Twin and Ryan Lakes Nutrient TMDL

Prepared for

Shingle Creek Watershed Management Commission

Minnesota Pollution Control Agency

October 2007

Wq-iw8-05e

Twin and Ryan Lakes Nutrient TMDL

Wenck File #1240

Prepared for:

SHINGLE CREEK WATERSHED MANAGEMENT COMMISSION

MINNESOTA POLLUTION CONTROL AGENCY

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October 2007

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APPENDICES

TMDL Summary

Waterbody ID	North Twin Lake 27-0042-01 Middle Twin Lake 27-0042-02 South Twin Lake 27-0042-03 Ryan Lake 27-0058-00	TMDL Page #
Location	Cities of Brooklyn Center, Crystal, Minneapolis, and Robbinsdale in Hennepin County, Minnesota, in the Upper Mississippi River Basin	1-1
303(d) Listing Information	The waterbodies listed above were added to the 303(d) list in 2002 because of excess nutrient concentrations impairing aquatic recreation. This TMDL was prioritized to start in 2003 and be completed by 2005.	2-1
Impairment / TMDL Pollutant(s) of Concern	Nutrients	2-1
Impaired Beneficial Use(s)	Aquatic recreation as set forth in Minnesota Rules 7050.0150	2-1 – 2-2
Applicable Water Quality Standards/ Numeric Targets	Narrative criteria set forth in Minn. R. 7050.0150 (3) and (5) for which the Minnesota Pollution Control Agency has established "numeric translators." For these lakes, the numeric target is total phosphorus concentration of 40 µg/L or less. The State of Minnesota is in the process of revising water quality standards, which would affect the targets for two of these lakes. At such time as those revised standards are adopted by the State, then the numeric targets for total phosphorus concentration will be 40 µg/L for Middle Twin and Ryan Lakes and 60 µg/L for North and South Twin Lakes. The TMDL sets forth load allocations and reductions for both the current and the proposed standards.	2-1 – 2-2
Loading Capacity (expressed as daily load)	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 for wet, dry, and average precipitation years. The loading capacity is set forth in Table 7.2 for the current standards and Table 7.3 for the proposed standards for each of the critical conditions.	7-3 – 7-4

Current Standards: maximum daily total phosphorus load

	Average Year (kg/day)	Wet Year (kg/day)	Dry Year (kg/day)
North Twin	1.4	2.2	1.3
Middle Twin	0.6	0.9	0.5
South Twin	1.6	2.4	1.6
Ryan	0.6	0.9	0.5

TMDL Summary

	Proposed Standards: maximum daily total phosphorus load				
		Average Year (kg/day)	Wet Year (kg/day)	Dry Year (kg/day)	
	North Twin	2.3	3.4	2.1	
	Middle Twin	0.6	0.9	0.5	
	South Twin	2.5	3.7	2.5	
	Ryan	0.6	0.9	0.5	
Wasteload Allocation	**Source**	**Permit #**	**Individual WLA**		
	Permitted Stormwater	MS400006 MS400007 MS400012 MN0061018 MS400039 MS400046 MS400138 MS400170	Wasteload Allocations are Gross Allocations allocated to the permit holders as set forth in Table 7.1. See Tables 7.2 and 7.3 for WLA by lake for each critical condition		7-2 – 7-4
Load Allocation	**Source**	**Individual LA**			
	Atmospheric Load	See Tables 7.2, 7.3, 9.2 and 9.4			7-3–7-4, 9-2 –9-4
	Internal Load	See Tables 7.2, 7.3, 9.2 and 9.4			
Margin of Safety	The margin of safety is implicit in each TMDL due to the conservative assumptions of the model and the proposed iterative nutrient reduction strategy with monitoring.				7-9 – 7-10
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.				7-9
Reasonable Assurance	Reasonable assurance is provided by the cooperative efforts of the Shingle Creek Watershed Commission, a joint powers organization with statutory responsibility to protect and improve water quality in the water resources in the Shingle Creek watershed in which these lakes are located, and by the member cities of this organization. In addition, 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 10
Monitoring	The Shingle Creek Watershed Management Commission periodically monitors these lakes and will continue to do so through the implementation period.				10-4
Implementation	This TMDL sets forth an implementation framework and				Section

	general load reduction strategies that will be expanded and refined through the development of an Implementation Plan.	9
Public Participation	Public Comment period: September 17, 2007 – October 15, 2007 Meeting location: None Comment received: One comment letter received from Minnesota Department of Transportation requesting some corrections.	

Executive Summary

This Total Maximum Daily Load (TMDL) study addresses a nutrient impairment in the Twin Lake chain of lakes. The goal of this TMDL is to quantify the pollutant reductions needed to meet State water quality standards for nutrients in South Twin (27-0042-03), Middle Twin (27-0042-02), North Twin (27-0042-01) and Ryan (27-0058-00). South Twin is more commonly known as Lower Twin and North Twin is more commonly known as Upper Twin.

The Twin Lake chain of lakes is a regional water resource located in Hennepin County, Minnesota, in the Shingle Creek watershed, specifically in the cities of Brooklyn Center, Crystal, Minneapolis, and Robbinsdale. The lakes are highly used recreational water bodies that support fishing and swimming as well as provide aesthetic values. The drainage area to the lake chain is 5,550 acres of fully developed urban and suburban land. The lakes are connected to each other by channels of varying lengths. The lake system discharges into Shingle Creek, which ultimately discharges into the Mississippi River. Water quality in North and South Twin Lakes is considered poor with frequent algal blooms while Ryan and Middle Twin Lakes have more moderately degraded water quality. North and South Twin Lakes do not currently support recreational activities while Ryan and Middle Twin Lakes partially support recreational activities.

Monitoring data in the Twin Lake chain of lakes suggest that the chain is a highly productive system, with the greatest water quality problems occurring in North Twin Lake. North Twin Lake, the uppermost lake in the chain, is a hypereutrophic lake where both internal and watershed loading appear to be significant sources of phosphorous. The majority of phosphorous in Middle Twin Lake is from water coming from North Twin Lake and from the watershed. South Twin Lake is a eutrophic lake where internal loading has the potential to increase algal productivity throughout the season. Ryan Lake, the last lake in the chain, is a deep, mesotrophic lake that has relatively good water quality for an urban lake.

Wasteload and Load Allocations to meet State standards indicate that nutrient load reductions ranging from 0-76 percent would be required to consistently meet standards under average precipitation conditions. North Twin contributes a substantial load downstream to the other lakes, thus improvements to that lake should result in improvement to the lower lakes in the chain. A wetland just upstream of the lake, DNR wetland 639W, was found in previous study to export a significant phosphorus load. Improvements to wetland 639W, internal load management, and reduction of nonpoint sources of phosphorus in the watershed by retrofitting BMPs would have the most impact on reducing phosphorus load and improving water quality in the chain of lakes.

1.0 Introduction

1.1 PURPOSE

This Total Maximum Daily Load (TMDL) study addresses a nutrient impairment in the Twin Lake chain of lakes. The goal of this TMDL is to quantify the pollutant reductions needed to meet State water quality standards for nutrients in North, Middle, and South Twin Lake and Ryan Lake in Hennepin County, Minnesota. This TMDL is required in accordance with section 303(d) of the federal Clean Water Act, because the State of Minnesota has determined waters in these lakes exceed the State established standards for nutrients.

This TMDL provides waste load allocations (WLAs) and load allocations (LAs) for the four lakes in the Twin Lake chain of lakes. Based on the current State narrative standard for nutrients, the TMDL establishes a numeric target of 40 ug/L total phosphorus concentration for all lakes in the North Central Harwood Forest ecoregion. The Minnesota Pollution Control Agency (MPCA) is in the process of considering revisions to the numeric standard to provide an alternate standard for shallow lakes. This TMDL also provides WLAs and LAs based on that proposed revised numeric standard. If the proposed standard is adopted by the State, then these alternate WLAs and LAs will apply.

1.2 PROBLEM IDENTIFICATION

The Twin Lake chain of lakes is a regional water resource located in the Shingle Creek watershed, specifically in the cities of Brooklyn Center, Crystal, Minneapolis and Robbinsdale. Twin Lake is a highly used recreational water body that supports fishing and swimming as well as providing aesthetic values. Water quality in North and South Twin Lake is considered poor (hypereutrophic; average Carlson's Trophic Status (TSI) of 75 and 71 respectively) with frequent algal blooms while Ryan and Middle Twin Lake have more moderately degraded water quality (eutrophic; TSI of 65) but with nuisance algal blooms (>30 µg/L chlorophyll-a). A TSI value less than 57 is generally regarded as suitable water quality for swimming. North and South Twin Lake do not currently support recreational activities while Ryan and Middle Twin Lake partially support recreational activities (based on MPCA guidelines). All three basins of Twin Lake were in 2002 added to the Minnesota Pollution Control Agency's list of impaired waters (303(d) list) for nutrients in and fish consumption advisories (mercury and PCB), while Ryan was listed in 2002 for nutrients only.

2.0 Target Identification and Determination of Endpoints

2.1 IMPAIRED WATERS

The MPCA first included all three basins of the Twin Lake chain of lakes and Ryan Lake on the 303(d) impaired waters list for Minnesota in 2002 (see 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. The project was scheduled to be completed in 2005. Ranking criteria for scheduling TMDL projects include, but are not limited to: impairment impacts on public health and aquatic life; public value of the impaired water resource; likelihood of completing the TMDL in an expedient manner, including a strong base of existing data and restorability of the waterbody; technical capability and willingness locally to assist with the TMDL; and appropriate sequencing of TMDLs within a watershed or basin.

Table 2.1. Impaired waters in the Twin-Ryan Lake chain of lakes.

Lake	DNR Lake #	Listing Year	Affected use	Pollutant or Stressor	Target TMDL Start	Target TMDL Completion
Twin-Middle	27-0042-02	2002	Aquatic recreation	Excess nutrients	2003	2005
Twin-North	27-0042-01	2002	Aquatic recreation	Excess nutrients	2003	2005
Twin-South	27-0042-03	2002	Aquatic recreation	Excess nutrients	2003	2005
Ryan Lake	27-0058-00	2002	Aquatic recreation	Excess nutrients	2003	2005

2.2 MINNESOTA WATER QUALITY STANDARDS AND ENDPOINTS

2.2.1 State of Minnesota Standards

Minnesota's standards for nutrients are narrative criteria that limit the quantity of nutrients which may enter waters. Minnesota's standards (Minnesota Rules 7050.0150(3)) state 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 waterbody is in an impaired condition the MPCA has 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 establish numeric thresholds for phosphorus, chlorophyll-a, and clarity as measured by Secchi depth. Table 2.2 lists the thresholds for listing lakes on the 303(d) list of impaired waters in Minnesota.

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)

2.2.2 Proposed Standards

A water quality standards rules revision is in progress in Minnesota. Since the State's standards are currently narrative and not numeric, the numeric targets in this TMDL must result in the attainment of the narrative water quality standard set forth in the current rules (Minn. Rules 7050.0150(3) and (5)). The MPCA has designed the proposed numeric standards to meet the current applicable narrative water quality standards and designated uses. The translators in Table 2.2 above and the proposed numeric standards are based on the known relationship between phosphorus concentrations and levels of algae growth. The numeric standards indicate the point at which the average lake will experience severe nuisance blooms of algae. The proposed rules would also establish different standards for deep and shallow lakes, taking into account nutrient cycling differences between shallow and deep lakes and resulting in more appropriate standards for Minnesota lakes.

2.2.3 End Points Used in this TMDL

Two sets of end points are evaluated in this TMDL. The numeric target used to list these four lakes was the current numeric translator threshold phosphorus standard for Class 2B waters in the North Central Hardwood Forest ecoregion (40µg/L). However, South Twin and North Twin are shallow lakes and would be subject to the proposed numeric target of 60µg/L once the proposed standards are approved. Therefore, this TMDL assumes that the current water quality standards will apply and will guide the development of an implementation plan and necessary reductions until the proposed standards have been adopted. At such time as the State adopts the proposed standards, this TMDL assumes the proposed standards in Table 2.3 will apply. This TMDL presents load and wasteload allocations and estimated load reductions for both scenarios.

Table 2.3. Target total phosphorus concentration end points used in this TMDL.

	Current TP Standard (µg/L)	Proposed TP Standard (µg/L)
North Twin Lake	40	60
Middle Twin Lake	40	40
South Twin Lake	40	60
Ryan Lake	40	40

2.3 PRE-SETTLEMENT CONDITIONS

Another consideration when evaluating nutrient loads to lakes is the natural background load. Ultimately, the background load represents the load the lake would be expected to receive under natural, undisturbed conditions. This load can be determined using ecoregion pre-settlement nutrient concentrations as determined by diatom fossil reconstruction. Diatom inferred total phosphorus concentrations are presented in Table 2.4.

Table 2.4. Pre-settlement total phosphorus concentrations based on water quality reconstructions from fossil diatoms (MPCA 2002). All are the concentration at the 75th percentile.

	Ecoregions			
	North Central Hardwood Forest		**Western Corn Belt Plains**	
Parameter	**Shallow[1]**	**Deep**	**Shallow[1]**	**Deep**
Phosphorus concentration (µg/L)	47	26	89	56

[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).

Based on the diatom fossils, pre-settlement concentrations were approximately 26 µg/L for deep lakes in the North Central Hardwood Forests ecoregion.

Another benchmark that may be useful in determining goals and load reductions are expected stream concentrations under natural or undisturbed conditions. Table 2.5 provides data from minimally impacted streams in the North Central Hardwood Forest ecoregion.

Table 2.5. Iinterquartile range of summer mean concentrations by ecoregion for minimally impacted streams in Minnesota (McCollor and Heiskary 1993).

Region	**Total Phosphorus (µg/L)**		
	25th Percentile	**50th Percentile**	**75th Percentile**
North Central Hardwood Forest	70	100	170

To achieve the predicted background load, average in stream concentrations would need to be approximately 30 to 40 µg/L, significantly lower than the low end of the interquartile range (70 µg/L).

3.0 Watershed and Lake Characterization

3.1 LAKE AND WATERSHED DESCRIPTION

The three basins of Twin Lake and Ryan Lake are located in the northwestern suburban Twin Cities metropolitan area. The cities of Brooklyn Center, Crystal, Minneapolis and Robbinsdale immediately abut the lakes, while the drainage area includes portions of those cities plus portions of Brooklyn Park and New Hope (see Figure 3.1 and 3.2). The tributary area is about 5,550 acres, or about 19.5 percent of the Shingle Creek watershed. The Twin and Ryan Lake watersheds are fully developed, with a 2000 Census population of about 50,500. The chain discharges to Shingle Creek and ultimately to the Mississippi River.

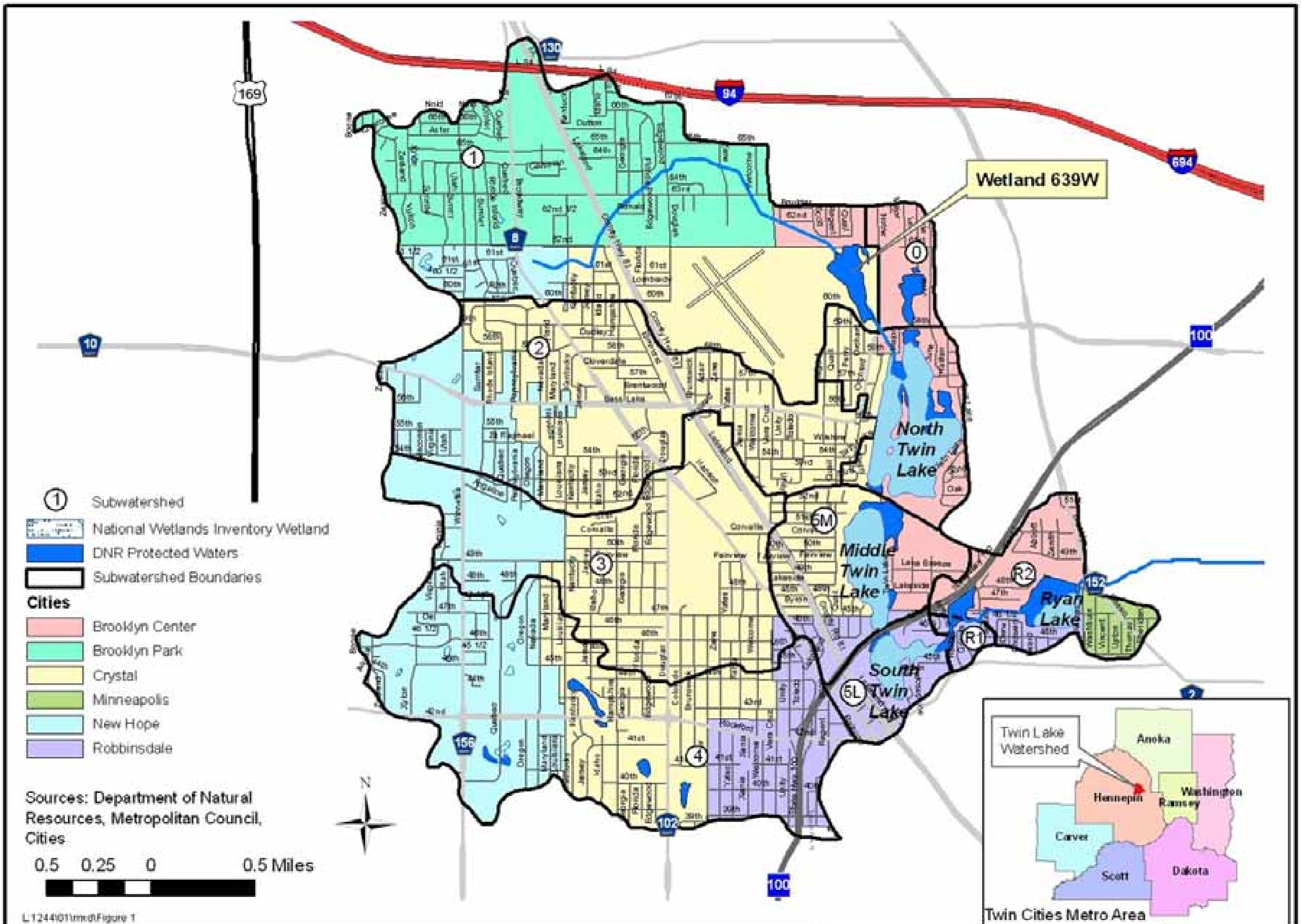
Protected waters within the Twin and Ryan Lake watersheds are presented in Table 3.1.

Table 3.1. DNR protected waters in the Twin-Ryan Lakes watershed.

Waterbody	DNR Number
North Twin	42-01P
Middle Twin	42-02P
South Twin	42-03P
Ryan Lake	27-58P
Wetland 639W	639W
Memory Lane Pond	641W
Hagermeister Pond	642W
Gaulke Pond	643W
Wetland 528W	528W

3.1.1 North Twin Lake

North Twin Lake is the northernmost and highest basin in the chain. It is known locally as Upper Twin Lake. It has a surface area of 118 acres and average depth of 3.8 feet. North Twin Lake is shallow, with a maximum depth of 10 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.



TWIN AND RYAN LAKES NUTRIENT TMDL

Municipal and Street Location Map

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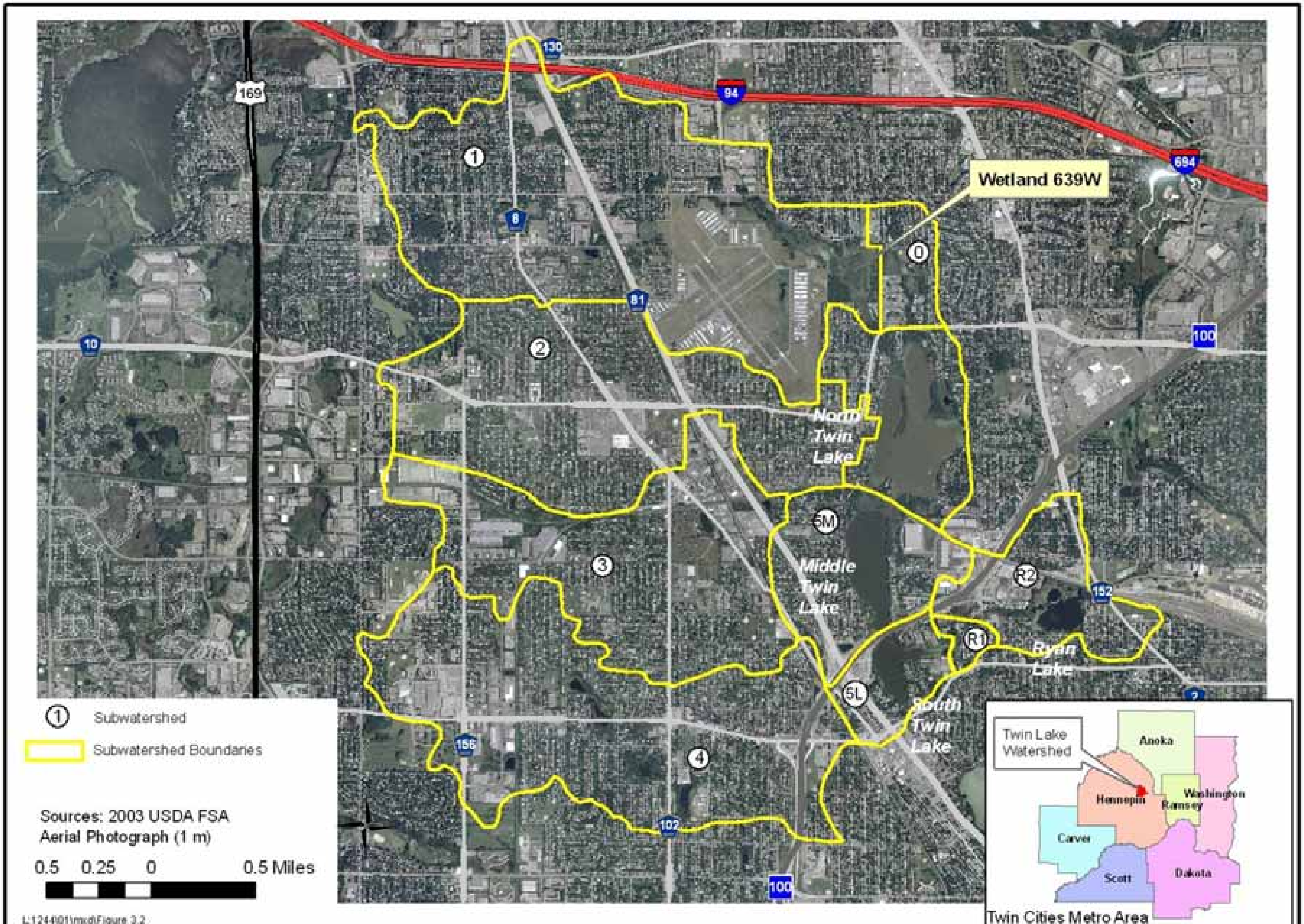
Figure 3.1



TWIN AND RYAN LAKES NUTRIENT TMDL

Watershed Aerial Map

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Figure 3.2

Table 3.2. Lake characteristics of the Twin-Ryan Lakes chain of lakes.

Parameter	North Twin Lake	Middle Twin Lake	South Twin Lake	Ryan Lake
Surface Area (ac)	118	54	30	15
Average Depth (ft)	3.8	14.5	6.9	15
Maximum Depth (ft)	10	42	21	36
Volume (ac-ft)	448	786	208	235
Residence Time (years)	0.28	0.43	0.10	0.06
Littoral Area (ac)	118	31.6	25.4	10
Watershed (ac) (cumulative)	3,657	354 (4,011)	1,248 (5,259)	291 (5,550)

North Twin Lake receives stormwater runoff from a 3,657 acre, fully developed urban watershed. The contributing area is primarily to the west, and extends nearly to Boone Avenue in New Hope to the west; just short of I-94/694 to the north; and as far south as 49th Avenue in New Hope and 44th Avenue in Crystal. The contributing area to the east extends only a few blocks to the east of the lake in Brooklyn Center. Subwatersheds are outlined in Figure 3.2.

Stormwater is conveyed mostly through a network of storm sewers, although there are some ponds and channels. The area was developed prior to implementation of regulations requiring stormwater treatment, so there is little pretreatment of runoff. Subwatershed 1 drains to Wetland 693W, which outlets by channel at the north end of North Twin. The small Subwatershed 0 also outlets by a channel at the north end of the lake. Subwatershed 2 is collected in a trunk storm sewer that is discharged through a 72” pipe outletting into the lake on the west. Subwatershed 3 is collected in a trunk storm sewer that is discharged through an 84” pipe that outlets into the lake into the southwest corner of the lake. Stormwater is also discharged into the lake from several smaller local storm sewers as well as overland flow.

North Twin Lake outlets to Middle Twin Lake through a channel that is periodically dredged to maintain clearance under the CP Rail bridge that crosses the channel.

3.1.2 Middle Twin Lake

Middle Twin Lake has a surface area of 54 acres and an average depth of 14.5 feet. It is the deepest of the three basins, with a maximum depth of 42 feet. Approximately 59 percent of the lake area is littoral.

The lake receives direct stormwater runoff from a 4,011 acre, fully developed urban watershed. The direct contributing area is relatively small. Subwatershed 5M extends to TH 100 to the south; the CP Rail tracks to the north and east; and approximately Broadway Avenue to the west (Figure 3.4). Stormwater is conveyed primarily through local storm sewers and overland runoff. Because of its direct connection by channel to North Twin Lake, Middle Twin Lake is directly influenced by flow from that lake and indirectly influenced by North Twin Lake’s watershed.

Prior to construction of Lilac Way, now known as TH 100, Middle and South Twin Lakes were considered a single lake, with two larger basins connected by a narrower throat. Construction of TH 100 resulted in partial filling at that throat to facilitate construction of the Twin Lake Narrows bridge. Today Middle Twin Lake outlets to South Twin Lake through the Narrows.

3.1.3 South Twin Lake

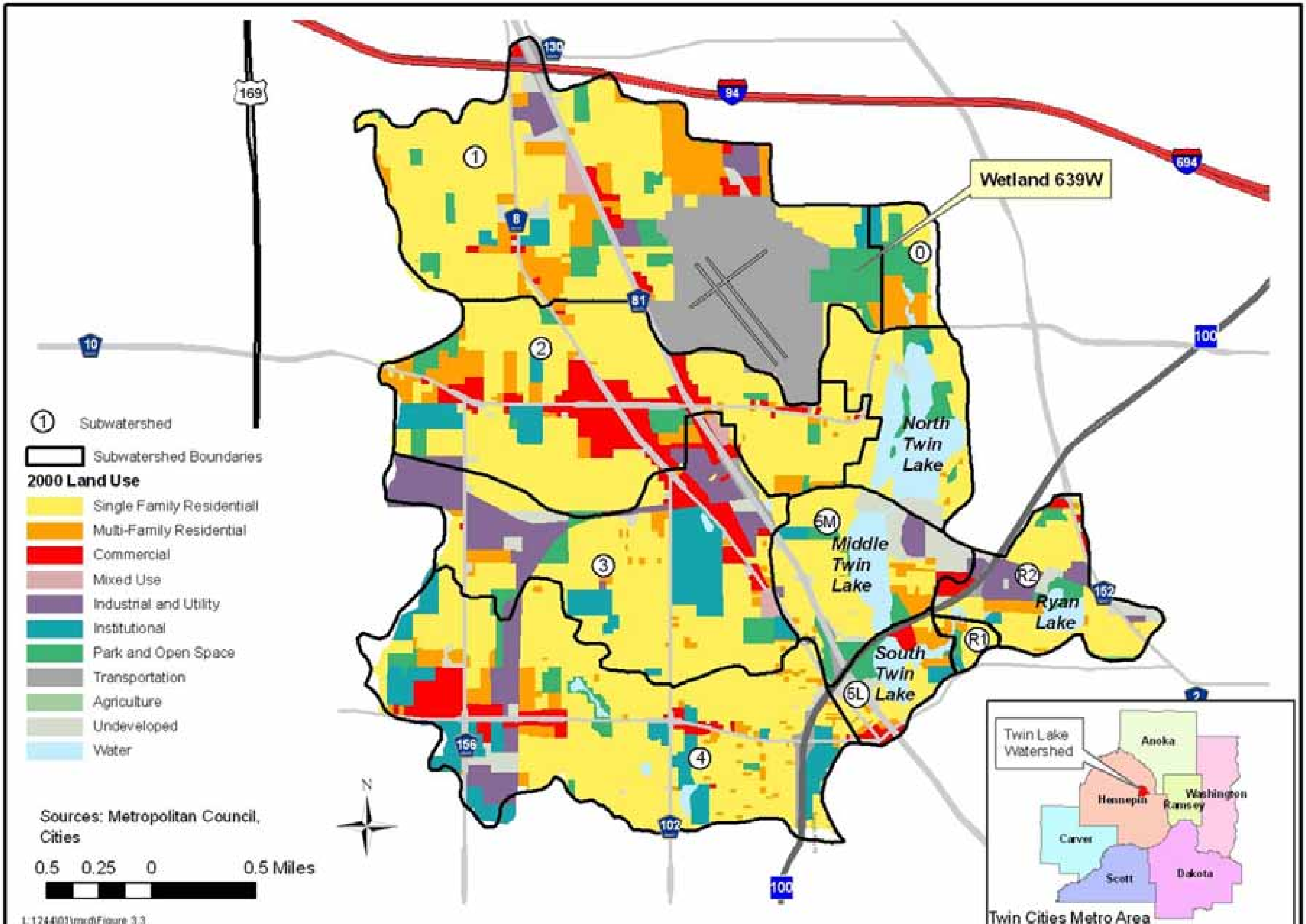
South Twin Lake has a surface area of 30 acres and an average depth of 6.9 feet. It is known locally as Lower Twin Lake. Its maximum depth is 21 feet and it is 85 percent littoral.

The lake receives direct stormwater runoff from a 5,259 acre, fully developed urban watershed. The direct contributing area includes subwatersheds 4 and 5L shown on Figure 3.2. Subwatershed 4 extends to about Boone Avenue to the west; 39th Avenue to the south; and as 49th Avenue in New Hope and 44th Avenue in Crystal and Robbinsdale to the north. Subwatershed 5L includes the area immediately adjacent to the lake in Robbinsdale, between TH 100 to the north and Lake Drive to the south. Stormwater in Subwatershed 4 is collected in trunk storm sewers that are routed through a series of natural ponds – Memory Lane, Brownwood, Hagemeister, and Gaulke. Gaulke Pond is pumped to a storm sewer as necessary to prevent overflow, and that storm sewer discharges to the TH 100 storm sewer system that flows north and is discharged to South Twin Lake.

Subwatershed 5L includes local storm sewer and overland flow as well as discharge from TH 100 and CSAH 81. Mn/DOT has a small amount of water that goes to South Twin after first going through Boat Ramp Pond. Because of its direct connection to North and Middle Twin Lake, South Twin Lake is directly influenced by flow from those lakes. South Twin Lake outlets to the east through Ryan Creek and wetland 640W to Ryan Lake.

3.1.4 Ryan Lake

Ryan Lake is a small, deep lake that receives direct runoff from a developed 291-acre watershed. Ryan Lake also receives runoff from South Twin Lake through a channel (Ryan Creek) when the elevation of South Twin exceeds a weir elevation at France Avenue, mainly in the spring and after large rain events. The lake surface area covers 15 acres with a maximum depth of 36 feet. Ryan Lake has a 15-acre littoral area that is mostly quite shallow except for a deeper pool in the southern part of the lake. The watershed is predominantly single family residential. Ryan Lake outlets through a pipe and open channel system to Shingle Creek.



