Lino Lakes Chain of Lakes Nutrient TMDL

Prepared for

Rice Creek Watershed District

Minnesota Pollution Control Agency

July 2013

wq-iw11-13e

Lino Lakes Chain of Lakes Nutrient TMDL

Wenck File #1137-05

Prepared for:

RICE CREEK WATERSHED DISTRICT

MINNESOTA POLLUTION CONTROL AGENCY

July 2013

Prepared by:

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TMDL Summary

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<tr><th>EPA/MPCA Required Elements</th><th colspan="3">Summary</th><th>TMDL Page #</th></tr>
<tr><td>Location</td><td colspan="3">City of Lino Lakes in Anoka County, Minnesota, in the Upper Mississippi River Basin</td><td>3-1 – 3-4</td></tr>
<tr><td>303(d) Listing Information</td><td colspan="3">George Watch Lake 02-0005
Marshan Lake 02-0007
Reshanau Lake 02-0009
Rice Lake 02-0008
Baldwin Lake 02-0013

The lakes above were added to the 303(d) list because of excess nutrient concentrations impairing aquatic recreation, as set forth in Minnesota Rules 7050.0150. George Watch and Marshan Lakes were added in 2002, Reshanau in 2006 and Rice and Baldwin in 2010.</td><td>2-1</td></tr>
<tr><td>Applicable Water Quality Standards/ Numeric Targets</td><td colspan="3">Criteria set forth in Minn. R. 7050.0150 (3) and (5). These lakes are shallow lakes, so the target is total phosphorus concentration of 60 µg/L or less.</td><td>2-1 – 2-3</td></tr>
<tr><td rowspan="7">Loading Capacity (expressed as daily load)</td><td colspan="3">The loading capacity is the total maximum daily load for each of these conditions. The critical condition for these lakes is the summer growing season. The loading capacity is set forth in Table 5.4.</td><td rowspan="7">5-5</td></tr>
<tr><td colspan="3">Total maximum daily total phosphorus load (lb/day)</td></tr>
<tr><td colspan="2">George Watch</td><td>31.95</td></tr>
<tr><td colspan="2">Marshan</td><td>26.0</td></tr>
<tr><td colspan="2">Reshanau</td><td>0.71</td></tr>
<tr><td colspan="2">Rice</td><td>30.68</td></tr>
<tr><td colspan="2">Baldwin</td><td>27.94</td></tr>
<tr><td rowspan="5">Wasteload Allocation</td><td colspan="3">Portion of the loading capacity allocated to existing and future point sources. Note: Mn/DOT (MS400170) is provided with an individual WLA; the remaining MS4s are aggregated into a categorical WLA (see Table 5.4 for apportionment)</td><td rowspan="5">5-6</td></tr>
<tr><td>Source</td><td>Permit #</td><td>WLA (lb/day)</td></tr>
<tr><td colspan="3">Permitted Stormwater:</td></tr>
<tr><td>George Watch</td><td>MS400100 MS400078
MS400066
MS400170</td><td>0.43</td></tr>
<tr><td>Marshan</td><td>MS400100 MS400078
MS400163 MS400121
MS400075 MS400092
MS400066 MS400170
MS400191
MS400177</td><td>1.5</td></tr>
</table>

TMDL Summary

<table>
<tr><th colspan="5">TMDL Summary Table</th></tr>
<tr><th>EPA/MPCA Required Elements</th><th colspan="3">Summary</th><th>TMDL Page #</th></tr>
<tr><td rowspan="3"></td><td>Reshanau</td><td>MS400100 MS400163
MS400121 MS400075
MS400092 MS400191
MS400066
MS400109</td><td>0.03</td><td rowspan="3"></td></tr>
<tr><td>Rice</td><td>MS400100 MS400078
MS400009 MS400163
MS400121 MS400075
MS400092 MS400066
MS400191 MS400170</td><td>1.2</td></tr>
<tr><td>Baldwin</td><td>MS400100 MS400078
MS400009 MS400163
MS400121 MS400075
MS400092 MS400066
MS400191</td><td>0.22</td></tr>
<tr><td rowspan="26">Load Allocation
Watershed Load</td><td colspan="3">The portion of the loading capacity allocated to existing and future nonpoint sources.</td><td rowspan="26">5-6</td></tr>
<tr><td>Source</td><td colspan="2">Load Allocation (lb/day)</td></tr>
<tr><td>Atmospheric Load</td><td colspan="2"></td></tr>
<tr><td>George Watch</td><td colspan="2">0.3</td></tr>
<tr><td>Marshan</td><td colspan="2">0.1</td></tr>
<tr><td>Reshanau</td><td colspan="2">0.02</td></tr>
<tr><td>Rice</td><td colspan="2">0.17</td></tr>
<tr><td>Baldwin</td><td colspan="2">0.08</td></tr>
<tr><td>Internal Load</td><td colspan="2"></td></tr>
<tr><td>George Watch</td><td colspan="2">10.4</td></tr>
<tr><td>Marshan</td><td colspan="2">1.8</td></tr>
<tr><td>Reshanau</td><td colspan="2">0.2</td></tr>
<tr><td>Rice</td><td colspan="2">6.3</td></tr>
<tr><td>Baldwin</td><td colspan="2">4.6</td></tr>
<tr><td>Watershed Load</td><td colspan="2"></td></tr>
<tr><td>George Watch</td><td colspan="2">0.92</td></tr>
<tr><td>Marshan</td><td colspan="2">2.3</td></tr>
<tr><td>Reshanau</td><td colspan="2">0.04</td></tr>
<tr><td>Rice</td><td colspan="2">0.81</td></tr>
<tr><td>Baldwin</td><td colspan="2">0.34</td></tr>
<tr><td>Upstream Lake Load</td><td colspan="2"></td></tr>
<tr><td>George Watch</td><td colspan="2">19.9</td></tr>
<tr><td>Marshan</td><td colspan="2">20.3</td></tr>
<tr><td>Reshanau</td><td colspan="2">0.42</td></tr>
<tr><td>Rice</td><td colspan="2">22.2</td></tr>
<tr><td>Baldwin</td><td colspan="2">22.7</td></tr>
<tr><td>Margin of Safety</td><td colspan="3">The margin of safety is implicit in each TMDL due to the</td><td>5-14</td></tr>
</table>

TMDL Summary

TMDL Summary Table		
EPA/MPCA Required Elements	**Summary**	**TMDL Page #**
	conservative assumptions of the model.	
Seasonal Variation	Seasonal variation is accounted for by developing targets for the summer critical period where the frequency and severity of nuisance algal growth is greatest. Although the critical period is the summer, lakes are not sensitive to short-term changes but rather respond to long term changes in annual load.	5-14
Reasonable Assurance	Reasonable assurance is provided by oversight from the Rice Creek Watershed District. In addition, almost the entire contributing area to these lakes is regulated under the NPDES program, and Minnesota's General Permit requires MS4s to amend their NPDES permit's Storm Water Pollution Prevention Plan within 18 months after adoption of a TMDL to set forth a plan to meet the TMDL wasteload allocation.	Section 8.0
Monitoring	The Rice Creek Watershed District periodically monitors these lakes and will continue to do so through the implementation period.	8-4
Implementation	This TMDL sets forth an implementation framework and general load reduction strategies that will be expanded and refined through the development of an Implementation Plan.	Section 7.0
Public Participation	Included Stakeholder Advisory Committee, public meetings and 30-day public comment period	Section 6.0

Executive Summary

This Total Maximum Daily Load (TMDL) study addresses nutrient impairments in the Lino Lakes chain of lakes. The goal of this TMDL is to quantify the pollutant reductions needed to meet state water quality standards for nutrients in George Watch (02-0005), Marshan (02-0007), Reshanau (02-0009), Rice (02-0008) and Baldwin Lakes (02-0013).

The Lino Lakes chain of lakes is a regional water resource located in Anoka County, Minnesota, in the Rice Creek watershed, specifically in the city of Lino Lakes. The lakes are highly used recreational water bodies that support fishing and boating as well as provide aesthetic values. Four of the lakes are wholly or partially located within the Rice Creek Regional Park Reserve. The drainage area to the lake chain is 12,000 acres of suburban, regional park, undeveloped wetland, and agricultural land. The lakes are connected to each other by channels of varying lengths. George Watch, Marshan, Rice, and Baldwin Lakes are part of a longer flow-through chain of lakes receiving outflow from Peltier Lake upstream, while Reshanau receives outflow from some smaller lakes and discharges to Rice Lake. The lake system discharges into Rice Creek, which ultimately discharges into the Mississippi River. Water quality is poor with frequent algal blooms. All of the lakes in this study are shallow lakes, with maximum depths generally less than 10 feet.

Peltier Lake is located upstream of this chain, and is an impaired water for excess nutrients. A separate TMDL is being developed for that lake. Outflow from Peltier into George Watch Lake is the source of about 90 percent of the annual flow of water through the chain of lakes, and most of the external nutrient load. The two most significant sources of excess phosphorus to these lakes are the outflow from Peltier Lake and internal loading.

Wasteload and load allocations to meet state standards indicate that nutrient load reductions ranging from 65 to 85 percent would be required to consistently meet standards under average precipitation conditions. To achieve these reductions, Peltier Lake must achieve its TMDL goal and internal loads in the chain of lakes must be significantly reduced through a combination of aquatic vegetation and fishery management.

1.0 Introduction

1.1 PURPOSE

This Total Maximum Daily Load (TMDL) study addresses a nutrient impairment in the Lino Lakes chain of lakes. The goal of this TMDL is to establish wasteload allocations (WLAs) and load allocations (LAs) and quantify the pollutant reductions needed to meet the water quality standards for nutrients in George Watch, Marshan, Reshanau, Rice and Baldwin Lakes. The Lino Lakes chain of lakes TMDL for nutrients is being established in accordance with section 303(d) of the Clean Water Act because the State of Minnesota has determined these waters exceed the state established standards for nutrients.

1.2 PROBLEM IDENTIFICATION

The Lino Lakes chain of lakes is a regional water resource located in the Rice Creek watershed, specifically in the city of Lino Lakes. Four of the five lakes in this chain are located partially or entirely within the Rice Creek Chain of Lakes Regional Park Reserve. The lakes are hypereutrophic, with average summer total phosphorus concentrations ranging from 140 µg/L to 292 µg/L, compared to the State of Minnesota standard of 60 µg/L for shallow lakes in the North Central Hardwood Forest Ecoregion. Single family homes abut most of Reshanau's shoreline, which averages 149 µg/L. Extensive mats of the non-native plant curly-leaf pondweed (*Potamogeton crispus*) form annually on some of the lakes. All lakes are also infested with significant populations of rough fish, such as carp and black bullhead. These conditions limit the fishery and the aesthetic enjoyment of the lakes. The lakes do not meet water quality standards for aquatic life and recreation.

At the start of this TMDL, neither Rice nor Baldwin Lakes were included on the 303(d) list because not enough data were available to meet the state's listing criteria. Data for both lakes were collected in 2007 to evaluate the lakes' water quality and to validate the need to include these lakes in this TMDL (Appendix B). In 2007, Rice Lake had a summer total phosphorus average of 264 µg/L and 62 µg/L chlorophyll-a while Baldwin Lake had a summer total phosphorus average of 232 µg/L and 70 µg/L chlorophyll-a. Based on the data collected in 2007, both lakes are impaired and are included on the state's 303(d) draft 2010 list.

2.0 Target Identification and Determination of Endpoints

2.1 IMPAIRED WATERS

The listings for the five lakes in this study are shown in Table 2.1. The lakes are impaired by excess nutrient concentrations, which inhibit aquatic recreation. 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 water body; technical capability and willingness locally to assist with the TMDL; and appropriate sequencing of TMDLs within a watershed or basin.

Table 2.1. Impaired waters in the Lino Lakes chain of lakes

Lake	DNR Lake #	Listing Year	Affected use	Pollutant or Stressor	Target TMDL Start	Target TMDL Completion
George Watch	02-0005	2002	Aquatic recreation	Excess nutrients	2008	2010
Marshan	02-0007	2002	Aquatic recreation	Excess nutrients	2005	2010
Reshanau	02-0009	2006	Aquatic recreation	Excess nutrients	2008	2010
Rice	02-0008	2010	Aquatic recreation	Excess nutrients	2010	2012
Baldwin	02-0013	2010	Aquatic recreation	Excess nutrients	2010	2012

Source: MPCA.

2.2 MINNESOTA WATER QUALITY STANDARDS AND ENDPOINTS

2.2.1 State of Minnesota Standards

Minnesota's standards at the time of listing (Minnesota Rules 7050.0150(3)) stated that in all Class 2 waters of the state (i.e., "…waters…which do or may support fish, other aquatic life, bathing, boating, or other recreational purposes…") "…there shall be no material increase in undesirable slime growths or aquatic plants including algae…" In accordance with Minnesota Rules 7050.0150(5), to evaluate whether a water body is impaired the MPCA developed "numeric translators" for the narrative standard for purposes of determining which lakes should be included in the section 303(d) list as being impaired for nutrients. The numeric translators established numeric thresholds for phosphorus, chlorophyll-a, and clarity (Secchi disk depth). Table 2.2 lists the thresholds for listing lakes on the 303(d) list of impaired waters in Minnesota that were in place when these lakes were listed. The numeric criteria used to list these lakes was the numeric translator threshold phosphorus standard for Class 2B waters in the North Central Hardwood Forest ecoregion (40 µg/L) prior to the adoption of new standards in 2008.

Table 2.2. Trophic status thresholds for determination of use support for lakes.

305(b) Designation	Full Support			Partial Support to Potential Non-Support			
303(d) Designation	**Not Listed**			**Review**	**Listed**		
Ecoregion	**TP (ppb)**	**Chl-a (ppb)**	**Secchi (m)**	**TP Range (ppb)**	**TP (ppb)**	**Chl-a (ppb)**	**Secchi (m)**
Northern Lakes and Forests	< 30	<10	> 1.6	30 – 35	> 35	> 12	< 1.4
(Carlson's TSI)	(< 53)	(< 53)	(< 53)	(53-56)	(> 56)	(> 55)	(> 55)
North Central Hardwood Forests	< 40	< 15	> 1.2	40 - 45	> 45	> 18	< 1.1
(Carlson's TSI)	(<57)	(<57)	(<57)	(57 – 59)	(> 59)	(> 59)	(> 59)
Western Cornbelt Plain and Northern Glaciated Plain	< 70	< 24	> 1.0	70 - 90	> 90	> 32	< 0.7
(Carlson's TSI)	(< 66)	(< 61)	(< 61)	(66 – 69)	(> 69)	(> 65)	(> 65)

Source: MPCA.

2.2.2 Endpoints Used in this TMDL

In accordance with Minnesota Rules 7050.0150 (4), all of the lakes meet the definition of a shallow lake and thus the shallow lake standards in Minnesota Rules 7050.0222 (4) and (4a) apply. Therefore, the total phosphorus endpoint in this TMDL is the shallow lake standard of 60 µg/L. This TMDL presents load and wasteload allocations and estimated load reductions based on the endpoints presented in Table 2.3.

An alternative water quality endpoint of 80 µg/L was previously proposed as part of the concurrent Peltier / Centerville Nutrient TMDL. This endpoint was a natural background condition standard and was based on paleolimnological diatom reconstructions done by the Science Museum of Minnesota for Peltier Lake. Based on the dominating influence Peltier has on the water quality of the downstream Lino Lakes chain of lakes, the natural background condition was also sought for George Watch, Marshan, Rice, and Baldwin Lakes (Appendix A). At this time, however, a formal natural background condition standard is not being proposed for Peltier Lake, or for any of the lakes covered in this TMDL. Thus, only the current state eutrophication standards will apply. However, information and results relating to the previously sought natural background condition standard will remain in this TMDL document solely for reference and for possible reconsideration of an alternative endpoint in the future.

Table 2.3. Target total phosphorus concentration endpoints used in this TMDL.

	Listing TP Standard (µg/L)	TMDL Shallow Lake TP Standard (µg/L)	Previously Proposed TP Natural Background Condition (µg/L)[1]
George Watch Lake	40	60	80
Marshan Lake	40	60	80
Reshanau Lake	40	60	NA
Rice Lake	40	60	80
Baldwin	40	60	80

[1] A natural background condition standard is not being proposed in this TMDL.

Although the TMDL is set for the total phosphorus standard, two other lake response parameters are included for Minnesota’s lakes including chlorophyll-a and Secchi depth (Table 2.4). All three of these parameters were assessed in this TMDL to assure that the TMDL will result in compliance with state standards.

Table 2.4. Numeric criteria for Lakes in the North Central Hardwood Forest and Western Corn Belt Plains Ecoregions. This TMDL uses the North Central Hardwood Forest Ecoregion standards. However, the Western Corn Belt Plains Ecoregion is included for reference.

	Ecoregions			
	North Central Hardwood Forest		**Western Corn Belt Plains**	
Parameters	**Shallow[1]**	**Deep**	**Shallow[1]**	**Deep**
Phosphorus Concentration (µg/L)	60	40	90	65
Chlorophyll-a Concentration (µg/L)	20	14	30	22
Secchi disk transparency (meters)	>1	>1.4	>0.7	>0.9

[1] Shallow lakes are defined as lakes with a maximum depth of 15 feet or less, or with 80% or more of the lake area shallow enough to support emergent and submerged rooted aquatic plants (littoral zone).

3.0 Watershed and Lake Characterization

3.1 LAKE AND WATERSHED DESCRIPTION

The Lino Lakes chain of lakes is located in the northeastern suburban Twin Cities metropolitan area. The lakes are located in the city of Lino Lakes, while the drainage area includes portions of seven other cities and townships (see Figure 3.1 and Figure 3.2). The tributary area (not including Peltier Lake inflows) is about 12,000 acres, or about nine percent of the Rice Creek watershed. When including the Peltier Lake inflow, and drainage areas above Peltier Lake, the total watershed area for the Chain of Lakes is approximately 79,800 acres. However, Peltier Lake, and areas draining to Peltier Lake, will be addressed in the Peltier and Centerville Lake TMDL Report. The chain discharges to Rice Creek, and ultimately to the Mississippi River.

The most significant tributary to the Chain of Lakes is Peltier Lake outflow, which enters George Watch Lake from the northeast. George Watch Lake then flows into Marshan Lake, which flows into Rice, and then Baldwin. Reshanau Lake flows into Rice Lake from the east. The Chain generally flows from the northeast to the southwest through a series of natural channels before entering Rice Creek. Two public ditch systems enter the Chain of Lakes. Anoka County Ditch 10-22-32 enters Marshan Lake from the northwest and Anoka County Ditch 25 enters Reshanau Lake from the east. See Figure 3.0 for detail.

Table 3.1. Lake characteristics of the Lino Lakes chain of lakes.

Parameter	George Watch	Marshan	Reshanau	Rice	Baldwin
Surface Area (ac)	886	312	372	442	220
Average Depth (ft)	3.9	2.5	5.8	4.0	3.9
Maximum Depth (ft)	7	5	16	5	5
Volume (ac-ft)	3,458	781	2,159	1,769	859
Residence Time (years)[1]	0.07-0.18	0.02-0.04	1.1-3.0	0.04-0.08	0.02-0.04
Littoral Area (ac)	886	312	372	442	220
Cumulative Watershed (ac)	1,981	6,344	3,465	11,554	12,015

Source: Minnesota DNR and Wenck Associates.
[1] Range of residence times from three years of modeled data.

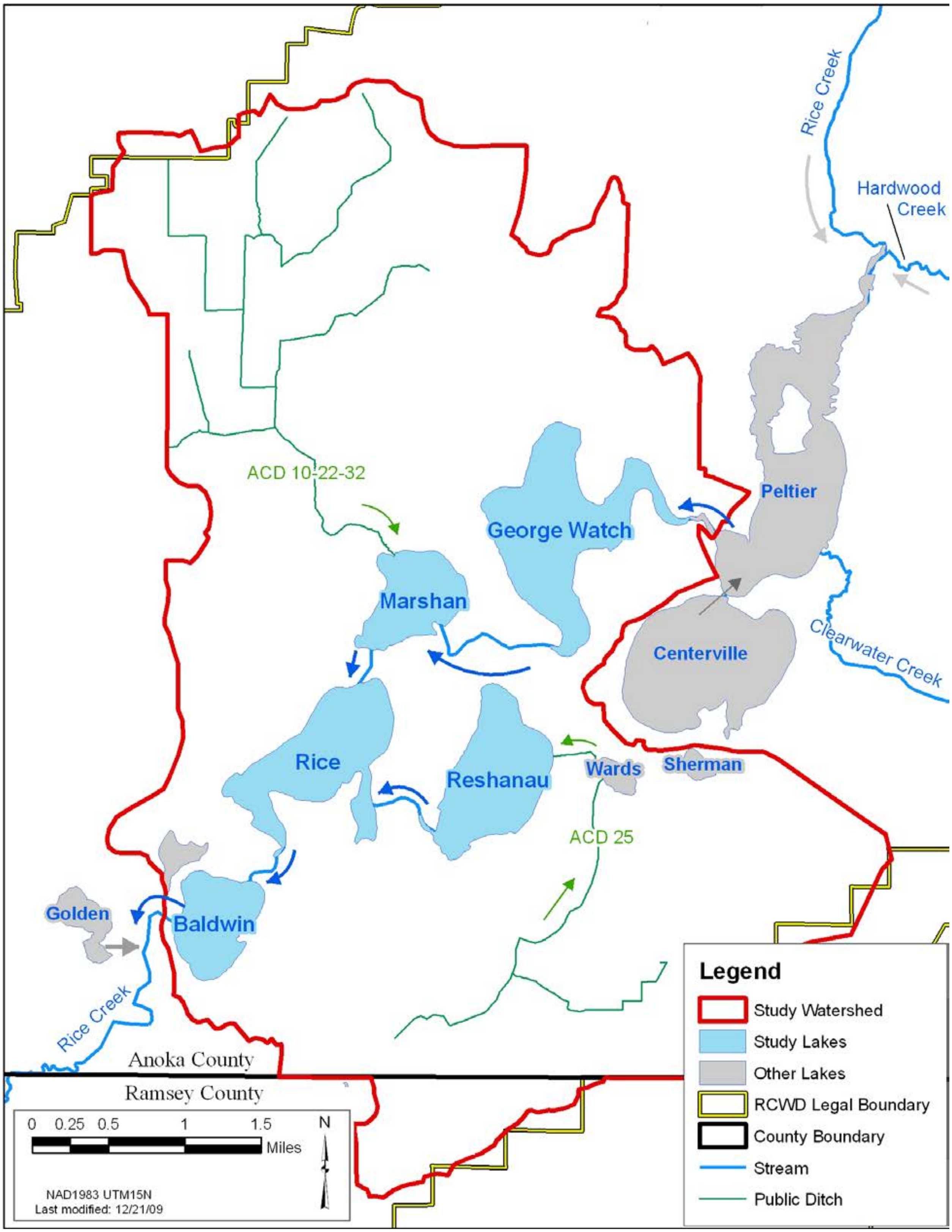

Figure 3.0. Flow direction map

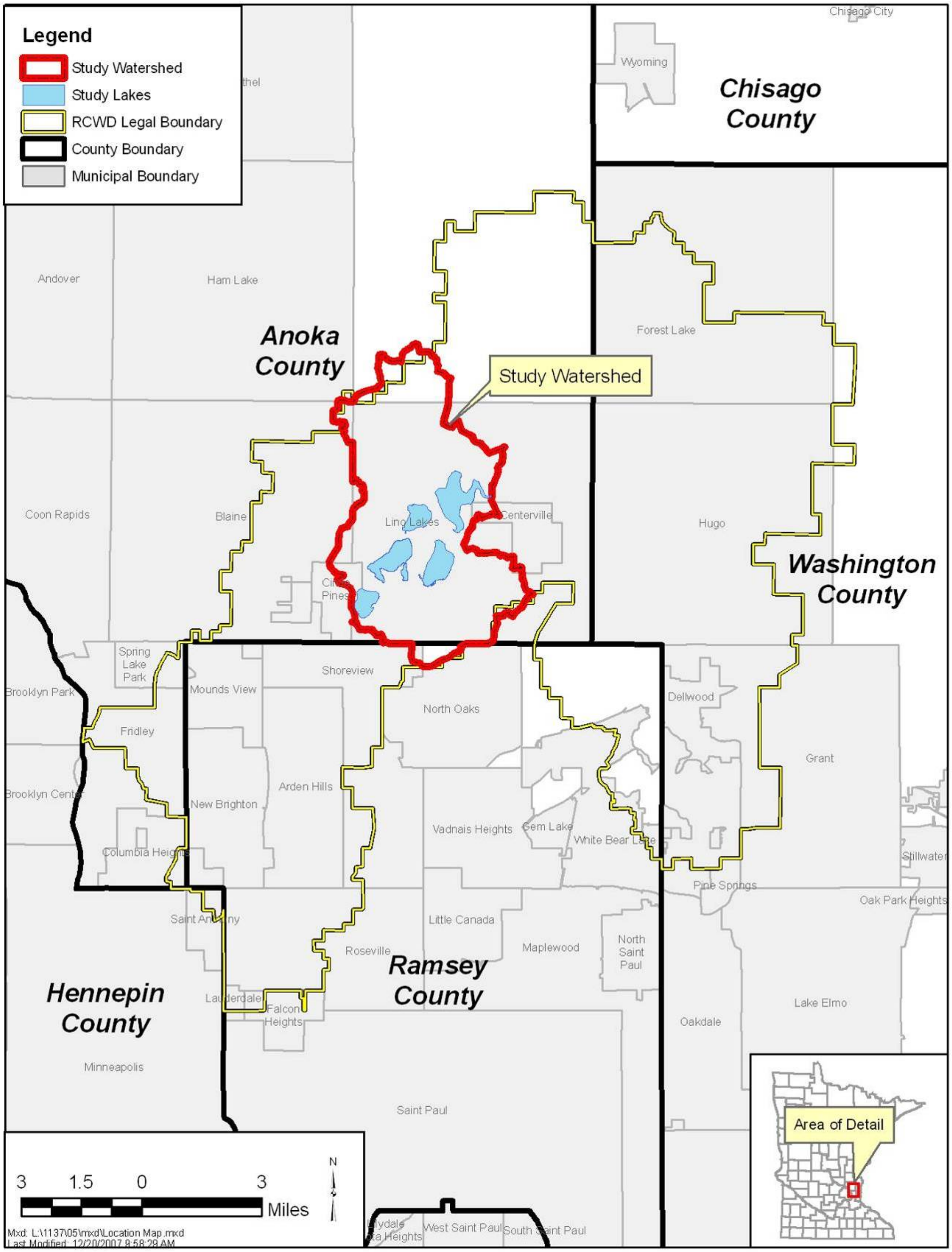

Figure 3-1. Location map.

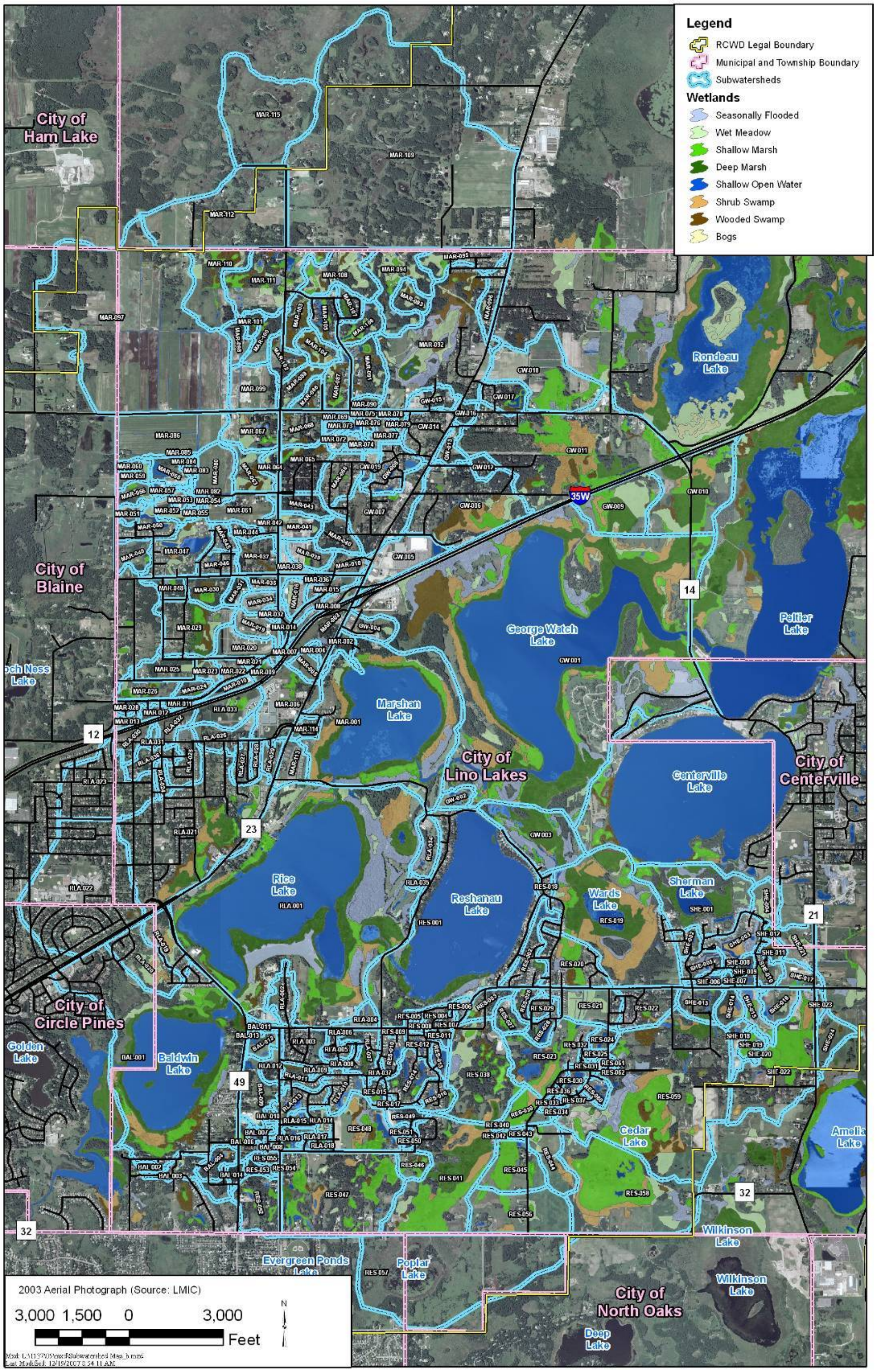

Figure 3-2. Aerial photo.

3.1.1 George Watch Lake

George Watch Lake is the northernmost basin in the chain. It is third in a larger chain of lakes that includes the upstream lakes of Peltier Lake and Centerville Lake. Both of those lakes are impaired waters for excess nutrients; a separate TMDL is being developed for Peltier and Centerville Lakes. George Watch has a surface area of 886 acres and average depth of 3.9 feet. The lake is shallow, with a maximum depth of 7 feet, and entirely littoral. The littoral zone is that portion of the lake that is less than 15 feet in depth, and is where the majority of the aquatic plants grow.

George Watch receives stormwater runoff from a 69,816 acre, developed and developing suburban watershed. Approximately 67,835 acres drain to Peltier Lake upstream of George Watch Lake and subsequently a significant (greater than 90%) of the inflow volume for George Watch is from Peltier Lake. The boundary condition between Peltier and George Watch Lakes is discussed in a technical memorandum in Appendix C. The contributing area for George Watch Lake is 1,981 acres. Subwatersheds are outlined in Figure 3.2. Stormwater is conveyed mostly through a network of storm sewers, ponds, and wetlands. Stormwater is also discharged into the lake from several smaller local storm sewers as well as overland flow. George Watch flows to Marshan Lake through a natural channel.

3.1.2 Marshan Lake

Marshan Lake has a surface area of 312 acres. It is the shallowest of the basins, with an average depth of 2.5 feet and a maximum depth of 5 feet. The entire lake area is littoral.

The lake receives direct stormwater runoff from a 6,344 acre, developed and developing suburban watershed (excluding Peltier Lake drainage). The direct contributing area is 4,363 acres. Stormwater is conveyed primarily through local storm sewers, ponds, wetlands, and overland runoff. Because the drainage area for Peltier Lake is significantly larger than the direct drainage for Marshan, a significant portion (greater than 90%) of the water budget for Marshan comes from Peltier (through George Watch). Marshan flows to Rice Lake through a natural channel.

3.1.3 Reshanau Lake

Reshanau Lake has a surface area of 372 acres and an average depth of 5.8 feet. It is the deepest of the lakes with a maximum depth of 16 feet, although it is predominantly littoral.

The lake receives direct stormwater runoff from a 3,465 acre, developed and developing suburban watershed. The sole tributary to Reshanau Lake is Anoka County Ditch 25, which carries limited flow from Wards Lake (2,490) and Sherman Lake (594 acres). The direct contributing area for Reshanau Lake is 381 acres. Stormwater is conveyed primarily through local storm sewers, ponds, wetlands, and overland runoff. Reshanau Lake flows through a wetland channel to Rice Lake.

3.1.4 Rice Lake

Rice Lake has a surface area of 442 acres and an average depth of 4 feet. Its maximum depth is 5 feet and it is entirely littoral.

The lake receives direct stormwater runoff from a 11,554 acre, developed and developing suburban watershed (excluding Peltier Lake drainage). The direct contributing area is 1,745 acres. Rice Lake receives outflow from Marshan and Reshanau Lakes with the majority (greater than 90%) coming from Peltier (through Marshan). Rice Lake flows to Baldwin Lake through a natural channel.

3.1.5 Baldwin Lake

Baldwin Lake has a surface area of 220 acres and an average depth of 3.9 feet. Its maximum depth is 5 feet and it is entirely littoral.

The lake receives direct stormwater runoff from a 12,015 acre, developed and developing suburban watershed (excluding Peltier Lake drainage). The direct contributing area is 461 acres. Baldwin Lake flows into Rice Creek.

3.1.6 Related TMDLs

A number of other TMDLs have been developed within the greater Rice Creek Watershed, including the Hardwood Creek TMDL, Golden Lake TMDL, and the Peltier/Centerville TMDL. The Golden Lake TMDL does not influence volume or phosphorus loading to the Chain of Lakes (see Figure 3.0). In the Hardwood Creek TMDL, the stressor identification process indicated that loss of habitat due to sedimentation and low dissolved oxygen were the primary stressors. As such, the TMDL was written for total suspended solids (TSS) and biochemical oxygen demand (BOD). Although TP is often strongly correlated with TSS, TP reductions were not addressed in the Hardwood Creek TMDL. However, many of the actions outlined in the implementation strategy of the Hardwood Creek TMDL, such as stormwater management and streambank stabilization, are expected to benefit Peltier Lake by reducing TP loading. Regarding the Peltier Lake TMDL, since much of volume for the Chain of Lakes does come through Peltier Lake, a number of products generated from the Peltier/Centerville TMDL were used in this TMDL, including volumes and phosphorus loading values. See Section 4.3.6 and Appendix C for more detail. In addition to using outputs from the Peltier/Centerville TMDL, the Lino Lakes Chain of Lakes TMDL was developed concurrently with the Peltier/Centerville TMDL. Certain language within the TMDL reports and public and technical meetings were integrated.

3.2 LAND USE

The 2005 land use data are presented in Table 3.2 and Figure 3.3 Land use in the Lino Lakes watershed is dominated by Undeveloped (31%), Single Family Residential (23.5%), and Park/Recreation areas (16.9%).

Table 3.2. 2005 land use in the Lino Lakes watershed by lake. Area in acres.

Sub-Watershed ID	George Watch	Marshan	Reshanau	Rice	Baldwin	Total Area	% of Watershed
Undeveloped	541.2	2,256.2	1,540.4	270.4	123.3	4,731.5	31%
Single Family Residential	362.5	942.5	1,094.5	971.5	214.8	3,585.8	23%
Park and Recreation	1186.3	160.0	694.9	377.9	164.5	2,583.5	17%
Water	484.2	206.9	416.9	376.1	190.1	1,674.2	11%
Agricultural	73.7	927.9	385.1	16.1	0.0	1,402.7	9%
Institutional	18.6	210.7	17.8	167.7	3.9	418.7	3%
Golf Course	63.3	41.6	3.7	102.5	0.0	211.2	1%
Major Highway	105.1	70.7	0.0	20.9	0.0	196.7	1%
Industrial	10.2	150.7	3.7	3.9	9.4	177.8	1%
Commercial	61.6	36.4	2.7	18.0	10.0	128.7	1%
Multifamily Residential	13.3	30.0	1.2	27.4	27.9	99.9	1%
Airport	0.0	40.1	0.0	23.0	0.0	63.1	0%
Mixed Use	0.0	1.4	0.0	0.4	0.0	1.8	0%
Total Area	2,920.0	5,075.0	4,161.0	2,376.0	744.0	15,276.0	100%

Source: Metropolitan Council.

3.3 RECREATIONAL USES

George Watch Lake. George Watch Lake is a recreational use lake that supports some public activity. The lake is located completely within the Rice Creek Chain of Lakes Regional Park Reserve. The Wargo Nature Center is located on the north end of George Watch Lake and the Chain of Lakes Campground is located along the southeast shores of the lake. Recreation activities associated with the campground and nature center include canoeing, biking, bird watching and picnicking. There are no fishing piers or swimming beaches associated with George Watch Lake, but some public shore fishing does take place at the upper end of the lake along the inflow creek.

Marshan Lake. Marshan Lake is a recreational use lake that supports limited public activity. The majority of the lake is located within the Rice Creek Chain of Lakes Regional Park Reserve, within only the western shoreline publicly owned. Public access is limited on Marshan Lake, with access mainly confined to canoeing into the lake from George Watch Lake through the Rice Creek channel or from the Rice Creek channel access at Aqua Lane connecting Marshan and Rice Lakes. Some public shore fishing does take place at the Aqua Lane channel access point to Marshan Lake.

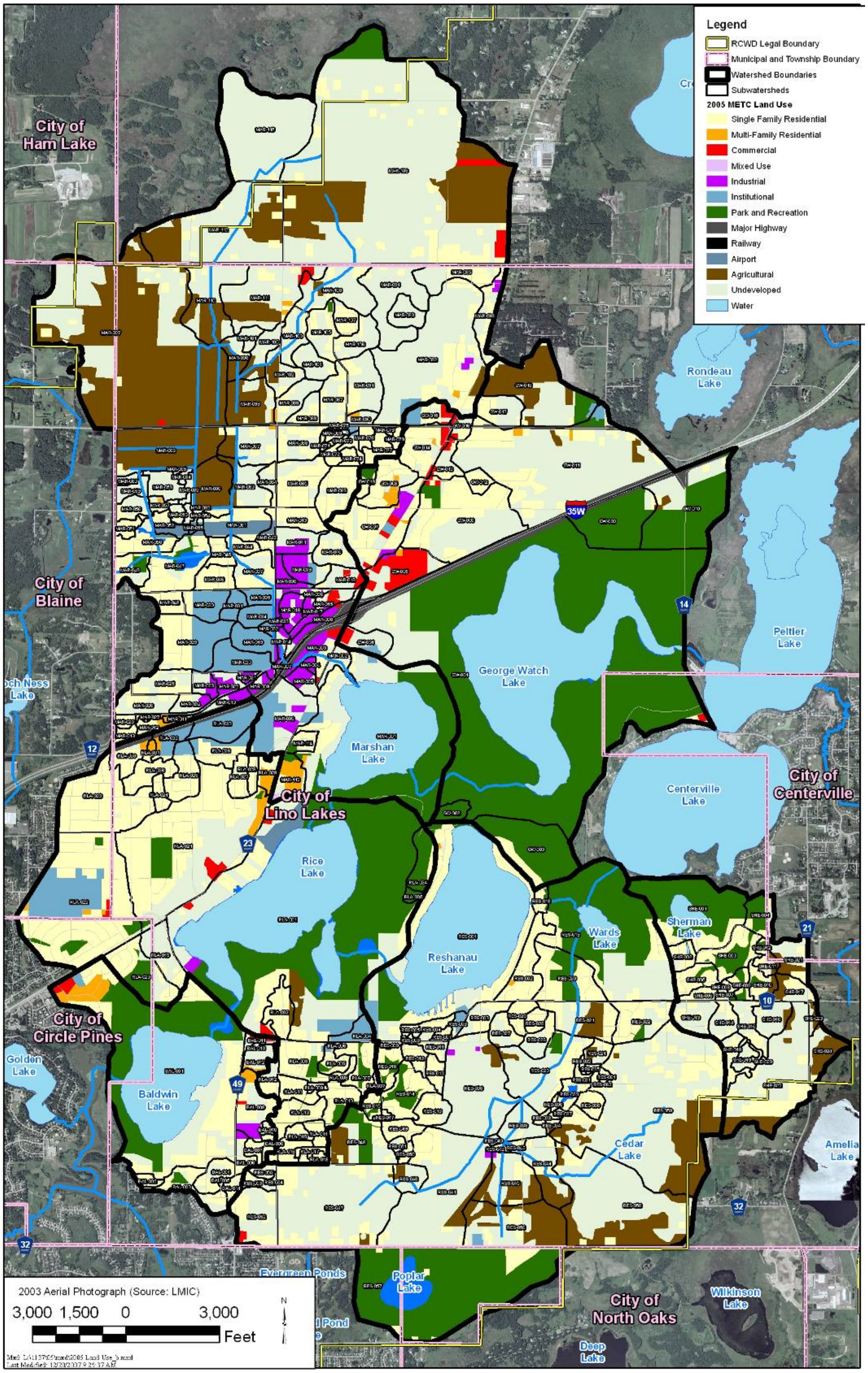

Figure 3-3. 2005 land use.

