Typo Lake and Martin Lake TMDL

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TMDL Summary Table

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North Central Hardwood Forest Ecoregion<table>
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<tr><td rowspan="2">Construction Stormwater</td><td>MNR100001</td><td>Martin</td><td>0.055</td></tr>
<tr><td>MNR100001</td><td>Typo</td><td>0.0064</td></tr>
<tr><td rowspan="2">Industrial Stormwater</td><td>MNR50000</td><td>Martin</td><td>0.055</td></tr>
<tr><td>MNR50000</td><td>Typo</td><td>0.0064</td></tr>
<tr><td>Reserve Capacity</td><td>NA</td><td>Both</td><td>--</td></tr>
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<tr><td>Load Allocation</td><td>The load allocation is based on the following sources of phosphorus that do not require NPDES permit coverage, as applicable to each lake.
Non-regulated stormwater runoff
Loading from upstream waters
Runoff from feedlots not requiring NPDES permit coverage
Atmospheric deposition
Subsurface sewage treatment systems (SSTS)
Groundwater
Internal Loading
<table><tr><th>Lake</th><th>LA (lbs TP/day)</th></tr><tr><td>Martin</td><td>10</td></tr><tr><td>Typo</td><td>4.0</td></tr></table></td><td>56

Table 25

Table 28</td></tr>
<tr><td>Margin of Safety</td><td>A moderate explicit MOS was applied to both TMDLs by reserving ten percent of the allowable load. Ten percent (10%) is considered an appropriate explicit MOS based on the following considerations:
Uncertainty is associated with the monitored water quality concentrations in both the TMDL lakes and in upstream lakes used to estimate upstream loading.
Export coefficients were identified through a thorough literature review. However, uncertainty is associated with them due to the inherently site-specific nature of pollutant runoff.
There are uncertainties in predicting how lakes respond to changes in phosphorus loading.</td><td>52,

Table 23

Table 26</td></tr>
<tr><td>Critical Conditions and Seasonal Variation</td><td>Critical conditions in these lakes occur during the growing season, which is when the lakes are used for aquatic recreation. Similar to the manner in which the standards take into account seasonal variation, since the TMDL is based on growing season averages, the critical condition is covered by the TMDL.</td><td>61</td></tr>
<tr><td>Reasonable Assurance</td><td>Active local partners and agencies (Sunrise WMO and Anoka Conservation District)
NPDES Permit compliance</td><td>62</td></tr>
<tr><td>Monitoring</td><td>The Sunrise River Watershed Management Organization and Anoka Conservation District plan to continue monitoring these waterbodies. Monitoring will be timed to assess the effectiveness of implementation activities.</td><td>64</td></tr>
<tr><td>Implementation</td><td>This TMDL includes a menu of recommended nutrient reduction strategies. This shall be the basis for an Implementation Plan which is will be submitted to the MPCA upon approval of this document.</td><td>65</td></tr>
<tr><td>Public Participation</td><td>Public participation in this TMDL included:
Informational and comment meeting for the public, public officials, and landowners near likely water quality improvement project sites.
Regular meetings with affected organizations such as lake associations, neighboring government agencies, state agencies and watershed organization.
Publications including fact sheet fliers, a project website, and newspaper articles.</td><td>68</td></tr>
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ACD	Anoka Conservation District
BMP	Best Management Practice
Chl-a	Chlorophyll-a
ft	Feet
HUC	Hydrologic Unit Code
LA	Load Allocation
Lbs/yr	Pounds per year
NCHF	North Central Hardwood Forest
m	Meters
MN DNR	Minnesota Department of Natural Resources
MOS	Margin of Safety
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer Systems
NLCD	National Land Cover Dataset
SSTS	Subsurface Sewage Treatment System
TP	Total Phosphorus
TMDL	Total Maximum Daily Load
WLA	Wasteload Allocation
WMO	Watershed Management Organization

Executive Summary

Typo Lake and Martin Lake in Anoka and Isanti Counties, Minnesota (Figure 1) are on the Minnesota Pollution Control Agency's 303(d) list of impaired waters for excess nutrients (Phosphorus). The lakes are linked, with Typo Lake flowing to Martin Lake via the West Branch of the Sunrise River (HUC# 07030005-563), aka Typo Creek. This reach of Typo Creek was added to the 303(d) list of impaired waters in 2006 for pH and excess turbidity. These lakes and the stream linking them were studied together because their problems are related. This report details the current conditions, sources of phosphorus (P), water quality targets, and prioritizes phosphorus reduction opportunities.

Typo Lake

Typo Lake is a shallow lake located in the North Central Hardwood Forest Eco-region, and lies on the border of Isanti County and Anoka County. The lake has a surface are of 280 acres, with a maximum depth of 6 feet (ft) (1.8 m). Its watershed area is 11,000 acres, with the lake area subtracted. The primary drainage to Typo Lake is Data Creek. The reaches of Data Creek closest to the lake are a ditch through a large wetland area. The Data Creek area has been found to be a large contributor of phosphorus at times with rising and falling water levels flushing phosphorus out of the wetland areas.

In 2004, the Minnesota Pollution Control Agency (MPCA) assessed the water quality of Typo Lake and found that it was not meeting state water quality standard. Since Typo Lake was exceeding the water quality standards, it was determined that a TMDL study would be done for this lake. This study found that approximately 7,550 lb/yr of phosphorus from direct watershed runoff, with an in-lake contribution of 1,002 lb/yr, 38 lbs/yr of phosphorus from Subsurface Sewage Treatment Systems (SSTS), and 78 lbs/yr from atmospheric; for a total of 8,668 lbs/yr (23.7 lb/day). Modeling was done to determine Typo Lakes loading capacity. This number was found to be 1,627 lbs/yr, or 4.5 lb/day. The overall reduction required to achieve this goal is 81% or 7,041 lbs/year (19.3 lb/day).

Martin Lake

Martin Lake is a shallow lake located in the North Central Hardwood Forest Eco-region. This lake located entirely within Anoka County, and is downstream from Typo Lake. Both lakes are connected by the West Branch of the Sunrise River, with this reach also known locally as Typo Creek. Martin Lake has a surface area of 238 acres, with a maximum depth of 17 ft (5.2 m), but has a littoral area of 198 acres (or 83%). It has a watershed area of 22,888 acres (includes Typo Lake area). This information was taken from the Minnesota Department of Natural Resources (MN DNR) 1990 Bathometric map.

Martin Lake was listed as impaired for excess nutrients (phosphorus) in 2004 by the MPCA, since it is not meeting water quality standards. The work documented in this report indicates that current watershed loadings to Martin Lake are 7,213 lb/yr. The current watershed loading to Martin Lake can be broken into the following source areas: Typo Lake (4,787 lb/yr or 67% of the load), direct watershed runoff (1,790 lb/yr or 25%), the Island Lake watershed (408 lb/yr or

5.7%), SSTS at 164 lb/yr, and a Atmospheric Loading of 64 lb/yr. It should also be noted that while internal loading to Martin Lake was not explicitly called out as a source, it is something that will be looked into as future implementation takes place.

Martin Lake also receives loadings from two permitted sources; the City of East Bethel (MS4) and the John Iacarella – Linwood Terrace Co. Wastewater Treatment Plant (WWTP). Since both of these permittees are located in the drainage area to Martin Lake, each of them received a wasteload allocation which can be found in Table 24.

The overall TMDL was calculated for Martin Lake, and was found to be 4,240 lb/yr (12 lb/day). This equates to a necessary percent reduction goal of 41%, or 2,973 lb/yr (8.1 lb/day). As indicated above, a large part of this reduction is going to have to come from the Typo Lake Watershed. So any reductions done to improve Typo Lake will have a direct impact on Martin Lake.

While this TMDL deals specifically with the Typo Lake and Martin Lake impairments, any improvements in the Typo Lake watershed would also improve the water quality in the West Branch of the Sunrise River (Typo Creek) which connects Typo Lake and Martin Lake. Typo Creek is currently on the MPCA's 303 d list for elevated pH and turbidity. Typo Creek's impairments are reflective of Typo Lake's problems. The elevated pH is due to high algal productivity in Typo Lake, while the turbidity (suspended solids) in Typo Creek was on average 55% volatile (algae and other organics), with the remainder due to in-lake wind mixing. Therefore, any improvements in upstream water quality will improve the water quality in Typo Creek.

It should also be noted that the modeling for this TMDL used monitoring data from a 10 year period (1998 to 2007); it has set 2007 as its baseline year. Therefore, any BMPs or other practices put into place after 2007 were not taken into account in the modeling. So, any BMP that was put on the ground after 2007 should be given credit towards their wasteload or load allocation.

Strategies and projects to improve water quality are contained in this TMDL's Implementation Plan, a separate document that follows this report. Implementation will focus on shifting from a turbid, algae-dominated state to clearer water with more macrophytes. This work's priority is elevated because downstream impaired waters, including the St. Croix River, are high priority.

1. Description of Waters and Problem Identification

1.1 303(d) Listings

This TMDL addresses two lake impairments within the Sunrise River Watershed, which is a tributary to the St. Croix River and Lake St. Croix. The two lakes are listed on the 2010 EPA's 303(d) impaired waters list due to excess nutrients: Martin Lake and Typo Lake (Table 1). The following applies to both of the impaired lakes in this project and to the West Branch of the Sunrise River (aka Typo Creek):

Table 1. Impaired Waters Listings

Waterbody Name	Lake ID/AUID	Pollutant	Impaired Use	Year Listed	Target Start/Completion
Typo Lake	30-0009-00	Nutrient/ Eutrophication	Aquatic Recreation	2002	2003/2010
Martin Lake	02-0034-00	Nutrient/ Eutrophication	Aquatic Recreation	2002	2003/2010
West Branch of the Sunrise River*	07030005-563	pH	Aquatic Life	2006	2006/2010
West Branch of the Sunrise River*	07030005-563	Turbidity	Aquatic Life	2006	2006/2010

*This reach connects Typo Lake and Martin Lake. They are included in this TMDL report, but no TMDL was specifically developed for the impairments.

1.2 Background and Location

These waterbodies (Table 1) are located in northeast Anoka County and southeast Isanti County, Minnesota (Figure 1). This is the northern suburban fringe of the Minneapolis/St. Paul metropolitan area, currently only lightly developed but expected to have a 7% growth in the number of households each of the next two decades (Metropolitan Council 2008). Ecologically, this area is within the North Central Hardwood Forest ecoregion. Geologically, both lakes and their watersheds are within the Anoka Sand Plain, characterized by broad glacial outwash plains of sand. Most lakes in the Anoka Sand Plain, including the study lakes, were formed by glacial ice blocks buried in sediment which later melted, leaving a depression (Zumberge 1952). Topographically, the region is flat, with elevation changes of less than 10 ft per mile within the study lakes' watersheds. Total elevation change within the watersheds of both lakes is approximately 30 ft. On average, Martin Lake is only 1.72 ft lower than upstream Typo Lake.

These lakes and the creek that joins them were the subject of a joint TMDL because of their hydrologic connectivity, because effective management of Martin Lake and Typo Creek would likely require management of Typo Lake, and because of their shared impact on the water quality of downstream waterbodies. Typo Lake is the largest pollutant source to Typo Creek and Martin

Lake. Martin Lake's outlet is the West Branch of the Sunrise River which is impaired for pH, turbidity, and fish biota. The Sunrise River has been identified as Minnesota's largest contributor of suspended solids and nutrients to the St. Croix River and Lake St. Croix (St. Croix Basin Water Resources Planning Team 2004). The St. Croix is a Federal Scenic and Recreational River where a multi-agency team has called for a 20% phosphorus loading reduction to Lake St. Croix (St. Croix Basin Water Resources Planning Team 2004), which was placed on the Minnesota's 2008 303(d) Impaired waters list.

Water quality of these lakes is a local and regional priority. Martin Lake is identified as a high priority in the Sunrise River Watershed Management Organization Watershed Management Plan because of high lakeshore home density and moderate recreational use. Typo Lake receives little recreational use but remains a medium priority due to the severity of impairment and direct impact on its downstream counterpart, Martin Lake. Remediation of both lakes is a regional priority because of their downstream impacts to the West Branch of the Sunrise River, the St. Croix River, and Lake St. Croix.

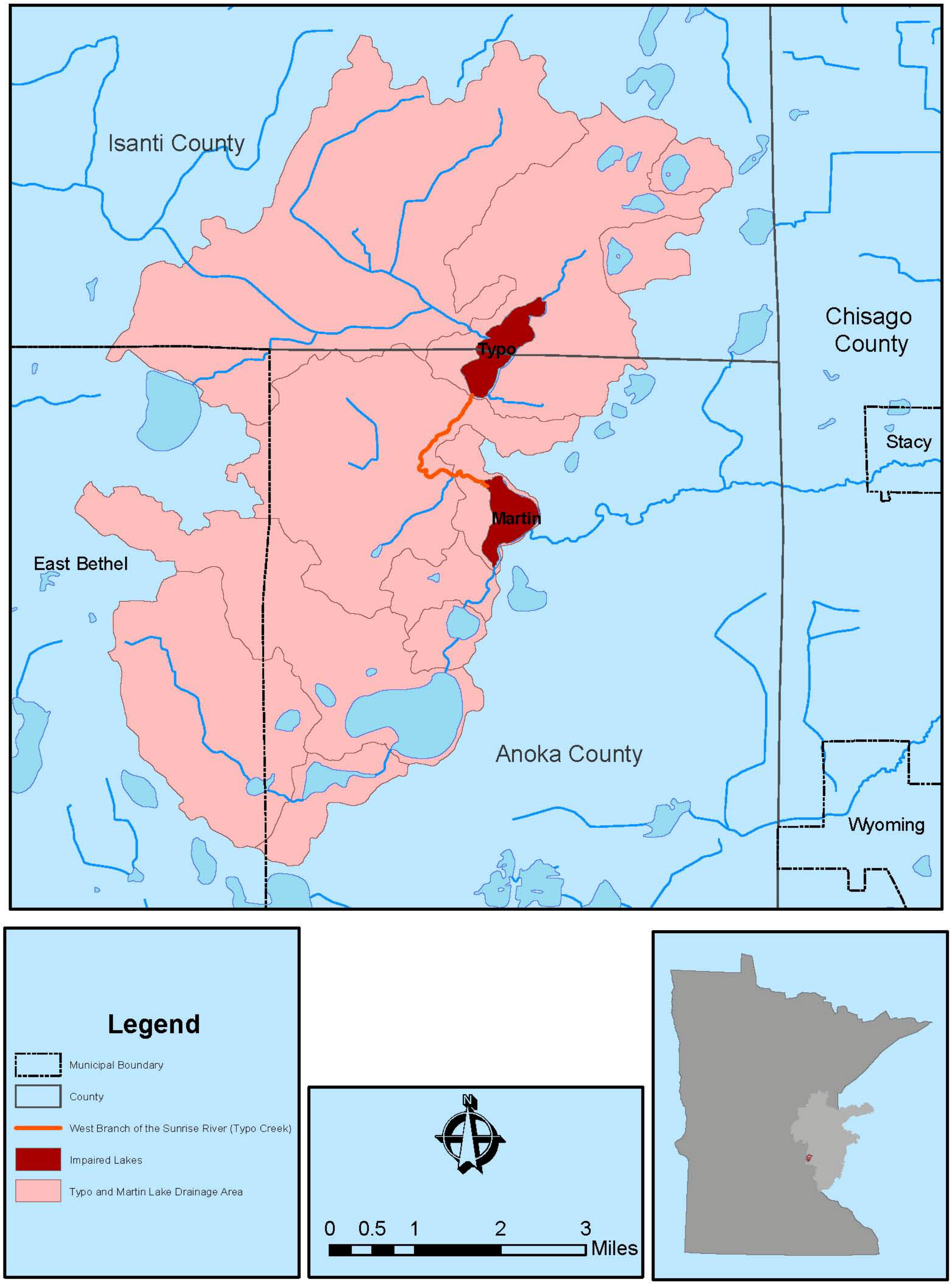


Figure 1. Martin and Typo Lake Location

1.3 Martin Lake

1.3.1 Water Quality Conditions and Impairment

HISTORY

The earliest records for Martin Lake indicate high nutrients and high algae. A Minnesota Department of Natural Resources (MN DNR) fisheries crew in 1954 noted a Secchi depth of 3.3 ft (1 m), which is similar to the clarity experienced today and is identical to the long-term average. They also noted that the water color was "green algae." The same was true in 1969. Secchi depth readings taken by resident volunteers in 1975-77 and 1985-1997 consistently had an annual average around 3 ft (Figure 2;Table 2).

In recent years, monitoring has tracked Martin Lake water quality (Figure 2;Table 2). Nine years of water quality data have been collected by the Minnesota Pollution Control Agency (1983), Metropolitan Council (1998), and Anoka Conservation District (1997, 1999-2001, 2003, 2005, and 2007). Citizens monitored Secchi depths 17 other years. A water quality change from 1983 to 2005 is detectable with statistical tests (repeated measures MANOVA with response variables Total Phosphorus (TP), Chlorophyll-a (Chl-a), and Secchi depth; $F_{2,6}$=5.69, p=0.04). However, examination of the response variables individually shows a mixture of changes, some indicating improvement and other indicating deterioration. It is worth noting that one instance when all three response variables showed improved water quality was in 1999, possibly as a result of carp harvests during the previous two winters.

Figure 2. Martin Lake Historical Water Quality

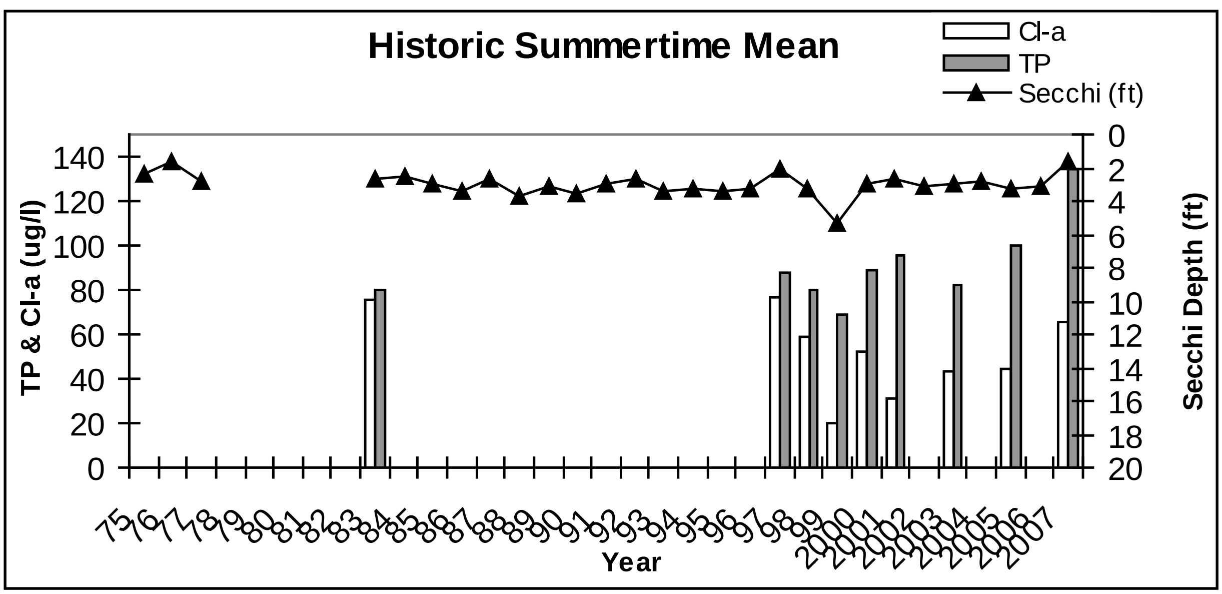


Table 2. Martin Lake Historical Water Quality

Agency	CLMP	CLMP	CLMP	MPCA	CLMP	CLMP	CLMP	CLMP	CLMP	CLMP	CLMP	CLMP	CLMP	CLMP
Year	75	76	77	83	84	85	86	87	88	89	90	91	92	93
TP				79.6										
Cl-a				75.4										
Secchi (m)	0.73	0.49	0.85	0.78	0.75	0.90	1.05	0.81	1.11	0.93	1.07	0.89	0.82	1.05
Secchi (ft)	2.4	1.6	2.8	2.6	2.5	3.0	3.4	2.7	3.6	3.1	3.5	2.9	2.7	3.4
Carlson's Tropic State Indices														
TSIP				67										
TSIC				73										
TSIS	65	70	62	64	64	62	59	63	58	61	59	62	63	59
TSI				68										
Martin Lake Water Quality Report Card														
Year	75	76	77	83	84	85	86	87	88	89	90	91	92	93
TP				D										
Cl-a				D										
Secchi	D	F	D	D	D	D	D	D	D	D	D	D	D	D
Overall				**D**										

Agency	CLMP	CLMP	CLMP	ACD	MC	ACD	ACD	ACD	CLMP	ACD	CLMP	ACD	CLMP	ACD
Year	94	95	96	97	98	99	2000	2001	2002	2003	2004	2005	2006	2007
TP				88.0	80.0	61.7	89.4	95.4		81.9		100		135.0
Cl-a				77.0	58.8	18.0	52.5	31.4		43.3		44.3		65.8
Secchi (m)	1.00	1.02	0.98	0.61	0.97	1.80	0.88	0.78	0.93	0.90	0.85	1.00	0.97	0.5
Secchi (ft)	3.3	3.4	3.22	2.0	3.3	5.3	2.9	2.6	3.1	3.0	2.8	3.3	3.2	1.7
Carlson's Tropic State Indices														
TSIP				69	67	64	68	69		68		71		75
TSIC				73	71	59	67	63		68		68		72
TSIS	60	60	60	67	60	52	63	65	65	62	62	60	60	70
TSI				70	66	58	66	66		66		66		72
Martin Lake Water Quality Report Card														
Year	94	95	96	97	98	99	2000	2001	2002	2003	2004	2005	2006	2007
TP				D	D	C	D	D		D		D		D
Cl-a				D	D	B	C	C		C		C		D
Secchi	D	D	D	F	D	C	D	D	D	D	D	D	D	F
Overall				**D**	**D**	**C**	**D**	**D**		**D**		**D**		**D**

CLMP= Minnesota Pollution Control Agency's Citizen Lake Monitoring Program, MPCA = Minnesota Pollution Control Agency staff, ACD= Anoka Conservation District

CURRENT WATER QUALITY

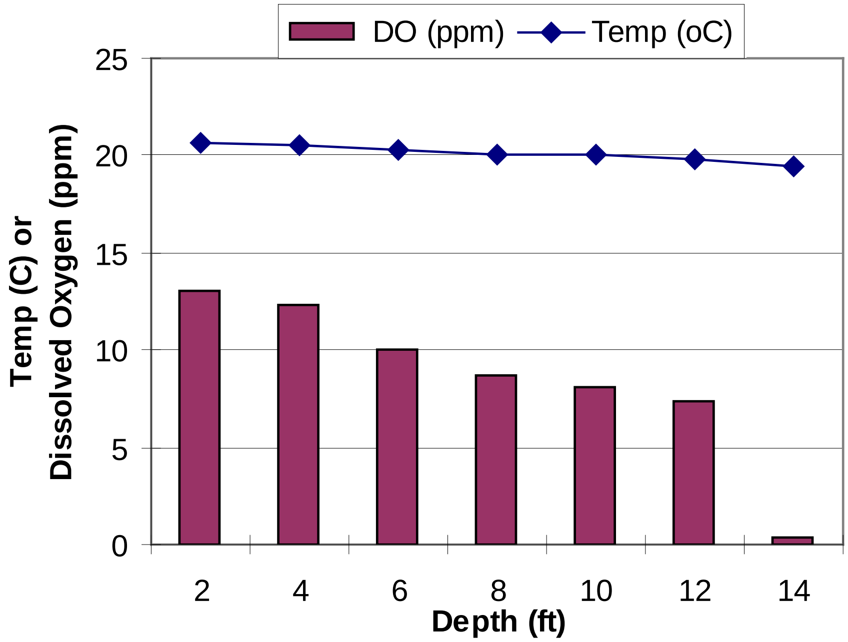
Current Martin Lake water quality is similar to conditions experienced over the last 20 or more years: highly eutrophic. The most recent data is from 2007. In 2007 (and all previous years except 1999) Martin Lake earned a overall "D" letter grade on the Metropolitan Council's lake grading system, which incorporates total phosphorus, chlorophyll-a ,and Secchi depths compared to other lakes in the ecoregion (Anhorn 2007). 2007 had some of the worst water quality of all years monitored. Average total phosphorus (135 µg/L) was the highest of 9 years that it has been monitored and chlorophyll-a (65.8 mg/L) was the third worst. Secchi transparency (0.57 m) was the second worst of 27 years that it has been monitored. The cause of especially poor conditions in 2007 was likely internal loading in upstream Typo Lake (and Martin, to a lesser extent) driven by drought-induced low water. Generally, since 1997 Martin Lake ranks near the 70-85th percentile for this region of Minnesota (Table 3).

