2013

CHISAGO LAKES CHAIN OF LAKES WATERSHED

TOTAL MAXIMUM DAILY LOAD STUDY

wq-iw6-10e

CHISAGO LAKES CHAIN OF LAKES WATERSHED TMDL

Final Report

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CLEAN WATER, LAND, AND LEGACY AMENDMENT)

TMDL Summary Table

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<tr><td>303(d) Listing Information</td><td>Describe the waterbody as it is identified on the State/Tribe’s 303(d) list:
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<tr><th>LAKE NAME</th><th>LAKE ID</th><th>YEAR LISTED</th><th>TARGET START/COMPLETION</th></tr>
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<i>Impaired Use:</i> Aquatic Recreation
<i>Pollutant or Stressor:</i> Nutrient/Eutrophication Biological Indicators
<i>* Listed on the Draft 2012 303(d) impaired waters list.</i>
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<tr><td>South Center</td><td>15</td><td>81</td></tr>
<tr><td>Emily</td><td>0.082</td><td>89</td></tr>
<tr><td>Linn</td><td>0.99</td><td>96</td></tr>
<tr><td>Little</td><td>0.90</td><td>104</td></tr>
<tr><td>Ogren</td><td>1.8</td><td>113</td></tr>
<tr><td>Pioneer</td><td>0.22</td><td>119</td></tr>
<tr><td>School</td><td>0.66</td><td>126</td></tr>
<tr><td>Wallmark</td><td>0.67</td><td>133</td></tr>
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<tr><td>Wasteload Allocation</td><td colspan="2">
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<tr><td>Industrial Stormwater</td><td>MNR50000</td><td>all</td><td>various</td><td></td></tr>
<tr><td>Reserve Capacity</td><td>NA</td><td>-</td><td>-</td><td>50</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:

Watershed runoff
Loading from upstream waters
Atmospheric deposition
Subsurface sewage treatment systems (SSTS)
Groundwater
Internal loading
</td><td></td></tr>
</table>

	Lake	**LA (lb/ day)**	
Load Allocation Cont’d	North Center	13	71
	South Center	13	81
	Emily	0.074	89
	Linn	0.89	96
	Little	0.81	104
	Ogren	1.6	113
	Pioneer	0.20	119
	School	0.59	126
	Wallmark	0.60	133
Margin of Safety	A 10% explicit margin of safety (MOS) was accounted for in the TMDL for each lake. This MOS is sufficient to account for uncertainties in predicting loads to the lakes and predicting how lakes respond to changes in phosphorus loading.		48
Seasonal Variation	Critical conditions in these lakes occur in the summer, when TP concentrations peak and clarity is at its worst. The water quality standards are based on growing season averages. The load reductions are designed so that the lakes will meet water quality standards over the course of the growing season (June-September).		135
Reasonable Assurance	Active Local Partners: Chisago SWCD, Chisago Lakes LID, Local Communities NPDES permit compliance		143
Monitoring	***Monitoring Plan included?*** Yes		136
Implementation	***1. Implementation Strategy included?*** yes ***2. Cost estimate included?*** yes		137
Public Participation	· Public Comment period · Comments received? From MPCA, Chisago County · Public meeting and Steering Committee meeting held on September 19, 2011		144

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Abbreviations

CAFO – Concentrated Animal Feeding Operation
CALM - Consolidation Assessment and Listing Methodology
Chl-*a* – Chlorophyll-*a*
CLLID – Chisago Lakes Lake Improvement District
CV – Coefficient of Variation
EPA – Environmental Protection Agency
HRU – Hydrologic Response Unit
ITPHS – Imminent Threat to Public Heath Septic System
LA – Load Allocation
MN DNR – Minnesota Department of Natural Resources
MOS – Margin of Safety
MPCA – Minnesota Pollution Control Agency
MS4 – Municipal Separate Storm Sewer System
NPDES – National Pollutant Discharge Elimination System
SDS – State Disposal System
SE – Standard Error
SLICE – Sustaining Lakes in a Changing Environment
SSTS – Subsurface Sewage Treatment System
SWAT – Soil and Water Assessment Tool
SWPPP – Stormwater Prevention Pollution Plan
SWCD – Soil and Water Conservation District
TMDL – Total Maximum Daily Load
TP – Total Phosphorus
US ACOE – United States Army Corps of Engineers
USDA – United States Department of Agriculture
USGS – United States Geological Survey
WLA – Wasteload Allocation

EXECUTIVE SUMMARY

The Clean Water Act (1972) requires that each State develop a plan to identify and restore any waterbody that is deemed impaired by state regulations. A Total Maximum Daily Load Study (TMDL) is required by the Environmental Protection Agency (EPA) as a result of the federal Clean Water Act. A TMDL identifies the pollutant that is causing the impairment and how much of that pollutant can enter the water body and still meet water quality standards.

In the case of the Chisago Lakes Chain of Lakes Watershed, the lake impairment affects the lake's ability to support aquatic recreation (which includes: fishing, swimming, boating, and aesthetics). The impairment is caused by excessive nutrients in the lakes; the nutrient found to be causing the main problem is phosphorus. Phosphorus is a necessary nutrient in lake ecology; however, too much phosphorus can cause excessive algae blooms. These algae blooms can sometimes be toxic and have unpleasant odors.

Nine lakes within the Chisago Lakes Chain of Lakes Watershed are currently on the EPA's 303(d) Impaired Waters List (or Draft list): North Center, South Center, Wallmark, Little, Ogren, Linn, Pioneer, School, and Emily (see Table 10 for impairment listing). This TMDL report will address the impairments, provide an assessment of the ecological health of each lake, assess potential phosphorus sources, and provide guidelines on how to restore the aquatic recreational use of each lake.

Information from multiple sources was used to evaluate the ecological health of each lake:

- In-lake water quality data over the past ten years, including phosphorus and chlorophyll-*a* concentrations, and Secchi transparency
- Sediment phosphorus concentrations
- Fisheries surveys
- Plant surveys

The following phosphorus sources were evaluated for each lake: watershed runoff, animal operations, subsurface sewage treatment systems (SSTS), loading from upstream lakes, atmospheric deposition, shallow groundwater sources, and internal loading. An inventory of phosphorus sources was then used to develop a lake response model for each lake, and these models were used to determine the phosphorus reductions needed for the lakes to meet water quality standards. The implementation approach will include education and outreach, technical assistance, and partnerships with landowners, cities, Chisago County, lake associations, and the Chisago Lakes Lake Improvement District. A summary of necessary reductions is below.

LAKE	LOADING CAPACITY (TMDL) (LB /DAY)	WASTELOAD ALLOC. (LB /DAY)	LOAD ALLOC. (LB /DAY)	REDUCTION NEEDED (LB/YR)	REDUCTION NEEDED (%)
North Center	15	0.0066	13	1,108	18%
South Center	15	0.0072	13	1,260	21%
Emily	0.082	0.000054	0.074	362	93%
Linn	0.99	0.00088	0.89	2,395	88%
Little	0.90	0.0013	0.81	2,658	90%
Ogren	1.8	0.0038	1.6	467	45%
Pioneer	0.22	0.0000054	0.20	1,771	96%
School	0.66	0.00072	0.59	1,593	88%
Wallmark	0.67	0.00040	0.60	3,997	95%

North Center Lake

North Center Lake (MN DNR Lake ID 13-0032-01) is a shallow lake located in southern Chisago County and borders Lindstrom to the west and Center City to the east. The dominant land cover in the watershed is agriculture and woodland. The lake does not meet shallow lake water quality standards for total phosphorus (TP) or chlorophyll-*a* (Chl-*a*), and just meets the Secchi transparency standard.

Watershed assessment summary:

- The lake water quality violates the phosphorus and chlorophyll-*a* water quality standards and just meets the Secchi transparency standard.
- The lake vegetation is dominated by curly-leaf pondweed and Eurasian watermilfoil. Curly-leaf pondweed contributes to internal loading from the sediments.
- Black bullhead and carp are present in the lake, which could lead to high internal loading rates due to their habit of foraging in bottom sediments.
- Phosphorus concentration in sediments is high, indicating a high potential for internal loading from sediments.
- A large portion of the shoreline is developed.
- Approximately 50% of the watershed is cropland, and there are 15 animal operations in the watershed.
- Approximately half of the watershed is served by private on-site septic systems, which are estimated to have a 25% failure rate.
- Seven imminent threat to public health septic systems, three of which were in the shoreland area, were recently upgraded.
- Three other impaired lakes drain to North Center Lake: Little Lake, Pioneer Lake (shallow groundwater only), and South Center Lake.

Phosphorus sources to the lake are dominated by upstream loading, watershed runoff, animal operations, and internal loading. An overall reduction of 18% of phosphorus loading to North Center Lake is needed to restore the lake to suitable aquatic recreation uses. To meet the TMDL, taking into account the MOS, total loading to the lake needs to be reduced by 1,108 lb/yr, or 18% (Table 1Table 71). If the upstream lakes (Little, Pioneer, and South Center Lakes) all meet their water quality goals, the load to North Center Lake would be reduced by 520 lb/yr. The remaining 588 lb/yr reduction should come from watershed BMPs. Watershed load reduction practices will include urban stormwater reduction practices, lakeshore and streambank buffers, and a wide variety of agricultural Best Management Practices (BMPs). Internal loading is not excessively high in North Center Lake and is not a primary focus of restoration efforts.

Table 1 - North Center Lake Phosphorus Reduction Summary

PHOSPHORUS SOURCE	EXISTING ANNUAL TP LOAD (LB/YR)	IMPLEMENTATION SCENARIO ANNUAL TP LOAD (LB/YR)	LOAD REDUCTION NEEDED (LB/YR)	PERCENT REDUCTION (%)
Watershed	2,813	1,703	1,108	39%
Atmospheric Deposition	200	200	0	0%
Internal	3,000	3,000	0	0%
Total	**6,013**	**4,903**	**1,108**	**18%**

South Center Lake

South Center Lake (MN DNR Lake ID 13-0037) is a lake located in southern Chisago County and borders Lindstrom to the west. The dominant land cover of the watershed is agricultural and wetland. The lake does not meet lake water quality standards for total phosphorus, chlorophyll-*a*, or Secchi transparency.

Watershed assessment summary:

- The lake water quality violates the phosphorus, chlorophyll-*a*, and Secchi transparency water quality standards.
- The lake vegetation is dominated by curly-leaf pondweed. Curly-leaf pondweed contributes to internal loading from the sediments.
- Black bullhead and carp are present in the lake, which could lead to high internal loading rates due to their habit of foraging in bottom sediments.
- Phosphorus concentration in sediments is high, indicating a high potential for internal loading from sediments.
- A large portion of the shoreline is developed.
- Approximately 51% of the watershed is cropland, and there are 3 animal operations in the direct drainage area.
- Approximately half of the watershed is served by private on-site septic systems, which are estimated to have a 25% failure rate.
- Ten imminent threat to public health septic systems, 2 of which were in the shoreland area, were recently upgraded.
- Two other impaired lakes drain to South Center Lake: Linn Lake and Ogren Lake.

Phosphorus sources to the lake are dominated by upstream loading, watershed runoff, animal operations, and internal loading. An overall reduction of 21% of phosphorus loading to South Center Lake is needed to restore the lake to suitable aquatic recreation uses. To meet the TMDL, taking into account the MOS, total loading to the lake needs to be reduced by 1,260 lb/yr, or 21% (Table 2). If the upstream lakes (Linn and Ogren Lakes) all meet their water quality goals, the load to South Center Lake would be reduced by 210 lb/yr. Of the remaining load reduction needed, approximately 842 lb/yr should come from the watershed load and approximately 208 lb/yr should come from internal load. Watershed load reduction practices will include urban stormwater reduction practices, lakeshore and streambank buffers, and a wide variety of agricultural Best Management Practices (BMPs). Due to the small amount of internal load reduction needed for South Center Lake, internal load reduction practices should not be a primary focus of restoration efforts. As watershed loads to the lake are reduced, the lake should respond with lower internal loading rates.

Table 2 - South Center Lake Phosphorus Reduction Summary

PHOSPHORUS SOURCE	EXISTING ANNUAL TP LOAD (LB/YR)	IMPLEMENTATION SCENARIO ANNUAL TP LOAD (LB/YR)	LOAD REDUCTION NEEDED (LB/YR)	PERCENT REDUCTION (%)
Watershed	2,385	1,330	1,052	44%
Atmospheric Deposition	240	240	0	0%
Internal	3,500	3,292	208	6%
Total	**6,125**	**4,862**	**1,260**	**21%**

Lake Emily

Lake Emily (MN DNR Lake ID 13-0046) is a lake located in southern Chisago County. This waterbody is listed as a wetland on the Public Waters Inventory; however, it is used as a lake. There is no public access on Lake Emily. Major land use within the watershed is agricultural. The lake does not meet shallow lake water quality standards for total phosphorus, chlorophyll-*a*, or Secchi transparency.

Watershed assessment summary:

- The lake water quality violates the phosphorus, chlorophyll-*a*, and Secchi transparency water quality standards. The lake is hypereutrophic, with an average phosphorus concentration of 350 µg/l.
- Lake Emily is a classified as a wetland by MN DNR but is used recreationally as a lake.
- Curly-leaf pondweed exists in the lake, although the extent is not known. Curly-leaf pondweed contributes to internal loading from the sediments.
- There is an abundance of stunted sunfish and black bullhead. The presence of stunted sunfish often indicates an overabundance of planktivorous fish such as sunfish. This overabundance leads to overgrazing on zooplankton and a resultant increase in algae. Black bullhead can lead to high internal loading rates due to their habit of foraging in bottom sediments.
- A large portion of the shoreline is developed.
- Approximately 80% of the watershed is cropland.
- The entire watershed is served by private on-site septic systems, which are estimated to have a 25% failure rate.
- The lake model indicated that there is a large phosphorus load that is unaccounted for in the current phosphorus source inventory. This load is likely a mix of internal load and load from failing septic systems.

Phosphorus sources to the lake are dominated by internal loading and watershed runoff. A reduction of 93% will be needed to achieve water quality goals. To meet the TMDL, taking into account the MOS, total loading to the lake needs to be reduced by 362 lb/yr, or 93% (Table 3). Approximately 100 lb/yr should come from the watershed load and approximately 262 lb/yr should come from internal load. Watershed load reduction practices will include stormwater reduction practices, lakeshore buffers, and a wide variety of agricultural Best Management Practices (BMPs). In-lake practices may consist of fish and aquatic plant management and management of internal nutrient cycling.

Table 3 - Lake Emily Phosphorus Reduction Summary

PHOSPHORUS SOURCE	EXISTING ANNUAL TP LOAD (LB/YR)	IMPLEMENTATION SCENARIO ANNUAL TP LOAD (LB/YR)	LOAD REDUCTION NEEDED (LB/YR)	PERCENT REDUCTION (%)
Watershed	106	6.2	100	94%
Atmospheric Deposition	4.6	4.6	0	0%
Internal	278	16	262	94%
Total	**389**	**27**	**362**	**93%**

Linn Lake

Linn Lake (MN DNR Lake ID 13-0014) is a shallow lake located in southern Chisago County, south of Lindstrom. The dominant land cover in the watershed is agriculture and woodland. The lake does not meet shallow lake water quality standards for total phosphorus, chlorophyll-*a*, or Secchi transparency.

Watershed assessment summary:

- The lake water quality violates the phosphorus, chlorophyll-*a*, and Secchi transparency water quality standards. The lake is hypereutrophic, with an average phosphorus concentration of 217 µg/l.
- Curly-leaf pondweed exists in the lake, although the extent is not known. Curly-leaf pondweed contributes to internal loading from the sediments. Many emergent macrophytes also exist.
- In a 1978 fish survey, black bullheads were abundant; there has not been a fish survey since then. Black bullhead can lead to high internal loading rates due to their habit of foraging in bottom sediments.
- Approximately 58% of the watershed is cropland, and there are three small animal operations in the watershed.
- The majority of the watershed is served by private on-site septic systems, which are estimated to have a 25% failure rate.
- Two imminent threat to public health septic systems, both of which were in the shoreland area, were recently upgraded.
- The lake model indicated that there is a large phosphorus load that is unaccounted for in the current phosphorus source inventory. This load is likely a mix of internal load and load from failing septic systems.

Phosphorus sources to Linn Lake are dominated by internal loading and watershed runoff. A phosphorus load reduction of 88% is needed in Linn Lake to achieve water quality goals. To meet the TMDL, taking into account the MOS, total loading to the lake needs to be reduced by 2,395 lb/yr, or 88% (Table 4). Approximately 848 lb/yr should come from the watershed load and approximately 1,547 lb/yr should come from internal load. Watershed load reduction practices will include stormwater reduction practices, lakeshore and streambank buffers, and a wide variety of agricultural Best Management Practices (BMPs). In-lake practices may consist of fish and aquatic plant management and management of internal nutrient cycling.

Table 4 - Linn Lake Phosphorus Reduction Summary

PHOSPHORUS SOURCE	EXISTING ANNUAL TP LOAD (LB/YR)	IMPLEMENTATION SCENARIO ANNUAL TP LOAD (LB/YR)	LOAD REDUCTION NEEDED (LB/YR)	PERCENT REDUCTION (%)
Watershed	945	97	848	90%
Atmospheric Deposition	49	49	0	0%
Internal	1,725	178	1,547	90%
Total	**2,719**	**324**	**2,395**	**88%**

Little Lake

Little Lake (MN DNR Lake ID 13-0033) is a lake located in southern Chisago County, two miles northeast of Center City. The dominant land cover in the watershed is agriculture and woodland. The lake does not meet lake water quality standards for total phosphorus, chlorophyll-*a*, or Secchi transparency.

Watershed assessment summary:

- The lake water quality violates the phosphorus, chlorophyll-*a*, and Secchi transparency water quality standards. The lake is hypereutrophic, with an average phosphorus concentration of 173 µg/l.
- Curly-leaf pondweed exists in the lake, and was the most common plant in the lake in a 2004 survey. Curly-leaf pondweed contributes to internal loading from the sediments.
- Phosphorus concentration in sediments is high, indicating a high potential for internal loading from sediments.
- Approximately 55% of the watershed is cropland, and there are ten animal operations in the watershed.
- The entire watershed is served by private on-site septic systems, which are estimated to have a 25% failure rate.
- Five imminent threat to public health septic systems, two of which were in the shoreland area, were recently upgraded.
- The lake model indicated that there is a large phosphorus load that is unaccounted for in the current phosphorus source inventory. This load is likely a mix of internal load, load from animal operations, and load from failing septic systems.

Phosphorus sources to Little Lake are dominated by internal loading and watershed runoff. A phosphorus load reduction of 90% is needed to achieve water quality standards in Little Lake. To meet the TMDL, taking into account the MOS, total loading to the lake needs to be reduced by 2,658 lb/yr, or 90% (Table 5). Approximately 1,562 lb/yr should come from the watershed load and approximately 1,096 lb/yr should come from internal load. Watershed load reduction practices will include a wide variety of agricultural Best Management Practices (BMPs) and lakeshore and streambank buffers. In-lake practices may consist of fish and aquatic plant management and management of internal nutrient cycling.

Table 5 - Little Lake Phosphorus Reduction Summary

PHOSPHORUS SOURCE	EXISTING ANNUAL TP LOAD (LB/YR)	IMPLEMENTATION SCENARIO ANNUAL TP LOAD (LB/YR)	LOAD REDUCTION NEEDED (LB/YR)	PERCENT REDUCTION (%)
Watershed	1,710	148	1,562	91%
Atmospheric Deposition	44	44	0	0%
Internal	1,200	104	1,096	91%
Total	**2,954**	**296**	**2,658**	**90%**

Ogren Lake

Ogren Lake (MN DNR Lake ID 13-0011) is a lake located in southern Chisago County to the southeast of South Center Lake. Ogren Lake has a very large watershed area that is primarily dominated by agricultural land use and wetlands. The lake does not meet shallow lake water quality standards for total phosphorus or chlorophyll-*a*, but meets the standard for Secchi transparency.

Watershed assessment summary:

- The lake water quality violates the phosphorus and chlorophyll-*a* water quality standards but meets the Secchi transparency standard.
- There are no invasive aquatic macrophytes in the lake; the lake has a desirable mix of emergent and submergent macrophytes.
- Phosphorus concentration in sediments is high, indicating a high potential for internal loading from sediments.
- A 1989 fish survey indicated the presence of black bullhead; there has not been a fish survey since then. Black bullhead can lead to high internal loading rates due to their habit of foraging in bottom sediments.
- Approximately 54% of the watershed is cropland, and there are nine animal operations in the watershed.
- The entire watershed is served by private on-site septic systems, which are estimated to have a 25% failure rate.
- Ten imminent threat to public health septic systems, four of which were in the shoreland area, were recently upgraded.

Phosphorus sources to Ogren Lake are mainly rural watershed runoff. A phosphorus load reduction of 45% is needed to bring the aquatic recreation of Ogren Lake back to a useable state. To meet the TMDL, taking into account the MOS, total loading to the lake needs to be reduced by 467 lb/yr, or 45% (Table 6). Approximately 430 lb/yr should come from the watershed load and approximately 37 lb/yr should come from internal load. Watershed load reduction practices will include a wide variety of agricultural Best Management Practices (BMPs) and lakeshore and streambank buffers. In-lake practices may consist of fish and aquatic plant management and management of internal nutrient cycling.

Table 6 - Ogren Lake Phosphorus Reduction Summary

PHOSPHORUS SOURCE	EXISTING ANNUAL TP LOAD (LB/YR)	IMPLEMENTATION SCENARIO ANNUAL TP LOAD (LB/YR)	LOAD REDUCTION NEEDED (LB/YR)	PERCENT REDUCTION (%)
Watershed	860	430	430	50%
Atmospheric Deposition	13	13	0	0%
Internal	170	133	37	22%
Total	**1,043**	**576**	**467**	**45%**

Pioneer Lake

Pioneer Lake (MN DNR Lake ID 13-0034) is a shallow lake located in southern Chisago County, 0.5 mile north of Center City. The watershed for Pioneer Lake is very small (roughly twice the size of the lake) and is dominated by cropland and woodland. The lake does not meet shallow lake water quality standards for total phosphorus, chlorophyll-a, or Secchi transparency.

Watershed assessment summary:

- The lake water quality violates the phosphorus, chlorophyll-*a*, and Secchi transparency water quality standards. The lake is hypereutrophic, with an average phosphorus concentration of 345 µg/l.
- The lake is very shallow, with a mean depth of five feet and a maximum depth of eight feet.
- Curly-leaf pondweed exists in the lake, although the extent is not known. Curly-leaf pondweed contributes to internal loading from the sediments. A dense mat of Canada waterweed was present in a 2001 survey.
- Black bullheads were the most abundant fish observed in a 2001 fish survey. Black bullhead can lead to high internal loading rates due to their habit of foraging in bottom sediments.
- A large portion of the shoreline is developed.
- Approximately 30% of the watershed is cropland.
- Approximately 20% of the watershed is served by private on-site septic systems, which are estimated to have a 25% failure rate.
- One imminent threat to public health septic system located in the shoreland area was recently upgraded.
- The lake model indicated that there is a large phosphorus load that is unaccounted for in the current phosphorus source inventory. This load is likely due to internal load.

The main phosphorus source to Pioneer Lake is internal load. A phosphorus load reduction of 96% is needed to bring water quality standards for a shallow lake.

To meet the TMDL, taking into account the MOS, total loading to the lake needs to be reduced by 1,771 lb/yr, or 96% (Table 7). Approximately 21 lb/yr should come from the watershed load and approximately 1,750 lb/yr should come from internal load. Watershed load reduction practices will include urban stormwater reduction practices, lakeshore and streambank buffers, and a wide variety of agricultural Best Management Practices (BMPs). In-lake practices may consist of fish and aquatic plant management and management of internal nutrient cycling.

Table 7 - Pioneer Lake Phosphorus Reduction Summary

PHOSPHORUS SOURCE	EXISTING ANNUAL TP LOAD (LB/YR)	IMPLEMENTATION SCENARIO ANNUAL TP LOAD (LB/YR)	LOAD REDUCTION NEEDED (LB/YR)	PERCENT REDUCTION (%)
Watershed	22	0.61	21	95%
Atmospheric Deposition	21	21	0	0%
Internal	1,800	50	1,750	97%
Total	**1,843**	**72**	**1,771**	**96%**

School Lake

School Lake (MN DNR Lake ID 13-0044) is a shallow lake located in southern Chisago County, 0.5 mile north of Chisago City. School Lake has a watershed area that is primarily dominated by agricultural land use and wetlands. The lake does not meet shallow lake water quality standards for total phosphorus, chlorophyll-*a*, or Secchi transparency.

Watershed assessment summary:

- The lake water quality violates the phosphorus, chlorophyll-*a*, and Secchi transparency water quality standards.
- The lake is very shallow, with a mean depth of five feet and a maximum depth of eight feet.
- Curly-leaf pondweed exists in the lake, although the extent is not known. Curly-leaf pondweed contributes to internal loading from the sediments.
- There is an abundance of stunted sunfish and black bullhead. The presence of stunted sunfish often indicates an overabundance of planktivorous fish such as sunfish. This overabundance leads to overgrazing on zooplankton and a resultant increase in algae. Black bullhead can lead to high internal loading rates due to their habit of foraging in bottom sediments.
- Approximately 43% of the watershed is cropland, and there are three small animal operations in the watershed.
- The majority of the watershed is served by private on-site septic systems, which are estimated to have a 25% failure rate.
- Three imminent threat to public health septic systems, one of which was in the shoreland area, were recently upgraded.
- The lake model indicated that there is a large phosphorus load that is unaccounted for in the current phosphorus source inventory. This load is likely a mix of internal load, load from animal operations, and load from failing septic systems.

The main phosphorus sources to School Lake are watershed runoff and internal load. A phosphorus load reduction of 88% is needed to meet water quality standards for a shallow lake.

To meet the TMDL, taking into account the MOS, total loading to the lake needs to be reduced by 1,591 lb/yr, or 88% (Table 8). Approximately 818 lb/yr should come from the watershed load and approximately 773 lb/yr should come from internal load. Watershed load reduction practices will include urban stormwater reduction practices, lakeshore and streambank buffers, and a wide variety of agricultural Best Management Practices (BMPs). In-lake practices may consist of fish and aquatic plant management and management of internal nutrient cycling.

Table 8 - School Lake Phosphorus Reduction Summary

PHOSPHORUS SOURCE	EXISTING ANNUAL TP LOAD (LB/YR)	IMPLEMENTATION SCENARIO ANNUAL TP LOAD (LB/YR)	LOAD REDUCTION NEEDED (LB/YR)	PERCENT REDUCTION (%)
Watershed	918	100	818	89%
Atmospheric Deposition	39	39	0	0%
Internal	850	77	773	91%
Total	**1,807**	**216**	**1,591**	**88%**

Wallmark Lake

Wallmark Lake (MN DNR Lake ID 13-0029) is a shallow lake located in southern Chisago County, one mile north of Chisago City. Agricultural cropland and woodland are the main cover types within the watershed. At one time, Wallmark Lake accepted wastewater from the communities of Chisago City and Lindstrom. This was discontinued in the mid-1980s and routed to an unnamed ditch and eventually to the Chisago Lakes Joint Sewage Treatment Commission facility (MPCA, CLMP+ Report, 2002). The lake does not meet shallow lake water quality standards for total phosphorus, chlorophyll-*a*, or Secchi transparency.

Watershed assessment summary:

- The lake water quality violates the phosphorus, chlorophyll-*a*, and Secchi transparency water quality standards. The lake is hypereutrophic, with an average phosphorus concentration of 322 µg/l.
- Curly-leaf pondweed exists in the lake, although the extent is not known. Curly-leaf pondweed contributes to internal loading from the sediments.
- There is an abundance of stunted sunfish and black bullhead. The presence of stunted sunfish often indicates an overabundance of planktivorous fish such as sunfish. This overabundance leads to overgrazing on zooplankton and a resultant increase in algae. Black bullhead can lead to high internal loading rates due to their habit of foraging in bottom sediments.
- Approximately 33% of the watershed is cropland.
- The majority of the watershed is served by private on-site septic systems, which are estimated to have a 25% failure rate.
- Two imminent threat to public health septic systems located in the shoreland area were recently upgraded.
- Wallmark Lake was the receiving water for the discharge from the Chisago City and Lindstrom wastewater treatment facility from the cities of until the mid-1980s.
- The model indicated that there is a large phosphorus load that is unaccounted for in the phosphorus source inventory. This load is likely a mix of internal load and load from failing septic systems.

The main phosphorus sources to Wallmark Lake are watershed runoff and internal load. A phosphorus load reduction of 95% is needed to meet water quality standards for a shallow lake. To meet the TMDL, taking into account the MOS, total loading to the lake needs to be reduced by 3,997 lb/yr, or 95% (Table 9). Approximately 1,052 lb/yr should come from the watershed load and approximately 2,945 lb/yr should come from internal load. Watershed load reduction practices will include urban stormwater reduction practices, and lakeshore and buffers. In-lake practices may consist of fish and aquatic plant management and management of internal nutrient cycling.

Table 9 - Wallmark Lake Phosphorus Reduction Summary

PHOSPHORUS SOURCE	EXISTING ANNUAL TP LOAD (LB/YR)	IMPLEMENTATION SCENARIO ANNUAL TP LOAD (LB/YR)	LOAD REDUCTION NEEDED (LB/YR)	PERCENT REDUCTION (%)
Watershed	1,098	46	1,052	96%
Atmospheric Deposition	40	40	0	0%
Internal	3,075	130	2,945	96%
Total	**4,213**	**216**	**3,997**	**95%**

1 BACKGROUND

1.1 303(d) Listings

This TMDL addresses nine lake impairments within the Chisago Lakes Chain of Lakes Watershed. These nine lakes are listed on the 2010 EPA's 303(d) list of impaired waters, or are proposed to be listed on the 2012 EPA's 303(d) list of impaired waters due to excess nutrients.

The following applies to all lakes within this watershed:

Impaired Use:	Aquatic Recreation
Pollutant or Stressor:	Nutrient/Eutrophication Biological Indicators
Hydrologic Unit Code:	070300050406

Table 10 – Impaired Waters Listing

LAKE NAME	LAKE ID	YEAR LISTED	TARGET START/COMPLETION	LAKE CLASSIFICATION	CALM CATEGORY
South Center	13-0027	2008	2009/2017	Lake	5B
North Center	13-0032	2008	2009/2017	Shallow Lake	5C
Kroon	13-0013	2008*	N/A	Lake	5B
Wallmark	13-0029	2008	2009/2017	Shallow Lake	5C
Little	13-0033	2010	2015/2020	Lake	5B
Ogren	13-0011	2012**	2012/2013	Lake	5C
Linn	13-0014	2012**	2012/2013	Shallow Lake	5C
Pioneer	13-0034	2012**	2012/2013	Shallow Lake	5C
School	13-0044	2012**	2012/2013	Shallow Lake	5C
Emily	13-0046	2012**	2012/2013	Shallow Lake	5C

* Waters expected to be removed (delisted) in 2014
**Waters are proposed to be listed in 2012

MPCA's projected schedule for TMDL completions (Table 10), as indicated on the 303(d) impaired waters list, implicitly reflects Minnesota's priority ranking of this TMDL. Ranking criteria for scheduling TMDL projects include, but are not limited to, impairment impacts on public health and aquatic life; public value of the impaired water resource; likelihood of completing the TMDL in an expedient manner, including a strong base of existing data and restorability of the waterbody; technical capability and willingness locally to assist with the TMDL; and appropriate sequencing of TMDLs within a watershed or basin.

Kroon Lake Delisting

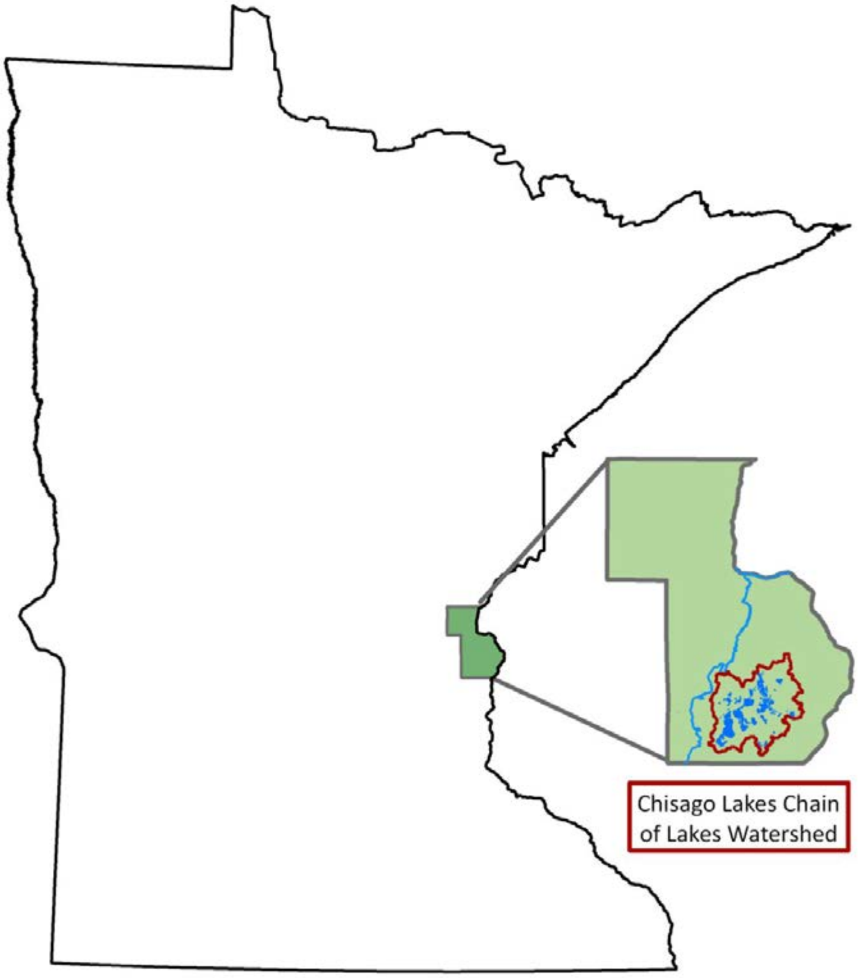
In 2008, Kroon Lake was placed on the State's 303(d) impaired waters list since it was not meeting the state water quality standards. Since then, more data has been collected; and in 2012 the MPCA reassessed the data and determined that Kroon Lake is currently meeting water quality standards (see Table 83 in Appendix A). Based on this information the MPCA is expected to delist Kroon Lake on the 2014 303(d) impaired waters list when it is prepared. Since the information regarding delisting came out after this project was underway, the information collected and work that has been done will be used to develop a plan to keep off the 303(d) list.

A Protection Plan will be developed and included in the Restoration and Protection Plan for the Chisago Chain of Lakes TMDL that will be developed and submitted to the MPCA for approval within one year of TMDL approval. The Protection Plan will use the modeling data and other information collected to target and prioritize activities in the Kroon Lake watershed. Appendix A of this report briefly discusses Kroon Lake, as well as other unimpaired or unassessed lakes in the Chisago Chain of Lakes, and lays the groundwork for the Protection section of that plan.

1.2 Lake and Watershed Descriptions

The Chisago Lakes Chain of Lakes Watershed is made up of 15 lakes over 100 acres, and many streams within Chisago County. The area includes four incorporated cities (Chisago City, Lindstrom, Center City, and Wyoming) and covers portions of four townships (Lent, North Chisago Lake, South Chisago Lake, and Franconia). This region of Chisago County is highly populated and has been experiencing rapid growth.

The watershed is a high priority subwatershed of the Sunrise River. Chisago County, the United States Army Corps of Engineers (US ACOE), the Minnesota Pollution Control Agency (MPCA), and several additional cooperators have begun a study of the Sunrise River Watershed. The goal of the study is to develop a watershed based plan and strategies for water quality and aquatic ecosystem management, restoration, and protection. A Total Maximum Daily Load (TMDL) Study of Impaired Waters within the Sunrise River Watershed is also underway.



The waters within the Chisago Lakes Chain of Lakes Watershed boundary outlet to the Sunrise River which eventually enters the St. Croix River near the town of Sunrise in Wild River State Park. This project will not only address the impairments within the Chisago Lakes Chain of Lakes Watershed and the Sunrise River Watershed, but will also aid understanding the phosphorus loading to Lake St. Croix from the project area. Lake St. Croix was listed on the 2008 303(d) impaired waters list for “Nutrient/Eutrophication Biological Indicators,” which impairs the aquatic recreation designated use of the lake.

Population

The following data are from 2010 U.S. Census Data (http://www.census.gov).

Chisago City, MN 55013
Population: 4,967
Lindstrom, MN 55045
Population: 4,442
Center City, MN 55012
Population: 628

Related Plans and Studies

Numerous studies have been completed within the Chisago Lakes Chain of Lakes Watershed by the Chisago Lakes Lake Improvement District (CLLID). These plans include: water quantity, water levels, water quality, aquatic macrophytes, etc. These plans have been done over the years since 1976 when the CLLID was formed.

Topography and Land Use

The landscape across the entire watershed consists of rolling hills. The landscape increases in elevation from west to east. The lakeshore consists of steep slopes on many of the lakes within the watershed.

There are three general land use categories throughout the watershed. The three areas are: the East and North East portion of the District, which is mainly agricultural/rural; the Central portion, which is mostly developed; and the North West portion, which is mainly wildlife land.

Agriculture/Rural (East/North East): This area mainly consists of corn and soybean rotations and alfalfa crops. Many of the landowners own livestock, such as horses, dairy and beef cattle, bison, and red deer. Eight producers have registered animal operations with the Minnesota Pollution Control Agency (Figure 12). A windshield survey of the watershed was completed to locate potential feedlot concerns (Table 13 - Animal Operations). A high concentration of animal operations and other agricultural practices were located in the Little Lake sub-watershed.

Another potential concentration of pollutants in the rural area could be failing on-site septic systems (Figure 11). The water from this area of the watershed eventually drains to North Center Lake.

Developed (Central): Included in this area are the cities of Chisago City, Lindstrom, and Center City. These cover most of the populated and developed area. The largest issue facing water quality degradation in this area is the amount of storm water that reaches the lakes (Figure 13).

Wildlife (North West): This area is heavily forested and includes many wetlands. The North West area is adjacent to the Carlos Avery Wildlife Area. The outlet of the CLLID lakes and the outlet of the CLLID watershed to the Sunrise River are in this region. This area has very little agriculture, and is dominated by wetlands according to the National Wetlands Inventory (Figure 10). Many types of forest cover are also very common in this region (Figure 8).

More information on watershed wide topics is available in Section 3: Watershed Characteristics.

1.3 Water Quality Standards

Designated Uses

All listed lakes are classified as 2B or 3C waters. These lakes are protected for Aquatic Recreation by Minnesota Rules Chapter 7050.0140. The Water Use Classification for Waters of the State reads:

> Subp. 3. Class 2 waters, aquatic life and recreation. Aquatic life and recreation includes all waters of the state that support or may support fish, other aquatic life, bathing, boating, or other recreational purposes and for which quality control is or may be necessary to protect aquatic or terrestrial life or their habitats or the public health, safety, or welfare.

Pollutant of Concern

Phosphorus

Total phosphorus (TP) is often the limiting factor controlling primary production in freshwater lakes. It is the nutrient of focus for this TMDL, and is referred to as the causal factor. As phosphorus concentrations increase, primary production also increases, as measured by higher chlorophyll-*a* concentrations. Higher concentrations of chlorophyll-*a* lead to lower water transparency. Both chlorophyll-*a* and Secchi transparency are referred to as response factors, since they indicate the ecological response of a lake to excessive phosphorus input.

Role of Phosphorus in Shallow Lakes

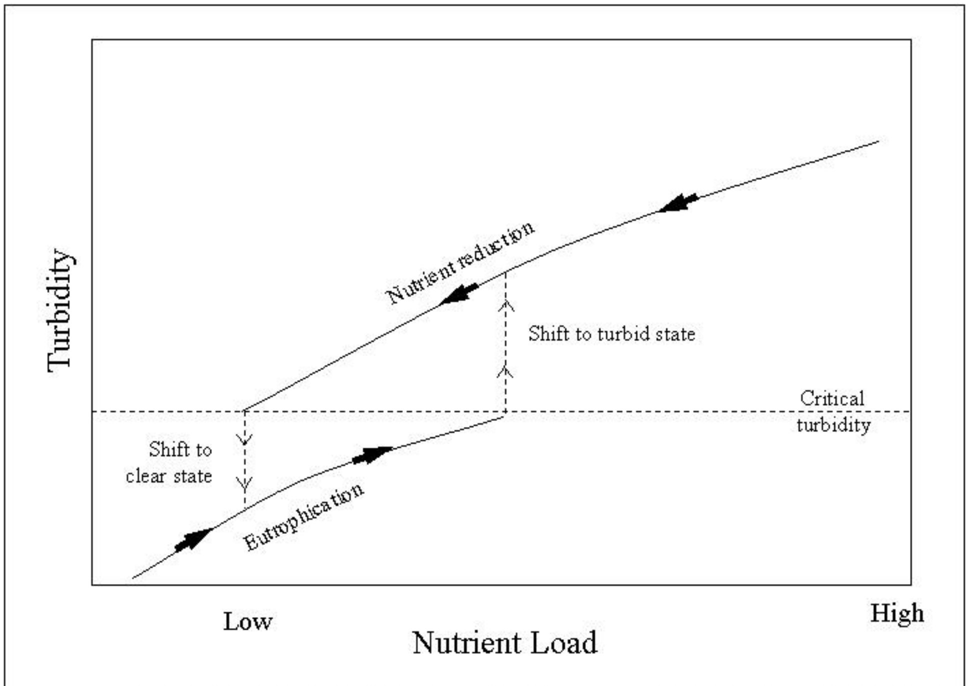
Six of the nine lakes in this study are classified by the MPCA as shallow lakes. The MPCA defines a lake as shallow if its maximum depth is less than 15 ft, or if the littoral zone covers at least 80% of the lake’s surface area.