Reshanau Lake. Reshanau Lake is a recreational use lake that supports some public activity. The majority of land surrounding Reshanau Lake is privately owned. The north end of Reshanau Lake is within the Rice Creek Chain of Lakes Regional Park Reserve, and a City of Lino Lakes park is located at the southwest corner of the lake. Public access is limited on Reshanau Lake. The Minnesota Department of Natural Resources (MNDNR) identifies carry-in access through the Lino Lakes city park on the southwest shore, but a public ramp is not available. A fishing pier is also located in the Lino Lakes city park.

Rice Lake. Rice Lake is a recreational use lake that supports limited public activity. The majority of Rice Lake is located within the Rice Creek Chain of Lakes Regional Park Reserve, with only the western shoreline being publicly owned. Public access is limited on Rice Lake, with access mainly confined to canoeing into the lake through Rice Creek channel access at Aqua Lane connecting Marshan and Rice Lakes. Some public shore fishing does take place at the Aqua Lane channel access point to Rice Lake. There is a private sea-plane access located on the west-central shore of Rice Lake.

Baldwin Lake. Baldwin Lake is a recreational use lake that supports limited public activity. The majority of land surrounding Baldwin Lake is privately owned. The north end of Baldwin Lake is within the Rice Creek Chain of Lakes Regional Park Reserve. Public access is limited on Baldwin Lake, with access mainly confined to canoeing into the lake from Rice Lake through Rice Creek channel. A small number of lake residents have private fishing docks and small fishing boats, indicating some recreational fishing takes place on Baldwin Lake.

3.4 WATER CONDITION

Water quality in Minnesota lakes is often evaluated using three associated parameters: total phosphorus, chlorophyll-a, and Secchi depth. Phosphorus is typically the limiting nutrient in Minnesota lakes, meaning that algal growth will increase with increased inputs of phosphorus. Chlorophyll-a is the primary pigment in aquatic algae and has been shown to have a direct correlation with algal biomass. Since chlorophyll-a is a relatively inexpensive measurement, it is often used to evaluate algal abundance rather than cell counts. Secchi depth is a physical measurement of water clarity. It is measured by lowering a black and white disk into the water column until it can no longer be seen from the surface. Higher Secchi depths indicate less light refracting particulates in the water column and better water quality. Conversely, high total phosphorus and chlorophyll-a concentrations point to poor water quality. Measurements of these three parameters are interrelated and can be combined into an index that describes water quality.

3.4.1 Monitoring on Lino Lakes

Water quality monitoring has been conducted periodically in these lakes by volunteers, the Anoka Conservation District, and the Rice Creek Watershed District.

3.4.1.1 Citizen Assisted Monitoring Program (CAMP)

George Watch Lake, Marshan Lake, and Reshanau Lake have been periodically monitored by volunteers through the Citizen Assisted Monitoring Program. The CAMP program is operated by

Metropolitan Council Environmental Services, which provides coordination and data analysis for almost 200 lakes monitored annually in the Metro area. Citizen volunteers collect data and surface samples biweekly. Quality control tests conducted periodically by Met Council staff have found that CAMP volunteer-collected data are generally accurate, and provide acceptable surface water quality data.

3.4.2 Monitoring Parameters

3.4.2.1 Temperature and Dissolved Oxygen

Very limited temperature and dissolved oxygen data are available for these lakes. Consequently these data were not used in the development of this TMDL.

3.4.2.2 Phosphorus and Nitrogen

Lake algal production is typically limited by phosphorus and nitrogen availability. Minnesota lakes are almost exclusively limited by phosphorus; however excessive phosphorus can lead to nitrogen limiting conditions. Phosphorus and nitrogen are measured to determine the availability of the nutrients for algal production. Dissolved and ortho-phosphorus are the most readily available forms of phosphorus while total phosphorus is a measure of all the phosphorus, bound and unbound. Nitrate is the most readily available form of nitrogen for algal production and Total Kjeldahl nitrogen is a measure of all nitrogen in the water column.

3.4.2.3 Chlorophyll-a and Secchi Depth

Algal biomass can be measured directly by developing cell-by-cell counts and volumes. However, this is time intensive and often expensive. Chlorophyll-a has been shown to be a good estimator of algal biomass and is relatively inexpensive and easy to analyze.

Secchi depth is also a predictor of algal production by measuring the clarity of lake water. This is accomplished by lowering a round disk shaded black and white over the shady side of the boat and recording the depth at which the disc is no longer visible.

3.4.3 Lake Monitoring Results

Current (2007) water quality is presented in Table 3.3 as summer (June 1 through September 30) average concentration (total phosphorus and chlorophyll-a) or summer average water clarity (Secchi depth). On average, total phosphorus and chlorophyll-a concentration in all lakes is approximately three to four times more than the state standard. Water clarity in George Watch, Rice, and Baldwin lakes is at or near the state standard of 1.0 meters while clarity in Marshan and Reshanau is below the state standard.

Table 3.3. Current (2007) water quality in the Lino Lakes chain of lakes. Values are summer (June 1 through September 30) averages.

Lake	Total Phosphorus (µg/L)	Chlorophyll-a (µg/L)	Secchi Depth (m)
George Watch	247	89.3	0.92
Marshan	205	56.3	0.80
Reshanau	120	88.5	0.48
Rice	264	62.3	1.00
Baldwin	232	69.6	0.90
State Standard	60	20	1.0

Source: STORET.
Note: All the lakes are subject to the shallow lake standard for the North Central Hardwood Forest

Historical summer mean total phosphorus concentrations for the chain of lakes are presented in Figure 3.4. There are very limited data available for these lakes, but for each year that data are available, the growing-season average total phosphorus concentration ranged from 93 µg/L to 436 µg/L, which exceeds the state standard of 60 µg/L.

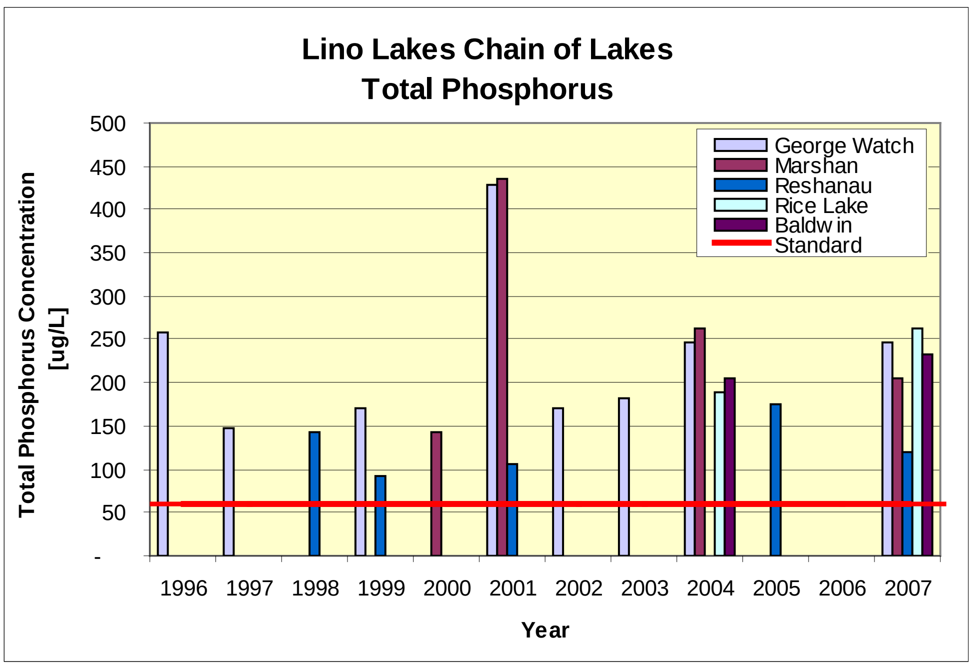

Figure 3-4. Summer (June 1 – September 30) mean total phosphorus concentrations for the chain of lakes. The red line indicates the Minnesota state standard of 60 µg/L.

Summer mean chlorophyll-a concentration is presented in Figure 3.5. Chlorophyll-a concentrations closely follow the total phosphorus concentrations. Again, for each year that data are available, the growing-season average chlorophyll-a concentration ranged from 31 µg/L to 128 µg/L, which exceeds the state standard of 20 µg/L.

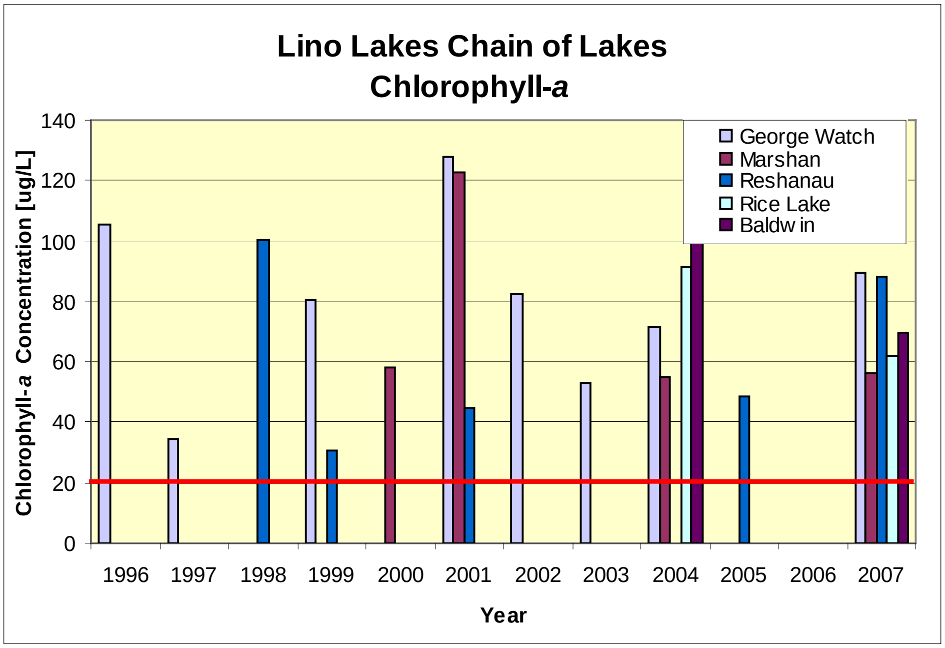

Figure 3-5. Summer (June 1 – September 30) mean chlorophyll-a concentrations for the chain of lakes. The red line indicates the Minnesota state standard of 20 µg/L.

Summer mean Secchi depth is presented in Figure 3.6. Clarity is limited in these lakes but for each year that data are available, the growing-season average Secchi depth ranged from 0.26 meters to 1.0 meters, which meets the state minimum standard of 1.0 meter for one year in one lake.

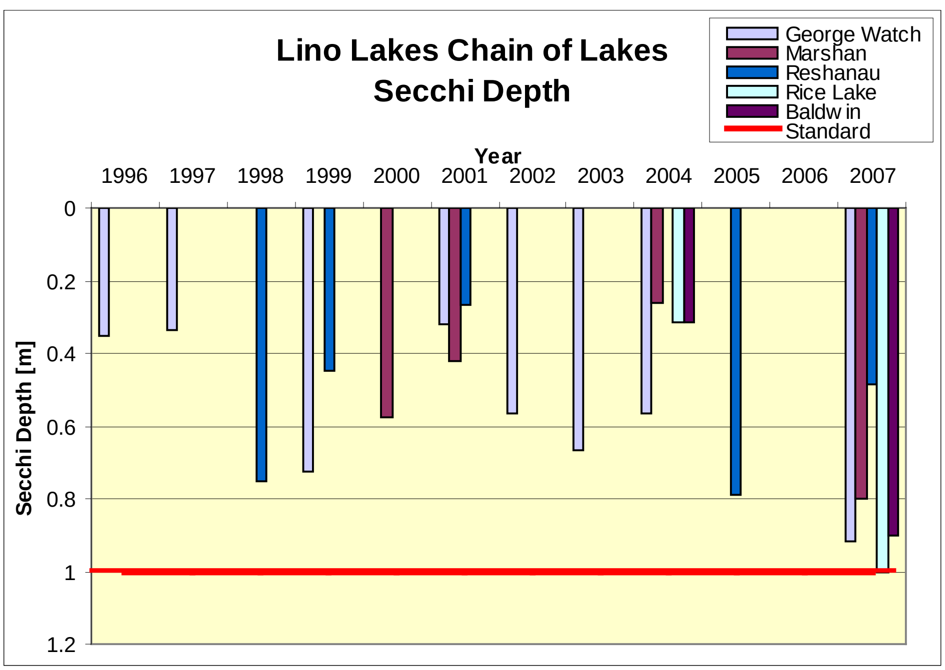

Figure 3-6. Summer (June 1 – September 30) mean Secchi depth (meters) for the chain of lakes. The red line indicates the Minnesota state standard of 1 meter.

3.4.3.1 George Watch Lake

3.4.3.1.1 Historic Data

Historic chlorophyll-a, total phosphorus, and Secchi depth data are presented in Table 3.4. Water quality has been historically poor in George Watch Lake with extremely high phosphorus concentrations dating back to 1978.

Table 3.4. Historic data for George Watch Lake.

	Chlorophyll-a (mg/L)		Total Phosphorus (µg/L)		Secchi Disk (m)	
Year	**N**	**Mean**	**N**	**Mean**	**N**	**Mean**
1978	2	11.0	2	325	2	1.25
1996	8	105.8	8	258	8	0.35
1997	6	34.7	6	147	6	0.33
1999	8	80.6	8	170	8	0.73
2000	2	32.5	1	180	2	0.30
2001	5	127.6	5	428	4	0.40
2002	6	82.2	6	171	6	0.57
2003	3	53.3	3	182	3	0.67
2004	7	71.6	7	246	7	0.56
2007	8	89.3	8	247	7	0.92

Source: STORET.

3.4.3.1.2 Total Phosphorus

George Watch Lake demonstrates extremely high total phosphorus concentrations. In past years' monitoring, the lowest summer average concentration was still more than twice the state standard.

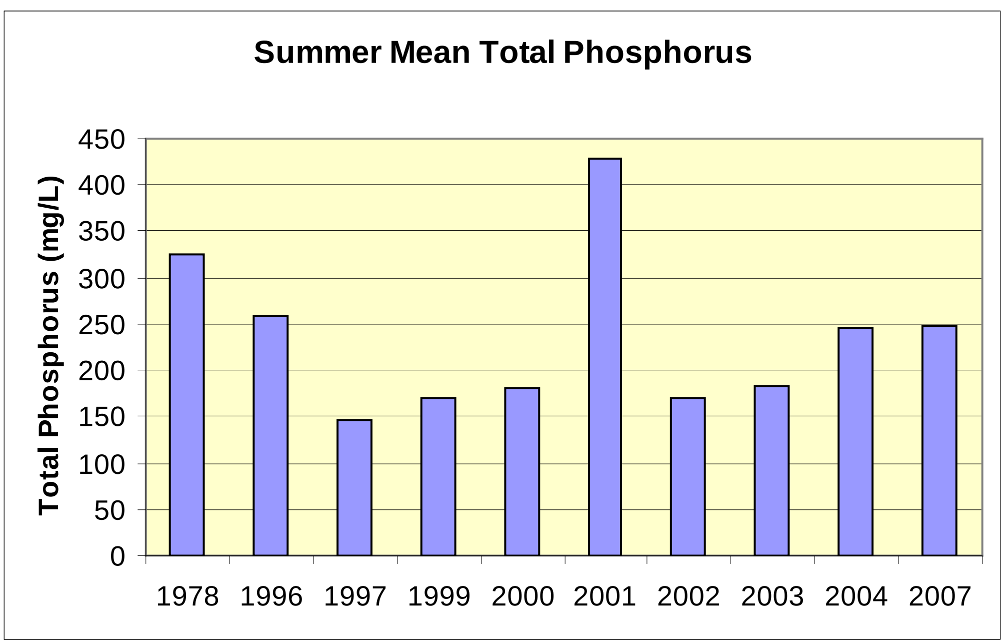

Figure 3-7. Summer mean total phosphorus concentrations for George Watch Lake.

3.4.3.1.3 Chlorophyll-a

Chlorophyll-a concentrations generally track with TP concentrations, although that relationship is not evident in every year. In shallow lakes, the state standard for chlorophyll-a is 20 µg/L or less. George Watch exceeded that standard every year but 1978.

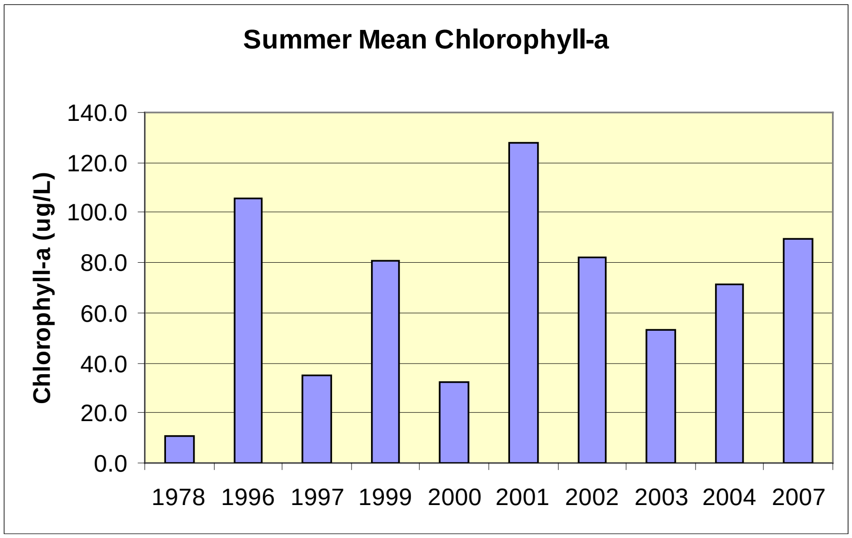

Figure 3-8. Summer mean chlorophyll-a concentrations for George Watch Lake.

3.4.3.1.4 Secchi Depth

Secchi depth is a measure of clarity. In shallow lakes, the state standard for clarity is a Secchi depth of 1.0 meter or greater. George Watch did not meet that standard in any year except 1978.

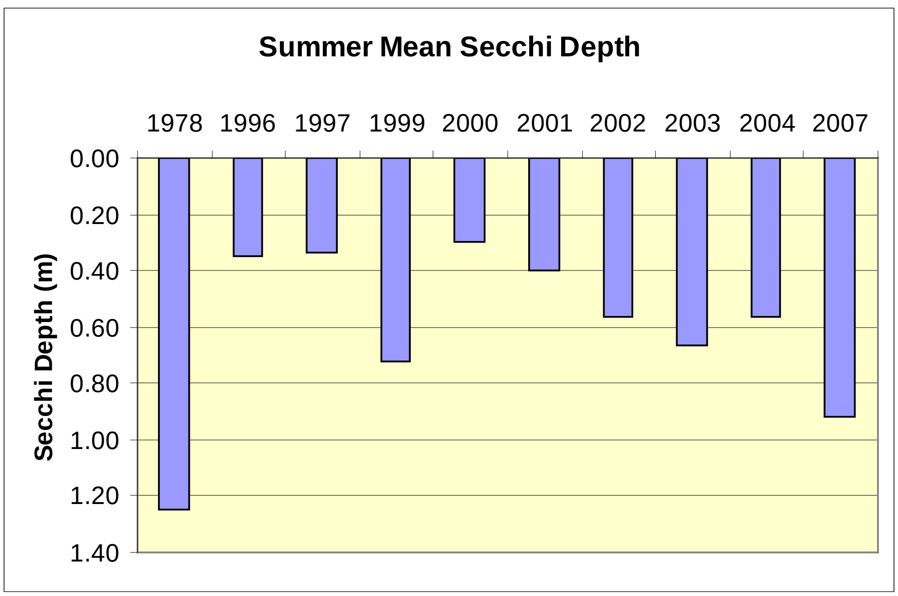

Figure 3-9. Summer mean Secchi depth in meters of George Watch Lake.

3.4.3.2 Marshan Lake

3.4.3.2.1 Historic Data

Historic chlorophyll-a, total phosphorus, and Secchi depth data are presented in Table 3.5.

Table 3.5. Historic data for Marshan Lake.

Year	Chlorophyll-a (mg/L)		Total Phosphorus (µg/L)		Secchi Disk (m)	
	N	Mean	N	Mean	N	Mean
1978	2	8.5	2	445	2	1.05
2000	4	58.4	4	142	4	0.58
2001	5	122.8	5	436	5	0.42
2003	2	83.8	1	108	2	0.55
2004	3	73.4	4	264	2	0.52
2005	1	28.5	1	158	--	--
2007	8	56.3	8	205	6	0.8

Source: STORET.

3.4.3.2.2 Phosphorus

Marshan Lake demonstrates extremely high total phosphorus concentrations. In past years' monitoring, the lowest summer average concentration was nearly twice the state standard.

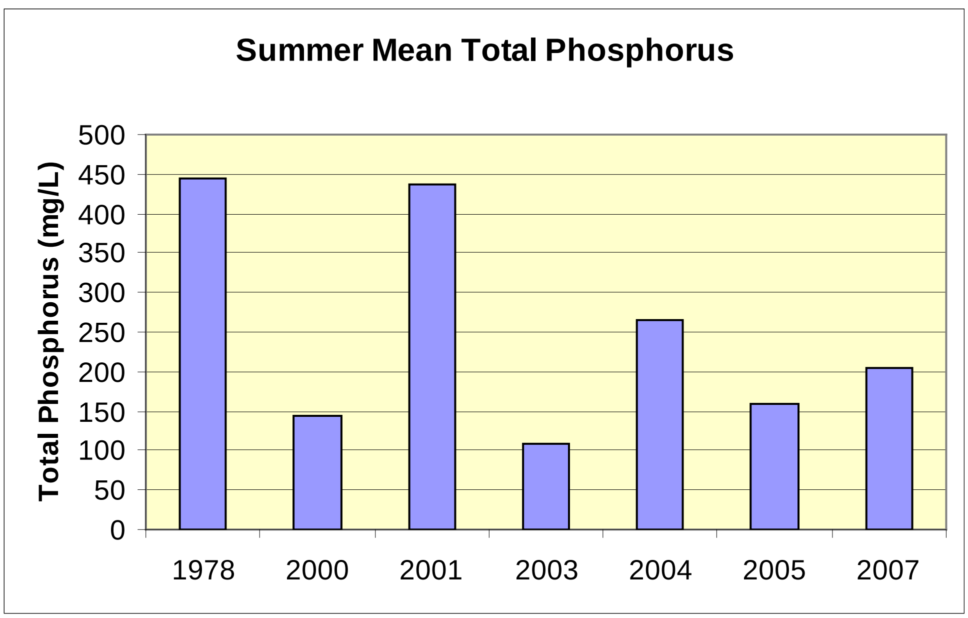

Figure 3-10. Summer mean total phosphorus concentrations for Marshan Lake.

3.4.3.2.3 Chlorophyll-a

Chlorophyll-a concentrations generally track with TP concentrations, although that relationship is not evident in every year. In shallow lakes, the state standard for chlorophyll-a is 20 µg/L or less. Marshan Lake exceeded that standard every year but 1978.

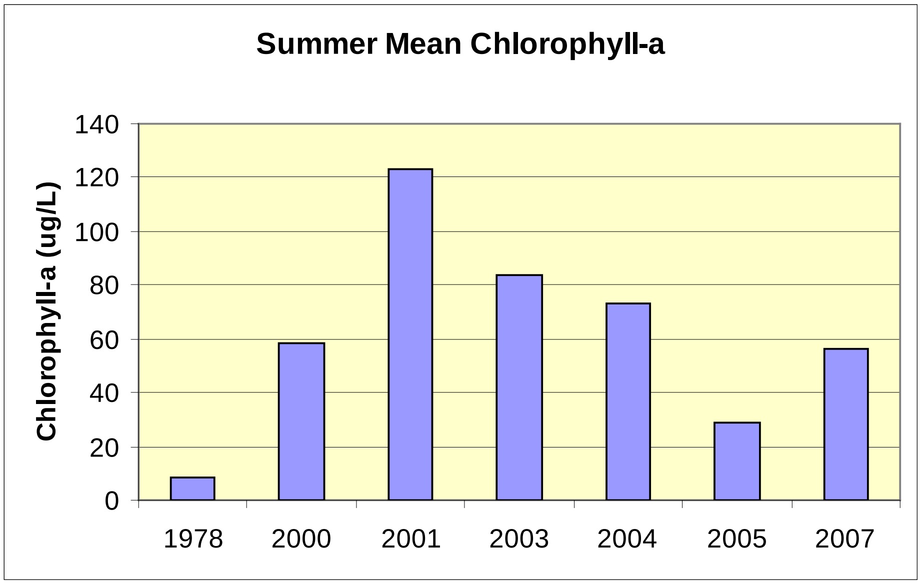

Figure 3-11. Mean summer chlorophyll-a concentrations in Marshan Lake.

3.4.3.2.4 Secchi Depth

Secchi depth is a measure of clarity. In shallow lakes, the state standard for clarity is a Secchi depth of 1.0 meter or greater. Marshan Lake did not meet that standard in any year except 1978.

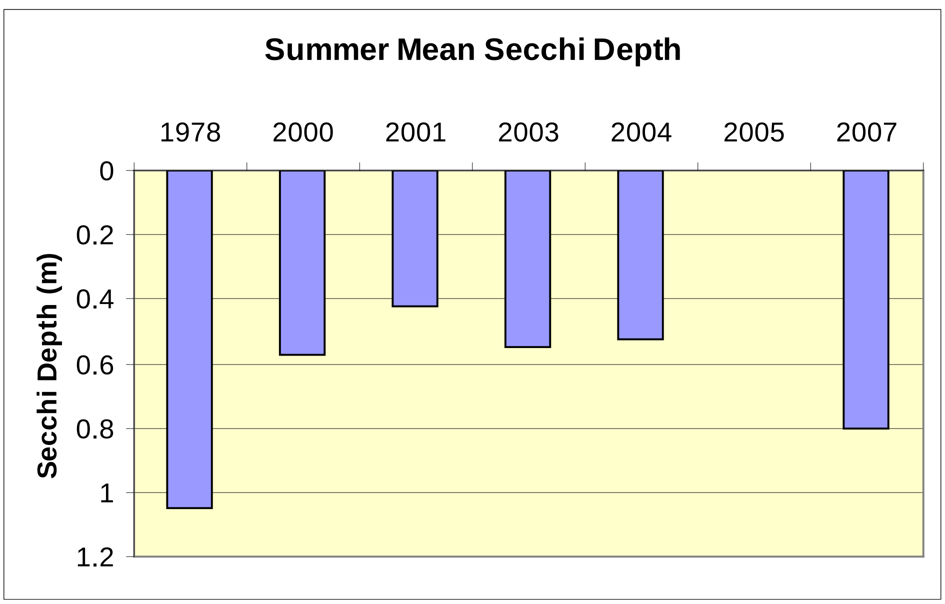

Figure 3-12. Summer mean Secchi depth in meters in Marshan Lake.

3.4.3.3 Reshanau Lake

3.4.3.3.1 Historic Data

Historic chlorophyll-a, total phosphorus, and Secchi depth data are presented in Table 3.6.

Table 3.6. Historic data for Reshanau Lake.

Year	Chlorophyll- a (mg/L)		Total Phosphorus (mg/L)		Secchi Disk (m)	
	N	Mean	N	Mean	N	Mean
1978	2	8.5	2	110	2	0.72
1991	4	58.4	3	107	3	0.50
1995	5	122.8	6	115	6	0.65
1998	2	83.8	4	143	4	0.75
1999	3	73.4	4	93	4	0.45
2001	1	28.5	3	107	3	0.27
2005	2	48.5	5	175	3	1.32
2007	6	88.5	6	120	6	0.48

Source: STORET.

3.4.3.3.2 Phosphorus

Reshanau Lake demonstrates high total phosphorus concentrations. In past years' monitoring, the summer average concentration often approached twice the state standard.

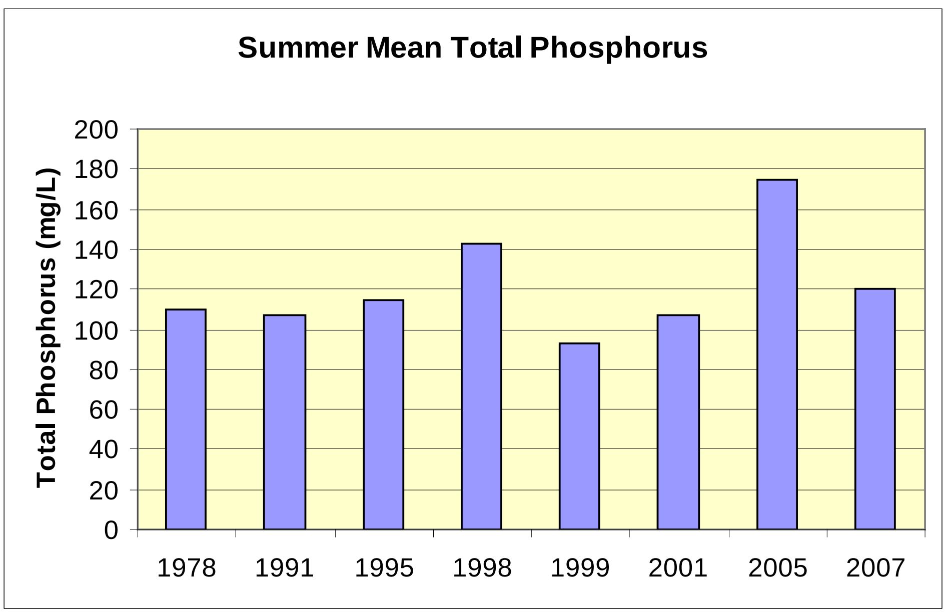

Figure 3-13. Mean summer total phosphorus concentration in Reshanau Lake.

3.4.3.3.3 Chlorophyll-a

Chlorophyll-a concentrations generally track with TP concentrations, although that relationship is not evident in every year. In shallow lakes, the state standard for chlorophyll-a is 20 µg/L or less. Reshanau Lake exceeded that standard every year.

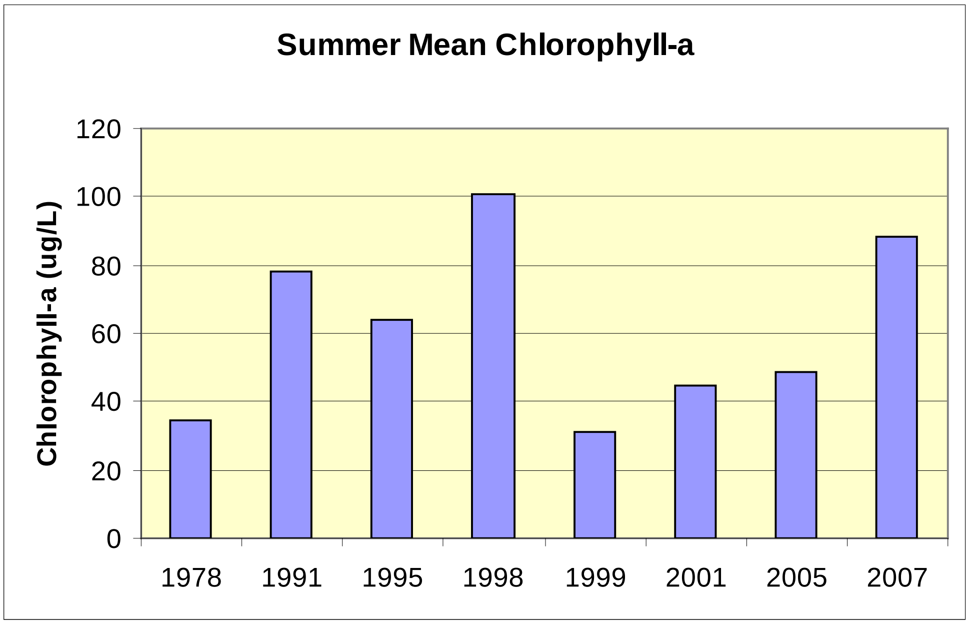

Figure 3-14. Summer mean chlorophyll-a concentration in Reshanau Lake.

3.4.3.3.4 Secchi Depth

Secchi depth is a measure of clarity. In shallow lakes, the state standard for clarity is a Secchi depth of 1.0 meter or greater. Reshanau Lake did not meet that standard in any year except 2005.

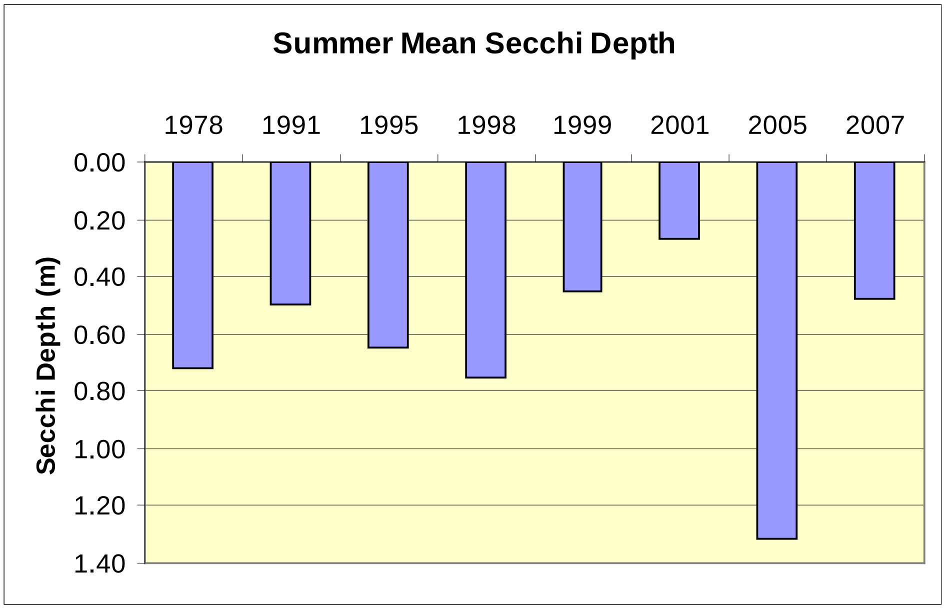

Figure 3-15. Summer mean Secchi depth in meters in Reshanau Lake.

3.4.3.4 Rice Lake

3.4.3.4.1 Historic Data

Historic chlorophyll-a, total phosphorus, and Secchi depth data are presented in Table 3.7.

Table 3.7. Historic data for Rice Lake.

Year	Chlorophyll- a (mg/L)		Total Phosphorus (µg/L)		Secchi Disk (m)	
	N	Mean	N	Mean	N	Mean
1974			1	198	1	0.5
1978	2	18	2	325	2	1.1
1991	3	101	3	207	3	0.8
2003	2	88	1	105	2	0.6
2004	3	91	3	188	2	0.5
2005	1	70	1	264	0	
2007	10	62.3	8	198	6	1

Source: STORET.

3.4.3.4.2 Phosphorus

Rice Lake demonstrates high total phosphorus concentrations. In past years' monitoring, the summer average concentration often two to three times the state standard.

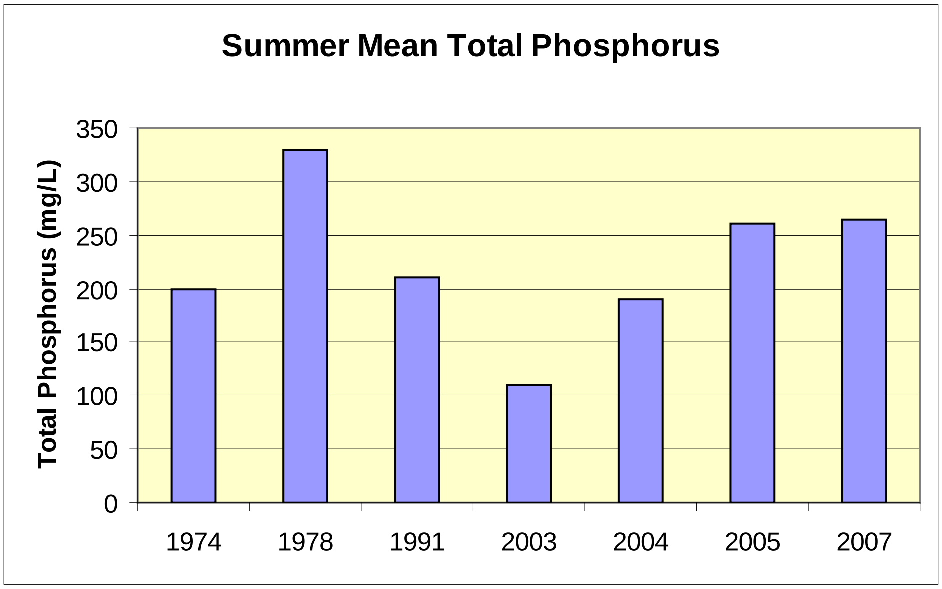

Figure 3-16, Summer mean total phosphorus concentration in Rice Lake.

3.4.3.4.3 Chlorophyll-a

Chlorophyll-a concentrations generally track with TP concentrations, although that relationship is not evident in every year. In shallow lakes, the state standard for chlorophyll-a is 20 µg/L or less. Rice Lake exceeded that standard every year except 1978.

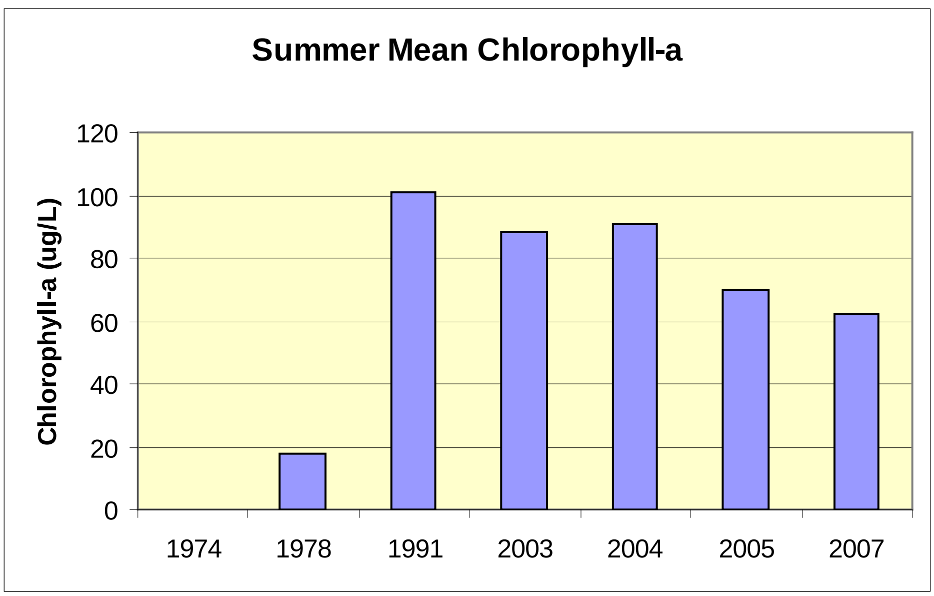

Figure 3-17. Summer mean chlorophyll-a concentration in Rice Lake.

3.4.3.4.4 Secchi Depth

Secchi depth is a measure of clarity. In shallow lakes, the state standard for clarity is a Secchi depth of 1.0 meter or greater. Rice Lake did not meet that standard in any year except 1978.

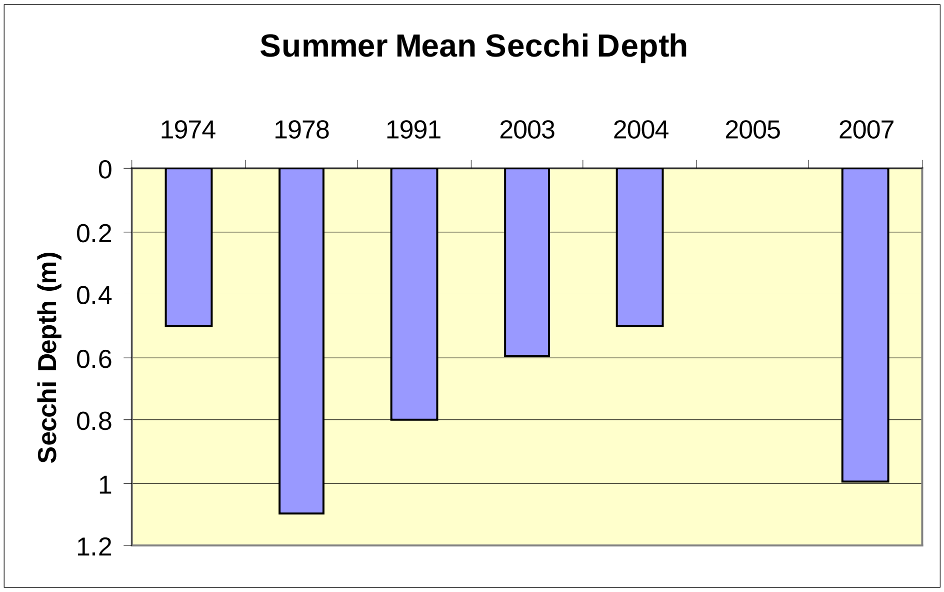

Figure 3-18. Summer mean Secchi depth in meters in Rice Lake. No data were available for 2005.

3.4.3.5 Baldwin Lake

3.4.3.5.1 Historic Data

Historic chlorophyll-a, total phosphorus, and Secchi depth data are presented in Table 3.8.

Table 3.8. Historic data for Baldwin Lake.

Year	Chlorophyll- a (mg/L)		Total Phosphorus (µg/L)		Secchi Disk (m)	
	N	Mean	N	Mean	N	Mean
1978	2	13.5	2	395	2	1.20
1991	2	52.0	3	183	3	0.77
1995	6	95.8	6	167	6	0.43
2003	2	83.0	1	084	2	0.65
2004	3	104.2	3	205	2	0.48
2007	12	69.6	8	232	7	0.9

Source: STORET.