Martin Lake is well-mixed; a late August 2004 depth profile indicated a 1.2^{o} C temperature difference between the surface and bottom, and dissolved oxygen showed no abrupt transitions until within 2 ft (0.61 m) of the bottom when dissolved oxygen dropped sharply (Figure 3). This is similar to results of depth profiles done throughout 2000, when temperature remained nearly constant with depth, but dissolved oxygen dropped sharply below 9-12 ft (2.7-3.7 m) (Klang et al. 2001). Given that the average depth is 9.5 ft (2.9 m), most of the lake is mixed to the bottom.

Table 3. Martin Lake Percentile Ranking Compared to Other Area Lake

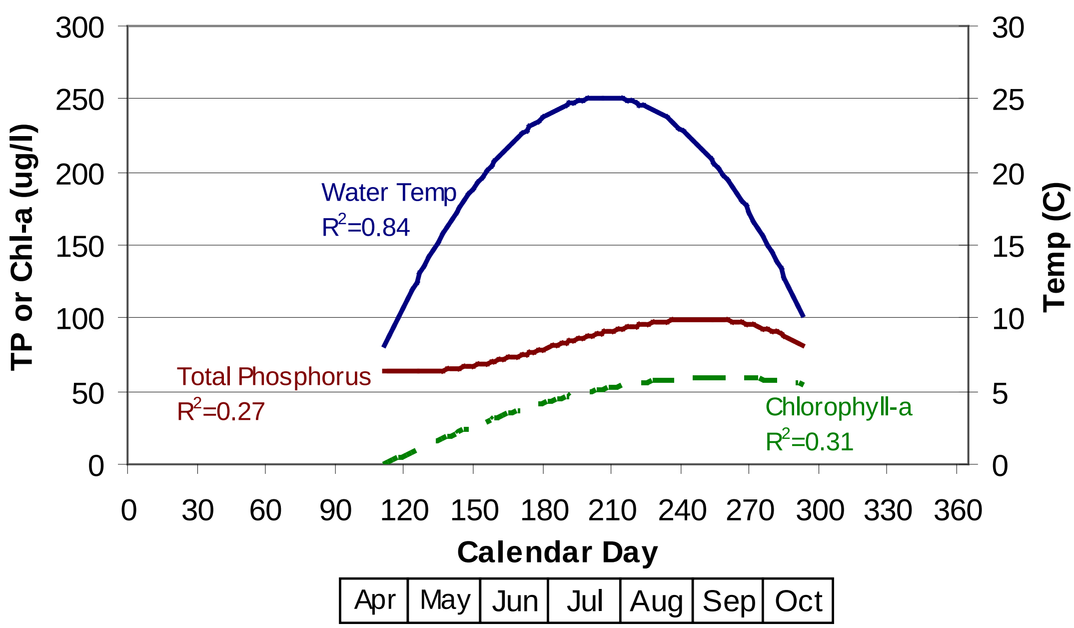
Parameter	North Central Hardwoods Forest Ecoregion (Heiskary and Wilson 1989; n=408, 491)	Twin Cities Metro Area (Anhorn 2007; n=186)	Anoka County Monitored Lakes (source: Anoka Conservation District; n=21)
	Percentile	Percentile	Percentile
Total Phosphorus	65-80th	70-90th	81st
Chlorophyll-a	NA	~60-75th	81st
Secchi Depth	~75th	70->90th	76th

Figure 3. August 2004 Dissolved Oxygen and Temperature Profile for Martin Lake



Martin Lake water quality shows seasonal trends typical of the region (Figure 4). Total phosphorus begins to increase in early June, and peaks in the beginning of September. During the period monitored (April-Sept) total phosphorus remains above 60 µg/L. A summer mean TP of >60 µg/L is used by the Minnesota Pollution Control Agency to classify a lake in this ecoregion as impaired. Algae growth is mild in the spring, but peaks with severe blooms in August and early September.

Figure 4. Martin Lake Water Quality and Temperature Seasonality (six years, from 1983-2003)



Recreational suitability of this lake suffers from July through September because of abundant algae. We used a subjective scale to rank recreational suitability (Schurbon 2008). Generally there were minimal problems or only slight swimming impairment until mid to late June. July through early September is typically unsuitable for swimming, and at times unsuitable for boating too due to algal scums and foul odor.

1.3.2 Morphometry and Lakeshore

Martin Lake is a moderately shallow lake with high residential lakeshore development and recreational use potential (Table 9). Martin Lake has a surface area of 238 acres, maximum depth of 17 ft (5.2 m), and average depth of 9.5 ft (2.9 m) (Figure 5). The lake is almost entirely surrounded by 146 homes, with an average of one home per 113 ft of lakeshore (homes within 300 ft of the lakeshore). Fifty-three percent (53%) of the lakeshore is manicured lawns to the water's edge (Appendix A. Shoreline Survey Maps). Twenty percent of the shoreline has moderate to severe erosion, and an additional 21% has mild erosion.

Martin Lake is polymictic, with mixing occurring throughout the water column. Computer modeling with the Wisconsin Lake Modeling Suite (Wisconsin Department of Natural Resources, version 3.1) estimates an Osgood Lake Mixing Index of 3.3, indicating moderate, but continuous mixing. The Lake Mixing Index ranges from 0 to 14; zero represents the most extreme mixing. Values between one and five are considered polymictic. The model estimates are supported by depth profiles in August of 1997, 1999, and 2004 which found no abrupt temperature or dissolved oxygen changes with depth to within 2 ft (0.61 m) of the maximum lake depth of 15 ft (4.6 m).

The typical range of water levels seen in a given year is 2 ft (0.61 m). Martin Lake level fluctuations are similar to those of Typo Lake, but slightly more dampened, probably because the outlet structure is a raised spillway instead of a culvert. Martin Lake has an estimated water residence time of roughly 70 days.

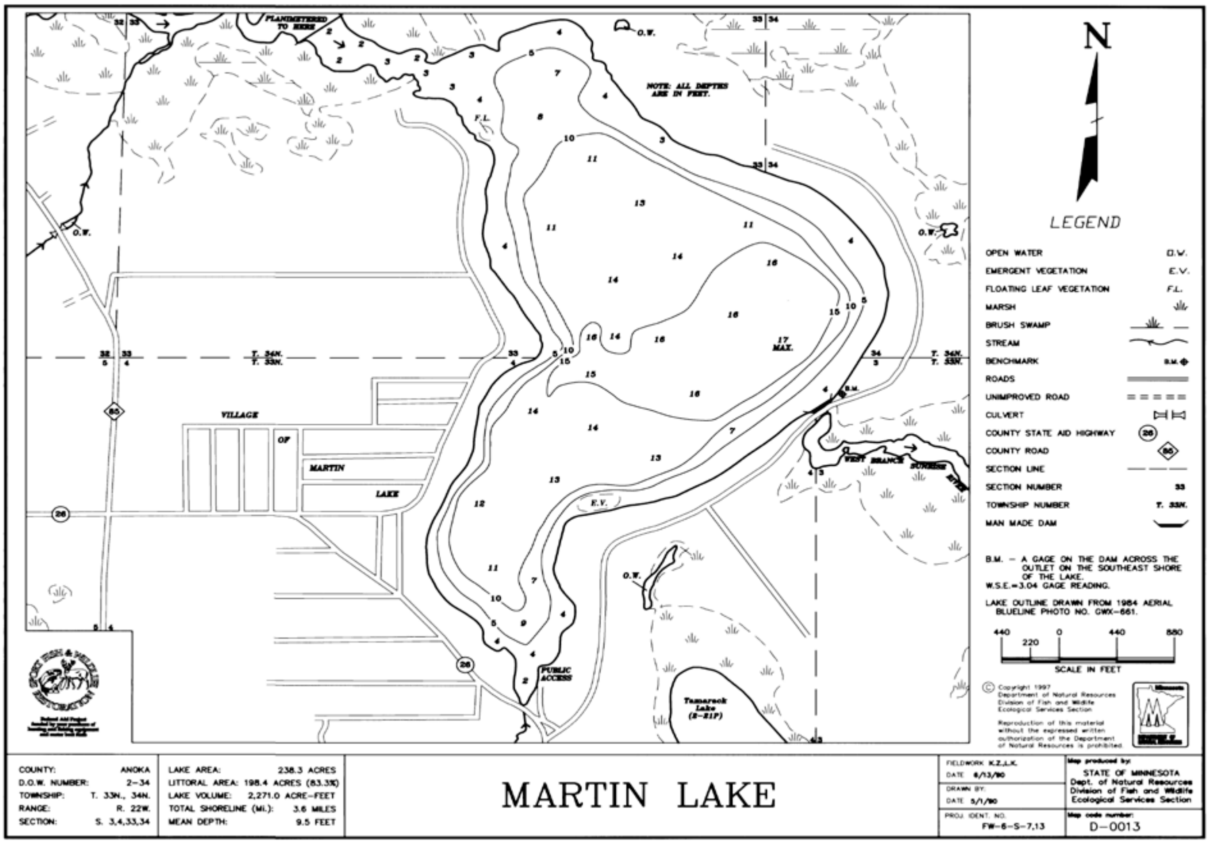


Figure 5. Martin Lake Bathymetry

1.3.3 Watershed

Martin Lake has a direct watershed of 4,832 acres, excluding the lake (Figure 6). The direct watershed is the area that drains directly to Martin Lake, without first passing through another major lake (i.e. Island or Typo Lakes). This direct watershed can be dissected into three major sub-watersheds (Figure 6) draining the major streams. An indirect watershed of 7,486 acres drains through Rice, Boot, and Linwood Lakes to Island Lake and finally Martin Lake's southern inlet. Additional indirect watershed is the Typo Lake watershed (11,289 ac); water from Typo Lake enters Martin Lake's northern inlet.

Land use in Martin Lake's watershed (Table 4) is primarily deciduous forest (29.6%), cultivated crops (25%), and emergent herbaceous wetlands (16.8%). Most of the wetland occurs adjacent to streams and ditches that drain to the lake. Residential development is concentrated around the lake, especially the west side of the lake. Moderate additional residential development is expected to occur in the near future. Approximately 1052 acres (9%) of the watershed is publicly owned.

Table 4. Martin Lake's Watershed Landcover (2001 NLCD).

	Sub-watershed*				
LANDCOVER	Martin Lake Direct Drainage[1] [acres]	Typo Lake Drainage[2] [acres]	Island Lake Drainage[2] [acres]	Total Acres	Percent of Total
Open Water	17.6	366.0	824.5	1208.1	5.1%
Developed, Open Space	255.9	272.5	174.0	702.4	3.0%
Developed, Low Intensity	134.1	145.9	139.8	419.8	1.8%
Developed, Medium Intensity	22.7	9.6	36.0	68.3	0.3%
Developed, High Intensity	1.1	0.0	0.0	1.1	0.005%
Barren Land	2.8	0.0	0.0	2.8	0.012%
Deciduous Forest	2106.5	2544.3	2346.5	6997.3	29.6%
Evergreen Forest	197.7	718.1	265.1	1180.9	5.0%
Mixed Forest	1.9	4.7	2.6	9.2	0.039%
Shrub/Scrub	19.9	62.0	31.6	113.5	0.5%
Grassland/Herbaceous	220.0	491.9	258.5	970.4	4.1%
Pasture/Hay	279.0	1034.0	564.4	1877.4	8.0%
Cultivated Crops	730.5	4133.0	1044.3	5907.7	25.0%
Woody Wetlands	20.9	85.4	85.4	191.8	0.8%
Emergent Herbaceous Wetlands	821.3	1421.7	1713.4	3956.4	16.8%
Total Acres	**4832**	**11289**	**7486**	**23607**	**100%**

* Subwatershed delineations can be found in Figure 6
[1] Does not include Martin Lake's surface area (238 acres)
[2] Surface areas of Typo Lake (290 acres) and Island Lake (99 acres) are included in their Open Water cover type data.

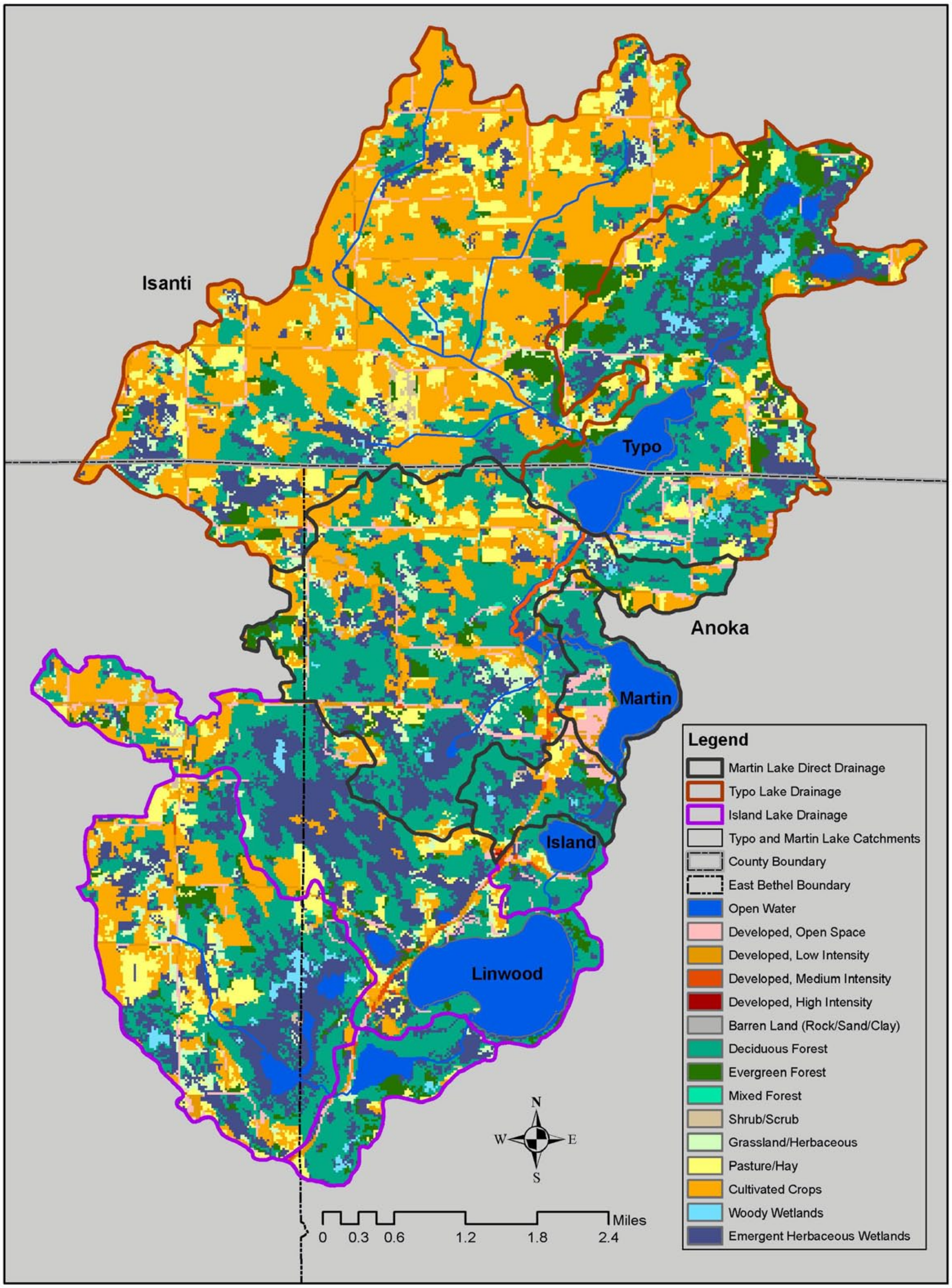


Figure 6. Martin Lake Watershed Landuse (2001 NLCD)

1.3.4 Fisheries and Recreational Uses

<u>HISTORY</u>

Martin Lake has chronically had high rough fish numbers throughout its recorded history (Minnesota Department of Natural Resources [MN DNR] Fisheries Records, 1940's to present). Rough fish control attempts began in the late 1940's when about 10,000 bullheads and 15,000 carp were removed. The next rough fish removal was a 1970 hoop netting of bullheads. In 1978, a DNR fish survey found that black bullhead abundance was about 22 times greater than that of any other species except common carp and black crappie which were 14 and 10 times more abundant than any of the other species, respectively. Rough fish removal was conducted again in 1987, 1998, and 1999. A one-year water quality improvement was documented in 1999 after two consecutive years of harvests, though this could have been due to other factors. No water quality monitoring was done before 1994, so any responses to other rough fish harvests were not documented. Stocking of predatory fish has also occurred many times in an attempt to provide a quality fishery and control rough fish.

Game fish stocking in Martin Lake began in the 1940's (MN DNR Fisheries Records). Walleye, largemouth bass, sunfish and crappie were stocked every year from 1946 to 1954. Numerous other stockings of these species occurred through the current date including largemouth bass in 1979 and 1988, and northern pike in 1981-84 and 1986-87. A highlight of recent stocking is the focus upon walleye beginning in 1985. From 1997-2003 an average of 508,000 walleye fry were stocked per year, totaling 3,556,000 during that six year period. The most recent stocking was 2,080,000 walleye fry in 2004, 280,000 in 2006, 1,180,000 in 2007, and 280,000 in 2008.

Martin Lake has a history of fish winterkills. Five of the ten winters between 1974 and 1984 experienced winterkills. A winter aeration system was installed at the south end of the lake in 1993, and winterkills have not occurred since.

<u>CURRENT</u>

The most recent fish community data for Martin Lake are from 1999 and 2004 MN DNR surveys, but because sampling between the two years seemed to be strongly influenced by weather differences, comparisons are difficult (Shane McBride, MN DNR Fisheries, personal comm.). The 2004 data is least trustworthy because weather patterns seemed to have restricted fish movements and altered the catch composition. However, some of the changes in fish captures could be due to real changes in the lake's fish community.

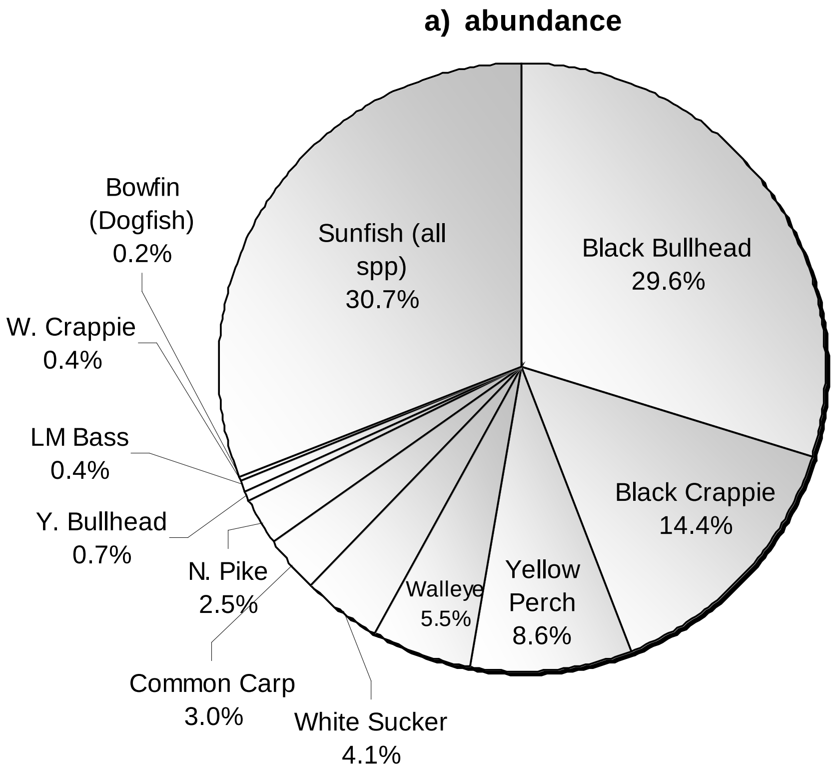
Sunfish, black crappie, and black bullhead dominate Martin Lake (Figure 7 & Figure 8). Sunfish were a much larger percent of captures in 2004 than in 1999, increasing from 30.7% to 63.8% of captures. They also increased from being just 7.8% to 46.4% of fish biomass (an example of a likely bias in sampling among years). Rough fish estimates were lower in 2004 than in 1999. In 1999 black bullhead and carp comprised 37% of biomass, but in 2004 are 18%. Despite the stocking of over three-and-a-half million walleye fry since 1997, walleye were only 1.3% of fish in 2004 and 5.5% in 1999. Both the 1999 and 2004 surveys were conducted by the MN DNR using trap and gill nets in the month of June.

Martin Lake draws moderate numbers of anglers, recreational boaters, and some swimmers. Public access to the lake is available at two locations: a <0.5 acre township park on the west side of the lake and a Minnesota Department of Natural Resources boat landing at the southern tip of the lake. The most recent creel survey in 2002 estimated 32 angler-hours per acre per year in summer and 29 in winter (MN DNR 2003). Ice fishing's popularity has grown on this lake, from less than 10 fish houses in the early 1980's to greater than fifty in the late 1980's (source: MN DNR Fisheries Records) to up to 100 currently on a busy weekend (Grant Haffley, resident, personal comm.). The MN DNR long range fisheries goal is "to provide a game fish population with walleye, northern pike, and pan fish that will support 75 angler-hours per acre" (MN DNR 1995). Martin Lake usage would probably increase if water quality improved, given the large number of lake shore homes and nearby communities.

Non-fishing water recreation for this lake is light considering the number of lakeshore homes and proximity to a large population base. During Anoka Conservation District summer weekday visits to the lake, there was typically only 1 to 3 boats on the lake, and only occasionally were there boat trailers at the public boat launch, indicating few people travel to Martin Lake.

Estimates from lakeshore residents indicate higher usage on weekends, typically 25 boats per day and up to 50 on a sunny Saturday; roughly 60% of these are believed to be recreational boaters and 40% fishers (Grant Haffely, resident, personal comm.). Roughly 60% of weekend boat traffic is people who own lakeshore property and 40% trailer their boat from elsewhere (Grant Haffley, personal comm.). The MN DNR estimates recreational usage of Martin Lake is 33 hours per acre per year (MN DNR 2003).

Figure 7. Martin Lake 1999 Fish Community; a) abundance, and b) biomass. Adopted from the June of 1999 MN DNR Fish Survey.