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2000 Land Use

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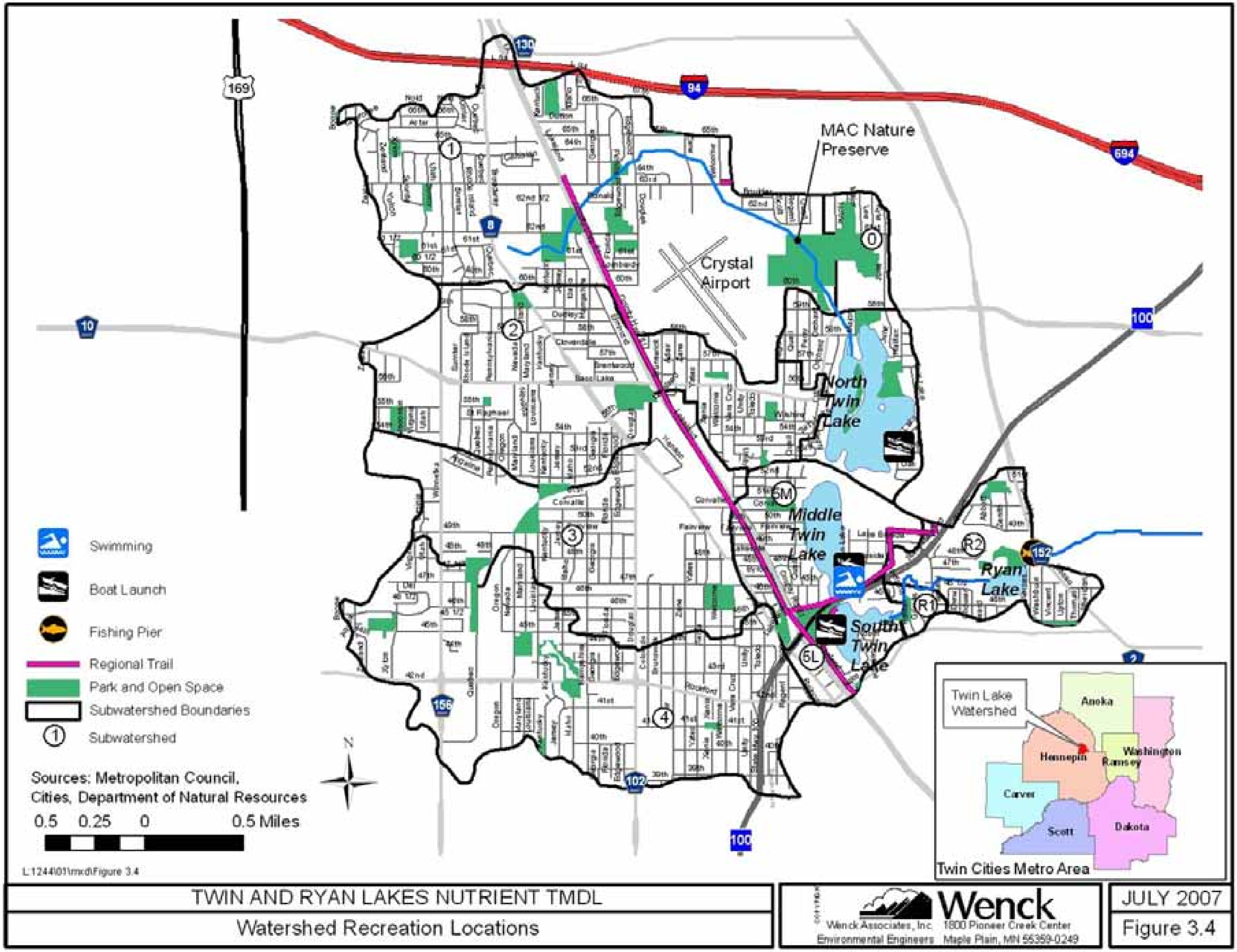
Figure 3.3



MAC Nature Preserve
Crystal Airport
North Twin Lake
Middle Twin Lake
South Twin Lake
Ryan Lake
Swimming
Boat Launch
Fishing Pier
Regional Trail
Park and Open Space
Subwatershed Boundaries
Subwatershed
Sources: Metropolitan Council, Cities, Department of Natural Resources
0.5 0.25 0 0.5 Miles
L:1244\01\mxd\Figure 3.4
Twin Lake Watershed
Anoka
Hennepin
Washington
Ramsey
Carver
Scott
Dakota
Twin Cities Metro Area
TWIN AND RYAN LAKES NUTRIENT TMDL
Watershed Recreation Locations
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Figure 3.4

3.2 LAND USE

The 2000 land use data are presented in Table 3.3 and Figure 3.3. Land use in the Twin Lake watershed is dominated by single and multifamily residential use (59%). Crystal Airport comprises about 7% of the watershed and drains into DNR wetland 639W.

Table 3.3. 2000 land use in the Twin-Ryan Lakes watershed by subwatershed. Area in acres.

Sub-Watershed ID	Single Family Residential	Multi Family Residential	Comm-ercial	Industrial and Utility	Public Semi-Public	Airport	Parks & Recre-ation	Vacant/ Agri-cultural	Major Highway	Water	Total Area
0	30	27	0	0	9	0	32	0.1	0	3	102
1	620	167	32	54	21	374	115	24	17	0	1,423
2	605	91	148	10	48	7	51	7	0	0	967
3	394	36	60	167	102	0	31	24	16	3	833
4	659	73	78	62	151	0	35	23	25	11	1,115
5-south	41	18	16	0	6	0	12	11	9	33	146
5-middle	158	20	4	16	6	0	27	51	13	57	352
5-north	154	3	0	0	2	0.6	25	16	0	120	321
Ryan	153	22	4	34	7		25	15	9	24	291
Total area	2,814	457	342	343	352	382	353	171	89	251	5,550
Percent of watershed	51%	8%	6%	6%	6%	7%	6%	3%	2%	5%	N/A

3.3 RECREATIONAL USES

Recreational features in the Twin Lake watershed are presented in Figure 3.4.

Parks and Open Space

Parks and open space facilities are located throughout the watershed, including multiple parks adjacent to the three basins. Parks immediately adjacent to the three basins are:

North Twin Lake:
- No parks
- Extensive open space

Middle Twin Lake:
- Twin Lake Park (Brooklyn Center)
- Twin Lake Shores (Crystal)

South Twin Lake:
- Lions Park (Robbinsdale)
- Hubert H. Humphrey Park (Robbinsdale)

Ryan Lake:
- Open space
- Fishing pier

Significant parks and open space in the watershed include:

- MAC Park Preserve (Brooklyn Center and Crystal)
- Arboretum/Kylawn Park (Brooklyn Center
- Crystal Airport (Crystal)
- Glen Havens Memorial Gardens (Crystal)
- Becker Park (Crystal)
- New Hope Village Green Golf Course (New Hope)
- North Lions Park (Crystal)
- John Grogan Park/Crystal Community Center (Crystal)
- Bethel and Herzl Cemeteries (Crystal)
- Memory Lane/Brownwood Park (Crystal)

Numerous other neighborhood parks as well as school and public building grounds and open space are featured in the watershed.

Trails

Each city within the watershed maintains a system of pedestrian/bicycle trails. Two regional corridor trails are in development, to be constructed with CSAH 81 and TH 100 improvement projects. These include:

- The Brooklyn Center/Robbinsdale Corridor Trail connecting North Mississippi Regional Park to the Crystal/Robbinsdale Corridor Trail, through Brooklyn Center and Twin Lake Park, across Twin Lake at TH 100.
- The Crystal/Robbinsdale Corridor Trail connecting Robbinsdale and Crystal along CSAH 81 to Minneapolis' Grand Round.

Boat Launches

There are three boat launches on Twin Lake including one on each of the basins (North, Middle, and South Twin Lakes). A parking lot is available at the South Twin boat launch, but no off street parking is provided for the Middle and North boat launches. Boating and personal watercraft are popular activities. A water ski club has operated on Twin Lake in the past. Canoe launching is possible from the Ryan Lake fishing pier.

Swimming and Fishing

A beach is available on Middle Twin Lake at Twin Lake Park. However, this beach is not maintained or operated as a swimming beach by the City of Brooklyn Center. The beach can be heavily used during hot summer days and weekends, with anywhere from 30 to 50 people in the beach area (Jim Glasoe, pers. comm.). Wading and some swimming have been available on South Twin at Lions Park in the past, but most of that park has been reclaimed by Mn/DOT for construction of the CSAH 81/TH 100 interchange. Shoreline fishing areas are popular on South Twin Lake in Robbinsdale.

3.4 WATER CONDITION

3.4.1 Introduction

Water quality in Minnesota lakes is often evaluated using three associated parameters: total phosphorus, chlorophyll-a, and Secchi depth. Total phosphorus is typically the limiting nutrient in Minnesota's lakes meaning that algal growth will increase with increases in phosphorus. There are cases where phosphorus is widely abundant and the lake becomes limited by nitrogen availability. 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 simple measurement, it is often used to evaluate algal abundance rather than expensive cell counts. Secchi depth is a physical measurement of water clarity by lowering a black and white disk 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.

3.4.2 Current Water Quality

Summer mean total phosphorus concentrations are presented in Figure 3.5. Summer mean total phosphorus concentrations are highest in North and South Twin Lakes, which are also the two shallow lakes in the chain.

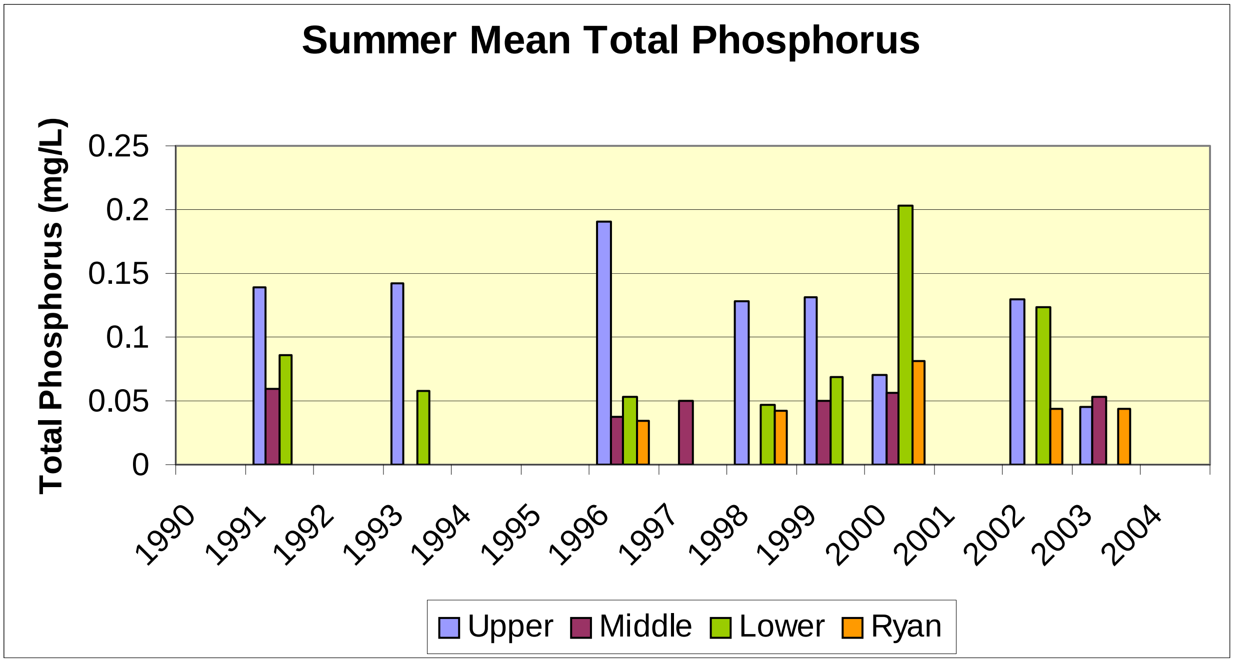


Figure 3.5. Summer (June 1 –September 30) Mean Total Phosphorus Concentrations for the Chain of Lakes.

Chlorophyll-a data for the chain is presented in Figure 3.6. Data for chlorophyll-a is limited in all four of the lakes. Chlorophyll-a concentrations on the shallow lakes were significantly higher than the deeper lakes, with extremely high summer averages in 2002. 2002 was an extremely wet year with almost 45 inches of precipitation monitored at the New Hope monitoring station.

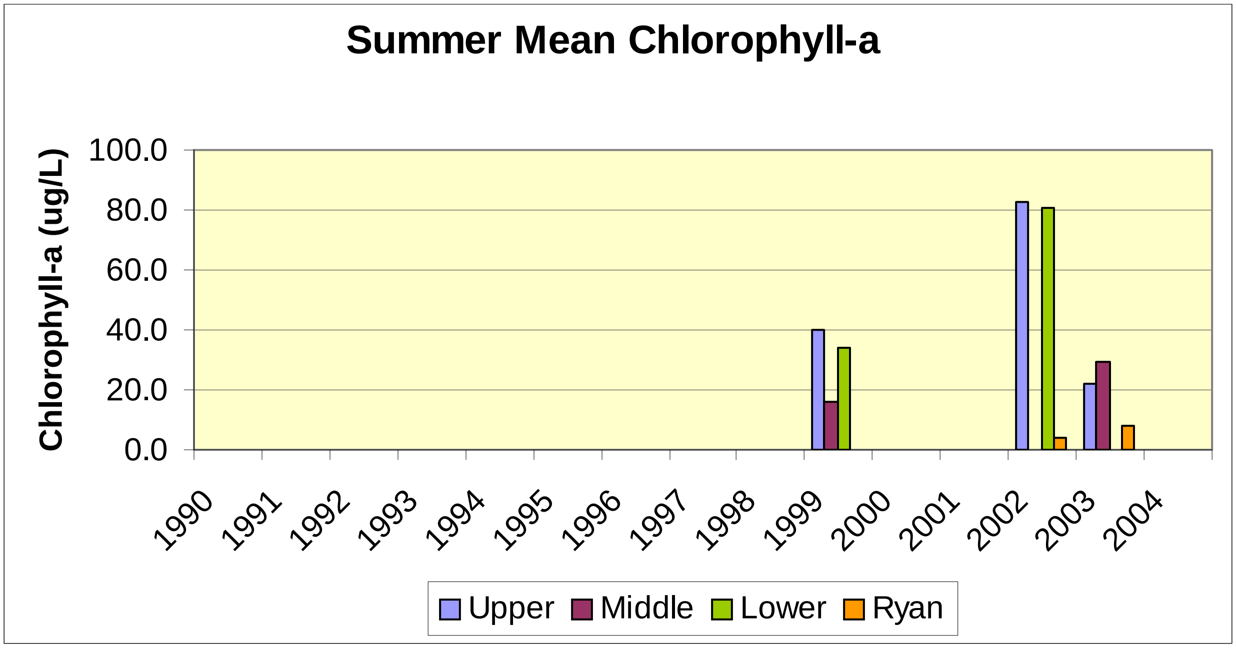


Figure 3.6. Summer (June 1 –September 30) Mean Chlorophyll-a Concentrations for the Chain of Lakes.

Summer mean Secchi depth is presented in Figure 3.7. Again, the shallow lakes had the shallowest Secchi depth.

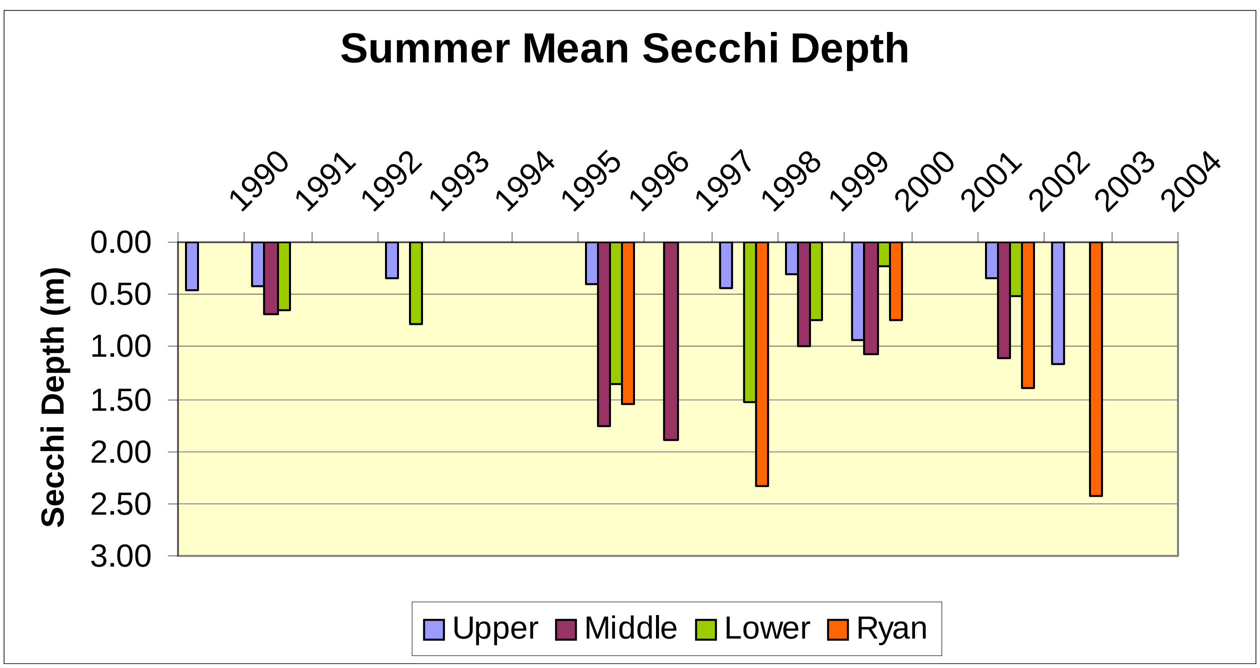


Figure 3.7. Summer (June 1 –September 30) Mean Secchi Depth (Meters) for the Chain of Lakes.

3.4.3 Trend Analysis

Available water quality data for the Twin Lake chain of lakes was extracted from the Storet database. This data was combined with the 1999 and 2002 data and analyzed for possible trends. Although trends can appear on plots of data over time, there are many factors that can cause a false trend to appear. To test for the statistical significance of these trends, a Kendall-Tau nonparametric test was applied to the annual summer data. Pseudoreplication can occur as a result of significant relationships between the parameter of concern and season. To avoid this issue, we only used summer data for the trend analysis. There were no significant trends in any of the lakes.

3.5 FISH POPULATIONS AND FISH HEALTH

3.5.1 Fish Populations

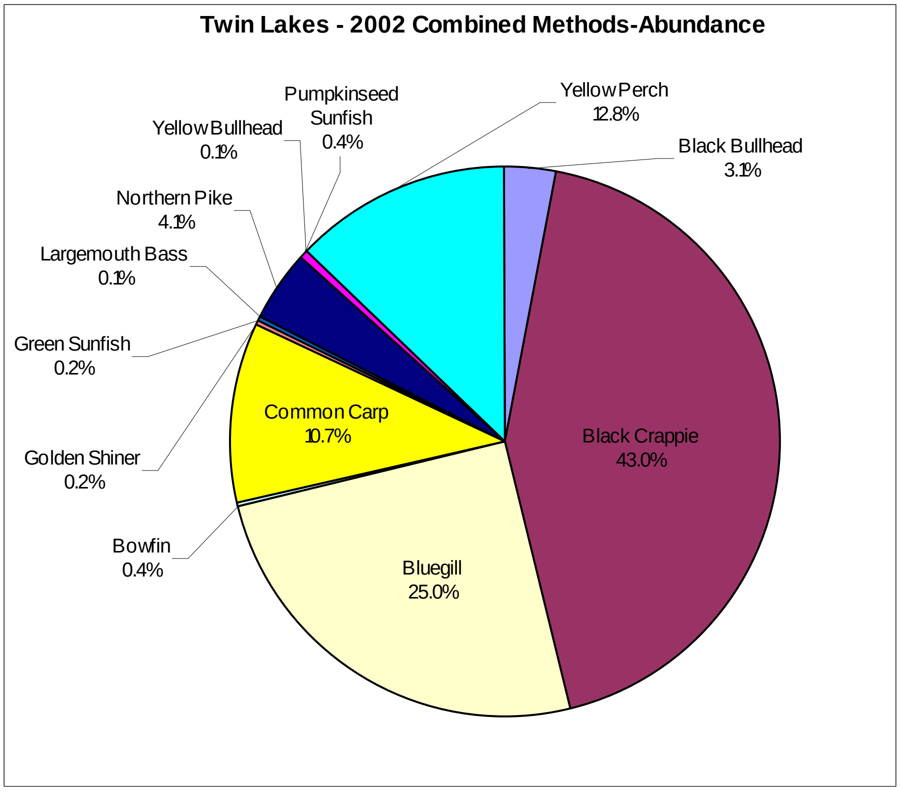
Results from a 1995 DNR fish survey indicated that panfish were very abundant with black crappie and bluegill abundance above average but small in size. Northern pike were average in size and abundance. Largemouth bass abundance was above average but individuals were small in size and growth was slow. Twin Lake was stocked with walleye, northern pike, bass, and crappie starting in 1908, but has not been stocked since 1976.

The Minnesota DNR conducted a more recent fish survey in 2002. Fish species captured during the survey include:

- Black Bullhead
- Black Crappie
- Common Carp
- Green Sunfish
- Northern Pike
- Yellow Perch
- Bowfin (Dogfish)
- Golden Shiner
- Largemouth Bass
- Pumpkinseed Sunfish
- Yellow Bullhead

Black crappie and bluegill are the most abundant panfish in the lake although they tend to be small in size (Figure 3.8). The most abundant predator species are Northern Pike with catch rates high over the last 20 years. Of the northern pike caught during the surveys, 44% were greater than 24 inches in length.

The Ryan Lake fishery is dominated by bluegill and crappie with a significant bullhead population (Figure 3.9). Carp were not very abundant in Ryan Lake. Ryan Lake also has an above average number of northern pike. Overall the Ryan Lake fishery appears to be healthy and offers an abundance of fish species, which is uncommon in the Metro area.



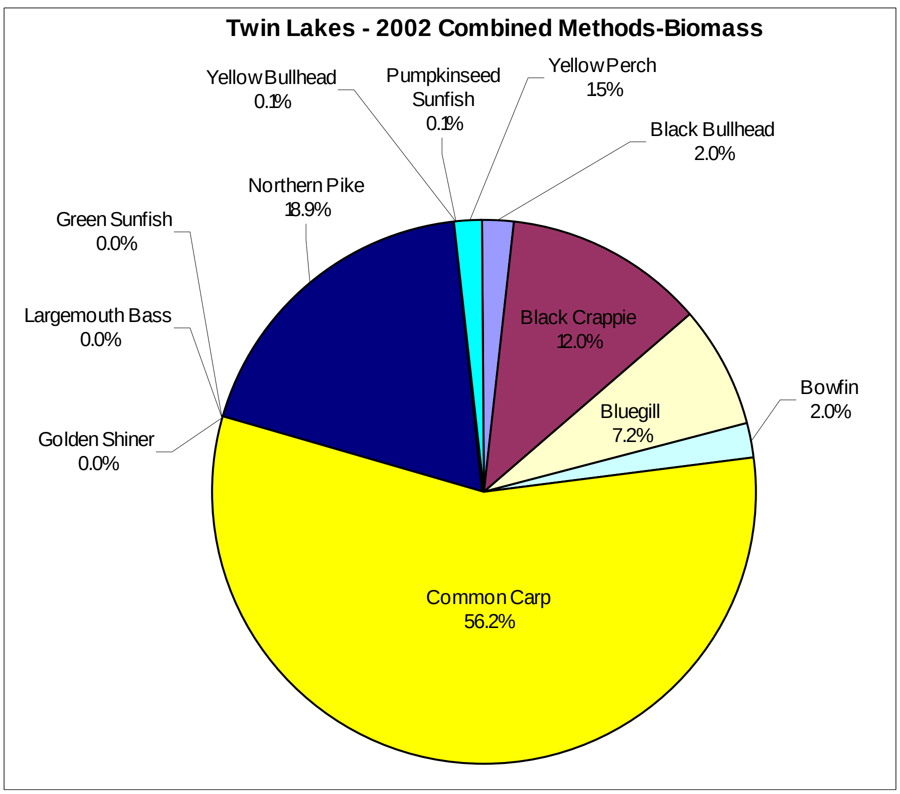
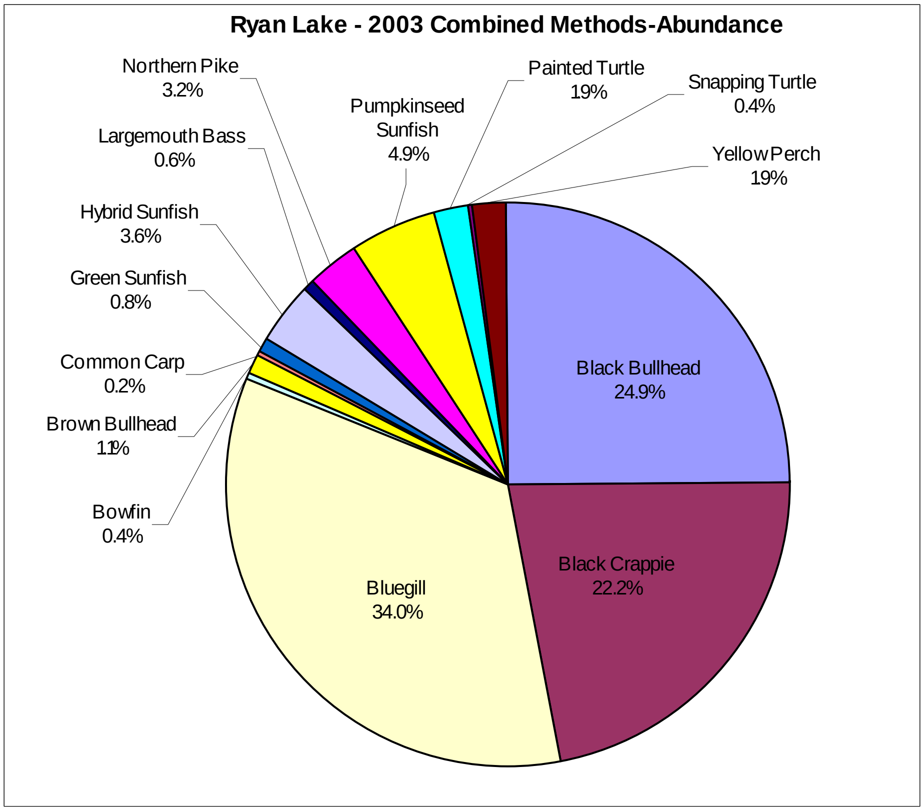


Figure 3.8. Fish Abundance and Biomass for the Twin Lake Chain of Lakes.

The survey was conducted in 2002 and includes all three basins.



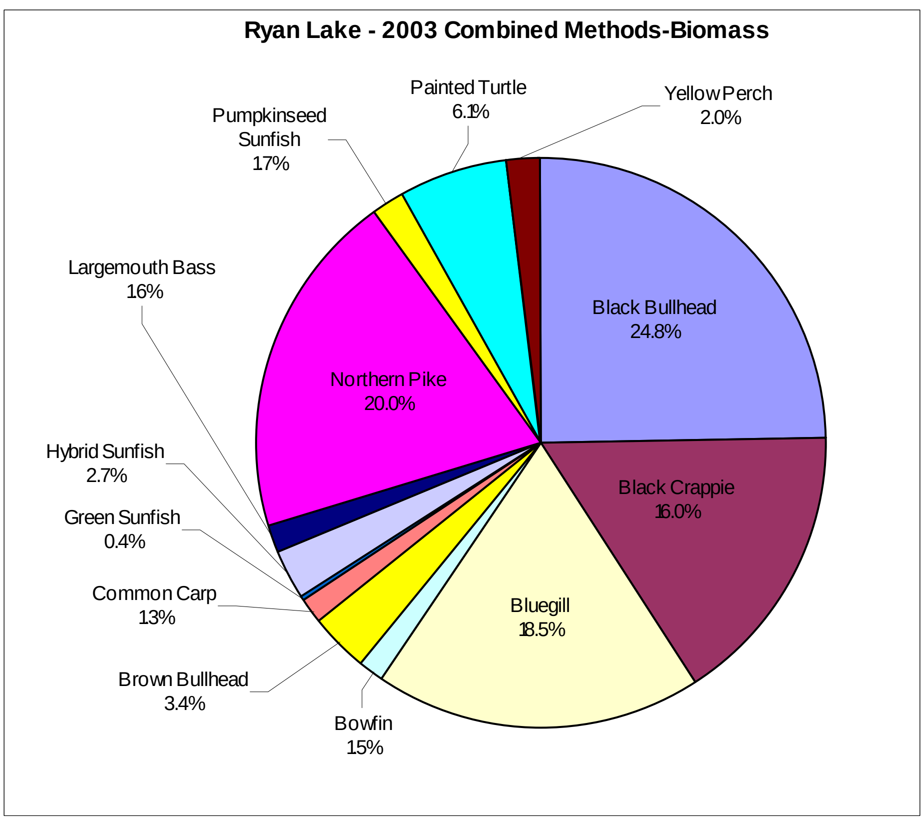


Figure 3.9. Fish Abundance and Biomass for Ryan Lake

3.5.2 Fish Kills

Fish kills occur when dissolved oxygen levels are so low that fish begin to die from the lack of oxygen. Fish kills 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 by bacteria demands oxygen, which depletes dissolved oxygen (D.O.) in the water column. These conditions can result in a summer fish kill. Winter fish kills are the result of snow-covered ice that shades out photosynthesis under the ice. These conditions, coupled with a high sediment oxygen demand can deplete the D.O. under the ice and result in a fish kill.

All three basins of Twin Lake have the potential for a fish kill. A massive winter fish kill was reported by the DNR in 1950 although dissolved oxygen conditions were ruled out as the cause. The lakes have experienced numerous fish kills over the years according to a Shingle Creek report on existing water quality data for Twin Lake. North Twin Lake is highly productive, that is the concentrations of nutrients results in efficient growth of organic matter, and changes in the macrophyte cover could lead to summer kills. A small winter fish kill was observed during the winter of 2003-04 (Todd Blomstrom pers. comm.) Middle Twin Lake has a very large hypolimnion and seriously depletes oxygen in the water column when fall turnover occurs.

3.5.3 Carp

Common carp have both direct and indirect effects on aquatic environments. Carp uproot aquatic macrophytes during feeding and spawning, and re-suspend bottom sediments and nutrients. These activities can lead to increased nutrients in the water column, ultimately resulting in increased nuisance algal blooms. The carp population is rather large - 10 times the upper 10th percentile for regional lakes (DNR 2002). Especially in very shallow lakes such as North Twin Lake, this can be a significant source of phosphorus and is part of the internal load, or phosphorus from sources already in the lake. Carp management will be a key factor in managing nutrient levels in Twin Lake.

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 recreation activities such as boating and swimming as well as aesthetic appreciation. Excess nutrients in lakes can lead to aquatic weeds and exotics to taking over a lake. Some exotics can lead to special problems in lakes. For example, Eurasian water milfoil can reduce plant biodiversity in a lake because it grows in great densities and squeezes all the other plants out. 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 phosphorous loading. All in all, 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 warmwater fishes (e.g., bass, walleye, and panfish).

North Twin Lake is considered completely littoral with the entire less than 15 feet in depth. Consequently, the lake has the potential to be entirely covered with aquatic plants. Currently algal production is very high which limits the growth of aquatic macrophytes by shading out the bottom sediments. As water clarity improves, it is likely that aquatic plants will begin to invade the entire lake. Management strategies for North Twin Lake must take this into account when developing strategies and goals.

Middle and South Twin Lakes are also fairly shallow with 50 to 85% of the surface area considered to be littoral. Management activities must balance the desired lake uses with the aquatic macrophyte community. All of the basins in the Twin Lakes chain of lakes have the potential to carry quite large aquatic macrophyte communities.

3.6.3 Aquatic Plants in Twin Lake

Very little information exists on the aquatic plant community in Twin Lake. A map of aquatic plants (created in 1993) was provided in Brooklyn Center's 1997 Water Management Plan (Figure 3.10). Species found in North Twin Lake include water lily, yellow water lily, cattail, and curly leaf pondweed. No information was available for Middle or South Twin Lake, however they have the potential for large aquatic macrophyte communities. Visual observations in 2003 found these communities to be fairly small and located in the shallower shoreline areas. An aquatic plant survey is needed for North, Middle, and South Twin Lake.

3.6.4 Curly-Leaf Pondweed

Curly-leaf pondweed (*Potamogeton crispus)* is an exotic similar to Eurasian Water Milfoil in that it can easily take over a lake's aquatic macrophyte community. Curly-leaf pondweed provides a unique problem in that it is believed to significantly affect the in-lake production of phosphorous, contributing to the eutrophication problem. Curly-leaf pondweed grows under the ice, but dies back relatively early, releasing nutrients to the water column in summer possibly leading to algal blooms. Curly-leaf pondweed can also out-compete more desirable native plant species.

Curly-leaf pondweed was found in North Twin Lake according to the data provided in the City of Brooklyn Center's Water Management Plan. Consequently, it is likely that it exists in both the Middle and South basins of Twin Lake.

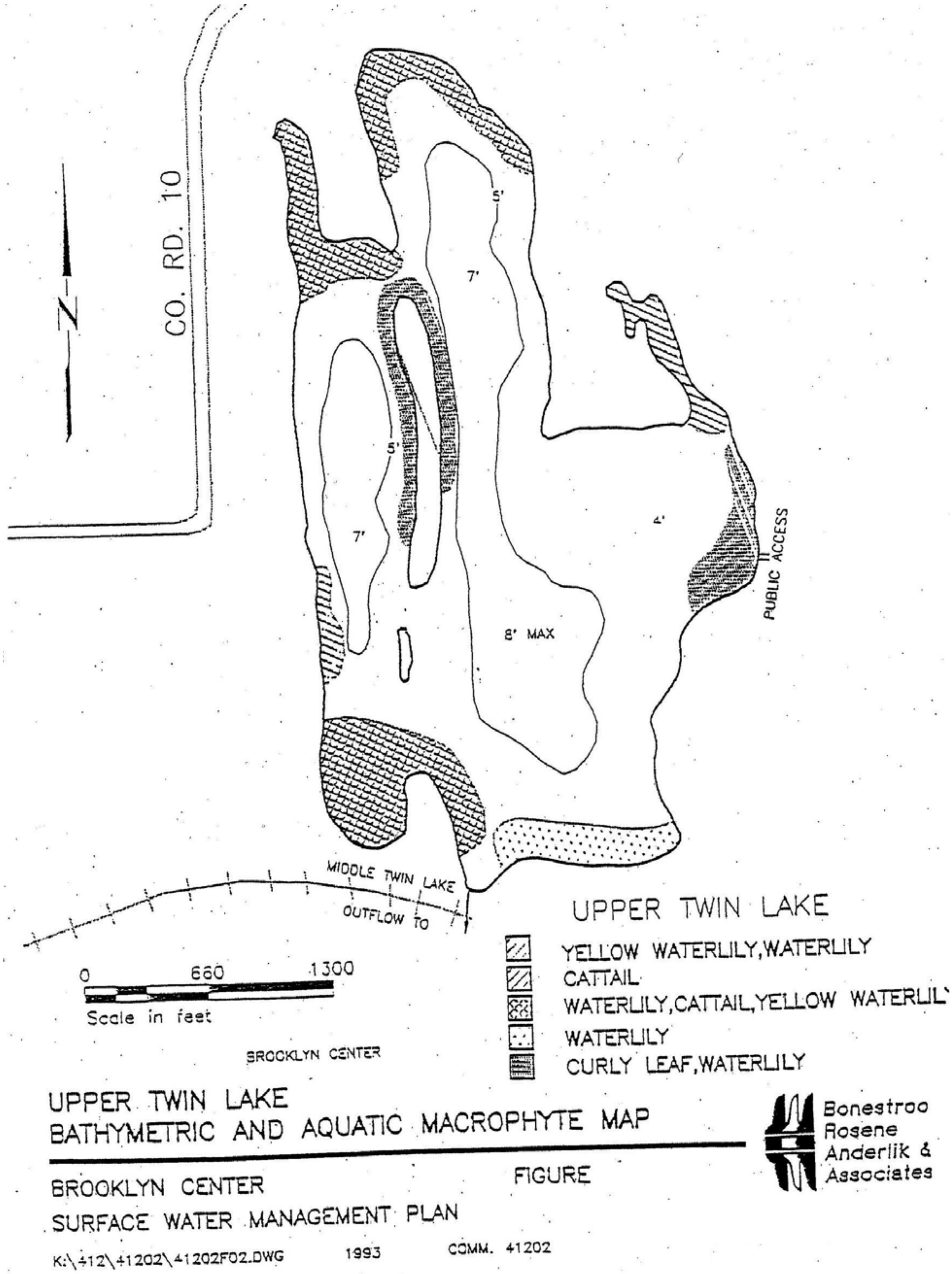


Figure 3.10. Aquatic Plants taken from Brooklyn Center's 1997 Water Management Plan

3.7 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.