3.4.3.5.2 Phosphorus

Baldwin Lake demonstrates high total phosphorus concentrations. In past years' monitoring, the summer average concentration was two to three times the state standard or more.

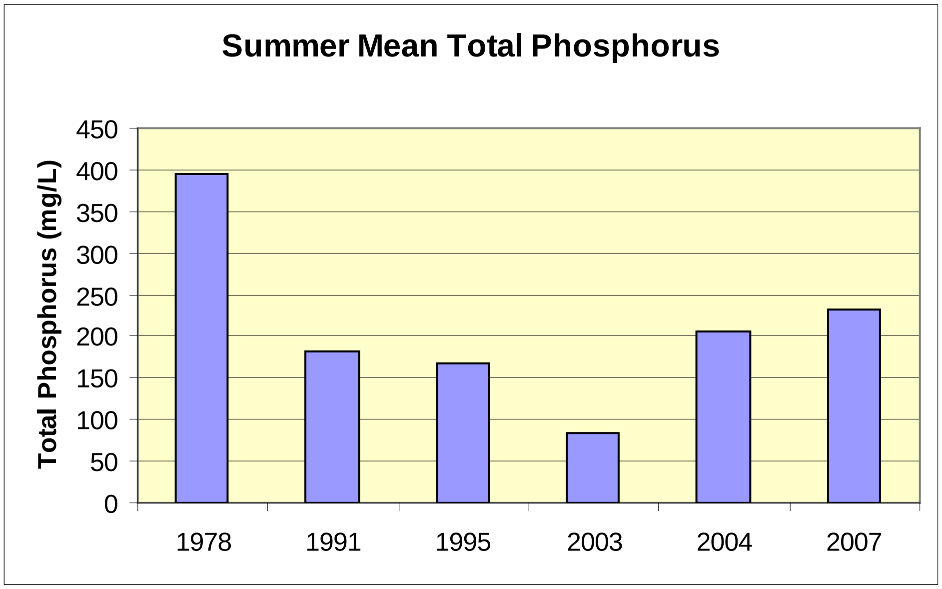

Figure 3-19. Summer mean total phosphorus in Baldwin Lake.

3.4.3.5.3 Chlorophyll-a

Chlorophyll-a concentrations generally track with TP concentrations, although that relationship is not evident in every year. In shallow lakes, the state standard for chlorophyll-a is 20 µg/L or less. Baldwin Lake exceeded that standard every year but 1978.

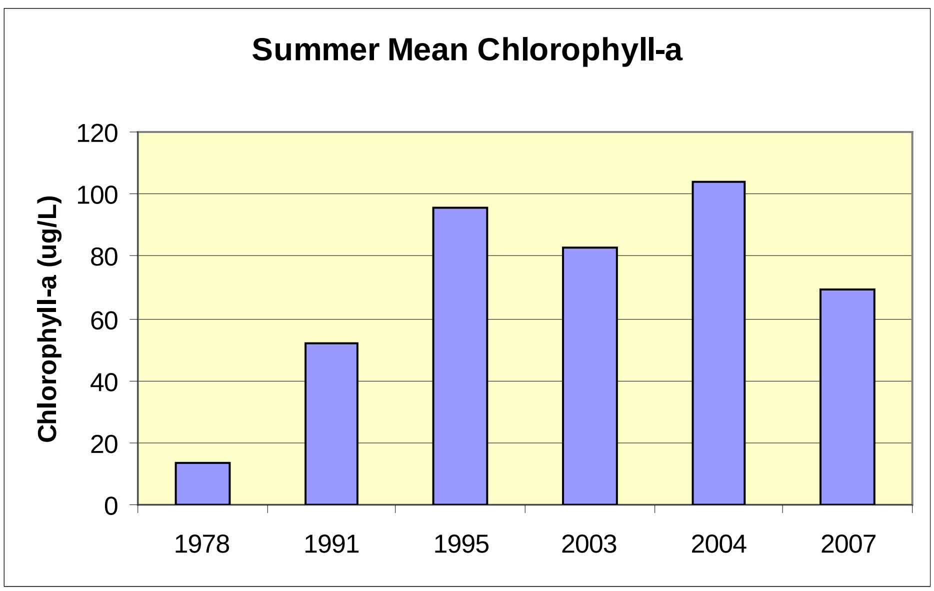

Figure 3-20. Summer mean chlorophyll-a concentration in Baldwin Lake.

3.4.3.5.4 Secchi Depth

Secchi depth is a measure of clarity. In shallow lakes, the state standard for clarity is a Secchi depth of 1.0 meter or greater. Baldwin Lake did not meet that standard in any year except 1978.

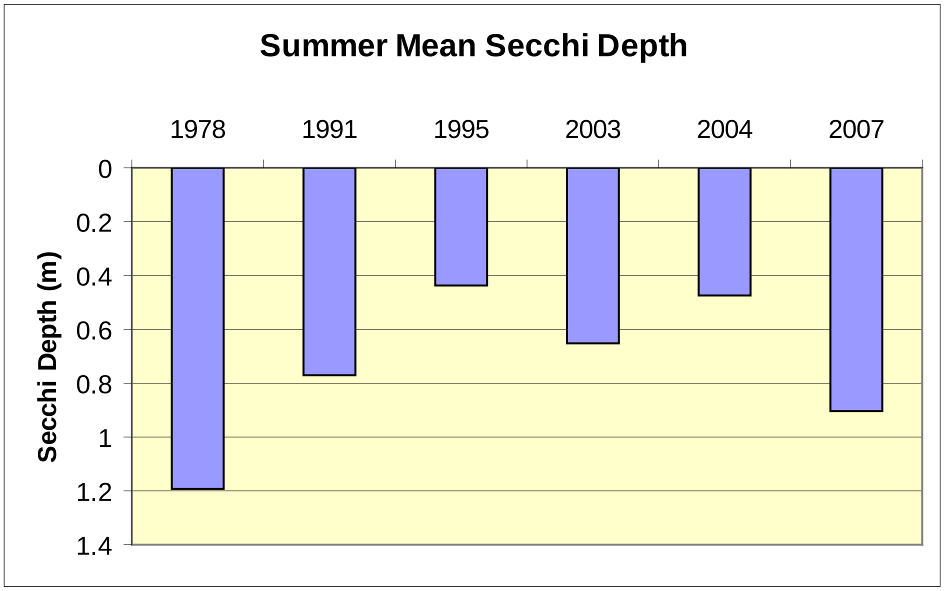

Figure 3-21. Summer mean Secchi depth in meters in Baldwin Lake.

3.4.4 Conclusions

Monitoring data in the Lino Lakes chain of lakes suggest that the chain of lakes is a highly productive system with the poorest water quality occurring in George Watch and Marshan. Specific conclusions for each of the five lakes are as follows:

George Watch Lake

- Historical average phosphorus concentrations vary from 147 µg/L to 428 µg/L; the concentration in 2007 was 246 µg/L,
- Historical average chlorophyll-a concentrations vary from 35 µg/L to 128 µg/L; the concentration in 2007 was 89 µg/L,
- Historical average Secchi depth varies from 0.32 meters to 0.92 meters; the water clarity in 2007 was 0.92 meters,
- Total phosphorus, chlorophyll-a, and water clarity in George Watch all exceed the state standards.

Marshan Lake

- Historical average phosphorus concentrations vary from 143 µg/L to 436 µg/L; the concentration in 2007 was 205 µg/L,
- Historical average chlorophyll-a concentrations vary from 55 µg/L to 123 µg/L; the concentration in 2007 was 56 µg/L,
- Historical average Secchi depth varies from 0.26 meters to 0.80 meters; the water clarity in 2007 was 0.80 meters,
- Total phosphorus, chlorophyll-a, and water clarity in Marshan all exceed the state standards.

Reshanau Lake

- Historical average phosphorus concentrations vary from 93 µg/L to 175 µg/L; the concentration in 2007 was 120 µg/L,
- Historical average chlorophyll-a concentrations vary from 31 µg/L to 101 µg/L; the concentration in 2007 was 89 µg/L,
- Historical average Secchi depth varies from 0.27 meters to 0.79 meters; the water clarity in 2007 was 0.48 meters,
- Total phosphorus, chlorophyll-a, and water clarity in Reshanau all exceed the state standards.

Rice Lake

- Historical average phosphorus concentrations vary from 188 µg/L to 264 µg/L; the concentration in 2007 was 264 µg/L,
- Historical average chlorophyll-a concentrations vary from 62 µg/L to 91 µg/L; the concentration in 2007 was 62 µg/L,
- Historical average Secchi depth varies from 0.32 meters to 1.0 meters; the water clarity in 2007 was 1.0 meters,
- Total phosphorus, chlorophyll-a, and water clarity in Rice Lake all exceed the state standards except for water clarity in 2007 which met the standard.

Baldwin Lake

- Historical average phosphorus concentrations vary from 205 µg/L to 232 µg/L; the concentration in 2007 was 232 µg/L,
- Historical average chlorophyll-a concentrations vary from 70 µg/L to 104 µg/L; the concentration in 2007 was 70 µg/L,
- Historical average Secchi depth varies from 0.32 meters to 0.90 meters; the water clarity in 2007 was 0.90 meters,
- Total phosphorus, chlorophyll-a, and water clarity in Baldwin all exceed the state standards.

3.5 FISH POPULATIONS AND FISH HEALTH

3.5.1 Rough Fish

Common carp, black bullheads, and other rough fish have both direct and indirect effects on aquatic environments. Rough fish are bottom-feeders and uproot aquatic plants during feeding and spawning activities, re-suspending bottom sediments and nutrients. These activities can lead to increased nutrients in the water column, ultimately resulting in increased nuisance algal blooms. Especially in very shallow lakes such as these, this can be a significant source of phosphorus and is part of the internal load, or phosphorus from sources already in the lake. Rough fish management will be a key factor in managing nutrient levels in the lakes.

3.5.2 Fish Populations

George Watch Lake. Historical fish survey data are not available from the DNR. Fish community sampling efforts conducted by the DNR typically focus on lakes with established game fish populations, large enough to support a public recreational fishery. The shallow nature of this lake makes it susceptible to winter kill and unlikely to support stable game fish populations. However, based on review of the DNR 1978 “game lake survey” and 2007 field monitoring, several fish species are known to exist in the lake including bluegill, black crappie, northern pike and common carp. Common carp, a non-native species, are abundant in George Watch Lake.

Marshan Lake. Historical fish survey data is not available from the DNR. The lake is shallow and susceptible to winter kill and unlikely to support a stable game fish population. Reports from shore fisherman at the Aqua Lane access indicate that bluegill, black crappie, largemouth bass and northern pike are present. Common carp, a non-native species, were observed in Marshan Lake during 2007 field monitoring, and are likely contributing to reduced water clarity and higher internal phosphorus loads.

Reshanau Lake. The lake management report and historical fish community surveys for Reshanau Lake were obtained from the DNR. The DNR has not identified a target management species for this lake and indicates that regular fish surveys are not conducted due to the lack of a sustainable public fishery and propensity for winter kills. Fish surveys were conducted by the DNR in 1962, 1972 and 1992. In all three surveys the catch was dominated by rough fish, including black bullhead and common carp. Rough fish accounted for approximately 95 percent of the total catch abundance and over 90 percent of the total catch biomass from all three surveys.

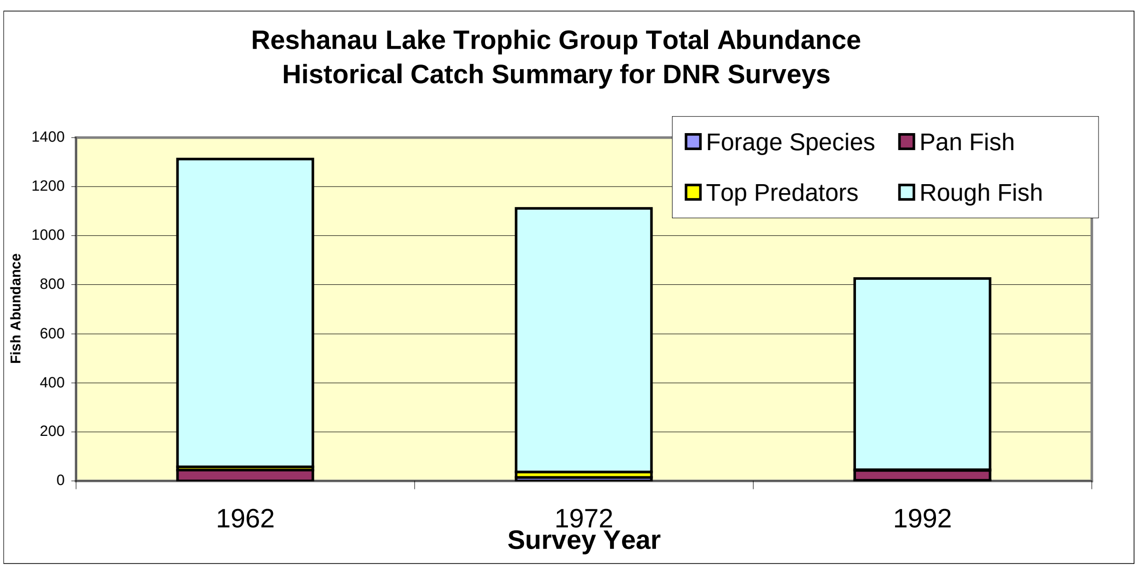

Figure 3-22. Historical DNR fish survey data for Reshanau Lake.

A trap net fish survey was conducted on Reshanau Lake by RCWD in September 2007. During the 2007 survey the catch was dominated by pan fish, with bluegill and black crappie accounting for over 85 percent of the total catch (Figure 3.23). Black crappie, especially, were sampled in great abundance; on average, 70 were captured per net, compared to the MNDNR “normal” range of 1.2-20.0. Rough fish were the second most abundant group in the 2007 survey including the species black bullhead, buffalo and common carp. The buffalo and common carp collected were medium to large size adults with individuals averaging 18.8 and 21.3 inches respectively.

Several top predator species were collected in the 2007 fish survey, including bowfin, largemouth bass, northern pike and walleye. Top predators accounted for approximately three percent of the total catch. Northern pike were the most common top predator collected and individuals collected were large for this lake type, averaging 26.4 inches in length. Large northern pike of this size are voracious feeders and should be able to provide some top-down control on panfish populations. However, the large number of bluegills and black crappies captured during the 2007 survey indicated that there may be refuge areas in vegetation for small panfish to hide from predators, or that the large northern pike are not present in sufficient numbers to effectively produce a top-down control effect in Reshanau Lake.

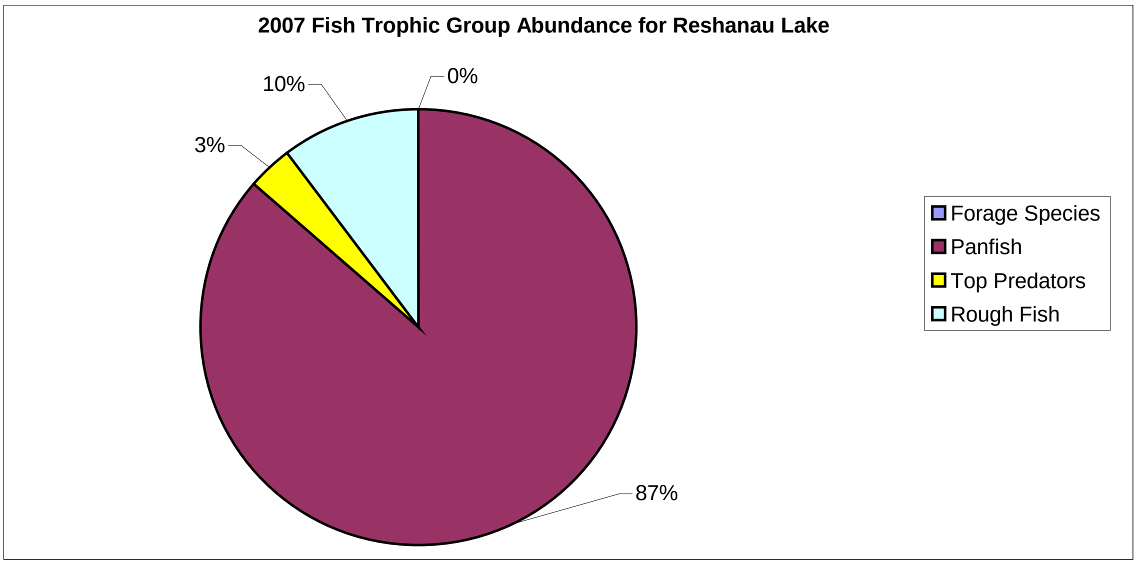

Figure 3-23. 2007 fish survey trophic group abundance for Reshanau Lake.

A high panfish population is indicative of a lack of top-down (predator) controls and can cause several problems with water quality. Most importantly, high numbers of panfish can increase grazing pressure on large-bodied zooplankton. This pressure reduces the number and size of the efficient zooplankton grazers resulting in less algae consumed by the zooplankton. Ultimately, this leads to poorer water quality and dominance of algae in the water column.

Rice Lake. Historical fish survey data is not available from the DNR for Rice Lake. Trap net fish surveys were conducted by RCWD on Rice Lake in September 2007. Panfish were the most abundant group of fish collected during the 2007 trap net survey, including bluegill and black crappie. Pan fish species accounted for over 60 percent of the total fish catch. The second most abundant group of fish collected was rough fish, including black bullhead and common carp. Rough fish accounted for approximately 30 percent of the total catch. The common carp individuals collected were medium to large sized adults averaging just over 20 inches in length. The feeding and spawning activities of species such as common carp and black bullhead can re-suspend mucky, unconsolidated sediments, which often reduces water clarity, increases phosphorus concentrations, and reduces numbers of rooted aquatic plants. Top predators were collected in small numbers from Rice Lake, including largemouth bass, northern pike, bowfin and channel catfish. Overall, top predators accounted for approximately two percent of the total catch. The majority of the top predators collected were small individuals and are not likely producing an effective top-down control on the abundant panfish and rough fish species in the lake. The shallow nature of Rice Lake makes it susceptible to winter kill and unlikely to support stable game fish populations.

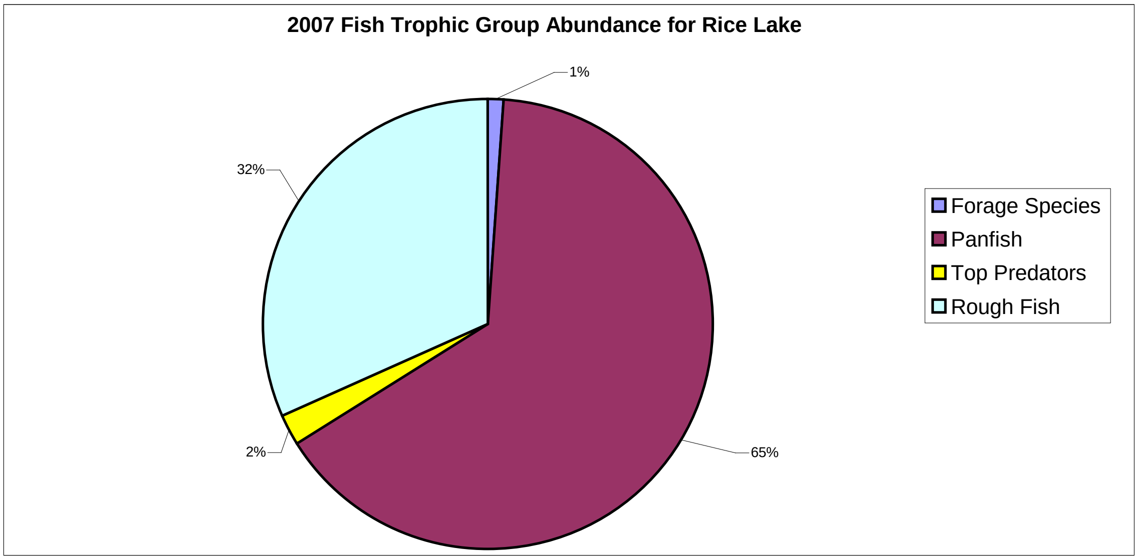

Figure 3-24. 2007 fish survey trophic group abundance for Rice Lake.

Baldwin Lake. Historical fish survey data are not available from the DNR. The shallow nature of Baldwin Lake makes it susceptible to winter kill and unlikely to support stable game fish populations. Due to the turbid water conditions no fish species were observed during 2007 field monitoring. However, as all the lakes in the chain are connected by the Rice Creek channel, it is likely that a fish community similar to other lakes in the chain exists in Baldwin Lake.

Fisheries data is limited for many of lakes in the Chain. However, the limited data indicate that fish populations are dominated by panfish and roughfish. Both of these groups can have negative effects on water clarity, and roughfish likely contribute to higher rates of internal phosphorus loading. Lake morphometry may limit the number of large-bodied predators (see 3.5.3), and thus limit top-down control on panfish and roughfish.

3.5.3 Fish Kills

Fish kills occur when dissolved oxygen levels fall below species-specific minimum requirements, and commonly occur during the summer or winter. Summer kills are the result of high productivity (algae and macrophyte) that eventually senesce, and are subsequently broken down by bacteria. The breakdown of algal and plant biomass by bacteria consumes oxygen, which depletes dissolved oxygen (DO) in the water column. Winter fish kills occur when thick ice and deep snow limit light penetration into the water column, thus limiting photosynthesis. These conditions, coupled with a high sediment oxygen demand, can deplete DO under the ice and result in a fish kill. The shallow nature of each of the lakes in the Chain (i.e. relatively low lake volume) contributes to an increased likelihood of winterkill. All the basins of the Lino Lakes chain of lakes have the potential for a fish kill.

3.6 AQUATIC PLANTS

3.6.1 Introduction

Aquatic plants are beneficial to lake ecosystems, providing spawning and cover for fish, habitat for macroinvertebrates, refuge for prey, and stabilization of sediments. However, in excess they limit recreational activities such as boating and swimming as well as aesthetic appreciation. Some non-native vegetation can lead to special problems in lakes. For example, Eurasian water milfoil can reduce plant biodiversity in a lake due to its ability to grow in high density and out-compete native plants. Ultimately, this can lead to a shift in the fish community because these high densities favor panfish over larger game fish. Species such as curly-leaf pondweed can cause very specific problems by changing the dynamics of internal phosphorus loading (see Section 3.6.4). There is a delicate balance between the aquatic plant community in any lake ecosystem.

3.6.2 Littoral Zone

The littoral zone is defined as that portion of the lake that is less than 15 feet in depth and is where the majority of the aquatic plants are found. The littoral zone of the lake also provides the essential spawning habitat for most warm water fishes (e.g., bass, walleye, and panfish). All these lakes are either entirely or almost entirely littoral. Consequently, they have the potential to be entirely covered with aquatic plants. Algal production is very high in these lakes. Vegetation survey data (see below) indicate that curly-leaf pondweed is dominant in many of these lakes. Curly-leaf pondweed grows in dense mats. Both the dense mats of vegetation and excessive algal growth limit the growth of beneficial aquatic macrophytes by shading out the bottom sediments.

3.6.3 Aquatic Vegetation

George Watch Lake. Vegetation surveys have been conducted in George Watch Lake by the DNR and the RCWD. Figure 3.25 displays the results of the DNR survey conducted in the fall of 1978 and the RCWD survey conducted in the spring of 2002. The survey results show that the diversity of submerged aquatic species has declined and that the dominant species in the lake is now the non-native species curly-leaf pondweed. Field observations from summer monitoring in 2007 confirmed that curly-leaf pondweed is the dominant species, growing in nuisance level mats across most of the lake. The thickness of the curly-leaf mats is likely limiting the diversity and distribution of other, more desirable submerged vegetation species. Additionally the early summer die off curly-leaf pondweed is releasing large nutrients loads into the water column and reducing water clarity. George Watch Lake is entirely within the Rice Creek Chain of Lakes Regional Park and as a result there is an established emergent vegetation community surrounding the lake.

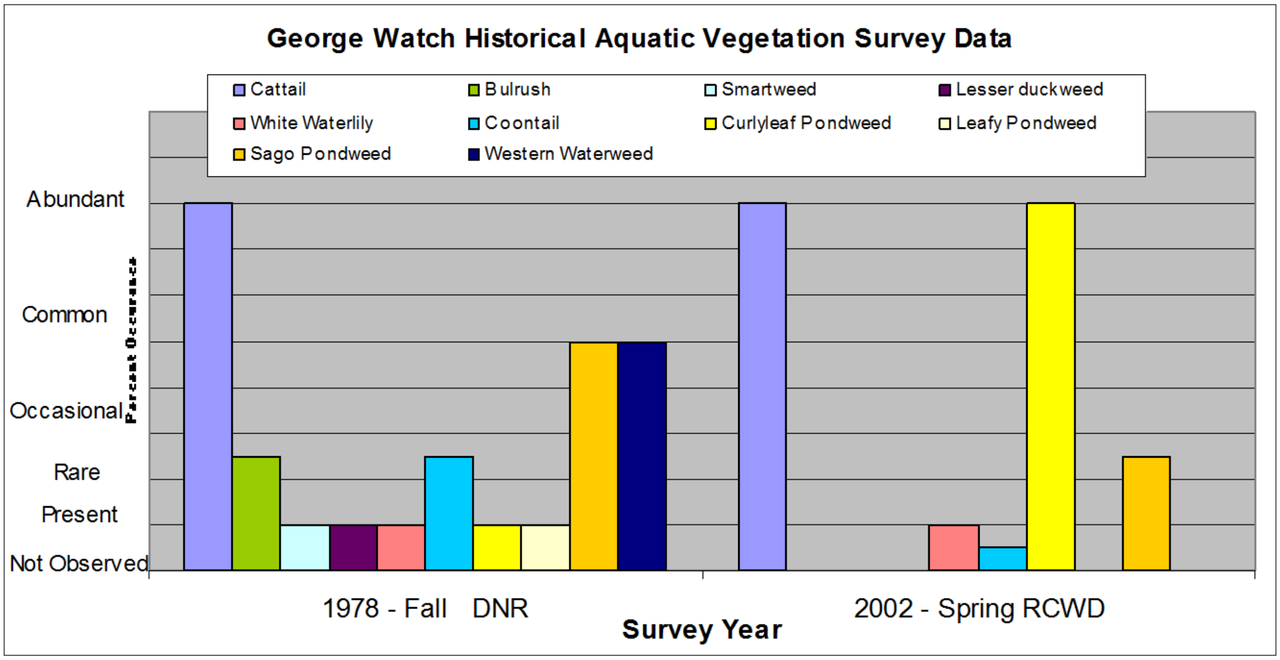

Figure 3-25. Aquatic vegetation survey results: George Watch Lake.

Marshan Lake. Vegetation surveys have been conducted in Marshan Lake by the DNR and the RCWD; the results are shown in Figure 3.26. There were more species observed during the DNR survey than during the RCWD survey. Curly-leaf pondweed was observed in the 2002 survey and during 2007 summer monitoring. However, curly-leaf is not a dominant species in the lake. Field observations in 2007 noted floating leaf and emergent species to be prevalent in Marshan Lake, with dense stands of arrowhead, white water lily and bulrush observed. The majority of Marshan Lake is within the Rice Creek Chain of Lakes Regional Park and as a result there is an established emergent vegetation community surrounding the lake.

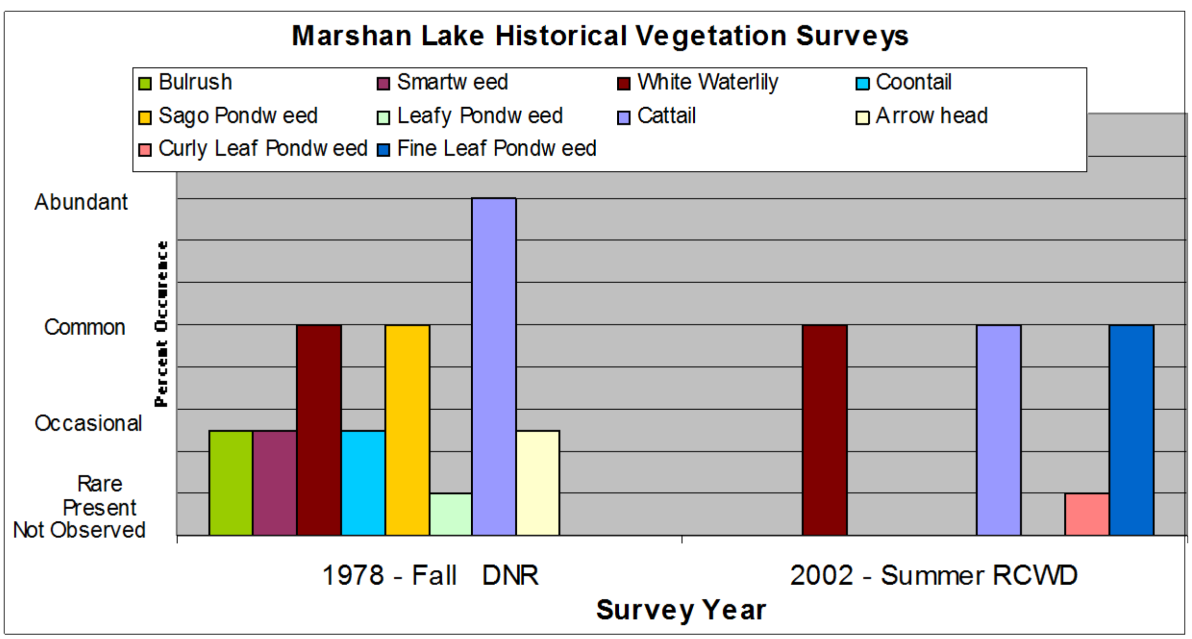

Figure 3-26. Aquatic vegetation survey results: Marshan Lake.

Reshanau Lake. Vegetation surveys were conducted in Reshanau Lake by RCWD in the spring of 2005 and summer of 2007. Figure 3.27 displays the results of the three RCWD vegetation surveys in Reshanau Lake. The 2005 survey revealed that curly-leaf pondweed was the dominant species observed, present in thick mats across over 90 percent of the lake surface. No other submerged vegetation species were identified during the 2005 survey. Spring and summer vegetation surveys were conducted by RCWD on Reshanau Lake in 2007. The spring 2007 survey was very similar to the 2005 spring survey. Curly-leaf pondweed was present in think mats over the majority of the lake. No other submerged aquatic plant species were observed during the 2007 spring survey. During the summer 2007 survey, curly-leaf pondweed was not observed, which is due to the senescence that occurs in early summer. Some emergent and floating leaf vegetation was observed around Reshanau Lake during the summer 2007 survey. Small amounts of the submerged species chara and sago pondweed were observed during summer 2007 survey. These are desirable submerged species that would be present in larger amounts in a lake that was not impacted by curly-leaf pondweed. The thickness of the curly-leaf mats is likely limiting the diversity and distribution of other, more desirable submerged vegetation species. Additionally, the early summer die off of curly-leaf is releasing a large nutrient load into the water column and reducing water clarity. A large portion of the shoreline around Reshanau Lake is developed as single family homes and as a result emergent vegetation is not abundant along the shoreline of the lake.

The Rice Creek Watershed District, in cooperation with local homeowner groups, has treated Reshanau Lake with herbicides to control curly-leaf pondweed. Control efforts began in 2005 and have continued through 2008. Herbicides are applied off-shore soon after ice-out each spring per MNDNR regulations. Control measures have been successful at reducing curly-leaf populations each year. Unfortunately, cumulative benefits have not yet been observed, as pre-control plant surveys indicate significant curly-leaf growth each spring. Additionally, native vegetation has yet to become established, perhaps due to spawning and feeding behaviors of rough fish.

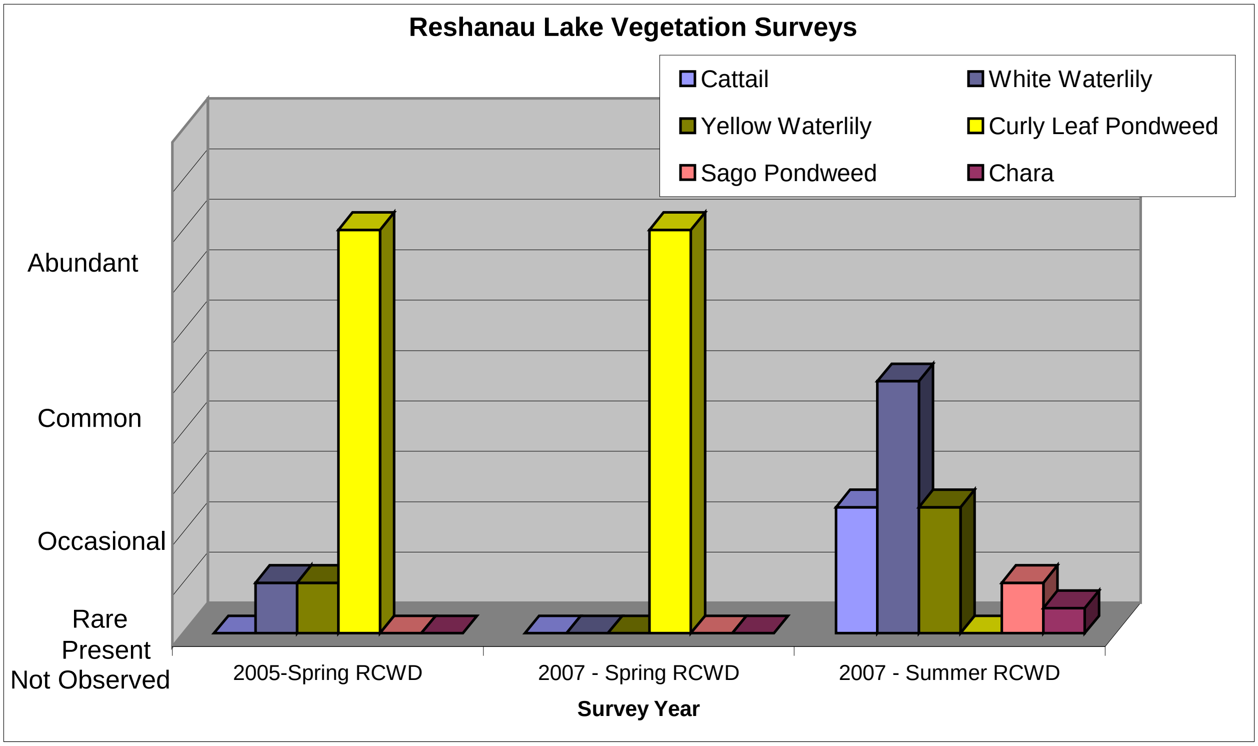

Figure 3-27. Aquatic vegetation survey results: Reshanau Lake.

Rice Lake. Vegetation surveys have been conducted in Rice Lake by the DNR and the RCWD. Figure 3.28 displays the results of the DNR survey conducted in the fall of 1979 and the RCWD survey conducted in the spring of 2005. The major differences between the two surveys is the decrease in the diversity of submerged species from the 1978 survey to the 2005 and the presence of curly-leaf pondweed in Rice Lake. Curly-leaf pondweed was observed to be growing in nuisance-level mats across majority of the lake during 2007 field monitoring. The thickness of the curly-leaf mats is likely limiting the diversity and distribution of other, more desirable submerged vegetation species. Additionally the early summer die off of curly-leaf is releasing large nutrient loads into the water column and reducing water clarity. The majority of Rice Lake is within the Rice Creek Chain of Lakes Regional Park and as a result there is an established emergent vegetation community surrounding the lake.

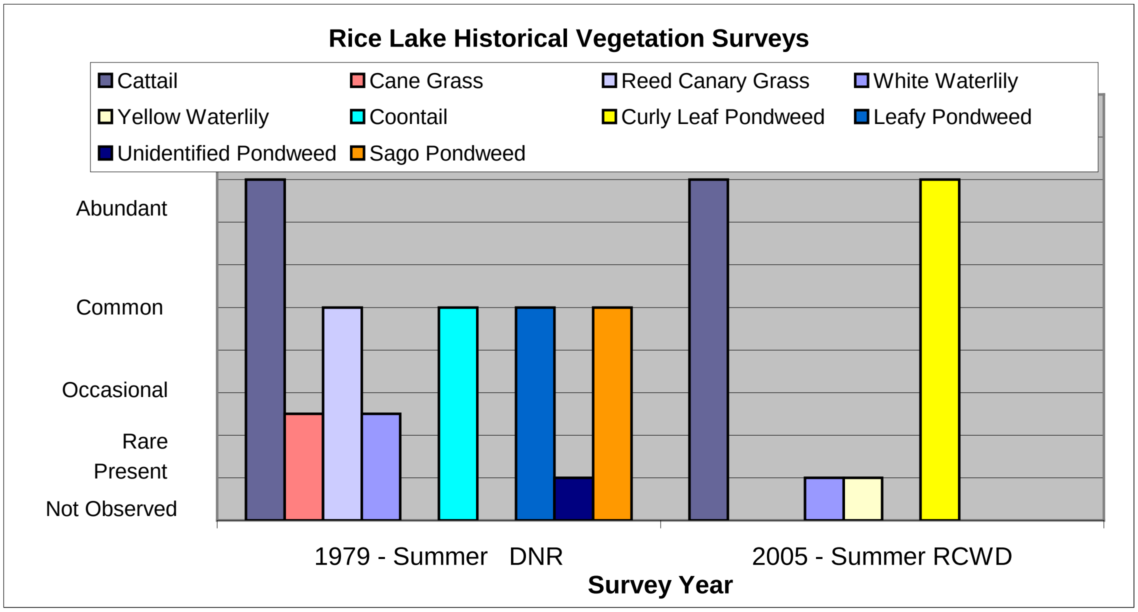

Figure 3-28. Aquatic vegetation survey results: Rice Lake.

Baldwin Lake. Vegetation surveys have been conducted in Baldwin Lake by the DNR and the RCWD, with the results displayed in Figure 3.29. The major difference between the two surveys is the decrease in the diversity and abundance of submerged species from the 1981 survey to the 2004. Observations from 2007 field monitoring revealed that water clarity was extremely low and is likely limiting the growth of submergent species. Very little submerged vegetation was observed during 2007 field monitoring. Curly-leaf pondweed was observed during the RCWD 2004 but is not a dominant species in Baldwin Lake. There is an established emergent vegetation community growing around the majority of Baldwin Lake and several large emergent cattail islands are also present.

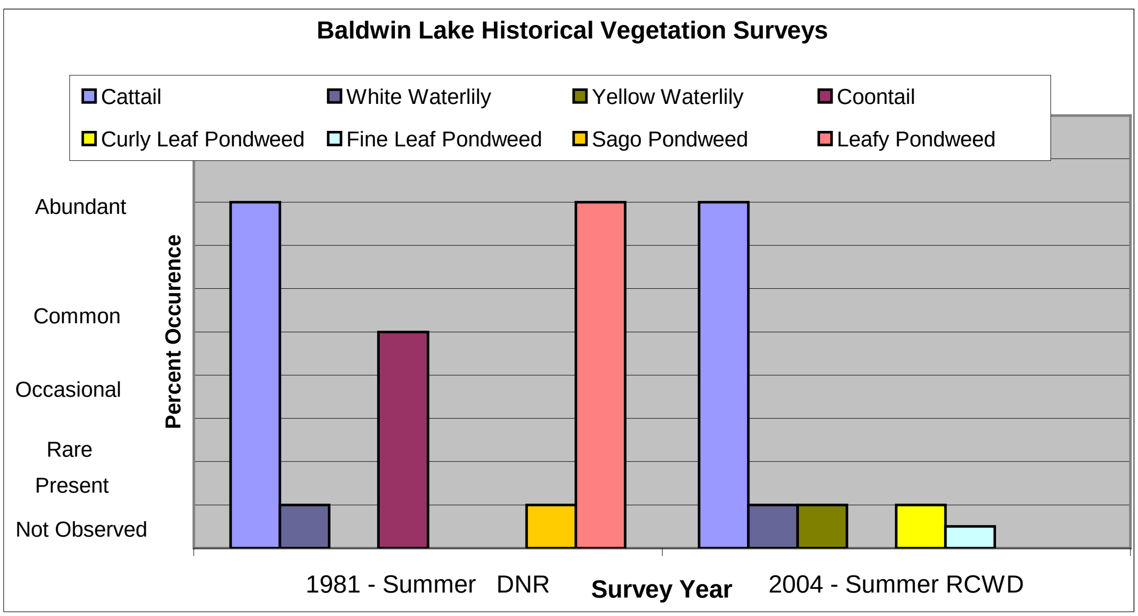

Figure 3-29. Aquatic vegetation survey results: Baldwin Lake.

3.6.4 Shoreline Habitat and Conditions

The shoreline areas are defined as the areas adjacent to the lakes edge with hydrophytic vegetation and water up to 1.5 feet deep or a water table within 1.5 feet from the surface. Natural shorelines provide water quality treatment, wildlife habitat, and increased biodiversity of plants and aquatic organisms. Natural shoreline areas also provide important habitat to fisheries including spawning areas and refugia as well as aesthetic values.

Much of the shoreline on George Watch, Marshan, Rice, and Baldwin Lakes is located within the Rice Creek Chain of Lakes Regional Park Reserve. Riparian wetlands of diverse vegetation types ring the lakes, providing significant shoreline and habitat protection. Much of the shoreline of Reshanau Lake is developed with single-family homes.

Vegetated shorelines provide numerous benefits to both lakeshore owners and lake users including improved water quality, increased biodiversity, important habitat for both aquatic and terrestrial animals, and stabilizing erosion resulting in reduced maintenance of the shoreline. No data are available on shoreline conditions for Reshanau Lake.