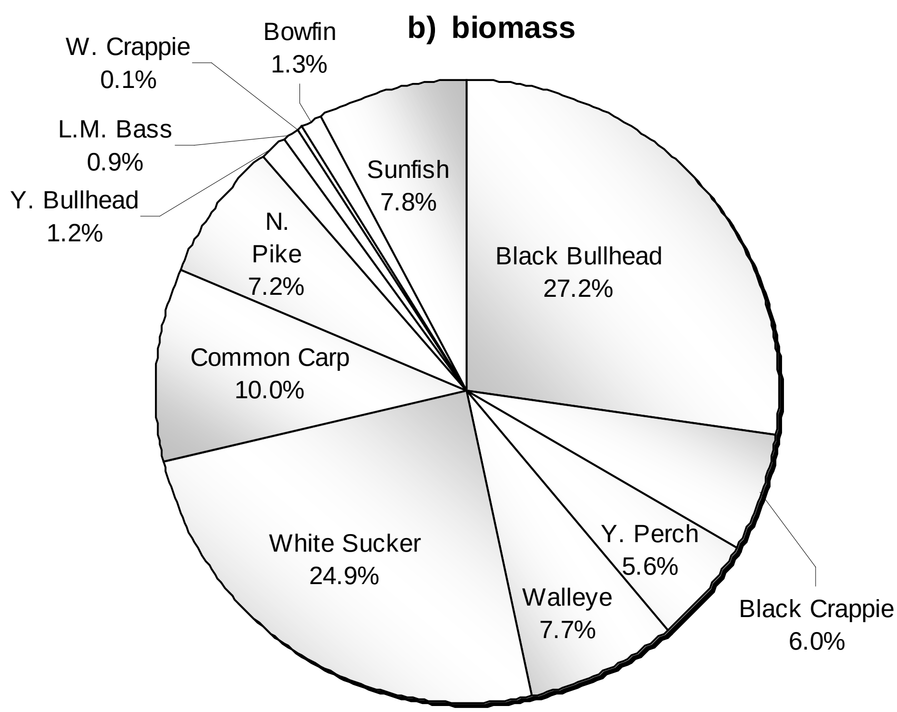
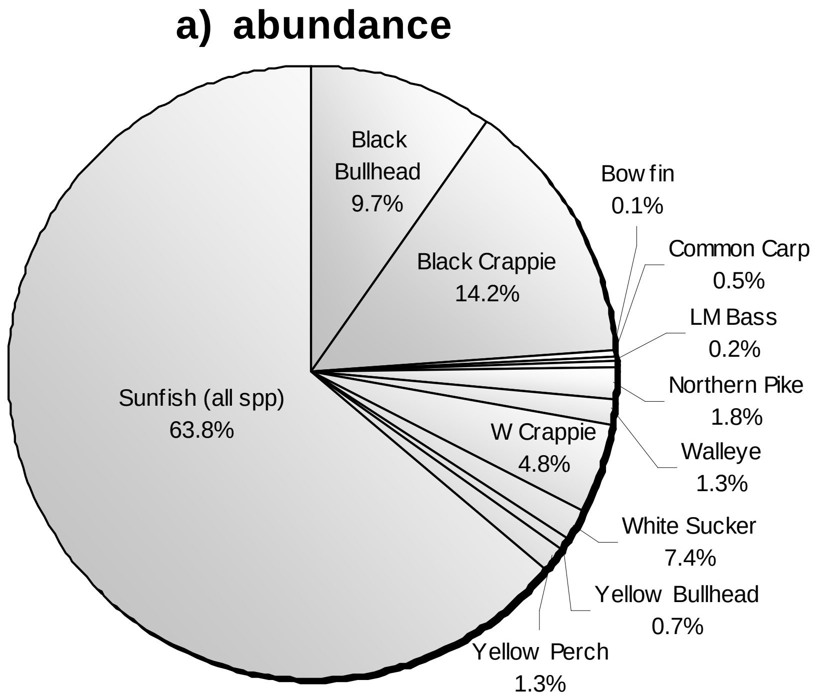
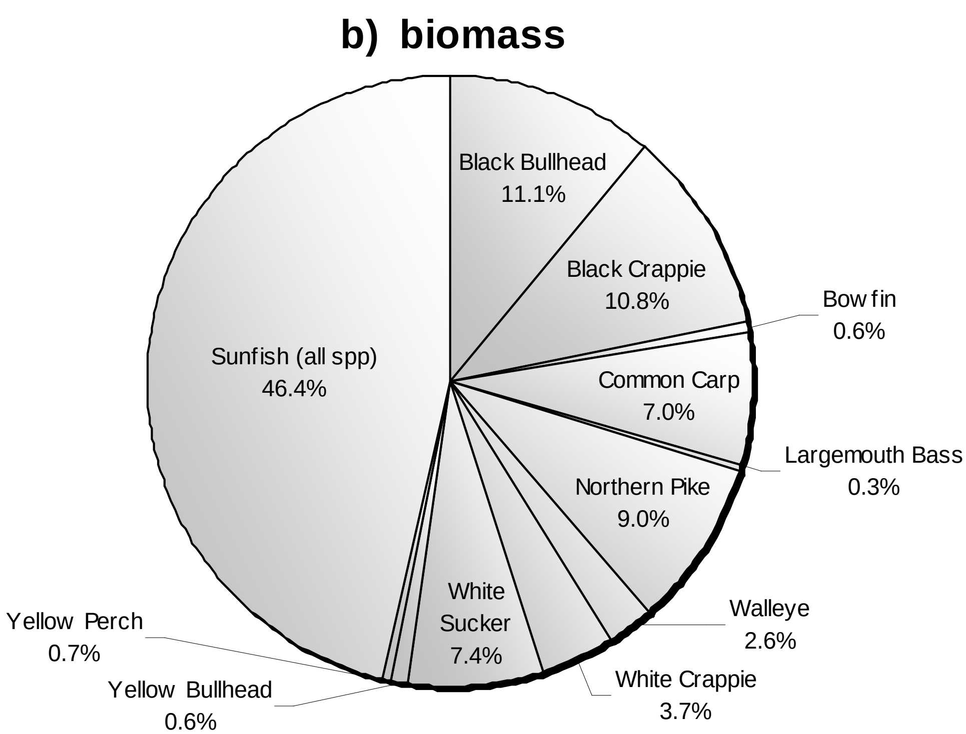


Figure 8. Martin Lake 2004 Fish Community; a) abundance, and b) biomass. Adopted from the June 2004 MN DNR fish survey.





1.3.5 Current Lake Management

The MN DNR manages the Martin Lake fishery primarily through annual stocking of walleye fry. The stocking goal is 2,000 fry per littoral acre. The aim of this stocking is primarily increasing angling potential of this lake, though increasing the number of predatory fish may also act as a biological control of rough fish. The MN DNR does "support and encourage removal of underutilized species by licensed commercial fishermen" and this was most recently done in 1998 and 1999 (MN DNR 1995). The MN DNR also conducts periodic creel and recreational use surveys, and fisheries assessments. There are no effective fish barriers in place at any of the inlets or outlets to minimize rough fish immigration or to minimize breeding in nearby wetlands. Anoka County Parks Department operates a winter aeration system at the south end of the lake, under a permit from the MN DNR, to prevent fish winterkills that sometimes occurred in the past.

The Martin Lakers Association is a lake association of about 92 lakeshore households who facilitate lake management and provide education for lake users and homeowners. The lake association has facilitated septic system care workshops delivered by University of Minnesota Extension, and is actively involved in efforts to improve stormwater treatment around the lake and address abundant rough fish. . Their newsletter and annual meeting serve as vehicles for other educational information. In the past, the lake association has facilitated rough fish removal by a commercial fisherman.

The Anoka Conservation District (ACD) and the Sunrise River Watershed Management Organization (SRWMO) worked together to provide lake monitoring, facilitate lakeshore restoration projects, implement rough fish control projects, and install stormwater retrofits. . Water quality monitoring is conducted every 1-3 years, every other week throughout the growing season. Cost share dollars are provided for landowners interested in restoring their manicured or eroding shoreline with a native vegetation buffer and aquatic plants.

In 2003 and 2004 the ACD and SRWMO mapped poor shoreland management practices and erosion problems, and contacted those landowners to offer corrective technical assistance and cost share. The SRWMO is a major funder of this impaired waters project and the ACD conducted this study.

1.4 Typo Lake

1.4.1 Water Quality Conditions and Impairment

HISTORY

The earliest anecdotal notes for Typo Lake indicate the lake changed dramatically from a macrophyte- to algae-dominated system sometime during the first four decades 1900's. Long-time residents indicate Typo had 80% coverage of emergent plants, especially wild rice, and harbored many ducks and game fish when they were children. The lake's ability to support this community (especially the plants) suggests good water clarity during that time. However, aerial photos from 1938 show the lake devoid of emergent plants and with noticeably turbid water. The timing of these changes coincides with a period of land use changes and hydrological transformations in the watershed – most notably, ditching of wetlands for agricultural purposes. Notes from MN DNR fisheries crews from 1960 to the present suggest that the lake has remained in an algae-dominated state.

Monitoring data in recent years documented the extremely poor condition of Typo Lake (Figure 9, Table 5). Volunteers taking Secchi depth readings in 1974-75 found summertime readings of less than 6 inches. Nine years of monitoring have been conducted by the Minnesota Pollution Control Agency (1993-94, and 1995) and the Anoka Conservation District (1997-2001, 2003, 2005, 2007), including a 1995 Lake Assessment by the Minnesota Pollution Control Agency (Klang et al. 1995). Water quality has not significantly changed from 1993 to 2007 (repeated measures MANOVA with response variables TP, Chl-a, and Secchi depth, $F_{2,8}$=3.74, p=0.07). The lake has received an "F" letter grade every year monitored (for lake grading system see Anhorn 2007).

Figure 9. Typo Lake Historical Water Quality

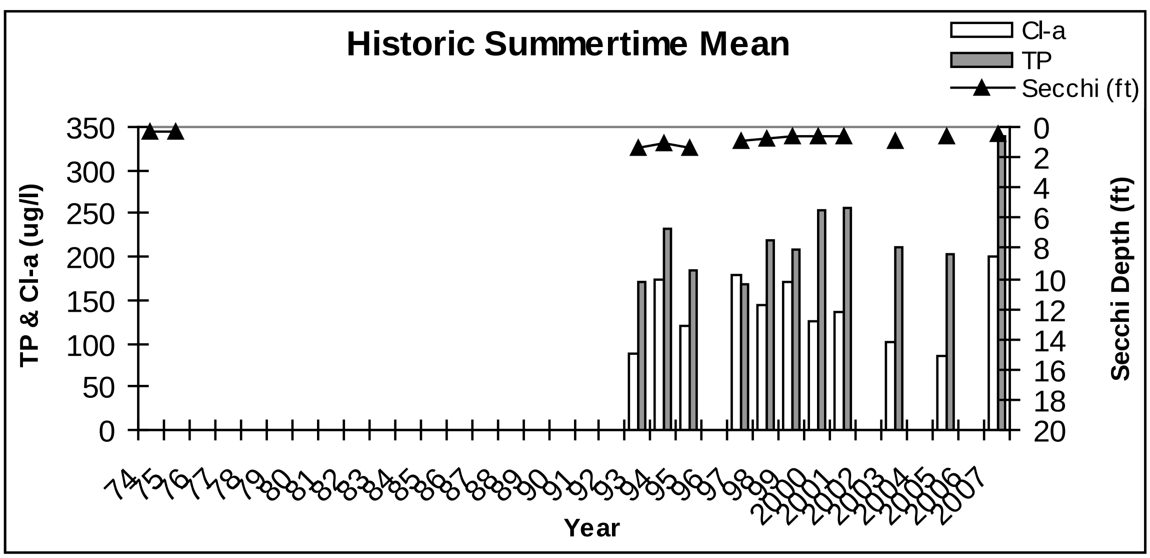


Table 5. Typo Lake Historical Water Quality

Lake Typo Summertime Historic Mean													
Agency	CLMP	CLMP	MPCA	MPCA	MPCA	ACD	ACD	ACD	ACD	ACD	ACD	ACD	ACD
Year	74	75	93	94	95	97	98	99	2000	2001	2003	2005	2007
TP			172.0	233.0	185.6	168.0	225.7	202.1	254.9	256.0	209.8	204	340.5
Cl-a			88.1	172.8	119.6	177.8	134.7	67.5	125.3	136.0	102.5	84.7	200.9
Secchi (m)	0.23	0.27	0.43	0.29	0.38	0.27	0.21	0.25	0.18	0.19	0.3	0.2	0.1
Secchi (ft)	0.2	0.3	1.4	1.0	1.3	0.9	0.7	0.8	0.6	0.6	0.9	0.6	0.4
Carlson's Tropic State Indices													
TSIP			78	83	79	78	82	81	83	82	81	81	88
TSIC			75	81	78	82	79	72	74	77	76	74	83
TSIS	81	79	72	78	74	79	82	80	86	85	77	83	93
TSI			75	81	77	79	81	78	81	81	78	79	88
Lake Typo Water Quality Report Card													
Year	74	75	93	94	95	97	98	99	2000	2001	2003	2005	2007
TP			F	F	F	F	F	F	F	F	F	F	F
Cl-a			F	F	F	F	F	D	F	F	F	F	F
Secchi	F	F	F	F	F	F	F	F	F	F	F	F	F
Overall			**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**

Current Water Quality

Typo Lake is currently hypereutrophic, as in the past, and has worse water quality than Martin Lake. It earns an overall "F" letter grade on the Metropolitan Council's lake grading system, which incorporates total phosphorus, chlorophyll-a, and Secchi depths compared to other lakes in the ecoregion (Anhorn 2007). In 2007 the average summer total phosphorus, chlorophyll-a, and Secchi depth were 340.5 µg/L, 200.9 µg/L, and 0.4 ft (0.12 m), respectively. These 2007 levels are the highest ever measured on this lake and are exceptionally extreme for any lake. The reason for the especially poor conditions in 2007 seems to be drought-induced low water levels. The lake's major inlet was monitored in 2007 and found to be similar to previous years or better. During drought it seems that internal loading (wind, rough fish, etc) builds nutrients and algae to very high levels because there is little flushing by storm water. Phosphorus and algae levels dropped by more than half when the dry period ended and ample rains fell in late August and September. In other years with better water quality than 2007, Typo Lake still ranks above the 90^{th} percentile compared to other lakes in the area (Table 6), and is the worst of 20 recreational lakes monitored in Anoka County.

Table 6. Typo Lake Percentile Ranking Compared to Other Area Lakes

Parameter	North Central Hardwoods Forest Ecoregion (Heiskary and Wilson 1989; n=408)	Twin Cities Metro Area (Anhorn 2007; n=120)	Anoka County Monitored Lakes (source: Anoka Conservation District; n=20)
	Percentile	Percentile	Percentile
Total Phosphorus	~90^{th}	>90^{th}	99^{th}
Chlorophyll-a	NA	>90^{th}	93^{rd}
Secchi Depth	>90^{th}	~90^{th}	99^{th}

Extreme seasonal fluctuation in water quality occurs with Typo Lake, but the casual observer wouldn't notice much change (Figure 10). Even early in the spring, when water quality is typically best, Typo Lake has extreme nutrients and algae. Later in the season, when phosphorus and chlorophyll-a often double, most users would say things went "from bad to worse." The algae shifts quickly from yellow-brown algae in late spring to blue-green algae dominance through September (Figure 11). Thorough mixing and high pH due to high productivity likely cause strong internal loading in this lake when temperatures are greater than 20^{o} C leading to continually worsening conditions throughout the summer months. Overall, recreational suitability of this lake remains relatively unchanged throughout the year, with the exception that spring water levels are usually higher, which allows more boat activity.

Figure 10. Typo Lake Water Quality and Temperature Seasonality (nine year period from 1993-2003)

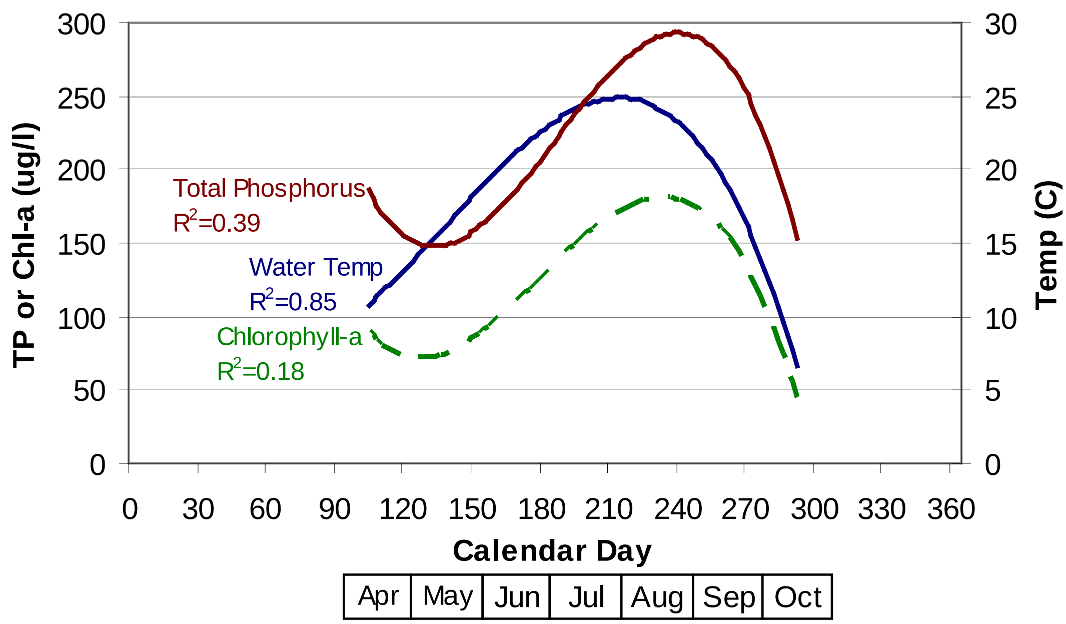
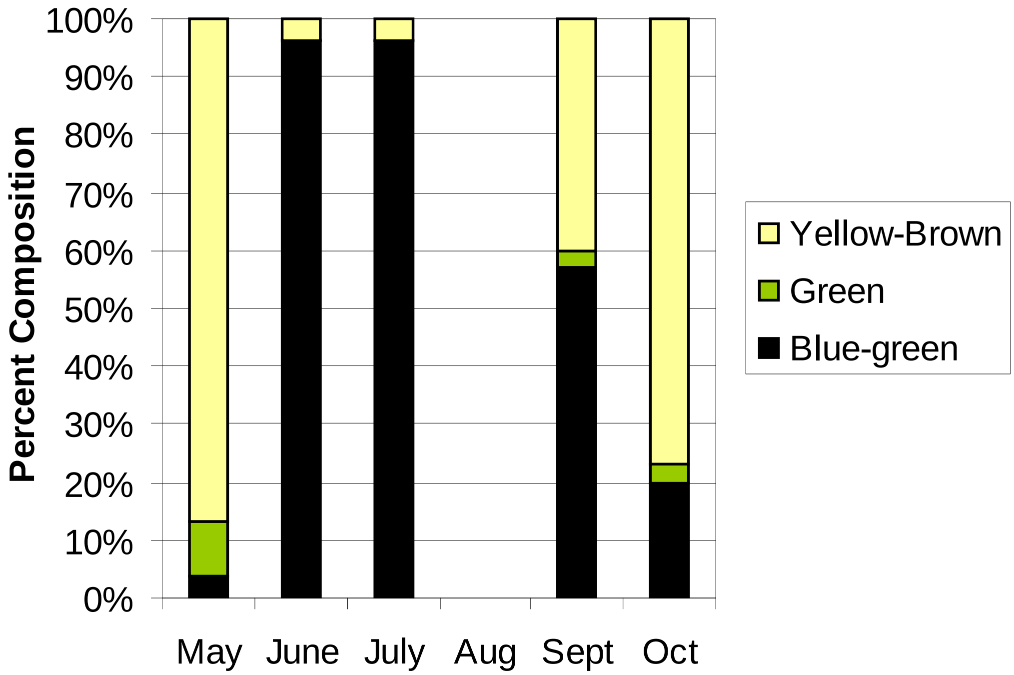


Figure 11. Typo Lake 1995 Algal Composition (Adapted from Klang, et al. 1995)



1.4.2 Morphometry and Lakeshore

Typo Lake is shallower, less developed, and has limited recreational use potential (Table 9), but has high wildlife value potential. It has poorer water quality than Martin Lake. Typo Lake has a surface area of 290 acres and a maximum depth of 5 ft (1.52 m); though most of the lake is about 3 ft (0.91 m) deep (Figure 12). Because of its shallow depth, Typo Lake would technically be best described as an "open water wetland" or "shallow lake." Roughly half of the lake bottom is mucky, loose and unconsolidated, while the other half is sandy.

The lakeshore is lightly developed, with almost all development on the southern half of the lake. The southern half of the lake has 32 homes. There is one home on the northern half of the lake. On average there is 1 home per 612.8 ft (186.8 m) of lakeshore (homes within 300 ft of the lakeshore only). Only 7% (466 m) of the shoreline is manicured lawns to the water's edge (see Typo Lake Shoreline Map – Appendix A). Three percent (196 m) of the shoreline has moderate or severe erosion problems. An additional four percent (248 m) has mild erosion problems, and the remainder is stable.

Typo Lake is also a polymictic lake, with mixing occurring throughout the water column. Computer modeling with the Wisconsin Lake Modeling Suite estimates an Osgood Lake Mixing

Index of 0.8, indicating intense and continuous mixing. The Lake Mixing index ranges from 0 to 14; zero represents the most extreme mixing.

Typo Lake levels fluctuate quickly, with a typical range of 2 ft (0.61 m) between the highest and lowest water levels annually. Water levels sometimes drop by as much as 0.1 foot per day during dry periods. Typo Lake has an estimated water residence time of roughly 85 days.

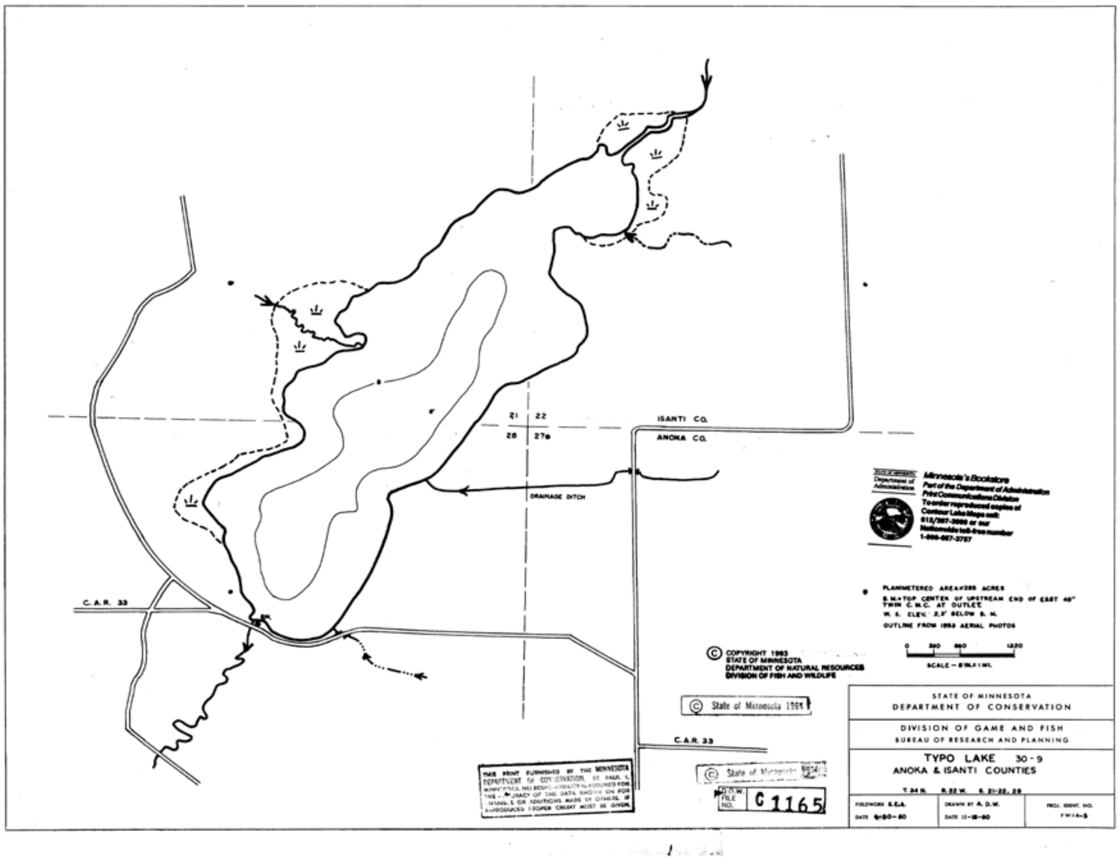


Figure 12. Typo Lake Bathymetry

1.4.3 Watershed

Typo Lake has a watershed of 11,000 acres, excluding the lake (Figure 13; Table 7). The watershed can be dissected into two primary sub-watersheds (Figure 13; Table 7): one for Data Creek west of the lake and the direct drainage, which includes various small intermittent streams on the north and east side of the lake.