Shoreline conditions were identified and mapped in 1993 by the Shingle Creek Watershed Management Commission (Figure 3.11). The shoreline reconnaissance was conducted by Twin Lake Association volunteers and classified shoreline conditions as natural vegetation, lawn, sandy shore, retaining walls and eroding areas. Although some of these features may have changed, there were numerous eroding areas particularly in shorelines where a grass lawn was maintained to the lakes edge.

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. Identifying projects where natural shoreline habits can be restored or protected will enhance the overall lake ecosystem.

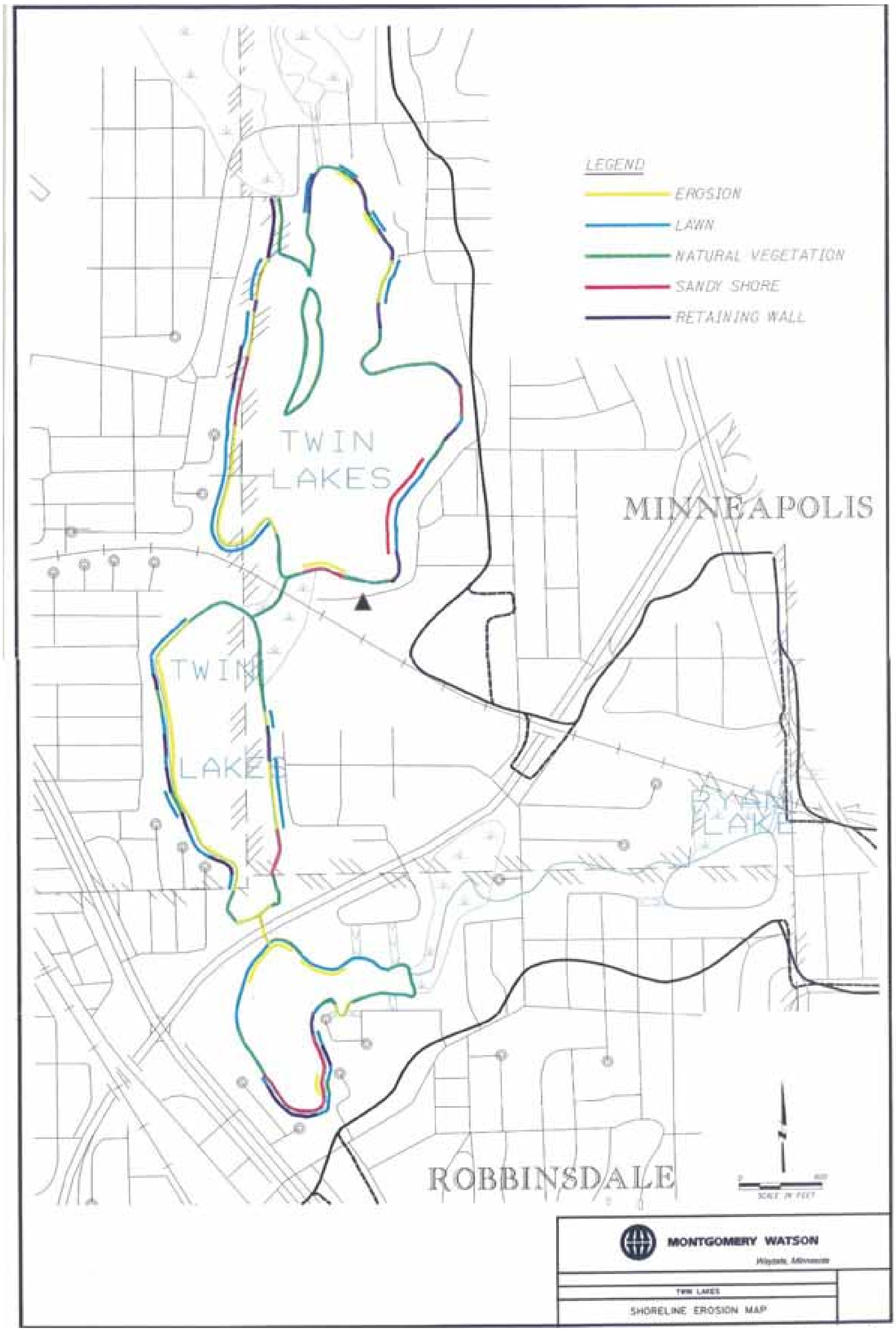


Figure 3.11. Twin Lake Shoreline Erosion Map

4.0 Nutrient Source Assessment

4.1 INTRODUCTION

Understanding the sources of nutrients to the lakes is a key component to developing the TMDL for the Twin Lake chain of lakes. In this section, we provide a brief description of the potential sources of phosphorus to the lakes. A detailed nutrient budget was developed for the Twin Lakes chain of lakes in Chapter 5.

4.2 POINT SOURCES

There are few point sources in the Shingle Creek watershed. There are no wastewater treatment plant effluent discharges in the watershed. NPDES permits regulating industrial water discharges in the Twin Lake watershed are listed in Table 4.1. This permit regulates the discharge of non-contact cooling water and requires the operator to monitor volume, temperature, and pH of discharge (Belinda Nicholas, MPCA pers. comm.). It is unlikely that this discharge is a phosphorus source and therefore it has not been included in the TMDL equation and wasteload allocations. If in the future it is determined that this discharge is a phosphorus source, then this discharger will be assigned a wasteload allocation.

Table 4.1. NPDES Industrial Discharge Permits in the Twin-Ryan Lakes watershed.

NPDES ID	Facility Name	Address	SIC Description
MNG250048	Robinson Rubber Products Co Inc	4600 Quebec Ave N New Hope	Fabricated Rubber Products

Source: Minnesota Pollution Control Agency.

In addition to this industrial NPDES permit in the watershed, NPDES Phase II permits for small municipal separate storm sewer systems (MS4) have been issued to the member cities in the watershed as well as Hennepin County and Mn/DOT. The City of Minneapolis has an individual NPDES permit for stormwater. The MS4 cities, Hennepin County and MnDOT Metro District, are covered under the Phase II General NPDES Stormwater Permit – MNR040000. Not all the MS4s in the Shingle Creek watershed drain to the Twin Lake chain. The unique permit numbers assigned to Hennepin County, MnDOT Metro District, and the cities that drain to the Twin Lake chain, are as follows:

- Brooklyn Center – MS400006
- Brooklyn Park – MS400007
- Crystal – MS400012
- Minneapolis – MN0061018
- New Hope – MS400039
- Robbinsdale – MS400046
- Hennepin County – MS400138
- MnDOT Metro District – MS400170

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 are combined in this TMDL as Gross Wasteload Allocations (see Table 7.1). The Load Allocation is allocated in the same manner including atmospheric deposition, internal loading, and additional loading from the degraded wetland complex (639w) as a gross load. The relative proportions of these sources are presented in Section 9 of this report.   Each permittee has agreed to implement BMPs to the maximum extent practicable.   This collective approach allows for greater reductions for permit holders with more opportunities and less for those with greater constraints. The collective approach is to be outlined in an implementation plan.

The following MS4s, while located in the Shingle Creek watershed, do not drain to the Twin Lake chain, and thus are not part of the Gross Wasteload Allocation:

- Maple Grove – MS400102
- Osseo – MS400043
- Plymouth – MS400112

Although the sources of phosphorous in the watershed are nonpoint in nature, because they are conveyed by storm sewer or channel to the lakes 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 phosphorous.

4.3 NONPOINT SOURCES

4.3.1 Stormwater

Phosphorous transported by stormwater represents one of the largest contributors of phosphorus to lakes in Minnesota. In fact, phosphorous export from urban watersheds rivals that of agricultural watersheds. Impervious surfaces in the watershed improves the efficiency of water moving to streams and lakes resulting in increased transport of phosphorous into local water bodies. Phosphorous 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.

4.3.1.1 Fertilizers

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.

4.3.1.2 Urban Runoff

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 phosphorous 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 phosphorous release from lake sediments.

4.3.2 Wetland 639W

The traditional paradigm for wetlands and water quality is that wetlands act as a sink for nutrients such as nitrogen and phosphorous. However, it is becoming more common in the State of Minnesota, especially in urban areas, to find wetlands that are acting as a source of phosphorous to surface waters. A detailed study of wetland 639W identified it as a rather large source of phosphorous to the Twin Lakes chain of lakes. Understanding the nutrient dynamics of wetlands, especially those that have been impacted by urban runoff for a long period, is critical in understanding the nutrient sources to lakes.

4.3.3 Atmospheric Deposition

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.

4.3.4 Internal Phosphorus Release

Internal phosphorus loading from sources already in 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. Internal loads were estimated independently for each of the basins (Section 6.4.3).

4.3.5 Lake Exchange

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 Twin Lake basins, diffusive exchange was assumed to be negligible. All exchange of phosphorous was assumed to occur through advection. Furthermore, no backwater affects were assumed in the exchange process. North Twin Lake receives the largest volume of water by far, suggesting water pushing through the chain of lakes. The watershed is small enough that it is unlikely that there are significant geographic differences in rainfall intensity and amounts across the watershed.

5.0 Assessment of Water Quality Data

5.1 INTRODUCTION

Water quality monitoring has been conducted since 1990 as a part of the CAMP program. In 1999, the Shingle Creek Watershed Management Commission (SCWMC) conducted a water quality evaluation of the Twin Lake chain of lakes to better understand nutrient loading in the watershed. This evaluation suggested that DNR wetland 639W was a major source of phosphorous to North Twin Lake. Additional monitoring was conducted as a part of this study to evaluate the wetland as a phosphorous source. Part of that effort included monitoring water quality in North Twin Lake. Following is a description of lake monitoring activities in 1999 and 2002 that is the groundwork for developing the phosphorous budgets for the chain of lakes.

5.2 PREVIOUS STUDIES AND MONITORING ON TWIN LAKES

5.2.1 Citizen Assisted Monitoring Program (CAMP) and Other Monitoring

All three of the Twin Lake basins and Ryan Lake have been periodically monitored from 1990 to present by volunteers sponsored and trained by the SCWMC. The Citizen Assisted Monitoring Program (CAMP) is operated by Metropolitan Council Environmental Services, which provides coordination and data analysis for the almost 200 lakes monitored annually in the Metro area. Citizen volunteers collect data and samples biweekly.

Before, during, and after recent construction of TH 100 highway improvement projects, MnDOT monitored Middle and South Twin Lakes.

5.2.2 1997 City of Brooklyn Center Water Management Plan

A brief analysis of water quality and biological conditions in North Twin Lake was conducted as a part of the City of Brooklyn Center's Water Management Plan. Based on application of the Canfield-Bachmann Model, the study concluded that significant reductions in the watershed phosphorus load will not result in lowered in-lake phosphorus concentrations in North Twin Lake. Consequently, some in-lake restoration would be required to see improved water quality in North Twin Lake. No water quality monitoring was conducted as a part of this analysis.

5.2.3 1999 and 2003 Diagnostic Studies

In 1999, SCWMC conducted routine monitoring in all three of the Twin Lake basins to identify nutrient sources and loads to Twin Lake. This study concluded that the large DNR wetland 639W and its subwatershed located on the northwest corner of North Twin Lake was responsible for contributing an estimated 1,188 pounds per year (lb/yr) of phosphorus to North Twin Lake.

This amounts to 53 percent of the lake's estimated total phosphorus load of 2,245 lb/yr. The average total phosphorus concentration in North Twin Lake for 1999 was 140 micrograms per liter (µg//l), indicative of a hypereutrophic condition. However, the conclusion that DNR wetland 639W was the main contributor of phosphorus to North Twin Lake was based on modeling assumptions and not actual measured data.

North Twin Lake was again monitored in 2002 in conjunction with a DNR wetland 639W evaluation conducted for the City of Brooklyn Center. Samples and profiles were collected weekly for May through October. Global positioning units and depth finders were used to locate sampling sites to ensure that samples were taken from the same relative location throughout this study and the 1999 study. Surface samples were collected about a half-foot below the surface and bottom samples were collected within 1 foot of the bottom using a Van Dorn sampler. Surface samples were analyzed for total phosphorus (TP), dissolved phosphorus (DP), nitrate (NO_3), chlorophyll-a, volatile suspended solids (VSS) and total suspended solids (TSS). Bottom samples were analyzed for TP, DP, and total iron.

5.2.4 MnDNR Fish Population Monitoring

The DNR has periodically monitored fish populations in Twin Lake since 1950. Fish population surveys were conducted in 1950, 1975, 1980, 1985, 1995 and 2002. The DNR also maintains historical fish stocking records for Twin Lake. Twin Lake has not been stocked since 1976.

5.3 MONITORING PARAMETERS

5.3.1 Temperature and Dissolved Oxygen

Understanding lake stratification is important to the development of both the nutrient budget for a lake as well as ecosystem management strategies. Lakes that are dimictic (mix from top to bottom in the spring and fall) can have very different nutrient budgets than lakes that are completely mixed all year. Typically, temperature drives the stratification of a lake because water density changes with water temperature. However, the larger impact usually lies with the dissolved oxygen profile. As cooler, denser water is trapped at the bottom of a lake, it can become devoid of oxygen affecting both aquatic organisms and the sediment biogeochemistry. Dissolved oxygen and temperature isopleths were created for all three basins of Twin Lake in 1999 and 2002. Profile data was not collected for South Twin Lake in 2002 because monitoring was focused on interactions between DNR wetland 639W and North Twin Lake.

5.3.2 Phosphorous and Nitrogen

Lake algal production is typically limited by phosphorous and nitrogen availability. Minnesota lakes are almost exclusively limited by phosphorous; however excessive phosphorous can lead to nitrogen limiting conditions. Phosphorous and nitrogen are measured to determine the availability of the nutrients for algal production. Dissolved and Orthophosphorous are the most readily available forms of phosphorous while total phosphorous is a measure of all the phosphorous, 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.

5.3.3 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 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 disc shaded black and white over the shady side of the boat and recording the depth at which the disc is no longer visible.

5.3.4 Total Iron

Total iron in the hypolimnion is an indicator of phosphorus release from the sediments as a result of breaking the weak bond between iron and phosphorous under oxygenated conditions. Large increases in total iron and soluble phosphorous available in the water column can indicate sediment phosphorous release.

5.4 LAKE MONITORING RESULTS

Following is a discussion of the lake monitoring results for the Twin Lake chain of lakes and Ryan Lake. The discussion is focused on monitoring years to present nutrient cycling dynamics in the lakes.

5.4.1 North Twin Lake

5.4.1.1 Historical Data

Historical chlorophyll-a, total phosphorus, Secchi depth and total Kjeldahl nitrogen data are presented in Table 5.1. North Twin Lake demonstrates extremely high total phosphorus and chlorophyll-a concentrations, often times more than doubling the MPCA water quality standard.

Table 5.1. Historical data for North Twin Lake.

	Chlorophyll-a (µg/L)		Total Phosphorus (µg/L)		Secchi Disk (m)		Total Kjeldahl Nitrogen (mg/L)	
Year	**N**	**Mean**	**N**	**Mean**	**N**	**Mean**	**N**	**Mean**
1990					14	0.47		
1991			8	139	24	0.41	8	1.6
1993			7	141	7	0.34	7	1.7
1996			8	191	8	0.40	8	1.9
1998			9	129	9	0.43	9	1.7
1999	7	40	7	131		0.30		1.4
2000			9	70	7	0.94	9	1.1
2002	14	83	16	129	14	0.35		
2003	7	21.7	7	45	7	1.16	7	1.3

Note: Data was acquired from the MPCA website and STORET.

North Twin Lake was intensively monitored in both 1999 and 2002. These data are presented in Tables 5.2 and 5.3. Surface water quality was similar in both years. The only difference was significantly higher chlorophyll-a concentrations in 2002. The following discussion of North Twin Lake water quality focuses on 2002 data although both years exhibited similar patterns in the data.

Table 5.2. Water quality in North Twin Lake in the summer of 1999.

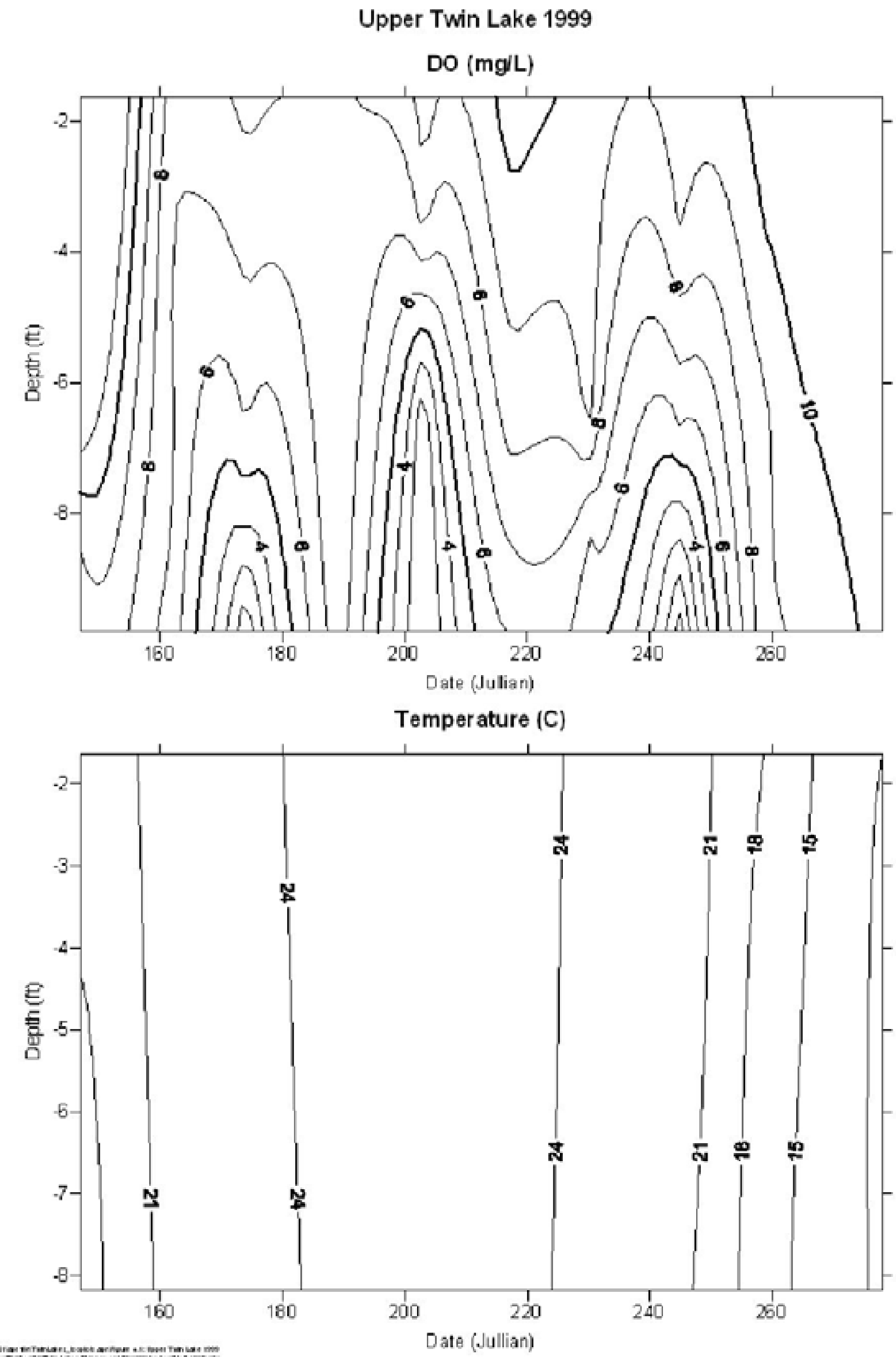
	Chlorophyll-a (µg/L)	Surface TP (µg/L)	Surface DP (µg/L)	Secchi (m)
Average	39	140	14	0.4
Min	27	80	6	0.3
Max	55	265	49	0.7
N	9	9	9	8

Table 5.3. Water quality in North Twin Lake in the summer of 2002.

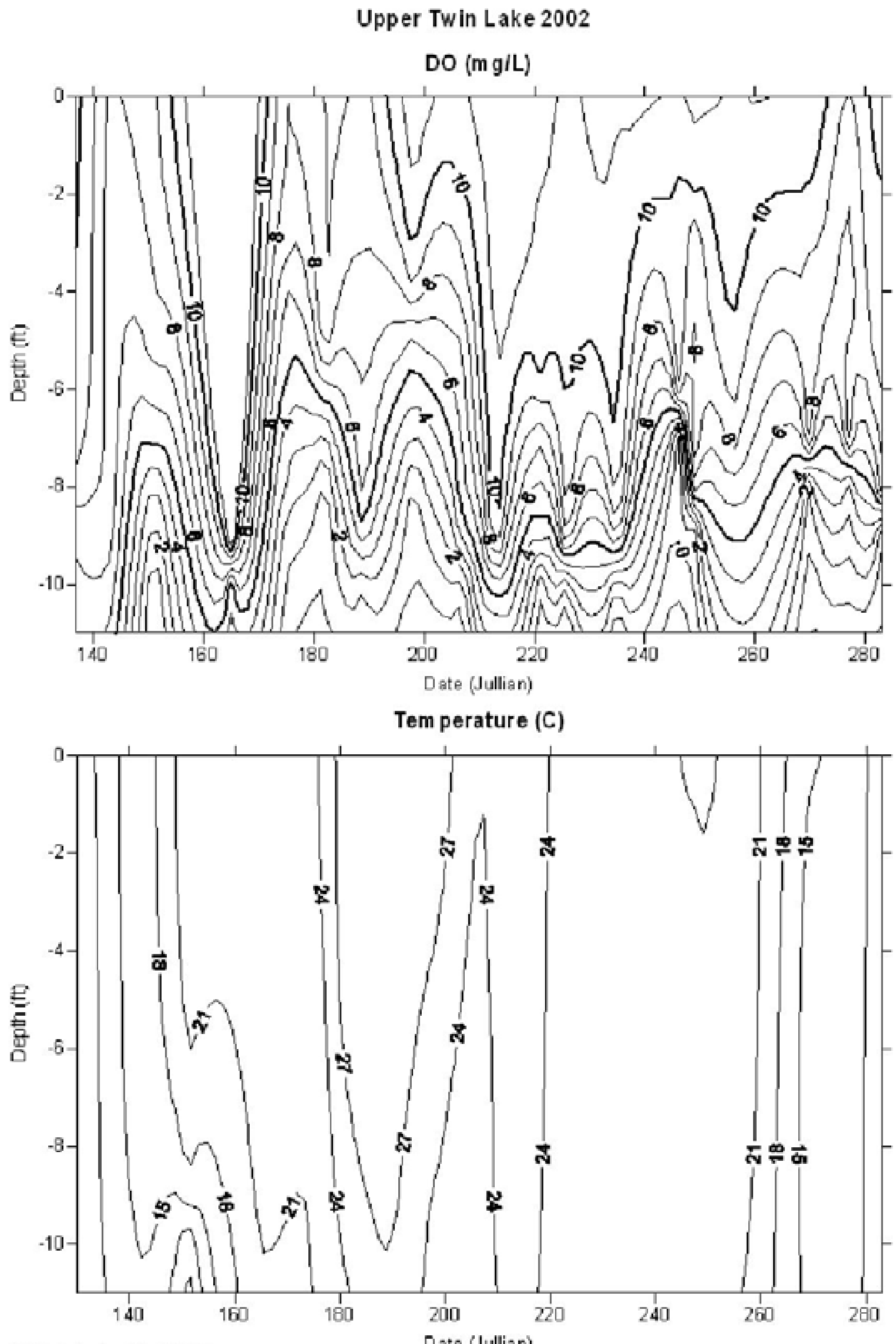
	Chlorophyll-a (µg/l)	Surface TP (µg/l)	Surface DP (µg/l)	NO_3 (mg/l)	Secchi (m)
Average	72	122	22	0.06	0.4
Min	15	43	16	0.02	0.2
Max	140	177	40	0.32	1
N	20	22	23	22	19

5.4.1.2 Temperature and Dissolved Oxygen

North Twin Lake does not exhibit temperature stratification; however there are periods when dissolved oxygen is quite low or zero at the sediment water interface (Figure 5.1 and 5.2). These periods most likely follow calm periods where wind speed was not sufficient to induce mixing of the lake. These periods of depleted dissolved oxygen at the sediment water interface can result in phosphorous release from the sediments by releasing phosphorous bound to the sediment iron.



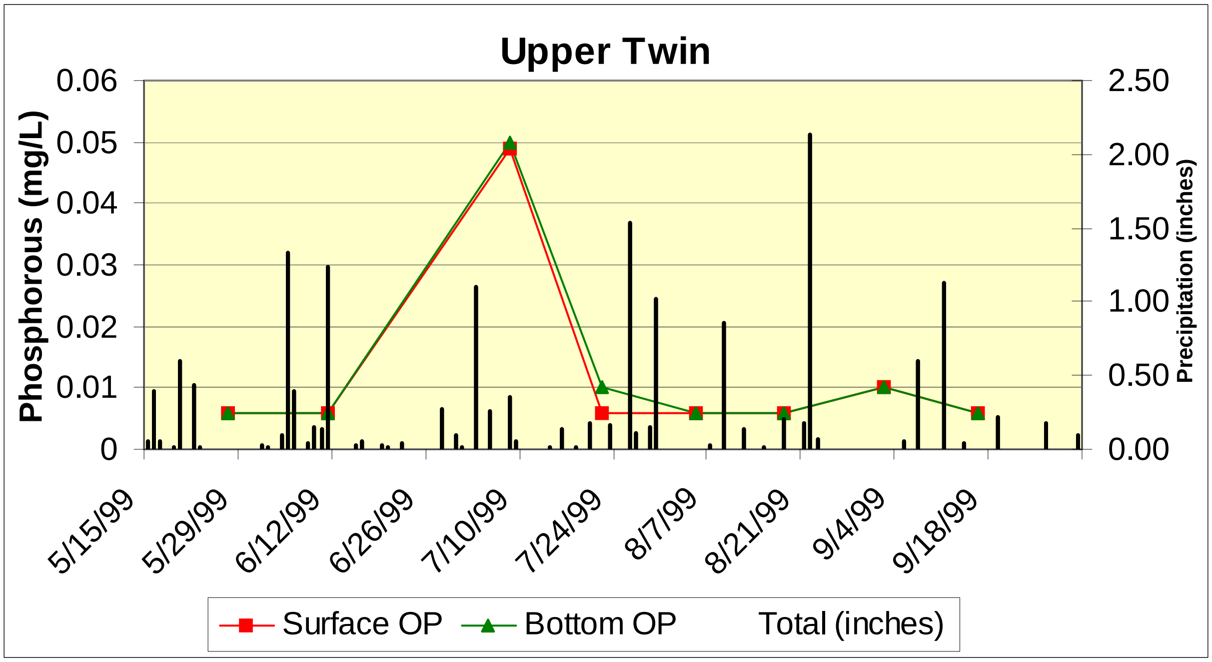
CITY OF BROOKLYN CENTER	Wenck	JUN 2003
1999 UpperTwin Lake Isoplots	Wenck Associates, Inc. 1800 Pioneer Creek Center Environmental Engineers Maple Plain, MN 55359-0249	Figure 5.1



CITY OF BROOKLYN CENTER	Wenck	JUN 2003
2002 UpperTwin Lake Isoplots	Wenck Associates, Inc. 1800 Pioneer Creek Center Environmental Engineers Maple Plain, MN 55359-0249	Figure 5.2

5.4.1.3 Phosphorus

In 2002, total phosphorous concentrations ranged from 43 to 177 micrograms per liter with the dissolved phosphorous fraction remaining fairly low with a range of 16 to 40 micrograms per liter. Surface TP was higher than bottom TP trough the end of July (Figure 5.3). After July, surface and bottom TP concentrations are essentially the same.



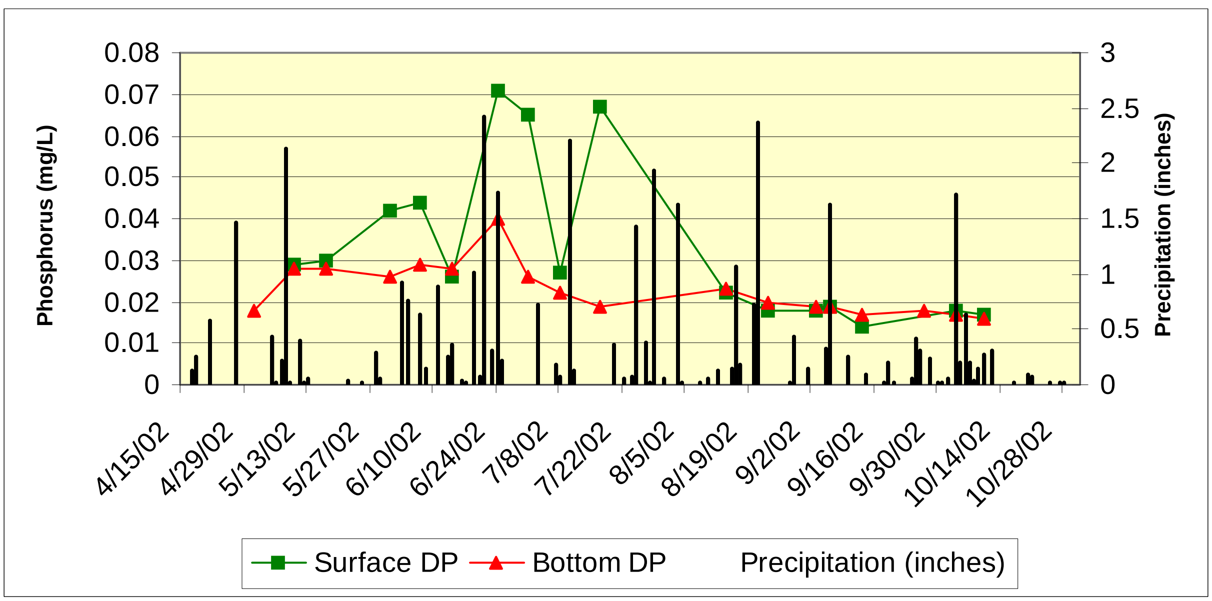
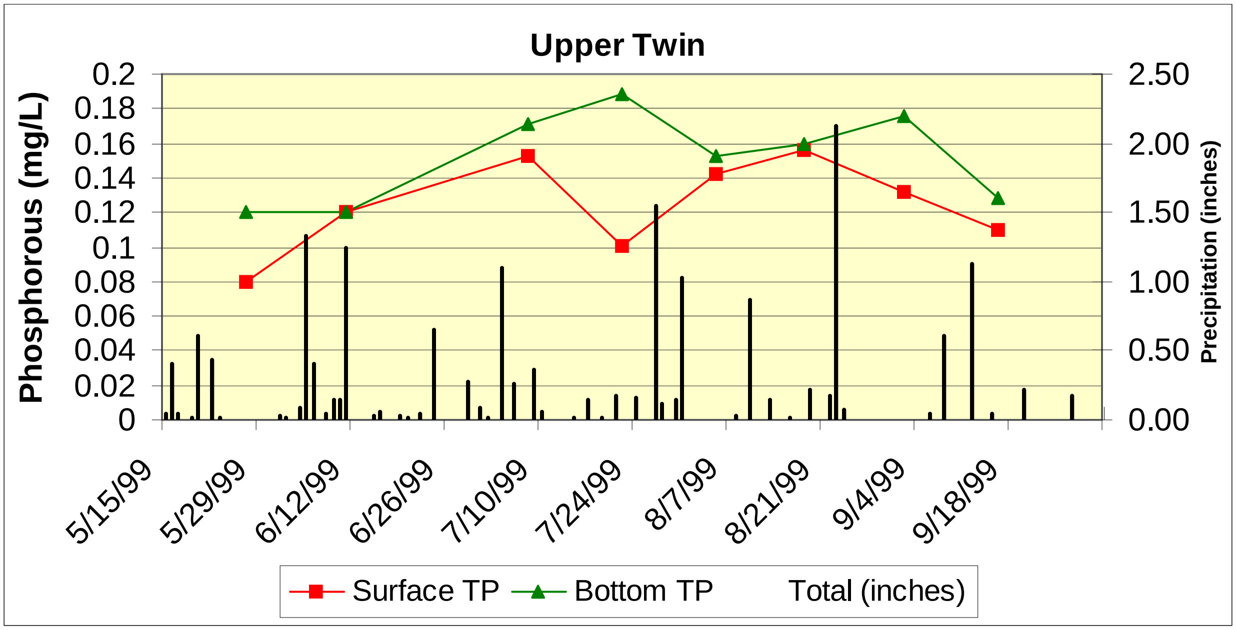


Figure 5.3. Surface and Bottom Total Phosphorous Concentrations for North Twin Lake in 1999 and 2002

Evaluating surface and bottom dissolved phosphorous can provide indications of internal phosphorous cycling in shallow lakes, although this is more difficult in very shallow lakes that do not demonstrate stratification such as North Twin Lake. Early season DP concentrations at the bottom of the lake were consistently higher than the surface DP (Figure 5.4). This may suggest internal loads of P since the lake is well mixed during this period but demonstrates low D.O. concentrations at the sediment surface. Later in the season the values are essentially the same.