The relationship between phosphorus concentration and the response factors (chlorophyll-*a* and transparency) is often different in shallow lakes as compared to deeper lakes. In deeper lakes, primary productivity is often controlled by physical and chemical factors such as light availability, temperature, and nutrient concentrations. The biological components of the lake (such as microbes, algae, macrophytes, zooplankton and other invertebrates, and fish) are distributed throughout the lake, along the shoreline, and on the bottom sediments. In shallow lakes, the biological components are more concentrated into less volume and exert a stronger influence on the ecological interactions within the lake. There is a more dense biological community at the bottom of shallow lakes than in deeper lakes because of the fact that oxygen is replenished in the bottom waters and light can often penetrate to the bottom. These biological components can control the relationship between phosphorus and the response factors.

The result of this impact of biological components on the ecological interactions is that shallow lakes normally exhibit one of two ecologically alternative stable states (Figure 1): the turbid, phytoplankton-dominated state, and the clear, macrophyte (plant)-dominated state. The clear state is the most preferred, since phytoplankton communities (composed mostly of algae) are held in check by diverse and healthy zooplankton and fish communities. Fewer nutrients are released from the sediments in this state. The roots of the macrophytes stabilize the sediments, lessening the amount of sediment stirred up by the wind.

Nutrient reduction in a shallow lake does not lead to a linear improvement in water quality (indicated by turbidity in Figure 1). As external nutrient loads are decreased in a lake in the turbid state, slight improvements in water quality may at first occur. At some point, a further decrease in nutrient loads will cause the lake to abruptly shift from the turbid state to the clear state. The general pattern in Figure 1 is often referred to as "hysteresis," meaning that when forces are applied to a system, it does not return completely to its original state nor does it follow the same trajectory on the way back.

Figure 1 – Alternative Stable States in Shallow Lakes



Adapted from M. Scheffer. 2001. Alternative Attractors of Shallow Lakes. *The Scientific World* 1:254-263.

The biological response of the lake to phosphorus inputs will depend on the state that the lake is in. For example, if the lake is in the clear state, the macrophytes may be able to assimilate the phosphorus instead of algae performing that role. However, if enough stressors are present in the lake, increased phosphorus inputs may lead to a shift to the turbid state with an increase in algal density and decreased transparency. The two main categories of stressors that can shift the lake to the turbid state are:

- Disturbance to the macrophyte community, for example from wind, benthivorous (bottom feeding) fish, boat motors, water skiing, or light availability (influenced by algal density or water depth)
- A decrease in zooplankton grazer density, which allows unchecked growth of sestonic (suspended) algae. These changes in zooplankton density could be caused by an increase

in predation, either directly by an increase in planktivorous fish that feed on zooplankton, or indirectly through a decrease in piscivorous fish that feed on the planktivorous fish.

This complexity in the relationships among the biological communities in shallow lakes leads to less certainty in predicting the in-lake water quality of a shallow lake based on the phosphorus load to the lake. The relationships between external phosphorus load and in-lake phosphorus concentration, chlorophyll-a concentration and transparency are less predictable than in deeper lakes, and therefore lake response models are less accurate.

Another implication of the alternative stable states in shallow lakes is that different management approaches are used for shallow lake restoration than those used for restoration of deeper lakes.

Shallow lake restoration often focuses on restoring the macrophyte, zooplankton, and fish communities to the lake.

Water Quality Standards

Water quality standards are established to protect the designated uses of the state's waters. Minnesota's Rule 7050 includes eutrophication standards for lakes (Table 11). Eutrophication standards were developed for lakes and reservoirs and for shallow lakes in particular. Standards provide for higher phosphorus concentrations, higher chlorophyll-a concentrations, and poorer transparency in shallow lakes, due to higher rates of internal loading in shallow lakes and different ecological characteristics.

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 transparency. Based on these relationships it is expected that by meeting the phosphorus target in each lake, the chlorophyll-*a* and Secchi standards will likewise be met.

Standards are applied based on the ecoregion in which the lake is located; all of the lakes in this study are within the North Central Hardwood Forest ecoregion.

Table 11 – MN Eutrophication Standards

PARAMETER	NORTH CENTRAL HARDWOOD FOREST ECOREGION	
	EUTROPHICATION STANDARD LAKES AND RESERVOIRS	EUTROPHICATION STANDARD SHALLOW LAKES
Total Phosphorus (µg/l)	TP <40	TP <60
Chlorophyll-a (µg/l)	CHL-A <14	CHL-A <20
Secchi Transparency (m)	SD >1.4	SD >1.0
Standard applies to:	South Center, Little, Ogren	North Center, Emily, Linn, Pioneer, School, Wallmark

According to the MPCA definition of shallow lakes, a lake is considered shallow if its maximum depth is less than 15 ft, or if the littoral zone (area where depth is less than 15 feet) covers at least 80% of the lake's surface area. North Center, Emily, Wallmark, Linn, Pioneer, and School Lakes are shallow according to this definition.

To be listed as impaired, the monitoring data must show that the standards for both total phosphorus (the causal factor) and either chlorophyll-*a* or Secchi transparency (the response factors) were violated. If a lake is impaired with respect to only one of these criteria, it may be placed on a review list; a weight of evidence approach is then used to determine if it will be listed as impaired. For more details regarding the listing process, see the Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment (MPCA 2009).

2 METHODS

2.1 Lake Assessments

Water quality

Ten-year growing season (June through September) means were calculated from the most recent ten-year (2001-2010) time period for total phosphorus, chlorophyll-*a*, and Secchi transparency. Data were obtained from the MPCA Environmental Data Access database in June of 2011. The 10-year means were used to evaluate compliance with water quality standards and to calibrate the Bathtub model (see Section 2.3). If water quality data were available from before 2001, the data were included in graphs for illustration but were not used to calculate the 10-year growing season means. For each lake, an example graph of seasonal trends is shown in the report and was picked as the most recent year containing data from the entire growing season (June through September) for total phosphorus, chlorophyll-*a*, and Secchi transparency.

Aquatic macrophytes

Aquatic plant surveys from the MN DNR were referenced to determine species of plants present and their relative abundance in all lakes. These surveys date back to the 1960s and are completed as time permits on the small lakes and every few years on the large lakes. The CLLID also had aquatic plant surveys completed by Steve McComas, Blue Water Science. These surveys were used as secondary reference to the MN DNR surveys.

Fish

Information on the fish species within these lakes was compiled from many sources. The most comprehensive data was found on the MN DNR LakeFinder website. LakeFinder was most inclusive for the large lakes (North Center, South Center, Little). Information from MN DNR fisheries staff and information from volunteer lake monitors and citizens filled in many of the other data gaps.

Plankton

The only known plankton data has been collected through the Sustaining Lakes in a Changing Environment (SLICE) program that is a partnership between the Minnesota Pollution Control Agency and the Minnesota Department of Natural Resources. South Center Lake was chosen as a Sentinel Lake as part of this program. Zooplankton samples were collected monthly from ice-out (April/May) through October 2010 using the rapid assessment technique. Details on sample collection can be found at http://www.pca.state.mn.us.publications/wq-s1-16.pdf or in the Sentinel Lake Assessment Report, MN DNR, 2011.

2.2 Phosphorus Source Assessment

A phosphorus source assessment was conducted for each of the lakes included in this study. Sources of phosphorus can be either external or internal. Examples of external sources include watershed runoff, point sources, and atmospheric deposition. Internal sources of phosphorus can be released from sediments due to anoxic conditions or due to suspension caused by wind mixing or benthic fish, or from biological processes in the lake such as senescence of curly-leaf pondweed.

This section provides a description of the potential sources of phosphorus to each of the lakes in the TMDL study area and the methods used to estimate existing phosphorus loads. Reported phosphorus loads are rounded to two significant digits.

Sources of Phosphorus Requiring NPDES Permit Coverage

The regulated sources of phosphorus within the study area are point sources, those originating from a single, identifiable source in the watershed. Point sources are regulated through the National Pollutant Discharge Elimination System (NPDES) and State Disposal System (SDS) permits. Point sources include the following:

- Regulated stormwater
- Municipal and industrial wastewater treatment systems
- Feedlots requiring NPDES permit coverage

Regulated Stormwater

Watershed runoff is generated during precipitation and snowmelt events. Certain types of watershed runoff are permitted under the NPDES/ SDS program including regulated Municipal Separate Storm Sewer Systems (MS4), construction stormwater, and industrial stormwater. While there is some regulated watershed runoff in the watersheds, the majority of watershed runoff in the project area is not regulated through NPDES permits.

Phosphorus loads from watershed runoff were estimated using the existing Sunrise River SWAT model; this approach is described in *Section 2.2: Sources of Phosphorus Not Requiring NPDES Permit Coverage, Watershed Runoff*.

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

MS4

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. Certain MS4 discharges are regulated by NPDES/SDS permits administered by the MPCA.

MS4s outside of urbanized areas with a population of at least 5,000 and discharging or having the potential to discharge to impaired waters are required to obtain an NPDES stormwater permit. The MPCA designates communities as regulated MS4s as populations hit the threshold of 5,000 and updated information becomes available from the U.S. Census Bureau. If MS4 communities come under permit coverage in the future, a portion of the Load Allocation (LA) will be shifted to the Wasteload Allocation (WLA) (Section 2.3).

Transportation-related MS4s (state and county) require coverage under NPDES MS4 permits when the facility is within the U.S. Census Bureau Urban Area. This area does not currently extend into any of the lake TMDL watersheds, and WLAs are not provided for transportation MS4s. If transportation MS4s come under permit coverage in the future, a portion of the LA will be shifted to the WLA.

Based on the information listed in this section, and a review of the study area; there are currently no municipalities or transportation related MS4s that fall within this TMDL study area.

Construction

Construction sites can contribute substantial amounts of sediment and phosphorus to watershed runoff. The NPDES/SDS Construction Stormwater Permit administered by the MPCA requires that all construction activity disturbing areas equal to 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 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 phosphorus sources.

The GIS coverage from the MPCA's permitted sources database suggests that several Chisago County Highway Department sites that are covered under the Nonmetallic Mining & Associated Activities General NPDES/SDS (MNG490000) permit might be located in the project watershed. Further investigation of MPCA data determined that none of the permitted locations are in the watershed.

Based on a desktop review of MPCA data there are no facilities with an industrial stormwater permit or nonmetallic mining and associated activities permit in any of the lakes' watersheds.

Municipal and Industrial Wastewater Treatment Systems

For any discharge of municipal or industrial wastewater to a surface water, ground-surface, or subsurface, an NPDES/SDS permit is required and administered by the MPCA. Based on a desktop review of MPCA data there are no NPDES permitted wastewater facilities within the TMDL lakes' watersheds.

Feedlots Requiring NPDES Permit Coverage

Animal waste containing phosphorus can be transported in watershed runoff to surface waters. The primary goal of the state feedlot program is to ensure that surface waters are not contaminated by the runoff from animal operations, manure storage or stockpiles, and cropland with improperly applied manure. Feedlots that either (a) have a capacity of 1,000 animal units or more, or (b) meet or exceed the EPA's Concentrated Animal Feeding Operation (CAFO) threshold, are required to apply for coverage under an NPDES/SDS permit for livestock production from the MPCA. Based on a desktop review of MPCA data there are no feedlots under NPDES permit coverage within the study area.

Sources of Phosphorus Not Requiring NPDES Permit Coverage

The following are the sources of phosphorus not requiring NPDES permit coverage that were evaluated:

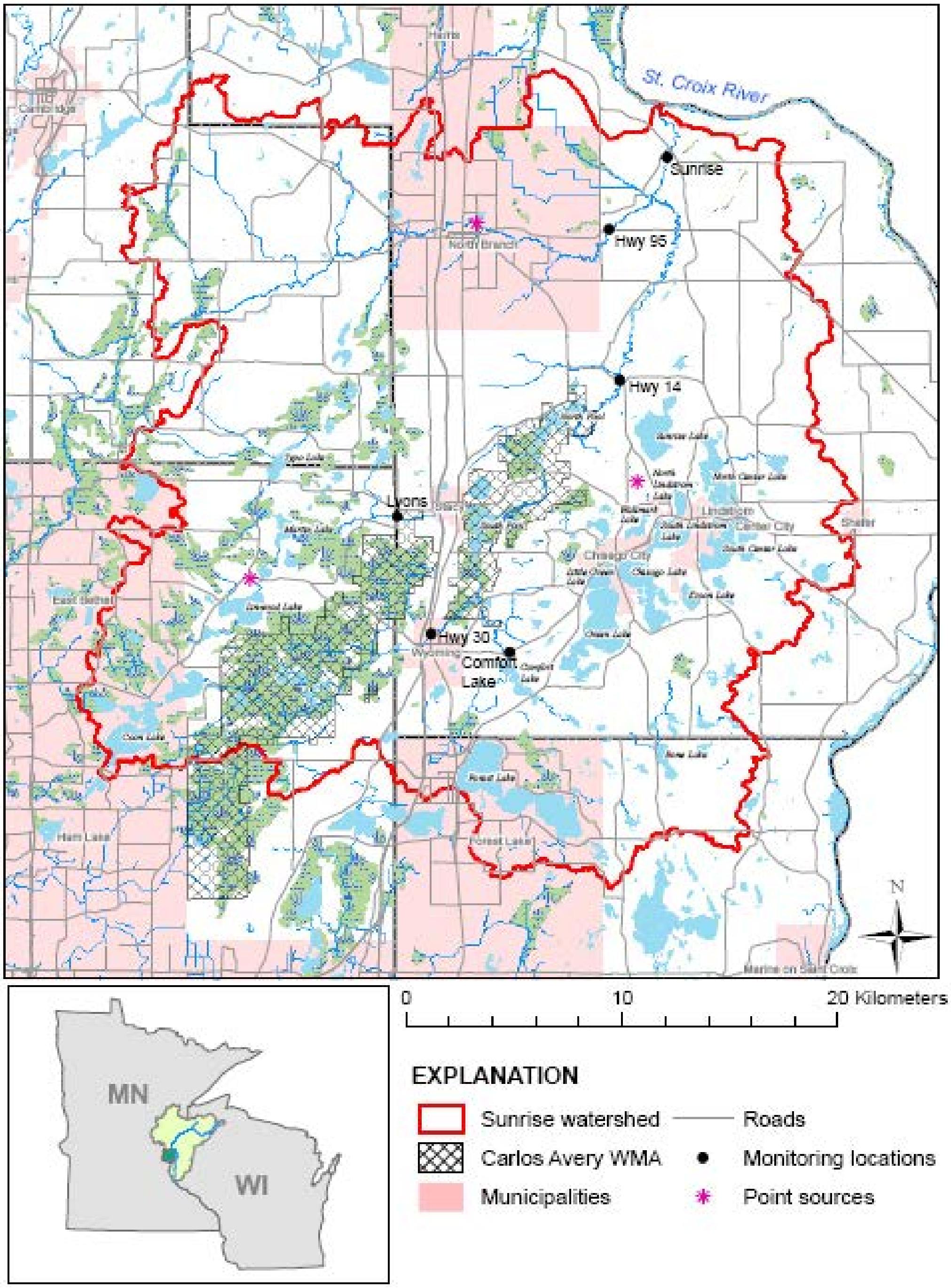
- Watershed runoff
- Loading from upstream waters
- Runoff from feedlots not requiring NPDES permit coverage
- Atmospheric deposition
- Septic systems
- Groundwater
- Internal loading

Watershed Runoff

The Sunrise River Soil and Water Assessment Tool (SWAT) Model was constructed in 2010 by Almendinger and Ulrich with funding provided by the National Park Service and the MPCA (Almendinger and Ulrich 2010b). Results from this model were used for determination of average annual watershed runoff and phosphorus load from subwatersheds of impaired lakes except in cases where upstream lakes had water quality monitoring data (see *Loading from Upstream Waters* for a description of the use of in-lake data from upstream lakes). Sunrise River SWAT model results represent the average annual water and phosphorus loading for the 20-year period from 1990 through 2009. SWAT model results include water and phosphorus loads derived from both watershed runoff and shallow groundwater. These two constituents were not disaggregated in water and phosphorus loading estimates to impaired lakes (see *Groundwater* for further discussion).

SWAT was developed by the United States Department of Agriculture (USDA) Agricultural Research Service to predict water, sediment, and agricultural chemical yields in large watersheds based on soils, land use, and management conditions over long periods. SWAT is a continuous simulation model that simulates hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management (Neitsch et al. 2002 as referenced in Borah et al. 2006). Simulations are performed on a daily time step (typically) on hydrologic response units (HRUs), which are unique combinations of soils and land uses throughout the modeled watershed. Results are summarized by subwatersheds as defined by the user. Simulated variables (e.g. water and phosphorus) are routed through the stream network to the overall watershed outlet. SWAT is a physically-based, parameter-intensive model. SWAT simulates the physical processes related to water and sediment movement, crop growth, and nutrient cycling using model inputs associated with weather, soils, topography, vegetation, and land management practices.

Figure 2 – Sunrise River Watershed SWAT Model Study Area

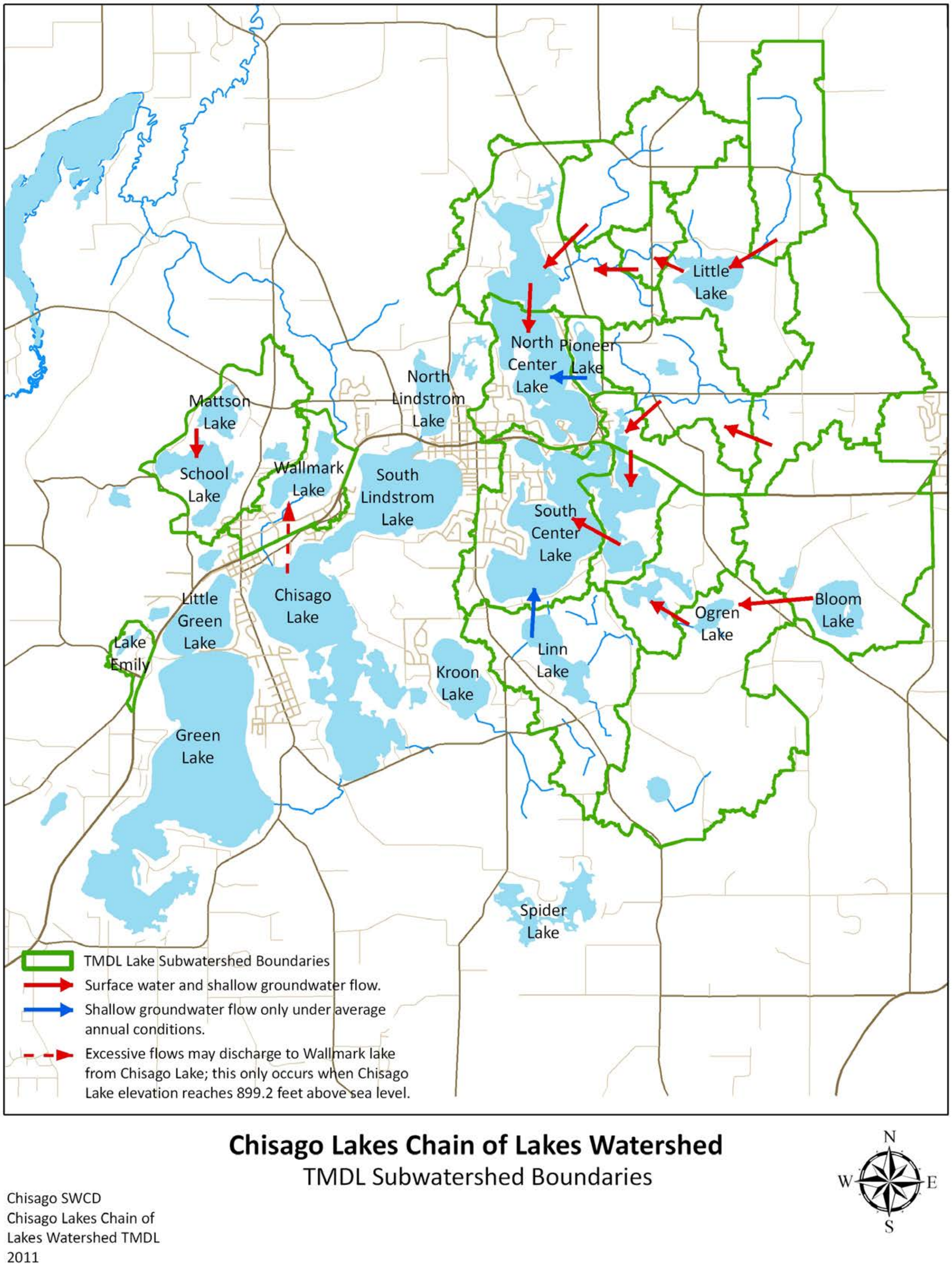


Source: Almendinger and Ulrich (2010a)

The Sunrise River SWAT model watershed study area (Figure 2) was divided into 142 subwatersheds based on topographic and hydrographic data. Land cover data were taken from the 2007 USDA Crop Data Layer. Soils data were generated based on available USDA Soil Survey Geographic data. Land cover, soils, and slopes were spatially intersected to create HRUs within each subwatershed. A total of 1,642 HRUs were created, about 11 to 12 per subbasin on average. In addition, topographic data were analyzed to identify depressional storage on the landscape, which was entered into SWAT in order to account for the impact of such depressions both on the hydraulics of rainfall-runoff response and on transport of nonpoint-source pollutant loads. The Sunrise River SWAT model was calibrated to crop yield, flow, sediment, and phosphorus data. For a full description of model construction of the Sunrise River SWAT Model refer to *Constructing a SWAT model of the Sunrise River watershed, eastern Minnesota* (Almendinger and Ulrich 2010a).

Subwatersheds of the Sunrise River SWAT model were delineated based on a USGS 10-meter digital elevation model from the USGS and a high-density flow network from the MN DNR. The CLLID underwent delineation of subwatersheds based on Chisago County Light Detection and Ranging (LiDAR) data obtained in 2008 or 2009 with vertical precision of plus or minus 6 inches and infrastructure data such as pipes, channels, and weirs (HDR 2008). The TMDL study used the CLLID subwatersheds for most of the impaired lakes because the CLLID subwatersheds used more detailed data for delineation and had separate drainage areas to a greater number of the impaired lakes (Figure 3). Subwatersheds for School and Wallmark Lakes were not delineated by the CLLID and were determined using a combination of the Sunrise River SWAT model subwatersheds and the MN DNR Level 8 (catchment) watersheds. Annual water and phosphorus loading from the subwatersheds of impaired lakes were derived based on aerial loading rates from the respective Sunrise River SWAT model subwatersheds, which were applied to the TMDL subwatersheds. SWAT model results for phosphorus loads in the year 2030 are also presented in the phosphorus source assessment. Projected loads are based on population growth estimates and resulting development.

Figure 3 – TMDL Lake Watershed Boundaries and Flow Direction



Loading from Upstream Waters

Lakes and streams upstream of impaired waters were evaluated in each watershed to determine if there were sufficient data to determine a TP load from that source. Annual average TP loads were calculated for the watersheds of upstream lakes, which were determined from in-lake phosphorus concentration data, and flow (watershed runoff + shallow groundwater) was derived from the Sunrise River SWAT model (see *Watershed Runoff*). The phosphorus load estimated using results from the Sunrise River SWAT model (described in *Watershed Runoff*) excluded the upstream lake and that lake's watershed area. Table 12 summarizes the upstream lake loading calculations.

Table 12 – Summary of Phosphorus Loading from Upstream Waters

Receiving Water	Upstream Lake	Averaging Period	In-Lake TP (µg/L)	Flow Volume[1] (AF/yr)	Drainage Area (acres)[2]	Equivalent Depth of Flow (in/yr)	Phosphorus Load (lb/yr)
North Center	Little	2007-2008	161	1,307	2,178	7.2	570
	Pioneer[3]	2009	311	125	168	8.9	53
	South Center	2002-2009	46	6,968	11,000	7.6	870
School	Mattson	2008-2009	23	301	602	6.0	19
South Center	Ogren	2009-2010	61	2,490	4,150	7.2	410
	Linn[3]	2008-2009	214	983	1,326	8.9	290
Wallmark	Chisago[4]	2002-2010	37	0	N/A	N/A	N/A

[1] Watershed runoff plus shallow groundwater flow.

[2] Calculations are from lake outlet; includes lake area and drainage area.

[3] Pioneer and Linn Lakes are land-locked on an average annual basis. However, because the lakes are connected through shallow groundwater movement they both contribute dissolved phosphorus to downstream waters. It was assumed that the modeled volume (from SWAT) of discharge from Pioneer and Linn Lakes was shallow groundwater only. Dissolved phosphorus concentration in shallow groundwater was estimated to be half of total phosphorus concentration in the lake. The actual ratio of groundwater to surface water discharge from the other four upstream lakes (Little, South Center, Mattson, and Ogren) was uncertain; therefore, no adjustments were made to estimated loadings from those lakes.

[4] Wallmark Lake receives water from Chisago Lake when the elevation is above 899.2'. This has only occurred a few times since the weirs were installed in 1986. Currently the water in Chisago Lake is six feet below this point. The water quality of Chisago Lake far exceeds the quality of Wallmark Lake.

Feedlots (Animal Operations)

Runoff during precipitation and snow melt can carry phosphorus from uncovered feedlots to nearby surface waters. For the purpose of this study, non-permitted feedlots are defined as being all registered feedlots without an NPDES/SDS permit that house under 1,000 animal units. While these feedlots do not fall under NPDES regulation, other regulations still apply.

Table 13 - Animal Operations

Number of Animal Operations	Number of Animals	Average Animals per Operation
48 operations	1,076 animals	22.4 animals
Total Animals = 440 Beef, 200 Buffalo, 225 Dairy, 161 Horse, 50 Red Deer		

Phosphorus loading from feedlots was accounted for within the SWAT model. County-wide feedlot numbers for Chisago County were obtained from the National Agricultural Statistics Service (NASS) and adjusted with advice from Chisago SWCD personnel. Livestock numbers were converted to manure quantities and the model simulated the location, timing, and spreading rate (mass per area) of manure applications on the landscape. Refer to Almendinger and Ulrich (2010a) for additional information.

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 were calculated for the St. Croix River Basin (MPCA 2004). The report determined that atmospheric deposition equaled 0.27 lb/ac of TP per year. 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.

Septic Systems

Phosphorus loads attributed to septic systems were accounted for within the SWAT model by assigning a phosphorus concentration of 0.3-120µg/l to shallow groundwater to calibrate the SWAT watershed phosphorus loads (Almendinger and Ulrich 2010a). The groundwater P concentrations used to calibrate the SWAT model were similar to groundwater phosphorus concentrations typically found below agricultural and urban settings (10-20 µg/l; Nolan and Stoner 2000).

Groundwater

The dominant shallow groundwater flow direction in the Chisago Lakes area is north-northwest toward the Sunrise River, as reported in the Chisago Lakes Lake Improvement District groundwater study (CLLID 2008). SWAT model results include water and phosphorus loads derived from both watershed runoff and shallow groundwater. Therefore, phosphorus contributions from shallow groundwater are accounted for in this TMDL study.

Contributions from watershed runoff and shallow groundwater were not disaggregated in water and phosphorus loading estimates to impaired lakes. Due to the scale of the original Sunrise River SWAT model and the significantly smaller scale of the subwatersheds to the impaired lakes in this TMDL study, there is enough uncertainty in extracting the groundwater contribution from the SWAT model to warrant leaving groundwater and surface water contributions coupled for this study.

The CLLID groundwater study measured lake levels throughout the winter ice cover to determine the extent of lake drawdown and, therefore, the extent of groundwater loss (CLLID 2008). North Center, South Center, Little, School, and Wallmark Lakes were included in the study (among other lakes). Little, School, and Wallmark Lakes were found to have steady lake levels and, therefore, approximately equal groundwater inflow and outflow (i.e. flow-through lakes). Data showed that North Center and South Center Lakes lost approximately 20% and 10%, respectively, of their lake volume to groundwater during the winter ice cover. In-lake models do not explicitly model groundwater outflow (see *System Representation in Model* in Section 2.3), but account for long-term average conditions with a one-year averaging period. Under these conditions North Center and South Center Lakes do not lose volume; watershed runoff during spring thaw and the growing season offset the effects of groundwater loss on lake volume.

Internal Loading

Internal loading in lakes refers to the phosphorus load that originates in the bottom sediments and is released back into the water column. The phosphorus in the sediments was originally deposited in the lake sediments through the settling of particulates (attached to sediment that entered the lake from watershed runoff, or as phosphorus incorporated into biomass) out of the water column. Internal loading can occur through various mechanisms:

- Anoxic (lack of oxygen) conditions in the overlying waters. Water at the sediment-water interface may remain anoxic for a portion of the growing season, and low oxygen concentrations result in phosphorus release from the sediments. If a lake's hypolimnion (bottom area) remains anoxic for a portion of the growing season, the phosphorus released due to anoxia will be mixed throughout the water column when the lake loses its stratification at the time of fall mixing. Alternatively, in shallow lakes, the periods of anoxia can last for short periods of time; wind mixing can then destabilize the temporary stratification, thus releasing the phosphorus into the water column.
- Physical disturbance by bottom-feeding fish such as carp and bullhead. This is exacerbated in shallow lakes since bottom-feeding fish inhabit a greater portion of the lake bottom than in deeper lakes.
- Physical disturbance due to wind mixing. This is more common in shallow lakes than in deeper lakes. In shallower depths, wind energy can vertically mix the lake at numerous instances throughout the growing season.
- Physical disturbance by boats.
- Phosphorus release from decaying curly-leaf pondweed (*Potamogeton crispus*). This is more common in shallow lakes since shallow lakes are more likely to have nuisance levels of curly-leaf pondweed.

Internal loading due to the anoxic release from the sediments of each lake was estimated in this study. Internal loading due to physical disturbance and decaying curly-leaf pondweed is difficult to estimate reliably and was therefore not included in the lake phosphorus analyses. In lakes where internal loading due to these sources is believed to be substantial, the internal load estimates derived from lake sediment data presented here are likely an underestimate of the actual internal load.

The internal phosphorus loading to the lake was estimated based on the expected release rate (RR) of phosphorus from the lakebed sediment, the lake anoxic factor (AF), and the lake area. Lake sediment samples were taken and tested for concentration of total phosphorus (TP) and bicarbonate dithionite extractable phosphorus (BD-P), which analyzes iron-bound phosphorus. Phosphorus release rates were calculated using two different equations relating the sediment concentrations to release rate. Given the potential error and uncertainty in the estimates, multiple equations were used in order to increase confidence and arrive at a reasonable range of internal loading values.

Both equations are statistical regression equations developed using measured release rate and sediment concentration data from different sets of lakes (Nürnberg 1988; Nürnberg 1996). The approach assumes that if a regression equation adequately characterizes the relationship between release rate and sediment phosphorus concentration data in the study set of lakes, then it is reasonable to apply the same equation to other lakes for which the sediment phosphorus concentration is known.

In general, this is appropriate if the lakes under consideration are similar in nature to the lakes in the studies from which the equations were developed, and if the sediment phosphorus concentrations are within the range of the observed values. In this particular study, the lower sediment phosphorus concentrations from the TMDL lakes were within range of that of the study sets. The TMDL lakes data exhibit a couple of values that are well above the range of concentrations of the study sets, but they are still applicable to some extent. Given that the study set data and equations are the best available, these equations were used to arrive at the estimated range for internal phosphorus loading for all of the TMDL study lakes.

These internal loading estimates were not used as direct inputs to the Bathtub lake models, since the Bathtub model includes an implicit amount of internal loading (see *Internal vs. External Load* in Section 2.3). However, for each lake, an estimate of internal loading was added to the lake phosphorus budget, independent of the Bathtub model. The internal load estimate for each lake was derived from one of two methods: 1) the range of the low and the high estimates calculated from the sediment phosphorus content, as described above, or 2) the internal load estimate derived through calibration of the lake models (also described in *Internal vs. External Load* in Section 2.3). The highest of these estimates was used in the phosphorus budget of lakes that exhibit symptoms of excessive internal loading (hypereutrophication). The lowest of these estimates was used in the phosphorus budget of lakes that did not exhibit symptoms of excessive internal loading (North Center, South Center, and Ogren). Internal loading is expected to be excessive in the hypereutrophic shallow lakes in this project; therefore the higher estimate is assumed to be more realistic than the lower.

2.3 TMDL Derivation

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 assessment (Section 2.2). The loading capacity (TMDL) of each lake was then estimated using an in-lake phosphorus response model and was divided among Wasteload Allocations (WLAs) and Load Allocations (LAs).

- Loading capacity (=TMDL): the total amount of pollutant that the water body can assimilate and still maintain water quality standards.
- Wasteload Allocations (WLAs): the pollutant load that is allocated to point sources covered under NPDES permits, including regulated municipal stormwater, regulated construction stormwater, and regulated industrial stormwater.
- Load Allocations (LA): the pollutant load that is allocated to sources not requiring NPDES permit coverage, including non-regulated watershed runoff, atmospheric deposition, and internal loading.

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; and outputs through the lake outlet, water loss via evaporation, and phosphorus sedimentation and retention in the lake sediments.

Long-term averages were used as input data to the models, due to the lack of detailed annual loading and water balance data for each of the lakes. The outputs from the phosphorus source assessment (Section 2.2) were used as inputs to the Bathtub lake models. The models were calibrated to existing water quality data (2001-2010), and then were used to determine the phosphorus reductions needed to meet each lake's phosphorus standard. Since the Bathtub model does not explicitly account for internal loading, the independent internal load estimate was added to the phosphorus budget after the Bathtub model was completed. The phosphorus reduction needed to meet the phosphorus standard, calculated from the Bathtub model, was subtracted from the total existing phosphorus load to determine each lake's loading capacity. The loading capacity of each lake is the TMDL; the TMDL is then split into Wasteload Allocations (WLAs), Load Allocations (LAs), and a margin of safety (MOS).

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 then converted to daily loads by dividing the annual loads by 365.

Appendix A: Supporting Data for Bathtub Models contains for all lakes Bathtub modeling case data (inputs), diagnostics (results), and segment balances (water and phosphorus budgets) for both the calibrated (benchmark/existing) models and the TMDL scenarios.

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, the direct drainage area for each lake (i.e., segment) and loading from upstream water bodies were lumped as a single tributary input. Three lakes have loading from upstream lakes (North Center, School, and South Center Lakes).

Internal Load

Under normal use, internal loading is not represented explicitly in Bathtub. 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. Including an additional load is generally not recommended, but the provision is made if circumstances warrant. In the lake models, adjustments to internal loading were used for model calibration for all lakes except Ogren (see *Model Calibration* for more detail). The internal loading estimates calculated from the lake sediment data were not directly entered into the model, but were used as an independent estimate of internal loading and, for some lakes, to represent internal loading in the overall lake phosphorus budget. See discussion titled *Internal Loading* under Section 2.2 *Phosphorus Source Assessment* for more details regarding the independent estimate of internal loading.

Groundwater

Bathtub does not explicitly model groundwater loss; all volumetric losses are via surface outflow at the same total phosphorus concentration as the water column. Lake volumes reflect long-term average conditions with a one-year averaging period during which watershed runoff typically offsets the effects of groundwater loss on lake volume. Therefore, lake volumes of the TMDL study lakes would remain unchanged whether or not groundwater was explicitly modeled. However, the nutrient balance is affected, to some extent, by groundwater loss; only dissolved phosphorus is lost through groundwater, whereas dissolved *and* particulate phosphorus are lost via surface outflow. Therefore, phosphorus loss via groundwater can have the effect of concentrating, to some extent, the in-lake total phosphorus concentration. Refer to *Model Calibration* for implications on model calibration of some lakes.

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 Bathtub program in order to facilitate model verification and calibration. Table 14 lists the key input values used in the simulations.

Table 14 – Bathtub Model Input Data

Lake	Surface Area (acres)	Major Flow Axis Length (ft)	Avg Depth (ft)	Observed Lake Quality (surface growing season mean)			Watershed Runoff and Shallow Groundwater [1]			Precip (in)	Evap (in)
				TP (µg/L)	Chl-*a* (µg/L)	Secchi (m)	Phosphorus Load (lb/yr)	Flow (ac-ft/yr)	TP (µg/L)		
Emily	17	1900	3.7	341	152	0.3	13	82	59	29.5	34.75
Linn	177	5,090	6.0	217	88	0.4	368	689	197	29.5	34.5
Little	164	3,890	9.4	173	71	0.7	505	1,208	154	29.5	34.5
North Center	754	6,070	5.8	70	45	1.0	2,066	10,404	73	29.5	34.5
Ogren	49	1150	15	64	29	2.5	858	2153	147	29.5	34.5
Pioneer	77	940	5.0	345	103	0.4	22	67	120	29.5	34.5
School	145	4,070	5.0	216	82	0.4	68	475	53	29.5	34.75
South Center	889	7,640	13	50	40	1.3	1,762	6,409	101	29.5	34.5
Wallmark	145	4,990	6.6	322	165	0.6	73	294	91	29.5	34.75

[1] Contributing area includes SWAT model results (watershed runoff and shallow groundwater) and, for North Center, School, and South Center Lakes, upstream lake loading.

Precipitation and Evaporation

Estimates of annual precipitation and evaporation rates were based on data from the MN Hydrology Guide (SCS 1992). Precipitation and evaporation rates apply only to the lake surface areas.

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 2.2 for more details.

Segment Data: Lake Morphometry and Observed Water Quality

Lake morphometry data were gathered primarily from the MN DNR and aerial photography or were data collected for this study. Data sources are provided in the individual lake TMDL chapters. Observed water quality averages are from the lake assessments (Section 2.1: *Lake Assessments*); ten-year (2001-2010) growing season means (June through September) were calculated for total phosphorus, chlorophyll-*a*, and Secchi transparency.

Tributary Data: Flow Rate and Phosphorus Concentration

All of the watershed sources (Section 2.2) were combined into a single tributary input for each lake. Watershed phosphorus sources include watershed runoff (including runoff from feedlots), shallow groundwater (including subsurface sewage treatment systems), and loading from upstream waters.

Chlorophyll-a-Secchi Coefficient

Among the empirical model parameters is the non-algal turbidity, a term that reflects turbidity due to the presence of color and inorganic solids in the water column. This parameter uses the chlorophyll-*a*-Secchi coefficient, which is the ratio of the inverse of Secchi transparency (the inverse being proportional to the light extinction coefficient) to the chlorophyll-*a* concentration. The default coefficient in Bathtub is 0.025 m^2/mg, which was calibrated to United States Army Corps of Engineers reservoir data. A value of 0.015 m^2/mg has been found to be more representative of Minnesota lakes and was used in this study.

Selection of Equations

Bathtub allows a choice among several different mass balance phosphorus models. For deep lakes in Minnesota, the option of the Canfield-Bachmann lake formulation (Canfield and Bachmann 1981) has proven to be appropriate in most cases. In order to perform a uniform analysis it 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

In all lake models except for Ogren Lake, the predicted in-lake total phosphorus concentration was lower than the average observed (monitored) concentration. It is widely recognized that the shallow lakes of this region have histories of high phosphorus loading and/or very poor water quality despite the relatively low watershed area to lake surface area ratios. North Center, Emily, Linn, Pioneer, School, and Wallmark Lakes are all shallow lakes by MPCA's definition; although Little is not considered a shallow lake according to MPCA's definition, it has a mean depth of only 9.4 feet and 76% of the lake is littoral. For these lakes, it is reasonable that internal loading may be higher than that of the lakes in the data set used to derive the Canfield-Bachmann lakes formulation. It is also possible that SWAT model loading estimates do not account for certain hot spots of phosphorus loading such as imminent threat septic systems and runoff from feedlots that are out of compliance with regulatory controls. In addition, the effects of groundwater outflow, though minor[1], are not explicitly accounted for in the Bathtub model. For these reasons, an explicit additional load was added to the lake models until the modeled total phosphorus concentration was equal to the monitored total phosphorus concentration. Matches were made to the nearest whole number for phosphorus (µg/L).

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[1] Phosphorus loss via groundwater can have the effect of concentrating, to some extent, the in-lake total phosphorus concentration (refer to *System Representation in Model* in Section 2.3). The extent of this effect on the TMDL study lakes was estimated using a modification of the Canfield-Bachmann equation for natural lakes (Canfield and Bachmann 1981). The outflow concentration was assumed to be a fixed fraction of the in-lake concentration (based on the fraction of flow that leaves via groundwater and the fraction of total phosphorus that is dissolved); this fraction was multiplied by the hydraulic flushing rate (1/yr) in the Canfield-Bachmann equation for natural lakes. Conservative groundwater outflow estimates from Wallmark Lake found the predicted in-lake total phosphorus concentration to increase by 11% and 14% by accounting for groundwater outflow at 80% and 95% of total outflow, respectively. However, the true in-lake phosphorus concentration is 8.7 times (870%) that of the uncalibrated in-lake concentration. Therefore, the groundwater loss component, while a factor, does not account for the majority of the unknown load to the lake.

In the Ogren Lake model, the predicted in-lake total phosphorus concentration was *higher* than the average monitored concentration; the phosphorus calibration coefficient was increased to calibrate the model.

For all lake models, calibration coefficients were then modified so that the predicted values of chlorophyll-*a* and Secchi transparency matched the observed values. Matches were made to the nearest whole number for chlorophyll-*a* concentrations (µg/L) and to the nearest tenth of a meter for Secchi transparencies.

Internal vs. External Load

For all lakes except for Ogren, an explicit load was added during model calibration (described above under *Model Calibration*). This explicit load is from a mix of sources, both internal and external. To estimate the proportion of additional load likely to be from external versus internal sources, a risk factor table was created (Table 15). Risk factors for external additional loads were high densities of feedlot animals in the watershed (calculated on a per area basis), past history of shoreline imminent threat public health septic systems, and a majority of households in the watershed with on-site septic systems. Risk factors for internal additional loads were lake mean depths of 5 feet or less, presence of curly-leaf pondweed, and sediment phosphorus loads contributing a significant percentage of the total lake phosphorus load (calculated from sediment samples). For lakes that met at least two internal and two external risk factors, the additional loads were distributed 50% to external and 50% to internal sources. For lakes that met at least two internal but one or fewer external risk factors, the additional loads were distributed 25% to external and 75% to internal sources. For lakes that met at least one internal but no external risk factors, the additional loads were distributed 100% to internal sources.

