SMC Diagnostic Overview:

Management Units:
The Six Mile Creek watershed was broken into **five Management Units** including Pierson-Marsh-Wassermann, Carver Park Reserve, Turbid-Lunsten, Auburn-North Lunsten, and Parley-Mud. Each of these units were assessed as individual subwatersheds but also as a whole based on interactions among the Watershed Management Units.

Piersons-Marsh-Wasserman MU:

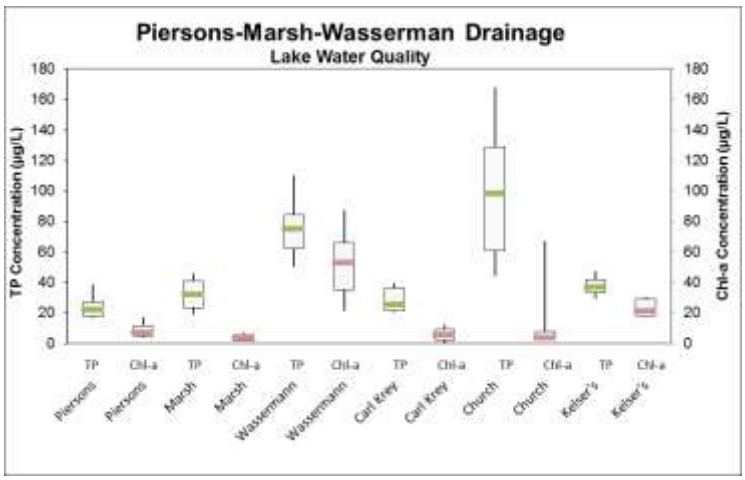
The Pierson and Wassermann drainage areas as well as the wetland area between Wassermann Lake and East Auburn Lake (Figure 4.3). The drainage area starts at Pierson Lake and flows through Marsh Lake and then Wassermann Lake. Wassermann discharges into a large wetland that also receives drainage from Carl Krey and Church lakes as well as Kelser's Pond before discharging into East Auburn Lake.

Parameter	Pierson	Marsh	Wassermann	Carl Krey	Church	Kelser's
Surface Area (acres)	297	143	164	50	16	21
Average Depth (ft)	18.1	2.8	10.3	5.7	13	10
Maximum Depth (ft)	40	5	41	16	54	34
Volume (acre-feet)	5,383	394	1,698	353	207	200
Residence Time (years)	6.0	0.6	0.94	1.9	0.9	2.5
Littoral Area (acres)	119	143	112	50	7	13
Littoral Area (%)	40%	100%	68%	99%	46%	62%
Direct Watershed Area (acres)	903	250	876	265	109	87

Water Quality
Water quality is relatively good in Pierson and Marsh lakes, with total phosphorus concentrations typically below the state water quality standards for shallow and deep lakes (<60 µg/L and <40 µg/L as a summer average, respectively).

However, water quality is significantly degraded in downstream Wassermann Lake with total phosphorus concentrations ranging between 60 and 80 µg/L and some values over 100 µg/L. Chlorophyll-*a* concentrations are quite high in Wassermann Lake, ranging between 40 and 60 µg/L with severe algal blooms as high as 80 µg/L.

Both Carl Krey Lake and Kelser's Pond have relatively good water quality with total phosphorus values typically below 40 µg/L. Church Lake has high total phosphorus concentrations, with some values exceeding 160 µg/L.



Fisheries:

Anecdotal evidence shows carp movement between Wassermann and Marsh lakes, with Marsh Lake showing pockets of vegetation degradation from the carp population.

Aquatic Plants:

All three of the lakes are dominated by coontail. . Pierson, Marsh, and Wassermann all have Eurasian watermilfoil and curly-leaf pondweed present with Pierson Lake demonstrating the densest populations.

