

## Special Investigation: Typo Lake Watershed

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The SRWMO contracted the ACD to study the West Branch of the Sunrise River west of Typo Lake and its tributaries to identify pollution sources impacting Typo Lake. Both a 1995 Minnesota Pollution Control Agency (MPCA) Lake Assessment and a 1999 ACD Water Quality Assessment identified this stream as a major source of phosphorus loading to Typo Lake. Due to its high total phosphorus Typo Lake has consistently had the worst lake water quality in Anoka County. This section details our findings regarding watershed phosphorus sources. The next section addresses in-lake contributions to poor water quality. General information on water quality parameters is in Chapter 1.

### **Methods**

The ACD used a three-pronged approach to identify watershed phosphorus sources:

**Quality Monitoring** – We established a network of water monitoring stations including the Sunrise River inlet to Typo Lake (Data Creek) and four upstream tributaries (Appendix I). Sites were monitored during at least four base and four storm flow events for all parameters ACD measures as part of routine stream water quality monitoring.

Water levels were also monitored, but loading calculations were not possible because rating curves (mathematical relationship between water level and discharge) were not completed. Faulty equipment during key portions of the hydrograph prevented the work. A Data Creek rating curve will be completed in the future.

**Landuse Analysis** – We acquired documentation of all known feedlots from MPCA and coordinated with the Athens Township Zoning Administration Office to investigate all known landfills (closed and open) and hazardous waste generating facilities in the contributing watershed.

We also examined GIS landuse coverages from MN DNR. The DNR coverage did not properly identify many wetlands within the watershed, which were of particular interest in our analysis, so ACD staff used National Wetlands Inventory Maps to correct the landuse. Landuse statistics were then input into the Wisconsin Lake Modeling Suite (WLMS) to estimate phosphorus

contributions from each landuse. The model assigns a phosphorus export coefficient to each landuse. We elevated model values for wetlands to better represent the ditched wetlands found in the study watershed, as opposed to undisturbed wetlands represented by model defaults. This GIS analysis considered the entire Typo Lake watershed. The Sunrise River watershed, which is the focus of this investigation, comprises 70% of the Typo Lake Watershed.

**Soils Analysis** – Because soils of ditched wetlands were a suspected phosphorus source, we examined soil survey maps to determine if the soils present were capable of serving as a large phosphorus source. Once we determined that these soils were likely to hold large phosphorus loads, we took soil samples at the County Ditch 20 site at a depth of 18 inches to determine if soil phosphorus was, or could easily become, soluble and delivered to the ditch by subsurface flow. These samples were analyzed by saturation phosphorus extraction by the University of Minnesota Research Analytical Laboratory. This procedure involves saturating the soil for several hours and analyzing the resulting water. Samples were taken along a transect perpendicular to the stream at 50 ft intervals to reveal patterns in soluble phosphorus with distance from the ditch.

### **Results**

**Water Quality Monitoring** – Total phosphorus concentrations in County Ditch 20 were about 2.5 times higher than the ecoregion mean (220 ug/l) and all other tributaries to the Sunrise River West of Typo Lake (Table 2-3, Fig. 2-21). All sites showed a general pattern of increased TP during mid-summer when rainfall was generally lower (Fig. 2-21 & 2-22), but there was no significant difference in phosphorus levels between base flow and storm flow for all sites combined (Fig. 2-23; one-way ANOVA,  $F=0.01$ ,  $p=0.91$ ). TP during base flows (648.5 ug/l) and storm flows (538.7 ug/l) was also similar for County Ditch 20 when considered alone.

Table 2-3. Sunrise River (and tributaries) west of Typo Lake water quality results.

**Data Creek at Typo Creek Drive**

Event	Type	pH	Conductivity	Turbidity	DO	Temp	Salinity	TP	TSS	VSS	Cl	Stage
			mS/cm	NTU	mg/l	C	%	ug/l	mg/l	mg/l	mg/l	feet
5/22/2001	storm	6.8	0.28	24	7.89	11.1	0.01	195	32		6.0	898.33
5/31/2001	base			Equipment Failure				280	27	13	6.0	898.29
6/15/2001	storm	6.57	0.274	27		19.3	0.01	373	39		6.0	898.59
6/21/2001	base	7.05	0.312	30		17.5	0.01	376	27		6.8	898.23
6/26/2001	base	7.24	0.334	20	6.21	20.7	0.01	484	31		7.2	898.04
7/5/2001	base	7.78	0.356	17	10.13	19.8	0.01	190	11		7.2	897.76
7/23/2001	storm	8.22	0.343	9	6.04	24.2	0.01	223	9	6.7	7.3	897.85
8/2/2001	storm	7.73	0.302	5.3	18	20.7	0.01	336	24	10	8.0	897.92
Min		6.57	0.274	5.3	6.04	11.1	0.01	190	9	6.7	6.0	897.76
Mean		7.34	0.314	19	9.65	19.0	0.01	307	25	9.9	6.8	898.13
Max		8.22	0.356	30	18	24.2	0.01	484	39	13	8.0	898.59

