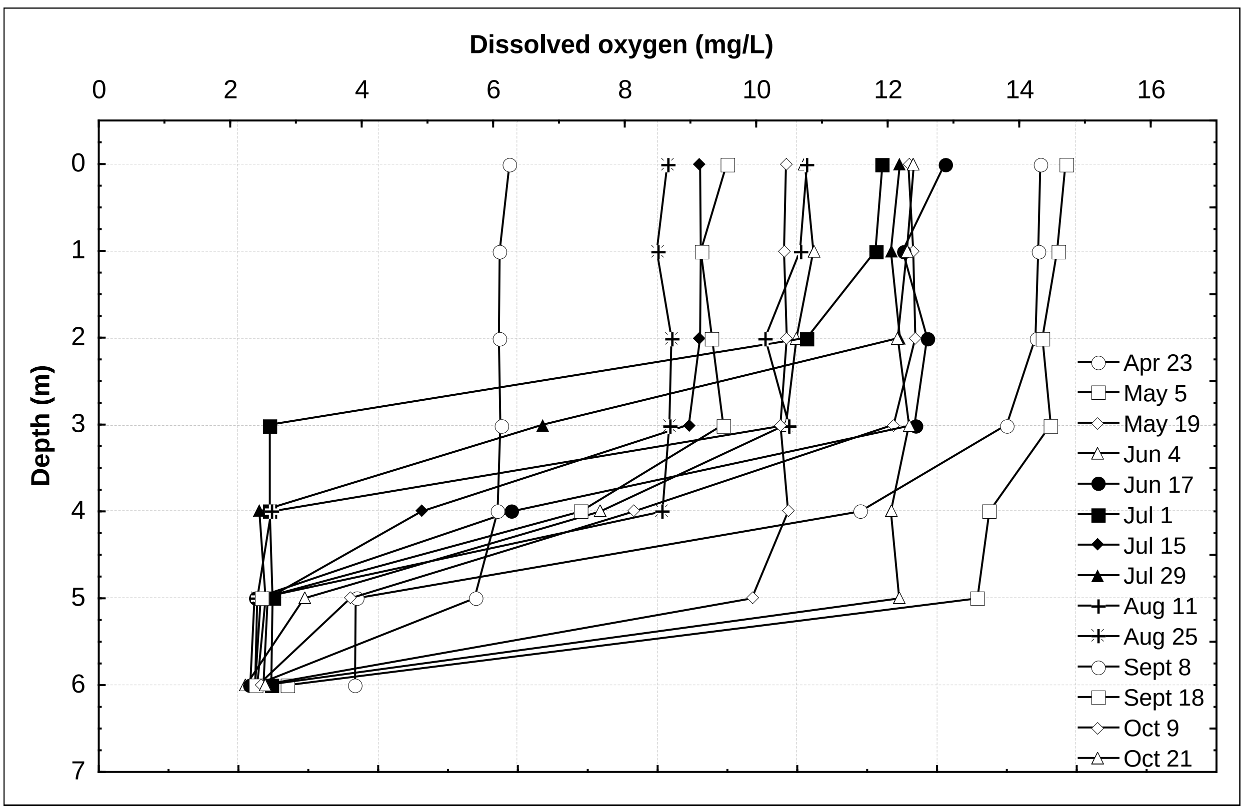

Figure 54. Goose Lake Dissolved Oxygen, 2008

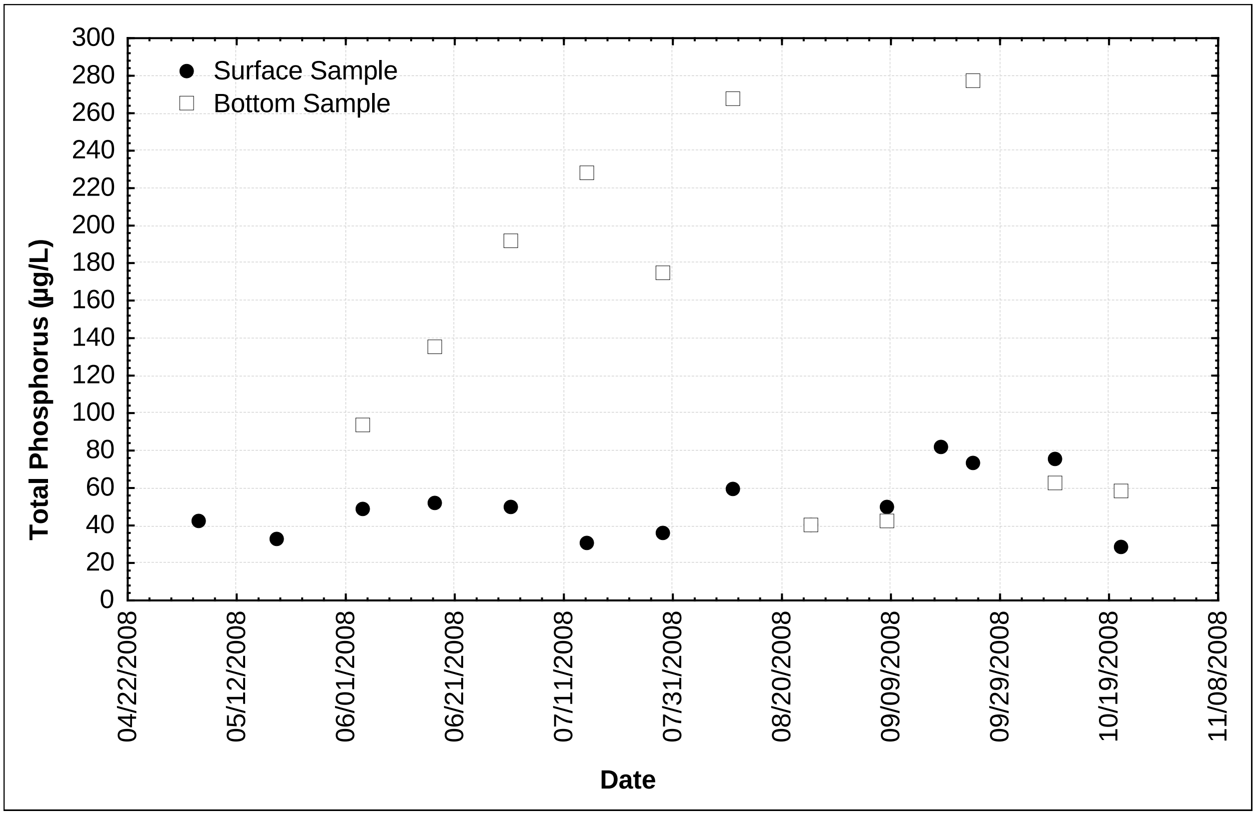

Figure 55. Goose Lake Surface and Bottom Total Phosphorus Samples, 2008

6.7 In-Lake Impairment Assessment Summary

- Goose Lake is managed by the DNR as a fishery for bluegill and northern pike; a winter aeration system is used to prevent winter kill. There is a high potential of internal loading due to benthivorous fish (black bullhead and potentially bluegill under certain conditions).
- Curly-leaf pondweed was present in the lake in June 2008. While not abundant, its presence in the lake indicates the potential for increased internal loading during curly-leaf pondweed die-back if the plant becomes more abundant.
- The algal community is dominated by blue-green algae, including both *Anabaena* and *Microcystis*, which has the potential to form the toxin microcystin. An Anabaena bloom occurred in June and a green algae (*Chlamydomonas*) bloom occurred later in the season.
- The zooplankton community is dominated by copepods in the spring, followed by dominance by a hard-shelled rotifer in the summer. Cladocera are present, although not in large numbers. This community composition suggests strong predation by planktivores, leading to low grazing potential in the lake.
- Portions of the lake stratify during the growing season and a high concentration of phosphorus builds up in the hypolimnion.

6.8 Phosphorus Source Inventory

6.8.1 Watershed Phosphorus Sources

It is estimated that Goose Lake receives 152 pounds of phosphorus annually from watershed runoff (Table 29). The largest watershed source of phosphorus is from direct watershed runoff from the contributing watershed (517 acres). SSTS is the second largest contributor of phosphorus to the lake. There are approximately 28 houses on the lake contributing 34 pounds of phosphorus annually.

A likely source of phosphorus to Goose Lake is from erosion at the public access to the lake.

The 2030 phosphorus load from direct watershed runoff is estimated to be 113 lb/yr, a minor change from 118 lb/yr under existing conditions. No major land use changes are projected between now and 2030 (see Section 6.2). The change in future loading is assumed to be the result of Metropolitan Council's re-categorization of 2030 land use as compared to 2005 land use (see *Direct Watershed Runoff: Direct Watershed Runoff under Future (2030) Conditions* in Section 3.1.2 for further discussion).

Table 29. Goose Lake Watershed Phosphorus Source Summary, Existing Loads

Phosphorus Source	Annual TP Load (lb/yr)	Percent of Watershed TP Load	Area (ac)	Average Areal TP Load (lb/ac-yr)[1]	Average TP Concentra-tion (µg/L)[2]
Direct Watershed Runoff	118	78%	517	0.23	256
SSTS	34	22%	n/a	n/a	n/a
Total	**152**	**100%**			

[1] Annual TP load (lb/yr) divided by drainage area (ac)
[2] Annual TP load (lb/yr) divided by average annual volume of runoff [3.94 (average annual depth of runoff in inches) * drainage area (ac) * conversion factor]

6.8.2 Atmospheric Phosphorus Sources

Atmospheric deposition is estimated to be 23 lb/yr (see *Atmospheric Deposition* in Section 3.1.2 for more information).

6.8.3 Internal Phosphorus Sources

Internal loading accounts for an additional 20 to 321 lb/yr (171 lb/yr average) of phosphorus loading to the lake, representing 10% to 65%, respectively, of the total loading to the lake.

6.8.4 Phosphorus Load Summary

The total modeled phosphorus load to Goose Lake is 346 lb/yr (Table 14).

Table 30. Goose Lake Phosphorus Source Summary, Existing Loads

Phosphorus Source	Phosphorus Load (lb/yr)
Watershed	152
Atmospheric	23
Internal	171
Total	**346**

6.9 TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Goose Lake is 254 lb/yr, to be split among allocations according to Table 31. To meet the TMDL, the total load to the lake needs to be reduced by 117 lb/yr.

Watershed scale pollutant load modeling was conducted and analyzed on an annual basis to establish this TMDL at a level necessary to attain and maintain applicable water quality standards. Daily wasteload allocations were derived from this analysis.

Table 31. Goose Lake Existing Loads, TMDL Allocations, and Reductions Needed

Load Component	TP Existing	TP TMDL Allocation		TP Reduction	
	lb/yr	lb/yr	lb/day	lb/yr	%
WLA					
Construction stormwater (permit #MNR100001)	0.44	0.44	0.0012	0	0%
Industrial stormwater (permit # MNR50000)	0.44	0.44	0.0012	0	0%
Total WLA	**0.88**	**0.88**	**0.0024**	**0**	**0%**
LA*					
Watershed	151	76	0.21	75	50%
Atmospheric	23	23	0.063	0	0%
Internal	171	129	0.35	42	25%
Total LA	***345***	***228***	**0.62**	***117***	**34%**
MOS	**--**	**25**	**0.07**	**--**	**--**
Total	***346***	***254***	***0.69***	***117****	***34%***

*LA components are broken down for guidance in implementation planning; the LA should be considered categorical.
**117 lb/yr reduction takes into account MOS; 92 lb/yr reduction (=117-MOS) needed to reach total loading capacity

7 HAY LAKE TMDL

With a maximum depth of seven feet, 100% of Hay Lake is characterized as littoral. Hay Lake displays many characteristics of a wetland. The vegetation is dominated by floating leaf macrophytes around the perimeter and by submergent macrophytes in the remainder of the lake (see *Section 7.5.2: Macrophytes)*. The water column is well-mixed and does not thermally stratify. The lake is not managed for a sport fishery by the DNR, and there is little fish information available.

7.1 Physical Characteristics

Hay Lake (ID 82-0065) is an extremely shallow lake located in the City of Scandia. Hay Lake outlets to the east to Sand Lake, which in turn intermittently outlets to Mill Stream, a high quality trout stream, and eventually to the St. Croix River.

Table 32 summarizes the lake's characteristics and Figure 56 illustrates the lake's bathymetry.

Table 32. Hay Lake Characteristics

Characteristic	Value	Source
Lake total surface area (ac)	41.4	2008 MLCCS revised based on 2008 aerial photos
Percent lake littoral surface area	100	Calculated based on 2008 WCD bathymetry data
Lake volume (ac-ft)	157	Calculated (mean depth x surface area)
Mean depth (ft)	3.8	Calculated based on 2008 WCD bathymetry data
Maximum depth (ft)	7	Based on 2008 WCD bathymetry data
Drainage area (acres)	214	CMSCWD
Watershed area:lake area	5.2	Calculated

Figure 56. Hay Lake Bathymetry
Contour units are feet.

7.2 Land Use

The Hay Lake watershed is currently dominated by undeveloped land (Table 33). Other prominent land uses in the watershed include agricultural and single family residential. No major land use changes are projected between now and 2030 (Table 34); changes are assumed to be the result of Metropolitan Council's re-categorization of 2030 land use as compared to 2005 land use.

Table 33. Hay Lake Watershed Land Use, 2005
(2005 Generalized Land Use for the Twin Cities Metropolitan Area)

Land Use	Total Acres	% of Watershed
Agricultural	59.3	27.7%
Farmstead	2.7	1.2%
Industrial and Utility	-	-
Institutional	-	-
Park, Recreation, or Preserve	-	-
Retail and Other Commercial	-	-
Seasonal/Vacation	-	-
Single Family Detached	57.9	27.1%
Undeveloped	74.6	34.9%
Water	19.6	9.1%
Total	**214.0**	**100.0%**

Table 34. Hay Lake Watershed Land Use, 2030
(Regional Planned Generalized Land Use for the Twin Cities Metropolitan Area)

Land Use	Total Acres	% of Watershed
Agricultural	-	-
Airport	-	-
Commercial	-	-
Industrial	-	-
Institutional	-	-
Mixed Use	-	-
Multifamily Residential	-	-
Multi-Optional Development	-	-
Open Space or Restrictive Use	-	-
Park and Recreation	2.4	1.1%
Railway (inc. LRT)	-	-
Rights-of-Way (i.e., Roads)	-	-
Rural or Large-Lot Residential	192.0	89.7%
Single Family Residential	-	-
Vacant or No Data	-	-
Water	19.6	9.2%
Total	**214.0**	**100.0%**

7.3 Existing Studies, Monitoring, and Management

The Lower St. Croix River Spring Creek Stewardship Plan (MWMO 2003) was completed in 2003. The primary reasons for undertaking this project were to describe and evaluate spring creeks and associated groundwater-dependent resources, and, based on this increased understanding of these unique resources, to define stewardship strategies towards their long-term protection. The plan included a watershed fact sheet for the Mill Stream watershed, which encompasses Hay Lake. The fact sheet includes the following management recommendations for the Mill Stream watershed:

- Retain overall groundwater recharge.
- Maintain stormwater volume for the 2-year event at predevelopment levels.
- Maintain stormwater peak flow rates for the 2-year event at predevelopment levels.
- Where infiltration functions are lost due to creation of impervious surfaces, reintroduce through practices that replace these functions.
- Where private or public infrastructure is upgraded, retrofit or incorporate improvements to hydrologic and water quality conditions.
- Require phosphorus concentration standard of 50 μg/L for stormwater discharges to tributaries of the St. Croix River.
- Ditches, tiles, storm sewers, and roadway surfaces should not collect and concentrate stormwater into drainage systems tributary to spring creeks.
- Require an erosion control plan, consistent with the specifications of the MPCA manual "*Protecting Water Quality in Urban Areas*" for all projects that result in 10,000 ft^2 of disturbance.
- Identify stream and/or wetland restoration sites that improve and/or protect other important groundwater-dependent resources.
- Establish protective riparian corridors along streams, and buffers around wetlands.
- Initiate a citizen monitoring program.

The Hay Lake Watershed Management Plan was written as part of the Carnelian-Marine-St. Croix Watershed District's 2010 Watershed Management Plan (CMSCWD 2010). Management, monitoring, and implementation activities are expected to be driven by an implementation plan developed based on this TMDL study.

7.4 Lake Uses

Hay Lake does not have a public access. Primary uses of this lake are boating and fishing by residents who live on the lake. The DNR used the lake for minnow rearing in the past.

7.5 Biological Characteristics

7.5.1 Fish

The DNR has not conducted a fish survey on Hay Lake. The lake was used for minnow rearing by the DNR in the past.

7.5.2 Macrophytes

Macrophyte surveys were completed for Hay Lake in June and August of 2008. Curly-leaf pondweed was not observed during either survey (Figure 57). The distribution of macrophyte communities remained essentially the same between the June and August survey. A diversity of macrophyte species was present in the lake during both surveys (Table 35).

Table 35. Plant Species Observed During 2008 Hay Lake Macrophyte Surveys

Scientific Name	Common Name	June	August
Brasenia schreberi	Watershield	ü	ü
Ceratophyllum demersum	Coontail		ü
Chara vulgaris	Muskgrass	ü	ü
Elodea canadensis	Elodea	ü	ü
Nuphar lutea	Yellow water-lily	ü	ü
Nymphaea odorata	White water-lily	ü	ü
Potamogeton amplifolius	Large-leaved pondweed	ü	ü
Potamogeton natans	Floating-leaved pondweed		ü
Vallisneria americana	Wild Celery	ü	

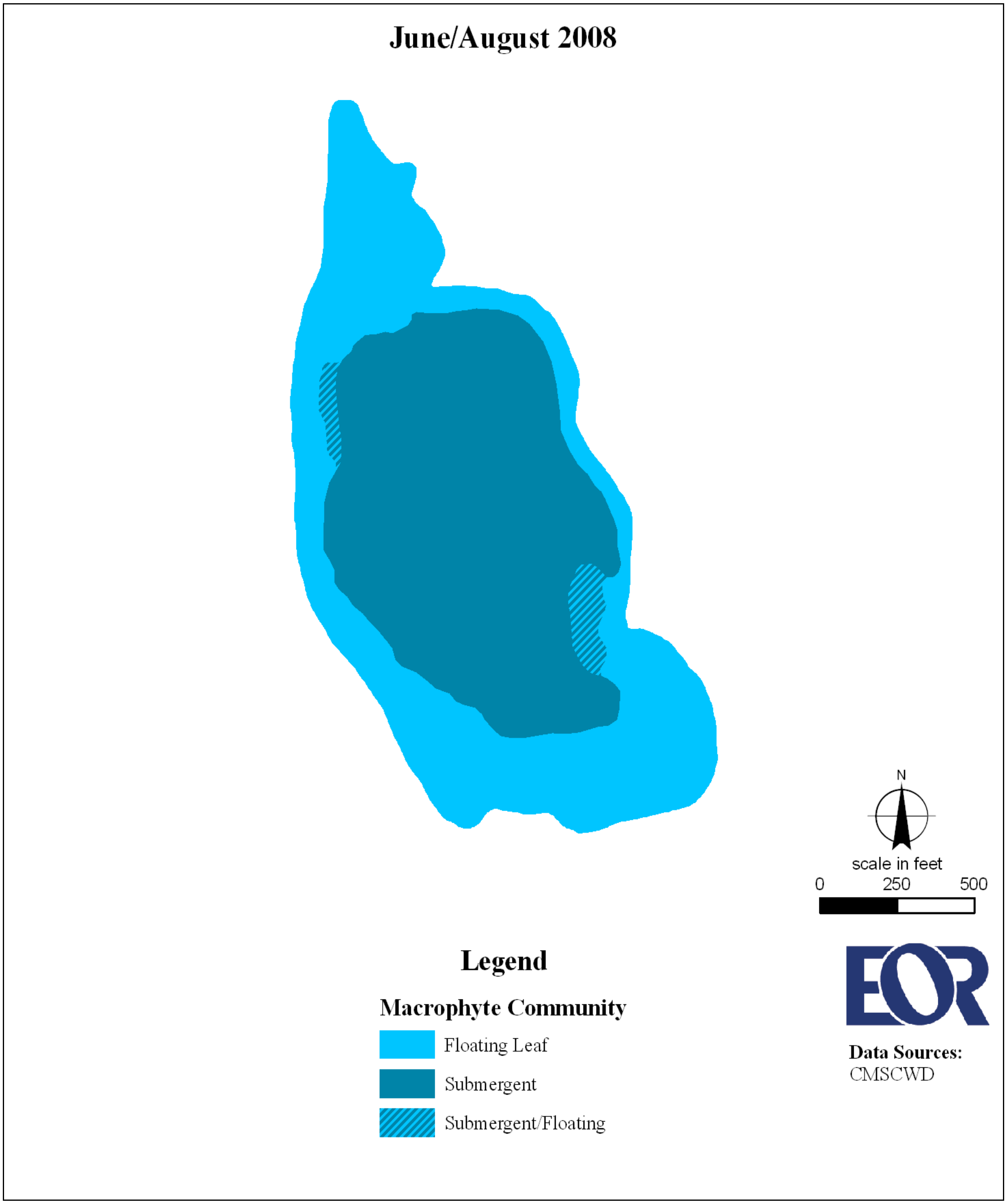

Figure 57. Distribution of Macrophyte Communities in Hay Lake.

7.5.3 Plankton Community

Phytoplankton

There were 23 algal species found in Hay Lake. The most common algal species in Hay Lake was the dinoflagellate *Ceratium*, a small algae with a hard case. *Anabaena* (blue-green algae) and *Chlamydomonas* (green algae), both indicative of high nutrients, possible eutrophication, and algal blooms, were the next two most common genera. The predominance of these two species together represents a high potential for blooms.

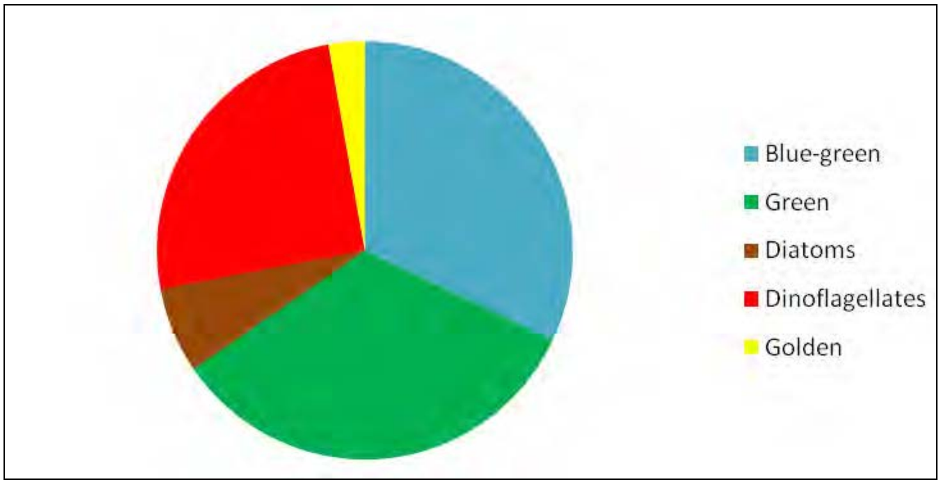

Figure 58. Percent composition of major algae groups in Hay Lake, May to September 2008

Zooplankton

Zooplankton species richness is moderate in Hay Lake, with 18 species found. The two most common organisms, *Conochiloides* and *Keratella*, are rotifers with low grazing capacity, indicating predation pressures may be impacting the zooplankton grazers. The next most common zooplankter is *Diacyclops*, a small copepod omnivore.

The community composition in Hay Lake shows dominance by rotifers, followed by copepods with few cladocera (Figure 59). The zooplankton community has low grazing capacity due to the lack of cladocera and larger copepods.

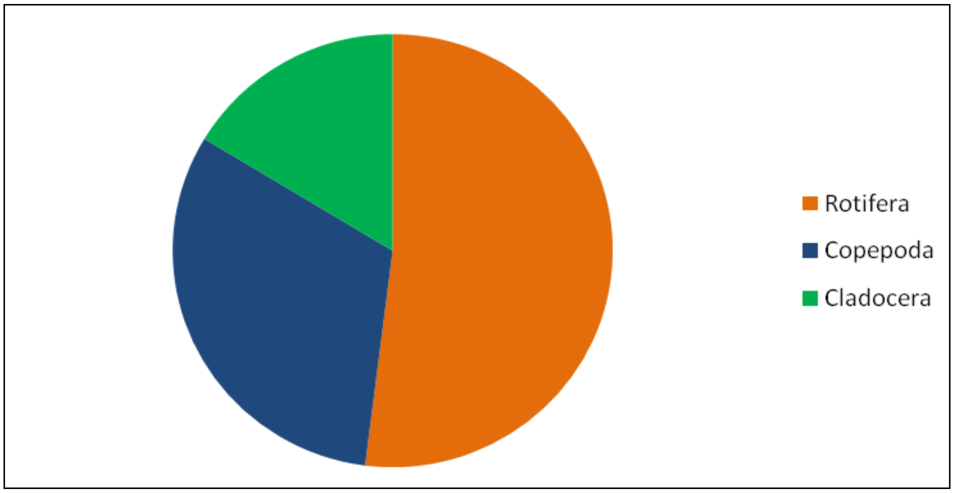

Figure 59. Percent composition of major zooplankton groups in Hay Lake, May to September 2008.

7.6 Water Quality

Monitoring data are available from 1998-2001 and 2003-2008. A summary of the data indicates that the lake is meeting lake water quality standards for Secchi transparency, but not for total phosphorus nor chlorophyll-*a* (Table 36).

Table 36. Hay Lake, Surface Water Quality Means and Standards (1998-2001 and 2003-2008)

Parameter	Growing Season Mean (June – September)	Shallow Lake Standard
TP (µg/L)	92	60
Chlor-*a* (µg/L)	41	20
Secchi transparency (m)	1.1	1.0

Figure 60 through Figure 62 show the mean growing season total phosphorus (TP), chlorophyll-*a*, and Secchi transparency data for Hay Lake. Water quality has fluctuated over the years, with the standard being met in some years, but not for the majority of years. The Secchi transparency standard was met from 2006 to 2008.

No clear seasonal patterns were observed for any of the three parameters. There are relatively strong relationships between TP, chlorophyll-*a*, and Secchi transparency (chlorophyll-*a* vs. Secchi transparency) shown in Figure 63).

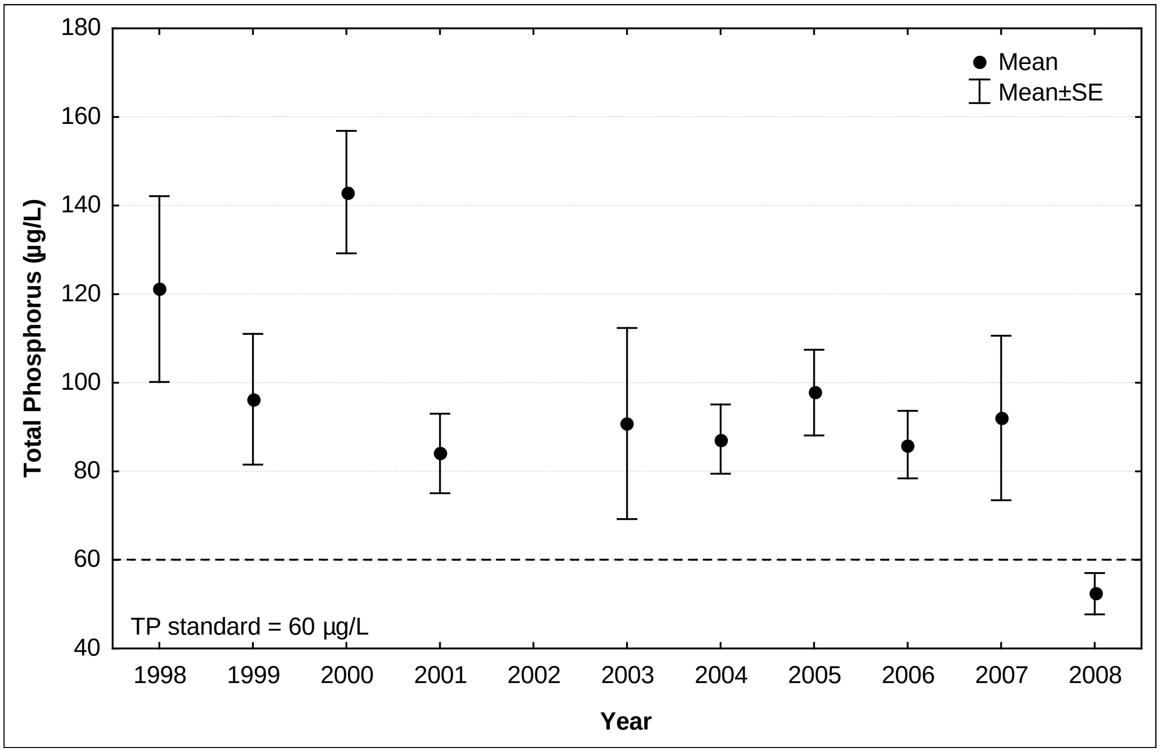

Figure 60. Hay Lake, Growing Season Means Total Phosphorus

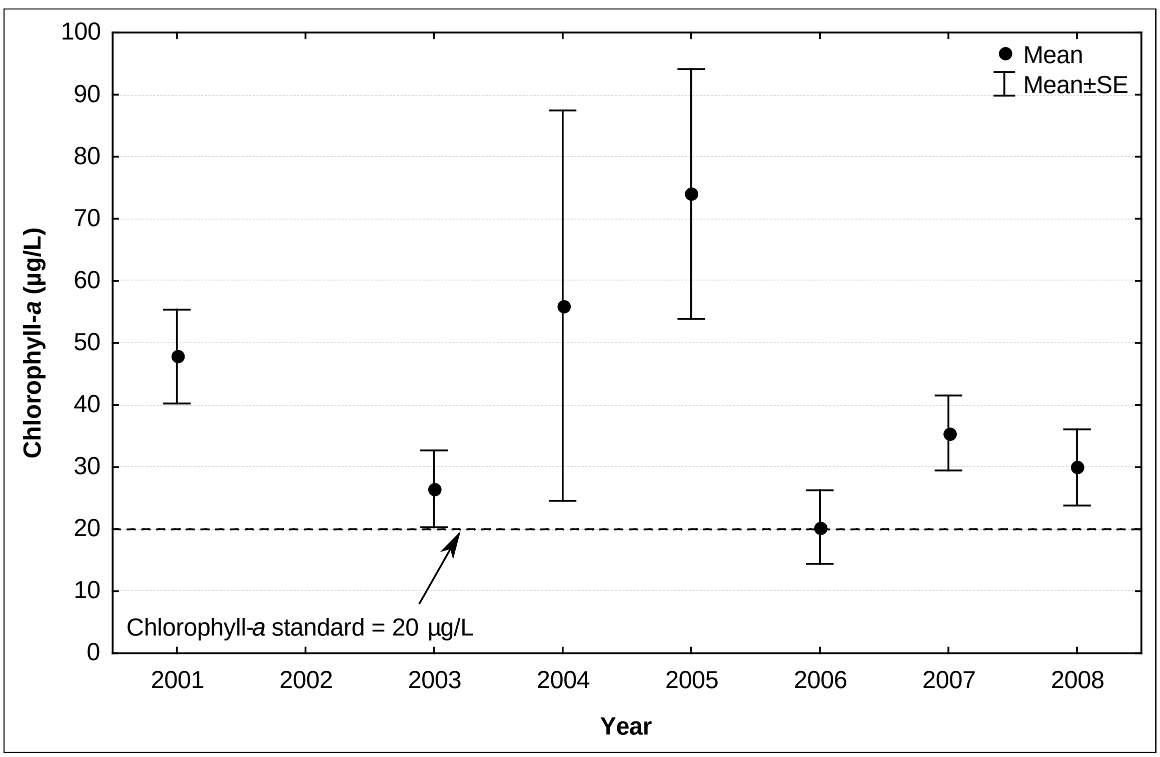

Figure 61. Hay Lake, Growing Season Means Chlorophyll-*a*

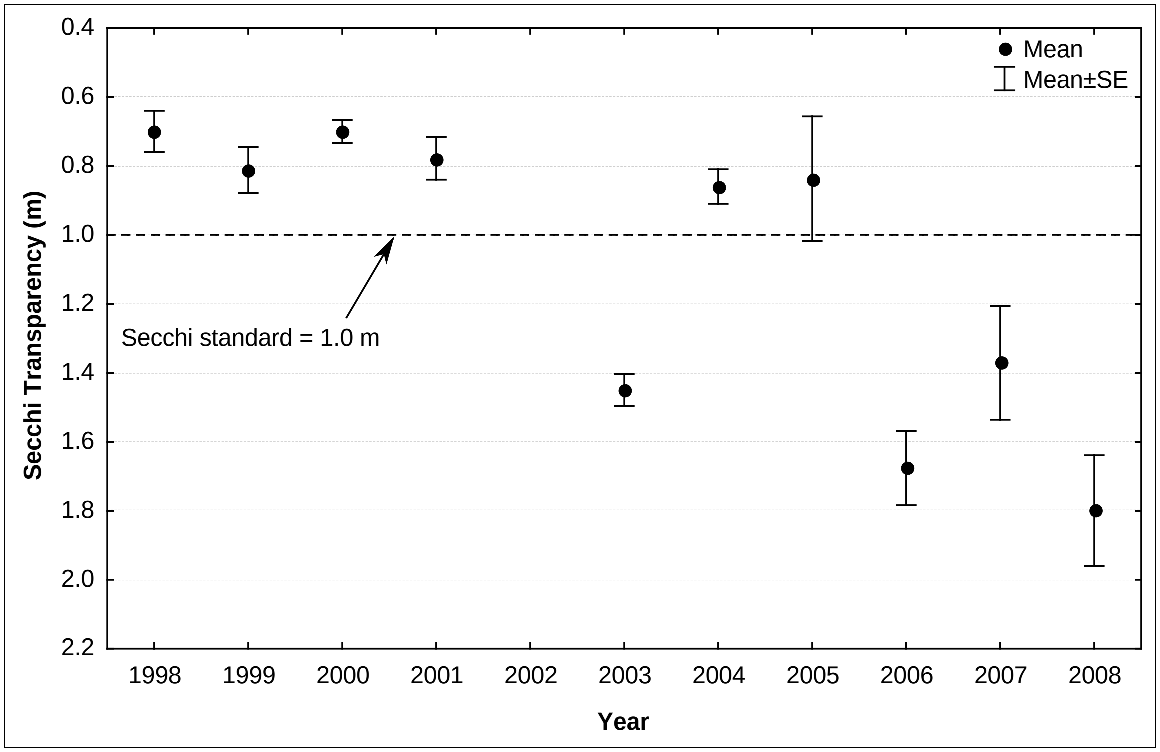

Figure 62 Hay Lake, Growing Season Means Secchi Transparency

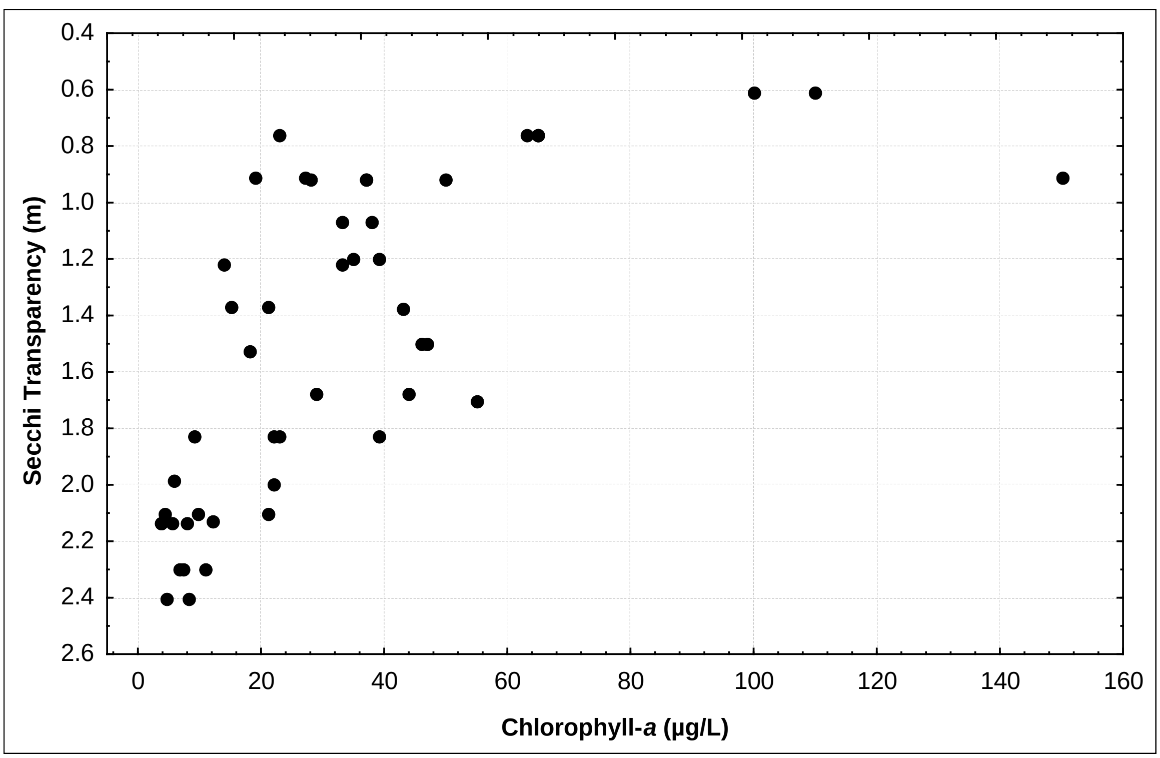

Figure 63. Relationship of Secchi Transparency to Chlorophyll-*a* in Hay Lake

7.7 In-Lake Impairment Assessment Summary

- The lake is a very shallow lake (mean depth under four feet) with a diverse community of submergent and floating leaf macrophytes, with no areas of open water.
- The predominance of two algal species that are indicative of high nutrients represents a high potential for algal blooms.
- The zooplankton community is dominated by rotifers, with fewer numbers of copepods and cladocera, indicating a low grazing capacity.
- Hay Lake has high transparency but has poor chlorophyll-*a* and TP concentration, which could be indicating that blue-green algae may be problematic. (Blue-green algae contain chlorophyll, but their relatively large size does not affect transparency in the same way that smaller sized algae does.)

7.8 Phosphorus Source Inventory

7.8.1 Watershed Phosphorus Sources

It is estimated that Hay Lake receives 63 pounds of phosphorus annually from watershed runoff (Table 37). The largest watershed source of phosphorus is from direct watershed runoff from the contributing watershed (214 acres). SSTS is the second largest contributor of phosphorus to the lake. There are approximately 11 houses on the lake contributing 13 pounds of phosphorus annually.

The 2030 phosphorus load from direct watershed runoff is estimated to be 47 lb/yr, a minor change from 50 lb/yr under existing conditions. No major land use changes are projected between now and 2030 (see Section 7.2). The change in future loading is assumed to be the result of Metropolitan Council's re-categorization of 2030 land use as compared to 2005 land use (see *Direct Watershed Runoff: Direct Watershed Runoff under Future (2030) Conditions* in Section 3.1.2 for further discussion).

Table 37. Hay Lake Watershed Phosphorus Source Summary, Existing Loads

Phosphorus Source	Annual TP Load (lb/yr)	Percent of Watershed TP Load	Area (ac)	Average Areal TP Load (lb/ac-yr)[1]	Average TP Concentra-tion (µg/L)[2]
Direct Watershed Runoff	50	79%	214	0.23	262
SSTS	13	21%	n/a	n/a	n/a
Total	**63**	**100%**			

[1] Annual TP load (lb/yr) divided by drainage area (ac)
[2] Annual TP load (lb/yr) divided by average annual volume of runoff [3.94 (average annual depth of runoff in inches) * drainage area (ac) * conversion factor]

7.8.2 Atmospheric Phosphorus Sources

Atmospheric deposition is estimated to be 11 lb/yr (see *Atmospheric Deposition* in Section 3.1.2 for more information).

7.8.3 Internal Phosphorus Sources

Internal loading accounts for an additional estimated 0 to 125 lb/yr (63 lb/yr average) of phosphorus loading to the lake, representing 0% to 63%, respectively, of the total loading to the lake.

7.8.4 Phosphorus Load Summary

The total modeled phosphorus load to Hay Lake is 137 lb/yr (Table 14).

Table 38. Hay Lake Phosphorus Source Summary, Existing Loads

Phosphorus Source	Phosphorus Load (lb/yr)
Watershed	63
Atmospheric	11
Internal	63
Total	**137**

7.9 TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Hay Lake is 101 lb/yr, to be split among allocations according to Table 39. To meet the TMDL, the total load to the lake needs to be reduced by 46 lb/yr.

Watershed scale pollutant load modeling was conducted and analyzed on an annual basis to establish this TMDL at a level necessary to attain and maintain applicable water quality standards. Daily wasteload allocations were derived from this analysis.

Table 39. Hay Lake Existing Loads, TMDL Allocations, and Reductions Needed

Load Component	TP Existing	TP TMDL Allocation		TP Reduction	
	lb/yr	lb/yr	lb/day	lb/yr	%
WLA					
Construction stormwater (permit #MNR100001)	0.19	0.19	0.00052	0	0%
Industrial stormwater (permit # MNR50000)	0.19	0.19	0.00052	0	0%
Total WLA	**0.38**	**0.38**	**0.00104**	**0**	**0%**
LA*					
Watershed	63	32	0.088	31	49%
Atmospheric	11	11	0.030	0	0%
Internal	63	48	0.13	15	24%
Total LA	***137***	***91***	**0.25**	***46***	**34%**
MOS	**--**	**10**	**0.027**	**--**	**--**
Total	***137***	***101***	***0.28***	***46****	***34%***

*LA components are broken down for guidance in implementation planning; the LA should be considered categorical.
**46 lb/yr reduction takes into account MOS; 36 lb/yr reduction (=46-MOS) needed to reach total loading capacity

8 JELLUM'S BAY TMDL

8.1 Physical Characteristics

Jellum's Bay (ID 82-0052) is a shallow lake located in the City of Scandia, MN, adjacent to Big Marine Lake. Jellum's Bay has a piped connection to Big Marine Lake and is considered to be a bay of Big Marine. The Jellum's Bay watershed includes Long Lake to the east, which is also impaired for excess nutrients.

Table 40 summarizes the lake's characteristics. Figure 64 illustrates the bathymetry for Jellum's Bay.

Table 40. Jellum's Bay Characteristics

Characteristic	Value	Source
Lake total surface area (ac)	64	2008 MLCCS revised based on 2008 aerial photos
Percent lake littoral surface area	100	Calculated based on 2002 WCD bathymetry data
Lake volume (ac-ft)	378	Calculated (mean depth x surface area)
Mean depth (ft)	5.9	Calculated based on 2002 WCD bathymetry data
Maximum depth (ft)	13.5	Based on 2002 WCD bathymetry data
Drainage area (acres)	549.8	CMSCWD
Watershed area:lake area	8.6	Calculated

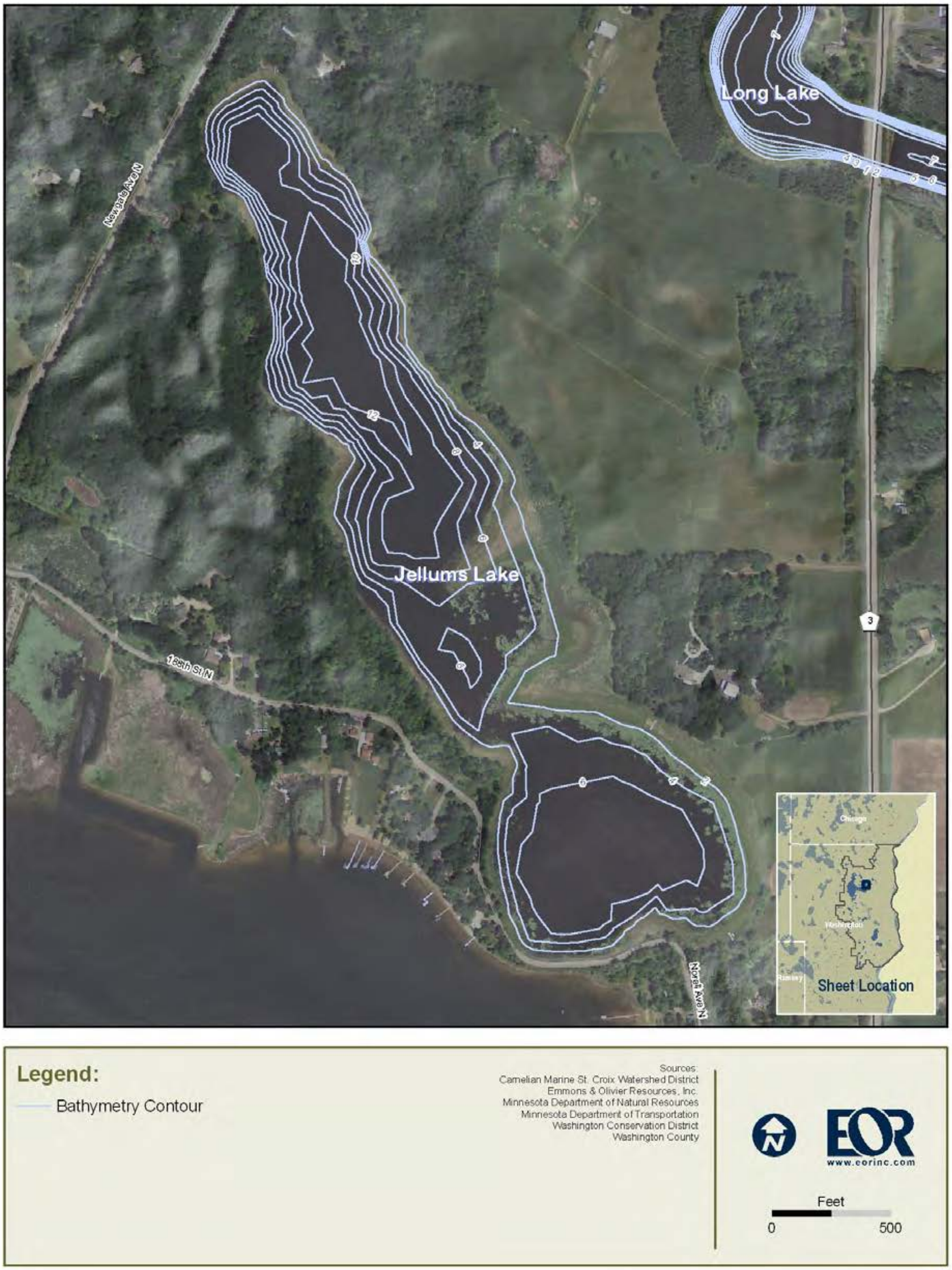

Figure 64. Jellum's Bay Bathymetry
Contour units are feet.

8.2 Land Use

Currently, Jellum’s Bay watershed, which includes the watershed of Long Lake, is dominated by undeveloped land (Table 41). Agriculture is the second most dominant land use. Farmsteads and single family residential land uses are found throughout the watershed. No major land use changes are projected between now and 2030 (Table 42); changes are assumed to be the result of Metropolitan Council’s re-categorization of 2030 land use as compared to 2005 land use.

Table 41. Jellum's Bay Watershed Land Use, 2005
(2005 Generalized Land Use for the Twin Cities Metropolitan Area)

Land Use	Direct Drainage		Entire Drainage (including Long Lake watershed and lake)	
	Total Acres	% of Watershed	Total Acres	% of Watershed
Agricultural	127.6	43.8%	198.1	36.0%
Farmstead	-	-	5.3	1.0%
Industrial and Utility	-	-	0.7	0.1%
Institutional	-	-	1.2	0.2%
Park, Recreation, or Preserve	-	-	-	-
Retail and Other Commercial	-	-	-	-
Seasonal/Vacation	0.1	0.0%	0.1	0.0%
Single Family Detached	33.4	11.5%	54.7	9.9%
Undeveloped	121.9	41.9%	240.7	43.8%
Water	8.2	2.8%	49.1	8.9%
Total	**291.1**	**100.0%**	**549.8**	**100.0%**

Table 42. Jellum's Bay Watershed Land Use, 2030
(Regional Planned Land Use for the Twin Cities Metropolitan Area)

Land Use	Direct Drainage		Entire Drainage (including Long Lake watershed and lake)	
	Total Acres	% of Watershed	Total Acres	% of Watershed
Agricultural	-	-	-	-
Airport	-	-	-	-
Commercial	-	-	-	-
Industrial	-	-	-	-
Institutional	-	-	-	-
Mixed Use	-	-	-	-
Multifamily Residential	-	-	-	-
Multi-Optional Development	-	-	-	-
Open Space or Restrictive Use	-	-	-	-
Park and Recreation	-	-	5.7%	1.0%
Railway (inc. LRT)	-	-	-	-
Rights-of-Way (i.e., Roads)	-	-	-	-
Rural or Large-Lot Residential	282.9	97.2%	494.9%	90.0%
Single Family Residential	-	-	-	-
Vacant or No Data	-	-	-	-
Water	8.2	2.8%	49.2%	8.9%
Total	**291.1**	**100.0%**	**549.8%**	**99.9%***

* Total % does not equal 100.0 due to rounding.

8.3 Existing Studies, Monitoring, and Management

In 2000 a phosphorus sensitivity analysis for several lakes in the Carnelian-Marine Watershed District was completed (CMWD 2000). The study noted that the water quality of Jellum's Bay does not meet the ecoregion goal of 40 µg/L of total phosphorus and that the lake warrants projects or programs to actively improve the water quality because of its connection to Big Marine Lake, an important recreational lake with good water quality.

In 2002, the "Water Quality Report and Lake Management Plan for Jellum's Bay" was completed (CMWD 2002a). The goal of the report was to develop a detailed plan for improving Jellum's Bay. The water quality of Jellum's Bay is a concern because of its proximity and connection to Big Marine Lake. The report found that the poor water quality in Jellum's Bay is primarily due to the shallow nature of the lake; frequent mixing during the growing season causes nutrients to be redistributed throughout the water column. The report identifies several possible projects to address internal nutrient loading in the lake, including dredging, alum treatment, aeration with hypolimnetic withdrawal, barley straw application, aquatic macrophyte restoration, and rough fish removal. To address external nutrient loading, the report suggests riparian restoration, overflow improvements, proper fertilizer management, and septic system maintenance education.

In 2003, the Carnelian-Marine Watershed District and the Washington Conservation District applied barley straw to Jellum's Bay, as recommended in the "Water Quality Report and Lake

Management Plan for Jellum's Bay." The barley straw application was chosen from the several recommendations described in the report because it would address internal loading in the lake and is relatively inexpensive.

The barley straw was applied to Jellum's Bay on April 29-30, 2003. The straw was applied at a rate of approximately 250 pounds per acre of lake surface area. To monitor the effects of the application on water quality, Jellum's Bay was monitored bi-weekly from April to October, 2003. Data on Secchi transparency, dissolved oxygen, temperature profile, surface chlorophyll-*a* concentrations, surface total phosphorus concentrations, and surface total Kjeldahl nitrogen were collected. The barley straw was removed from the lake in October, 2003.

The results of the monitoring data show that overall water quality did not improve (CMWD 2004a). The lack of visible improvement in sampled parameters was thought to be caused by a large influx of water from Fish Lake. Four to five inches of rainfall fell in the area between June 23 and June 26, 2003. During this event, a beaver dam on Fish Lake broke and approximately 159 acre-feet of water flowed from Fish Lake into Jellum's Bay. The total volume of Jellum's Bay is 535 acre-feet; the additional water from Fish Lake therefore flushed about 30% of the volume of Jellum's Bay. Based on the total phosphorus samples collected on Fish Lake, an estimated 32 pounds of phosphorus was added to the Jellum's Bay system.

Due to the unusual inflow of water from Fish Lake during the initial barley straw application and the potential for improvement in water quality as demonstrated by barley straw applications in other metro area lakes, the application was repeated in 2004. Water quality in 2004 was improved relative to previous years.

The Jellum's Bay Watershed Management Plan was written as part of the Carnelian-Marine-St. Croix Watershed District's 2010 Watershed Management Plan (CMSCWD 2010). Management, monitoring, and implementation activities are expected to be driven by an implementation plan developed based on this TMDL study. Potential future projects are to implement roadside revegetation and conduct a water quality diagnostic feasibility study.

8.4 Lake Uses

Jellum's Bay is currently managed as a walleye rearing pond by the DNR.

8.5 Biological Characteristics

8.5.1 Fisheries

Jellum's Bay is currently managed as a walleye rearing pond by the DNR. A fish toxin was applied in 2003 to eliminate the existing fish, and the lake was first stocked in 2004. In May of 2008 the lake was stocked with 500,000 walleye fry. A harvest was completed in early October 2008 removing 408 pounds of walleye, largemouth bass, and bluegills. A high abundance of green sunfish and bluegills was noted by the DNR. Other species captured in harvesting nets included golden shiners, white suckers, flathead minnows, largemouth bass, hybrid sunfish, and pumpkinseed sunfish. A fish toxin (rotenone) was applied again in November 2009 to eliminate the existing fish.

8.5.2 Macrophytes

Macrophyte surveys were completed for Jellum's Bay in June and August of 2008. Curly-leaf pondweed was not observed during either survey (Figure 65). The distribution of macrophyte communities remained essentially the same between the June and August survey. A diversity of macrophyte species was present in the lake during both surveys (Table 43).