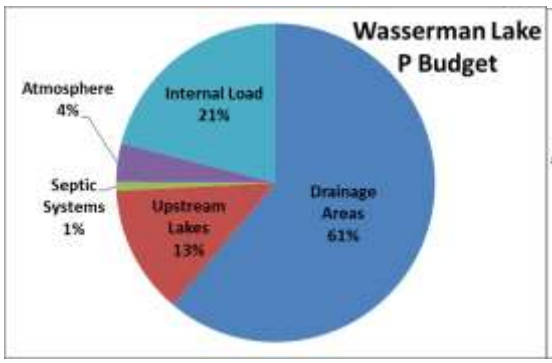
Watershed Nutrient Sources:

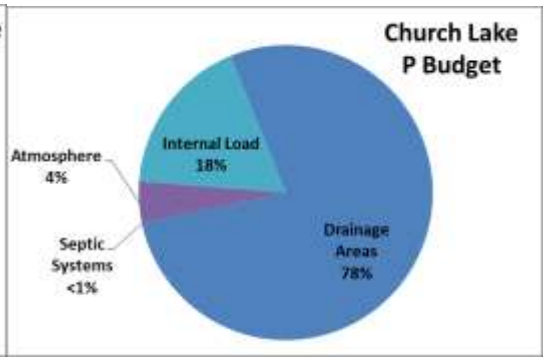
Watershed nutrient loading in the Management Unit is highest in the area directly draining to Wassermann Lake and the SMC-11 and Church Lake watersheds (Figure 3.10). Nutrient loading was highest in the SMC-11 subwatershed where runoff concentrations appear to exceed 800 µg/L total phosphorus.

Internal Loading:

For Marsh Lake, no phosphorus release occurred under oxic or anoxic conditions.

Wassermann Lake demonstrated a low to moderate phosphorus release rate.





Nutrient loads and required reductions to meet state water quality standards (<40 µg/L TP) in Wassermann Lake.

Source	**Existing TP Load**	**TP Allocations**	**Load Reduction**	
	(lbs/year)	**(lbs/year)**	**(lbs/year)**	**%**
Drainage Areas	613	156	457	**75%**
SSTS	9	0	9	**100%**
Upstream Lakes	83	83	0	**0%**
Atmosphere	39	39	0	**0%**
Internal Load	374	165	209	**56%**
TOTAL	**1,118**	**443**	**675**	**60%**

Nutrient loads and required reductions to meet state water quality standards (<40µg/L TP) in Church Lake.

Source	**Existing TP Load** [1]	**TP Allocations**	**Load Reduction**	
	(lbs/year)	**(lbs/year)**	**(lbs/year)**	**%**
Drainage Areas	132	49	83	**63%**
SSTS	3	0	3	**100%**
Atmosphere	4	4	0	**0%**
Internal Load	15	3	12	**80%**
TOTAL	**154**	**56**	**98**	**64%**

Carver Park Reserve MU:

The Carver Park Reserve Management Unit includes most of the lakes in the Carver Park Reserve, which all have relatively good water quality (Figure 3.13). These lakes receive most of their drainage from the relatively undeveloped park areas and are managed by the Three Rivers Park District. (Steiger Stone Zumbra)

Water Quality Monitoring

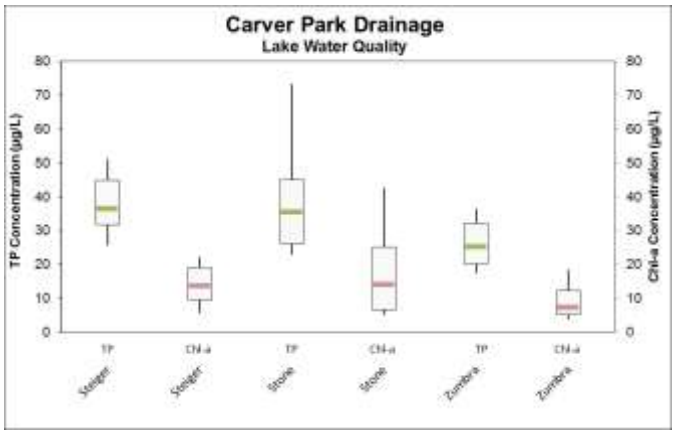
Lakes in the Carver Park Reserve demonstrate relatively good water quality with typical summer average total phosphorus concentrations below state water quality standards (Figure 3.14 Appendix E). Stone Lake has historically demonstrated summer average concentrations above the state water quality standards, but water quality has been improving over the past 10 years and has not exceeded the standard since 2007. Steiger Lake exceeded the standard in two of the past ten years, but only slightly. Chlorophyll-*a* concentrations are low in all three lakes. **Measured phosphorus concentrations in the watershed are relatively low coming out of the lakes, but jump significantly prior to discharging to Auburn Lake.** The jump in phosphorus between the lakes suggests that the wetland area is contributing phosphorus to surface waters.