Table 15 – Internal vs. External Risk Factors for Additional Loads

Lake	Calibration Load (P lb/yr)	External			Internal			Additional Load Estimates for % External vs. % Internal
		High # of feedlot animals per acre?*	History of shoreline ITPHSS	> 75% on-site septic?	Mean depth 5' or less?	CLP present?	Sediment P load estimate (% of total)	
North Center	1,500	ü	ü			ü	44%-53%	50%-50%
South Center	780	ü	ü			ü (low)	55%-87%	75%-25%
Emily	370			ü	ü	ü	0-17%	25%-75%
Linn	2,300			ü		ü	0-25%	25%-75%
Little	2,400	ü	ü	ü		ü	15-23%	50%-50%
Pioneer	1,800				ü		32-33%	0%-100%
School	1,700	ü	ü	ü	ü	ü	0-10%	50%-50%
Wallmark	4,100		ü	ü		ü	16-19%	25%-75%

*High number of Animals per acre = > 0.1 animal per acre

Estimated Phosphorus Load Reduction Requirements

With calibrated existing conditions models completed for all the 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 the total phosphorus state standard. Once the total phosphorus goals are met, it is assumed that the chlorophyll-*a* and Secchi transparency standards are also met. 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 transparency. Based on these relationships it is expected that by meeting the phosphorus target in each lake, the chlorophyll-*a* and Secchi standards will likewise be met.

Using the calibrated existing conditions model as a starting point, the phosphorus concentrations associated with tributaries were reduced until the model indicated that the total phosphorus state standard was met, to the nearest whole number.

With this process, a series of models were developed that included a level of phosphorus loading consistent with lake water quality state standards, or the TMDL goal. Actual load values 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. Reported modeled loads and load reductions are rounded to two significant digits.

TMDL Allocations

In the TMDL allocation tables in each individual lake section, all values less than ten are rounded to two significant digits; all values greater than ten are rounded to the nearest whole number.

Margin of Safety

A 10% explicit margin of safety (MOS) was accounted for in the TMDL for each lake. This MOS is sufficient to account for uncertainties in predicting loads to the lakes and predicting how lakes respond to changes in phosphorus loading. This explicit MOS is considered to be appropriate based on the generally good agreement between the water quality models' predicted and observed values. Since the models reasonably reflect the conditions in the lakes and their watersheds, the 10% MOS is considered to be adequate to address the uncertainty in the TMDL, based upon the data available.

Wasteload Allocations

Regulated MS4 Stormwater

There is no regulated MS4 stormwater in any of the impaired lakes' watersheds. If MS4 communities come under permit coverage in the future, a portion of the LA will be shifted to the WLA to account for the regulated stormwater. MS4 permits for state (MnDOT) and county 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, a portion of the LA will be shifted to the WLA.

One transfer rate was defined for each impaired lake as the runoff loading goal (lb/yr) divided by the watershed area (acres). If there is another impaired lake in the watershed, then the transfer rate was defined for only the watershed area downstream of the upstream impaired lake. If there is another lake in the watershed that is not impaired, then the transfer rate was defined for the total watershed area.

In the case of a load transfer, the amount transferred from LA to WLA will be based on the area of land coming under permit coverage times the transfer rate. The MPCA will make these allocation shifts. The transfer rates are provided for each lake TMDL in the individual *TMDL Loading Capacity and Allocation* sections.

Regulated Construction Stormwater

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

Regulated Industrial Stormwater

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

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 Section 2.2. The remainder of the loading capacity (TMDL) after subtraction of the MOS and calculation of the WLA was used to generate the LA for each lake.

Loading Goals

Phosphorus reduction goals for each lake were developed to identify the load reductions needed from watershed and internal loads in order to meet the TMDL loading goal. The overall loading goal describes the amount of load that needs to be reduced in order to meet the TMDL, with the margin of safety taken into account. The reduction goals presented for loads from internal sources and watershed runoff are guidelines to be used when prioritizing efforts to improve the lakes. These goals can be adapted as more information is learned about each lake's specific phosphorus sources and in-lake ecological interactions.

Determination of Loading Goals

The total phosphorus loads for each lake, less the margin of safety, were divided by source category (atmosphere, upstream lake, runoff, and internal) to develop loading goals for each source category.

Reductions in atmospheric loading were assumed to be zero; therefore the atmosphere loading goal is equal to the total modeled atmospheric load.

Two TMDL lakes had upstream impaired lakes in their watershed: North Center (Little, Pioneer, and South Center Lakes) and South Center (Linn and Ogren). For these lakes, the upstream lake loading goal was equal to the calculated upstream lake load assuming the lake meets the total phosphorus water quality standard. Since Linn and Pioneer Lakes do not contribute surface water to downstream lakes but do contribute shallow groundwater, the in-lake TP concentration contributing to downstream flow was assumed to be half of the water quality standard (see *Model Input* section above). The reduction in upstream lake loading was calculated based on the existing upstream lake load compared to the upstream lake load at the TP standard.

The School Lake watershed has an unimpaired lake, Mattson Lake, in its watershed. The load reduction goal of the Mattson Lake watershed is to maintain Mattson Lake at existing conditions (load reduction of zero).

For three of the lakes (South Center, North Center, and Ogren Lakes), once the upstream load was reduced (where applicable), the watershed load goal was to reduce up to 50%. If there were additional load reductions necessary, the remaining load reductions were from internal load.

For the other six lakes (Emily, Linn, Little, Pioneer, School, and Wallmark), the remaining loading goal (total load less atmosphere load goal and upstream lake load goal) was distributed between watershed runoff and internal sources such that equal percent reductions are required for each category.

Reserve Capacity

There are no new traditional permitted point sources (regulated stormwater or municipal and industrial wastewater systems) planned in the watershed, and changes in loading due to land use changes will need to fit within the allocations presented here. No portion of the allowable loading was explicitly set aside as reserve capacity.

TMDL Baseline Years

The TMDLs are based on data through 2008, 2009, or 2010 (Table 16). Any activities implemented during or after the years indicated in Table 16 that lead to a reduction in phosphorus loads to the lake or an improvement in lake water quality may be considered as progress towards meeting a WLA or LA.

Table 16 – Baseline Years for TMDL Implementation

Lake	TMDL Baseline Year
North Center	2010
South Center	2010
Emily	2009
Linn	2009
Little	2008
Ogren	2010
Pioneer	2009
School	2009
Wallmark	2010

2.4 Summary of Model Applications

This section provides a summary of how the models that were applied to each lake in this TMDL study interact. Details are provided throughout Section 2: *Methods*. Results from the Sunrise River SWAT model (modeling conducted under a separate project) were used to estimate existing phosphorus loading to lakes. Phosphorus loading from the Sunrise River SWAT model includes loading from shallow groundwater (including septic systems) and feedlots. Phosphorus loading results from the Sunrise River SWAT model were combined with phosphorus loading from atmospheric deposition and upstream lake loading. Ultimately, external phosphorus loading served as input to the Bathtub model, which estimates in-lake water quality. The Bathtub models were calibrated to existing in-lake water quality data (10-year growing season means) and were then used to identify the phosphorus load reductions needed to meet State in-lake water quality standards.

3 WATERSHED CHARACTERISTICS

The following section describes information about the watershed as a whole, rather than each lake's watershed individually.

The Chisago Lakes Chain of Lakes Watershed is large chain including 20 lakes; these lakes range in size from 20 acres to over 1,500 acres (Figure 4). The largest of the lakes included in the TMDL study is South Center Lake at 889 acres, while the smallest is Lake Emily which is 20 acres. The lakes within in the chain are all connected either through surface water tributaries or groundwater inflow/outflow (Figure 3). The principal outlet from the Chain of Lakes is located at Lake Ellen and flows out of that outlet at 898.2 feet above sea level; when the lakes reach 899.9 feet above sea level the outlet to Wallmark Lake functions as the secondary outlet to the Chain of Lakes. The outlet at Lake Ellen and the outlet from Chisago to Green Lake are controlled by weirs which are opened only during times of high waters. Tributaries leaving the two outlets eventually meet up at Bloomquist Creek near the Sunrise River.

Nine lakes within the Chain of Lakes have been identified as impaired. These lakes have been listed on the 303(d) Impaired Waters List from 2008 to the draft 2012 list (Figure 5). The waters listed on the Impaired Waters list do not meet State water quality standards; waters on the list need to have a TMDL completed.

The lakes within this watershed are covered by many municipal jurisdictions, including: Chisago City, Lindstrom, Center City, Lent Township, North Chisago Lakes Township, South Chisago Lakes Township, Shafer Township, and Franconia Township (Figure 6).

Presettlement vegetation was very different than it is today. The Chisago Lakes area was mostly comprised of Maple/Basswood and Aspen/Oak forests (Figure 7). Today's changed land cover and land use are large factors in determining the sources of pollutants to the lakes; both urban and rural land uses factor into the nutrient load in the lakes (Figure 8). Soil types (Figure 9) and wetland abundance (Figure 10) are good indications of surface water to groundwater interaction as well as the filtering abilities provided by wetlands.

Sanitary sewer service is available within the most populated areas of the Chain of Lakes (Figure 11); however, many individual sewage treatment systems (septic systems) still exist within the watershed. Wastewater that is expelled into the sanitary sewer is managed at the Chisago Lakes Joint Sewage Treatment Commission north of Chisago City. This wastewater plant has a permitted discharge allowance that does not drain to any of the Chain of Lakes. All areas that are not serviced by the sanitary sewer are assumed to be treated with onsite septic systems.

Animal operations are known to exist across the watershed (Figure 12). The only mapped feedlots are feedlots that are registered to the MPCA Feedlot program. Some of these feedlots do not currently have animals. Other, non-registered feedlots or animal operations do exist within the watershed, but are unable to be mapped.

Stormwater runoff occurs at a high rate in these areas. A large portion of the watershed does not have stormwater controls in place. In these situations, runoff from roads, driveways, houses, businesses, and other impervious surfaces drains untreated, directly to the lakes. Storm sewers exist across the entire urban area. Due to the large number, the map shows the last outlets along the lake (Figure 13).

Aquatic macrophytes

Phosphorus can be released into the lake from decaying plant matter, specifically curly-leaf pondweed *(Potamogeton crispus).* Curly-leaf pondweed has been identified in the following impaired lakes: South Center, North Center, Wallmark, Linn, Pioneer, School, and Emily. In late June and early July, the plant starts to die back and decay; as it does this, it can let large amounts of phosphorus back into the water column. This phosphorus release can cause algae blooms during the prime lake recreation season. Curly-leaf pondweed has been known to be in these area lakes since at least 1969. The MN DNR has many years of aquatic surveys on the larger lakes within the Chisago Lakes Chain of Lakes Watershed.

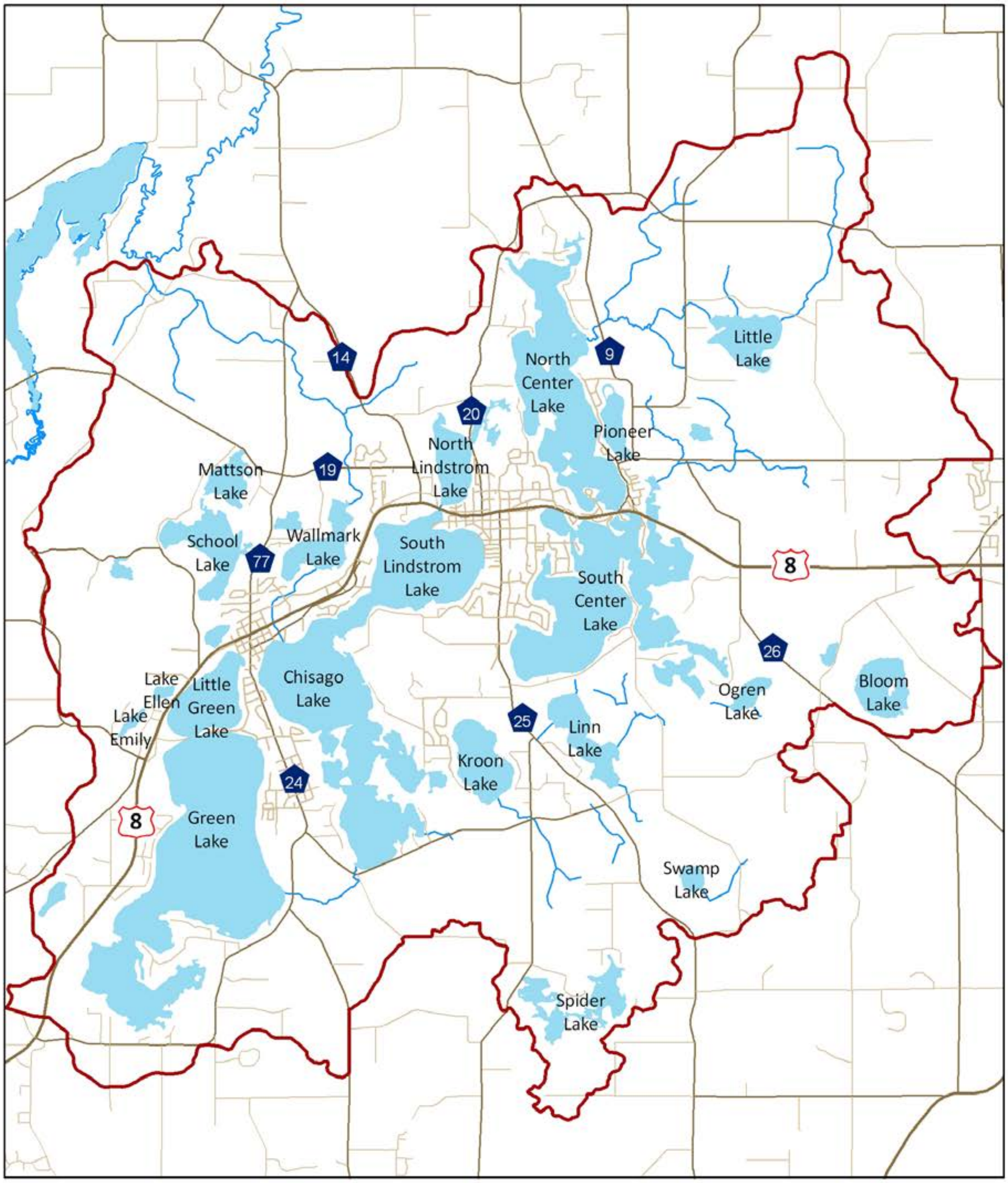
Eurasian watermilfoil *(Myriophyllum spicatum)* has been present in the Chisago Lakes Chain of Lakes (first found in Green Lake by the MN DNR) since at least 1996. Of the TMDL lakes Eurasian watermilfoil has been found in North Center and South Center lakes.

Over the years, as development pressures have increased, the abundance of the emergent plants has been reduced. Deep rooted native plants within the riparian zones of the lakes have been removed and replaced with shallow rooted turfgrass. These native plants use phosphorus and other nutrients both from the lake and reduce the amount of runoff carrying these pollutants that can reach the lake.

Fish

Even though there are undesirable fish species present in the lakes, none of the lakes have higher than expected populations of rough fish and other undesirable fish species.

Figure 4 – Chisago Lakes Chain of Lakes Watershed

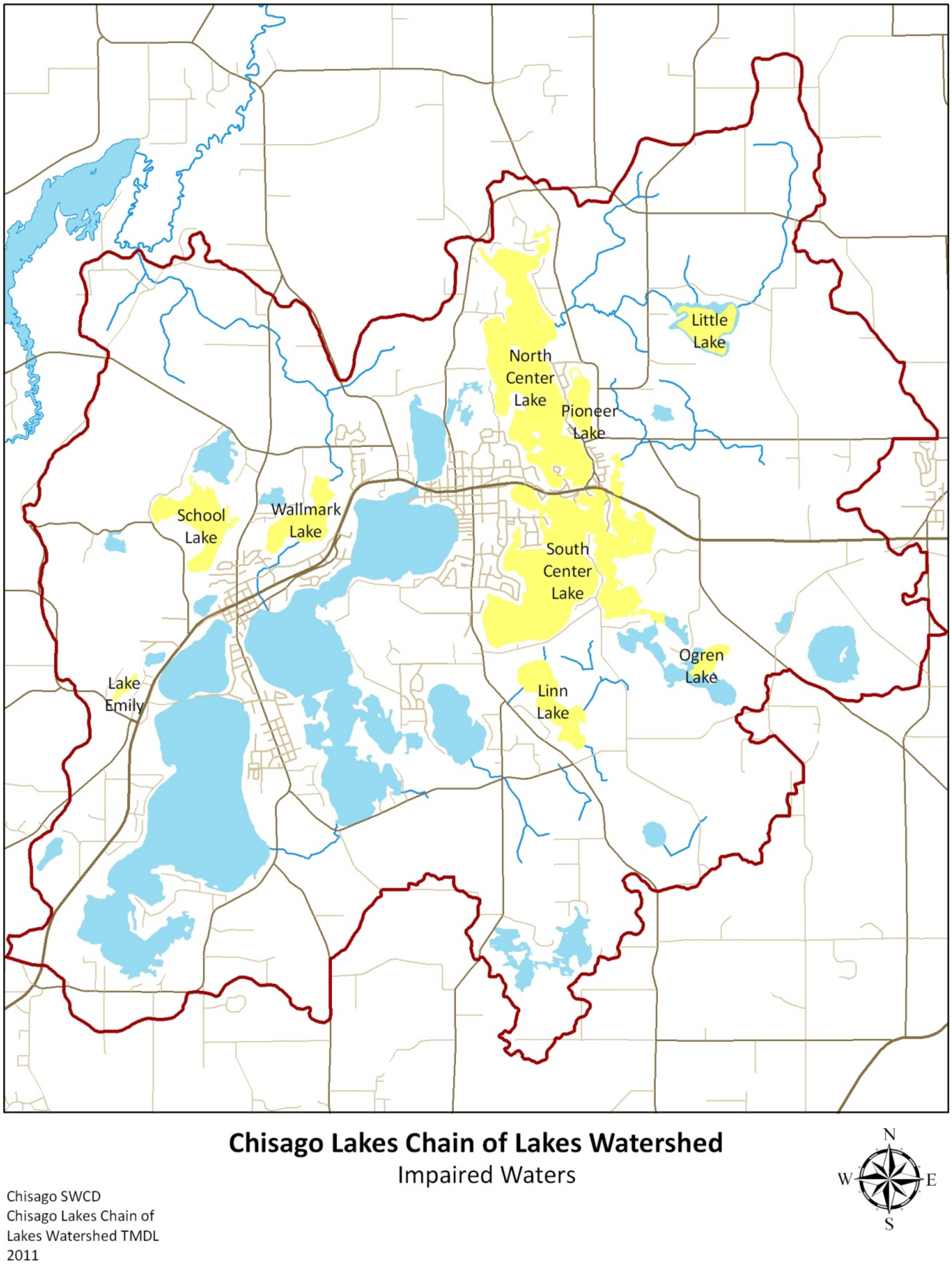


Chisago Lakes Chain of Lakes Watershed

Lakes

Chisago SWCD
Chisago Lakes Chain of
Lakes Watershed TMDL
2011

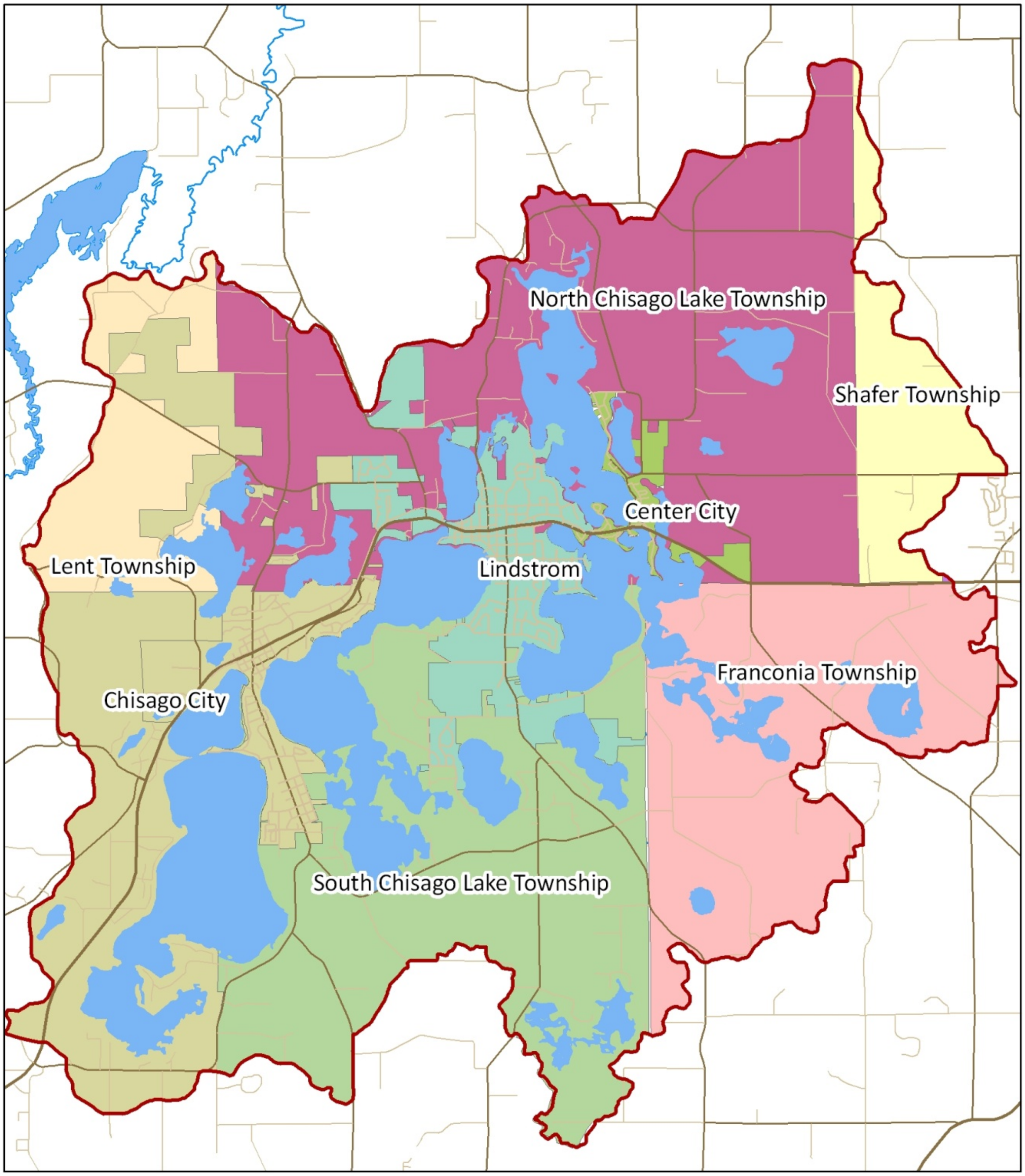
Figure 5 – Chisago Lakes Chain of Lakes Impaired Waters



Chisago Lakes Chain of Lakes Watershed
Impaired Waters

Chisago SWCD
Chisago Lakes Chain of
Lakes Watershed TMDL
2011

Figure 6 – Chisago Lakes Chain of Lakes City and Township Boundaries

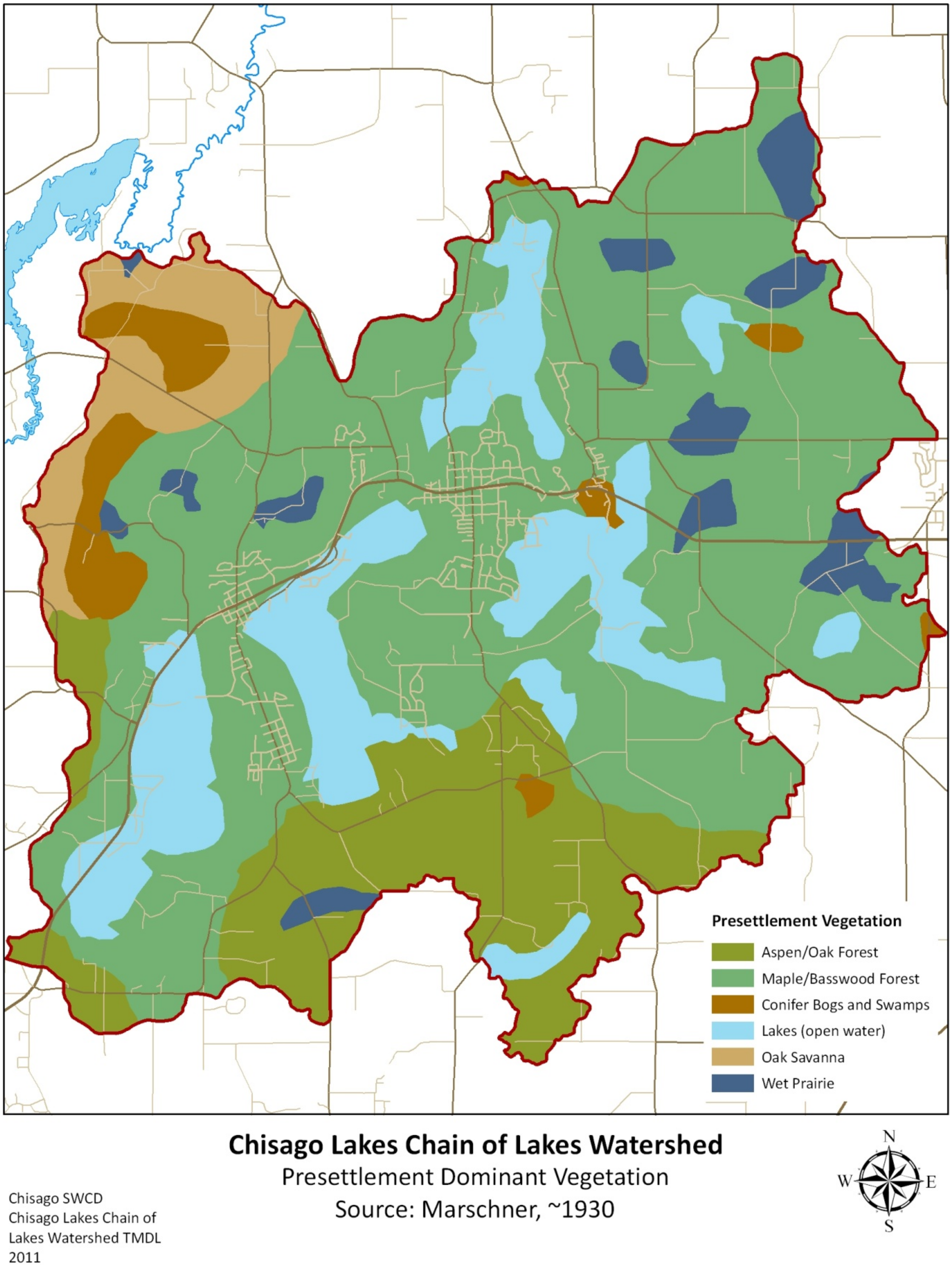


Chisago Lakes Chain of Lakes Watershed

City/Township Boundaries

Chisago SWCD
Chisago Lakes Chain of
Lakes Watershed TMDL
2011

Figure 7 – Chisago Lakes Chain of Lakes Presettlement Vegetation



Chisago Lakes Chain of Lakes Watershed
Presettlement Dominant Vegetation
Source: Marschner, ~1930

Chisago SWCD
Chisago Lakes Chain of
Lakes Watershed TMDL
2011

Figure 8 – Chisago Lakes Chain of Lakes Land Cover

Chisago Lakes Chain of Lakes Watershed
Land Cover
Source: MN DNR GAP Data

Chisago SWCD
Chisago Lakes Chain of
Lakes Watershed TMDL
2011

Figure 9 – Chisago Lakes Chain of Lakes Soil Types

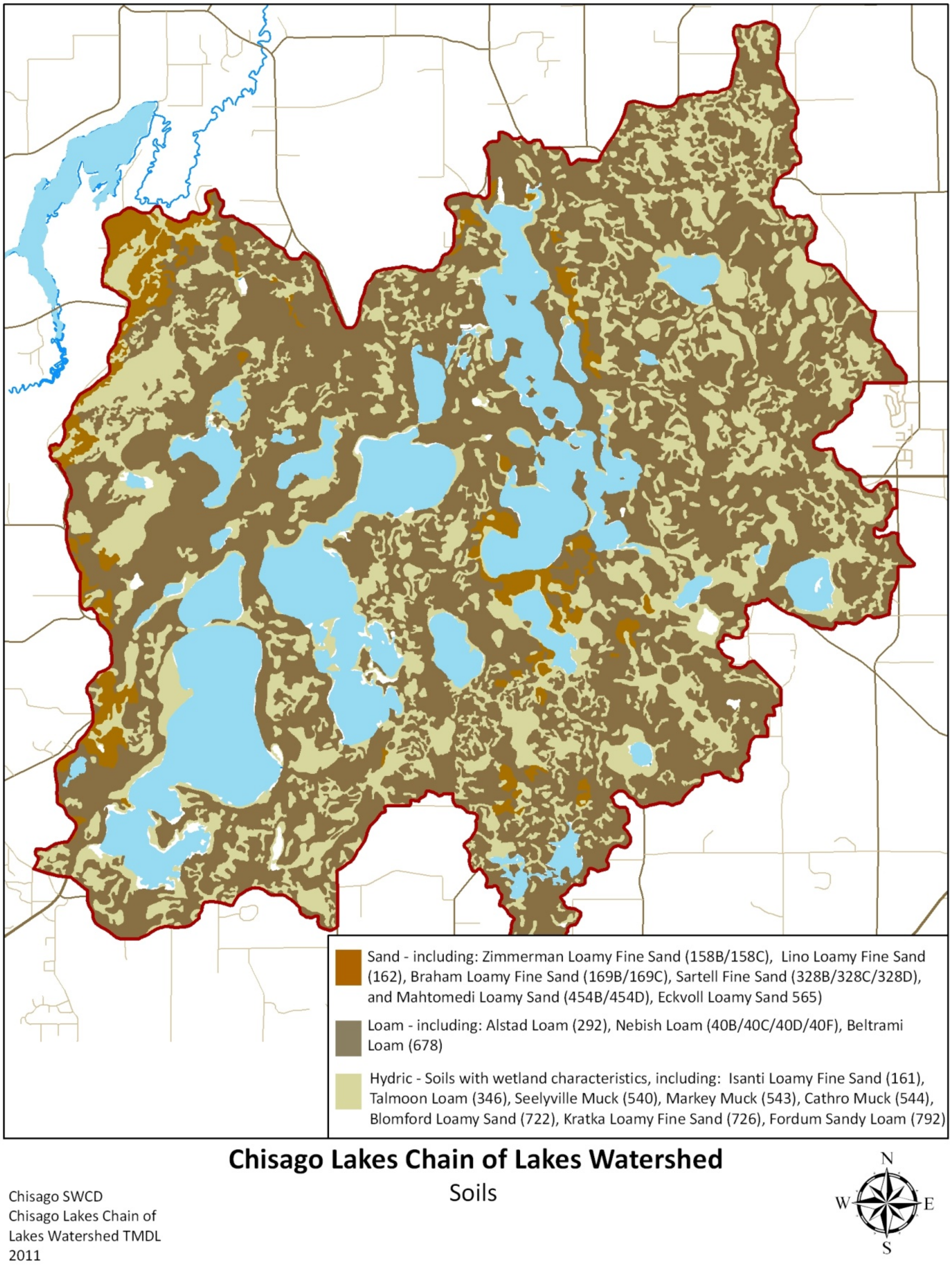
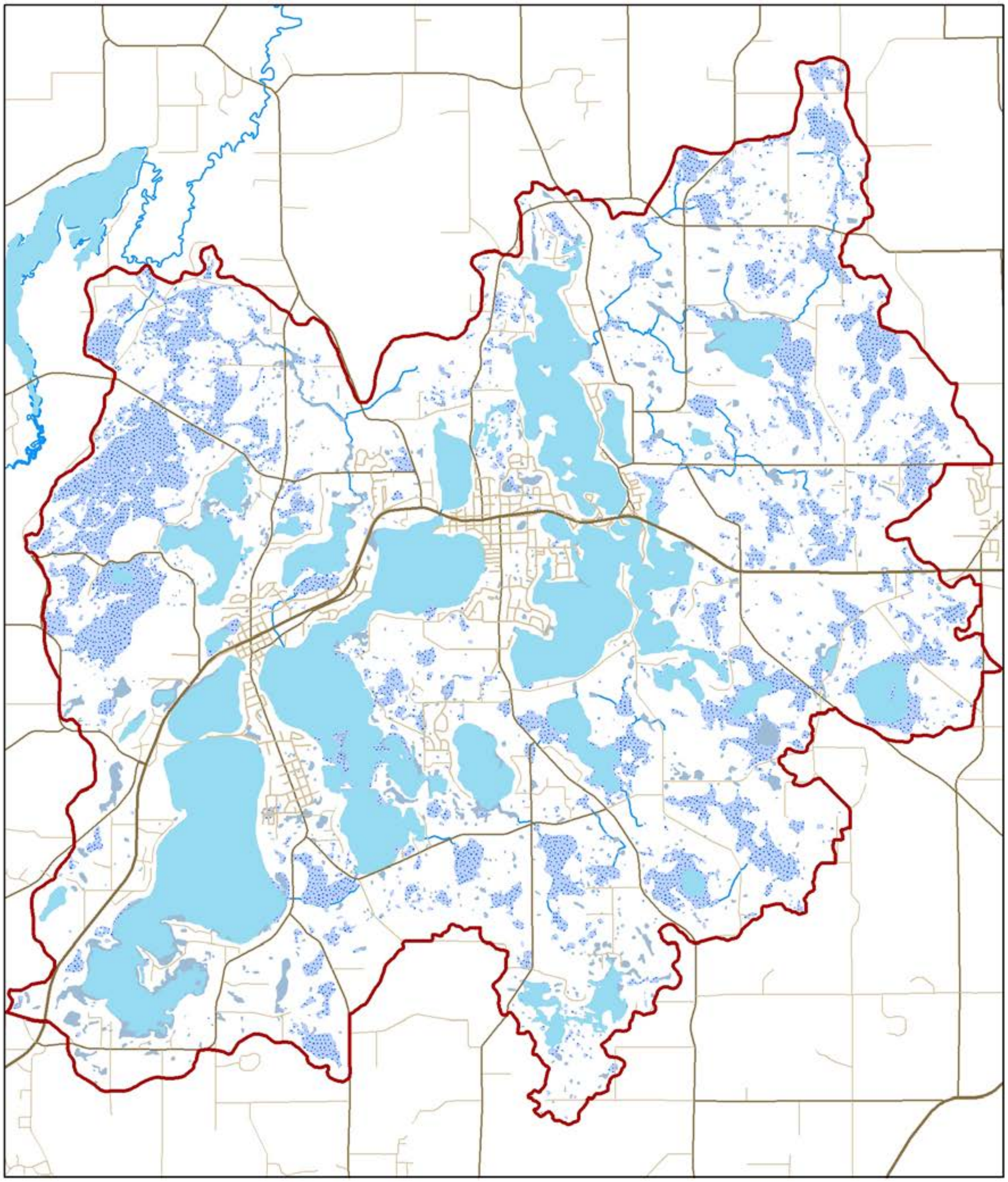


Figure 10 – Chisago Lakes Chain of Lakes Wetlands



Chisago Lakes Chain of Lakes Watershed

Wetlands

Source: National Wetlands Inventory, 1994

Chisago SWCD
Chisago Lakes Chain of
Lakes Watershed TMDL
2011

Figure 11 – Chisago Lakes Chain of Lakes Sanitary Sewer

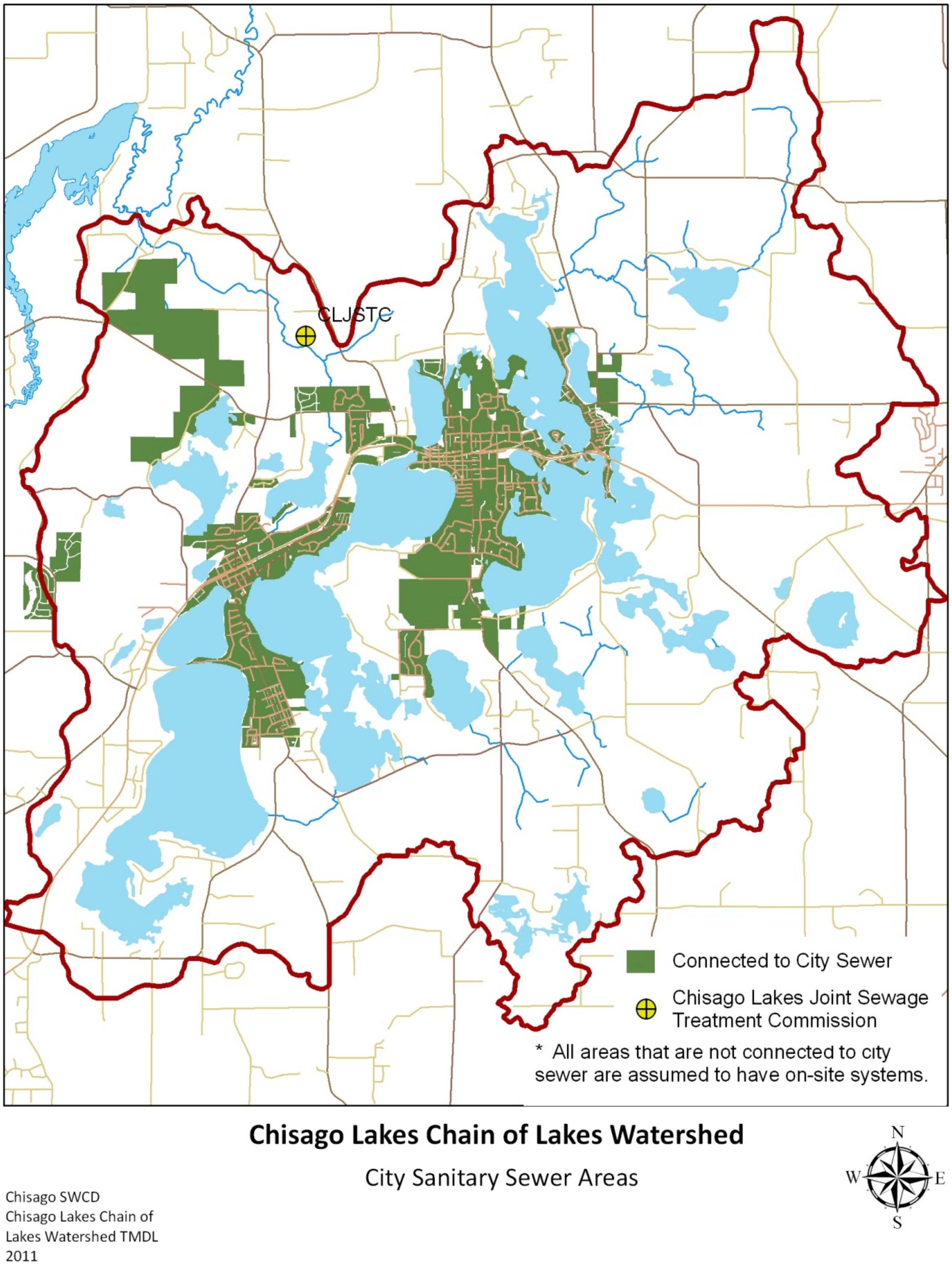
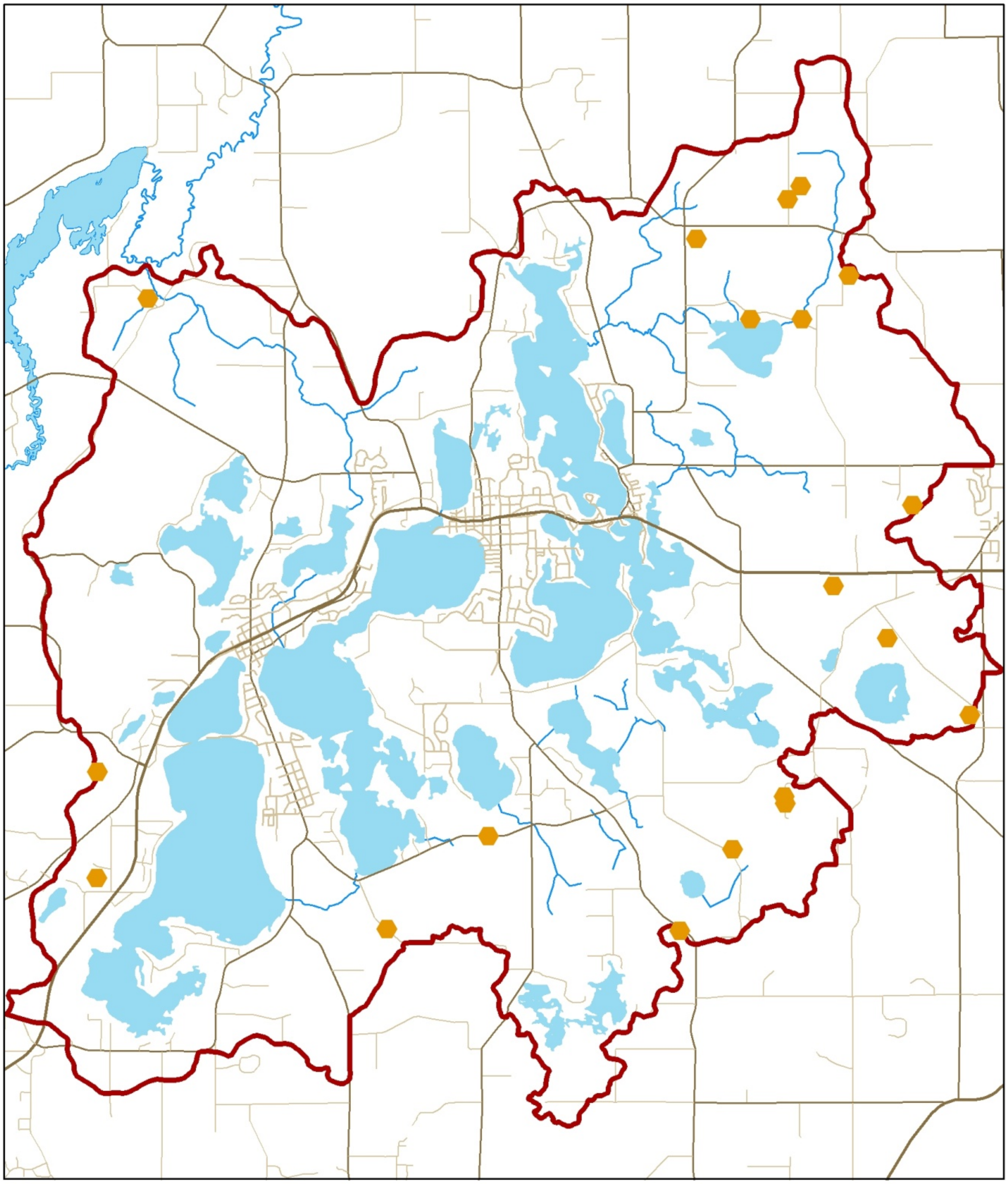