**County Ditch 13 at Hwy 20**

Event	Type	pH	Conductivity	Turbidity	DO	Temp	Salinity	TP	TSS	VSS	Cl	Stage
			mS/cm	NTU	mg/l	C	%	mg/l	mg/l	mg/l	mg/l	feet
5/22/2001	storm	6.22	0.292	17	7.31	10.7	0.01	191	24		10.0	
5/31/2001	base			Equipment Failure				264	25	11	10.0	98.29
6/15/2001	storm	6.42	0.27	19		18.9	0.01	308	20		9.2	99.07
6/21/2001	base	6.97	0.304	7		17.2	0.01	274	17		10.0	98.10
6/26/2001	base	7.35	0.321	4.5	6.77	19.8	0.01	222	15		10.0	97.85
7/5/2001	base	7.37	0.351	10	10.4	19.2	0.01	133	10		11.0	97.47
7/23/2001	storm	8.16	0.344	2	5.05	22	0.01	149	6.7	6.7	9.2	97.60
8/2/2001	storm	7.09	0.295	19	2.43	22.8	0.01	347	17	10	11.0	98.43
Min		6.22	0.27	2	2.43	10.7	0.01	133	6.7	6.7	9.2	97.47
Mean		7.08	0.311	11	6.39	18.7	0.01	236	17	9	10.1	98.12
Max		8.16	0.351	19	10.4	22.8	0.01	347	25	11	11.0	99.07

**Dog Fork of County Ditch 13**

Event	Type	pH	Conductivity	Turbidity	DO	Temp	Salinity	TP	TSS	VSS	Cl	Stage
			mS/cm	NTU	mg/l	C	%	mg/l	mg/l	mg/l	mg/l	feet
5/22/2001	storm	6.35	0.296	19	8.32	10.5	0.01	153	23		5.0	
5/31/2001	base			Equipment Failure				187	22	8	6.0	98.29
6/15/2001	storm	6.63	0.277	34		19.6	0.01	277	39		5.1	99.07
6/21/2001	base	7.11	0.307	13		18.4	0.01	244	23		5.7	98.10
6/26/2001	base	7.52	0.329	15	5.85	23.5	0.01	179	24		6.2	97.85
7/5/2001	base	7.45	0.354	9	6.99	19.6	0.01	183	12		6.3	97.47
7/23/2001	storm	8.27	0.351	19	4.88	26.2	0.01	285	22	10	6.2	97.60
8/2/2001	storm	7.64	0.324	3	5.53	21.6	0.01	165	11	6.7	6.0	98.43
Min		6.35	0.277	3	4.88	10.5	0.01	153	11	6.7	5.0	97.47
Mean		7.28	0.320	16	6.31	19.9	0.01	209	22	8	5.8	98.12
Max		8.27	0.354	34	8.32	26.2	0.01	285	39	10	6.3	99.07

**Straight Fork of County Ditch 13**

Event	Type	pH	Conductivity	Turbidity	DO	Temp	Salinity	TP	TSS	VSS	Cl	Stage
			mS/cm	NTU	mg/l	C	%	mg/l	mg/l	mg/l	mg/l	feet
5/22/2001	storm	6.31	0.316	5	7.15	9.9	0.01	81	10		7.0	
5/31/2001	base			Equipment Failure				96	15	8	7.0	98.29
6/15/2001	storm	6.42	0.334	3	7.02	17	0.01	198	35		6.2	99.07
6/21/2001	base	7.01	0.365	3	4.72	15.9	0.01	75	7		7.4	98.10
6/26/2001	base	7.25	0.39	4.5	5.7	21.8	0.01	96	12		7.7	97.85
7/5/2001	base	6.73	0.412	8	3.41	19.2	0.01	141	26		5.6	97.47
7/23/2001	storm	7.83	0.397	21	3.96	25	0.01	182	6.7	6.7	9.0	97.60
8/2/2001	storm	7.26	0.395	2	4.71	20.7	0.01	174	9	6.7	9.0	98.43
Min		6.31	0.316	2	3.41	9.9	0.01	75	6.7	6.7	5.6	97.47
Mean		6.97	0.373	7	5.24	18.5	0.01	130	15	7	7.4	98.12
Max		7.83	0.412	21	7.15	25	0.01	198	35	8	9.0	99.07