4.0 Linking Water Quality Targets and Sources

4.1 INTRODUCTION

A detailed nutrient budget for the Lino Lakes chain of lakes can be a useful tool for identifying management options and their potential effects of water quality. Additionally, models can be developed to understand the response of other variables such as chlorophyll-a and Secchi depth. Through this knowledge, managers can make educated decisions about how to allocate restoration dollars and efforts as well as the resultant effect of such efforts.

4.2 SELECTION OF MODELS AND TOOLS

Modeling was completed using three independent platforms including SWMM, P8, and model equations extracted from BATHTUB. SWMM was used to develop watershed hydraulics and runoff volumes through calibration to collected data. The P8 model was subsequently calibrated to match the watershed runoff volumes developed from the SWMM model. Watershed loads were calculated using P8 (50^{th} percentile particle file) for each of the subwatersheds. Watershed loads were input into the BATHTUB model equations in a spreadsheet to predict lake effects and exchange between the lakes. Modeling methods are explained below and results are provided in Appendix D.

4.2.1 SWMM Modeling

An XP-SWMM model was previously developed for the Lino Lakes watershed as part of a resource management planning by the Rice Creek Watershed District and the City of Lino Lakes. XP-SWMM is an EPA supported model capable of completing multi-year continuous simulation of watershed runoff (EPA 2005). XP-SWMM explicitly models ponds and wetlands as live volume allowing a high resolution of results and analysis. The RCWD has been developing XP-SWMM models in the district as a planning tool for runoff management. More information on the XP-SWMM model including construction and calibration can be found in the Lino Lakes Resource Management Plan (EOR 2008).

Water quantity data for Peltier Lake outflow is calculated from a stage-discharge relationship (St. Paul Water Utility, 1998). Water depth and stage-discharge relationships for County Ditch 25 (outflow from Wards Lake) and County Ditch 32 (outflow into Marshan at Lake Drive) were provided by RCWD. All other water quantity data is predicted by the XP-SWMM model. That model was used to simulate annual water budgets for the period of October 1, 2001, through September 30, 2006.

4.2.2 P8 Modeling

Pollutant load generation and delivery within the watershed is estimated by the P8 model (Walker, 2007, Version 3.2). P8 (Program for Predicting Polluting Particle Passage thru Pits, Puddles, & Ponds; Walker 1990) is a public domain (**http://wwwalker.net/p8/**), industry standard model developed to assess pollutant loading in urban watersheds. P8 was developed using National Urban Runoff Program (NURP) data and provides loading estimates based on data collected as a part of the NURP program. The model estimates the build-up and wash-off of particulates from impervious surfaces in the watershed. The NURP 50^{th} percentile particle file was used to estimate watershed pollutant loading. P8 inputs include device (e.g., detention ponds, pipes) and routing information from XP-SWMM and watershed information (e.g., area, percent impervious, etc.) from GIS data.

The XP-SWMM and P8 models are built such that stormwater runoff from one or more subwatersheds is routed through one or more devices (e.g., wet pond, infiltration basin) and delivered through links into each receiving lake (George Watch, Marshan, Reshanau, Rice, and Baldwin). The P8 model was calibrated by comparing the annual discharge volumes for each link that flows into a lake as computed by XP-SWMM to corresponding volumes predicted by the P8 model and adjusting the P8 model until corresponding runoff volumes matched. For this watershed, P8 over-predicts the amount of runoff generated by sub-watersheds as compared to XP-SWMM. Thus the P8 model was calibrated by reducing the "Impervious Runoff Coefficient" until volumes predicted by P8 matched those predicted by XP-SWMM.

Water quality data was used to verify the P8 model simulation of pollutant load generation and delivery. Growing season (June 1 through September 30) total phosphorus concentrations as predicted by P8 were compared to the available monitoring data. The P8 model reasonably predicts the measured data and therefore no other modifications were made to the pollutant simulation in P8. Details on the model construction and calibration can be found in Appendix D.

4.3 CURRENT PHOSPHORUS BUDGET COMPONENTS

A phosphorus budget that sets forth the current phosphorus load contributions from each potential source was developed for the Lino Lakes chain of lakes using the modeling and collected data described above. Following is a brief description of the budget components and how these values were developed.

4.3.1 Point Sources

There are no permitted industrial dischargers in the Lino Lakes chain watershed.

NPDES Phase II permits for small municipal separate storm sewer systems (MS4) have been issued to all but one of the cities and townships that drain to the chain of lakes as well as Anoka and Ramsey Counties, and Mn/DOT. Columbus Township is not a regulated MS4. The MS4s are covered under the Phase II General NPDES Stormwater Permit – MNR040000. The unique identification numbers assigned to the cities, townships, and counties that drain to the Lino Lakes chain, are as follows:

- Lino Lakes – MS400100
- Centerville – MS400078
- Circle Pines – MS400009
- White Bear Township – MS400163
- Shoreview – MS400121
- Blaine – MS400075
- Ham Lake – MS400092
- North Oaks – MS400109Anoka County – MS400066
- Ramsey County – MS400191
- Mn/DOT Metro District – MS400170
- Minnesota Correctional Institute – Lino Lakes – MS400177

Stormwater discharges are regulated under NPDES, and allocations of nutrient reductions are considered Wasteloads that must be divided among permit holders. Because there is not enough information available to assign loads to individual permit holders, the wasteload allocations (with the exception of Mn/DOT Metro District) are combined in this TMDL as categorical wasteload allocations (see Table 5.1). The Load Allocation is allocated in the same manner. The relative proportions of these sources are presented in Section 5 of this report.

Although many of the sources of phosphorus in the watershed are nonpoint in nature, because they are regulated by NPDES permits, they are allocated in the wasteload allocation portion of this TMDL, as required by the EPA. However, the discussion of the sources recognizes the fundamental nonpoint source nature of phosphorus.

4.3.2 Tributary or Watershed Load

Phosphorus transported by stormwater represents one of the largest contributors of phosphorus to lakes in Minnesota. In fact, phosphorus export from urban watersheds rivals that of agricultural watersheds. Impervious surfaces in the watershed improve the efficiency of water moving to streams and lakes resulting in increased transport of phosphorus into local water bodies. Phosphorus in stormwater is a result of transporting organic material such as leaves and grass clippings, fertilizers, and sediments to the water body. Consequently, stormwater is a high priority pollution concern in urban and urbanizing watersheds.

Transport of urban runoff to local water bodies is quite efficient as a result of local storm sewer systems. As a result of this efficiency, other materials are transported to the water bodies including grass clippings, leaves, car wash wastewater, and animal waste. All of these materials contain phosphorus which can impair local water quality. Some of the material may add to increased internal loading through the breakdown of organics and subsequent release from the sediments. Additionally, the addition of organic material increases the sediment oxygen demand further exacerbating the duration and intensity of sediment phosphorus release from lake sediments.

Excess fertilizer applied to lawns is readily transported to local streams and lakes during runoff events and is immediately available for algal growth. Consequently, excess fertilizer represents a significant threat to lake water quality in urban watersheds.

The tributary load from stormwater runoff from the watershed was developed using the P8 model as described in section 4.2.2 above. The particle data that represents the median for particle sedimentation developed during the National Urban Runoff Program studies was used to develop the watershed loads.

4.3.3 Advective or Upstream Load

Lakes or bays can exchange nutrients through either advective exchange (water moving through) or diffusive exchange (molecules moving along a gradient). Since shallow channels connect the basins, diffusive exchange was assumed to be negligible. All exchange of phosphorus was assumed to occur through advection. Furthermore, no backwater affects were assumed in the exchange process. Outflow from Peltier Lake is the source of approximately 90 percent of the volume to the downstream chain of lakes, suggesting water pushing through the chain of lakes. Measured water quality and quantity data from Peltier Lake is the source of upstream load to George Watch Lake (see section 4.3.6, Appendix C). The results from lake response modeling of George Watch are used as tributary contributions to Marshan and so on throughout the system of lakes.

4.3.4 Atmospheric Load

Precipitation contains phosphorus that can ultimately end up in the lakes as a result of direct input on the lake surface or as a part of stormwater running off of impervious surfaces in the watershed. Although atmospheric inputs must be accounted for in development of a nutrient budget, these inputs are impossible to control.

Atmospheric inputs of phosphorus from wet and dry deposition are estimated using rates set forth in the MPCA report “Detailed Assessment of Phosphorus Sources to Minnesota Watersheds” (Barr Engineering, 2004), and are based on annual precipitation. The aerial loading rates for dry (<25 inches of rain), average, and wet (>38 inches of rain) precipitation years are 0.109, 0.133, and 0.158 lbs/ac-year, respectively. This aerial loading rate was applied to the entire lake surface area to estimate the annual atmospheric phosphorus load to the lake. The watershed is small enough that it is unlikely that there are significant geographic differences in rainfall intensity and amounts across the watershed.

4.3.5 Internal Load

Internal phosphorus loading from lakes has been demonstrated to be an important aspect of the phosphorus budgets of lakes. However, measuring or estimating internal loads can be difficult, especially in shallow lakes that may mix many times throughout the year.

Two methods were performed and compared to estimate internal load. The first method was calculation of the internal phosphorus load from in-lake and sediment phosphorus concentrations. This method uses Nürnberg’s (2005) equations to calculate load using measured data to calculate an anoxic factor for shallow lakes and estimate phosphorus released from sediments. Sediment cores were collected from George Watch, Reshanau, Rice, and Baldwin Lakes and lab analysis of sediment TP used to estimate the internal TP load for each lake.

A mass balance approach was also used to estimate internal load for George Watch Lake. These methods resulted in estimated average summer release rates varying from 7 mg/m^2-day to 11 mg/m^2-day. The results of the mass balance analysis for 2001 are shown in Figure 4.1.

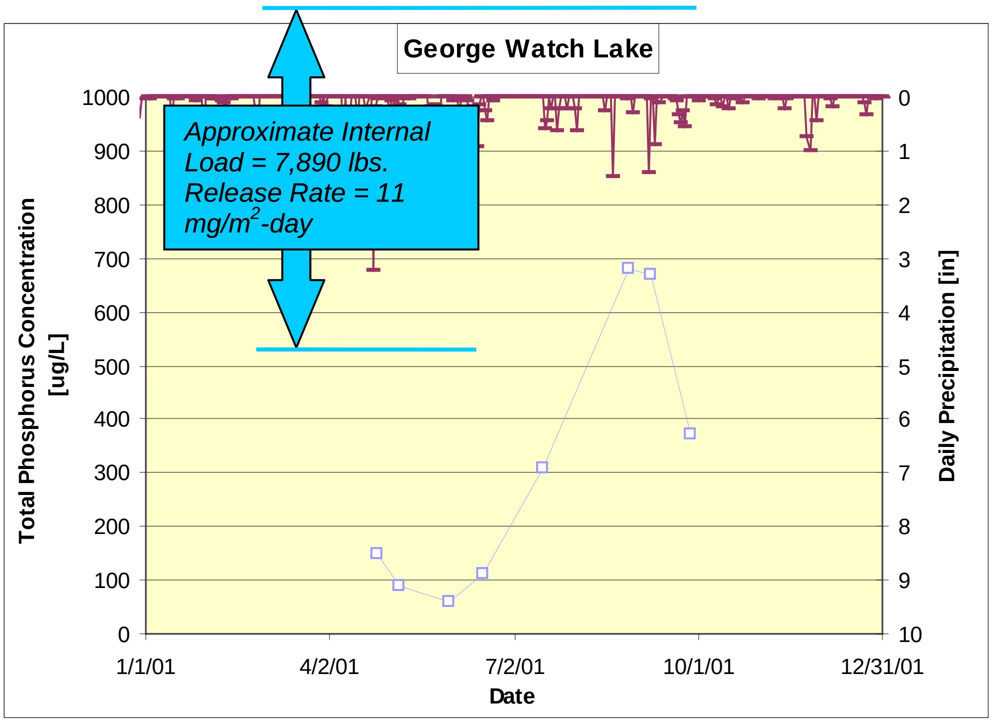

Figure 4-1. Mass balance analysis of internal load in George Watch Lake for 2001.

Nürnberg's (1988) findings of median values for sediment release in eutrophic to hypereutrophic lakes are 10-20 mg/m^2-day. Because the Lino Lakes chain of lakes are hypereutrophic, a conservative value of 10 mg/m^2-day was used in estimating internal load for these lakes (excluding Reshanau) for years in which measured data was not available. Internal load was calibrated to measured in-lake total phosphorus concentration for lakes and years in which measured data was available. Analysis of Reshanau Lake indicates that the average release rate is approximately 6.45 mg/m^2-day. The release rates for each lake for the years between 2001 and 2006 are given in Table 4.1. A detailed analysis of internal load is presented in Appendix E.

Table 4.1. Internal load release rates for sediment-bound phosphorus in the Lino Lakes Chain for 2001 through 2006.

	Release Rate (mg/m^2-day)					
Lake	2001	2002	2003	2004	2005	2006
George Watch	10	5.95	8.49	14.8	10	10
Marshan	10	10	10	15.29	10	10
Reshanau	2.56	6.45	6.45	6.45	7.11	6.45
Rice	10	10	10	11.66	10	10
Baldwin	10	10	10	18.92	10	10

4.3.6 Boundary Condition

George Watch Lake receives inflow from Peltier Lake. For purposes of this TMDL, the upstream boundary condition is the outflow from Peltier Lake, calculated from a known stage-discharge relationship (St. Paul Water Utility 1998). Peltier Lake outflow loads were estimated from the product of monthly discharge volume and average monthly Peltier in-lake total phosphorus concentration. The details for this load calculation are provided in a technical memorandum in Appendix C.

Sherman and Wards Lakes are two small lakes within the Reshanau Lake subwatershed. No bathymetry or water quality data is currently available for these lakes but monitoring data between Wards Lake and Reshanau Lake in 2005 and 2006 is available. Sherman and Wards Lakes were modeled as small lake basins upstream of Reshanau Lake and the available monitoring data was used to calibrate the upstream lake load into Reshanau Lake. The flow-weighted average total phosphorus concentrations in the outflow from Wards Lake were approximately 242 µg/L and 245 µg/L in 2005 and 2006, respectively.

4.3.7 Total Phosphorus Budget

The current total phosphorus budgets for the chain of lakes are set forth in Table 4.2. Several years' data were examined, and an average of the growing seasons (122 days) for 2002-2004 were used for the phosphorus budget presented in Table 4.2. Results of the Lake Response Model which were used to develop the phosphorus budget may be found in Appendix F.

Table 4.2. Current total phosphorus budget for the chain of lakes based on the average from 2002 - 2004.

Lake		**Source**	**Average Growing Season TP Load (lb)**	**Average Annual TP Load (lb)**
George Watch Lake	Wasteload	Stormwater Load	164	491
	Load	Upstream Load	7,679	22,990
		Atmospheric Load	42	125
		Internal Load	9,408	28,165
		TOTAL LOAD	*17,292*	*51,770*
Marshan Lake	Wasteload	Stormwater Load	307	893
	Load	Watershed Load	161	468
		Upstream Load	7,802	23,357
		Atmospheric Load	15	44
		Internal Load	3,997	11,968
		TOTAL LOAD	*12,282*	*36,730*
Reshanau Lake	Wasteload	Stormwater Load	28	85
	Load	Upstream Load	219	655
		Atmospheric Load	6	17
		Internal Load	596	1,786
		TOTAL LOAD	*849*	*2,542*
Rice Lake	Wasteload	Stormwater Load	248	743
	Load	Upstream Load	7,734	23,155
		Atmospheric Load	21	62
		Internal Load	5,082	15,214
		TOTAL LOAD	*13,085*	*39,175*
Baldwin Lake	Wasteload	Stormwater Load	68	205
	Load	Upstream Load	7,546	22,591
		Atmospheric Load	10	31
		Internal Load	3,109	9,308
		TOTAL LOAD	*10,734*	*32,125*

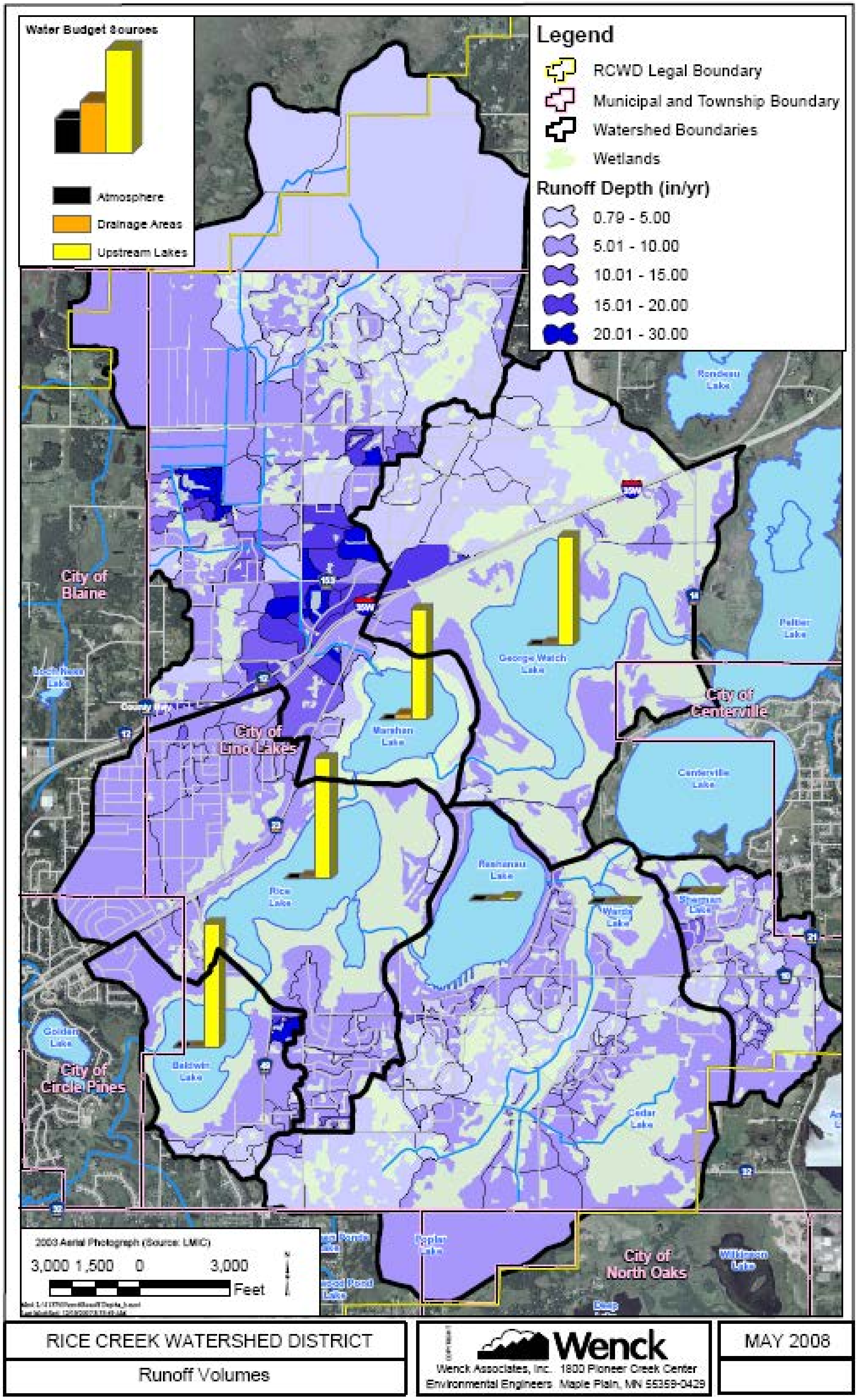

Figure 4-2. Runoff volume for the Lino Lakes Chain of Lakes.

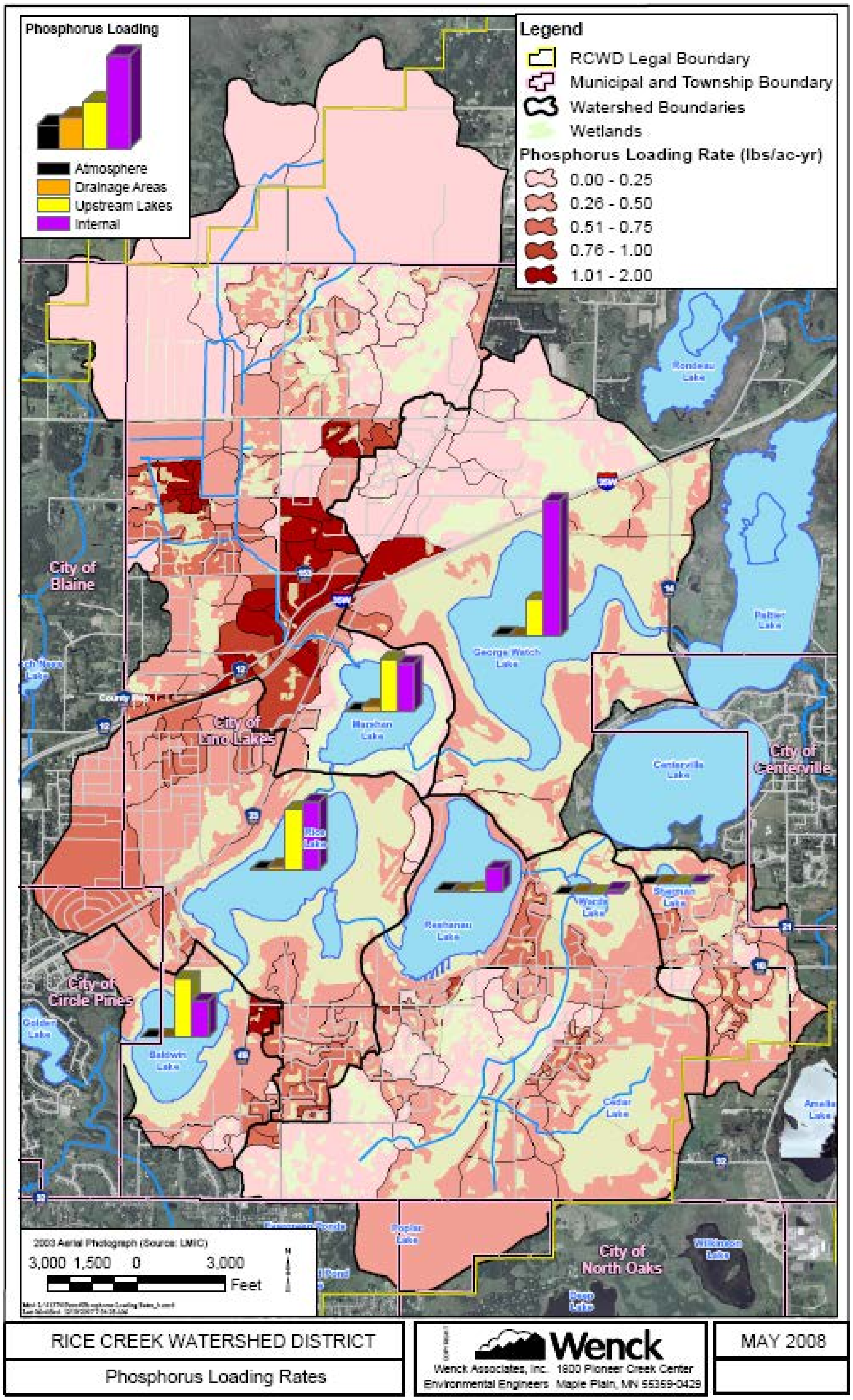

Figure 4-3. Phosphorus loading rates for the Lino Lakes Chain of Lakes.

4.4 LAKE RESPONSE MODELING (BATHTUB)

For this TMDL, the BATHTUB model was selected to link phosphorus loads with in-lake water quality. A publicly available model, BATHTUB was developed by William W. Walker for the U.S. Army Corps of Engineers (Walker 1999). BATHTUB has been used successfully in many lake studies in Minnesota and throughout the United States. BATHTUB is a steady-state annual or seasonal model that predicts a lake's summer (June – September) mean surface water quality. BATHTUB's time-scales are appropriate because watershed P 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 P model that accounts for water and P 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 P sedimentation and retention in the lake sediments. Bathtub's in-lake water quality predictions include two response variables, chlorophyll-*a* concentration and Secchi depth, in addition to total phosphorus concentration. Empirical relationships between in-lake total phosphorus, chlorophyll-*a*, and Secchi depth form the basis for predicting the two response variables. Among the key empirical model parameters is the ratio of the inverse of Secchi depth (the inverse being proportional to the light extinction coefficient) to the chlorophyll-*a* concentration

Several equations used within the BATHTUB model are used to estimate the phosphorus, chlorophyll-a, and Secchi depth response in George Watch, Marshan, Sherman, Wards, Reshanau, Rice, and Baldwin lakes. Several models (subroutines) are available for use within the BATHTUB model. The selection of the subroutines is based on past experience in modeling lakes in Minnesota and is focused on subroutines that were developed based on data from natural lakes. The Canfield-Bachmann natural lake model was chosen for the phosphorus model. This was chosen due to many successful applications in other Minnesota lakes. The chlorophyll-a response model used was model 1 from the BATHTUB package, which accounts for nitrogen, phosphorus, light, and flushing rate. Secchi depth was predicted using the "VS. CHLA & TURBIDITY" equation. Modelers were allowed flexibility in selecting other subroutines if the Canfield-Bachmann model did not function well for the given system. For more information on these model equations, see the BATHTUB model documentation (Walker 1999). Model coefficients are also available in the model for calibration or adjustment based on known cycling characteristics. The coefficients were left at the default values. No calibration factors were applied to the response models.

Annual runoff volume and phosphorus load were used as input into the equations to estimate lake response. The average residence time in George Watch, Marshan, Rice, and Baldwin Lakes is approximately 0.1 years which means that the lake volume is replaced approximately 10 times per year by runoff. Therefore in-lake concentration and water clarity is expected to respond to the growing season volume and pollutant load because pollutant load during the rest of the year is flushed through the lake system before the aquatic biota utilizes it. The average residence time in Reshanau Lake is approximately one to three years and therefore the in-lake concentration and water clarity is expected to respond to annual runoff volume and phosphorus load.

A significant portion of the water budget for the chain of lakes (excluding Reshanau) comes from Lake Peltier upstream of George Watch Lake. The assumptions and calculations for this upstream boundary condition are discussed in section 4.3.6 and in Appendix C. Results of the lake response modeling can be found in Appendix F.

4.4.1 Model Validation

To test the assumptions applied in the model, the model was compared to available phosphorus, chlorophyll-a, and Secchi depth data collected from 2001 through 2004. The model adequately predicted the available data for phosphorus, chlorophyll-a, and Secchi depth from most years excluding 2001. The model does not adequately predict phosphorus and chlorophyll-a concentration in 2001 for George Watch and Marshan Lakes because measured values are unusually large (approximately twice the average from other years). In-lake data for Peltier Lake was not available in 2005 and therefore the model predictions are not appropriate for comparison to the available data. A majority (~95%) of volume discharged from Peltier in 2006 does not occur during the growing season (June 1 through September 30) and therefore the model predictions are not appropriate for comparison to the available data. The water quality response model and internal load estimates were considered reasonable for the chain of lakes. Results from the calibrated lake response model are provided in figures 4.4 through 4.8.

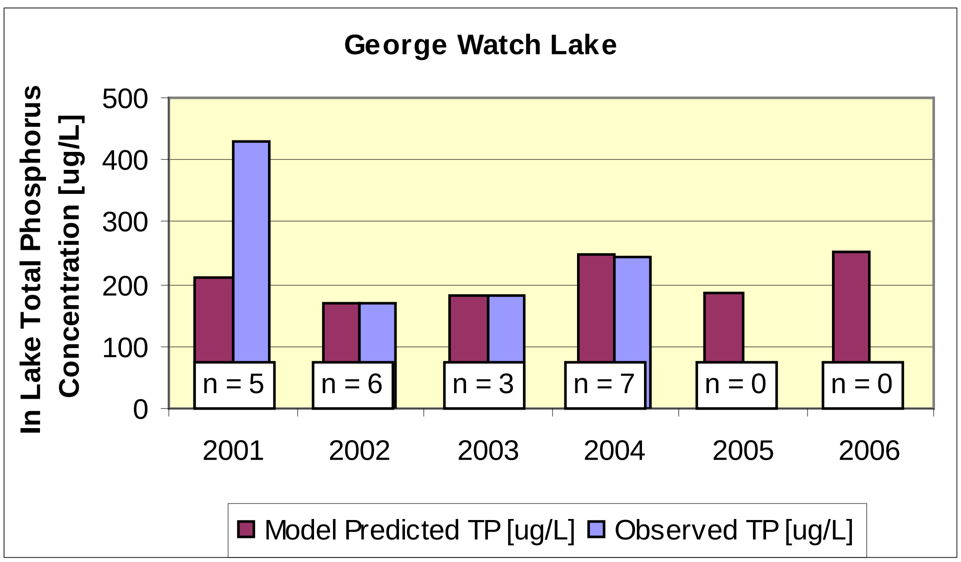

Figure 4-4. Calibrated model results for George Watch Lake, 2001-2006.

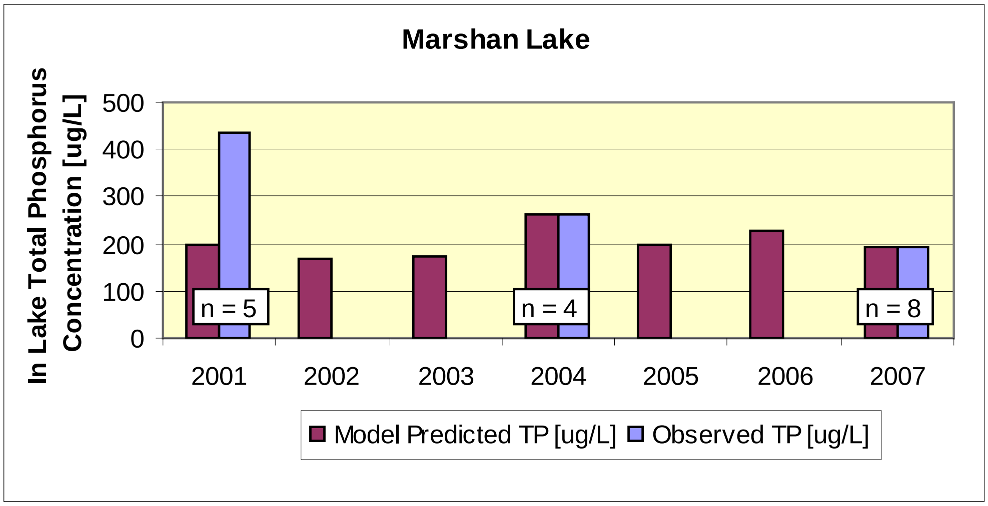

Figure 4-5. Calibrated model results for Marshan Lake, 2001-2007.

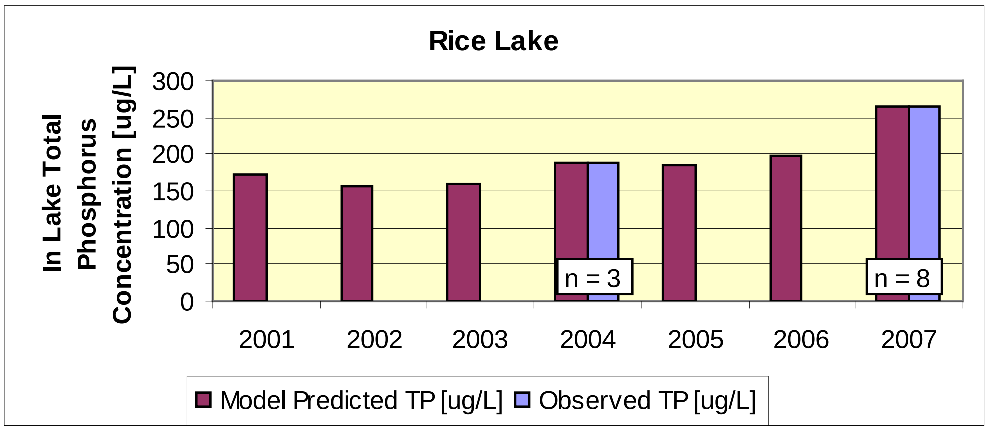

Figure 4-6. Calibrated model results for Rice Lake, 2001-2007.

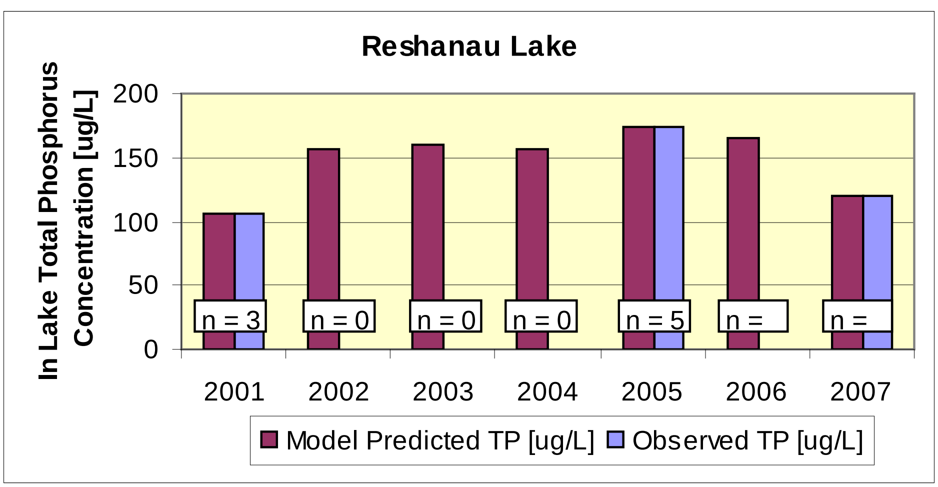

Figure 4-7. Calibrated model results for Reshanau Lake, 2001-2007.

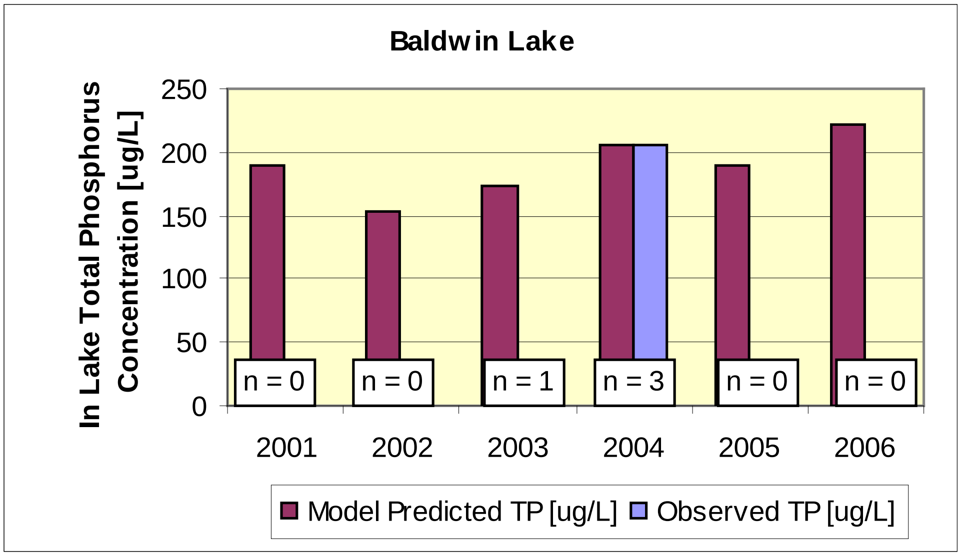

Figure 4-8. Calibrated model results for Baldwin Lake, 2001-2006.

4.5 CONCLUSIONS

George Watch Lake

- Internal phosphorus load was estimated at approximately 54% of the total load,
- Most (98%) of the external load (44% of the total load) into George Watch lake is exported from Peltier Lake.

Marshan Lake

- Internal phosphorus load was estimated at approximately 33% of the total load,
- The largest external load is the upstream load from George Watch Lake, representing approximately 64% of the phosphorus load to Marshan.

Reshanau Lake

- Internal phosphorus load was estimated at approximately 70% of the total load,
- Watershed and upstream lake (Wards Lake) load represents approximately 29% of the total load.

Rice Lake

- Internal phosphorus load was estimated at approximately 39% of the total load,
- The largest external load is upstream load from Marshan Lake, representing approximately 59% of the total phosphorus load.

Baldwin Lake

- Internal phosphorus load was estimated at approximately 29% of the total load,
- The largest external load is upstream load from Rice Lake, representing approximately 70% of the total phosphorus load.

5.0 TMDL Allocation

5.1 LOAD AND WASTELOAD ALLOCATIONS

5.1.1 Water Quality Endpoint

Nutrient loads in this TMDL are set for phosphorus, because this is typically the limiting nutrient for nuisance aquatic plants. George Watch, Marshan, Reshanau, Rice, and Baldwin Lakes are shallow lakes and are subject to the water quality standard of 60 µg/L of total phosphorus as described in Section 2.0.

A natural background condition standard of 80 µg/L was previously proposed for the entire chain of lakes, with the exception of Reshanau Lake. The proposal was based on diatom reconstructions done by the Science Museum of Minnesota for Peltier Lake (Appendix A). At this time, a natural background condition standard is <u>not</u> proposed for any of the lakes covered in this TMDL. Thus, only the current state eutrophication standards will apply. However, information and results relating to the previously proposed natural background condition standard remains in this section of the TMDL document solely for reference and for possible reconsideration of an alternative endpoint in the future.

5.1.2 Allocation Approach

To arrive at both the load and wasteload allocations, a phosphorus budget was developed from the average input for each source from 2001 through 2006. To determine the total loading capacity, the current nutrient budget and the lake response modeling (average of 2001-2006) were used as the starting point. The nutrient inputs were then systematically reduced until the model predicted that the lakes met the appropriate total phosphorus standard. The reductions were applied first to the internal load and then the watershed sources. Once the total phosphorus goal is met, both the chlorophyll-a and Secchi response models are reviewed to ensure both response variables are predicted to meet the state standards as well. Direct atmospheric deposition was left unchanged because this source is impossible to control. Peltier Lake was set to discharge at either the current state standard (60 µg/L) or the site specific standard (80 µg/L) under the assumption that the current Peltier Lake TMDL would be met. To determine the allowable internal phosphorus load, measured release rates were compared to expected release rates for mesotrophic lakes (Figure 5.1; Nurnberg 1997) as well as to a nearby healthy shallow lake in the Rice Creek watershed (Oneka Lake). Mesotrophic lakes demonstrate internal phosphorus release rates ranging from 0 to 12 mg/m^2/day with a median release rate around 4 mg/m^2/day. The measured release rate for Oneka Lake is zero. An internal release rate range 0.5 – 2.0 mg/m^2/day (depending on the lake and the endpoint) was determined to be the lowest achievable rate for this TMDL and is considered conservative in this geographic area. If the analysis showed that reducing the internal load to a release rate higher than 2.0 mg/m^2/day achieved the TMDL target, the remaining phosphorus sources were left at current loading. In all of the lakes, the TMDL could be achieved by reducing the internal load, so external loads (excluding Peltier inflow) were held at current conditions.

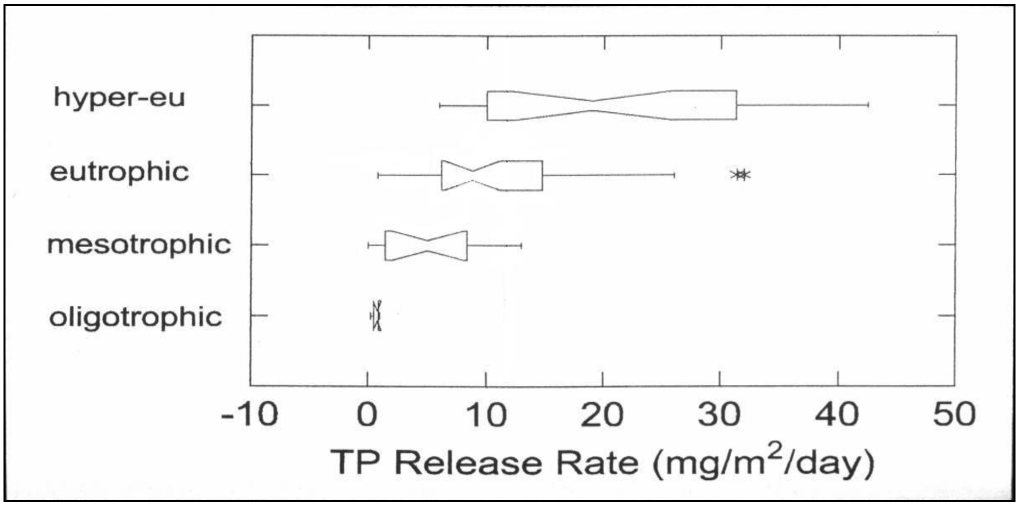

Figure 5.5-1. Sediment phosphorus release rates by eutrophic condition (Nürnberg 1997).

Stormwater discharges are regulated under NPDES, and allocations of nutrient reductions are considered Wasteloads that must be divided among permit holders. Because it was judged that there is not enough information available to fairly and accurately assign loads to individual permit holders, the wasteload allocations are combined in this TMDL as categorical wasteload allocations assigned to all permitted dischargers in the contributing watershed, with the exception of Mn/DOT Metro District (see Table 5.1). Mn/DOT has requested individual WLAs for those watersheds in which it has roads. Those WLAs are simply based on their fraction of right-of way in the total land area receiving a stormwater load. Mn/DOT's right-of-way land area in the George Watch, Marshan and Rice watersheds are 25.6, 9.7 and 9.2 acres, respectively, based on data provided by them. It should be noted that Rice Creek Watershed District is considered a regulated MS4 due to its authority over some public ditches. However, for the drainage area covered by this TMDL it has not been determined if the public ditches here are "waters of the state" or treatment conveyances that treat stormwater. It is not possible to be both. For the purposes of moving forward with this TMDL the RCWD drainages systems will be considered part of the load allocation for this TMDL. Should it later be determined that the ditches are stormwater conveyances a correction will be made to the TMDL to move them to the categorical WLA. It should further be noted that the district has expressed that they are committed to the same level of work to pursue pollutant load reductions regardless of which category they are placed in.