Figure 12 – Chisago Lakes Chain of Lakes MPCA Registered Feedlots

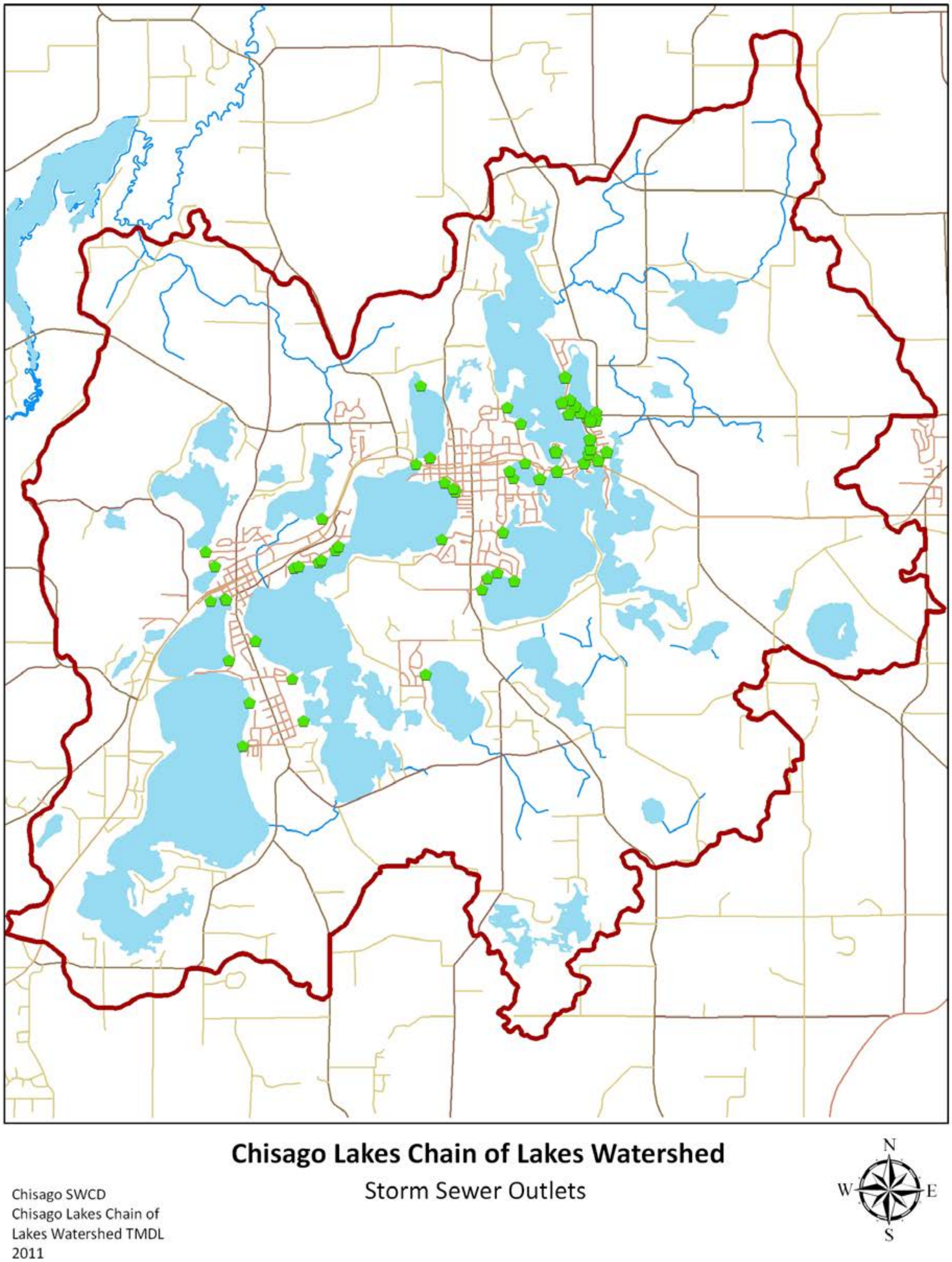


Chisago Lakes Chain of Lakes Watershed

MPCA Registered Feedlots
As of 2011

Chisago SWCD
Chisago Lakes Chain of
Lakes Watershed TMDL
2011

Figure 13 – Chisago Lakes Chain of Lakes Stormsewer Outlets



Chisago Lakes Chain of Lakes Watershed

Storm Sewer Outlets

Chisago SWCD
Chisago Lakes Chain of
Lakes Watershed TMDL
2011

4 NORTH CENTER LAKE TMDL

4.1 Physical Characteristics

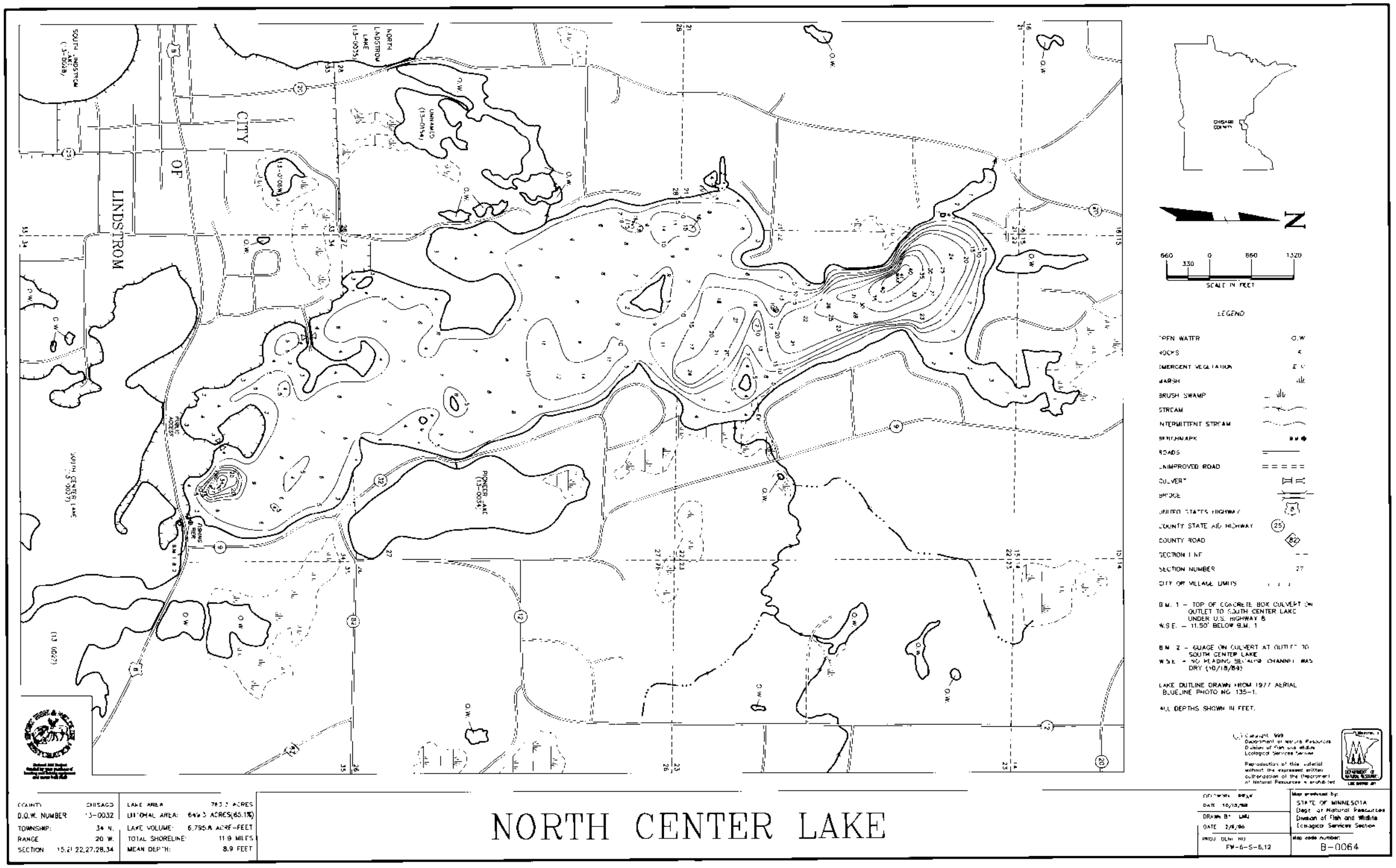
North Center Lake (MN DNR Lake ID 13-0032-01) is a shallow lake located in southern Chisago County and borders Lindstrom to the west and Center City to the east. Table 17 summarizes the lake's physical characteristics, Figure 14 shows the 2007 aerial photography, and Figure 15 illustrates the available bathymetry.

Table 17 – North Center Lake Physical Characteristics

Characteristic	Value	Source
Lake total surface area (acre)	754	MN DNR bathymetric data – 0 m depth contour digitized from 1991-92 aerial photography
Percent lake littoral surface area (%)	81	MN DNR Lake Finder
Lake volume (acre-feet)	4,463	Calculated from MN DNR bathymetric data using 2010 surface contour (aerial photo) and 1991-92 depth contours
Mean depth (feet)	5.9	Lake volume ÷ surface area
Maximum depth (feet)	46	MN DNR Lake Finder
Drainage area (acre)	16,048	SWAT model (HDR 2008)
Watershed area: Lake area	21	Calculated

Figure 14 – North Center 2007 Aerial Photograph

Figure 15 – North Center Lake Bathymetry



4.2 Land Cover

Table 18 – North Center Lake Watershed Land Cover

Land Use	Direct Drainage		Entire Drainage (including Little, Pioneer, South Center, Linn, Ogren)	
	Total Acres	% of Watershed	Total Acres	% of Watershed
Developed	137.6	6.1	588.1	3.5
Cropland	816.5	36.0	8,510.2	50.7
Grassland	174.0	7.7	1115.0	6.6
Aquatic Habitats	126.1	5.6	3,580.7	21.3
Woodland	258.7	11.4	2,254.1	13.4
North Center Lake Surface Area	754.0	33.2	754.0	4.5
Total	**2,266.8**	**100**	**16,802**	**100%**

4.3 Existing Studies, Monitoring, and Management

North Center Lake has been monitored for water level and water quality through the CLLID and volunteers for many years. Data in the MPCA's water quality database dates back to 1986.

4.4 Lake Uses

Aquatic recreation is the designated use for North Center Lake which incorporates swimming, wading, aesthetics, and other related uses. North Center Lake is heavily used for fishing, swimming, and recreation. The lake is fished heavily during the summer and large numbers of fish houses are seen throughout the winter. Tournament fishing for bass also occurs during the summer months.

4.5 Lake Assessment

Water Quality

Water quality monitoring data for North Center Lake are available from 1976 to 2010. Only data from within the most recent 10 years (2001-2010) were used to determine whether North Center Lake meets shallow lake water quality standards. The lake does not meet shallow lake water quality standards for total phosphorus (TP) or chlorophyll-*a* (Chl-*a*), and just meets the Secchi transparency standard (Table 19).

Table 19 – 10-year Growing Season Mean TP, Chl-*a*, and Secchi for North Center Lake, 2001-2010.

Parameter	Growing Season Mean (June – September)	Growing Season CV (June – September)	Shallow Lake Standard
Total phosphorus (µg/L)	70	0.08	≤ 60
Chlorophyll-*a* (µg/L)	45	0.15	≤ 20
Secchi transparency (m)	1.0	0.04	≥ 1.0

*CV = coefficient of variation. CV is used as input into the Bathtub model, and is defined in Bathtub as standard error divided by mean

Water quality has improved since monitoring began in 1976 (Figure 16, Figure 17, and Figure 18). Between 2001 and 2010, the growing season mean annual TP, Chl-*a*, and Secchi transparency were variable with no visible trend. In 2010, growing season mean TP and Chl-*a* slightly exceeded the shallow lake water quality standard (Figure 16 and Figure 17), while

Secchi transparency met the shallow lake water quality standard (Figure 18). In 2010, maximum TP and Chl-*a* and minimum transparency occurred at the end of July with continued low transparency through September (Figure 19).

Figure 16 – Growing Season Means ± SE of Total Phosphorus for North Center Lake by Year. The dashed line represents the shallow lake water quality standard for TP (60 µg/L).

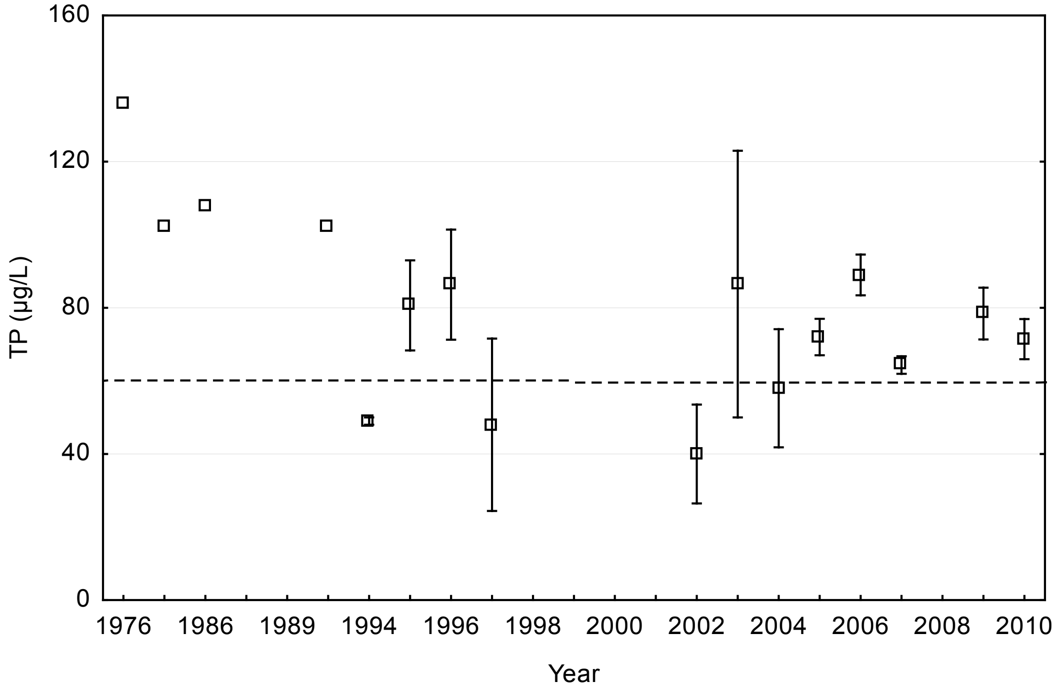


Figure 17 – Growing Season Means ± SE of Chlorophyll-*a* for North Center Lake by Year. The dashed line represents the shallow lake water quality standard for Chl-*a* (20 µg/L).

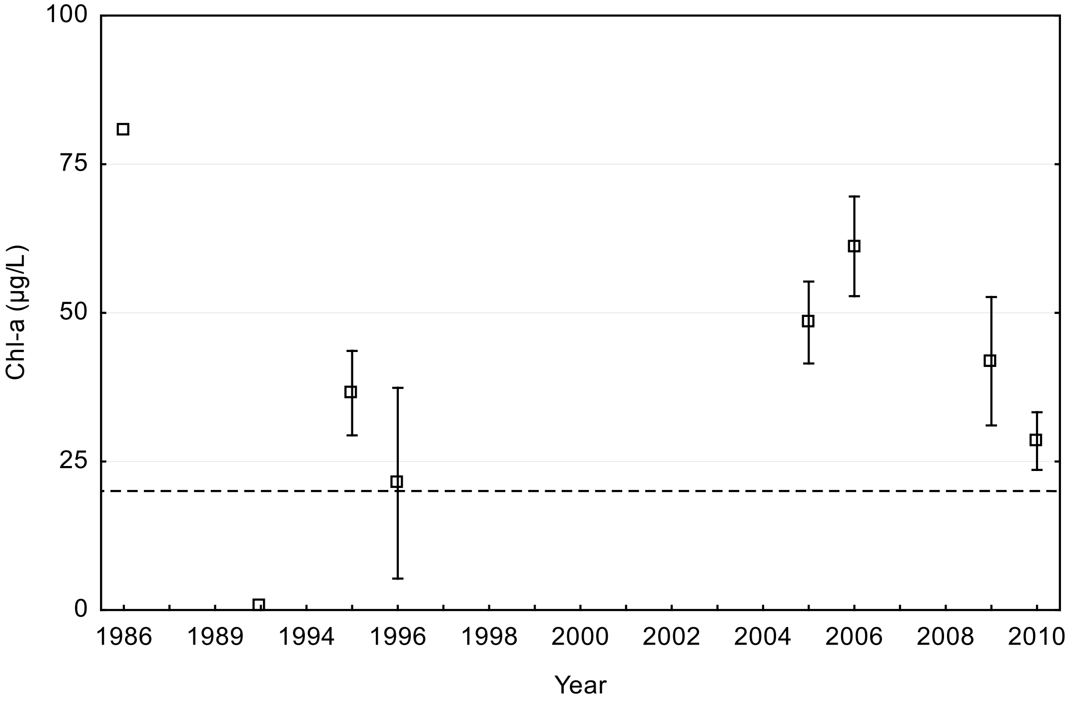


Figure 18 – Growing Season Means ± SE of Secchi Transparency for North Center Lake by Year. The dashed line represents the shallow lake water quality standard for transparency (1.0 m).

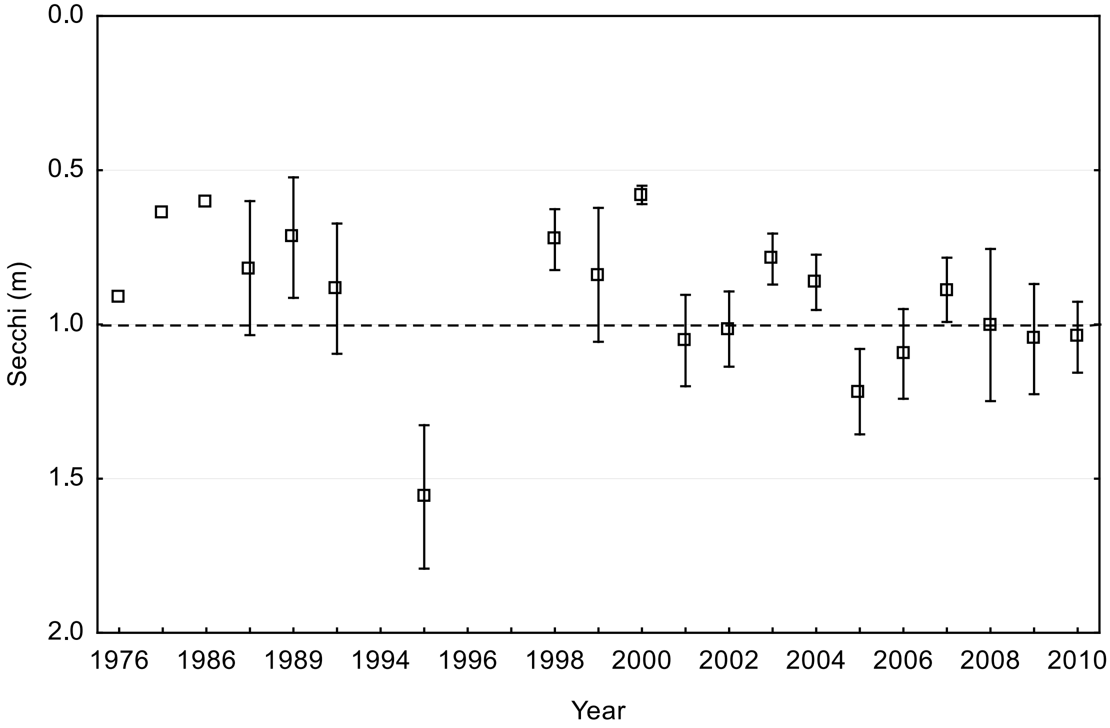
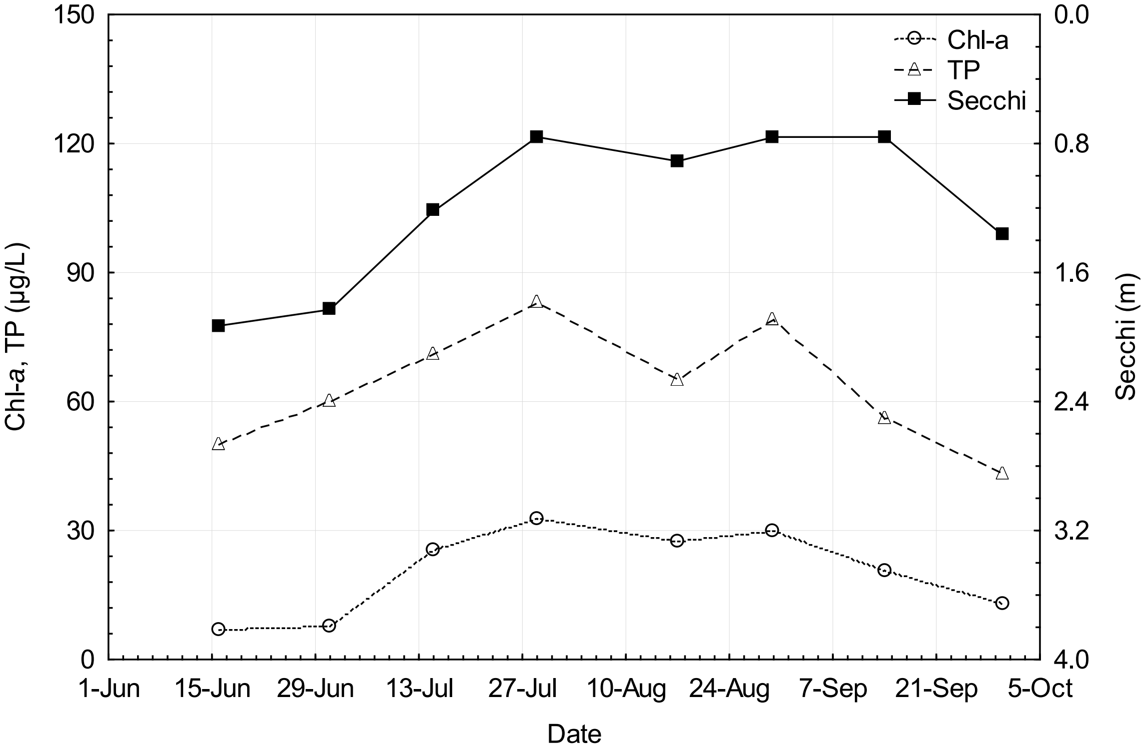


Figure 19 – Growing Season Trends of Chl-*a*, TP, and Secchi Transparency for North Center Lake, 2010.



Macrophytes

Curly-leaf pondweed and Eurasian watermilfoil dominate the vegetation in North Center Lake. Curly-leaf pondweed has been in North Center Lake since at least 1969. Eurasian watermilfoil was found in North Center Lake in 2008. The maximum depth of aquatic plant growth was 5.5 feet in 2005.

The main complaint from lakeshore residents is the Eurasian watermilfoil due to the dense weed mats that it forms which makes navigation in this shallow lake difficult during the summer. Although curly-leaf pondweed is known to cause algae blooms, the residents are relieved when the curly-leaf pondweed dies back in July. Dense mats of Eurasian watermilfoil were observed in 2010 which made navigation difficult.

Fish

Species identified in the 2010 MN DNR fish survey include: black bullhead, black crappie, bluegill, bowfin, brown bullhead, common carp, golden shiner, hybrid sunfish, largemouth bass, northern pike, pumpkinseed sunfish, walleye, white sucker, yellow bullhead, and yellow perch. The average weight of northern pike in North Center Lake is well above average, almost three times the average size for similar lakes, due to low numbers of young fish recruiting to the population. This has exacerbated by recent low water levels and possibly modifications to historical spawning runs. Common carp were first identified in 1995; however, the abundance of carp is low. The lake is stocked approximately every other year with walleye.

4.6 Phosphorus Source Inventory

Through model calibration, 1,500 pounds of phosphorus were determined to be from a mix of watershed and internal load sources. These mixed sources were distributed as follows: 50% (750 lb/yr) to external load and 50% (750 lb/yr) to internal load (see Table 15 on page 47).

Watershed + Shallow Groundwater Phosphorus Sources

The contributing watershed to North Center Lake includes watershed runoff and shallow groundwater coming from the direct drainage to the lake and drainage from upstream waters: Little, Pioneer, and South Center Lakes. Drainage from Pioneer Lake is via shallow groundwater only; drainage from Little Lake and South Center Lake is from watershed runoff and shallow groundwater.

The SWAT model estimated that North Center Lake receives 2,100 pounds of phosphorus annually from watershed runoff and shallow groundwater flow: 570 pounds from the direct watershed and 1,493 pounds from upstream lakes. An additional 750 pounds were added from the mixed sources, for a total of 1,320 pounds per year from the direct watershed (Table 20).

The SWAT model estimated the 2030 phosphorus load from watershed runoff and shallow groundwater from the direct watershed (areas excluding upstream lakes) to be 650 lb/yr based on projected population estimates and resulting development. This represents a 14% increase in phosphorus loading from existing conditions (570 lb/yr). Due to the changed economic climate, development is slower than projections; the total additional load may not be realized until 2040 or later.

Table 20 – North Center Lake Watershed Runoff and Shallow Groundwater Phosphorus Source Summary

Phosphorus Source	Annual P Load (lb/yr)	Percent of P Load (%)	Flow Volume[1] (AF/yr)	Area (ac)	Equiv. Depth of Flow (in/yr)	Average Areal P Load (lb/ac-yr)[2]	Average P Conc. (µg/L)[3]
Direct Loading	1,320	47%	2,004	2,702	8.9	0.4999	243
Loading from Upstream Waters (Little)[4]	570	20%	1,307	2,178	7.2	0.26	161
Loading from Upstream Waters (Pioneer[5])[4]	53	1.9%	125	168	8.9	0.32	156
Loading from Upstream Waters (South Center)[4]	870	31%	6,968	11,000	7.6	0.079	46
Total	**2,813**	**100%**	**10,404**	**16,048**	**7.8**	**0.18**	**100**

[1] Watershed runoff plus shallow groundwater flow
[2] Annual TP load (lb/yr) divided by drainage area (ac)
[3] Annual TP load (lb/yr) divided by average annual flow volume; values are rounded to the nearest whole number
[4] Calculations are from immediately downstream of lake; includes lake area and drainage area
[5] Shallow groundwater only; P load and concentration are dissolved P only

About half of the North Center Lake watershed is serviced by city sanitary sewer. The homes not serviced by city sewer are assumed to have private on-site septic systems, which are estimated to have a 25% failure rate. Seven imminent threat to public health septic systems have been recently upgraded; three of these are within the shoreland area. Fifteen animal operations exist within the contributing watershed area. Three other impaired lakes subwatersheds (Little, Pioneer, and South Center) flow into North Center Lake.

Atmospheric Phosphorus Sources

Atmospheric deposition is estimated to be 200 lb/yr (see *Atmospheric Deposition* in Section 2.2 for more information).

Internal Phosphorus Sources

The modeled internal load based on sediment phosphorus content indicates that internal loading accounts for an additional 3,000 to 4,200 lb/yr of phosphorus loading to the lake, representing 50% to 58%, respectively, of the total loading to the lake. These rates of internal loading are relatively high for a lake that does not exhibit symptoms of excessive internal loading. It was assumed that the internal load is the lower of these two values, or 3,000 lb/yr.

Phosphorus Load Summary

The total modeled phosphorus load to North Center Lake is 6,013 lb/yr (Table 21).

Table 21 – North Center Lake Phosphorus Source Summary, Existing Loads

Phosphorus Source	Phosphorus Load (lb/yr)
Watershed + Shallow Groundwater	2,813
Atmospheric	200
Internal Load	3,000
Total	**6,013**

4.7 Impairment Assessment Summary

- The lake water quality violates the phosphorus and chlorophyll-*a* water quality standards and just meets the Secchi transparency standard.
- The lake vegetation is dominated by curly-leaf pondweed and Eurasian watermilfoil. Curly-leaf pondweed contributes to internal loading from the sediments.
- Black bullhead and carp are present in the lake, which could lead to high internal loading rates due to their habit of foraging in bottom sediments.
- Phosphorus concentration in sediments is high, indicating a high potential for internal loading from sediments.
- A large portion of the shoreline is developed.
- Approximately 50% of the watershed is cropland, and there are 15 animal operations in the watershed.
- Approximately half of the watershed is served by private on-site septic systems, which are estimated to have a 25% failure rate.
- Seven imminent threat to public health septic systems, three of which were in the shoreland area, were recently upgraded.
- Three other impaired lakes drain to North Center Lake: Little Lake, Pioneer Lake (shallow groundwater only), and South Center Lake.

4.8 TMDL Loading Capacity and Allocations

The phosphorus loading capacity of North Center Lake is 5,450 lb/yr, to be split among allocations according to Table 22. While there are currently no regulated MS4s in the North Center Lake watershed, should a portion of the watershed come under regulation by a MS4 permit in the future, the transfer rate from LA to WLA for regulated MS4 stormwater runoff is 0.27 lb/ac-yr, or 0.00074 lb/ac-day. This transfer rate applies to the direct drainage area of North Center Lake; it does not apply to the watersheds of the upstream impaired lakes (Little, Pioneer, South Center, Linn and Ogren).

Table 22 – North Center Lake TP Allocations

Load Component	TP Existing	TP TMDL Allocation		TP Reduction	
	lb/yr	lb/yr	lb/day	lb/yr	%
WLA					
Construction stormwater (permit #MNR100001)	1.2	1.2	0.0033	0	0%
Industrial stormwater (permit # MNR50000)	1.2	1.2	0.0033	0	0%
Total WLA	**2.4**	**2.4**	**0.0066**	**0**	**0%**

LA*					
Watershed (direct runoff)	1,318	723	2.0	595	45%
Watershed (upstream lakes)	1,493	980	2.7	513	34%
Atmospheric	200	200	0.55	0	0%
Internal	3,000	3,000	8.2	0	0%
Total LA	**6,011**	**4,903**	**13**	**1,108**	**18%**
MOS	**--**	**545**	**1.5**		
Total	***6,013***	***5,450***	***15***		

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

To meet the TMDL with a 10% margin of safety, the total load to the lake needs to be reduced by 1,108 lb/yr (18%).

The load reduction goals are based on the following:

- If the impaired upstream lakes attain water quality standards, the load to North Center Lake will be reduced by 520 lb/yr.
- The remaining reductions needed should come from watershed runoff from the direct drainage area.

5 SOUTH CENTER LAKE TMDL

5.1 Physical Characteristics

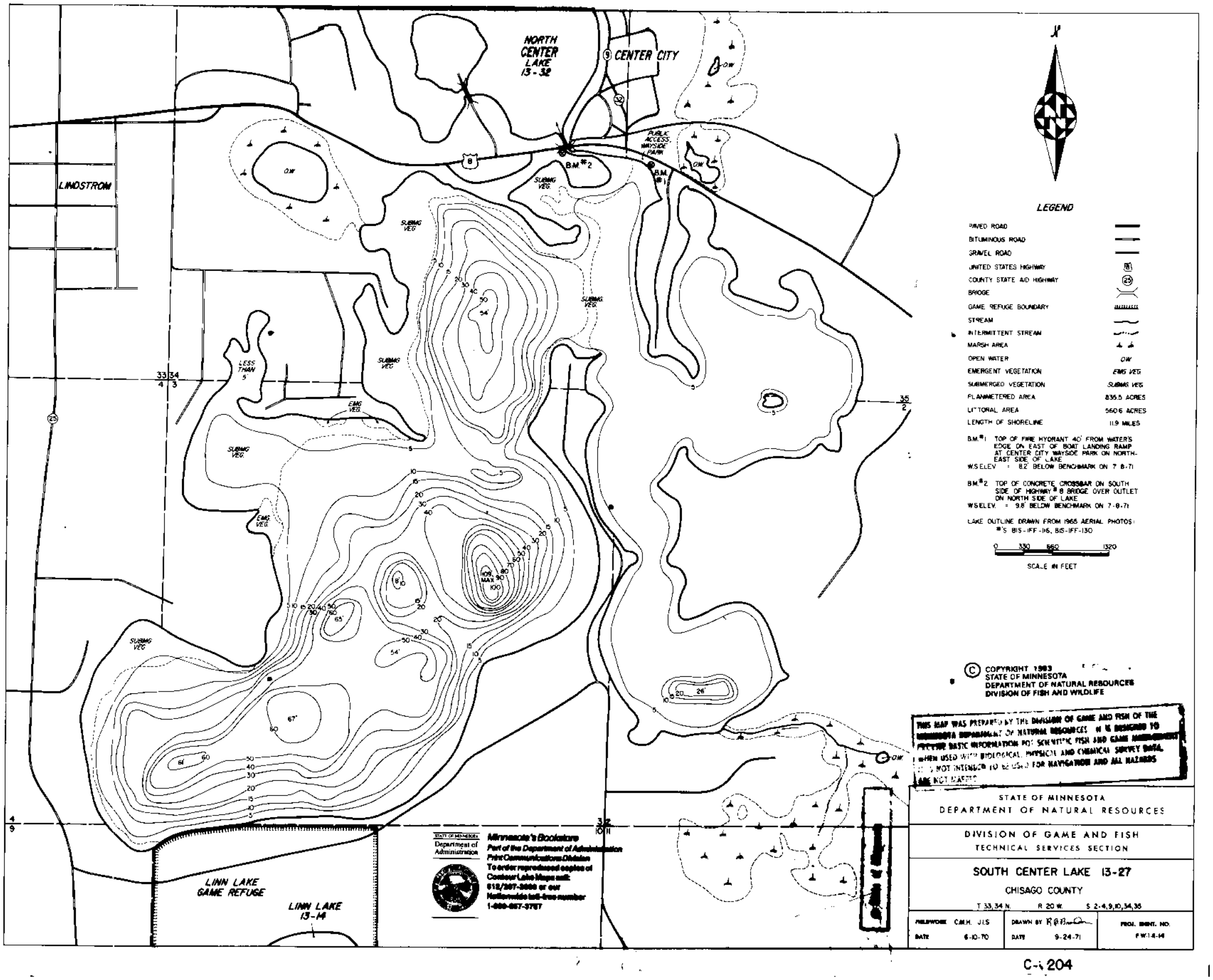
South Center Lake (MN DNR Lake ID 13-0037) is a lake located in southern Chisago County and borders Lindstrom to the west. Table 23 summarizes the lake's physical characteristics, Figure 20 shows the 2007 aerial photography**,** and Figure 21 illustrates the available bathymetry.

Table 23 – South Center Lake Physical Characteristics

Characteristic	Value	Source
Lake total surface area (ac)	889	MN DNR Public Waters Inventory GIS Shapefile
Percent lake littoral surface area (%)	63	MN DNR Lake Finder
Lake volume (ac-ft)	11,269	Calculated from MN DNR bathymetric data using 2010 surface contour (aerial photo) and 1991-92 depth contours
Mean depth (ft)	12.6	Lake volume ÷ surface area
Maximum depth (ft)	109	MN DNR Lake Finder
Drainage area (ac)	10,111	SWAT model (HDR 2008)
Watershed area: Lake area	11	Calculated

Figure 20 – South Center 2007 Aerial Photograph

Figure 21 – South Center Lake Bathymetry



5.2 Land Cover

Table 24 – South Center Lake Watershed Land Cover

Land Use	Direct Drainage		Entire Drainage (including Linn, Ogren)	
	Total Acres	% of Watershed	Total Acres	% of Watershed
Developed	251.0	14.5	414.1	3.8
Cropland	312.0	18.0	5,596.3	50.9
Grassland	38.3	22.0	672.0	6.1
Aquatic Habitat	95.9	5.5	1,948.2	17.7
Woodland	149.8	8.6	1,480.4	13.5
South Center Lake Surface Area	889.0	51.2	889.0	8.0
Total	**1,736.0**	**100%**	**11,000**	**100%**

5.3 Existing Studies, Monitoring, and Management

South Center Lake is one of the twenty-four SLICE: Sentinel Lakes in Minnesota sponsored by the MN DNR and the MPCA. The Sentinel Lakes are the focus of a long-term, collaborative monitoring effort that is being led by the MN DNR. The overall program, referred to as SLICE, is designed to understand and predict the consequences of land use and climate change on lake habitats.

This program will involve long-term monitoring of water chemistry, fisheries, habitat, and other factors in these lakes as well as detailed assessment of watershed and related characteristics. The MPCA is a partner in this effort, with a primary focus on collection and assessment of water quality data for these lakes (http://www.dnr.state.mn.us/fisheries/slice/index.html).

5.4 Lake Uses

Aquatic recreation is the designated use for South Center Lake which incorporates swimming, wading, aesthetics, and other related uses. South Center Lake is heavily used for fishing, swimming, and recreation.

5.5 Lake Assessment

Water Quality

Water quality monitoring data for South Center Lake are available from 1956 to 2010. Only data from within the most recent 10 years (2001-2010) were used to determine whether South Center Lake meets lake water quality standards. The lake does not meet lake water quality standards for total phosphorus, chlorophyll-*a*, or Secchi transparency (Table 25).

Table 25 – 10-year Growing Season Mean TP, Chl-*a*, and Secchi for South Center Lake, 2001-2010.

Parameter	Growing Season Mean (June – September)	Growing Season CV* (June – September)	Lake Standard
Total phosphorus (µg/L)	50	0.09	≤ 40
Chlorophyll-*a* (µg/L)	40	0.18	≤ 14
Secchi transparency (m)	1.3	0.09	≥ 1.4

*CV = coefficient of variation. CV is used as input into the Bathtub model, and is defined in Bathtub as standard error divided by mean

Between 2001 and 2010, the growing season mean annual TP, Chl-*a*, and Secchi transparency were variable with no visible trend (Figure 22, Figure 23, and Figure 24). In 2010, growing season mean TP slightly exceeded the lake water quality standard (Figure 22) and Chl-*a* greatly exceeded the lake water quality standard (Figure 23). In 2010, growing season mean Secchi transparency met the lake water quality standard but the lowest transparency reading did not (Figure 24). In 2008, maximum TP and Chl-*a* levels and minimum transparency occurred in August (Figure 25).

Figure 22 – Growing Season Means ± SE of Total Phosphorus for South Center Lake by Year. The dashed line represents the lake water quality standard for TP (40 µg/L).

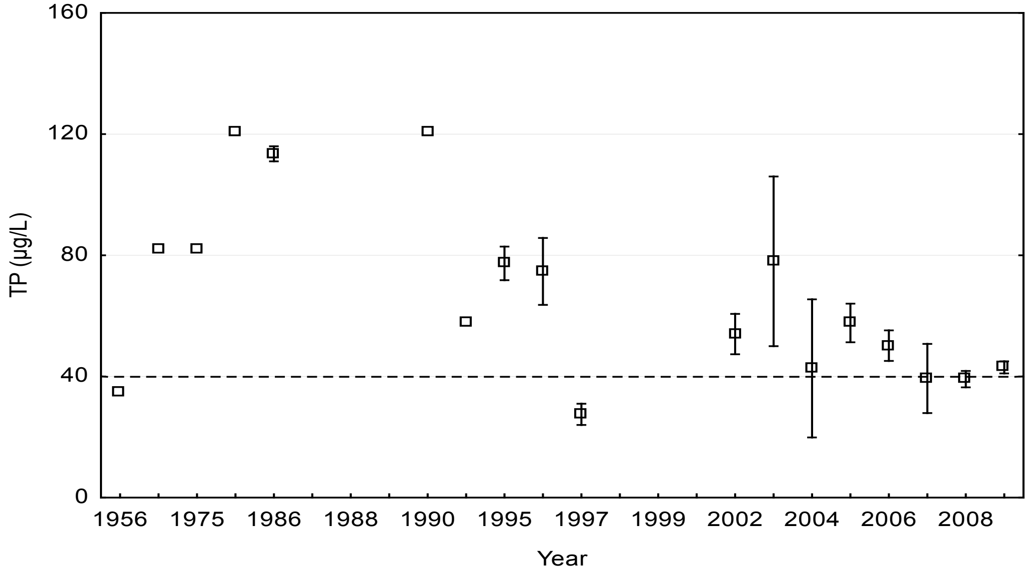


Figure 23 – Growing Season Means ± SE of Chlorophyll-*a* for South Center Lake by Year. The dashed line represents the lake water quality standard for Chl-a (14 µg/L).