Table Error! No text of specified style in document.**-1. Physical characteristics of lakes in the Carver Park Reserve Management Unit.**

Parameter	Steiger	Stone	Zumbra
Surface Area (acres)	166	99	193
Average Depth (ft)	13.2	10.2	14.9
Maximum Depth (ft)	37	30	50
Volume (acre-feet)	2,183	1,009	2,872
Residence Time (years)	2.8	1.8	12.0
Littoral Area (acres)	103	71	77
Littoral Area (%)	62%	72%	40%
Watershed (acres)	412	692	331

Nutrient Budgets

Only Stone and Steiger lakes have years that exceeded state water quality standards, and both of these lakes have not exceeded the standard since 2007 and 2006, respectively. Consequently, nutrient budgets and reductions were not developed for these lakes.



Watershed Sources

Watershed sources are highest in the southern portions of the watershed and the land area draining to East Auburn Lake. . Loading to Steiger Lake appears to be a little higher due to development in the watershed; however, water quality in the lake is relatively good and watershed practices can be considered protection activities.

Internal Loading

In the Carver Park Reserve Management Unit, only Stone Lake was assessed for internal phosphorus release. Stone Lake demonstrated a moderate internal phosphorus release rate typical of mesotrophic to slightly eutrophic lakes.

AUBURN-NORTH LUNSTEN DRAINAGE MU

This management unit includes Auburn and North Lunsten lakes. These lakes act as collection points from the rest of the upper watershed, receiving drainage from Sunny, Steiger, Wassermann, Church, and Carl Key lakes as well as Kelser's Pond. All three of these lakes have healthy, dense aquatic vegetation populations, suggesting minimal impacts from carp. Additionally, water quality in both North Lunsten and West Auburn lakes is good, with East Auburn Lake taking the brunt of water quality impacts from the upper watershed.

Water Quality Monitoring

East Auburn Lake demonstrates some eutrophication, with four out of the last five monitoring years exceeding the state water quality standards. West Auburn Lake, which receives most of its drainage from East Auburn Lake, demonstrates very good water quality with all the years meeting the state water quality standard in the past 13 years. North Lunsten Lake has some potential for eutrophication, although none of the summer average data with four or more samples exceeded the water quality standard. The key drivers for water quality in this segment of the watershed are East Auburn Lake and inflow from South Lunsten Lake.

Table Error! No text of specified style in document.**-2. Physical characteristics of lakes in the Auburn-North Lunsten Management Unit.**

Parameter	East Auburn	West Auburn	North Lunsten
Surface Area (acres)	148	145	114
Average Depth (ft)	12.0	25.0	4.4
Maximum Depth (ft)	40	80	7
Volume (acre-feet)	1,781	3,615	508
Residence Time (years)	0.7	4.7	0.1
Littoral Area (acres)	42	83	114