Internal loading in North Twin Lake is most likely sporadic relying on calm dry periods where D.O. is depleted at the sediment surface. It is during these periods where the greatest potential for internal loading to occur.



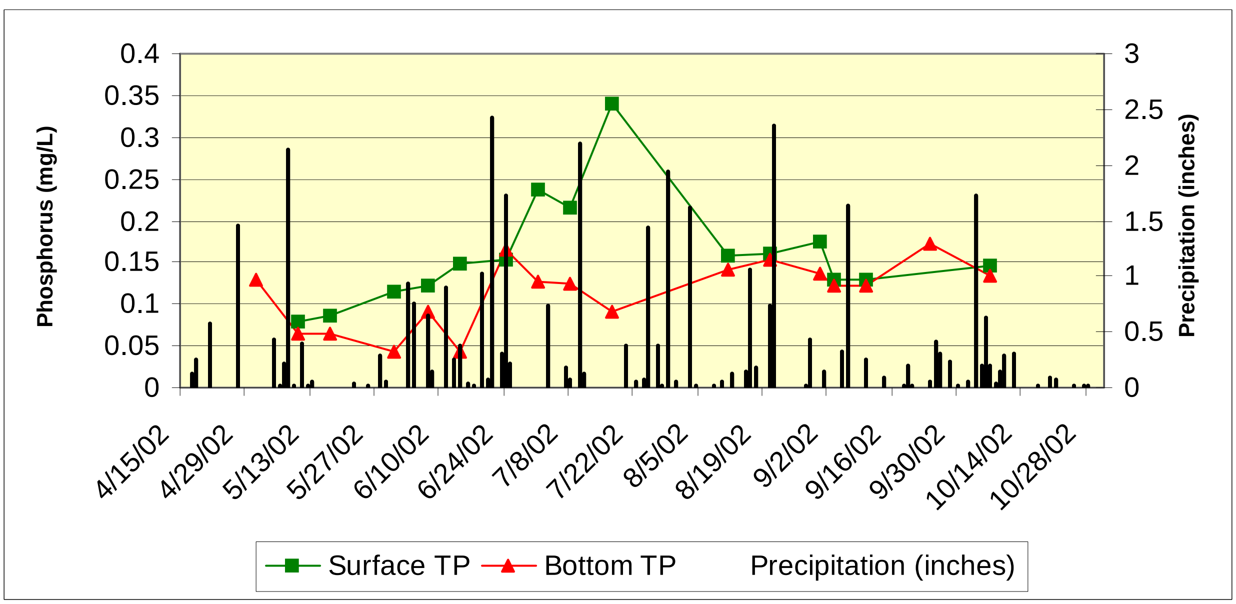


Figure 5.4. Surface and Bottom Dissolved Phosphorous Concentrations for North Twin Lake in 1999 and 2002

5.4.1.4 Chlorophyll-a

Chlorophyll-concentrations generally track with TP concentrations increasing through the spring and early summer (Figure 5.5). DP concentrations remain low throughout the year with the algae utilizing the readily available forms of phosphorous. If the lake becomes nitrogen limited we would expect to see some increases in phosphorous without an algal response. This is not the case in North Twin Lake, suggesting that algal growth still responds to inputs of phosphorous.

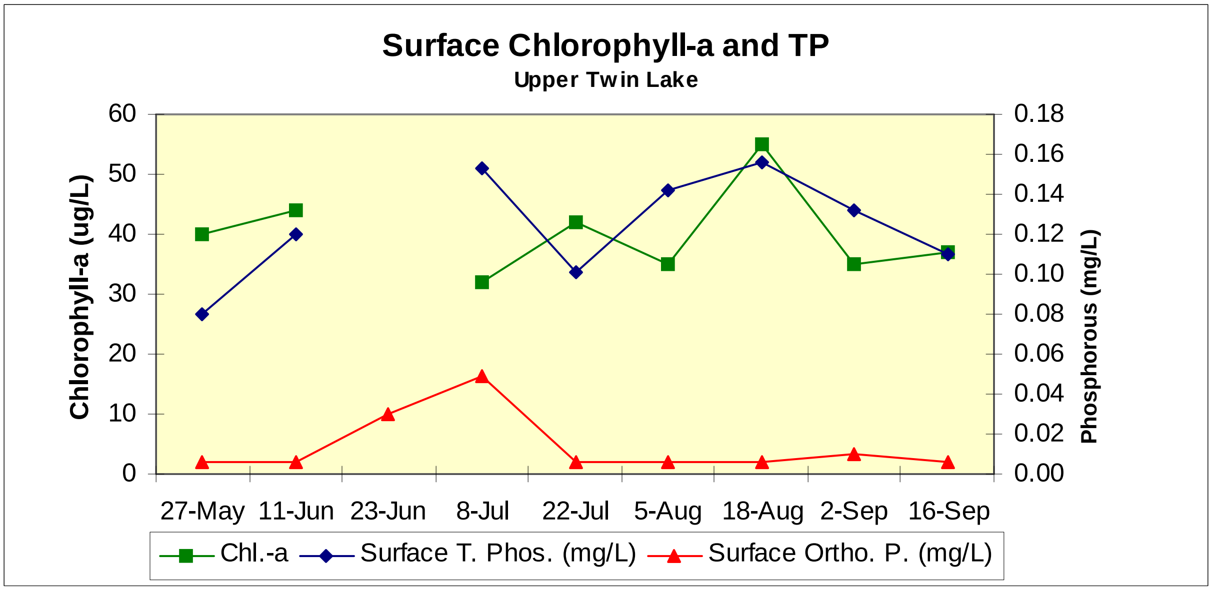


Figure 5.5. 1999 Chlorophyll-a and Phosphorus Concentrations in the Epilimnion of North Twin Lake

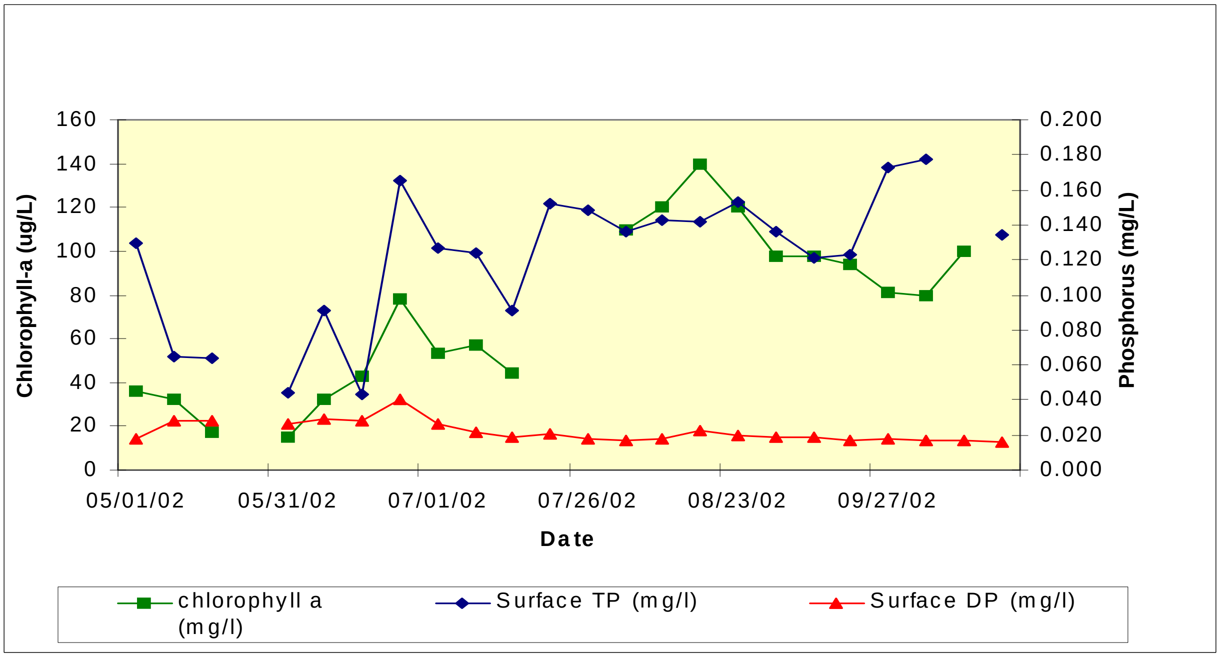


Figure 5.6. 2002 Chlorophyll-a and Phosphorous Concentrations in the Epilimnion of the North Twin Lake

5.4.1.5 Total Iron

Total iron can be another indicator of internal phosphorous release from lake sediments. Phosphorous release from the sediments is the result of breaking a weak bond between iron and phosphorous that occurs in oxygenated conditions and forms a precipitate. When anoxic conditions exist, this bond is broken and dissolved iron and phosphorous are released into the water column. Total iron at the bottom of North Twin Lake was highest in spring and early summer, with values decreasing after the end of July (Figure 5.7). These concentrations coincide with the high bottom dissolved phosphorus concentrations further implicating internal cycling as a phosphorous source in North Twin Lake.

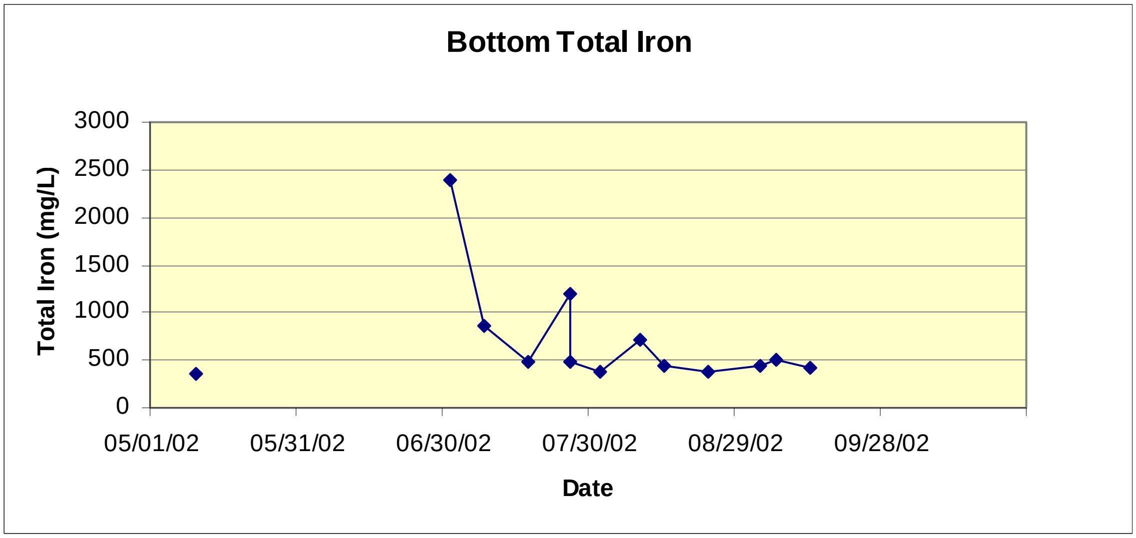


Figure 5.7. Total Iron Concentrations in the Bottom Water (Hypolimnion) of North Twin Lake

5.4.2 Middle Twin Lake

5.4.2.1 Historical Data

Middle Twin Lake does not demonstrate annual variability in total phosphorus concentrations with summer mean concentrations typically around 50 µg/L (Table 5.4). This is somewhat surprising given that North Twin Lake, which drains directly to Middle Twin Lake, does demonstrate strong annual variability. These differences suggest that a buffer exists between North and Middle Twin Lakes that dampens the effects of loads from North Twin Lake.

Table 5.4 Historical data for Middle Twin Lake.

	Chlorophyll- a (µg/L)		Total Phosphorus (µg/L)		Secchi Disk (m)		Total Kjeldahl Nitrogen (mg/L)	
Year	**N**	**Mean**	**N**	**Mean**	**N**	**Mean**	**N**	**Mean**
1985	--	--	4	45	4	2.5	4	1.2
1991	--	--	8	59	8	0.7	8	1.5
1996	--	--	8	38	8	1.8	8	1.0
1997	--	--	8	50	8	1.9	8	1.2

Year	Chlorophyll- a (µg/L)		Total Phosphorus (µg/L)		Secchi Disk (m)		Total Kjeldahl Nitrogen (mg/L)	
	N	Mean	N	Mean	N	Mean	N	Mean
1999a[1]	--	--	10	50	10	1.0	10	1.2
1999b[1]	7	16	7	40	7	1.0	4	0.7
2000	--	--	9	56	9	1.1	9	1.1
2003	8	30	8	53	7	1.1	8	1.0

[1]Data in 1999 was collected by both CAMP and MCES. Data was acquired from the MPCA website and STORET. Data are presented here separately due to differences in collection procedures.

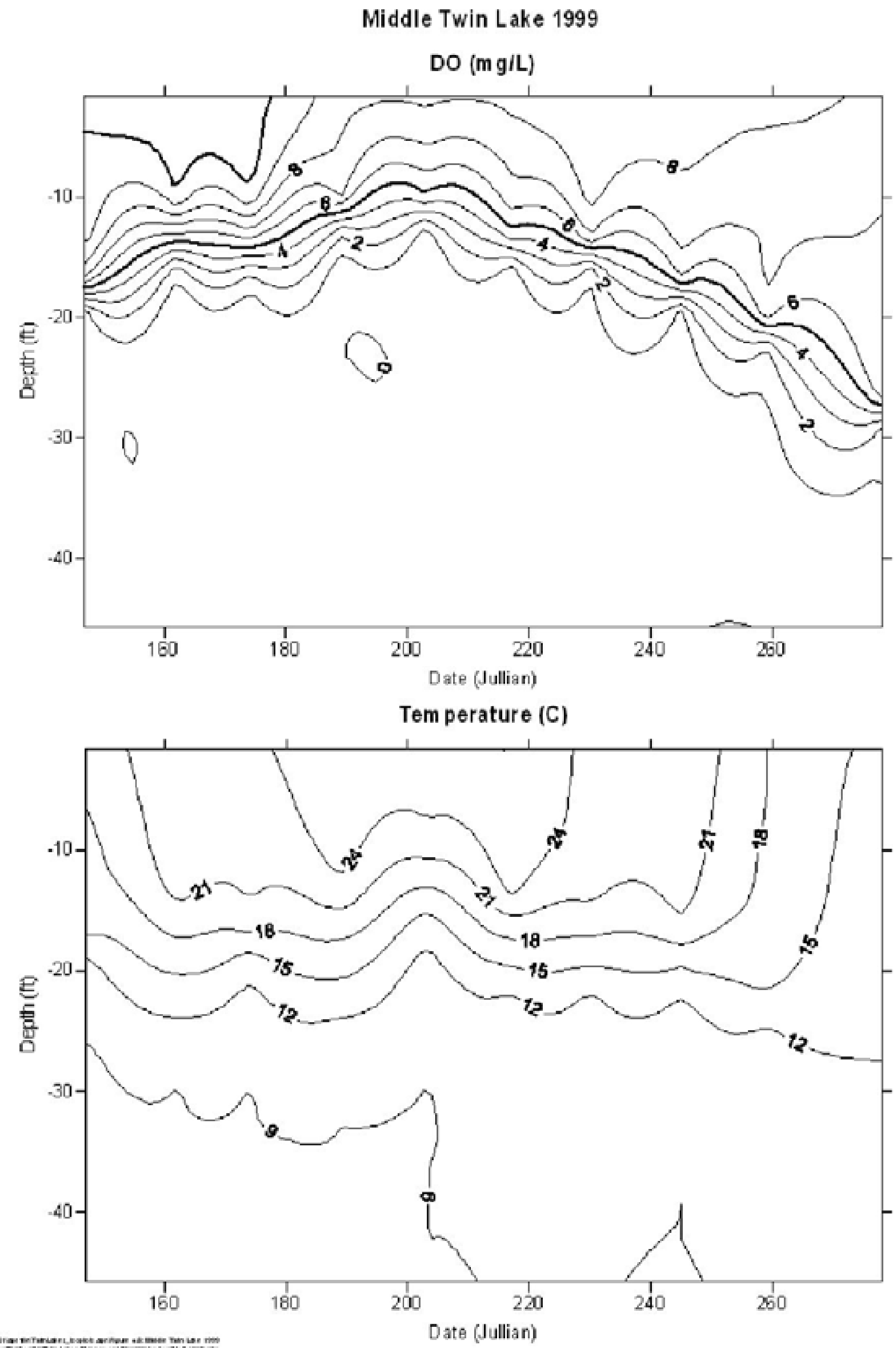
Water quality data collected on Middle Twin Lake during the summer of 1999 are presented in Table 5.5.

Table 5.5 Water quality in the epilimnion of Middle Twin Lake during the summer of 1999.

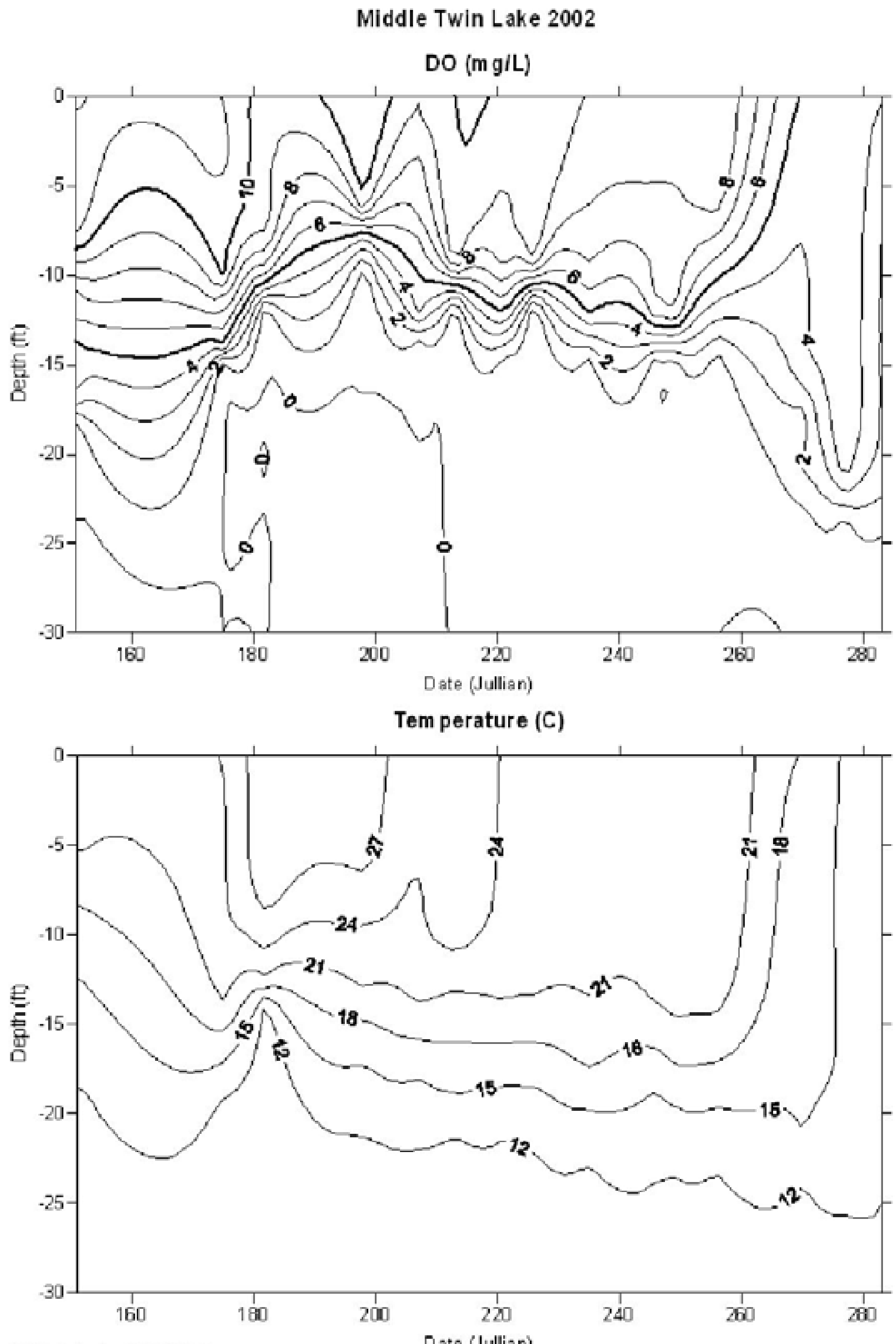
	Chlorophyll -a (µg/L)	Total Phosphorus (µg/L)	Ortho-phosphorus (µg/L)	Total Kjeldahl Nitrogen (mg/L)	Secchi (m)
Average	15	45	9	0.96	1.3
Min	8	27	6	0.49	0.7
Max	26	77	25	1.50	3.2
N	9	9	9	4	8

5.4.2.2 Temperature and Dissolved Oxygen

Middle Twin Lake is a dimictic lake with stratification onset occurring in May and fall turnover typically occurring in late September or early October Figure 5.8 and 5.9). Dissolved oxygen is depleted in the hypolimnion during this period and can extend from the bottom to as shallow as 15 feet. Since Middle Twin Lake has a depth of approximately 40 feet, this is a rather large proportion of the lake to be devoid of oxygen. These effects are seen in the lake turnover in 2002 where the dissolved oxygen concentrations in the entire lake fall below 5 mg/L, which is the standard for the protection of warm water fisheries.



CITY OF BROOKLYN CENTER	Wenck Wenck Associates, Inc. 1800 Pioneer Creek Center Environmental Engineers Maple Plain, MN 55359-0249	JUN 2003
1999 Middle Twin Lake Isoplots		Figure 5.8



CITY OF BROOKLYN CENTER	Wenck	JUN 2003
2002 MiddleTwin Lake Isoplots	Wenck Associates, Inc. 1800 Pioneer Creek Center Environmental Engineers Maple Plain, MN 55359-0249	Figure 5.9

5.4.2.3 Phosphorus

In 1999 total phosphorus concentrations in Middle Twin Lake ranged from 27 to 77 µg/L, with an average concentration of 45 µg/L (Table 5.5). Both total and orthophosphorous demonstrated increasing trends in the hypolimnion suggesting internal phosphorous release from the lake sediments (Figures 5.10 and 5.11). Additionally, the majority of phosphorous in the hypolimnion is in the dissolved fraction, further indicating significant internal release of phosphorous. It is important to note that these concentrations are an order of magnitude higher than surface concentrations with bottom concentrations as high as 700 µg/L and surface TP averaging 77 µg/L. Although much of the phosphorous is trapped in the bottom waters, there may be some turbulent diffusion of phosphorous into the surface waters making it available for algal production. However, chlorophyll-a concentrations suggest that this source is minimal.

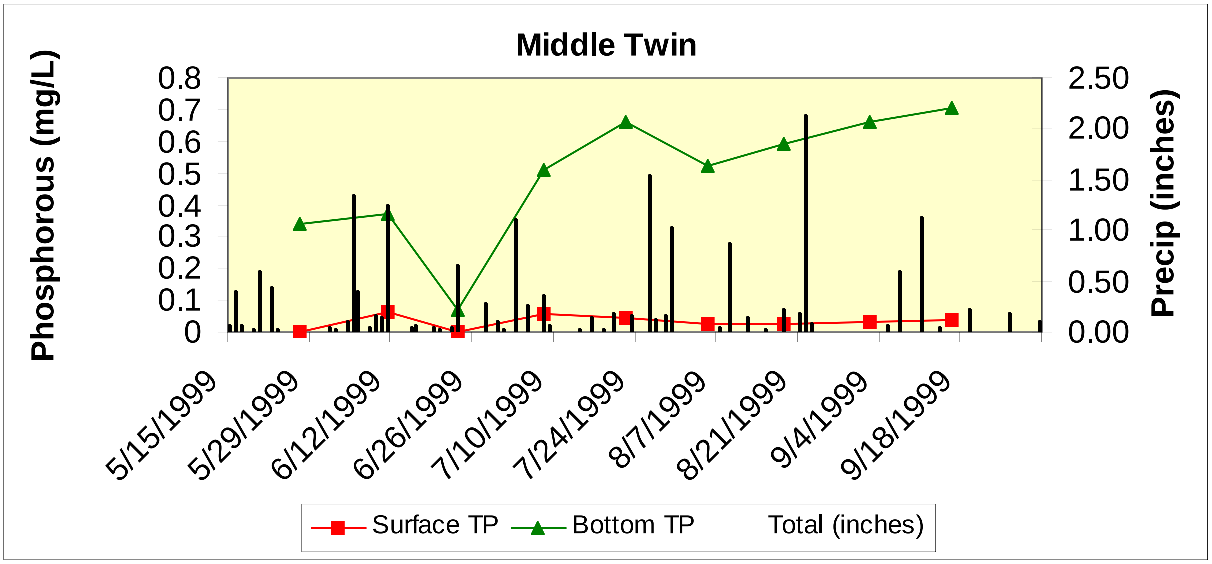


Figure 5.10. Bottom and Surface Total Phosphorus in Middle Twin Lake During the Summer of 1999

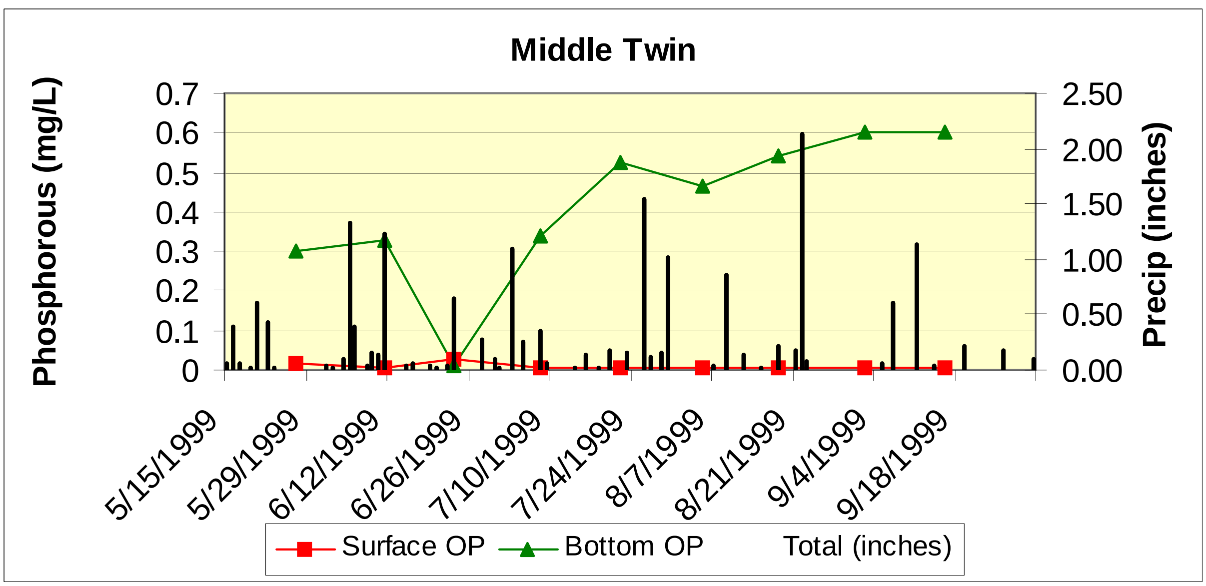


Figure 5.11. Bottom and Surface Orthophosphorous in Middle Twin Lake during the Summer of 1999

5.4.2.4 Chlorophyll-a

Chlorophyll-a data suggest that Middle Twin Lake experiences an early summer algal bloom but spends the rest of the summer with fairly low algal concentrations (Figure 5.12). Chlorophyll-a concentrations peaked in mid-June associated with the early summer algal bloom. Chlorophyll-a decreased after this bloom, generally stabilizing around 15 µg/L.

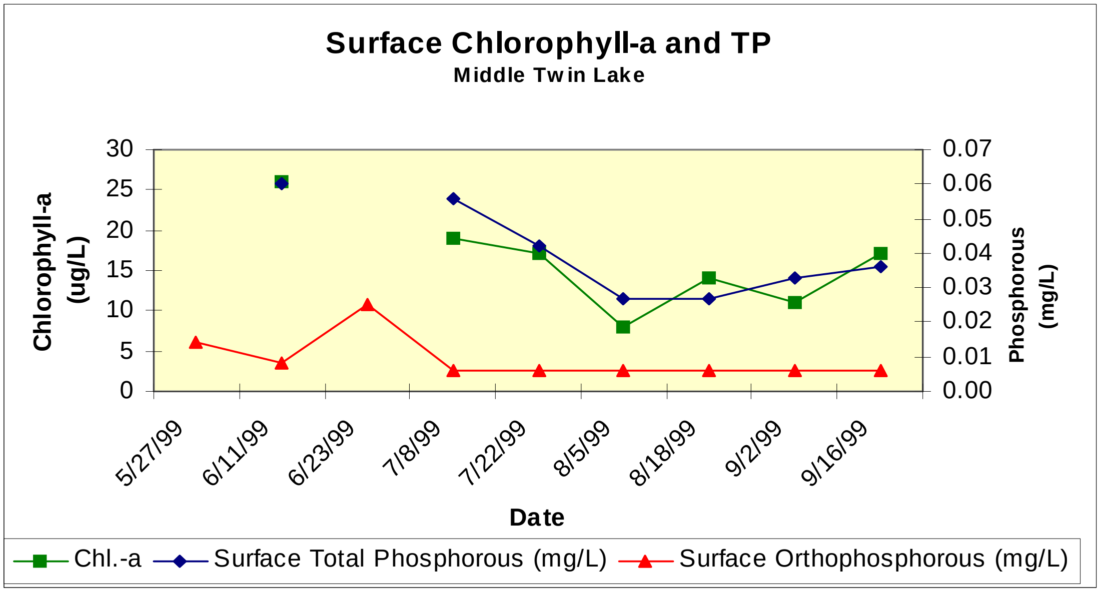


Figure 5.12. Chlorophyll-a and Phosphorous Concentrations in the Epilimnion of Middle Twin Lake during the Summer of 1999.

5.4.2.5 Total Iron

Total iron in the epilimnion increased significantly after the end of June, signifying the onset of sediment phosphorous release (Figure 5.13).

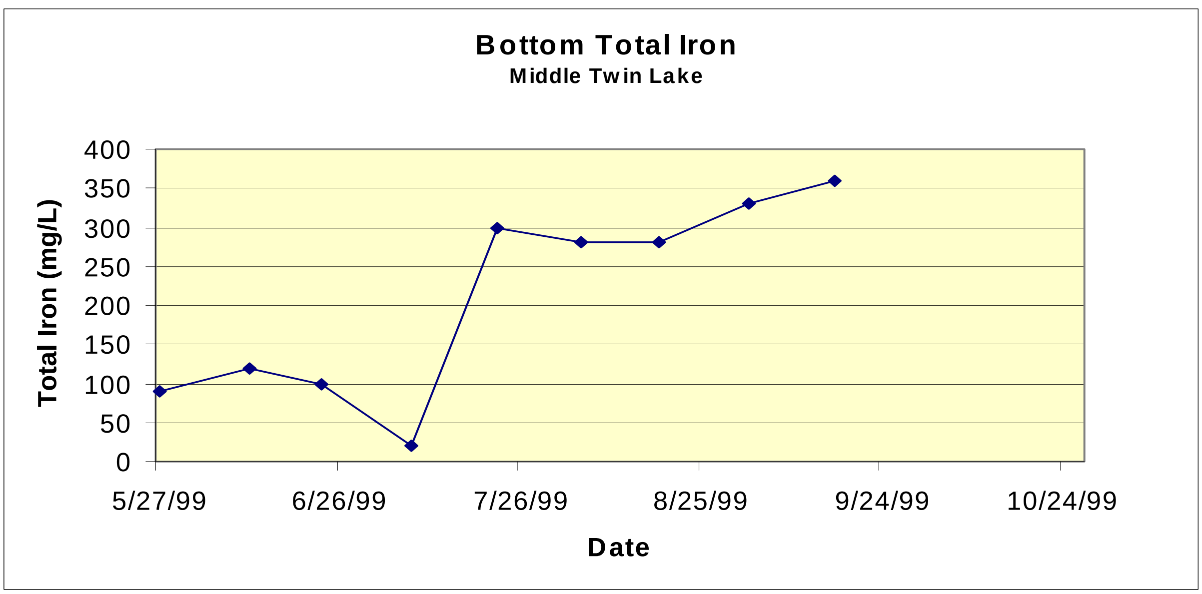


Figure 5.13. Total Iron Concentrations in the Bottom Water (Hypolimnion) of Middle Twin Lake during the Summer of 1999

5.4.3 South Twin Lake

5.4.3.1 Historical Data

Annual summer average water quality for South Twin is presented in Table 5.6. South Twin demonstrates a wide range of nutrient conditions with some summer average total phosphors concentrations below the standard and some almost three times the State water quality standard. This broad range of conditions is probably a result of changes in watershed runoff loads as well as internal loads. Since Middle Twin does not demonstrate strong annual variability and drains directly to South Twin, it is unlikely that the broad range of conditions is affected by water quality in Middle Twin. Data collected during the summer of 1999 are presented in Table 5.7.