Permitted construction stormwater and industrial stormwater are included in the categorical wasteload allocation. Currently, there are no industrial permits in the watershed.

Some portions of the MS4 communities are not covered under NPDES permits, including agricultural areas and other areas not served by stormwater conveyances owned by the MS4. Consequently, the permitted and nonpermitted areas are split between the wasteload and load allocation categories, respectively. In this TMDL the permitted source areas falling under the wasteload allocation are termed stormwater loads and the nonpermitted areas falling within the load allocation are called watershed loads. Also, the allowable phosphorus load export on a per acre basis is set equally between the land uses falling in the stormwater load and watershed load categories. To account for future growth in the watershed, land use projections for 2020 are used, as shown in Table 5.2 (data source: Metropolitan Council). Therefore, those 2020 land use areas designated as agriculture, open space, parks and recreation, mixed use, and rural residential were assigned to the load allocation. All other 2020 land use areas were assigned to the wasteload allocation. The acreage falling within the stormwater load category for George Watch, Marshan, and Rice Lake's watersheds was determined to be 25.6, 9.7, and 9.2 respectively.

Table 5.1. Wasteload allocation by NPDES permitted entity for each lake.

NPDES Permit Number	George Watch	Marshan	Reshanau	Rice	Baldwin
Lino Lakes – MS400100	Categorical WLA	Categorical WLA	Categorical WLA	Categorical WLA	Categorical WLA
Centerville – MS400078	Categorical WLA	Categorical WLA	N/A	Categorical WLA	Categorical WLA
Circle Pines – MS400009	N/A	N/A	N/A	Categorical WLA	Categorical WLA
White Bear Township – MS400163	N/A	Categorical WLA	Categorical WLA	Categorical WLA	Categorical WLA
Shoreview – MS400121	N/A	Categorical WLA	Categorical WLA	Categorical WLA	Categorical WLA
Blaine – MS400075	N/A	Categorical WLA	Categorical WLA	Categorical WLA	Categorical WLA
Ham Lake – MS400092	N/A	Categorical WLA	Categorical WLA	Categorical WLA	Categorical WLA
North Oaks– MS400109	N/A	N/A	Categorical WLA	N/A	N/A
Anoka County – MS400066	Categorical WLA	Categorical WLA	Categorical WLA	Categorical WLA	Categorical WLA
Ramsey County – MS400191	N/A	Categorical WLA	Categorical WLA	Categorical WLA	Categorical WLA
Mn/DOT Metro District – MS400170	Individual WLA	Individual WLA	N/A	Individual WLA	N/A
Minnesota Correctional Institute – Lino Lakes – MS400177	N/A	Categorical WLA	N/A	N/A	N/A
Industrial Stormwater – NA	Categorical WLA	Categorical WLA	Categorical WLA	Categorical WLA	Categorical WLA
Construction Stormwater – Various	Categorical WLA	Categorical WLA	Categorical WLA	Categorical WLA	Categorical WLA

N/A = Not applicable – does not drain to lake.

If additional stormwater discharges come under permit coverage within the watershed, it may be necessary to transfer WLA from one MS4 to another. This may occur if the Census Bureau-defined Urban Area expands, if new county- or state-owned roads within the Urban Area are built, or if existing roads are expanded. In these cases, WLA will be transferred to these new entities based on the process used to set wasteload allocations in the TMDL. Affected permittees will be notified and will have an opportunity to comment on the reallocation.

Table 5.2. 2020 land use in the Lino Lakes watershed by lake. Area in acres.

Land Use	George Watch	Marshan	Reshanau	Rice	Baldwin	Total Area	% of Watershed
Single-Family Residential	326.5	1040.9	1267.4	697.0	103.8	3435.5	22%
Rural Residential	221.6	2140.8	601.5	261.4	133.8	3359.1	22%
Park and Recreation	1133.8	136.7	631.0	369.3	112.0	2382.8	15%
Water	557.2	244.2	551.8	454.9	220.0	2028.1	13%
Open Space	237.3	448.8	778.1	57.9	56.3	1578.3	10%
Roadway	175.9	291.6	273.5	281.0	46.7	1068.6	7%
Institutional	7.5	186.0	109.2	130.3	7.4	440.3	3%
Multi-Family Residential	90.0	147.6	56.1	28.0	29.1	350.8	2%
Commercial	104.9	54.4	31.6	58.3	34.9	284.1	2%
Industrial	0.3	263.1	0.0	2.0	0.0	265.4	2%
Mixed Use	65.1	84.5	0.0	17.6	0.0	167.2	1%
Airport	0.0	31.2	0.0	18.3	0.0	49.5	0%
Agricultural	0.0	5.5	0.0	0.0	0.0	5.5	0%
Total Area	2920.1	5075.1	4300.0	2376.0	743.9	15415.1	

5.1.3 Critical Conditions

The TMDL equations represent loads for the critical conditions in the lakes. The critical condition for these lakes is the summer growing season. Minnesota lakes typically demonstrate impacts from excessive nutrients during the summer recreation season (June 1 through September 30) including excessive algal blooms and fish kills. Lake goals have focused on summer-mean total phosphorus, Secchi transparency and chlorophyll-a concentrations. These parameters have been linked to user perception (Heiskary and Wilson 2005). Consequently, the lake response models have focused on the summer growing season as the critical condition. Additionally, these lakes tend to have relatively short residence times and therefore respond to summer growing season loads.

5.1.4 Allocations

The total loading capacity is the total maximum daily load and was determined using the methods described in Section 5.1.2. The load and wasteload allocations are shown in Table 5.3, with additional source apportionment in Table 5.4. These allocations will guide the development of an implementation plan and necessary reductions. The TMDL was established using an average load for 2002 through 2004 because these years had the most robust data set for the entire chain. Because Reshanau Lake only discharges to the chain and no data were collected during those years, the TMDL was set using an average of 2001, 2005, and 2007 where data were available. Additionally, allocations for the chain are growing season loads due to the short residence time (<3 months) of these lakes while Reshanau Lake allocations are annual loads because of the longer residence time of the lake (>1 year).

Table 5. 3. TMDL total phosphorus allocations expressed as daily loads for the Lino Lakes chain of lakes assuming the shallow lake standard of 60 µg/L.

Lake	Wasteload TP Allocation (lb/day)[1]	Load TP Allocation (lb/day)	Margin of Safety	Total Phosphorus TMDL (lb/day)
George Watch Lake	0.43	31.52	Implicit	31.95
Marshan Lake	1.5	24.5	Implicit	26
Reshanau Lake	0.03	0.68	Implicit	0.71
Rice Lake	1.2	29.48	Implicit	30.68
Baldwin Lake	0.22	27.72	Implicit	27.94

[1]The wasteload allocation is allocated to NPDES-permitted entities in accordance with Table 5.1.

Load allocations by source are provided in Table 5.4. To determine the wasteload and load allocations, the lake response model was used to determine necessary reductions from each source. No reduction in atmospheric loading is targeted because this source is impossible to control on a local basis. Because the internal loading is so high in most of the lakes, reductions were applied here first to determine if the standard could be met by reducing only internal loads. The state phosphorus standard could be met in all of the lakes by reducing internal loads to a range of 0.5 to 2 mg/m^2/day. Consequently, watershed loads were held at current conditions.

Table 5. 4. TMDL total phosphorus daily loads partitioned among the major sources for each lake in the chain of lakes.

Lake	Allocation Type	Source	Existing Load (lb/day)	Shallow Lake Standard (60 µg/L)		Previously Proposed Natural Background Condition (80 µg/L)[2]	
				Total TP Load (lb/day)	Percent Reduction	Total TP Load (lb/day)	Percent Reduction
George Watch Lake	Wasteload	Stormwater Load	0.42	0.42	0%	0.42	0%
		Stormwater Load—Mn/DOT	0.01	0.01	0%	0.01	0%
	Load	Watershed Load	0.92	0.92	0%	0.92	0%
		Upstream Lake Load	62.9	19.9	68%	26.5	58%
		Atmospheric Load	0.3	0.3	0%	0.3	0%
		Internal Load	77.1	10.4	87%	17.1	78%
		TOTAL LOAD	141.65	31.95	77%	45.25	68%
Marshan Lake	Wasteload	Stormwater Load	1.54	1.54	0%	1.54	0%
		Stormwater Load—Mn/DOT	0.01	0.01	0%	0.01	0%
	Load	Watershed Load	2.3	2.3	0%	2.3	0%
		Upstream Lake Load	64.0	20.3	68%	27.0	58%
		Atmospheric Load	0.1	0.1	0%	0.1	0%
		Internal Load	32.8	1.8	95%	4.7	86%
		TOTAL LOAD	100.75	26.05	74%	35.65	65%
Reshanau Lake	Wasteload	Stormwater Load	0.03	0.03	0%	Not Applicable	
	Load	Watershed Load	0.04	0.04	0%		
		Upstream Lake Load	0.60	0.42	30%		
		Atmospheric Load	0.02	0.02	0%		
		Internal Load	1.6	0.2	90%		
		TOTAL LOAD	2.29	0.71	71%		

[2] A natural background condition standard is not proposed in this TMDL. Information remains for reference.

Lake	Allocation Type	Source	Existing Load (lb/day)	Shallow Lake Standard (60 µg/L)		Previously Proposed Natural Background Condition (80 µg/L)[2]	
				Total TP Load (lb/day)	Percent Reduction	Total TP Load (lb/day)	Percent Reduction
Rice Lake	Wasteload	Stormwater Load	1.21	1.21	0%	1.21	0%
		Stormwater Load—Mn/DOT	0.01	0.01	0%	0.01	0%
	Load	Watershed Load	0.81	0.81	0%	0.81	0%
		Upstream Lake Load	63.4	22.2	65%	29.5	53%
		Atmospheric Load	0.17	0.17	0%	0.17	0%
		Internal Load	41.7	6.3	85%	10.8	74%
		TOTAL LOAD	107.3	30.7	71%	42.5	60%
Baldwin Lake	Wasteload	Stormwater Load	0.22	0.22	0%	0.22	0%
	Load	Watershed Load	0.34	0.34	0%	0.34	0%
		Upstream Lake Load	61.9	22.7	63%	30.3	51%
		Atmospheric Load	0.08	0.08	0%	0.08	0%
		Internal Load	25.5	4.6	82%	7.5	71%
		TOTAL LOAD	88.04	27.94	68%	38.44	56%

No reduction in atmospheric loading is targeted because this source is impossible to control on a local basis. The remaining load reductions were applied based on our understanding of the lakes as well as output from the model.

5.2 RATIONALE FOR LOAD AND WASTELOAD ALLOCATIONS

The TMDL presented here is developed to be protective of the aquatic recreation beneficial use in lakes. However there is no loading capacity *per se* for nuisance aquatic plants. Consequently, to understand the impacts of the phosphorus loads to the lake, a water quality response model was used to predict the water quality after load reductions were implemented. Utilization of this approach allows for a better understanding of potential lake conditions under numerous load scenarios. The following sections describe the results from the water quality response modeling.

5.2.1 Modeled Historic Loads

Using the Canfield-Bachmann equation, historic loads and load reductions were calculated for each of the basins. Historical allowable loads were calculated using the Canfield-Bachmann model to predict the total phosphorus load at that year's conditions to the load that would achieve the current state standards. These calculations provide some insight into the assimilative capacity of the lake under historical hydrologic conditions as well as over time. Additionally, these results provide a sense for the level of effort necessary to achieve the TMDL and whether that TMDL will be protective of the water quality standard.

George Watch Lake requires a 72 to 85 percent reduction to meet the proposed water quality standard of a summer average of 60 µg/L total phosphorus (Figure 5.2).

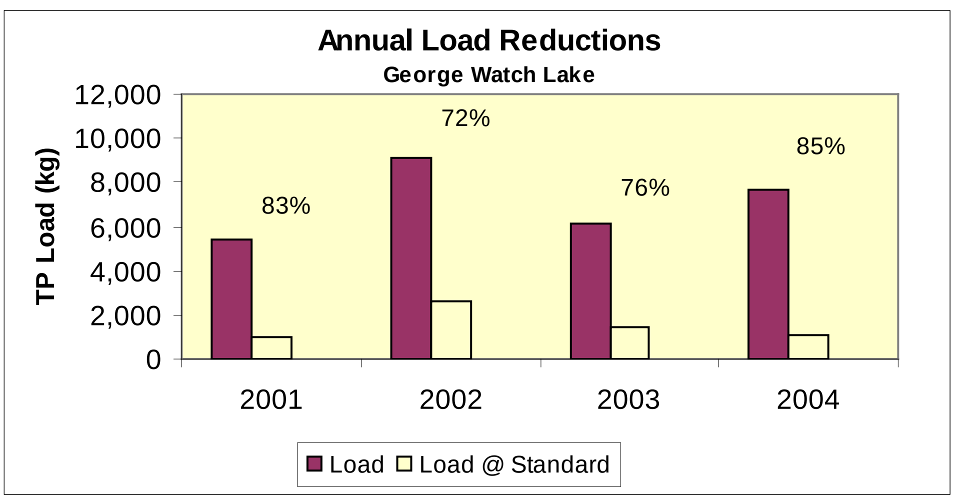

Figure 5-2. Modeled annual load and load at the standard for George Watch Lake The percentages represent the reduction needed to meet the standard.

Marshan Lake requires a 69 to 83 percent reduction to meet the proposed water quality standard of a summer average of 60 µg/L total phosphorus (Figure 5.3).

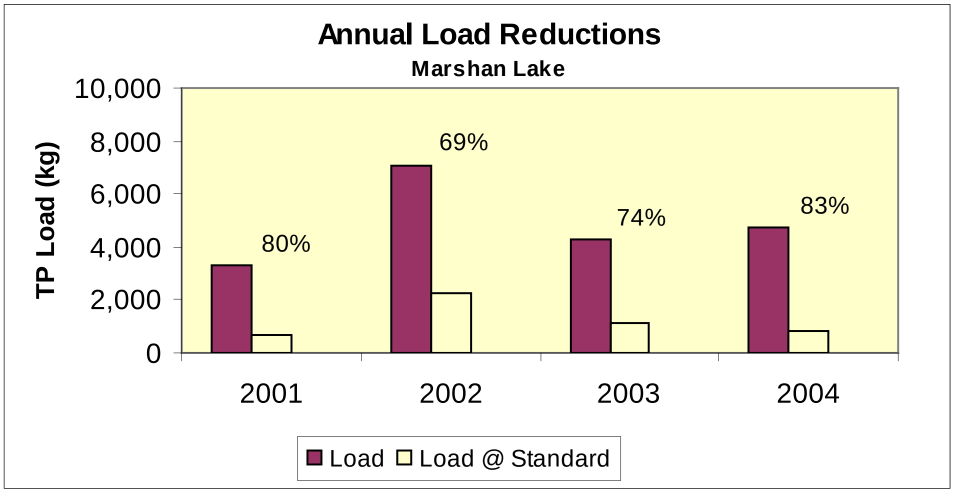

Figure 5-3. Modeled annual load and load at the standard for Marshan Lake.
The percentages represent the reduction needed to meet the standard.

Reshanau Lake requires a 63 to 84 percent reduction to meet the proposed water quality standard of a summer average of 60 µg/L total phosphorus (Figure 5.4).

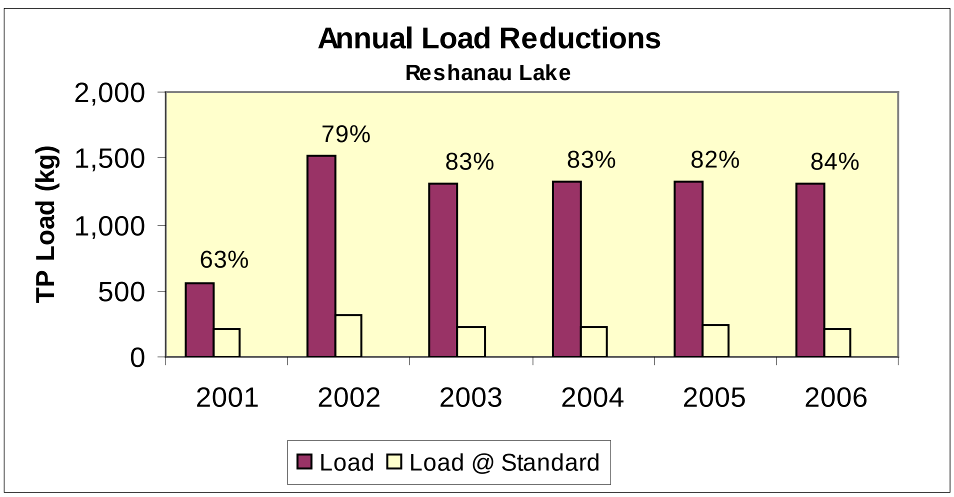

Figure 5-4. Modeled annual load and load at the standard for Reshanau Lake. The percentages represent the reduction needed to meet the standard.

Rice Lake requires a 68 to 80 percent reduction to meet the proposed water quality standard of a summer average of 60 µg/L total phosphorus (Figure 5.5).

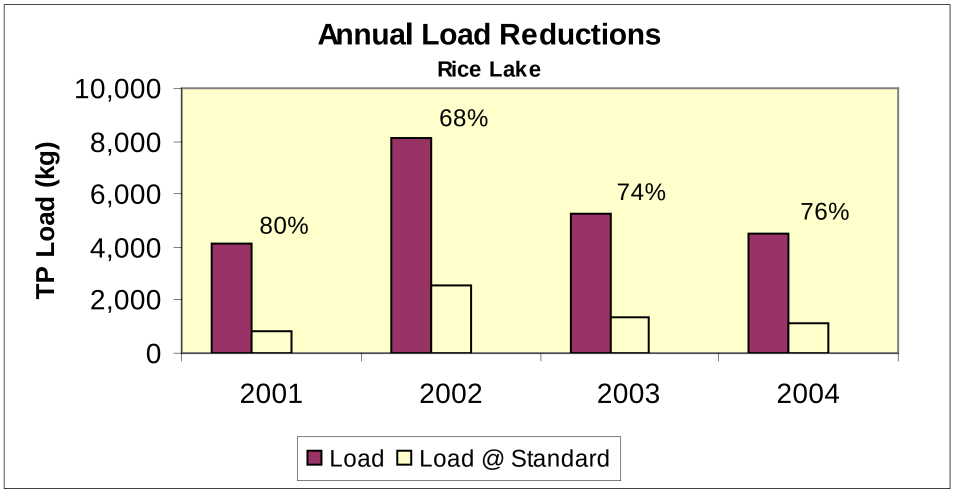

Figure 5-5. Modeled annual load and load at the standard for Rice Lake. The percentages represent the reduction needed to meet the standard.

Baldwin Lake requires a 64 to 76 percent reduction to meet the proposed water quality standard of a summer average of 60 µg/L total phosphorus (Figure 5.6).

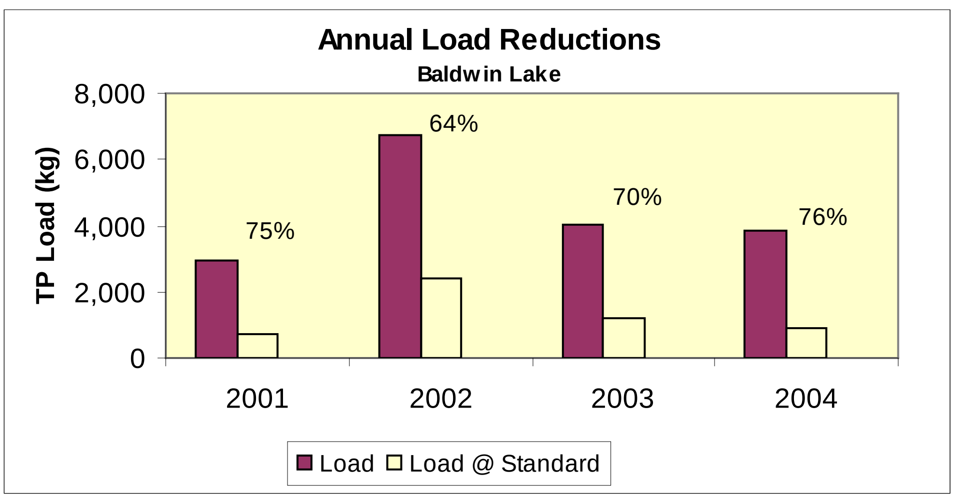

Figure 5-6. Modeled annual load and load at the standard for Baldwin Lake. The percentages represent the reduction needed to meet the standard

5.2.2 Water Quality Response to Load Reductions

Using the previously described BATHTUB water quality response model, total phosphorus, chlorophyll-a, and Secchi depth were predicted for load reductions in 5% increments. These predicted responses can be used to develop goals for load reductions with an understanding of the overall water quality benefits.

5.2.3 Phosphorus

The modeled response to phosphorus load reductions in George Watch, Marshan, Rice, and Baldwin Lakes for 2004 is presented in Figure 5.7. The modeled response to phosphorus load reductions in Sherman, Ward, and Reshanau Lakes for 2004 is presented in Figure 5.8. Required reductions as shown in Figure 5.7 and Figure 5.8 are consistent with the reductions described above.

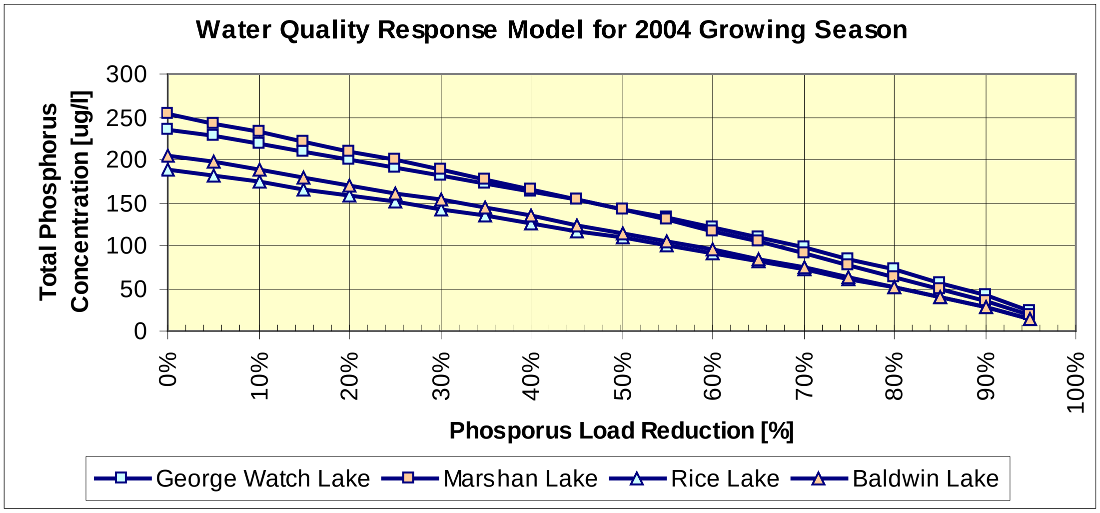

Figure 5-7. In-lake total phosphorus concentrations predicted for total phosphorus load reductions applied to all sources in George Watch, Marshan, Rice, and Baldwin Lakes for 2004.

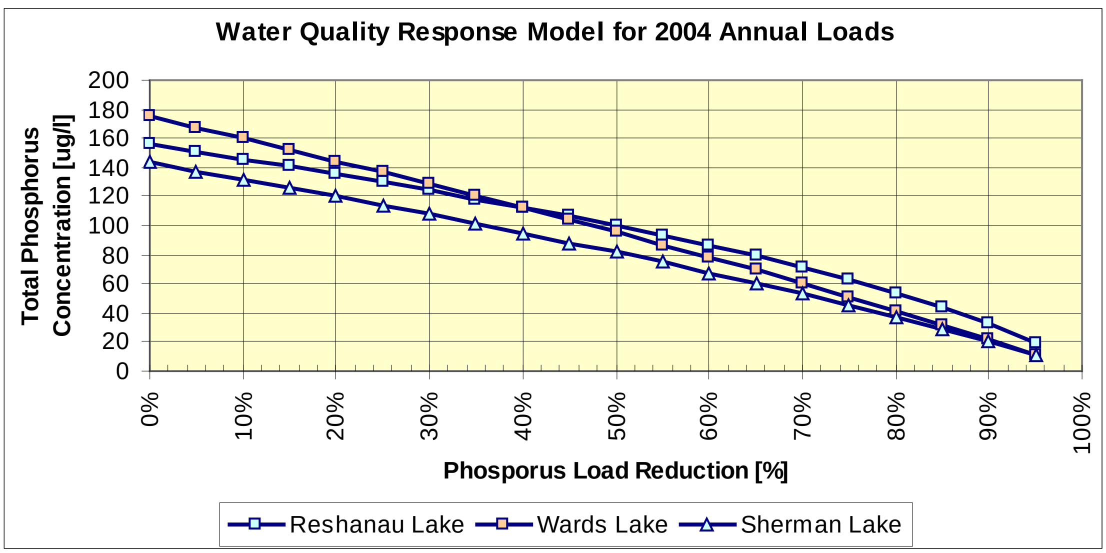

Figure 5-8. In-lake total phosphorus concentrations predicted for total phosphorus load reductions applied to all sources in Sherman, Ward, and Reshanau Lakes for 2004.

5.2.4 Chlorophyll-a

Modeled chlorophyll-a concentrations in George Watch, Marshan, Rice, and Baldwin Lakes for 2004 are presented in Figure 5.9. The modeled response to phosphorus load reductions for chlorophyll-a in Sherman, Ward, and Reshanau Lakes for 2004 is presented in Figure 5.10. Chlorophyll-a concentrations go down with reductions in total phosphorus. However, there is substantial variability in the model, so chlorophyll-a response to phosphorus concentrations will be monitored under adaptive management. Required reductions to meet chlorophyll-a concentration standards for shallow lakes (20 µg/L) range from 85 to 95% for the Lino Lakes chain of lakes. These values indicate that additional management for biological activity may be needed to meet these water quality standards.

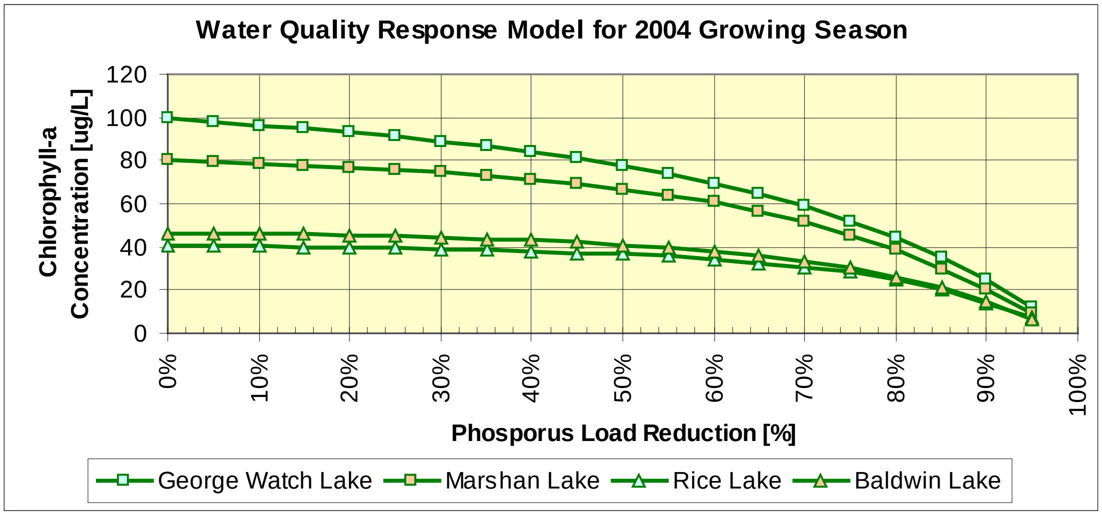

Figure 5-9. In-lake chlorophyll-a concentrations predicted for total phosphorus load reductions applied to all sources in George Watch, Marshan, Rice, and Baldwin Lakes for 2004.

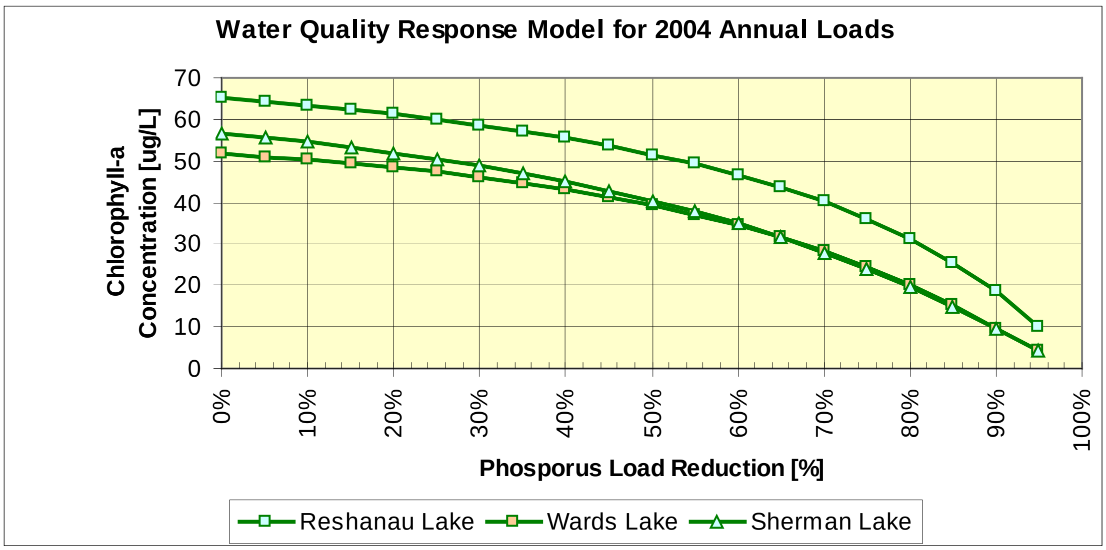

Figure 5-10. In-lake chlorophyll-a concentrations predicted for total phosphorus load reductions applied to all sources in Sherman, Ward, and Reshanau Lakes for 2004.

5.2.5 Secchi Depth

Secchi depth is not very responsive to load reductions, with a stronger response after a 60% load reduction (Figure 5.11 and Figure 5.12). George Watch and Marshan Lakes both demonstrate poor water clarity and require reductions greater than 95% to meet the state standard of 1.0 meters for Secchi depth. Reshanau, Rice, and Baldwin Lakes require approximately 75% load reductions to meet the state standard which should be satisfied if the standards for total phosphorus and chlorophyll-a are met.

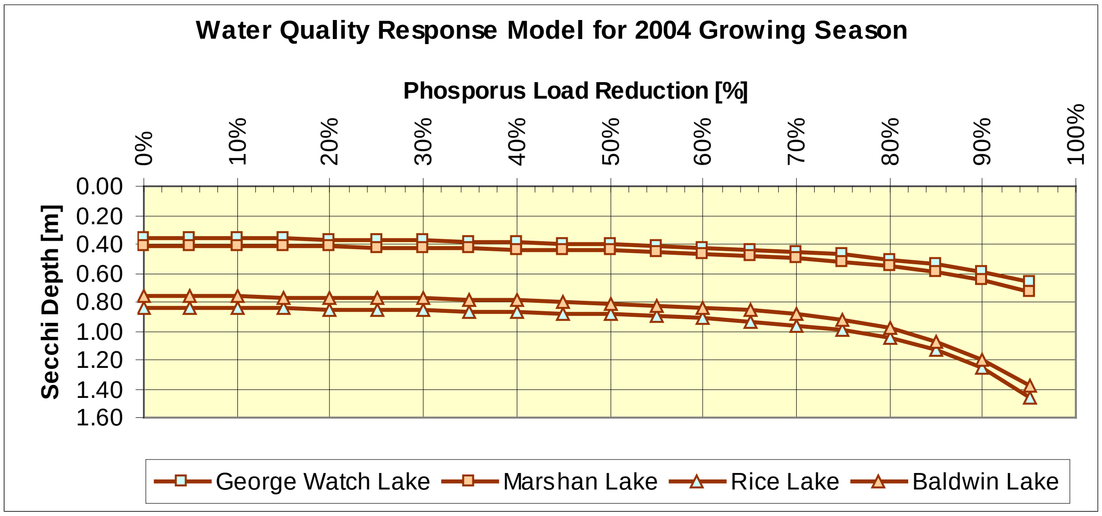

Figure 5-11. In-lake Secchi depth predicted for total phosphorus load reductions applied to all sources in George Watch, Marshan, Rice, and Baldwin Lakes for 2004.

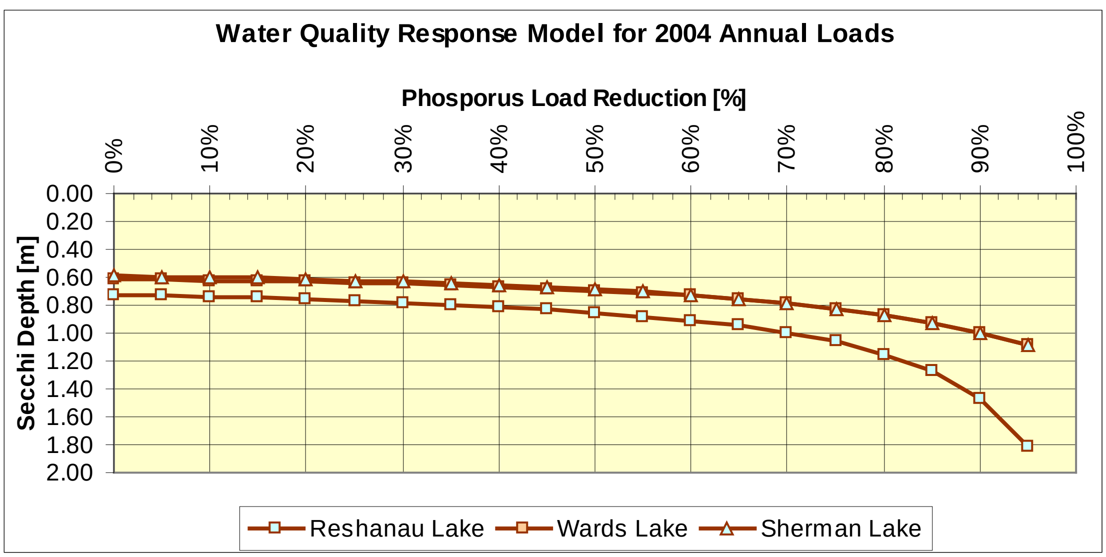

Figure 5-12. In-lake Secchi depth predicted for total phosphorus load reductions applied to all sources in Sherman, Ward, and Reshanau Lakes for 2004.

5.3 SEASONAL AND ANNUAL VARIATION

The daily load reduction targets in this TMDL are calculated from the current phosphorus budget for each of the lakes. The budget is an average of three years of monitoring data.

The average annual residence time in George Watch, Marshan, Rice, and Baldwin Lakes is less than 0.1 years. Therefore, the in-lake response to external and internal nutrient loads during the summer months is very quick, if at all. Nutrient loading during the fall, winter, and spring is often flushed through this chain of lakes before algal and other biological activity begins and therefore only growing season nutrient loads are measured by the lake response. For this reason, lake response models described above are based on growing season (122 days) runoff volume and nutrient load and are calibrated to growing season average concentration.

Residence time in Reshanau Lake is approximately one year or more and therefore annual runoff volume and nutrient loads were used in the lake response model for Reshanau. Seasonal variation is accounted for through the utilization of annual loads and developing targets for the summer period where the frequency and severity nuisance algal growth will be the greatest.

Additionally, by setting the TMDL to meet targets established for the most critical period (summer), the TMDL will inherently be protective of water quality during all the other seasons.

5.4 MARGIN OF SAFETY

A margin of safety has been incorporated into this TMDL by using conservative assumptions. These were utilized to account for an inherently imperfect understanding of the lake system and to ultimately ensure that the nutrient reduction strategy is protective of the water quality standard.

Conservative modeling assumptions included applying sedimentation rates from the Canfield-Bachmann model that likely under-predict the sedimentation rate for shallow lakes. Zooplankton grazing plays a large role in algal and subsequent phosphorus sedimentation in shallow lakes. However, the Canfield-Bachmann equation does not account for the higher sedimentation rates expected in healthy shallow lake systems.

Additionally, empirical relationships used to predict chlorophyll-a and Secchi depth are more established for deep lakes and do not account for zooplankton grazing critical to maintaining a clear water state in shallow lakes. Consequently, the models likely under-predict the clarity response of the lake to reduced phosphorus concentrations.

The Canfield-Bachmann model was used to match data by only adjusting the loads and not applying calibration factors. It is likely that the sedimentation rates used in the model are conservatively low for shallow Minnesota lakes providing an additional margin of safety.

5.5 RESERVE CAPACITY/FUTURE GROWTH

Because future land use is already factored into the wasteload allocation of the TMDL, no portion of the allowable load is being explicitly set aside for reserve capacity.

6.0 Public Participation

6.1 INTRODUCTION

A robust stakeholder process was conducted during the development of the TMDL including both Technical Advisory Committee meetings and public stakeholder meetings. The meetings were focused on the development of the TMDL including load and wasteload allocations, MS4 permit implications and restoration strategies. In addition, an opportunity for public comment on the draft TMDL report was provided via a public notice in the State Register from January 30 to February 29, 2012.

6.2 TECHNICAL ADVISORY COMMITTEE

A series of technical advisory committee meetings have been held during the development of this TMDL which included invitations to all governing units charged with managing water quality in the chain of lake's watershed. Invited parties included all MS4 permit holders, representatives from the State agencies including the Minnesota Pollution Control Agency, MnDOT, and the Minnesota DNR, and representatives from lake associations. The technical meetings were focused on technical issues in the development of the TMDL.

6.3 STAKEHOLDER MEETINGS

Two stakeholder meetings were conducted as a part of the development of this TMDL including an introductory meeting describing the purpose and scope of a TMDL and a public meeting after the draft TMDL was completed. The purpose of these meetings was to provide an understanding of the TMDL and collect any public comments on the TMDL.

7.0 Implementation

7.1 IMPLEMENTATION FRAMEWORK

7.1.1 Watershed and Local Plans

Numerous governing units have water quality responsibilities in the watershed, including all MS4 permit holders and the Rice Creek Watershed District. These agencies are focused on protecting water quality through implementation of their watershed and local plans as well as MS4 Stormwater Pollution Prevention Plans (SWPPPs). These plans and permits will outline the activities to be undertaken by each governing unit, including best management practices and capital improvements. A TMDL implementation plan will be developed separate from this TMDL document that will guide the governing units in the implementation of Best Management Practices (BMPs) focused on achieving the TMDL.

7.2 SHALLOW LAKE IMPLEMENTATION STRATEGY

7.2.1 Adaptive Management

The load allocations in the TMDL represent aggressive goals for nutrient reductions and are highly dependent on the achievement of reductions in an upstream watershed. Consequently, implementation will be conducted using adaptive management principles (Figure 7.1). Adaptive management is appropriate because it is difficult to predict the lake response that will occur from implementing strategies with the paucity of information available to demonstrate expected reductions. Future technological advances may alter the course of actions detailed here. Continued monitoring and “course corrections” responding to monitoring results are the most appropriate strategy for attaining the water quality goals established in this TMDL.

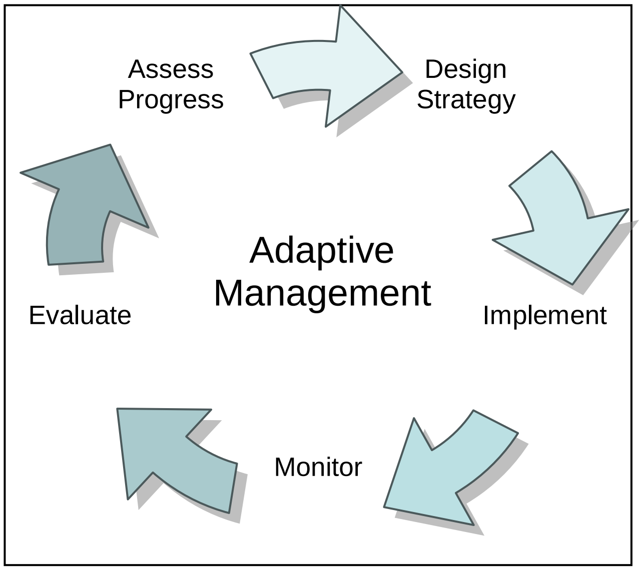

Figure 7-1. Adaptive management.

Based on this understanding of the appropriate standards for lakes, this TMDL has been established with the intent to implement all the appropriate activities that are not considered greater than extraordinary efforts. If all of the appropriate BMPs and activities have been implemented and any of the lakes still do not meet the current water quality standards, the TMDL will be reevaluated and the Rice Creek Watershed District will begin a process with the MPCA to develop more appropriate site-specific standards for the lake. The process will be based on the MPCA's methodology for determining site-specific standards.

7.2.2 Sequencing for Shallow Lake Restoration

An important aspect of shallow lake restoration is the sequence in which BMPs or restoration activities are applied to the lake and watershed. Because shallow lakes demonstrate alternative stable states (Scheffer 1998) including a turbid and a clear water state, many activities will result in minimal improvements if not undertaken prior to or after other dependent restoration activities. For example, attempting a biomanipulation such as a whole lake drawdown prior to effective external nutrient controls will likely result in minimal or short lived improvements in lake water quality. To that end, implementation of this TMDL should follow the five step process outlined by Moss et al. (1996). The five steps in the process include:

1. Forward switch detection and removal
2. External and internal nutrient control
3. Biomanipulation
4. Plant establishment
5. Stabilizing and managing restored system

Applying these steps to the Lino Lakes chain of lakes results in a sequence of restoration activities that must be accomplished in order to have any chance of success in restoring water quality in these shallow lakes. The sequence of events will generally follow the following list. A more detailed outline of the sequence of activities will be developed in the implementation plan.