**County Ditch 20 at Mattson Property**

Event	Type	pH	Conductivity	Turbidity	DO	Temp	Salinity	TP	TSS	VSS	Cl	Stage
			mS/cm	NTU	mg/l	C	%	mg/l	mg/l	mg/l	mg/l	feet
5/31/2001	storm			Equipment Failure				462	22	22	4.0	96.10
6/15/2001	base	6.08	0.255	43		21.7	0.00	631	38	38	4.2	96.61
6/21/2001	storm	6.59	0.289	77		19.9	0.01	822	47	47	4.6	96.05
6/26/2001	base	6.84	0.311	50	2.01	23.5	0.01	676	32	32	5.4	96.65
7/5/2001	base	6.8	0.332	19	3.5	21.6	0.01	634	23	23	5.2	95.71
7/23/2001	base	7.8	0.311	21	2.96	25.1	0.01	476	15	15	6.6	95.75
8/2/2001	storm	6.96	0.32	29	2.29	21.3	0.01	509	29	29	6.0	95.78
9/7/2001	storm							496				
Min		6.08	0.255	19	2.01	19.9	0	462	15	15	4.0	95.71
Mean		6.85	0.303	40	2.69	22.2	0.01	588	29	29	5.1	96.09
Max		7.8	0.332	77	3.5	25.1	0.01	822	47	47	6.6	96.65

Figure 2-21: Total phosphorus in three Sunrise River tributaries.

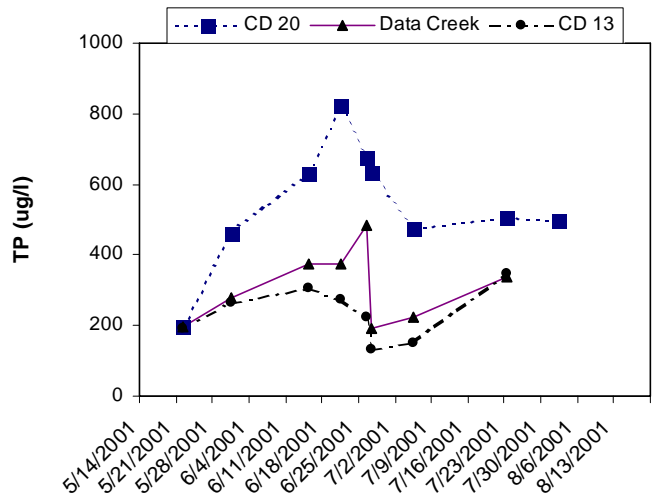


Figure 2-22: Summer 2001 precipitation in East Bethel, Anoka County.

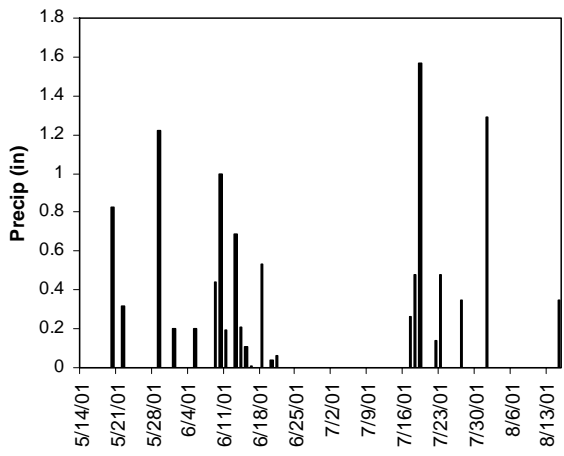
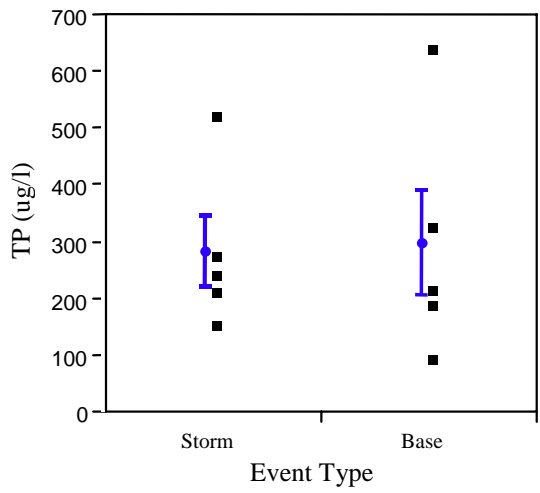


Figure 2-23: TP during base and storm flows for all Sunrise west of Typo monitoring sites. (Lines show the mean with one standard deviation.)



**Landuse Analysis** - Cultivated land and wetlands are the most widespread land uses in the Typo Lake watershed, accounting for 33.7% and 27.0% of the land, respectively (Table 2-4, Appendix II). Appendix III, the results of computer modeling, details predicted phosphorus export from each landuse.

We did not identify any feedlots or waste generating facilities that were substantially impacting ditches in the subwatershed.