Table 5.6. Historical data for South Twin Lake.

	Chlorophyll- a (µg/L)		Total Phosphorus (µg/L)		Secchi Disk (m)		Total Kjeldahl Nitrogen (mg/L)	
Year	**N**	**Mean**	**N**	**Mean**	**N**	**Mean**	**N**	**Mean**
1980	1	67	1	170	1	0.4	1	2.5
1991	--	--	8	86	8	0.7	8	1.5
1993	--	--	7	59	7	0.8	7	1.1
1996	--	--	8	54	8	1.4	8	1.2
1998	--	--	4	48	4	1.5	4	1.2
1999	8	34	8	69	7	0.8	4	0.7
2000			7	203	7	0.2	7	2.1
2002	8	81	10	123	10	0.5	10	1.7

Note: Data was acquired from the MPCA website and STORET

Table 5.7 South Twin Lake water quality in the epilimnion during the summer of 1999.

	Chlorophyll-a (µg/L)	Total Phosphorus (µg/L)	Ortho-Phosphorus (µg/L)	Total Kjeldahl Nitrogen (mg/L)	Secchi (m)
Average	32	67	7	0.71	0.9
Min	14	44	6	0.09	0.6
Max	63	117	13	1.10	2.1
N	9	9	9	5	8

5.4.3.2 Temperature and Dissolved Oxygen

South Twin Lake is also dimictic with spring onset of stratification and remaining stratified until fall (Figure 5.15). The hypolimnion can reach a depth of 15 feet and remains devoid of dissolved oxygen during the stratification period.

5.4.3.3 Phosphorus

In 1999 total phosphorous in the surface water of South Twin Lake ranged from 44 to 117 µg/L, with an average concentration of 67 µg/L (Table 5.7). Hypolimnion total and orthophosphorous concentrations increased at the onset of stratification and were very high reaching TP concentrations greater than 1,700 µg/L and OP concentrations greater than 400 µg/L (Figures 5.14 and 5.15). Bottom concentrations generally decreased throughout the season suggesting loss of phosphorous from the hypolimnion. The thermocline generally grows deeper throughout the season. Phosphorous may be moving from the hypolimnion to the surface waters as the thermocline grows deeper and phosphorous rich water is mixed into the photic (growing) zone.

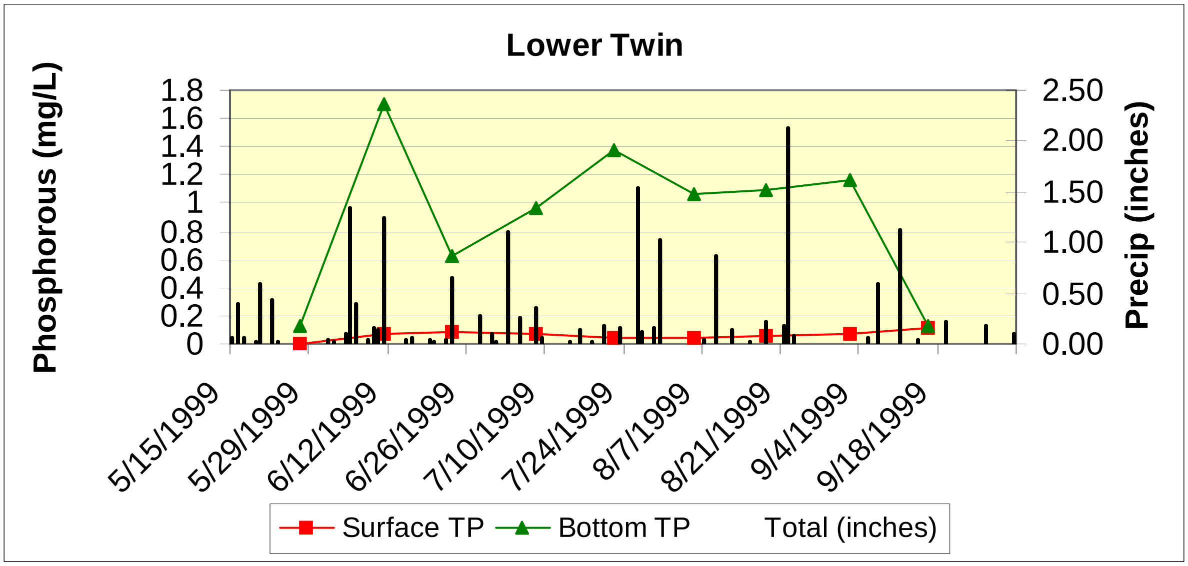


Figure 5.14. Bottom and Surface Total Phosphorous in South Twin Lake During the Summer of 1999

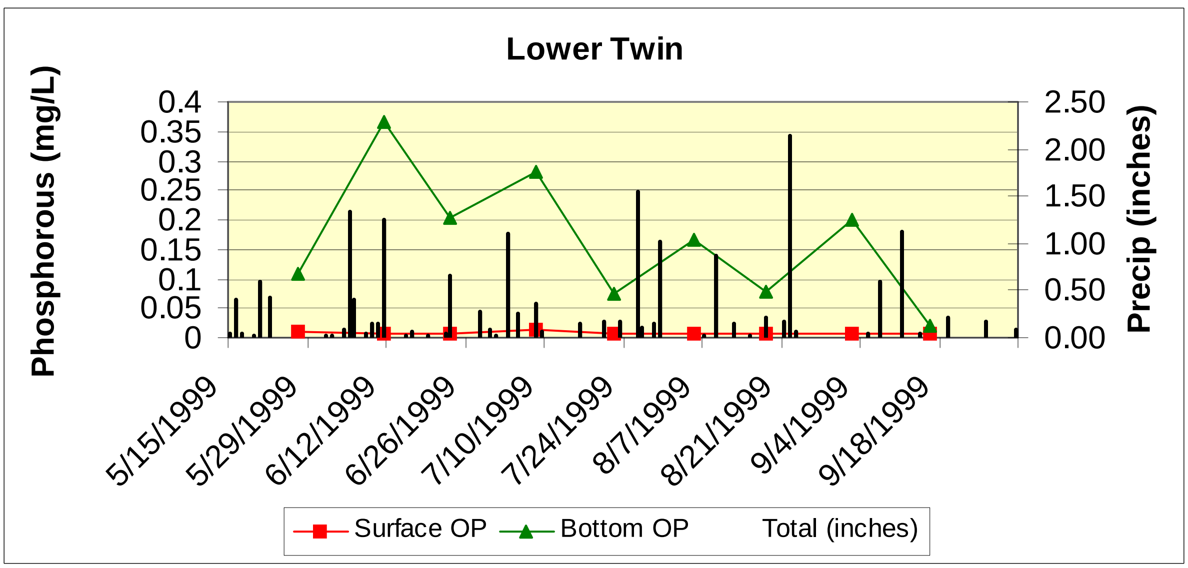


Figure 5.15. Bottom and Surface Orthophosphorous in South Twin Lake During the Summer of 1999

5.4.3.4 Chlorophyll-a

Chlorophyll-a concentrations in South Twin Lake demonstrate both and early summer and fall algal bloom (Figure 5.16). The highest chlorophyll-a concentrations occurred in September with the increase beginning in early August. This increase is associated with the deepening of the thermocline and subsequent turnover (mid-August) where phosphorous rich water from the epilimnion is mixed into the surface water. These results suggest that internal sources of phosphorous are playing a significant role in the algal blooms of South Twin Lake.

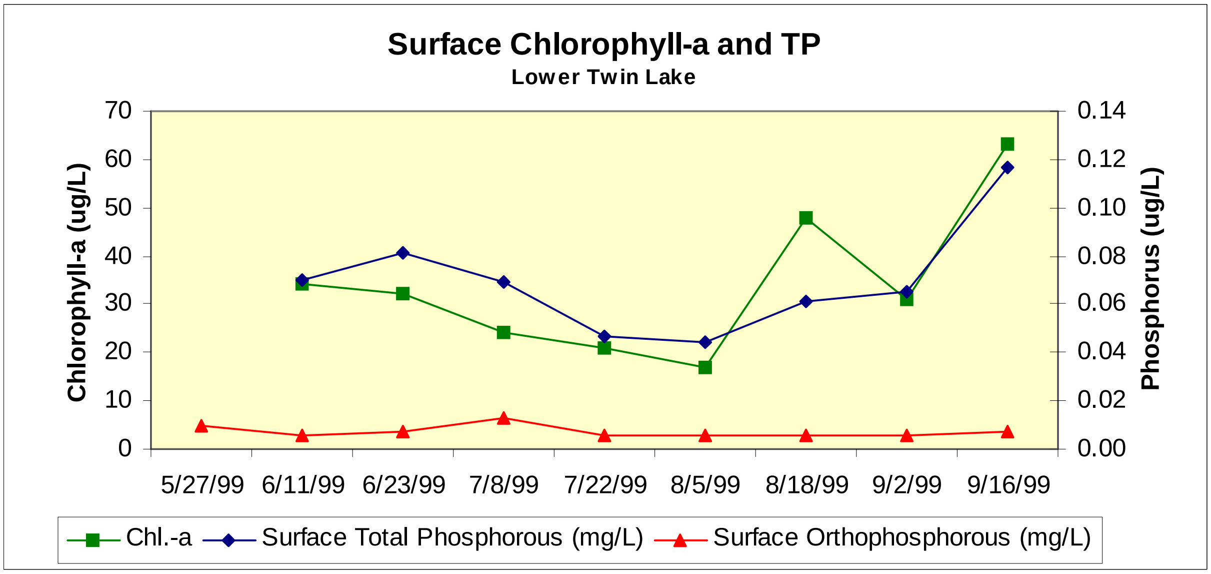


Figure 5.16. Chlorophyll-a and Phosphorous Concentrations in the Surface Waters (Epilimnion) of South Twin Lake

5.4.3.5 Total Iron

Total iron concentrations follow the same pattern as orthophosphorous concentrations in the hypolimnion further corroborating the importance of internal phosphorous release (Figure 5.17). Total iron concentrations are very high in the early and late summer with a dip occurring in early July. This dip may be associated with a mixing event where the epilimnion was mixed with oxygenated water. Subsequently, the lake restratified and the internal release of P started again.

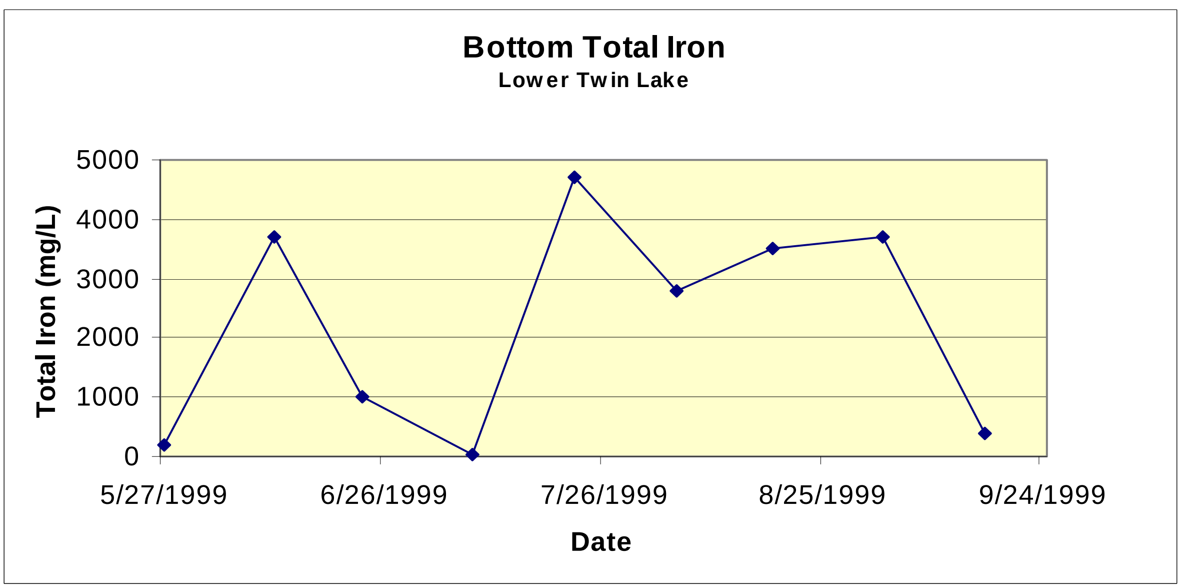


Figure 5.17. Total Iron Concentrations in the Bottom Water (Hypolimnion) of South Twin Lake During the Summer of 1999

5.4.4 Ryan Lake

Data presented for Ryan Lake are from 2002 and 2003. Although limited, these data are the most complete data available for Ryan Lake.

5.4.4.1 Historical Data

Historical water quality data for Ryan Lake are presented in Table 5.8. Recent water quality conditions are good, with four out of the last five sampled years near the State water quality standard. These results are in contrast to data collected in the early eighties where total phosphorus concentrations were two to three times the current State standard. However, these may be a result of changes in lab techniques and improvements to the watershed. The most recent conditions suggest the Ryan Lake can be brought into compliance with the State standard with a relatively small effort.

Table 5.8. Historical data for Ryan Lake.

Year	Chlorophyll- a (μg/L)		Total Phosphorus (μg/L)		Secchi Disk (m)		Total Kjeldahl Nitrogen (mg/L)	
	N	Mean	N	Mean	N	Mean	N	Mean
1977	--	--	--	--	8	0.7	--	--
1979	--	--	4	62	15	1.0	--	--
1980	--	--	3	92	14	0.7	--	--
1981	--	--	2	141	--	--	--	--
1996	--	--	9	34	9	1.5	9	0.97
1998	--	--	4	43	4	2.3	4	1.28
2000	--	--	6	82	6	0.8	6	1.37
2002	2	4	2	44	2	1.4	2	0.88
2003	3	8	4	44	4	2.4	4	0.85

Note: Data was acquired from the MPCA website and STORET.

5.4.4.2 Temperature and Dissolved Oxygen

Temperature profiles were collected in May, July, and September of 2003 (Figure 5.18). Ryan Lake demonstrates stratification with a thermocline forming around the 2 to 4 meter depth range. It is likely that Ryan Lake is stratified throughout the summer.

Dissolved oxygen profiles are presented in Figure 5.19. Ryan Lake experienced anoxic conditions in the hypolimnion during the summer with conditions beginning in May and lasting through October. It is likely that sediments release phosphorus during the anoxic hypolimnetic conditions, which may end up in the growing zone of the lake and add to possible eutrophic conditions. However, hypolimnetic phosphorus samples have not been collected from Ryan Lake.

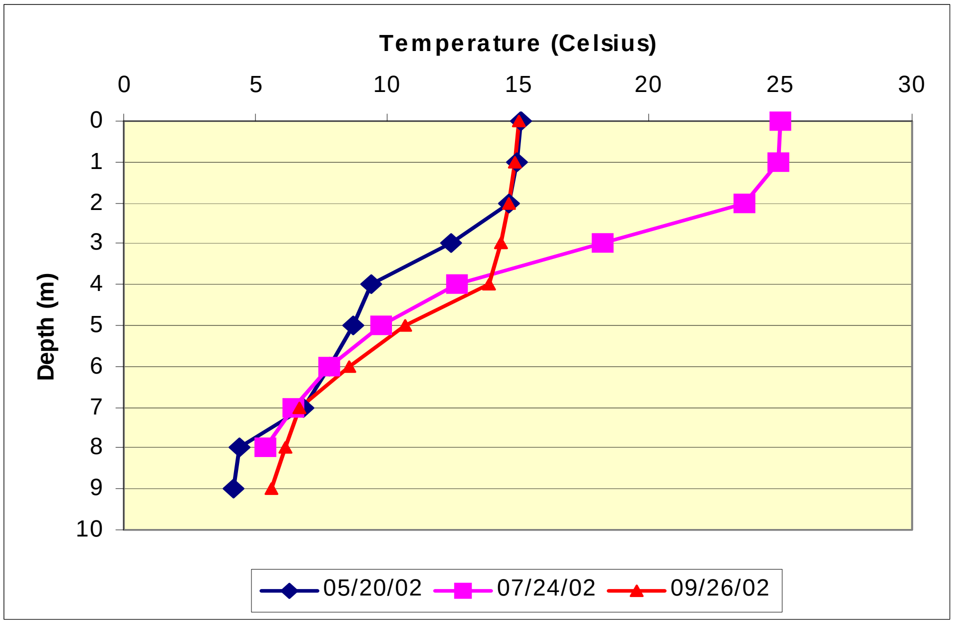


Figure 5.18. Ryan Lake Temperature Profiles for 2002

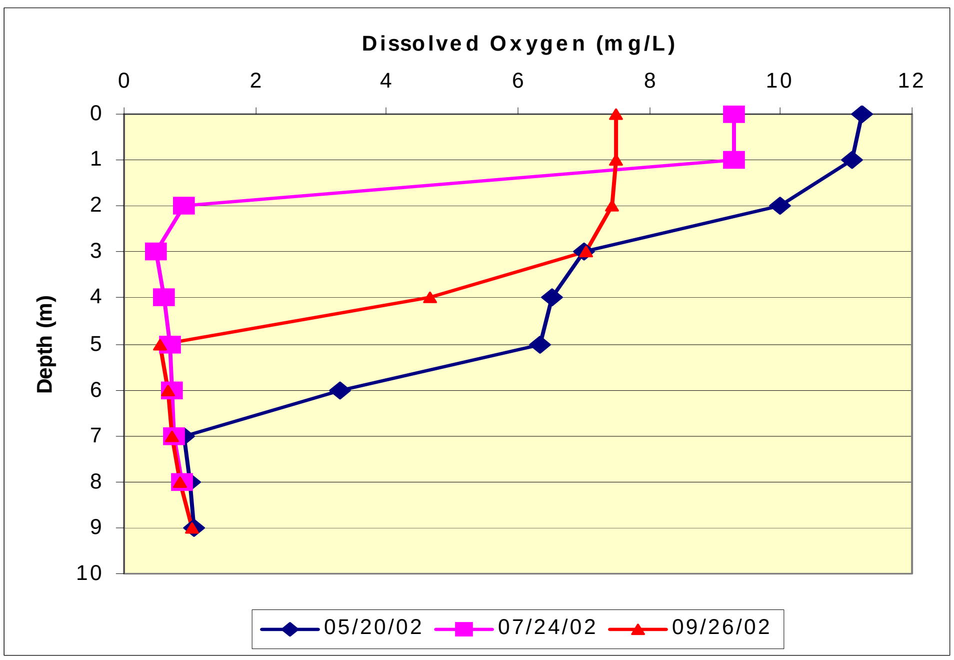


Figure 5.19. Ryan Lake Dissolved Oxygen Profiles for 2002

5.4.4.3 Phosphorus and Chlorophyll-a

Data collected in 2003 represents to most complete data available for Ryan Lake although the sampling only runs into early July. Prior to 2002, no chlorophyll-a data exists and data collected in 2002 was incomplete. Chlorophyll-a concentrations were relatively low during the growing season (Figure 5.20). However the last sample was collected on July 1.

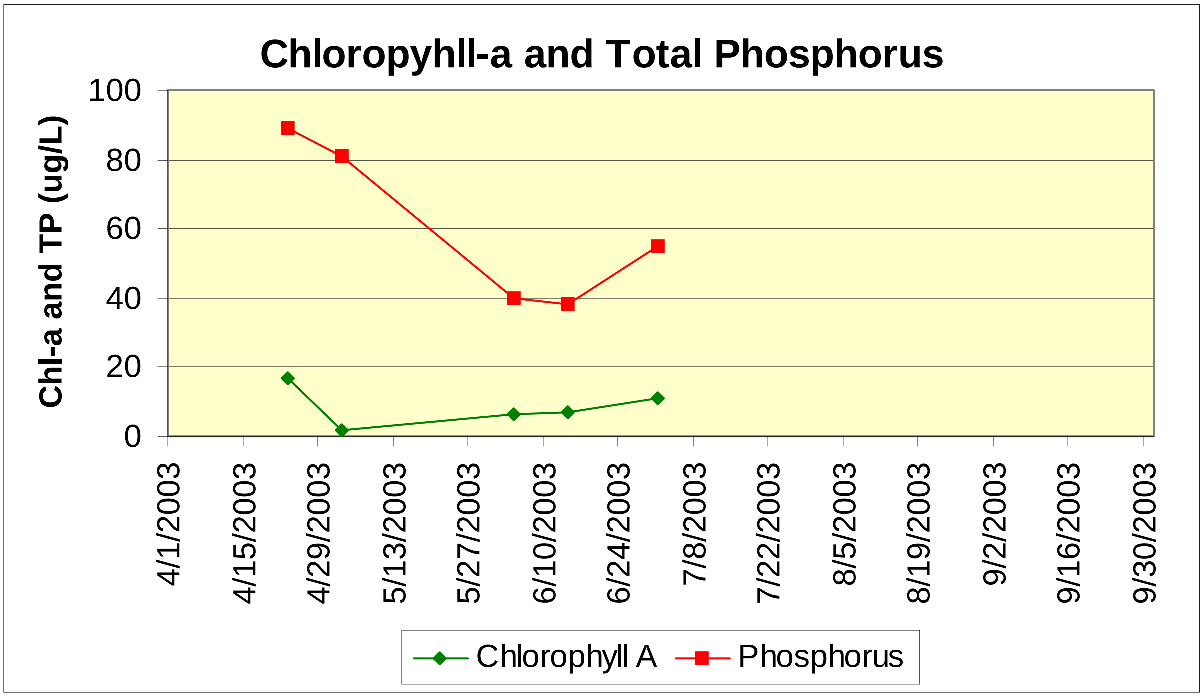


Figure 5.20. Chlorophyll-a and Total Phosphorus Concentrations for Ryan Lake in 2003

5.5 CONCLUSIONS

Monitoring data in the Twin Lakes chain of lakes suggest that the chain of lakes is a highly productive system with the greatest water quality problems occurring in North Twin Lake. North Twin Lake is a hypereutrophic lake where both internal and external phosphorous appear to be significant sources of phosphorous. Middle Twin Lake is a mesotrophic lake that is deep enough that internal loading of phosphorous may not be a significant source of phosphorous, although sediment release of phosphorous does occur. The majority of phosphorous in Middle Twin Lake is most likely from watershed loading and water coming from North Twin Lake. The hypolimnion in Middle Twin Lake can be rather large and has the potential to drop dissolved oxygen concentrations below the standard of 5.0 mg/L dissolved oxygen for the protection of warm water fisheries. Middle Twin Lake appears to experience an early summer algal bloom and then maintains a chlorophyll-a concentration around 15 µg/L. South Twin Lake is a eutrophic lake where internal loading has the potential to increase algal productivity throughout the season. Although South Twin Lake stratifies during the summer, the hypolimnion tended to erode throughout the season providing nutrient rich water to the growing zone. Ryan Lake is a deep, mesotrophic lake that has relatively good water quality for an urban lake. Much of the water balance for Ryan Lake comes from South Twin Lake through a drainage channel.

6.0 Linking Water Quality Targets and Sources

6.1 INTRODUCTION

A detailed nutrient budget for Twin 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.

6.2 SELECTION OF MODELS AND TOOLS

Modeling was completed using three independent platforms including SWMM, P8, and model equations extracted from BATHTUB for data from 1999. 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 basins.

6.2.1 SWMM Modeling

Hydrologic and hydraulic modeling was completed using an existing XP-SWMM model. The existing XP-SWMM model was completed in 1999 in the Twin Lakes Diagnostic Study. The 2003 Twin Lakes Management Plan used the 1999 XP-SWMM model as hydraulic and hydrologic basis for the study. The existing model was then calibrated to surface water monitoring records from 1999 and 2002. Calibration of the model was based on runoff volume for summer months.

Calibration of the model was based on runoff volumes computed by XP-SWMM compared to monitoring data collected by the Watershed Commission or the City of Brooklyn Center. Monitoring data was generally collected from June until August. Results from the volume calibration are shown in the Table 6.1.

Table 6.1. XP-SWMM calibration data for the summer months.

Monitoring Station	Monitored Volume (ft^3)	XP-SWMM Model Volume (ft^3)	Percent Difference (%)
Station #1 (2002)	43,080,840	37,766,520	-12
Station #1 (1999)	12,598,409	11,686,843	-7
Station #3 (1999)	10,141,509	9,084,563	-10

6.2.2 P8 Modeling

Montgomery Watson developed a P8 model for the Twin Lakes basin in 1999, however this model was not calibrated to data collected in 1999. Consequently, we developed the appropriate precipitation input and calibrated runoff volumes to volumes generated by the SWMM model. Table 6.2 shows the SWMM predicted volumes and calibrated P8 predicted volumes for the Twin Lakes watershed.

Table 6.2. Runoff predictions from the SWMM and P8 models after calibration.

Subwatershed	SWMM Predicted Volume (ac-ft)	P8 Predicted Volume (ac-ft)	Percent Difference
0	25	26	+4%
1	558	563	+9%
2	238	253	+6%
3	593	595	+0.03%
4	425	447	+5%
5A	113	103	-9%
5B	224	233	+4%
5C	116	127	+9%

Note: The P8 Model was calibrated to match runoff volumes from the SWMM Model.

Since P8 assumes that all wetlands provide some treatment, the current model would under predict loads from watershed 4 with DNR wetland 639W. Wetlands in watersheds 1 and 0 were set to provide no treatment of water quality. No pond data were available for ponds in subwatershed 1. However, using a particle scale factor of 1 and the 2002 water quality data, total phosphorous loads matched measured loads surprisingly well. We maintained this scale factor for the 1999 modeling assuming that the wetland loads offset any benefits from the treatment ponds not entered into the model. All other watersheds included significant ponds.

6.3 CURRENT PHOSPHOROUS BUDGET COMPONENTS

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

6.3.1 Tributary or Watershed Load

The tributary load from stormwater runoff from the watershed was developed using the P8 model calibrated to the SWMM runoff volumes for 1999. For development of the loads, we used the particle data that represents the median for particle sedimentation developed during the National Urban Runoff Program studies.

6.3.2 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 Twin Lake basins, diffusive exchange was assumed to be negligible. All exchange of phosphorous was assumed to occur through advection. Furthermore, no backwater affects were assumed in the exchange process. North Twin Lake receives the largest volume of water by far suggesting water pushing through the chain of lakes. The watershed is small enough that it is unlikely that there are significant geographic differences in rainfall intensity and amounts across the watershed.

6.3.3 Atmospheric Load

Atmospheric inputs were developed using areal loading rates for nearby lakes developed and published by Metropolitan Council Environmental Services (MCES 1981). Rates used for this study are provided in Table 6.3. However, based on discussion with MPCA, these rates were considered high for the area (Bruce Wilson, pers. com.). To account for the perceived overestimation, we reduced the atmospheric loading by half.

Table 6.3. Areal loading rates for lakes near Twin Lakes.

Lake	Area (ha)	Atmospheric Load (kg/yr)	Areal Load (kg/ha/yr)
Medicine	359	271	0.76
Parkers	39	27	0.69
Eagle	118	111	0.94
Fish	90	91	1.0
Bass	70	54	0.77
		Arithmetic Mean =	0.83
		Median =	0.77

6.3.4 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. Internal loads were estimated independently for each of the basins. The methods for estimating these loads are described below.

6.3.4.1 North Twin Lake Internal Load

Since North Twin Lake stays mixed throughout the season, estimating internal loads from measured data becomes quite difficult. However, North Twin Lake does demonstrate periods of dissolved oxygen stratification where the sediments experience periods of low oxygen or anoxic conditions. Additionally, phosphorus concentrations at the bottom of the lake were consistently higher suggesting release of phosphorus from the sediments. Based on the stratification data, North Twin Lake was assumed to release for 20% of the growing season (24 days) at a rate of 10 $mg/m^2/day$ or an annual rate of 0.7 $mg/m^2/day$. The release rate was assumed to be the median for eutrophic lakes (Nurnburg 1994). This release rate is most likely an underestimate of the internal load since littoral or shallow areas of lakes have been shown to release phosphorus at a rate of 2 to 5 mg/m2/year under oxygenated conditions (Wenck 1998) and this process would occur all year.

6.3.4.2 Middle Twin Lake Internal Load

Middle Twin Lake is a dimictic lake (mixes twice a year) that is fairly deep (maximum depth ~42 feet). Since the lake holds stratified conditions throughout the summer, the internal load was estimated using a turbulent diffusion relationship that has been successfully applied to Lakes Nokomis and Hiawatha in Minneapolis (Wenck 1998). A turbulent diffusion coefficient was determined as a function of lake surface area (Hondzo and Steffan 1993). Internal loads were estimates were based on orthophosphorous gradients between the surface and the hypolimnion, the duration of stratification, and the estimated diffusion coefficient.

6.3.4.3 South Twin Lake Internal Load

Although South Twin Lake does demonstrate stratification, it mixed quite early (mid-august) in the season that resulted in a late algal bloom. Consequently, all of the phosphorus released from the sediments became available for algal production. So, all of the phosphorus released from the sediments were included in the internal load. To calculate the internal load, a mass balance was performed for hypolimnetic total phosphorus from the beginning of the season to just prior to mixing. Based on these calculations, South Twin Lake received a total of 40 kg phosphorus during the summer period or an annual rate of 6 mg/m^2/day.

6.4 CURRENT PHOSPHORUS BUDGET

Monitoring data from 1996 and 1999 and modeling were used to estimate the current sources of phosphorus to the lakes. These phosphorous budgets are presented in Table 6.4. For purposes of this TMDL, Tributary Load and Advective Load comprise the Wasteload while Atmospheric Load and Internal Load comprise the Load. Phosphorus load from subwatersheds 1 and 3 (see Figure 3.1) represent 76% of the tributary load to North Twin Lake. Area 1 includes DNR wetland 693W. Subwatershed 3 drains a large portion of the City of Crystal. Tributary load to Middle Twin represents only 31% of the total load with the majority coming from advective load from North Twin. About half of the load for South Twin Lake comes from its watershed with the other half coming from advective flow from Middle Twin and internal loading.

All three of the basins demonstrate significant internal loading, sometimes representing as much as 15% of the total load. North Twin has a large internal phosphorous load although it only represents 15% of the total phosphorus budget for North Twin. South Twin also has a large internal load but a very short hydraulic residence time (0.095 years). Middle Twin also receives a significant phosphorous load from North Twin representing 58% of the total load into Middle Twin. The interaction between the basins is an important factor in the loading to the lakes.

Table 6.4. Current total phosphorus budget for Twin and Ryan Lakes based on 1996 and 1999 monitoring.

		Source	1999 Annual TP Load (kg/yr)	1996 Annual TP Load (kg/yr)
North Twin Lake	Wasteload	Watershed Load	591	467
		Upstream Load	0	0
	Load	Atmospheric Load	15	17
		Internal Load	115	115
		TOTAL LOAD	721	599

		Source	1999 Annual TP Load (kg/yr)	1996 Annual TP Load (kg/yr)
Middle Twin Lake	Wasteload	Watershed Load	87	70
		Upstream Load	102	82
	Load	Atmospheric Load	9	9
		Internal Load	54	54
		TOTAL LOAD	252	215
South Twin Lake	Wasteload	Watershed Load	156	148
		Upstream Load	160	133
	Load	Atmospheric Load	5	5
		Internal Load	40	40
		TOTAL LOAD	361	326
Ryan Lake	Wasteload	Watershed Load	86	84
		Upstream Load	143	127
	Load	Atmospheric Load	3	3
		Internal Load	40	40
		TOTAL LOAD	272	254

6.5 WATER QUALITY RESPONSE MODELING

The BATHTUB model was developed using the P8 loads and runoff volumes for 1996 and 1999. Two years were modeled to validate the assumptions of the model. Several models are available for use within the BATHTUB model. We chose the Canfield-Bachmann lake model for the phosphorus model. Since channels connect the lakes, diffusive exchange of nutrients is expected to be minimal, and the model was set so that no diffusive exchange would occur. Model 1 from the BATHTUB package was used for the chlorophyll-a model, which accounts for nitrogen, phosphorus, light, and flushing rate. For Secchi depth we chose the Heiskary and Wilson relationship (Heiskary and Wilson 1988). Detailed model results are presented in Appendix C.