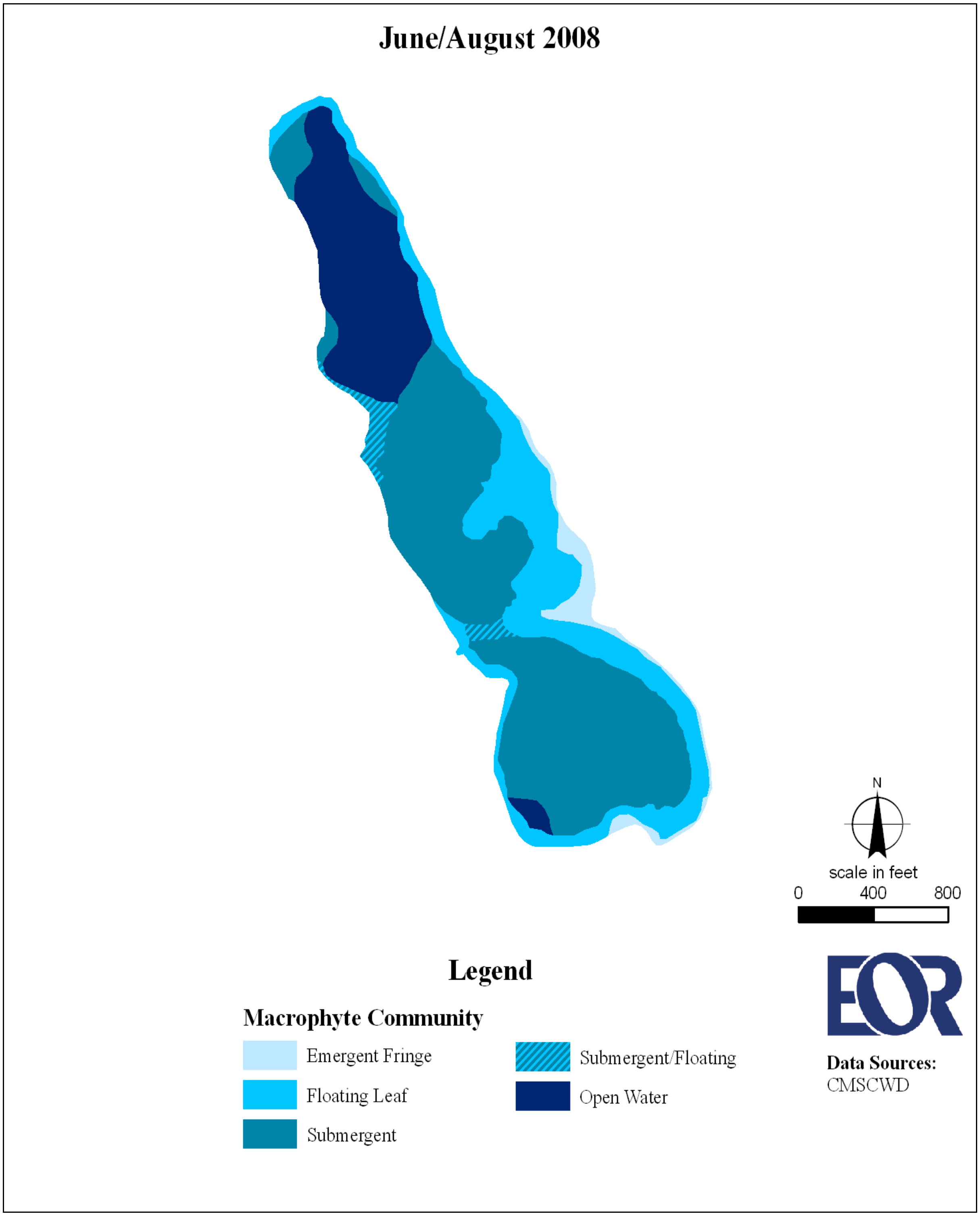

Figure 65. Distribution of Macrophyte Communities in Jellum's Bay

Table 43. Plant Species Observed During 2008 Jellum's Bay Macrophyte Surveys

Scientific Name	Common Name	June	August
Brasenia schreberi	Watershield	ü	ü
Ceratophyllum demersum	Coontail		ü
Chara vulgaris	Muskgrass	ü	
Elodea canadensis	Elodea	ü	ü
Nymphaea odorata	White water-lily	ü	ü
Potamogeton foliosus	Leafy pondweed	ü	ü
Potamogeton natans	Floating-leaved pondweed	ü	ü
Potamogeton robbinsii	Fern-leaved pondweed	ü	
Vallisneria americana	Wild Celery	ü	ü

8.5.3 Plankton Community

Phytoplankton

Jellum's Bay supports a diverse algae community. Thirty phytoplankton genera were found in Jellum's Bay, with the three most common genera being *Eudorina*, *Dictyosphaerium*, and *Synedra*, two green algae and one diatom genus, respectively. *Eudorina* and *Dictyosphaerium* are not generally associated with large or problematic algae blooms.

Overall, green algae are the most common in Jellum's Lake, and blue-green algae are relatively uncommon (Figure 66). This composition may be a product of the high abundance of the filter-feeding Bryozoan population (discussed below).

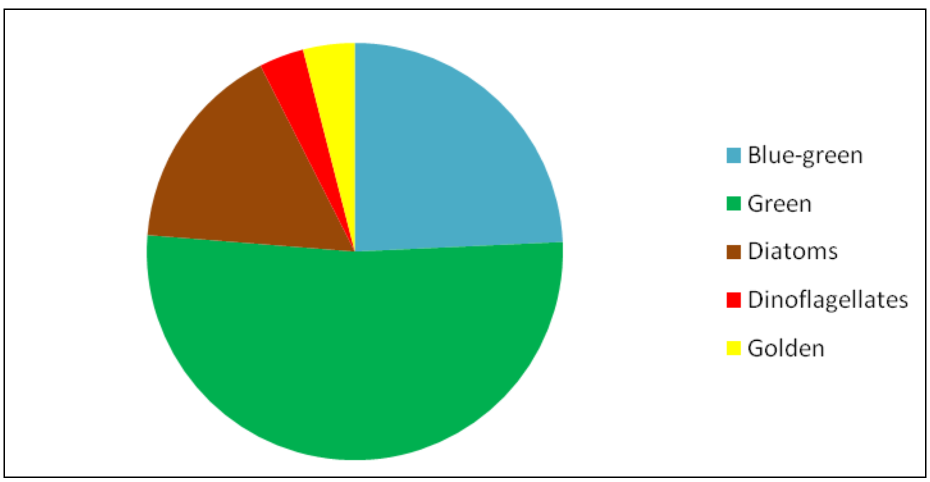

Figure 66. Percent composition of major algae groups in Jellum's Bay, May to September 2008

Zooplankton

Twenty zooplankton species were found in Jellum's Bay. The two most common zooplankton genera in Jellum's Bay are the rotifers *Keratella* and *Conochiloides*, followed by the copepod *Diacyclops*.

The zooplankton community composition is dominated by rotifers (Figure 67). These smaller organisms escape fish predation but do not graze on algae to the extent that the larger Cladocera do (Cladocera are very rare in Jellum's Bay.) The rotifer dominance suggests grazing pressure by planktivorous fish and a reduced capacity of the zooplankton to mitigate algal blooms.

The impact of the zooplankton community may be smaller in Jellum's Bay due to the extreme abundance of the Bryozoan *Pectinatella magnifica*. This colonial invertebrate is a sessile (attached) filter feeder, and colonies in Jellum's Bay were observed up to basketball size, covering nearly 100% of all surfaces in late summer. Water clarity may be increased by these organisms, but it is unclear if their predominance is regular or cyclical. Given the patterns in other similar lakes, it is highly likely that the Bryozoan colonies in Jellum's Bay have a far greater impact on the algae composition and consequently water clarity than zooplankton do. Bryozoans likely do not have much of an impact directly on zooplankton but may out-compete them for resources.

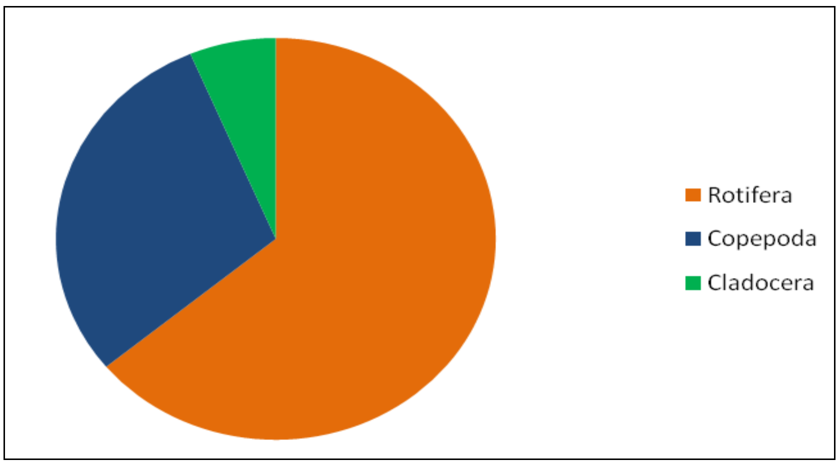

Figure 67. Percent composition of major zooplankton groups in Jellum's Lake, May to September 2008.

8.6 Water Quality

Monitoring data for total phosphorus (TP) and Secchi transparency are available from 2000-2008. Chlorophyll-*a* data are available from 2001-2008. A summary of the data suggests that the lake is not meeting the TP or chlorophyll-*a* lake water quality standards, and is just meeting the standard for Secchi transparency (Table 44).

Table 44. Jellum's Bay, Surface Water Quality Means and Standards, 2000-2008

Parameter	Growing Season Mean (June – September)	Shallow Lake Standard
TP (µg/L)	97	60
Chlor-a (µg/L)	52	20
Secchi transparency (m)	1.0	1.0

TP seems to have improved in 2007 (Figure 68), and there appears to be a trend in water quality improvement as indicated by the chlorophyll-*a* (Figure 69) and Secchi transparency data (Figure 70). Preliminary data from 2009 suggest that water quality continued to improve, with the following growing season means: 53µg/L TP, 9 µg/L chlorophyll-*a*, and 2.9 meters transparency. These data strongly suggest that the lake switched from a turbid, phytoplankton dominated phase to a clear-water, macrophyte dominated phase in 2007. The macrophyte data also support this (Figure 65).

Transparency is relatively good in the spring and early summer, declines in the summer, and improves again in the fall (Figure 71). There are no clear seasonal patterns in TP or chlorophyll-*a*.

Oxygen levels at times are low in the deeper portions of Jellum's Bay (Figure 72), but the lake does not develop a stable thermal stratification due to its overall shallow depths.

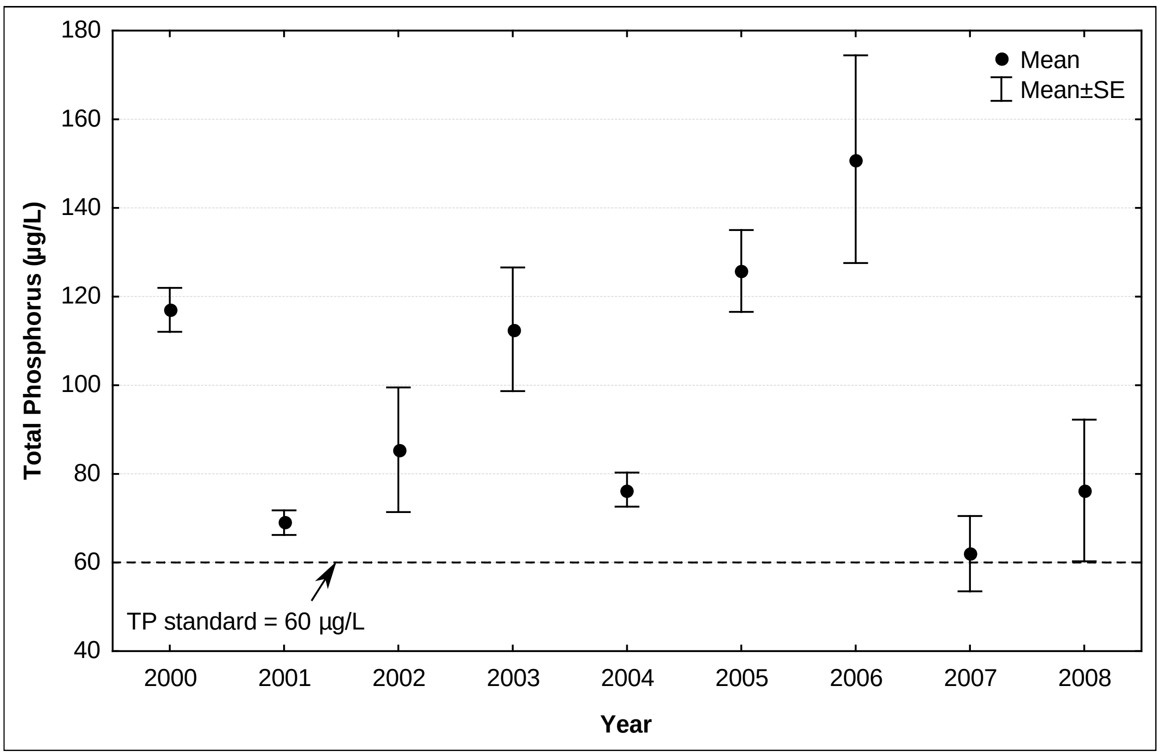

Figure 68. Jellum's Bay, Growing Season Means Total Phosphorus

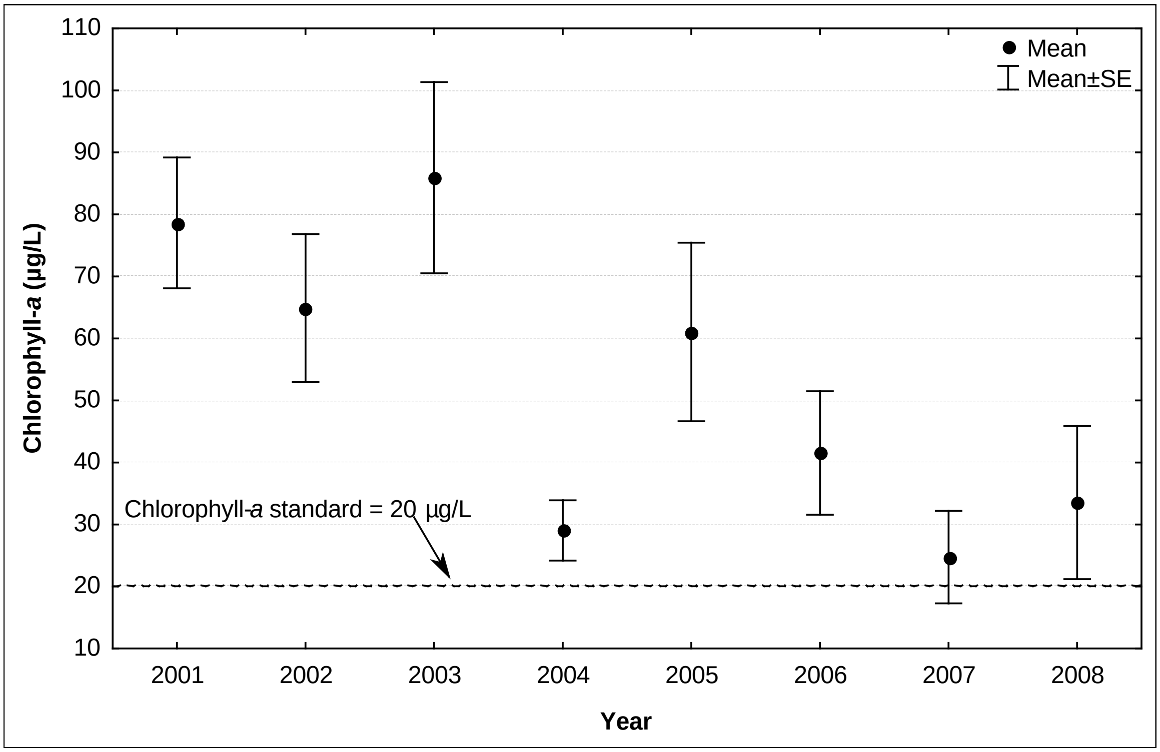

Figure 69. Jellum's Bay, Growing Season Means Chlorophyll-*a*

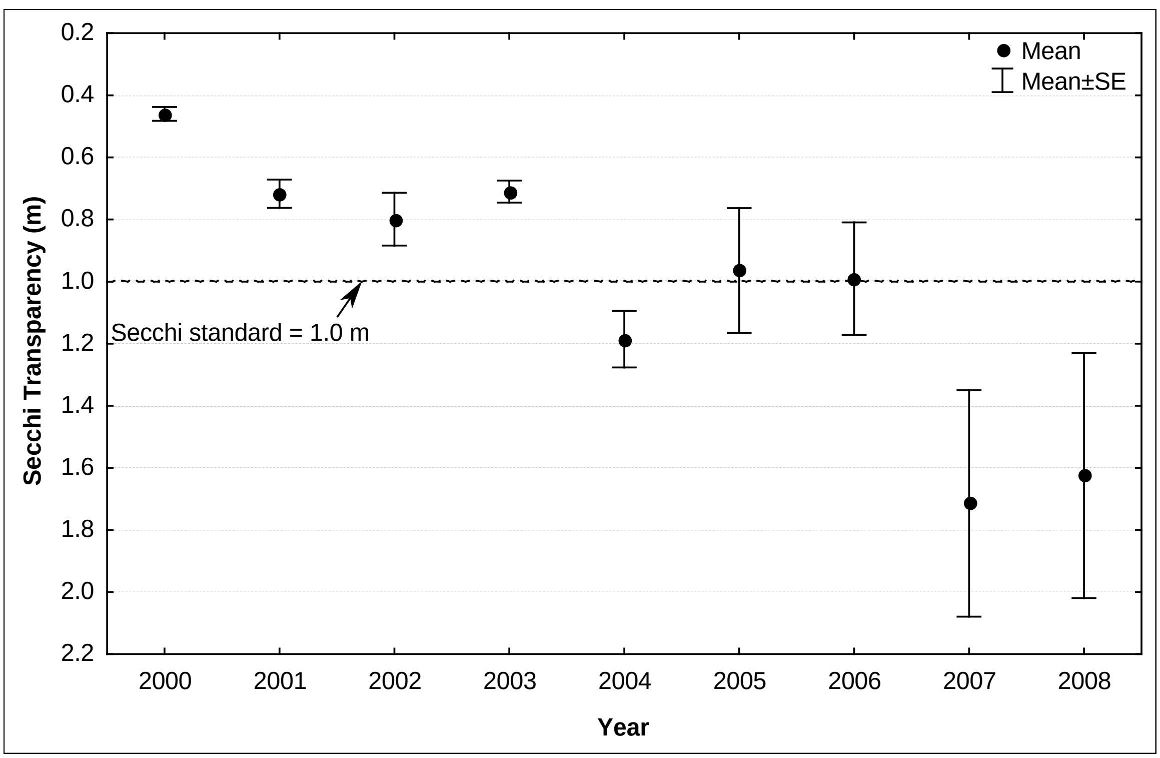

Figure 70. Jellum's Bay, Growing Season Means Secchi Transparency

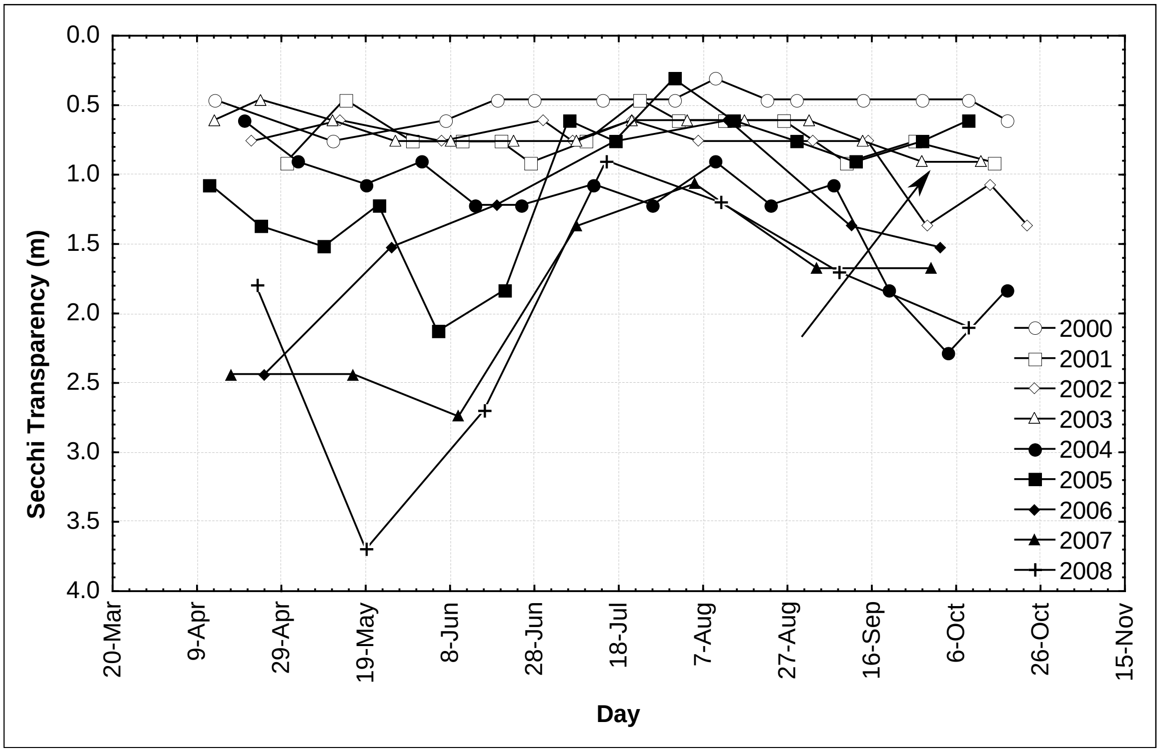

Figure 71. Jellum's Bay Seasonal Secchi Transparency Patterns

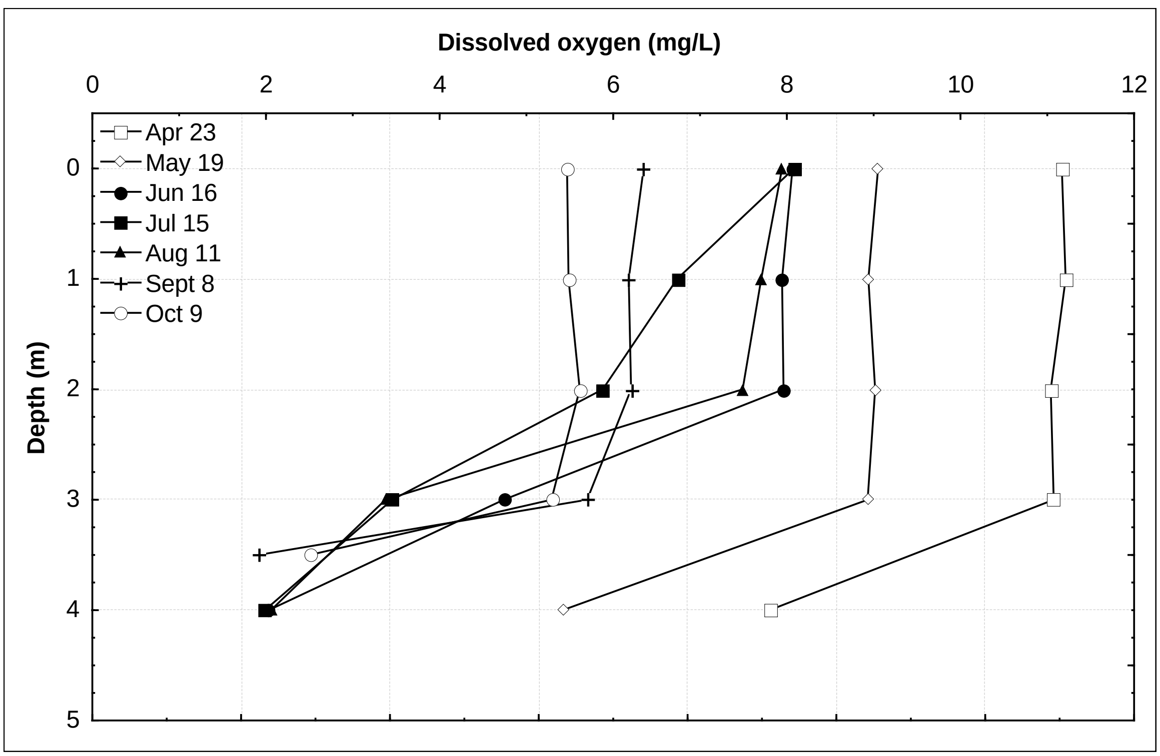

Figure 72. Jellum's Bay Dissolved Oxygen, 2008

8.7 In-Lake Impairment Assessment Summary

- The lake is used as a walleye rearing pond by the DNR. During a 2008 harvest, large populations of bluegill and green sunfish were observed.
- The lake is a shallow lake with a diverse community of native macrophytes.
- The zooplankton community is dominated by rotifers, leading to a low grazing capacity by zooplankton.
- The abundant bryozoan population likely impacts the transparency of the lake through its filter-feeding action.

8.8 Phosphorus Source Inventory

8.8.1 Watershed Phosphorus Sources

The contributing watershed to Jellum’s Bay (550 acres) includes watershed runoff from the direct drainage area around the lake and drainage coming from Long Lake. It is estimated that Jellum’s Bay receives 81 pounds of phosphorus annually from watershed runoff (Table 45). More than half of the watershed phosphorus is from direct watershed runoff. Approximately 19 pounds annually are coming from Long Lake upstream.

The 2030 phosphorus load from direct watershed runoff is estimated to be 54 lb/yr, a minor change from 56 lb/yr under existing conditions. No major land use changes are projected between now and 2030 (see Section 8.2). The change in future loading is assumed to be the result of Metropolitan Council’s re-categorization of 2030 land use as compared to 2005 land use (see *Direct Watershed Runoff: Direct Watershed Runoff under Future (2030) Conditions* in Section 3.1.2 for further discussion).

Table 45. Jellum's Bay Watershed Phosphorus Source Summary, Existing Loads

Phosphorus Source	Annual TP Load (lb/yr)	Percent of Watershed TP Load	Area (ac)	Average Areal TP Load (lb/ac-yr)[1]	Average TP Concentration (µg/L)[2]
Direct Watershed Runoff	56	69%	291	0.19	216
SSTS	6	7%	n/a	n/a	n/a
Upstream Lake Loading (Long Lake)[3]	19	23%	259	0.073	82[5]
Total	**81**	**99%**[4]			

[1] Annual TP load (lb/yr) divided by drainage area (ac)
[2] Annual TP load (lb/yr) divided by average annual volume of runoff [3.94 (average annual depth of runoff in inches) * drainage area (ac) * conversion factor]
[3] Calculations are from lake outlet; includes lake area and drainage area
[4] Total does not equal 100% due to rounding
[5] Calculated concentration does not equal measured concentration (81 µg/L as in Table 6 from Lo*ading from Upstream Waters* in Section 3.1.2) due to rounding

8.8.2 Atmospheric Phosphorus Sources

Atmospheric deposition is estimated to be 17 lb/yr (see *Atmospheric Deposition* in Section 3.1.2 for more information).

8.8.3 Internal Phosphorus Sources

Internal loading accounts for an additional 14 to 235 lb/yr (124 lb/yr average) of phosphorus loading to the lake, representing 13% to 71%, respectively, of the total loading to the lake.

8.8.4 Phosphorus Load Summary

The total modeled phosphorus load to Jellum's Bay is 222 lb/yr (Table 14).

Table 46. Jellum's Bay Phosphorus Source Summary, Existing Loads

Phosphorus Source	Phosphorus Load (lb/yr)
Watershed	81
Atmospheric	17
Internal	124
Total	**222**

8.9 TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Jellum's Bay is 175 lb/yr, to be split among allocations according to Table 47. To meet the TMDL, the total load to the lake needs to be reduced by 65 lb/yr.

Watershed scale pollutant load modeling was conducted and analyzed on an annual basis to establish this TMDL at a level necessary to attain and maintain applicable water quality standards. Daily wasteload allocations were derived from this analysis.

Table 47. Jellum's Bay Existing Loads, TMDL Allocations, and Reductions Needed

Load Component	TP Existing	TP TMDL Allocation		TP Reduction	
	lb/yr	lb/yr	lb/day	lb/yr	%
WLA					
Construction stormwater (permit #MNR100001)	0.41	0.41	0.0011	0	0%
Industrial stormwater (permit # MNR50000)	0.41	0.41	0.0011	0	0%
Total WLA	**0.82**	**0.82**	**0.0022**	**0**	**0%**
LA*					
Watershed	80	70	0.19	10	13%
Atmospheric	17	17	0.047	0	0%
Internal	124	69	0.19	55	44%
Total LA	***221***	***156***	**0.43**	***65***	**29%**
MOS	**--**	**18**	**0.049**	**--**	**--**
Total	***222***	***175***	***0.48***	***65****	***29%***

*LA components are broken down for guidance in implementation planning; the LA should be considered categorical.
**65 lb/yr reduction takes into account MOS; 47 lb/yr reduction (=65-MOS) needed to reach total loading capacity

9 LONG LAKE TMDL

9.1 Physical Characteristics

Long Lake (ID 82-0068) is a shallow lake located in the City of Scandia. The lake typically outlets to the northwest into Jellum's Bay, another impaired lake. Table 48 summarizes the lake's characteristics, and Figure 73 illustrates the lake's bathymetry.

Table 48. Long Lake Characteristics

Characteristic	Value	Source
Lake total surface area (ac)	39.8	2008 MLCCS revised based on 2008 aerial photos
Percent lake littoral surface area	100	Calculated based on 2008 WCD bathymetry data
Lake volume (ac-ft)	175	Calculated (mean depth x surface area)
Mean depth (ft)	4.4	Calculated based on 2008 WCD bathymetry data
Maximum depth (ft)	7	Based on 2008 WCD bathymetry data
Drainage area (acres)	218.9	CMSCWD
Watershed area:lake area	5.5	Calculated

Figure 73. Long Lake Bathymetry
Contour units are feet.

9.2 Land Use

The watershed of Long Lake is currently dominated by undeveloped land and agriculture (Table 49). Farmsteads and single family residential land uses are found throughout the watershed along with a small amount of industrial and institutional land uses. No major land use changes are projected between now and 2030 (Table 50); changes are assumed to be the result of Metropolitan Council's re-categorization of 2030 land use as compared to 2005 land use.

Table 49. Long Lake Watershed Land Use, 2005
(2005 Generalized Land Use for the Twin Cities Metropolitan Area)

Land Use	Total Acres	% of Watershed
Agricultural	70.5	32.2%
Farmstead	5.3	2.4%
Industrial and Utility	0.7	0.3%
Institutional	1.2	0.5%
Park, Recreation, or Preserve	-	-
Retail and Other Commercial	-	-
Seasonal/Vacation	-	-
Single Family Detached	21.3	9.7%
Undeveloped	118.8	54.3%
Water	1.1	0.5%
Total	**218.8**	**100.0%**

Table 50. Long Lake Watershed Land Use, 2030
(Regional Planned Land Use for the Twin Cities Metropolitan Area)

Land Use	Total Acres	% of Watershed
Agricultural	-	-
Airport	-	-
Commercial	-	-
Industrial	-	-
Institutional	-	-
Mixed Use	-	-
Multifamily Residential	-	-
Multi-Optional Development	-	-
Open Space or Restrictive Use	-	-
Park and Recreation	5.7	2.6%
Railway (inc. LRT)	-	-
Rights-of-Way (i.e., Roads)	-	-
Rural or Large-Lot Residential	212.0	96.8%
Single Family Residential	-	-
Vacant or No Data	-	-
Water	1.2	0.5%
Total	**218.9***	**99.9%**º

* 2030 total acres does not match 2005 total acres due to rounding.
º Total % does not equal 100.0 due to rounding.

9.3 Existing Studies, Monitoring, and Management

In 2000 a phosphorus sensitivity analysis for several lakes in the Carnelian-Marine Watershed District was completed (CMWD 2000). The study noted that the water quality of Long Lake exceeded the ecoregion goal of 40 µg/L of total phosphorus and the report suggests that the lake be passively maintained.

The Long Lake Watershed Management Plan was written as part of the Carnelian-Marine-St. Croix Watershed District's 2010 Watershed Management Plan. Management, monitoring, and implementation activities are expected to be driven by an implementation plan developed based on this TMDL study.

9.4 Lake Uses

There is no public access to Long Lake and the majority of the shoreland is in private ownership. The primary use of the lake is boating and fishing by residents who live on the lake. Long Lake is currently managed as a walleye rearing pond by the DNR.

9.5 Biological Characteristics

9.5.1 Fisheries

Long Lake is currently being managed by the DNR as a walleye rearing pond. A fish toxin was applied in 2003 to eliminate the existing fish, and the lake was first stocked in 2004. In May of 2008 the lake was stocked with 280,000 walleye fry. A harvest was completed by the DNR in late September of 2008 removing 481 pounds of walleye fingerlings, yearlings, and adults. Green sunfish were abundant in the net catch and the DNR reported that this could be a problem to future production in the lake. A fish toxin (rotenone) was applied again in November 2009 to eliminate the existing fish. The lake experiences occasional winter kills.

9.5.2 Macrophytes

Macrophyte surveys were completed for Long Lake in June and August of 2008. Curly-leaf pondweed was not observed during either survey (Figure 74). The distribution of macrophyte communities remained essentially the same between the June and August survey. A diversity of macrophyte species was present in the lake during both surveys (Table 51).

Table 51. Plant Species Observed During 2008 Long Lake Macrophyte Surveys

Scientific Name	Common Name	June	August
Chara vulgaris	Muskgrass	ü	ü
Elodea canadensis	Elodea	ü	ü
Nuphar lutea	Yellow water-lily	ü	ü
Nymphaea odorata	White water-lily	ü	ü
Potamogeton amplifolius	Large-leaved pondweed	ü	
Potamogeton foliosus	Leafy pondweed		ü
Potamogeton natans	Floating-leaved pondweed	ü	
Potamogeton robbinsii	Fern-leaved pondweed	ü	
Vallisneria americana	Wild Celery	ü	ü

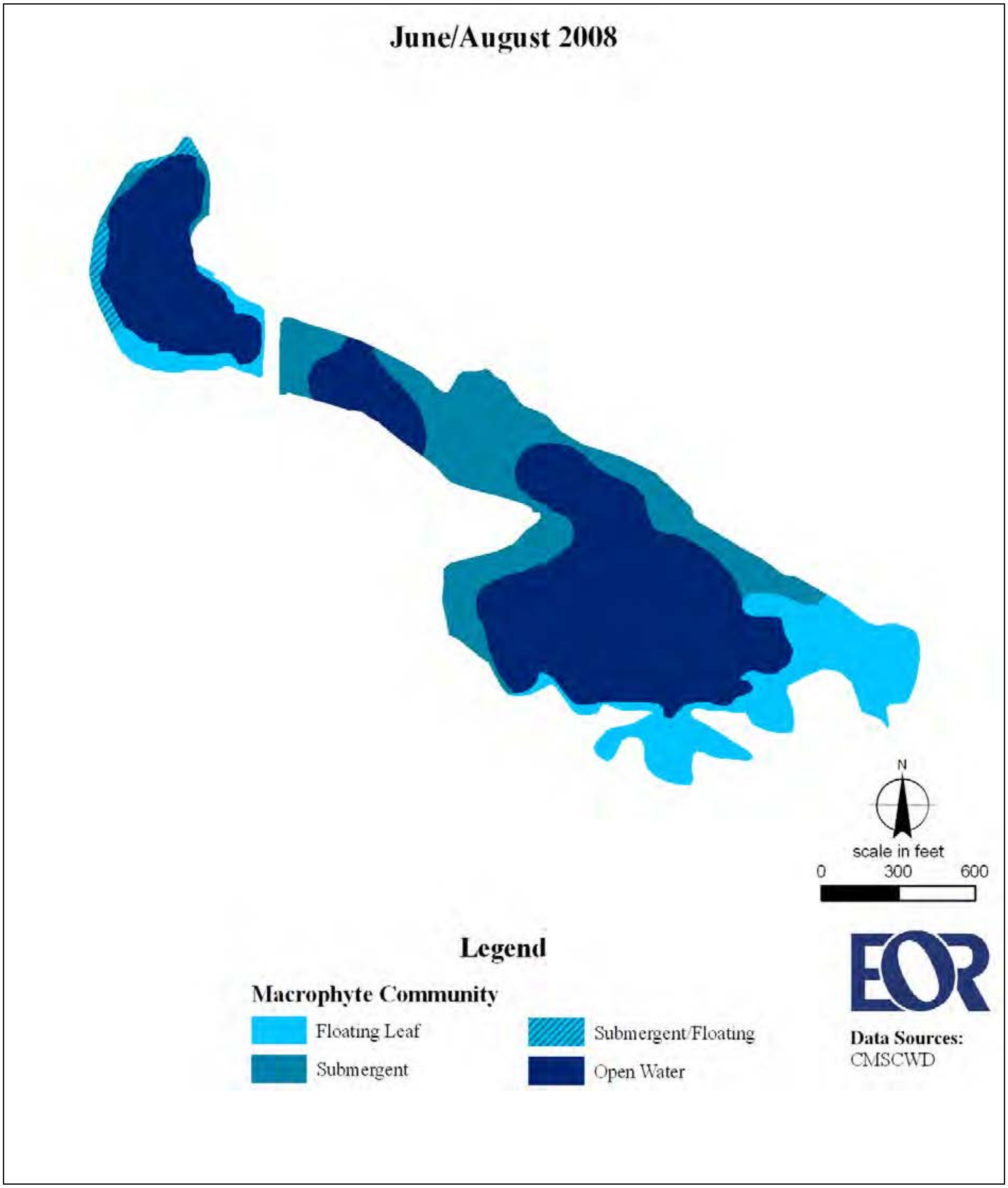

Figure 74. Distribution of Macrophyte Communities in Long Lake

9.5.3 Plankton Community

Phytoplankton

Twenty-four phytoplankton genera were found in Long Lake, and the three most common genera were two types of green algae (*Eudorina* and *Dictyosphaerium*), and a blue-green algae (*Anabaena*). This composition shows some potential for algal blooms, but overall the algal community is relatively balanced (Figure 75), reflecting an even distribution of different zooplankton grazers that have different size preferences.

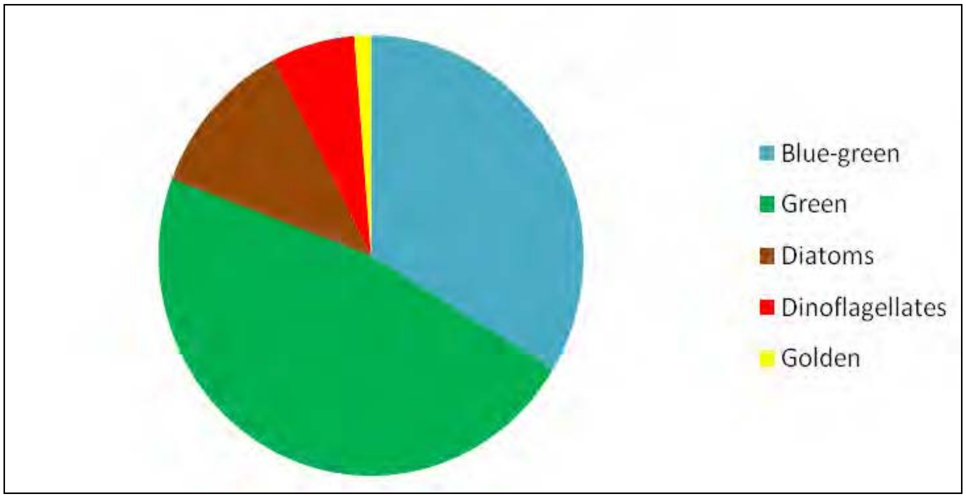

Figure 75. Percent composition of major algae groups in Long Lake, May to September 2008

Zooplankton

Seventeen zooplankton species were found in Long Lake. The most common zooplankton in Long Lake is the rotifer *Conochiloides unicornis*, followed by a cladoceran (*Bosmina*) and a copepod (*Diaptomus*). This distribution is reflected in the composition of the entire zooplankton community being almost evenly split between rotifers, copepods, and cladocera (Figure 76). The zooplankton community is relatively balanced between predation pressures by planktivorous fish and the capacity to mitigate algal blooms by grazing.

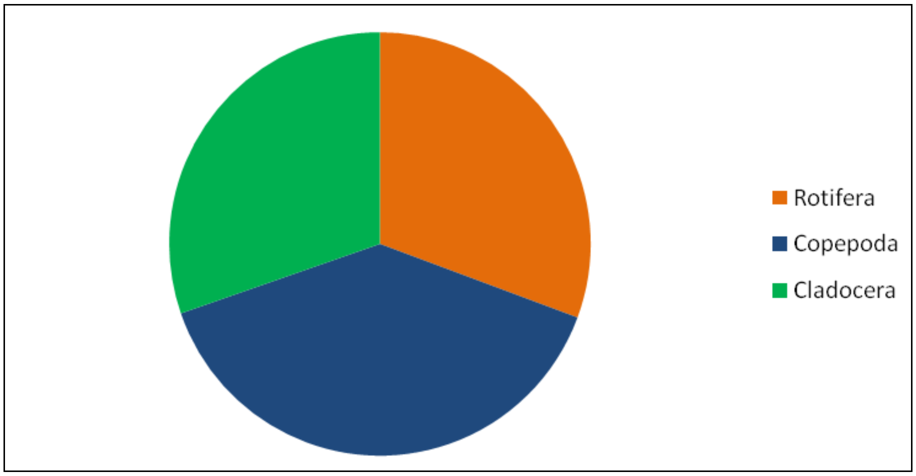

Figure 76. Percent composition of major zooplankton groups in Long Lake, May to September 2008

9.6 Water Quality

Monitoring data are available from 2000-2008. A summary of the data indicates that the lake is not meeting either the TP or the chlorophyll-*a* standard, but it is meeting the Secchi transparency standard (Table 52).

Table 52. Long Lake, Surface Water Quality Means and Standards, 2000-2008

Parameter	Growing Season Mean (June – September)	Shallow Lake Standard
TP (µg/L)	81	60
Chlor-*a* (µg/L)	43	20
Secchi transparency (m)	1.1	1.0

Figure 77 through Figure 79 show the mean growing season total phosphorus (TP), chlorophyll-*a*, and Secchi transparency data from Long Lake. Annual mean TP concentrations remained consistent at approximately 80 to 100 µg/L for the years 2003-2006, with an improvement seen in 2007 and 2008. Chlorophyll-*a* concentrations have been decreasing since 2004, with 2006 and 2008 meeting water quality standards. Secchi transparency has been improving in the lake since 2003 and has been meeting water quality standards since 2006. The trend in improved water quality did not continue into 2009. Preliminary data from 2009 suggest that water quality worsened, with the following growing season means based on four monthly samples: 59µg/L TP, 52 µg/L chlorophyll-*a*, and 1.0 meters transparency. These data suggest that the lake may have been in a clear-water, macrophyte dominated phase in 2007, but that it switched to a turbid, phytoplankton dominated phase in either 2008 or 2009. There is a weak positive relationship between average water levels and water quality (Figure 80), which is often seen in shallow lakes. When water levels rise, the rooted aquatic vegetation does not receive as much light and macrophyte coverage can decrease, which can switch the lake to the turbid phase (Moss 1996). The observed decrease in water quality in 2009 is not explained by lake levels.

Chlorophyll-*a* tends to peak in August (Figure 81). The seasonal patterns for TP and Secchi transparency were less evident. Moderate relationships exist between chlorophyll-*a* and TP (Figure 82), and between TP and transparency (Figure 83).

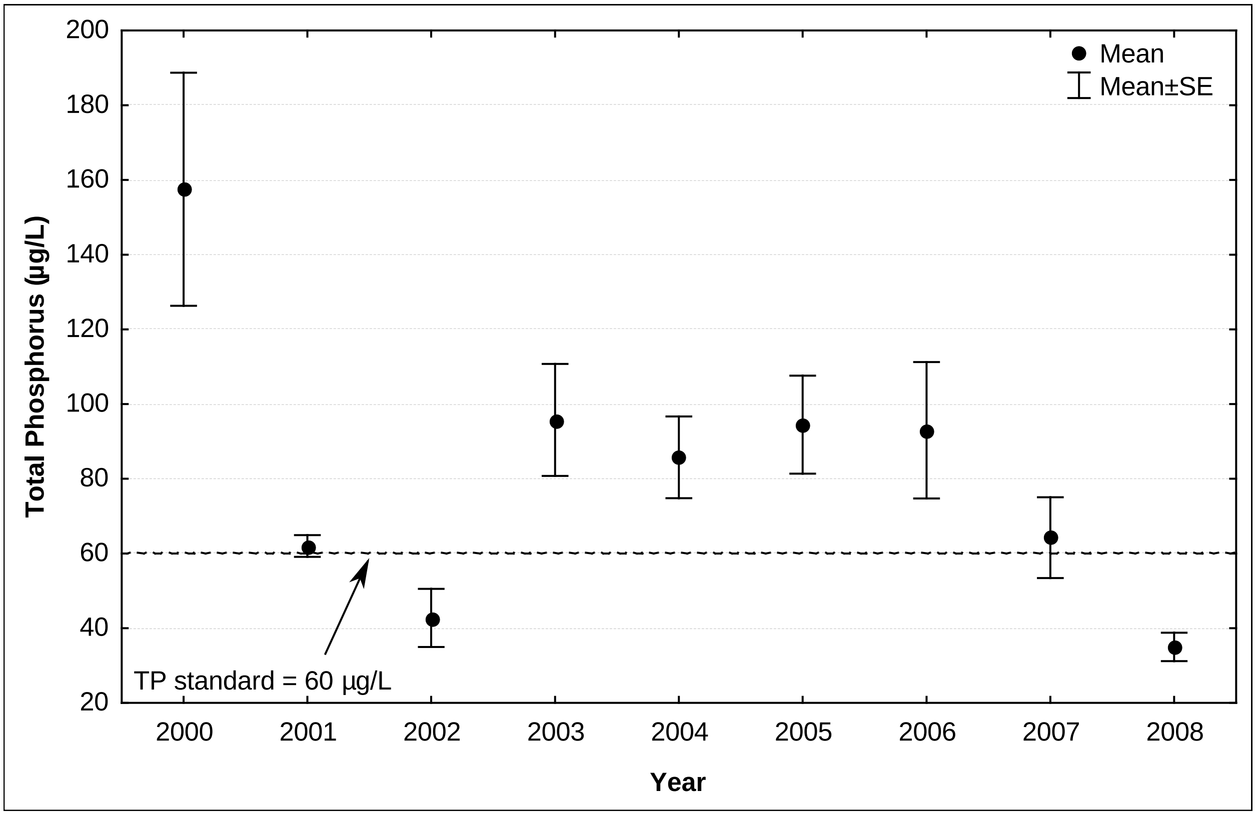

Figure 77. Long Lake, Growing Season Means Total Phosphorus

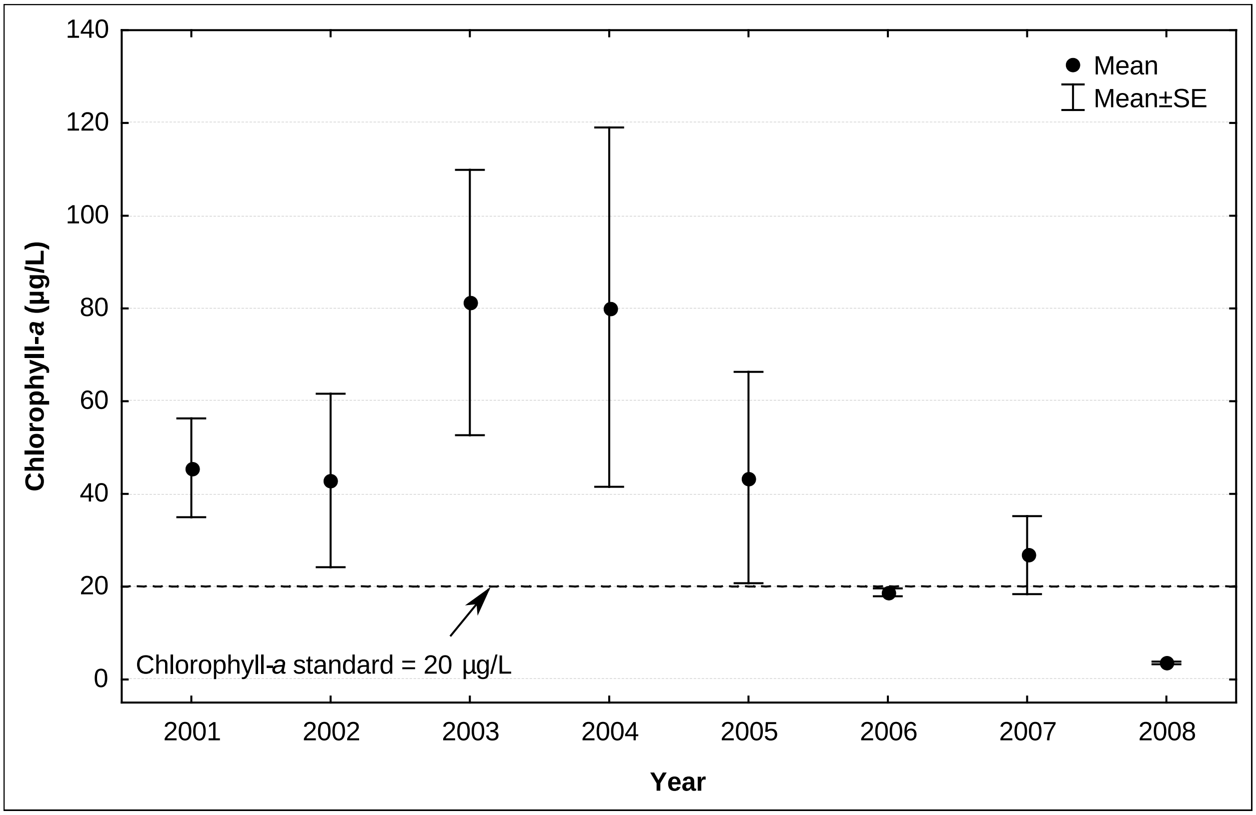

Figure 78. Long Lake, Growing Season Means Chlorophyll-*a*

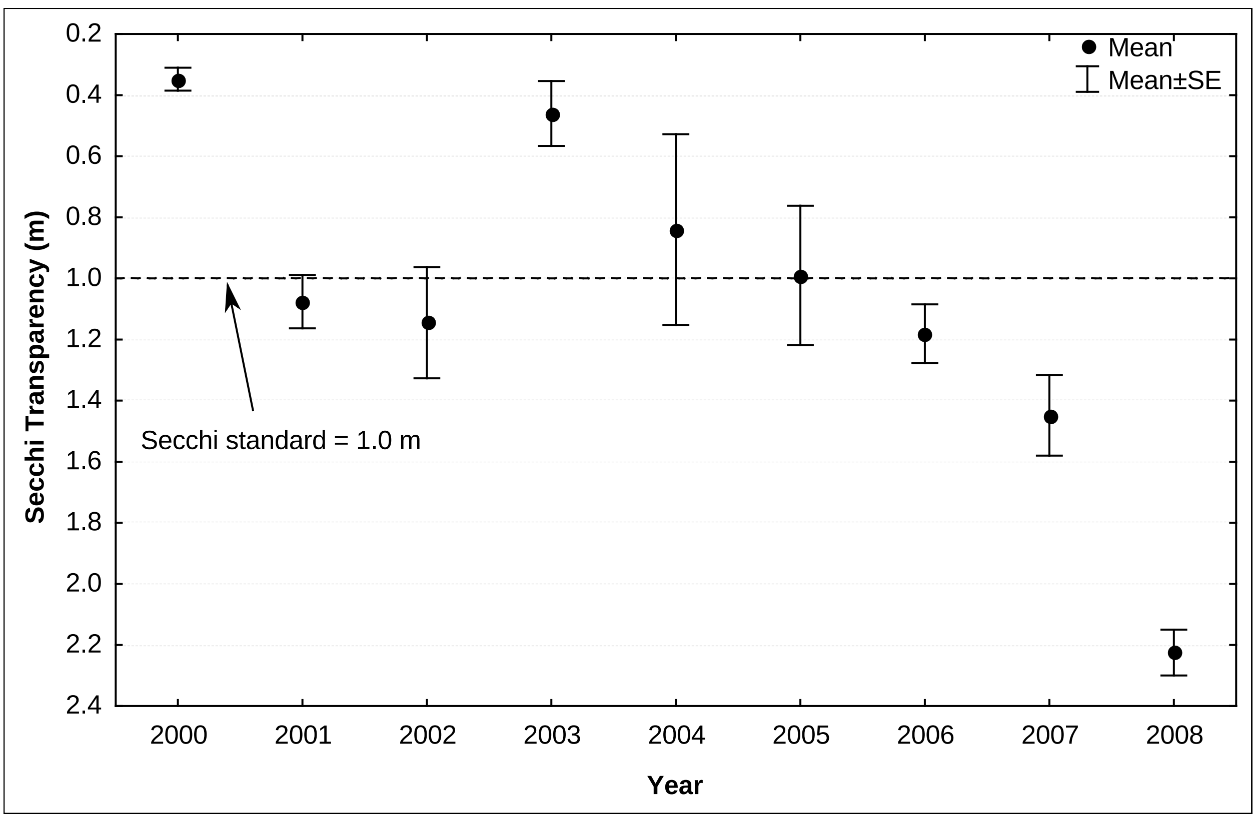

Figure 79. Long Lake, Growing Season Means Secchi Transparency

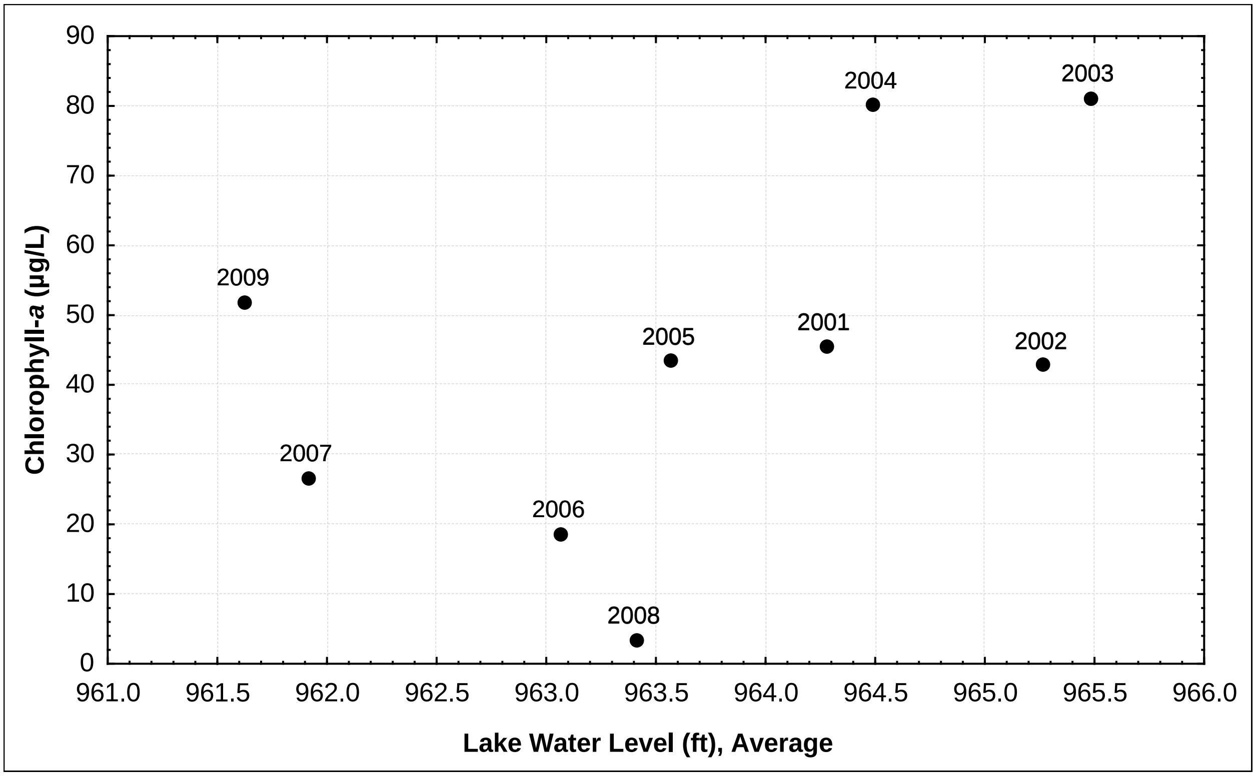

Figure 80. Relationship between average lake water level and chlorophyll-*a* (growing season mean), Long Lake