Littoral Area (%)	28%	58%	100%
Watershed (acres)	214	184	232

Aquatic Plants

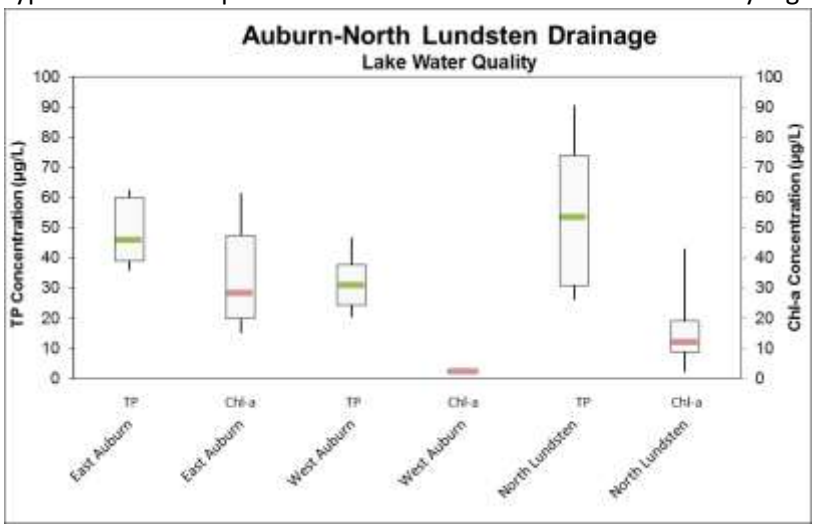
All three of the lakes in the Management Unit had recent vegetation survey data. The three lakes are dominated by coontail, a native species that is tolerant of more eutrophic conditions. East and West Auburn lakes are dominated by Eurasian watermilfoil and all three lakes have curly-leaf pondweed.

Watershed Sources

Nutrient loading in the direct subwatersheds to East and West Auburn and North Lunsten lakes is relatively low. Most of the load to these lakes comes from upstream lakes, such as Wassermann Lake and South Lunsten Lake. SMC15 and SMC-25, also are large contributors to East Auburn Lake. A third large contributor is the large wetland between Wassermann Lake and East Auburn Lake.

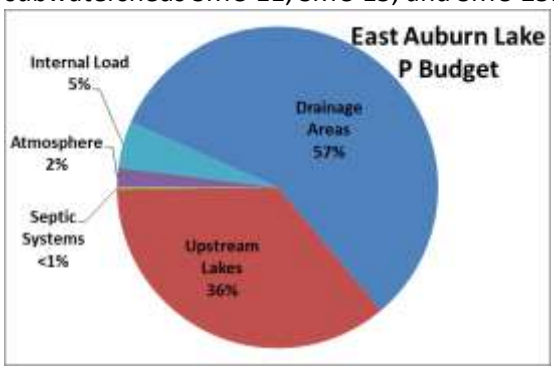
Internal Loading:

East Auburn demonstrated a moderate release rate under anoxic conditions, whereas North Lunsten had relatively low rates more typical of mesotrophic lakes. South Lunsten demonstrated very high internal release rates with oxic loading at 6 mg/m^2/day.



East Auburn Lake

The key lake in this management unit is East Auburn Lake, which receives water and nutrients from the entire upper watershed. The majority of phosphorus coming into East Auburn Lake comes from the drainage areas, specifically subwatersheds SMC-11, SMC-15, and SMC-25.



Nutrient loads and required reductions to meet state water quality standards (40 µg/L TP) in East Auburn Lake.

Source	Existing TP Load (lbs/year)	TP Allocations (lbs/year)	Load Reduction	
			(lbs/year)	%
Drainage Areas	1,337	996	341	**26%**
Upstream Lakes	680	480	199	**29%**
SSTS	6	0	6	**100%**
Atmosphere	35	35	0	**0%**
Internal Load	41	41	0	**0%**
TOTAL	**2,099**	**1,553**	**546**	**26%**

Turbid-South Lunsten Drainage MU:

The Turbid-South Lunsten Management Unit includes two poor quality lakes, with Turbid draining into South Lunsten. Both of these lakes have anecdotal reports of large carp populations, with South Lunsten Lake having very poor water quality and no submerged aquatic vegetation.

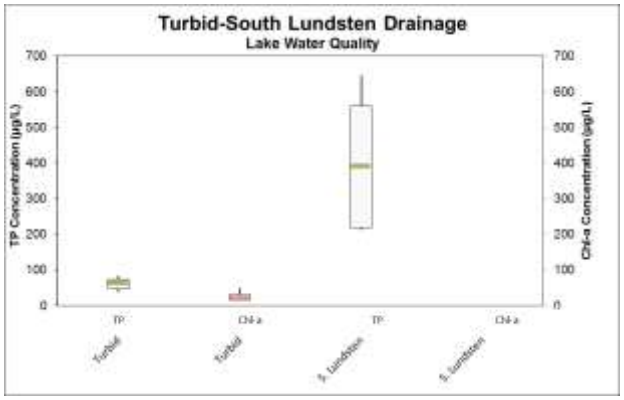
Parameter	Turbid	South Lunsten
Surface Area (acres)	40	77
Average Depth (ft)	10.4	3.5
Maximum Depth (ft)	35	9
Volume (acre-feet)	417	267
Residence Time (years)	1.3	0.3
Littoral Area (acres)	26	77
Littoral Area (%)	65%	100%