Land use in Typo Lake's watershed is primarily row crop agriculture (38%), deciduous forest (22.7%), and emergent herbaceous wetlands (13%). The agricultural land is in closest proximity to waterways in the Data Creek watershed. Developed land is only 3.8% of land use. Future residential development in the watershed is expected to be moderate.

Table 7. Typo Lake Watershed Landcover (2001 NLCD)

	Sub-watersheds*			
Landcover	**Typo Lake Direct (Acres)**	**Data Creek (Acres)**	**Total Acres**	**Percent of Total**
Open Water**	76	0	76	0.7%
Developed, Open Space	116.5	156	272.5	2.5%
Developed, Low Intensity	58	87.9	145.9	1.3%
Developed, Medium Intensity	3	6.6	9.6	0.09%
Developed, High Intensity	0	0	0	0%
Barren Land (Rock/Sand/Clay)	0	0	0	0%
Deciduous Forest	1362	1183.3	2545.3	23.1%
Evergreen Forest	455	263	718	6.5%
Mixed Forest	4.7	0	4.7	0.04%
Shrub/Scrub	15	47	62	0.6%
Grassland/Herbaceous	113.4	378.5	491.9	4.5%
Pasture/Hay	262.5	771.5	1034	9.4%
Cultivated Crops	309	3824	4133	37.5%
Woody Wetlands	82	3.4	85.4	0.8%
Emergent Herbaceous Wetlands	778	643.7	1421.7	13.9%
Total Acres	**3635.1**	**7364.9**	**11000**	**100.0%**

* Subwatershed delineations can be found in Figure 13.

** Does not include Typo Lake Area of 290 acres.

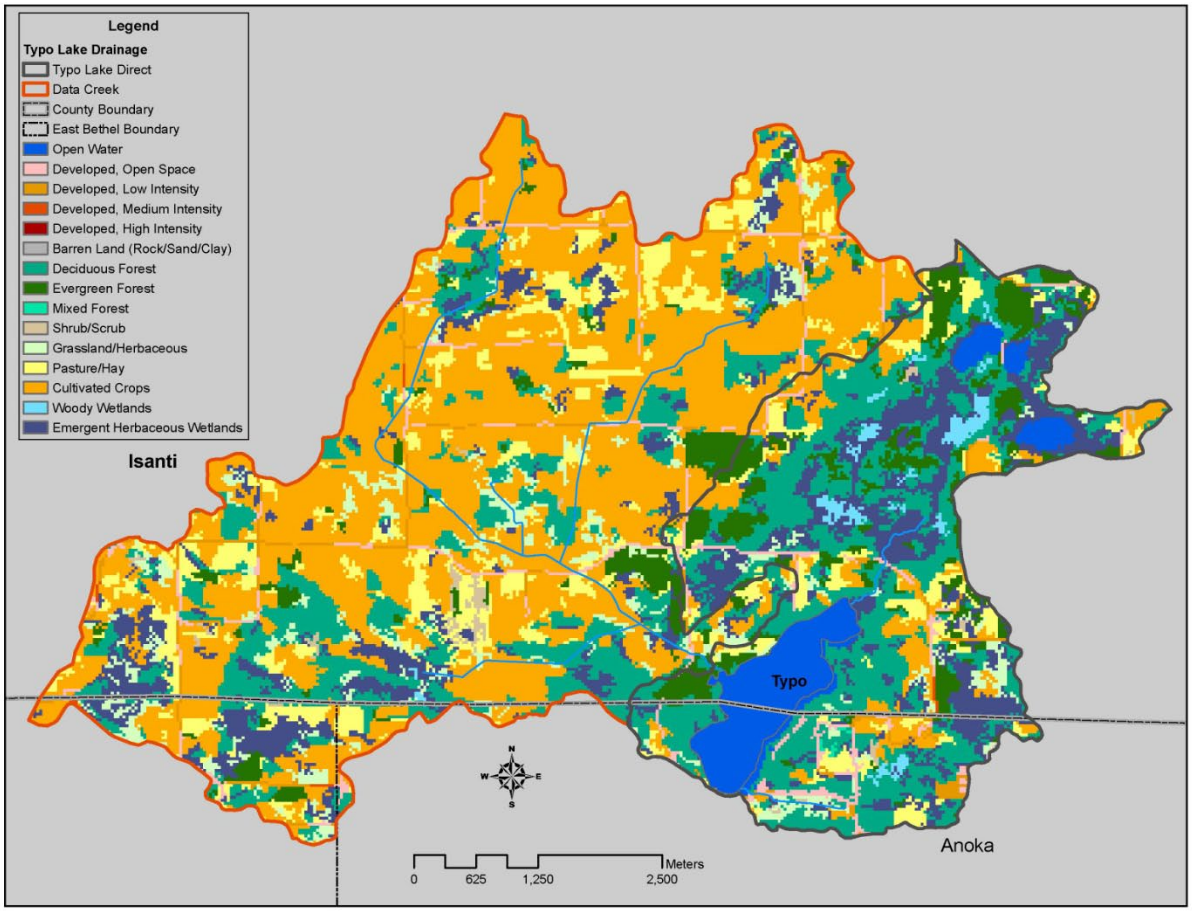


Figure 13. Typo Lake Landuse (2001 NLCD)

1.4.4 Fisheries and Recreational Uses

HISTORY

Historically, recreational boating on Typo Lake has been limited because of its shallow nature. A 1984 MN DNR lake survey estimated 2.42 hours per acre of recreational boating on the lake each year, and an additional 0.76 hours per acre waterskiing. In the 1970's and 80's a slalom waterskiing course was sometimes set up on Typo Lake. Sixteen boats were on the lakeshore during the 1984 MN DNR survey. Fishing pressure has historically been light due to the shallow nature of the lake, abundance of rough fish, and poor water quality. The 1984 MN DNR survey estimated only 3.42 person-hours of fishing per acre per year.

Wildlife values and hunting uses of Typo Lake have also been severely limited. Long-time residents of the community tell stories about Typo Lake full of emergent plants and providing good duck hunting and crappie fishing (Vernon Boettcher, resident, personal comm.). In more recent times duck use of this lake has been light, probably coinciding with losses of aquatic vegetation and associated invertebrates that waterfowl prefer. Aerial photos from 1938 show almost no emergent aquatic vegetation. The same is true for aerial photos from all other subsequent years. A 1974 MN DNR survey noted "little to no aquatic vegetation." At that time species present included wild rye, soft-stem bulrush, sweet flag, and cattails. Generally, the lake has received little recreational attention over the last generation.

Rough fish have dominated Typo Lake for many years, and there have been many efforts to reduce their numbers. The earliest records in MN DNR fisheries files note fish harvests during 1936-39 when 13,357 pounds of fish were removed, though the species is not indicated. Almost yearly rough fish removal was conducted between the winter of 1958-59 and 1974. From 1940 to 1961 harvests of carp and/or black bullheads were conducted on 5 occasions yielding a total harvest of 29,378 pounds. The most recent rough fish harvests were in the winters of 1985-86 and 1986-87. Fish traps and barriers have been placed at Typo Lake's outlet at various times, but were most recently removed in 1992 because they were not maintained.

Little fish stocking occurred in Typo Lake until recently. In the 1960's sunfish and crappies were stocked. Walleye stocking was conducted every year from 1988 to 1992 as well as in 1995, 1997, 1999, 2001, 2003, 2005, and 2007. The stocking rate has been about 1,000 walleye per acre per stocking (or 295,000 fry per stocking).

Despite being shallow, Typo Lake has not historically winterkilled often. Winter dissolved oxygen testing by the MN DNR has found that well-oxygenated water flowing in a stream from the primary inlet to the outlet provides a refuge for fish, minimizing the potential for severe winterkills. Known winterkills occurred in four winters of 1961-1964 (MN DNR Fisheries Records). The lake was opened to promiscuous fishing in those years as well as in 1974.

CURRENT

Today, like in the past, recreational use of Typo Lake is very light. A public boat landing is at the south end of the lake off of Fawn Lake Drive, but during 40+ weekday visits to the lake during 2001, 2003, 2005, and 2007 Anoka Conservation District staff witnessed only one other boat on the lake, a canoe, and only two shore anglers. During a 2001 survey ACD staff saw 35 boats on the shore (Table 8). These boats were mostly less than 16 ft in length, and most appeared to be used infrequently and were in dilapidated, but usable, condition. Ten usable docks are around the lake. One dock has a water slide, but no other areas used for swimming were apparent. Lakeshore homeowners use the lake most in spring, when water levels are usually higher and water quality is best.

Table 8. Typo Lake Boats on Shoreline in 2001

Boat Style	Number	Motor Sizes (hp)
Canoe	4	na
Kayak	6	na
Paddleboat	8	na
Sailboat (£ 14 ft)	3	na
Pontoon	5	20, 20, 25, 30, none
Fishing (£ 16 ft)	9	5, 10, 15, ~110 remainder use oars
Skiing	1	~30
Jet Ski	1	unknown

Wildlife usage of Typo Lake is also very light. Although the lake's morphometry and surrounding land uses are desirable for many wildlife species, it appears the poor water quality and related factors negate those assets. Few waterfowl frequent the lake, with the exception of some Canada Geese. Likewise, other animals often associated with shallow lakes like wading birds and turtles are relatively uncommon in Typo Lake (J. Schurbon, personal observation).

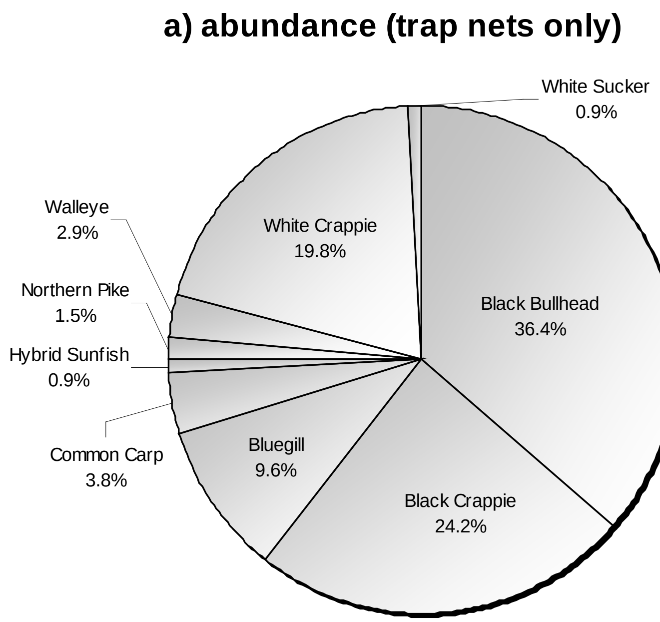
The Minnesota Department of Natural Resources long range fisheries goal for Typo Lake is to support 25 angler-hours per acre per year, primarily for walleye. A 1980 MN DNR Recreational Use Survey estimated 3.4 hours of fishing were occurring per acre. Water quality and the shallow nature of the lake impede many types of fishing, but a modest number of ice anglers are pursuing walleyes.

Minnesota DNR fisheries surveys in 1999 and 2004 lend insight into the structure of the fish community (Figure 14, Figure 15, & Figure 16). Careful examination of the data is needed to draw appropriate conclusions because the sampling methods were not the same among years. In 1999 both trap and gill nets were set, but in 2004 only trap nets were used. The two methods have different effectiveness capturing various species. Comparing trap and gill net data from 1999 (Figure 15) with trap net data alone from that year (Figure 14) reveals that the trap nets are poor at capturing walleye, black bullhead, and common carp that are of particular interest to this study. Each gill net caught 21 times more walleye than trap nets, 5.4 times more black bullhead, and about four times more carp.

With confidence, we can conclude that carp and black bullhead are dominant in Typo Lake. The 1999 data from all trap types show that black bullheads and common carp account for 73% of all fish and 68% of fish biomass (Figure 16). Carp alone were 50% of fish biomass in Typo Lake in 1999. By comparing only the trap net data from 1999 and 2004 (Figure 14 & Figure 16) we see carp numbers about the same in 1999 and 2004, and their biomass increased. Black bullhead captures in trap nets were similar between 1999 and 2004, but their proportion of the biomass was roughly halved.

Walleye numbers in Typo Lake are moderate, despite intense stocking. 1999 trap and gill nets combined indicate walleye are 13% of fish numbers and 19% of biomass. 2004 trap nets caught fewer walleye than 1999 trap nets, but in both years walleye were <4% of trap net fish captures and biomass.

Figure 14. Typo Lake, June 1999 MN DNR Fish Community Survey (Trap Nets Only)



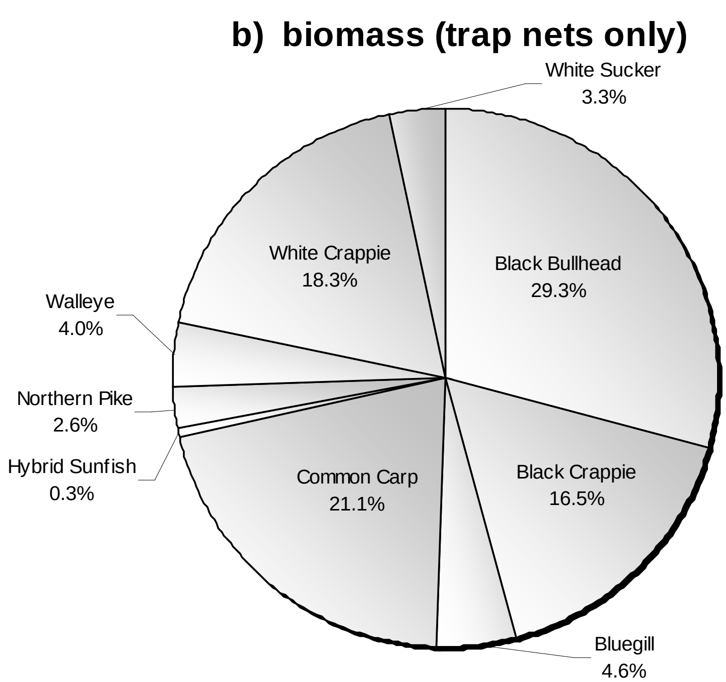
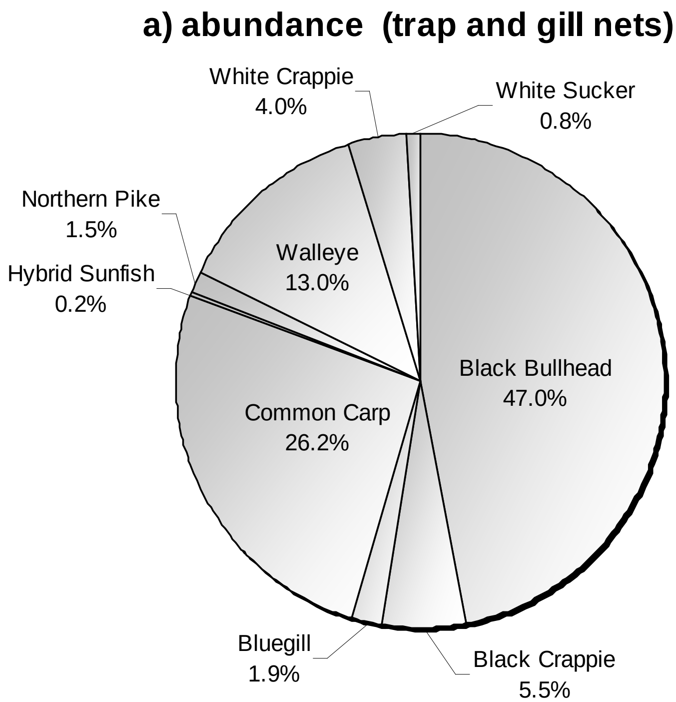


Figure 15. Typo Lake, June 1999 MN DNR Fish Community Survey (Trap and Gill Nets)



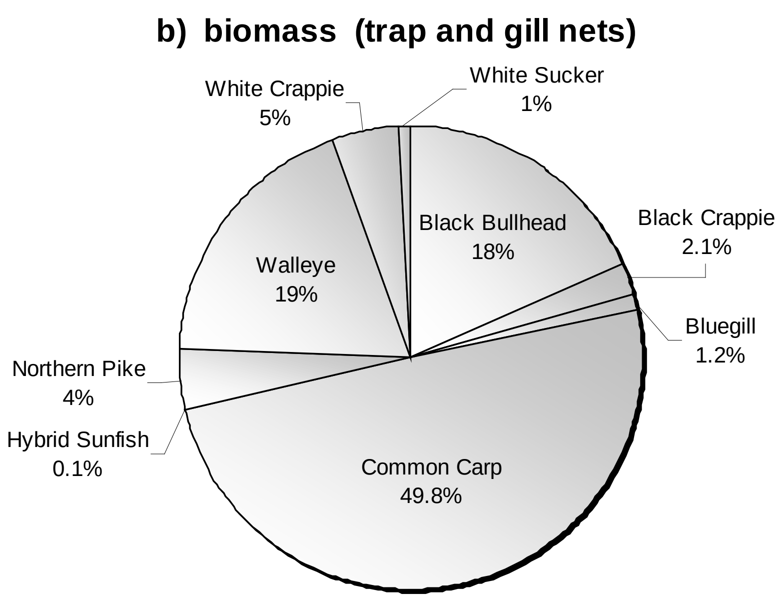
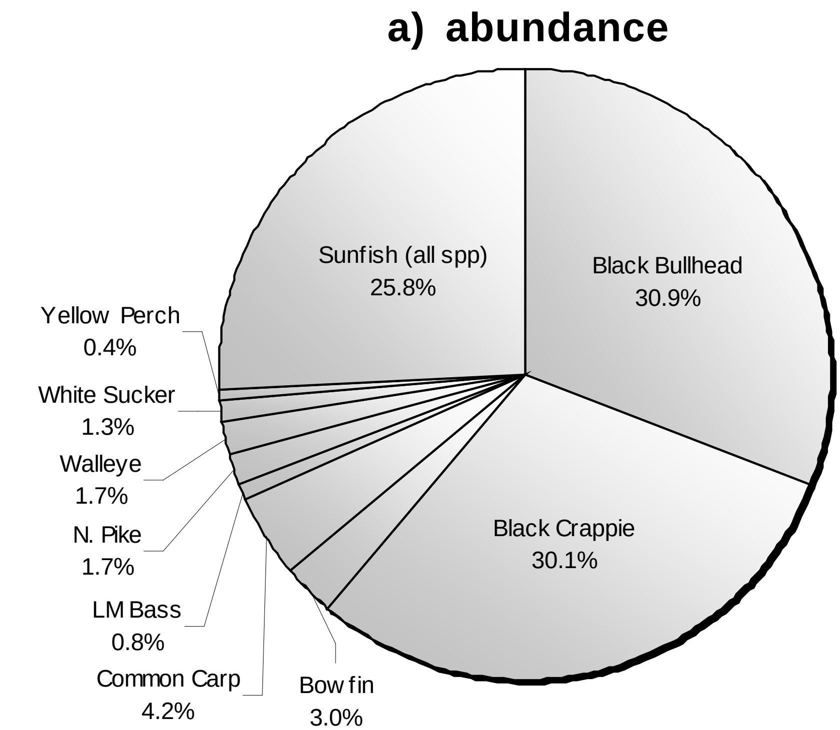
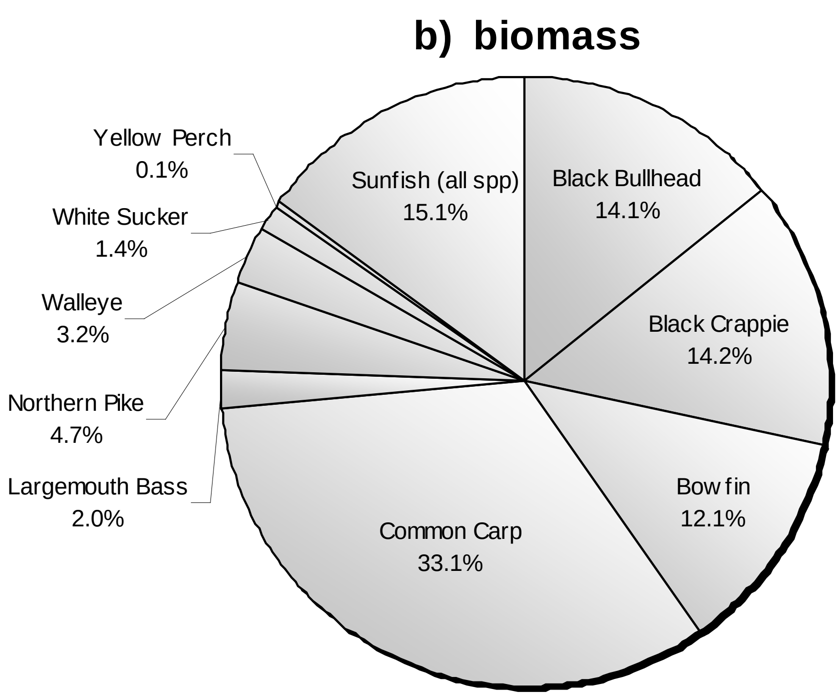


Figure 16. Typo Lake, June 2004 MN DNR Fish Community Survey (Trap Nets Only)





1.4.5 Current Lake Management

Typo Lake's fishery is managed by the MN DNR through stocking of walleye fry every other year. The stocking rate is 1,000 per acre, or about 295,000 each stocking. Goals of this stocking include (1) increasing angling potential of this lake and (2) increasing the number of predatory fish which may act as a biological control of rough fish. The MN DNR also conducts periodic creel and recreational use surveys, and fisheries assessments. There are no effective fish barriers in place at any of the inlets or outlets to minimize rough fish immigration or to minimize breeding in nearby wetlands. There is no aeration system on Typo Lake.

No active lake association exists for Typo Lake. In the past, a lake association did exist. News of this TMDL project has motivated some residents to attempt organizing their neighbors into an active association once again.

The ACD and SRWMO work together to provide lake monitoring and facilitate lakeshore restoration projects. Water quality monitoring is conducted every 1-3 years, every other week throughout the growing season. The same lakeshore restoration and erosion control cost share program available on Martin Lake is also promoted on Typo Lake.

Table 9. Morphometric, Shoreline, Watershed, and Fishery Characteristics for Martin Lake and Fish Lake.

Characteristic	Martin Lake	Typo Lake
Lake Identification Number	02-0034	30-0009
Mean Depth	9.5 ft (2.9 m)	3 ft (0.9 m)
Maximum Depth	17 ft (5.2 m)	5 ft (1.5 m)
Lake Area	238.3 ac	290.1 ac
Littoral Area	198.4 ac (83.3%)	290.1 ac (100%)
Direct Watershed Area (excludes lake)	4,832 ac	3,635 ac
Watershed Area : Lake Area	~24:1	~40:1
Shoreline Length	3.13 mi	3.83 mi
Volume[1]	2,314 ac-ft (2.9 hm^3)	869.3 ac-ft (1.1 hm^3)
Fetch	1.09 mi	1.43 mi
Est. Water Residence Time	80 days (2001) 91 days (2003)	76 days (2001) 70days (2003)
Fisheries[2] Primary Management Secondary Management Schupp's Lake Class	 Walleye and Largemouth Bass Bluegill 24	 Walleye 43
Public Accesses	2	1
Inlets	2 major	2 major, 3 minor
Outlets	1	1
Approx. # Homes within 300 ft of lakeshore	146	33
Shoreline Housing Density (homes per 100 ft lakeshore; only homes within 300 ft of shore)	1.132	0.163
Percent shoreline manicured to water's edge	53%	7%
Percent shoreline with moderate or severe erosion	20%	3%

[1]MN Pollution Control Agency Lake "1995 Typo Lake Assessment" and "2000 Linwood and Martin Lakes Assessment"
[2]MN Department of Natural Resources Lake Management Plans

1.5 Typo Creek

1.5.1 Water Quality Conditions and Impairment

Water quality in the segment of the West Branch of the Sunrise River between Typo Lake and Martin Lake (aka Typo Creek; AUID 07030005-563) is reflective of Typo Lake water quality. The creek flows approximately 1.5 miles from Typo Lake to Martin Lake, with minimal new water entering the creek throughout this length. Water quality problems for this stream reach include high pH and turbidity.

pH

pH is a measure of acidity. pH of 7.0 is neutral, while lesser values indicate acidity and greater values are alkaline. Natural waters typically have pH values from 6.5 to 8.5. pH water quality standards are provided in Minn. Rules Ch. 7050.0222 for Class 2B and 2C waters and are further described in the MPCA's assessment guidance (MPCA, 2007) as follows: "the applicable pH standard for most Class 2 waters is a minimum of 6.5 and a maximum of 8.5, based on the more stringent of the standards for the applicable multiple beneficial uses. The pH values that are either too high or too low can be harmful to aquatic organisms". Thus, the designated use that this standard protects is aquatic life.