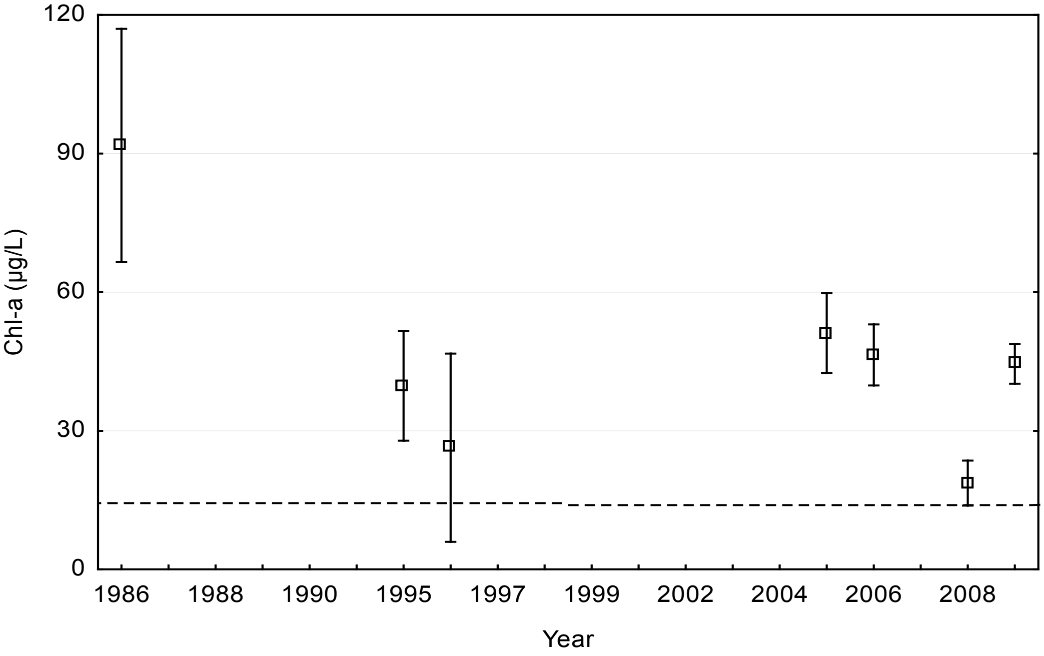


Figure 24 – Growing Season Means ± SE of Secchi Transparency for South Center Lake by Year. The dashed line represents the lake water quality standard for transparency (1.4 m).

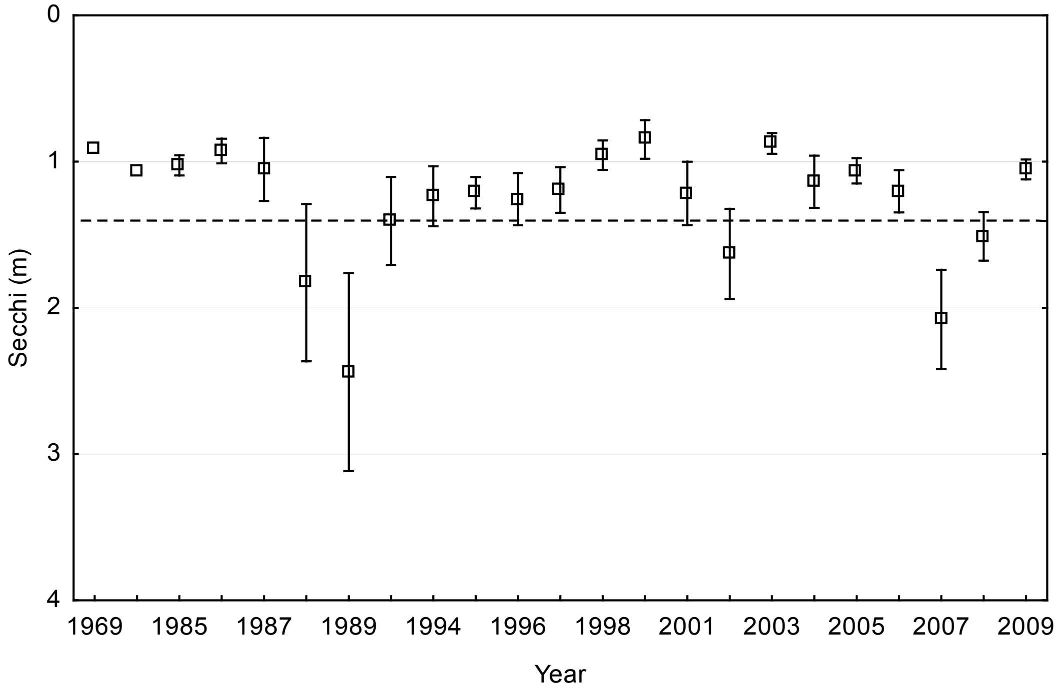
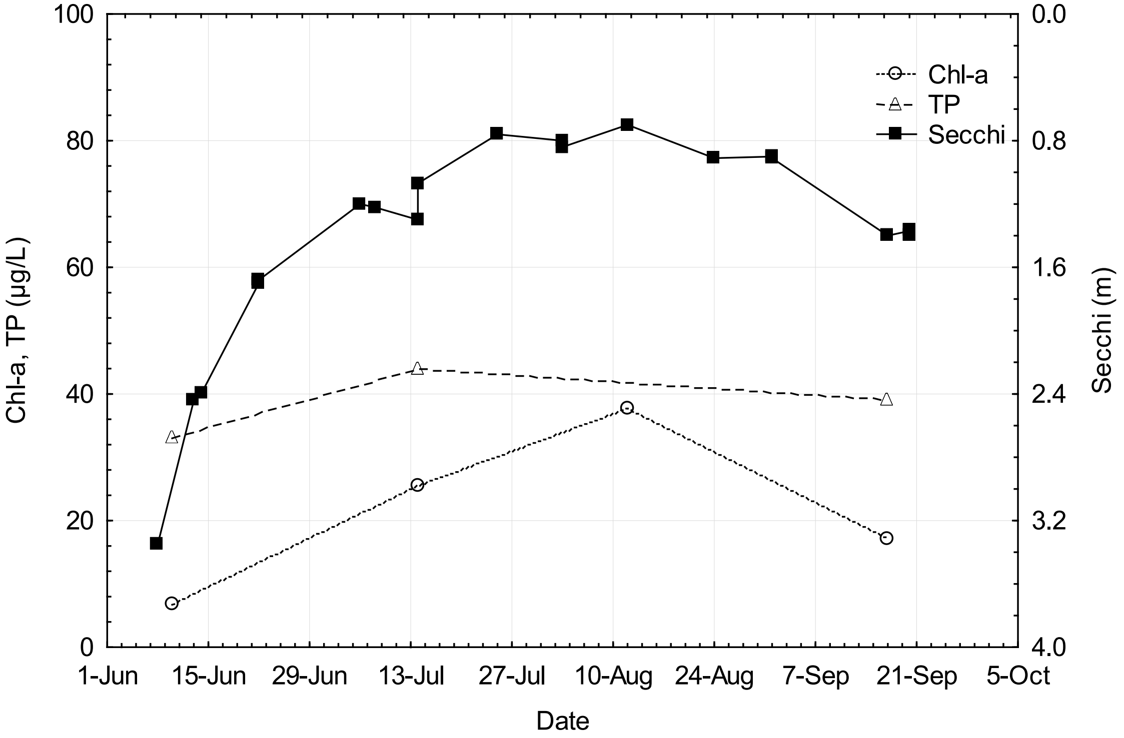


Figure 25 – Growing Season Trends of Chl-*a*, TP, and Secchi Transparency in 2008 for South Center Lake.



Macrophytes

Heavy algae blooms have been noted since at least 1956. Curly-leaf pondweed has been in South Center Lake since at least 1969. Curly-leaf pondweed is the most common aquatic plant found in the vegetation surveys. Eurasian watermilfoil was found in South Center Lake in 2009 (one year earlier it was found in North Center Lake which is connected by a channel). Although curlyleaf pondweed has been the dominant species in early to mid summer sampling, point-intercept surveys done in August for SLICE monitoring have shown coontail (Ceratophyllum demersum) as the most abundant species, at least until 2010. Hybrid watermilfoil went from 2.2% occurrence in 2009 to 65.8% in 2010. Preliminary results from August 2011 sampling indicate hybrid milfoil abundance was down slightly (53.7%) while coontail increased from 35.8% in 2010 to 69.6% in 2011. Dense mats of Eurasian watermilfoil were observed in 2010 which made navigation difficult.

An unexpected result of the 4 year SLICE monitoring was that curlyleaf abundance declined in several lakes over the course of the study. This may have had to do more with short term variations in snow cover than a long term trend.

Plankton Community

The only known plankton data has been collected through the SLICE program that is a partnership between the MPCA and the MN DNR. South Center Lake was chosen as a Sentinel Lake. Zooplankton samples were collected monthly from ice-out (April/May) through October 2010. Two replicate vertical tows were taken at each sampling event. The net was lowered to within 0.5 meter of the bottom and withdrawn at a rate of approximately 0.5 meters per second. Contents were rinsed into sample bottles and preserved with 100% reagent alcohol. Analysis was conducted by MN DNR personnel. More information can be found when the results are published (http://www.dnr.state.mn.us/fisheries/slice/index.html Sentinel Lake Assessment Report, MN DNR, 2011).

Fish

South Center Lake was noted as a “Walleye Lake” in 1975. The lake has been primarily managed for walleye and northern pike with largemouth bass, black crappie, and bluegill as secondary species. South Center was historically the best suited of the connected lakes for walleye and has had some natural spawning of walleye over the years. Stocking has been taking place about every other year for many years. Fishing pressure has been heavy for years – in 1941, 200 boats were counted on a busy Sunday. Species identified in the 2010 MN DNR fish survey include black bullhead, black crappie, bluegill, bowfin, brown bullhead, common carp, golden shiner, hybrid sunfish, largemouth bass, northern pike, pumpkinseed sunfish, walleye, white sucker, yellow bullhead, and yellow perch. Tournament fishing for bass also occurs during the summer months. The average weight of northern pike in South Center Lake is well above average, over two times the average size for similar lakes, due to low numbers of young fish recruiting to the population. This has exacerbated by recent low water levels and possibly modifications to historical spawning runs. Common carp were first identified in 1995; however, the abundance of carp is low.

5.6 Phosphorus Source Inventory

Through model calibration, 780 pounds of phosphorus were determined to be from a mix of watershed and internal load sources. These mixed sources were distributed as follows: 75% (585 lb/yr) to external load and 25% (195 lb/yr) to internal load (see Table 15 on page 47).

Watershed + Shallow Groundwater Phosphorus Sources

The contributing watershed to South Center Lake includes watershed runoff and shallow groundwater coming from the direct drainage to the lake and drainage from upstream waters: Linn and Ogren Lakes. Drainage from Linn Lake is via shallow groundwater only; drainage from Ogren Lake is from watershed runoff and shallow groundwater.

The SWAT model estimated that South Center Lake receives 1,800 pounds of phosphorus annually from watershed runoff and shallow groundwater flow: 1,100 pounds from the direct watershed and 700 pounds from upstream lakes. An additional 585 pounds were added from the mixed sources, for a total of 1,685 pounds per year from the direct watershed (Table 26). Approximately 30% of the load comes from upstream lakes.

The SWAT model estimated the 2030 phosphorus load from watershed runoff and shallow groundwater from the direct watershed (areas excluding upstream lakes) to be 1,200 lb/yr based on projected population estimates and resulting development. This represents a 9% increase in phosphorus loading from existing conditions (1,100 lb/yr). Due to the changed economic climate, development is slower than projections; the total additional load may not be realized until 2040 or later.

Table 26 – South Center Lake Watershed Runoff and Shallow Groundwater Phosphorus Source Summary

Phosphorus Source	Annual P Load (lb/yr)	Percent of P Load (%)	Flow Volume[1] (AF/yr)	Area (ac)	Equiv. Depth of Flow (in/yr)	Average Areal P Load (lb/ac-yr)[2]	Average P Conc. (µg/L)[3]
Direct Loading	1,685	71%	2,936	4,635	7.6	0.36	212
Loading from Upstream Waters (Linn[4])[5]	290	12%	983	1,326	8.9	0.22	109
Loading from Upstream Waters (Ogren)[5]	410	17%	2,490	4,150	7.2	0.10	61
Total	**2,385**	**100%**	**6,409**	**10,111**	**7.6**	**0.24**	**138**

[1] Watershed runoff plus shallow groundwater flow

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

[3] Annual TP load (lb/yr) divided by average annual flow volume; values are rounded to the nearest whole number

[4] Shallow groundwater only; P load and concentration are dissolved P only

[5] Calculations are from immediately downstream of lake; includes lake area and drainage area

About half of the South Center Lake watershed is serviced by city sanitary sewer. The homes not serviced by city sewer are assumed to have private on-site septic systems, which are estimated to have a 25% failure rate. Ten imminent threat to public health septic systems in the direct drainage area have been recently upgraded, two of these are within the shoreland area. Nine animal operations exist within the entire drainage area. Two other impaired lakes subwatersheds (Linn, Ogren) flow into South Center Lake.

Atmospheric Phosphorus Sources

Atmospheric deposition is estimated to be 200 lb/yr (see *Atmospheric Deposition* in Section 2.2 for more information).

Internal Phosphorus Sources

The modeled internal load based on sediment phosphorus content indicates that internal loading accounts for an additional 19,000 lb/yr of phosphorus loading to the lake. The sediment sample was taken from the small deep hole in South Center Lake (109 feet deep). Phosphorus is likely concentrated in the sediments in this deep hole and the modeled internal loading rate is an overestimate. The internal loading rate from North Center Lake was applied to the surface area of South Center Lake, for a total of 3,500 lb/yr internal loading to South Center Lake.

Phosphorus Load Summary

The total modeled phosphorus load to South Center Lake is 6,125 lb/yr (Table 27).

Table 27 – South Center Lake Phosphorus Source Summary, Existing Loads

Phosphorus Source	Phosphorus Load (lb/yr)
Watershed + Shallow Groundwater	2,385
Atmospheric	240
Internal Load	3,500
Total	**6,125**

5.7 Impairment Assessment Summary

- The lake water quality violates the phosphorus, chlorophyll-*a*, and Secchi transparency water quality standards.
- The last aquatic plant survey noted that the lake vegetation is dominated by curly-leaf pondweed, visual inspections by area residents have also noted a substantial increase in Eurasian water milfoil over the past 2 years. Curly-leaf pondweed contributes to internal loading from the sediments.
- Black bullhead and carp are present in the lake, which could lead to high internal loading rates due to their habit of foraging in bottom sediments.
- Phosphorus concentration in sediments is high, indicating a high potential for internal loading from sediments.
- A large portion of the shoreline is developed.
- Approximately 51% of the watershed is cropland, and there are 3 animal operations in the direct drainage area.
- Approximately half of the watershed is served by private on-site septic systems, which are estimated to have a 25% failure rate.
- Ten imminent threat to public health septic systems, 2 of which were in the shoreland area, were recently upgraded.
- Two other impaired lakes drain to South Center Lake: Linn Lake and Ogren Lake.

5.8 TMDL Loading Capacity and Allocations

The phosphorus loading capacity of South Center Lake is 5,405 lb/yr, to be split among allocations according to Table 28. While there are currently no regulated MS4s in the South Center Lake watershed, should a portion of the watershed come under regulation by a MS4 permit in the future the transfer rate from LA to WLA for regulated MS4 stormwater runoff is 0.18 lb/ac-yr, or 0.00049 lb/ac-day. This transfer rate applies to the direct drainage area of South Center Lake; it does not apply to the watersheds of the upstream impaired lakes (Linn and Ogren).

Table 28 – South Center Lake TP Allocations

Load Component	TP Existing	TP TMDL Allocation		TP Reduction	
	lb/yr	lb/yr	lb/day	lb/yr	%
WLA					
Construction stormwater (permit #MNR100001)	1.3	1.3	0.0036	0	0%
Industrial stormwater (permit # MNR50000)	1.3	1.3	0.0036	0	0%
Total WLA	**2.6**	**2.6**	**0.0072**	**0**	**0%**
LA*					
Watershed (direct runoff)	1,682	840	2.3	842	50%
Watershed (upstream lakes)	700	490	1.3	210	30%
Atmospheric	240	240	0.66	0	0%
Internal	3,500	3,292	9.0	208	5.9%
Total LA	**6,122**	**4,862**	**13**	**1,260**	**21%**
MOS	**--**	**541**	**1.5**		
Total	***6,125***	***5,405***	***15***		

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

To meet the TMDL with a 10% margin of safety, the total load to the lake needs to be reduced by 1,260 lb/yr (21%).

The load reduction goals are based on the following:

- If the impaired upstream lakes attain water quality standards, the load to South Center will be reduced by 210 lb/yr.
- The watershed runoff load from the direct drainage area should be reduced by 842 lb/yr (50%).
- The remaining reductions should come from internal loading (208 lb/yr, or 5.9%).

6 LAKE EMILY TMDL

6.1 Physical Characteristics

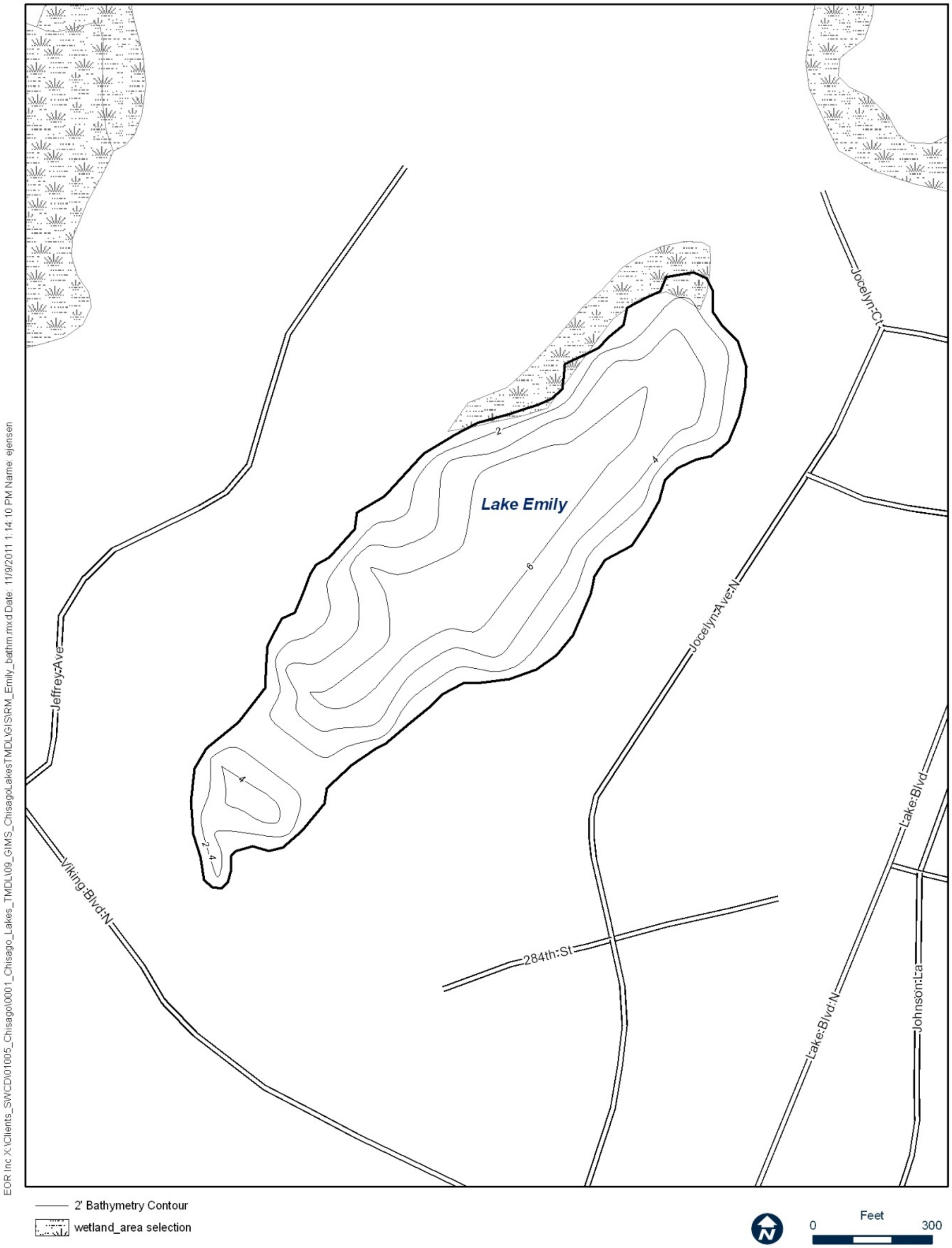
Lake Emily (MN DNR Lake ID 13-0046) is a lake located in southern Chisago County. This waterbody is listed as a wetland on the Public Waters Inventory; however, it is used as a lake. There is no public access on Lake Emily. Table 29 summarizes the lake's physical characteristics, Figure 26 shows the 2007 aerial photography, and Figure 27 illustrates the available bathymetry.

Table 29 – Lake Emily Physical Characteristics

Characteristic	Value	Source
Lake total surface area (ac)	17	MN DNR Public Waters Inventory GIS Shapefile
Percent lake littoral surface area (%)	100	MN DNR Lake Finder
Lake volume (ac-ft)	64	Calculated from bathymetric data collected by EOR in 2011
Mean depth (ft)	3.7	Lake volume ÷ surface area
Maximum depth (ft)	7	MN DNR Lake Finder
Drainage area (ac)	110	SWAT model (HDR 2008)
Watershed area: Lake area	6.5	Calculated

Figure 26 – Lake Emily 2007 Aerial Photography

Figure 27 – Lake Emily Bathymetry
Data collected in July 2011



6.2 Land Cover

Table 30 – Lake Emily Watershed Land Cover

Land Use	Direct Drainage		Entire Drainage	
	Total Acres	% of Watershed	Total Acres	% of Watershed
Developed	2.3	1.8	No other contributing drainage areas	
Cropland	100.6	79.2		
Grassland	5.1	4.0		
Aquatic Habitat	0.0	0.0		
Woodland	2.0	1.6		
Lake Emily Lake Surface Area	17.0	13.4		
Total	**127.0**	**100%**		

6.3 Existing Studies, Monitoring, and Management

Lake Emily was monitored through the Surface Water Assessment Grant program with the MPCA and SWCD in 2008 and 2009. This monitoring was completed by volunteers who live on the lake.

6.4 Lake Uses

Aquatic recreation is the designated use for Lake Emily which incorporates swimming, canoeing, aesthetics, and other related uses. Lake Emily is used as a lake rather than a wetland.

6.5 Lake Assessment

Water Quality

Water quality monitoring data for Lake Emily are available from 2008 to 2009. The lake does not meet shallow lake water quality standards for total phosphorus, chlorophyll-*a*, or Secchi transparency (Table 31).

Table 31 – 10-year Growing Season Mean TP, Chl-*a*, and Secchi for Lake Emily, 2001-2010.

Parameter	Growing Season Mean (June – September)	Growing Season CV* (June – September)	Shallow Lake Standard
Total phosphorus (µg/L)	341	0.02	≤ 60
Chlorophyll-*a* (µg/L)	152	0.40	≤ 20
Secchi transparency (m)	0.3	0.15	≥ 1.0

*CV = coefficient of variation. CV is used as input into the Bathtub model, and is defined in Bathtub as standard error divided by mean

The growing season mean of TP, Chl-*a*, and Secchi transparency in Lake Emily violated shallow lake water quality standards in 2008 and 2009 (Figure 28, Figure 29, and Figure 30). In addition, Chl-*a* increased in 2009 relative to 2008 (Figure 29) with a corresponding decrease in transparency (Figure 30). In 2008, water quality varied throughout the season, but Chl-*a* peaked in August and TP peaked at the beginning of October (Figure 31).

Figure 28 – Growing Season Means ± SE of Total Phosphorus for Lake Emily by Year. The dashed line represents the shallow lake water quality standard for TP (60 µg/L).

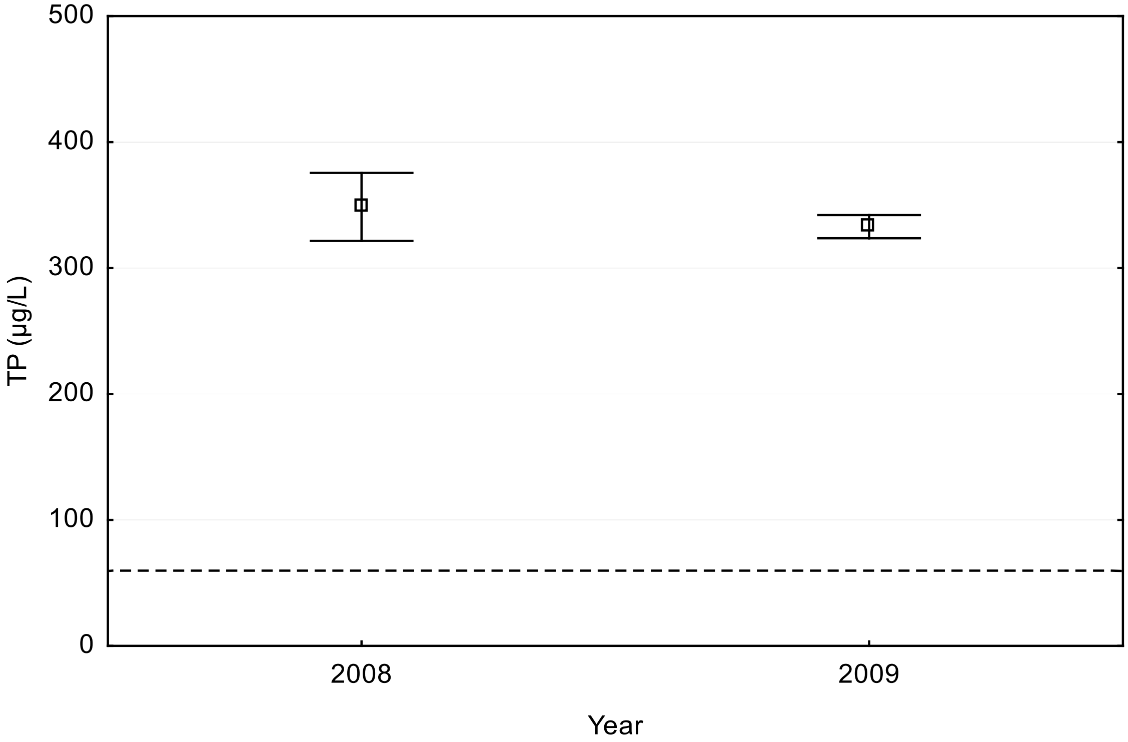


Figure 29 – Growing Season Means ± SE of Chlorophyll-*a* for Lake Emily by Year. The dashed line represents the shallow lake water quality standard for Chl-a (20 µg/L).

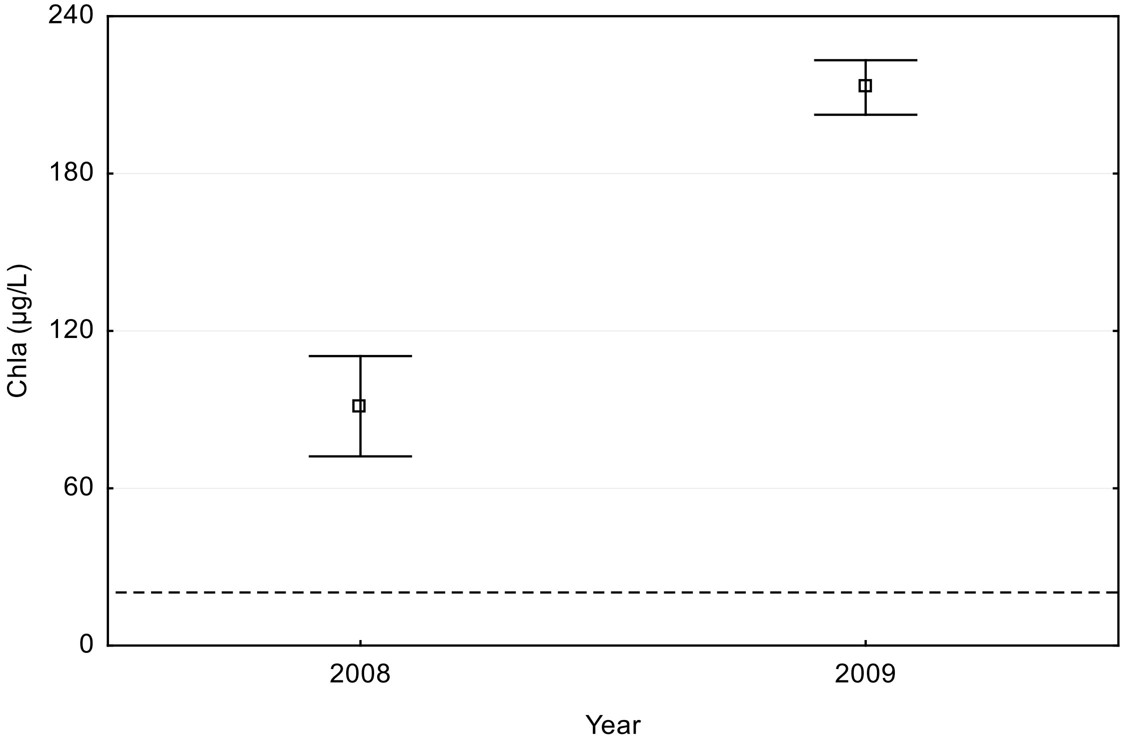


Figure 30 – Growing Season Means ± SE of Secchi Transparency for Lake Emily by Year. The dashed line represents the shallow lake water quality standard for transparency (1.0 m).

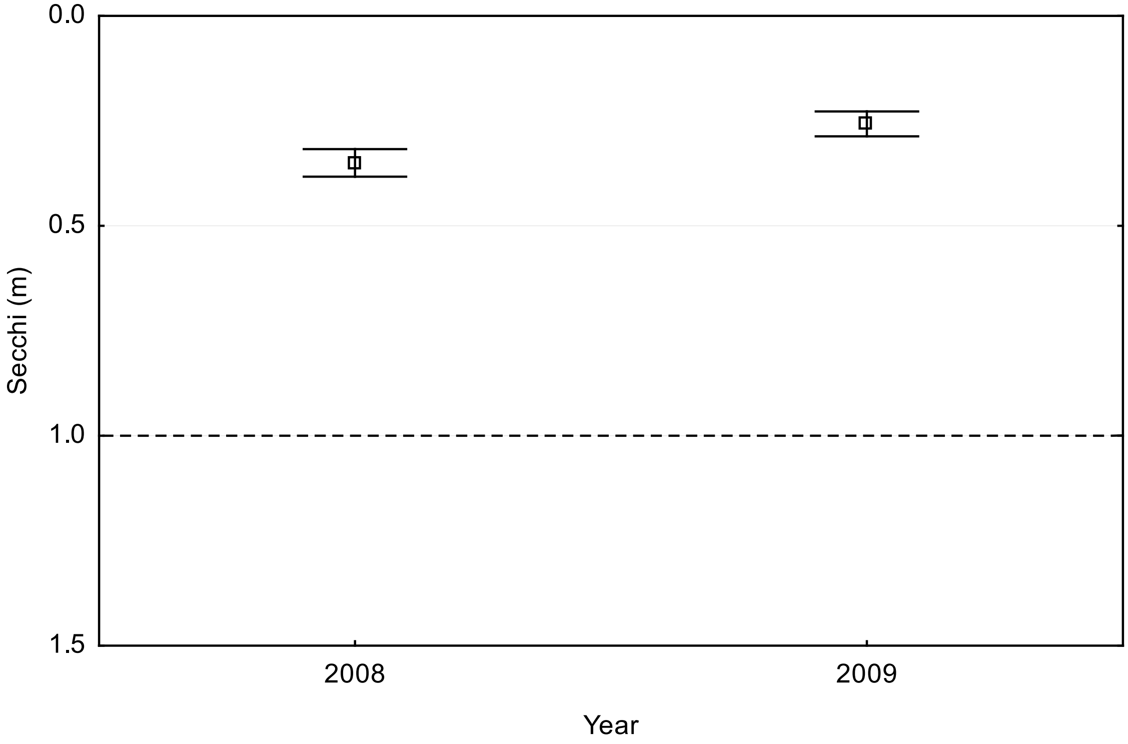
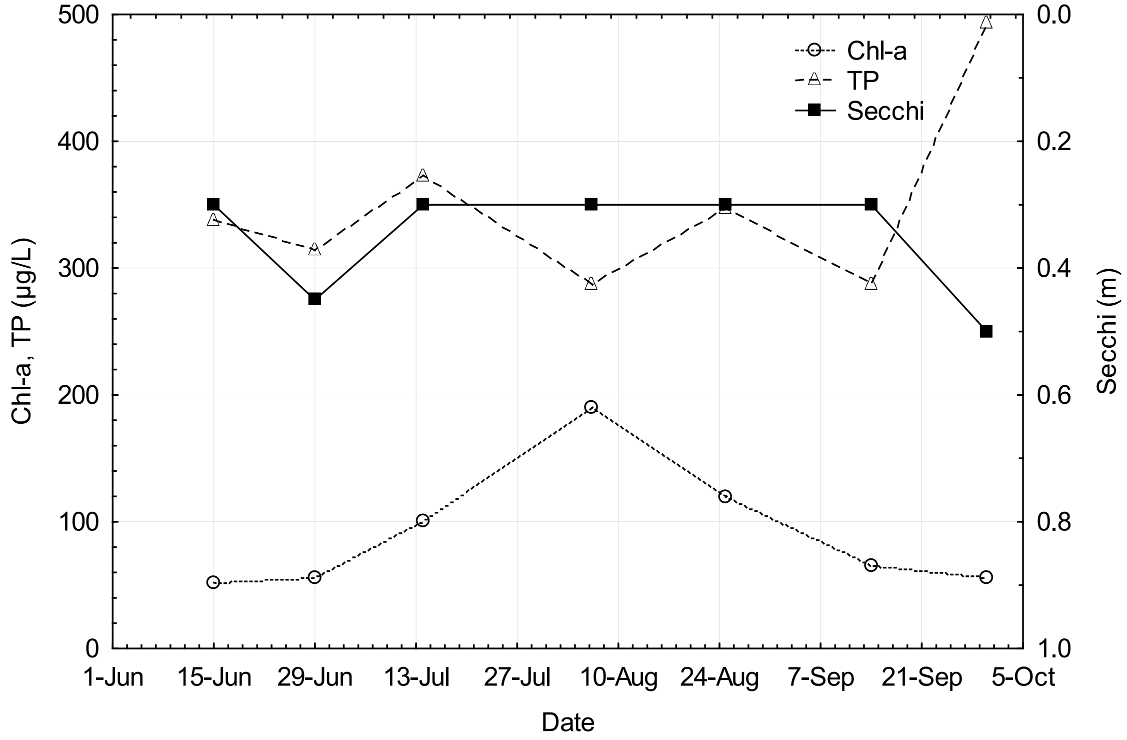


Figure 31 – Growing Season Trends of Chl-*a*, TP, and Secchi Transparency for Lake Emily, 2008.



Macrophytes

Very few submergent plants exist; a small cattail fringe exists on the lake edge. The lake is known to have curly-leaf pondweed, which contributes to the poor water quality when it dies off in the summer.

Fish

Very few species of fish live in Lake Emily. There is an abundance of stunted sunfish and black bullheads. High black bullhead populations are indicative of lakes that experience partial or near-complete winterkill. Lakes without a public water access are not actively managed for recreational fishing and are not routinely surveyed by the MN DNR Section of Fisheries.

6.6 Phosphorus Source Inventory

Through model calibration, 370 pounds of phosphorus were determined to be from a mix of watershed and internal load sources. These mixed sources were distributed as follows: 25% (93 lb/yr) to external load and 75% (278 lb/yr) to internal load (see Table 15 on page 47).

Watershed + Shallow Groundwater Phosphorus Sources

The SWAT model estimated that Lake Emily receives 13 pounds of phosphorus annually from watershed runoff and shallow groundwater flow, and an additional 93 pounds were added from the mixed sources, for a total of 106 pounds per year from direct loading (Table 32). The 2030 phosphorus load from watershed runoff and shallow groundwater (based on projected population estimates and resulting development) shows no increase from existing conditions.

Table 32 – Lake Emily Watershed Runoff and Shallow Groundwater Phosphorus Source Summary

Phosphorus Source	Annual P Load (lb/yr)	Flow Volume[1] (AF/yr)	Area (ac)	Equiv. Depth of Flow (in/yr)	Average Areal P Load (lb/ac-yr)[2]	Average P Conc. (µg/L)[3]
Direct Loading	106	82	110	8.9	0.96	477

[1] Watershed runoff plus shallow groundwater flow
[2] Annual TP load (lb/yr) divided by drainage area (ac)
[3] Annual TP load (lb/yr) divided by average annual flow volume; values are rounded to the nearest whole number

None of the Lake Emily watershed is serviced by city sanitary sewer. The homes have private on-site septic systems, which are estimated to have a 25% failure rate. Zero imminent threat to public health septic systems were identified within the watershed. Zero animal operations exist within the contributing watershed area.

Atmospheric Phosphorus Sources

Atmospheric deposition is estimated to be 4.6 lb/yr (see *Atmospheric Deposition* in Section 2.2 for more information).

Internal Phosphorus Sources

The modeled internal load based on sediment phosphorus content indicates that internal loading accounts for an estimated 0 to 23 lb/yr of phosphorus loading to the lake. Mixed phosphorus sources identified through the lake modeling suggest that the internal load is 278 lb/yr. An internal load of 278 lb/yr phosphorus was assumed for Lake Emily, representing approximately 71% of the total load to the lake.

Phosphorus Load Summary

The total modeled phosphorus load to Lake Emily is 389 lb/yr (Table 33).

Table 33 – Lake Emily Phosphorus Source Summary, Existing Loads

Phosphorus Source	Phosphorus Load (lb/yr)
Watershed + Shallow Groundwater	106
Atmospheric	4.6
Internal	278
Total	**389**

6.7 Impairment Assessment Summary

- The lake water quality violates the phosphorus, chlorophyll-*a*, and Secchi transparency water quality standards. The lake is hypereutrophic, with an average phosphorus concentration of 350 µg/l.
- Lake Emily is a classified as a wetland by MN DNR but is used recreationally as a lake.
- Curly-leaf pondweed exists in the lake, although the extent is not known. Curly-leaf pondweed contributes to internal loading from the sediments.
- There is an abundance of stunted sunfish and black bullhead. The presence of stunted sunfish often indicates an overabundance of planktivorous fish such as sunfish. This overabundance leads to overgrazing on zooplankton and a resultant increase in algae. Black bullhead can lead to high internal loading rates due to their habit of foraging in bottom sediments.
- A large portion of the shoreline is developed.
- Approximately 80% of the watershed is cropland.
- The entire watershed is served by private on-site septic systems, which are estimated to have a 25% failure rate.
- The lake model indicated that there is a large phosphorus load that is unaccounted for in the current phosphorus source inventory. This load is likely a mix of internal load and load from failing septic systems.

6.8 TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Lake Emily is 30 lb/yr, to be split among allocations according to Table 34. While there are currently no regulated MS4s in the Lake Emily watershed; should a portion of the watershed come under regulation by a MS4 permit in the future, the transfer rate from LA to WLA for regulated MS4 stormwater runoff is 0.056 lb/ac-yr, or 0.00015 lb/ac-day.

Table 34 – Lake Emily TP Allocations

Load Component	TP Existing	TP TMDL Allocation		TP Reduction	
	lb/yr	lb/yr	lb/day	lb/yr	%
WLA					
Construction stormwater (permit #MNR100001)	0.0099	0.0099	0.000027	0	0%
Industrial stormwater (permit # MNR50000)	0.0099	0.0099	0.000027	0	0%
Total WLA	**0.020**	**0.020**	**0.000054**	**0**	**0%**
LA*					
Watershed	106	6.2	0.017	100	94%
Atmospheric	4.6	4.6	0.013	0	0%
Internal	278	16	0.044	262	94%
Total LA	**389**	**27**	**0.074**	**362**	**93%**
MOS	**--**	**3**	**0.0082**		
Total	***389***	***30***	***0.082***		

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

To meet the TMDL with a 10% margin of safety, the total load to the lake needs to be reduced by 362 lb/yr (93%).

The load reduction goals are based on the following:

- Equal percent reductions were assigned for runoff and internal load.

7 LINN LAKE TMDL

7.1 Physical Characteristics

Linn Lake (MN DNR Lake ID 13-0014) is a shallow lake located in southern Chisago County, south of Lindstrom. Table 35 summarizes the lake's physical characteristics. Figure 32 shows the 2007 aerial photography. There are no bathymetric data available for Linn Lake.

Table 35 – Linn Lake Physical Characteristics

Characteristic	Value	Source
Lake total surface area (ac)	177	Digitized from LMIC WMS Server 2010 aerial photograph
Percent lake littoral surface area (%)	100	MN DNR Lake Finder
Lake volume (ac-ft)	1,062	Mean depth x surface area
Mean depth (ft)	6	EOR field estimation (August 2011)
Maximum depth (ft)	11	EOR field measurement (August 2011)
Drainage area (ac)	1,149	SWAT model (HDR 2008)
Watershed area: Lake area	6.5	Calculated

Figure 32 – Linn Lake 2007 Aerial Photography

7.2 Land Cover

Table 36 – Linn Lake Watershed Land Cover

Land Use	Direct Drainage		Entire Drainage	
	Total Acres	% of Watershed	Total Acres	% of Watershed
Developed	8.7	0.6	No other contributing drainage areas	
Cropland	767.2	57.9		
Grassland	85.2	6.4		
Aquatic Habitat	134.7	10.2		
Woodland	153.2	11.6		
Linn Lake Surface Area	177.0	13.3		
Total	**1,326.0**	**100%**		

7.3 Existing Studies, Monitoring, and Management

Linn Lake is designated as a State Game Refuge and has been managed for waterfowl throughout the years. Linn Lake was monitored through the Surface Water Assessment Grant program with the MPCA and SWCD in 2008 and 2009. This monitoring was completed by volunteers who live on the lake.

7.4 Lake Uses

Aquatic recreation is the designated use for Linn Lake which incorporates swimming, wading, aesthetics, and other related uses. There is no public access to the lake. Residents of this lake use it for canoeing, boating, and some fishing.

7.5 Lake Assessment

Water Quality

Water quality monitoring data for Linn Lake are available from 2008 to 2009. The lake does not meet shallow lake water quality standards for total phosphorus, chlorophyll-*a*, or Secchi transparency (Table 37).

Table 37 – 10-year Growing Season Mean TP, Chl-*a*, and Secchi for Linn Lake, 2001-2010.