Table 2-4. Landuse for the entire Typo Lake watershed and the Sunrise River subset of the watershed. (source: ACD and MN DNR)

Landuse	Sunrise River W. of Typo Wateshed		Entire Typo Lake Watershed	
	Acres	Percent	Acres	Percent
Urban and Industrial	0	0.0	0.00	0.0
Farmsteads and Rural Residences	137.8	1.5	209.10	1.6
Rural Residential Development Complex	0	0.0	111.50	0.9
Other Rural Developments	4.1	0.0	26.80	0.2
Cultivated Land	3585.6	40.3	4272.10	33.7
Pasture and Hayland	0	0.0	9.40	0.1
Transitional Agricultural Land	9.5	0.1	9.50	0.1
Grassland	1044	11.7	1270.10	10.0
Grassland-Tree-Shrub (deciduous)	241.5	2.7	460.00	3.6
Grassland-Tree-Shrub (coniferous)	0	0.0	4.20	0.0
Deciduous Forest	1521.9	17.1	2569.60	20.3
Coniferous Forest	138	1.6	231.90	1.8
Water	6.5	0.1	81.00	0.6
Wetlands	2206.8	24.8	3417.10	27.0
Gravel Pits and Open Mines	0.8	0.0	0.80	0.0
<b>Totals</b>	<b>8896.5</b>	<b>100.0</b>	<b>12673.10</b>	<b>100.0</b>

**Soil Analysis** – Because County Ditch 20 had much higher phosphorus concentrations than the other tributaries, our soil analysis focused upon that portion of the watershed. Peat is the dominant soil type within 300 feet of waterways. Peat occurs in low-lying wet areas and consists of plant remains in various states of decomposition. These soils tend to be rich in phosphorus and are not able to retain it as well as mineral soils. Saturation extracts at the County Ditch 20 site show that those soils contain high levels of phosphorus that easily becomes soluble. Soluble phosphorus increased with proximity to the ditch (Fig. 2-24).

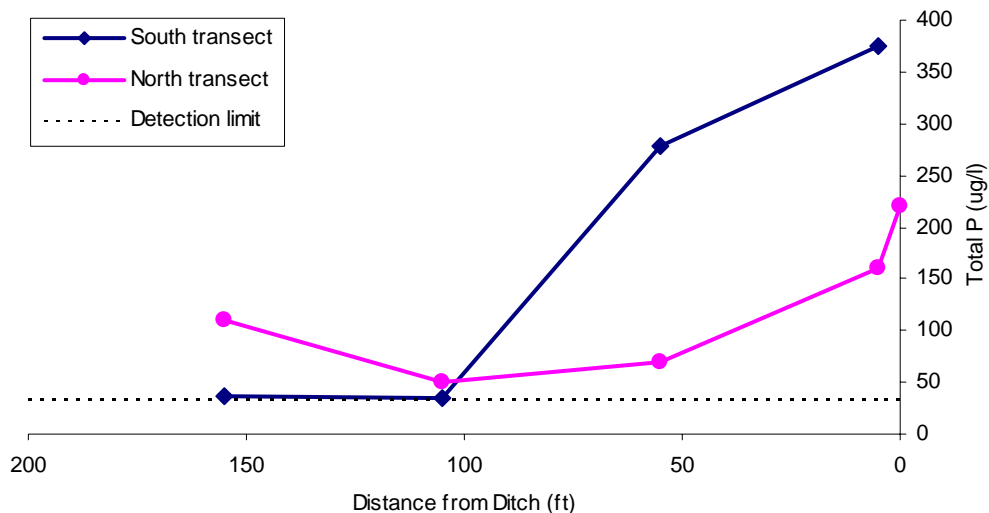


Figure 2-24: Results of soil TP saturation extracts at County Ditch 20 (Mattsson property).

### Discussion

The County Ditch 20 (CD20) tributary is contributing far more phosphorus (P) to Typo Lake than any other tributary. While three of the five monitoring sites (Data Creek and its main tributaries CD13 and CD20) had mean total phosphorus (TP) levels higher than the ecoregion mean (22.0 ug/l), levels at CD20 were more than double that at any other site and the ecoregion mean. Fertilizer runoff from agricultural fields could account for some of the phosphorus. Roughly 1/3 of the land in the watershed is cultivated and the Wisconsin Lake Modeling Suite estimated that 72.1% of watershed phosphorus loading to the lake could be attributed to agriculture. Yet, aerial photos reveal that very little land within 500 feet of the ditch is farmed for row crops. Most of it is lowland and is hayed, if it is farmed at all. These grasses act as a filter strip slowing surface runoff and removing some phosphorus fertilizers from water as it moves through the soils. The computer model therefore may overestimate agricultural phosphorus loading by assuming the agriculture present is row crops and that no filter strips are present. No other anthropogenic point sources (feedlots, waste generating facilities, etc) were found in the CD20 watershed. The water quality data also suggest that the majority of phosphorus loading was not derived from runoff because stream phosphorus levels were not significantly different during storm and base flow.