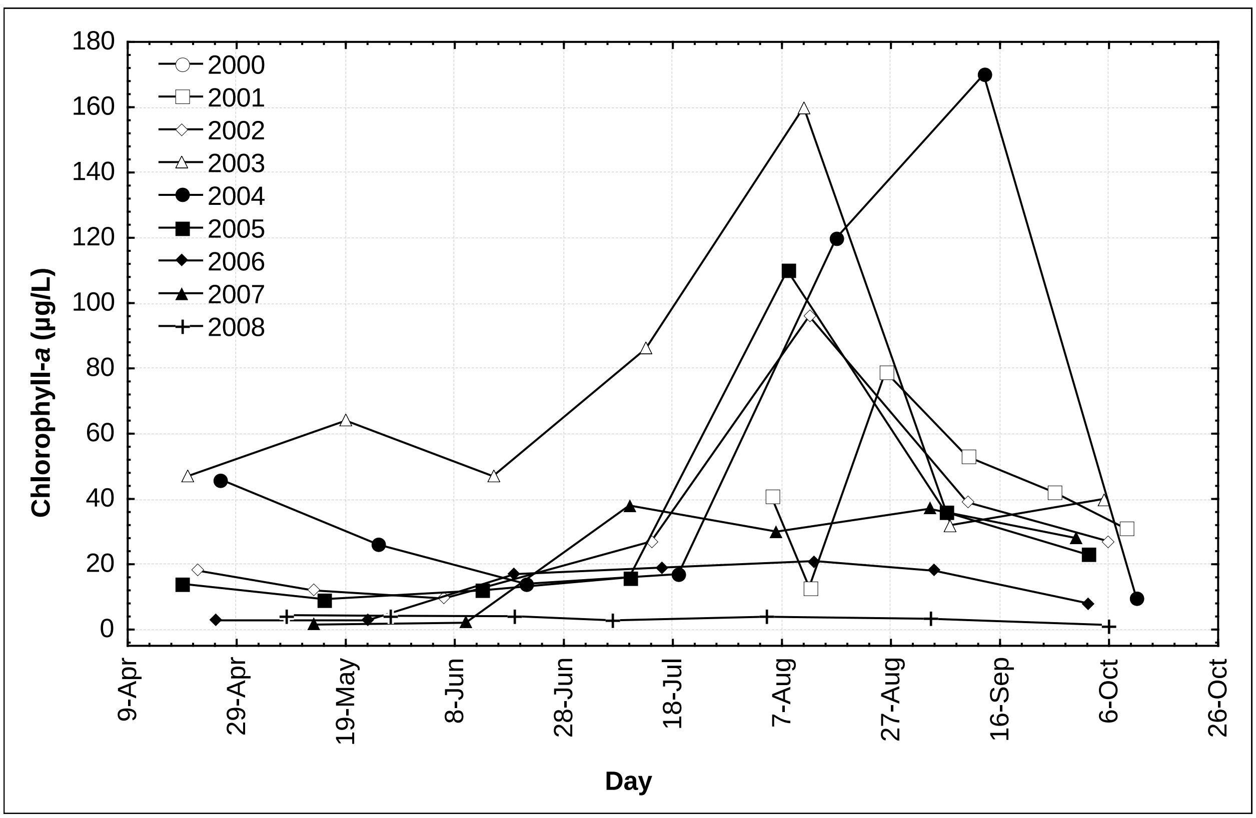

Figure 81. Long Lake Seasonal Chlorophyll-*a* Patterns

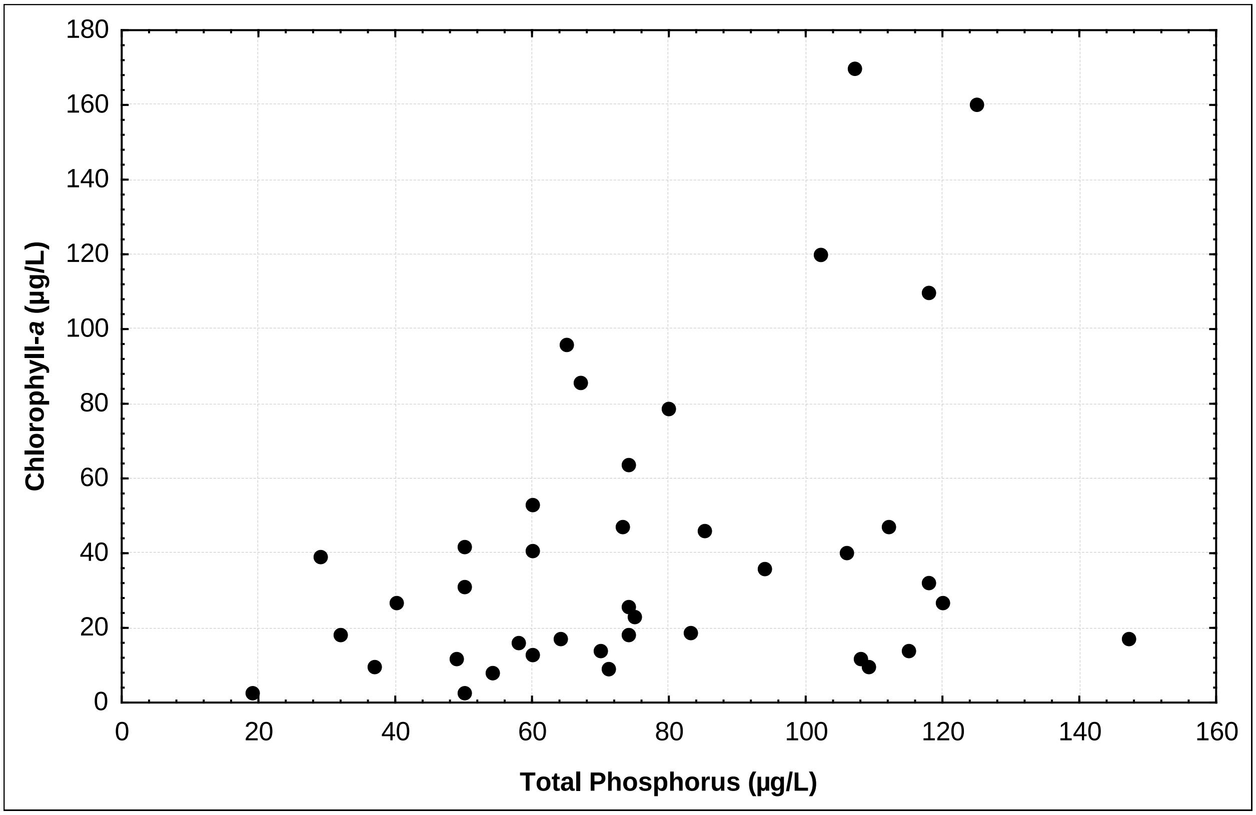

Figure 82. Long Lake Relationship of Chlorophyll-*a* to Total Phosphorus

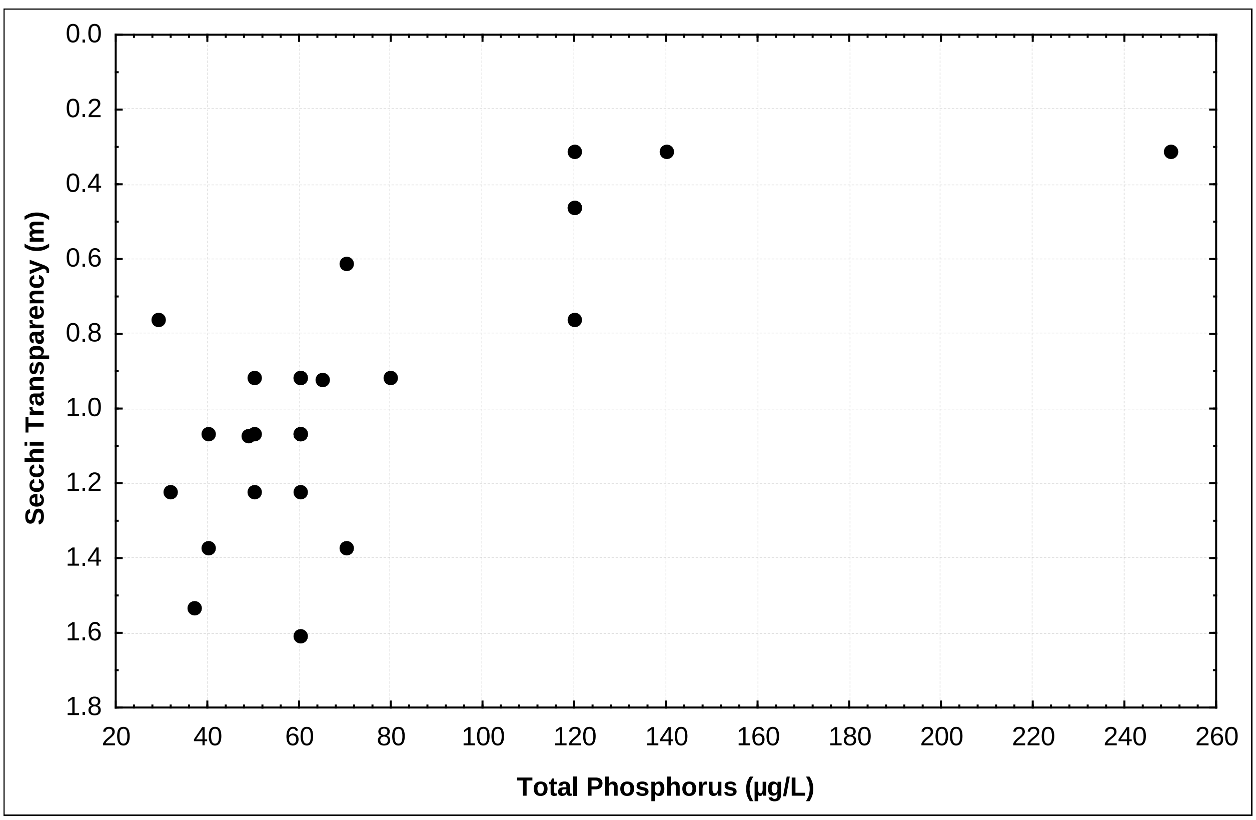

Figure 83. Long Lake Relationship of Secchi Transparency to Total Phosphorus

9.7 In-Lake Impairment Assessment Summary

- The lake is used as a walleye rearing pond by the DNR. During a 2008 harvest, large populations of green sunfish were observed.
- Long Lake is a shallow lake with a diverse population of macrophytes and good water transparency. The lake appears to be in the clearwater, macrophyte-dominated phase often seen in shallow lakes. This clearwater phase is advantageous for water quality.
- The phytoplankton and zooplankton communities within the lake are well-balanced.
- The lake's water quality has been improving during recent years.

9.8 Phosphorus Source Inventory

9.8.1 Watershed Phosphorus Sources

It is estimated that Long Lake receives 52 pounds of phosphorus annually from watershed runoff (Table 53). The largest watershed source of phosphorus is direct watershed runoff from the contributing watershed (219 acres). SSTS contributes 21% of the phosphorus to the lake. There are approximately 9 houses on the lake contributing 11 pounds of phosphorus annually.

The 2030 phosphorus load from direct watershed runoff is estimated to be 40 lb/yr, a minor change from 41 lb/yr under existing conditions. No major land use changes are projected between now and 2030 (see Section 9.2). The change in future loading is assumed to be the result of Metropolitan Council's re-categorization of 2030 land use as compared to 2005 land use (see *Direct Watershed Runoff: Direct Watershed Runoff under Future (2030) Conditions* in Section 3.1.2 for further discussion).

Table 53. Long Lake Watershed Phosphorus Source Summary, Existing Loads

Phosphorus Source	Annual TP Load (lb/yr)	Percent of Watershed TP Load (%)	Area (ac)	Average Areal TP Load (lb/ac-yr)[1]	Average TP Concentration (µg/L)[2]
Direct Watershed Runoff	41	79%	219	0.19	210
SSTS	11	21%	n/a	n/a	n/a
Total	**52**	**100%**			

[1] Annual TP load (lb/yr) divided by drainage area (ac)
[2] Annual TP load (lb/yr) divided by average annual volume of runoff [3.94 (average annual depth of runoff in inches) * drainage area (ac) * conversion factor]

9.8.2 Atmospheric Phosphorus Sources

Atmospheric deposition is estimated to be 11 lb/yr (see *Atmospheric Deposition* in Section 3.1.2 for more information).

9.8.3 Internal Phosphorus Sources

Internal loading accounts for an additional 8 to 134 lb/yr (71 lb/yr average) of phosphorus loading to the lake, representing 11% to 68%, respectively, of the total loading to the lake.

9.8.4 Phosphorus Load Summary

The total modeled phosphorus load to Long Lake is 134 lb/yr (Table 14).

Table 54. Long Lake Phosphorus Source Summary, Existing Loads

Phosphorus Source	Phosphorus Load (lb/yr)
Watershed	52
Atmospheric	11
Internal	71
Total	**134**

9.9 TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Long Lake is 111 lb/yr, to be split among allocations according to Table 55. To meet the TMDL, the total load to the lake needs to be reduced by 34 lb/yr.

Watershed scale pollutant load modeling was conducted and analyzed on an annual basis to establish this TMDL at a level necessary to attain and maintain applicable water quality standards. Daily wasteload allocations were derived from this analysis.

Table 55. Long Lake Existing Loads, TMDL Allocations, and Reductions Needed

Load Component	TP Existing	TP TMDL Allocation		TP Reduction	
	lb/yr	lb/yr	lb/day	lb/yr	%
WLA					
Construction stormwater (permit #MNR100001)	0.17	0.17	0.00047	0	0%
Industrial stormwater (permit # MNR50000)	0.17	0.17	0.00047	0	0%
Total WLA	**0.34**	**0.34**	**0.00094**	**0**	**0%**
LA*					
Watershed	52	26	0.071	26	50%
Atmospheric	11	11	0.030	0	0%
Internal	71	63	0.17	8	11%
Total LA	***134***	***100***	**0.27**	***34***	**25%**
MOS	**--**	**11**	**0.030**	**--**	**--**
Total	***134***	***111***	***0.30***	***34*****	***25%***

*LA components are broken down for guidance in implementation planning; the LA should be considered categorical.
**34 lb/yr reduction takes into account MOS; 23 lb/yr reduction (=34-MOS) needed to reach total loading capacity

10 LOON LAKE TMDL

10.1 Physical Characteristics

Loon Lake (ID 82-0015) is a shallow lake located in Stillwater Township. Loon Lake outlets intermittently into Silver Creek, a high quality perennial creek that drains to the St. Croix River. A county park is located along the northern shore of the lake. Table 56 summarizes the lake's characteristics, and Figure 84 illustrates the lake bathymetry.

Table 56. Loon Lake Characteristics

Characteristic	Value	Source
Lake total surface area (ac)	52.8	2008 MLCCS revised based on 2008 aerial photos
Percent lake littoral surface area	100	Calculated based on bathymetry data provided by the WCD in Aug 2009
Lake volume (ac-ft)	295.7	Calculated (mean depth x surface area)
Mean depth (ft)	5.6	Calculated based on bathymetry data provided by the WCD in Aug 2009
Maximum depth (ft)	15	Based on bathymetry data provided by the WCD in Aug 2009
Drainage area (acres)	394.1	CMSCWD
Watershed area:lake area	7.5	Calculated

Figure 84. Loon Lake Bathymetry
Contour units are feet.

10.2 Land Use

Currently, the dominant land uses within the Loon Lake watershed are agriculture and park, recreation, or preserve (Table 57). The large area of parkland is Pine Point Park, and the Gateway State Trail also passes through the watershed. Single family residential and undeveloped land uses are also prevalent. A small area of industrial land use is located west of Myeron Road. Residents report that, historically, a sawmill operated at the southeastern end of the lake that discharged wood waste into the lake.

No major land use changes are projected between now and 2030 (Table 58); changes are assumed to be the result of Metropolitan Council's re-categorization of 2030 land use as compared to 2005 land use.

Table 57. Loon Lake Watershed Land Use, 2005
(2005 Generalized Land Use for the Twin Cities Metropolitan Area)

Land Use	Total Acres	% of Watershed
Agricultural	129.3	32.8%
Farmstead	5.3	1.3%
Industrial and Utility	13.2	3.4%
Institutional	-	-
Park, Recreation, or Preserve	112.9	28.7%
Retail and Other Commercial	-	-
Seasonal/Vacation	-	-
Single Family Detached	55.9	14.2%
Undeveloped	75.3	19.1%
Water	2.2	0.5%
Total	**394.1**	**100.0%**

Table 58. Loon Lake Watershed Land Use, 2030
(Regional Planned Land Use for the Twin Cities Metropolitan Area)

Land Use	Total Acres	% of Watershed
Agricultural	-	-
Airport	-	-
Commercial	-	-
Industrial	-	-
Institutional	-	-
Mixed Use	-	-
Multifamily Residential	-	-
Multi-Optional Development	-	-
Open Space or Restrictive Use	-	-
Park and Recreation	116.5	29.6%
Railway (inc. LRT)	-	-
Rights-of-Way (i.e., Roads)	-	-
Rural or Large-Lot Residential	275.4	69.9%
Single Family Residential	-	-
Vacant or No Data	-	-
Water	2.2	0.6%
Total	**394.1**	**100.1%***

* Total % does not equal 100.0 due to rounding.

10.3 Existing Studies, Monitoring, and Management

Based on an Aerial Lakeshore Analysis study (CMWD 1999), the most common influence on the lake was runoff non-point source pollution. The most common problem is the lack of a vegetative buffer and insufficient lake setback. The recommendations from that study are to investigate and correct all sources of pollution to the lake, to create a forested buffer adjacent to the shoreline to reduce impacts of runoff from adjacent fields and homes, keep the forested areas intact and to implement minor erosion control in particularly identified areas.

In 2000 a phosphorus sensitivity analysis for several lakes in the Carnelian-Marine Watershed District was completed (CMWD 2000). The study noted that the water quality of Loon Lake does not meet the ecoregion goal of 40 µg/L of total phosphorus but that the lake warrants projects or programs to actively improve the water quality.

In 2001 the Carnelian-Marine Watershed District completed a paleolimnological investigation of trophic changes in several lakes in the watershed, including Loon Lake (CMWD 2001b). The purpose of the investigation was to establish the baseline trophic conditions existing in the lake prior to European settlement in the mid-1800s. Although the sediment core collected from Loon Lake is 196 cm, lead-210 dating shows that the bottom of the core was deposited in 1915; therefore, inferring total phosphorus values prior to European settlement was not possible. The high rate of sedimentation in Loon Lake is believed to be the result of an old sawmill on the southeastern shore of the lake that dumped wood waste into the lake. The portion of the core dated to 1915 has the highest diatom-inferred total phosphorus (65 µg/L). Another spike in total phosphorus (TP) occurs around 1977 (60 μg/L). All other values range between 19-44 μg/L, but diatom-inferred TP values after 1970 are generally higher than those from 1915-1970.

In 2002, the Carnelian-Marine Watershed District completed the Loon Lake Sediment Survey (CMWD 2002b), which included collection of data related to lake morphometry and lake sediment depth. The depth of water and depth of soft lake sediments were measured. Two distinct holes were found in the lake measuring 45.3 and 50.5 feet to hard bottom. These holes are in locations where the water depth is less than 10 feet deep. The majority of the lake had at least 10 feet of soft lake sediment. The survey outlines sediment removal alternatives to improve the overall lake quality.

In 2004, the Carnelian-Marine Watershed District completed a corridor plan for Silver Creek (CMWD 2004b). The plan included an assessment of the shallow lakes in the Silver Creek watershed, including Loon Lake. The assessment looked at surface water quality trends, lake macrophyte communities, and provided recommendations on how to improve water quality. Poor water quality was reported throughout Loon Lake. A very thin fringe of near-shore littoral emergent plants surround most of Loon Lake's perimeter, and floating leaf plant communities occur scattered along the lake's shallow edges. The central portion of Loon Lake is largely barren except for a small portion along the eastern shore containing a few submergent plant species. Recommendations for Loon Lake included conducting a diagnostic study to identify the key pollution sources, working with MN DNR Fisheries to remove bullhead from the lake, and working with Washington County Parks to manage shoreland on the northern side of the lake in Pine Point Park.

The Loon Lake Watershed Management Plan was written as part of the Carnelian-Marine-St. Croix Watershed District's 2010 Watershed Management Plan. Management, monitoring, and implementation activities are expected to be driven by an implementation plan developed based on this TMDL study. In addition, installed best management practices undergo ongoing monitoring.

10.4 Lake Uses

Loon Lake does not have a public access. It is used as a walleye rearing pond by the DNR. It is used for water skiing and has a water-ski slalom course.

10.5 Biological Characteristics

10.5.1 Fisheries

According to the 1993 MN DNR Lake Management Plan, Loon Lake has intermittently been used by the DNR as a walleye rearing pond following severe winterkill events. A 1984 fish survey showed that the lake had an abundance of black bullhead and walleye.

10.5.2 Macrophyte Community

Macrophyte surveys were completed for Loon Lake in June and August of 2008. Curly-leaf pondweed was not observed during either survey (Figure 85). The distribution of macrophyte communities remained essentially the same between the June and August survey (Table 59), with the majority of the lake lacking macrophyte vegetation.

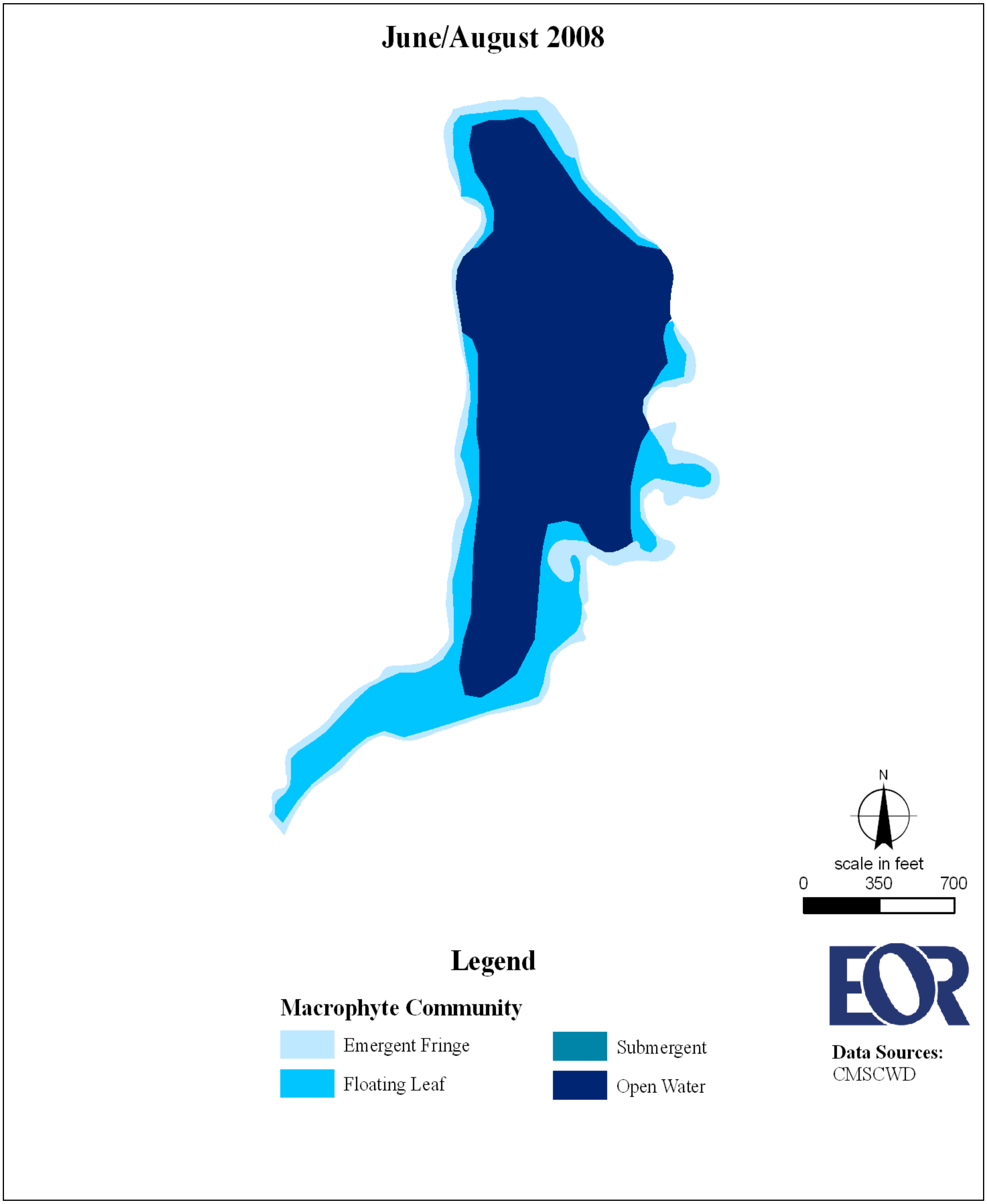

Figure 85. Distribution of Macrophyte Communities in Loon Lake

Table 59. Plant Species Observed During 2008 Loon Lake Macrophyte Surveys

Scientific Name	Common Name	June	August
Ceratophyllum demersum	Coontail	ü	ü
Elodea canadensis	Elodea	ü	ü
Nuphar lutea	Yellow water-lily	ü	ü
Nymphaea odorata	White water-lily	ü	ü

10.5.3 Plankton Community

Phytoplankton

The algal community of Loon Lake over the sampling season of 2008 was dominated by blue-green algae (Figure 86). The dominance of blue-green algae increases over the summer while the proportion of green algae decreases after initial dominance (Figure 87). Algal indicators of eutrophy decrease over spring and increase slightly in late summer (Figure 87).

Blue-green algae are dominated by *Anabaena limneticus* (Figure 88), which produces a gelatinous sheath making it nearly inedible by plankton. This species can also produce an odor and aesthetically unpleasant water conditions. The blue-green *Microcystis* is present, primarily in spring, showing potential of toxic blooms. *Eudorina* and *Scenedesmus* are the most common genera of green algae over most of the year.

There is no clear pattern of total phosphorus, algal density (chlorophyll-*a* concentration), and individual algal species responses (Figure 89). Phosphorus remains consistently high over time, supporting a fairly constant bloom of algae. The spikes in particular species concentrations and species shifts are likely biologically driven.

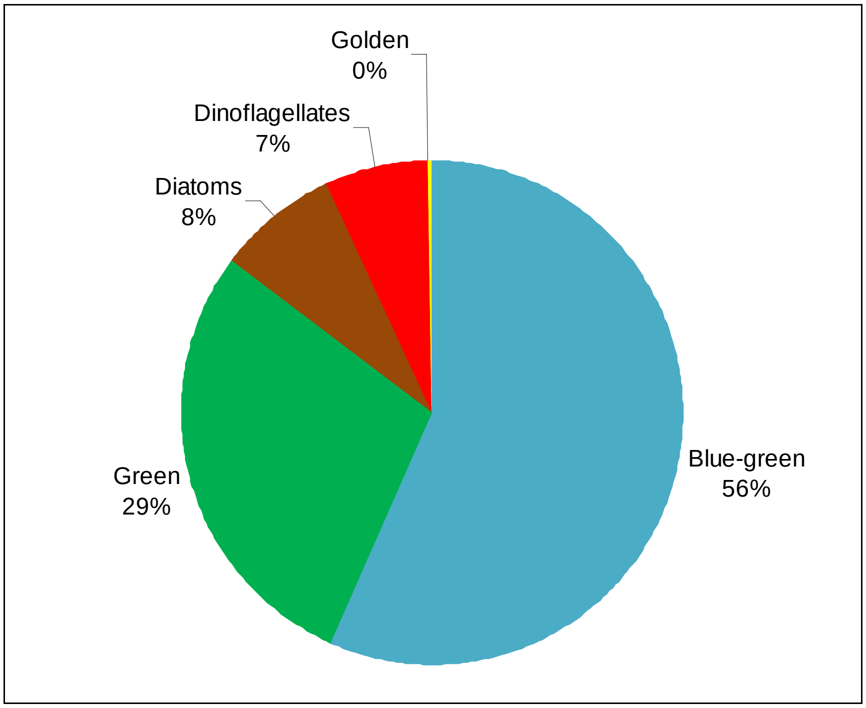

Figure 86. Total algal composition of major groups (%) in Loon Lake over 5 monthly sampling periods, 2008

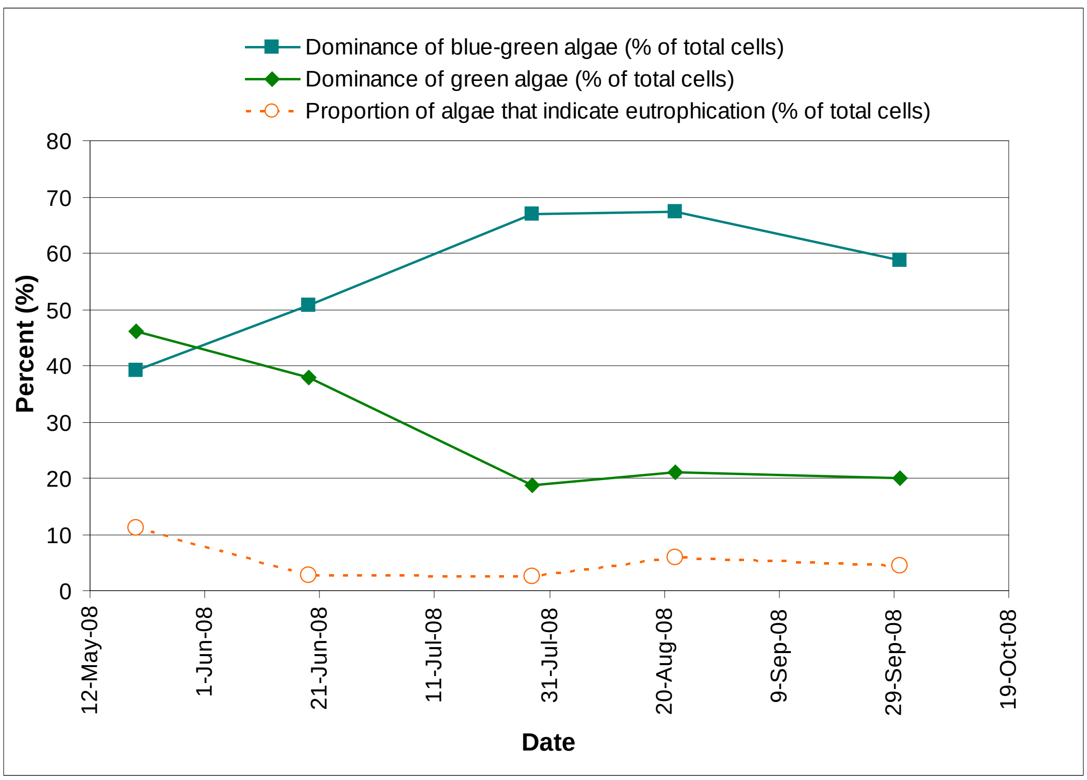

Figure 87. Dominance of major algal groups and indicator species in Loon Lake over five monthly sampling periods in 2008 (% of cells/300 counted)

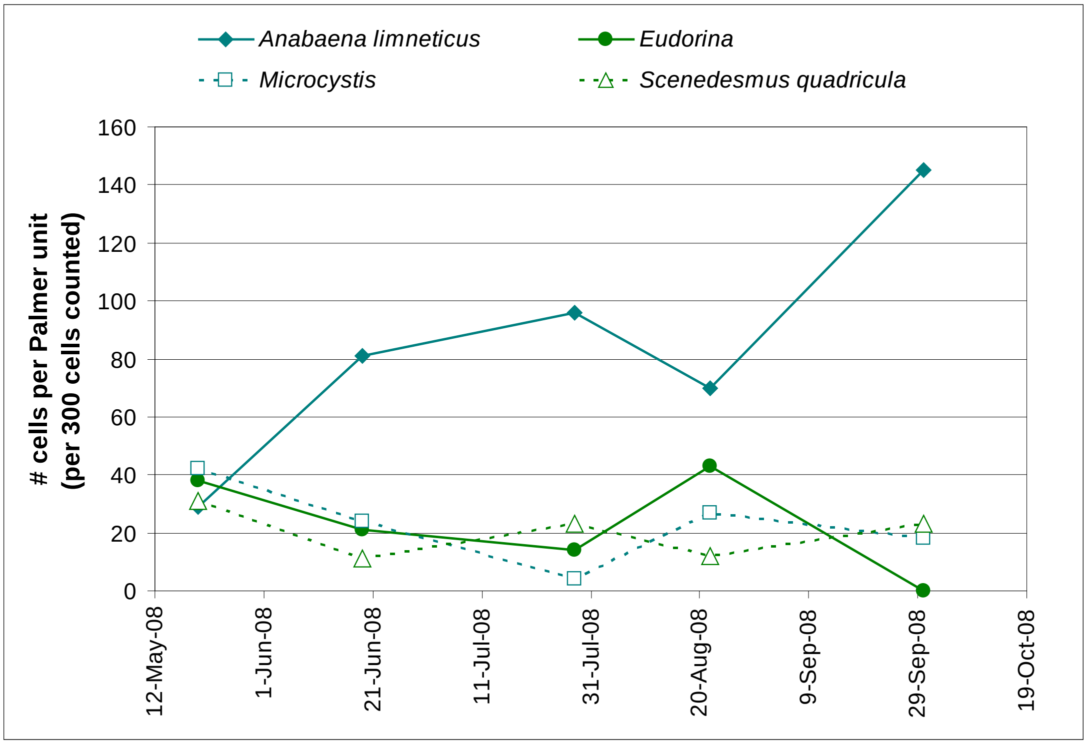

Figure 88. Dominance of the most abundant algal taxa in Loon Lake over five monthly sampling periods in 2008 (# of cells/300 counted)

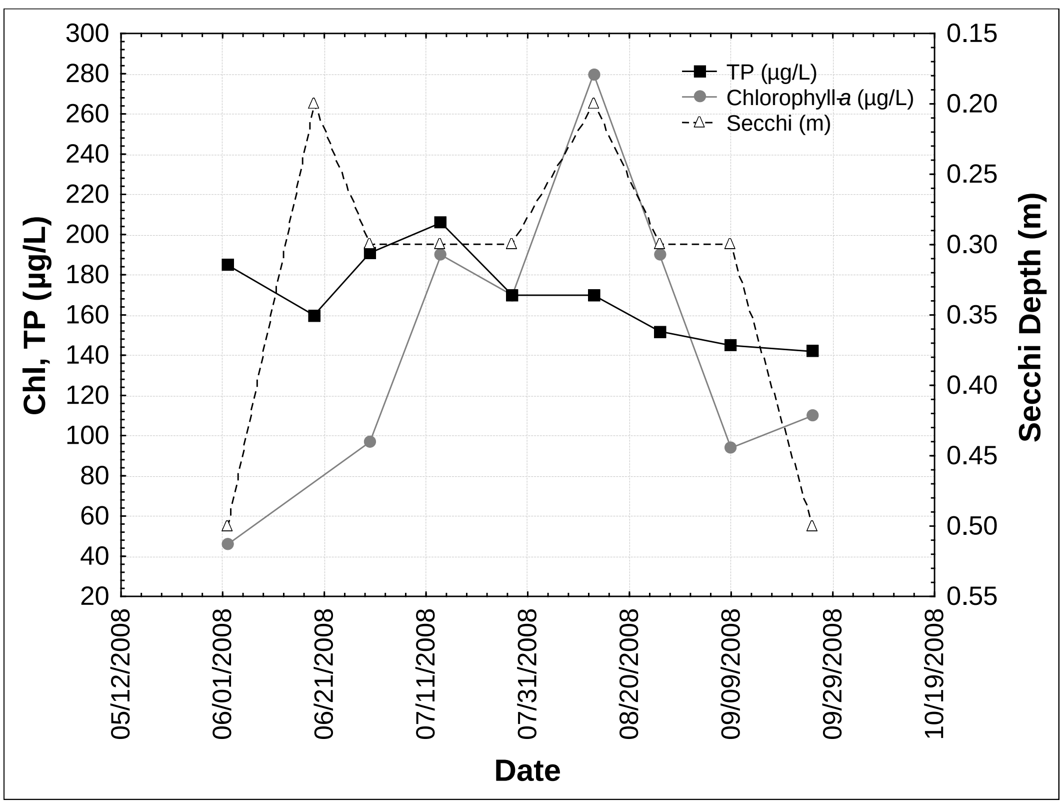

Figure 89. Chlorophyll-*a* concentrations (as a proxy for algal density), total phosphorus, and Secchi transparency for Loon Lake over five monthly sampling periods, 2008

Zooplankton

The zooplankton of Loon Lake over all sampling periods in 2008 were co-dominated by rotifers and cladocerans, with copepods only a small component of the community (Figure 90). The relative dominance of cladocerans and rotifers changes dramatically over time in Loon Lake (Figure 91). Cladocerans peak in June and August, while rotifers are dominant in May, July, and September. This pattern is not likely due to patchiness of zooplankton because the changes in individual species over time show distinct patterns that explain this variation (Figure 92). The first peak in cladoceran dominance is due to a spike in *Bosmina longirostrus*, which quickly crashes. The second is due to a spike in *Ceriodaphnia lacustris*, which crashes shortly after. A mix of rotifers compose the initial dominance in spring, followed by a dramatic increase in *Kellicottia bostoniensis* in July. No single species of rotifer dominates the rotifer increase in September.

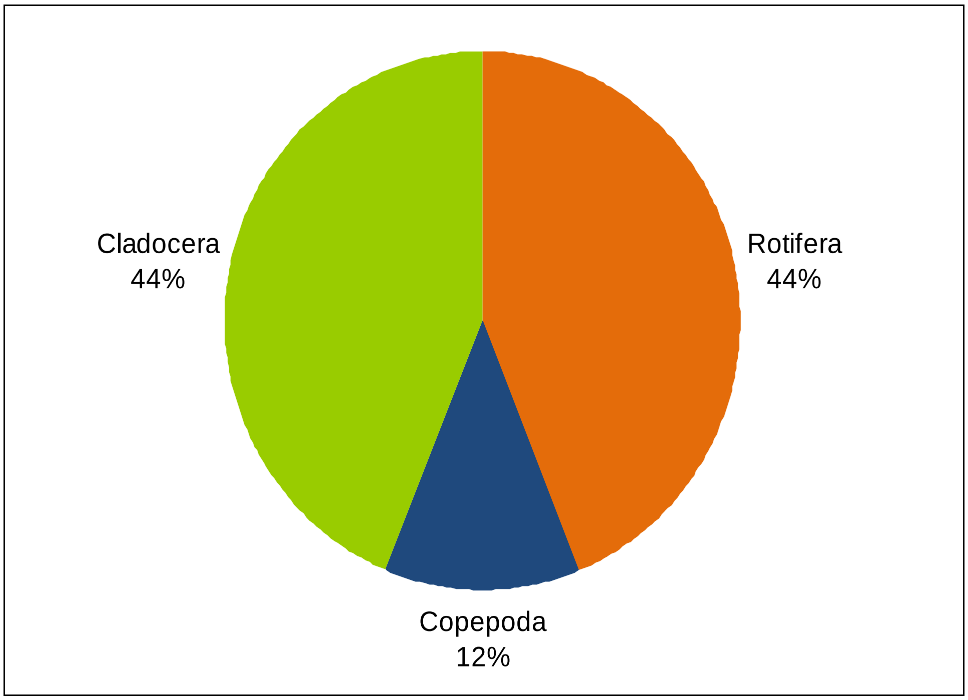

Figure 90. Total zooplankton composition of major groups (%) in Loon Lake over 5 monthly sampling periods, 2008

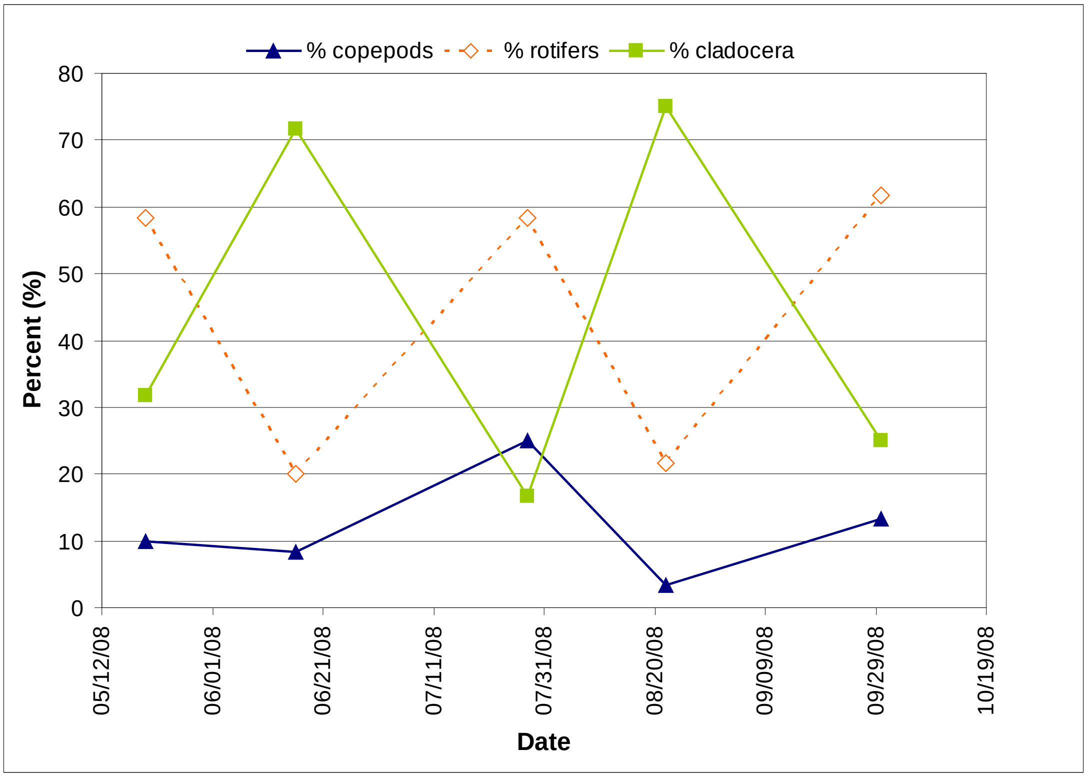

Figure 91. Dominance of major zooplankton groups and indicator species in Loon Lake over five monthly sampling periods in 2008 (as % of individuals counted)

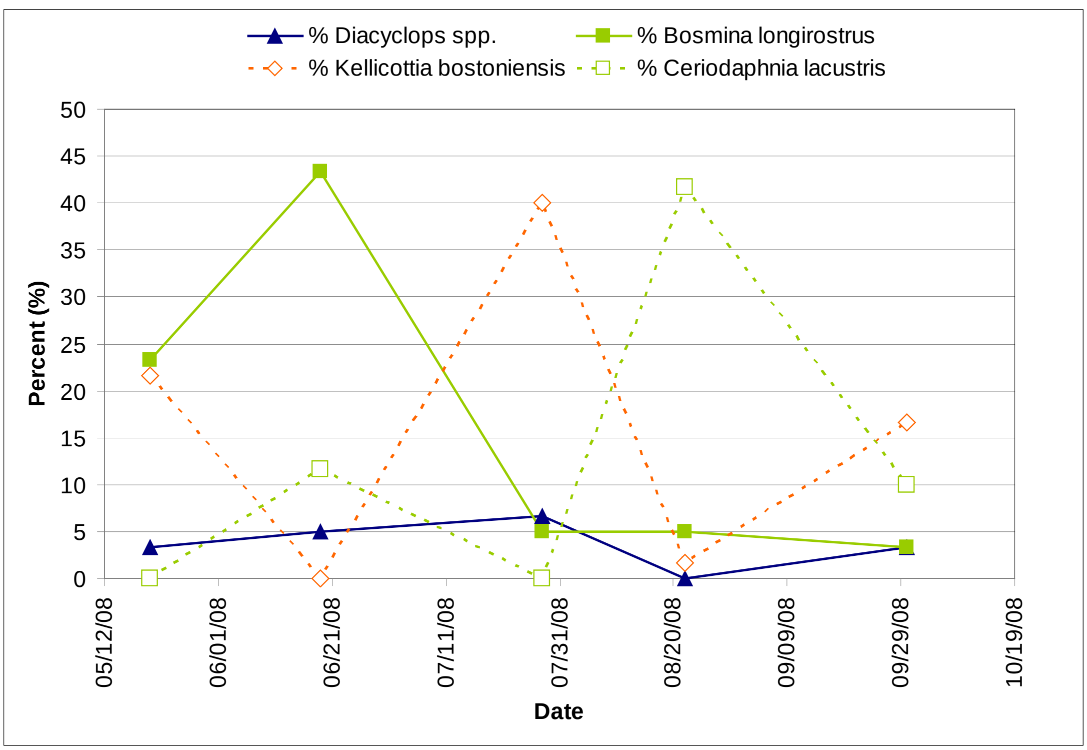

Figure 92. Dominance of the most abundant zooplankton taxa in Loon Lake over five monthly sampling periods in 2008 (as % of individuals counted)

Discussion

Since the algal community is dominated by blue-green algae, Loon Lake has a high potential to produce nuisance blooms. Toxin-producing algae are not common in Loon Lake but were present over the entire sampling period. Algal indicators of eutrophy are highest in the spring, indicating nutrient cycling under ice. The sustained dominance of the blue-green algae *Anabaena limneticus* is an indicator of high phosphorus and relatively lower nitrogen in a system with little or no flushing. The dominant green algae *Eudorina* is also an indicator of eutrophy and high phosphorus. Finally, the rotifer *Kellicottia bostoniensis* is an indicator species of high phosphorus. Taken together, the algal and zooplankton species present are strong indicators of high phosphorus in Loon Lake. Lack of clear patterns of algal and zooplankton response to nutrients suggests either very high nutrient loading, a decoupling of grazer response to algae due to piscivores, or both.

The zooplankton community overall is co-dominated by cladocerans and rotifers, showing some grazing potential (cladoceran dominance) but also high planktivory (rotifer dominance). Zooplankton community composition is not as informative in this case as the patterns in zooplankton community phenology.

The cladoceran zooplankton are dominated by *Bosmina* and *Ceriodaphnia*, peaking in June and August, respectively. Rotifer populations are inversely related to these peaks, crashing in June and August, but very high in May, July, and September. Rotifers are expected to dominate the zooplankton in spring because they are often most active over winter. The patterns of rotifer versus cladoceran dominance in summer and fall, however, are suggestive of planktivory by fish. Other factors may explain this pattern, including blooms of the less edible *Anabaena*. The absence or very low number of larger cladocerans and the quick disappearance of *Bosmina* and *Ceriodaphnia*, both highly susceptible to planktivory by fish, indicate that planktivory is suppressing the ability of the zooplankton to mediate algal blooms. The disassociation of algal blooms and peaks of phosphorus indicate two important things about Loon Lake. First, there is enough phosphorus present to support algal blooms. Second, most of the algal species dynamics are most likely determined by trophic impacts on zooplankton. Correcting the latter could change the timing and possibly the nature of the blooms, but phosphorus levels are high enough that the phosphorus loads to the lake need to be reduced in order to reduce the high algal concentrations.

10.6 Water Quality

Monitoring data are available from 2000-2008 for total phosphorus (TP) and Secchi transparency. Monitoring data are available from 2001-2008 for chlorophyll-*a*. A summary of the data indicates that the lake is not meeting any of the lake water quality standards (Table 60).

Figure 93 through Figure 95 show the mean growing season total phosphorus (TP), chlorophyll-*a*, and Secchi transparency data from Loon Lake. The means consistently do not meet the standards for all three parameters. Chlorophyll-*a* tends to peak in August (Figure 96). The seasonal patterns for TP and Secchi transparency were less evident. Moderate relationships exist between chlorophyll-*a* and TP (Figure 97).