While natural waters can exhibit pH values outside the 6.5 to 8.5 range, the high pH documented within Typo Creek appears to be directly the result of eutrophication (high algal production) in Typo Lake. pH in Typo Creek water is most elevated when it leaves Typo Lake, but decreases further downstream (Table 10). In his description of inorganic carbon chemical processes in fresh water systems, Wetzel (2001) includes the relationship of carbon dioxide dissolution, carbon dioxide utilization (during photosynthesis) and pH. Specifically, atmospheric carbon dioxide dissolves in water and is in equilibrium with the hydrated dissolved carbon product carbonic acid. During rapid photosynthesis (e.g., resulting from abundant algal production) the dissolved carbon dioxide concentration is rapidly reduced, which in turn reduces the carbonic acid concentration and raises the pH. High pH in highly eutrophic lakes has been commonly observed in Minnesota (Bruce Wilson, MPCA, 2007; personal communication). For these reasons a separate TMDL analysis for the pH listing for Typo Creek (Typo Lake Outlet) will not be done and instead will be addressed via the Typo Lake excess nutrient TMDL analysis.

Table 10. Typo Creek pH Data (1998 – 2007). Data is shown for sites from Typo Lake (Headwaters) to Martin Lake Inlet.

	pH Upstream --> Downstream				
	Typo Lake (30-0009)	**Typo Creek at Fawn Lake Drive, Typo Lake outlet (S003-217)**	**Typo Creek at Typo Creek Drive north/upstream crossing (S003-225)**	**Typo Creek at Typo Creek Drive south/downstream crossing (S003-188)**	**Typo Creek at Martin Lake Inlet (S003-219)**
Average	9.11	9.09	7.56	7.92	7.86
# Observations	63	4	4	23	3
# Exceedences of 6.5 to 8.5 Standard	NA	4	0	8	1
Dates and values of exceedances	NA	5/16/98 – 8.61 6/16/98 - 8.55 7/16/98 – 9.54 8/13/98 – 9.66		7/16/98 – 8.52 6/26/01 – 8.92 7/16/01 – 9.49 7/23/01 – 9.15 8/2/01 – 9.20 4/16/03 – 6.23 6/2/03 – 8.54 9/8/03 – 8.96	7/16/01 – 9.42

Turbidity

Turbidity is also a problem in Typo Creek (Table 11). Turbidity measures solids suspended or algae in the water. Surrogate measurements are total suspended solids and transparency. Turbidity water quality standards are provided in Minn. Rules Ch. 7050.0222 for Class 2B and 2C waters and are further described in the MPCA's assessment guidance (MPCA, 2007). The Minnesota turbidity standard is 25 NTU (nephelometric turbidity units), with a minimum of 20 observations needed for assessment. Three observations and 10% of all observations must exceed the standard for the waterbody to be in violation of the standard. High turbidity affects aesthetics, recreational suitability, and can harm aquatic life by making it more difficult to find food, affecting gill function, and covering spawning beds.

Typo Lake is the source of turbidity for Typo Creek. The creek's turbidity is highest near the outlet of Typo Lake, and decreases with as the water gets further from the lake (Table 11). The average turbidity near the Martin Lake inlet is less than half of the turbidity at the Typo Lake outlet. This is likely due to some settling in the slow-moving stream. This upstream-to-downstream turbidity decline also provides assurances that other sources of suspended solids between the two lakes are not contributing the stream's impairment.

Table 11. Turbidity Data for Typo Creek (1998 – 2007)

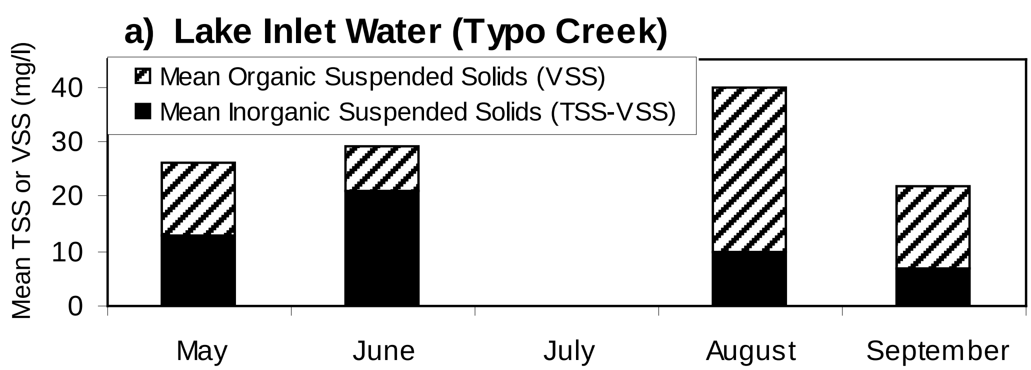
	Turbidity* Upstream --> Downstream				
	Typo Lake (30-0009)	**Typo Creek at Fawn Lake Drive, Typo Lake outlet (S003-217)**	**Typo Creek at Typo Creek Drive north/upstream crossing (S003-188)**	**Typo Creek at Typo Creek Drive south/downstream crossing (S003-188)**	**Typo Creek at Martin Lake Inlet (S003-219)**
Average	124	166	16	45	39
# Observations	62	4	4	23	2
# Exceedences of 25 NTU standard	NA	4	0	14	1
Dates and values of exceedances	NA	5/16/98 – 88 6/16/98 – 153 7/16/98 – 214 8/13/98 – 207		5/16/98 – 45 6/16/98 – 112 7/16/98 – 108 8/13/98 – 42 11/01/00 – 66 5/7/01 – 35 5/23/01 – 38 6/12/01 – 64 6/26/01 – 67 7/16/01 – 133 7/23/01 – 105 8/2/01 – 27 10/10/01 – 36 8/4/03 - 30	6/12/01 - 60

* Turbidity units are in FNRU and not NTU.

More than half of Typo Creek's turbidity is due to algal production in Typo Lake. The ACD took eight paired measurements of total suspended solids (TSS) and volatile suspended solids (VSS) in 2003 in Typo Creek near its inlet to Martin Lake (Figure 17). TSS is a measure of organic and inorganic solids suspended in the water column. VSS is primarily the organic portion of the TSS, such as algae and detritus, and is often expressed as a percentage of TSS.

These tests allow us to determine how much of the solids suspended in the water column are due to algae versus inorganic suspended solids. Solids in Typo Creek were on average 55% volatile (algae and other organics; Figure 17). In the month of August, when algal production typically peaks, 75% of solids were algae and other organics.

Figure 17. Mean Total and Volatile Suspended Solids for Typo Creek (2003)



Like the pH impairment, the turbidity impairment is a symptom of the eutrophication (phosphorus) impairment. For this reason, a separate TMDL analysis for the turbidity listing for Typo Creek (Typo Lake Outlet) will not be done and instead will be addressed via the Typo Lake excess nutrient TMDL analysis.

1.5.2 Morphometry and Lakeshore

Typo Creek flows approximately 1.5 miles from Typo Lake to Martin Lake. It is shallow (1-3 ft) and the bottom is deep, loose sediment. The land immediately adjacent to the creek is not actively used and is in a natural state.

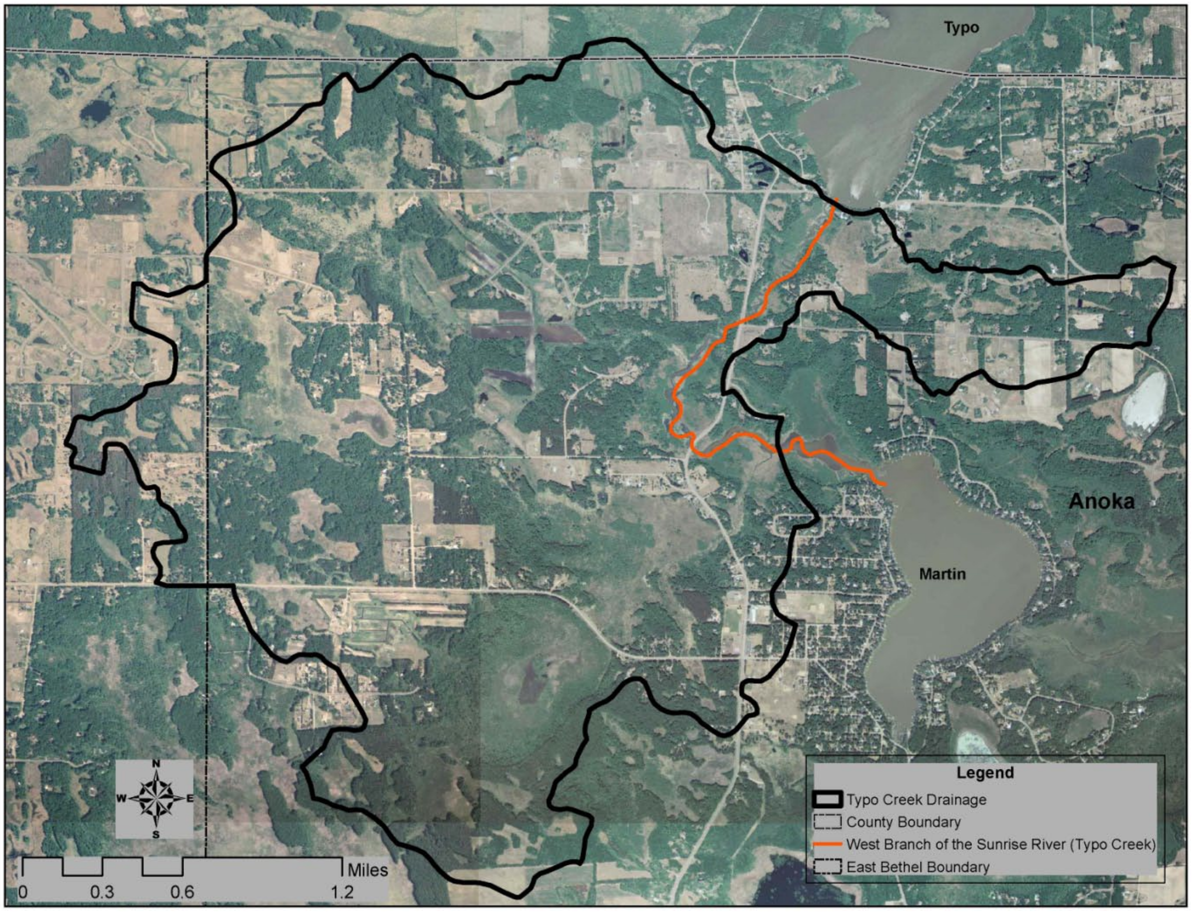


Figure 18. West Branch of the Sunrise River (Typo Creek) Watershed Area (2009 FSA Aerial Image**)**

1.5.3 Watershed

The watershed for Typo Creek includes the drainage area of the Typo Lake area, and a direct watershed area of 3,915 acres. Overall, all drainages into Typo Creek are small and intermittent (sometimes flowing, sometimes not). The watershed is dominated by wetland such that defined flow into the creek is not present in many locations.

1.5.4 Fisheries and Recreational Uses

This reach of the Sunrise River gets little recreational use. Access is limited to road crossings, water depths are 1-3 ft (0.3 – 0.9 m), and the bottom is deep muck, Fish are believed to migrate between the lakes via this stream, but this activity is likely seasonal. During >5 years of study, Anoka Conservation District staff have never seen anglers or recreational boaters on this stretch of creek.

2. Applicable Water Quality Indicators and Target Values

Specific numerical thresholds were used to determine whether Typo and Martin Lakes, and the reach of the West Branch of the Sunrise River between the lakes, should be placed on the 303(d) list of impaired waters. These criteria are in Minn. Rules Ch. 7050.0222 and the MPCA's assessment guidance (MPCA, 2007), and are summarized below. These criteria also provide a framework for goal-setting and ultimately serve as a basis for listing and delisting of lakes and streams. Table 12 and Table 13 present eutrophication standards for lakes and corresponding data from Typo and Martin for comparison. Table 14 provides pH and turbidity standards for streams, while Table 10 and Table 11 provide corresponding data from the West Branch of the Sunrise River for comparison.

Table 12. Eutrophication Standards for Lake in the North Central Hardwood Forest (NCHF) Ecoregion

Ecoregion	TP	Chl-a	Secchi
	µg/L	µg/L	m
NCHF – Stream trout (Class 2a)	< 20	< 6	> 2.5
NCHF – Aquatic Rec. Use (Class 2b)	< 40	< 15	> 1.4
NCHF – Aquatic Rec. Use (Class 2b) Shallow lakes (***Applies to Martin Lake &Typo Lake***)	< 60	< 20	> 1.0

TP = Total phosphorus
Chl-a = Chlorophyll-a, includes both phaeophytin-corrected and non-phaeophytin-corrected values
Secchi = Secchi disk transparency

Table 13. Typo Lake and Martin Data (2001 & 2003)

Lake	TP	Chl-a	Secchi
	µg/L	µg/L	m
Typo: Mean - 2001 & 2003	**246**	**126**	**0.3**
Typo: 2001	282	149	0.3
Typo: 2003	210	103	0.3
Martin: Mean - 2001 & 2003	**89**	**37**	**0.9**
Martin: 2001	95	31	0.8
Martin: 2003	82	43	0.9

Table 14. pH and Turbidity Standards for Streams in the North Central Hardwood Forest Ecoregion (NCHF)

Class 2B Waters Standards	
Turbidity	
Standard	25 NTU
# observations for assessment	20
# exceedences to be considered polluted	3 and 10% of all
pH	
Minimum	6.5
Maximum	8.5

It is important to note that a variety of units for measuring turbidity exist. The standard is in Nephelometric Turbidity Units (NTU). All of the turbidity data collected on Martin Lake, Typo Lake, and Typo Creek were with a device that measured in FRNU units. The comparability of these units is not clear. Still, other data and professional judgment provides assurances that Typo Creek does indeed exceed the turbidity standard. 22 independent measurements of total suspended solids (TSS), a surrogate for turbidity, are also available from 1998 to 2003. TSS ranged from 7 to 100 mg/L, and averaged 36. TSS of >100 is considered a violation of the turbidity standard in the North Central Hardwood Forest (NCHF) Ecoregion (MPCA 2007). The water has been, during every observation described in this report, strongly brown or green in color (J. Schurbon, personal observations). As discussed earlier, the turbidity and pH impairments for Typo Creek are symptoms of the Typo Lake eutrophication impairment, and therefore TMDL analyses for pH and turbidity will not be done and instead will be addressed via the Typo Lake excess nutrient TMDL analysis

As we begin to explore some load-reduction scenarios it is also valuable to have some benchmarks to assess what might constitute reasonable concentrations for streams (watersheds) in this ecoregion. Previously summarized data from minimally impacted streams serves as one basis for comparison (Table 15).

Table 15. Interquartile Range of Summer-mean Concentrations for Minimally Impacted Streams in Minnesota, by Ecoregion. ***Data from 1970 – 1992 (McCollor and Heiskary, 1993*****)**

	TP (µg/L)			***Turbidity (NTU)***			***TSS (mg/L)***			***BOD (mg/L)***		
Region	***25%***	***50%***	***75%***	***25%***	***50%***	***75%***	***25%***	***50%***	***75%***	***25%***	***50%***	***75%***
NLF	30	40	50	2	2	4	2	4	6	0.9	1.2	1.6
NMW	50	60	90	5	7	12	7	11	20	1.2	1.5	1.9
NCHF	**70**	**100**	**170**	**5**	**7**	**10**	**8**	**10**	**18**	**1.6**	**2.2**	**3.3**
NGP	160	220	290	20	23	37	37	55	89	2.6	3.8	5.6
RRV	140	220	330	13	19	28	28	50	74	2.0	2.8	4.5
WCBP	210	270	350	14	19	27	26	47	76	2.2	4.3	6.6

Aside from numerical water quality indicators in the form of summertime averages, it is useful to discuss some qualitative targets for the lakes. Reductions in rough fish and increases in desirable macrophytes should be viewed as desired qualitative goals for Typo and Martin Lakes. Management strategies recommended in this report are aimed at trading the current algae-dominated systems for macrophyte (large plant)-dominated systems. This type of lake system is also typified by low rough fish populations. Benefits include clearer water and developing positive feedback mechanisms that maintain the lake in this condition (Scheffer 1998). Positive feedback mechanisms could include increased zooplankton because of habitat provided by plants, which in turn provide improved water clarity by eating algae so that plants can survive at greater depths, which in turn provide even more zooplankton habitat (Moss et al. 1996). Similarly, the healthier plant community will tend to reduce the disturbance of bottom sediments, which results in better water clarity. The wildlife value of these lakes, particularly Typo Lake, will be substantially greater under such a scenario.

Improving public perception of the recreational suitability of each lake is also a desirable goal. Currently, ACD staff ranks Typo Lake as not swimmable during the entire monitored period from May through September. A public perception that Typo Lake is swimmable for all except 4-6 weeks per year may be a reasonable goal. For Martin Lake, a reasonable goal may be to reduce the perceived unswimmable period from the current 12 weeks to four weeks per year. The ultimate goal is 100% swimmable.

3. Computer Modeling

3.1 Approach

Data and source assessments conducted as a part of this study informed the phosphorus budget for each of the TMDL lakes in this study. Export coefficients were used to estimate existing watershed phosphorus loading to lakes based on land cover data. Phosphorus loading from the export coefficient calculations was combined with phosphorus loading from all other estimated external sources: atmospheric deposition, SSTS, and upstream lake loading. A phosphorus budget was prepared based on these estimates. Ultimately, external phosphorus loading served as input to the Bathtub model, a lake response model that implicitly takes internal loading into account. The Bathtub models were calibrated to existing in-lake water quality data (multi-year growing season means from available data from the 10-year period from 1998 to 2007) and were then used to identify the phosphorus load reductions needed to meet state in-lake water quality standards. The specific methods and results associated with this approach are discussed in the following sections.

It should also be noted that since the modeling used data from a 10 year period from 1998 to 2007, it has set 2007 as its baseline year. Therefore, any BMPs or other practices put into place after 2007 were not taken into account in the modeling. So, any BMP that was put on the ground after 2007 should be given credit towards their wasteload or load allocation.

3.2 Phosphorus Inventory

3.2.1 Approach

Point Sources of Phosphorus

Municipal and Industrial Wastewater Treatment Systems

For any discharge of municipal or industrial wastewater to a surface water, ground surface or subsurface, a National Pollutant Discharge Elimination System/State Disposal System (NPDES/SDS) permit is required and administered by the MPCA. The Linwood Terrace Mobile Home Park WWTF (Permit No. MN0054372) discharges within the watershed; discharge is to an isolated wetland (Figure 19). Water quality monitoring data from Island Lake were used to estimate phosphorus loading from Island Lake to Martin Lake; these data would account for any overflows from the isolated wetland (see *Loading from Upstream Waters*).

The WWTF is a small activated sludge facility with extended aeration, which also includes a manual bar-screen, chlorination and dechlorination for disinfection, a secondary clarifier, sludge storage, and chemical phosphorus removal. The WWTF is designed to treat 0.0167 mgd or 16,700 gallons per day – Average Wet Weather design. The influent flow consists of primarily domestic waste from a manufactured homes development.

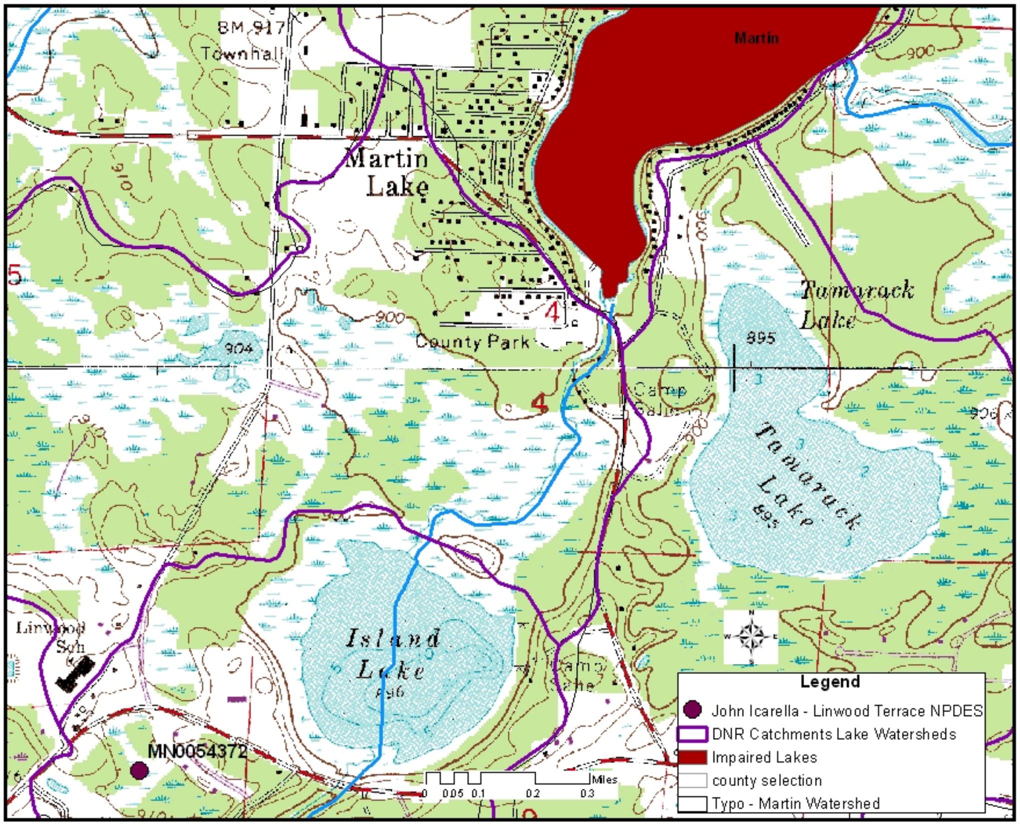


Figure 19. Location of John Iacarella – Linwood Terrace WWTP in reference to Martin Lake

Regulated Stormwater Runoff
Stormwater runoff regulated by an MS4 permit was modeled together with the unregulated stormwater runoff (non-point source runoff), since all stormwater runoff was modeled based on land use and export coefficients. (For the purpose of setting WLAs and LAs, regulated stormwater runoff was considered separately from unregulated runoff. The use of the same modeling approach for both types of runoff will facilitate the transfer of load from LA to WLA in the case of additional areas being covered under an MS4 permit in the future.)

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

MS4
The boundary of one regulated MS4 (City of East Bethel) overlaps the watersheds draining to study area (Figure 20).

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

Within the City of East Bethel's community, 2020 land use data was used to approximate the areas that are (or will be) regulated by the MS4 permit. Regulated land uses are considered to be those having stormwater conveyances owned by the MS4. Only those land uses that are regulated under the MS4 permit were considered to be part of regulated stormwater runoff:

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

The only lake that contains areas within the city of East Bethel, and contains land uses that are or will be regulated by an MS4 permit is Martin Lake.

Construction

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

Industrial

The NPDES/SDS Industrial Stormwater Multi-Sector General Permit re-issued in April of 2010 applies to facilities with Standard Industrial Classification Codes in 29 categories of industrial activity with the potential for significant materials and activities to be exposed to stormwater. Significant materials include any material handled, used, processed, or generated that when exposed to stormwater may leak, leach, or decompose and be carried offsite. The permit identifies a phosphorus benchmark monitoring value for facilities within certain sectors that are known to be a phosphorus sources.