Ditched wetland soils are probably serving as the major phosphorus source within the CD20 watershed. Wetlands are a dominant feature in the CD20 watershed, especially adjacent to the ditch. They are less widespread along the other tributaries we monitored, which had lower phosphorus levels. Wetlands that are most likely to serve as phosphorus sources drain readily to a waterway, have low water retention, undergo alternating wet/dry periods, had past agricultural activity, and have peat soils. Before ditching phosphorus would have cycled within the wetland. Peat soils contain much higher phosphorus levels than other soils because they are primarily plant material in various states of decomposition. Also, phosphorus is not held as tightly as it is in soils with higher mineral content. When these already phosphorus rich soils are fertilized with manure or chemical fertilizer over many years they can become supersaturated with phosphorus (Moss et al. 1996). Even if they have not been heavily fertilized, as is probably the case with CD20 watershed soils, these soils can still release large quantities of phosphorus through natural processes. Phosphorus release from these soils occurred during the wet and alternating wet/dry conditions often experienced along CD 20. Most soil phosphorus is bound to the ferric form of iron (Patrick 1994). Under continuously wet conditions, however, iron is transformed into its ferrous (reduced) form that is more soluble and cannot bind tightly with phosphorus (Patrick 1994). As a result, phosphorus is released to the soil water and is transported by

subsurface flow to waterways. Saturated soils may have 50 to 100 ppm of soluble phosphorus, as opposed to about 1 ppm phosphorus in the same soil under dry conditions (Patrick and Khalid 1974).

Under alternating wet/dry conditions even greater phosphorus release can occur from soils (Koltz and Lin 2001; Turner and Haybarth 2001). This release is strongly related to microbial phosphorus content, soil phosphorus, and soil organic matter content. When soils dry or freeze these microbes undergo osmotic shock and often rupture, releasing their P-rich contents. Most (56-100%) of this phosphorus is released in organic form. Re-wetting of dried or frozen soils increases soil phosphorus release up to 84 times. These releases peak 3 to 4 days after the rewetting, so high phosphorus levels would not be expected during the first several days of storm flow. This is especially true if rains occur periodically, leading to alternating wetting and drying. We did find that TP increased during summer drying periods in all streams monitored (Fig. 1 and 2).

Also notice in Figure 1 that phosphorus level fluctuations in each tributary seemed to coincide throughout the summer, suggesting that environmental conditions are driving these changes, not anthropogenic releases, which would be less likely to coincide in different parts of the watershed. Our soil transects at CD20 further verified that the soil itself was likely serving as a phosphorus source. The soil did contain high phosphorus levels. Phosphorus levels were highest near the ditch where the wettest conditions prevailed, consistent with the phosphorus release mechanisms detailed above and with the idea that much of the soluble phosphorus would move towards the ditch with subsurface water flow.

These results beg the question, “why don’t all ditched wetlands in Anoka County release such large amounts of phosphorus?” The answer is probably multifaceted. Differences in soils may be one factor. For example, phosphorus release under saturated conditions is most likely to occur in soils rich in iron and less likely to occur in soils high in aluminum or calcium phosphates (Engelstad 1970). Peats have higher phosphorus and do not hold it as tightly as inorganic soils (Masscheleyn et al. 1992) Past agricultural activity may also play a role in soil phosphorus levels, and hydrological differences of ditches have a strong influence on phosphorus releases. Yet, regardless of these potential

differences, all ditched wetlands probably export phosphorus to the watershed to some degree, just some more than others.

### ***Management Implications***

The most effective means of reducing phosphorus loading from CD20 would be restoring the drained wetlands to a condition that does not promote phosphorus export. This might be accomplished by changing the hydrology of the ditch or by chemical treatments.

Ditch hydrology could be changed to avoid cycles of drying and rewetting, which cause the release of the greatest amount of phosphorus. This might involve re-meandering the stream and/or raising the water level to restore drained wetlands. The most likely location for water level modification would be at the Data Creek monitoring site at Typo Creek Drive where the Schubring Wildlife Management Area (WMA) is located. Despite public ownership of much of this area, easements on other upstream properties would be needed for an increase in water level. Some, though substantially less, phosphorus release will still occur in this continuously wet environment, but if water contact with plants and sediments is lengthy and expansive this phosphorus will be more likely to remain within the wetland system.

A ditch with slow water flow might also facilitate an aeration system to reduce phosphorus in the stream water. In a well-aerated environment, phosphorus can combine with ambient iron to form an insoluble precipitate. The aeration system would need to be lengthy so that contact time of the water within the aerated zone is long.

This area at the Schubring WMA could also be used as a chemical treatment basin. Wastewater treatment facilities have long used chemical treatment to remove phosphorus from water. These methods usually involve adding aluminum, iron, or calcium salts, which combine with the phosphorus to produce an insoluble precipitate. Some of these chemicals are inappropriate for treating stream water. Chemical treatment of stream water can also be expensive.

One other strategy might be to fill lateral ditches so that soil phosphorus cannot be quickly transported to the waterway. Lateral ditches are those smaller channels dug as tributaries to the main channel to

more completely drain areas farther from the main ditch. This method would restore some currently drained areas to a more contained wetland system.