Table 60. Loon Lake, Surface Water Quality Means and Standards, 2000-2008

Parameter	Growing Season Mean (June – September)	Shallow Lake Standard
TP (µg/L)	136	60
Chlor-*a* (µg/L)	109	20
Secchi transparency (m)	0.5	1.0

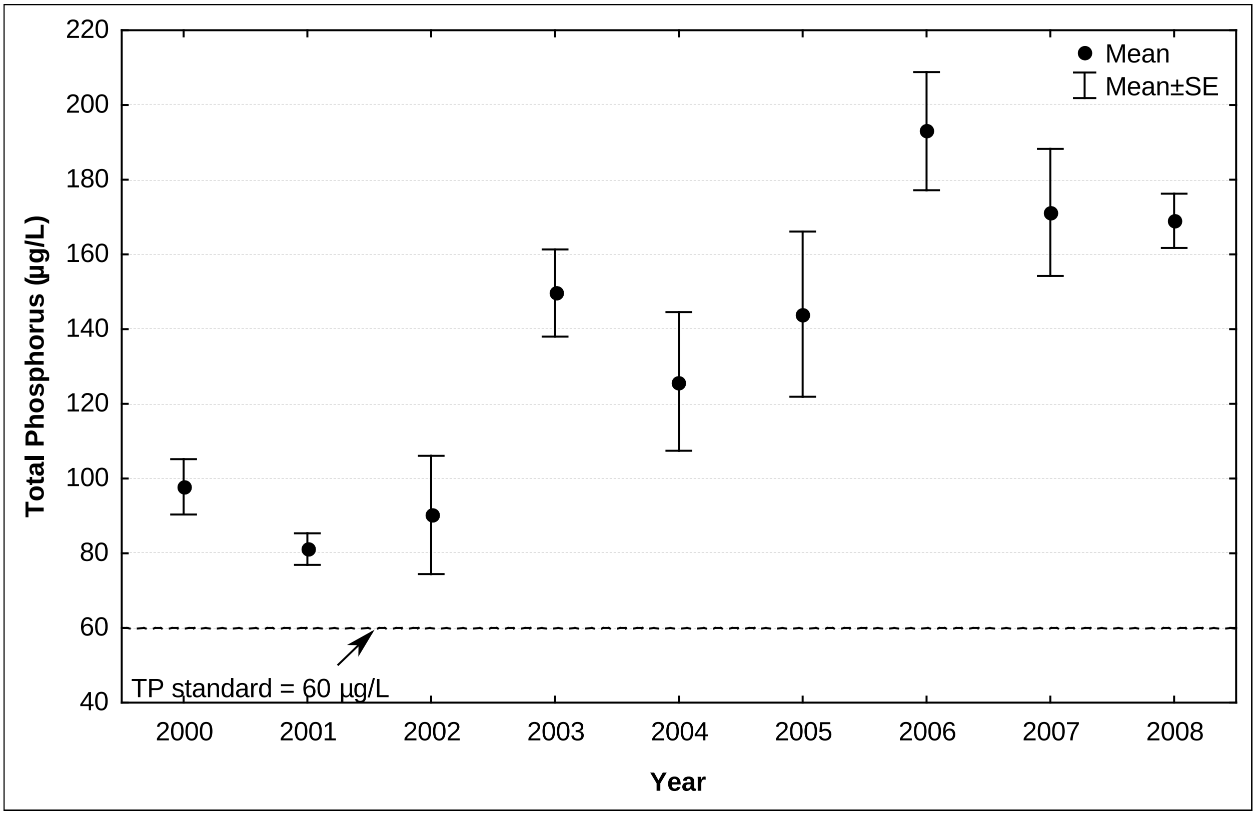

Figure 93. Loon Lake, Growing Season Means Total Phosphorus

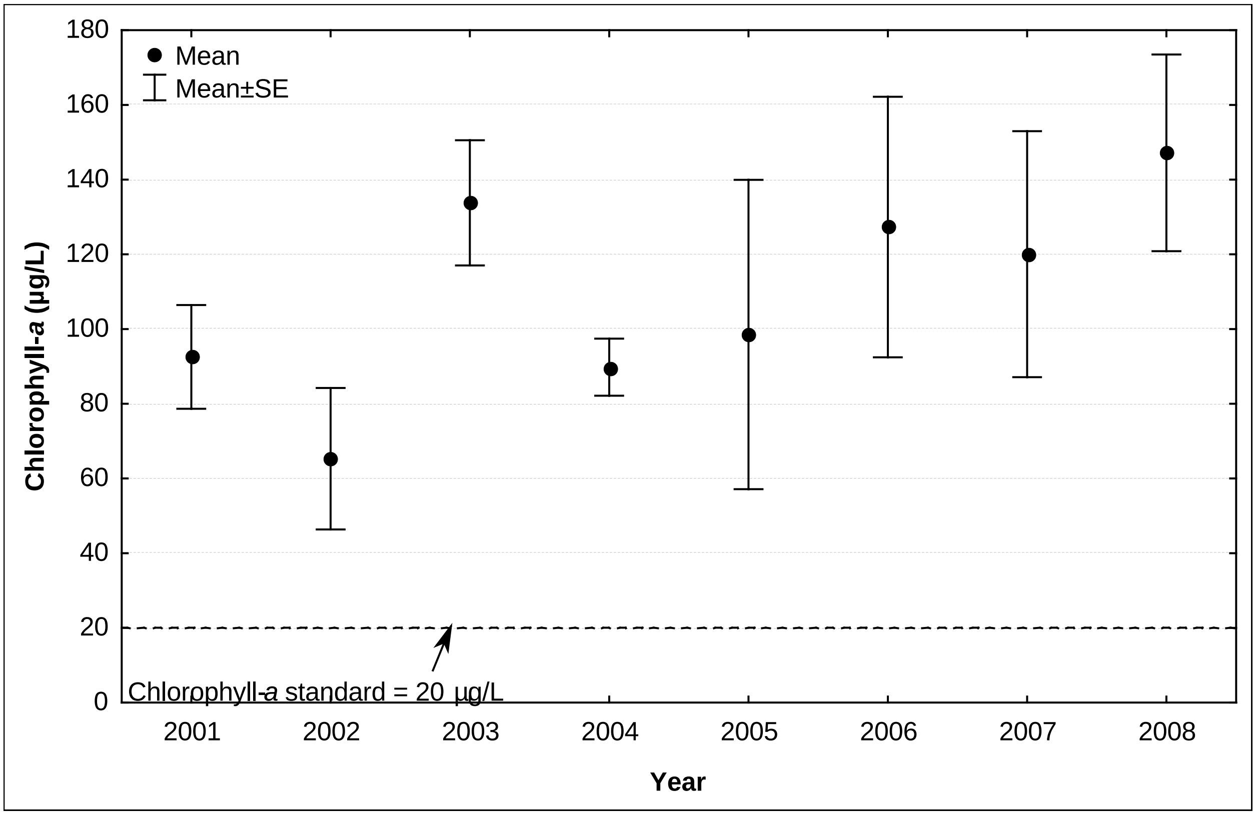

Figure 94. Loon Lake, Growing Season Means Chlorophyll-*a*

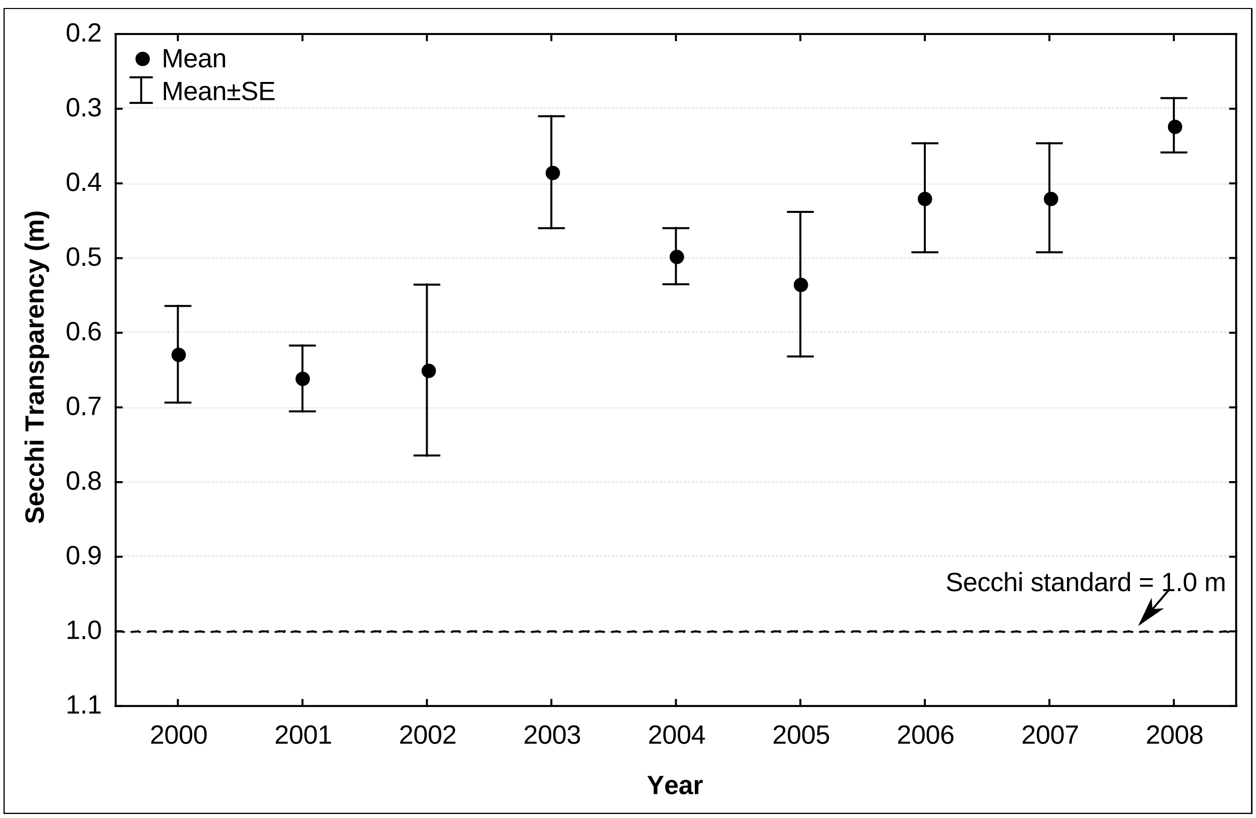

Figure 95. Loon Lake, Growing Season Means Secchi Transparency

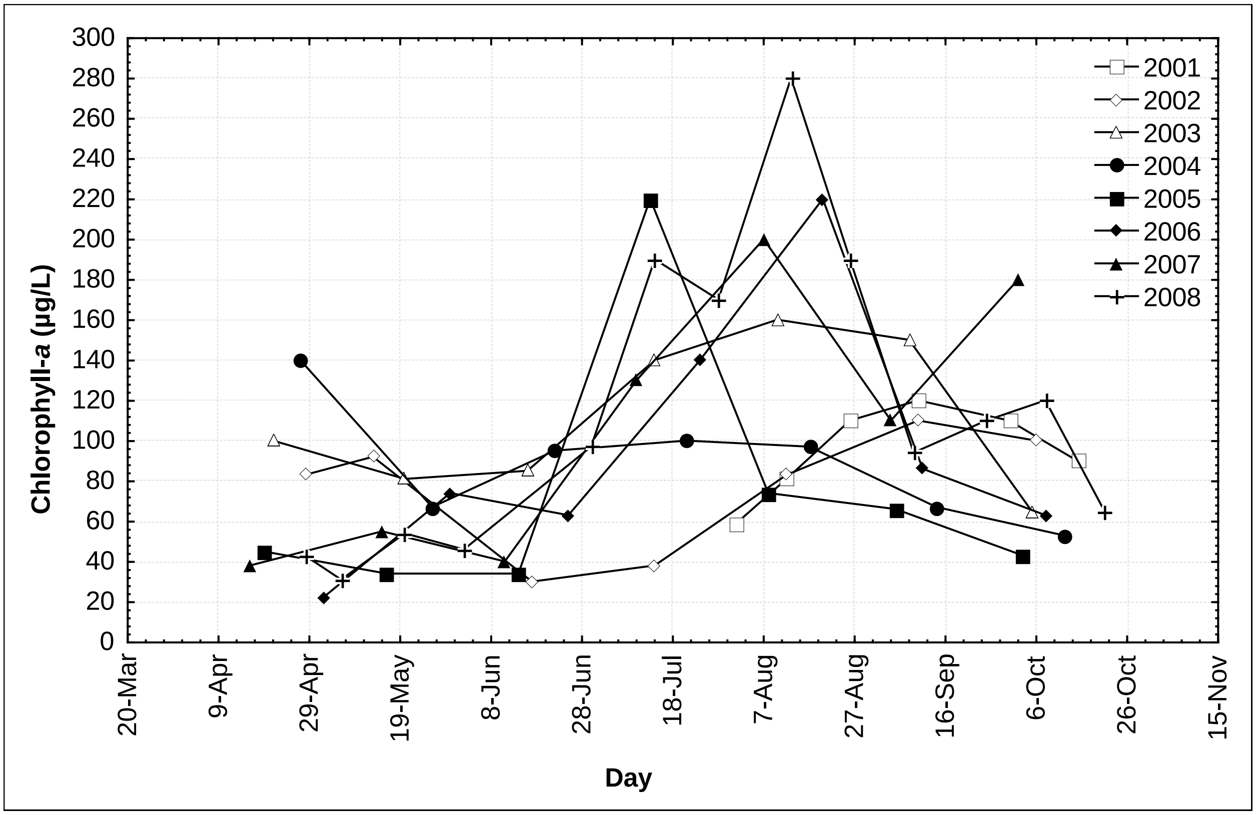

Figure 96. Loon Lake Seasonal Chlorophyll-*a* Patterns

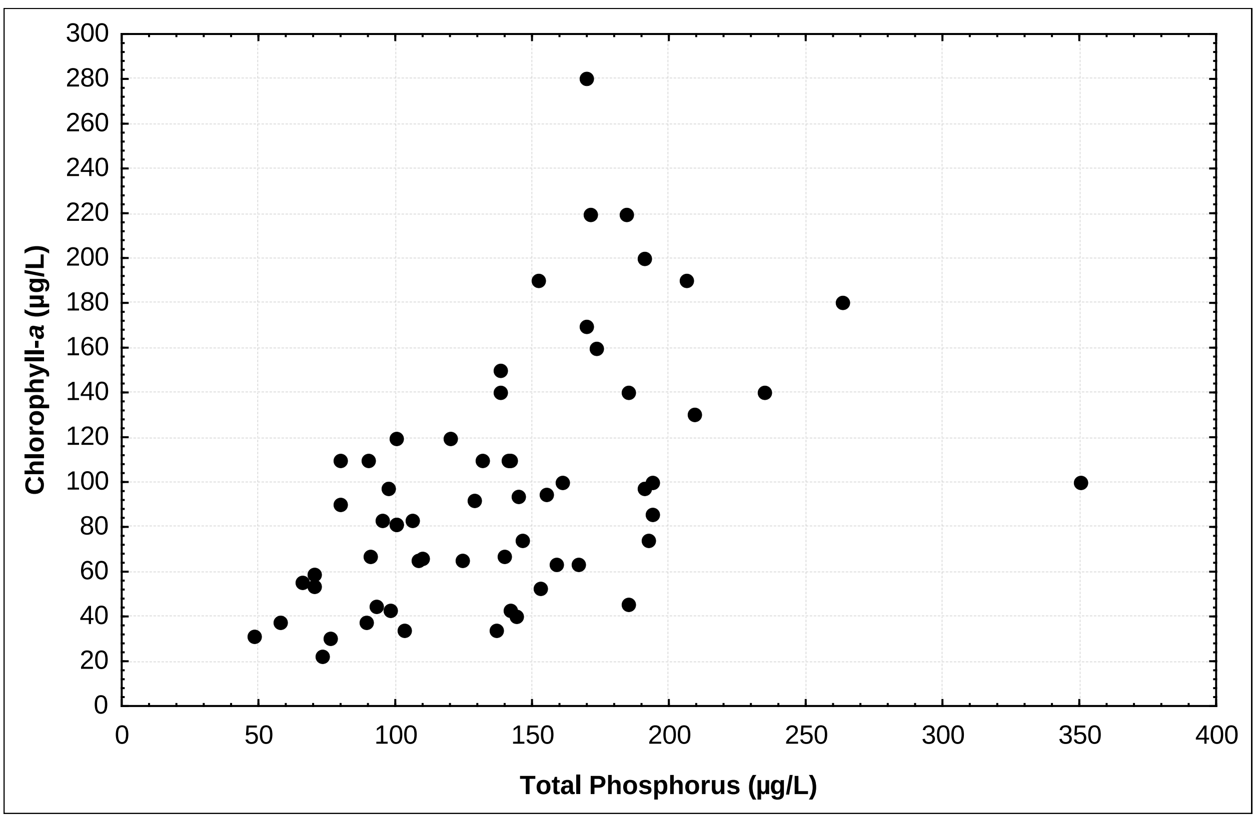

Figure 97. Relationship between Chlorophyll-*a* and Total Phosphorus in Loon Lake

10.7 In-Lake Impairment Assessment Summary

- The most recent fisheries information from 1984, combined with anecdotal information, indicates a high population of black bullhead. The lake likely experiences winterkills.
- Loon Lake is a shallow lake with a low density and diversity of macrophytes.
- The phytoplankton community is dominated by blue-green algae.
- The patterns of cycling zooplankton suggest that planktivory by fish is driving zooplankton dynamics and therefore the grazing capacity of the lake.
- All three water quality parameters are not meeting the standards. The lake is hypereutrophic and is in the turbid, phytoplankton-dominated phase seen in poor quality shallow lakes.

10.8 Phosphorus Source Inventory

10.8.1 Watershed Phosphorus Sources

It is estimated that Loon Lake receives 107 pounds of phosphorus annually from watershed runoff (Table 61). The largest watershed source of phosphorus is from direct watershed runoff from the contributing watershed (394 acres). SSTS contributes 21% of the phosphorus to the lake. There are approximately 18 houses on the lake contributing 22 pounds of phosphorus annually.

The 2030 phosphorus load from direct watershed runoff is estimated to be 82 lb/yr, a minor change from 85 lb/yr under existing conditions. No major land use changes are projected between now and 2030 (see Section 10.2). The change in future loading is assumed to be the result of Metropolitan Council's re-categorization of 2030 land use as compared to 2005 land use (see *Direct Watershed Runoff: Direct Watershed Runoff under Future (2030) Conditions* in Section 3.1.2 for further discussion).

Table 61. Loon Lake Watershed Phosphorus Source Summary, Existing Loads

Phosphorus Source	Annual TP Load (lb/yr)	Percent of Watershed TP Load (%)	Area (ac)	Average Areal TP Load (lb/ac-yr)[1]	Average TP Concentration (µg/L)[2]
Direct Watershed Runoff	85	79%	394	0.22	242
SSTS	22	21%	n/a	n/a	n/a
Total	**107**	**100%**			

[1] Annual TP load (lb/yr) divided by drainage area (ac)
[2] Annual TP load (lb/yr) divided by average annual volume of runoff [3.94 (average annual depth of runoff in inches) * drainage area (ac) * conversion factor]

10.8.2 Atmospheric Phosphorus Sources

Atmospheric deposition is estimated to be 14 lb/yr (see *Atmospheric Deposition* in Section 3.1.2 for more information).

10.8.3 Internal Phosphorus Sources

Internal loading accounts for an additional 51 to 370 lb/yr (210 lb/yr average) of phosphorus loading to the lake, representing 30% to 75%, respectively, of the total loading to the lake.

10.8.4 Phosphorus Load Summary

The total modeled phosphorus load to Loon Lake is 331 lb/yr (Table 14).

Table 62. Loon Lake Phosphorus Source Summary, Existing Loads

Phosphorus Source	Phosphorus Load (lb/yr)
Watershed	107
Atmospheric	14
Internal	210
Total	**331**

10.9 TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Loon Lake is 249 lb/yr, to be split among allocations according to Table 63. To meet the TMDL, the total load to the lake needs to be reduced by 107 lb/yr..

Watershed scale pollutant load modeling was conducted and analyzed on an annual basis to establish this TMDL at a level necessary to attain and maintain applicable water quality standards. Daily wasteload allocations were derived from this analysis.

Table 63. Loon Lake Existing Loads, TMDL Allocations, and Reductions Needed

Load Component	TP Existing	TP TMDL Allocation		TP Reduction	
	lb/yr	lb/yr	lb/day	lb/yr	%
WLA					
Construction stormwater (permit #MNR100001)	0.31	0.31	0.00085	0	0%
Industrial stormwater (permit # MNR50000)	0.31	0.31	0.00085	0	0%
Total WLA	**0.62**	**0.62**	**0.0017**	**0**	**0%**
LA*					
Watershed	106	53	0.15	53	50%
Atmospheric	14	14	0.038	0	0%
Internal	210	156	0.43	54	26%
Total LA	***330***	***223***	**0.62**	***107***	**32%**
MOS	**--**	**25**	**0.068**	**--**	**--**
Total	***331***	***249***	***0.69***	***107****	***32%***

*LA components are broken down for guidance in implementation planning; the LA should be considered categorical.
**107 lb/yr reduction takes into account MOS; 82 lb/yr reduction (=107-MOS) needed to reach total loading capacity

11 LAKE LOUISE TMDL

11.1 Physical Characteristics

Lake Louise (ID 82-0025) is a shallow lake located in Stillwater and May Townships and is landlocked. Table 64 summarizes the lake's characteristics, and Figure 98 illustrates the lake's bathymetry.

Table 64. Lake Louise Characteristics

Characteristic	Value	Source
Lake total surface area (ac)	46.1	2008 MLCCS revised based on 2008 aerial photos
Percent lake littoral surface area	100	Calculated based on 2008 WCD bathymetry data
Lake volume (ac-ft)	184	Calculated (mean depth x surface area)
Mean depth (ft)	4	Calculated based on 2008 WCD bathymetry data
Maximum depth (ft)	8	Based on 2008 WCD bathymetry data
Drainage area (acres)	219.5	CMSCWD
Watershed area:lake area	4.8	Calculated

Figure 98. Lake Louise Bathymetry
Contour units are feet.

11.2 Land Use

The land use within the Lake Louise watershed is dominated by agriculture and undeveloped land (Table 65). A large area of parkland, Pine Point Park, and the Gateway State Trail are both located within the watershed. Farmsteads and single family residential land uses are found throughout the watershed, and there is a projected increase in residential land use (Table 66).

Table 65. Lake Louise Watershed Land Use, 2005
(2005 Generalized Land Use for the Twin Cities Metropolitan Area)

Land Use	Total Acres	% of Watershed
Agricultural	88.5	40.3%
Farmstead	4.1	1.9%
Industrial and Utility	4.0	1.8%
Institutional	-	-
Park, Recreation, or Preserve	25.6	11.7%
Retail and Other Commercial	-	-
Seasonal/Vacation	-	-
Single Family Detached	20.0	9.1%
Undeveloped	72.1	32.8%
Water	5.1	2.3%
Total	**219.5**	**100.0%**

Table 66. Lake Louise Watershed Land Use, 2030
(Regional Planned Land Use for the Twin Cities Metropolitan Area)

Land Use	Total Acres	% of Watershed
Agricultural	14.8	6.7%
Airport	-	-
Commercial	-	-
Industrial	-	-
Institutional	-	-
Mixed Use	-	-
Multifamily Residential	-	-
Multi-Optional Development	-	-
Open Space or Restrictive Use	-	-
Park and Recreation	37.8	17.2%
Railway (inc. LRT)	1.2	0.5%
Rights-of-Way (i.e., Roads)	-	-
Rural or Large-Lot Residential	160.6	73.1%
Single Family Residential	-	-
Vacant or No Data	-	-
Water	5.2	2.4%
Total	**219.6***	**99.9%º**

* 2030 total acres does not match 2005 total acres due to rounding.
º Total % does not equal 100.0 due to rounding.

11.3 Existing Studies, Monitoring, and Management

Based on an Aerial Lakeshore Analysis study (CMWD 1999), the greatest influence on the lake is non-point source runoff, particularly from adjacent agricultural fields and 120th Street. The recommendations from that study are to develop or expand vegetative buffers between the homes and the lake, install berms or other retention devices where vegetative buffers are not feasible and to remove nuisance waste and debris from specific locations.

In 2000 a phosphorus sensitivity analysis for several lakes in the Carnelian-Marine Watershed District was completed (CMWD 2000). Lake Louise exceeded the ecoregion goal of 40 µg/L of total phosphorus but the report suggests that this lake be passively maintained.

The Louise Lake Watershed Management Plan was written as part of the Carnelian-Marine-St. Croix Watershed District's 2010 Watershed Management Plan. A stormwater treatment basin was installed by Washington County as part of the 2001 reconstruction of County Highway 61 (Myeron Rd.). Management, monitoring, and implementation activities are expected to be driven by an implementation plan developed based on this TMDL study. In addition, installed best management practices undergo ongoing monitoring.

11.4 Lake Uses

Lake Louise is currently managed as a walleye rearing pond by the DNR.

11.5 Biological Characteristics

11.5.1 Fisheries

Lake Louise is currently being managed by the DNR as a walleye rearing pond. It was first stocked in 1980 and has been used periodically following years of winterkill. The lake experienced a winterkill in 2007-08, and in May of 2008 the DNR stocked the lake with 350,000 walleye fry. A harvest was completed in late October, removing 98 pounds of walleye fingerlings, bluegills, and black crappie. The DNR noted large quantities of bluegill being captured. Other species observed included golden shiners, flathead minnows, and white suckers.

11.5.2 Macrophytes

Macrophyte surveys were completed for Lake Louise in June and August of 2008. Curly-leaf pondweed was observed throughout the lake in the June survey (Figure 99) and was observed in the August survey in a small area near the south shore of the lake. The amount of the lake without macrophyte vegetation (open water) grew between the June and August surveys. Open water was observed in the August survey in areas that had abundant curly-leaf pondweed in the June survey. The macrophyte species observed in Lake Louise are listed in Table 67.

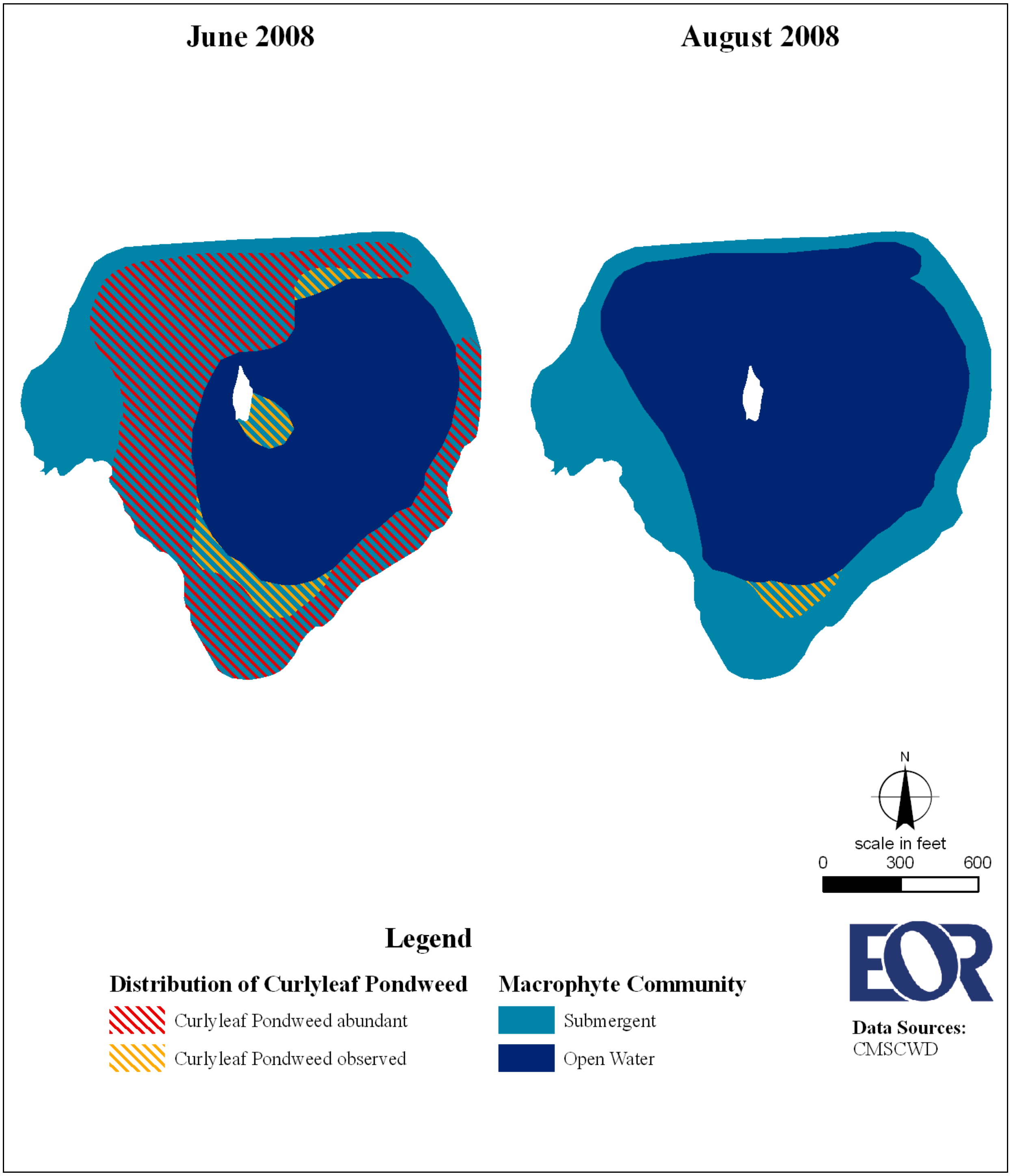

Figure 99. Distribution of Macrophyte Communities in Lake Louise

Table 67. Plant Species Observed During 2008 Lake Louise Macrophyte Surveys

Scientific Name	Common Name	June	August
Ceratophyllum demersum	Coontail	ü	ü
Elodea canadensis	Elodea	ü	ü
Potamogeton crispus	Curly-leaf pondweed	ü	ü
Potamogeton foliosus	Leafy pondweed	ü	ü

11.5.3 Plankton Community

Phytoplankton

Nineteen algal genera were found in Lake Louise, and the three most common genera were two types of blue-green algae (*Microcystis* and *Anabaena*), and a green algae (*Scenedesmus*). The predominance of blue-green algae (Figure 100) indicates high potential for algal blooms.

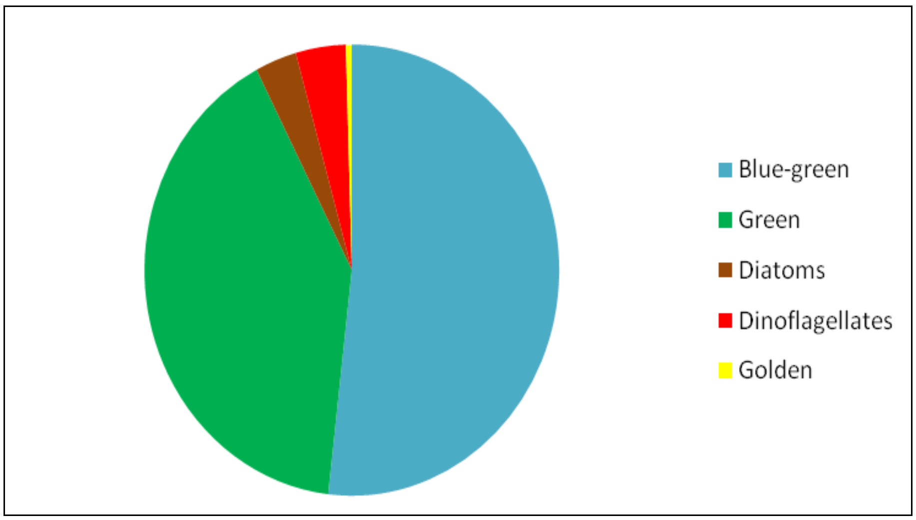

Figure 100. Percent composition of major algae groups in Louise Lake, May to September 2008

Zooplankton

Nineteen zooplankton species were found in Lake Louise. The most common genera in Louise Lake are two smaller cladocera (*Bosmina* and *Ceriodaphnia*) that graze on algae and bacteria. *Conochiloides* is a small rotifer. This composition suggests some predation effects on the zooplankton community, but the overall dominance of cladocera (Figure 101) shows good potential for grazing mitigation of algal blooms.

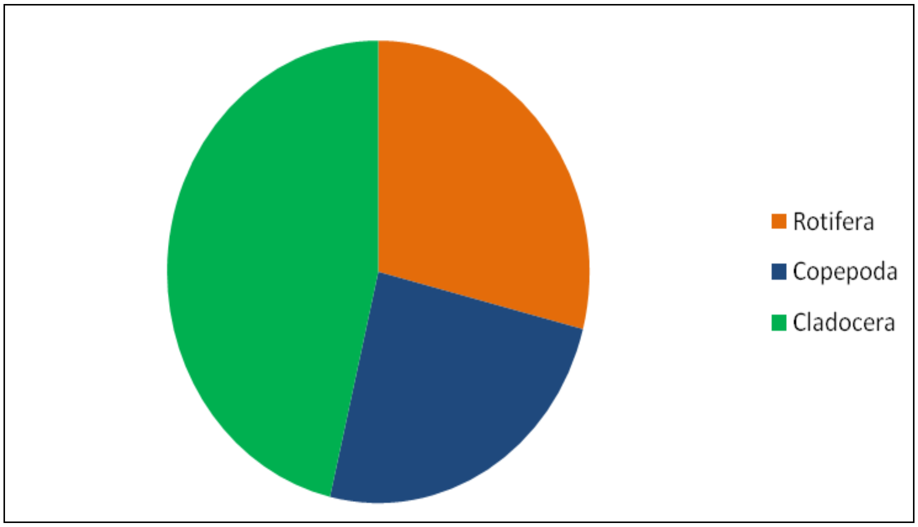

Figure 101. Percent composition of major zooplankton groups in Louise Lake, May to September 2008

11.6 Water Quality

Secchi transparency monitoring data are available from 2000-2008. Total phosphorus data are available for 2000-2002 and 2008. Chlorophyll-*a* data are only available for 2001-2002 and 2008. A summary of the limited data indicates that, over a ten-year average, the lake is just meeting the lake water quality standard for Secchi transparency, but is not meeting the standards for total phosphorus nor chlorophyll-*a* (Table 68). Figure 102 through Figure 104 show the mean growing season total phosphorus (TP), chlorophyll-*a*, and Secchi transparency data from Lake Louise. Even though the ten-year average Secchi transparency just meets the standard, the standard has not been met in an individual year since before 2005.

Water clarity generally is worst in August (Figure 105). The seasonal patterns of TP and chlorophyll-*a* are less clear. Moderate relationships exist between TP and transparency (Figure 106).

Table 68. Lake Louise, Surface Water Quality Means and Standards, 2000-2008

Parameter	Growing Season Mean (June – September)	Shallow Lake Standard
TP (µg/L)	120	60
Chlor-a (µg/L)	52	20
Secchi transparency (m)	1.0	1.0

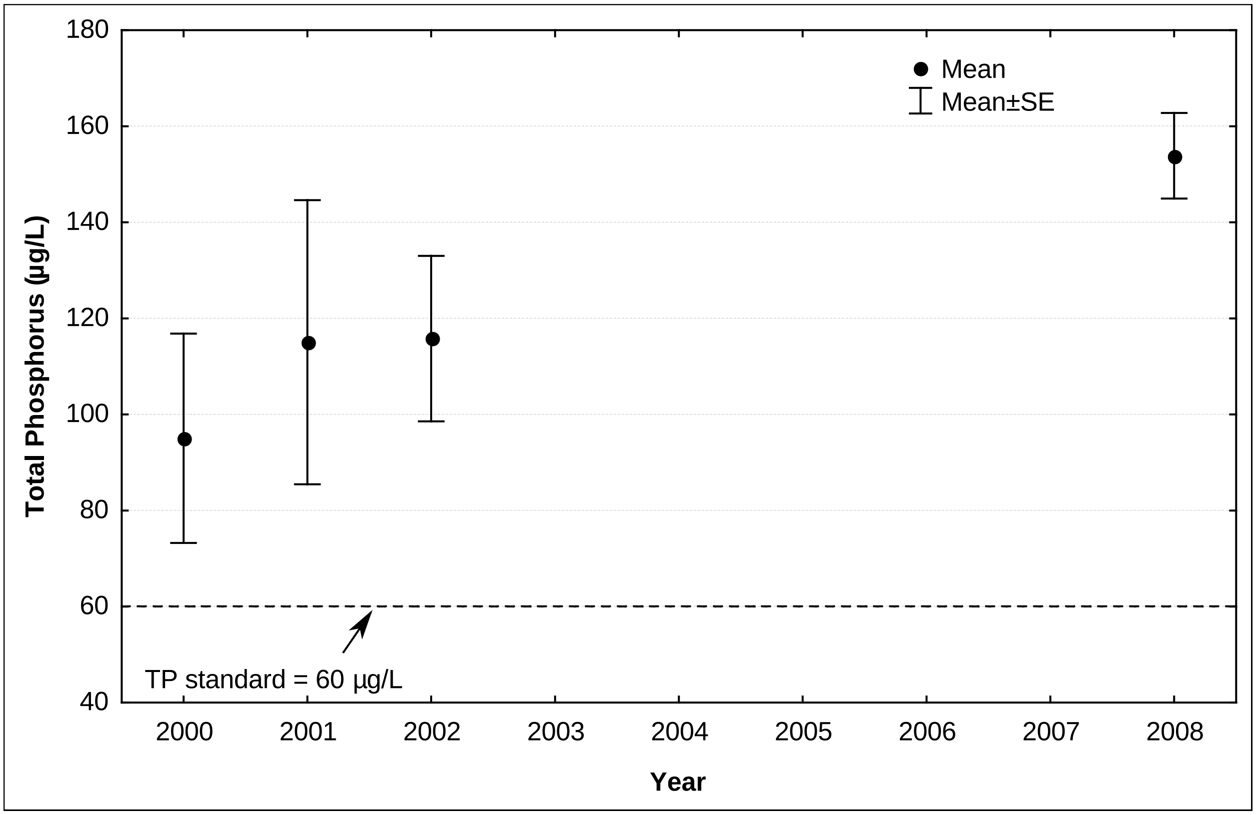

Figure 102. Lake Louise, Growing Season Mean Total Phosphorus

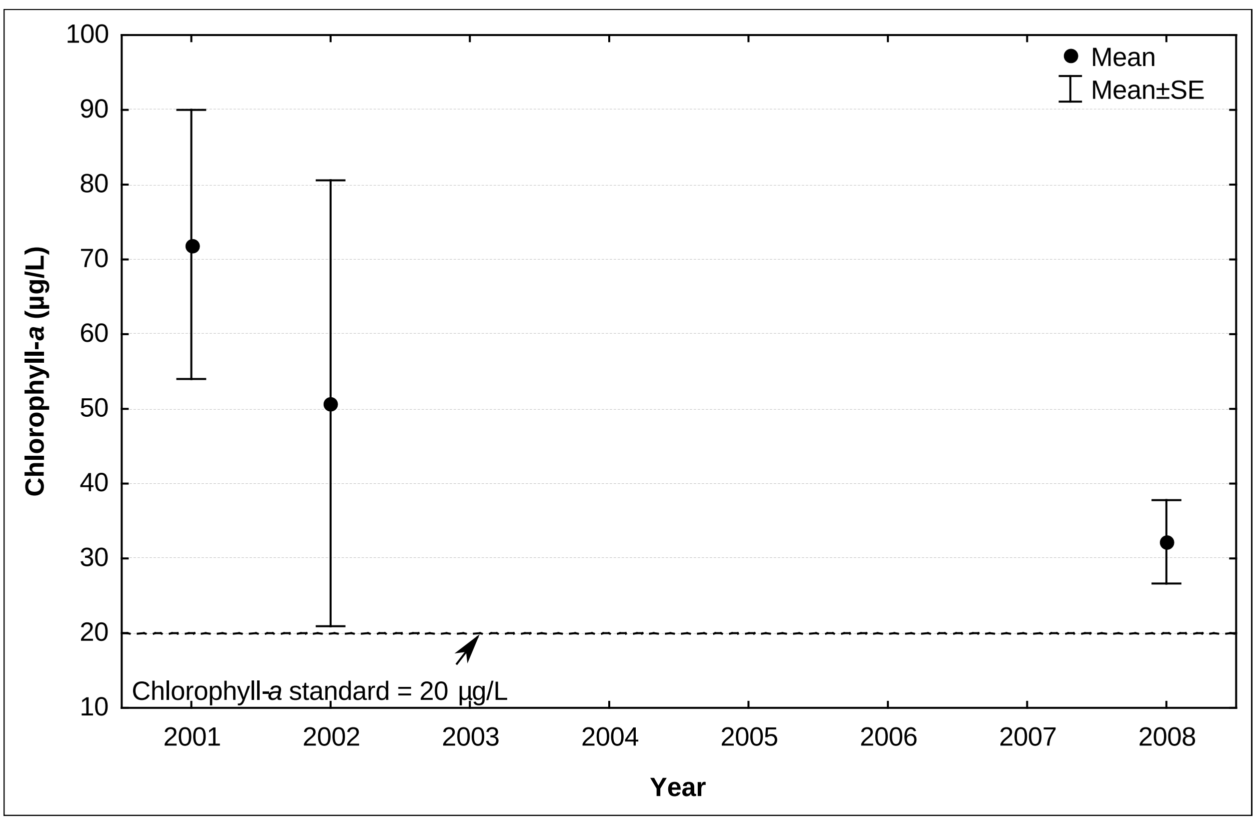

Figure 103. Lake Louise, Growing Season Means Chlorophyll-*a*

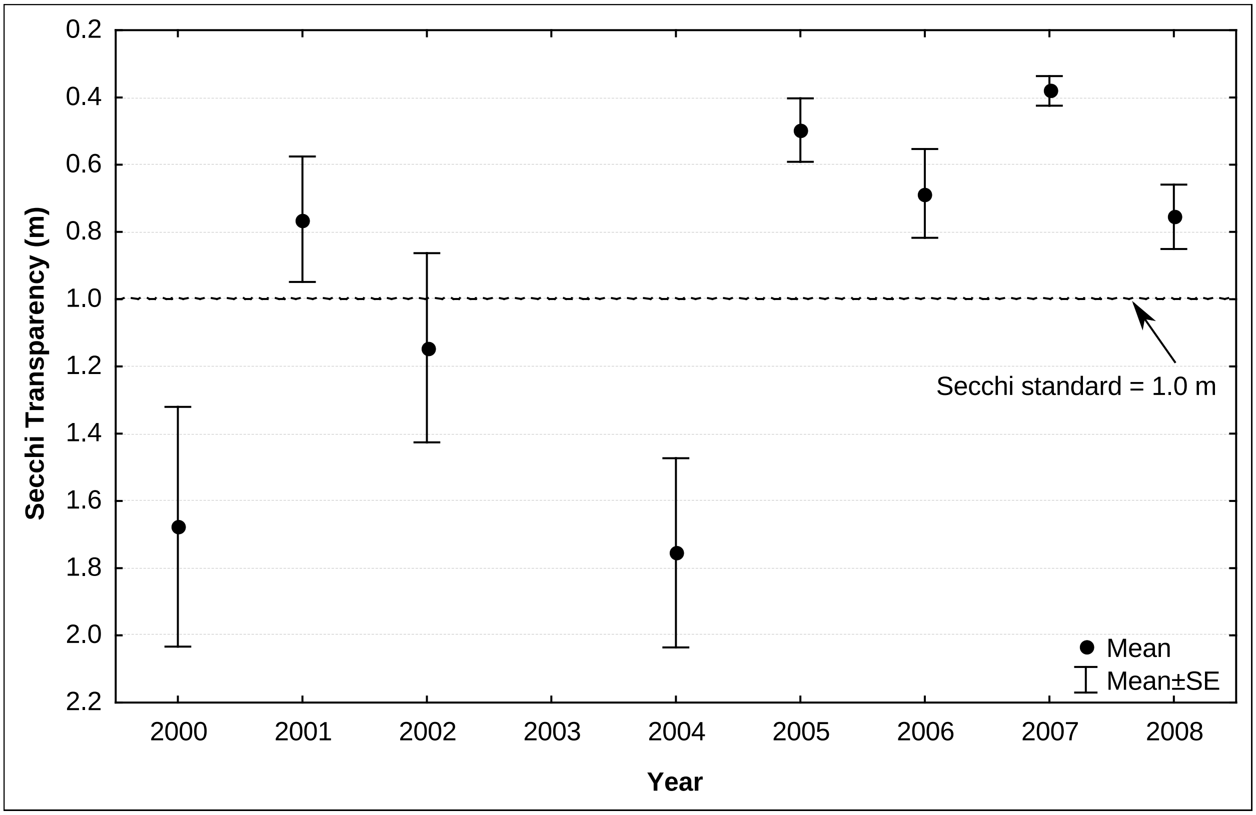

Figure 104. Lake Louise, Growing Season Means Secchi Transparency

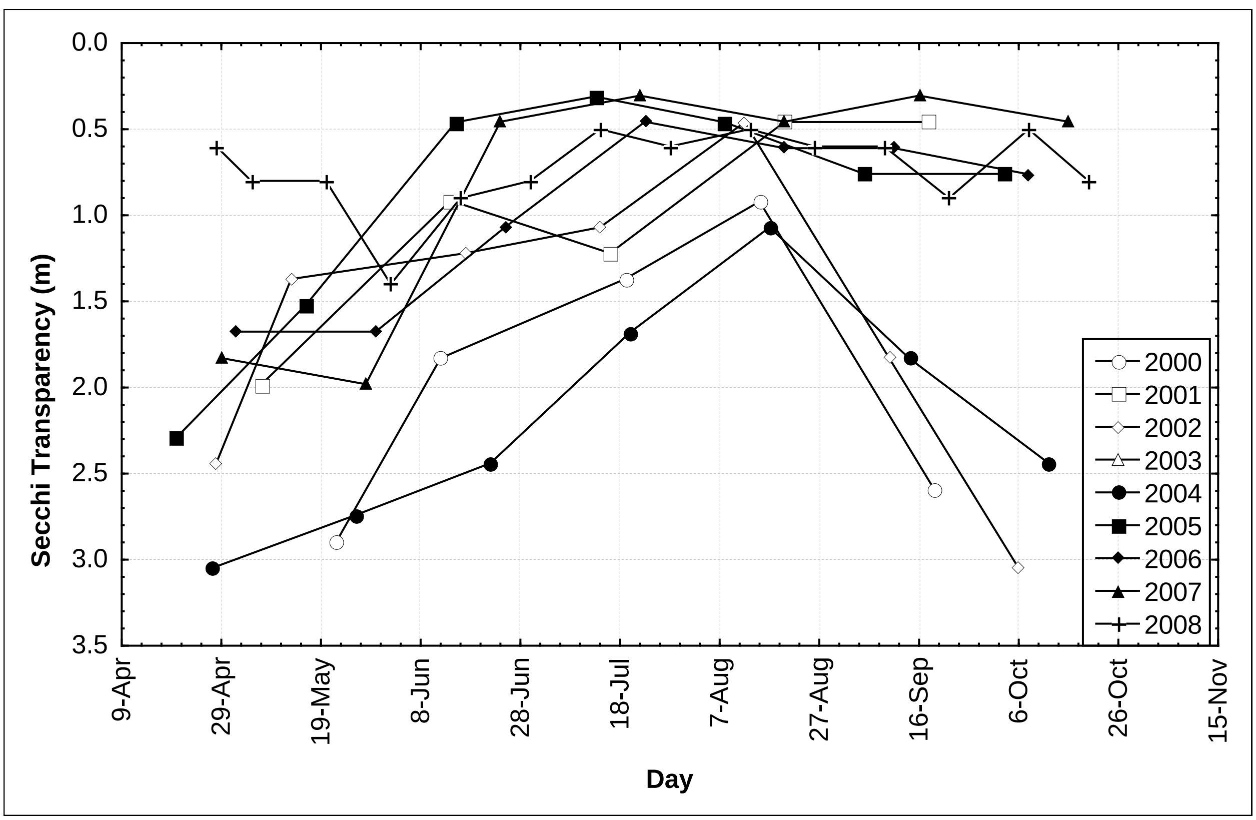

Figure 105. Lake Louise, Seasonal Secchi Transparency Patterns

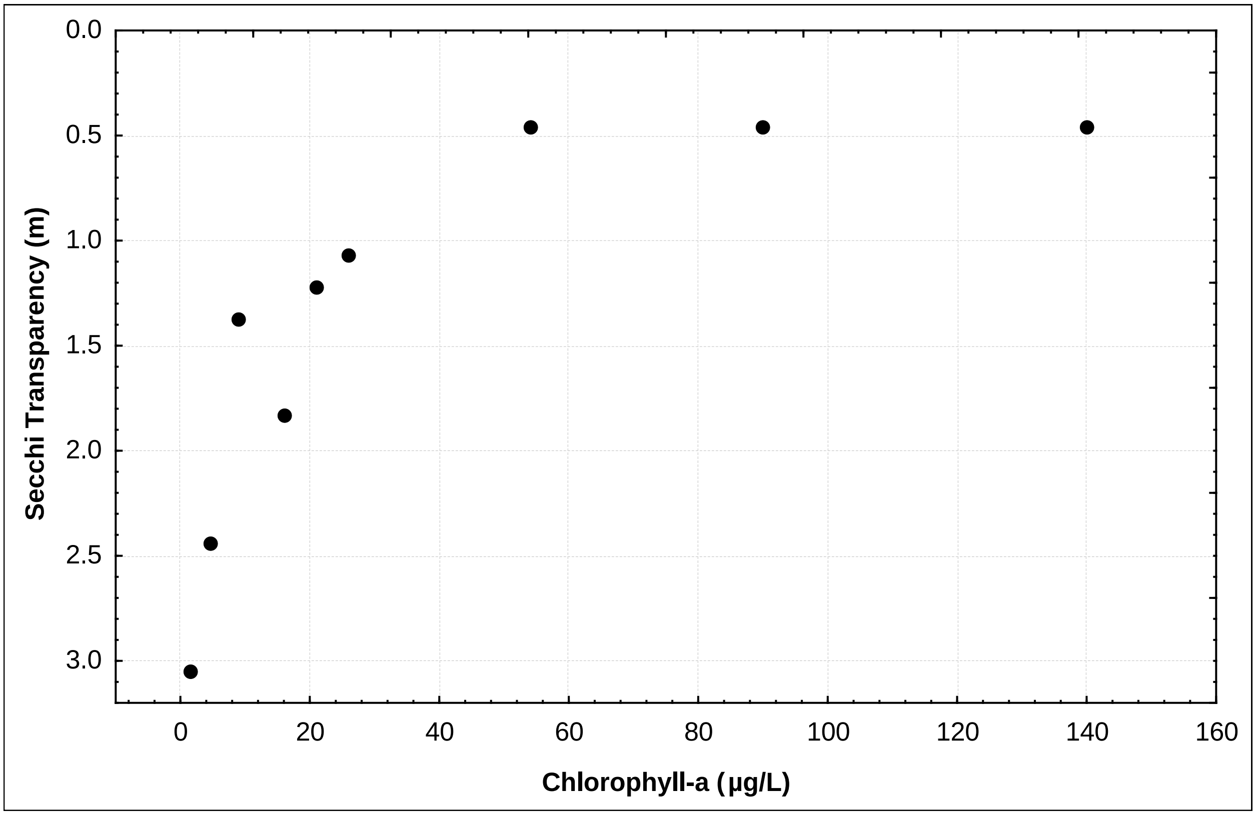

Figure 106. Relationship between Secchi Transparency and Chlorophyll-*a* in Lake Louise

11.7 In-Lake Impairment Assessment Summary

- The lake is used as a walleye rearing pond by the DNR. During a 2008 harvest, large populations of bluegill were observed. There have not been any fish surveys completed.
- Curly-leaf pondweed is abundant in the lake and likely contributes to internal phosphorus loading.
- The phytoplankton community is dominated by blue-green algae, with a high potential for algal blooms.
- The zooplankton community is dominated by cladocera, large zooplankton that have a high grazing capacity.

11.8 Phosphorus Source Inventory

11.8.1 Watershed Phosphorus Sources

It is estimated that Lake Louise receives 51 pounds of phosphorus annually from watershed runoff (Table 69). The largest watershed source of phosphorus is from direct watershed runoff from the contributing watershed (220 acres). SSTS contributes 18% of the phosphorus to the lake. There are approximately seven houses on the lake contributing nine pounds of phosphorus annually.

The 2030 phosphorus load from direct watershed runoff is estimated to be 39 lb/yr, a minor change from 42 lb/yr under existing conditions. No major land use changes are projected between now and 2030 (see Section 11.2). The change in future loading is assumed to be the result of Metropolitan Council's re-categorization of 2030 land use as compared to 2005 land use (see *Direct Watershed Runoff: Direct Watershed Runoff under Future (2030) Conditions* in Section 3.1.2 for further discussion).

Table 69. Lake Louise Watershed Phosphorus Source Summary, Existing Loads

Phosphorus Source	Annual TP Load (lb/yr)	Percent of Watershed TP Load (%)	Area (ac)	Average Areal TP Load (lb/ac-yr)[1]	Average TP Concentra-tion (µg/L)[2]
Direct Watershed Runoff	42	82%	220	0.19	214
SSTS	9	18%	n/a	n/a	n/a
Total	**51**	**100%**			

[1] Annual TP load (lb/yr) divided by drainage area (ac)
[2] Annual TP load (lb/yr) divided by average annual volume of runoff [3.94 (average annual depth of runoff in inches) * drainage area (ac) * conversion factor]

11.8.2 Atmospheric Phosphorus Sources

Atmospheric deposition is estimated to be 12 lb/yr (see *Atmospheric Deposition* in Section 3.1.2 for more information).

11.8.3 Internal Phosphorus Sources

Internal loading accounts for an additional 31 to 284 lb/yr (158 lb/yr average) of phosphorus loading to the lake, representing 33% to 82%, respectively, of the total loading to the lake.

11.8.4 Phosphorus Load Summary

The total modeled phosphorus load to Lake Louise is 221 lb/yr (Table 14).

Table 70. Lake Louise Phosphorus Source Summary, Existing Loads

Phosphorus Source	Phosphorus Load (lb/yr)
Watershed	51
Atmospheric	12
Internal	158
Total	**221**

11.9 TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Lake Louise is 181 lb/yr, to be split among allocations according to Table 71. To meet the TMDL, the total load to the lake needs to be reduced by 58 lb/yr.

Watershed scale pollutant load modeling was conducted and analyzed on an annual basis to establish this TMDL at a level necessary to attain and maintain applicable water quality standards. Daily wasteload allocations were derived from this analysis.

Table 71. Lake Louise Existing Loads, TMDL Allocations, and Reductions Needed

Load Component	TP Existing	TP TMDL Allocation		TP Reduction	
	lb/yr	lb/yr	lb/day	lb/yr	%
WLA					
Construction stormwater (permit #MNR100001)	0.15	0.15	0.00041	0	0%
Industrial stormwater (permit # MNR50000)	0.15	0.15	0.00041	0	0%
Total WLA	**0.30**	**0.30**	**0.00082**	**0**	**0%**
LA*					
Watershed	51	26	0.071	25	49%
Atmospheric	12	12	0.033	0	0%
Internal	158	125	0.34	33	21%
Total LA	***221***	***163***	**0.44**	***58***	**26%**
MOS	**--**	**18**	**0.049**	**--**	**--**
Total	***221***	***181***	***0.49***	***58******	***26%***

*LA components are broken down for guidance in implementation planning; the LA should be considered categorical.
**58 lb/yr reduction takes into account MOS; 40 lb/yr reduction (=58-MOS) needed to reach total loading capacity

12 MUD LAKE TMDL

12.1 Physical Characteristics

Mud Lake (ID 82-0026-02) is located in May Township and is a shallow lake bordered by pasture land on the west and south, and by forested areas to the northeast. There is no public access to the lake. Water levels in Mud Lake are maintained by the Turtle Lake control weir. This weir was installed by the District as part of the District's 1985 outlet project for the purpose of maintaining water levels in the upstream lakes and wetlands. The project also included a series of dikes around Mud Lake for maintenance of water levels. Table 72 summarizes the lake's characteristics and Figure 107 illustrates the available bathymetric data.

Table 72. Mud Lake Characteristics

Characteristic	Value	Source
Lake total surface area (ac)	60.3	2008 MLCCS
Percent lake littoral surface area	100	Calculated based on 2010 EOR bathymetry data
Lake volume (ac-ft)	302	Calculated (mean depth x surface area)
Mean depth (ft)	5	Calculated based on 2010 EOR bathymetry data
Maximum depth (ft)	8	Calculated based on 2010 EOR bathymetry data
Drainage area (acres)	317.9	CMSCWD
Watershed area:lake area	5.3	Calculated

EOR Inc X:\Clients_WD\051_CMWD\0092_Lakes_Phase1_TMDL_Study\09_GIMS\GIS\bathymeter_reportmaps.mxd Date: 5/9/2011 4:09:44 PM Name: ejensen

Figure 107. Mud Lake Bathymetry
Contour units are feet.

12.2 Land Use

At present, the dominant land use in the Mud Lake watershed is agriculture (Table 73). The lake is bordered by a large, private livestock grazing operation that uses rotational grazing to manage pasture lands. Projected land use (2030) indicates that land categorized as *undeveloped* in 2005 will be categorized as *park and recreation* and a portion of land categorized as *agricultural* in 2005 will be categorized as *rural or large-lot residential*. In addition, portion of land categorized as *agricultural* in 2005 will be categorized as *park and recreation*.

Table 73. Mud Lake Watershed Land Use, 2005
(2005 Generalized Land Use for the Twin Cities Metropolitan Area)

Land Use	Total Acres	% of Watershed
Agricultural	141.2	44.4%
Farmstead	-	-
Industrial and Utility	-	-
Institutional	-	-
Park, Recreation, or Preserve	-	-
Retail and Other Commercial	-	-
Seasonal/Vacation	-	-
Single Family Detached	0.6	0.2%
Undeveloped	149.4	47.0%
Water	26.8	8.4%
Total	**317.9**	**100.0%**

Table 74. Mud Lake Watershed Land Use, 2030
(Regional Planned Land Use for the Twin Cities Metropolitan Area)

Land Use	Total Acres	% of Watershed
Agricultural	-	-
Airport	-	-
Commercial	-	-
Industrial	-	-
Institutional	-	-
Mixed Use	-	-
Multifamily Residential	-	-
Multi-Optional Development	-	-
Open Space or Restrictive Use	-	-
Park and Recreation	206.8	65.1%
Railway (inc. LRT)	-	-
Rights-of-Way (i.e., Roads)	-	-
Rural or Large-Lot Residential	84.3	26.5%
Single Family Residential	-	-
Vacant or No Data	-	-
Water	26.8	8.4%
Total	**317.9**	**100.0%**

12.3 Existing Studies, Monitoring, and Management

Based on an Aerial Lakeshore Analysis study (CMWD 1999), the most common influence on the lake was runoff from non-point source pollution from adjacent fields caused by the lack of a maintained vegetative buffer between fields and the lake. The recommendations from that study are to investigate and correct all point and non-point sources of pollution to the lake and to keep the forested areas intact.

The Mud Lake Watershed Management Plan was written as part of the Carnelian-Marine-St. Croix Watershed District's 2010 Watershed Management Plan. Management, monitoring, and implementation activities are expected to be driven by an implementation plan developed based on this TMDL study. In addition, an operational priority is to provide input to the Big Marine Regional Park planning process.

12.4 Lake Uses

Mud Lake has been used as a walleye and muskie rearing pond.

12.5 Biological Characteristics

12.5.1 Fisheries

Mud Lake has been used as walleye and muskie rearing pond. During harvests in the 1900s, high numbers of bullhead and panfish were observed. A fish toxin was applied in 2001 to eliminate the existing fish (although a total kill was not achieved), and the lake was stocked in 2002.

12.5.2 Macrophytes

Macrophyte surveys were completed for Mud Lake in June and September of 2010. Curly-leaf pondweed was not observed during either survey (Figure 108). There was a greater distribution of submergents and floating leaf macrophytes in the September survey; the September survey also showed a small area of open water that did not exist in the June survey. A diversity of native macrophyte species was present in the lake during both surveys (Table 51).