Parameter	Growing Season Mean (June – September)	Growing Season CV* (June – September)	Shallow Lake Standard
Total phosphorus (µg/L)	217	0.03	≤ 60
Chlorophyll-*a* (µg/L)	88	0.33	≤ 20
Secchi transparency (m)	0.4	0.16	≥ 1.0

*CV = coefficient of variation. CV is used as input into the Bathtub model, and is defined in Bathtub as standard error divided by mean

The growing season mean of TP, Chl-*a*, and Secchi transparency in Linn Lake violated shallow lake water quality standards in 2008 and 2009. In addition, TP and Chl-*a* increased slightly in 2009 relative to 2008 with a corresponding decrease in transparency (Figure 33, Figure 34, and Figure 35). In 2009, water quality varied throughout the season, but was generally worse in July and August (Figure 36).

Figure 33 – Growing Season Means ± SE of Total Phosphorus for Linn Lake by Year. The dashed line represents the shallow lake water quality standard for TP (60 µg/L).

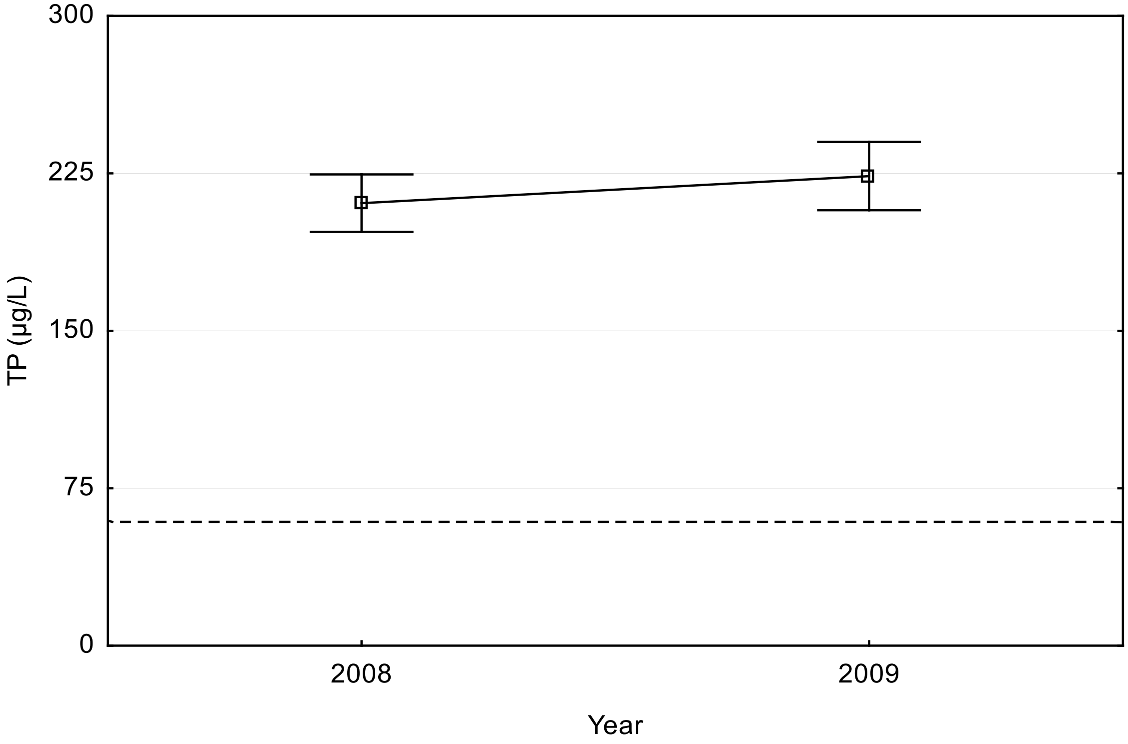


Figure 34 – Growing Season Means ± SE of Chlorophyll-*a* for Linn Lake by Year. The dashed line represents the shallow lake water quality standard for Chl-a (20 µg/L).

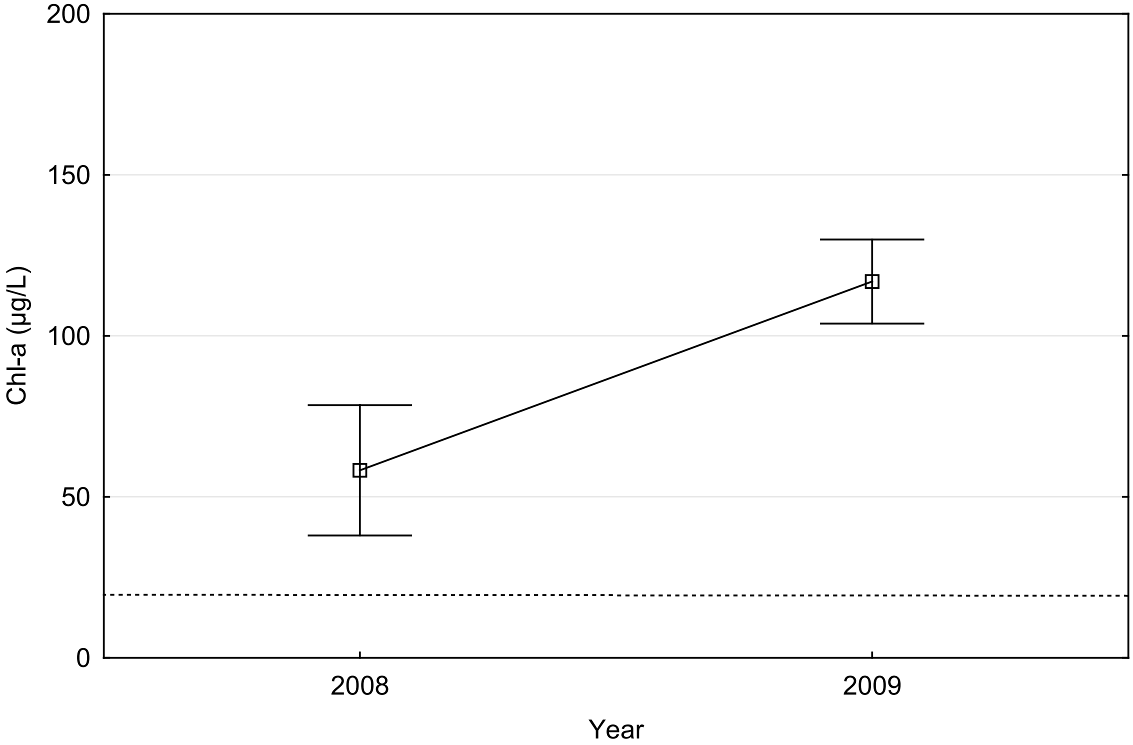


Figure 35 – Growing Season Means ± SE of Secchi Transparency for Linn Lake by Year. The dashed line represents the shallow lake water quality standard for transparency (1.0 m).

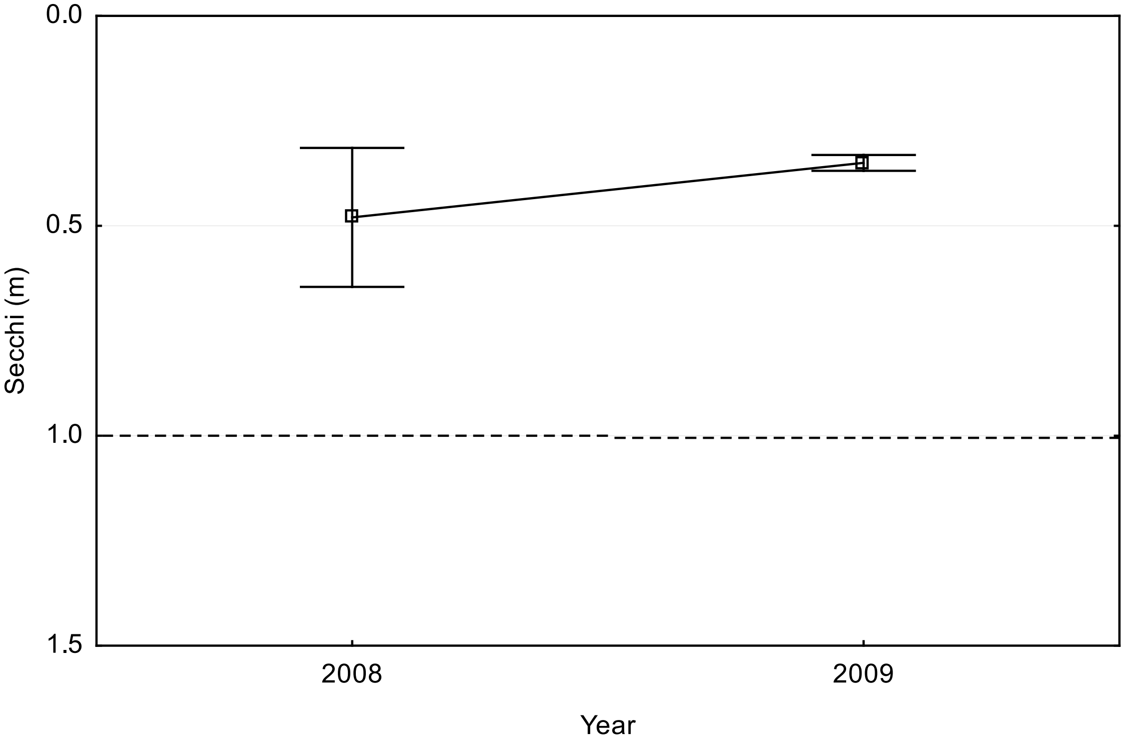
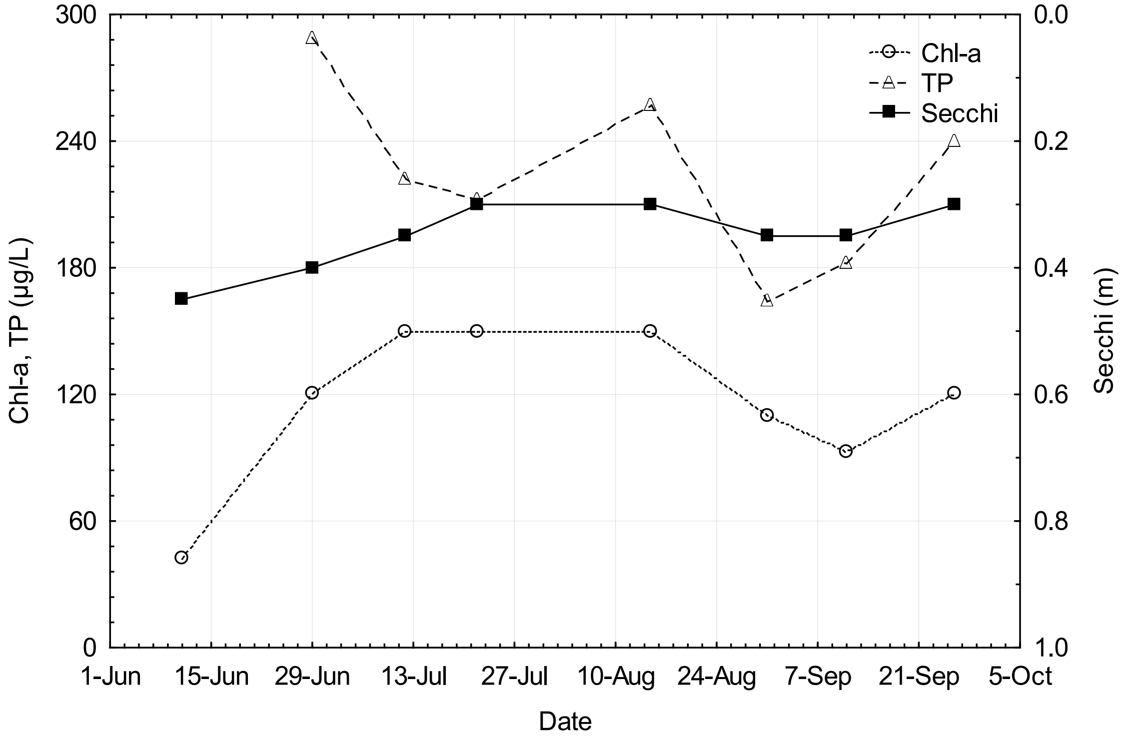


Figure 36 – Growing Season Trends of Chl-*a*, TP, and Secchi Transparency for Linn Lake, 2009.



Macrophytes

Linn Lake has very few macrophytes present. Curly leaf pondweed has been identified in this lake. Curly-leaf pondweed was not present in 1978, but was verified in 2008. Canada waterweed, water lily, and duckweed are also present in the lake. Many emergent plants are also present. The entire fringe of the lakeshore is cattails.

Fish

Many fish species were surveyed in 1978; however a more recent fish survey is not available. Species caught include: northern pike, hybrid sunfish, brown bullhead, black bullhead, pumpkinseed sunfish, and bluegill. In 1978, the numbers of black and brown bullhead were extremely high compared to state medians. High black bullhead populations are indicative of lakes that experience partial or near-complete winterkill. Northern pike population was also very high compared to similar lakes throughout Minnesota. Lakes without a public water access are not actively managed for recreational fishing and are not routinely surveyed by the MN DNR Section of Fisheries.

7.6 Phosphorus Source Inventory

Through model calibration, 2,300 pounds of phosphorus were determined to be from a mix of watershed and internal load sources. These mixed sources were distributed as follows: 25% (575 lb/yr) to external load and 75% (1,725 lb/yr) to internal load (see Table 15 on page 47).

Watershed + Shallow Groundwater Phosphorus Sources

The SWAT model estimated that Linn Lake receives 370 pounds of phosphorus annually from watershed runoff and shallow groundwater flow, and an additional 575 pounds were added from the mixed sources, for a total of 945 pounds per year from direct loading (Table 38). The 2030 phosphorus load from watershed runoff and shallow groundwater (based on projected population estimates and resulting development) shows no increase from existing conditions.

Table 38 – Linn Lake Watershed Runoff and Shallow Groundwater Phosphorus Source Summary

Phosphorus Source	Annual P Load (lb/yr)	Flow Volume[1] (AF/yr)	Area (ac)	Equiv. Depth of Flow (in/yr)	Average Areal P Load (lb/ac-yr)[2]	Average P Conc. (µg/L)[3]
Direct Loading	945	689	1,149	7.2	0.82	506

[1] Watershed runoff plus shallow groundwater flow
[2] Annual TP load (lb/yr) divided by drainage area (ac)
[3] Annual TP load (lb/yr) divided by average annual flow volume; values are rounded to the nearest whole number

A very small portion of the Linn Lake watershed is serviced by city sanitary sewer. The majority of the homes have private on-site septic systems, which are estimated to have a 25% failure rate. Two imminent threat to public health septic systems have been recently upgraded; both of these are within the shoreland area. Three small animal operations exist within the contributing watershed area.

Atmospheric Phosphorus Sources

Atmospheric deposition is estimated to be 49 lb/yr (see *Atmospheric Deposition* in Section 2.2 for more information).

Internal Phosphorus Sources

The modeled internal load based on sediment phosphorus content indicates that internal loading accounts for an estimated 0 to 340 lb/yr of phosphorus loading to the lake. Mixed phosphorus sources identified through the lake modeling suggest that the internal load is 1,725 lb/yr. An internal load of 1,725 lb/yr phosphorus was assumed for Linn Lake, representing approximately 63% of the total load to the lake.

Phosphorus Load Summary

The total modeled phosphorus load to Linn Lake is 2,719 lb/yr (Table 39).

Table 39 – Linn Lake Phosphorus Source Summary, Existing Loads

Phosphorus Source	Phosphorus Load (lb/yr)
Watershed + Shallow Groundwater	945
Atmospheric	49
Internal	1,725
Total	**2,719**

7.7 Impairment Assessment Summary

- The lake water quality violates the phosphorus, chlorophyll-*a*, and Secchi transparency water quality standards. The lake is hypereutrophic, with an average phosphorus concentration of 217 µg/l.
- Curly-leaf pondweed exists in the lake, although the extent is not known. Curly-leaf pondweed contributes to internal loading from the sediments. Many emergent macrophytes also exist.
- In a 1978 fish survey, black bullheads were abundant; there has not been a fish survey since then. Black bullhead can lead to high internal loading rates due to their habit of foraging in bottom sediments.
- Approximately 58% of the watershed is cropland, and there are three small animal operations in the watershed.
- The majority of the watershed is served by private on-site septic systems, which are estimated to have a 25% failure rate.
- Two imminent threat to public health septic systems, both of which were in the shoreland area, were recently upgraded.
- The lake model indicated that there is a large phosphorus load that is unaccounted for in the current phosphorus source inventory. This load is likely a mix of internal load and load from failing septic systems.

7.8 TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Linn Lake is 360 lb/yr, to be split among allocations according to Table 40. While there are currently no regulated MS4s in the Linn Lake watershed, should a portion of the watershed come under regulation by a MS4 permit in the future, the transfer rate from LA to WLA for regulated MS4 stormwater runoff is 0.084 lb/ac-yr, or 0.00023 lb/ac-day.

Table 40 – Linn Lake TP Allocations

Load Component	TP Existing	TP TMDL Allocation		TP Reduction	
	lb/yr	lb/yr	lb/day	lb/yr	%
WLA					
Construction stormwater (permit #MNR100001)	0.16	0.16	0.00044	0	0%
Industrial stormwater (permit # MNR50000)	0.16	0.16	0.00044	0	0%
Total WLA	**0.32**	**0.32**	**0.00088**	**0**	**0%**
LA*					
Watershed	945	97	0.27	848	90%
Atmospheric	49	49	0.13	0	0%
Internal	1,725	178	0.49	1547	90%
Total LA	**2,719**	**324**	**0.89**	**2395**	**88%**
MOS	**--**	**36**	**0.10**		
Total	***2,719***	***360***	***0.99***		

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

To meet the TMDL with a 10% margin of safety, the total load to the lake needs to be reduced by 2,395 lb/yr (88%).

The load reduction goals are based on the following:

- Equal percent reductions were assigned for runoff and internal load.

8 LITTLE LAKE TMDL

8.1 Physical Characteristics

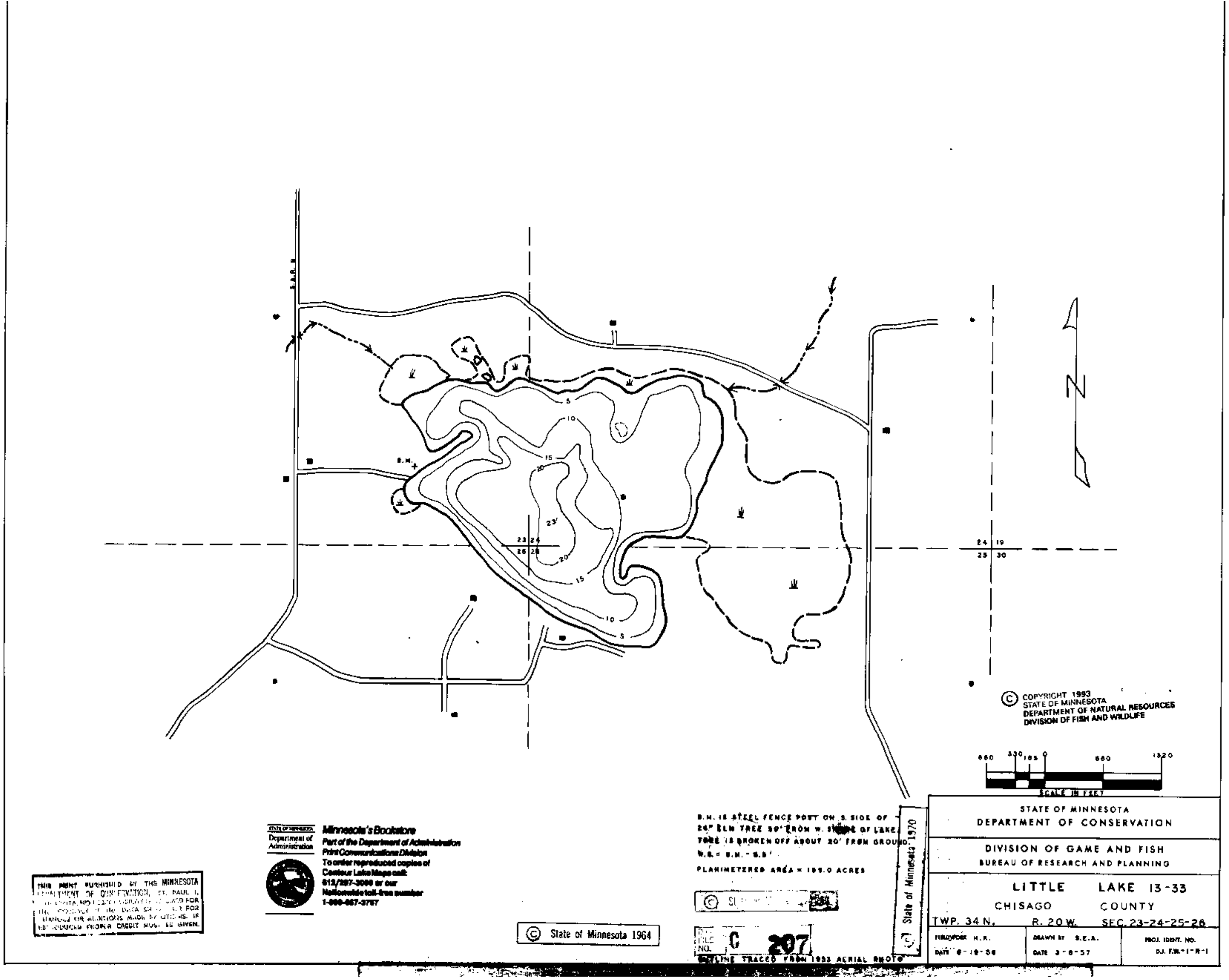
Little Lake (MN DNR Lake ID 13-0033) is a lake located in southern Chisago County, two miles northeast of Center City. Table 41 summarizes the lake's physical characteristics, Figure 37 shows the 2007 aerial photography, and Figure 38 illustrates the available bathymetry.

Table 41 – Little Lake Physical Characteristics

Characteristic	Value	Source
Lake total surface area (ac)	164	Digitized from LMIC WMS Server 2010 aerial photograph
Percent lake littoral surface area (%)	76	MN DNR Lake Finder
Lake volume (ac-ft)	1,408	Calculated from MN DNR bathymetric data using 2010 surface contour (aerial photo) and 1991-92 depth contours
Mean depth (ft)	9.4	Lake volume ÷ surface area
Maximum depth (ft)	23	MN DNR Lake Finder
Drainage area (ac)	2,014	SWAT model (HDR 2008)
Watershed area: Lake area	12.3	Calculated

Figure 37 – Little Lake 2007 Aerial Photography

Figure 38 – Little Lake Bathymetry



8.2 Land Cover

Table 42 – Little Lake Watershed Land Cover

Land Use	Direct Drainage		Entire Drainage	
	Total Acres	% of Watershed	Total Acres	% of Watershed
Developed	11.9	0.9	18.2	0.8
Cropland	595.3	47.3	1,185.7	54.5
Grassland	79.5	6.3	155.4	7.1
Aquatic Habitat	162.3	12.8	278.8	12.8
Woodland	248.9	19.7	375.9	17.3
Little Lake Surface Area	164.0	13.0	164.0	7.5
Total	**1,261.9**	**100%**	**2,178.0**	**100%**

8.3 Existing Studies, Monitoring, and Management

Little Lake has been monitored for water level and water quality through the CLLID and volunteers for many years. Data in the MPCA's water quality database dates back to 1995.

8.4 Lake Uses

Aquatic recreation is the designated use for Little Lake which incorporates swimming, wading, aesthetics, and other related uses. There are very few homes on Little Lake compared to other lakes in the area. This lake is heavily used for fishing, especially in the summer. The public access is often full to capacity in the summer.

8.5 Lake Assessment

Water Quality

Water quality monitoring data for Little Lake are available for TP and Chl-*a* in 2007 and 2008, and for Secchi transparency in 1995 and 2006-2009. Only data from within the most recent 10 years (2001-2010) were used to determine whether Little Lake meets lake water quality standards. The lake does not meet lake water quality standards for total phosphorus, chlorophyll-*a*, or Secchi transparency (Table 43).

Table 43 – 10-year Growing Season Mean TP, Chl-*a*, and Secchi depth for Little Lake, 2001-2010.

Parameter	Growing Season Mean (June – September)	Growing Season CV* (June – September)	Lake Standard
Total phosphorus (µg/L)	173	0.11	≤ 40
Chlorophyll-*a* (µg/L)	71	0.20	≤ 14
Secchi transparency (m)	0.7	0.04	≥ 1.4

*CV = coefficient of variation. CV is used as input into the Bathtub model, and is defined in Bathtub as standard error divided by mean

Growing season means of TP, Chl-*a*, and Secchi transparency in Little Lake greatly violated lake water quality standards for all available years of monitoring data. The growing season mean TP and Chl-*a* decreased in 2008 relative to 2007 (Figure 39 and Figure 40), but transparency remained relatively stable from 2006 to 2009 (Figure 41). This suggests that overall lake water quality did not significantly improve between 2008 and 2009. In 2007, maximum TP and Chl-*a* and minimum transparency occurred in mid- to late July with continued low transparency through September (Figure 42).

Figure 39 – Growing Season Means ± SE of Total Phosphorus for Little Lake by Year. The dashed line represents the lake water quality standard for TP (40 µg/L).

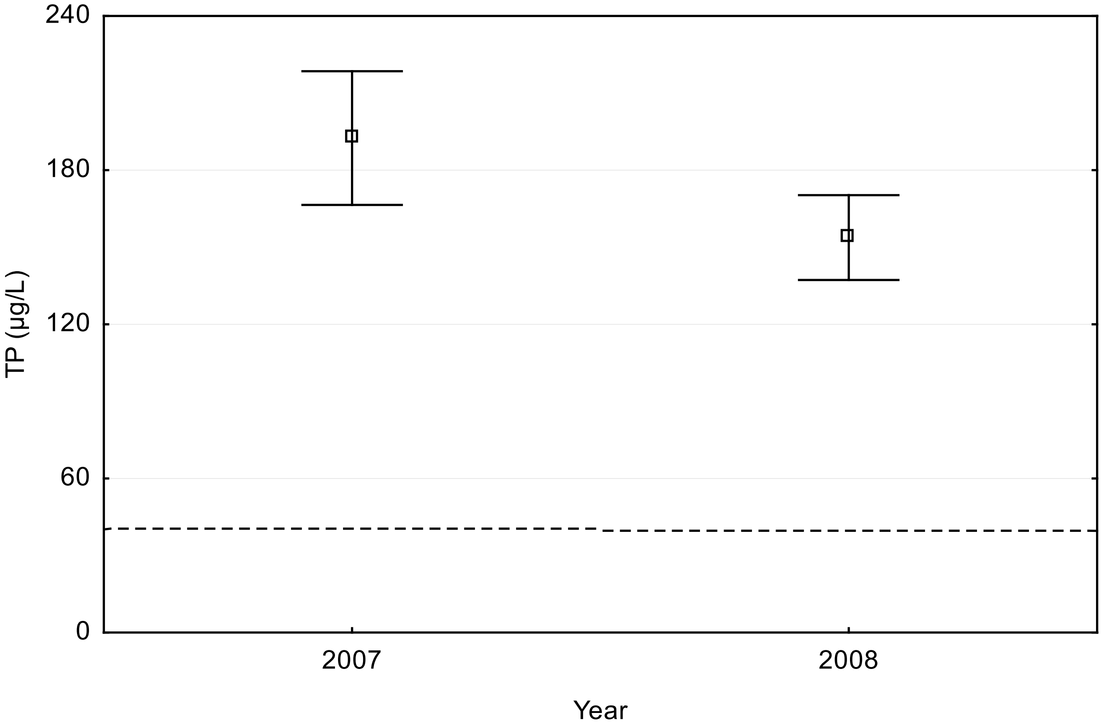


Figure 40 – Growing Season Means ± SE of Chlorophyll-*a* for Little Lake by Year. The dashed line represents the lake water quality standard for Chl-a (14 µg/L).

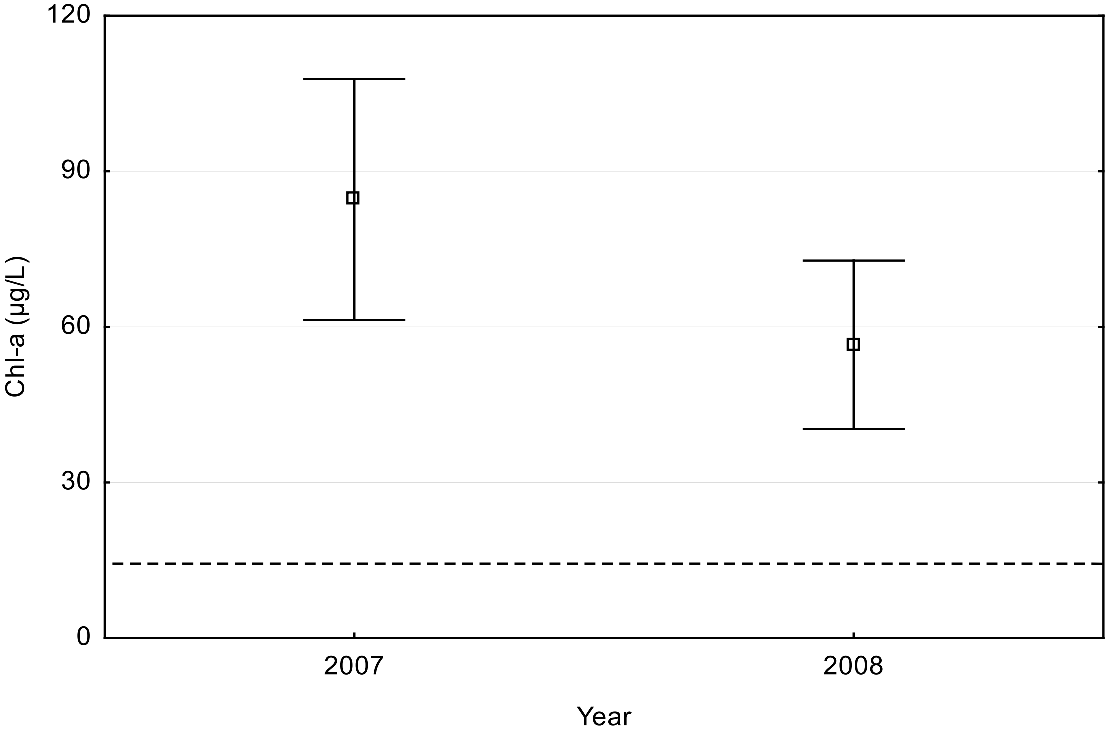


Figure 41 – Growing Season Means ± SE of Secchi Transparency for Little Lake by Year. The dashed line represents the lake water quality standard for transparency (1.4 m).

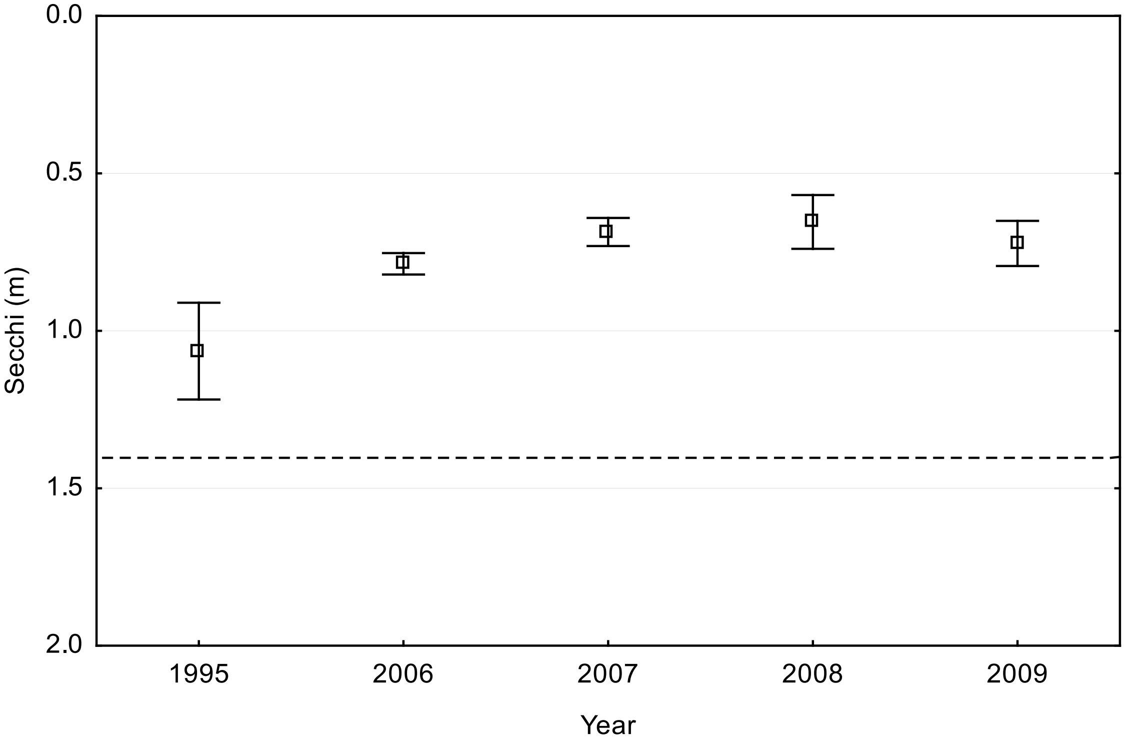
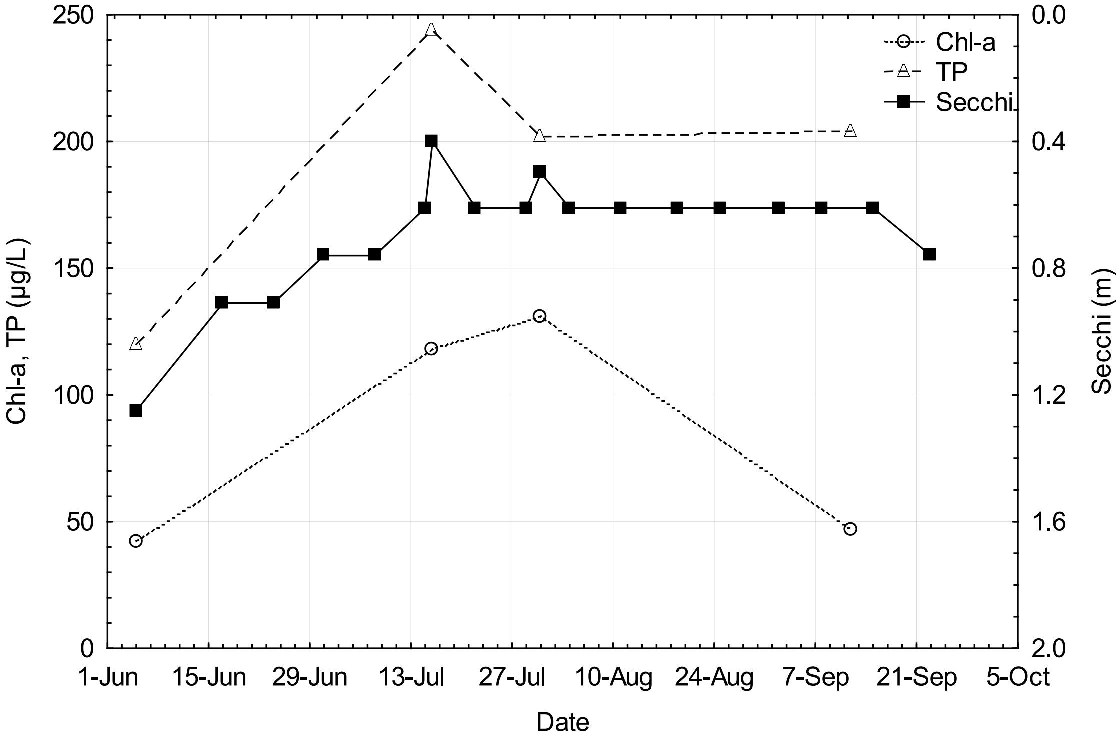


Figure 42 – Growing Season Trends of Chl-*a*, TP, and Secchi Transparency for Little Lake, 2007.



Macrophytes

Many macrophytes are present in Little Lake. Coontail and Canada waterweed were the most abundant submerged plants reported in the 1994 MN DNR vegetation survey. By the 2004 vegetation survey, the most common plant was reported as curly-leaf pondweed. This change in aquatic plant life could contribute to the increased phosphorus levels in the lake.

Fish

Little Lake is fished quite heavily throughout the year. Even with high levels of fishing pressure, the lake produces many medium to large sized fish. Species caught in the 2009 survey include black crappie, bluegill, bowfin, northern pike, pumpkinseed sunfish, walleye, yellow bullhead, and yellow perch. Little Lake has been stocked with walleye in 2003, 2006, 2008, and 2010.

8.6 Phosphorus Source Inventory

Through model calibration, 2,400 pounds of phosphorus were determined to be from a mix of watershed and internal load sources. These mixed sources were distributed as follows: 50% (1,200 lb/yr) to external load and 50% (1,200 lb/yr) to internal load (see Table 15 on page 47).

Watershed + Shallow Groundwater Phosphorus Sources

The SWAT model estimated that Linn Lake receives 510 pounds of phosphorus annually from watershed runoff and shallow groundwater flow, and an additional 1,200 pounds were added from the mixed sources, for a total of 1,710 pounds per year from direct loading (Table 44). The 2030 phosphorus load from watershed runoff and shallow groundwater (based on projected population estimates and resulting development) shows no increase from existing conditions.

Table 44 – Little Lake Watershed Runoff and Shallow Groundwater Phosphorus Source Summary

Phosphorus Source	Annual P Load (lb/yr)	Flow Volume[1] (AF/yr)	Area (ac)	Equiv. Depth of Flow (in/yr)	Average Areal P Load (lb/ac-yr)[2]	Average P Conc. (µg/L)[3]
Direct Loading	1,710	1,208	2,014	7.2	0.85	522

[1] Watershed runoff plus shallow groundwater flow

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

[3] Annual TP load (lb/yr) divided by average annual flow volume; values are rounded to the nearest whole number.

None of the Little Lake watershed is serviced by city sanitary sewer. The homes have private on-site septic systems, which are estimated to have a 25% failure rate. Five imminent threat to public health septic systems have been recently upgraded; two of these are within the shoreland area. Ten animal operations exist within the contributing watershed area.

Atmospheric Phosphorus Sources

Atmospheric deposition is estimated to be 44 lb/yr (see *Atmospheric Deposition* in Section 2.2 for more information).

Internal Phosphorus Sources

The modeled internal load based on sediment phosphorus content indicates that internal loading accounts for an estimated 300 to 520 lb/yr of phosphorus loading to the lake. Mixed phosphorus sources identified through the lake modeling suggest that the internal load is 1,200 lb/yr. An internal load of 1,200 lb/yr phosphorus was assumed for Little Lake, representing approximately 41% of the total load to the lake.

Phosphorus Load Summary

The total modeled phosphorus load to Little Lake is 2,954 lb/yr (Table 45).

Table 45 – Little Lake Phosphorus Source Summary, Existing Loads

Phosphorus Source	Phosphorus Load (lb/yr)
Watershed + Shallow Groundwater	1,710
Atmospheric	44
Internal	1,200
Total	**2,954**

8.7 Impairment Assessment Summary

- The lake water quality violates the phosphorus, chlorophyll-*a*, and Secchi transparency water quality standards. The lake is hypereutrophic, with an average phosphorus concentration of 173 µg/l.
- Curly-leaf pondweed exists in the lake, and was the most common plant in the lake in a 2004 survey. Curly-leaf pondweed contributes to internal loading from the sediments.
- Phosphorus concentration in sediments is high, indicating a high potential for internal loading from sediments.
- Approximately 55% of the watershed is cropland, and there are ten animal operations in the watershed.
- The entire watershed is served by private on-site septic systems, which are estimated to have a 25% failure rate.
- Five imminent threat to public health septic systems, two of which were in the shoreland area, were recently upgraded.
- The lake model indicated that there is a large phosphorus load that is unaccounted for in the current phosphorus source inventory. This load is likely a mix of internal load, load from animal operations, and load from failing septic systems.

8.8 TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Little Lake is 330 lb/yr, to be split among allocations according to Table 46. While there are currently no regulated MS4s in the Little Lake watershed: should a portion of the watershed come under regulation by a MS4 permit in the future, the transfer rate from LA to WLA for regulated MS4 stormwater runoff is 0.073 lb/ac-yr, or 0.00020 lb/ac-day.

Table 46 – Little Lake TP Allocations

Load Component	TP Existing	TP TMDL Allocation		TP Reduction	
	lb/yr	lb/yr	lb/day	lb/yr	%
WLA					
Construction stormwater (permit #MNR100001)	0.24	0.24	0.00066	0	0%
Industrial stormwater (permit # MNR50000)	0.24	0.24	0.00066	0	0%
Total WLA	**0.48**	**0.48**	**0.0013**	**0**	**0%**
LA*					
Watershed	1,710	148	0.41	1,562	91%
Atmospheric	44	44	0.12	0	0%
Internal	1,200	104	0.28	1,096	91%
Total LA	**2,954**	**296**	**0.81**	**2,658**	**90%**
MOS	**--**	**33**	**0.09**		
Total	***2,954***	***330***	***0.90***		

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

To meet the TMDL with a 10% margin of safety, the total load to the lake needs to be reduced by 2,658 lb/yr (90%).

The load reduction goals are based on the following:

- Equal percent reductions were assigned for runoff and internal load.