1. Control external nutrient loads
2. Minimize and control rough fish population
3. Minimize and control invasive aquatic plants, especially curly-leaf pondweed
4. Establish biomanipulation techniques such as whole lake drawdown or fishery reestablishment
5. Reestablish native vegetation through sediment manipulation or native plant introduction
6. Establish long term management techniques for maintaining the clear water state such as periodic drawdown

This implementation strategy is focused on developing activities for addressing each of these areas and identifying areas where further investigation is needed to outline feasible restoration activities. In the subsequent Implementation Plan, a detailed list of activities and there sequence will be developed.

7.3 NUTRIENT REDUCTION STRATEGIES

7.3.1 Growing Season Load Reductions

The focus in implementation will be on reducing the growing season phosphorus loads to the lakes. Because of the short residence times in each of the lakes (with the exception of Reshanau Lake), the Total Maximum Daily Loads established for these lakes are growing season loads, for both the current water quality standard and the proposed natural background condition standard (Table 7.1 and Table 7.2).

Table 7.1. TMDL total phosphorus allocations expressed as growing season loads for the chain of lakes assuming the shallow lakes standard of 60 μg/L.

Lake	Wasteload TP Allocation (lb/growing season)[1]	Load TP Allocation (lb/growing season)	Margin of Safety	Total Phosphorus TMDL (lb/growing season)
George Watch Lake	52	3,852	Implicit	3,904
Marshan Lake	189	2,987	Implicit	3,176
Reshanau Lake[2]	12	236	Implicit	248
Rice Lake	149	3,592	Implicit	3,741
Baldwin Lake	27	3,388	Implicit	3,415

[1]The wasteload allocation is allocated to NPDES-permitted entities in accordance with Table 5.1.
[2]Allocations for Reshanau are pounds per year.

Load allocations by source are provided in Table 7.2. No reduction in atmospheric loading is targeted because this source is impossible to control on a local basis. The remaining load reductions were applied based on our understanding of the lakes as well as output from the model. (Note: The stormwater load category in Table 7.2 includes Mn/DOT's loads. Separate loads for Mn/DOT are not displayed since no reduction is called for.)

Table 7.2. TMDL total phosphorus loads expressed as growing season loads partitioned among the major sources for each lake in the chain of lakes assuming the shallow lakes standard of 60 µg/L. A natural background condition standard is not proposed at this time; information remains for reference.

Lake	Allocation Type	Source	Existing Load (lb/growing season)	Shallow Lake Standard (60 µg/L)		Previously Proposed Natural Background Condition (80 µg/L)[3]	
				Total Annual TP Load (lb/growing season)	Percent Reduction	Total Annual TP Load (lb/growing season)	Percent Reduction
George Watch Lake	Wasteload	Stormwater Load	52	52	0%	52	0%
	Load	Watershed Load	112	112	0%	112	0%
		Upstream Lake Load	7,679	2,429	68%	3,238	58%
		Atmospheric Load	42	42	0%	42	0%
		Internal Load	9,408	1,270	87%	2,091	78%
		TOTAL LOAD	*17,292*	**3,904**	77%	**5,535**	68%
Marshan Lake	Wasteload	Stormwater Load	189	189	0%	189	0%
	Load	Watershed Load	279	279	0%	279	0%
		Upstream Lake Load	7,802	2,476	68%	3,299	58%
		Atmospheric Load	15	15	0%	15	0%
		Internal Load	3,997	218	95%	570	86%
		TOTAL LOAD	*12,282*	**3,176**	74%	**4,352**	65%
Reshanau Lake[1]	Wasteload	Stormwater Load	12	12	0%	**Not Applicable**	
	Load	Watershed Load	16	16	0%		
		Upstream Lake Load	219	153	30%		
		Atmospheric Load	6	6	0%		
		Internal Load	596	61	90%		
		TOTAL LOAD	*849*	**248**	71%		

[3] A natural background condition standard is not proposed at this time.

Lake	Allocation Type	Source	Existing Load (lb/growing season)	Shallow Lake Standard (60 μg/L)		Previously Proposed Natural Background Condition (80 μg/L)[3]	
				Total Annual TP Load (lb/growing season)	**Percent Reduction**	**Total Annual TP Load (lb/growing season)**	**Percent Reduction**
Rice Lake	Wasteload	Stormwater Load	149	149	0%	149	0%
	Load	Watershed Load	99	99	0%	99	0%
		Upstream Lake Load	7,734	2,705	65%	3,604	53%
		Atmospheric Load	21	21	0%	21	0%
		Internal Load	5,082	767	85%	1,322	74%
		TOTAL LOAD	*13,085*	**3,741**	71%	**5,196**	60%
Baldwin Lake	Wasteload	Stormwater Load	27	27	0%	27	0%
	Load	Watershed Load	41	41	0%	41	0%
		Upstream Lake Load	7,546	2,770	63%	3,691	51%
		Atmospheric Load	10	10	0%	10	0%
		Internal Load	3,109	567	82%	912	71%
		TOTAL LOAD	*10,734*	**3,415**	68%	**4,681**	56%

No reduction in atmospheric loading is targeted because this source is impossible to control on a local basis. The remaining load reductions were applied based on our understanding of the lakes as well as output from the model.

7.3.2 Actions

Restoration options for lakes are numerous with varying rates of success. Consequently, each technology must be evaluated in light of our current understanding of physical and biological processes in that lake.

Following is a description of potential actions for controlling nutrients in the Lino Lakes chain of lakes watershed that will be further developed in the Implementation Plan.

7.3.2.1 External Nutrient Load Reductions

Outflow from Peltier Lake is the most significant source of external load to George Watch and the downstream lakes. A separate TMDL has been prepared for Peltier Lake that includes implementation activities to reduce phosphorus load to Peltier and thus reduce in-lake TP concentration. Until Peltier Lake meets its water quality goal of 60 µg/L, it is unlikely that any of the Lino Lakes chain of lakes (with the exception of Reshanau) will be able to achieve their water quality goals.

Reducing the total phosphorus load exported from Peltier Lake is the key external load reduction activity. Peltier Lake water quality, however, does not affect water quality in Reshanau Lake. The second key source that requires reduction is internal loading. Addressing these two sources will be difficult and will be the main focus of future implementation funds, but reducing these source contributions is key to meeting the TMDL. In addition to those important sources various watershed load reductions will be implemented on an opportunistic basis, including the following:

Enforce existing local infiltration/filtration regulations. The Rice Creek Watershed District regulates development and redevelopment. The rules require new development to incorporate Better Site Design principles into site plans, and to retain on site through infiltration or other volume management the runoff from a 2-year (2.8 inch in 24 hours) rain event. Small events convey the majority of the annual phosphorus and sediment load (Pitt 1998) to downstream receiving waters. Redevelopment is also required to provide volume management. Enforcing this volume management rule will limit new phosphorus and sediment loading to the lakes.

Maximize load reduction through development and redevelopment. As redevelopment occurs, areas with little or no treatment will be required to meet current water quality standards. It may be possible to “upsize” water quality treatment BMPs for both development and redevelopment projects to increase treatment efficiency beyond the minimum required by the rules.

Protect high-value wetlands to prevent phosphorus export. Numerous high-value wetlands are present in the watershed. As development or redevelopment occurs, there is the potential to discharge to them stormwater and additional nutrients and sediment, altering the hydroperiod and natural assimilative characteristics and converting the wetlands from nutrient sinks to nutrient sources. The proposed RCWD rules revision includes standards limiting impacts to wetland hydroperiod based on wetland classification as well as requiring pretreatment of discharges to wetlands.

In addition, the City of Lino Lakes is currently preparing a Resource Management Plan for the City to protect and restore wetlands, lakes, streams, and other natural and water resources in the city. This Resource Management Plan will take into account full build out conditions to determine if additional preventative or mitigation actions will be required to maintain or improve these resources.

Increase infiltration and filtration in the watershed. As described above, the RCWD rules require Better Site Design minimizing new impervious surface and management of new runoff volumes on new development and redevelopment. On existing development, the use of rain gardens, native plantings, and reforestation should be encouraged as a means to increase infiltration, evapotranspiration, and filtration of runoff conveying pollutant loads to the lakes.

Target street sweeping. To maintain existing phosphorus loads, cities could improve the timing and number of street sweeping events.

Retrofit BMPs. Street or highway reconstruction projects, park improvements, and other projects may provide opportunities to incorporate BMPs to add or increase treatment in the watershed. In addition, the Lino Lakes Resource Management Plan will include a number of potential retrofit BMPs, including the following by watershed:

> <u>George Watch:</u> Develop source control plan for areas north of Hwy 14 to prevent loading to wetlands; source control retrofits in areas draining to groundwater wetlands; evaluate the feasibility of regional infiltration projects.
>
> <u>Reshanau:</u> Reduce loading to contributing small lakes; manage the urban ditches; restore partially drained wetlands.
>
> <u>Marshan:</u> Manage the urban ditches; evaluate opportunities for volume reduction in key subwatersheds; consider flexible zoning.
>
> <u>Rice:</u> Further investigate opportunities for infiltration in key subwatersheds.
>
> <u>Baldwin:</u> Further investigate opportunities for infiltration in key subwatersheds.

Encourage shoreline restoration. While much of the shoreline on four of the lakes is natural, Reshanau is edged with single-family homes. Most property owners maintain a turfed edge to the shoreline. The implementation plan will encourage property owners to restore their shoreline with native plants to reduce erosion and capture direct runoff, and to limit removal of beneficial vegetation that is perceived to be a nuisance or undesirable.

Conduct education and outreach awareness programs. Educate property owners in the subwatershed about proper fertilizer use, low-impact lawn care practices, and other topics to increase awareness of sources of pollutant loadings to the lakes and encourage the adoption of good individual property management practices. Lakeshore property owners should be educated about aquatic vegetation management practices and how they relate to beneficial biological communities and water quality.

Implement Construction and Industrial Stormwater Regulation. The wasteload allocation for stormwater discharges from sites where there is construction activities reflects the number of construction sites > 1 acre expected to be active in the watershed at any one time, and the Best Management Practices (BMPs) and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at construction sites are defined in the State's NPDES/SDS General Stormwater Permit for Construction Activity (MNR100001). If a construction site owner/operator obtains coverage under the NPDES/SDS General Stormwater Permit and properly selects, installs and maintains all BMPs required under the permit, including those related to impaired waters discharges and any applicable additional requirements found in Appendix A of the Construction General Permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. It should be noted that all local construction stormwater requirements must also be met.

The wasteload allocation for stormwater discharges from sites where there is industrial activity reflects the number of sites in the watershed for which NPDES industrial stormwater permit coverage is required, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at the industrial sites are defined in the State's NPDES/SDS Industrial Stormwater Multi-Sector General Permit (MNR050000) or NPDES/SDS General Permit for Construction Sand & Gravel, Rock Quarrying and Hot Mix Asphalt Production facilities (MNG490000). If a facility owner/operator obtains coverage under the appropriate NPDES/SDS General Stormwater Permit and properly selects, installs and maintains all BMPs required under the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. It should be noted that all local stormwater management requirements must also be met.

7.3.2.2 Internal Nutrient Load Reductions

The primary option for the control of internal load is likely to be biological manipulation. This will include integrated plans for each lake to manage the aquatic vegetation, fish, and zooplankton communities to reduce nutrient loads and maintain a level of water clarity that is desirable both aesthetically and for maintenance of a fishery.

Significant internal load reductions in all the study lakes are required to meeting the total phosphorus concentration standard. Discussion of the required internal load reductions are provided in a technical memorandum in Appendix E.

Vegetation management. Curly-leaf pondweed is present in all lakes, and is at nuisance levels in some. Senescence of the curly-leaf pondweed in summer can be a significant source of internal phosphorus load that often results in a late summer nuisance algal bloom. Vegetation management, such as several successive years of chemical treatment, will be required to keep this exotic invasive species at non-nuisance levels.

Conduct periodic aquatic plant surveys and prepare and implement vegetation management plans. As BMPs are implemented and water clarity improves, the aquatic vegetation community will change. Surveys should be updated periodically and vegetation management plans amended to take into account appropriate management activities for that changing community.

Manage fish populations. The fish community should be managed to benefit water quality. Specifically, rough fish such as carp and bullhead should managed to mitigate their impact on native aquatic vegetation. Options to reduce rough fish populations should be evaluated, and the possibility of fish barriers explored to reduce rough fish access to spawning areas and to minimize rough fish migration between lakes. These tasks should be done in partnership with the Minnesota DNR.

7.3.3 Studies and Biological Management Plans

Following are recommended studies needed to further refine management actions in the Lino Lakes chain of lakes:

Lake Level Management Study. These shallow lakes may benefit from periodic lake level manipulations. A feasibility study should investigate possibilities such as lake level control structures to direct flow from or into various basins. Periodic drawdowns would be beneficial in consolidating sediments, restoring desirable aquatic vegetation, and reducing rough fish populations. Winter drawdowns are effective for managing invasive aquatic species such as curly-leaf pondweed, but also have side benefits of sediment consolidation and native plant establishment. Summer drawdowns are more widely used to reinvigorate native aquatic plant communities, and are expected to be more effective after invasive vegetation controls are in place.

Rough Fish and Fisheries Management Plan. Although rough fish have been recognized as having severe negative consequences for shallow lakes for a long time (Crivelli, 1983; Parkos, 2003), little is known about their life cycles and history, management and control. Current strategies have been focused on removal and have had limited or short term success. There has recently been a renewed interest in controlling carp and new research is being conducted on carp populations at the University of Minnesota and Iowa State University. The research has been focused on a better understanding carp reproduction, habitat use, and management techniques. Because our understanding of carp management is still young, identifying management techniques is often difficult and does not always result in the desired outcomes.

A key step in the restoration of the Lino Lakes chain will be rough fish control. To have the greatest chance of success, a rough fish management plan should be established for the chain of lakes. Minimally, the management plan should include:

1. Collection of carp population data to identify the severity of the carp infestation
2. Monitoring of carp movement to identify source areas as well as critical habitat areas
3. Identification of carp management techniques such as better removal techniques, source area control (carp barriers), and key habitats or predator information

Aquatic Vegetation Management Plan. Another key aspect of establishing a clear water state in shallow lakes is the establishment of native vegetation. Once again, the science behind the management of aquatic vegetation is still quite young. Our understanding of the requirements to establish native vegetation is limited resulting in a need for a management plan and experimental management techniques.

The aquatic vegetation management plan should minimally include:

1. Evaluation of the current and historical vegetation community
2. Management techniques and endpoints for invasive aquatic vegetation
3. Key habitat needs for reestablishing native vegetation including water quality and sediment chemistry
4. Evaluation of hydrologic controls on plant establishment including drawdown

Alum Injection Feasibility Study for Peltier Outflow. Improving water quality in Peltier Lake will be a difficult task and will likely be a long term process. More immediate improvements may be obtainable in the downstream chain of the outflow from Peltier Lake was first treated with alum to remove phosphorus and then discharged to the downstream lakes. The feasibility of cost of such a system should be evaluated.

The Clean Water Legacy Act requires that a TMDL include an overall approximation ("…a range of estimates") of the cost to implement a TMDL [Minn. Statutes 2007, section 114D.25]. We estimate the cost of implementing this TMDL to range between $500,000 and $10M. This estimate will be refined when the detailed implementation plan is developed, following approval of the TMDL study.

8.0 Reasonable Assurance

8.1 INTRODUCTION

When establishing a TMDL, reasonable assurances must be provided demonstrating the ability to reach and maintain water quality endpoints. Several factors control reasonable assurance, including a thorough knowledge of the ability to implement BMPs as well as the overall effectiveness of the BMPs. This TMDL establishes aggressive goals for the reduction of phosphorus loads to the lakes. In fact, there are few if any examples where these levels of reductions have been achieved where the sources were primarily nonpoint source in nature.

TMDL implementation will be implemented on an iterative basis so that implementation course corrections based on periodic monitoring and reevaluation can adjust the strategy to meet the standard. After the first phase of nutrient reduction efforts, reevaluation will identify those activities that need to be strengthened or other activities that need to be implemented to reach the standards. This type of iterative approach is more cost effective than over-engineering to conservatively inflated margins of safety (Walker 2003). Implementation will also address other lake problems not directly linked to phosphorus loading such as invasive plant species (curly-leaf pondweed) and invasive fish (carp and rough fish). These practices go beyond the traditional nutrient controls and provide additional protection for lake water quality.

8.2 RICE CREEK WATERSHED DISTRICT

The Rice Creek Watershed District was formed in 1972 under Minnesota Watershed Law. The District is over 200 square miles in size, and contains parts of 29 municipalities and townships in four counties. The District's mission is "To conserve and restore the water resources of the District for the beneficial use of current and future generations."

The District is also a watershed management organization as defined by the Metropolitan Surface Water Management Act (Chapter 509, Laws of 1982, Minnesota Statute Section 473.875 to 473.883 as amended). That law establishes requirements for watershed management plans within the Twin Cities Metropolitan Area. The law requires the plan to focus on preserving and using natural water storage and retention systems to:

- Improve water quality.
- Prevent flooding and erosion from surface flows.
- Promote groundwater recharge.
- Protect and enhance fish and wildlife habitat and water recreation facilities.
- Reduce, to the greatest practical extent, the public capital expenditures necessary to control excessive volumes and rate of runoff and to improve water quality.
- Secure other benefits associated with proper management of surface water.

Minnesota Rules Chapter 8410 requires watershed management plans to address eight management areas and to include specific goals and policies for each to serve as a management framework. To implement its approved watershed management plan, the RCWD has undertaken a number of activities, including administering rules and standards regulating stormwater runoff quantity and quality from development and redevelopment in the district; developing Resource Management Plans for resources in the district; and constructing improvements in the District such as a project to remeander Rice Creek.

RCWD Regulatory Program

The RCWD enforces several rules pertinent to the TMDL, including a volume management standard requiring infiltration or other abstraction of a 1.1 inch rain event for new development and redevelopment, limitations on wetland impacts, and pretreatment of new discharges to wetlands and other public waters.

In addition to its standard set of rules, RCWD adopted special rules for two RMP areas within the Lino Lakes Chain of Lakes watershed. The JD4 RMP (“RMP-2”) rules were adopted in 2008 and will be used to implement the details of the JD4 RMP. These more specific rules are meant to preserve high quality wetland habitat and promote wetland restoration to benefit water quality.

RCWD Water Quality BMP Cost-Share Program

The RCWD offers grants to local residents and businesses to install stormwater BMPs. This program, collectively, and over time, will result in decreased stormwater phosphorus loading to the Lino Lakes Chain of Lakes. As an example, RCWD’s recently completed (2010) Rice Lake Neighborhood Raingarden project utilized this program for funding.

RCWD’s Rice Lake Neighborhood Raingarden Retrofit

RCWD Rough Fish Management Activities

Beginning in the Fall of 2013, the RCWD will work with the University of Minnesota to develop a rough fish management plan to address internal loading (LA) in the Lino Lakes Chain of Lakes. The RCWD is committed to managing carp and other rough fish to promote growth of native lake plants, therefore enabling a shallow lake “backward switch” to the clear water, plant-dominant state (see Section 7.2.2 and 7.3.3 for details). Funding for this work will come from the RCWD and the University of Minnesota.

8.3 NPDES MS4 STORMWATER PERMITS

NPDES Phase II stormwater permits are in place for all but one of the cities and townships draining to the chain of lakes watershed as well as the Rice Creek Watershed District, Anoka and Ramsey Counties and Mn/DOT. Under the stormwater program, permit holders are required to develop and implement a Stormwater Pollution Prevention Program (SWPPP; MPCA, 2004). The SWPPP must cover six minimum control measures:

- Public education and outreach;
- Public participation/involvement;
- Illicit discharge, detection and elimination;
- Construction site runoff control;
- Post-construction site runoff control; and
- Pollution prevention/good housekeeping.

The permit holder must identify BMPs and measurable goals associated with each minimum control measure.

According to federal regulations, NPDES permit requirements must be consistent with the assumptions and requirements of an approved TMDL and associated wasteload allocations. See 122.44(d)(1)(vii)(B). To meet this regulation, Minnesota's MS4 general permit requires the following:

> If a USEPA-approved **TMDL(s)** has been developed, you must review the adequacy of your Storm Water Pollution Prevention Program to meet the **TMDL's Waste Load Allocation** set for storm water sources. If the **Storm Water Pollution Prevention Program** is not meeting the applicable requirements, schedules and objectives of the **TMDL**, you must modify your **Storm Water Pollution Prevention Program**, as appropriate, within 18 months after the TMDL is approved.

MS4s contributing stormwater to the lakes will comply with this requirement during the implementation planning period of the TMDL. The implementation plan will identify specific BMP opportunities sufficient to achieve their load reduction and the individual SWPPPs will be modified accordingly as a product of this plan.

MS4s contributing stormwater to the chain of lakes are covered under the Phase II General NPDES Stormwater Permit – MNR040000. The unique NPDES Phase II permit numbers assigned to the small municipal separate storm sewer systems (MS4) that contribute drainage to the chain of lakes are as follows:

- Lino Lakes – MS400100
- Centerville – MS400078
- Circle Pines – MS400009

- White Bear Township – MS400163
- Shoreview – MS400121
- Blaine – MS400075
- Ham Lake – MS400092
- North Oaks – MS400109
- Anoka County – MS400066
- Ramsey County – MS400191
- Mn/DOT Metro District – MS400170
- Minnesota Correctional Institute – Lino Lakes – MS400177

Stormwater discharges are regulated under NPDES, and allocations of nutrient reductions are considered wasteloads that must be divided among permit holders. Because there is not enough information available to assign loads to individual permit holders, the wasteload allocations (with the exception of Mn/DOT Metro District) are combined in this TMDL as categorical wasteload allocations (see Table 7.1). The load allocation is also allocated in the same manner. This collective approach allows for greater reductions for some permit holders with greater opportunity and less for those with greater constraints. The collective approach is to be outlined in an implementation plan developed by the Rice Creek Watershed District.

8.4 MONITORING

Two monitoring components are necessary to evaluate progress toward meeting TMDL goals.

8.4.1 Watershed / BMP Monitoring

The Rice Creek Watershed District maintains a watershed monitoring program. This program will monitor concentrations of phosphorus flowing into the Lino Lakes Chain of Lakes at three primary volume input locations: Anoka County Ditch 10-22-32 flowing into Marshan Lake, Anoka County Ditch 24 flowing into Reshanau Lake, and within Peliter Lake, which flows into George Watch Lake (Figure 8-1). Water samples will be collected approximately every two weeks throughout the growing season and analyzed for total phosphorus. Data will be used to assess changes in watershed phosphorus loading over time, and in response to management practices. Data may also be used to further refine and calibrate the watershed loading model (P8) used in the TMDL. All water quality data will be submitted to the State's water quality database (EQuIS). Data will be also incorporated into the RCWD's *Stream Monitoring* report.

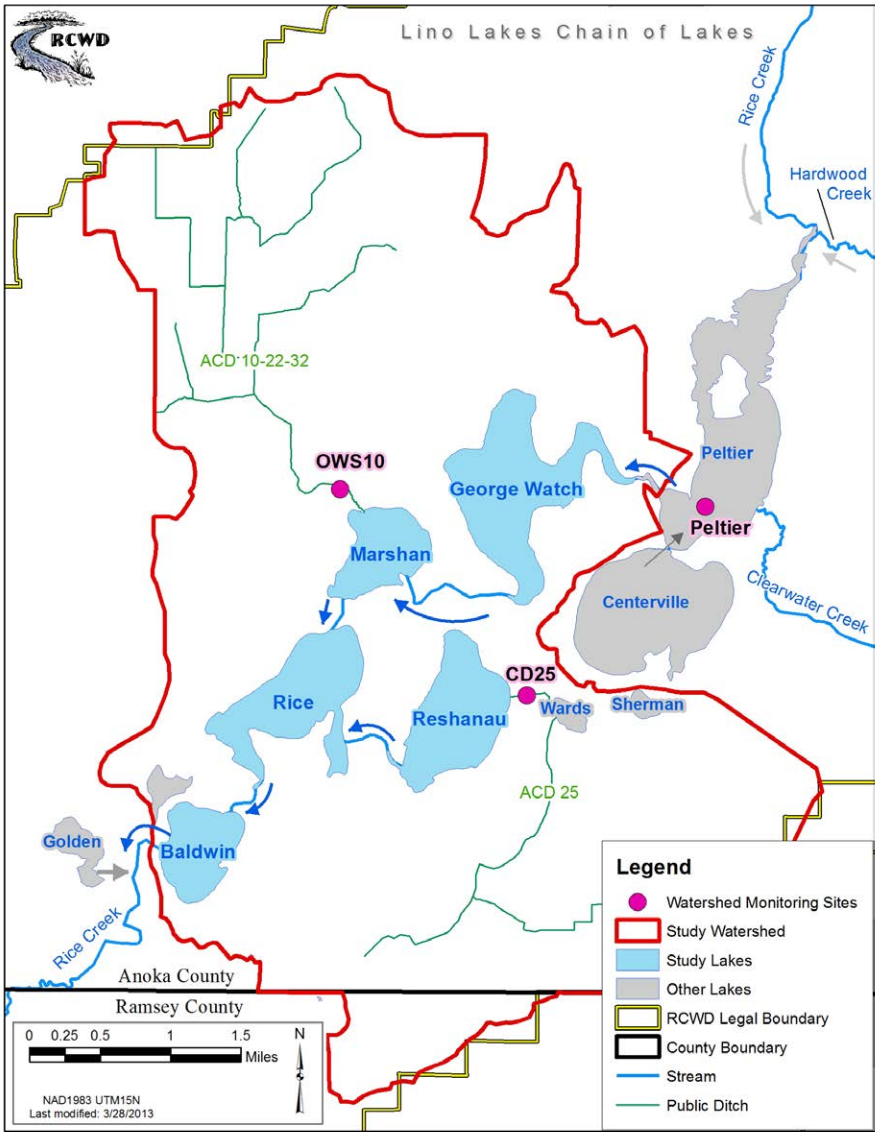

Figure 8-1. Watershed water quality monitoring locations.

When technically feasible, assessment of individual BMPs will also be conducted. For example, if a large stormwater BMP were installed, pre- and post-outflow water quality and/or quantity monitoring may evaluate the effectiveness of the BMP.

8.4.2 Resource Monitoring

The Rice Creek Watershed District maintains a comprehensive lake monitoring program, utilizing both in-house monitoring capabilities, and the Citizen Assisted Monitoring Program (CAMP), administered by Metropolitan Council Environmental Services. Water quality (total phosphorus, chlorophyll-a, and clarity) has been monitored in both George Watch and Reshanau Lakes through the CAMP program. Samples are collected every two weeks throughout the open water season. This monitoring program should continue. Water quality has been monitored in both Rice and Marshan Lakes by the RCWD. Water quality has been monitored in Baldwin Lake periodically by both the CAMP program and the RCWD. Analysis of data among the three lakes indicates no statistical difference. Future monitoring should be conducted in at least 1 of these three lakes (Marshan, Rice, and Baldwin) each year. Samples should be collected every two weeks during the open water period. Lake water quality data can be used to assess changes in lake quality over time, and in response to management actions.

Additional RCWD monitoring activities could, depending on available resources, include:

- Periodic plant surveys in each lake to assess changes in abundance and distribution of both native and invasive plant species
- Rough fish surveys to categorize impacts on internal phosphorus loading and native plant distribution

All water quality data will be submitted to the State's water quality database (EQuIS). Data will be also incorporated into the RCWD's *State of the Lakes* report.

9.0 Literature Cited

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Appendix A

Chain of Lakes Natural Background Condition

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TECHNICAL MEMORANDUM

TO: Doug Thomas, Rice Creek Watershed District
Matt Kocian, Rice Creek Watershed District

FROM: Joe Bischoff; Andy Erickson

DATE: December 13, 2007

SUBJECT: Site Specific Standards in the Peltier-Lino Lakes Chain of Lakes

---

The purpose of this memorandum is to document the potential impacts of a site specific standard in Peltier Lake on the downstream lakes in the Lino Lakes chain of lakes including George Watch, Marshan, Rice and Baldwin Lakes. George Watch and Marshan Lakes are currently on the State's 303(d) list of impaired waters for excess nutrients. Both Rice and Baldwin are not currently on the 303(d) list of impaired waters due to lack of data but are considered impaired based on the limited data available. Data collected in 2007 is expected to demonstrate nutrient impaired conditions in both of those water bodies.

Lino Lakes Chain of Lakes

The Lino Lakes Chain of Lakes is a series of lakes that begin with Peltier Lake and flow into George Watch, Marsh, Rice, and Balwin Lakes. An additional chain of lakes including Sherman, Wards, and Reshanau Lakes drains into Rice Lake. However, the Reshanau chain of lakes is not affected by flows from Peltier Lake and will not be discussed any further in this technical memorandum. All of these lakes are extremely shallow with maximum depths ranging from 3 to 5 feet.

The water budget for the Lino Lakes chain of lakes is dominated by flow from Peltier which represents as much as 90 percent of flow to George Watch Lake and 56% of the flow to the entire chain of lakes (figure 1). Consequently, the lakes have similarly high flushing rates due to the large contributing areas to the lakes.

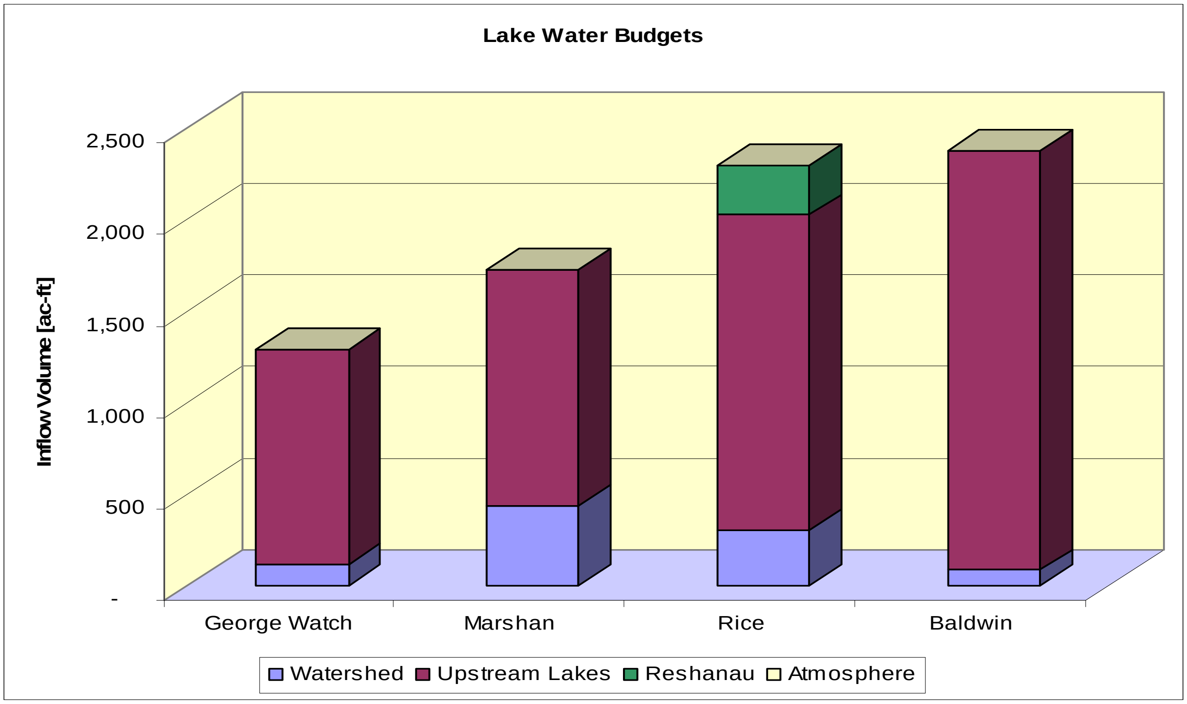

Figure 1. Water sources for the Lino Lakes Chain of Lakes.

Phosphorus loading to the lakes is similar to the water loading with internal loading and upstream lake inputs dominating the phosphorus sources to the lakes (Figure 2). The dominance of internal loading suggests long term phosphorus loading and retention in these lakes.

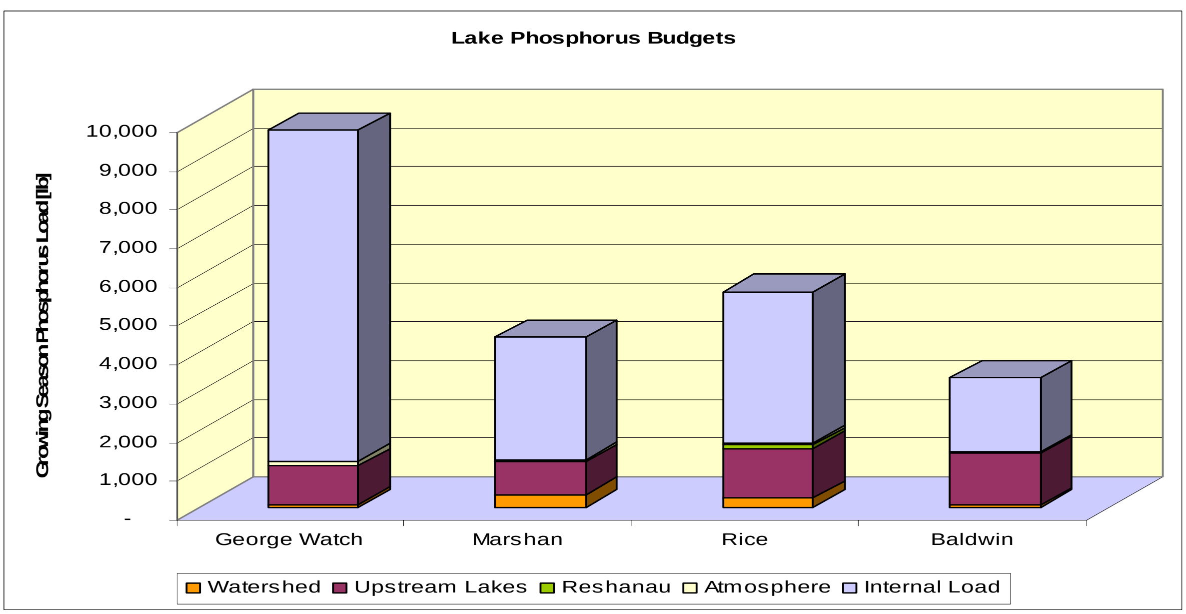

Figure 2. Phosphorus sources for the Lino Lakes Chain of Lakes.

Effects of a Site Specific Standard in Peltier

Because the water and phosphorus budgets are dominated by Peltier Lake, a site specific standard in Peltier Lake will have direct effects on the downstream chain of Lakes. Figure 3 represent modeled lake responses in each of the downstream lakes for 2001 through 2006 for five scenarios with Peltier Lake at a summer average of 80 µg/L including:

1. Current internal loading conditions (0% internal load reduction)
2. 25% internal load reduction
3. 50% internal load reduction
4. 75% internal load reduction
5. 100% internal load reduction

A site specific standard of 80 µg/L in Peltier Lake would require an internal load reduction of 100% for any of the downstream lakes to meet the current proposed State Standard of 60 µg/L summer average total phosphorus.

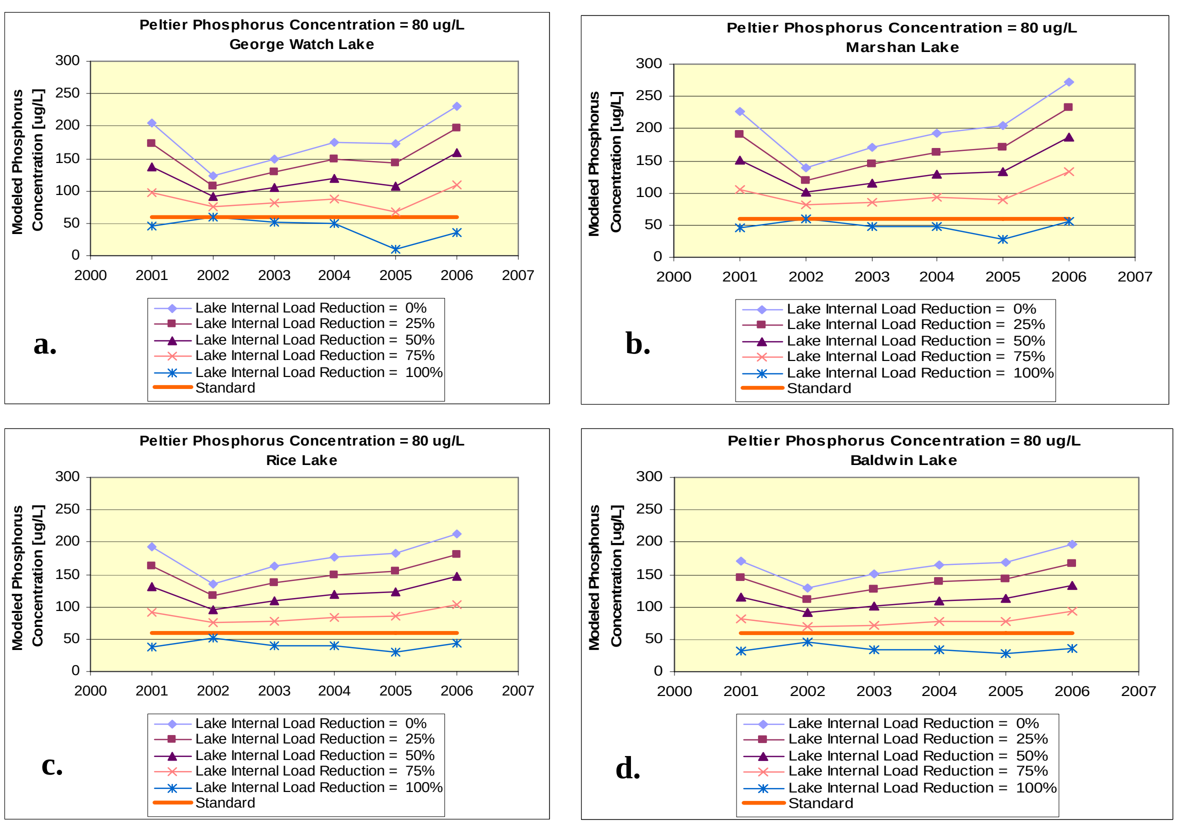

Figure 3. Lake response model output for the Lino Lakes Chain of Lakes assuming a site specific standard of 80 µg/L in Peltier Lake. The solid represents the proposed State standard of 60 µg/L a. George Watch b. Marshan c. Rice d. Baldwin

Determining a Site Specific Standard for the Chain of Lakes

Based of the background information provided in this memorandum, there are several reasons to consider a site specific standard for the entire chain of lakes including:

1. Due to the relative connectedness of the lakes, similar landscape features including land use and soils, and similar morpohmetric characteristics, it is reasonable to assume that all of the lakes exhibited similar water quality conditions.

2. The dominance of water and nutrient outflow from Peltier Lake in the Chain of Lakes budgets suggests that higher nutrient concentrations in Peltier will have a direct cascading effect through the chain of lakes

3. Meeting the proposed State standard of 60 µg/L in the remaining chain with a site specific standard of 80 µg/L in Peltier Lake would require an internal loading of 0 in all of the downstream lakes which is unlikely to have occurred even in unimpacted, natural conditions of the lakes.

Based on these conclusions, it is our best professional opinion that a site specific standard should include the entire Lino Lakes chain including Peltier, George Watch, Marshan, Rice, and Baldwin Lakes.

Appendix B

Listing Data for Rice and Baldwin Lakes

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TECHNICAL MEMORANDUM

TO: Chris Zadak, TMDL Project Manager, Minnesota Pollution Control Agency

FROM: Joe Bischoff, M.S., Project Manager, and Andy Erickson, M.S., EIT, Project Engineer

DATE: May 7, 2008

SUBJECT: Supporting Information for listing Rice and Baldwin Lakes as Impaired Waters

---

The purpose of this memo is to provide information in support of adding Rice (02-0008) and Baldwin (02-0013) Lakes to the 303(d) list of Impaired Waters.

Background

The Rice Creek Watershed District (RCWD) has contracted Wenck Associates, Inc. (Wenck) to perform Total Maximum Daily Load (TMDL) studies on the five lakes that comprise the Lino Lakes Chain of Lakes, which includes George Watch, Marshan, Rice, Reshanau and Baldwin Lakes. The current (2008) 303(d) list of impaired waters does not include Rice or Baldwin Lakes as impaired waters. Historical data, however, show that these lakes do not meet the state standards for water quality. Detailed discussion and analysis for Rice and Baldwin Lakes can be found in the Total Maximum Daily Load Study (Wenck, 2008).

Summary of Historical Data

Data from STORET, CAMP, and RCWD are provided in an attached spreadsheet (Data to Chris Zadak (May 2008).xls). The data is organized into tabs for each lake in the chain (George Watch, Marshan, etc.) with STORET data appearing in the upper left corner of each tab. CAMP data is provided, when available, to the right of the STORET data and RCWD monitoring data, when available is provided to the right of CAMP and STORET data. This format should clearly show which data are currently included in STORET. This data is summarized below.

In the last ten years (1998 – 2008), the only historical data for the growing season (June 1 through September 30) for Rice Lake from the STORET database is four Secchi depth measurements of “>1 meter” and five chlorophyll-a measurements (average = 12.3 µg/L) in 2002. Significant historical data, however, is available from STORET for the period of 1974-1991. Additional data from CAMP and RCWD was provided for the TMDL development process and is summarized in Table 1 and Table 2, respectively.