Non-Point Sources of Phosphorus

The following are the non-point sources of phosphorus that were estimated in the phosphorus inventory:

- Watershed runoff
- Loading from upstream waters
- Atmospheric deposition

- Subsurface sewage treatment systems (SSTS)
- Internal loading

Direct Watershed Runoff
Direct watershed runoff was estimated using export coefficients based on land cover categories. This methodology was applied to the direct watersheds of the impaired lakes (excluding areas discharging to upstream lakes – see *Loading from Upstream Waters*). Martin Lake's direct watershed excludes Island and Typo Lakes and their drainage areas. Typo Lake's direct watershed includes its total drainage area.

Watershed Drainage Area

The drainage area discharging to Typo and Martin Lakes was determined based on Minnesota DNR Catchments, which are the smallest delineated and digitized drainage area mapped by the Minnesota DNR Watershed Delineation Project. The total drainage area for Martin Lake is 23,607 acres, excluding the lake itself (238.3 acres). Martin Lake's total drainage area includes Island and Typo Lakes and their drainage areas. Island Lake's drainage area is 7,387 acres, excluding Island Lake itself (98.6 acres). Typo Lake's drainage area is 11,000 acres, excluding Typo Lake itself (290.1 acres).

Land Use, Land Cover and Export Coefficients

Land cover data were obtained from the 2001 National Land Cover Dataset (NLCD). Each land cover category was assigned an export coefficient, which serves to estimate the phosphorus export from watershed runoff. Site specific export coefficients were not readily available; therefore, export coefficients were obtained from available, relevant literature. Table 16 identifies the export coefficients assigned to each land use category and the percent area of each category within each lake's direct watershed. The following is a list of references used to select export coefficients:

Boelter, D.H.; Verry, E.S. 1977. Peatland and water in the northern Lake States. General Technical Report NC-31, US Department of Agriculture – Forest Service, St. Paul, MN.

Burton, G.A.; Pitt, R.E. 2002. Stormwater effects handbook. Lewis Publishers, CRC Press, Boca Raton, FL.

Heiskary, S.; Wilson, B. 1994. Phosphorus export coefficients: and the Reckhow-Simpson Spreadsheet: Use and application in routine assessments of Minnesota lakes -- A working paper --. Nonpoint Source Section Water Quality Division, Minnesota Pollution Control Agency, St. Paul, MN.

King, K.; Harmel, D.; Torbert, H.; Balogh, J. 2001. Impact of a turfgrass system on nutrient loadings to surface water. Journal of the American Water Resources Association, 37(3):629-640.

Kunimatsu, T.; Sudo, M.; Kawachi, T. 1999. Loading rates of nutrients discharging from a golf course and a neighboring forested basin. Water Science and Technology, 39(12):99–107.

Lee, J. 2003. MPCA's detailed assessment of phosphorus sources to Minnesota watersheds, Appendix I: Non-agricultural rural runoff technical memorandum. Prepared for MPCA.

Lee, J.; Pilgrim, K. 2003. MPCA's detailed assessment of phosphorus sources to Minnesota watersheds, Appendix J: Urban runoff technical memorandum. Prepared for MPCA.

Loehr, R.C. 1974. Characteristics and comparative magnitude of non-point sources. Journal of the Water Pollution Control Federation, 46(8).

Marsalek, J. 1978. Research on the design storm concept. Technical Memo 33, ASCE, New York, NY.

McDowell, T.R.; Omernik, J.M. 1977. Nonpoint source - stream nutrient level relationships: A nationwide study. EPA-600/3-77-105. Environmental Research Laboratory, United States Environmental Protection Agency, Corvalis, OR.

Menzel, R.G.; Rhoades, E.D.; Olness, A.E.; Smith, S.J. 1978. Variability of annual nutrient and sediment discharges in runoff from Oklahoma cropland and rangeland. Journal of Environmental Quality, 7:401-406.

Mulla, D.J.; Gowda, P.H.; Wilson, G.; Runke, H. 2002. MPCA's detailed assessment of phosphorus sources to Minnesota watersheds, Appendix C: Cropland and pasture runoff technical paper. Prepared for MPCA.

Olness A.; Rhodes, E.D.; Smith S.J.; Menzel, R.G. 1980. Fertilizer nutrient losses from rangeland watersheds in central Oklahoma. Journal of Environmental Quality, 9(1):81-85.

Rast W.; Lee, G.F. 1983. Nutrient loading estimates for lakes. Journal of Environmental Engineering, 109(2).

Reckhow, K.H.; Beaulac, M.N.; Simpson, J.T. 1980. Modeling phosphorus loading and lake response under uncertainty: A manual and compilation of export coefficients. EPA 440/5-80-011. Office of Water Regulations and Standards Criteria & Standards Division, United States Environmental Protection Agency, Washington, D.C.

Robertson, D.M. 1996. Sources and transport of phosphorus in western Lake Michigan drainages. Fact Sheet FS-208-96. United States Geological Survey, Madison, WI.

Sonzogni, W.C.; Chesters, G.; Coote, D.R.; Jeffs, D.N.; Konrad, J.C.; Ostry, R.C.; Robinson, J.B. 1980. Pollution from land runoff. Environmental Science and Technology, 14(2).

Timmons, D.R.; Holt, R.F. 1977. Nutrient losses in surface runoff from a native prairie. Journal of Environmental Quality, 4(6): 369-73.

U.S. Environmental Protection Agency. 1999. Protocol for Developing Nutrient TMDLs. EPA 841-B-99-007. Office of Water (4503F), United States Environmental Protection Agency, Washington D.C. 135 pp.

U.S. Environmental Protection Agency. 2001. PLOAD version 3.3: An ArcView GIS tool to calculate nonpoint sources of pollution in watershed and stormwater projects, user’s manual.

Uttormark, P.D.; Chapin, J.D.; Green., K.M. 1974. Estimating nutrient loadings of lakes from non-point sources. EPA-660/3-74/020. Water Resources Center, Wisconsin University, Madison, WI, and National Environmental Research Center, United States Environmental Protection Agency, Corvalis, OR.

The export coefficients range from 0.0 lb/ac-yr from wetlands (representing a net zero phosphorus load assuming an equal potential for both source and sink conditions) to 1.5 lb/ac-yr from cultivated crops and barren land. Forests have an estimated phosphorus export of 0.1 lb/ac-yr. Cultivated crops is the most common land cover in the Typo Lake watershed (37.6%). In the Martin Lake watershed (excluding areas discharging to upstream lakes), deciduous forest is the most common land cover (43.6%), which exports less phosphorus on a per acre basis. In both watersheds, developed areas constitute a low portion of the watersheds.

Export coefficients for different land covers are intended to take into account management practices that may occur within that land cover category. For example, the export coefficient for cultivated crops includes runoff from fertilizers and manure applied to land of that cover type. Land use practices and/or BMPs implemented within the study areas of the referenced literature are assumed to be comparable to those within the TMDL study area.

While the 2001 NLCD was used in this project, the modeling did use in-lake and stream data from 2007. Therefore, any BMPs installed or incorporated after 2007 should be given credit toward implementation.

Table 16. Total Phosphorus Export Coefficients by NLCD Land Cover Category

Land Cover	Phosphorus Export (lb/ac-yr)	Direct Watershed Percent Area[1]	
		Martin Lake	Typo Lake
Open Water	0	0.4%	0.7%
Developed, Open Space[2]	0.6	5.3%	2.5%
Developed, Low Intensity	0.5	2.8%	1.3%
Developed, Medium Intensity	0.8	0.5%	0.1%
Developed, High Intensity	1.0	0.0%	0.0%
Barren Land	1.5	0.1%	0.0%
Deciduous Forest	0.1	43.6%	23.1%
Evergreen Forest	0.1	4.1%	6.5%
Mixed Forest	0.1	0.0%	0.0%
Shrub/Scrub	0.1	0.4%	0.6%
Grassland/Herbaceous	0.1	4.6%	4.5%
Pasture/Hay	0.7	5.8%	9.4%
Cultivated Crops	1.5	15.1%	37.6%
Woody Wetlands	0	0.4%	0.8%
Emergent Herbaceous Wetlands	0	17.0%	12.9%

[1] Martin Lake's direct watershed excludes the lake itself and excludes Island and Typo Lakes and their drainage areas. Typo Lake's direct watershed excludes Typo Lake itself. For drainage area values, see *Watershed Drainage Area* on page 43.
[2] NLCD metadata: *Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes*.

Loading from Upstream Waters

Lakes and streams upstream of Martin Lake were evaluated to determine if there were sufficient data to estimate a TP load from that resource. Annual average TP loads were calculated for the Island Lake and Typo Lake Watersheds, which were determined from in-lake phosphorus concentration data and average annual runoff volumes during the 10-year time period used for long-term average in-lake modeling (1998-2007). Growing season data used for Island Lake were from the years 2003 through 2007; data from Typo Lake were from 1998-2007 excluding 2002, 2004, and 2006. The average annual runoff was derived using the MN Hydrology Guide. The watershed area being modeled using the export coefficients, described above, excluded these upstream lakes and the lakes' watershed areas. Table 17 summarizes the upstream lake loading calculations.

Table 17. Summary of Phosphorus Loading from Upstream Waters to Martin Lake

Receiving Water	Upstream Lake	Averaging Period	TP (µg/L)	Runoff Depth (in/yr)	Drainage Area (acres)*	Runoff Volume (AF/yr)	TP Load (lb/yr)
Martin Lake	Typo Lake	1998-2001, 2003, 2005, 2007	241.4	7.75	11,290	7,291	4,787
	Island Lake	2003-2007	31	7.75	7,486	4,835	408

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

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

Subsurface Sewage Treatment Systems
Phosphorus loads attributed to subsurface sewage treatment systems (SSTS) adjacent to each of the lakes were calculated using data provided by Washington County and the MPCA's *Detailed Assessment of Phosphorus Sources to Minnesota Watersheds* (MPCA 2004). Total loading is based upon the number of houses within 300 ft of the lake, whether the SSTS system is conforming or failing, the number of people using the system, and an average value for phosphorus production per person per year.

Conforming versus failing systems were calculated based on an estimate that 11.4% of SSTS are failing within the St. Croix River Basin (MPCA 2004). The Isanti and Anoka County capita per residence values are derived from the 2000 Census. Values for phosphorus production per capita per year and the percentage of phosphorus passing through the SSTS for both conforming and non-conforming systems are derived from the MPCA's *Detailed Assessment of Phosphorus Sources to Minnesota Watersheds* (MPCA 2004).

Internal Loading
Internal loading was estimated through the in-lake (Bathtub) modeling process and is described in Section 3.3.2: *Model calibration and internal load.*

3.2.2 Martin Lake Phosphorus Inventory

The total modeled phosphorus load to Martin Lake is 7,213 lb/yr (Table 18), discussed in the following sections.

Table 18. Martin Lake Phosphorus Source Summary

Phosphorus Source	Phosphorus Load (lb/yr)	Phosphorus Load (lb/day)
Watershed	7,149	19.6
Atmospheric	64	0.18
Total	**7,213**	**19.8**

Watershed Phosphorus Sources

It is estimated that Martin Lake receives 7,149 pounds of phosphorus annually from watershed sources (Table 19). The largest source of external phosphorus is from discharge from Typo Lake (67%). Watershed runoff from Martin Lake's direct watershed area contributes 25% of the phosphorus to the lake.

Table 19. Martin Lake Watershed Phosphorus Source Summary

Phosphorus Source	Annual TP Load (lb/yr)	Area (ac)	Average Areal Load (lb/ac-yr)[1]	Percent of Watershed TP Load (%)
Direct Watershed Runoff	1,790	4,832	0.37	25%
SSTS	164	n/a	n/a	2.3%
Upstream Lake Loading (Typo Lake)[2]	4,787	11,290	0.42	67%
Upstream Lake Loading (Island Lake)[2]	408	7,486	0.054	5.7%
Total	**7,149**	**23,608**	**n/a**	**100%**

[1] Annual TP load (lb/yr) divided by drainage area (ac)
[2] Calculations are from lake outlet; includes lake area and drainage area

As shown in Table 19, the average areal load from Martin Lake's direct watershed is 0.37 lb/ac-yr. The areal loads shown above for the upstream lakes, it should be noted, reflect retention of phosphorus within those lakes. For example, Typo Lake delivers an estimated 4,787 lb/yr to Martin Lake (Table 19) while receiving an estimated 7,550 lb/yr from its own direct watershed (see Table 21). Accordingly, the average areal load from Typo Lake's watershed into Martin Lake is 0.42 lb/ac-yr (Table 19), whereas the areal load from Typo Lake's watershed into Typo Lake itself is 0.69 lb/ac-yr (see again Table 21). (A fine point here: the watershed area used to calculate the average areal load from Typo Lake to Martin Lake includes Typo Lake itself, while the watershed area used to calculate the areal load *into* Typo Lake excludes Typo Lake. But this has only a small effect on the areal loads because Typo Lake represents just 2.5% of its watershed.) Similarly, Island Lake's watershed delivers phosphorus into Martin Lake at an average areal rate of 0.054 lb/ac-yr but into Island Lake itself at an areal rate of 0.332 lb/ac-yr.

In-Lake Phosphorus Sources

Internal loading is inherent in the Canfield-Bachmann model that is used in Bathtub, and cannot be explicitly estimated. The in-lake modeling did not identify an unknown load to be attributed to internal loading (see Section 3.3.2: *Model calibration and internal load*). This does not suggest that internal load is non-existent, but rather that the amount of internal loading falls within the range of internal loads in the lakes used to develop the algorithms in the Bathtub model.

Atmospheric Phosphorus Sources

Atmospheric deposition is estimated to be 64 lb/yr (see *Atmospheric Deposition* for more information). This is equal to 0.89% of external phosphorus loading to the lake.

3.2.3 Typo Lake Phosphorus Inventory

The total modeled phosphorus load to Typo Lake is 8,668 lb/yr (Table 20), discussed in the following sections.

Table 20. Typo Lake Phosphorus Source Summary

Phosphorus Source	Phosphorus Load (lb/yr)	Phosphorus Load (lb/day)
Watershed	7,588	20.8
Internal	1,002	2.7
Atmospheric	78	0.2
Total	**8,668**	**23.7**

Watershed Phosphorus Sources

It is estimated that Typo Lake receives 7,588 pounds of phosphorus annually from watershed sources (Table 21). The largest source of external phosphorus is from watershed runoff from the contributing watershed (11,000 acres).

Table 21. Typo Lake Watershed Phosphorus Source Summary

Phosphorus Source	Annual TP Load (lb/yr)	Area (ac)	Areal Load (lb/ac-yr)[1]	Percent of External TP Load (%)
Direct Watershed Runoff	7,550	11,000	0.69	99.5%
SSTS	38	n/a	n/a	0.5%
Total	**7,588**	**11,000**	**n/a**	**100.0%**

[1] Annual TP load (lb/yr) divided by drainage area (ac)

In-Lake Phosphorus Sources

Internal loading accounts for an additional 1,002 lb/yr of phosphorus loading to the lake, representing 10% of the total loading to the lake. This internal loading estimate does not account for the internal loading inherent in the Canfield-Bachmann model of Bathtub, which cannot be explicitly estimated. Therefore, the actual internal load may represent more than 10% of the total load to the lake, and evidence suggests that this is the case. When inflows are very low, observed TP concentrations in the lake are often the highest. Dense carp populations lead to suspended sediment in the lake. The sediments are unconsolidated and easily disturbed by wind, fish, and boats.

Atmospheric Phosphorus Sources

Atmospheric deposition is estimated to be 78 lb/yr (see *Atmospheric Deposition* for more information). This is equal to 1.0 % of external phosphorus loading to the lake.

3.3 In-Lake Model and TMDL Derivation

3.3.1 Approach

This section presents the overall approach to estimating the components of the TMDL. The phosphorus sources were first identified and estimated in the phosphorus source inventory (Section 3.2.2 and 3.2.3). The loading capacity (TMDL) of each lake was then estimated (Section 3.3.2) using an in-lake phosphorus response model and was divided among wasteload allocations (WLAs) and load allocations (LAs).

<u>Loading capacity (=TMDL)</u>: the total amount of pollutant that the water body can assimilate and still maintain water quality standards.

<u>Wasteload allocations (WLAs)</u>: the pollutant load that is allocated to point sources, including wastewater treatment facilities, regulated construction stormwater, and regulated industrial stormwater, all covered under NPDES permits. A source can receive a WLA for a current or future permitted pollutant source.

<u>Load allocations (LA)</u>: the pollutant load that is allocated to sources not requiring NPDES permit coverage, including non-regulated watershed runoff, atmospheric deposition, and internal loading.

3.3.2 Loading Capacity: Lake Response Model

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

The TMDL (or loading capacity) was first determined in terms of annual loads. In-lake water quality models predict annual averages of water quality parameters based on annual loads.

Symptoms of nutrient enrichment normally are the most severe during the summer months; the state eutrophication standards (and, therefore, the TMDL goals) were established with this seasonal variability in mind. The annual loads were converted to daily loads by dividing the annual loads by 365.

System Representation in Model

In typical applications of Bathtub, lake and reservoir systems are represented by a set of segments and tributaries. Segments are the basins (lakes, reservoirs, etc.) or portions of basins for which water quality parameters are being estimated, and tributaries are the defined inputs of flow and pollutant loading to a particular segment. For this study, separate models were developed for each of the impaired lakes, and the direct drainage area for each lake (i.e., segment) and loading from upstream water bodies were lumped as a single tributary input. Only Martin Lake has loading from upstream lakes (Typo Lake and Island Lake).

An average rate of internal loading is implicit in Bathtub since the model is based on empirical data. The model provides an option to include an additional load identified as an internal load if circumstances warrant. In the lake models, adjustments to internal loading were conducted only for Typo Lake, where the uncalibrated model underestimated the in-lake phosphorus concentration. This is discussed in greater detail under *Model Calibration and Internal Loading*.

Model Input

The input required to run the Bathtub model includes lake geometry, climate data, and water quality and flow data for runoff contributing to the lake. Observed lake water quality data are also entered into the program in order to facilitate model verification and calibration. Table 22 lists the key input values used in the simulations.

Table 22. Bathtub Model Input Data

Lake	Surface Area (acres)	Lake Fetch (ft)	Avg Depth (ft)	Observed Lake Quality (surface growing season mean)			Contributing Area[1]			Precip (in)	Evap (in)
				TP (µg/L)	Chl-a (µg/L)	Secchi (m)	Wtrshed Load (lb/yr)	Flow (ac-ft/yr)	TP (µg/L)		
Martin	238.3	5,755	9.5	91.9	44.9	0.96	7,149	15,355	171.2	29.0	34.8
Typo	290.1	8,230	3.0	241.9	121.7	0.2	7,588	7,272	383.7	29.0	34.8

[1] Contributing area includes direct watershed runoff, SSTS, and, for Martin Lake, upstream lake loading.

Precipitation and Evaporation

The MN Hydrology Guide (SCS 1992) was used to determine the annual precipitation and evaporation by watershed.

Flow

The MN Hydrology Guide (SCS 1992) was used to determine an annual runoff depth of 7.75 inches. Annual flow was calculated based on runoff depth and watershed area.

Atmospheric Deposition
Average phosphorus atmospheric deposition loading rates were estimated to be 0.27 lb/ac-yr for the St. Croix River Basin (MPCA 2004), applied over each lake's surface area. See discussion titled *Atmospheric Deposition* in Section 3.2 for more details.

Segment Data: Lake Morphometry and Observed Water Quality
Lake morphometry data as identified in Sections 1.2 and 1.3 were used. Observed water quality averages are multi-year (1998-2007) growing season (June through September) means of total phosphorus, chlorophyll-*a*, and Secchi transparency. Observed water quality data were available for seven of the ten years (excluding 2002, 2004, and 2006) with the exception of Secchi transparency for Martin Lake, which was available for all ten years.

Tributary Data: Flow Rate and Phosphorus Concentration
All of the watershed sources (see Section 3.2.2 and 3.2.3) were combined into inputs for a single tributary for each lake. Watershed phosphorus sources include direct watershed runoff, loading from upstream waters, and subsurface sewage treatment systems.

Selection of Equations

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

Model Calibration and Internal Load

In the calibration process, it is first necessary to check that the lake behaves like the lakes in the dataset used to develop the regression equation. Before the model was calibrated, it was verified that the predictions made by the uncalibrated model were sufficiently close to the observed concentrations to warrant using the normal calibration process.

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

Bathtub does not, under normal use, account explicitly for internal load. It employs empirical equations derived from actual lakes and reservoirs, including a certain average level of internal loading, which is implicit in the results. In addition, Bathtub provides the option to include an additional internal load if circumstances warrant. In the case of Typo Lake, the uncalibrated model under-predicted the long-term average in-lake phosphorus concentration. This was assumed to be on account of an internal loading contribution greater than the average level of the lakes and reservoirs used to develop the Canfield-Bachmann model. Therefore, the model was calibrated by including an additional internal load to the model so that predicted in-lake phosphorus concentration matched the observed phosphorus. The model was then calibrated to chlorophyll-*a* and Secchi transparency by modifying calibration coefficients so that the predicted values matched the observed values. Matches were made to the nearest whole number for phosphorus and chlorophyll-*a* concentrations (µg/L), and to the nearest tenth of a meter for Secchi transparencies.

The additional internal loading rate was found to be 1.06 mg/m^2-day (Table 35), corresponding to an internal load of 454.5 kg/yr, or 1,002 lbs/yr (Table 37). Overall this accounts for a 12% contribution to Typo Lake's benchmark phosphorus budget.

The Martin Lake uncalibrated model slightly over-predicted the long-term average in-lake phosphorus concentration. Therefore, the implicit average level of internal loading was assumed adequate. The model was then calibrated by modifying calibration coefficients so that the predicted values of phosphorus, chlorophyll-*a*, and Secchi transparency matched the observed values. Matches were made to the nearest whole number for phosphorus and chlorophyll-*a* concentrations (µg/L), and to the nearest tenth of a meter for Secchi transparencies.

Estimated Phosphorus Load Reduction Requirements

With calibrated existing conditions models completed for the two lakes, reductions in phosphorus loading could be simulated in order to estimate the effects on lake water quality. Specifically, the goal of the analysis was to identify the reduction in phosphorus loading required in order to meet water quality TMDL goals for total phosphorus and either chlorophyll-*a* or Secchi transparency. Using the calibrated existing conditions model as a starting point, the phosphorus concentrations associated with tributaries were reduced until the model indicated that the requisite two out of three water quality standards were being met.

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

3.4 TMDL Loading Capacity and Allocations

3.4.1 Approach

Margin of Safety

A moderate explicit Margin of Safety (MOS) was applied to both TMDLs by reserving ten percent of the allowable load. The use of explicit MOSs for these TMDLs was indicated by the following considerations:

- Uncertainty is associated with the monitored water quality concentrations in both the TMDL lakes and in upstream lakes used to estimate upstream loading.

- Export coefficients were identified through a thorough literature review. However, uncertainty is associated with them due to the inherently site-specific nature of pollutant runoff.
- There are uncertainties in predicting how lakes respond to changes in phosphorus loading.

Ten percent is considered an appropriate MOS based upon the generally good agreement between the water quality models' predicted values and the observed values, as demonstrated in the calibration and validation processes. Since the models reasonably reflect the conditions in the lake watershed, the 10% MOS is considered to be adequate to address the uncertainty in the TMDL, based upon the data available.

Wasteload Allocations

The following is a description of the regulated stormwater runoff in the project area, which will receive WLAs.

Regulated MS4 Stormwater
The only regulated MS4 stormwater (existing or future) in the project area is the City of East Bethel (Permit No. MN400087), which is the only municipality that will receive a WLA for regulated MS4 runoff.

The MS4 permit only regulates storm-sewered portions (current and expected future) of the regulated MS4 community. Planned land use data (Regional Planned Land Use – Twin Cities Metropolitan Area) were used to approximate the land areas that are regulated or will be regulated by the MS4 permit in 2020. Only those land uses that are regulated under the MS4 permit were considered to be part of regulated stormwater runoff (Figure 20):

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

Currently, only 21 acres (Figure 20) within the City of East Bethel are regulated within the Martin Lake Watershed. The remaining portions of East Bethel within the Martin Lake watershed are not regulated by the MS4 permit.

The Typo Lake watershed does not contain any land regulated by an MS4 permit.