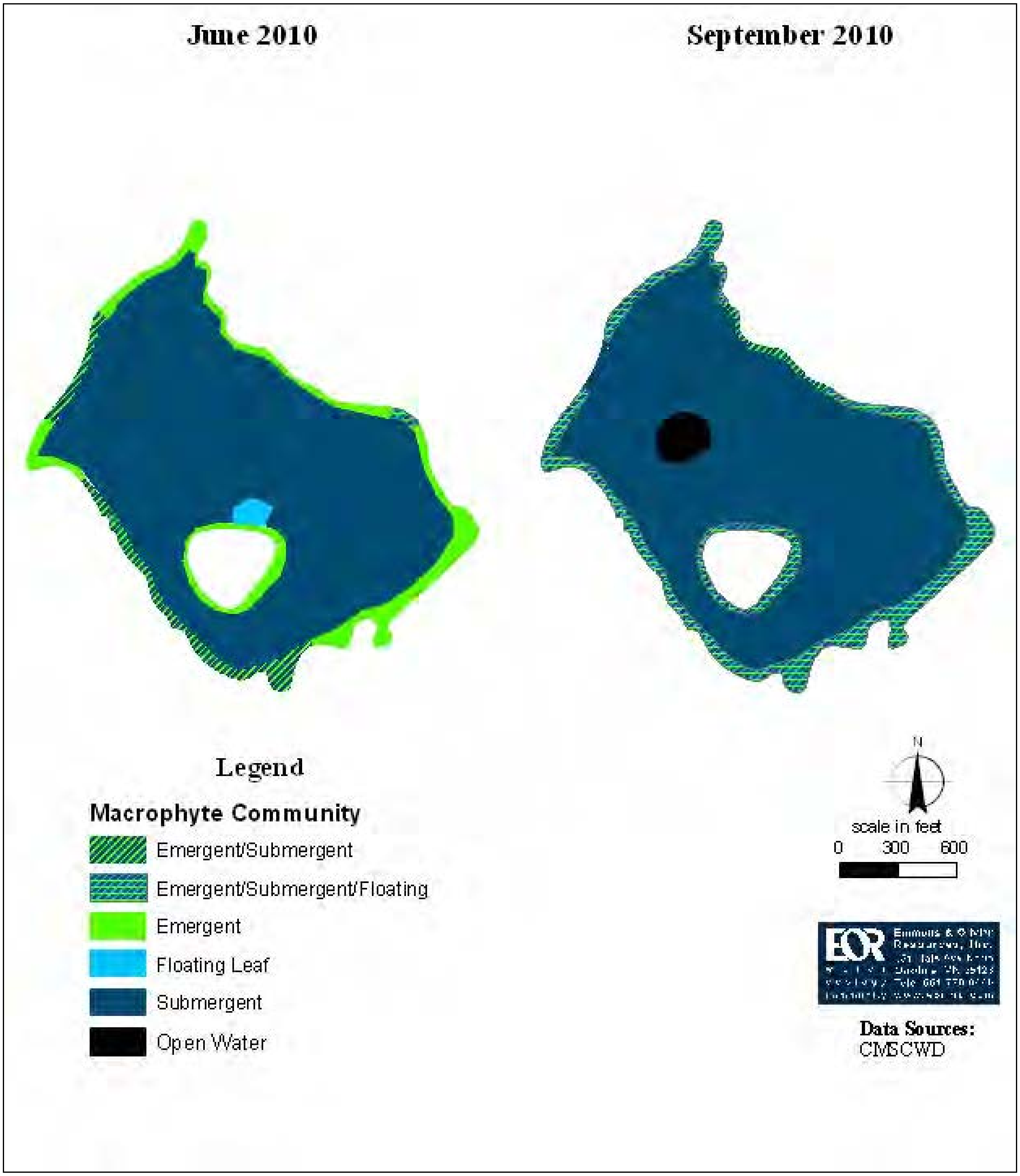

Figure 108. Distribution of Macrophyte Communities in Mud Lake

Table 75. Plant Species Observed During 2010 Mud Lake Macrophyte Surveys

Scientific Name	Common Name	June	August
Ceratophyllum demersum	Coontail	ü	ü
Chara vulgaris	Muskgrass	ü	ü
Elodea canadensis	Elodea	ü	ü
Lemna minor	Lesser duckweed		ü
Myriophyllum exalbescens	Northern water milfoil	ü	ü
Najas guadalupensis	Southern waternymph		ü
Nuphar lutea	Yellow water-lily	ü	
Nymphaea odorata	White water-lily	ü	ü
Potamogeton pectinatus	Sago pondweed	ü	ü
Potamogeton richardsonii	Claspingleaf pondweed	ü	ü
Potamogeton zosteriformis	Flat-stemmed pondweed	ü	ü
Sagittaria latifolia	Broadleaf arrowhead		ü
Scirpus acutus	Hardstem bulrush		ü
Lemna trisulca	Star duckweed	ü	ü

12.6 Water Quality

Monitoring data are available sporadically from 2001 through 2010, with more years of Secchi transparency data than either total phosphorus or chlorophyll-*a*. The lake is not meeting any of the lake water quality standards (Table 76). Table 76 presents means from only 2010; while data were taken previous to 2010, there are phosphorus and chlorophyll-*a* data from only two or one additional year(s), respectively, and the sample sizes are variable. Growing season means are the most comparable among the three water quality parameters for 2010. All data are presented in the figures below.

Mud Lake data was scarce for TP (2000, 2001, and 2010 only) and chlorophyll-*a* (2001 and 2010 only). 2000 and 2001 data showed poorer water quality in comparison to 2010 data, and more complete Secchi transparency data (2000, 2001, 2004-2007, and 2010) illustrate some improvements. The fish toxin applied in 2001 may have lead to water quality improvements through reductions in the black bullhead and panfish population numbers. Land management practices within the previous 10 years (e.g. rotational grazing and reseeding) also may have contributed to the improved water quality. Figure 109 through Figure 111 show the mean growing season total phosphorus, chlorophyll-*a,* and Secchi transparency data from Mud Lake.

Water quality in 2010 declined throughout the course of the growing season, with poorer water quality observed in August and September (Figure 52). There is a strong relationship between total phosphorus and Secchi transparency (Figure 53); relationships between the other parameters are similar.

Table 76. Mud Lake, Surface Water Quality Means and Standards, 2010

Parameter	Growing Season Mean (June – September)	Lake Standard
TP (µg/L)	79	60
Chlor-a (µg/L)	34	20
Secchi transparency (m)	0.7	1.0

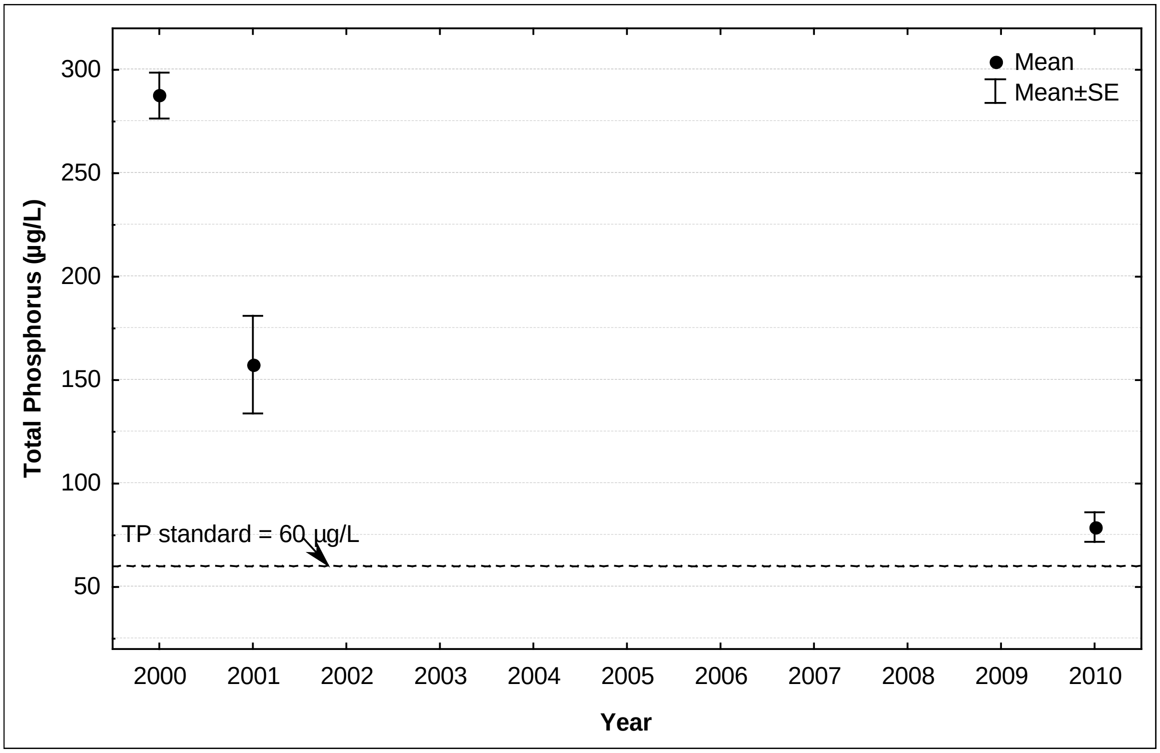

Figure 109. Mud Lake, Growing Season Means Total Phosphorus

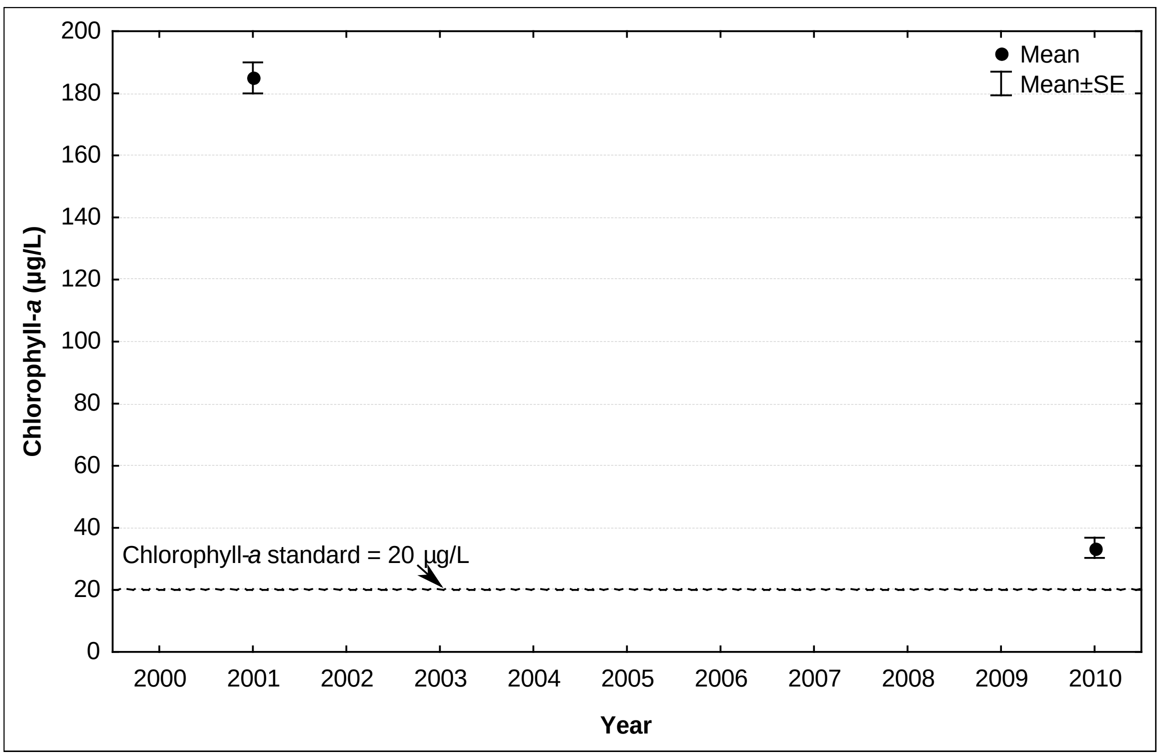

Figure 110. Mud Lake Growing Season Means Chlorophyll-*a*

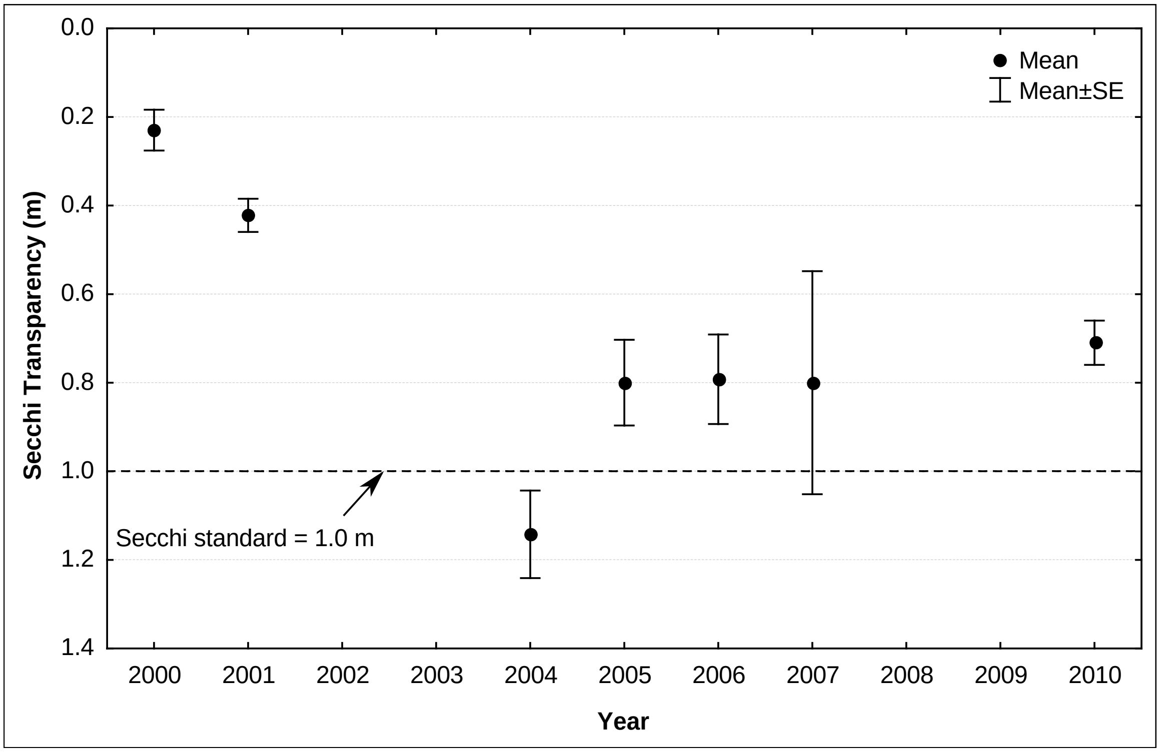

Figure 111. Mud Lake, Growing Season Means Secchi Transparency

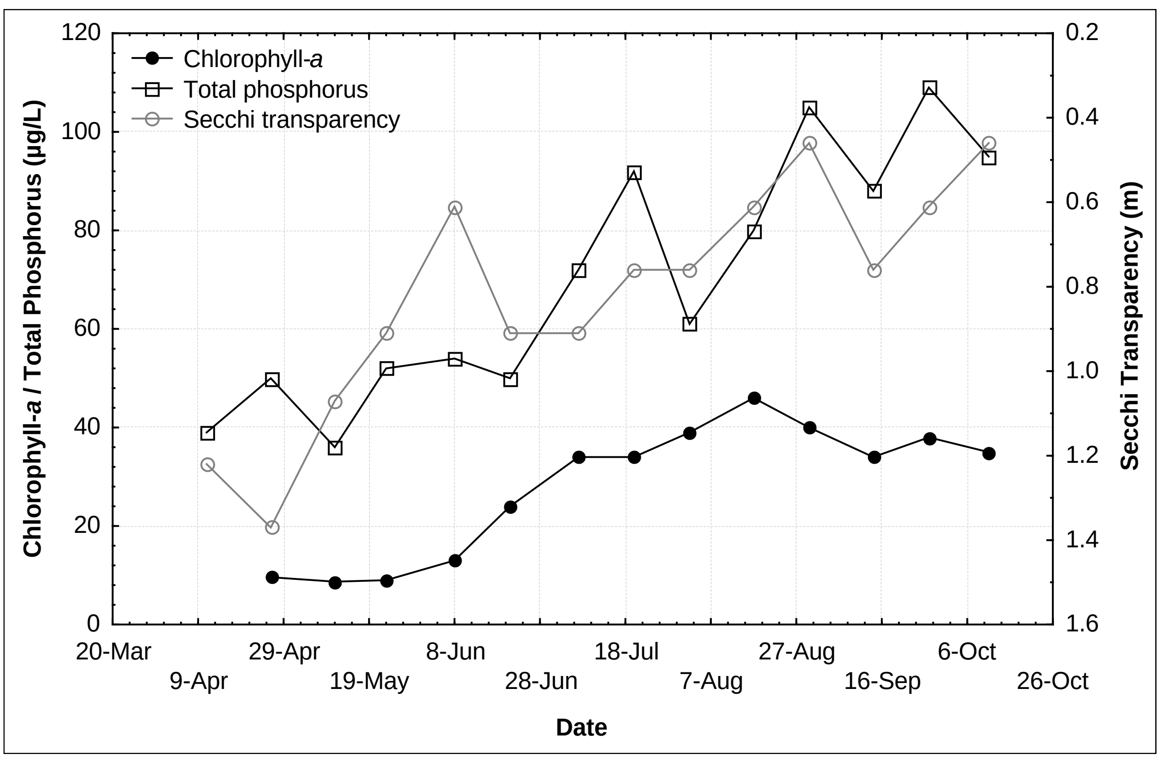

Figure 112. Mud Lake Seasonal Water Quality Patterns

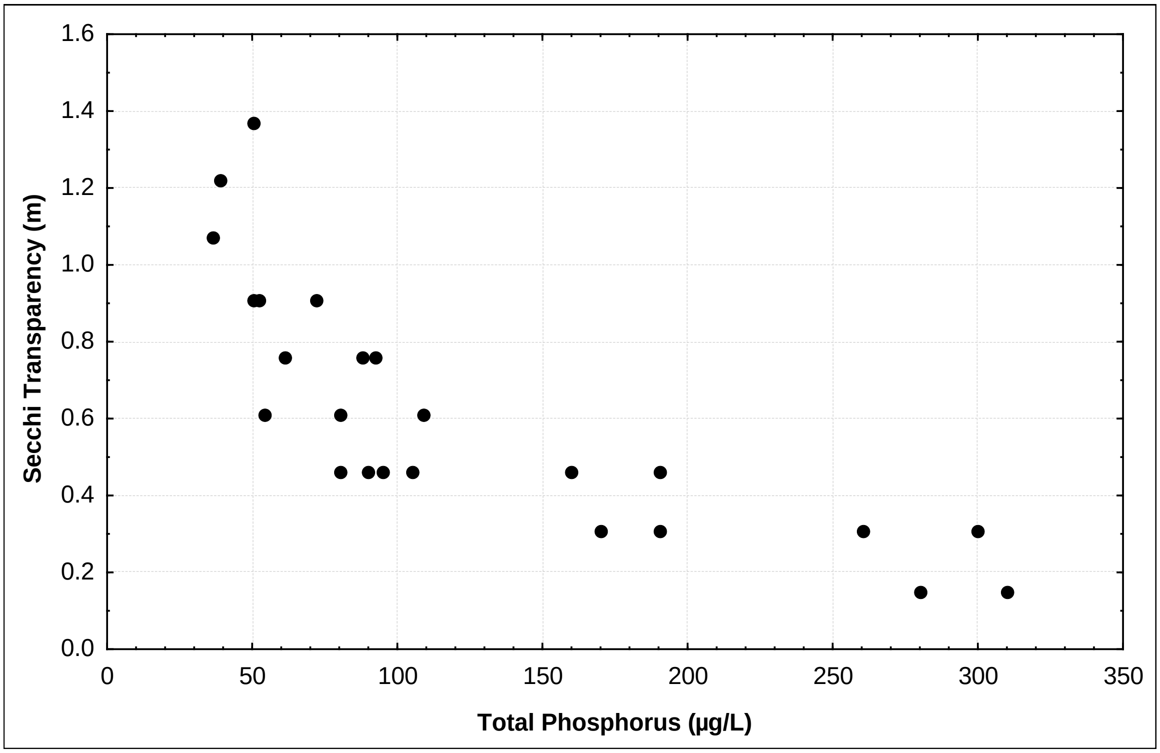

Figure 113. Relationship of Secchi Transparency to Total Phosphorus in Mud Lake

12.7 In-Lake Impairment Assessment Summary

- The lake is used as a walleye and musky rearing pond by the DNR. The fish kill in 2001 prior to stocking may have lead to water quality improvements.
- Water quality declines throughout the growing season; internal loading likely leads to these changes.
- Phytoplankton and zooplankton data are not available.
- The Secchi transparency standard was met in 2004; the standards were not met in any other years of water quality data collection.

12.8 Phosphorus Source Inventory

12.8.1 Watershed Phosphorus Sources

It is estimated that Mud Lake receives 27 pounds of phosphorus annually from watershed runoff (Table 77). The largest watershed source of phosphorus is from direct watershed runoff from the contributing watershed (318 acres). Atmospheric deposition is the second largest contributor of phosphorus to the lake. Atmospheric deposition contributes approximately 16 pounds of phosphorus annually.

The 2030 phosphorus load from direct watershed runoff is estimated to be 26 lb/yr, no change from that of existing conditions. Land use changes projected between now and 2030 (see Section

12.2 and *Direct Watershed Runoff: Direct Watershed Runoff under Future (2030) Conditions* in Section 3.1.2 for further discussion) are not expected to change pollutant loading. Changes are a conversion of a portion of agricultural land, which is rotationally-grazed pasture land, to park and recreation (natural area in this case).

Table 77. Mud Lake Watershed Phosphorus Source Summary, Existing Loads

Phosphorus Source	Annual TP Load (lb/yr)	Percent of Watershed TP Load (%)	Area (ac)	Average Areal TP Load (lb/ac-yr)[1]	Average TP Concentration (µg/L)[2]
Direct Watershed Runoff	26	96%	318	0.082	92
SSTS	1	4%	n/a	n/a	n/a
Total	**27**	**100%**			

[1] Annual TP load (lb/yr) divided by drainage area (ac)
[2] Annual TP load (lb/yr) divided by average annual volume of runoff [3.94 (average annual depth of runoff in inches) * drainage area (ac) * conversion factor]

12.8.2 Atmospheric Phosphorus Sources

Atmospheric deposition is estimated to be 16 lb/yr (see *Atmospheric Deposition* in Section 3.1.2 for more information).

12.8.3 Internal Phosphorus Sources

Internal loading accounts for an additional 0 to 254 lb/yr (127 lb/yr average) of phosphorus loading to the lake, representing 0% to 86%, respectively, of the total loading to the lake.

12.8.4 Phosphorus Load Summary

The total modeled phosphorus load to Mud Lake is 170 lb/yr (Table 14).

Table 78. Mud Lake Phosphorus Source Summary, Existing Loads

Phosphorus Source	Phosphorus Load (lb/yr)
Watershed	27
Atmospheric	16
Internal	127
Total	**170**

12.9 TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Mud Lake is 157 lb/yr, to be split among allocations according to Table 79. To meet the TMDL, the total load to the lake needs to be reduced by 29 lb/yr.

Watershed scale pollutant load modeling was conducted and analyzed on an annual basis to establish this TMDL at a level necessary to attain and maintain applicable water quality standards. Daily wasteload allocations were derived from this analysis.

Table 79. Mud Lake Existing Loads, TMDL Allocations, and Reductions Needed

Load Component	TP Existing	TP TMDL Allocation		TP Reduction	
	lb/yr	lb/yr	lb/day	lb/yr	%
WLA					
Construction stormwater (permit #MNR100001)	0.080	0.080	0.00022	0	0%
Industrial stormwater (permit # MNR50000)	0.080	0.080	0.00022	0	0%
Total WLA	**0.16**	**0.16**	**0.00044**	**0**	**0%**
LA*					
Watershed	27	14	0.038	13	48%
Atmospheric	16	16	0.044	0	0%
Internal	127	111	0.30	16	13%
Total LA	***170***	***141***	**0.38**	***29***	**17%**
MOS	**--**	**16**	**0.044**	**--**	**--**
Total	***170***	***157***	***0.42***	***29*****	***17%***

*LA components are broken down for guidance in implementation planning; the LA should be considered categorical.
**58 lb/yr reduction takes into account MOS; 40 lb/yr reduction (=58-MOS) needed to reach total loading capacity

13 SOUTH TWIN LAKE TMDL

13.1 Physical Characteristics

South Twin Lake (ID 82-0019) is a shallow lake located in the City of Stillwater. The lake outlets to North Twin Lake, which eventually drains to the St. Croix River via Silver Creek. A large portion of the watershed was developed in 2008 (the Millbrook Development), which resulted in the diversion of 13.5 acres and its associated runoff away from the lake. There is significant development pressure within South Twin Lake's watershed. Table 80 summarizes the lake's characteristics, and Figure 114 illustrates the lake bathymetry.

Table 80. South Twin Lake Characteristics

Characteristic	Value	Source
Lake total surface area (ac)	55.9	2008 MLCCS revised based on 2008 aerial photos
Percent lake littoral surface area	100	Calculated based on 2008 WCD bathymetry data
Lake volume (ac-ft)	296.3	Calculated (mean depth x surface area)
Mean depth (ft)	5.3	Calculated based on 2008 WCD bathymetry data
Maximum depth (ft)	9	Based on 2008 WCD bathymetry data
Drainage area (acres)	83	CMSCWD
Watershed area:lake area	1.5	Calculated

Figure 114. South Twin Lake Bathymetry
Contour units are feet.

13.2 Land Use

Land use within the South Twin Lake watershed is currently dominated by agriculture and undeveloped land (Table 81). Developments in the watershed since 2005 are not reflected in the land use dataset. Small areas of single family residential land uses are found throughout the watershed.

Land use changes are projected between now and 2030 (Table 82). Some of these changes are assumed to be the result of Metropolitan Council's re-categorization of 2030 land use as compared to 2005 land use. However, a total of 4.6 acres of land is projected to change from either agricultural or undeveloped to multi- or single family residential, and 17.9 acres of land is projected to change from either agricultural or undeveloped to park and recreation.

Table 81. South Twin Lake Watershed Land Use, 2005
(2005 Generalized Land Use for the Twin Cities Metropolitan Area)

Land Use	Total Acres	% of Watershed
Agricultural	36.1	43.5%
Farmstead	-	-
Industrial and Utility	-	-
Institutional	-	-
Park, Recreation, or Preserve	-	-
Retail and Other Commercial	-	-
Seasonal/Vacation	-	-
Single Family Detached	11.8	14.2%
Undeveloped	31.4	37.8%
Water	3.7	4.5%
Total	**83.0**	**100.0%**

Table 82. South Twin Lake Watershed Land Use, 2030
(Regional Planned Land Use for the Twin Cities Metropolitan Area)

Land Use	Total Acres	% of Watershed
Agricultural	-	-
Airport	-	-
Commercial	-	-
Industrial	-	-
Institutional	-	-
Mixed Use	-	-
Multifamily Residential	1.0	1.2%
Multi-Optional Development	-	-
Open Space or Restrictive Use	-	-
Park and Recreation	17.9	21.6%
Railway (inc. LRT)	-	-
Rights-of-Way (i.e., Roads)	-	-
Rural or Large-Lot Residential	45.0	54.2%
Single Family Residential	15.4	18.6%
Vacant or No Data	-	-
Water	3.7	4.5%
Total	**83.0**	**100.1%***

* Total % does not equal 100.0 due to rounding.

13.3 Existing Studies, Monitoring, and Management

Based on an Aerial Lakeshore Analysis study (CMWD 1999), the greatest influence on the lake is agricultural runoff from non-point source pollution. The recommendations from that study are to develop and/or expand a vegetative buffer around the lake and to install berms to redirect watershed runoff away from the lake.

In 2000 a phosphorus sensitivity analysis for several lakes in the Carnelian-Marine Watershed District was completed (CMWD 2000). South Twin Lake exceeds the ecoregion goal of 40 µg/L of total phosphorus but the report suggests that the lake should be passively maintained.

In 2004, the Carnelian-Marine Watershed District completed a corridor plan for Silver Creek (CMWD 2004b). The plan included an assessment of the shallow lakes in the Silver Creek watershed, including South Twin Lake. The assessment looked at surface water quality trends, lake macrophyte communities, and provided recommendations on how to improve water quality.

The shallow lakes assessment reported a very narrow fringe of emergent plants around most of the perimeter of South Twin Lake. The deeper portions of the South Twin Lake contained a high diversity of submerged aquatic plants, with floating-leaf pondweeds particularly common along the southwest shore.

In part based on recommendations in the shallow lakes assessment and as part of the Millbrook Development, a permanent native vegetation buffer has been established along the entire western shoreline and roadside swale improvements have been implemented. In addition, a portion of the eastern shoreline was donated to the District by former owners and a conservation easement established.

The South Twin Lake Watershed Management Plan was written as part of the Carnelian-Marine-St. Croix Watershed District's 2010 Watershed Management Plan. Management, monitoring and implementation activities are expected to be driven by an implementation plan developed based on this TMDL study. The management plan also identified a potential future project to implement a buffer and develop management strategies for the newly established conservation easement as discussed in the preceding paragraph.

13.4 Lake Uses

South Twin Lake does not have a public access. Primary uses of this lake are boating and fishing by residents who live on the lake. The lake has been used by the DNR in the past for minnow rearing.

13.5 Biological Characteristics

13.5.1 Fisheries

The DNR has not conducted a fish survey on South Twin Lake. The lake has been used for minnow rearing in the past.

13.5.2 Macrophytes

Macrophyte surveys were completed for South Twin Lake in June and August of 2008 (Figure 115). Curly-leaf pondweed was observed throughout the lake in the June survey, but not in the August survey. The amount of the lake without macrophyte vegetation (open water) grew between the June and August surveys. Open water was observed in the August survey in areas that had abundant curly-leaf pondweed in the June survey. The macrophyte species observed in South Twin Lake are listed in Table 83.

Table 83. Plant Species observed during 2008 South Twin Lake Macrophyte Surveys

Scientific Name	Common Name	June	August
Ceratophyllum demersum	Coontail	ü	ü
Elodea canadensis	Elodea	ü	ü
Potamogeton crispus	Curly-leaf pondweed	ü	
Potamogeton foliosus	Leafy pondweed	ü	
Potamogeton pectinatus	Sago pondweed	ü	ü
Potamogeton robbinsii	Fern-leaved pondweed		ü

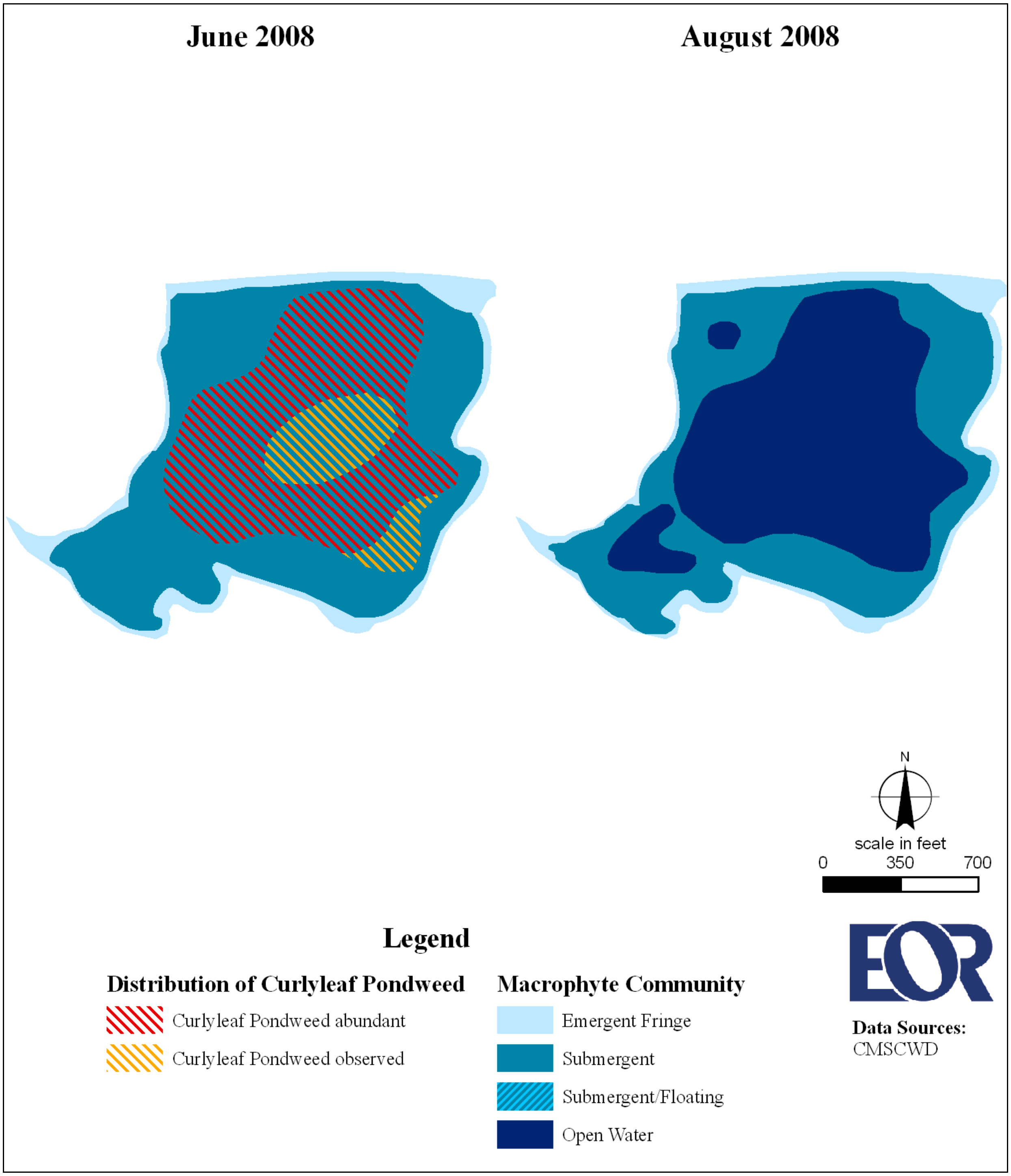

Figure 115. Distribution of Macrophyte Communities in South Twin Lake

13.5.3 Plankton Community

Phytoplankton

The algal community in South Twin Lake over the 2008 sampling period was not dominated by any particular group (Figure 116). Over time, different groups do show more dominance. Green algae are dominant in spring, followed by an increase in the dominance of blue-green algae (Figure 117). Eutrophic indicator algae stay relatively constant at a low proportion of the community over the sampling period.

The green algae *Eudorina* is the most dominant species in spring, and both *Eudorina* and *Dictyosphaerium* are present in relatively high numbers over the season. These green algae are less dominant later in the summer in favor of the blue-green *Anabaena limneticus* and the diatom *Cocconeis* (Figure 118). The shift to *Anabaena* represented an algal bloom response following increased nutrients. High densities are seen by the increase in chlorophyll-*a* concentrations and resultant poor water clarity (Figure 119). The blue-green *Microcystis* and other blue-greens were present over most sampling periods but were not dominant.

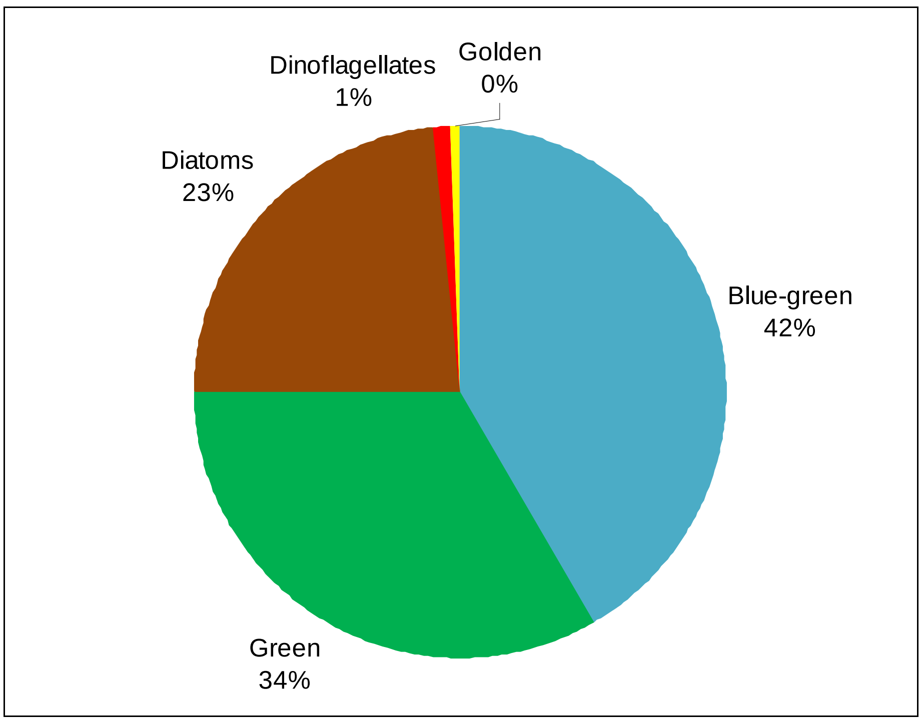

Figure 116. Total algal composition of major groups (%) in South Twin Lake over 5 monthly sampling periods, 2008

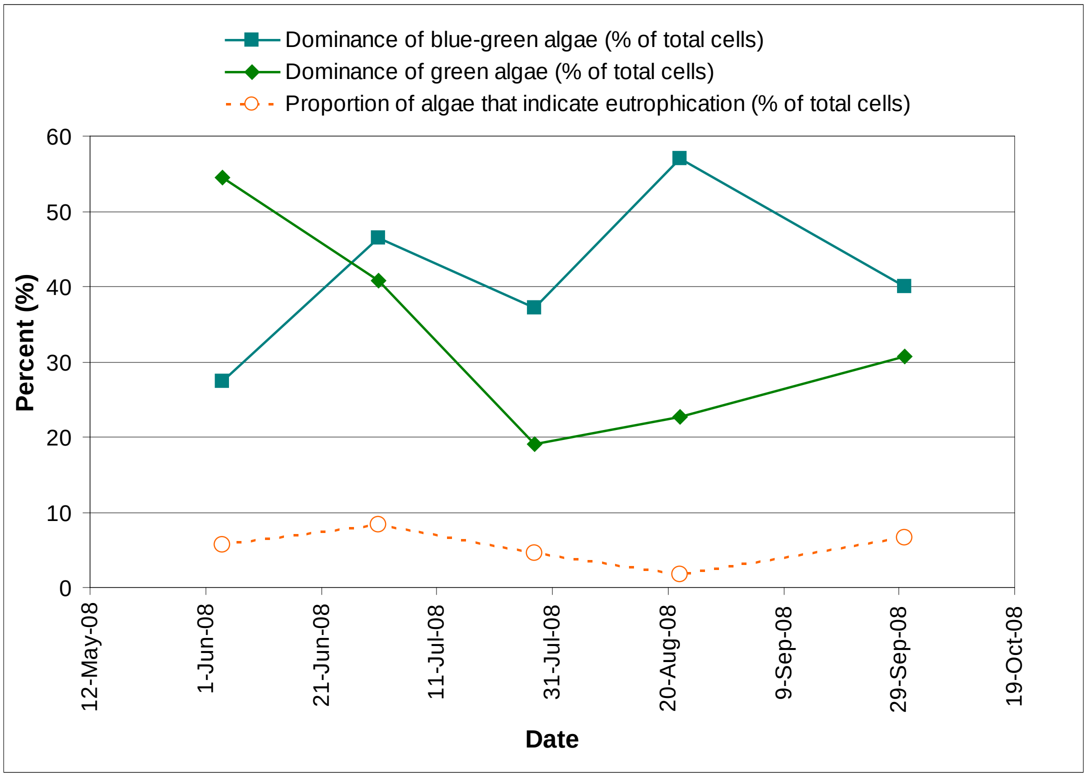

Figure 117. Dominance of major algal groups and indicator species in South Twin Lake over five monthly sampling periods in 2008 (% of cells/300 counted)

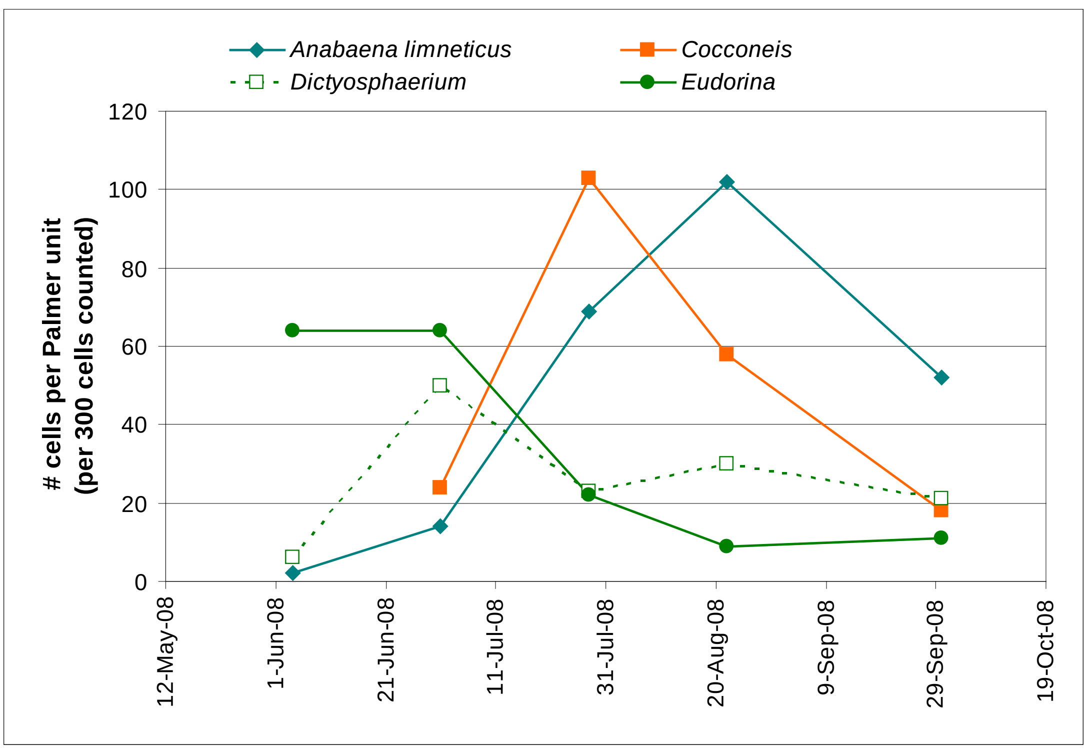

Figure 118. Dominance of the most abundant algal taxa in South Twin Lake over five monthly sampling periods in 2008 (# of cells/300 counted)

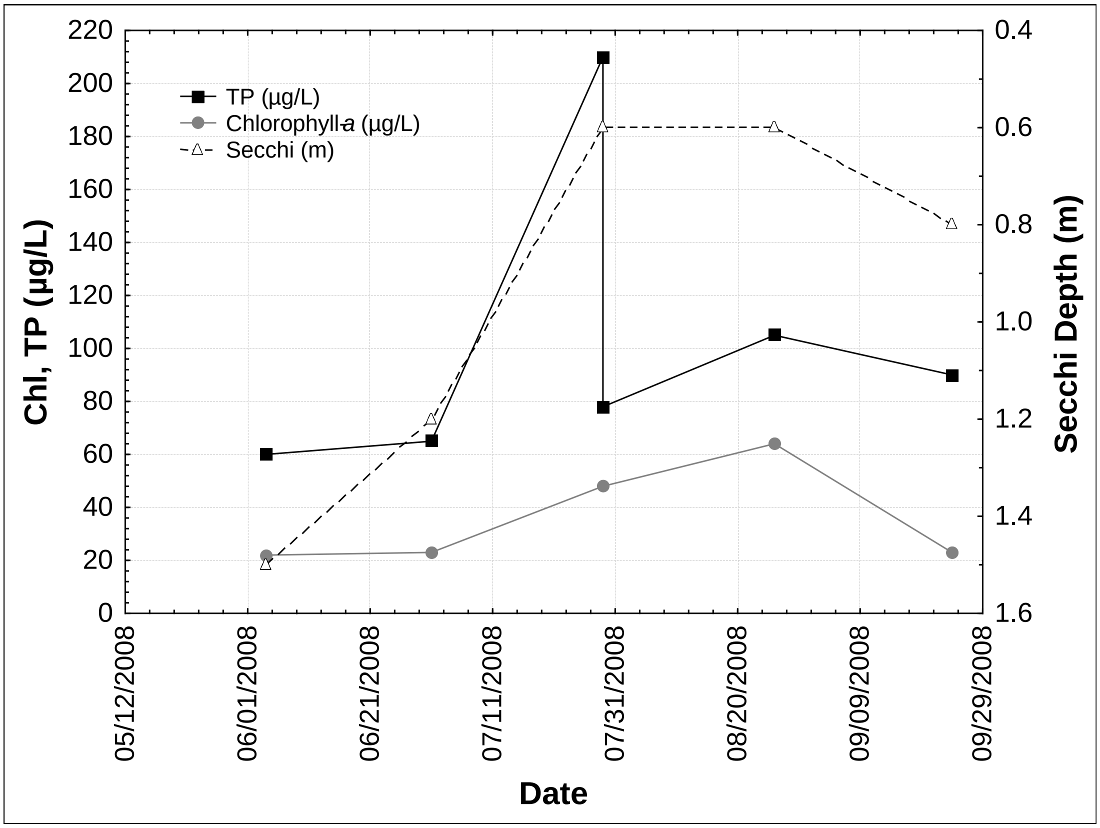

Figure 119. Chlorophyll-a concentrations (as a proxy for algal density), total phosphorus, and Secchi transparency for South Twin Lake over five monthly sampling periods, 2008

Zooplankton

The zooplankton community in South Twin Lake over the 2008 sampling period was dominated by cladocerans (Figure 120). The community composition was fairly balanced in spring, followed by an increase in cladoceran dominance over the summer (Figure 121). Over August and September sampling, cladoceran dominance decreases slightly as copepods become more common.

The changes in species composition show that two key cladocerans are responsible for the dominance of this group in the zooplankton community (Figure 122). *Ceriodaphnia* was dominant in June, but was replaced by *Bosmina* in July. The two are equally common in August but *Bosmina* becomes dominant again in September. This effect looks very much like natural cycling due to competition, but could also be an artifact of the patchy distribution of zooplankton.

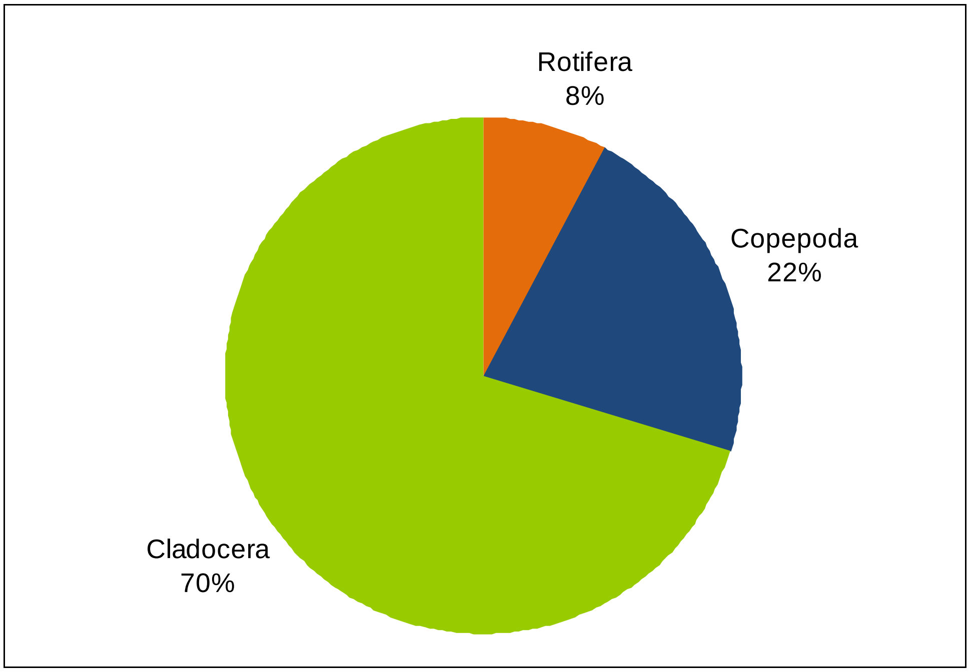

Figure 120. Total zooplankton composition of major groups (%) in East Boot Lake over 5 monthly sampling periods, 2008

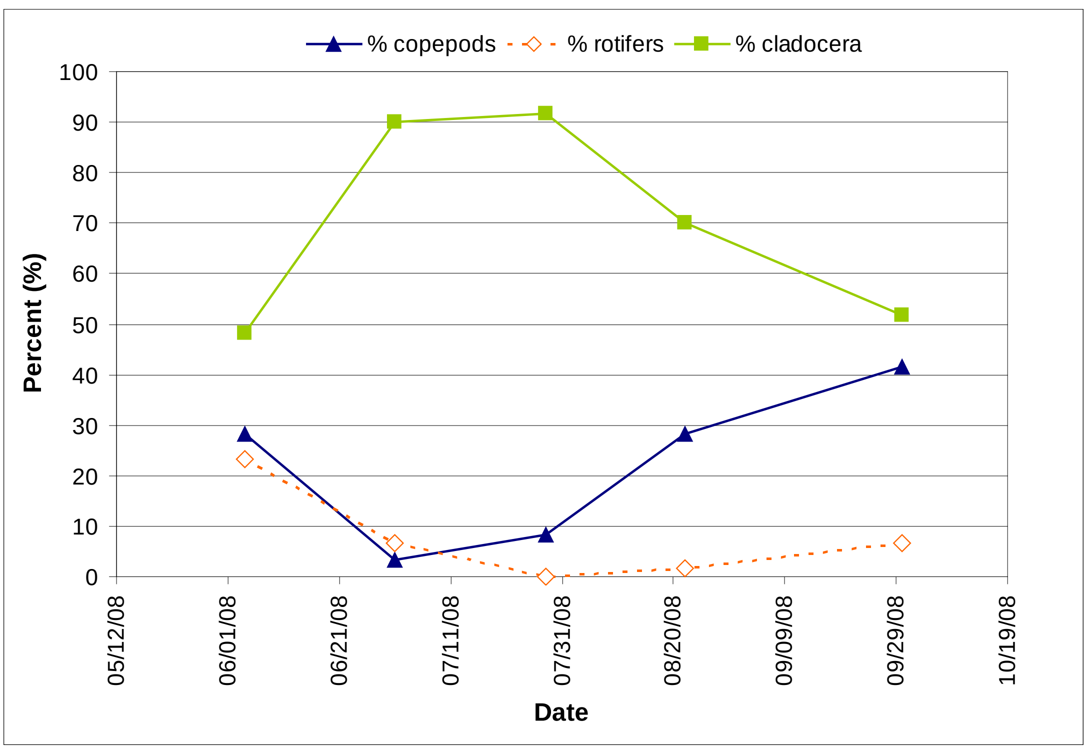

Figure 121. Dominance of major zooplankton groups and indicator species in South Twin Lake over five monthly sampling periods in 2008 (as % of individuals counted)

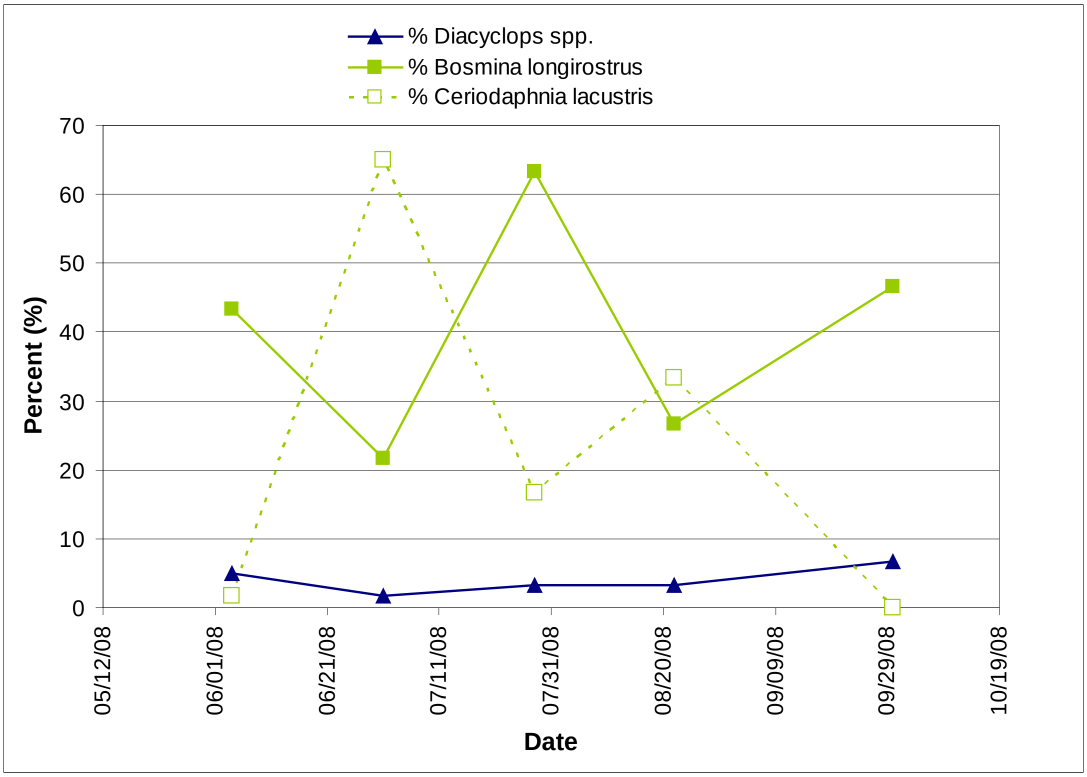

Figure 122. Dominance of the most abundant zooplankton taxa in South Twin Lake over five monthly sampling periods in 2008 (as % of individuals counted

Discussion

The overall algal community in South Twin Lake was not dominated by any one group, but blue-green algae compose a significant proportion. The algae *Anabaena* is a general indicator of eutrophic conditions, and the green algae *Dictyosphaerium* is tolerant of high turbidity.

Cladocerans decline into fall as rotifers become more dominant, indicating a depression in late summer and early fall reduction in grazing capacity. Presence of these zooplankton indicates low planktivory, but there is an absence of larger cladocerans.