Table 1. Historic data for Rice Lake (CAMP).

Year	Chlorophyll- a (µg/L)		Total Phosphorus (mg/L)		Secchi Disk (m)	
	N	Mean	N	Mean	N	Mean
2003	2	88.2	1	0.105	2	0.58
2004	3	91.1	3	0.188	2	0.48
2005	1	70.2	1	0.264	0	

Table 2. Historic data for Rice Lake (RCWD).

Year	Chlorophyll- a (µg/L)		Total Phosphorus (mg/L)		Secchi Disk (m)	
	N	Mean	N	Mean	N	Mean
2007	9	66.1	9	0.264	5	1.0

In the last ten years (1998 – 2008), there is no historical data for the growing season (June 1 through September 30) for Baldwin Lake from the STORET database. Significant historical data, however, is available from STORET for the period of 1974-1991. Additional data from CAMP and RCWD was provided for the TMDL development process and is summarized in Table 3 and Table 4, respectively.

Table 3. Historic data for Baldwin Lake (CAMP).

Year	Chlorophyll- a (µg/L)		Total Phosphorus (mg/L)		Secchi Disk (m)	
	N	Mean	N	Mean	N	Mean
2003	2	83.05	1	0.084	2	0.65
2004	3	104.2	3	0.205	2	0.475

Table 4. Historic data for Baldwin Lake (RCWD).

Year	Chlorophyll- a (µg/L)		Total Phosphorus (mg/L)		Secchi Disk (m)	
	N	Mean	N	Mean	N	Mean
2007	10	72.0	10	0.239	6	0.90

Data Assessment for 303(d) list

As described above, the water quality data in STORET is limited for Rice and Baldwin Lakes. There are no total phosphorus measurements within the last ten years and only five chlorophyll-a measurements for one year (2002) in Rice Lake. The threshold for listing a lake in the impaired condition is 10 measurements for total phosphorus, chlorophyll-a, and Secchi depth (MPCA, 2007) which are not met by the data available in STORET. Additional data for Rice and Baldwin Lakes meet the “spirit” of guidance by providing at least 14 measurements for total phosphorus and chlorophyll-a, and at least nine measurements for Secchi depth.

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Sample ID	Lake Name	Sample Type	Date	month	Time	Depth (ft)	Depth (m)	Temperature (deg C)	Dissolved Oxygen (mg/L)	Secchi Disk (ft)	TP (mg/L)	SRP (mg/L)	TKN (mg/L)	CCHLA-MG/M3
7406	Rice		5/18/2007	5	11:35	1	0.3	15.8	7.24					
7406	Rice	Surface	5/18/2007	5	11:35	0	0.0	16.6	9.8	1.00	0.207	0.009		55.9
7406	Rice		5/18/2007	5	11:35	2	0.6	14.8	6.2					
7414	Rice	Surface	5/31/2007	5	12:40	1	0.3	22.0	5.42		0.130	0.009		
7414	Rice		5/31/2007	5	12:40	2	0.6	21.1	3.82					
7414	Rice		5/31/2007	5	12:40	3	0.9	20.2	2.09					
7414	Rice		5/31/2007	5	12:40	3.5	1.1	19.0	0.4					
7422	Rice	Surface	6/13/2007	6	13:55	0.5	0.2	26.1	5.41	1.25	0.169	0.009		8.7
7422	Rice		6/13/2007	6	13:55	0.75	0.2	25.7	4.28					
7431	Rice	Surface	6/28/2007	6	13:45	0.5	0.2	23.6	2.18	1.25	0.452	0.009		41.4
7439	Rice	Surface	7/12/2007	7	13:30	1	0.3	22.3	9.44	0.75	0.224	0.009		72.3
7439	Rice		7/12/2007	7	13:30	1.5	0.5	22.2	8.58					
7447	Rice	Surface	7/26/2007	7	12:18	1.5	0.5				0.318	0.009		69.0
7454	Rice	Surface	8/9/2007	8	11:50	0	0.0	29.5	9.56	0.50	0.207	0.009		64.0
7454	Rice		8/9/2007	8	11:50	1	0.3	29.4	2.01					
7454	Rice		8/9/2007	8	11:50	1.5	0.5	28.8	3.4					
7463	Rice	Surface	8/23/2007	8	12:30		0.0				0.238	0.009		94.1
7470	Rice	Surface	9/6/2007	9	12:30	1.5	0.5				0.272	0.009		89.5
7472	Rice	Duplicate	9/6/2007	9	12:30	1.5	0.5				0.268	0.009		96.8
7479	Rice	Surface	9/25/2007	9	12:30		0.0	18.6	6.69	1.25	0.228	0.009		59.1
7407	Baldwin		5/18/2007	5	12:45	1	0.3	16.7	9.25					
7407	Baldwin	Surface	5/18/2007	5	12:45	0	0.0	16.7	6.32	1.25	0.128	0.009		22.4
7407	Baldwin		5/18/2007	5	12:45	2	0.6	16.7	9.11					
7407	Baldwin		5/18/2007	5	12:45	3	0.9	16.7	8.44					
7415	Baldwin		5/31/2007	5	13:45	2	0.6	22.6	8.01					
7415	Baldwin		5/31/2007	5	13:45	3	0.9	21.8	4.63					
7415	Baldwin	Surface	5/31/2007	5	13:45	1	0.3	24.0	8.48		0.081	0.009		16.9
7423	Baldwin	Surface	6/13/2007	6	15:00	0.5	0.2	27.6	7.63	1.50	0.123	0.009		25.4
7432	Baldwin	Surface	6/28/2007	6	13:55	0.5	0.2	23.4	8.83	1.25	0.164	0.009		23.3
7432	Baldwin		6/28/2007	6	13:55	0.75	0.2	23.3	3.71					
7440	Baldwin	Surface	7/12/2007	7	14:25	1	0.3	22.8	9.25	0.50	0.235	0.009		46.2
7441	Baldwin	Duplicate	7/12/2007	7	14:25	1.5	0.5				0.229	0.009		36.7
7448	Baldwin	Surface	7/26/2007	7	12:50	1.5	0.5				0.294	0.009		59.1
7455	Baldwin	Surface	8/9/2007	8	12:10	0	0.0	29.6	8.97	0.25	0.316	0.009		144.4
7455	Baldwin		8/9/2007	8	12:10	1	0.3	29.4	6.01					
7455	Baldwin		8/9/2007	8	12:10	2	0.6	28.6	3.02					
7456	Baldwin	Duplicate	8/9/2007	8	12:10		0.0				0.309	0.009		127.2
7464	Baldwin	Surface	8/23/2007	8	13:20	1	0.3	21.6	10.72	0.90	0.204	0.009		108.2
7464	Baldwin		8/23/2007	8	13:20	2	0.6	21.5	9.84					
7471	Baldwin	Surface	9/6/2007	9	13:00	1.5	0.5				0.318	0.009		103.0
7477	Baldwin	Surface	9/25/2007	9	11:20	1	0.3	19.0	7.62	1.00	0.199	0.009		46.8
7477	Baldwin		9/25/2007	9	11:20	2	0.6	19.1	7.52					
7477	Baldwin		9/25/2007	9	11:20	3	0.9	19.2	3.43					

Appendix C

Upstream Boundary Condition for the Lino Lakes TMDL Study

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TECHNICAL MEMORANDUM

TO: Joe Bischoff, M.S., Project Manager

FROM: Andy Erickson, M.S., EIT, Project Engineer

DATE: December 18, 2007

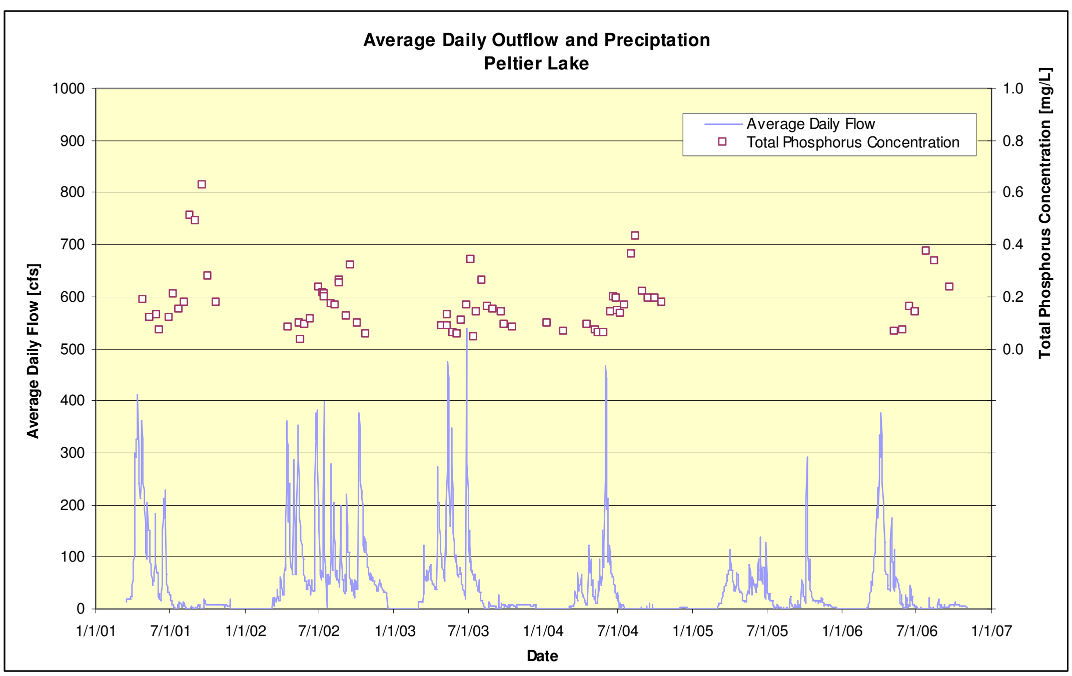
SUBJECT: Upstream Boundary Condition for the Rice Creek Watershed District Chain of Lakes Study

---

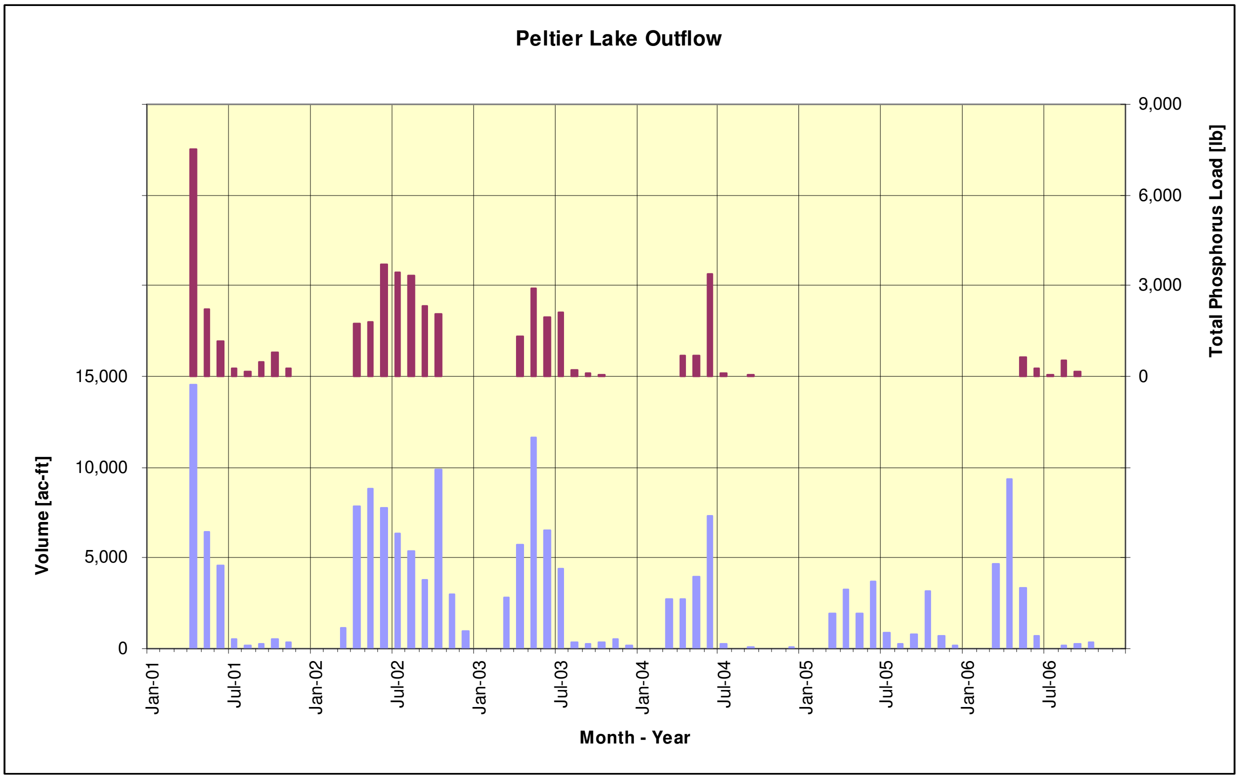
The purpose of this memo is to document the upstream boundary condition used in a study of five Lakes in the Rice Creek Watershed District. The five lakes of interest are George Watch, Marshan, Reshanau, Rice, and Baldwin Lakes. Peltier and Centerville Lakes are upstream of George Watch and Baldwin Lake discharges to Rice Creek. The upstream boundary condition for the study is the Peltier Lake outflow.

Data Analysis

Daily discharge for Peltier Lake outflow is calculated from a stage-discharge relationship (St. Paul Water Utility 1998) and continuously measured depth. Average Daily flow is shown in the figure below. Lake water quality data for Peltier Lake is available at the Minnesota Pollution Control Agency website (http://www.pca.state.mn.us/data/edaWater/index.cfm) and is shown in the figure below.



Daily flow was summed to estimate the total monthly flow from March 2001 to November 2006. Average monthly in-lake phosphorus concentration was calculated from measured data in Peltier Lake. Total monthly load was calculated as the product of the total monthly discharge volume and the average monthly in-lake phosphorus concentration. Monthly volume and total phosphorus load is shown in the figure below. Total monthly loads were summed to estimate the total growing season (June 1 – September 30) phosphorus load in the Peltier Lake outflow.



Data Application

In-lake total phosphorus concentration (Canfield and Bachmann 1981) is predicted from runoff volume and load from drainage areas, upstream lakes, the atmosphere, groundwater interactions, and internal phosphorus load for George Watch, Marshan, Sherman, Wards, Reshanau, Rice, and Baldwin lakes. Peltier Lake outflow volume and load is used as the upstream lake contribution for George Watch Lake.

References

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Canfield, D. E., Jr., and Bachmann, R. W. (1981). "Prediction of total phosphorus concentrations, chlorophyll *a*, and Sec8chi depths in natural and artificial lakes." *Canadian Journal of Fisheries and Aquatic Science*, 38, 414-423.

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Appendix D

P8 Model Development

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TECHNICAL MEMORANDUM

TO: **Joe Bischoff, Project Manager**

FROM: **Jeremy Schultz**

DATE: November 15, 2007

SUBJECT: Lino Lakes TMDL P8

CC:

Pollutant Loading

Phosphorous loading due to direct runoff from the lake watersheds was estimated using P8, the Program for Predicting Polluting Particle Passage through Pits, Puddles and Ponds (Walker 2007, Version 3.2). P8 models simulate the build up and wash off of stormwater pollutants using mass and water balance calculations through a user defined drainage system. The key components of P8 models are watersheds, devices, particles and water quality components. The rainfall and snowmelt causing runoff is generated by hourly precipitation and daily air temperature files.

The P8 model tracks pollutant loading by building up particles on a watershed, then washing off the particles through the precipitation and temperature files and routing them to devices (ponds, infiltration basins, pipes, ect.). The pollutant removal efficiency of the device is then evaluated and the pollutants not removed are routed downstream in the watershed until finally depositing in a lake.

P8 models for the Rice Creek Watershed District (RCWD) TMDL were separated by water body and have a varying amount of subwatersheds within each model. In total 9 P8 models were built and they are organized as follows:

- Baldwin Lake (1 model)
- Rice Lake (1 model)
- Reshenau Lake (1 model)
- Marshan Lake (3 models)
- George Watch Lake (1 model)
- Ward wetland (1 model)
- Sherman wetland (1 model)

P8 Model Development

P8 input parameters not discussed within this memo remain as the P8 model default values.

Watersheds

Key watershed input parameters are:

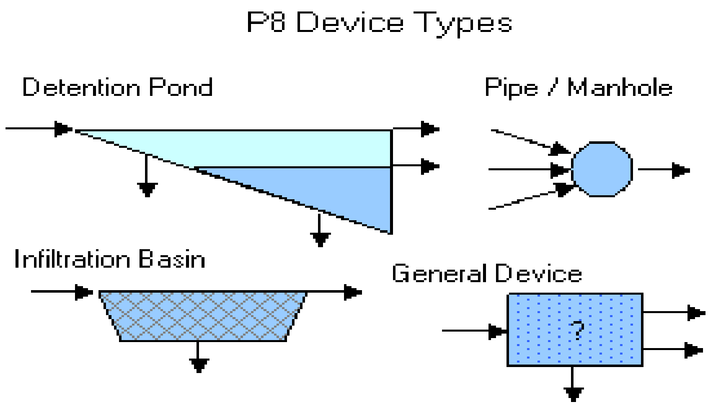
- Total area
- Total area impervious fraction
- Pervious area SCS curve number

These 3 parameters were obtained from the RCWD and match the inputs in the districts XP-SWMM model. It should be noted that the total area is the total upland area not including open water. The total area includes the area of wetlands type 1,2,6,7,8 and does not include the area of wetlands type 3,4,5 and lake surface areas. The total area impervious fraction is the impervious fraction of the upland area described above and the pervious area SCS curve number is the area weighted average of the upland area based on land cover and soil type.

Devices

The table and diagram below describe the type of devices used to evaluate phosphorus removal and are taken directly from the P8 help website at http://wwwalker.net/p8/webhelp/p8HelpWebMain.html.

Device Type	Input Values	Description	Removes Particles	Infil - tration Outlet	Normal Outlet	Spillway/ Overflow
Detention Pond	Permanent & flood pool areas & volumes infiltration rates outlet type & size	configured as wet, dry, or extended detention	X	X	X	X
Infiltration Basin	storage pool area & volume, infiltration rate; void fraction	storage area with infiltration	X	X		X
General Device	area & discharge vs. elevation,3 outflow streams (normal, overflow, infiltration)	user-defined hydraulics from independent model/ analysis	X	X	X	X
Pipe / Manhole	time of concentration (linear reservoir)	collects watershed and/or device outflows and directs them to downstream device			X	



The device type, input values, and outlet configurations were obtained directly from the RCWD or were taken from the districts XP-SWMM model. Infiltration rates were adjusted to match as best as possible the yearly average infiltration volume predicted by the districts XP-SWMM model. Wetlands were modeled as general devices and rating curves were developed for outlets based on the districts XP-SWMM model.

Particles

Particle values are provided with the P8 model that are based on "typical urban runoff" concentrations and settling velocities measured under NURP (Athayede et al.,1983,1986; Driscoll, 1983). The NURP 50th % particle values were determined to be reasonable for the RCWD and therefore used to predict phosphorus runoff.

The particle calibration as stated by the P8 website http://wwwalker.net/p8/webhelp/p8HelpWebMain.html is as follows:

Washoff parameters for particle fractions P10% - P80% are contained in particle files NURP50.P8P, NURP90.P8C, & SIMPLE.P8C have been calibrated as follows:

Accumulation Rate = 1.75 lbs/ac-day (P10%,P30%,P50%), = 3.5 lbs/ac-day (P80%) calibrated to provide median EMC = 100 ppm Total Susp. Solids ; using Providence Airport weather data.

Accum. Decay Rate = .25 1/day; assumes buildup on impervious surfaces reaches 90% of steady-state after 10 days of dry weather without sweeping

Washoff Exponent = 2; provides intensity-dependent washoff, as in SWMM (Huber et al., 1988)

Washoff Coefficient = 20 calibrated so that load/volume relationship for impervious watersheds saturates at ~1 inch of rainfall; provides 92% washoff for a 1-inch, 8-hour storm.

Impervious Runoff Conc = 0; buildup/washoff dynamics are used to predict impervious runoff conc.

Pervious runoff concentration parameters contained in particle files NURP50.P8C, NURP90.P8C, & SIMPLE.P8C have been calibrated as follows:

Model:
CONC = a RUNOFF ^{b}

Variables:
CONC = concentration in pervious runoff (ppm)
RUNOFF = runoff intensity from pervious areas (inches/hr)

Parameters:

a = intercept = conc. @ runoff intensity of 1 in/hr = 100 ppm; calibrated so that flow-weighted mean TSS EMC from pervious watersheds = 100 ppm; calibration period = 1983-1987; Curve Number = 74; Providence Rhode Island Rainfall.

b = exponent = 1; linear log(c) vs. log(q) relationship; typical of stream sediment rating curves (Huber & Dikinson,1988)

Water Quality Components

The default NURP 50^{th} % values were also used for water quality components. As stated by the P8 website

http://wwwalker.net/p8/webhelp/p8HelpWebMain.html :

Particle Compositions (mg/kg) have been calibrated so that median, event-mean runoff concentrations correspond to values reported by the Nationwide Urban Runoff Program:

Component	NURP50.P8P Particle File	% Dissolved
Total Suspended Solids	100	0
Total Phosphorus	.22	30

Precipitation

Runoff is a direct result from rainfall and snowmelt. P8 combines rainfall and snowmelt in to one precipitation file. The precipitation file used for the RCWD TMDL was derived from the precipitation data used in the districts XP-SWMM model. The RCWD derived rainfall for the years 2001 – 2006 as follows:

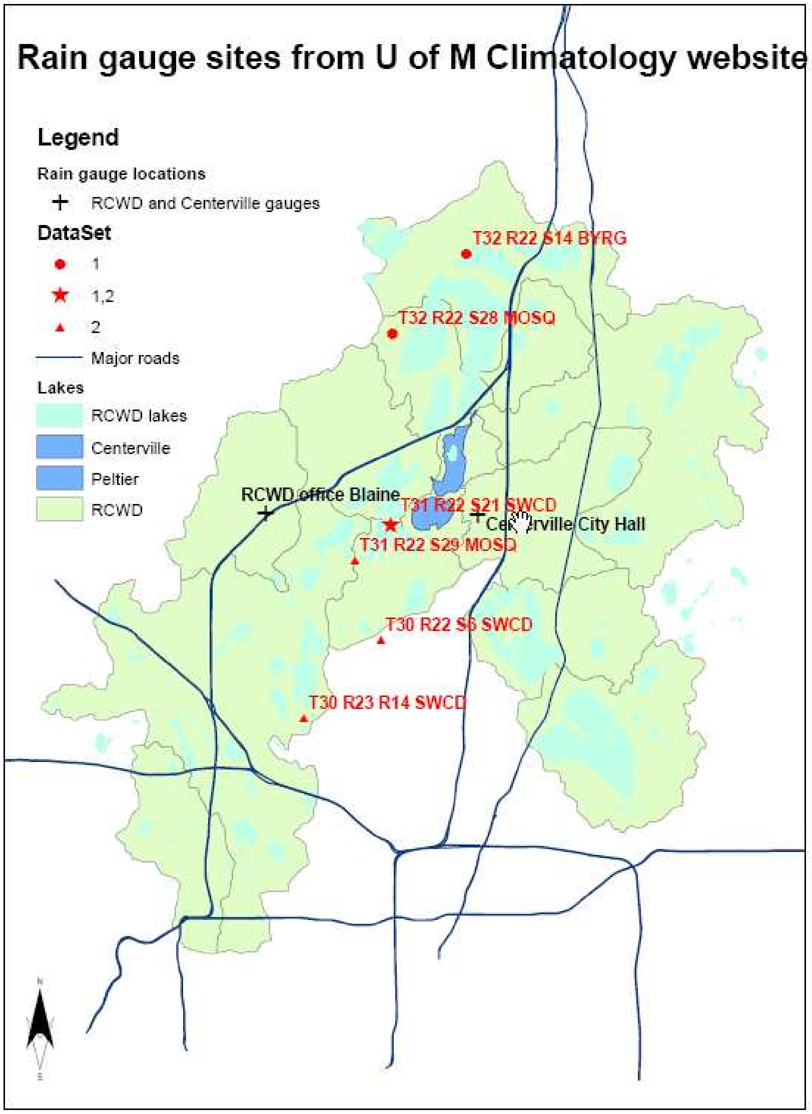
Precipitation data was obtained from the Climatology Working Group (http://climate.umn.edu/) database. With this database, the target location is set using section, township, and range, and the allowable maximum number of missing data points per month. The various sites are then searched so that the closest data set with less than the allowable number of missing data points can be identified.

For the precipitation data, two separate data sets were obtained (see Figure 3), using the following search criteria:

Set 1: Target T31 R22 S28 (located in Upper Rice Creek Watershed); 3 missing days allowed per month

Set 2: Target T38 R22 S21 (located near Peltier Lake); 3 missing days allowed per month

Figure 3. Rain Gauge Sites from U of M Climatology Web-Site



To compile the precipitation data set for the model, the following guidelines were followed:

On days for which precipitation data were recorded in both data sets, the two values were averaged.

On days for which there were data for only one of the sites, that value was used.

If data were missing from both data sets, a value of zero was used.

The daily totals were then distributed based on a SCS 24-hour distribution at hourly intervals.

<u>Temperature</u>

The temperature data was also obtained from the Climatology Working Group (http://climate.umn.edu/) database Centerville station, using average daily temperature values.

Model Calibration

The P8 models were built to mimic the XP-SWMM models. In both models stormwater runoff from one or more subwatersheds is routed through one or more devices (e.g., wet pond, infiltration basin) and delivered through links into each receiving lake (George Watch, Marshan, Reshanau, Rice, ect.). P8 models were calibrated to the annual discharge volumes for each link that flows directly into a lake as computed by XP-SWMM. The "Impervious Runoff Coefficient" was adjusted if necessary in all subwatersheds upstream of the link in question to match the XP-SWMM yearly discharge volumes as closely as possible. The "Impervious Runoff Coefficient" as it appears in P8 is shown in the figure below.

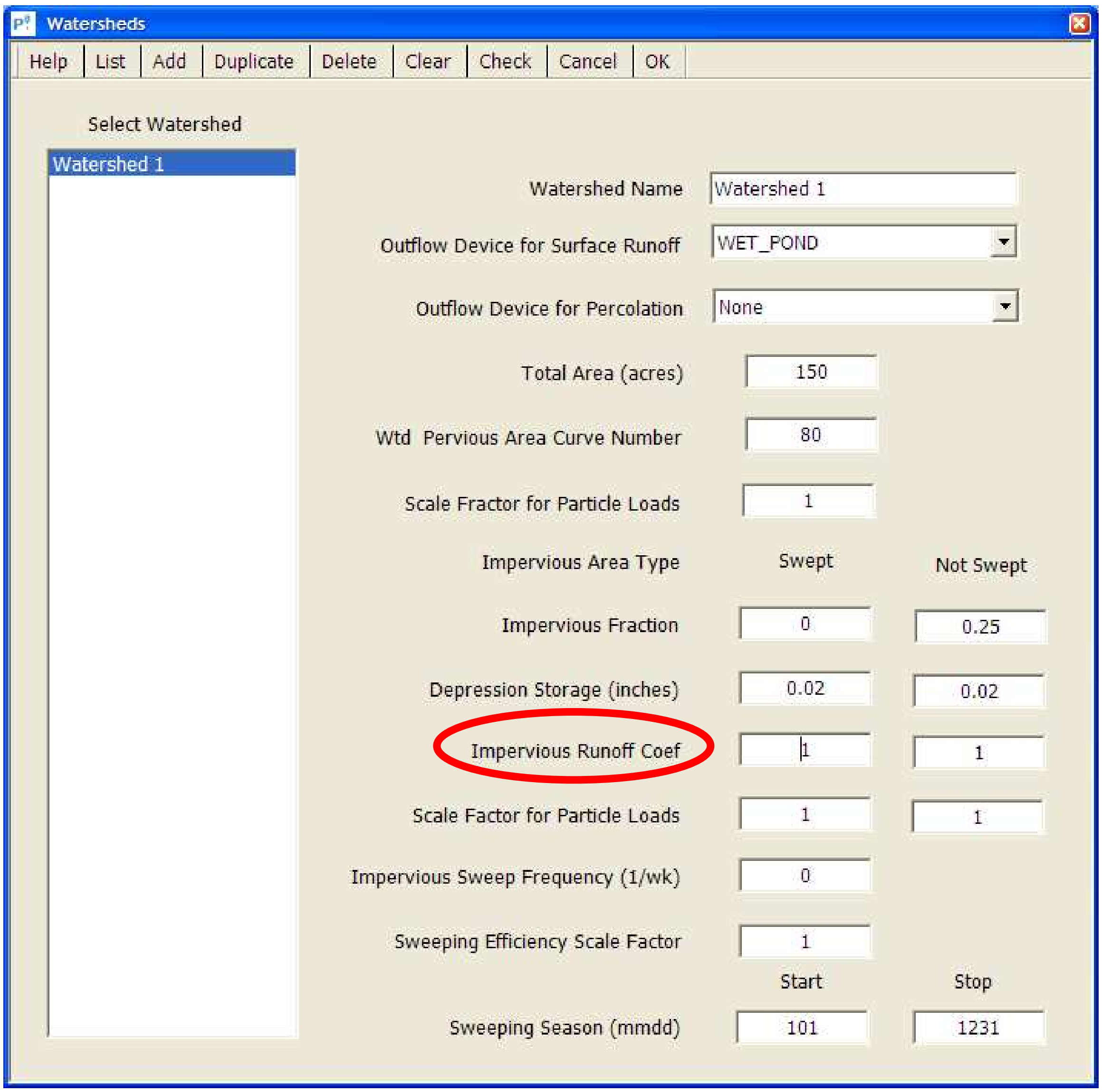


Figure 1: The "Impervious Runoff Coefficient" was modified to calibrate runoff volumes predicted by P8 Model to match XPSWMM for all links flowing into RCWD lakes.

The discharge from the area directly surrounding each lake as estimated by XPSWMM is greater than the discharge as estimated by P8. This occurs because the XP-SWMM models include both upland and open water areas while the P8 models only consider upland area. Because the “Impervious Runoff Coefficient” can not be larger than one, the P8 model could not be calibrated for these watersheds using the method describe above. The runoff volumes as predicted by P8 are assumed to be correct for the drainage area that directly surrounds the lakes.

Future Build Out Conditions Model

P8 models for the Rice Creek Watershed District TMDL were also built for the future build out scenario. Of the 271 subwatersheds in the existing condition 154 will remain the same because they are currently fully developed. 114 subwatersheds will experience development and therefore have an increase in impervious surface. The 114 subwatersheds are considered to be developing subwatersheds and will be split in to 2 areas. The first area represents the fully developed portion of a developing subwatershed and will be routed to the device the area is routed to in the existing condition model. The second area represents the developing portion of a developing subwatershed and is routed to a new device that is assumed to be in place at built out conditions. In total there are 382 subwatersheds in the future build out condition.

The naming convention for the subwatershed is as follows:

- An “R” will be placed in front of the existing subwatershed name if it is currently fully developed and will experience no change. (154 subwatersheds)
- An “X” will be placed in front of the existing subwatershed name to represent the fully developed portion of a developing subwatershed.
- A “P” will be placed in front of the existing subwatershed name to represent the developing portion of a developing subwatershed.

For example: BAL-002 is fully developed and not developing further so it is renamed RBAL-002. BAL-001 does contain parcels that will develop so it is split into two areas. The area that is already fully developed is renamed XBAL-002. The developing area is renamed PBAL-001.

This is the same naming convention used in the RCWDs future build out conditions XP-SWMM model.

The future conditions P8 models are separated by water body as the are for the existing conditions. In total there are 10 P8 models and they are organized as follows:

- Baldwin Lake (1 model)
- Rice Lake (1 model)
- Reshenau Lake (1 model)
- Marshan Lake (4 models)
- George Watch Lake (1 model)
- Warrd wetland (1 model)
- Sherman wetland (1 model)

Watersheds

The three watershed input parameters are 1) total area 2) total area impervious fraction and 3) pervious area SCS curve number.

The parameters for the future build out condition subwatersheds were obtained from the RCWD and match the inputs in the districts future build out XP-SWMM model. It should be noted once again that the total area is the total upland area not including open water. This includes the area of wetlands type 1,2,6,7,8 and does not include wetlands type 3,4,5 and lake surface areas. The total area impervious fraction is the impervious fraction of the upland area described above and the pervious area SCS curve number is the area weighted average of the upland area based on land cover and soil type.

Devices

All new devices for the future build out condition were assumed to be ponds. This mimics the RCWDs XP-SWMM model. The input values for a pond are shown again below.

Device Type	Input Values	Description	Removes Particles	Infil - tration Outlet	Normal Outlet	Spillway/ Overflow
Detention Pond	Permanent & flood pool areas & volumes infiltration rates outlet type & size	configured as wet, dry, or extended detention	X	X	X	X

The detention pond input values and outlet configuration were obtained directly from the districts future build out XP-SWMM model. It was assumed the ponds would not infiltrate.

Particles

In order for the existing and future build out conditions models to be comparable the same particle file was used in both scenarios. *See the particles section above.*

Water Quality Components

In order for the existing and future build out conditions models to be comparable the same water quality conponents were used in both scenarios. *See the particles section above.*

Precipitation

The precipitation file created for the existing conditions models was also used for the future conditions models.

Temperature

The temperature file created for the existing conditions models was also used for the future conditions models.

Appendix E

Internal Load Estimation

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Maple Plain, MN 55359-0249

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Fax (763) 479-4242
E-mail: wenckmp@wenck.com

TECHNICAL MEMORANDUM

TO: Joe Bischoff, M.S., Project Manager

FROM: Jeff Madejczyk, M.S., and Andy Erickson, M.S., EIT, Project Engineers

DATE: May 2, 2008

SUBJECT: Internal Phosphorus Load Estimation for Chain of Lakes in Rice Creek Watershed District

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The purpose of this memo is to document the methodology used to estimate internal phosphorus load for a Total Maximum Daily Load (TMDL) study in Rice Creek Watershed District. The memo is separated into several sections: 1) calculation of internal phosphorus load from in-lake and sediment phosphorus concentration, 2) estimation of internal load from phosphorus mass balance, and 3) use of internal load estimates for Lake Response Model calibration.

CALCULATION OF INTERNAL PHOSPHORUS LOAD FROM IN-LAKE AND SEDIMENT PHOSPHORUS CONCENTRATION

Background

The Rice Creek Watershed District (RCWD) has contracted Wenck Associates, Inc. (Wenck) to perform Total Maximum Daily Load (TMDL) studies on the five lakes that comprise the Lino Lakes Chain of Lakes, which includes George Watch, Marshan, Rice, Reshanau and Baldwin Lakes. These lakes are listed for excessive nutrients (total phosphorus or TP) under the TMDL program. The total load of nutrients entering and exiting the lake needs to be understood as completely as possible in order to determine the sustainable condition for a lake and measures that need to be taken to achieve that lake condition. One important piece of determining the total nutrient load for a lake is internal load produced by the lake, typically from the lake sediments. The internal nutrient load can vary greatly depending on lake conditions. Deep, oligotrophic lakes often have sand or gravel sediments that are nutrient poor and contribute only a small load of nutrients to the lake water column. Conversely, shallow eutrophic lakes typically have organic muck sediments that are rich in nutrients, which can contribute significant nutrient loads to the lake water column.

Methods

Determining the contributing internal load from lake sediments is a subject that has been widely researched. Several modeling efforts utilizing existing data sets have been conducted in an attempt to quantify a lakes contributing internal load. Methods for quantifying internal loads from deep lakes include an anoxic factor (AF) estimation, which accounts for the portion of the total lake volume that stratifies and becomes anoxic. The anoxic volume of the lake is then paired with hypolimnion (i.e., lake bottoms) TP samples to calculate the internal load (Nürnberg 1998). The lakes that comprise the Rice Creek Chain of Lakes are classified as shallow lakes, averaging less than five feet in depth Shallow lakes rarely stratify and are classified as polymictic, meaning they are constantly mixing and do not have significant portions of the lake volume that become anoxic. As a result, internal TP loads can not be calculated using the same methods as are used for deep, stratified lakes. Shallow lakes, however, do have anoxic sediments at the sediment-water interface and do have an active anoxic sediment area which contributes an internal TP load to the water column. Research by Nűrnberg (2005) used multiple regression analysis of multi-year TP data sets from lakes to develop an equation to predict AF for shallow polymictic lakes as given by equation 1:

Equation 1: $AF_{pred} = -35.4 + 44.2 \log (TP) + 0.95\ z/A^{0.5}$ (Nürnberg 2005)

Where TP is the measured water column TP of the lake, z is the depth in meters, and A is the lake area in hectares. The sediment TP release rate (RR) for the active anoxic sediments can be calculated by equation 2:

Equation 2: $\text{Log}(RR) = 0.8 + 0.76 \log (TP_{sed})$ (Nürnberg 2005)

Where TP_{sed} is the measured TP concentration of the lakes sediments. The results of the calculations from Equations 1 and 2 could then be combined to estimate internal TP load for shallow polymictic lakes using equation 3:

Equation 3: Internal TP Load = $AF_{pred} \times RR$ (Nürnberg 2005)

These equations were used with field data to calculate the internal TP loads for the lakes in the Rice Creek Chain of Lakes.

Results

Water quality data sets from RCWD annual water quality monitoring were used to calculate the water column summer annual average TP values used in Equation 1. Sediment cores were collected by Wenck in November 2006 from Baldwin, George Watch, Rice and Reshanau Lakes and were used to measure the TP_{sed} values used in Equation 2. Results of the internal load estimates using Equation 3 are presented in Table 1.

Lake	Sediment TP (mg/g)	Average Annual In-Lake TP (ug/L)	Mean Depth (m)	Area (km^2)	AF_{pred} (days)	RR ($mg/m^2/day$)	Unit Area Internal Load (mg/m^2)	Total Load (kg/year)
Baldwin 1	0.98	207	1.19	0.89	68.16	6.213	423.52	377.36
Baldwin 2	0.94	207	1.19	0.89	68.16	6.020	410.32	365.59
Reshanau 1 - Top	0.96	121	1.77	1.51	58.03	6.117	354.94	534.76
Reshanau 2 - Top	1.1	121	1.77	1.51	58.03	6.784	393.63	593.05
George Watch 1-Top	0.74	180	1.19	3.59	64.88	5.019	325.63	1168.45
George Watch 2- Top	1.3	180	1.19	3.59	64.88	7.702	499.69	1793.04
Rice 1- Top	1	148	1.22	1.79	61.39	6.310	387.35	693.40
Rice 2-Top	0.92	148	1.22	1.79	61.39	5.922	363.57	650.82

ESTIMATION OF INTERNAL LOAD FROM PHOSPHORUS MASS BALANCE

A mass balance analysis of George Watch Lake was performed to estimate the internal phosphorus load. The purpose of this analysis was to verify the results from internal estimates based on in-lake and sediment total phosphorus. The analysis compares inflow load, in-lake mass, and outflow load.

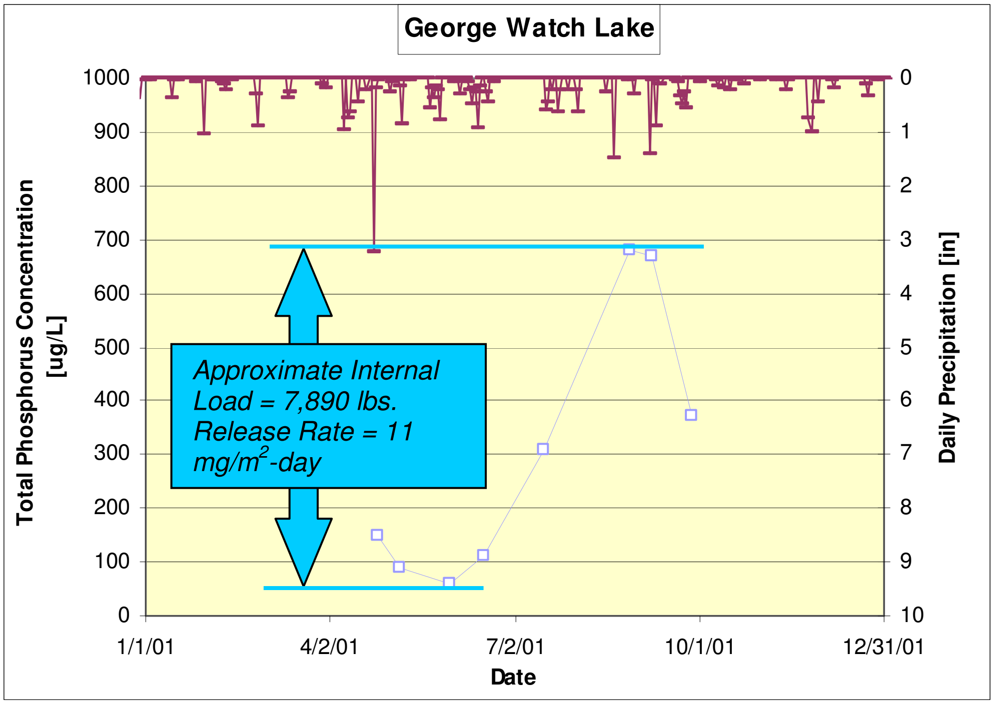
Peltier Lake Data Analysis

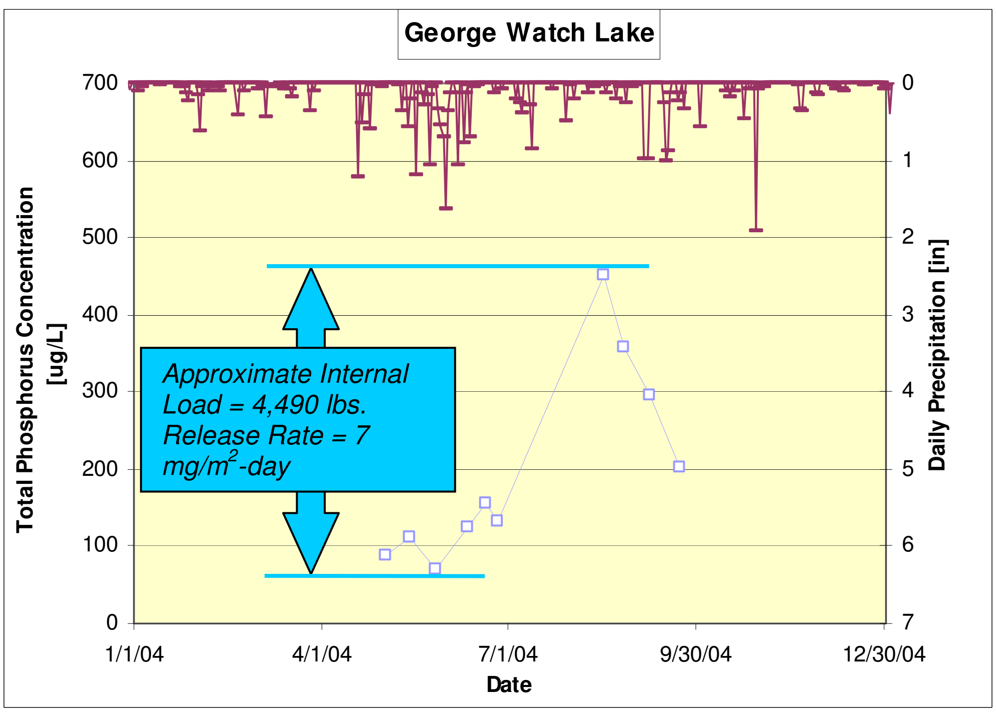
George Watch Lake receives inflow from Peltier Lake. Peltier Lake outflow discharge is calculated from a stage-discharge relationship (St. Paul Water Utility 1998) and water quality data for Peltier Lake was downloaded from the Minnesota Pollution Control Agency website (http://www.pca.state.mn.us/data/edaWater/index.cfm). Peltier Lake outflow loads were estimated from the product of monthly discharge volume and average monthly Peltier in-lake total phosphorus concentration.