9 OGREN LAKE TMDL

9.1 Physical Characteristics

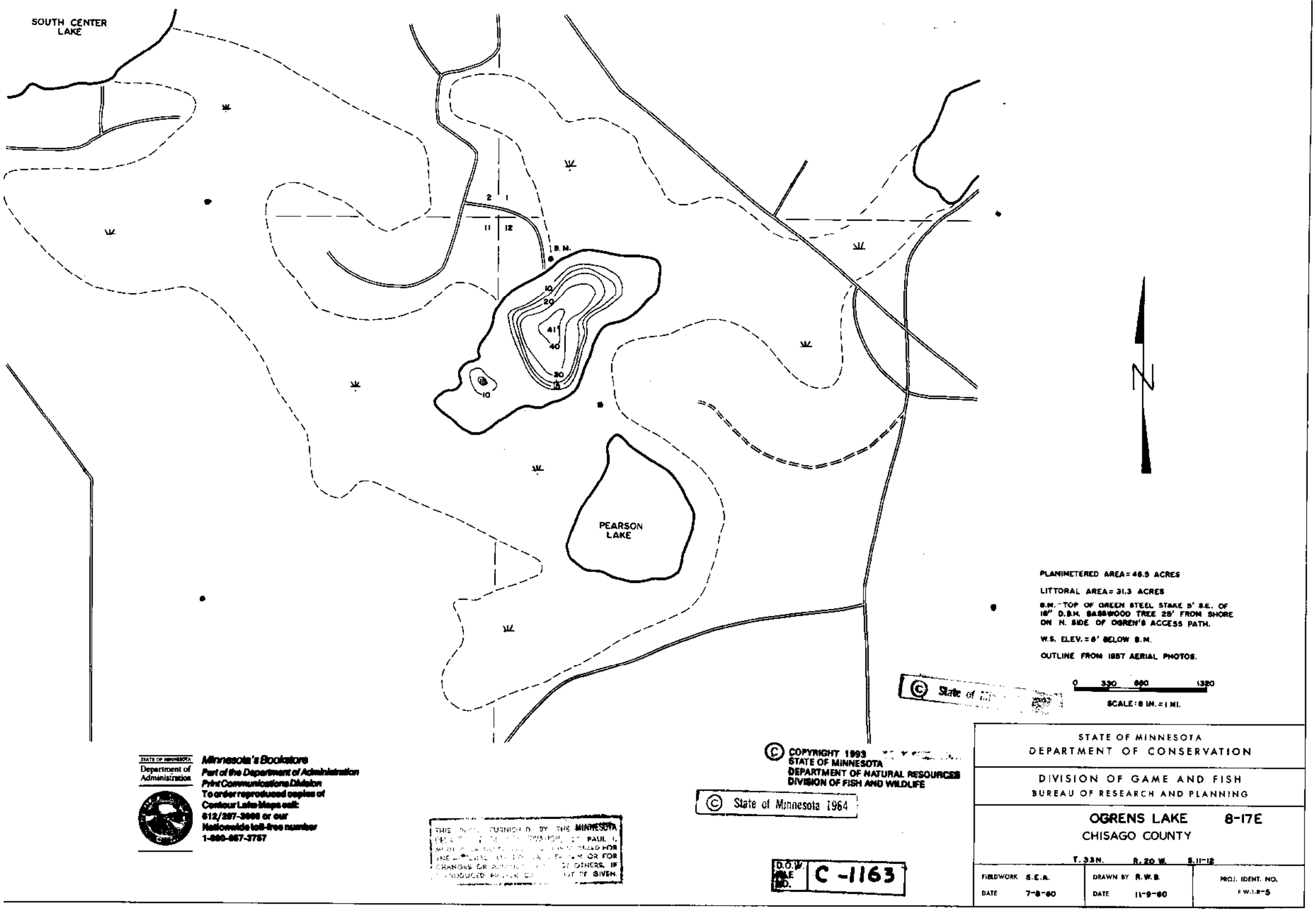
Ogren Lake (MN DNR Lake ID 13-0011) is a lake located in southern Chisago County to the southeast of South Center Lake. Table 47 summarizes the lake's physical characteristics, Figure 43 shows the 2007 aerial photography**,** and Figure 44 illustrates the available bathymetry.

Table 47 – Ogren Lake Physical Characteristics

Characteristic	Value	Source
Lake total surface area (ac)	49	Digitized from LMIC WMS Server 2010 aerial photograph
Percent lake littoral surface area (%)	63	MN DNR Lake Finder
Lake volume (ac-ft)	735	Calculated from MN DNR bathymetric data using 2010 surface contour (aerial photo) and 1991-92 depth contours
Mean depth (ft)	15	Lake volume ÷ surface area
Maximum depth (ft)	41	MN DNR Lake Finder
Drainage area (ac)	4,101	SWAT model (HDR 2008)
Watershed area: Lake area	84	Calculated

Figure 43 – Ogren Lake 2007 Aerial Photography

Figure 44 – Ogren Lake Bathymetry



9.2 Land Cover

Table 48 – Ogren Lake Watershed Land Cover

Land Use	Direct Drainage		Entire Drainage	
	Total Acres	% of Watershed	Total Acres	% of Watershed
Developed	38.6	1.8	86.2	2.1
Cropland	1122.6	51.6	2256.4	54.4
Grassland	124.8	5.7	296.5	7.1
Aquatic Habitat	511.2	23.4	904.3	21.8
Woodland	330.0	15.4	557.6	13.4
Ogren Lake Surface Area	49.0	2.3	49.0	1.2
Total	**2176.2**	**100%**	**4150.0**	**100%**

9.3 Existing Studies, Monitoring, and Management

Ogren Lake was monitored through the Surface Water Assessment Grant program with the MPCA and SWCD. This monitoring was completed by volunteers who live in the area.

9.4 Lake Uses

Aquatic recreation is the designated use for Ogren Lake, which incorporates swimming, wading, aesthetics, and other related uses. Ogren Lake is not used as a recreational lake. There are very few property owners around the lake; one dock exists on the lake. Occasionally, the lake is used for canoeing. The lake is mostly surrounded by cattail wetlands, which hinders aquatic recreation on the lake.

9.5 Lake Assessment

Water Quality

Water quality monitoring data for Ogren Lake are available for TP, Chl-*a*, and Secchi transparency in 2009 and 2010. The lake does not meet shallow lake water quality standards for total phosphorus or chlorophyll-*a*.

Table 49 – 10-year Growing Season Mean TP, Chl-*a*, and Secchi depth for Ogren Lake, 2001-2010.

Parameter	Growing Season Mean (June – September)	Growing Season CV* (June – September)	Lake Standard
Total phosphorus (µg/L)	64	0.14	≤ 40
Chlorophyll-a (µg/L)	29	0.001	≤ 14
Secchi transparency (m)	2.5	0.58	≥ 1.4

*CV = coefficient of variation. CV is used as input into the Bathtub model, and is defined in Bathtub as standard error divided by mean

The growing season mean of TP and Chl-*a* in Ogren Lake violated lake water quality standards in 2009 and 2010, and the growing season mean of Secchi transparency violated lake water quality standards in 2009 only. From 2009 to 2010, the growing season mean TP decreased (Figure 45), Chl-a remained stable but became more variable (Figure 46), and Secchi transparency improved but became more variable (Figure 47). In 2009, Chl-*a* and TP peaked in mid-summer, but TP peaked again in September potentially corresponding to a lake mixing event (Figure 48).

Figure 45 – Growing Season Means ± SE of Total Phosphorus for Ogren Lake by Year. The dashed line represents the lake water quality standard for TP (40 µg/L).

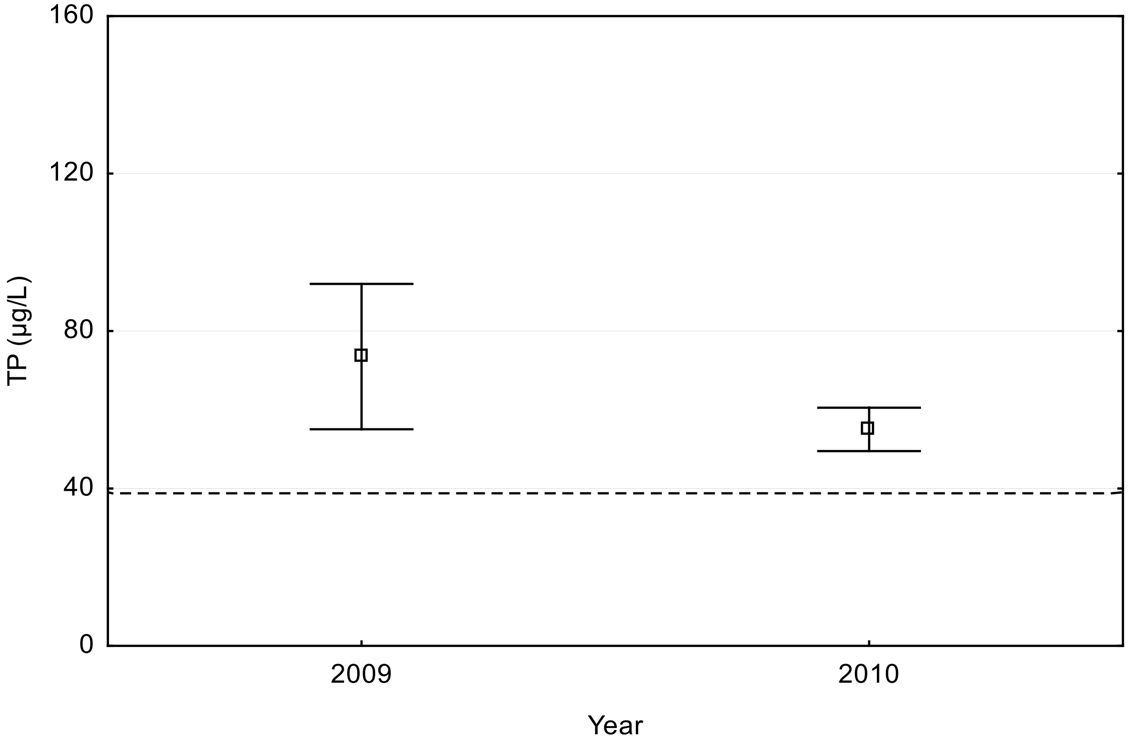


Figure 46 – Growing Season Means ± SE of Chlorophyll-*a* for Ogren Lake by Year. The dashed line represents the lake water quality standard for Chl-a (14 µg/L).

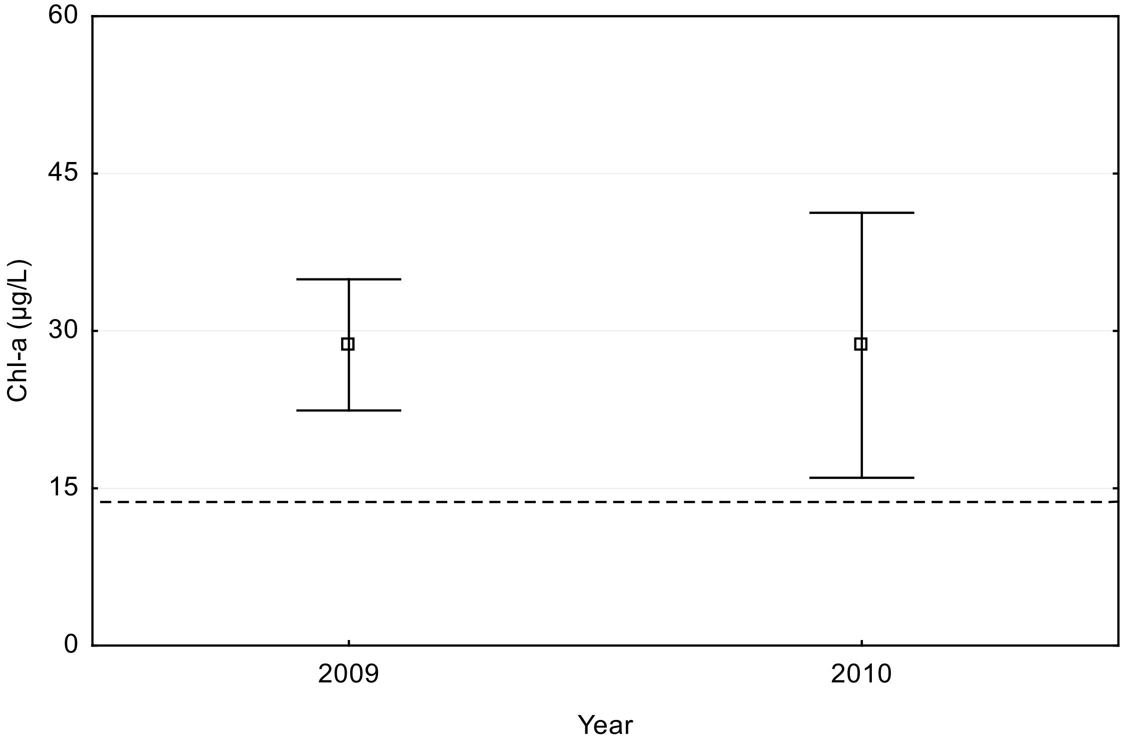


Figure 47 – Growing Season Means ± SE of Secchi Transparency for Ogren Lake by Year. The dashed line represents the lake water quality standard for transparency (1.4 m).

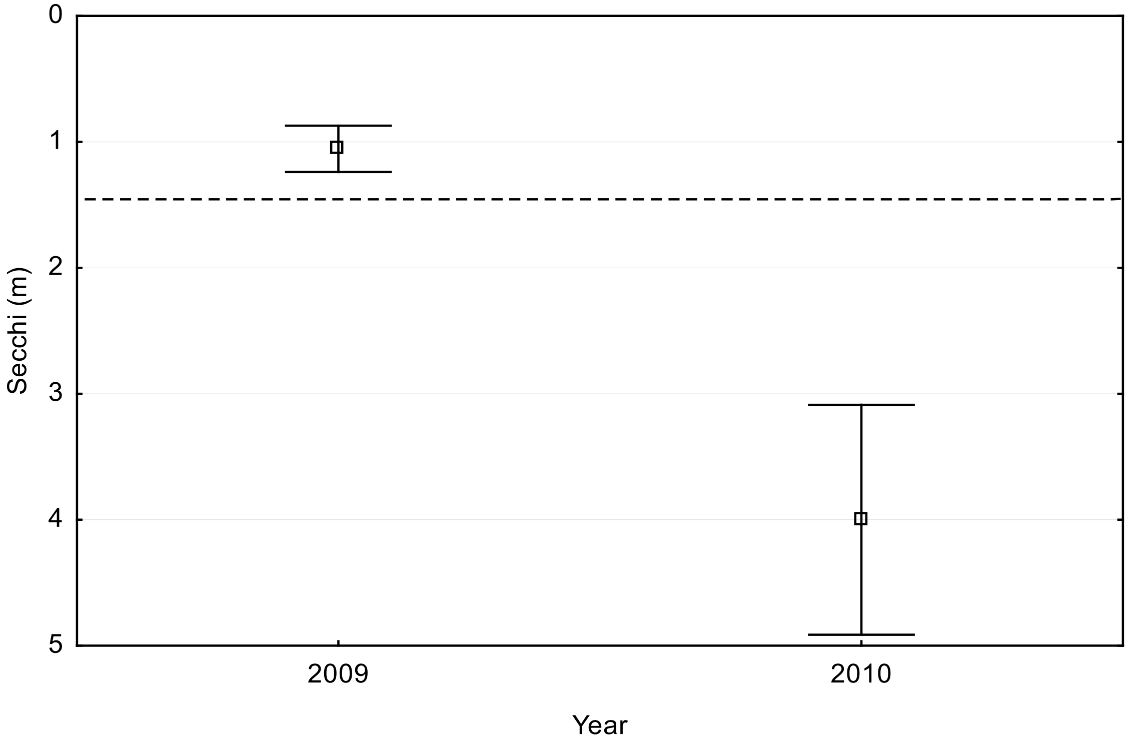
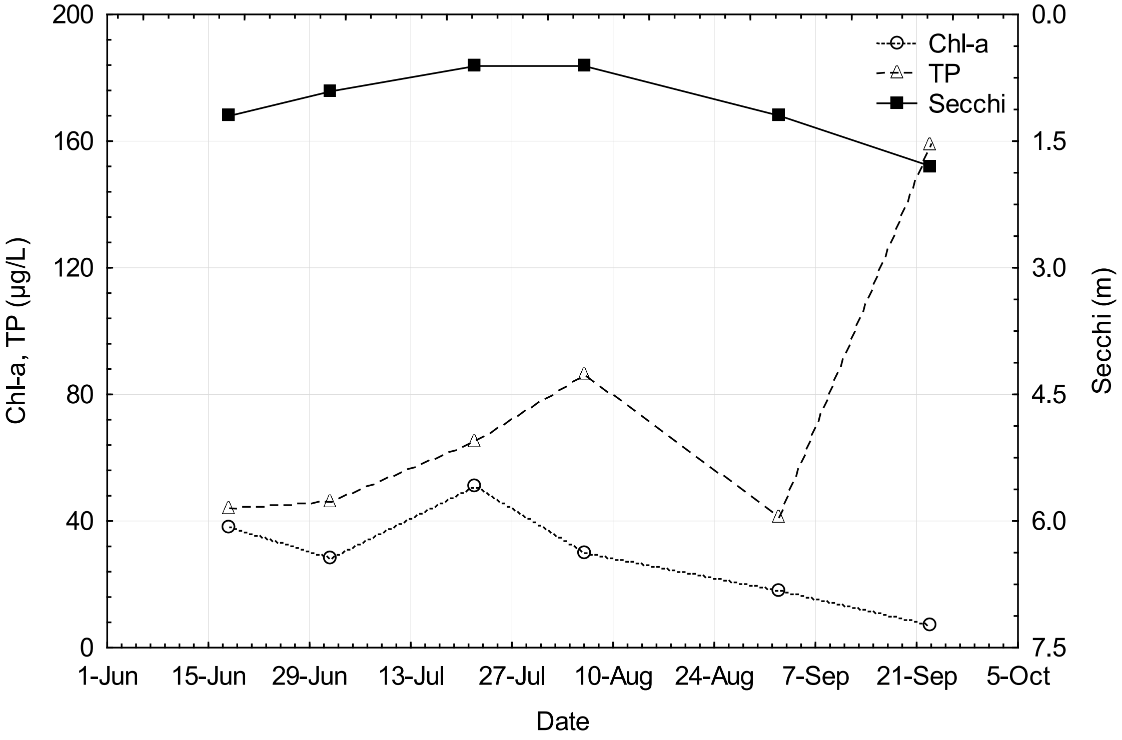


Figure 48 – Growing Season Trends of Chl-*a*, TP, and Secchi Transparency for Ogren Lake, 2009.



Macrophytes

Aquatic plants are abundant on the lake. Desirable species of macrophytes are present as emergent and submergent plants. At this time, there are no invasive species present.

Fish

The most recent fish survey of Ogren Lake was completed in 1989. At the time many species were collected, including white sucker, northern pike, black crappie, black bullhead, pumpkinseed sunfish, hybrid sunfish, golden shiner, brown bullhead, bowfin, and bluegill. Lakes without a public water access are not actively managed for recreational fishing and are not routinely surveyed by the MN DNR Section of Fisheries.

9.6 Phosphorus Source Inventory

Watershed + Shallow Groundwater Phosphorus Sources

The SWAT model estimated that Ogren Lake receives 860 pounds of phosphorus annually from watershed runoff and shallow groundwater flow (Table 50). The SWAT model estimated the 2030 phosphorus load from watershed runoff and shallow groundwater to be 870 lb/yr based on projected population estimates and resulting development. This represents a 1% increase in phosphorus loading from existing conditions (860 lb/yr). Due to the changed economic climate, development is slower than projections; the total additional load may not be realized until 2040 or later.

Table 50 – Ogren Lake Watershed Runoff and Shallow Groundwater Phosphorus Source Summary

Phosphorus Source	Annual P Load (lb/yr)	Flow Volume[1] (AF/yr)	Area (ac)	Equiv. Depth of Flow (in/yr)	Average Areal P Load (lb/ac-yr)[2]	Average P Conc. (µg/L)[3]
Direct Loading	860	2,153	4,101	6.3	0.21	147

[1] Watershed runoff plus shallow groundwater flow

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

[3] Annual TP load (lb/yr) divided by average annual flow volume; values are rounded to the nearest whole number.

None of the Ogren Lake watershed is serviced by city sanitary sewer. The homes have private on-site septic systems, which are estimated to have a 25% failure rate. Ten imminent threat to public health septic systems have been recently upgraded; four of these are within the shoreland area. Nine animal operations exist within the contributing watershed area.

Atmospheric Phosphorus Sources

Atmospheric deposition is estimated to be 13 lb/yr (see *Atmospheric Deposition* in Section 2.2 for more information).

Internal Phosphorus Sources

The modeled internal load based on sediment phosphorus content indicates that internal loading accounts for an additional 170 to 530 lb/yr of phosphorus loading to the lake, representing 16% to 38%, respectively, of the total loading to the lake. These rates of internal loading are relatively high for a lake that does not exhibit symptoms of excessive internal loading. It was assumed that the internal load is the lower of these two values, or 170 lb/yr.

Phosphorus Load Summary

The total modeled phosphorus load to Ogren Lake is 1,043 lb/yr (Table 51).

Table 51 – Ogren Lake Phosphorus Source Summary, Existing Loads

Phosphorus Source	Phosphorus Load (lb/yr)
Watershed + Shallow Groundwater	860
Atmospheric	13
Internal Load	170
Total	**1,043**

9.7 Impairment Assessment Summary

- The lake water quality violates the phosphorus and chlorophyll-*a* water quality standards but meets the Secchi transparency standard.
- There are no invasive aquatic macrophytes in the lake; the lake has a desirable mix of emergent and submergent macrophytes.
- Phosphorus concentration in sediments is high, indicating a high potential for internal loading from sediments.
- A 1989 fish survey indicated the presence of black bullhead; there has not been a fish survey since then. Black bullhead can lead to high internal loading rates due to their habit of foraging in bottom sediments.
- Approximately 55% of the watershed is cropland, and there are nine animal operations in the watershed.
- The entire watershed is served by private on-site septic systems, which are estimated to have a 25% failure rate.
- Ten imminent threat to public health septic systems, four of which were in the shoreland area, were recently upgraded.

9.8 TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Ogren Lake is 640 lb/yr, to be split among allocations according to Table 52. While there are currently no regulated MS4s in the Ogren Lake watershed; should a portion of the watershed come under regulation by a MS4 permit in the future the transfer rate from LA to WLA for regulated MS4 stormwater runoff is 0.10 lb/ac-yr, or 0.00027 lb/ac-day.

Table 52 – Ogren Lake TP Allocations

Load Component	TP Existing	TP TMDL Allocation		TP Reduction	
	lb/yr	lb/yr	lb/day	lb/yr	%
WLA					
Construction stormwater (permit #MNR100001)	0.69	0.69	0.0019	0	0%
Industrial stormwater (permit # MNR50000)	0.69	0.69	0.0019	0	0%
Total WLA	**1.38**	**1.38**	**0.0038**	**0**	**0%**
LA*					
Watershed	859	429	1.2	430	50%
Atmospheric	13	13	0.036	0	0%
Internal	170	133	0.36	37	22%
Total LA	**1,042**	**575**	**1.6**	**467**	**45%**
MOS	**--**	**64**	**0.18**		
Total	***1,043***	***640***	***1.8***		

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

To meet the TMDL with a 10% margin of safety, the total load to the lake needs to be reduced by 467 lb/yr (45%).

The load reduction goals are based on the following:

- The watershed runoff load should be reduced by 430 lb/yr (50%).
- The remaining reductions should come from internal loading (37 lb/yr, or 22%).

10 PIONEER LAKE TMDL

10.1 Physical Characteristics

Pioneer Lake (MN DNR Lake ID 13-0034) is a shallow lake located in southern Chisago County, 0.5 mile north of Center City. Table 53 summarizes the lake's physical characteristics. Figure 49 shows the 2007 aerial photography. There are no bathymetric data available for Pioneer Lake.

Table 53 – Pioneer Lake Physical Characteristics

Characteristic	Value	Source
Lake total surface area (ac)	77	MN DNR Public Waters Inventory GIS Shapefile
Percent lake littoral surface area (%)	100	MN DNR Lake Finder
Lake volume (ac-ft)	385	Mean depth x surface area
Mean depth (ft)	5	Mean depth unknown; best professional judgment
Maximum depth (ft)	8	MN DNR Lake Finder
Drainage area (ac)	91	SWAT model (HDR 2008)
Watershed area: Lake area	1.2	Calculated

Figure 49 – Pioneer Lake 2007 Aerial Photography

10.2 Land Use

Table 54 – Pioneer Lake Watershed Land Cover

Land Use	Direct Drainage		Entire Drainage	
	Total Acres	% of Watershed	Total Acres	% of Watershed
Developed	10.3	6.1	No other contributing drainage areas	
Cropland	48.6	28.9		
Grassland	5.6	3.3		
Aquatic Habitat	6.6	3.9		
Woodland	20.0	12.0		
Pioneer Lake Surface Area	77.0	45.8		
Total	**168.0**	**100%**		

10.3 Existing Studies, Monitoring, and Management

Pioneer Lake has been monitored for water level and water quality through the CLLID and volunteers for many years. Data in the MPCA's water quality database dates back to 2000. More intensive monitoring was completed through the Surface Water Assessment Grant program with the MPCA and SWCD in 2009. This monitoring was completed by volunteers who live on the lake.

10.4 Lake Uses

Aquatic recreation is the designated use for Pioneer Lake, which incorporates swimming, wading, aesthetics, and other related uses. Very little recreation is done on Pioneer Lake. Occasionally, the residents use the lake for canoeing, boating, and waterskiing. Several of the residents have watercraft and docks on the lake.

10.5 Lake Assessment

Water Quality

Water quality monitoring data for Pioneer Lake are available from 2000 to 2009 for Secchi transparency and in 2009 for total phosphorus and chlorophyll-*a*. Only data from within the most recent 10 years (2001-2010) were used to determine whether Pioneer Lake meets shallow lake water quality standards. The lake does not meet shallow lake water quality standards for total phosphorus, chlorophyll-a, or Secchi transparency (Table 55).

Table 55 – 10-year Growing Season Mean TP, Chl-*a*, and Secchi depth for Pioneer Lake, 2001-2010.

Parameter	Growing Season Mean (June – September)	Growing Season CV* (June – September)	Shallow Lake Standard
Total phosphorus (µg/L)	345	0	≤ 60
Chlorophyll-*a* (µg/L)	103	0	≤ 20
Secchi transparency (m)	0.4	0.17	≥ 1.0

*CV = coefficient of variation. CV is used as input into the Bathtub model, and is defined in Bathtub as standard error divided by mean. Only one year of data is available for TP and chl-a; therefore the CV is zero.

Growing season mean transparency decreased between 2000 and 2009 in Pioneer Lake (Figure 51). This suggests that overall lake water quality has been declining since 2000. In 2009, TP and

Chl-*a* peaked in Pioneer Lake at the end of June with a corresponding decrease in transparency (Figure 51).

Figure 50 – Growing Season Means ± SE of Secchi Transparency for Pioneer Lake by Year. The dashed line represents the shallow lake water quality standard for transparency (1.0 m).

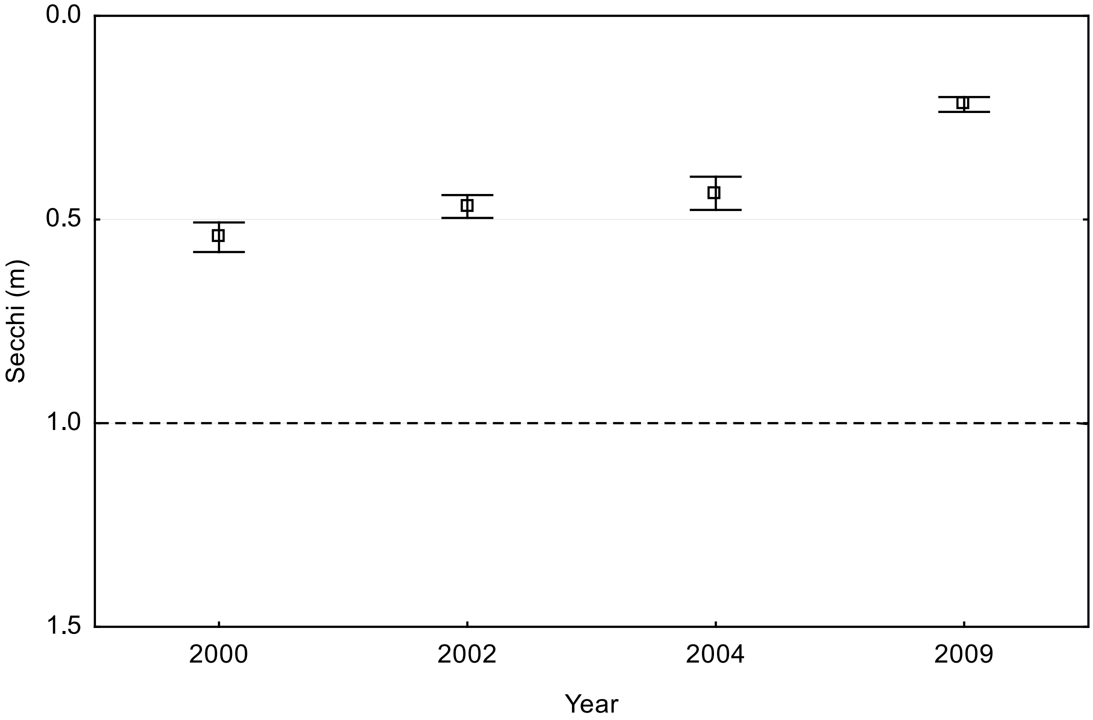
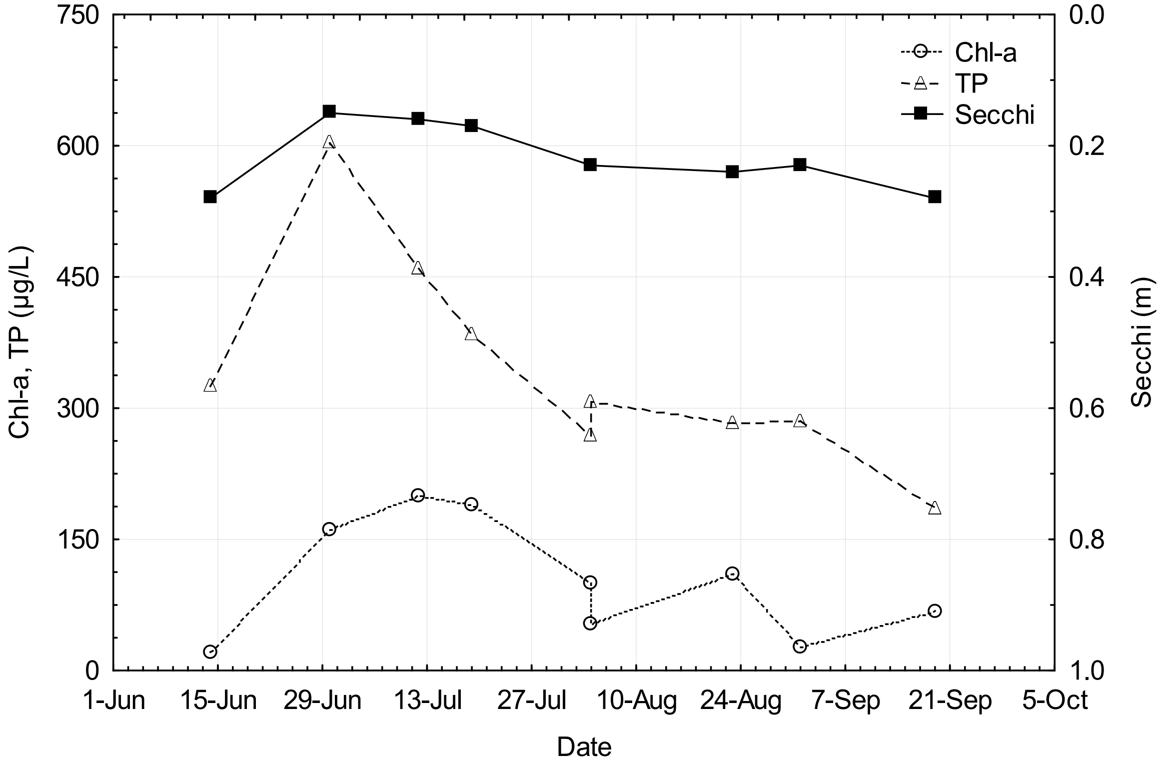


Figure 51 – Growing Season Trends of Chl-*a*, TP, and Secchi Transparency for Pioneer Lake, 2009.



Macrophytes

Macrophytes are abundant in Pioneer Lake. A dense mat of Canada waterweed, the most dominant vegetation in the lake, is present. Residents have reported that at one time the lake surface was almost entirely covered with cattails. Many emergent species are also present around the lake. Curly-leaf pondweed was not present at the time of the 2001 survey, but it has been identified since 2001; in 2010 it grew in dense mats on the south shore of the lake.

Fish

Few fish species are present in Pioneer Lake. Species sampled in a 2001 MN DNR survey included: black bullhead, bluegill, pumpkinseed sunfish, and yellow bullhead. Black bullheads were the most abundant fish species and fish sizes range from very small to small. High black bullhead populations are indicative of lakes that experience partial or near-complete winterkill. High populations of largemouth bass and panfish populations were reported in 2000. A winterkill of fish was reported in 2001 at ice out. Lakes without a public water access are not actively managed for recreational fishing and are not routinely surveyed by the MN DNR Section of Fisheries.

10.6 Phosphorus Source Inventory

Through model calibration, 1,800 pounds of phosphorus were determined to be from a mix of watershed and internal load sources. One hundred percent (1,800 lb/yr) of the mixed sources were distributed to internal load (see Table 15 on page 47).

Watershed + Shallow Groundwater Phosphorus Sources

The SWAT model estimated that Pioneer Lake receives 22 pounds of phosphorus annually from watershed runoff and shallow groundwater flow (Table 56). The SWAT model estimated the 2030 phosphorus load from watershed runoff and shallow groundwater to be 28 lb/yr based on projected population estimates and resulting development. This represents a 27% increase in phosphorus loading from existing conditions (22 lb/yr). Due to the changed economic climate, development is slower than projections; the total additional load may not be realized until 2040 or later.

Table 56 – Pioneer Lake Watershed Runoff and Shallow Groundwater Phosphorus Source Summary

Phosphorus Source	Annual P Load (lb/yr)	Flow Volume[1] (AF/yr)	Area (ac)	Equiv. Depth of Flow (in/yr)	Average Areal P Load (lb/ac-yr)[2]	Average P Conc. (µg/L)[3]
Direct Loading	22	67	91	8.8	0.24	121

[1] Watershed runoff plus shallow groundwater flow
[2] Annual TP load (lb/yr) divided by drainage area (ac)
[3] Annual TP load (lb/yr) divided by average annual flow volume; values are rounded to the nearest whole number

The Pioneer Lake watershed is mostly serviced by city sanitary sewer. About 20% of parcels have on-site septic systems, which are estimated to have a 25% failure rate. One imminent threat to public health septic system has been recently upgraded within the shoreland district. Zero animal operations exist within this watershed.

Atmospheric Phosphorus Sources

Atmospheric deposition is estimated to be 21 lb/yr (see *Atmospheric Deposition* in Section 2.2 for more information).

Internal Phosphorus Sources

The modeled internal load based on sediment phosphorus content indicates that internal loading accounts for an estimated 21 to 22 lb/yr of phosphorus loading to the lake. Mixed phosphorus sources identified through the lake modeling suggest that the internal load is 1,800 lb/yr. An internal load of 1,800 lb/yr phosphorus was assumed for Pioneer Lake, representing approximately 100% of the total load to the lake.

Phosphorus Load Summary

The total modeled phosphorus load to Pioneer Lake is 1,843 lb/yr (Table 57).

Table 57 – Pioneer Lake Phosphorus Source Summary, Existing Loads

Phosphorus Source	Phosphorus Load (lb/yr)
Watershed + Shallow Groundwater	22
Atmospheric	21
Internal	1,800
Total	**1,843**

10.7 Impairment Assessment Summary

- The lake water quality violates the phosphorus, chlorophyll-*a*, and Secchi transparency water quality standards. The lake is hypereutrophic, with an average phosphorus concentration of 345 µg/l.
- The lake is very shallow, with a mean depth of five feet and a maximum depth of eight feet.
- Curly-leaf pondweed exists in the lake, although the extent is not known. Curly-leaf pondweed contributes to internal loading from the sediments. A dense mat of Canada waterweed was present in a 2001 survey.
- Black bullheads were the most abundant fish observed in a 2001 fish survey. Black bullhead can lead to high internal loading rates due to their habit of foraging in bottom sediments.
- A large portion of the shoreline is developed.
- Approximately 30% of the watershed is cropland.
- Approximately 20% of the watershed is served by private on-site septic systems, which are estimated to have a 25% failure rate.
- One imminent threat to public health septic system located in the shoreland area was recently upgraded.
- The lake model indicated that there is a large phosphorus load that is unaccounted for in the current phosphorus source inventory. This load is likely due to internal load.

10.8 TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Pioneer Lake is 80 lb/yr, to be split among allocations according to Table 58. While there are currently no regulated MS4s in the Ogren Lake watershed; should a portion of the watershed come under regulation by a MS4 permit in the future the transfer rate from LA to WLA for regulated MS4 stormwater runoff is 0.0067 lb/ac-yr, or 1.8 x 10^{-5} lb/ac-day.

Table 58 – Pioneer Lake TP Allocations

Load Component	TP Existing	TP TMDL Allocation		TP Reduction	
	lb/yr	lb/yr	lb/day	lb/yr	%
WLA					
Construction stormwater (permit #MNR100001)	0.00099	0.00099	0.0000027	0	0%
Industrial stormwater (permit # MNR50000)	0.00099	0.00099	0.0000027	0	0%
Total WLA	**0.0020**	**0.0020**	**0.0000054**	**0**	**0%**
LA*					
Watershed	22	0.61	0.0017	21	95%
Atmospheric	21	21	0.058	0	0%
Internal	1,800	50	0.14	1,750	97%
Total LA	**1,843**	**72**	**0.20**	**1,771**	**96%**
MOS	**--**	**8**	**0.022**		
Total	***1,843***	***80***	***0.22***		

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

To meet the TMDL with a 10% margin of safety, the total load to the lake needs to be reduced by 1,771 lb/yr (96%).

The load reduction goals are based on the following:

- Equal percent reductions were assigned for runoff and internal load.

11 SCHOOL LAKE TMDL

11.1 Physical Characteristics

School Lake (MN DNR Lake ID 13-0044) is a shallow lake located in southern Chisago County, 0.5 mile north of Chisago City. Table 59 summarizes the lake's physical characteristics. Figure 52 shows the 2007 aerial photography. There are no bathymetric data available for School Lake.

Table 59 – School Lake Physical Characteristics

Characteristic	Value	Source
Lake total surface area (ac)	145	Digitized from LMIC WMS Server 2010 aerial photograph
Percent lake littoral surface area (%)	100	MN DNR Lake Finder
Lake volume (ac-ft)	580	Mean depth x surface area
Mean depth (ft)	5	Mean depth unknown; best professional judgment
Maximum depth (ft)	8	Field observation, volunteers
Drainage area (ac)	950	SWAT model (Almendinger & Ulrich 2010) and MN DNR level 8 watersheds
Watershed area: Lake area	6.6	Calculated

Figure 52 – School Lake 2007 Aerial Photography

11.2 Land Cover

Table 60 – School Lake Watershed Land Cover

Land Use	Direct Drainage (including Mattson Lake)		Entire Drainage	
	Total Acres	% of Watershed	Total Acres	% of Watershed
Developed	12.5	1.1	No other contributing drainage areas	
Cropland	472.5	43.2		
Grassland	84.9	7.8		
Aquatic Habitat	252.7	23.1		
Woodland	127.4	11.6		
School Lake Surface Area	145.0	13.2		
Total	**1095.0**	**100%**		

11.3 Existing Studies, Monitoring, and Management

School Lake was monitored through the Surface Water Assessment Grant program with the MPCA and SWCD in 2008 and 2009. This monitoring was completed by volunteers who live on the lake.

11.4 Lake Uses

Aquatic recreation is the designated use for School Lake, which incorporates swimming, wading, aesthetics, and other related uses. There is no public access on School Lake; therefore, only residents use the lake for recreation. There are many docks and watercraft on the lake; however, it is not often used for recreation.

11.5 Lake Assessment

Water Quality

Water quality monitoring data for School Lake are available in 2008 and 2009 for Chlorophyll-*a* and Secchi transparency and in 2008 for total phosphorus. The lake does not meet shallow lake water quality standards for total phosphorus, chlorophyll-*a*, or Secchi transparency (Table 61).

Table 61 – 10-year Growing Season Mean TP, Chl-*a*, and Secchi depth for School Lake, 2001-2010.

Parameter	Growing Season Mean (June – September)	Growing Season CV*((June – September)	Shallow Lake Standard
Total phosphorus (µg/L)	216	0.11	≤ 60
Chlorophyll-*a* (µg/L)	82	0.11	≤ 20
Secchi transparency (m)	0.4	0.02	≥ 1.0

*CV = coefficient of variation. CV is used as input into the Bathtub model, and is defined in Bathtub as standard error divided by mean

The growing season mean TP, Chl-*a*, and Secchi transparency in School Lake violated shallow lake water quality standards in 2008 and 2009. Mean TP, Chl-*a*, and transparency was stable between the two years (Figure 53, Figure 54, and Figure 55). In 2008, TP and Chl-*a* peaked in mid-July with a corresponding decrease in transparency (Figure 56).

Figure 53 – Growing Season Means ± SE of Total Phosphorus for School Lake by Year. The dashed line represents the shallow lake water quality standard for TP (60 µg/L).