These or other watershed management strategies should be the first step towards improving Typo Lake, but alone will not produce a dramatic (or perhaps even noticeable) change in lake condition. Refer to the next section for in-lake conditions and management recommendations.

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## Special Investigation: Typo Lake Basin

The SRWMO contracted the ACD to conduct a special study of the water quality of Typo Lake, in addition to routine annual monitoring tasks (see Lake Water Quality section, this chapter). This study complements the investigation of stream water quality in the West Branch of the Sunrise River entering Typo Lake (previous section). The purpose of this study was to determine the degree to which in-lake phosphorus sources, rough fish, and watercraft are contributing to poor lake water quality.

### Methods

The ACD used a four-pronged approach to identify and determine the magnitude of in-lake causes of poor water quality:

**Recreational Use Survey** – On July 30, 2001 we circumscribed the shoreline via boat and noted the number of lake homes and the number and size of watercraft. We also noted the number of usable docks.

**Fish Survey** – The MN DNR conducts Fish surveys on Typo Lake every five years. The most recent survey was in June 1999. We will summarize the MN DNR fish survey data, which is available at: <http://www.dnr.state.mn.us/lakefind/index.html>

**Total Suspended Solids Analysis** – We analyzed water samples for total suspended solids (TSS) and volatile suspended solids (VSS) from Typo Lake and from the Data Creek Inlet at Typo Creek Drive. TSS is a measure of organic and inorganic solids suspended in the water column. VSS is primarily the organic portions of the TSS, such as algae and detritus, and is often expressed as a percentage of TSS. If a large percentage of the TSS is volatile, algae and organic lake sediments dominate suspended materials. If a small percentage of the TSS is volatile, eroded soils and inorganic lake sediments stirred by rough fish, powerboats, and the wind dominate suspended materials. Comparisons of incoming stream water and lake water reveal the relative magnitudes of suspended solids from these two possible sources.

**Computer Modeling** – Lake water quality and morphometric data, along with the landuse analysis data presented in the preceding section were input into the Minnesota Lake Eutrophication Analysis Procedure (MNLEAP) from the Minnesota Pollution Control Agency, and the Wisconsin Lake Modeling Suite (WLMS) from the Wisconsin DNR to estimate the relative magnitudes of watershed and in-lake phosphorus loading.

### Results

**Recreational Use Survey** – Residential development on Typo lakeshore is light. There are currently twenty-four homes on Typo Lake, with an additional two under construction. Eighteen (75%) of these homes mow their lawns to the water, while the remainder leave a buffer of unmanicured vegetation between yard and the lake. The remainder of the lakeshore is naturally vegetated.

Boat traffic is also light and mostly limited to boats under 16 feet. During ten trips to the lake in the summer of 2001 ACD staff only saw one boater on the lake, a lone fisherman in a canoe. Of the boats docked in the lake or resting on the shore (Table 2-5), only two appeared to be less than 10 years old. Similarly few appeared to be used frequently and many were in a dilapidated, but usable condition.

Table 2-5: Results of the Typo Lake boat survey.

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

\* trailered

Ten usable docks are present around the lake. One dock had a water slide, but no other areas used for swimming were apparent.

**Fish Survey** – The 1999 MN DNR fish survey found that Black Bullhead and Common Carp were the most abundant species, representing 49.6% and 31.9% of gillnet captures, respectively. Average carp length was 13.5 inches. Brown Bullheads were uncommon, and not captured in the 1999 fish survey and representing 0.1% of captures during the 1995 fish survey. Walleye populations have increased dramatically since the 1995 fish survey, and currently accounted for 15.6% of gill net captures. Walleye fingerlings have been stocked biannually since 1988.

**Total Suspended Solids Analysis** – On a monthly basis, mean TSS was between 3 and 14.5 times higher in the lake than Data Creek inlet (Fig. 2-25 and 2-26). In both the lake and the inlet water VSS was approximately 50% of TSS.

Figure 2-25: Typo Lake average monthly TSS and VSS.

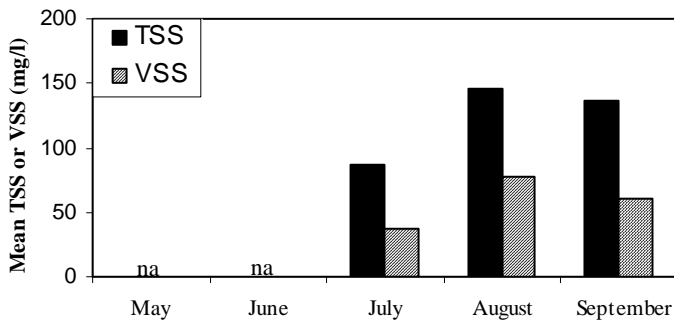
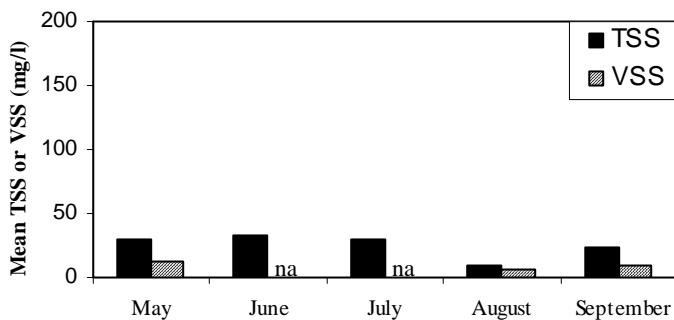