Watershed (acres)	492	121

Water Quality Monitoring

Turbid exceeded state standards for phosphorus in all years monitored (six years) since 2006, with summer average concentrations ranging from 40 to 70 µg/L as a summer average. Water quality has been sampled only in 2012, but concentrations in South Lunsten Lake were extremely high, with a summer average of almost 450 µg/L.

Phosphorus concentrations increase after leaving Turbid Lake, and then remain relatively constant as the water moves to lower Lunsten Lake. By the time the water reaches the first water quality station, S005-527, phosphorus concentrations have almost doubled with the majority dissolved ortho-phosphorus, which is an indicator of wetland phosphorus release. Based on the water quality data, it appears that the wetlands between Turbid and South Lunsten lakes are contributing phosphorus to surface waters.



Aquatic Plants

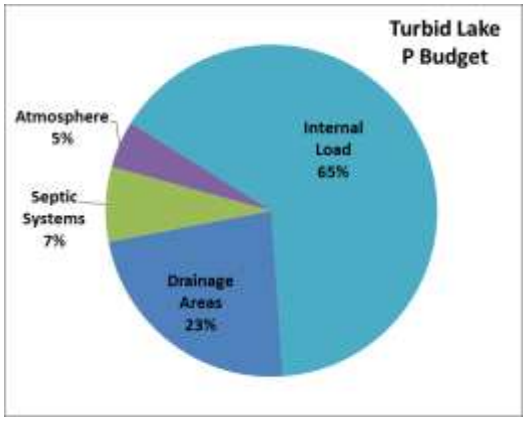
South Lunsten Lake lacks a robust submerged vegetation community with only a few species found sporadically around the lake. A few coontail plants were found along with some narrow leaf pondweed. Overall, the vegetation community in South Lunsten Lake is in very poor condition. MCWD plans on conducting vegetation surveys for Turbid Lake in 2013.

Watershed Sources

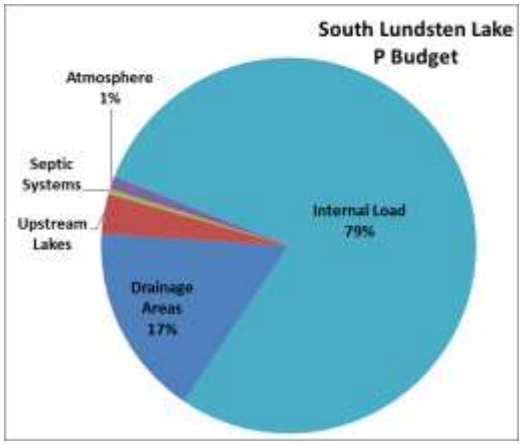
Watershed nutrient loading to Turbid Lake is relatively low with average runoff concentrations estimated around 80 µg/L phosphorus. The lake then discharges to a drainage ditch that flows through several modified wetlands prior to discharging to South Lunsten Lake. Based on monitoring data and mass balance calculations, runoff from these watersheds averages 225 to 325 µg/L total phosphorus. Consequently, it appears that most of the loading to South Lunsten Lake is coming along the drainage ditch between Turbid and South Lunsten Lake.

Internal Loading

Turbid Lake had a relatively high release rate typical of moderately eutrophic lakes (Table 3.14). Lower Lunsten Lake had very low rates for both oxic and anoxic release of phosphorus more typical of healthy shallow lake systems.



Overall, Turbid Lake needs a 53% reduction in phosphorus loading to the lake with the majority of the reduction coming from internal loading



For South Lunsten Lake to meet state water quality standards, large reductions are needed from the watershed and internal loads. Internal load needs to be reduced by 97%, whereas watershed loading needs to be reduced by 82%.