The WLA for East Bethel was based on a phosphorus export coefficient (areal loading rate) of 0.332 lb/ac-yr. This export/areal rate is the average for Island Lake's direct watershed under both TMDL and benchmark conditions (see Martin Lake Allocations, below).

If additional portions of MS4 communities come under permit coverage in the future due to urban expansion and increased population densities, a portion of the LA will be shifted to the

WLA. The allocation shifts will be based on applying the areal loading rate for the portion of the watershed in which the change occurs (i.e., Typo Lake, Island Lake, or Martin Lake direct). For the direct watershed of Martin Lake, the areal loading rate is 0.370 lb/ac-yr. As for Island Lake, this loading rate is the average for both TMDL and benchmark conditions (see again Martin Lake Allocations, below). Under Typo Lake's TMDL, its watershed's areal loading rate is considerably lower than its benchmark rate of 0.690 lb/ac-yr (see Typo Lake Allocations, below). The resulting allocated load will be shifted from the LA to the WLA. The MPCA will make these allocation shifts.

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

- If the road under question falls under an area currently covered by a WLA, a portion of the WLA will be shifted from the municipality or township in which the roads occur. The load transfer will be made on the basis of the appropriate areal loading rate, as described above for MS4 expansions. This would result in no change in the overall WLA for the impaired receiving water.
- If the road under question falls under an area currently covered by the LA, a portion of the LA will be shifted to the WLA. The load transfer will be made on the basis of the appropriate areal loading rate, again as described above for MS4 expansions.

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

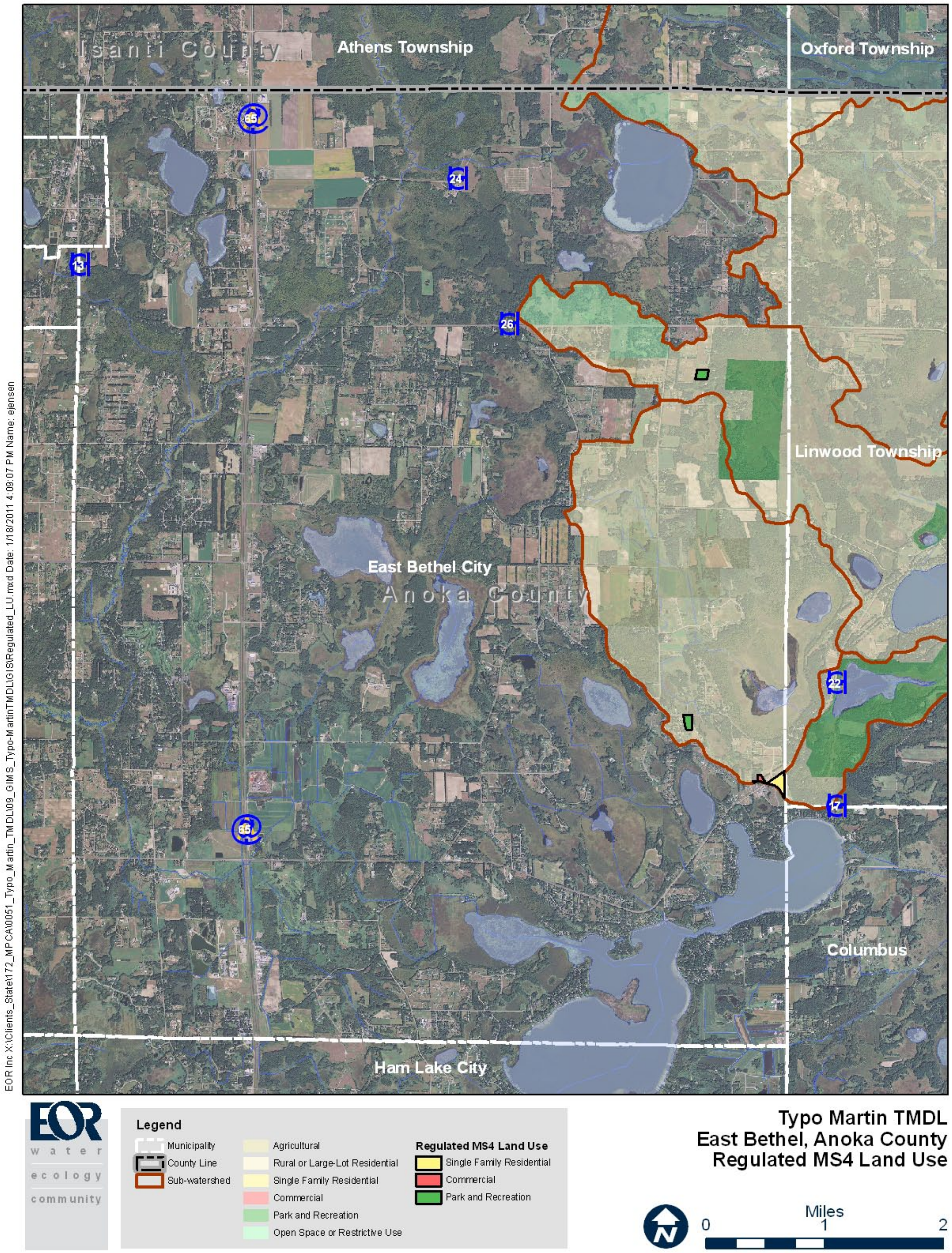


Figure 20. Land uses Regulated by the MS4 Permit in the City of East Bethel that receive a WLA for the Martin Lake TMDL

Highlighted areas (4 individual polygons) represent those areas (21 acres) within the City of East Bethel that are regulated by the MS4 stormwater permit. See discussion in this report section above titled *Regulated MS4 Stormwater*.

Regulated Construction Stormwater
The construction stormwater wasteload allocations were calculated based on the estimated annual area of Isanti and Anoka County under permitted construction activity using approximately 5 years (January 2005 to January 2010) of data. Project areas of permits were summed up within the county and presented as an annual average percent of total county area that has been issued a construction stormwater permit. These percents were then applied to each watershed, area-weighted based on the distribution of each county in each watershed. In the Martin and Typo watersheds, respectively, 0.52% and 0.16% were the estimates for the annual average percent area under a construction stormwater permit.

This percentage was multiplied by the total TMDL (loading capacity) minus the MOS to determine the construction stormwater WLA.

Regulated Industrial Stormwater
There are no regulated industrial stormwater sources located in either lake watershed. A small portion of the TMDL for each lake was set aside for future regulated industrial stormwater sources especially in anticipation of new applicants with the recent re-issuance of the permit. The industrial stormwater WLA is equal to the amount allocated for regulated construction stormwater (0.52% and 0.16% of the total TMDL for the Martin and Typo watersheds, respectively, minus the MOS).

Municipal and Industrial Wastewater Treatment Systems
The Linwood Terrace Mobile Home Park WWTF (Permit No. MN0054372) has a permitted daily phosphorus discharge limit of 0.06 kg/d (48 lb/yr, or 0.13 lb/day), which was used to establish the WLA.

Load Allocations

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

Reserve Capacity

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

3.5 Martin Lake Allocations

The phosphorus loading capacity of Martin Lake is 4,240 lb/yr, to be split among allocations according to Table 23. To meet the TMDL, the total load to the lake needs to be reduced by 2,973 lb/yr, or 41%. The permitted sources in the Martin Lake watershed receive individual WLAs (Table 24). A breakout of the load allocation sources for the Martin Lake watershed is included in Table 25.

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

Table 23. Martin Lake Allocation Summary

Allocation	lb/yr	lb/day
WLA[1]	94	0.26
LA[2]	3,722	10
MOS	424	1.2
TMDL	**4,240**	**12**

* MOS+WLA+LA do not equal TMDL due to rounding.
[1] Breakdown of the WLA can be found in Table 24.
[2] Breakdown of the LA can be found in Table 25.

Table 24. Martin Lake WLAs

Source	Permit #	WLA	
		lb/yr	lb/day
Construction Stormwater	MNR100001	20	0.055
Industrial Stormwater	MNR50000	20	0.055
MS4 Stormwater, East Bethel (MS4 ID MS400087)	MNR04000	7.0	0.019
Wastewater Discharger, John Iacarella - Linwood Terrace Mobile Home Park WWTF	MN0054372	47	0.13

Table 25. Martin Lake LAs

Source	LA	
	lb/yr	lb/day
Direct Watershed	1,790	4.9
Island Lake Watershed Non-Regulated Load*	361	0.99
Typo Lake Watershed	1,507	4.13
SSTS	0	0
Atmospheric	64	0.18
Total	**3,722**	**10**

* Does not include the 47 lb/yr (0.13 lb/day) for the regulated load in Table 24.

The Martin Lake direct and Island Lake load portions are the same as under the benchmark condition (Table 19). The Typo Lake portion was obtained by difference, and it is considerably reduced (benchmark load was 4,787 lb/yr; see again Table 19). To meet the downstream load requirement for Martin Lake, Typo Lake must reduce its in-lake TP concentration from 242 µg/L (benchmark) down to 78 µg/L. As described below, the TMDL for Typo Lake will require an even greater load reduction than required here. Meeting Typo Lake's load reduction for Martin Lake, therefore, represents a natural milestone along the way to achieving Typo Lake's TMDL.

Continuing to pursue BMP implementation in Martin Lake's direct watershed will yield water quality improvement in Martin Lake in the interim until achievement of the ambitious load reductions required for Typo Lake under its own TMDL (see next section).

In-lake conditions under TMDL scenario, Martin Lake

In developing the lake nutrient standards for Minnesota lakes (Minn. Rule 7050), the MPCA evaluated data from a large cross-section of lakes within each of the state's ecoregions (Heiskary and Wilson, 2005). Clear relationships were established between the causal factor total phosphorus and the response variables chlorophyll-*a* and Secchi disk. Based on these relationships it is expected that by meeting the phosphorus target of 60 µg/L for Martin Lake the chlorophyll-*a* and Secchi standards (20 µg/L and 1.0 m, respectively) will likewise be met.

3.6 Typo Lake Allocations

The phosphorus loading capacity of Typo Lake is 1,627 lb/yr, to be split among allocations according to Table 25. To meet the TMDL, the total load to the lake needs to be reduced by 7,041 lb/yr, or 81%. This high reduction needed is quite aggressive. However, smaller reductions in external and/or internal loads may shift the lake from the turbid phase to the clear-water phase, and the more aggressive load reductions may not be needed. The permitted sources in the Typo Lake watershed receive individual WLAs (Table 27). A breakout of the load allocation sources for the Typo Lake watershed is included in Table 28.

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

Table 26. Typo Lake Allocation Summary

Allocation	lb/yr	lb/day
WLA[1]	4.6	0.013
LA[2]	1,459	4.0
MOS	163	0.45
TMDL	**1,627**	**4.5**

* MOS+WLA+LA do not equal TMDL due to rounding.
[1] Breakdown of the WLA can be found in Table 27.
[2] Breakdown of the LA can be found in Table 28.

Table 27. Typo Lake WLAs

Source	Permit #	WLA	
		lb/yr	lb/day
Construction Stormwater	MNR100001	2.3	0.0064
Industrial Stormwater	MNR50000 (No current regulated sources)	2.3	0.0064

Table 28 Typo Lake LAs

Source	LA	
	lb/yr	lb/day
Direct Watershed Non-Regulated Load	1,078	2.95
SSTS	0	0
Internal	303	0.83
Atmospheric	78	0.21
Total	**1,459**	**4.0**

Under Typo Lake's TMDL, the combined watershed-plus-internal load (TMDL excluding the MOS and atmospheric load) is 1,385 lb/yr. The watershed phosphorus load accordingly could vary from 1,385 lb/yr (with elimination of the internal load) to 383 lb/yr (with no internal load reduction; internal load 1,002 lb/yr). The corresponding areal loading rates from the watershed are 0.126 and 0.035 lb/ac-yr. The modeled scenario (Appendix B) assumed a 70% internal load reduction, with the watershed load being 1,083 lb/yr and areal loading rate 0.098 lb/ac-yr.

In-lake conditions under TMDL scenario, Typo Lake

In developing the lake nutrient standards for Minnesota lakes (Minn. Rule 7050), the MPCA evaluated data from a large cross-section of lakes within each of the state's ecoregions (Heiskary and Wilson, 2005). Clear relationships were established between the causal factor total phosphorus and the response variables chlorophyll-*a* and Secchi disk. Based on these relationships it is expected that by meeting the phosphorus target of 60 µg/L for Typo Lake the chlorophyll-*a* and Secchi standards (20 µg/L and 1.0 m, respectively) will likewise be met.

4. Seasonal Variation and Critical Conditions

4.1 Seasonal Variation

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

In Typo and Martin Lakes, the highest monthly chlorophyll-*a* means generally occur in either August or September. This seasonal variation is taken into account in the TMDL by using the eutrophication standards, which are based on growing season averages, as the TMDL goals. The eutrophication standards were set with seasonal variability in mind. The load reductions are designed so that the lakes will meet the water quality standards over the course of the growing season (June through September).

4.2 Critical Conditions

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

5. Reasonable Assurances

Reasonable assurances are those factors that lend confidence that this TMDL will be successfully implemented. In this case, several factors at the local, county, and state level could serve as reasonable assurances that this TMDL will be successfully implemented. These factors are:

- The necessary leadership and support for future implementation efforts must come from local jurisdictions and citizens. Local water resource management groups are active and have collaborative relationships. These groups include the Sunrise River Watershed Management Organization, Typo Lake residents, Martin Lakers Association, and Anoka Conservation District. The Sunrise River Watershed Management Organization is a local special purpose unit of government. Its board members live in the vicinity of these lakes. They have identified Martin and Typo Lakes as high priorities in their Watershed Management Plan. Typo Lake residents are not currently organized into a lake association, but as a result of this TMDL and TMDL public meetings they formed an informal network and discussed becoming more formally organized. The Martin Lakers Association is already active, has begun a water quality improvement fund, and is working toward accomplishing recommendations in this TMDL. The Anoka Conservation District was the local lead for this TMDL and has a continued commitment to improvement of these lakes.
- Local funding covered >60% of this TMDL's costs, so local groups have a vested interest in implementation.
- Implementation of this TMDL has already begun using the iterative approach discussed earlier. Feasibility of certain implementation strategies has been done during periods of delay in this TMDL (when MPCA was updating shallow lakes standards) and has resulted in improvements to this TMDL. Local partners have begun investing in the smaller-scale implementation strategies that are within their financial means. For example, in 2008 the Sunrise River Watershed Management Organization funded commercial rough fish harvests. After approval of this TMDL and an implantation plan lake managers will be able to apply for larger state-level grants to undertake larger lake improvement efforts.
- The Sunrise River Watershed Management Organization included implementation of this TMDL as a focus area of their new 10-year watershed management plan, which was completed in late 2009.
- The MN DNR actively manages both lakes' fisheries. Their past fisheries management efforts have included measures directed at water quality issues. They have indicated their efforts will continue.
- The MN DNR manages a wildlife area just west of Typo Lake where some nutrient reduction projects, especially lateral ditch blocks, could be implemented. The MN DNR has expressed support of pursuing projects that could improve both the lakes and wildlife habitat.
- Regulatory authority and technical assistance exist for addressing septic system problems. Anoka County enforces shoreland septic system ordinances and the University of Minnesota Extension is providing technical assistance. Greater effort from the townships could result in more effective utilization of these resources.

- Local units of government are aware that the Typo and Martin Lake watersheds are priority areas for strong enforcement of existing regulatory programs; including storm water, grading, or construction permit programs. These regulatory programs, as well as other voluntary Best Management Practices (BMPs) are important for assuring no additional degradation of these lakes, and have therefore been included in the Nutrient Management Strategies section of this TMDL. The importance of these efforts was discussed at an information meeting for local leaders on August 22, 2005.
- New development in the watershed may create opportunities for local government to correct past land use alterations that have been detrimental to water quality. A recent example is the "Boettcher Farm Preserve" residential development where past agricultural ditches were converted to a wetland mitigation bank.
- A Sunrise River Watershed study is underway that may identify more opportunities for water quality improvement and increase the likelihood of funding. That study is being coordinated by Chisago County and the US Army Corps of Engineers, and will ultimately take the form of a TMDL.

6. Monitoring

A key element to implementation of this TMDL will be effectiveness monitoring. Achieving water quality standards for these waterbodies, especially Typo Lake and Typo Creek, will require large phosphorus reductions from all sources. The types of sources to be managed can be difficult. An adaptive management strategy will be utilized in which management strategies will be continuously re-evaluated and refined based on lessons learned from previous efforts. Periodic monitoring is necessary for adaptive management.

The implementation plan for this TMDL will contain a plan for effectiveness monitoring which includes sites, frequency of monitoring, and parameters. Sites will include both lakes, Typo Creek between the lakes, and tributaries to the lakes where phosphorus reduction activities take place. Sites will be monitored at least two years following significant phosphorus reduction work. Parameters shall include those for which these waterbodies are impaired, plus additional parameters determined helpful to understanding lake ecology. Given that both lakes already have a robust baseline dataset, continued baseline monitoring will be limited to every third year.

7. Implementation Strategies for Pollutant Reduction

An Implementation Plan of specific phosphorus reduction strategies is being prepared. That separate document provides an action plan of specific work needed to improve water quality, cost estimations, and who will likely implement each task. The Implementation Plan is based upon the knowledge gained through this TMDL study.

It is also important to note that the TMDL used a baseline year of 2007, meaning it does not take into account any BMPs that may have been put in after that year. Therefore, any BMPs put in after 2007 will be given credit towards their allocation.

7.1 Reduction Strategy

Restoration options for lakes are numerous with varying rates of success. Consequently, each technology must be evaluated in light of our current understanding of physical and biological processes in that lake. Following is a description of potential actions for controlling nutrients in the Typo and Martin Lake watersheds that will be further developed in the Typo and Martin Lakes Implementation Plan. The estimated cost of implementing these and other potential BMPs ranges from $1,500,000 to $5,000,000.

7.2 Implementation Framework

7.2.1 Watershed and Local Plans

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

7.2.2 Construction and Industrial Stormwater Regulation

Construction stormwater

To meet the WLA for construction stormwater, construction storm water activities are required to meet the conditions of the Construction General Permit under the NPDES program and properly select, install and maintain all BMPs required under the permit, including any applicable additional BMPs required in Appendix A of the Construction General Permit for discharges to impaired waters, or meet local construction stormwater requirements if they are more restrictive than requirements of the State General Permit.

Industrial Stormwater

To meet the WLA for industrial stormwater, industrial storm water activities are required to meet the conditions of the industrial stormwater general permit or General Sand and Gravel general permit (MNG49) under the NPDES program and properly select, install and maintain all BMPs required under the permit.

7.3 Nutrient Reduction Strategies

An Implementation Plan of specific phosphorus reduction strategies is being prepared. That separate document provides an action plan specific work needed to improve water quality, cost estimations, and who will likely implement each task. Additionally, it discusses phosphorus reduction strategies that were discussed but rejected, and outlines the reasons for rejecting those strategies. The Implementation Plan is based upon the knowledge gained through this TMDL study.

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

Based on this understanding of the appropriate standards for lakes, this TMDL has been established with the intent to implement all the appropriate activities that are not considered greater than extraordinary efforts. It is expected that it will take 20 years to implement BMPs and load-reduction activities.

7.4 Priority Areas for Pollutant Reductions

While the magnitude of phosphorus reductions needed to meet water quality standards necessitate large phosphorus reductions from all sources, some prioritization of implementation work is appropriate. First and foremost, Typo Lake should be a focal area for implementation work because is causes the impairment of Typo Creek and is by far the largest phosphorus source to Martin Lake. None of the waterbodies can reach water quality standards without large improvements to Typo Lake.

Prioritization for phosphorus reductions should be:

- Typo Lake internal loading
- Direct drainage to Typo Lake (Data Creek)
- SSTS’s around Martin Lake
- Direct drainage to Martin Lake
- Others

Reasoning for this prioritization:

The top two priorities should be reducing both internal and external loading to Typo Lake. While the models presented in this report indicated that Data Creek was the largest phosphorus source to Typo Lake, recent monitoring during drought years indicates that internal loading is equally or more important depending upon climatological conditions. This is because when Data

Creek water quality improved during drought the lake's water quality worsened. Internal loading was stronger during those drought conditions, and would also likely increase in compensatory fashion if incoming water quality improved for other reasons. In other words, internal loading is capable of keeping the lake in its current condition even if Data Creek is improved. Under all climatological conditions internal loading causes Typo Lake water to be poorer than Data Creek. For this reason, Typo Lake internal loading should be the highest implementation priority, while Data Creek should be second.

A key measure to address Typo Lake internal loading in both lakes is installation of a new outlet to Typo Lake and inlet to Martin Lake. The current structures are culverts. Structures which serve as fish barriers and allow water level manipulations (if even by pumping) are desirable. Effective management of rough fish populations, draw-downs, and other management tools require these types of water control structures.

Phosphorus loading from Data Creek seems to be largely due to past hydrological manipulation (ditching). Blocking lateral ditches is feasible with landowner cooperation and could yield measurable, reliable benefits. Other options for phosphorus reductions are a water treatment facility near the inlet to Typo Lake, a water control structure in the main ditch, and agricultural best management practices (BMP's) throughout the watershed.

Septic system improvements should be a medium-level priority, and focus on neighborhoods near Martin Lake. They contribute a relatively small amount of phosphorus, but contribute to both environmental and human health threats. As documented in research for this TMDL, at least 30% of systems in the shoreland zone are older than their expected lifespan and 30% are not maintained properly. In 2010 the Minnesota Pollution Control Agency updated their rules for septic systems (MN Rules 7080 et al.). Enforcement of these rules will help address these issues. Additional work could include grant or loan programs for septic system improvements (none currently exist in this area) and maintenance education.

Farther down the priority list, phosphorus sources in the areas directly draining to Martin Lake should receive attention. Some direct discharges of stormwater to the lake do occur. A goal of no untreated stormwater entering the lake is realistic and should be pursued.

All other phosphorus sources discussed in this TMDL should also be addressed, but are of lowest priority because they are of small size and/or are least cost effective to address. For example, the south inlet to Martin Lake already has exceptional water quality and further large improvements are unlikely. Still, every opportunity to improve water quality must be taken if these water bodies are to achieve goals.

8. TMDL Development and Public Participation

Development of this TMDL included investigative study, public input processes, and multiple agencies. The primary investigator was the Anoka Conservation District (ACD). The Sunrise River Watershed Management Organization (SRWMO) was the other major local partner, providing impetus for the study and partial funding. The Martin Lakers Association provided minor funding, created a water quality committee to periodically meet with agency staff, and orchestrated several opportunities for agency staff to meet with lake residents. The Minnesota Pollution Control Agency (MPCA) provided partial funding for this TMDL, as well as computer modeling.

This TMDL was developed from data and investigative studies across multiple years. It originated with an investigative study of water quality problems in 2001 by the ACD and SRWMO. From 2003 to 2005 the Minnesota Pollution Control Agency (MPCA) provided funding for a more formalized TMDL process. Work during this period included additional monitoring and investigative study, a formal public input process, computer modeling, and formatting the study as a TMDL. The approvals process at MPCA was delayed until the state shallow lakes standards were updated in 2008. During the interim, ACD and the SRWMO completed additional investigative study to refine understanding of phosphorus sources and management strategies. In 2008 the TMDL was updated with the new information. MPCA reviews and edits occurred in 2009 and early 2010. In 2011 a final draft of the TMDL was submitted to MPCA.

Public involvement occurred throughout the TMDL development, including:

- A project summary flier including draft results was distributed widely to residents, agencies, municipalities, and others in 2005.
- Public informational and comment meetings were held on August 29, 2005 and September 8, 2011. Promotion included informational fliers to all lakeshore homes, notices at Linwood Town Hall, an article in the Anoka Union newspaper, and website notices. The public was also invited to submit written comments.
- Public officials informational and comment meeting August 22, 2005. Direct invitations were sent to township and other local officials.
- Informational and comment meeting on August 24, 2005 for residents with property along or near Data Creek, which will likely be an important area for implementation activities. Direct invitations were sent to these landowners.
- Presentation to the Isanti Conservation District Board in August 2005.
- Minnesota Department of Natural Resources fisheries staff commented on TMDL drafts.
- Updates to the Sunrise River Watershed Management Organization no less than once per year.
- Presentation and periodic updates to the Anoka Conservation District Board of Supervisors.
- Regular communications with downstream water resource professionals in Chisago County.