No initial calibration factors were applied to any of the lakes except for the export of phosphorus from North to Middle Twin and from South Twin to Ryan Lake. This worked well for North and South Twin; however, Middle Twin was predicted to have much higher concentrations than were observed. This may have to do with the transition between the two lakes, which is highly vegetated with cattails. The sedimentation rate may increase through this complex due to slower velocities, shallower water, and increased contact with macrophytes and epiphytes. Because of this discrepancy in the model, a 75% loss of total phosphorus between North and Middle Twin was assumed based on the load needed to meet the total phosphorus concentrations measured in Middle Twin. This loss factor worked well for both modeled years. The same phenomenon was seen in Ryan Lake, where water coming from South Twin has to pass through a deep, slow moving channel dominated by macrophytes before it reaches the lake. It was assumed that 50% of the total phosphorus was lost between South Twin and Ryan Lake.

The model predicted reasonable results for chlorophyll-a in 1999, so no calibration factors were applied to the model. The model did under predict chlorophyll-a in South Twin Lake.

6.5.1 Model Validation

To test the assumptions applied in the model, the model was applied to data collected in 1996 and 1999. Phosphorus data for the 1996 season was the most complete available for all of the lakes, consequently, model validation focused on the phosphorus model. During both years, there was a significant difference in the observed and predicted concentrations in Middle Twin and Ryan Lake. This was assumed to be a result of over estimation of the load from the upstream lake. Both lakes have a significant macrophyte area between these basins where significant loss of phosphorus can occur from increased sedimentation, algae senescence from loss of light, and uptake by macrophytes and epiphytes. This was observed in both model years.

The model predicted total phosphorus concentrations in both years reasonably well. The 1996 model under-predicted summer mean total phosphorus in North Twin (123 μg/L versus 191 μg/L) which may be due to annual variability in internal loading or export from wetland 639W. No chlorophyll data was available for 1996, but Secchi depth was predicted reasonably well in all of the lakes. The water quality response model and internal load estimates were considered reasonable for the chain of lakes.

6.6 CONCLUSIONS

North Twin Lake

- Internal phosphorous load was estimated at 15 to 20% of the total load
- Much of the load from the watershed is likely a direct result of loading from DNR wetland 639W (between 15% and 42% of watershed load; see Appendix A).

Middle Twin Lake

- The largest load to Middle Twin Lake is upstream load from North Twin Lake, representing approximately 40% of the phosphorus load to Middle Twin Lake.
- Significant phosphorus loss occurred between North Twin and Middle Twin Lakes suggesting that the wetland area between the lakes may be a phosphorus sink.

South Twin Lake

- South Twin Lake has a very short residence time (0.10 years) resulting in high P-export downstream.
- Upstream loads represent 44% of the total load.

Ryan Lake

- More than half of the load to Ryan Lake is from the upstream lake (South Twin Lake).

7.0 TMDL Allocation

7.1 LOAD AND WASTELOAD ALLOCATIONS

7.1.1 Dual End Points

Minnesota's current standards for nutrients are narrative criteria that limit the quantity of nutrients which may enter waters. Minnesota's standards (Minnesota Rules 7050.0150(3)) state that in all Class 2 waters of the State "…there shall be no material increase in undesirable slime growths or aquatic plants including algae…" In accordance with Minn. Rules 7050.0150(5), to evaluate whether a waterbody is in an impaired condition the MPCA has 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 establish numeric thresholds for phosphorus, chlorophyll-a, and clarity as measured by Secchi depth.

These translators are based on the known relationship between phosphorus concentrations and levels of algae growth. The numeric standards indicate the point at which the average lake will experience severe nuisance blooms of algae. The actual threshold varies from lake to lake based on individual assimilative capacity, and from year to year based on precipitation and other external forces.

Nutrient loads in this TMDL are set for phosphorus, since this is typically the limiting nutrient for nuisance aquatic plants. This TMDL is written to solve the TMDL equation for both the current water quality standards and the proposed standards that provide different criteria for shallow lakes. The new rules provide for nutrient cycling differences between shallow and deep lakes, resulting in more appropriate standards for Minnesota Lakes. South Twin and North Twin are shallow lakes and would be subject to the numeric target of 60µg/L of total phosphorus once the proposed standards are approved. Therefore, this TMDL assumes that the current water quality standards (the numeric translator threshold of 40µg/L of total phosphorus for all four lakes) will apply and will guide the development of an implementation plan and necessary reductions until the proposed standards have been adopted. At that time the targets will be 40µg/L of total phosphorus for Middle Twin and Ryan and 60µg/L of total phosphorus for South and North Twin. This TMDL presents load and wasteload allocations and estimated load reductions for both scenarios.

7.1.2 Allocation Approach

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 are combined in this TMDL as Gross Wasteload Allocations (see Table 7.1) assigned to all permitted dischargers in the contributing lakeshed. Only one industrial discharger (MNG250048; non-contact cooling water) exists in the watershed. As discussed in Section 4.2 above, it is unlikely that this discharge is a phosphorus source and thus the discharger has not been assigned a wasteload allocation. If in the future it is determined that this discharge is a phosphorus source, then this discharger will be assigned a wasteload allocation.

The Load Allocation is allocated in the same manner including atmospheric deposition, internal loading, and additional loading from the degraded wetland complex (639W) as a gross load. The relative proportions of these sources are presented in Section 9 of this report. Each permitee has agreed to implement BMPs to the maximum extent practicable. 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.

Table 7.1. Wasteload allocation by NPDES permitted facility for each lake.

NPDES Permit Number	North Twin	Middle Twin	South Twin	Ryan
MS400006-Brooklyn Center	Gross WLA	Gross WLA	Gross WLA	Gross WLA
MS400007-Brooklyn Park	Gross WLA	Gross WLA	Gross WLA	Gross WLA
MS400012-Crystal	Gross WLA	Gross WLA	Gross WLA	Gross WLA
MN0061018-Minneapolis	N/A	N/A	N/A	Gross WLA
MS400039-New Hope	Gross WLA	Gross WLA	Gross WLA	Gross WLA
MS400046-Robbinsdale	N/A	Gross WLA	Gross WLA	Gross WLA
MS400138-Hennepin	Gross WLA	Gross WLA	Gross WLA	Gross WLA
MS400170-MnDOT	N/A	Gross WLA	Gross WLA	Gross WLA

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

7.1.3 Critical Condition

The assimilative capacity of the lake varies with changes in the water load and ultimately precipitation amounts. To address these changes a TMDL was set for average, dry, and wet conditions. For each of these conditions, the load allocation, which includes atmospheric loading and internal loading, was assumed to remain the same. It is possible that the internal load may increase in dry years. However, the scientific tools and data are not available to predict these changes. However, comparing the internal load proportions in a dry versus wet year does give some insight into the importance of this source under varied conditions. Additionally, the variability in internal loading will be monitored and addressed under implementation through adaptive management. As the scientific tools improve and we understand more about nutrient cycling in the lakes, the BMPs will be adjusted to address those concerns. The selected average precipitation year was 1999 when an average precipitation total was measured. For the wet and dry years, the maximum and minimum allowable loads were used as calculated using the Canfield-Bachmann equation for monitored years over the past ten years (see Section 7.2.1). The annual precipitation conditions are based on actual precipitation received during the period of our monitoring record. The wet year TMDL was calculated from the lake response model for the wettest year in the record, 2002. The dry year was calculated from the driest year, 1996. The average year was 1999, when actual annual precipitation was close to the long-term average annual precipitation for the region. The TMDL equations represent loads for the critical conditions in the lakes.

The critical condition for these lakes is the summer growing season for wet, dry and average precipitation years. Minnesota lakes typically demonstrate impacts from excessive nutrients during the summer recreation season (June 1 through September 31) 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 liked 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.

7.1.4 Allocations

The loading capacity is the total maximum daily load. The load and wasteload allocations are shown in Tables 7.2 and 7.3. Table 7.2 shows the allocations necessary to achieve the current water quality standard, while Table 7.3 shows the allocations necessary to achieve the proposed standard. The current water quality standards will guide the development of an implementation plan and necessary reductions until the proposed standards have been adopted, at which time those allocations and reductions will guide implementation.

Table 7.2. TMDL total phosphorus allocations expressed as daily loads for North Twin, Middle Twin, South Twin, and Ryan Lakes, assuming current standards (40 µg/L) for North and South Twin Lake.

Critical Conditions	Lake	Wasteload TP Allocation (kg/day)[1]	Load TP Allocation (kg/day)	Margin of Safety	Total Phosphorus TMDL (kg/day)
Average Precipitation Year	North Twin Lake[2]	0.9	0.5	Implicit	1.4
	Middle Twin Lake	0.4	0.2	Implicit	0.6
	South Twin Lake	1.5	0.1	Implicit	1.6
	Ryan Lake	0.5	0.1	Implicit	0.6
Wet Precipitation Year	North Twin Lake[2]	1.7	0.5	Implicit	2.2
	Middle Twin Lake	0.7	0.2	Implicit	0.9
	South Twin Lake	2.3	0.1	Implicit	2.4
	Ryan Lake	0.8	0.1	Implicit	0.9
Dry Precipitation Year	North Twin Lake[2]	0.8	0.5	Implicit	1.3
	Middle Twin Lake	0.3	0.2	Implicit	0.5
	South Twin Lake	1.5	0.1	Implicit	1.6
	Ryan Lake	0.4	0.1	Implicit	0.5

[1]The wasteload allocation is allocated to NPDES-permitted facilities in accordance with Table 7.1.
[2]The load allocation includes 15% of the stormwater load due to loading from wetland 639W.

Table 7.3. TMDL total phosphorus allocations expressed as daily loads for North Twin, Middle Twin, South Twin, and Ryan Lakes assuming shallow lake standards(60 µg/L) for North and South Twin Lake.

Critical Conditions	Lake	Wasteload TP Allocation (kg/day)[1]	Load TP Allocation (kg/day)	Margin of Safety	Total Phosphorus TMDL (kg/day)
Average Precipitation Year	North Twin Lake[2]	1.6	0.7	Implicit	2.3
	Middle Twin Lake	0.4	0.2	Implicit	0.6
	South Twin Lake	2.1	0.4	Implicit	2.5
	Ryan Lake	0.5	0.1	Implicit	0.6
Wet Precipitation Year	North Twin Lake[2]	2.7	0.7	Implicit	3.4
	Middle Twin Lake	0.7	0.2	Implicit	0.9
	South Twin Lake	3.3	0.4	Implicit	3.7
	Ryan Lake	0.8	0.1	Implicit	0.9
Dry Precipitation Year	North Twin Lake[2]	1.4	0.7	Implicit	2.1
	Middle Twin Lake	0.3	0.2	Implicit	0.5
	South Twin Lake	2.1	0.4	Implicit	2.5
	Ryan Lake	0.4	0.1	Implicit	0.5

[1]The wasteload allocation is allocated to NPDES-permitted facilities in accordance with Table 7.1.
[2]The load allocation includes 15% of the stormwater load due to loading from wetland 639W.

7.2 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.

7.2.1 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.

North Twin Lake requires a 16 to 76 percent reduction to meet the proposed water quality standard of a summer average of 60 µg/L total phosphorus (Figure 7.1). Over the past ten years the lowest allowable load on an annual basis was 253 kilograms phosphorus and the maximum allowable load was 420 kilograms of phosphorus.

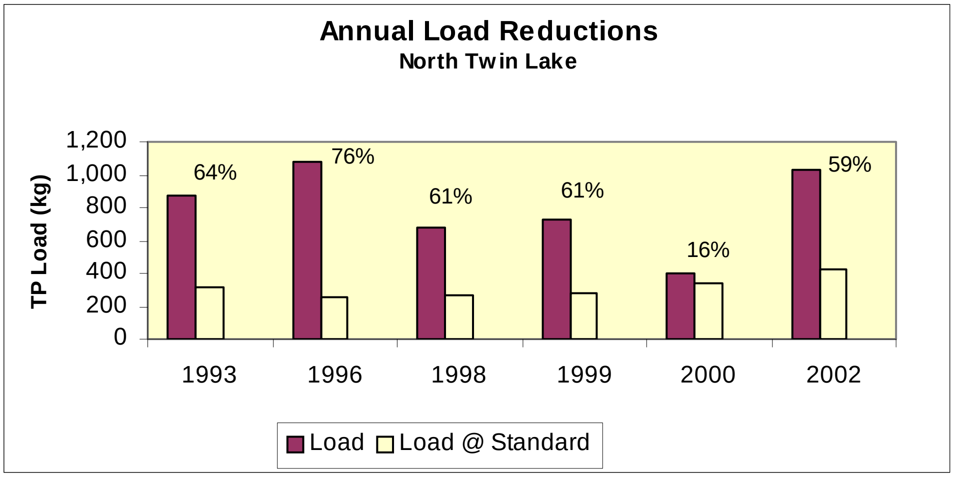


Figure 7.1. Modeled Annual Load and Load at the Standard for North Twin Lake
The percentages represent the reduction needed to meet the standard.

Middle Twin Lake met the standard (40 µg/L) in 1996 and required a 13 to 33 percent reduction in the remaining years (Figure 7.2). The reductions required would be exceeded in Middle Twin Lake if North Twin Lake were brought into compliance.

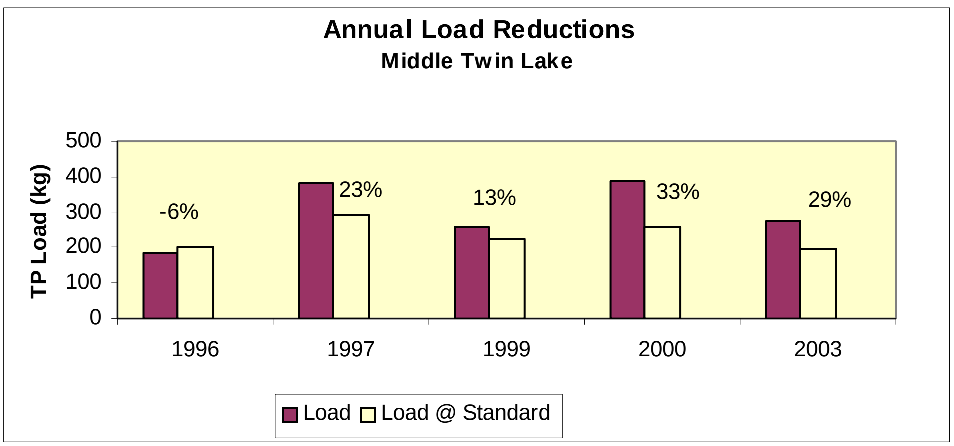


Figure 7.2. Modeled Annual Load and Load at the Standard for Middle Twin Lake
The percentages represent the reduction needed to meet the standard.

South Twin Lake demonstrates a great deal of variability in water quality conditions with load reductions raging from 0 to 65 percent (Figure 7.3) to meet the proposed standard (60 µg/L). The greatest opportunities for reducing loads to South Twin Lake are through watershed and internal load reductions since the load from Middle Twin is lower in total phosphorus than the proposed standard for South Twin Lake (60 µg/L).

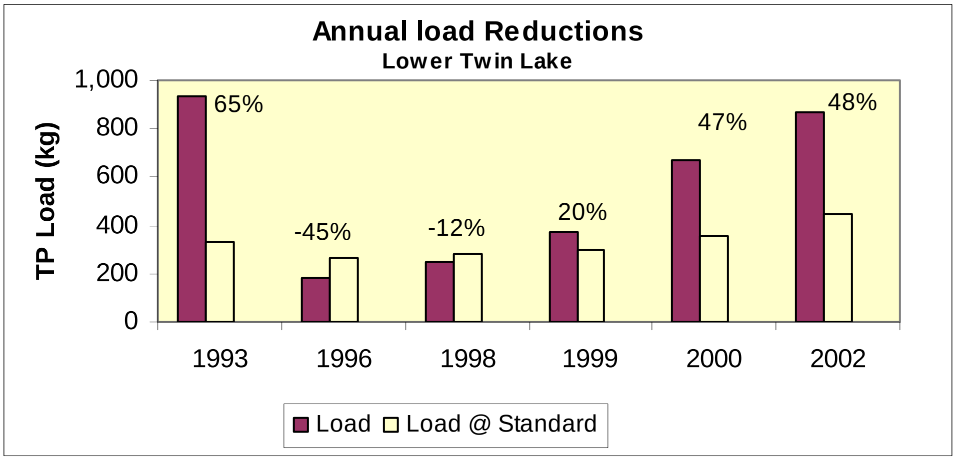


Figure 7.3. Modeled Annual Load and Load at the Standard for South Twin Lake
The percentages represent the reduction needed to meet the standard.

Ryan Lake met the water quality standard (40 μg/L) in 1996 and required an 8 to 54 % reduction in the remaining years (Figure 7.4). Most years only required an 8 to 10 percent reduction to meet the standard, which could be achieved by compliance in South Twin Lake through reduced loads from South Twin to Ryan Lake.

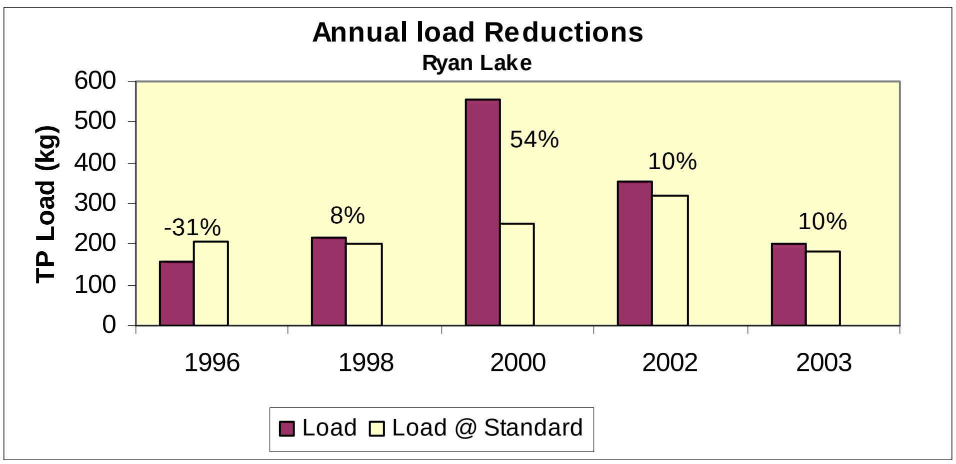


Figure 7.4. Modeled Annual Load and Load at the Standard For Ryan Lake.
The percentages represent the reduction needed to meet the standard.

7.2.2 Water Quality Response to Load Reductions

Using the previously described BATHTUB water quality response model, total phosphorous, 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.

Two scenarios were evaluated for the Twin Lakes basins. The first scenario evaluated was performing load reductions to all of the basins and their watershed equally. The reductions were applied to the overall loads including precipitation and internal loading. The second scenario evaluated load reductions to the North Twin Lake basin only. This scenario was developed to evaluate the impacts of North Twin Lake on the other basins since the majority of the water balance runs through North Twin Lake. These reductions help provide an understanding of the response of the lakes for load reductions regardless of their source.

7.2.3 Phosphorus

The modeled response to phosphorus load reductions in all basins is presented in Figure 7.5.

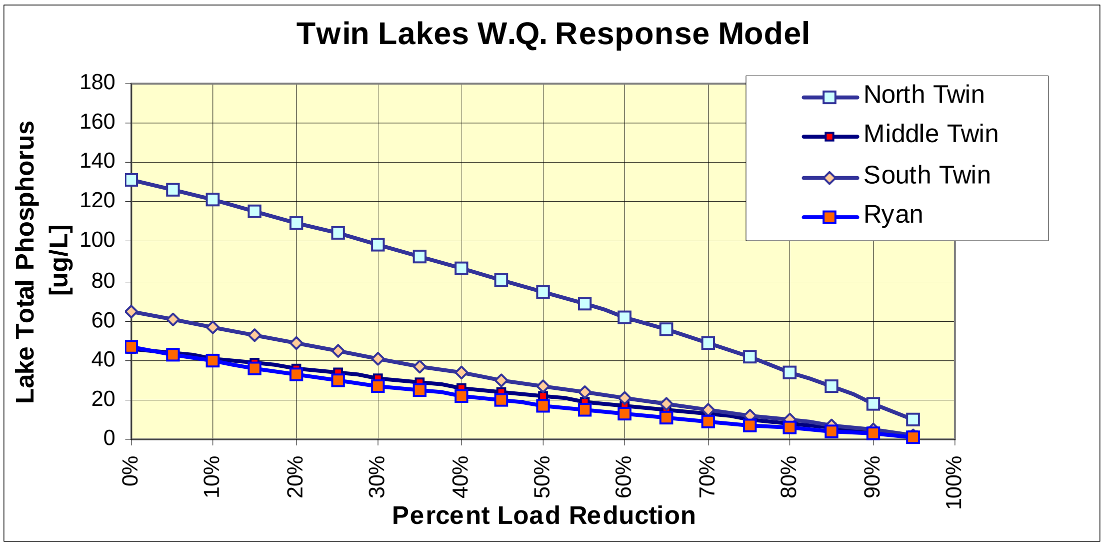


Figure 7.5. In Lake Total Phosphorus Concentrations Predicted for Total Phosphorus Load Reductions Applied to all Sources

The majority of the water load to the lakes comes from North Twin. Consequently, Middle and South Twin Lakes receive large loads from North Twin Lake. Since the water quality in Middle Twin is much better than South Twin, changes in North Twin have little effect on South Twin Lake's water quality.

To evaluate the interaction between the North Twin and Middle Twin basins, load reductions to North Twin only were evaluated (Figure 7.6). Middle Twin Lake could reach 40 µg/L total phosphorus through a 40% reduction in loading to North Twin. Ryan Lake is similarly linked to South Twin Lake where a reduction in summer average total phosphorus concentrations in South Twin Lake reduces the load to Ryan Lake, ultimately improving water quality in Ryan Lake.

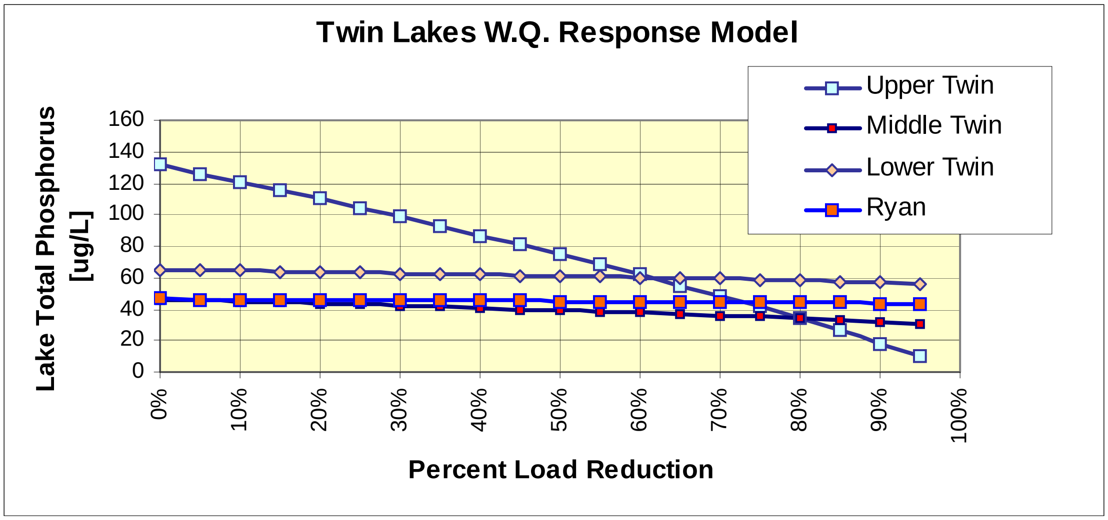


Figure 7.6. In Lake Total Phosphorus Concentrations Predicted for Total Phosphorus Load Reductions applied to North Twin Lake

7.2.4 Chlorophyll-a

Modeled chlorophyll-a concentrations with each load reduction are presented in Figure 7.7. Chlorophyll-a concentrations go down with reductions in total phosphorus. Based on the results of the model, North Twin would need a greater reduction in total phosphorus to reach the chlorophyll-a goal for shallow lakes (20 µg/L). However, there is a fair amount of variability in the model, so chlorophyll-a response to phosphorus concentrations will be monitored under adaptive management.

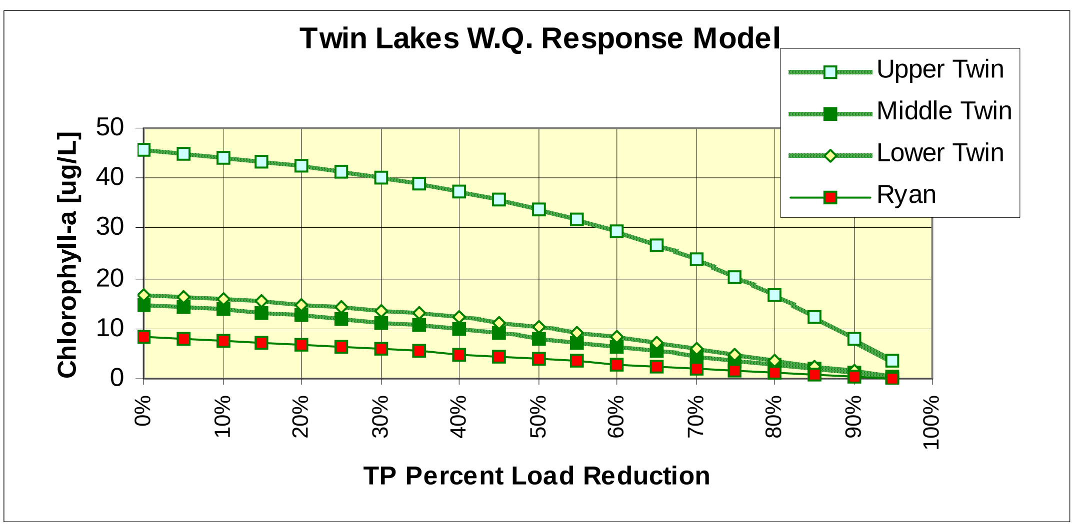


Figure 7.7. In Lake Chlorophyll-a Concentrations Predicted for Total Phosphorus Load Reductions applied to all Basins

7.2.5 Secchi Depth

Secchi depth was not very responsive to load reductions, with a stronger response after a 40% load reduction (Figure 7.8). North Twin Lake demonstrated a stronger response after a 70% reduction in loads. Based on the model, Secchi depth should respond to changes in total phosphorus loads.

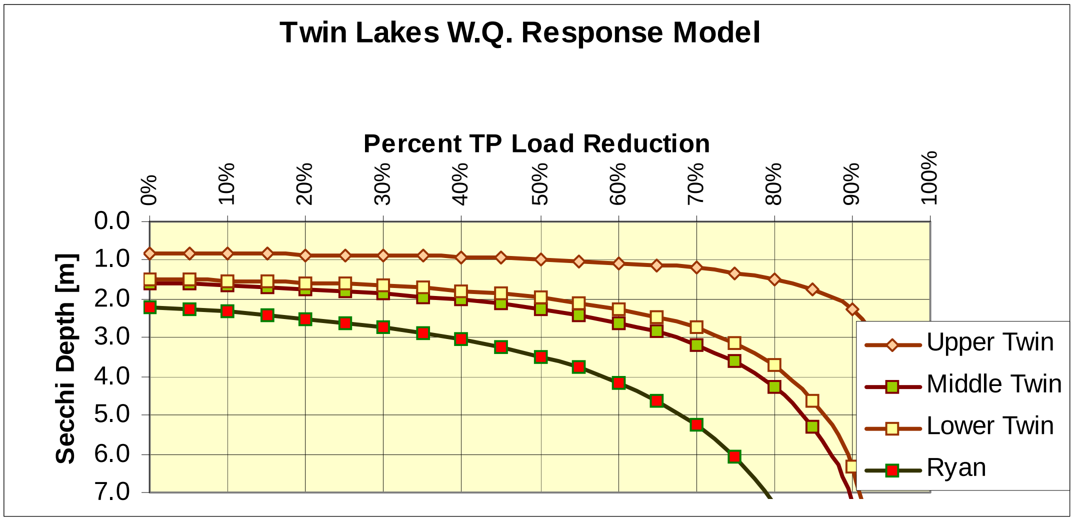


Figure 7.8. Secchi Depth Predicted for Total Phosphorus Load Reductions Applied to All Basins

7.3 SEASONAL AND ANNUAL VARIATION

Total precipitation in 1999 was 30.6 inches with a 30-year normal around 28.3 inches. 1999 was a fairly average year for precipitation and is used in the modeling to represent an average year. Consequently, the 1999 model is an average year model that can be used as a benchmark for load analyses. The TMDL was also established for wet and dry conditions to reflect the variable assimilative capacity of the lakes dependent on water loads and resultant flushing.

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. Although the critical period is the summer, lakes are not sensitive to short term changes in water quality, rather lakes respond to long-term changes such as changes in the annual load. Therefore, seasonal variation is accounted for in the annual loads. 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.

7.4 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-predicts 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 expected higher sedimentation rates expected in healthy shallow lake systems.

Secondly, 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 Minnesota lakes providing an additional margin of safety.

7.5 RESERVE CAPACITY/FUTURE GROWTH

The watersheds for these lakes are all fully covered by MS4 communities and are included in the Wasteload Allocation. Land use in the Twin-Ryan Lake watershed did not change significantly between 1997 and 2000. The watershed is essentially built out, and a vast majority of the development projects that occur are redevelopment. There was an increase of about 80 acres in park space and almost 125 acres of vacant land was converted between 1997 and 2000. No new NPDES sources are anticipated in these watersheds, therefore no portion of the Wasteload Allocation is being held in reserve.

Future growth will not affect this TMDL. Additionally, the Shingle Creek Watershed Management Commission has rules in place for development and redevelopment that are protective of water quality. Consequently, future development will have to meet watershed requirements that will account for this TMDL.

Table 7.4. Change in land use in the Twin Lake watershed from 1997 to 2000.

Category	1997 area (acre)	2000 area (acre)	LU change (acre)	LU change (%)
Single Family Residential	2,611	2,662	+50.7	+0.96%
Multi-Family Residential	418	434	+15.3	+0.29%
Commercial	333	338	+5.1	+0.10%
Industrial and Utility	281	309	+28.0	+0.53%
Public Semi-Public	327	344	+16.8	+0.32%
Airport	410	381	-29.6	-0.56%
Parks & Recreation Areas	247	327	+80.2	+1.52%
Major Highway	125	80	-44.6	-0.85%
Water	227	227	+0.2	+0.00%
Vacant/Agricultural	281	156	-125.0	-2.38%

8.0 Public Participation

8.1 INTRODUCTION

As a part of the strategy to achieve implementation of the necessary allocations, the SCWMC seeks stakeholder and public engagement and participation regarding their concerns, hopes, and questions regarding the development of the TMDL. Specifically, meetings were held for a Technical Advisory Committee representing key stakeholders. Additionally, the SCWMC is planning on holding several stakeholder meetings to discuss the TMDL and implementation. Following the stakeholder meetings, public meetings will be held.

8.2 TECHNICAL ADVISORY COMMITTEE

A technical advisory committee was established to so that interested stakeholders were involved in key decisions involved in developing the TMDL. Stakeholders represented on the Technical Advisory Committee include local cities, Minnesota DNR, the Metropolitan Council, the USGS and the Minnesota Pollution Control Agency. All meetings were open to interested individuals and organizations. Technical Advisory Committee meetings to review this and other lake TMDLs in the watershed were held on December 8, 2005, February 10, 2006, March 9, 2006, and June 27, 2007.

8.3 STAKEHOLDER MEETINGS

A stakeholder meeting was held on October 11, 2005. Stakeholders included representatives from agencies, local permit holders including contributing cities, Hennepin County, and the Shingle Creek Watershed Management Commissions as well as other interested parties such as the Three Rivers Park District. The meetings were focused on allocation of the wasteload and implementation.

9.0 Implementation

9.1 IMPLEMENTATION FRAMEWORK

9.1.1 The Single Creek Watershed Management Commission

The SCWMC is committed to improving water quality in the Shingle Creek watershed. To this end, the SCWMC completed a Water Quality Plan and adopted it as a Major Plan Amendment to its Watershed Management Plan. A number of activities are detailed in the Management Plan over the next ten years, including developing individual management plans for water resources.

The Shingle Creek Water Quality Plan (WQP):

- Sets forth the Commissions' water quality goals, standards, and methodologies in more detail than the general goals and policies established in the Second Generation Watershed Management Plan.
- Provides philosophical guidance for completing water resource management plans and TMDLs; and
- Provides direction for the ongoing water quality monitoring programs that will be essential to determining if the TMDLs and implementation program are effectively improving water quality.

The Water Quality Plan is composed of four parts:

- A monitoring plan to track water quality changes over time;
- Detailed management plans for each resource to lay out a specific plan of action for meeting water quality goals;
- A capital improvement plan; and
- An education and public outreach plan.

This WQP charts the course the Commission will take to meet its Second Generation Watershed Management Plan goals to protect and improve water quality and meet Commission and State water quality standards. While the Plan lays out a series of activities and projects, implementation will occur as the Commission's and cities' budgets permit. The Commission as part of the Major Plan Amendment process also revised its cost share formula to provide for Commission participation in the cost of TMDL implementation projects.

The Commission has received significant grant funding from the Minnesota Pollution Control Agency, the Board of Water and Soil Resources, the Metropolitan Council, and the Department of Natural Resources to undertake planning and demonstration projects. The Commission intends to continue to solicit funds and partnerships from these and other sources to supplement the funds provided by the nine cities having land in the Shingle Creek watershed.

The Shingle Creek Watershed Management Commission's Second Generation Watershed Management Plan provides for the development over the next several years of individual management plans for each of the high priority water resources in the watershed. In its Work Plan and Capital Improvement Plan (CIP) the Commission set up a process and budgeted resources to systematically work in partnership with its member cities to develop lake management plans that meet both local and watershed needs, and do so in a consistent manner across the watershed.