Nutrient loads and required reductions to meet state water quality standards (<40 µg/L TP) in Turbid Lake.

Source	Existing TP Load [1]	TP Allocations	Load Reduction	
	(lbs/year)	(lbs/year)	(lbs/year)	%
Drainage Areas	89	77	12	**14%**
SSTS	15	0	15	**100%**
Atmosphere	10	10	0	**0%**
Internal Load	135	31	104	**77%**
TOTAL	**249**	**117**	**132**	**53%**

Nutrient loads and required reductions to meet state water quality standard (<60 µg/L TP) in South Lunsten Lake.

Source	Existing TP Load	TP Allocations	Load Reduction	
	(lbs/year)	(lbs/year)	(lbs/year)	%
Drainage Areas	388	68	320	**82%**
Upstream Lakes	84	71	13	**15%**
SSTS	8	0	8	**100%**
Atmosphere	18	18	0	**0%**
Internal Load	1,319	35	1,284	**97%**
TOTAL	**1,817**	**193**	**1,624**	**89%**

PARLEY-MUD DRAINAGE MU:

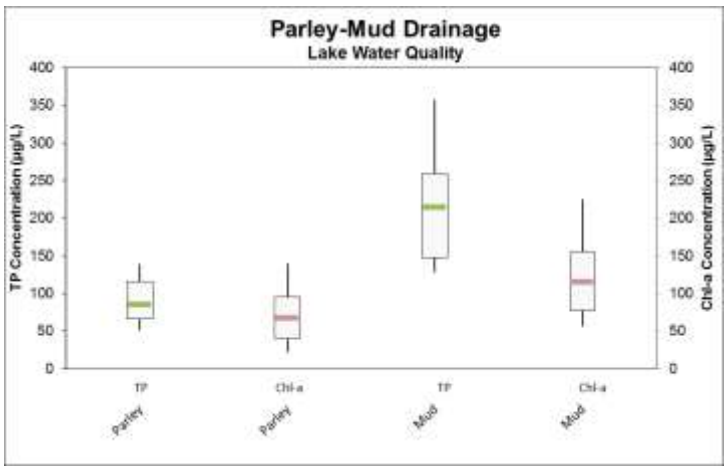
Both Parley and Mud lakes have dense carp populations and lack submerged aquatic vegetation. The vast majority of shoreline surrounding Parley and Mud lakes is in a natural state. Despite very little development around the lakes, water quality is poor. Parley and Mud Lakes are extremely shallow lakes with average depths less than 6.5 feet and maximum depths of 19 and 6 feet, respectively.

Physical characteristics of lakes in the Parley-Mud Management Unit.

Parameter	Parley	Mud
Surface Area (acres)	257	144
Average Depth (ft)	6.4	3.5
Maximum Depth (ft)	19	6
Volume (acre-feet)	1,654	501
Residence Time (years)	0.4	0.6
Littoral Area (acres)	257	144
Littoral Area (%)	100%	100%
Watershed (acres)	565	423

Water Quality Monitoring

Total phosphorus concentrations in **Parley Lake averaged around 80 µg/L, with some values as high as 150 µg/L**. Parley Lake experiences severe algal blooms in most years, with chlorophyll-*a* concentrations at times nearing 150 µg/L. Water quality in Mud Lake is even more severely degraded, with **total phosphorus concentrations at times reaching almost 350** µg/L. Mud Lake also experiences severe algal blooms, with chlorophyll-*a* concentrations reaching over 200 µg/L at some periods during the summer.



Aquatic Plants

Overall, the plant community in Parley Lake is not very diverse, with only a handful of species present during each survey (Figure 3.42; Appendix G). Exotics such as curly-leaf pondweed have been present within the lake during each of the last four surveys

conducted by the Minnesota DNR. The abundance of coontail has increased over the past three surveys (1980 to 1998), indicating the lake is moving toward more eutrophic conditions.

Internal Loading

Both lakes had relatively low oxic release rates of phosphorus, with both being below 1 mg/m^2/day. However, there was a surprising difference in anoxic release rates, with Mud Lake demonstrating relatively a low release of 2.0 mg/m^2/day. Parley Lake had a higher release rate, but the lack of anoxia over most of the lake suggests that internal loading may not be as important as previously suspected. However, the high anoxic release rate suggests that Parley Lake may be sensitive to periodic anoxia in years with high temperatures and quiescent conditions that promote anoxia.