Figure 2-26: Data Creek Inlet average monthly TSS and VSS.



**Computer Modeling** – The Wisconsin Lake Modeling Suite (WLMS) and the more basic MNLEAP lake model provide estimates of internal and external phosphorus loading to the lake (Table 2-6). They also estimate phosphorus retention coefficients; the proportion of phosphorus entering the system which is retained. Taken together, the models indicate that up to 50% of phosphorus in the lake is from in-lake sources and at least 19% of phosphorus entering the lake from the watershed is retained by the lake. It must be emphasized that these numbers are computer model estimates and not the result of an intensive lake budget study.

Table 2-6: Phosphorus loading and retention summary from computer models. (Atmospheric loading is not included)

	MNLEAP	WLMS
External P Loading (kg/yr)	2401	2584 (low estimate)
Internal P Loading (kg/yr)	NA	2486 (low estimate)
P Retention Coefficient	0.42 (predicted)	0.58 (predicted) 0.19 (observed)

In addition to phosphorus loading, WLMS also estimates phosphorus export and lake mixing coefficients. Phosphorus export from Typo to Martin Lake is estimated at 1857.4 kg/yr.

WLMS predicts a Lake Mixing Index for Typo Lake of 0.8. The Lake Mixing Index ranges from 0 to 14. Zero represents intense and continuous mixing. Fourteen represents strongly stratified lakes that mix only during fall and spring turnover.

See Appendix III for complete computer model outputs.

### Discussion

Both the TSS analysis and computer modeling indicate that in-lake conditions are contributing to poor Typo Lake water quality. Rough fish and

phosphorus release from lake sediments are likely causes, while recreational use has light impacts. A thorough understanding of these factors is necessary to plan successful management.

TSS analysis shows that in-lake suspended solids are a larger problem than sediments from the Data Creek inlet. While volatile suspended solids (algae and organic sediment) were approximately half of all suspended solids both in the lake and in the inlet stream, both VSS and TSS were 3 to 14.5 times higher in the lake. In other words, both organic and inorganic suspended solids were higher in the lake.

In-lake suspended solids (other than algae) probably result from sediment disturbance by rough fish and wind. Carp are the most abundant fish in the lake and are well known for their rooting behavior during feeding and mating. These fish not only disturb sediments, but also remove vegetation that would provide quiet areas for sediment settling. Because organic sediments are slower to settle than clay or sand, carp can have a greater impact on a shallow lake with organic sediments than a deeper lake with sandy sediments.

Shallow lakes with organic sediments and little vegetation, such as Typo, are also vulnerable to extensive mixing by the wind. Typo's Mixing Index of 0.8 and excess of inorganic suspended solids in the lake compared to the inlet support the theory of extensive wind mixing.

Like suspended solids, in-lake phosphorus sources are just as large a problem as phosphorus entering the lake at the primary inlet. WLMS estimated that 19% of phosphorus entering the lake is retained by the lake and its sediment. The phosphorus retention of a lake is not easily changed and is a function of several factors. First, phosphorus is kept in circulation within a shallow lake to a greater extent than in a deep lake. In deep lakes, phosphorus in algae or on sediments can sink to the depths where it is lost from the active portions of the lake system. Second, the lake flushing rate can affect phosphorus retention. For instance, phosphorus can build up in a lake if little water is entering and exiting the lake daily. Third, soil type can affect phosphorus retention.

Lake sediments retain and become supersaturated with phosphorus after many years of high phosphorus loading from the watershed, and subsequently are a source of phosphorus themselves (Scheffer 1998). Organic sediments, such as in

Typo Lake, are already naturally high in phosphorus because they are primarily decomposing plant material, and can therefore reach saturation faster than other soils.

Phosphorus in lake sediments can be released by three primary ways. First, phosphorus in organic matter is released in mineralized form through decomposition. It could most likely enter the water column through sediment mixing by wind, rough fish, or boats. Second, phosphorus saturated sediments release it if the phosphorus concentration is lower in the surrounding water (Patrick 1994). If sediments are disturbed, the release rates can be 20-30 times greater (Scheffer 1998). Third, phosphorus is released in anoxic (without oxygen) portions of the sediments, which exist even during thorough mixing. Under anoxic conditions phosphorus bound to iron (most of it is) is released as the iron is reduced to a form less capable of binding the phosphorus. Iron is also less able to bind phosphorus at high pH (Scheffer 1998). Typo Lake had the highest pH of all lakes monitored by the ACD in 2001 by 0.5. This higher pH was probably due to algae blooms. The photosynthetic activity of algae increases pH (Scheffer 1998).