- Regular updates to, and input from, the Martin Lakers Association water quality committee. Occasional presentations to the lake association general membership. Residents from Typo Lake were invited to some of these presentations.
- A website for the TMDL study was established and regularly updated at http://www.anokanaturalresources.com/srwmo/martin_typo_impaired_study.htm

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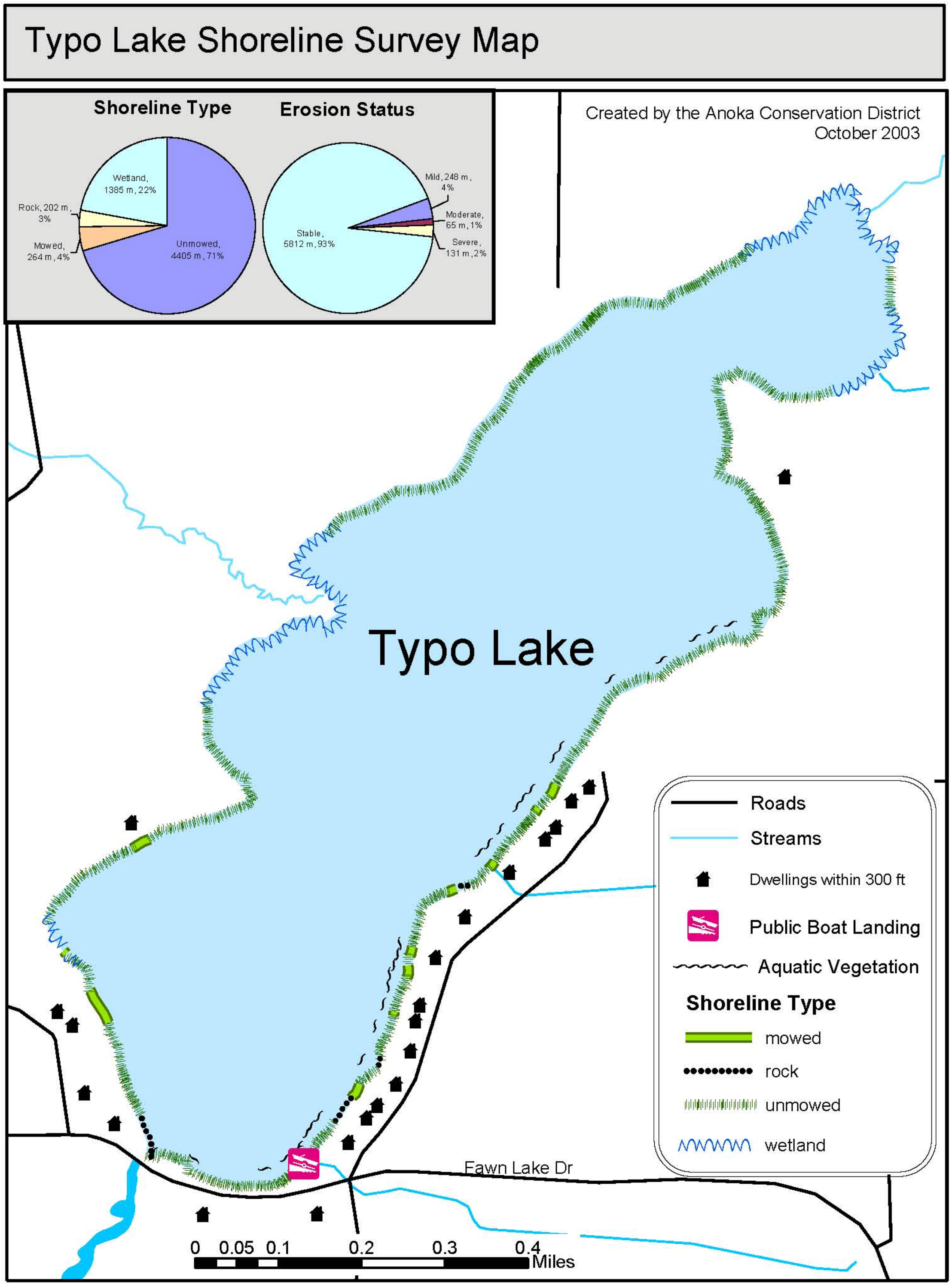
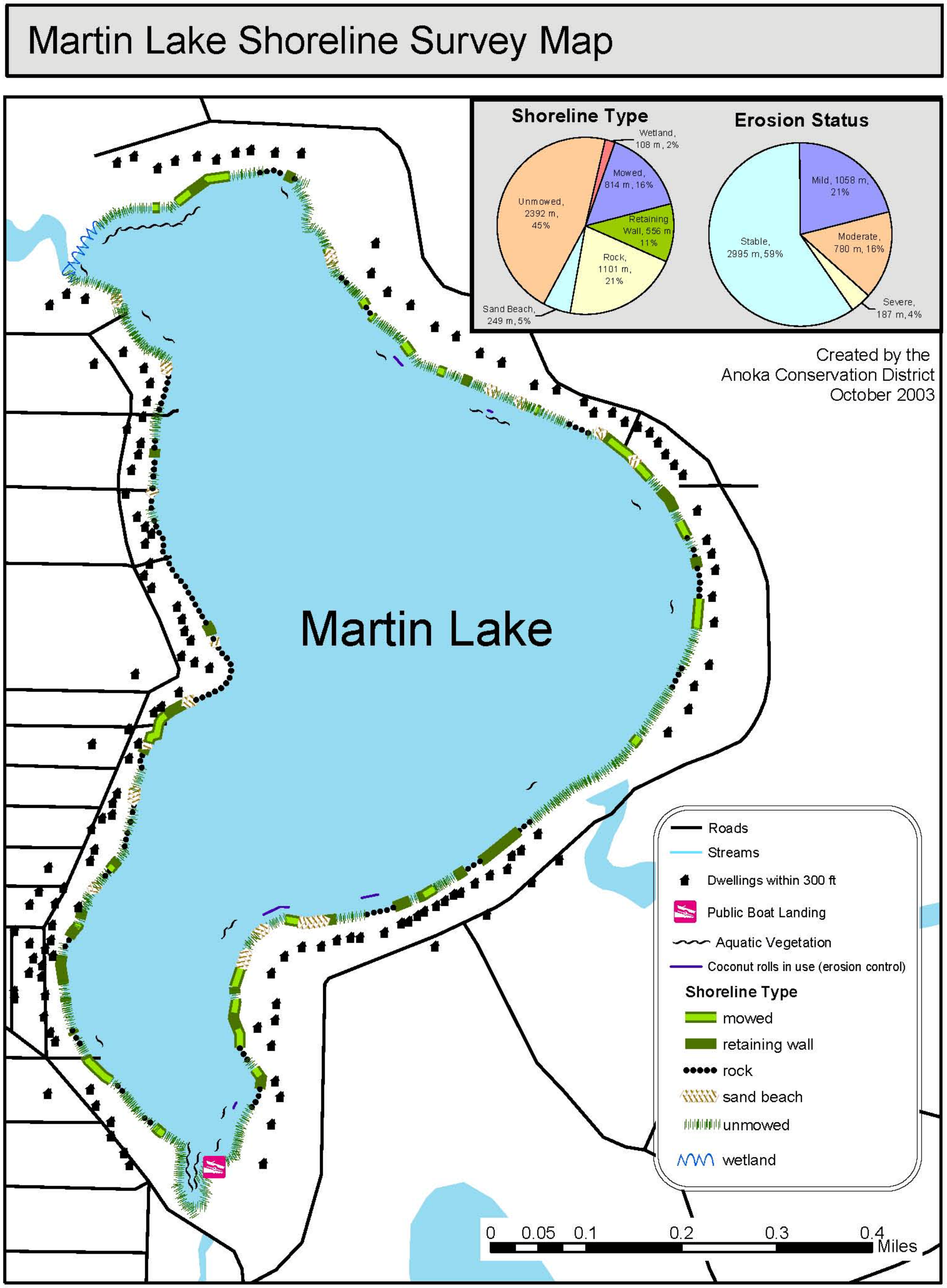
Appendix A. Shoreline Survey Maps



Typo Lake Shoreline Survey Map
Shoreline Type
Erosion Status
Wetland, 1385 m, 22%
Rock, 202 m, 3%
Mowed, 264 m, 4%
Unmowed, 4405 m, 71%
Mild, 248 m, 4%
Moderate, 65 m, 1%
Severe, 131 m, 2%
Stable, 5812 m, 93%
Created by the Anoka Conservation District
October 2003
Typo Lake
Fawn Lake Dr
Roads
Streams
Dwellings within 300 ft
Public Boat Landing
Aquatic Vegetation
Shoreline Type
mowed
rock
unmowed
wetland
0 0.05 0.1 0.2 0.3 0.4
Miles



Martin Lake Shoreline Survey Map
Shoreline Type
Wetland, 108 m, 2%
Mowed, 814 m, 16%
Retaining Wall, 556 m 11%
Rock, 1101 m, 21%
Sand Beach, 249 m, 5%
Unmowed, 2392 m, 45%
Erosion Status
Mild, 1058 m, 21%
Moderate, 780 m, 16%
Severe, 187 m, 4%
Stable, 2995 m, 59%
Created by the
Anoka Conservation District
October 2003
Martin Lake
Roads
Streams
Dwellings within 300 ft
Public Boat Landing
Aquatic Vegetation
Coconut rolls in use (erosion control)
Shoreline Type
mowed
retaining wall
rock
sand beach
unmowed
wetland
0 0.05 0.1 0.2 0.3 0.4 Miles

Appendix B. Bathtub Modeling Inputs and Outputs

Bathtub modeling case data (inputs), diagnostics (results), and segment balances (water and phosphorus budgets) are presented for both the calibrated (benchmark/existing) models and the TMDL scenarios. In-lake water quality concentrations for the calibrated and TMDL scenarios were evaluated to the nearest whole number for TP concentrations (µg/L) (see *Model Calibration and Internal Load* in Section 3.3.2). Data shown, for example, under the calibrated model diagnostics for Martin Lake (Table 28) show predicted (calibrated) total phosphorus at 92.2 µg/L and observed total phosphorus at 91.9 µg/L. These values were considered equal to each other (at 92 µg/L) using the rounding methods described.

Martin Lake

The direct drainage area for Martin Lake and loading from upstream Typo Lake were lumped as a single tributary input (see Section 3.3.2).

Table 29. Calibrated (benchmark) Bathtub model case data (input) for Martin Lake

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.74	0.0
Evaporation (m)	0.88	0.0
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	30.26	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	8	CANF & BACH, LAKES
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Martin	0	1	0.964	2.9	1.754	2.9	0.12	0	0	0.37	33.9	0	0	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	91.9	2.4	0	0	44.9	2.4	0.96	0.3	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1.45	0	1	0	1.42	0	1.43	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Monitored Inputs	1	1	95.53	18.94	0	0	0	171.2	0	0	0	0	0	0	0

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

Table 30. Calibrated (benchmark) Bathtub model diagnostics (model results) for Martin Lake

Segment:	1	Martin				
	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	92.2	0.21	76.6%	91.9	2.40	76.5%
CHL-A MG/M3	44.7	6.40	97.9%	44.9	2.40	97.9%
SECCHI M	1.0	3.63	43.9%	1.0	0.30	43.8%
ORGANIC N MG/M3	1203.4	4.64	96.6%			
TP-ORTHO-P MG/M3	84.2	2.53	86.1%			
ANTILOG PC-1	1136.9	2.75	87.9%	1144.4	2.29	88.0%
ANTILOG PC-2	17.0	7.12	96.8%	17.0	1.62	96.8%
TURBIDITY 1/M	0.4	33.90	28.6%	0.4	33.90	28.6%
ZMIX * TURBIDITY	1.1	33.90	8.3%	1.1	33.90	8.3%
ZMIX / SECCHI	3.0	3.64	21.5%	3.0	0.32	21.6%
CHL-A * SECCHI	43.0	10.00	97.9%	43.1	2.42	97.9%
CHL-A / TOTAL P	0.5	6.40	92.3%	0.5	3.35	92.5%
FREQ(CHL-a>10) %	98.2	0.46	97.9%	98.3	0.16	97.9%
FREQ(CHL-a>20) %	83.8	3.05	97.9%	84.0	1.08	97.9%
FREQ(CHL-a>30) %	63.0	6.21	97.9%	63.3	2.25	97.9%
FREQ(CHL-a>40) %	44.7	9.15	97.9%	45.1	3.36	97.9%
FREQ(CHL-a>50) %	31.1	11.73	97.9%	31.4	4.35	97.9%
FREQ(CHL-a>60) %	21.6	14.00	97.9%	21.8	5.24	97.9%
CARLSON TSI-P	69.4	0.04	76.6%	69.3	0.49	76.5%
CARLSON TSI-CHLA	67.9	0.93	97.9%	67.9	0.34	97.9%
CARLSON TSI-SEC	60.6	0.86	56.1%	60.6	0.07	56.2%

Table 31. Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for Martin Lake

Component:	TOTAL P		Segment:		1	Martin	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Monitored Inputs	18.9	96.4%	3242.5	99.1%	171
PRECIPITATION			0.7	3.6%	29.2	0.9%	41
TRIBUTARY INFLOW			18.9	96.4%	3242.5	99.1%	171
***TOTAL INFLOW			19.7	100.0%	3271.7	100.0%	166
ADVECTIVE OUTFLOW			18.8	95.7%	1733.0	53.0%	92
***TOTAL OUTFLOW			18.8	95.7%	1733.0	53.0%	92
***EVAPORATION			0.8	4.3%	0.0	0.0%	
***RETENTION			0.0	0.0%	1538.7	47.0%	
Hyd. Residence Time =			0.1487	yrs			
Overflow Rate =			19.5	m/yr			
Mean Depth =			2.9	m			

Table 32. TMDL scenario Bathtub model case data (input) for Martin Lake

Data shown here are the only data that were revised from the calibrated (benchmark) model.

Tributary Data											
				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV
1	Monitored Inputs	1	1	95.53	18.94	0	0	0	100	0

Table 33. TMDL scenario Bathtub model diagnostics (model results) for Martin Lake

Segment:	1	Martin				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	60.3	0.18	60.1%	91.9	2.40	76.5%
CHL-A MG/M3	34.3	6.40	95.4%	44.9	2.40	97.9%
SECCHI M	1.2	5.74	54.0%	1.0	0.30	43.8%
ORGANIC N MG/M3	966.0	4.20	91.9%			
TP-ORTHO-P MG/M3	65.7	1.45	79.5%			
ANTILOG PC-1	738.7	0.88	80.0%	1144.4	2.29	88.0%
ANTILOG PC-2	16.5	8.76	96.4%	17.0	1.62	96.8%
TURBIDITY 1/M	0.4	33.90	28.6%	0.4	33.90	28.6%
ZMIX * TURBIDITY	1.1	33.90	8.3%	1.1	33.90	8.3%
ZMIX / SECCHI	2.5	5.76	13.2%	3.0	0.32	21.6%
CHL-A * SECCHI	39.9	12.10	97.3%	43.1	2.42	97.9%
CHL-A / TOTAL P	0.6	6.40	95.3%	0.5	3.35	92.5%
FREQ(CHL-a>10) %	95.3	1.07	95.4%	98.3	0.16	97.9%
FREQ(CHL-a>20) %	71.2	4.98	95.4%	84.0	1.08	97.9%
FREQ(CHL-a>30) %	46.2	8.90	95.4%	63.3	2.25	97.9%
FREQ(CHL-a>40) %	28.8	12.24	95.4%	45.1	3.36	97.9%
FREQ(CHL-a>50) %	17.9	15.07	95.4%	31.4	4.35	97.9%
FREQ(CHL-a>60) %	11.2	17.50	95.4%	21.8	5.24	97.9%
CARLSON TSI-P	63.3	0.04	60.1%	69.3	0.49	76.5%
CARLSON TSI-CHLA	65.3	0.97	95.4%	67.9	0.34	97.9%
CARLSON TSI-SEC	57.8	1.43	46.0%	60.6	0.07	56.2%

Table 34. TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for Martin Lake

Component:	TOTAL P		Segment:	1	Martin	
		Flow	Flow	Load	Load	Conc
Trib Type Location		hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1 1	Monitored Inputs	18.9	96.4%	1894.0	98.5%	100
PRECIPITATION		0.7	3.6%	29.2	1.5%	41
TRIBUTARY INFLOW		18.9	96.4%	1894.0	98.5%	100
***TOTAL INFLOW		19.7	100.0%	1923.2	100.0%	98
ADVECTIVE OUTFLOW		18.8	95.7%	1133.9	59.0%	60
***TOTAL OUTFLOW		18.8	95.7%	1133.9	59.0%	60
***EVAPORATION		0.8	4.3%	0.0	0.0%	
***RETENTION		0.0	0.0%	789.3	41.0%	
Hyd. Residence Time =		0.1487	yrs			
Overflow Rate =		19.5	m/yr			
Mean Depth =		2.9	m			

Typo Lake

Table 35. Calibrated (benchmark) Bathtub model case data (input) for Typo Lake

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.74	0.0
Evaporation (m)	0.88	0.0
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr)	Mean	CV
Conserv. Substance	0	0.00
Total P	30.26	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	8	CANF & BACH, LAKES
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Typo	0	1	1.174	0.91	2.51	0.9	0.12	0	0	3.17	6.07	0	0	1.06	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	241.9	3.2	0	0	121.7	3.9	0.2	0.1	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0	1.54	0	1	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Monitored Inputs	1	1	44.51	8.97	0	0	0	383.7	0	0	0	0	0	0	0

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

Table 36. Calibrated (benchmark) Bathtub model diagnostics (model results) for Typo Lake

Segment:	1	Typo				
	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	242.1	0.20	96.4%	241.9	3.20	96.4%
CHL-A MG/M3	121.9	2.36	100.0%	121.7	3.90	100.0%
SECCHI M	0.2	1.94	0.6%	0.2	0.10	1.3%
ORGANIC N MG/M3	3175.2	1.62	100.0%			
TP-ORTHO-P MG/M3	288.0	0.33	99.1%			
ANTILOG PC-1	15608.9	0.61	99.9%	12719.0	3.70	99.9%
ANTILOG PC-2	8.3	3.07	68.6%	9.8	2.61	79.0%
TURBIDITY 1/M	3.2	6.07	97.0%	3.2	6.07	97.0%
ZMIX * TURBIDITY	2.9	6.07	44.9%	2.9	6.07	44.9%
ZMIX / SECCHI	5.6	1.95	60.8%	4.5	0.15	46.0%
CHL-A * SECCHI	19.6	4.25	82.2%	24.3	3.90	89.0%
CHL-A / TOTAL P	0.5	2.36	93.1%	0.5	4.99	93.1%
FREQ(CHL-a>10) %	100.0	0.00	100.0%	100.0	0.00	100.0%
FREQ(CHL-a>20) %	99.5	0.05	100.0%	99.5	0.08	100.0%
FREQ(CHL-a>30) %	97.4	0.24	100.0%	97.4	0.36	100.0%
FREQ(CHL-a>40) %	93.2	0.55	100.0%	93.1	0.85	100.0%
FREQ(CHL-a>50) %	87.0	0.94	100.0%	87.0	1.47	100.0%
FREQ(CHL-a>60) %	79.8	1.36	100.0%	79.7	2.15	100.0%
CARLSON TSI-P	83.3	0.04	96.4%	83.3	0.55	96.4%
CARLSON TSI-CHLA	77.7	0.30	100.0%	77.7	0.49	100.0%
CARLSON TSI-SEC	86.3	0.32	99.4%	83.2	0.02	98.7%

Table 37. Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for Typo Lake

Component: TOTAL P			Segment: 1 Typo				
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Monitored Inputs	9.0	91.2%	3441.8	87.5%	384
PRECIPITATION			0.9	8.8%	35.5	0.9%	41
INTERNAL LOAD			0.0	0.0%	454.5	11.6%	
TRIBUTARY INFLOW			9.0	91.2%	3441.8	87.5%	384
***TOTAL INFLOW			9.8	100.0%	3931.8	100.0%	400
ADVECTIVE OUTFLOW			8.8	89.5%	2131.6	54.2%	242
***TOTAL OUTFLOW			8.8	89.5%	2131.6	54.2%	242
***EVAPORATION			1.0	10.5%	0.0	0.0%	
***RETENTION			0.0	0.0%	1800.3	45.8%	
Hyd. Residence Time =			0.1213	yrs			
Overflow Rate =			7.5	m/yr			
Mean Depth =			0.9	m			

Table 38. TMDL scenario Bathtub model case data (input) for Typo Lake

Data shown here are the only data that were revised from the calibrated (benchmark) model (tributary TP concentration and TP internal loading rate).

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV
1	Monitored Inputs	1	1	44.51	8.97	0	0	0	**63**	0

Segment Morphometry — Internal Loads (mg/m^2-day)

		Outflow		Area	Depth	Total P	
Seg	Name	Segment	Group	km^2	m	Mean	CV
1	Typo	0	1	1.174	0.91	**0.32**	0

Table 39. TMDL scenario Bathtub model diagnostics (model results) for Typo Lake

Segment:	**1**	**Typo**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	60.2	0.13	60.0%	241.9	3.20	96.4%
CHL-A MG/M3	41.1	2.36	97.2%	121.7	3.90	100.0%
SECCHI M	0.2	3.94	2.3%	0.2	0.10	1.3%
ORGANIC N MG/M3	1331.7	0.61	97.9%			
TP-ORTHO-P MG/M3	144.1	1.99	95.1%			
ANTILOG PC-1	3851.6	1.52	98.2%	12719.0	3.70	99.9%
ANTILOG PC-2	5.4	4.63	37.3%	9.8	2.61	79.0%
TURBIDITY 1/M	3.2	6.07	97.0%	3.2	6.07	97.0%
ZMIX * TURBIDITY	2.9	6.07	44.9%	2.9	6.07	44.9%
ZMIX / SECCHI	3.8	4.02	34.4%	4.5	0.15	46.0%
CHL-A * SECCHI	9.8	6.24	47.6%	24.3	3.90	89.0%
CHL-A / TOTAL P	0.7	2.36	97.5%	0.5	4.99	93.1%
FREQ(CHL-a>10) %	97.5	0.23	97.2%	100.0	0.00	100.0%
FREQ(CHL-a>20) %	80.2	1.34	97.2%	99.5	0.08	100.0%
FREQ(CHL-a>30) %	57.8	2.60	97.2%	97.4	0.36	100.0%
FREQ(CHL-a>40) %	39.4	3.73	97.2%	93.1	0.85	100.0%
FREQ(CHL-a>50) %	26.5	4.71	97.2%	87.0	1.47	100.0%
FREQ(CHL-a>60) %	17.8	5.56	97.2%	79.7	2.15	100.0%
CARLSON TSI-P	63.2	0.03	60.0%	83.3	0.55	96.4%
CARLSON TSI-CHLA	67.0	0.35	97.2%	77.7	0.49	100.0%
CARLSON TSI-SEC	80.7	0.71	97.7%	83.2	0.02	98.7%

Table 40. TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for Typo Lake

Component:		TOTAL P		Segment:	1	Typo	
			Flow	Flow	Load	Load	Conc
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
1	1	Monitored Inputs	9.0	91.2%	565.1	76.6%	63
PRECIPITATIO N			0.9	8.8%	35.5	4.8%	41
INTERNAL LOAD			0.0	0.0%	137.2	18.6%	
TRIBUTARY INFLOW			9.0	91.2%	565.1	76.6%	63
***TOTAL INFLOW			9.8	100.0%	737.9	100.0%	75
ADVECTIVE OUTFLOW			8.8	89.5%	529.9	71.8%	60
***TOTAL OUTFLOW			8.8	89.5%	529.9	71.8%	60
***EVAPORATION			1.0	10.5%	0.0	0.0%	
***RETENTION			0.0	0.0%	208.0	28.2%	
Hyd. Residence Time =			0.1213	yrs			
Overflow Rate =			7.5	m/yr			
Mean Depth =			0.9	m			