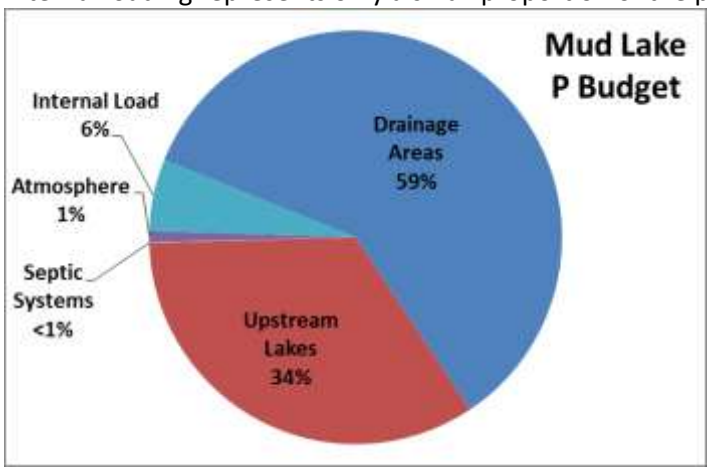
Nutrient Budgets

Parley Lake

Internal loading was determined to be on average 17% of the phosphorus loading to Parley Lake. The direct drainage area to the lake was 38%, while loading from Lunsten Lake represents 41% of the phosphorus load to Parley Lake.

Mud Lake

Internal loading represents only a small proportion of the phosphorus budget (6%).



The level of phosphorus reductions described to meet state water quality standards may not be necessary to make significant improvements in the ecological condition in Mud Lake. Moss et al. (1997) suggest a target value of 150 µg/L as a summer average as a good place to start thinking about more drastic measures to shift the lake to a clear lake state. If watershed concentrations were targeted at 150 µg/L, in-lake concentrations should drop to around 80 µg/L, providing prime conditions for considering a drawdown. A target of 80 µg/L still requires a 78% reduction in watershed loading (Table 3.20). It is important to note that watershed runoff concentrations need to be verified prior to large implementation efforts in the watershed.

Nutrient loads and required reductions to meet state water quality standards (<60 µg/L TP) in Mud Lake.

Source	**Existing TP Load (lbs/year)**	**TP Allocation (lbs/year)**	**Load Reduction (lbs/year)**	**%**
Drainage Areas	2,377	119	2,258	**95%**
Upstream Lakes	1,659	1,141	518	**31%**
Septic	3	0	3	**100%**
Atmosphere	34	34	0	**0%**
Internal Load	312	103	209	**67%**
TOTAL	**4,385**	**1,397**	**2,988**	**68%**

Nutrient loads and required reductions to meet a set target of <80 µg/L total phosphorus in Mud Lake.

Source	**Existing TP Load (lbs/year)**	**TP Allocations (lbs/year)**	**Load Reduction (lbs/year)**	**%**
Drainage Areas	2,377	513	1,864	**78%**
Upstream Lakes	1,659	1,141	518	**31%**
Septic	3	0	3	**100%**
Atmosphere	34	34	0	**0%**
Internal Load	312	312	209	**0%**
TOTAL LOAD	**4,385**	**1,999**	**2,594**	**54%**

SMC RESTORATION STRATEGY:

The overall strategy for restoring the Six Mile Creek watershed can be summarized in five steps:

1. Manage carp to appropriate levels to minimize impacts on lakes.
    a. Identify high priority potential reproduction areas.
    b. Track carp movements to identify spawning and wintering areas.
    c. Prevent winterkill in shallow water lakes and wetlands.
2. Implement watershed nutrient reduction projects.
3. Assess feasibility for whole-lake drawdown in South Lunsten, Parley, and Mud lakes.
4. Once carp are controlled, implement internal load reduction projects.
5. Manage and protect lake vegetation.
    a. Focus on nutrient reduction to increase diversity.
    b. Focus on invasive species control to increase diversity.