Internal Phosphorus Load Estimation

The measured in-lake phosphorus concentration for George Watch Lake is shown in the figures below for 2001 and 2004. Portions of the time series were analyzed in depth to estimate the internal phosphorus load within George Watch Lake. The method of analysis consisted of the following steps:

1. Calculate the in-lake total phosphorus mass for George Watch Lake,
2. Calculate the inflow volume and total phosphorus load from Peltier Lake into George Watch Lake,
3. Estimate the inflow volume and total phosphorus load from the George Watch subwatershed,
4. Estimate the George Watch Lake internal load.


George Watch Lake
Total Phosphorus Concentration [ug/L]
Daily Precipitation [in]
Date
1/1/01
4/2/01
7/2/01
10/1/01
12/31/01
Approximate Internal Load = 7,890 lbs. Release Rate = 11 mg/m2-day


George Watch Lake
Total Phosphorus Concentration [ug/L]
Daily Precipitation [in]
Date
1/1/04
4/1/04
7/1/04
9/30/04
12/30/04
Approximate Internal Load = 4,490 lbs. Release Rate = 7 mg/m2-day

A table showing the assumptions, equations, and the values obtained during each of these steps is given below:

Date	TP Conc. [ug/L]	In Lake TP Mass [lb]	Peltier Outflow Volume [ac-ft]	Peltier Outflow Load [lb]	GW Runoff Volume [ac-ft]	GW Runoff Load [lb]	Inflow Volume	Inflow Load	Internal Load [lb]	Estimated In-lake Conc. [ug/L]	Outflow Load	Estimated Release Rate [mg/m^2-d]
5/31/01	60	564										
6/17/01	110	1034	2282	589	24.4	11	2306	601	559	110.0	690	4.2
7/16/01	310	2915	2535	714	4.9	3	2540	717	3305	310.0	2141	14.4
8/28/01	680	6395	431	290	34.0	21	465	311	4028	680.0	859	11.8
5/24/04	69	649										
6/11/04	125	1175	3591	1401	176.4	81	3767	1483	324	125.0	1280	2.3
6/20/04	155	1458	2210	1019	0.2	0	2210	1019	195	155.0	932	2.7
6/26/04	133	1251										
8/16/04	451	4241	1254	571	20.5	13	1275	584	3970	451.0	1563	9.8

ASSUMPTIONS: 1. Inflow Volume = Outflow Volume
2. ΔStorage = Inflow + Internal - Outflow

EQUATIONS: In lake TP Load = Lake Volume x In lake TP Conc.
Inflow Volume = Peltier + GW
Inflow Load - Internal Load = Peltier + GW
Average Outflow Concentration = $C_1 + C_2 / 2$
Outflow Load = Outflow Concentration x Outflow Volume
Internal Load = In Lake Load - Previous In lake Load - Inflow Load + Outflow Load

Conclusions

It is evident from this analysis that internal load is a significant component of the phosphorus load budget for George Watch Lake. The estimated release rate for specific portions of the year varies from approximately 2.3 mg/m^2-day to 14.4 mg/m^2-day. The summer average release rate for 2001 and 2004 was approximately 11 and 7 mg/m^2-day, respectively. Median values (Nürnberg 1988) for sediment release rate in eutrophic lakes (10 mg/m^2-day) correlates well with the release rates estimated in this analysis.

INTERNAL LOAD ESTIMATES FOR LAKE RESPONSE MODEL CALIBRATION

Lake Response Modeling

In-lake total phosphorus concentration is predicted by Lake Response Modeling (Canfield and Bachmann 1981) from runoff volume and load from drainage areas, upstream lakes, the atmosphere, groundwater interactions, and internal phosphorus load for George Watch, Marshan, Sherman, Wards, Reshanau, Rice, and Baldwin lakes. P8 is used to estimate the runoff volume and pollutant loads from contributing drainage areas. Measured water quality and quantity data from Peltier Lake is the upstream tributary to George Watch Lake. The results from Lake Response Modeling of George Watch are used as tributary contributions to Marshan and so on throughout the system of lakes. Precipitation from local measured data is assumed to equal evaporation from each lake surface which results in a net zero volume contribution from the atmosphere. Aerial loading rates of phosphorus from wet and dry deposition are estimated based on precipitation (Barr Engineering 2004). Groundwater flux is assumed to be insignificant for all the lakes in this system.

Internal phosphorus load was estimated by several methods as described above. The anoxic factor (AF) and sediment release rate (RR) as estimated by the Nűrnberg equations were entered into the Lake Response Models for four of the study lakes (George Watch, Reshanau, Rice, and Baldwin). Similar values of anoxic factor and release rate were assumed for Marshan, Sherman, and Wards Lakes. When compared to measured in-lake data, the predicted in-lake phosphorus concentrations were found to be significantly lower values. An anoxic factor of 122 days (June 1 through September 30) was chosen to match the growing season time period because the growing season loads and runoff volumes were used in the Lake Response Model.

The watershed, upstream lake, and atmospheric loads were calibrated and correspond to literature values. As demonstrated by the mass balance analysis of George Watch Lake as described above, the internal phosphorus load as estimated by the Nűrnberg equations may be significantly under-predicted. The Carlson trophic state indices for the four lakes indicate that all are in the eutrophic to hyper-eutrophic state. According to research done on lakes throughout the world, median sediment TP release rates for eutrophic and hyper-eutrophic lakes are approximately 10 and 20 mg/m^2-day, respectively (Nürnberg 1988). Therefore, the sediment phosphorus release rate was calculated to match measured in-lake phosphorus concentration, where available. For years in which in-lake phosphorus data was not available in Reshanau Lake, the release rate as calculated by the Nűrnberg equations (6.45 mg/m^2-day) was used. For years in which in-lake phosphorus concentration was not available for George Watch, Marshan, Rice and Baldwin Lakes, a sediment phosphorus release rate of 10 mg/m^2-day was used. The release rates for each lake for 2001 through 2006 is shown in the table below. The predicted in-lake phosphorus concentrations adequately predicted the measured in-lake data using this release rate.

	Release Rate (mg/m^2-day)					
Lake	2001	2002	2003	2004	2005	2006
George Watch	10	5.95	8.49	14.8	10	10
Marshan	10	10	10	15.29	10	10
Reshanau	2.56	6.45	6.45	6.45	7.11	6.45
Rice	10	10	10	11.66	10	10
Baldwin	10	10	10	18.92	10	10

CONCLUSIONS

The internal phosphorus load for George Watch, Reshanau, Rice, and Baldwin Lakes was estimated from equations found in the literature. A mass balance analysis of George Watch Lake, literature values for eutrophic and hyper-eutrophic lakes, and comparison of model-predicted in-lake total phosphorus to measured data indicates that the estimated release rate may be significantly under-predicted. Therefore, a sediment phosphorus release rate of 10 mg/m^2-day was chosen based on literature values and measured in-lake phosphorus data for years in which measured data was not available.

References

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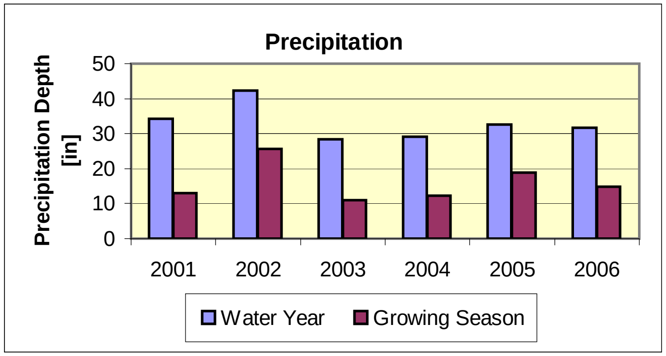
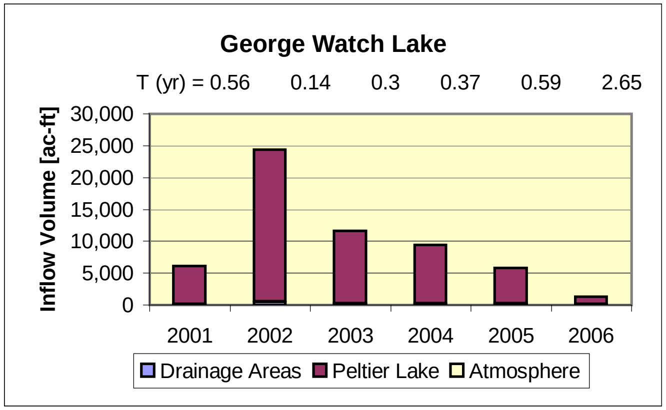
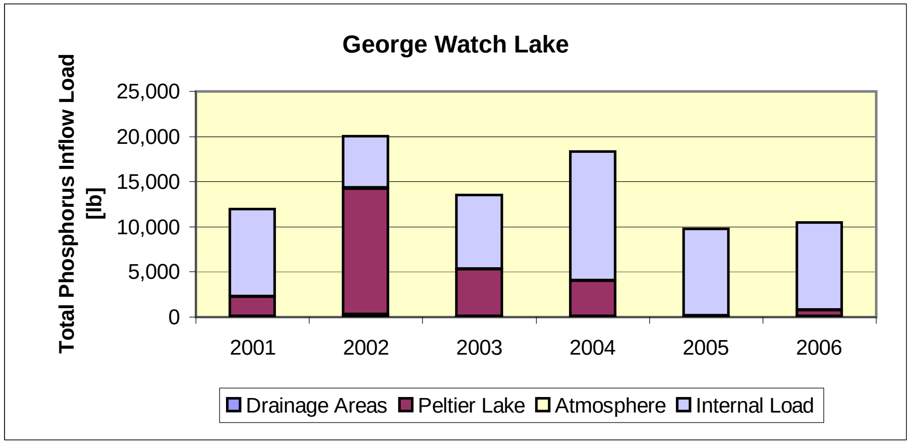
Appendix F

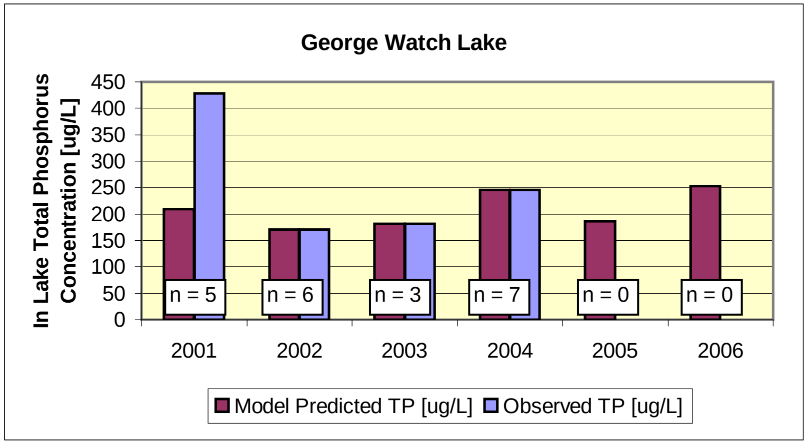
Lake Response Model Results

George Watch Lake	2001	2002	2003	2004	2005	2006
SOURCE			***Precipitation [in]***			
Water Year	34.2	42.4	28.4	29.2	32.7	31.6
Growing Season	13.0	25.7	10.9	12.3	18.9	14.8
SOURCE			***Inflow Volume [ac-ft/growing season]***			
Drainage Areas	97	515	158	171	201	113
Peltier Lake	6064	23876	11528	9250	5625	1192
Atmosphere	0	0	0	0	0	0
TOTAL =	6161	24390	11687	9422	5826	1305
SOURCE			***Total Phosphorus Load [lb/growing season]***			
Drainage Areas	63	307	94	91	109	74
Peltier Lake	2183	13935	5183	3919	0	700
Atmosphere	39	47	39	39	39	39
Internal Load	9651	5744	8195	14284	9651	9651
TOTAL =	11937	20033	13511	18333	9799	10465
			Model Results			
Model Predicted TP [ug/L]	210	171	182	246	186	253
Observed TP [ug/L]	428	171	182	246	N/A	N/A
Phosphorus Sedimentation [lb]	8426	8704	7734	12033	6846	9568
TOTAL OUTFLOW [lb] =	*3511*	*11328*	*5777*	*6300*	*2953*	*897*

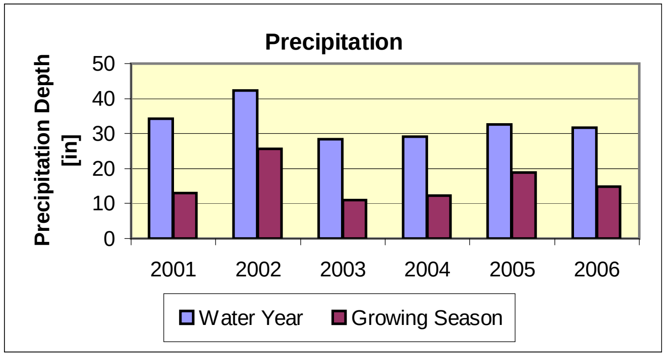


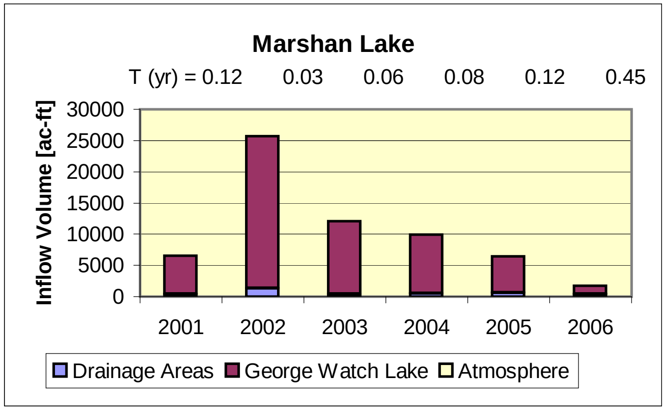


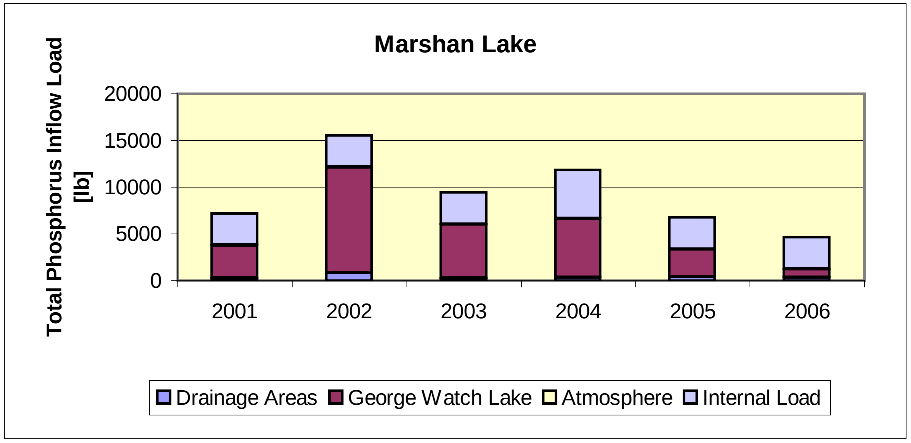


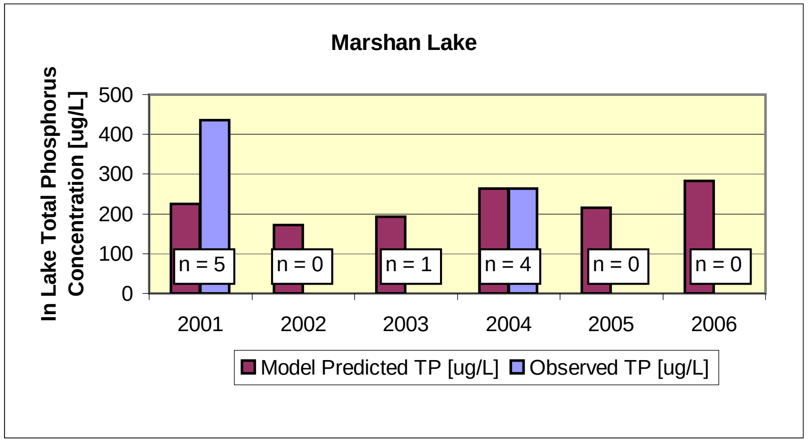


Marshan Lake	2001	2002	2003	2004	2005	2006
SOURCE	**Precipitation [in]**					
Water Year	34.2	42.4	28.4	29.2	32.7	31.6
Growing Season	13.0	25.7	10.9	12.3	18.9	14.8
SOURCE	**Inflow Volume [ac-ft/growing season]**					
Drainage Areas	378	1324	426	507	641	435
George Watch Lake	6161	24390	11687	9422	5826	1305
Atmosphere	0	0	0	0	0	0
TOTAL =	6539	25714	12113	9929	6466	1740
SOURCE	**Total Phosphorus Load [lb/growing season]**					
Drainage Areas	286	823	267	312	422	335
George Watch Lake	3511	11328	5777	6300	2953	897
Atmosphere	14	16	14	14	14	14
Internal Load	3399	3399	3399	5195	3399	3399
TOTAL =	7210	15567	9456	11822	6787	4644
Model Results						
Model Predicted TP [ug/L]	225	173	193	263	216	284
Observed TP [ug/L]	436	N/A	N/A	264	N/A	N/A
Phosphorus Sedimentation [lb]	3207	3498	3108	4707	2991	3303
TOTAL OUTFLOW [lb] =	*4003*	*12069*	*6348*	*7114*	*3796*	*1342*

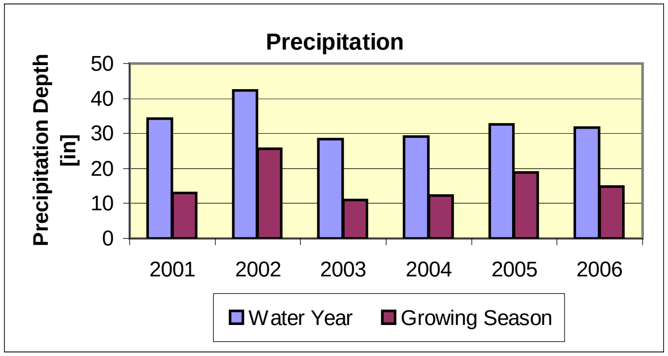


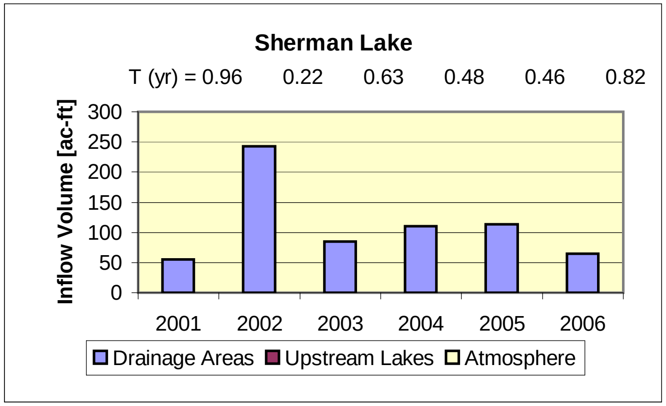


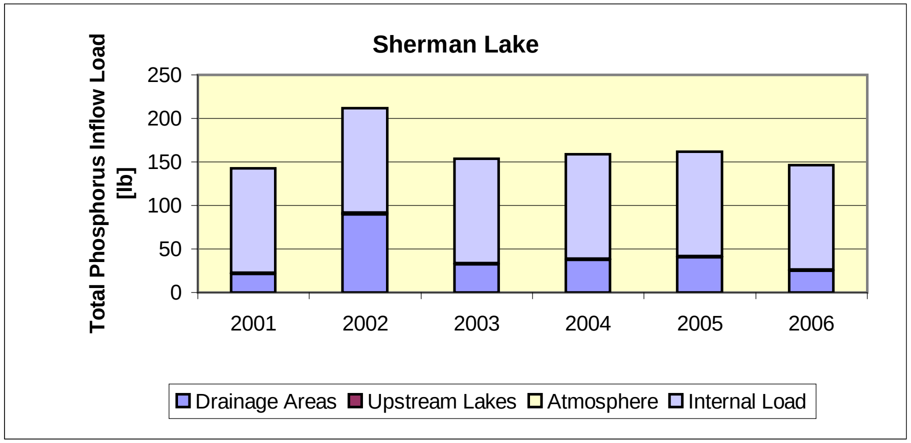


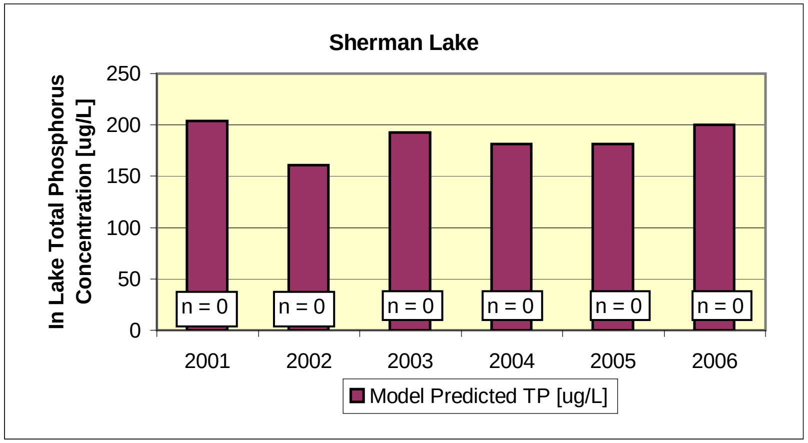


Sherman Lake	2001	2002	2003	2004	2005	2006
SOURCE	**Precipitation [in]**					
Water Year	34.2	42.4	28.4	29.2	32.7	31.6
Growing Season	13.0	25.7	10.9	12.3	18.9	14.8
SOURCE	**Inflow Volume [ac-ft/growing season]**					
Drainage Areas	55	242	85	110	114	65
Upstream Lakes						
Atmosphere	0	0	0	0	0	0
TOTAL =	55	242	85	110	114	65
SOURCE	**Total Phosphorus Load [lb/growing season]**					
Drainage Areas	21	90	32	37	40	25
Upstream Lakes						
Atmosphere	1	1	1	1	1	1
Internal Load	121	121	121	121	121	121
TOTAL =	143	212	154	159	162	147
Model Results						
Model Predicted TP [ug/L]	204	161	193	181	181	200
Observed TP [ug/L]	N/A	N/A	N/A	N/A	N/A	N/A
Phosphorus Sedimentation [lb]	112	106	110	105	105	111
TOTAL OUTFLOW [lb] =	*31*	*106*	*44*	*54*	*56*	*35*

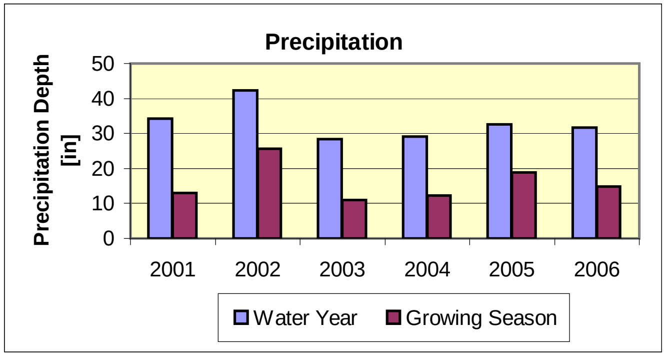


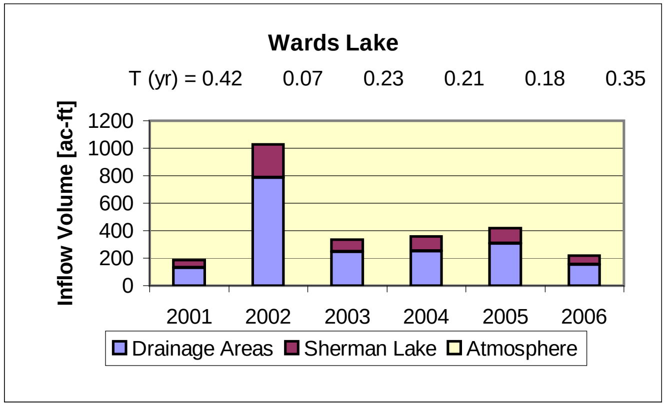


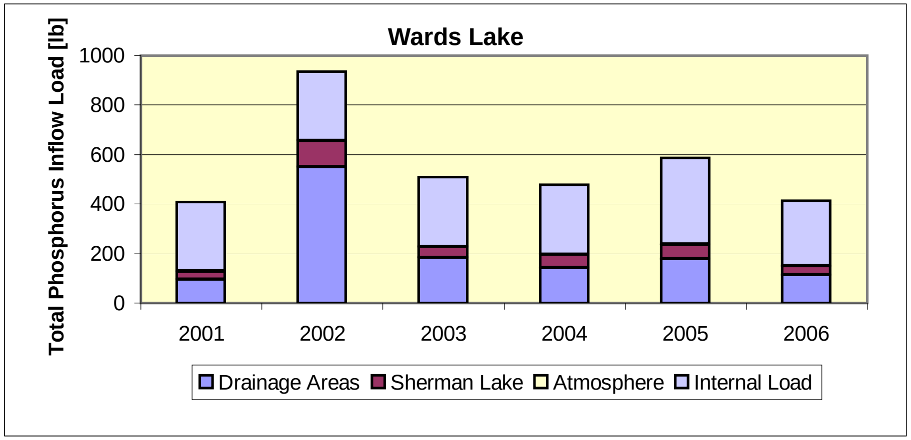


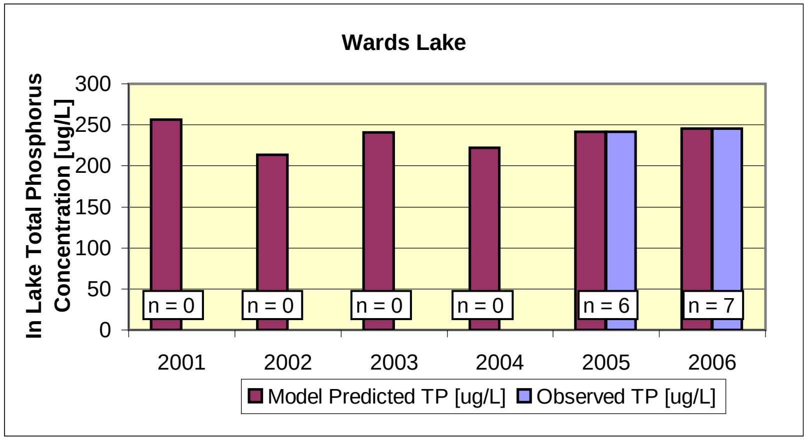


Wards Lake	***2001***	***2002***	***2003***	***2004***	***2005***	***2006***
SOURCE	***Precipitation [in]***					
Water Year	34.2	42.4	28.4	29.2	32.7	31.6
Growing Season	13.0	25.7	10.9	12.3	18.9	14.8
SOURCE	***Inflow Volume [ac-ft/growing season]***					
Drainage Areas	130	786	248	249	305	153
Sherman Lake	55	242	85	110	114	65
Atmosphere	0	0	0	0	0	0
TOTAL =	185	1029	333	359	419	218
SOURCE	***Total Phosphorus Load [lb/growing season]***					
Drainage Areas	97	549	183	142	180	114
Sherman Lake	31	106	44	54	56	35
Atmosphere	1	1	1	1	1	1
Internal Load	280	280	280	280	351	264
TOTAL =	408	936	508	477	587	414
	Model Results					
Model Predicted TP [ug/L]	256	213	241	222	242	245
Observed TP [ug/L]	N/A	N/A	N/A	N/A	242	245
Phosphorus Sedimentation [lb]	279	340	290	260	312	269
TOTAL OUTFLOW [lb] =	*129*	*596*	*218*	*217*	*276*	*145*

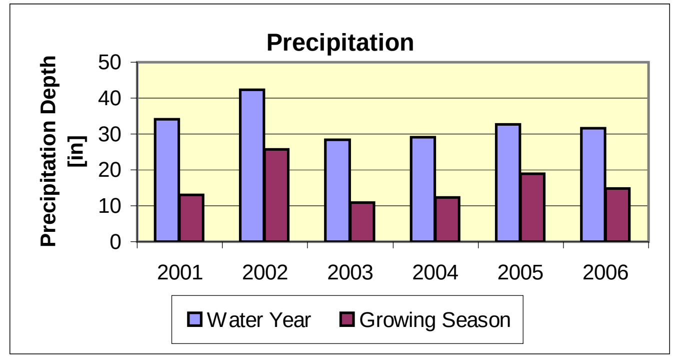


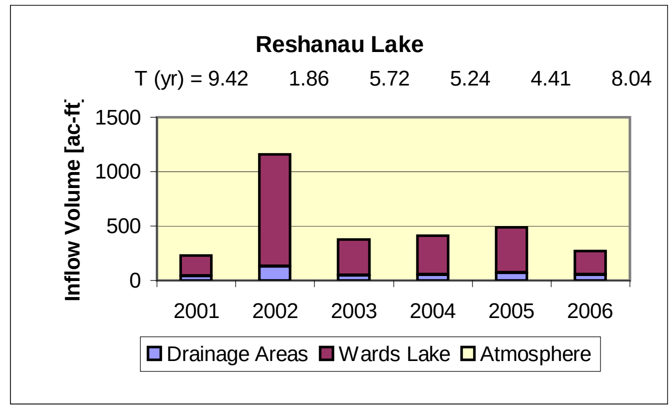


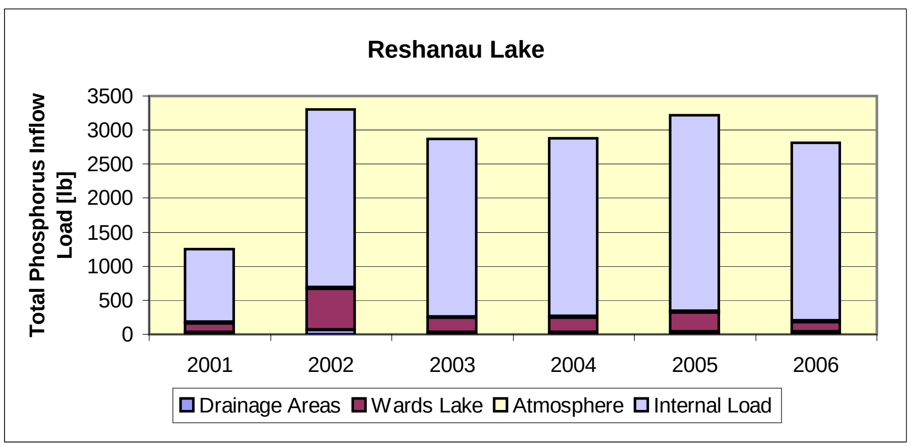


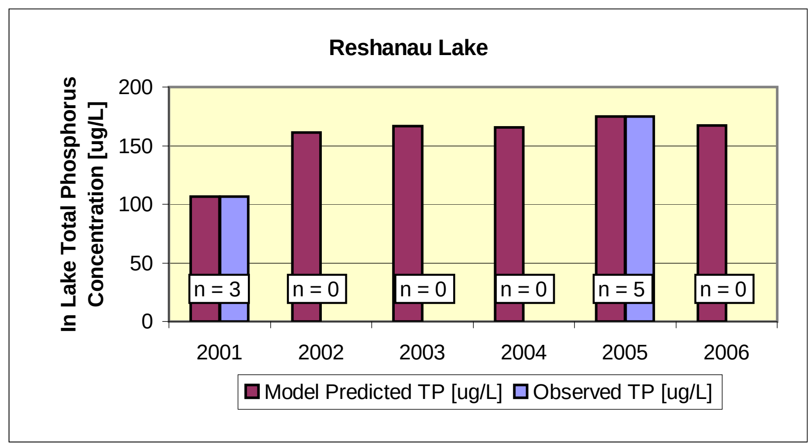


Reshanau Lake	2001	2002	2003	2004	2005	2006
SOURCE	***Precipitation [in]***					
Water Year	34.2	42.4	28.4	29.2	32.7	31.6
Growing Season	13.0	25.7	10.9	12.3	18.9	14.8
SOURCE	***Inflow Volume [ac-ft/growing season]***					
Drainage Areas	44	131	44	53	70	51
Wards Lake	185	1029	333	359	419	218
Atmosphere	0	0	0	0	0	0
TOTAL =	229	1159	377	412	490	269
SOURCE	***Total Phosphorus Load [lb/growing season]***					
Drainage Areas	30	68	24	30	42	35
Wards Lake	129	596	218	217	276	145
Atmosphere	17	20	17	17	17	17
Internal Load	1073	2614	2614	2614	2880	2614
TOTAL =	1248	3298	2872	2877	3214	2810
Model Results						
Model Predicted TP [ug/L]	107	161	167	166	175	167
Observed TP [ug/L]	107	N/A	N/A	N/A	175	N/A
Phosphorus Sedimentation [lb]	1181	2789	2701	2692	2982	2688
TOTAL OUTFLOW [lb] =	*67*	*509*	*171*	*186*	*233*	*122*

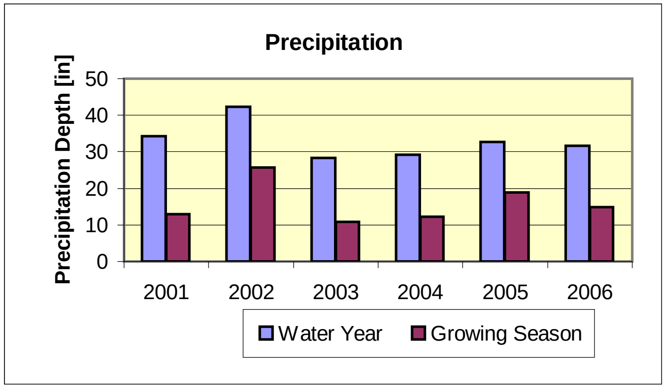


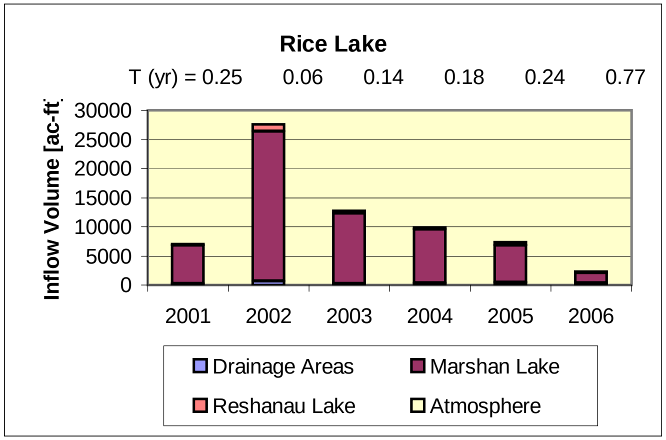


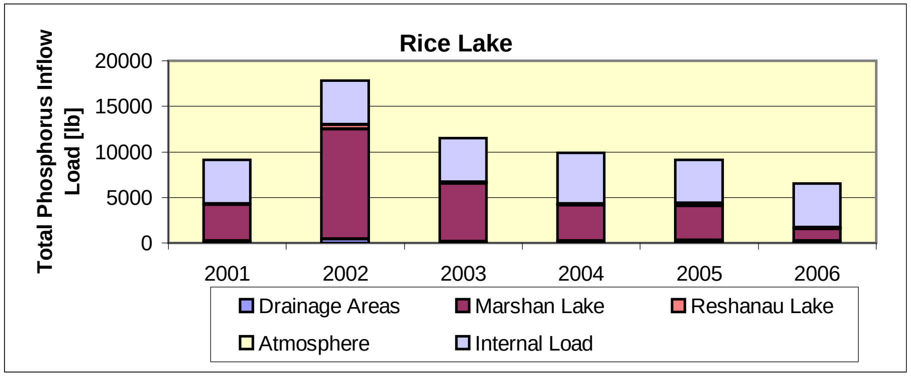


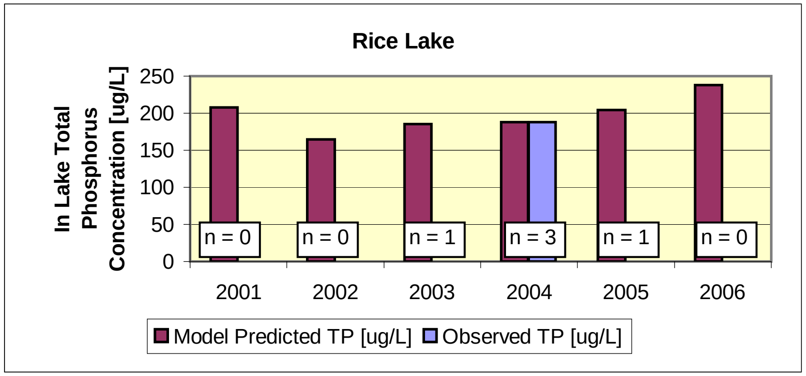


Rice Lake	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
SOURCE	***Precipitation [in]***					
Water Year	34.2	42.4	28.4	29.2	32.7	31.6
Growing Season	13.0	25.7	10.9	12.3	18.9	14.8
SOURCE	***Inflow Volume [ac-ft/growing season]***					
Drainage Areas	260	672	243	276	401	300
Marshan Lake	6539	25714	12113	9250	6466	1740
Reshanau Lake	229	1159	377	412	490	269
Atmosphere	0	0	0	0	0	0
TOTAL =	7029	27546	12733	9938	7357	2309
SOURCE	***Total Phosphorus Load [lb/growing season]***					
Drainage Areas	198	411	147	187	270	231
Marshan Lake	4003	12069	6348	3919	3796	1342
Reshanau Lake	67	509	171	186	233	122
Atmosphere	20	23	20	20	20	20
Internal Load	4815	4815	4815	5616	4815	4815
TOTAL =	9103	17827	11500	9928	9133	6529
	Model Results					
Model Predicted TP [ug/L]	208	164	185	188	204	238
Observed TP [ug/L]	N/A	N/A	N/A	188	N/A	N/A
Phosphorus Sedimentation [lb]	5131	5520	5089	4839	5049	5038
TOTAL OUTFLOW [lb] =	*3971*	*12307*	*6411*	*5089*	*4084*	*1491*









Baldwin Lake	2001	2002	2003	2004	2005	2006
SOURCE	Precipitation [in]					
Water Year	34.2	42.4	28.4	29.2	32.7	31.6
Growing Season	13.0	25.7	10.9	12.3	18.9	14.8

SOURCE	Inflow Volume [ac-ft/growing season]					
Drainage Areas	253	181	64	74	107	82
Rice Lake	7029	27546	12733	9250	7357	2309
Atmosphere	0	0	0	0	0	0
TOTAL =	7282	27726	12797	9324	7464	2391

SOURCE	Total Phosphorus Load [lb/growing season]					
Drainage Areas	57	113	40	53	77	67
Rice Lake	3971	12307	6411	3919	4084	1491
Atmosphere	10	12	10	10	10	10
Internal Load	2396	2396	2396	4534	2396	2396
TOTAL =	6435	14828	8857	8516	6567	3964

Model Results						
Model Predicted TP [ug/L]	189	154	173	205	189	221
Observed TP [ug/L]	N/A	N/A	N/A	205	N/A	N/A
Phosphorus Sedimentation [lb]	2692	3214	2847	3318	2722	2525
TOTAL OUTFLOW [lb] =	*3743*	*11613*	*6010*	*5198*	*3845*	*1439*