9.2 REDUCTION STRATEGIES

9.2.1 Annual Load Reductions

The focus in implementation will be on reducing the annual phosphorus loads to the lakes through structural and nonstructural Best Management Practices. The Total Maximum Daily Loads established for these lakes are shown in Tables 9.1 and 9.2 below as annual loads, for both the current water quality standard and the proposed standard.

Table 9.1. TMDL allocations expressed as annual loads for North Twin, Middle Twin, South Twin, and Ryan Lakes assuming current standards (40 µg/L) for North and South Twin Lake.

Critical Conditions	Lake	Wasteload Allocation (kg/yr)[1]	Load Allocation (kg/yr)	Margin of Safety	TMDL (kg/yr)
Average Precipitation Year	North Twin Lake[2]	118	55	Implicit	173
	Middle Twin Lake	150	63	Implicit	213
	South Twin Lake	179	15	Implicit	194
	Ryan Lake	170	43	Implicit	213
Wet Precipitation Year	North Twin Lake[2]	210	55	Implicit	265
	Middle Twin Lake	263	63	Implicit	326
	South Twin Lake	276	15	Implicit	291
	Ryan Lake	298	23	Implicit	321
Dry Precipitation Year	North Twin Lake[2]	100	55	Implicit	155
	Middle Twin Lake	127	63	Implicit	190
	South Twin Lake	176	15	Implicit	191
	Ryan Lake	162	43	Implicit	205

[1]The wasteload allocation is allocated to NPDES-permitted facilities in accordance with Table 7.1.
[2]The load allocation includes 15% of the stormwater load due to loading from wetland 639W.

Load allocations by source are provided in Tables 9.2 and 9.4 for average precipitation conditions. 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 (advective loads from the upstream basin). Based on the results of the model, if North Twin Lake met the standard for shallow lakes in the North Central Hardwood Forests ecoregion, the reduction of the outflow load would result in the remaining lakes in the chain complying with the State standards. However, this analysis is based on one year. Because lakes are uniquely dynamic systems, a dry year may result in increases in internal loading counteracting the effects of reduced advective inflow from upstream. As a result, implementation will address not only North Twin Lake, but also stormwater discharges to the other basins as well as internal loading where appropriate. However, the TMDLs established here remain protective of the water quality standards for each of the basins.

Table 9.2. TMDL total phosphorus loads (average conditions) partitioned among the major sources for each lake in the chain assuming current standards (40 µg/L) for North and South Twin Lake.

		Source	Total Maximum Daily TP Load (kg/day)	Percent of Total
North Twin Lake	Wasteload	Stormwater Load	1.0	71%
	Load	Atmospheric Load	0.1	7%
		Internal Load	0.3	22%
		TOTAL LOAD	**1.4**	**48 to 85% Reduction Required**
Middle Twin Lake	Wasteload	Stormwater Load	0.4	67%
	Load	Atmospheric Load	0.02	3%
		Internal Load	0.18	30%
		TOTAL LOAD	**0.6**	**0 to 33% Reduction Required**
South Twin Lake	Wasteload	Stormwater Load	1.5	94%
	Load	Atmospheric Load	0.02	3%
		Internal Load	0.08	5%
		TOTAL LOAD	**1.6**	**8 to 77% Reduction Required**
Ryan Lake	Wasteload	Stormwater Load	0.5	83%
	Load	Atmospheric Load	0.01	2%
		Internal Load	0.09	15%
		TOTAL LOAD	**0.6**	**0 to 54% Reduction Required**

Table 9.3. TMDL Allocations expressed as annual loads for North Twin, Middle Twin, South Twin, and Ryan Lakes assuming shallow lake standards(60 µg/L) for North and South Twin Lake.

Critical Conditions	Lake	Wasteload Allocation (kg/yr)[1]	Load Allocation (kg/yr)	Margin of Safety	TMDL (kg/yr)
Average Precipitation Year	North Twin Lake[2]	192	85	Implicit	277
	Middle Twin Lake	141	63	Implicit	204
	South Twin Lake	258	45	Implicit	303
	Ryan Lake	170	43	Implicit	213
Wet Precipitation Year	North Twin Lake[2]	335	85	Implicit	420
	Middle Twin Lake	263	63	Implicit	326
	South Twin Lake	405	45	Implicit	450
	Ryan Lake	278	43	Implicit	321
Dry Precipitation Year	North Twin Lake[2]	165	85	Implicit	250
	Middle Twin Lake	130	63	Implicit	193
	South Twin Lake	252	45	Implicit	297
	Ryan Lake	167	43	Implicit	210

[1]The wasteload allocation is allocated to NPDES-permitted facilities in accordance with Table 7.1.
[2]The load allocation includes 15% of the stormwater load due to loading from wetland 639W.

Table 9.4. TMDL total phosphorus loads (average conditions) partitioned among the major sources for each lake in the chain assuming shallow lake standards (60 µg/L) for North and South Twin Lake.

		Source	Total Maximum Daily TP Load (kg/day)	Percent of Total
North Twin Lake	Wasteload	Stormwater Load	1.6	70%
	Load	Atmospheric Load	0.1	4%
		Internal Load	0.6	26%
		TOTAL LOAD	**2.3**	**16 to 76% Reduction Required**
Middle Twin Lake	Wasteload	Stormwater Load	0.4	67%
	Load	Atmospheric Load	0.02	3%
		Internal Load	0.18	30%
		TOTAL LOAD	**0.6**	**0 to 33% Reduction Required**
South Twin Lake	Wasteload	Stormwater Load	2.1	84%
	Load	Atmospheric Load	0.04	2%
		Internal Load	0.36	14%
		TOTAL LOAD	**2.5**	**0 to 65% Reduction Required**
Ryan Lake	Wasteload	Stormwater Load	0.5	83%
	Load	Atmospheric Load	0.01	2%
		Internal Load	0.09	15%
		TOTAL LOAD	**0.6**	**0 to 54% Reduction Required**

9.2.2 Actions

Restoration options for lakes are numerous with varying rates of success. Consequently, each technology must be evaluated in light of our current understanding physical and biological processes in that lake. An investigation of current lake and watershed management technologies with recommendations compared to their effectiveness on Twin Lake was completed as a part of the Twin Lake Diagnostic Study and Management Plan (City of Brooklyn Center 2004). Following is a description of potential actions for controlling nutrients in the Twin Lake watershed that will be further developed in the Twin Lake Implementation Plan:

<u>All Lakes</u>

- Conduct aquatic plant surveys
- Shoreline restoration to improve runoff filtration
- Increase infiltration in direct runoff watershed
- Increase frequency of street sweeping

<u>North Twin Lake</u>

- Rough fish removal
- Focus on reducing external loads
    - Add water quality ponds in watershed 3
    - Monitor and maintain existing ponds to sustain removal effectiveness
    - Retrofit with offline underground treatment devices
- Restore DNR wetland 639W

Middle Twin Lake

- Load from North Twin Lake is important
    - Reductions in North Twin Lake will directly impact Middle Twin Lake

South Twin Lake

- Focus on reducing external loads
    - Add water quality ponds in watershed 4
    - Monitor and maintain existing ponds to sustain removal effectiveness
    - Retrofit with offline underground treatment devices
- Internal load management
    - Alum treatment may be feasible

Ryan Lake

- Focus on reducing external loads
    - Increase treatment in lakeshed
    - Monitor and maintain existing treatment to sustain removal effectiveness
    - Increase rain gardens, filtration in lakeshed
    - Shoreline restoration and maintenance
- Conduct plant survey and prepare management plan
- Internal load management
    - Biological management

9.2.3 Studies

Following are recommended studies needed to further refine management actions in Twin Lake and its watershed:

1. Aquatic Plant Management Plan
2. DNR wetland 693W Restoration Feasibility and Design

9.3 IMPLEMENTATION STRATEGY

An implementation plan has been developed by the City of Brooklyn Center for the Twin Lake chain of lakes (Appendix B). The goals presented in the management plan are aggressive goals for urban lakes since rarely have these reductions been achieved. Additionally, these goals may not be obtainable without some control of internal phosphorus sources. Established technologies for internal controls may be inappropriate, cost prohibitive, or unproven. Consequently, the management plan focuses on external phosphorus controls. However, internal controls will need to be addressed to reach the TMDL goals established in this document.

The Shingle Creek Watershed Management Commission is currently working with the cities to develop and adopt a management plan for each of these lakes and to incorporate many of the activities into its Capital Improvement Program and Management Activity schedule. Following adoption the Commission will work in partnership with the local cities to implement the recommended activities.

10.0 Reasonable Assurance

10.1 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.

10.2 THE SHINGLE CREEK WATERSHED MANAGEMENT COMMISSION

The Shingle Creek Watershed Management Commission was formed in 1984 using a Joint Powers Agreement developed under authority conferred to the member communities by Minnesota Statutes 471.59 and 103B.201 through 103B.251. The Commission's purpose is to preserve and use natural water storage and retention in the Shingle Creek watershed to meet Surface Water Management Act goals.

The Metropolitan Surface Water Management Act (Chapter 509, Laws of 1982, Minnesota Statute Section 473.875 to 473.883 as amended) establishes requirements for preparing 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. Strategies and policies for each goal were developed to serve as a management framework. To implement these goals, policies, and strategies, the Commissions have developed the Capital Improvement Program and Work Plan discussed in detail in the Second Generation Plan (SCWMC 2004). In 2007 the Commission adopted a Water Quality Plan, revised Capital Improvement Program, and Cost Sharing Policy to further progress toward meeting water quality goals.

The philosophy of the Joint Powers Agreement is that the management plan establishes certain common goals and standards for water resources management in the watersheds, agreed to by the nine cities having land in the watershed, and implemented by those cities by activities at both the Commission and local levels. TMDLs developed for water bodies in the watershed will be used as guiding documents for developing appropriate goals, policies, and strategies and ultimately sections of the Capital Improvement Program and Work Plan.

The Commission has received significant grant funding from the Minnesota Pollution Control Agency, the Board of Water and Soil Resources, the Metropolitan Council, and the Department of Natural Resources to undertake planning and demonstration projects. The Commission intends to continue to solicit funds and partnerships from these and other sources to supplement the funds provided by the nine cities having land in the watershed. It is expected that the Commission will continuously update the annual Capital Improvement Programs (CIPs) as a part of their annual budget process.

10.3 NPDES MS4 STORMWATER PERMITS

NPDES Phase II stormwater permits are in place for each of the member cities in the watershed as well as Hennepin County 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.

NPDES Phase II permits for small municipal separate storm sewer systems (MS4) have been issued to the member cities in the watershed as well as Hennepin County and Mn/DOT. The City of Minneapolis has an individual NPDES permit for Stormwater – NPDES Permit # MN 0061018. The other cities, Hennepin County and MnDOT Metro District, are covered under the Phase II General NPDES Stormwater Permit – MNR040000. Not all the MS4s in the watershed drain to the Twin Lake chain. The unique permit numbers assigned to the cities that drain to the chain of lakes, Hennepin County and MnDOT Metro District are as follows:

- Brooklyn Center – MS400006
- Brooklyn Park – MS400007
- Crystal – MS400012
- Minneapolis – MN0061018
- New Hope – MS400039
- Robbinsdale – MS400046
- Hennepin County – MS400138
- MnDOT Metro District – MS400170

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 are combined in this TMDL as Gross Wasteload Allocations (see Table 7.1). The Load Allocation is also allocated in the same manner. Each stakeholder has agreed to implement BMPs to the maximum extent practicable. 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 Shingle Creek Watershed Management Commission.

The following MS4s, while located in the Shingle Creek watershed, do not drain to the Twin Lake chain, and thus are not part of the Gross Wasteload Allocation:

- Maple Grove – MS400102
- Osseo – MS400043
- Plymouth – MS400112

10.4 MONITORING

10.4.1 Monitoring Implementation of Policies and BMPs

The SCWMC will evaluate progress toward meeting the goals and policies outlined in the Second Generation Plan and the Water Quality Plan. Success will be measured by completion of policies and strategies, or progress toward completion of policies and strategies. The Commission's Annual Report is presented to the public at the Commission's annual public meeting. The findings of the Annual Report and the comments received from the member cities and the public are used to formulate the work plan, budget, CIP and specific measurable goals and objectives for the coming year as well as to propose modifications or additions to the management goals, policies, and strategies.

10.4.2 Follow-up Monitoring

The SCWMC monitors water quality in local lakes through the funding of special studies and citizen volunteer efforts. Additional monitoring is proposed in the Commission's Water Quality plan in an effort to ensure the quality of data. Schedules of monitoring activities are identified in the Shingle Creek Water Quality Plan (SCWMC 2007). Results of all monitoring will be included in their annual water quality monitoring report.

All three of the Twin Lake basins and Ryan Lake will be periodically monitored by the CAMP program through the Shingle Creek Watershed Management Commission (SCWMC). The CAMP program is operated by MCES and is a volunteer monitoring program. Citizen volunteers collect data and samples biweekly.

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Twin and Ryan Lakes Nutrient TMDL

Appendix A
Wetland 639W Diagnostic Study

5.0 DNR Wetland 639W Nutrient Evaluation

5.1 INTRODUCTION

In 1999, the Shingle Creek Watershed Management Commission (SCWMC) conducted a water quality evaluation of the Twin Lake chain of lakes to better understand nutrient loading in the watershed. This evaluation suggested that DNR wetland 639W was a major source of phosphorous to Upper Twin Lake. However, this conclusion was based on modeling and not on actual data. As a result, monitoring was conducted in 2002 to evaluate DNR wetland 639W as a source of nutrients, particularly phosphorous. The goal of the study was to develop an understanding of nutrient dynamics in the wetland, identify whether it was an actual source or sink for nutrients, and quantify the export or uptake load for the wetland.

5.2 DATA COLLECTION

5.2.1 Discharge

Water levels were measured at a 15-minute interval for both the inlet and outlet sites of DNR wetland 693w during the summer of 2002. A rating curve was developed for both of these sites. The outlet site does experience some backwater effects due to its close proximity to Upper Twin Lake. These affects were accounted for in the development of the rating curves by using a dry period rating curve where no backwater affects were present and a wet-weather rating curve where the backwater affects were present. The resultant hydrographs were verified by developing a water balance for the wetland. The water balance yielded approximately 18 acre-feet more inflow to the wetland than outflow, representing a 2.5% difference. Generally, a difference of 5% or less is acceptable with a water balance spanning several months.

For calculating nutrient loads, we used a SWMM model calibrated to the wetland inlet volumes to generate hydrographs and assumed that the inflow and outflow over the water year would balance (this is also an assumption in SWMM). This provides a conservative approach to comparing loads at the wetland inlet and outlet. It is unlikely that water is lost through the wetland other than to evapotranspiration. Also some of the water entering the wetland is from Crystal Airport. However, these flow data were used in estimating inflow loads which was probably an over estimate. Over estimating inflow loads is a more conservative approach to determining what role the wetland plays in nutrient loading.

5.2.2 Water Quality

Routine water quality was monitored approximately biweekly from May to early October at the inlet and outlet of DNR wetland 639W (Figure 5.1). Two storms were sampled where water quality data was collected at three points along the hydrograph. Samples were analyzed for total suspended solids, volatile suspended solids, nitrate, total phosphorous, and dissolved phosphorous.

5.3 WATER QUALITY MONITORING RESULTS

Water quality monitoring results are presented in Table 5.1. All sample concentrations were higher at the outlet than the inlet except for nitrate. Following is a discussion of the water quality results.

Table 5.1. Water quality results at the inlet and outlet of DNR wetland 639W.

		N	Min	Max	Mean
Inlet	Sampled Flow (cfs)	21	0.47	63.4	11.6
	TSS (mg/L)	18	4	34	13.4
	VSS (mg/L)	18	4	16	7.2
	TP (mg/L)	18	0.063	0.330	0.146
	DP (mg/L)	18	0.015	0.131	0.062
	NO_3 (mg/L)	18	0.17	3.30	0.83
Outlet	Sampled Flow (cfs)	23	0.41	30.61	7.75
	TSS (mg/L)	20	4	300	50.3
	VSS (mg/L)	20	2	170	29.8
	TP (mg/L)	20	0.079	0.955	0.364
	DP (mg/L)	20	0.044	0.225	0.123
	NO_3 (mg/L)	20	0.02	2.00	0.28

5.3.1 Phosphorous

Average total and dissolved phosphorous concentrations doubled between the inlet and outlet (Table 5.1). Total phosphorus concentrations reached almost 1 mg/L for the maximum sample concentration. Box plots of the data are provided in Figure 5.2. The interquartile range for total and dissolved phosphorous is higher at the outlet then either of the middle or inlet sites. After late June, outlet phosphorous concentrations are consistently higher then inlet concentrations (Figure 5.3). Phosphorous can be released fro wetland sediments in much the same way as the hypolimnion of a lake. Wetland soils are saturated for long periods where the slow moving water can be deoxygenated by the aerobic breakdown of the wetland soils. As the oxygen is depleted, the same weak bonds that are broken to release phosphorous in the lake sediments are broken in the wetland soil (Faulkner and Richardson, 1989). Phosphorous may also be released by a change in the pH of the soils through the production of sulfuric or nitric acid by bacteria.

5.3.2 Nitrate

Nitrate concentrations are consistently lower at the outlet than the inlet (Figure 5.3) with mean concentrations (0.28 mg/L) at the outlet just above the detection limit (Table 5.1). The nitrate interquartile range is rather large at the middle sample site suggesting that nitrification might be adding nitrate to surface waters (Figure 5.2). However, all of this is lost before reaching the outlet site. Denitrification in the wetland is probably high accounting for the reduction in nitrate concentrations from the inlet to the outlet.

5.3.3 Suspended Solids

Total (TSS) and volatile (VSS) suspended solids concentrations were higher at the outlet then the inlet (Table 5.1 and Figure 5.2). Differences in TSS and VSS were mostly associated with storm events suggesting that storms are mobilizing suspended solids and carrying them from the wetland to the lake. Much of what is being mobilized is poorly degraded plant material. This material can be detrimental to the lakes in that it provides a source of phosphorous and is an oxygen demanding material. This can increase the organic content of the lake sediments, which in turn increases the sediment oxygen demand. These loads may be adding to the internal release of phosphorous in Upper Twin Lake by increasing the potential for deoxygenating the hypolimnion.

5.4 NUTRIENT LOADS

Annual loads for the wetland inlet and outlet were calculated using the FLUX water quality analysis tool (Walker 1999). The FLUX method uses daily average flow rates and monitored pollutant concentrations paired with instantaneous flows to calculate loads with six different methods. The analyst then selects the most appropriate method based on estimate variability, residuals distribution, stratification schemes, and knowledge of methods. The hydrograph used for this analysis was produced using a SWMM model calibrated to inlet volumes.

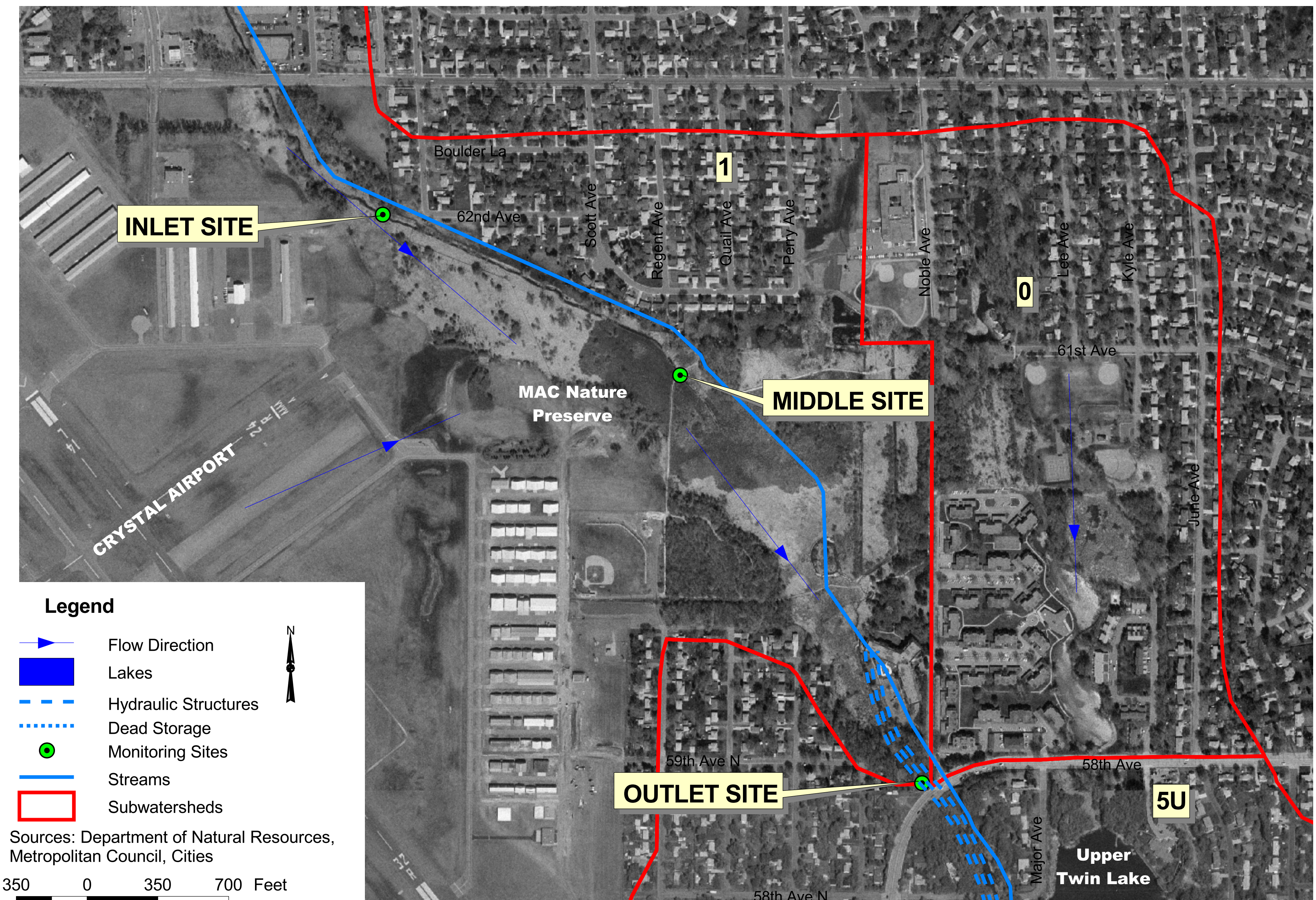
Results of load calculations for the inlet and the outlet of DNR wetland 639W are presented in Table 5.2. Outlet loads were more than double the inlet loads for suspended solids and phosphorous. The wetland is contributing approximately an additional 732 pounds of phosphorous to Upper Twin Lake and almost half of this is in a readily available dissolved form. Nitrate loads are fairly small and demonstrate loss of nitrogen from the wetland. Wetland 639W is acting as a significant source of phosphorous to Upper Twin Lake, contributing almost twice as much phosphorous as the watershed itself.

Table 5.2. Pollutant loads at the inlet and outlet of DNR wetland 639W.

Parameter	Wetland Inlet		Wetland Outlet		Load Difference
	Load (lbs/season)	Average Concentration (mg/L)	Load (lbs/season)	Average Concentration (mg/L)	
Water (acre-feet)	1,057	--	1,057	--	0
Total Suspended Solids (lbs/yr)	40,568	14.1	99,465	34.6	+58,897 (145%)
Volatile Suspended Solids (lbs/yr)	22,608	7.8	62,597	21.8	+39,989 (177%)
Total Phosphorous (lbs/yr)	366	0.127	1,098	0.382	+732 (200%)
Dissolved Phosphorous (lbs/yr)	179	0.062	386	0.134	+307 (172%)
Nitrate (lbs/yr)	1,614	0.56	833	0.29	-781 (48%)

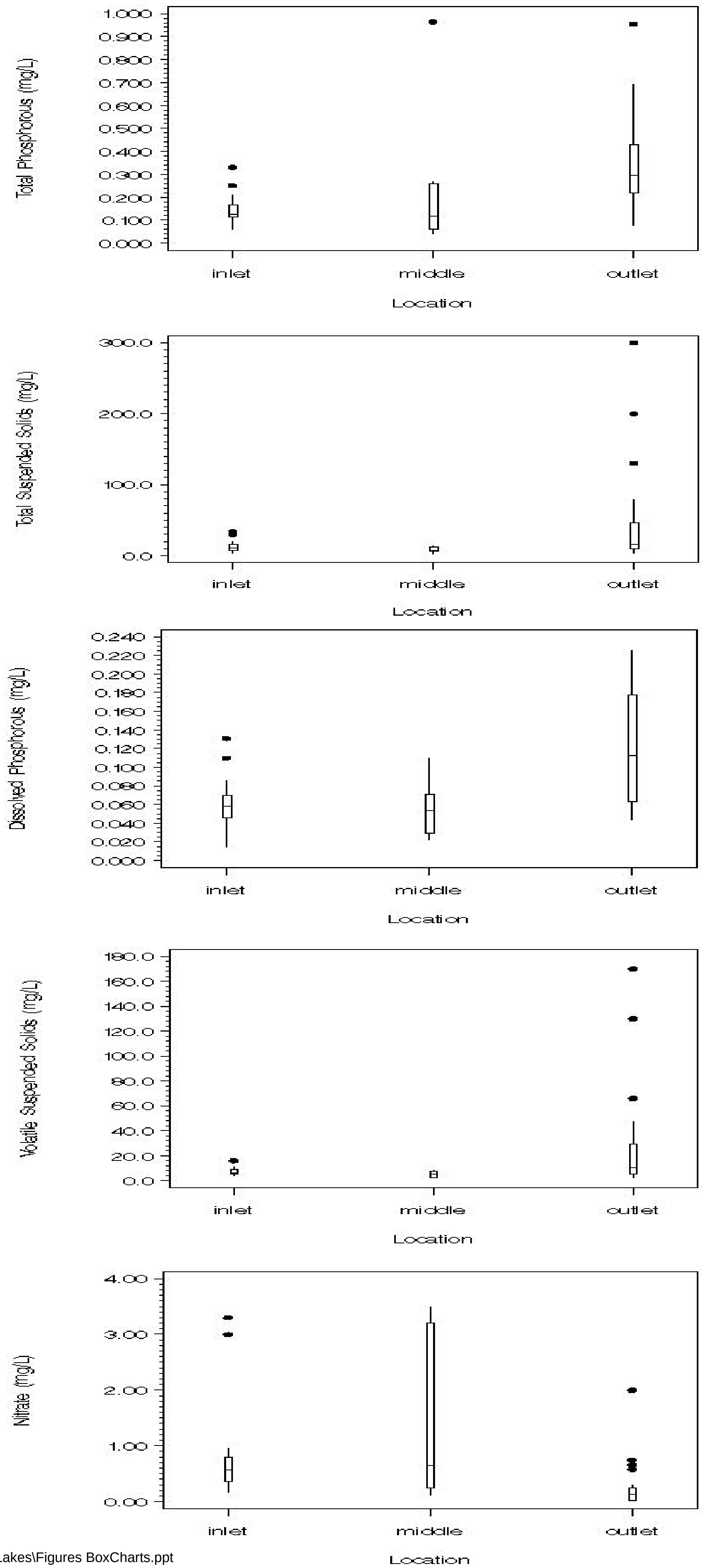
5.5 CONCLUSIONS

Although the traditional paradigm for wetlands and water quality is that wetlands act a filter for water quality, this is not the case for DNR wetland 639W. The DNR wetland is contributing very large amounts of phosphorous, almost doubling the input from the urban watershed itself. Almost half of the phosphorous is in a dissolved form that is readily available to algae. Additionally, the wetland is increasing the solids load, providing organic material to the lake sediments which develops a high sediment oxygen demand and increases the likelihood of internal phosphorous release. Restoration is needed to reduce phosphorous and sediments loads from DNR wetland 639W.



L:\1244\01\apr file\recreation.apr\Figure: Wetland Monitoring Sites (2000 1-m DOQ)

CITY OF BROOKLYN CENTER	Wenck	OCT 2003
Wetland Monitoring Sites	Wenck Associates, Inc. Environmental Engineers 1800 Pioneer Creek Center Maple Plain, MN 55359-0249	Figure 5.1



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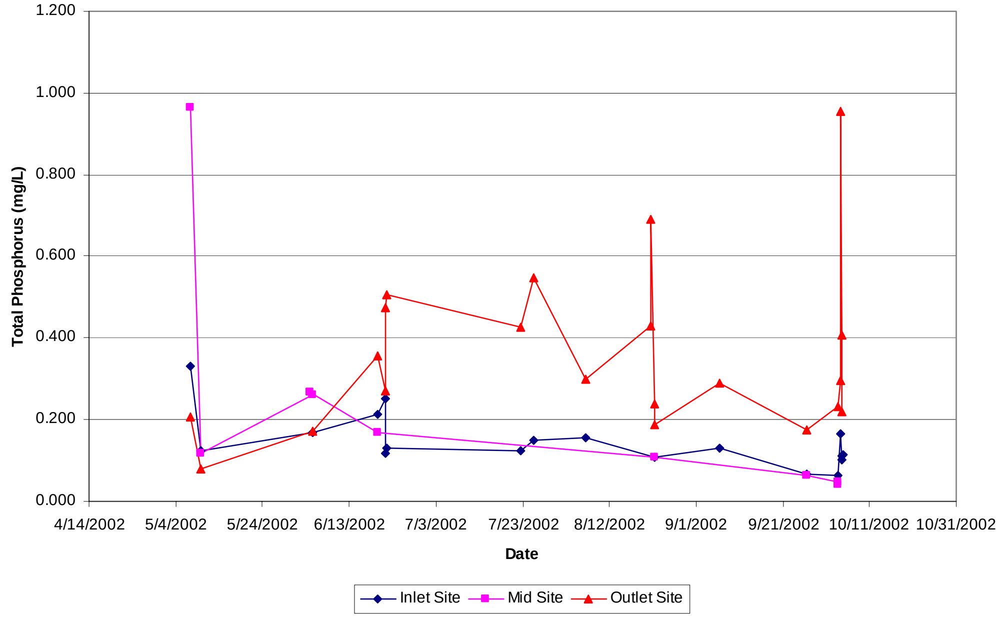
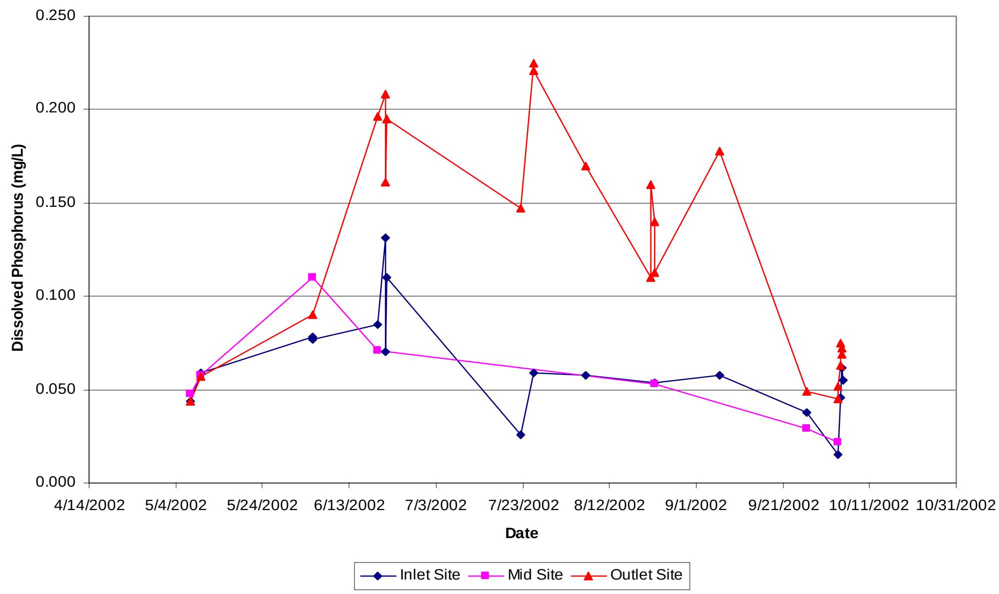
DNR Wetland 693w Box Plots	Wenck	JUN 2003
City of Brooklyn Center	Wenck Associates, Inc. Environmental Engineers 1800 Pioneer Creek Center Maple Plain, MN 55359	Figure 5.2

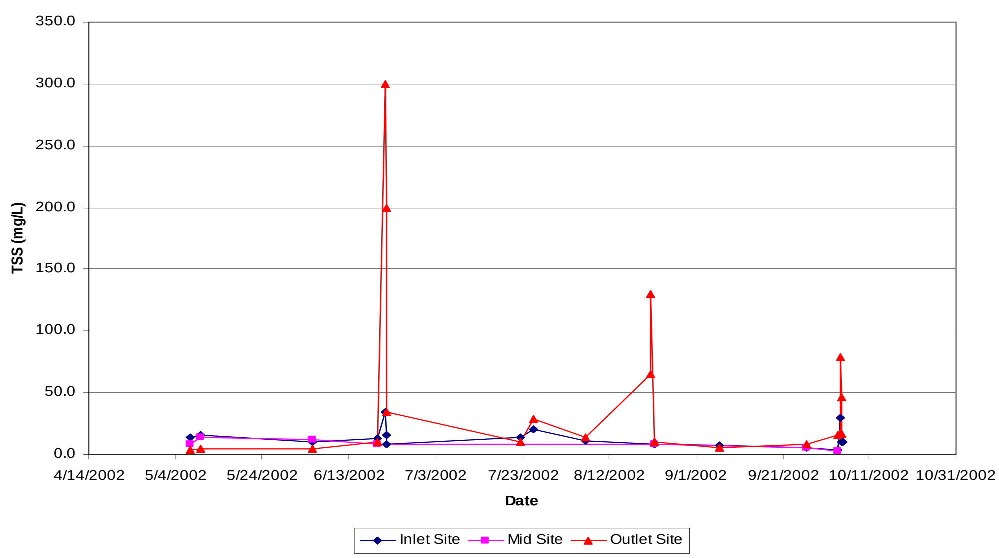
Twin Lake Wetland Total Phosphorus Concentrations