All three of these mechanisms probably occur to some degree in Typo Lake.

### ***Management Implications***

Suspended solids and phosphorus plaguing Typo Lake originate from both the watershed and the lake itself. An understanding of ecological feedback mechanisms in shallow lakes is necessary to plan successful management. These feedbacks tend to keep high quality lakes high quality and low quality lakes low quality.

Zooplankton, aquatic plants, and predatory fish are several components of a healthy shallow lake that help maintain that condition through feedbacks (Moss et al. 1996; Scheffer 1998). Vegetated lakes tend to stay vegetated and clear because plants reduce water turbulence (and hence TP and TSS) and provide refuges for zooplankton. Zooplankton, and particularly large zooplankton, eat algae and can therefore be important in controlling algae blooms. Daphnia, for instance, can filter the entire lake in less than a day in concentrations of a few 10's per liter (Moss et al. 1996). Lakes with predatory fish

also tend to stay clear because they eat rough fish and zooplanktivorous fish.

This system is, however, precariously balanced, particularly if phosphorus loading is high or one of the above components is missing. An increasing carp population, zooplankton crash, or loss of vegetation (among other problems) could tip the scales. Once algae dominate, plants are shaded out and suspended sediments increase. Rough fish may play a role too. The management implication is that controlling the lake's hypereutrophic state involves more than just phosphorus reduction.

To improve Typo Lake, managers should consider these activities, in this order:

1. Reduce phosphorus
2. Remove carp
3. Restore macrophytes
4. Biomanipulation

The management goal for Typo Lake will determine the degree to which each of these measures is implemented. It is unrealistic to expect to restore Typo to a clear-water condition. Rather, the goal should be to rehabilitate the lake to an acceptable condition.

If the primary goal of management is to improve water discharged to Martin Lake, lowering phosphorus levels will be most important. Watershed phosphorus is discussed in the previous section and should be addressed first since it provides much of the stock for internal releases. One must keep in mind, however, that if only watershed approaches are taken, water exported to Martin may not change much for years. Anoxic lake sediments may release more phosphorus when water column phosphorus is lowered (Patrick and Khalid 1974; Patrick 1994; Masscheleyn et al. 1992), though this may not always occur (Theis and McCabe 1978). It may take many years to deplete the in-lake phosphorus sources to acceptable levels.

An in-lake treatment alone, such as Alum might also yield some positive effects, but if used alone will also meet some stumbling blocks. Alum is a chemical treatment that binds phosphorus in the water and precipitates it to the lake bottom. Alum is also used to "seal" the lake bottom to prevent phosphorus release from the sediments. It may not be entirely effective because vigorous lake mixing will not allow effective sealing of the sediments. Another difficulty would be that incoming stream

water is untreated and probably contains enough phosphorus to maintain a eutrophic state. A comprehensive approach addressing both in-lake and watershed sources will have the greatest likelihood of success.

After phosphorus reduction, carp removal should precede efforts to reestablish aquatic vegetation or those efforts may be unsuccessful. Commercial carp harvest might be possible if markets are favorable and would be most successful if subsequent carp barriers are installed. Barriers might be helpful even without carp removal if they prevent fish from utilizing streams for breeding (pers. comm. Dave Zappetillo, MN DNR Fisheries). The lake contains a limited amount of suitable breeding habitat, so exclusion from streams should reduce total reproduction. Due to the flat topography, electric barriers would be most effective. Removal of carp will help reduce both phosphorus levels and suspended solids.

With improved water clarity and reduced rough fish, aquatic plants will be most likely to recover. Lake draw-down to consolidate sediments and create conditions favorable for plant growth is not feasible because no water level control structure currently exists except at the outlet to Martin Lake. Plantings may be needed if the seed bank is not sufficient. These plants will be critical in limiting lake mixing, providing refuges for zooplankton, and even taking up phosphorus from the sediments.

Biomanipulation is an additional measure that will favor healthy lake conditions. Biomanipulation is the manipulation of the fish population structure to favor zooplankton and discourage rough fish. This strategy is already being utilized by the MN DNR through walleye stocking and will be an important component of long-term solutions. Since these fish are visual feeders, their positive effect will increase with water quality and help to maintain it.

Because each of the management actions discussed above has positive feedbacks on the others, they will be more effective if used together than if used independently. This type of integrated management is recommended because while shallow lakes readily shift to a eutrophic state, it is usually very difficult to push them back to a healthier state. It is unrealistic to expect complete transformation of Typo into a clear water pristine lake.

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