13.6 Water Quality

Monitoring data are available from 2000-2001 and 2003-2008 for Secchi transparency and TP. Chlorophyll-*a* data are available for 2001 and 2003-2008. A summary of the data indicates that the lake is meeting lake water quality standards for Secchi transparency, but not meeting the standards for total phosphorus and chlorophyll-*a* (Table 84).

Figure 123 through Figure 125 show the mean growing season total phosphorus (TP), chlorophyll-*a*, and Secchi transparency data for South Twin Lake. In 2003 and 2004, the water quality was improved and all three standards were met. 2005 showed declines in water quality. Data suggest that the lake flipped from a clearwater phase to a turbid phase between 2004 and 2005. It is not clear what stressor led to this switch.

Seasonal chlorophyll-*a* patterns show that chlorophyll-*a* generally increases over the growing season (Figure 126). The seasonal patterns seen for TP and Secchi transparency are similar but not as strong.

Moderate relationships exist between chlorophyll-*a* and TP (Figure 127).

Table 84. South Twin Lake, Surface Water Quality Means and Standards, 2000-2001, 2003-2008

Parameter	Growing Season Mean (June – September)	Shallow Lake Standard
TP (µg/L)	73	60
Chlor-*a* (µg/L)	39	20
Secchi transparency (m)	1.1	1.0

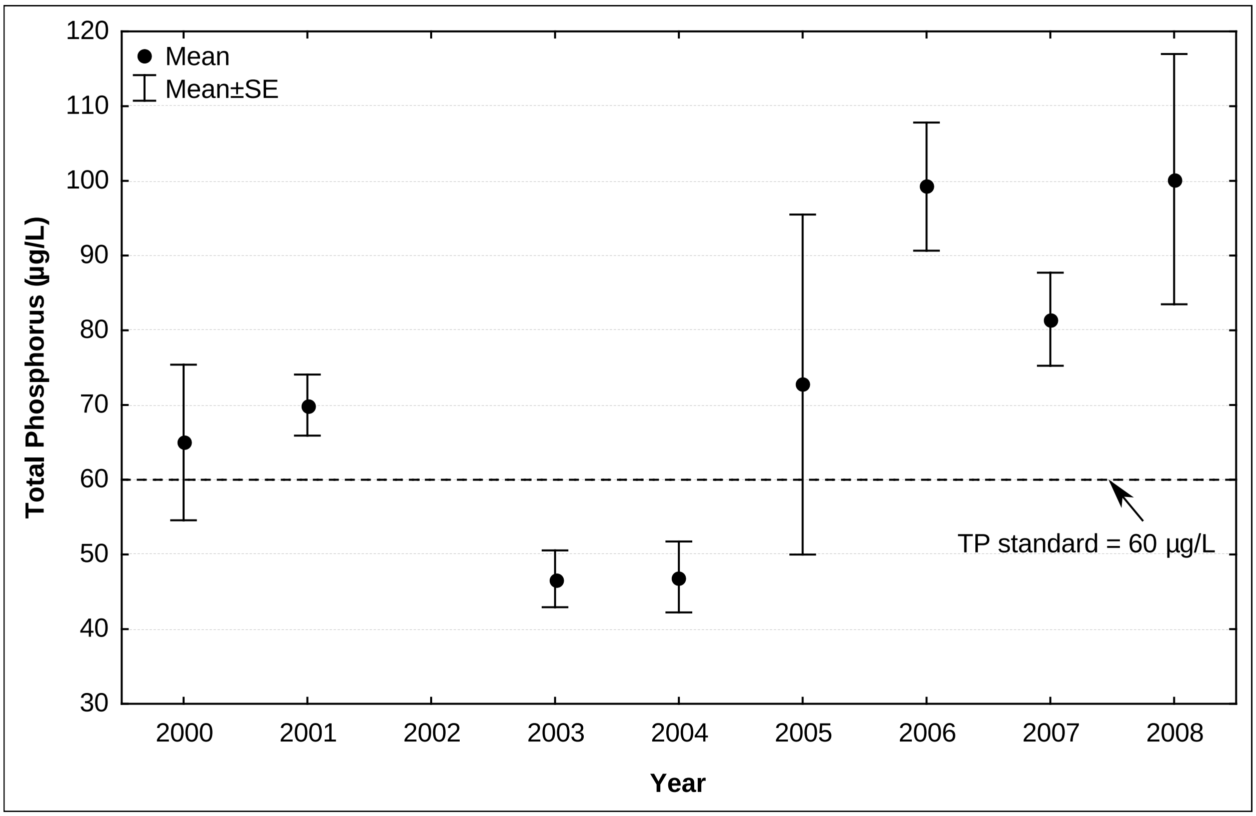

Figure 123. South Twin Lake, Growing Season Means Total Phosphorus

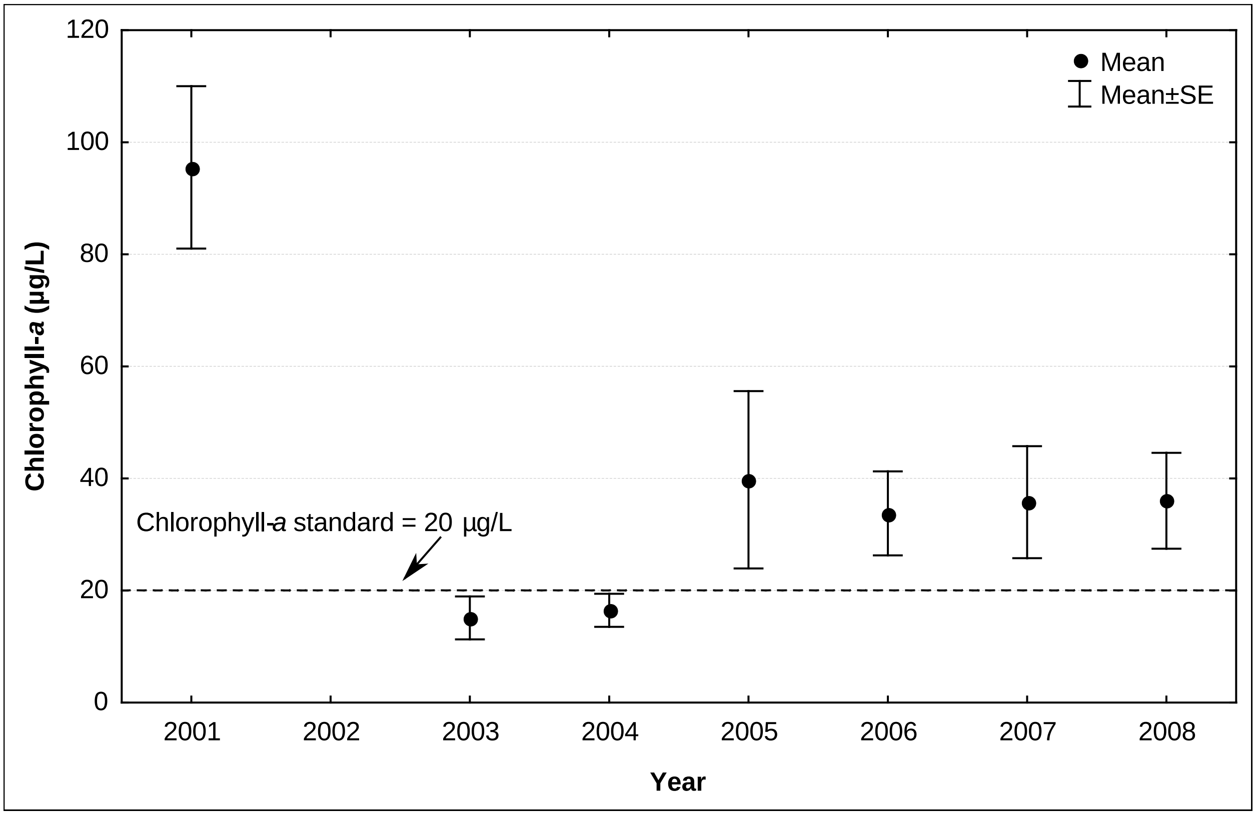

Figure 124. South Twin Lake, Growing Season Means Chlorophyll-*a*

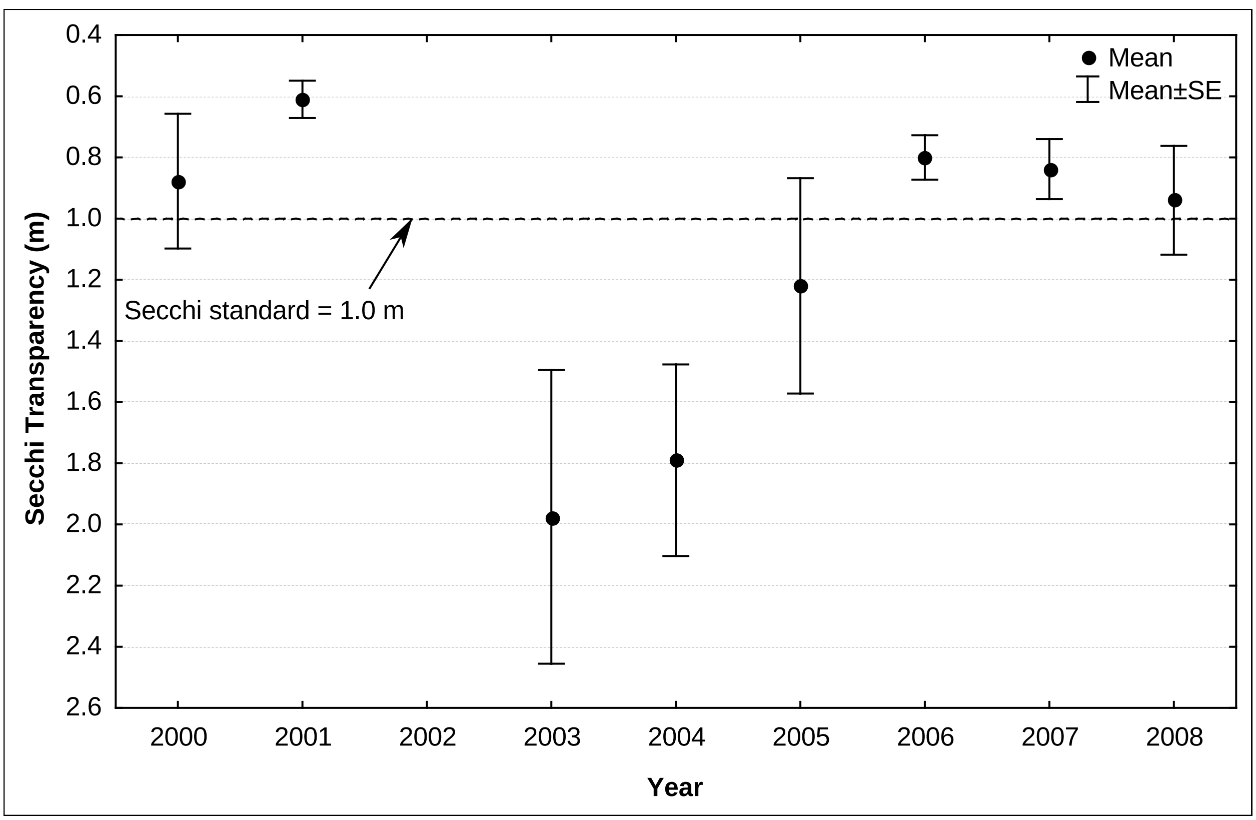

Figure 125. South Twin Growing Season Means Lake Secchi Transparency

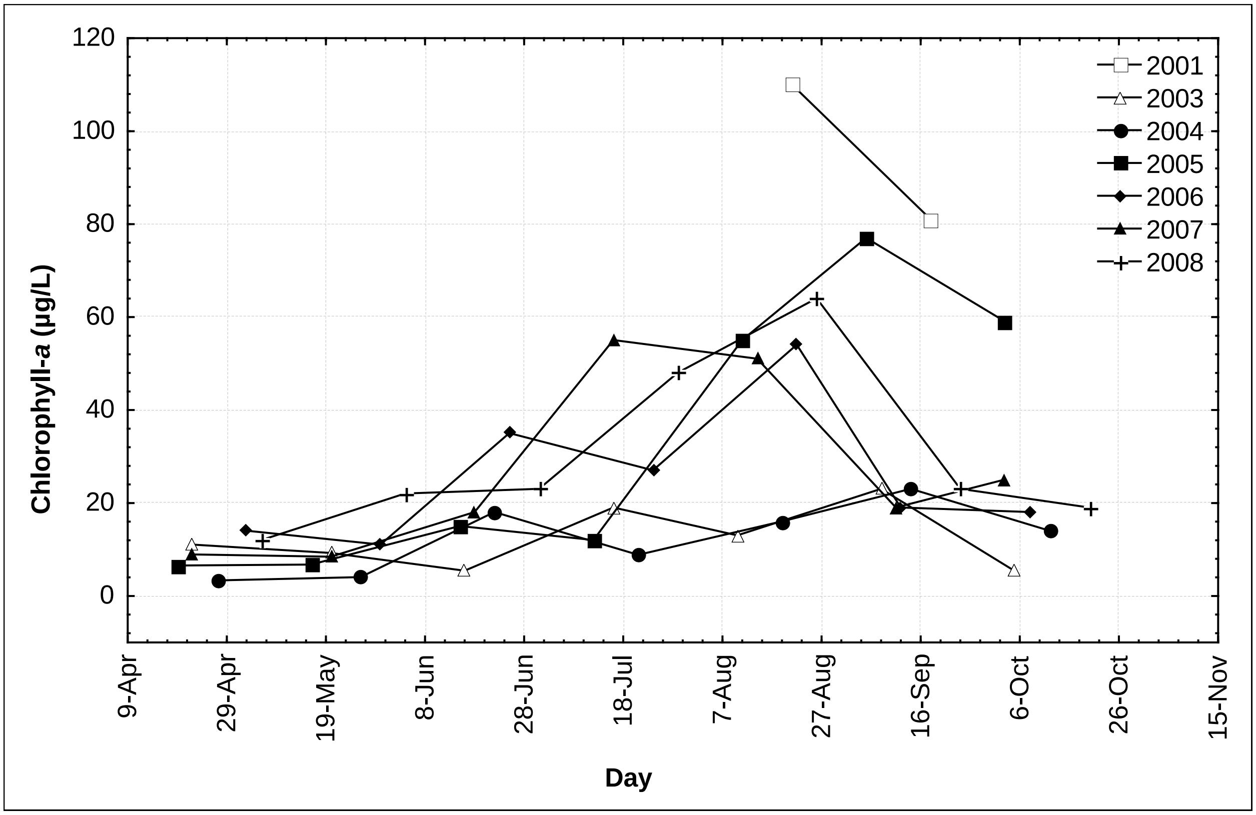

Figure 126. South Twin Lake Seasonal Chlorophyll-a Patterns

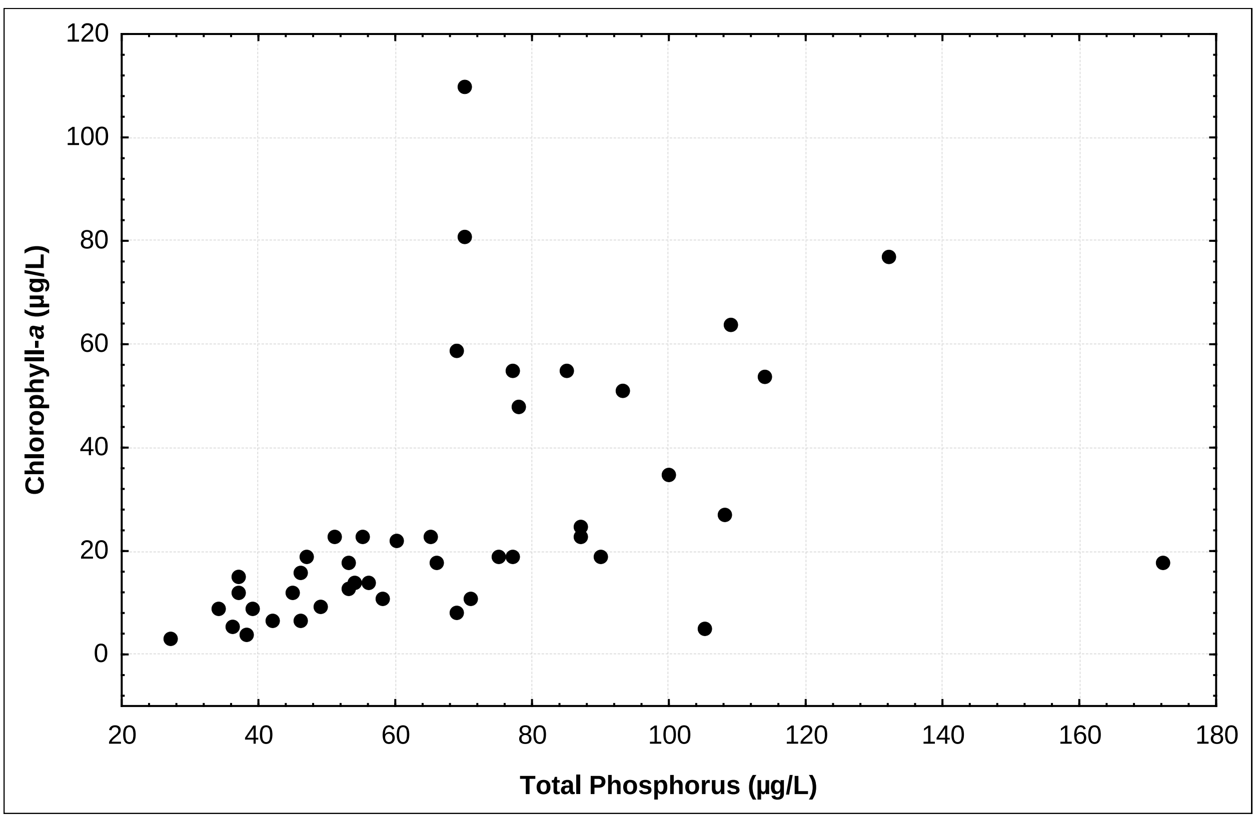

Figure 127. Relationship of Chlorophyll-*a* to Total Phosphorus in South Twin Lake

13.7 In-Lake Impairment Assessment Summary

- The are no fisheries data for the lake.
- Curly-leaf pondweed is abundant in the lake and likely contributes to internal phosphorus loading.
- The phytoplankton community is dominated by blue-green algae, with a high potential for algal blooms.
- The zooplankton community is dominated by cladocera, large zooplankton that have a high grazing capacity.
- Lake water quality met all three standards in 2003 and 2004 but has worsened in recent years.

13.8 Phosphorus Source Inventory

13.8.1 Watershed Phosphorus Sources

It is estimated the South Twin Lake receives 22 pounds of phosphorus annually from watershed runoff (Table 85). The largest watershed source of phosphorus is from direct watershed runoff from the contributing watershed (83 acres). SSTS contributes 27% of the phosphorus to the lake. There are approximately five houses on the lake contributing six pounds of phosphorus annually.

The 2030 phosphorus load from direct watershed runoff is estimated to be 15 lb/yr, a minor change from 16 lb/yr under existing conditions. Projected land use changes from agricultural and undeveloped in 2005 to multifamily residential, single family residential, and park and recreation in 2030 (see Section 13.2) result in a minor net change in phosphorus loading to South Twin Lake. The change in future loading is also assumed to be influenced by Metropolitan Council's re-categorization of 2030 land use as compared to 2005 land use (see *Direct Watershed Runoff: Direct Watershed Runoff under Future (2030) Conditions* in Section 3.1.2 for further discussion).

Table 85. South Twin Lake Watershed Phosphorus Source Summary, Existing Loads

Phosphorus Source	Annual TP Load (lb/yr)	Percent of Watershed TP Load (%)	Area (ac)	Average Areal TP Load (lb/ac-yr)[1]	Average TP Concentration (µg/L)[2]
Direct Watershed Runoff	16	73%	83	0.19	216
SSTS	6	27%	n/a	n/a	n/a
Total	**22**	**100%**			

[1] Annual TP load (lb/yr) divided by drainage area (ac)
[2] Annual TP load (lb/yr) divided by average annual volume of runoff [3.94 (average annual depth of runoff in inches) * drainage area (ac) * conversion factor]

13.8.2 Atmospheric Phosphorus Sources

Atmospheric deposition is estimated to be 15 lb/yr (see *Atmospheric Deposition* in Section 3.1.2 for more information).

13.8.3 Internal Phosphorus Sources

Internal loading accounts for an additional estimated 0 to 145 lb/yr (73 lb/yr average) of phosphorus loading to the lake, representing 0% to 80%, respectively, of the total loading to the lake.

13.8.4 Phosphorus Load Summary

The total modeled phosphorus load to South Twin Lake is 110 lb/yr (Table 14).

Table 86. South Twin Lake Phosphorus Source Summary, Existing Loads

Phosphorus Source	Phosphorus Load (lb/yr)
Watershed	22
Atmospheric	15
Internal	73
Total	**110**

13.9 TMDL Loading Capacity and Allocations

The phosphorus loading capacity of South Twin Lake is 99 lb/yr, to be split among allocations according to Table 87. To meet the TMDL, the total load to the lake needs to be reduced by 21 lb/yr. The allocations assume a watershed load reduction of 11 lb/yr (50%).

The City of Stillwater's regulated MS4 WLA also requires a 50% reduction in watershed load from applicable land uses; Figure 128 illustrates the City of Stillwater's regulated MS4 land areas based on the methods described in Section 3.1.1.

Watershed scale pollutant load modeling was conducted and analyzed on an annual basis to establish this TMDL at a level necessary to attain and maintain applicable water quality standards. Daily wasteload allocations were derived from this analysis.

Table 87. South Twin Lake Existing Loads, TMDL Allocations, and Reductions Needed

Load Component	TP Existing	TP TMDL Allocation		TP Reduction	
	lb/yr	lb/yr	lb/day	lb/yr	%
WLA					
Construction stormwater (permit #MNR100001)	0.060	0.060	0.00016	0	0%
Industrial stormwater (permit # MNR50000)	0.060	0.060	0.00016	0	0%
MS4 stormwater, Stillwater (permit #MNR040000)	6.0	3.0	0.0082	3.0	50%
Total WLA	**6.1**	**3.1**	**0.00032**	**3.0**	**49%**
LA*					
Watershed	16	8.0	0.022	8.0	50%
Atmospheric	15	15	0.041	0	0%
Internal	73	63	0.17	10	14%
Total LA	***104***	***86***	**0.23**	***18***	**17%**
MOS	**--**	**10**	**0.027**	**--**	**--**
Total	***110***	***99***	***0.26***	***21*** ***	***19%***

*LA components are broken down for guidance in implementation planning; the LA should be considered categorical.

**21 lb/yr reduction takes into account MOS; 11 lb/yr reduction (=21-MOS) needed to reach total loading capacity

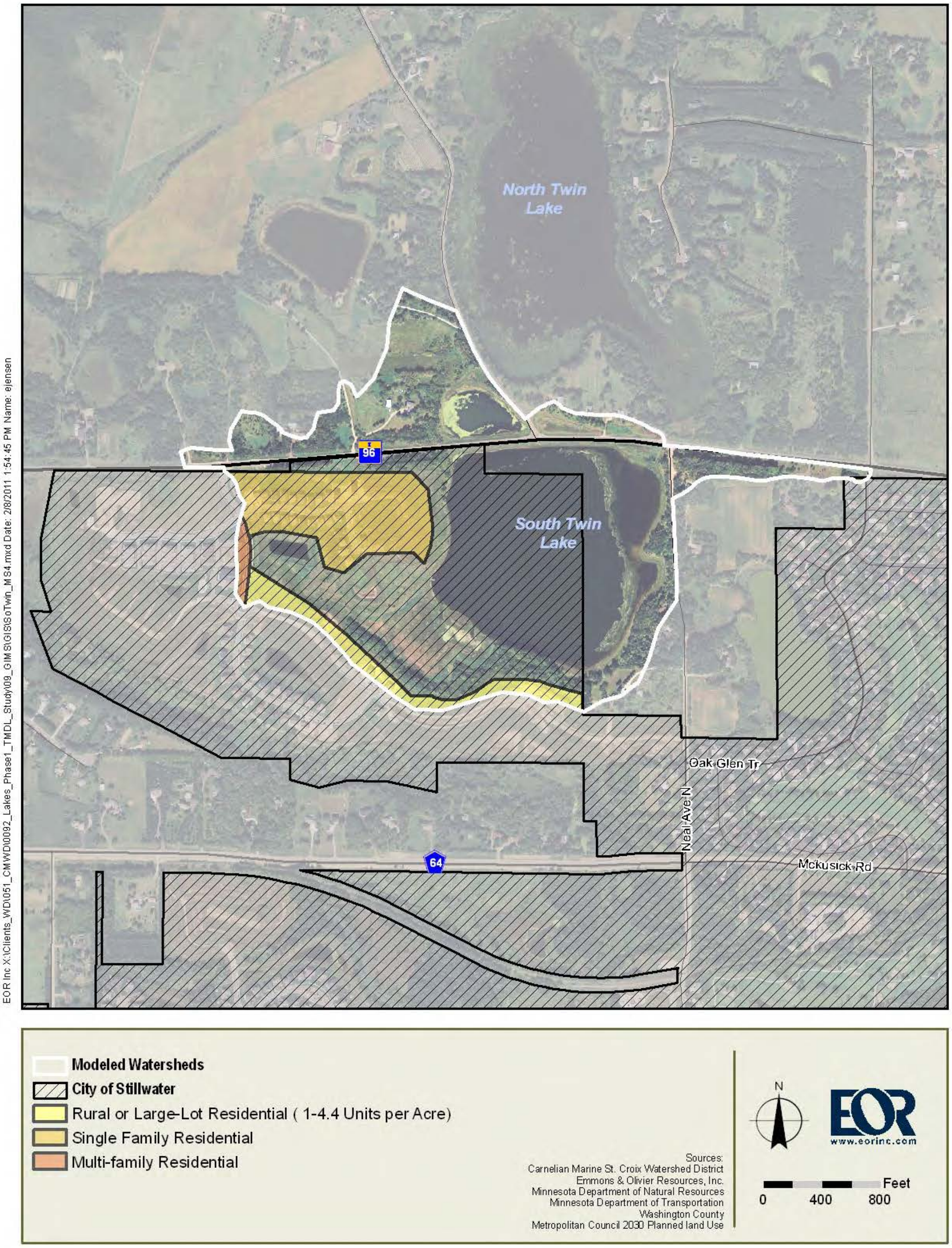

Figure 128. City of Stillwater's Regulated MS4 Land Areas Requiring a 50% reduction in Phosphorus Load to South Twin Lake

A GIS shapefile (Stillwater_MS4_regulated_land_uses_2030_SouthTwinLk) that delineates the regulated areas identified in this figure accompanies this report.

14.1 Seasonal Variation

In-lake water quality varies seasonally. In Minnesota lakes, the majority of the watershed phosphorus load often enters the lake during the spring. During the growing season months (June through September) in lakes, phosphorus concentrations may not change drastically if major runoff events do not occur. However, chlorophyll-*a* concentrations may still increase throughout the growing season due to warmer temperatures fostering higher algal growth rates. In shallow lakes, the phosphorus concentration more frequently increases throughout the growing season due to the additional phosphorus load from internal sources. This can lead to even greater increases in chlorophyll-*a* since not only is there more phosphorus but temperatures are also higher.

Some of these patterns are seen in the CMSCWD lakes. In all lakes, the highest monthly chlorophyll-*a* means across the ten years (1999-2008) of data occur in either August or September (Figure 129). This seasonal variation is taken into account in the TMDL by using the eutrophication standards, which are based on growing season averages, as the TMDL goals. The eutrophication standards were set with seasonal variability in mind. 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).

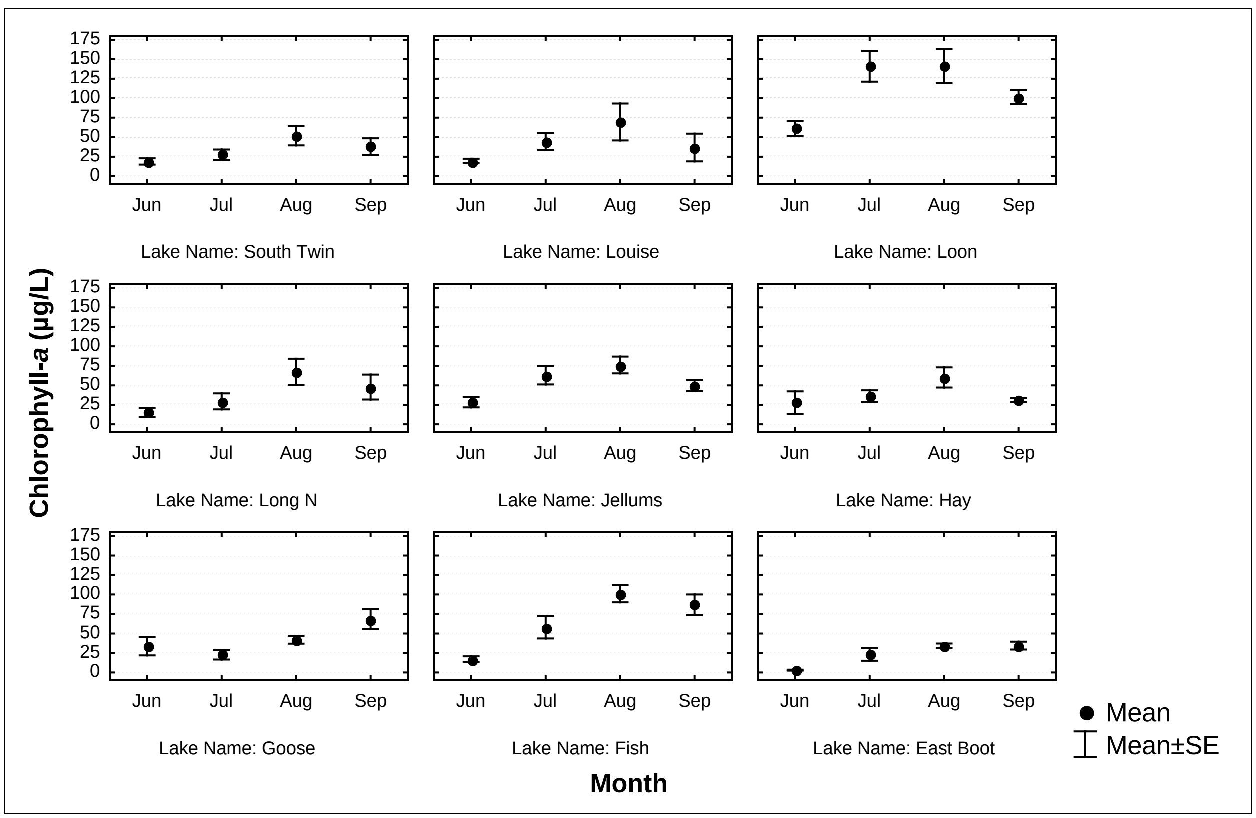

Figure 129. Seasonal Variation in Chlorophyll-*a*, Averaged over 1999-2008

14.2 Critical Conditions

Critical conditions in these lakes occur during the growing season, which is when the lakes are used for aquatic recreation. Similar to the manner in which the standards take into account seasonal variation, since the TMDL is based on growing season averages, the critical condition is covered by the TMDL.

15 MONITORING PLAN

15.1 Lake Monitoring

An adaptive approach to watershed management requires ongoing monitoring to assess the effectiveness and impact of BMPs on water quality. The CMSCWD will continue the existing water monitoring program on all lakes, which includes the collection of surface water quality samples, temperature and dissolved oxygen profiles, pH, and transparency on a monthly or semi-monthly basis from April though October. Water samples are to be analyzed for total phosphorus, total Kjeldahl nitrogen, and chlorophyll-*a*. For those lakes that thermally stratify, water quality samples should be collected from the hypolimnion on a monthly or semimonthly basis from May through September and analyzed for total phosphorus, dissolved orthophosphate, and iron, in order to evaluate the extent of internal loading. Planktonic samples should be collected monthly from May through September.

Existing baseline data is important when considering water quality trends and it is preferential to have at a minimum five to seven consecutive years of data, within the last ten to twelve years, for any lake. Monitoring of lakes that already have a sufficient dataset can be delayed until implementation has begun. Lakes that do not have a sufficient dataset should continue to be monitored until they have the minimum five to seven consecutive years of data. This will allow for a more efficient monitoring plan and help to create a scheduled approach for multiple lake monitoring.

After implementation activities have been initiated, in-lake monitoring should continue throughout the implementation period until water quality standards are met. Ideally, three consecutive years of monitoring should occur, followed by two to three years when monitoring is not conducted, followed by another round of three consecutive years of monitoring, and so on. This approach will allow for multiple lakes to be monitored on alternating schedules.

Macrophyte surveys should be conducted once in the spring and once in mid-summer on all lakes every five years. For lakes that have active management of macrophytes, surveys should occur more often after management practices occur.

For those lakes that are not actively used as DNR rearing ponds, fish surveys should be conducted once every five years to gather data on fish population abundance, size distribution, and year class strength in order to evaluate management activities.

15.2 BMP Monitoring

On-site monitoring of implementation practices should also take place in order to better assess BMP effectiveness. A variety of criteria such as land use, soil type, and other watershed characteristics, as well as monitoring feasibility, will be used to determine which BMPs to monitor. Under these criteria, monitoring of a specific type of implementation practice can be accomplished at one site but can be applied to similar practices under similar criteria and scenarios. Effectiveness of other BMPs can be extrapolated based on monitoring results.

16.1 Adaptive Implementation Framework

The foundation for successful implementation of watershed protection and TMDLs is rooted in an adaptive approach to watershed management that uses science to drive implementation. With a focus on implementation and receiving water benefits, this cyclical process is referred to as adaptive implementation and the components are shown in Figure 130.

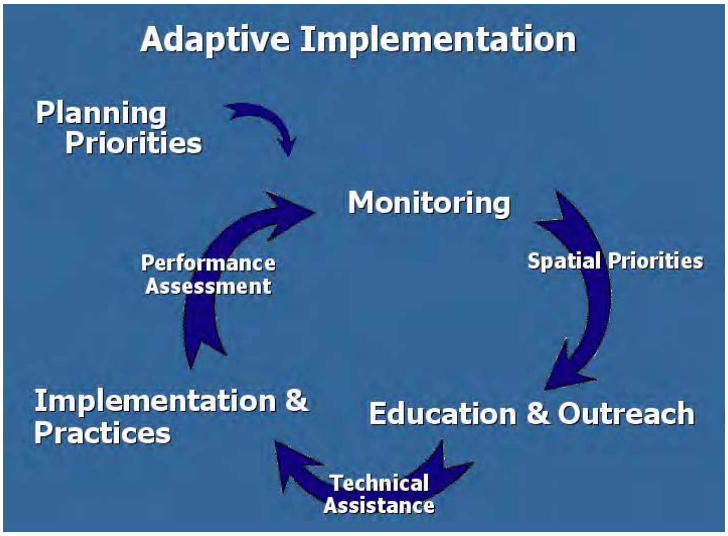

Figure 130. Adaptive implementation

Planning Priorities set the scope and type of activities needed to achieve watershed goals – The TMDL and load reductions set the stage for all of the activities below.

Monitoring (supplemented by modeling) drives prioritization.

ê

Prioritization focuses outreach, technical assistance, and implementation activities

ê

Outreach and technical assistance drives demand for implementation of practices

ê

Implementation of priority practices and programs results in environmental benefits

ê

Assessment of implementation activities informs future monitoring, priorities, and implementation activities

All components of adaptive implementation are directed toward implementation and positive environmental outcomes. The planning priorities stem from the TMDL report itself, which outlines pollutant load reduction goals. The foundation for adaptive implementation is based in an understanding of the receiving waters and requires a strategic monitoring regime.

16.1.1 Monitoring Program

A successful monitoring program identifies water quality trends and issues and assists with focusing implementation efforts. The CMSCWD currently monitors all of the lakes within this TMDL. See *Section 15: Monitoring Plan*.

16.1.2 Spatial Priorities: Watershed-wide BMP Prioritization and Subwatershed Assessments

A variety of tools and techniques exists to identify and prioritize locations in the watershed to implement best management practices. Recognition that there are multiple scales of prioritization is important. Larger-scale prioritization is used to identify priority areas for more focused assessment efforts. Modeling, monitoring, and prioritization criteria are all viable techniques for the first stage of prioritization. Focused assessments include a combination of modeling and field work. Implementation of a prioritized approach will occur for each of the impaired subwatersheds. Prioritization efforts will also focus the location and extent of education and outreach efforts.

16.1.3 Education, Outreach, and Technical Assistance

Education can be used to build awareness and support for watershed management as well as direct implementation efforts and result in measurable water quality benefits. There is a diverse range of educational activities that can build upon each other.

CMSCWD participates in the East Metro Water Resource Education Program (EMWREP), a collaboration of multiple watershed organizations, municipalities, WCD, and Washington County. EMWREP targets multiple audiences and includes activities such as newspaper articles, Blue Thumb workshops, and Stormwater U trainings. Additionally, CMSCWD staff and board members work to educate the residents of the watersheds about ways to clean up their lakes. Continued involvement in these and other educational activities is anticipated in order to motivate more citizens to become involved and to request technical assistance.

16.1.4 Technical Assistance

Individual assistance is designed to support design, implementation, and maintenance of management practices. Technical assistance also serves as one-on-one education and training (e.g. site visits with landowners). Technical assistance offerings must be paired with public education and outreach, commercial marketing, and social marketing approaches to motivate individuals to seek available assistance, such as voluntary cost-share assistance programs discussed below.

Technical assistance is provided by a variety of entities, including but not limited to the CMSCWD, WCD, and NRCS.

16.1.5 Implementation

Implementation in an adaptive and prioritized program involves identification of many implementation activities. The following are the six major implementation categories for a typical phosphorus-based TMDL:

- Regulation
- New development standards
- Redevelopment standards
- Public projects
- Private projects
- Municipal operation and maintenance
- Education

The percent load reduction expected from each category should be identified and varies based on many factors, such as the TMDL pollutant of concern, landscape characteristics, dynamics of the resource in question, and even demographics. The specific level of activity for each category for each of the lakes assessed in this TMDL will be detailed in the TMDL implementation plan. The following provides discussion on each of the implementation categories, and Table 88 summarizes the issues of each lake and the applicability of each of the implementation categories to each lake.

16.1.6 Performance Assessment

In addition to monitoring the impaired water bodies, assessment of the performance of implementation activities is needed to gauge success over time. Performance assessment can occur at multiple scales, depending on the data requirements, and includes the following:

- Subwatershed/catchment monitoring – pre- and post-BMP installation
- Site level monitoring – pre- and post-BMP installation
- BMP performance monitoring/assessment (see Section 15.2)

Table 88. Loading Issues Summary

Lake	Dominant Land Covers	Primary Load Sources and Issues	Internal Load Reduction Needed (lb/yr)	Watershed Load Reduction Needed (lb/yr)	Percentage of Watershed Load Reduction by Implementation Category						
					Regulations	New development standards	Redevelopment standards	Public projects	Private projects	Municipal O&M	Education
East Boot	Ag 20% Park 17% Undeveloped 55%	Inlake Feedlot 53% Stormwater 19%	4	23					100		*
Fish	Ag 27% Undeveloped 62%	Shallow – hypereutrophic Stormwater 73% Feedlots, unregistered	31	38					100		*
Goose	Ag 31% SFR 18% Undeveloped 45%	Inlake Stormwater 68% SSTS 19% Feedlots, unregistered	42	75		5		5	90		*
Hay	Ag 28% SFR 27% Undeveloped 35%	Very shallow lake Stormwater 67% SSTS 18% Feedlots, unregistered	15	31					100		*
Jellum's	Ag 36% Undeveloped 44%	Stormwater 57% Long Lake 19% Feedlots, unregistered	55	10					100		*
Long	Ag 32% Undeveloped 54%	Stormwater 66% SSTS 17% Feedlots, unregistered	8	26					100		*
Loon	Ag 33% Park 29% SFR 14% Undeveloped 19%	Inlake Shallow – hypereutrophic Stormwater 70% SSTS 18% Feedlots, unregistered	54	53					20		80
Louise	Ag 40% Park 12% Undeveloped 33%	Inlake Stormwater 67% SSTS 14% Feedlots, unregistered	33	25				10	90		*
Mud	Ag 44% Undeveloped 47%	Inlake Stormwater 60% SSTS 2% Feedlots, unregistered	16	13					100		*
South Twin	Ag 45% SFR 15% Undeveloped 39%	Inlake Stormwater 43% SSTS 16% Feedlots, unregistered	10	11				50	50		*

Implementation Timeline: 15-20 Years   * Important but difficult to quantify

16.2 Watershed vs. In-Lake Load Reduction

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.

Most of the lakes addressed in this study are shallow lakes. Shallow lakes tend to have alternative stable states: the clearwater, macrophyte-dominated phase and the turbid, phytoplankton-dominated phase. When restoring shallow lakes, the goal is to encourage the clearwater phase and prevent the lake from flipping back to the turbid phase. To do this, the first step is to reduce phosphorus loads from the watershed, which has resulted in accumulation of nutrients in the lakes. After the watershed phosphorus loads are reduced to levels that the lake can assimilate, an effort should be made to improve the in-lake dynamics, which may be necessary to achieve the clearwater state. However, if in-lake measures are undertaken before the watershed load is controlled, the lake's response may be short-lived, and the lake will not stabilize in the clearwater phase.

The following schematic was used to develop the implementation approach for each lake (Figure 131):

> <u>Step 1: Reduce watershed phosphorus loads.</u>
> Where possible, eliminate watershed phosphorus loading hot spots. Reduce watershed phosphorus loading watershed-wide, using best management practices where feasible. Evaluation of watershed phosphorus loading is based on the land use data and the phosphorus source inventory.
>
> <u>Step 2: Address in-lake dynamics to reduce internal loading and stabilize the clearwater phase.</u>
> For some lakes, Step 1 may be sufficient to return the lake to meeting water quality standards. In this case, in-lake action will not be necessary to meet the TMDL. However, recommendations will still be made in the implementation strategy with the goal of stabilizing the lake in the clearwater phase. These recommendations can be undertaken by the implementation partners depending on the water quality goals of the local partners and as opportunities arise.
>
> For other lakes, the implementation actions recommended in Step 2 will be necessary in order to return the lake to meeting water quality standards. In this case, a weight of evidence approach is used (described below in Section 17.2) to identify the practices that should be considered. When attempting to switch a lake to the clearwater phase and/or to stabilize it in the clearwater phase, the in-lake dynamics must be addressed from multiple angles. Often, if only one approach is taken, the desired changes do not result. For example, if a lake has high densities of curly-leaf pondweed and does not support a viable seed bed of native plants, herbicide treatment of curly-leaf pondweed may result in higher chlorophyll concentrations as the phosphorus in the lake is taken up by algae and not by rooted macrophytes. In that case, other approaches would need to be taken to

encourage the re-establishment of native vegetation after the curly-leaf pondweed herbicide treatment.

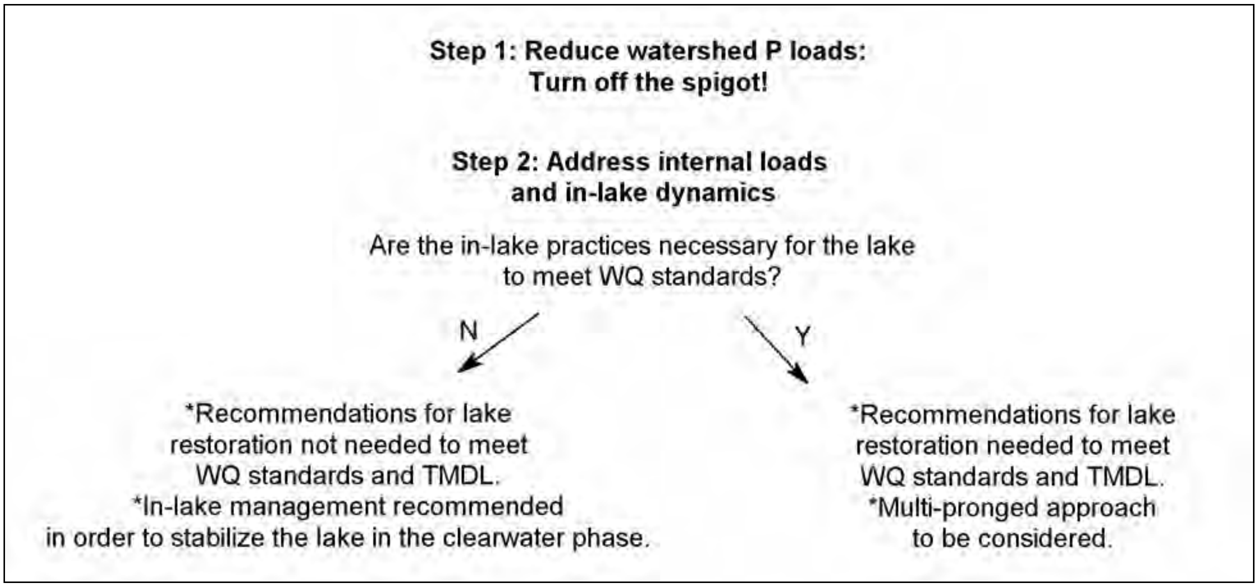

Figure 131. Implementation approach

Based on the above approach, a phosphorus reduction scenario for each lake was developed to identify the load reductions needed from watershed and internal loads in order to meet the TMDL loading goal. For all lakes, atmospheric sources of phosphorus are assumed to remain unchanged under the phosphorus reduction (TMDL) scenario. The reduction scenarios should be used as guidance for the project partners and will be further refined in the implementation plan that will be developed subsequent to this report.

The water quality evaluation for the lakes was completed using data from 1999 through 2008 for all lakes except for Mud Lake, and 2010 for Mud Lake. Practices implemented after 2008 (2010 for Mud Lake) will be considered to be part of the TMDL implementation activities and can be applied to load reduction goals.

16.3 Overview of Management Strategies

16.3.1 Watershed Management Strategies

See Section 16.1.5 and Table 88.

16.3.2 In-Lake Management Strategies

A majority of the phosphorus loading in the study area can be attributed to runoff, which ends up in lakes. Once the runoff gets into the lake, some of the phosphorus is directly available for algae and plant uptake, while another portion, bound to soil particles present in the watershed runoff, settles to the lake bottom and can be recycled to a form that can be used for algal and plant growth at a later date. Decaying algae also falls out of the water column and is deposited on the lake bottom, where it becomes another source of phosphorus that can be recycled back into the water column.

Over time, a considerable amount of phosphorus can accumulate in the bottom sediment of a lake. This phosphorus can be recycled back to the water through a variety of processes. Low oxygen conditions at the sediment-water interface can lead to the release of dissolved phosphorus into the water column. Insect larvae, bottom feeding fishes, wave action, and disturbance from boats can physically stir and resuspend phosphorus-bound sediment into the water. Plants can also recycle sediment phosphorus by taking it up through their roots and then releasing it into the water column as they decay.

In many of the lakes, a substantial portion of the total load to the lakes is from internal sources. It will be necessary to control the internal loading in order to achieve water quality standards. Internal loading control techniques are those that are conducted in the lake itself and may include physical, chemical, and biological components. No single management practice or approach will resolve the problem of internal loading. The following is a description of internal loading control techniques recommended for the lakes in the study area.

Aquatic Plant Management

Shallow lakes depend on the aquatic macrophyte community to provide refuge for zooplankton and fish and maintain a healthy lake. Invasive aquatic plant species can increase phosphorus recycling within a lake and harm ecosystems. Once introduced, invasive species can spread to new areas and can rarely be eliminated.

Curly-leaf pondweed is an invasive aquatic macrophyte that dies back in mid-summer and releases phosphorus into the water column that is then available for algal growth. This plant has a competitive advantage over many of the native aquatic plant species because it starts to grow well before ice-out, outcompeting the other plants by becoming established before them and limiting their access to light. When native plants are present in a lake, they may become established later in the growing season, after the die-off of curly-leaf pondweed. If native plants are not present, the lake may remain devoid of aquatic plants for the remainder of the season. Alternatively, other invasives, such as Eurasian watermilfoil, can become even more established in years following treatment of curly-leaf pondweed.

Herbicide treatments are commonly used for control when stands are for the most part a monoculture. Early spring application, in April or when water temperatures reach 50 to 55˚F, is effective for the invasives and minimizes effects on native species since they are generally not growing yet.

Control of curly-leaf pondweed does not always lead to an improvement in water quality, as measured by transparency. This may be because other plants are not able to establish themselves and stabilize the lake in a clear-water state. It may also be because the reduction in phosphorus loading to the lake is not enough to translate into reductions in chlorophyll. The state of the knowledge of curly-leaf pondweed treatment is still developing, and definitive recommendations often can not be made.

If undertaking a curly-leaf pondweed treatment program, the following should be considered:

- In lakes with dense curly-leaf pondweed, there are often no other aquatic macrophytes present. There are many reasons for this, including use of herbicides, abundance of rough fish (which can cause uprooting of vegetation), lack of a viable seed bed, wind mixing, and sedimentation within the lake. The establishment of a healthy macrophyte community may require an evaluation of the seed bed to ensure adequate viability, and analysis of alternatives to establish macrophytes, including lake drawdown, fish management, and transplanting of vegetation. Establishing a healthy macrophyte community will require education of the shoreland owners and other stakeholders as well as costs associated with implementation.
- Treatment of curly-leaf pondweed should be considered in conjunction with other methods to improve water clarity and control phosphorus loading. Treatment can be followed by an alum treatment, with the goal of increasing short-term water clarity to allow the re-establishment of native plants.
- As with other approaches to control internal loading, watershed phosphorus loads should be controlled before in-lake management is undertaken. Maintaining a stable clear-water state in a shallow lake is more feasible if the external loads have first been controlled.

Fish Management

The typical lake biological community consists of a broad base of primary producers (plants and algae) and consumers (animals). The primary producers support overlying levels of consumers, including herbivores (such as zooplankton), planktivores (which eat zooplankton), and much smaller numbers of piscivores (which eat other fish). Benthic organisms are consumers that live in, on, or near the lake bottom and forage in/near the sediments. Consumers often shift trophic levels throughout their life cycle. Water quality can be affected if there is a disproportionate amount of any one of these biological communities.

Biomanipulation is the practice of undergoing lake improvement procedures that alter the food web to favor grazing on algae by zooplankton, or that eliminate fish species that disturb the bottom sediments. Biomanipulation can involve eliminating certain fish species or restructuring the fish community to favor a balance that allows sufficient survival of zooplankton.

Benthic fish management is one type of biomanipulation. Typical benthivore species include carp, buffalo, freshwater drum, black bullhead, and white sucker. An over abundance of these fish species can degrade water quality by stirring up the lake sediment and re-suspending sediment and phosphorus. One management strategy is to install fish barriers on a lake inlet and/or outlet, which prevents fish migration into areas of concern, coupled with a fish kill. Another management technique is to remove these species by conducting a water level drawdown, netting, or treating the lake with rotenone. Benthic fish removal typically occurs after fish barriers are constructed.

Zooplanktivore management is another type of biomanipulation. Overpopulation of zooplanktivores (such as crappie, sunfish, and perch) within a lake is a common problem because they can over-graze the zooplankton community, which causes increases in algal density. Reductions in densities of zooplanktivorous fish can be accomplished by adding predatory fish, conducting a water level drawdown, chemical (e.g. rotenone) treatment, and/or trapping.

Phosphorus Inactivation

Aluminum sulfate (alum) is a chemical addition that binds with phosphorus to form a non-toxic precipitate, or floc. Alum reduces internal loading by binding with phosphorus and preventing its release, thereby forming a type of barrier between lake sediments and the water. In-lake alum treatments are often proposed to treat the deepest area of a lake and are not typically effective in shallow lakes or lakes that do not stratify. Alum treatments are only effective after external phosphorus inputs are significantly reduced, benthic fish have been removed, and fish barriers are installed to prevent their re-introduction.

Lake Drawdown

Drawdowns lower water levels in a lake in order to improve water quality and aquatic habitat. Lowering the water level in the winter exposes the sediment to both freezing and loss of water. A drawdown of lake levels can improve a lake's littoral vegetation through aeration of the sediments to allow the germination of certain native plant seeds; winter freeze-out of curly-leaf pondweed turions (dormant vegetative propagules); consolidation of the sediments to improve the sediment's ability to support rooted macrophytes; and promotion of oxygenation and consolidation of organic debris.

Summer drawdowns expose and consolidate the sediments, enhance conditions for the growth of perennial emergent species of aquatic vegetation, and consolidate the undesirable fish species for more efficient removal.

17 IMPLEMENTATION ACTIVITIES

This section describes the specific implementation strategies selected for each lake.

17.1 Approach to Determining Watershed Management Strategies

The watershed phosphorus loading estimates in this study were determined based on the Simple Method (also called the Rational Method), which expresses the relative watershed load. The adaptive implementation approach used here is outlined in Section 16 and will serve as the foundation for watershed management strategies. Evaluation of load reduction benefits from specific activities will be based on the models that were used to develop the TMDL. If different models are used, then the load reduction benefit associated with the proposed practice can not be compared to the load reductions identified in the TMDL study for each lake. Additionally, if different approaches are used to evaluate different types of practices, the load reduction benefits afforded by each practice can not be compared to one another to evaluate costs and benefits for prioritization purposes.

To facilitate evaluation of load reduction benefits, results of the watershed phosphorus loading model are reported as a GIS shapefile (*PhosLoad_2011LakesTMDL.shp*) and provided as a deliverable with this report. The GIS shapefile identifies phosphorus loading to each lake throughout its direct watershed (the area excluding upstream lakes and their watersheds); it includes direct watershed runoff based on land cover and land use and runoff from feedlots (see *Direct Watershed Runoff* and *Runoff from Feedlots Not Requiring NPDES Permit Coverage*, respectively, in *Section 3.1.2 Sources of Phosphorus Not Requiring NPDES Permit Coverage*, which begins on page 27). Data in *PhosLoad_2011LakesTMDL.shp* can be clipped to drainage areas of proposed management practices to provide the estimated total phosphorus load to that management practice. Other models (e.g. PondNet, P8, literature values) can then be used to estimate the phosphorus reduction of the practice.

Loading from subsurface sewage treatment systems (SSTS) and upstream waters are not included in *PhosLoad_2011LakesTMDL.shp*. If a proposed practice addresses loads from a failing septic system within 500 feet of the impaired lake, 1.2 lb/yr of phosphorus should be credited for each failing system that is upgraded and can be considered to be conforming.