Twin Lake Wetland Dissolved Phosphorus Concentrations



Twin Lake Wetland TSS Concentrations



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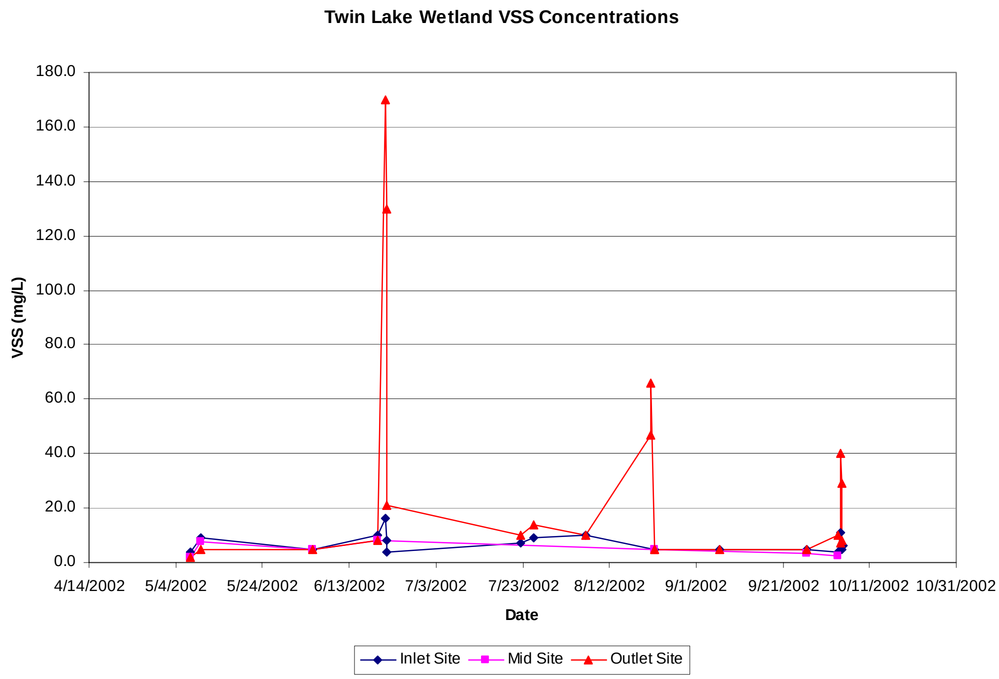
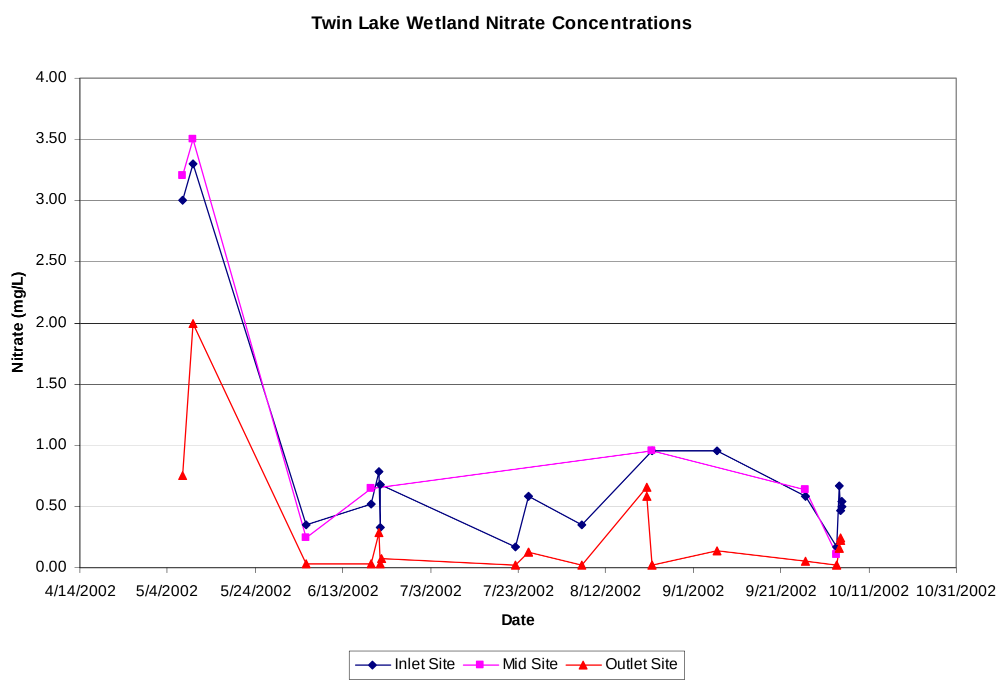
DNR Wetland 693w Water Quality Plots	Wenck	JUN 2003
City of Brooklyn Center	Wenck Associates, Inc. Environmental Engineers 1800 Pioneer Creek Center Maple Plain, MN 55359	Figure 5.3a





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DNR Wetland 693w Water Quality Plots (cont'd)	Wenck Wenck Associates, Inc. 1800 Pioneer Creek Center Environmental Engineers Maple Plain, MN 55359	JUN 2003
City of Brooklyn Center		Figure 5.3b

Twin and Ryan Lakes Nutrient TMDL

Appendix B
2003 Twin Lake Management Plan

Twin Lakes Management Plan

Wenck File #1244-01

Prepared for:

CITY OF BROOKLYN CENTER
6301 Shingle Creek Parkway
Brooklyn Center, Minnesota 55430

Prepared by:

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November 2003

Table of Contents

1.0 Introduction

Twin Lake is an outstanding water resource for the Brooklyn Center, Crystal, and Robbinsdale neighborhoods as well as one of the defining features of the Shingle Creek watershed. Recreational features in the three basins include a beach, several parks, and boat access on each of the three lakes. Protecting water quality will increase their value to the neighborhood, park users, the Cities, and the region.

2.0 Concerns

Several concerns have been identified as a result of the diagnostic study with respect to the water quality of Twin Lake. These concerns have been outlined in the following five categories:

Swimmability – nuisance algal blooms, the threat of fecal contamination and swimmers itch occurrences, and invasive aquatic plants impeding swimming.

Fishability – healthy and diverse fish communities, assure fish are safe to eat, prevent fish kills, and assure that weeds do not impede fishing access.

Aesthetics – displeasing odors, water clarity, nuisance algal blooms, and shoreline environments.

Diversity of plants and wildlife – remove exotic plant and animals and prevent occurrences, increase numbers and species of native plants and animals, improve wildlife habitat, and assure toxic agents are not inhibiting wildlife diversity.

Shoreline environment – manage shorelines to enhance filtration of runoff, provide natural water/land transitions, and prevent the formation of deltas.

3.0 Summary of Diagnostic Study

The Twin Lake chain of lakes is a regional water resource located in the Shingle Creek watershed, specifically in the cities of Brooklyn Center, Crystal and Robbinsdale. Twin Lake is a highly used recreational water body that supports fishing and swimming as well as providing other aesthetic values. Water quality in Upper and Lower Twin Lake is considered poor (hypereutrophic; Carlson's Trophic Status (TSI) of 75 and 71 respectively) with frequent algal blooms while Middle Twin Lake has more moderately degraded water quality (eutrophic; TSI of 65) but still have nuisance algal blooms. A TSI value less than 57 is generally regarded was suitable water quality for swimming. Upper and Lower Twin lakes do not currently support recreational activities while Middle Twin Lake partially supports recreational activities (based on MPCA guidelines). All three basins are on the Minnesota Pollution Control Agency's list of impaired waters (303(d) list) for nutrients and fish consumption advisories (mercury and PCB).

Water quality improvement projects in the Twin Lake watershed are considered a high priority in the recently completed Shingle Creek second-generation plan and by the Metropolitan Council - Environmental Services (MCES).

3.1 BENCHMARK PHOSPHORUS BUDGET

All three of the basins demonstrate significant internal loading sometimes representing as much as 15 % of the overall load (Table 1). Upper Twin has a large internal phosphorous load although it only represents 15% of the total phosphorus budget for Upper Twin Lake. Lower Twin Lake also has a large internal load but a very short hydraulic residence time (0.095 years). Middle Twin Lake also receives a significant phosphorous load from Upper Twin Lake representing 58% of the total load into Middle Twin Lake. The interaction between the basins is an important factor in the loading to the lakes.

Table 1. Overall loads for each of the Twin Lakes basins.

	Upper Twin Lake		Middle Twin Lake		Lower Twin Lake	
Source	Load (kg/yr)	Percent Total	Load (kg/yr)	Percent Total	Load (kg/yr)	Percent Total
Tributary Load	632	81%	124	26%	120	44%
Precipitation	37	5%	18	4%	10	4%
Internal Load	115	15%	54	11%	40	15%
Advective (from upstream basin)	--	--	276	58%	102	38%
TOTAL LOAD	784	100%	472	100%	272	100%

3.2 DIAGNOSTIC STUDY CONCLUSIONS

Upper Twin Lake

- Internal phosphorous load represents 15 % of the total load
- Watersheds 1 and 3 represent the largest external loads. Much of the load from watershed load is a direct result of loading from DNR wetland 639w (42% of total load).

Middle Twin Lake

- The largest load to Middle Twin Lake is from Upper Twin Lake representing approximately 58% of the phosphorus load to Middle Twin Lake.
- Middle Twin Lake had a high sedimentation rate calibration suggesting that the wetland area between the lakes may be a phosphorus sink.

Lower Twin Lake

- Early turnover (mid-August) led to a late season algal bloom by mixing phosphorus rich bottom water into the growing zone

- Lower Twin Lake has a very short residence time (0.10 years) resulting in high P-export downstream.

- Upstream loads represent 38% of the total load.

3.3 FEASIBILITY STUDY RECOMMENDATIONS

Following are the recommended actions for management of the three basins of Twin Lake and its watershed provided in the diagnostic and feasibility study.

Twin Lake – All Basins

1. Community outreach and education regarding lake water quality
2. Aquatic plant management and harvesting
3. Shoreline restoration
4. Goose management
5. Street sweeping biweekly from April 1 to October 31 using newer technology sweepers

Upper Twin Lake

1. Rough fish removal
2. Water Quality Ponds in watershed 3
3. Water Quality Pond maintenance
4. Grit Chambers
5. Restoration of DNR wetland 639(w)
6. Shoreline restoration to improve runoff filtration
7. Promote infiltration in direct runoff watershed

Middle Twin Lake

1. Shoreline restoration to improve runoff filtration
2. Promote infiltration in direct runoff watershed

Lower Twin Lake

1. Water quality ponds in watershed 4
2. Water Quality Pond maintenance in watershed 4
3. Shoreline restoration to improve runoff filtration
4. Promote infiltration in direct runoff watershed

Following are recommended studies needed to further refine management actions in Twin Lake and its watershed:

1. Aquatic Plant Management Plan
2. DNR Wetland 639(w) Restoration Feasibility and Design

4.0 Goals

Based on the concerns identified in the diagnostic study (Section 2.0), the flowing goals were identified goals with regard to the management of Twin Lake and it's watershed. These goals can be divided under three headings – recreation, environmental preservation, and lake management education.

Recreational Use

1. Reduce nuisance algal blooms and improve water clarity
2. Protect public health from fecal contamination, swimmer's itch, toxic chemicals, or other toxic agents.
3. Reduce the potential for weeds to impede swimming and fishing in designated areas
4. Promote healthy and diverse fish communities
5. Prevent fish kills

Environmental Preservation

6. Prevent the introduction of exotic plants and eliminate current populations
7. Preserve aquatic wildlife habitat including fish spawning areas
8. Achieve a healthy and diverse community of native plants and animals
9. Provide a natural land/water interface that reduces runoff and enhances pollutant filtration while providing access for recreational use of the lakes.
10. Manage watershed runoff to reduce sediment and pollutant transport to the lakes

Lake Management Education

11. Assure that decision makers have an understanding of lake ecology basics so they can make informed decisions about lake management
12. Identify target audiences
13. Raise awareness of boundaries of Twin Lake watershed
14. Raise awareness of nonpoint source pollution and its effects on lake water quality
15. Provide general and targeted information in various formats
16. Provide opportunities for active reinforcement of behavioral change

5.0 Management Targets

5.1 RECREATIONAL TARGETS

Goal 1. Eliminate Nuisance Algal Blooms

Based on our understanding of the lake system, we have determined the following goals for the Twin Lakes system (Table 1). An Upper Twin Lake concentration of <70 μg/L would result in concentrations of 38 and 60 μg/L of total phosphorus alone without any controls in the Middle and Lower Twin Lake watersheds respectively.

Table 1. Recommended water quality goals for each of the Twin Lake basins.

Basin	Total Phosphorus (ppb)	Chlorophyll-a (ppb)	Secchi Depth (meters)	Phosphorus Reduction needed
Upper	<70	<30	<0.6	60%
Middle	<35	<12	<1.5	40%
Lower	<40	<25	<1.3	50%

The goals presented in Table 9 are aggressive goals for urban lakes since rarely have these reductions been achieved. Additionally, these goals may not be obtainable without some control of internal phosphorus sources. Established technologies for internal controls may be inappropriate, cost prohibitive, or unproven. However, significant progress can be made through external phosphorous controls.

Goal 2. Protect public health from fecal contamination, swimmer's itch, toxic chemicals, or other toxic agents.

The presence of pathogenic bacteria, toxic chemicals such as pesticides or PCBs, or hazardous solid waste in lake water or sediments can pose threats to lake users. Swimmer's Itch has been associated with waterfowl and snails. A Swimmer's Itch infection is unpleasant, but not a health threat. The following targets are suggested for meeting goal 2:

1. Fecal Coliform levels should meet State Standards for beaches.
2. Meet State Standards for PCBs, heavy metals, and any other pollutant.
3. Reduce the level of mercury and PCBs in fish to levels where fish are safe to eat.

Goal 3. Reduce the potential for weeds to impede swimming and fishing in designated areas

Although aquatic plants are a part of any healthy lake system, overabundant native and exotic aquatic plants can become a nuisance. The following targets are suggested for meeting goal 3:

1. Develop a lake aquatic plant management plan
2. Meet goals set forth in aquatic management plan

Goal 4. Promote a healthy and diverse fish communities

The fish in all three basins suffer from poor water quality, poor habitat, an overabundance of carp, and contamination. The following targets are suggested for meeting goal 4:

1. Improve water quality to levels that support good fish diversity

Goal 5. Prevent fish kills

Fish kills occur when oxygen is depleted from the water column as a result of excess biological respiration. Although historical information is spotty, there have been reported fish kills in the Twin Lake. The following targets are suggested for meeting goal 6:

1. Maintain winter dissolved oxygen above 2 ppm
2. Maintain spring through fall dissolved oxygen concentrations above 5 ppm

5.2 ENVIRONMENTAL PRESERVATION TARGETS

Goal 6. Prevent the introduction of exotic plants and eliminate current populations

Several species of exotic plants have invaded Twin Lake including Eurasian water milfoil, reed canary grass, and curly leaf pondweed. These species need to be controlled and eliminated. This will be accomplished in conjunction with goal three and the development of an aquatic vegetation management plan.

Goal 7. Preserve aquatic wildlife habitat including fish spawning areas

Habitat preservation is key to maintaining a healthy aquatic ecosystem, particularly a healthy fishery. Over the years, the lake has been impacted by the elimination of native habitats. The following targets are suggested for meeting goal 7:

1. Cultivate native vegetation around 50% to 75% of the shoreline
2. Provide habitat for native aquatic plants in at least 25% of the littoral areas.

Goal 8. Achieve a healthy and diverse community of native plants and animals

In urban and suburban environments, ecosystems have been disturbed. One of the features that makes the Twin Cities desirable, are the natural areas and lakes. Protection of these natural features is essential to maintaining our quality of life. The following targets are suggested for meeting goal 8:

1. See goals 1, 4, 5, 6, 7, 9, and 10.

Goal 9. Provide a natural land/water interface that reduces runoff and enhances pollutant filtration while providing access for recreational use of the lakes.

A natural transition from the water to land areas provide key habitat, filters runoff, and protects shorelines from erosion. The following targets are suggested for meeting goal 9:

1. Reduce the number of artificial and abandoned retaining structures where native vegetation can be cultivated.
2. See goal number 6.

Goal 10. Manage watershed runoff to reduce sediment and pollutant transport to the lakes

Vegetated buffers and natural shorelines can decrease and filter runoff. Additionally, water quality ponds, infiltration, Low Impact Development practices, and other activities in the watershed can have large impacts on water quality. The following targets are suggested for meeting goal 10:

1. Identify areas where buffers, water quality ponds, and wetlands can enhance water quality

2. Implement capital improvements where opportunities exist to protect and improve water quality.

5.3 LAKE MANAGEMENT EDUCATION TARGETS

Educational success is often a function of quality and quantity. Therefore, setting quantitative educational goals does not necessarily reflect the success of educational programs. Additionally, measuring the success of education is difficult since the ultimate goal is not only to raise awareness but also to change people's behaviors. At this time, no quantitative goals are set for the educational goals of this plan. Rather, the educational goals are set to provide guidance on those topics that need to be addressed for improving lake water quality. These topics should be incorporated into other education activities such as those developed by the Shingle Creek Watershed Management Commission and as a result of the NPDES Phase II permit. Many of the concepts presented in this management plan are the same as those outlined in the State of Minnesota's environmental education plan (www.moea.state.mn.us/ee/greenprint.cfm).

6.0 Recommended Management Activities

The recommended management activities have been placed in order of priority.

6.1 ROUGH FISH REMOVAL

Action 1. Initial rough fish removal and fish screen installation from Upper Twin Lake

Rough fish populations in Twin Lake is incredibly high, approximately 10 times the upper 10^{th} quartile of all DNR sampled lakes. Initial removal of rough fish could be quite large. Additionally, access to the two Upper Twin Lake wetland complexes needs to be restricted to prevent spawning. This action includes design and installation of Carp barriers as well as a large initial effort for Carp removal focusing on Upper and Lower Twin Lakes.

Estimated Associated Cost: $25,000 to $50,000

Action 2. Biannual rough fish removal

To control Carp populations, biannual removal maintenance will be required. This action includes Carp removal biannually focusing on Upper and Lower Twin Lakes.

Estimated Associated Cost: $2,000 to $5,000 annually

6.2 AQUATIC PLANT MANAGEMENT AND HARVESTING

Action 1. Map aquatic vegetation in the three Twin Lake basins

Our current understanding of the extent and species of aquatic plants in the Twin Lake basins is limited. Mapping the plant communities will help develop an understanding of areas that may need restoration or harvesting.

Estimated Associated Cost: $2,000 to $5,000

Action 2. Develop an aquatic vegetation management plan

After completion of the mapping, an aquatic vegetation management plan will help map out activities intended to reach identified desired conditions.

Estimated Associated Cost: $5,000 to $10,000

Action 3. Harvest exotic aquatic plants such as curly leaf pondweed or Eurasian water milfoil

Harvesting of exotic aquatic plants can help improve water quality and allow native plants to flourish. Exotic weeds, especially curly leaf pondweed, should be harvested on an annual basis.

Estimated Associated Cost: Variable depending on volunteers and extent.

6.3 SHORELINE MANAGEMENT AND RESTORATION

Action 1. Identify property owners willing to restore shoreline

Identifying willing landowners is the first step in improving the water land interface. The diagnostic report identified shoreline areas that are currently hard armored or lawn.

Estimated Associated Cost: Staff Time.

Action 2. Restore shoreline areas where available

Restore shoreline areas with native vegetation and lakescaping where opportunities present themselves. The Shingle Creek Watershed Management Commission and the City of Brooklyn Center recently completed a shoreline restoration at Twin Lake Park. This project represents a good example of shoreline restoration projects.

Estimated Associated Cost: Variable depending on site.

6.4 WILDLIFE MANAGEMENT

Action 1. Goose population control

Controlling Goose populations can increase phosphorus loading as well as fecal coliform production. Geese harvesting should be conducted to maintain watershed populations.

Estimated Associated Cost: $3,000 to $5,000 annually.

6.5 STREET SWEEPING

Action 1. Upgrade street sweepers to newer technologies

Newer street sweeping technologies are available that use high pressure to remove a greater percent of the small particles that can carry phosphorus to the lakes. Using these newer technologies can help improve water quality. The Lakes Nokomis and Hiawatha studies suggested that improved street sweeping technologies and increased street sweeping frequency could reduce phosphorus loads by 7 percent.

Estimated Associated Cost: $100,000 to $200,000 per new sweeper.

Action 2. Increase the frequency of street sweeping during the summer growing season (April 1 through October 31)

Increased street sweeping frequency may be most effective in the direct watersheds to the three Twin Lake basins. These watersheds had surprisingly high phosphorus loads and little area available for other treatment technologies.

Estimated Associated Cost: $65 to $85 per mile

7.0 Recommended Capital Improvements

The recommended management activities have been placed in order of priority.

7.1 DNR WETLAND 639(w) RESTORATION

Action 1. Develop a feasibility and design report for DNR Wetland 639(w)

DNR wetland 639(w) increases stormwater phosphorus loads and accounts for an estimate 23% of the total phosphorus load to Upper Twin Lake. Restoring the wetland to a phosphorus sink or at a minimum eliminating additional phosphorus loads from the wetland can have large impacts on the water quality in Upper Twin Lake.

Alternatives for water quality impacts should include diversion of stormwater around wetland, an alum ferric chloride treatment plan, alum treatment to the wetland or dechannelization and increased storage in the wetland. The end product should include a recommended design.

Estimated Associated Cost: Dependent upon proposal. $25,000 to $50,000.

Action 2. Restore DNR Wetland 639(w)

Implementation of the recommended design to reduce phosphorus loads to Upper Twin Lake is one of the major steps toward reaching water quality goals.

Estimated Associated Cost: Dependent upon results of feasibility report.

7.2 WATER QUALITY PONDS

Action 1. Identify areas in the watershed where ponding may be implemented focusing on subwatersheds 2 and 3 and the direct watersheds

Water quality ponds constructed in subwatershed 4 (Crystal) have improved water quality in Lower Twin Lake (see Twin Lake Diagnostic and Feasibility Study). Additional ponds, especially in subwatersheds 2 and 3 and the direct watersheds will reduce phosphorus loads and improve lake water quality.

Estimated Associated Cost: Staff Time.

Action 2. Construct water quality ponds in watersheds 2 and 3 and the direct watersheds

Once suitable sites have been determined, construct water quality ponds sized to reduce phosphorus loads by 60 to 80%. It is important to note that site limitations may not allow pond designs for this high removal rate. However, these ponds could still significantly reduce phosphorus loads to the lakes.

Estimated Associated Cost: Variable depending on site.

7.3 GRIT CHAMBERS

Action 1. Install grit chambers in the major outfalls to the three Twin Lake basins

Grit chambers can reduce delta formation and have some effects on phosphorus loading. Targeting the larger outfalls is a good place to start, however the smaller outfalls in the direct drainage areas had significant phosphorus loads, especially in Middle Twin Lake.

Estimated Associated Cost: $100,000 to $200,000 per unit for installation and $3,000 annually for maintenance.

8.0 Recommended Lake Management Education Activities

No priorities have been established for the recommended lake management education activities. As such, all activities are considered to be of equal importance.

8.1 TARGET AUDIENCE EDUCATION

Action 1. Promote decision maker education.

Make available for decision makers self-study lake management background information from Water on the Web ("Understanding Lake Ecology"), Project NEMO (Nonpoint Education for Municipal Officials), UW Extension ("Understanding Lake Data") and other sources. These sources provide basic information about lake ecology to help staff, Councils and Commissions make informed decisions about lake management.

Action 2. Provide information to target audiences in the form of fliers, brochures, newsletter articles, Web pages, and links to online references.

The Twin Lake Homeowners Education Survey found that over 90 percent of the property owners surveyed knew that phosphorus is a common cause of lake and river pollution, but only 27 percent used phosphorus-free fertilizer. Soil tests on their lawns showed that 79 percent were already very high in phosphorus. Over half of those surveyed, never sweep up fertilizer that spills on the driveway and sidewalks. Better phosphorus management in the watershed is necessary to reduce nonpoint source loads to the Lake.

The Minnesota and Wisconsin Departments of Natural Resources, the University of Minnesota Extension Service, and University of Wisconsin Extension have prepared numerous fliers and brochures on various topics relating to lake management that can be made available to target audiences at Lake Management Plan meetings. Other distribution mechanisms include block clubs and National Night Out gatherings and links on the City's Web site. Potential topics are listed in Table 2.

Table 2. Education topics for both lakeshore and non-lakeshore owners.

Lakeshore Property Owners	**Other Property Owners**
Buffers Native plants Turf management Lake-friendly boating Fertilizer/pesticide selection and application Rain gardens	Turf management Fertilizer/pesticide selection and application Turf management Rain gardens

Action 3. Presentations at meetings.

Raise awareness of lake management education topics through periodic discussion of various topics at meetings of lake associations, homeownership associations, block clubs, garden clubs, service organizations, senior associations, advisory commissions, the City Council, or other groups. Make "discussion kits" available that include more detailed information about topics and questions and points for topic discussion.

Action 4. Displays.

Simple displays highlighting various education topics can be prepared from material available from other educational activities, and posted in locations such as City Halls, Community Centers, schools, and churches and displayed at open houses, festivals, neighborhood block parties, and special events.

Action 5. Demonstration projects.

Property owners may be reluctant to adopt good lake management practices without examples they can evaluate and emulate. Implement demonstration projects so property owners can see how a project or practice is implemented and how it looks. Examples might include planting native plants; restoring a shoreline; managing turf using low-impact practices such as phosphorus-free fertilizer, reduced herbicides and pesticides, and proper mowing and watering techniques; and improving drainage practices with redirected downspouts and rain barrels.

Action 6. Develop and implement elementary/secondary education.

Develop and implement elementary/secondary education opportunities including:

- Stenciling
- Monitoring
- Science fairs
- Field trips
- Presentations
- Poster contests
- Recognition from City Council

Action 7. Develop and distribute active reinforcement materials.

Develop and distribute active reinforcement such as signs, stickers, and bumper stickers to promote water quality friendly practices.

Twin and Ryan Lakes Nutrient TMDL

Appendix C
BATHTUB Modeling

Table C.1. Modeling inputs, equations and calibration coefficients for the 1996 water quality response model. All of the equations and references can be found in the BATHTUB documentation (Walker 1999).

1996 Modeled Parameter	Option & Equation		Upper Lake Model	Middle Lake Model[1]	Lower Lake Model	Ryan Lake Model[1]
Internal Phosphorus Load	**kg**		**570**	**54**	**40**	**40**
Atmospheric Phosphorus Load			**17**	**9**	**5**	**3**
Tributary Load			**467**	**70**	**148**	**84**
Load from Upstream Lake			**0**	**51**	**117**	**122**
Total Phosphorus Load			**1054**	**184**	**310**	**249**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION	Canfield & Bachmann 1980 f(W,Q,V) $P = P_i/(1+CP*a*P_i^b*T^c)$					
	CP	[--]	***1.00***	***1.00***	***1.00***	***1.00***
	a	[--]	0.162	0.162	0.162	0.162
	b	[--]	0.458	0.458	0.458	0.458
	c	[--]	0.542	0.542	0.542	0.542
	W= total P load (inflow + atm.)	[kg/yr]	1054	184	310	249
	Q=lake outflow	$[10^6 m^3/yr]$	2.67	3.02	3.92	4.28
	V=lake volume (modeled)	$[10^6 m^3]$	0.55	0.97	0.26	0.29
	T = V/Q	[yr]	0.21	0.32	0.07	0.07
	P_i = W/Q	[ug/l]	395	61	79	58
Modeled In-Lake [TP]		**[ug/l]**	**191**	**39**	**62**	**47**
Observed In-Lake [TP], May to September			**191**	**38**	**54**	**50**
CHL-A MODEL	**N, P, Flushing (Walker 1999)**					
	B= CB Bx /[(1+0.025 Bx					
	CB as used to calibrate		**1.0**	**1.0**	**1.0**	**1.0**
	P Total Phosphorus	**[ug/l]**	**191**	**38**	**54**	**47**
	N Total Nitrogen	**[ug/l]**	**1900**	**1000**	**1200**	**970**
	Zmix Mixing Depth	**m**	**1.2**	**4.6**	**2.1**	**5.0**
Q/V	**Fs Flushing Rate**	**year-1**	**4.8**	**3.1**	**15.3**	**14.8**
	S Secchi Depth	**(m)**	**0.4**	**1.3**	**0.9**	**1.7**
(1/s)-0.025B	**a Non algal turbidity**	**m-1**	**1.5**	**0.4**	**0.3**	**1.0**
	Xpn		**115.9**	**33.5**	**46.0**	**38.6**
	Bx		**129.1**	**24.8**	**37.7**	**29.9**
	G		**0.18**	**0.70**	**0.42**	**0.99**
Modeled Chlorophyll-a	**B**		**63.2**	**13.4**	**23.9**	**8.7**
Observed In-Lake [CHL-A]			**NA**	**NA**	**NA**	**NA**
SECCHI MODEL	as f(Chla) per Heiskary & Wilson					
	CS as used to calibrate	[--]	***0.50***	***1.00***	***1.00***	***0.70***
Calibrated In-Lake SD		**[m]**	**0.34**	**1.68**	**1.19**	**1.52**
Observed In-Lake [SD]			**0.40**	**1.80**	**1.40**	**1.50**
MODELED PHOSPHORUS	W-(Sedimentation)	**[kg/yr]**	**510**	**117**	**243**	**200**

Table C.2. Modeling inputs, equations and calibration coefficients for the 1999 water quality response model. All of the equations and references can be found in the BATHTUB documentation (Walker 1999).

1999 Modeled Parameter	Option & Equation		Upper Lake Model	Middle Lake Model[1]	Lower Lake Model	Ryan Lake Model[1]
Internal Phosphorus Load	**kg**		**115**	**54**	**40**	**40**
Atmospheric Phosphorus Load			**15**	**9**	**5**	**3**
Tributary Load			**591**	**87**	**166**	**86**
Load from Upstream Lake			**0**	**102**	**160**	**143**
Total Phosphorus Load			**721**	**252**	**371**	**272**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION	Canfield & Bachmann 1980 f(W,Q,V) $P = P_i/(1+CP*a*P_i^b*T^c)$					
	CP	[--]	***1.00***	***1.00***	***1.00***	***1.00***
	a	[--]	0.162	0.162	0.162	0.162
	b	[--]	0.458	0.458	0.458	0.458
	c	[--]	0.542	0.542	0.542	0.542
	W= total P load (inflow + atm.)	[kg/yr]	721	252	371	272
	Q=lake outflow	[$10^6 m^3$/yr]	3.09	3.48	3.98	4.36
	V=lake volume (modeled)	[$10^6 m^3$]	0.55	0.97	0.26	0.29
	T = V/Q	[yr]	0.18	0.28	0.06	0.07
	P_i = W/Q	[ug/l]	233	72	93	62
Modeled In-Lake [TP]		**[ug/l]**	**131.5**	**45.9**	**72.1**	**50.1**
Observed In-Lake [TP], May to September			**131.0**	**50.0**	**73.0**	**NA**
CHL-A MODEL	**N, P, Flushing (Walker 1999)**					
	B= CB Bx /[(1+0.025 Bx					
	CB as used to calibrate		**1.0**	**1.0**	**1.0**	**1.0**
	P Total Phosphorus	**[ug/l]**	**132**	**46**	**72**	**50**
	N Total Nitrogen	**[ug/l]**	**1400**	**950**	**700**	**1000**
	Zmix Mixing Depth	**m**	**1.2**	**4.6**	**2.1**	**5.0**
Q/V	**Fs Flushing Rate**	**year-1**	**5.6**	**3.6**	**15.5**	**15.0**
	S Secchi Depth	**(m)**	**0.4**	**1.3**	**0.9**	**1.0**
(1/s)-0.025B	**a Non algal turbidity**	**m-1**	**1.5**	**0.4**	**0.3**	**1.0**
	Xpn		**81.7**	**37.8**	**38.7**	**40.9**
	Bx		**81.0**	**29.1**	**30.0**	**32.3**
	G		**0.19**	**0.71**	**0.42**	**0.99**
Modeled Chlorophyll-a	**B**		**45.6**	**14.9**	**20.1**	**9.0**
Observed In-Lake [CHL-A]			**39.0**	**15.0**	**32.0**	
SECCHI MODEL	as f(Chla) per Heiskary & Wilson					
	CS as used to calibrate	[--]	***0.50***	***1.00***	***1.00***	***0.70***
Modeled In-Lake SD		**[m]**	**0.45**	**1.57**	**1.00**	**1.49**
Observed In-Lake [SD]			**0.40**	**1.30**	**0.90**	**NA**
MODELED PHOSPHORUS	W-(Sedimentation)	**[kg/yr]**	**406**	**160**	**287**	**218**