Watersheds of two impaired lakes, East Boot and Jellum's Bay, include upstream lakes and their watersheds. The upstream lakes and their watersheds were not incorporated into the watershed load GIS tool. The following should be used to evaluate watershed management practices proposed in the watersheds of the upstream lakes:

- East Boot Lake: West Boot Lake flows into East Boot Lake. The watershed reductions needed to meet the TMDL goals will come from agricultural practices within the direct watershed of East Boot Lake; therefore practices implemented in the watershed of West Boot Lake will not count toward meeting the TMDL.
- Jellum's Bay: Long Lake, which is also impaired, flows into Jellum's Bay. Practices being evaluated for the Long Lake watershed should be considered with respect to the Long Lake TMDL and not for the Jellum's Bay TMDL. If enough practices are completed in the Long

Lake watershed such that Long Lake meets the water quality standards, then a credit of 5 lb/year can be applied to the accounting of the Jellum's Bay TMDL (Sections 17.3.5 and 17.3.6).

Unregistered feedlots were not explicitly accounted for in watershed modeling. If a proposed practice addresses runoff from an unregistered feedlot that had been contributing runoff to one of the impaired lakes, the following approach should be used to credit the proposed practice. Loading from the unregistered feedlot will be based on the number of animal units (AU), phosphorus production rate via animal manure, and a delivery factor that estimates how much of the phosphorus produced is actually delivered to surface waters under average flow conditions. For each animal type, the number of animals is multiplied by each of these three factors to obtain the estimated phosphorus load to surface waters (Equation 1). Table 89 lists the multiplication factors by animal type.

Phosphorus load from unregistered feedlot animals of a single type (lb/yr) = number of animals (# animals) x animal unit factor (AU/animal) x phosphorus production rate (lb P/AU-yr) x delivery factor (unitless)

Equation 1

Table 89. Unregistered Feedlot Estimates of Phosphorus Load

Animal Type	Animal Unit Factor* (#AU/#animal)	Phosphorus Production Rate (lb P/AU-yr)**	Delivery Factor (unitless)***
Dairy cow over 1,000 pounds	1.4	69.9	0.0056
Dairy cow under 1,000 pounds	1.0		
Dairy heifer	0.7		
Dairy calf	0.2		
Beef slaughter steer or stock cow	1.0	63.9	
Beef feeder cattle or heifer	0.7		
Beef cow and calf pair	1.2		
Beef calf	0.2		
Swine over 300 pounds	0.4	67.1	
Swine between 55 and 300 pounds	0.3		
Swine under 55 pounds	0.05		
Horse	1.0	21.9	
Sheep and lambs	0.1	73.0	
Chicken: laying hen or broiler (liquid manure system)	0.033	80.4	
Chicken over 5 pounds (dry manure system)	0.005		
Chicken under 5 pounds (dry manure system)	0.003		
Turkey over 5 pounds	0.018		
Turkey under 5 pounds	0.005		
Ducks	0.01		
Goats	0.15	37.8	
Other animal	Average weight of the animal in pounds divided by 1,000 pounds		

*Source: Adapted from MDA 2011.
**Source: Adapted from MWPS 2004.
***Source: Adapted from MPCA 2004.

To meet the WLA for construction stormwater, construction stormwater activities are required to meet the conditions of the 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.

To meet the WLA for industrial stormwater, industrial stormwater activities are required to meet the conditions of the industrial stormwater general permit or Nonmetallic Mining and Associated Activities general permit (MNG49) under the NPDES program and properly select, install, and maintain all BMPs required under the permit.

17.2 Approach to Determining In-Lake Management Strategies

The TMDL was determined based on in-lake modeling using the lake response model Bathtub, which does not, under normal use, explicitly represent internal loading. An average rate of internal loading is implicit in Bathtub since the model is based on empirical data, but this average rate is not reported by Bathtub. To represent internal loading in the load reduction scenarios, the average of the independent high and low internal loading estimates for each lake was used. Phosphorus reduction scenarios meet the TMDL by meeting the reduction in annual phosphorus load needed as calculated based on the TMDL.

To evaluate whether or not internal loading should be a focus of implementation activities for each lake, the following internal loading risk factors were considered and are presented in Table 90:

- Substantial underprediction of the in-lake TP concentration in the uncalibrated Bathtub model (indicates that internal loading may be above and beyond the background levels represented in Bathtub)
- High modeled rates of phosphorus release from lake sediments
- Presence of curly-leaf pondweed
- Presence of bullhead
- Zooplankton community imbalance, where there is a low grazing capacity due to low densities of large Cladocera that are effective at grazing algae

Table 90. Internal Loading Risk Factors

Lake	Substantial Underprediction of In-Lake TP Concentration	High P Release Rate from Sediments	Presence of Curly-Leaf Pondweed	Known Presence of Bullhead	Zooplankton Community Imbalance
East Boot		ü	ü	ü	ü
Fish	ü				ü
Goose			ü (few)	ü	ü
Hay					ü
Jellum’s	ü				
Long					
Loon	ü	ü		ü	ü
Louise	ü	ü	ü		
Mud	ü			ü	no data
South Twin	ü		ü		

17.3 Individual Lake Approaches

17.3.1 East Boot Lake

To meet the TMDL, taking into account the MOS, total loading to the lake needs to be reduced by 27 lb/yr, or 14% (Table 91). Private practices in the agricultural land uses in the watershed will be the primary mechanism for reducing watershed loads; education will also play a role. Fish management and curly-leaf pondweed management are the main strategies to reduce internal loading in East Boot Lake. To improve the chances of success of in-lake management, reductions in watershed loading should first be completed. While East Boot Lake is not classified as a shallow lake according the MPCA's definition, 50% of the lake is less than 15 feet deep, and many shallow lake management practices apply.

Table 91. East Boot Lake Phosphorus Reduction Summary

Phosphorus Source	Existing Annual TP Load (lb/yr)	Implementation Scenario Annual TP Load (lb/yr)	Load Reduction Needed (lb/yr)	Percent Reduction (%)
Watershed	47	24	23	49%
Atmospheric Deposition	12	12	0	0%
Internal	134	130	4	3.0%
Total	**193**	**166**	**27**	**14%**

Watershed

See Section 16.1.5 and Table 88.

In-Lake

Fish Management

In late summer, TP and chlorophyll concentrations increase at the same time that large zooplankton decrease in abundance and less edible zooplankton increase in abundance, suggesting an effect of high planktivory on the plankton community. The presence at very low densities of the large copepod *Diaptomus* and two species of large cladoceran *Daphnia* indicate the potential for zooplankton grazing to be improved.

The implementation plan will address fish and zooplankton management. The goal will be to prevent summertime crashes in the population densities of cladocera.

Curly-leaf Pondweed Management

Curly-leaf pondweed was abundant in the majority of the lake in June 2008 (Figure 8). Native species were prevalent in the lake later on in the season, suggesting that control of curly-leaf pondweed could lead to the establishment of native species earlier in the growing season. A curly-leaf pondweed management program should be initiated and growth of native plant species in the shallow portions of the lake should be encouraged.

17.3.2 Fish Lake

To meet the TMDL, taking into account the MOS, total loading to the lake needs to be reduced by 69 lb/yr, or 33% (Table 92). Watershed load should be reduced by approximately 50% and internal load by approximately 27%. Private projects in the watershed will be the primary mechanism for reducing watershed loads; education will also play a role. Fish management is the main strategy to reduce internal loading in Fish Lake. To improve the chances of success of fisheries management, reductions in watershed loading should first be completed.

Table 92. Fish Lake Phosphorus Reduction Summary

Phosphorus Source	Existing Annual TP Load (lb/yr)	Implementation Scenario Annual TP Load (lb/yr)	Load Reduction Needed (lb/yr)	Percent Reduction (%)
Watershed	76	38	38	50%
Atmospheric Deposition	17	17	0	0%
Internal	113	82	31	27%
Total	**206**	**137**	**69**	**33%**

Watershed

See Section 16.1.5 and Table 88.

In-Lake

Fish Management

The cycling of the zooplankton community indicates planktivory and a reduction in grazing capacity. This is particularly evident in the early presence followed by the total absence of large species like *Diaptomus* and *Daphnia*, which are common fish food. A late-summer recovery by *Daphnia* shows the potential for better grazer representation in the zooplankton community.

The implementation plan will address fish and zooplankton management. The goal will be to prevent summer crashes in the population densities of cladocera.

17.3.3 Goose Lake

To meet the TMDL, total loading to the lake needs to be reduced by 117 lb/yr, or 34% (Table 93). Watershed load should be reduced by approximately 50% and internal load by approximately 25%. Private projects in the watershed (including a potential ravine stabilization) will be the primary mechanism for reducing watershed loads; public projects, new development standards, and education will also play a role. Fish and curly-leaf pondweed management are the main strategies to reduce internal loading in Goose Lake. To improve the chances of success of in-lake management, reductions in watershed loading should first be completed. While Goose Lake is not classified as a shallow lake according the MPCA's definition, over 60% of the lake is less than 15 feet deep, and many shallow lake management practices apply.

Table 93. Goose Lake Phosphorus Reduction Summary

Phosphorus Source	Existing Annual TP Load (lb/yr)	Implementation Scenario Annual TP Load (lb/yr)	Load Reduction Needed (lb/yr)	Percent Reduction (%)
Watershed	152	77	75	50%
Atmospheric Deposition	23	23	0	0%
Internal	171	129	42	25%
Total	**346**	**229**	**117**	**34%**

Watershed

See Section 16.1.5 and Table 88.

In-Lake

Fish Management

Bluegill and black bullhead were the most abundant fish species observed in 2005. Under the high densities observed, bluegill can be benthivorous, foraging in the bottom sediments similar to black bullhead. This action can increase internal loading through physical disturbance of the bottom sediments. More recent anecdotal evidence suggests that black bullhead and bluegill are not overabundant anymore.

Zooplankton community data indicate a poor grazing capacity: the rapid decline of a large copepod in July, the dominance of rotifers later in the growing season, a late summer bloom of *Chlamydomonas*, and an overall low representation of cladocera.

The implementation plan will address fish and zooplankton management. The goal will be to increase densities of cladocera and other large zooplankton.

Curly-leaf Pondweed Management

Curly-leaf pondweed was observed in the June survey in scattered patches in shallow water near the shore of the lake (Figure 41). While not abundant, the existence of curly-leaf pondweed indicates the potential for future increases in abundance and increases in internal loading as a result of summer die-off. A curly-leaf pondweed management program should be initiated to prevent the spread of curly-leaf pondweed.

17.3.4 Hay Lake

To meet the TMDL, total loading to the lake needs to be reduced by 46 lb/yr, or 34% (Table 94). Watershed load should be reduced by approximately 49% and internal load by approximately 24%. Private projects in the watershed will be the primary mechanism for reducing watershed loads; education will also play a role. Fish management is the main strategy to reduce internal loading in Hay Lake. To improve the chances of success of in-lake management, reductions in watershed loading should first be completed.

Table 94. Hay Lake Phosphorus Reduction Summary

Phosphorus Source	Existing Annual TP Load (lb/yr)	Implementation Scenario Annual TP Load (lb/yr)	Load Reduction Needed (lb/yr)	Percent Reduction (%)
Watershed	63	32	31	49%
Atmospheric Deposition	11	11	0	0%
Internal	63	48	15	24%
Total	**137**	**91**	**46**	**34%**

Watershed

See Section 16.1.5 and Table 88.

In-Lake

Fish Management
The zooplankton community has low grazing capacity due to the lack of cladocera and larger copepods.

The implementation plan will address fish and zooplankton management. The goal will be to increase densities of cladocera and other large zooplankton. The first step will be to complete a fish survey of the lake.

17.3.5 Jellum's Bay

Long Lake is upstream of Jellum's Bay. Phosphorus load from Long Lake was accounted for in Jellum's Bay watershed loading calculations as described in *Loading from Upstream Waters* in Section 3.1.2. Since Long Lake is impaired, it contributes more phosphorus to Jellum's Bay than if it were not impaired. In order to evaluate the phosphorus reduction requirement to Jellum's Bay under a scenario where Long Lake is no longer impaired, watershed loading calculations and in-lake modeling were updated to reflect an in-lake Long Lake phosphorus concentration of 60 µg/L (the MPCA standard for Long Lake). Under this scenario, watershed loading to Jellum's Bay is decreased by 5 lb/yr, from 81 lb/yr to 76 lb/yr. This exercise does not account for the long-term beneficial effects on the in-lake phosphorus concentration in Jellum's Bay if Long Lake were to meet the standard for an extended period of time (i.e. lower internal loading rates in Jellum's Bay). In addition, in a restoration scenario Long Lake could exhibit in-lake phosphorus concentrations well below the standard, which was not accounted for in this exercise. Therefore, it is possible that the effects of a non-impaired Long Lake could be more beneficial to Jellum's Bay than is illustrated in this exercise.

Water quality data strongly suggest that the lake switched from a turbid, phytoplankton dominated phase to a clear-water, macrophyte dominated phase in 2007. The macrophyte data also support this. The periodic chemical treatments of the lake to remove all fish likely keep densities of planktivorous fish at moderate levels. The abundant bryozoan, an attached filter-feeder, also likely contributes to the relatively high transparency. The lake should be re-evaluated after 2011 to see if the positive trends in water quality seen since 2007 continue and if the lake should be removed from the impaired waters list.

To meet the TMDL, total loading to the lake needs to be reduced by 65 lb/yr, or 29% (Table 95). To stabilize the lake in the clearwater phase, watershed load should be reduced by approximately 13% and internal load by approximately 44%. If the lake is maintained in the clearwater phase, it can be assumed that the internal load reductions have occurred. Private projects in the watershed will be the primary mechanism for reducing watershed loads; education will also play a role. Fish management is the main strategy to reduce internal loading in Jellum's Bay. To improve the chances of success of in-lake management, reductions in watershed loading should first be completed.

Table 95. Jellum's Bay Phosphorus Reduction Summary

Phosphorus Source	Existing Annual TP Load (lb/yr)	Implementation Scenario Annual TP Load (lb/yr)	Load Reduction Needed (lb/yr)	Percent Reduction (%)
Watershed	81	71*	10	13%
Atmospheric Deposition	17	17	0	0%
Internal	124	69	55	44%
Total	**222**	**157**	**65**	**29%**

*If Long Lake achieves water quality standards, it would account for a 5 lb/yr TP reduction, and an additional 5 lb/yr reduction from the watershed would be desirable to help stabilize the lake in the clearwater phase.

<u>Watershed</u>

See Section 16.1.5 and Table 88.

<u>In-Lake</u>

Fish Management

Fish management should continue to emphasize control of planktivorous fish and the prevention of any increases in internal loads.

17.3.6 Long Lake

None of the internal loading risk factors were present in Long Lake (Table 90), and, from approximately 2005 through 2008, the water quality was improving. Data suggest that the lake may have been in a clearwater, macrophyte dominated phase in 2007, but that it switched to a turbid, phytoplankton dominated phase in either 2008 or 2009. Lake data should be evaluated to determine which phase the lake is in. If it remains in the clear-water phase, management should focus on preventing any stressors that could cause it to flip back to the turbid phase. Such stressors include watershed phosphorus loading, sediment disturbance, overgrazing on zooplankton by planktivorous fish, and disturbance of the aquatic vegetation.

If recent data show that the lake has flipped to the turbid phase, the stressor that led to the switch needs to be identified and addressed.

To meet the TMDL, total loading to the lake needs to be reduced by 34 lb/yr, or 25% (Table 96). To stabilize the lake in the clearwater phase, watershed load should be reduced by approximately 50%. Private projects in the watershed will be the primary mechanism for reducing watershed loads; education will also play a role. Minor in-lake practices will be necessary to meet the TMDL. If the lake is maintained in the clearwater phase, it can be assumed that the internal load reductions have occurred.

Table 96. Long Lake Phosphorus Reduction Summary

Phosphorus Source	Existing Annual TP Load (lb/yr)	Implementation Scenario Annual TP Load (lb/yr)	Load Reduction Needed (lb/yr)	Percent Reduction (%)
Watershed	52	26	26	50%
Atmospheric Deposition	11	11	0	0%
Internal	71	63	8	11%
Total	**134**	**100**	**34**	**25%**

Watershed

See Section 16.1.5 and Table 88.

17.3.7 Loon Lake

To meet the TMDL, total loading to the lake needs to be reduced by 107 lb/yr, or 32% (Table 97). Watershed load should be reduced by approximately 50% and internal load by approximately 26%. Education and private projects in the watershed will be the primary mechanisms for reducing watershed loads, and sediment disturbance management and fish management are the main strategies to reduce internal loading in Loon Lake. To improve the chances of success of in-lake management, reductions in watershed loading should first be completed.

Table 97. Loon Lake Phosphorus Reduction Summary

Phosphorus Source	Existing Annual TP Load (lb/yr)	Implementation Scenario Annual TP Load (lb/yr)	Load Reduction Needed (lb/yr)	Percent Reduction (%)
Watershed	107	54	53	50%
Atmospheric Deposition	14	14	0	0%
Internal	210	156	54	26%
Total	**331**	**224**	**107**	**32%**

Watershed

See Section 16.1.5 and Table 88.

In-Lake

Sediment Disturbance Management

Water skiing on the lake has the potential to disturb sediments and lead to higher rates of phosphorus release from the sediments into the water column. The CMSCWD should work with lake users to develop a plan to reduce sediment disturbance from water skiing.

Fish Management

There was a decoupling of TP and chlorophyll in 2008, along with cycles in the zooplankton community, suggesting that some of the chlorophyll blooms may be mediated by biological interactions. Bullhead were found to be abundant in a 1984 survey.

The implementation plan will address fish and zooplankton management. The goal will be to reduce population densities of bullhead and to increase densities of cladocera and other large zooplankton throughout the spring and summer. A fish survey should be completed to update the 1984 survey.

While addressing the biological interactions will be important, priority should be given to addressing watershed loads and lake sediment management.

17.3.8 Lake Louise

To meet the TMDL, total loading to the lake needs to be reduced by 58 lb/yr, or 26% (Table 98). Watershed load should be reduced by approximately 49% and internal load by approximately 21%. Private projects in the watershed will be the primary mechanism for reducing watershed loads; public projects and education will also play a role. Curly-leaf pondweed management is the main strategy to reduce internal loading in Lake Louise. To improve the chances of success of in-lake management, reductions in watershed loading should first be completed.

Table 98. Lake Louise Phosphorus Reduction Summary

Phosphorus Source	Existing Annual TP Load (lb/yr)	Implementation Scenario Annual TP Load (lb/yr)	Load Reduction Needed (lb/yr)	Percent Reduction (%)
Watershed	51	26	25	49%
Atmospheric Deposition	12	12	0	0%
Internal	158	125	33	21%
Total	**221**	**163**	**58**	**26%**

<u>Watershed</u>

See Section 16.1.5 and Table 88.

<u>In-Lake</u>

Curly-leaf Pondweed Management

Curly-leaf pondweed was observed throughout the lake in the June survey (Figure 99) and was observed in the August survey in a small area near the south shore of the lake. A curly-leaf pondweed management program should be initiated. Caution should be taken since there is not a diverse native macrophyte community in the lake, and control of curly-leaf pondweed may not necessarily lead to improvements in water clarity; a comprehensive program that includes efforts to re-establish the native macrophyte community should be undertaken.

Fish Management

Large populations of bluegill were observed during a DNR 2008 walleye harvest. However, there has not been a fish survey on the lake. In order to evaluate whether or not the fish community composition contributes to high algal biomass, the first step will be to complete a fish survey of the lake.

17.3.9 Mud Lake

To meet the TMDL, total loading to the lake needs to be reduced by 29 lb/yr, or 17% (Table 99). Watershed load should be reduced by approximately 48% and internal load by approximately 13%. Private projects in the watershed will be the primary mechanism for reducing watershed loads; education will also play a role. Vegetation enhancement and cattle exclusion are the main strategies to reduce internal loading in Mud Lake. To improve the chances of success of in-lake management, reductions in watershed loading should first be completed.

Table 99. Mud Lake Phosphorus Reduction Summary

Phosphorus Source	Existing Annual TP Load (lb/yr)	Implementation Scenario Annual TP Load (lb/yr)	Load Reduction Needed (lb/yr)	Percent Reduction (%)
Watershed	27	14	13	48%
Atmospheric Deposition	16	16	0	0%
Internal	127	111	16	13%
Total	**170**	**141**	**29**	**17%**

<u>Watershed</u>

See Section 16.1.5 and Table 88.

<u>In-Lake</u>

Shoreline vegetation should be enhanced, focusing on the west and south shores of the lake where the existing buffer is lacking. Emergent macrophytes around the perimeter of the lake can also be enhanced to provide greater ecological and water quality benefit.

Current rotational grazing practices permit cattle access to the lake during approximately 16 days of the year. Activity of cattle in the lake can stir up sediments, which releases phosphorus into the water column and disturbs rooted macrophytes, and can introduce additional nutrients through manure. Livestock exclusion would minimize this stressor to the lake.

A fish survey should be completed to provide information as to whether or not fish management should be undertaken.

17.3.10 South Twin Lake

To meet the TMDL, total loading to the lake needs to be reduced by 21 lb/yr, or 19% (Table 100). Public and private projects in the watershed will be the primary mechanism for reducing watershed loads; education will also play a role. Curly-leaf pondweed management is the main strategy to reduce internal loading in South Twin Lake. To improve the chances of success of in-lake management, reductions in watershed loading should first be completed.

Table 100. South Twin Lake Phosphorus Reduction Summary

Phosphorus Source	Existing Annual TP Load (lb/yr)	Implementation Scenario Annual TP Load (lb/yr)	Load Reduction Needed (lb/yr)	Percent Reduction (%)
Watershed	22	11	11	50%
Atmospheric Deposition	15	15	0	0%
Internal	73	63	10	14%
Total	**110**	**89**	**21**	**19%**

Watershed

See Section 16.1.5 and Table 88.

In-Lake

Curly-leaf Pondweed Management

Curly-leaf pondweed was observed throughout the lake in the June 2008 macrophyte survey (Figure 115). A curly-leaf pondweed management program should be initiated. Caution should be taken since there is not a diverse native macrophyte community in the lake, and control of curly-leaf pondweed may not necessarily lead to improvements in water clarity; a comprehensive program that includes efforts to re-establish the native macrophyte community should be undertaken.

17.4 Cost

The Clean Water Legacy Act requires that a TMDL include an overall approximation of the cost to implement a TMDL (MN Statutes 2007, section 114D.25). The initial estimate for implementing the CMSCWD Multi-Lakes TMDL is approximately $1,500,000 to $6,500,000. This estimate will be refined when the more detailed implementation plan is developed.

18 REASONABLE ASSURANCES

As part of an implementation strategy, reasonable assurances provide a level of confidence that the TMDL allocations will be implemented by federal, state, or local authorities. Implementation of the CMSCWD Multi-Lakes TMDL will be accomplished by both state and local action on many fronts, both regulatory and non-regulatory. Multiple entities in the watershed already work towards improving the lakes' water quality. Water quality restoration efforts will be led by the CMSCWD and the WCD. In addition, phosphorus reductions by point sources will be made through permit compliance.

18.1 Non-Regulatory

At the local level, CMSCWD and WCD currently implement programs targeted at water quality improvement and have been actively involved in projects to improve water quality in the past. It is anticipated that their involvement will continue. Potential state funding of TMDL implementation projects includes Clean Water Fund grants and Section 319 funding. At the federal level, funding can be provided through Section 319 grants that provide cost share dollars to implement activities in the watershed. Various other funding and cost-share sources exist, which will be listed in the CMSCWD Multi-Lakes TMDL Implementation Plan.

The implementation strategies described in this TMDL have demonstrated to be effective in reducing nutrient loadings to lakes. CMSCWD and WCD have programs in place to continue many of the recommended activities. Monitoring will continue and adaptive management will be in place to evaluate progress made towards achieving the beneficial use of each lake.

18.2 Regulatory

State implementation of the TMDL will be through action on NPDES permits for regulated stormwater (MS4 and construction activities). Appendix A of the Construction General Permit contains BMPs that must be implemented if a project is within one mile of an impaired water body. The DNR is currently updating the state's shoreland rules, which will apply to this TMDL once promulgated.

Washington County's current septic system ordinance is based on septic system inspection at the time of property transfer or installation of any new or replacement on-site sewage disposal system.

Washington Conservation District staffs a primary county feedlot contact for all of Washington County. Washington County is not an MPCA delegated partner with the State Feedlot Program and does not employ a County Feedlot Officer; MPCA provides field staff for feedlot permitting and compliance checks on all registered feedlots.

19 STAKEHOLDER PARTICIPATION

19.1 Stakeholder Meetings

19.1.1 Stakeholder Meeting 1

An initial stakeholder meeting was held on December 9, 2008. This meeting served as the project kick-off meeting. Meeting attendees included lakeshore residents, lake associations; state and local agency staff; municipal officials, the CMSCWD Board of Managers, and project team staff from the Washington Conservation District and Emmons & Olivier Resources, Inc. There were over 80 participants at this stakeholder meeting.

The meeting agenda included the following items:

- Your watershed
- What's the problem?
- Small group discussion
- Public input – help us find solutions
- Next steps

19.1.2 Stakeholder Meeting 2

A second stakeholder meeting was held on September 22, 2009, to review the status of the TMDL, present the findings of the phosphorus source inventory, and begin discussion on implementation strategies. The following twelve residents attended: Curt Eckman (Loon Lake), David Seely (Hay Lake), John Bower (Big Carnelian Lake), Diane Rohan (Long Lake, May Twp.), Lester Rydeen (Big Marine Lake), Rich Burton (Big Marine Lake), Larry Whitaker (St. Croix), Jessica Parcheta (Loon Lake), Pete Riehle (Loon Lake), Roeland Reyers (Loon Lake), Wendy Heck (Lake Louise), and Alan Downie (Lake Louise).

The meeting agenda included the following items:

- Intro and welcome
- Sources of phosphorus and lake ecology: external and internal P sources, lake ecology, reduction in P needed for four lakes
- Implementation: external and internal sources
- Small group breakout to discuss implementation ideas: What do you think about the identified phosphorus sources and biological issues (fisheries and plants)? What types of implementation activities make sense for your lake? Which ones do not make sense? Who should be responsible for implementation/lake clean-up?
- Final thank you and next steps

19.1.3 Stakeholder Meeting 3

A third stakeholder meeting was held on March 16, 2011. Participants were able to view TMDL summary sheets and discuss specifics of their interests with project staff. A short presentation included a summary of the project, the plans for watershed and internal load management, and how residents and other stakeholders can get involved.

The following were items discussed:

- Mud Lake: Sago pondweed might be a problem. As part of the rotational grazing, the cattle are in the lake for approximately 16 days each year (the rotation is 3 to 4 days in the lake, then 30 days out of the lake). The cattle have access to approximately ¾ of the lake's shoreline. In the winter, the cattle are in pasture, there are no issues with surface-applied manure, which is spread in May.
- Loon Lake: there is a farm on the east side of the lake, what should be looked at? What should we keep an eye out for during spring runoff?
- Goose Lake: there are small horse farms.
- Fish lake: has all-time low water levels

19.2 Technical Advisory Committee Meetings

19.2.1 TAC Meeting 1

A meeting of the Technical Advisory Committee (TAC) was held on May 6, 2009. The meeting was focused on reviewing the available data for each lake and gaining input and consensus on methods to determine the phosphorus source inventory for each lake.

The meeting agenda included the following topics:

- Welcome and introductions
- TMDL Phase 1 overview
- Synchronization with Lake St. Croix TMDL and watershed plan update
- Delisting status
- Pollutant load modeling: watershed loads, internal loads, point sources, and other loading sources
- Next steps

Meeting minutes can be found in Appendix A.

19.2.2 TAC Meeting 2

A second TAC meeting was held on March 16, 2011. A summary of the TMDLs was presented, after which TAC members discussed the watershed implementation strategies and ranked the importance of the implementation categories for each of the lakes.

Meeting minutes can be found in Appendix A.

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21 APPENDIX A. MEETING MINUTES

21.1 TAC Meeting 1 – May 6, 2009

Attendees:

Chris Klucas, MPCA
Jay Riggs, WCD
Gerry Johnson, MDNR
Jessica Collin-Pilarski, Washington County
Erik Anderson, WCD
Jim Shaver, CMSCWD
Jim Almendinger, Research Station
Andrea Plevan, EOR
Emily Wert, EOR
Jennifer Olson, EOR

Welcome and Introductions

TMDL Phase 1 Overview
Jennifer Olson provided an overall project summary, including the timing and components of the Phase 1 project, Phase 2 focus, and future phase 3. The TMDL formula and load allocations will be developed as part of phase 3. See EOR presentation.

Jennifer provided a summary of the Phase 1 report and information available for each of the listed lakes.

East Boot Lake. MPCA staff feels it should be addressed as a deep lake (primarily because of the stratification and available bathymetric map). The TAC concurs with the MPCA interpretation.

Fish Lake. Shallow lake. Used as a walleye rearing pond. Will look closer at Fish surveys generally not conducted on lakes without public access.

Goose Lake. Deep lake. Largemouth bass have been stocked to predate on bluegills (in late 80s).

Hay Lake. Shallow lake. Minnow rearing pond. Secchi Diverse macrophyte community. Deepest depth is 7'. Functions more like a wetland than a shallow lake. If it is listed as a wetland, it may be delisted. It is used for recreation. DNR classifies it as a lake. Would keeping this classified as a lake potentially help protect Sand Lake? The TAC agreed that it likely would.

Jellum's Bay Lake. Shallow lake. Secchi OK. Walleye rearing.

Long Lake. Shallow lake. Secchi OK. Walleye rearing. Lake is "stiff with green sunfish." Hundreds of pounds per net lift. All sizes (including some really big ones). Proposal into reclaim Long Lake – to kill the sunfish.

Loon Lake. Shallow lake. Worst lake. Chlorophyll 109 µg/l “crazy high.” Likely very high internal loading. Historical location of sawmill. Used for water skiing. Loon outlets to Silver Creek intermittently.

Louise Lake. Shallow lake. Landlocked. Walleye rearing. Recent fish kill. Bluegill in the lake. Wastewater treatment from Lodge at Pine Point. If it is over 10,000 gpd it would need a MPCA permit. Jessica will check with Pete Ganzel at the County. County also has Industrial Stormwater discharge permit that discharges to Louise.

South Twin Lake. Shallow lake. Discharge from MS4 (Stillwater). Secchi poor in recent years.

Sediment samples collected last fall. In-lake loading is likely a significant issue on many of these shallow lakes.

Klucas mentioned the enhanced emphasis on protection of non-impaired waters in the TMDL.

There are only two permitted feedlots in the watershed.

WCD will review county feedlot data and coord with Jim about animal unit data. It is important for us to get a better grasp on livestock in the watershed.

Jim asked about high clarity and high nutrient lakes. Discussions are underway at state level about changing nutrient standard for lakes that are clear (good Secchi). Also studies under way to assess appropriateness of 60 µg/l standard for all shallow lakes (that may not ever be able to meet the standard). Changes will not likely affect this TMDL.

TMDL and Plan Synchronization
Chris discussed the St. Croix TMDL and how the MPCA is working through the “nested” TMDL process. St. Croix TMDL will assign a load allocation per large subwatershed. The role of protection will come into play for those non-listed tribs that are conveyed to the big river. Most of the lakes in the CarMar TMDL are isolated. Implementation strategies will need to address overall load reduction. Silver Creek and other smaller tribs will not likely have a specified load reduction goal.

Delisting Status
Notification of official delisting of Silver, Long (May), and Sand have not been received. MPCA staff concur with delisting request for these three lakes. See comments above regarding East Boot. Chris will follow up to provide written confirmation

Additional Data Needs
See above.

Modeling Discussion
Jennifer discussed alternative modeling approaches as summarized in “Phosphorus Sources – Proposed Technical Approach” EOR memo dated May 6, 2009.

Watershed Sources

Watershed boundaries are determined by 2' contours and field verification.

TAC discussed scale of subwatersheds for watershed modeling. Subareas will be broken down based on complexity of land use and drainage patterns. Focus will be on developing adequate detail in the output to allow for prioritization of implementation activities.

EOR recommends whole watershed approach and using EPA simple method (based on EMCs). TAC agrees with this approach.

Jim suggested looking into Bill James' ag contribution model to compare simple method .

Livestock Sources

See comments above. Additional information on livestock information should be obtained. See comments above.

STSS

Suggest using MPCA ULA approach for septics. EOR coordinating with Washington County staff. Septic load per lake will be determined. Would focus on STS adjacent to lake and scooch around directly adjacent wetlands.

Permitted Point Sources

Permits and monitoring information will be assessed.

Groundwater

EOR will review North Washington County Groundwater study to assess potential TP load from groundwater sources. Team will look at again as lake response modeling is completed.

Atmospheric Deposition

UAL approach will be used.

Other Sources

TAC discussed issue of septage/sludge/ash land application. We need to get a better grasp on the scope and potential impact of this process. Chris will look into biosolid management in Washington County. Jessica will touch base with County staff. Jim S. will talk to John Bower who has looked into this issue in the past.

Jim A. brought up streambank erosion and other mass erosion issues. Jim and Jim will discuss this issue.

Next Steps

Phase 1 report will be updated. Runoff modeling will move forward. Toward end of Phase 2 data and first part of TMDL report will be forwarded.

21.2 TAC Meeting 2 – March 16, 2011

Attendees:

Chris Klucas, MPCA
Jay Riggs, WCD
Jim Shaver, CMSCWD
Andrea Plevan, EOR
Nancy-Jeanne LeFevre, EOR
Erik Anderson, WCD
Jack Frost, Metropolitan Council Environmental Services
John Erdmann, MPCA
Molly Shodeen, DNR
Melissa Lewis, BWSR
Jason Husveth, CMSCWD
Victoria Dupre, CMSCWD
Anne Hurlburt, Scandia
Brian Johnson, Met Council
Amy Carolan, WCD
Randy Ferrin, St. Croix Basin Team
Eric Anderson, WCD
Deb Ryan, St. Croix River Assoc

Andrea Plevan gave a short summary of the TMDL project to date, and then presented the approach used to determine the reductions needed for internal and watershed loads. John Erdmann expressed support for the approach. Jack Frost commented that the success will depend on how easy it is to achieve 50% reduction in watershed loads. There was overall support from the group on the approach.

Jay Riggs then discussed the seven implementation categories for watershed management discussed in the TMDL report: regulation, new development standards, redevelopment standards, public projects, private projects, municipal O&M, and education. He then led a discussion on the relative importance of each of these categories for each of the lakes. A table that ranks the implementation categories for each lake was filled in by meeting attendees.

The following were miscellaneous items discussed in addition to the ranking of implementation categories:

- Feedlot in the East Boot Lake watershed: discussion about how to involve the owner in a feedlot improvement.
- Hay Lake: discussion regarding the classification of this lake as a shallow lake instead of as a wetland; there is an endangered Potamogeton that only survives in groundwater-dependent systems. Language will be added that suggests managing the water body as a wetland.
- Some of the loading goals are tough and might be unachievable, this should be acknowledged in the report.
- Jellum's Bay: there have been two years of barley straw treatment; stormwater facilities were put in during the past road reconstruction.
- Louise Lake: gravel road management
- Mud Lake: the cattle are not totally fenced off
- South Twin Lake: there is a lot of land owned by the watershed district

22 APPENDIX B. SUPPORTING DATA FOR BATHTUB MODELS

Bathtub modeling case data (inputs), diagnostics (results), and segment balances (water and phosphorus budgets) are presented for both the calibrated (benchmark/existing) models and the TMDL scenarios. In-lake water quality concentrations for the calibrated and TMDL scenarios were evaluated to the nearest whole number for TP and chlorophyll-*a* concentrations (µg/L) and to the nearest tenth of a meter for Secchi transparency (see *Model Calibration* in Section 3.3.1). Data shown, for example, under the calibrated model diagnostics for East Boot Lake (Table 102) show predicted (calibrated) chlorophyll-*a* at 23.6 µg/L, and observed chlorophyll-*a* at 24.2 µg/L. These values were considered equal to each other (at 24 µg/L) using the rounding methods described.

22.1 East Boot Lake

As discussed in Section 3.3.1 the direct drainage area for East Boot Lake and loading from upstream West Boot Lake were lumped as a single tributary input.

Table 101. Calibrated (benchmark) Bathtub model case data (input) for East Boot Lake

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.77	0.0
Evaporation (m)	0.9	0.0
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km²-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	30.26	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	8	CANF & BACH, LAKES
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km²	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	East Boot	0	1	0.185	4.51	0.221	4.3	0.12	0	0	0.09	6.23	0	0	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	43.9	0.33	0	0	24.2	0.663	2.2	0.65	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	0.77	0	1	0	1.21	0	1.47	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm³/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km²	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Monitored Inputs	1	1	1.217	0.12	0	0	0	176	0	0	0	0	0	0	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	1.000	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	1.000	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m²/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

Table 102. Calibrated (benchmark) Bathtub model diagnostics (model results) for East Boot Lake

Segment:	1	East Boot				
	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	44.2	0.37	46.4%	43.9	0.33	46.1%
CHL-A MG/M3	23.6	0.58	88.5%	24.2	0.66	89.1%
SECCHI M	2.2	0.58	81.9%	2.2	0.65	82.5%
ORGANIC N MG/M3	702.5	0.42	78.0%			
TP-ORTHO-P MG/M3	40.1	0.46	62.0%			
ANTILOG PC-1	292.3	0.71	55.4%	293.9	0.86	55.5%
ANTILOG PC-2	20.8	0.64	98.7%	21.5	0.67	98.9%
TURBIDITY 1/M	0.1	6.23	1.5%	0.1	6.23	1.5%
ZMIX * TURBIDITY	0.4	6.23	0.3%	0.4	6.23	0.3%
ZMIX / SECCHI	2.0	0.58	6.7%	2.0	0.64	6.3%
CHL-A * SECCHI	51.0	0.89	98.9%	53.2	0.93	99.0%
CHL-A / TOTAL P	0.5	0.51	94.3%	0.6	0.74	94.8%
FREQ(CHL-a>10) %	85.9	0.24	88.5%	86.8	0.25	89.1%
FREQ(CHL-a>20) %	48.4	0.78	88.5%	49.9	0.85	89.1%
FREQ(CHL-a>30) %	24.3	1.21	88.5%	25.6	1.35	89.1%
FREQ(CHL-a>40) %	12.3	1.56	88.5%	13.1	1.76	89.1%
FREQ(CHL-a>50) %	6.4	1.84	88.5%	6.9	2.10	89.1%
FREQ(CHL-a>60) %	3.5	2.08	88.5%	3.8	2.39	89.1%
CARLSON TSI-P	58.8	0.09	46.4%	58.7	0.08	46.1%
CARLSON TSI-CHLA	61.6	0.09	88.5%	61.9	0.10	89.1%
CARLSON TSI-SEC	48.9	0.17	18.1%	48.6	0.19	17.5%

Table 103. Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for East Boot Lake

Component:	TOTAL P		Segment:		1	East Boot	
			Flow	Flow	Load	Load	Conc
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
1	1	Monitored Inputs	0.1	45.7%	21.1	79.0%	176
PRECIPITATION			0.1	54.3%	5.6	21.0%	39
TRIBUTARY INFLOW			0.1	45.7%	21.1	79.0%	176
***TOTAL INFLOW			0.3	100.0%	26.7	100.0%	102
ADVECTIVE OUTFLOW			0.1	36.6%	4.2	15.9%	44
***TOTAL OUTFLOW			0.1	36.6%	4.2	15.9%	44
***EVAPORATION			0.2	63.4%	0.0	0.0%	
***RETENTION			0.0	0.0%	22.5	84.1%	
Hyd. Residence Time =			8.6957	yrs			
Overflow Rate =			0.5	m/yr			
Mean Depth =			4.5	m			

Table 104. TMDL scenario Bathtub model case data (input) for East Boot Lake

Tributary TP concentration was the only input that was revised from the calibrated (benchmark) model.

Tributary Data											
				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV
1	Monitored Inputs	1	1	1.217	0.12	0	0	0	146	0

Table 105. TMDL scenario Bathtub model diagnostics (model results) for East Boot Lake

Segment:	1	East Boot				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	40.4	0.37	42.5%	43.9	0.33	46.1%
CHL-A MG/M3	22.0	0.59	86.6%	24.2	0.66	89.1%
SECCHI M	2.3	0.63	84.0%	2.2	0.65	82.5%
ORGANIC N MG/M3	665.3	0.42	74.7%			
TP-ORTHO-P MG/M3	37.2	0.46	58.9%			
ANTILOG PC-1	257.8	0.72	51.6%	293.9	0.86	55.5%
ANTILOG PC-2	20.8	0.69	98.7%	21.5	0.67	98.9%
TURBIDITY 1/M	0.1	6.23	1.5%	0.1	6.23	1.5%
ZMIX * TURBIDITY	0.4	6.23	0.3%	0.4	6.23	0.3%
ZMIX / SECCHI	1.9	0.63	5.4%	2.0	0.64	6.3%
CHL-A * SECCHI	50.5	0.94	98.8%	53.2	0.93	99.0%
CHL-A / TOTAL P	0.5	0.51	94.6%	0.6	0.74	94.8%
FREQ(CHL-a>10) %	83.2	0.29	86.6%	86.8	0.25	89.1%
FREQ(CHL-a>20) %	43.8	0.86	86.6%	49.9	0.85	89.1%
FREQ(CHL-a>30) %	20.9	1.31	86.6%	25.6	1.35	89.1%
FREQ(CHL-a>40) %	10.1	1.67	86.6%	13.1	1.76	89.1%
FREQ(CHL-a>50) %	5.1	1.95	86.6%	6.9	2.10	89.1%
FREQ(CHL-a>60) %	2.7	2.20	86.6%	3.8	2.39	89.1%
CARLSON TSI-P	57.5	0.09	42.5%	58.7	0.08	46.1%
CARLSON TSI-CHLA	60.9	0.10	86.6%	61.9	0.10	89.1%
CARLSON TSI-SEC	48.0	0.19	16.0%	48.6	0.19	17.5%

Table 106. TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for East Boot Lake

Component: TOTAL P			Segment:		1	East Boot	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Monitored Inputs	0.1	45.7%	17.5	75.8%	146
PRECIPITATION			0.1	54.3%	5.6	24.2%	39
TRIBUTARY INFLOW			0.1	45.7%	17.5	75.8%	146
***TOTAL INFLOW			0.3	100.0%	23.1	100.0%	88
ADVECTIVE OUTFLOW			0.1	36.6%	3.9	16.8%	40
***TOTAL OUTFLOW			0.1	36.6%	3.9	16.8%	40
***EVAPORATION			0.2	63.4%	0.0	0.0%	
***RETENTION			0.0	0.0%	19.2	83.2%	
Hyd. Residence Time =			8.6957	yrs			
Overflow Rate =			0.5	m/yr			
Mean Depth =			4.5	m			

22.2 Fish Lake

Table 107. Calibrated (benchmark) Bathtub model case data (input) for Fish Lake

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.76	0.0
Evaporation (m)	0.89	0.0
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km²-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	30.26	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	8	CANF & BACH, LAKES
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Fish	0	1	0.256	1.19	0.413	1.19	0.12	0	0	0.21	15.48	0	0	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	112.7	0.36	0	0	69.2	0.635	0.8	0.458	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	0.49	0	1	0	0.95	0	1.45	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Monitored Inputs	1	1	1.727	0.17	0	0	0	199	0	0	0	0	0	0	0

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

Table 108. Calibrated (benchmark) Bathtub model diagnostics (model results) for Fish Lake

Segment:	1	Fish				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	113.4	0.28	83.1%	112.7	0.36	82.9%
CHL-A MG/M3	68.8	0.79	99.5%	69.2	0.63	99.5%
SECCHI M	0.8	1.10	31.7%	0.8	0.46	34.6%
ORGANIC N MG/M3	1741.0	0.60	99.5%			
TP-ORTHO-P MG/M3	123.3	0.38	93.2%			
ANTILOG PC-1	2155.0	0.70	95.2%	2044.8	0.73	94.7%
ANTILOG PC-2	18.8	1.30	97.9%	19.8	0.55	98.4%
TURBIDITY 1/M	0.2	15.48	11.3%	0.2	15.48	11.3%
ZMIX * TURBIDITY	0.2	15.48	0.1%	0.2	15.48	0.1%
ZMIX / SECCHI	1.6	1.10	2.9%	1.5	0.46	2.3%
CHL-A * SECCHI	51.7	1.76	98.9%	55.4	0.78	99.2%
CHL-A / TOTAL P	0.6	0.76	96.2%	0.6	0.72	96.4%
FREQ(CHL-a>10) %	99.7	0.01	99.5%	99.8	0.01	99.5%
FREQ(CHL-a>20) %	95.4	0.13	99.5%	95.5	0.10	99.5%
FREQ(CHL-a>30) %	84.8	0.35	99.5%	85.0	0.27	99.5%
FREQ(CHL-a>40) %	71.4	0.61	99.5%	71.7	0.47	99.5%
FREQ(CHL-a>50) %	58.1	0.85	99.5%	58.5	0.67	99.5%
FREQ(CHL-a>60) %	46.4	1.09	99.5%	46.8	0.86	99.5%
CARLSON TSI-P	72.4	0.06	83.1%	72.3	0.07	82.9%
CARLSON TSI-CHLA	72.1	0.11	99.5%	72.2	0.09	99.5%
CARLSON TSI-SEC	64.1	0.25	68.3%	63.2	0.10	65.4%

Table 109. Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for Fish Lake

Component:	TOTAL P		Segment:	1	Fish		
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Monitored Inputs	0.2	46.6%	33.8	81.4%	199
PRECIPITATION			0.2	53.4%	7.7	18.6%	40
TRIBUTARY INFLOW			0.2	46.6%	33.8	81.4%	199
***TOTAL INFLOW			0.4	100.0%	41.6	100.0%	114
ADVECTIVE OUTFLOW			0.1	37.5%	15.5	37.3%	113
***TOTAL OUTFLOW			0.1	37.5%	15.5	37.3%	113
***EVAPORATION			0.2	62.5%	0.0	0.0%	
***RETENTION			0.0	0.0%	26.1	62.7%	
Hyd. Residence Time =			2.2282	yrs			
Overflow Rate =			0.5	m/yr			
Mean Depth =			1.2	m			

Table 110. TMDL scenario Bathtub model case data (input) for Fish Lake

Tributary TP concentration was the only input that was revised from the calibrated (benchmark) model.

Tributary Data										
				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV
1	Monitored Inputs	1	1	1.727	0.17	0	0	0	58	0

Table 111. TMDL scenario Bathtub model diagnostics (model results) for Fish Lake

Segment:	1	Fish				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	60.3	0.29	60.1%	112.7	0.36	82.9%
CHL-A MG/M3	38.7	0.81	96.7%	69.2	0.63	99.5%
SECCHI M	1.2	2.20	56.9%	0.8	0.46	34.6%
ORGANIC N MG/M3	1054.3	0.50	94.2%			
TP-ORTHO-P MG/M3	69.7	0.59	81.3%			
ANTILOG PC-1	786.7	1.52	81.3%	2044.8	0.73	94.7%
ANTILOG PC-2	18.7	2.17	97.9%	19.8	0.55	98.4%
TURBIDITY 1/M	0.2	15.48	11.3%	0.2	15.48	11.3%
ZMIX * TURBIDITY	0.2	15.48	0.1%	0.2	15.48	0.1%
ZMIX / SECCHI	1.0	2.21	0.3%	1.5	0.46	2.3%
CHL-A * SECCHI	47.6	2.88	98.5%	55.4	0.78	99.2%
CHL-A / TOTAL P	0.6	0.75	96.9%	0.6	0.72	96.4%
FREQ(CHL-a>10) %	96.9	0.09	96.7%	99.8	0.01	99.5%
FREQ(CHL-a>20) %	77.4	0.51	96.7%	95.5	0.10	99.5%
FREQ(CHL-a>30) %	54.0	0.96	96.7%	85.0	0.27	99.5%
FREQ(CHL-a>40) %	35.8	1.37	96.7%	71.7	0.47	99.5%
FREQ(CHL-a>50) %	23.4	1.71	96.7%	58.5	0.67	99.5%
FREQ(CHL-a>60) %	15.4	2.02	96.7%	46.8	0.86	99.5%
CARLSON TSI-P	63.3	0.07	60.1%	72.3	0.07	82.9%
CARLSON TSI-CHLA	66.5	0.12	96.7%	72.2	0.09	99.5%
CARLSON TSI-SEC	57.0	0.56	43.1%	63.2	0.10	65.4%

Table 112. TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for Fish Lake

Component:	TOTAL P		Segment:	1	Fish		
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Monitored Inputs	0.2	46.6%	9.9	56.0%	58
PRECIPITATION			0.2	53.4%	7.7	44.0%	40
TRIBUTARY INFLOW			0.2	46.6%	9.9	56.0%	58
***TOTAL INFLOW			0.4	100.0%	17.6	100.0%	48
ADVECTIVE OUTFLOW			0.1	37.5%	8.3	46.9%	60
***TOTAL OUTFLOW			0.1	37.5%	8.3	46.9%	60
***EVAPORATION			0.2	62.5%	0.0	0.0%	
***RETENTION			0.0	0.0%	9.4	53.1%	
Hyd. Residence Time =			2.2282	yrs			
Overflow Rate =			0.5	m/yr			
Mean Depth =			1.2	m			

22.3 Goose Lake

Table 113. Calibrated (benchmark) Bathtub model case data (input) for Goose Lake

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.76	0.0
Evaporation (m)	0.89	0.0
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	30.26	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	8	CANF & BACH, LAKES
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Goose	0	1	0.34	3.35	0.394	3.35	0.12	0	0	0.08	10.11	0	0	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	63.5	0.432	0	0	42.7	0.73	1.7	0.37	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	0.83	0	1	0	1.44	0	1.93	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Monitored Inputs	1	1	2.092	0.21	0	0	0	330	0	0	0	0	0	0	0

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

Table 114. Calibrated (benchmark) Bathtub model diagnostics (model results) for Goose Lake

Segment:	1	Goose				
	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	64.3	0.38	62.9%	63.5	0.43	62.3%
CHL-A MG/M3	42.5	0.62	97.5%	42.7	0.73	97.5%
SECCHI M	1.7	0.44	72.2%	1.7	0.37	72.5%
ORGANIC N MG/M3	1132.8	0.50	95.6%			
TP-ORTHO-P MG/M3	73.5	0.48	82.7%			
ANTILOG PC-1	642.4	0.73	76.9%	640.6	0.77	76.8%
ANTILOG PC-2	25.5	0.53	99.6%	25.7	0.57	99.6%
TURBIDITY 1/M	0.1	10.11	1.1%	0.1	10.11	1.1%
ZMIX * TURBIDITY	0.3	10.11	0.1%	0.3	10.11	0.1%
ZMIX / SECCHI	2.0	0.44	6.6%	2.0	0.38	6.4%
CHL-A * SECCHI	71.8	0.75	99.7%	72.6	0.82	99.7%
CHL-A / TOTAL P	0.7	0.57	97.2%	0.7	0.84	97.4%
FREQ(CHL-a>10) %	97.9	0.05	97.5%	97.9	0.06	97.5%
FREQ(CHL-a>20) %	81.8	0.32	97.5%	81.9	0.36	97.5%
FREQ(CHL-a>30) %	60.0	0.64	97.5%	60.2	0.74	97.5%
FREQ(CHL-a>40) %	41.6	0.94	97.5%	41.9	1.09	97.5%
FREQ(CHL-a>50) %	28.4	1.19	97.5%	28.6	1.40	97.5%
FREQ(CHL-a>60) %	19.4	1.42	97.5%	19.5	1.67	97.5%
CARLSON TSI-P	64.2	0.09	62.9%	64.0	0.10	62.3%
CARLSON TSI-CHLA	67.4	0.09	97.5%	67.4	0.10	97.5%
CARLSON TSI-SEC	52.5	0.12	27.8%	52.4	0.10	27.5%

Table 115. Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for Goose Lake

Component:		TOTAL P	Segment:		1	Goose	
			Flow	Flow	Load	Load	Conc
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
1	1	Monitored Inputs	0.2	44.8%	69.3	87.1%	330
PRECIPITATION			0.3	55.2%	10.3	12.9%	40
TRIBUTARY INFLOW			0.2	44.8%	69.3	87.1%	330
***TOTAL INFLOW			0.5	100.0%	79.6	100.0%	170
ADVECTIVE OUTFLOW			0.2	35.4%	10.7	13.4%	64
***TOTAL OUTFLOW			0.2	35.4%	10.7	13.4%	64
***EVAPORATION			0.3	64.6%	0.0	0.0%	
***RETENTION			0.0	0.0%	68.9	86.6%	
Hyd. Residence Time =			6.8697	yrs			
Overflow Rate =			0.5	m/yr			
Mean Depth =			3.3	m			

Table 116. TMDL scenario Bathtub model case data (input) for Goose Lake

Tributary TP concentration was the only input that was revised from the calibrated (benchmark) model.

Tributary Data											
				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	
1	Monitored Inputs	1	1	2.092	0.21	0	0	0	129	0	

Table 117. TMDL scenario Bathtub model diagnostics (model results) for Goose Lake

Segment:	1 Goose					
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	40.5	0.37	42.6%	63.5	0.43	62.3%
CHL-A MG/M3	29.4	0.65	93.1%	42.7	0.73	97.5%
SECCHI M	2.4	0.68	84.9%	1.7	0.37	72.5%
ORGANIC N MG/M3	833.0	0.49	86.6%			
TP-ORTHO-P MG/M3	50.1	0.49	70.5%			
ANTILOG PC-1	329.8	0.77	59.0%	640.6	0.77	76.8%
ANTILOG PC-2	25.9	0.76	99.6%	25.7	0.57	99.6%
TURBIDITY 1/M	0.1	10.11	1.1%	0.1	10.11	1.1%
ZMIX * TURBIDITY	0.3	10.11	0.1%	0.3	10.11	0.1%
ZMIX / SECCHI	1.4	0.68	1.8%	2.0	0.38	6.4%
CHL-A * SECCHI	69.6	1.05	99.7%	72.6	0.82	99.7%
CHL-A / TOTAL P	0.7	0.56	98.0%	0.7	0.84	97.4%
FREQ(CHL-a>10) %	92.3	0.16	93.1%	97.9	0.06	97.5%
FREQ(CHL-a>20) %	62.2	0.64	93.1%	81.9	0.36	97.5%
FREQ(CHL-a>30) %	36.6	1.08	93.1%	60.2	0.74	97.5%
FREQ(CHL-a>40) %	21.0	1.44	93.1%	41.9	1.09	97.5%
FREQ(CHL-a>50) %	12.2	1.74	93.1%	28.6	1.40	97.5%
FREQ(CHL-a>60) %	7.2	2.00	93.1%	19.5	1.67	97.5%
CARLSON TSI-P	57.5	0.09	42.6%	64.0	0.10	62.3%
CARLSON TSI-CHLA	63.8	0.10	93.1%	67.4	0.10	97.5%
CARLSON TSI-SEC	47.6	0.21	15.1%	52.4	0.10	27.5%

Table 118. TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for Goose Lake

Component:		TOTAL P	Segment:		1 Goose		
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Monitored Inputs	0.2	44.8%	27.1	72.5%	129
PRECIPITATION			0.3	55.2%	10.3	27.5%	40
TRIBUTARY INFLOW			0.2	44.8%	27.1	72.5%	129
***TOTAL INFLOW			0.5	100.0%	37.4	100.0%	80
ADVECTIVE OUTFLOW			0.2	35.4%	6.7	18.0%	40
***TOTAL OUTFLOW			0.2	35.4%	6.7	18.0%	40
***EVAPORATION			0.3	64.6%	0.0	0.0%	
***RETENTION			0.0	0.0%	30.7	82.0%	
Hyd. Residence Time =			6.8697	yrs			
Overflow Rate =			0.5	m/yr			
Mean Depth =			3.3	m			

22.4 Hay Lake

Table 119. Calibrated (benchmark) Bathtub model case data (input) for Hay Lake

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.76	0.0
Evaporation (m)	0.89	0.0
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	30.26	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	8	CANF & BACH, LAKES
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Hay	0	1	0.168	1.16	0.231	1.16	0.12	0	0	0.29	7.65	0	0	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	92.1	0.308	0	0	41.4	0.563	1.1	0.207	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	0.9	0	1	0	0.68	0	1.4	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Monitored Inputs	1	1	0.866	0.086	0	0	0	330	0	0	0	0	0	0	0

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

Table 120. Calibrated (benchmark) Bathtub model diagnostics (model results) for Hay Lake

Segment:	1	Hay				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	91.9	0.36	76.5%	92.1	0.31	76.6%
CHL-A MG/M3	41.2	0.62	97.3%	41.4	0.56	97.3%
SECCHI M	1.1	1.36	49.1%	1.1	0.21	51.0%
ORGANIC N MG/M3	1117.4	0.44	95.4%			
TP-ORTHO-P MG/M3	76.0	0.50	83.6%			
ANTILOG PC-1	959.8	1.06	85.1%	933.3	0.57	84.6%
ANTILOG PC-2	17.4	1.34	97.1%	17.9	0.41	97.5%
TURBIDITY 1/M	0.3	7.65	20.0%	0.3	7.65	20.0%
ZMIX * TURBIDITY	0.3	7.65	0.2%	0.3	7.65	0.2%
ZMIX / SECCHI	1.1	1.37	0.6%	1.1	0.23	0.5%
CHL-A * SECCHI	43.7	1.78	98.0%	45.5	0.60	98.3%
CHL-A / TOTAL P	0.4	0.53	90.3%	0.4	0.64	90.4%
FREQ(CHL-a>10) %	97.6	0.06	97.3%	97.6	0.05	97.3%
FREQ(CHL-a>20) %	80.4	0.35	97.3%	80.6	0.30	97.3%
FREQ(CHL-a>30) %	57.9	0.68	97.3%	58.3	0.60	97.3%
FREQ(CHL-a>40) %	39.6	0.98	97.3%	39.9	0.87	97.3%
FREQ(CHL-a>50) %	26.6	1.24	97.3%	26.9	1.11	97.3%
FREQ(CHL-a>60) %	17.9	1.47	97.3%	18.2	1.33	97.3%
CARLSON TSI-P	69.3	0.08	76.5%	69.4	0.06	76.6%
CARLSON TSI-CHLA	67.1	0.09	97.3%	67.1	0.08	97.3%
CARLSON TSI-SEC	59.1	0.33	50.9%	58.6	0.05	49.0%

Table 121. Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for Hay Lake

Component: TOTAL P				Segment:	1	Hay	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Monitored Inputs	0.1	40.2%	28.4	84.8%	330
PRECIPITATION			0.1	59.8%	5.1	15.2%	40
TRIBUTARY INFLOW			0.1	40.2%	28.4	84.8%	330
***TOTAL INFLOW			0.2	100.0%	33.5	100.0%	157
ADVECTIVE OUTFLOW			0.1	30.0%	5.9	17.6%	92
***TOTAL OUTFLOW			0.1	30.0%	5.9	17.6%	92
***EVAPORATION			0.1	70.0%	0.0	0.0%	
***RETENTION			0.0	0.0%	27.6	82.4%	
Hyd. Residence Time =			3.0374	yrs			
Overflow Rate =			0.4	m/yr			
Mean Depth =			1.2	m			

Table 122. TMDL scenario Bathtub model case data (input) for Hay Lake
Tributary TP concentration was the only input that was revised from the calibrated (benchmark) model.

Tributary Data										
				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV
1	Monitored Inputs	1	1	0.866	0.086	0	0	0	141	0

Table 123. TMDL scenario Bathtub model diagnostics (model results) for Hay Lake

Segment: 1 Hay						
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	60.3	0.35	60.1%	92.1	0.31	76.6%
CHL-A MG/M3	27.4	0.65	91.8%	41.4	0.56	97.3%
SECCHI M	1.4	1.96	64.6%	1.1	0.21	51.0%
ORGANIC N MG/M3	803.9	0.40	85.0%			
TP-ORTHO-P MG/M3	51.6	0.74	71.6%			
ANTILOG PC-1	492.5	1.56	70.3%	933.3	0.57	84.6%
ANTILOG PC-2	16.7	1.82	96.5%	17.9	0.41	97.5%
TURBIDITY 1/M	0.3	7.65	20.0%	0.3	7.65	20.0%
ZMIX * TURBIDITY	0.3	7.65	0.2%	0.3	7.65	0.2%
ZMIX / SECCHI	0.8	1.98	0.1%	1.1	0.23	0.5%
CHL-A * SECCHI	39.3	2.40	97.2%	45.5	0.60	98.3%
CHL-A / TOTAL P	0.5	0.53	90.7%	0.4	0.64	90.4%
FREQ(CHL-a>10) %	90.6	0.19	91.8%	97.6	0.05	97.3%
FREQ(CHL-a>20) %	57.9	0.71	91.8%	80.6	0.30	97.3%
FREQ(CHL-a>30) %	32.4	1.16	91.8%	58.3	0.60	97.3%
FREQ(CHL-a>40) %	17.9	1.53	91.8%	39.9	0.87	97.3%
FREQ(CHL-a>50) %	10.0	1.83	91.8%	26.9	1.11	97.3%
FREQ(CHL-a>60) %	5.8	2.08	91.8%	18.2	1.33	97.3%
CARLSON TSI-P	63.3	0.08	60.1%	69.4	0.06	76.6%
CARLSON TSI-CHLA	63.1	0.10	91.8%	67.1	0.08	97.3%
CARLSON TSI-SEC	54.8	0.52	35.4%	58.6	0.05	49.0%

Table 124. TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for Hay Lake

Component: TOTAL P			Segment: 1 Hay				
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Monitored Inputs	0.1	40.2%	12.1	70.5%	141
PRECIPITATION			0.1	59.8%	5.1	29.5%	40
TRIBUTARY INFLOW			0.1	40.2%	12.1	70.5%	141
***TOTAL INFLOW			0.2	100.0%	17.2	100.0%	81
ADVECTIVE OUTFLOW			0.1	30.0%	3.9	22.5%	60
***TOTAL OUTFLOW			0.1	30.0%	3.9	22.5%	60
***EVAPORATION			0.1	70.0%	0.0	0.0%	
***RETENTION			0.0	0.0%	13.3	77.5%	
Hyd. Residence Time =			3.0374	yrs			
Overflow Rate =			0.4	m/yr			
Mean Depth =			1.2	m			

22.5 Jellum's Bay

As discussed in Section 3.3.1 the direct drainage area for Jellum's Bay and loading from upstream Long Lake were lumped as a single tributary input.

Table 125. Calibrated (benchmark) Bathtub model case data (input) for Jellum's Bay

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.76	0.0
Evaporation (m)	0.89	0.0
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	30.26	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	8	CANF & BACH, LAKES
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Jellums	0	1	0.259	1.8	0.371	1.8	0.12	0	0	0.21	9.93	0	0	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	97.3	0.271	0	0	52.4	0.553	1	0.326	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	0.44	0	1	0	1	0	1.5	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Monitored Inputs	1	1	2.225	0.22	0	0	0	165	0	0	0	0	0	0	0

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

Table 126. Calibrated (benchmark) Bathtub model diagnostics (model results) for Jellum's Bay

Segment:	1 Jellums					
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	97.3	0.27	78.5%	97.3	0.27	78.4%
CHL-A MG/M3	52.3	0.75	98.7%	52.4	0.55	98.7%
SECCHI M	1.0	0.85	45.4%	1.0	0.33	46.0%
ORGANIC N MG/M3	1364.5	0.56	98.1%			
TP-ORTHO-P MG/M3	93.9	0.38	88.5%			
ANTILOG PC-1	1285.8	0.60	89.7%	1275.6	0.60	89.6%
ANTILOG PC-2	19.3	1.07	98.2%	19.5	0.45	98.3%
TURBIDITY 1/M	0.2	9.93	11.3%	0.2	9.93	11.3%
ZMIX * TURBIDITY	0.4	9.93	0.3%	0.4	9.93	0.3%
ZMIX / SECCHI	1.8	0.85	4.9%	1.8	0.34	4.7%
CHL-A * SECCHI	51.7	1.47	98.9%	52.4	0.64	99.0%
CHL-A / TOTAL P	0.5	0.73	94.3%	0.5	0.61	94.4%
FREQ(CHL-a>10) %	99.1	0.03	98.7%	99.1	0.02	98.7%
FREQ(CHL-a>20) %	89.2	0.25	98.7%	89.3	0.18	98.7%
FREQ(CHL-a>30) %	72.1	0.56	98.7%	72.2	0.40	98.7%
FREQ(CHL-a>40) %	54.8	0.87	98.7%	55.0	0.63	98.7%
FREQ(CHL-a>50) %	40.6	1.15	98.7%	40.7	0.84	98.7%
FREQ(CHL-a>60) %	29.7	1.40	98.7%	29.9	1.03	98.7%
CARLSON TSI-P	70.2	0.06	78.5%	70.2	0.05	78.4%
CARLSON TSI-CHLA	69.4	0.11	98.7%	69.4	0.08	98.7%
CARLSON TSI-SEC	60.2	0.20	54.6%	60.0	0.08	54.0%

Table 127. Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for Jellum's Bay

Component:	TOTAL P		Segment:		1 Jellums		
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Monitored Inputs	0.2	52.8%	36.3	82.2%	165
PRECIPITATION			0.2	47.2%	7.8	17.8%	40
TRIBUTARY INFLOW			0.2	52.8%	36.3	82.2%	165
***TOTAL INFLOW			0.4	100.0%	44.1	100.0%	106
ADVECTIVE OUTFLOW			0.2	44.7%	18.1	41.1%	97
***TOTAL OUTFLOW			0.2	44.7%	18.1	41.1%	97
***EVAPORATION			0.2	55.3%	0.0	0.0%	
***RETENTION			0.0	0.0%	26.0	58.9%	
Hyd. Residence Time =			2.5020	yrs			
Overflow Rate =			0.7	m/yr			
Mean Depth =			1.8	m			

Table 128. TMDL scenario Bathtub model case data (input) for Jellum's Bay

Tributary TP concentration was the only input that was revised from the calibrated (benchmark) model.

Tributary Data											
				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	
1	Monitored Inputs	1	1	2.225	0.22	0	0	0	70	0	

Table 129. TMDL scenario Bathtub model diagnostics (model results) for Jellum's Bay

Segment:	1 Jellums					
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	60.3	0.26	60.1%	97.3	0.27	78.4%
CHL-A MG/M3	35.3	0.76	95.7%	52.4	0.55	98.7%
SECCHI M	1.4	1.39	62.4%	1.0	0.33	46.0%
ORGANIC N MG/M3	978.5	0.50	92.2%			
TP-ORTHO-P MG/M3	63.8	0.40	78.6%			
ANTILOG PC-1	653.7	0.89	77.3%	1275.6	0.60	89.6%
ANTILOG PC-2	19.2	1.51	98.1%	19.5	0.45	98.3%
TURBIDITY 1/M	0.2	9.93	11.3%	0.2	9.93	11.3%
ZMIX * TURBIDITY	0.4	9.93	0.3%	0.4	9.93	0.3%
ZMIX / SECCHI	1.3	1.40	1.3%	1.8	0.34	4.7%
CHL-A * SECCHI	48.5	2.03	98.6%	52.4	0.64	99.0%
CHL-A / TOTAL P	0.6	0.72	95.7%	0.5	0.61	94.4%
FREQ(CHL-a>10) %	95.8	0.11	95.7%	99.1	0.02	98.7%
FREQ(CHL-a>20) %	72.8	0.56	95.7%	89.3	0.18	98.7%
FREQ(CHL-a>30) %	48.2	1.01	95.7%	72.2	0.40	98.7%
FREQ(CHL-a>40) %	30.5	1.41	95.7%	55.0	0.63	98.7%
FREQ(CHL-a>50) %	19.2	1.74	95.7%	40.7	0.84	98.7%
FREQ(CHL-a>60) %	12.2	2.03	95.7%	29.9	1.03	98.7%
CARLSON TSI-P	63.3	0.06	60.1%	70.2	0.05	78.4%
CARLSON TSI-CHLA	65.6	0.11	95.7%	69.4	0.08	98.7%
CARLSON TSI-SEC	55.4	0.36	37.6%	60.0	0.08	54.0%

Table 130. TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for Jellum's Bay

Component: TOTAL P			Segment: 1 Jellums				
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Monitored Inputs	0.2	52.8%	15.4	66.3%	70
PRECIPITATION			0.2	47.2%	7.8	33.7%	40
TRIBUTARY INFLOW			0.2	52.8%	15.4	66.3%	70
***TOTAL INFLOW			0.4	100.0%	23.2	100.0%	56
ADVECTIVE OUTFLOW			0.2	44.7%	11.2	48.3%	60
***TOTAL OUTFLOW			0.2	44.7%	11.2	48.3%	60
***EVAPORATION			0.2	55.3%	0.0	0.0%	
***RETENTION			0.0	0.0%	12.0	51.7%	
Hyd. Residence Time =			2.5020	yrs			
Overflow Rate =			0.7	m/yr			
Mean Depth =			1.8	m			

Table 131. Calibrated (benchmark) Bathtub model case data (input) for Jellum's Bay where upstream Long Lake meets the water quality standard

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.76	0.0
Evaporation (m)	0.89	0.0
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	30.26	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	8	CANF & BACH, LAKES
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Jellums	0	1	0.259	1.8	0.371	1.8	0.12	0	0	0.21	9.93	0	0	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	97.3	0.271	0	0	52.4	0.553	1	0.326	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	0.415	0	1	0	1	0	1.5	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Monitored Inputs	1	1	2.225	0.22	0	0	0	155	0	0	0	0	0	0	0

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

Table 132. Calibrated (benchmark) Bathtub model diagnostics (model results) for Jellum's Bay where upstream Long Lake meets the water quality standard

Segment:	1 Jellums					
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	97.0	0.26	78.3%	97.3	0.27	78.4%
CHL-A MG/M3	52.1	0.74	98.7%	52.4	0.55	98.7%
SECCHI M	1.0	0.85	45.5%	1.0	0.33	46.0%
ORGANIC N MG/M3	1361.4	0.56	98.1%			
TP-ORTHO-P MG/M3	93.7	0.38	88.5%			
ANTILOG PC-1	1279.9	0.59	89.7%	1275.6	0.60	89.6%
ANTILOG PC-2	19.3	1.08	98.2%	19.5	0.45	98.3%
TURBIDITY 1/M	0.2	9.93	11.3%	0.2	9.93	11.3%
ZMIX * TURBIDITY	0.4	9.93	0.3%	0.4	9.93	0.3%
ZMIX / SECCHI	1.8	0.86	4.9%	1.8	0.34	4.7%
CHL-A * SECCHI	51.7	1.47	98.9%	52.4	0.64	99.0%
CHL-A / TOTAL P	0.5	0.73	94.4%	0.5	0.61	94.4%
FREQ(CHL-a>10) %	99.1	0.03	98.7%	99.1	0.02	98.7%
FREQ(CHL-a>20) %	89.2	0.25	98.7%	89.3	0.18	98.7%
FREQ(CHL-a>30) %	72.0	0.56	98.7%	72.2	0.40	98.7%
FREQ(CHL-a>40) %	54.7	0.87	98.7%	55.0	0.63	98.7%
FREQ(CHL-a>50) %	40.4	1.15	98.7%	40.7	0.84	98.7%
FREQ(CHL-a>60) %	29.6	1.40	98.7%	29.9	1.03	98.7%
CARLSON TSI-P	70.1	0.05	78.3%	70.2	0.05	78.4%
CARLSON TSI-CHLA	69.4	0.11	98.7%	69.4	0.08	98.7%
CARLSON TSI-SEC	60.1	0.20	54.5%	60.0	0.08	54.0%

Table 133. Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for Jellum's Bay where upstream Long Lake meets the water quality standard

Component:	TOTAL P		Segment:	1	Jellums		
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Monitored Inputs	0.2	52.8%	34.1	81.3%	155
PRECIPITATION			0.2	47.2%	7.8	18.7%	40
TRIBUTARY INFLOW			0.2	52.8%	34.1	81.3%	155
***TOTAL INFLOW			0.4	100.0%	41.9	100.0%	101
ADVECTIVE OUTFLOW			0.2	44.7%	18.1	43.1%	97
***TOTAL OUTFLOW			0.2	44.7%	18.1	43.1%	97
***EVAPORATION			0.2	55.3%	0.0	0.0%	
***RETENTION			0.0	0.0%	23.9	56.9%	
Hyd. Residence Time =			2.5020	yrs			
Overflow Rate =			0.7	m/yr			
Mean Depth =			1.8	m			

Table 134. TMDL scenario Bathtub model case data (input) for Jellum's Bay where upstream Long Lake meets the water quality standard

Data shown here is the only data that was revised from the calibrated (benchmark) model.

Tributary Data											
				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	
1	Monitored Inputs	1	1	2.225	0.22	0	0	0	66	0	

Table 135. TMDL scenario Bathtub model diagnostics (model results) for Jellum's Bay where upstream Long Lake meets the water quality standard

Segment:	1	Jellums				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	60.3	0.26	60.1%	97.3	0.27	78.4%
CHL-A MG/M3	35.3	0.76	95.7%	52.4	0.55	98.7%
SECCHI M	1.4	1.39	62.4%	1.0	0.33	46.0%
ORGANIC N MG/M3	978.5	0.50	92.2%			
TP-ORTHO-P MG/M3	63.8	0.40	78.6%			
ANTILOG PC-1	653.7	0.88	77.3%	1275.6	0.60	89.6%
ANTILOG PC-2	19.2	1.51	98.1%	19.5	0.45	98.3%
TURBIDITY 1/M	0.2	9.93	11.3%	0.2	9.93	11.3%
ZMIX * TURBIDITY	0.4	9.93	0.3%	0.4	9.93	0.3%
ZMIX / SECCHI	1.3	1.40	1.3%	1.8	0.34	4.7%
CHL-A * SECCHI	48.5	2.03	98.6%	52.4	0.64	99.0%
CHL-A / TOTAL P	0.6	0.72	95.7%	0.5	0.61	94.4%
FREQ(CHL-a>10) %	95.8	0.11	95.7%	99.1	0.02	98.7%
FREQ(CHL-a>20) %	72.8	0.56	95.7%	89.3	0.18	98.7%
FREQ(CHL-a>30) %	48.2	1.01	95.7%	72.2	0.40	98.7%
FREQ(CHL-a>40) %	30.5	1.40	95.7%	55.0	0.63	98.7%
FREQ(CHL-a>50) %	19.2	1.74	95.7%	40.7	0.84	98.7%
FREQ(CHL-a>60) %	12.2	2.03	95.7%	29.9	1.03	98.7%
CARLSON TSI-P	63.3	0.06	60.1%	70.2	0.05	78.4%
CARLSON TSI-CHLA	65.6	0.11	95.7%	69.4	0.08	98.7%
CARLSON TSI-SEC	55.4	0.36	37.6%	60.0	0.08	54.0%

Table 136. TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for Jellum's Bay where upstream Long Lake meets the water quality standard

Component:	TOTAL P		Segment:	1	Jellums		
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Monitored Inputs	0.2	52.8%	14.5	64.9%	66
PRECIPITATION			0.2	47.2%	7.8	35.1%	40
TRIBUTARY INFLOW			0.2	52.8%	14.5	64.9%	66
***TOTAL INFLOW			0.4	100.0%	22.4	100.0%	54
ADVECTIVE OUTFLOW			0.2	44.7%	11.2	50.2%	60
***TOTAL OUTFLOW			0.2	44.7%	11.2	50.2%	60
***EVAPORATION			0.2	55.3%	0.0	0.0%	
***RETENTION			0.0	0.0%	11.1	49.8%	
Hyd. Residence Time =			2.5020	yrs			
Overflow Rate =			0.7	m/yr			
Mean Depth =			1.8	m			

22.6 Long Lake

Table 137. Calibrated (benchmark) Bathtub model case data (input) for Long Lake

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.76	0.0
Evaporation (m)	0.89	0.0
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	30.26	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	8	CANF & BACH, LAKES
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Long	0	1	0.161	1.34	0.334	1.34	0.12	0	0	0.27	9.11	0	0	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	81.2	0.3	0	0	42.8	0.625	1.1	0.318	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	0.87	0	1	0	0.84	0	1.45	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Trib 1	1	1	0.886	0.088	0	0	0	269	0	0	0	0	0	0	0

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

Table 138. Calibrated (benchmark) Bathtub model diagnostics (model results) for Long Lake

Segment:	1	Long				
	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	81.1	0.36	72.1%	81.2	0.30	72.1%
CHL-A MG/M3	43.1	0.72	97.6%	42.8	0.63	97.6%
SECCHI M	1.1	1.39	49.8%	1.1	0.32	51.0%
ORGANIC N MG/M3	1159.4	0.50	96.0%			
TP-ORTHO-P MG/M3	79.0	0.46	84.6%			
ANTILOG PC-1	988.6	1.00	85.7%	963.2	0.66	85.2%
ANTILOG PC-2	18.1	1.45	97.6%	18.4	0.49	97.7%
TURBIDITY 1/M	0.3	9.11	17.8%	0.3	9.11	17.8%
ZMIX * TURBIDITY	0.4	9.11	0.3%	0.4	9.11	0.3%
ZMIX / SECCHI	1.2	1.40	1.0%	1.2	0.33	1.0%
CHL-A * SECCHI	46.4	1.94	98.4%	47.1	0.70	98.5%
CHL-A / TOTAL P	0.5	0.65	94.1%	0.5	0.69	94.0%
FREQ(CHL-a>10) %	98.0	0.06	97.6%	97.9	0.05	97.6%
FREQ(CHL-a>20) %	82.3	0.37	97.6%	82.0	0.31	97.6%
FREQ(CHL-a>30) %	60.8	0.74	97.6%	60.4	0.63	97.6%
FREQ(CHL-a>40) %	42.4	1.07	97.6%	42.0	0.93	97.6%
FREQ(CHL-a>50) %	29.1	1.37	97.6%	28.7	1.19	97.6%
FREQ(CHL-a>60) %	19.9	1.63	97.6%	19.6	1.43	97.6%
CARLSON TSI-P	67.5	0.08	72.1%	67.6	0.06	72.1%
CARLSON TSI-CHLA	67.5	0.10	97.6%	67.5	0.09	97.6%
CARLSON TSI-SEC	58.9	0.34	50.2%	58.6	0.08	49.0%

Table 139. Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for Long Lake

Component:	TOTAL P		Segment:	1	Long		
			Flow	Flow	Load	Load	Conc
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
1	1	Trib 1	0.1	41.8%	23.7	82.9%	269
PRECIPITATION			0.1	58.2%	4.9	17.1%	40
TRIBUTARY INFLOW			0.1	41.8%	23.7	82.9%	269
***TOTAL INFLOW			0.2	100.0%	28.5	100.0%	136
ADVECTIVE OUTFLOW			0.1	31.9%	5.4	19.1%	81
***TOTAL OUTFLOW			0.1	31.9%	5.4	19.1%	81
***EVAPORATION			0.1	68.1%	0.0	0.0%	
***RETENTION			0.0	0.0%	23.1	80.9%	
Hyd. Residence Time =			3.2166	yrs			
Overflow Rate =			0.4	m/yr			
Mean Depth =			1.3	m			

Table 140. TMDL scenario Bathtub model case data (input) for Long Lake

Tributary TP concentration was the only input that was revised from the calibrated (benchmark) model.

Tributary Data											
				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	
1	Trib 1	1	1	0.886	0.088	0	0	0	149	0	

Table 141. TMDL scenario Bathtub model diagnostics (model results) for Long Lake

Segment:	1	Long				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	60.4	0.35	60.2%	81.2	0.30	72.1%
CHL-A MG/M3	32.6	0.74	94.7%	42.8	0.63	97.6%
SECCHI M	1.3	1.85	61.1%	1.1	0.32	51.0%
ORGANIC N MG/M3	920.1	0.47	90.3%			
TP-ORTHO-P MG/M3	60.3	0.60	76.9%			
ANTILOG PC-1	619.8	1.36	76.1%	963.2	0.66	85.2%
ANTILOG PC-2	17.8	1.81	97.3%	18.4	0.49	97.7%
TURBIDITY 1/M	0.3	9.11	17.8%	0.3	9.11	17.8%
ZMIX * TURBIDITY	0.4	9.11	0.3%	0.4	9.11	0.3%
ZMIX / SECCHI	1.0	1.86	0.4%	1.2	0.33	1.0%
CHL-A * SECCHI	43.6	2.40	98.0%	47.1	0.70	98.5%
CHL-A / TOTAL P	0.5	0.64	94.4%	0.5	0.69	94.0%
FREQ(CHL-a>10) %	94.5	0.14	94.7%	97.9	0.05	97.6%
FREQ(CHL-a>20) %	68.3	0.62	94.7%	82.0	0.31	97.6%
FREQ(CHL-a>30) %	43.0	1.09	94.7%	60.4	0.63	97.6%
FREQ(CHL-a>40) %	26.1	1.48	94.7%	42.0	0.93	97.6%
FREQ(CHL-a>50) %	15.8	1.81	94.7%	28.7	1.19	97.6%
FREQ(CHL-a>60) %	9.8	2.09	94.7%	19.6	1.43	97.6%
CARLSON TSI-P	63.3	0.08	60.2%	67.6	0.06	72.1%
CARLSON TSI-CHLA	64.8	0.11	94.7%	67.5	0.09	97.6%
CARLSON TSI-SEC	55.8	0.48	38.9%	58.6	0.08	49.0%

Table 142. TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for Long Lake

Component: TOTAL P			Segment: 1 Long				
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Trib 1	0.1	41.8%	13.1	72.9%	149
PRECIPITATION			0.1	58.2%	4.9	27.1%	40
TRIBUTARY INFLOW			0.1	41.8%	13.1	72.9%	149
***TOTAL INFLOW			0.2	100.0%	18.0	100.0%	85
ADVECTIVE OUTFLOW			0.1	31.9%	4.1	22.5%	60
***TOTAL OUTFLOW			0.1	31.9%	4.1	22.5%	60
***EVAPORATION			0.1	68.1%	0.0	0.0%	
***RETENTION			0.0	0.0%	13.9	77.5%	
Hyd. Residence Time =			3.2166	yrs			
Overflow Rate =			0.4	m/yr			
Mean Depth =			1.3	m			

22.7 Loon Lake

Table 143. Calibrated (benchmark) Bathtub model case data (input) for Loon Lake

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.77	0.0
Evaporation (m)	0.9	0.0
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	30.26	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	8	CANF & BACH, LAKES
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seq	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Loon	0	1	0.214	1.71	0.263	1.71	0.12	0	0	0.36	17.84	0	0	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seq	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	135.8	0.218	0	0	109.3	0.468	0.5	0.32	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seq	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	0.465	0	1	0	1.7	0	1.4	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Monitored Inputs	1	1	1.595	0.16	0	0	0	306	0	0	0	0	0	0	0

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

Table 144. Calibrated (benchmark) Bathtub model diagnostics (model results) for Loon Lake

Segment:	1	Loon				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	136.2	0.30	87.7%	135.8	0.22	87.7%
CHL-A MG/M3	108.6	1.90	99.9%	109.3	0.47	99.9%
SECCHI M	0.5	0.53	12.8%	0.5	0.32	15.5%
ORGANIC N MG/M3	2660.3	1.60	100.0%			
TP-ORTHO-P MG/M3	197.8	1.12	97.6%			
ANTILOG PC-1	5304.0	1.50	99.1%	4889.7	0.53	98.9%
ANTILOG PC-2	17.3	1.60	97.0%	18.7	0.40	97.9%
TURBIDITY 1/M	0.4	17.84	27.5%	0.4	17.84	27.5%
ZMIX * TURBIDITY	0.6	17.84	1.8%	0.6	17.84	1.8%
ZMIX / SECCHI	3.8	0.52	34.1%	3.4	0.33	28.4%
CHL-A * SECCHI	49.4	2.31	98.7%	54.7	0.57	99.1%
CHL-A / TOTAL P	0.8	1.90	98.6%	0.8	0.51	98.7%
FREQ(CHL-a>10) %	100.0	0.00	99.9%	100.0	0.00	99.9%
FREQ(CHL-a>20) %	99.2	0.07	99.9%	99.2	0.01	99.9%
FREQ(CHL-a>30) %	96.1	0.27	99.9%	96.2	0.06	99.9%
FREQ(CHL-a>40) %	90.3	0.58	99.9%	90.5	0.13	99.9%
FREQ(CHL-a>50) %	82.7	0.95	99.9%	82.9	0.22	99.9%
FREQ(CHL-a>60) %	74.1	1.34	99.9%	74.5	0.32	99.9%
CARLSON TSI-P	75.0	0.06	87.7%	75.0	0.04	87.7%
CARLSON TSI-CHLA	76.6	0.24	99.9%	76.6	0.06	99.9%
CARLSON TSI-SEC	71.3	0.11	87.2%	70.0	0.06	84.5%

Table 145. Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for Loon Lake

Component:		TOTAL P		Segment:	1	Loon	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Monitored Inputs	0.2	49.3%	49.0	88.3%	306
PRECIPITATION			0.2	50.7%	6.5	11.7%	39
TRIBUTARY INFLOW			0.2	49.3%	49.0	88.3%	306
***TOTAL INFLOW			0.3	100.0%	55.4	100.0%	171
ADVECTIVE OUTFLOW			0.1	40.7%	18.0	32.5%	136
***TOTAL OUTFLOW			0.1	40.7%	18.0	32.5%	136
***EVAPORATION			0.2	59.3%	0.0	0.0%	
***RETENTION			0.0	0.0%	37.4	67.5%	
Hyd. Residence Time =			2.7685	yrs			
Overflow Rate =			0.6	m/yr			
Mean Depth =			1.7	m			

Table 146. TMDL scenario Bathtub model case data (input) for Loon Lake

Tributary TP concentration was the only input that was revised from the calibrated (benchmark) model.

Tributary Data										
				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV
1	Monitored Inputs	1	1	1.595	0.16	0	0	0	71	0

Table 147. TMDL scenario Bathtub model diagnostics (model results) for Loon Lake

Segment:	1	Loon				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	60.3	0.28	60.1%	135.8	0.22	87.7%
CHL-A MG/M3	58.6	1.91	99.1%	109.3	0.47	99.9%
SECCHI M	0.8	2.03	32.6%	0.5	0.32	15.5%
ORGANIC N MG/M3	1521.1	1.38	98.9%			
TP-ORTHO-P MG/M3	108.8	0.56	91.2%			
ANTILOG PC-1	1818.0	0.65	93.7%	4889.7	0.53	98.9%
ANTILOG PC-2	17.1	2.82	96.9%	18.7	0.40	97.9%
TURBIDITY 1/M	0.4	17.84	27.5%	0.4	17.84	27.5%
ZMIX * TURBIDITY	0.6	17.84	1.8%	0.6	17.84	1.8%
ZMIX / SECCHI	2.2	2.04	9.6%	3.4	0.33	28.4%
CHL-A * SECCHI	45.0	3.88	98.2%	54.7	0.57	99.1%
CHL-A / TOTAL P	1.0	1.89	99.4%	0.8	0.51	98.7%
FREQ(CHL-a>10) %	99.4	0.05	99.1%	100.0	0.00	99.9%
FREQ(CHL-a>20) %	92.3	0.49	99.1%	99.2	0.01	99.9%
FREQ(CHL-a>30) %	78.0	1.18	99.1%	96.2	0.06	99.9%
FREQ(CHL-a>40) %	62.1	1.89	99.1%	90.5	0.13	99.9%
FREQ(CHL-a>50) %	47.9	2.57	99.1%	82.9	0.22	99.9%
FREQ(CHL-a>60) %	36.4	3.18	99.1%	74.5	0.32	99.9%
CARLSON TSI-P	63.3	0.06	60.1%	75.0	0.04	87.7%
CARLSON TSI-CHLA	70.5	0.27	99.1%	76.6	0.06	99.9%
CARLSON TSI-SEC	63.8	0.46	67.4%	70.0	0.06	84.5%

Table 148. TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for Loon Lake

Component: TOTAL P			Segment:		1	Loon	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Monitored Inputs	0.2	49.3%	11.4	63.7%	71
PRECIPITATION			0.2	50.7%	6.5	36.3%	39
TRIBUTARY INFLOW			0.2	49.3%	11.4	63.7%	71
***TOTAL INFLOW			0.3	100.0%	17.8	100.0%	55
ADVECTIVE OUTFLOW			0.1	40.7%	8.0	44.7%	60
***TOTAL OUTFLOW			0.1	40.7%	8.0	44.7%	60
***EVAPORATION			0.2	59.3%	0.0	0.0%	
***RETENTION			0.0	0.0%	9.9	55.3%	
Hyd. Residence Time =			2.7685	yrs			
Overflow Rate =			0.6	m/yr			
Mean Depth =			1.7	m			

22.8 Lake Louise

Table 149. Calibrated (benchmark) Bathtub model case data (input) for Lake Louise

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.77	0.0
Evaporation (m)	0.9	0.0
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	30.26	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	8	CANF & BACH, LAKES
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seq	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Louise	0	1	0.187	1.22	0.16	1.22	0.12	0	0	0.22	12.05	0	0	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seq	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	119.9	0.379	0	0	51.7	0.683	1	0.387	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seq	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	0.51	0	1	0	0.7	0	1.5	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Monitored Inputs	1	1	0.888	0.089	0	0	0	257	0	0	0	0	0	0	0

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

Table 150. Calibrated (benchmark) Bathtub model diagnostics (model results) for Lake Louise

Segment:	1	Louise				
	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	120.5	0.33	84.7%	119.9	0.38	84.6%
CHL-A MG/M3	52.4	0.69	98.7%	51.7	0.68	98.7%
SECCHI M	1.0	1.27	44.9%	1.0	0.39	46.0%
ORGANIC N MG/M3	1368.0	0.50	98.1%			
TP-ORTHO-P MG/M3	94.4	0.40	88.6%			
ANTILOG PC-1	1298.8	0.87	89.9%	1259.4	0.74	89.4%
ANTILOG PC-2	19.2	1.35	98.1%	19.4	0.55	98.2%
TURBIDITY 1/M	0.2	12.05	12.4%	0.2	12.05	12.4%
ZMIX * TURBIDITY	0.3	12.05	0.1%	0.3	12.05	0.1%
ZMIX / SECCHI	1.2	1.27	1.0%	1.2	0.39	1.0%
CHL-A * SECCHI	51.4	1.82	98.9%	51.7	0.79	98.9%
CHL-A / TOTAL P	0.4	0.65	89.5%	0.4	0.78	89.2%
FREQ(CHL-a>10) %	99.1	0.03	98.7%	99.0	0.03	98.7%
FREQ(CHL-a>20) %	89.3	0.23	98.7%	88.9	0.22	98.7%
FREQ(CHL-a>30) %	72.2	0.52	98.7%	71.5	0.51	98.7%
FREQ(CHL-a>40) %	55.0	0.80	98.7%	54.1	0.79	98.7%
FREQ(CHL-a>50) %	40.7	1.06	98.7%	39.9	1.06	98.7%
FREQ(CHL-a>60) %	29.8	1.29	98.7%	29.1	1.29	98.7%
CARLSON TSI-P	73.2	0.07	84.7%	73.2	0.07	84.6%
CARLSON TSI-CHLA	69.4	0.10	98.7%	69.3	0.10	98.7%
CARLSON TSI-SEC	60.3	0.30	55.1%	60.0	0.09	54.0%

Table 151. Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for Lake Louise

Component:	TOTAL P		Segment:	1	Louise		
			Flow	Flow	Load	Load	Conc
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
1	1	Monitored Inputs	0.1	38.2%	22.9	80.2%	257
PRECIPITATION			0.1	61.8%	5.7	19.8%	39
TRIBUTARY INFLOW			0.1	38.2%	22.9	80.2%	257
***TOTAL INFLOW			0.2	100.0%	28.5	100.0%	122
ADVECTIVE OUTFLOW			0.1	27.8%	7.8	27.3%	120
***TOTAL OUTFLOW			0.1	27.8%	7.8	27.3%	120
***EVAPORATION			0.2	72.2%	0.0	0.0%	
***RETENTION			0.0	0.0%	20.7	72.7%	
Hyd. Residence Time =			3.5267	yrs			
Overflow Rate =			0.3	m/yr			
Mean Depth =			1.2	m			

Table 152. TMDL scenario Bathtub model case data (input) for Lake Louise
Tributary TP concentration was the only input that was revised from the calibrated (benchmark) model.

Tributary Data											
				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	
1	Monitored Inputs	1	1	0.888	0.089	0	0	0	54	0	

Table 153. TMDL scenario Bathtub model diagnostics (model results) for Lake Louise

Segment:	1	Louise				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	60.4	0.34	60.1%	119.9	0.38	84.6%
CHL-A MG/M3	28.3	0.73	92.4%	51.7	0.68	98.7%
SECCHI M	1.6	2.42	70.3%	1.0	0.39	46.0%
ORGANIC N MG/M3	817.7	0.42	85.7%			
TP-ORTHO-P MG/M3	51.4	0.79	71.5%			
ANTILOG PC-1	452.9	1.84	68.0%	1259.4	0.74	89.4%
ANTILOG PC-2	18.8	2.27	97.9%	19.4	0.55	98.2%
TURBIDITY 1/M	0.2	12.05	12.4%	0.2	12.05	12.4%
ZMIX * TURBIDITY	0.3	12.05	0.1%	0.3	12.05	0.1%
ZMIX / SECCHI	0.8	2.44	0.1%	1.2	0.39	1.0%
CHL-A * SECCHI	45.7	2.99	98.3%	51.7	0.79	98.9%
CHL-A / TOTAL P	0.5	0.64	91.4%	0.4	0.78	89.2%
FREQ(CHL-a>10) %	91.4	0.20	92.4%	99.0	0.03	98.7%
FREQ(CHL-a>20) %	59.8	0.76	92.4%	88.9	0.22	98.7%
FREQ(CHL-a>30) %	34.2	1.27	92.4%	71.5	0.51	98.7%
FREQ(CHL-a>40) %	19.2	1.68	92.4%	54.1	0.79	98.7%
FREQ(CHL-a>50) %	10.9	2.02	92.4%	39.9	1.06	98.7%
FREQ(CHL-a>60) %	6.4	2.31	92.4%	29.1	1.29	98.7%
CARLSON TSI-P	63.3	0.08	60.1%	73.2	0.07	84.6%
CARLSON TSI-CHLA	63.4	0.11	92.4%	69.3	0.10	98.7%
CARLSON TSI-SEC	53.1	0.66	29.7%	60.0	0.09	54.0%

Table 154. TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for Lake Louise

Component:		TOTAL P	Segment:		1	Louise	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Monitored Inputs	0.1	38.2%	4.8	45.9%	54
PRECIPITATION			0.1	61.8%	5.7	54.1%	39
TRIBUTARY INFLOW			0.1	38.2%	4.8	45.9%	54
***TOTAL INFLOW			0.2	100.0%	10.5	100.0%	45
ADVECTIVE OUTFLOW			0.1	27.8%	3.9	37.3%	60
***TOTAL OUTFLOW			0.1	27.8%	3.9	37.3%	60
***EVAPORATION			0.2	72.2%	0.0	0.0%	
***RETENTION			0.0	0.0%	6.6	62.7%	
Hyd. Residence Time =			3.5267	yrs			
Overflow Rate =			0.3	m/yr			
Mean Depth =			1.2	m			

22.9 Mud Lake

Table 155. Calibrated (benchmark) Bathtub model case data (input) for Mud Lake

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.76	0.0
Evaporation (m)	0.9	0.0
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	30.26	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	8	CANF & BACH, LAKES
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Mud	0	1	0.244	1.52	0.61	1.5	0.12	0	0	0.92	0.23	0	0	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	79	0.09	0	0	34	0.1	0.7	0.07	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	0.42	0	1	0	0.84	0	1.2	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Monitored Inputs	1	1	1.286	0.13	0	0	0	96.2	0	0	0	0	0	0	0

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

Table 156. Calibrated (benchmark) Bathtub model diagnostics (model results) for Mud Lake

Segment:	1	Mud				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	78.9	0.30	71.0%	79.0	0.09	71.1%
CHL-A MG/M3	34.2	0.38	95.3%	34.0	0.10	95.3%
SECCHI M	0.7	0.23	26.9%	0.7	0.07	28.4%
ORGANIC N MG/M3	1005.2	0.32	93.0%			
TP-ORTHO-P MG/M3	78.5	0.33	84.4%			
ANTILOG PC-1	1223.6	0.54	89.0%	1179.8	0.11	88.5%
ANTILOG PC-2	10.8	0.17	83.8%	11.1	0.09	84.9%
TURBIDITY 1/M	0.9	0.23	68.0%	0.9	0.23	68.0%
ZMIX * TURBIDITY	1.4	0.26	14.4%	1.4	0.26	14.4%
ZMIX / SECCHI	2.2	0.24	9.4%	2.1	0.14	8.5%
CHL-A * SECCHI	23.1	0.26	87.6%	23.8	0.12	88.4%
CHL-A / TOTAL P	0.4	0.28	89.4%	0.4	0.13	89.2%
FREQ(CHL-a>10) %	95.3	0.06	95.3%	95.2	0.02	95.3%
FREQ(CHL-a>20) %	71.0	0.29	95.3%	70.7	0.08	95.3%
FREQ(CHL-a>30) %	46.0	0.53	95.3%	45.7	0.14	95.3%
FREQ(CHL-a>40) %	28.6	0.73	95.3%	28.4	0.19	95.3%
FREQ(CHL-a>50) %	17.8	0.90	95.3%	17.6	0.24	95.3%
FREQ(CHL-a>60) %	11.1	1.05	95.3%	11.0	0.28	95.3%
CARLSON TSI-P	67.1	0.07	71.0%	67.2	0.02	71.1%
CARLSON TSI-CHLA	65.2	0.06	95.3%	65.2	0.01	95.3%
CARLSON TSI-SEC	65.6	0.05	73.1%	65.1	0.02	71.6%

Table 157. Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for Mud Lake

Component:		TOTAL P	Segment:		1	Mud	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Monitored Inputs	0.1	41.2%	12.5	62.9%	96
PRECIPITATION			0.2	58.8%	7.4	37.1%	40
TRIBUTARY INFLOW			0.1	41.2%	12.5	62.9%	96
***TOTAL INFLOW			0.3	100.0%	19.9	100.0%	63
ADVECTIVE OUTFLOW			0.1	30.4%	7.6	38.0%	79
***TOTAL OUTFLOW			0.1	30.4%	7.6	38.0%	79
***EVAPORATION			0.2	69.6%	0.0	0.0%	
***RETENTION			0.0	0.0%	12.3	62.0%	
Hyd. Residence Time =			3.8698	yrs			
Overflow Rate =			0.4	m/yr			
Mean Depth =			1.5	m			

Table 158. TMDL scenario Bathtub model case data (input) for Mud Lake

Tributary TP concentration was the only input that was revised from the calibrated (benchmark) model.

Tributary Data											
				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV
1	Monitored Inputs	1	1	1.286	0.13	0	0	0	49	0

Table 159. TMDL scenario Bathtub model diagnostics (model results) for Mud Lake

Segment:	1	Mud				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	60.4	0.32	60.1%	79.0	0.09	71.1%
CHL-A MG/M3	26.7	0.42	91.3%	34.0	0.10	95.3%
SECCHI M	0.8	0.23	31.9%	0.7	0.07	28.4%
ORGANIC N MG/M3	834.9	0.32	86.7%			
TP-ORTHO-P MG/M3	65.2	0.34	79.3%			
ANTILOG PC-1	872.9	0.57	83.4%	1179.8	0.11	88.5%
ANTILOG PC-2	10.0	0.20	79.8%	11.1	0.09	84.9%
TURBIDITY 1/M	0.9	0.23	68.0%	0.9	0.23	68.0%
ZMIX * TURBIDITY	1.4	0.26	14.4%	1.4	0.26	14.4%
ZMIX / SECCHI	2.0	0.25	6.6%	2.1	0.14	8.5%
CHL-A * SECCHI	20.2	0.30	83.2%	23.8	0.12	88.4%
CHL-A / TOTAL P	0.4	0.27	90.0%	0.4	0.13	89.2%
FREQ(CHL-a>10) %	89.9	0.13	91.3%	95.2	0.02	95.3%
FREQ(CHL-a>20) %	56.2	0.47	91.3%	70.7	0.08	95.3%
FREQ(CHL-a>30) %	30.9	0.76	91.3%	45.7	0.14	95.3%
FREQ(CHL-a>40) %	16.8	1.00	91.3%	28.4	0.19	95.3%
FREQ(CHL-a>50) %	9.3	1.21	91.3%	17.6	0.24	95.3%
FREQ(CHL-a>60) %	5.3	1.38	91.3%	11.0	0.28	95.3%
CARLSON TSI-P	63.3	0.07	60.1%	67.2	0.02	71.1%
CARLSON TSI-CHLA	62.8	0.06	91.3%	65.2	0.01	95.3%
CARLSON TSI-SEC	64.0	0.05	68.1%	65.1	0.02	71.6%

Table 160. TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for Mud Lake

Component:	TOTAL P		Segment:		1	Mud	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Monitored Inputs	0.1	41.2%	6.4	46.3%	49
PRECIPITATION			0.2	58.8%	7.4	53.7%	40
TRIBUTARY INFLOW			0.1	41.2%	6.4	46.3%	49
***TOTAL INFLOW			0.3	100.0%	13.8	100.0%	44
ADVECTIVE OUTFLOW			0.1	30.4%	5.8	42.1%	60
***TOTAL OUTFLOW			0.1	30.4%	5.8	42.1%	60
***EVAPORATION			0.2	69.6%	0.0	0.0%	
***RETENTION			0.0	0.0%	8.0	57.9%	
Hyd. Residence Time =			3.8698	yrs			
Overflow Rate =			0.4	m/yr			
Mean Depth =			1.5	m			

22.10 South Twin Lake

Table 161. Calibrated (benchmark) Bathtub model case data (input) for South Twin Lake

Global Variables	Mean	CV	Model Options	Code	Description
Averaging Period (yrs)	1	0.0	Conservative Substance	0	NOT COMPUTED
Precipitation (m)	0.77	0.0	Phosphorus Balance	8	CANF & BACH, LAKES
Evaporation (m)	0.9	0.0	Nitrogen Balance	0	NOT COMPUTED
Storage Increase (m)	0	0.0	Chlorophyll-a	2	P, LIGHT, T
			Secchi Depth	1	VS. CHLA & TURBIDITY
Atmos. Loads (kg/km^2-yr	**Mean**	**CV**	Dispersion	1	FISCHER-NUMERIC
Conserv. Substance	0	0.00	Phosphorus Calibration	1	DECAY RATES
Total P	30.26	0.50	Nitrogen Calibration	1	DECAY RATES
Total N	1000	0.50	Error Analysis	1	MODEL & DATA
Ortho P	15	0.50	Availability Factors	0	IGNORE
Inorganic N	500	0.50	Mass-Balance Tables	1	USE ESTIMATED CONCS
			Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	South Twin	0	1	0.226	1.62	0.209	1.62	0.12	0	0	0.33	7.25	0	0	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	72.8	0.278	0	0	38.9	0.487	1.1	0.369	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	0.66	0	1	0	0.92	0	1.4	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Monitored Inputs	1	1	0.336	0.034	0	0	0	296	0	0	0	0	0	0	0

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

Table 162. Calibrated (benchmark) Bathtub model diagnostics (model results) for South Twin Lake

Segment:	1	South Twin				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	73.2	0.44	68.1%	72.8	0.28	67.9%
CHL-A MG/M3	39.2	0.82	96.8%	38.9	0.49	96.8%
SECCHI M	1.1	1.37	49.5%	1.1	0.37	51.0%
ORGANIC N MG/M3	1074.8	0.56	94.6%			
TP-ORTHO-P MG/M3	73.4	0.49	82.7%			
ANTILOG PC-1	909.0	0.99	84.2%	879.7	0.57	83.5%
ANTILOG PC-2	16.9	1.48	96.7%	17.2	0.43	96.9%
TURBIDITY 1/M	0.3	7.25	24.3%	0.3	7.25	24.3%
ZMIX * TURBIDITY	0.5	7.25	1.1%	0.5	7.25	1.1%
ZMIX / SECCHI	1.5	1.38	2.4%	1.5	0.38	2.2%
CHL-A * SECCHI	41.9	1.99	97.7%	42.8	0.61	97.9%
CHL-A / TOTAL P	0.5	0.72	94.3%	0.5	0.56	94.3%
FREQ(CHL-a>10) %	97.1	0.09	96.8%	97.0	0.05	96.8%
FREQ(CHL-a>20) %	78.1	0.50	96.8%	77.7	0.29	96.8%
FREQ(CHL-a>30) %	54.8	0.96	96.8%	54.3	0.56	96.8%
FREQ(CHL-a>40) %	36.5	1.36	96.8%	36.1	0.81	96.8%
FREQ(CHL-a>50) %	24.1	1.70	96.8%	23.7	1.02	96.8%
FREQ(CHL-a>60) %	15.9	2.01	96.8%	15.6	1.21	96.8%
CARLSON TSI-P	66.0	0.10	68.1%	66.0	0.06	67.9%
CARLSON TSI-CHLA	66.6	0.12	96.8%	66.5	0.07	96.8%
CARLSON TSI-SEC	59.0	0.34	50.5%	58.6	0.09	49.0%

Table 163. Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for South Twin Lake

Component:		TOTAL P		Segment:	1	South Twin	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Monitored Inputs	0.0	16.3%	10.1	59.5%	296
PRECIPITATION			0.2	83.7%	6.8	40.5%	39
TRIBUTARY INFLOW			0.0	16.3%	10.1	59.5%	296
***TOTAL INFLOW			0.2	100.0%	16.9	100.0%	81
ADVECTIVE OUTFLOW			0.0	2.2%	0.3	2.0%	73
***TOTAL OUTFLOW			0.0	2.2%	0.3	2.0%	73
***EVAPORATION			0.2	97.8%	0.0	0.0%	
***RETENTION			0.0	0.0%	16.6	98.0%	
Hyd. Residence Time =			79.2467	yrs			
Overflow Rate =			0.0	m/yr			
Mean Depth =			1.6	m			

Table 164. TMDL scenario Bathtub model case data (input) for South Twin Lake

Tributary TP concentration was the only input that was revised from the calibrated (benchmark) model.

Tributary Data										
				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV
1	Monitored Inputs	1	1	0.336	0.034	0	0	0	151	0

Table 165. TMDL scenario Bathtub model diagnostics (model results) for South Twin Lake

Segment:	1	South Twin				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	60.5	0.46	60.2%	72.8	0.28	67.9%
CHL-A MG/M3	32.9	0.84	94.8%	38.9	0.49	96.8%
SECCHI M	1.2	1.63	56.1%	1.1	0.37	51.0%
ORGANIC N MG/M3	932.0	0.55	90.8%			
TP-ORTHO-P MG/M3	62.3	0.58	77.9%			
ANTILOG PC-1	684.2	1.19	78.3%	879.7	0.57	83.5%
ANTILOG PC-2	16.6	1.69	96.4%	17.2	0.43	96.9%
TURBIDITY 1/M	0.3	7.25	24.3%	0.3	7.25	24.3%
ZMIX * TURBIDITY	0.5	7.25	1.1%	0.5	7.25	1.1%
ZMIX / SECCHI	1.3	1.65	1.4%	1.5	0.38	2.2%
CHL-A * SECCHI	40.0	2.26	97.3%	42.8	0.61	97.9%
CHL-A / TOTAL P	0.5	0.72	94.6%	0.5	0.56	94.3%
FREQ(CHL-a>10) %	94.6	0.16	94.8%	97.0	0.05	96.8%
FREQ(CHL-a>20) %	68.9	0.70	94.8%	77.7	0.29	96.8%
FREQ(CHL-a>30) %	43.6	1.23	94.8%	54.3	0.56	96.8%
FREQ(CHL-a>40) %	26.6	1.67	94.8%	36.1	0.81	96.8%
FREQ(CHL-a>50) %	16.2	2.05	94.8%	23.7	1.02	96.8%
FREQ(CHL-a>60) %	10.0	2.37	94.8%	15.6	1.21	96.8%
CARLSON TSI-P	63.3	0.10	60.2%	66.0	0.06	67.9%
CARLSON TSI-CHLA	64.9	0.13	94.8%	66.5	0.07	96.8%
CARLSON TSI-SEC	57.2	0.41	43.9%	58.6	0.09	49.0%

Table 166. TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for South Twin Lake

Component:	TOTAL P		Segment:	1	South Twin		
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Monitored Inputs	0.0	16.3%	5.1	42.9%	151
PRECIPITATION			0.2	83.7%	6.8	57.1%	39
TRIBUTARY INFLOW			0.0	16.3%	5.1	42.9%	151
***TOTAL INFLOW			0.2	100.0%	12.0	100.0%	58
ADVECTIVE OUTFLOW			0.0	2.2%	0.3	2.3%	60
***TOTAL OUTFLOW			0.0	2.2%	0.3	2.3%	60
***EVAPORATION			0.2	97.8%	0.0	0.0%	
***RETENTION			0.0	0.0%	11.7	97.7%	
Hyd. Residence Time =			79.2467	yrs			
Overflow Rate =			0.0	m/yr			
Mean Depth =			1.6	m			