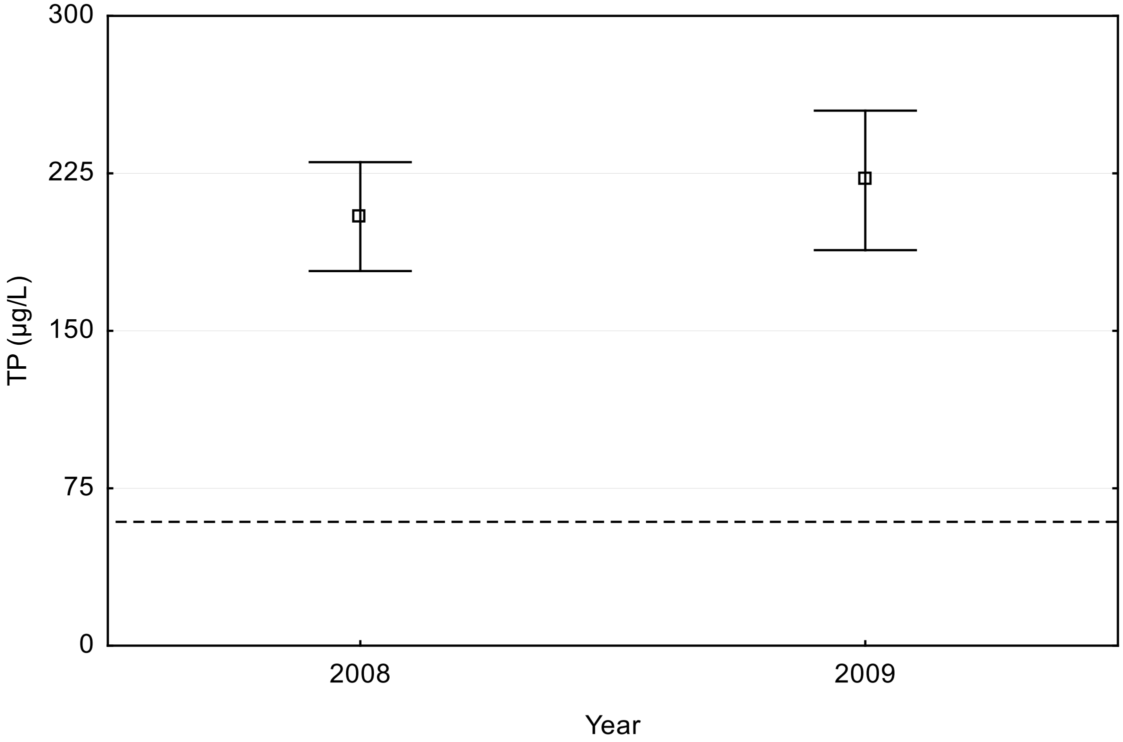


Figure 54 – Growing Season Means ± SE of Chlorophyll-*a* for School Lake by Year. The dashed line represents the shallow lake water quality standard for Chl-a (20 µg/L).

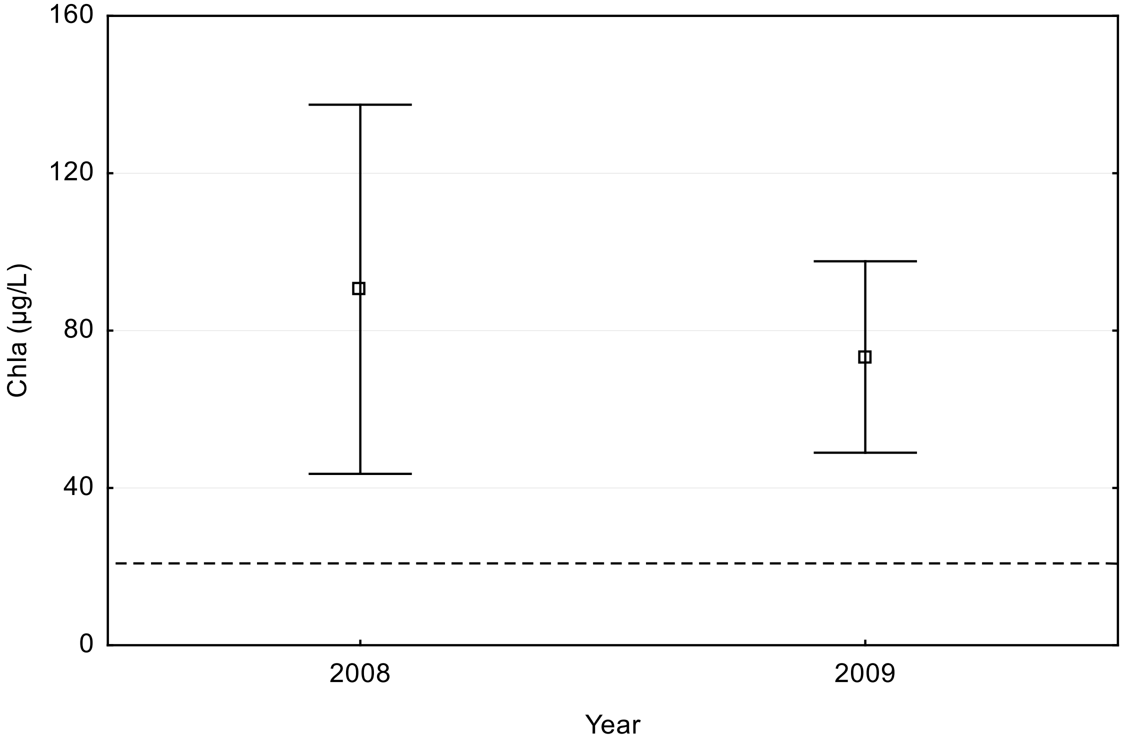


Figure 55 – Growing Season Means ± SE of Secchi Transparency for School Lake by Year. The dashed line represents the shallow lake water quality standard for transparency (1.0 m).

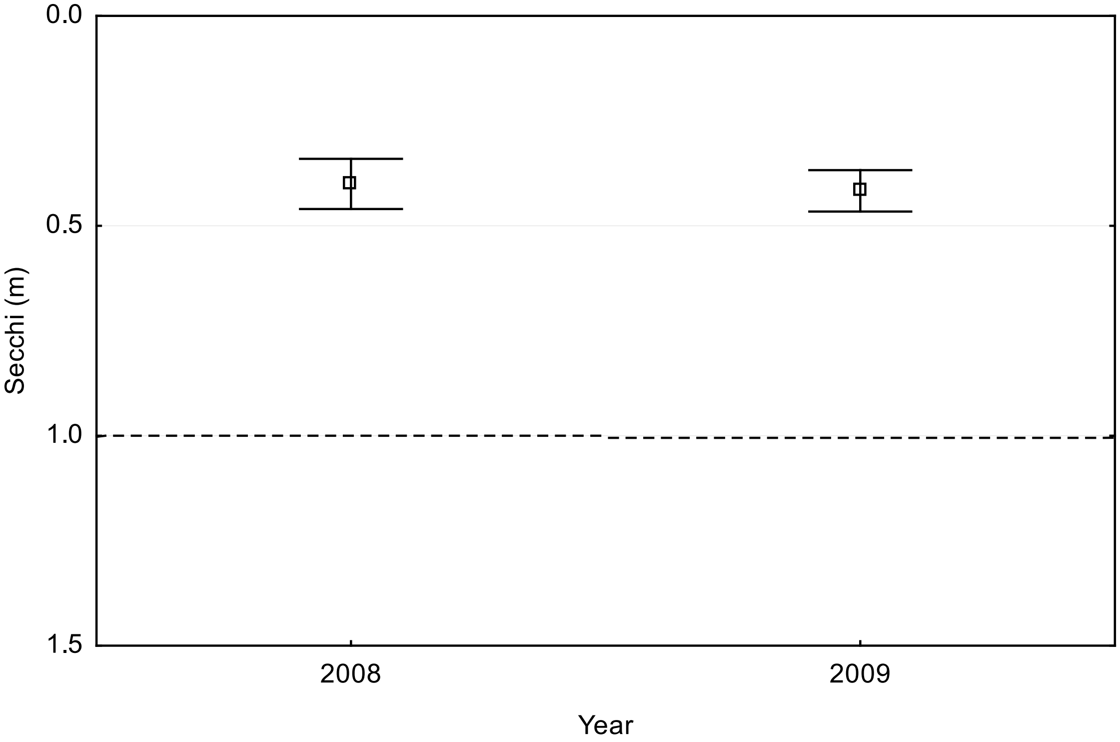
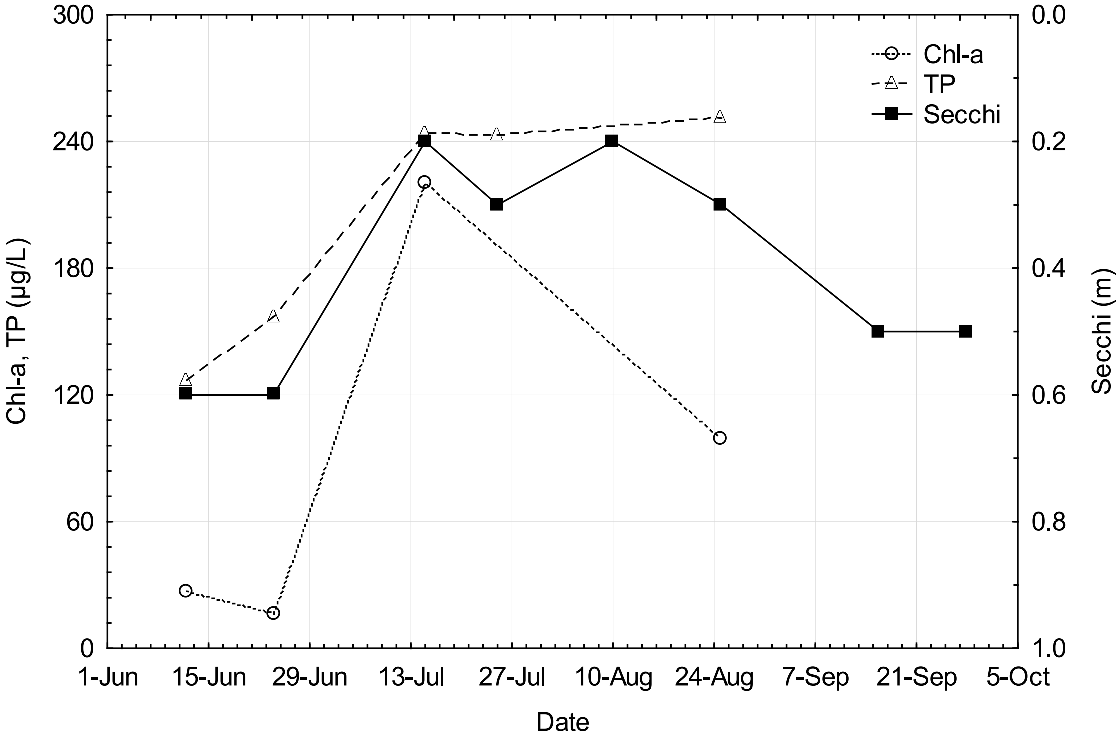


Figure 56 – Growing Season Trends of Chl-*a*, TP, and Secchi Transparency for School Lake, 2008.



Macrophytes

Macrophytes are not abundant in School Lake. Curly leaf pondweed has been identified in this lake. The extent of other species is not known at this time. In the channel between Mattson Lake and School Lake there is a thick bed of white water lily and other desirable emergent plants.

Fish

Very few species of fish live in School Lake. There are an abundance of stunted sunfish and black bullheads. High black bullhead populations are indicative of lakes that experience partial or near-complete winterkill. Lakes without a public water access are not actively managed for recreational fishing and are not routinely surveyed by the MN DNR Section of Fisheries.

11.6 Phosphorus Source Inventory

Through model calibration, 1,700 pounds of phosphorus were determined to be from a mix of watershed and internal load sources. These mixed sources were distributed as follows: 50% (850 lb/yr) to external load and 50% (850 lb/yr) to internal load (see Table 15 on page 47).

Watershed + Shallow Groundwater Phosphorus Sources

The contributing watershed to School Lake includes watershed runoff and shallow groundwater coming from the direct drainage to the lake and from Mattson Lake.

The SWAT model estimated that School Lake receives 68 pounds of phosphorus annually from watershed runoff and shallow groundwater flow: 49 pounds from the direct watershed and 19 pounds from upstream lakes. An additional 850 pounds were added from the mixed sources, for a total of 899 pounds per year from the direct watershed (Table 62). The 2030 phosphorus load from watershed runoff and shallow groundwater from the direct watershed (areas excluding Mattson Lake drainage) shows no increase from existing conditions.

Table 62 – School Lake Watershed Runoff and Shallow Groundwater Phosphorus Source Summary

Phosphorus Source	Annual P Load (lb/yr)	Percent of P Load (%)	Flow Volume[1] (AF/yr)	Area (ac)	Equiv. Depth of Flow (in/yr)	Average Areal P Load (lb/ac-yr)[2]	Average P Conc. (µg/L)[3]
Direct Loading	899	98%	174	348	6.0	2.6	1,905
Loading from Upstream Waters (Mattson Lake)[4]	19	2%	301	602	6.0	0.032	23
Total	**918**	**100%**	**475**	**950**	**6.0**	**0.97**	**713**

[1] Watershed runoff plus shallow groundwater flow
[2] Annual TP load (lb/yr) divided by drainage area (ac)
[3] Annual TP load (lb/yr) divided by average annual flow volume; values are rounded to the nearest whole number.
[4] Calculations are from lake outlet; includes lake area and drainage area

A very small portion of the School Lake watershed is serviced by city sanitary sewer. The majority of homes have private on-site septic systems, which are estimated to have a 25% failure rate. Three imminent threat to public health septic systems have been recently upgraded, one of these was within the shoreland area. Three small animal operations exist within this watershed.

Atmospheric Phosphorus Sources

Atmospheric deposition is estimated to be 39 lb/yr (see *Atmospheric Deposition* in Section 2.2 for more information).

Internal Phosphorus Sources

The modeled internal load based on sediment phosphorus content indicates that internal loading accounts for an estimated 0 to 110 lb/yr of phosphorus loading to the lake. Mixed phosphorus sources identified through the lake modeling suggest that the internal load is 850 lb/yr. An internal load of 850 lb/yr phosphorus was assumed for School Lake, representing approximately 47% of the total load to the lake.

Phosphorus Load Summary

The total modeled phosphorus load to School Lake is 1,807 lb/yr (Table 63).

Table 63 – School Lake Phosphorus Source Summary, Existing Loads

Phosphorus Source	Phosphorus Load (lb/yr)
Watershed + Shallow Groundwater	918
Atmospheric	39
Internal	850
Total	**1,807**

11.7 Impairment Assessment Summary

- The lake water quality violates the phosphorus, chlorophyll-*a*, and Secchi transparency water quality standards.
- The lake is very shallow, with a mean depth of five feet and a maximum depth of eight feet.
- Curly-leaf pondweed exists in the lake, although the extent is not known. Curly-leaf pondweed contributes to internal loading from the sediments.
- There is an abundance of stunted sunfish and black bullhead. The presence of stunted sunfish often indicates an overabundance of planktivorous fish such as sunfish. This overabundance leads to overgrazing on zooplankton and a resultant increase in algae. Black bullhead can lead to high internal loading rates due to their habit of foraging in bottom sediments.
- Approximately 43% of the watershed is cropland, and there are three small animal operations in the watershed.
- The majority of the watershed is served by private on-site septic systems, which are estimated to have a 25% failure rate.
- Three imminent threat to public health septic systems, one of which was in the shoreland area, were recently upgraded.
- The lake model indicated that there is a large phosphorus load that is unaccounted for in the current phosphorus source inventory. This load is likely a mix of internal load, load from animal operations, and load from failing septic systems.

11.8 TMDL Loading Capacity and Allocations

The phosphorus loading capacity of School Lake is 240 lb/yr, to be split among allocations according to Table 64. While there are currently no regulated MS4s in the Ogren Lake watershed, should a portion of the watershed come under regulation by a MS4 permit in the future the transfer rate from LA to WLA for regulated MS4 stormwater runoff is 0.23 lb/ac-yr, or 0.00063 lb/ac-day.

Table 64 – School Lake TP Allocations

Load Component	TP Existing	TP TMDL Allocation		TP Reduction	
	lb/yr	lb/yr	lb/day	lb/yr	%
WLA					
Construction stormwater (permit #MNR100001)	0.13	0.13	0.00036	0	0%
Industrial stormwater (permit # MNR50000)	0.13	0.13	0.00036	0	0%
Total WLA	**0.26**	**0.26**	**0.00072**	**0**	**0%**
LA*					
Watershed (direct runoff)	899	81	0.22	818	91%
Watershed (upstream lakes)	19	19	0.052	0	0%
Atmospheric	39	39	0.11	0	0%
Internal	850	77	0.21	773	91%
Total LA	**1,807**	**216**	**0.59**	**1,591**	**88%**
MOS	**--**	**24**	**0.066**		
Total	***1,807***	***240***	***0.66***		

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

To meet the TMDL with a 10% margin of safety, the total load to the lake needs to be reduced by 1,591 lb/yr (88%).

The load reduction goals are based on the following:

- Mattson Lake (the upstream lake) is not impaired and reductions from that lake are not priority.
- Equal percent reductions were assigned for direct runoff and internal load.

12 WALLMARK LAKE TMDL

12.1 Physical Characteristics

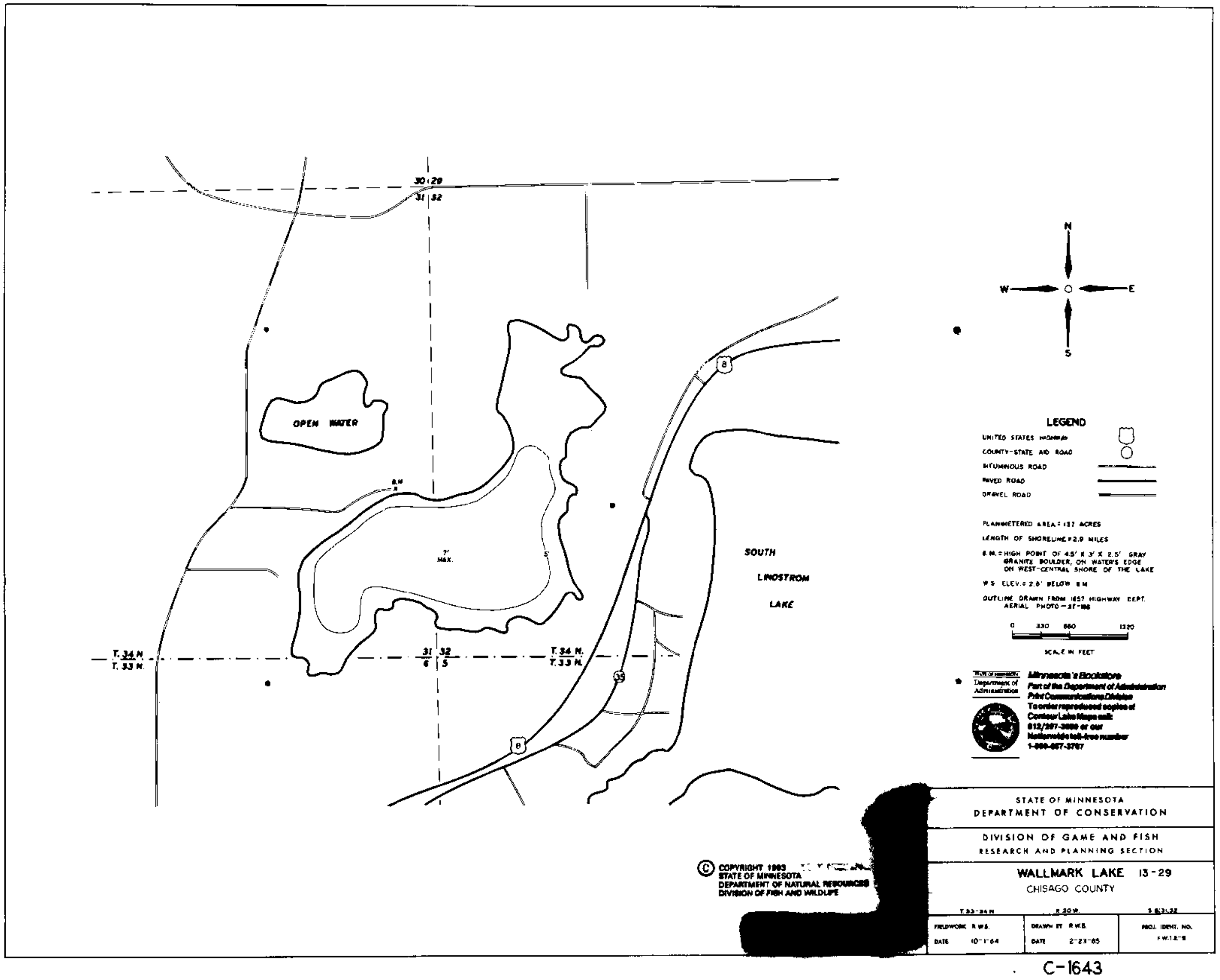
Wallmark Lake (MN DNR Lake ID 13-0029) is a shallow lake located in southern Chisago County, one mile north of Chisago City. Table 65 summarizes the lake's physical characteristics, Figure 57 shows the 2007 aerial photography, and Figure 58 illustrates the available bathymetry.

Table 65 – Wallmark Lake Physical Characteristics

Characteristic	Value	Source
Lake total surface area (ac)	145	MN DNR Public Waters Inventory GIS Shapefile
Percent lake littoral surface area (%)	100	MN DNR Lake Finder
Lake volume (ac-ft)	957	Calculated from MN DNR bathymetric data using 2010 surface contour (aerial photo) and 1991-92 depth contours
Mean depth (ft)	6.6	Lake volume ÷ surface area
Maximum depth (ft)	7.0	MN DNR Lake Finder
Drainage area (ac)	397	SWAT model (Almendinger & Ulrich 2010) and MN DNR level 8 watersheds
Watershed area: Lake area	2.7	Calculated

Figure 57 – Wallmark Lake 2007 Aerial Photography

Figure 58 – Wallmark Lake Bathymetry



12.2 Land Cover

Table 66 – Wallmark Lake Watershed Land Cover

Land Use	Direct Drainage		Entire Drainage	
	Total Acres	% of Watershed	Total Acres	% of Watershed
Developed	78.2	14.4	No other contributing drainage areas	
Cropland	176.0	32.5		
Grassland	35.7	6.6		
Aquatic Habitat	23.9	4.4		
Woodland	83.2	15.3		
Wallmark Lake Surface Area	145.0	26.8		
Total	**542**	**100%**		

12.3 Existing Studies, Monitoring, and Management

Wallmark Lake has been monitored for water level and water quality through the CLLID and volunteers for many years. Data in the MPCA's water quality database dates back to 1972. In 2001, the MPCA evaluated Wallmark Lake through the Citizen Lake Monitoring Program; the report concluded that all measured parameters were well above or outside the expected range for a lake within the North Central Hardwood Forest ecoregion. EPA National Eutrophication Survey from 1975 stated that Wallmark is eutrophic with monitoring data exceeding standards or area expectations. Wallmark Lake was monitored through the Surface Water Assessment Grant program with the MPCA and SWCD in 2008.

12.4 Lake Uses

Aquatic recreation is the designated use for Wallmark Lake, which incorporates swimming, wading, aesthetics, and other related uses. Since there is no public access, Wallmark Lake is used only by property owners for recreation.

12.5 Lake Assessment

Water Quality

Water quality monitoring data for Wallmark are available from 1972 to 2010. Only data from within the most recent 10 years (2001-2010) were used to determine whether Wallmark Lake meets shallow lake water quality standards. The lake does not meet shallow lake water quality standards for total phosphorus, chlorophyll-*a*, or Secchi transparency (Table 67).

Table 67 – 10-year Growing Season Mean TP, Chl-*a*, and Secchi for Wallmark Lake, 2001-2010.

Parameter	Growing Season Mean (June – September)	Growing Season CV* (June – September)	Shallow Lake Standard
Total phosphorus (µg/L)	322	0.21	≤ 60
Chlorophyll-*a* (µg/L)	165	0.30	≤ 20
Secchi transparency (m)	0.6	0.41	≥ 1.0

*CV = coefficient of variation. CV is used as input into the Bathtub model, and is defined in Bathtub as standard error divided by mean

The 10-year growing season mean TP, Chl-*a*, and Secchi transparency in Wallmark Lake violated shallow lake water quality standards between 2001 and 2010. The growing season mean annual TP decreased between 2001 and 2010 (Figure 59), while Chl-*a* and Secchi transparency varied between 2006 and 2010 (Figure 60 and Figure 61). In 2010, growing season mean TP and Chl-*a* exceeded the shallow lake water quality standard (Figure 59 and Figure 60) but Secchi transparency met the shallow lake water quality standard (Figure 61). In 2008, maximum TP occurred in mid-August but maximum Chl-*a* and minimum transparency occurred in September (Figure 62).

Figure 59 – Growing Season Means ± SE of Total Phosphorus for Wallmark Lake by Year. The dashed line represents the shallow lake water quality standard for TP (60 µg/L).

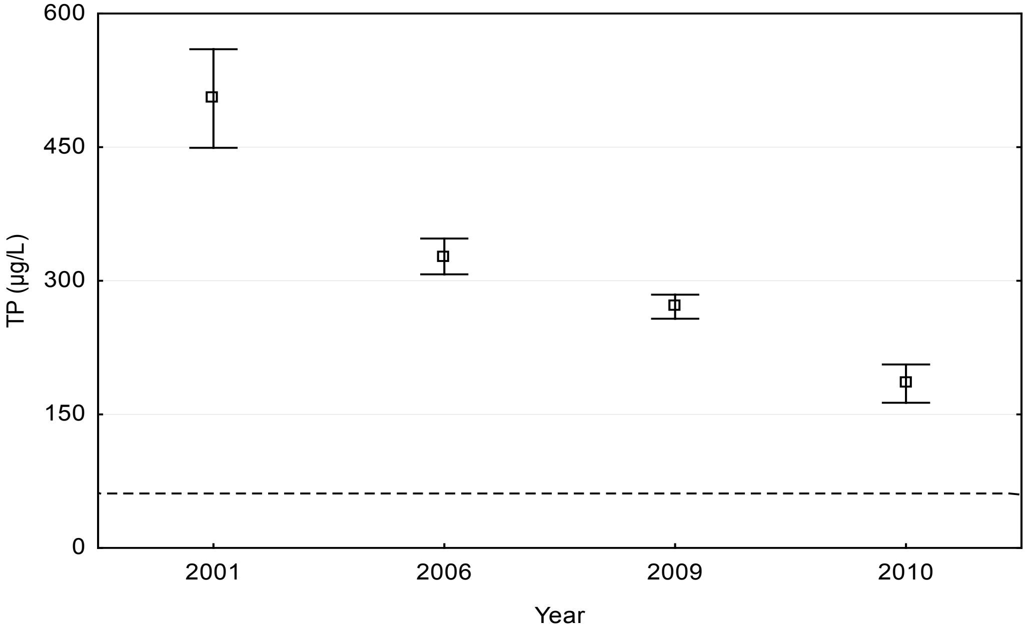


Figure 60 – Growing Season Means ± SE of Chlorophyll-*a* for Wallmark Lake by Year. The dashed line represents the shallow lake water quality standard for Chl-a (20 µg/L).

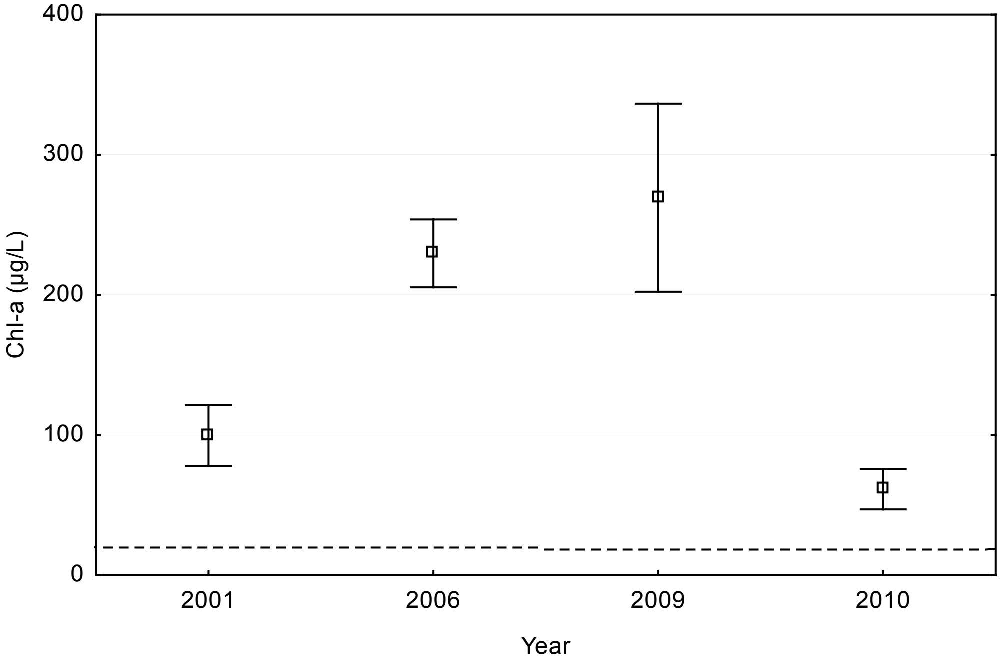


Figure 61 – Growing Season Means ± SE of Secchi Transparency for Wallmark Lake by Year. The dashed line represents the shallow lake water quality standard for transparency (1.0 m).

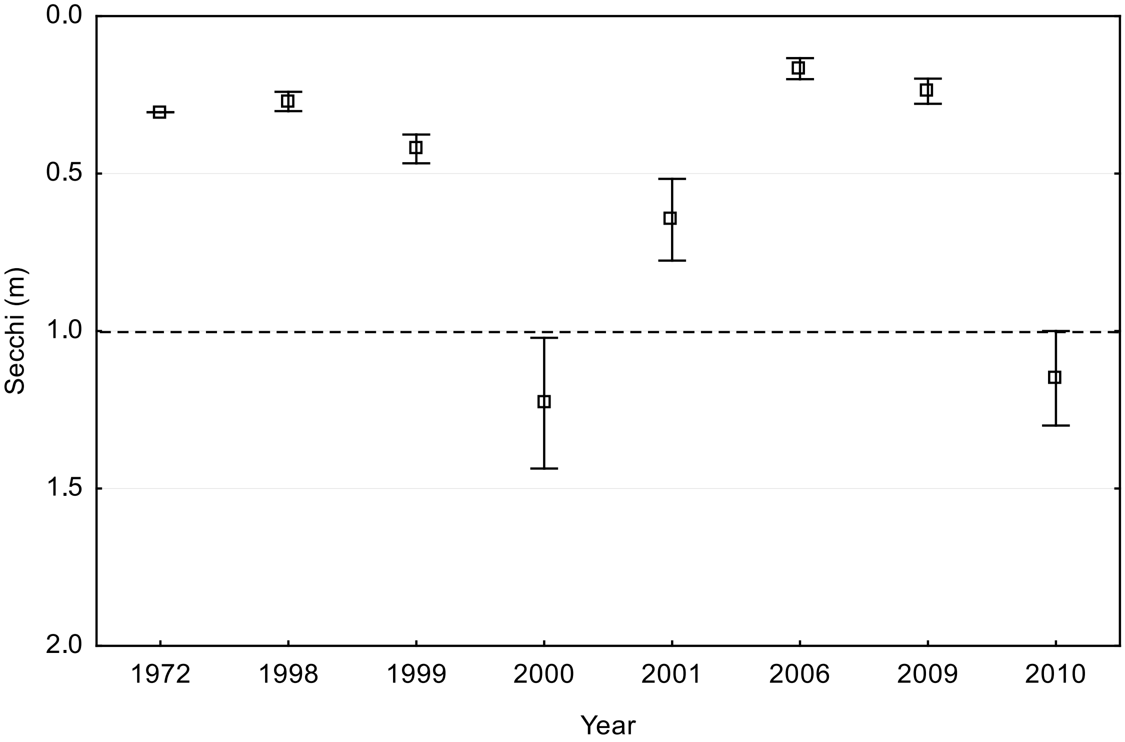
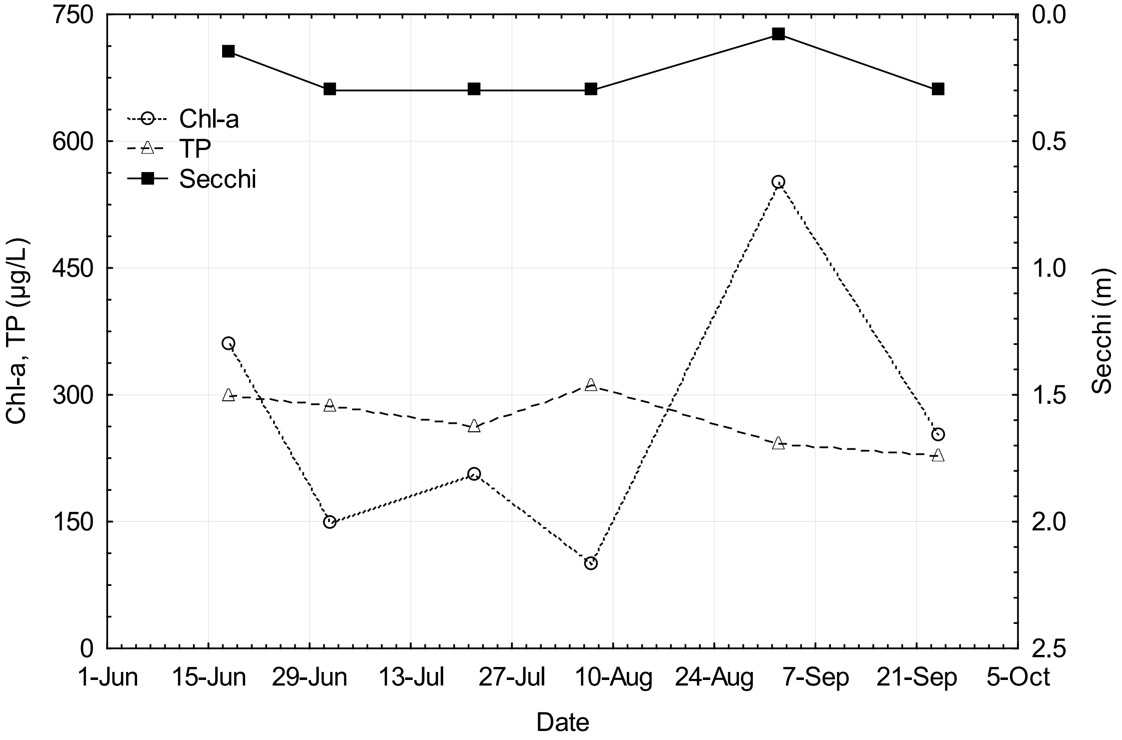


Figure 62 – Growing Season Trends of Chl-*a*, TP, and Secchi Transparency for Wallmark Lake, 2009.



Macrophytes

Macrophytes are abundant in Wallmark Lake. Curly leaf pondweed has been identified in this lake. The extent of other species is not known at this time.

Fish

Very few species of fish live in Wallmark Lake. There is an abundance of stunted sunfish and black bullheads. High black bullhead populations are indicative of lakes that experience partial or near-complete winterkill. Lakes without a public water access are not actively managed for recreational fishing and are not routinely surveyed by the MN DNR Section of Fisheries.

12.6 Phosphorus Source Inventory

Through model calibration, 4,100 pounds of phosphorus were determined to be from a mix of watershed and internal load sources. These mixed sources were distributed as follows: 25% (1,025 lb/yr) to external load and 75% (3,075 lb/yr) to internal load (see Table 15 on page 47).

Watershed + Shallow Groundwater Phosphorus Sources

The contributing watershed to Wallmark Lake includes watershed runoff and shallow groundwater flow.

The SWAT model estimated that Wallmark Lake receives 73 pounds of phosphorus annually from watershed runoff and shallow groundwater flow, and an additional 1,025 pounds were added from the mixed sources, for a total of 1,098 pounds per year from direct loading (Table 68). The SWAT model estimated the 2030 phosphorus load from watershed runoff and shallow groundwater to be 83 lb/yr based on projected population estimates and resulting development. This represents a 14% increase in phosphorus loading from existing conditions (73 lb/yr). Due to the changed economic climate, development is slower than projections; the total additional load may not be realized until 2040 or later.

Table 68 – Wallmark Lake Watershed Runoff and Shallow Groundwater Phosphorus Source Summary

Phosphorus Source	Annual P Load (lb/yr)	Flow Volume[1] (AF/yr)	Area (ac)	Equiv. Depth of Flow (in/yr)	Average Areal P Load (lb/ac-yr)[2]	Average P Conc. (µg/L)[3]
Direct Loading	1,098	294	397	8.9	2.8	1,377

[1] Watershed runoff plus shallow groundwater flow
[2] Annual TP load (lb/yr) divided by drainage area (ac)
[3] Annual TP load (lb/yr) divided by average annual flow volume; values are rounded to the nearest whole number

A very small portion of the Wallmark Lake watershed is serviced by city sanitary sewer. The majority of homes have private on-site septic systems, which are estimated to have a 25% failure rate. Two imminent threat to public health septic systems within the shoreland area have been recently upgraded. Zero animal operations exist within this watershed. At one time, Wallmark Lake accepted wastewater from the Chisago Lakes Sanitary District (Chisago City and Lindstrom). This was disconnected in the mid-1980s to an unnamed ditch to the Chisago Lakes Joint Sewage Treatment Commission facility (MPCA, CLMP+ Report, 2002).

Atmospheric Phosphorus Sources

Atmospheric deposition is estimated to be 40 lb/yr (see *Atmospheric Deposition* in Section 2.2 for more information).

Internal Phosphorus Sources

The modeled internal load based on sediment phosphorus content indicates that internal loading accounts for an estimated 220 to 270 lb/yr of phosphorus loading to the lake. Mixed phosphorus sources identified through the lake modeling suggest that the internal load is 3,075 lb/yr. An internal load of 3,075 lb/yr phosphorus was assumed for Wallmark Lake, representing approximately 73% of the total load to the lake.

Phosphorus Load Summary

The total modeled phosphorus load to Wallmark Lake is 4,213 lb/yr (Table 69).

Table 69 – Wallmark Lake Phosphorus Source Summary, Existing Loads

Phosphorus Source	Phosphorus Load (lb/yr)
Watershed + Shallow Groundwater	1,098
Atmospheric	40
Internal	3,075
Total	**4,213**

12.7 Impairment Assessment Summary

- The lake water quality violates the phosphorus, chlorophyll-*a*, and Secchi transparency water quality standards. The lake is hypereutrophic, with an average phosphorus concentration of 322 µg/l.
- Curly-leaf pondweed exists in the lake, although the extent is not known. Curly-leaf pondweed contributes to internal loading from the sediments.
- There is an abundance of stunted sunfish and black bullhead. The presence of stunted sunfish often indicates an overabundance of planktivorous fish such as sunfish. This overabundance leads to overgrazing on zooplankton and a resultant increase in algae. Black bullhead can lead to high internal loading rates due to their habit of foraging in bottom sediments.
- Approximately 33% of the watershed is cropland.
- The majority of the watershed is served by private on-site septic systems, which are estimated to have a 25% failure rate.
- Two imminent threat to public health septic systems located in the shoreland area were recently upgraded.
- Wallmark Lake was the receiving water for the discharge from the Chisago City and Lindstrom wastewater treatment facility from the cities of until the mid-1980s.
- The lake model indicated that there is a large phosphorus load that is unaccounted for in the current phosphorus source inventory. This load is likely a mix of internal load and load from failing septic systems.

12.8 TMDL Loading Capacity and Allocations

The phosphorus loading capacity of Wallmark Lake is 240 lb/yr, to be split among allocations according to Table 70. While there are currently no regulated MS4s in the Wallmark Lake watershed; should a portion of the watershed come under regulation by a MS4 permit in the future the transfer rate from LA to WLA for regulated MS4 stormwater runoff is 0.12 lb/ac-yr, or 0.00033 lb/ac-day.

Table 70 – Wallmark Lake TP Allocations

Load Component	TP Existing	TP TMDL Allocation		TP Reduction	
	lb/yr	lb/yr	lb/day	lb/yr	%
WLA					
Construction stormwater (permit #MNR100001)	0.074	0.074	0.00020	0	0%
Industrial stormwater (permit # MNR50000)	0.074	0.074	0.00020	0	0%
Total WLA	**0.15**	**0.15**	**0.00040**	**0**	**0%**
LA*					
Watershed	1,098	46	0.13	1,052	96%
Atmospheric	40	40	0.11	0	0%
Internal	3,075	130	0.36	2,945	96%
Total LA	**4,213**	**216**	**0.60**	**3,997**	**95%**
MOS	**--**	**24**	**0.066**		
Total	***4,213***	***240***	***0.67***		

*LA components are broken down for guidance in implementation planning; loading goals for these components may change through the adaptive implementation process, but the total LA for each lake will not be modified from the total listed in the table above.

To meet the TMDL with a 10% margin of safety, the total load to the lake needs to be reduced by 3,997 lb/yr (95%).

The load reduction goals are based on the following:

- Equal percent reductions were assigned for runoff and internal load.

13 SEASONAL VARIATION AND CRITICAL CONDITIONS

13.1 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 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.

Some of these patterns are seen in the Chisago Lakes Chain of Lakes. The highest monthly chlorophyll-*a* means across the ten years (2001-2010) of data occur in either July or August for all lakes except Wallmark Lake (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).

13.2 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.

14 MONITORING PLAN

14.1 Lake Monitoring

The lakes within the Chisago Lakes Chain of Lakes Watershed have been monitored by volunteers and staff over the years. This monitoring is planned to continue to keep a record of the changing water quality. Lakes are generally monitored for chlorophyll-*a*, total phosphorus, and Secchi disk transparency.

In-lake monitoring will continue as implementation activities are installed across the watershed. These monitoring activities should continue until water quality goals are met. Some tributary monitoring has been completed on the inlets to the Chain of Lakes. Monitoring on the tributaries and stormwater inlets may be continued as water levels come back in to measure pollutants and quantify pollutant loads entering the lakes through streams and pipes.

The MN DNR will continue to conduct macrophyte and fish surveys as allowed by their regular schedule. Currently fish surveys are conducted every 5 years and macrophyte surveys are conducted as staffing and funding allow on a 10-year rotation, unless there are special situations.

14.2 BMP Monitoring

On-site monitoring of implementation practices should also take place in order to better assess BMP effectiveness. A variety of criteria such as land use, soil type, and other watershed characteristics, as well as monitoring feasibility, will be used to determine which BMPs to monitor. Under these criteria, monitoring of a specific type of implementation practice can be accomplished at one site but can be applied to similar practices under similar criteria and scenarios. Effectiveness of other BMPs can be extrapolated based on monitoring results.

15 IMPLEMENTATION STRATEGY

15.1 Adaptive Management

The response of the lakes will be evaluated as management practices are implemented. This evaluation will occur every five years after the commencement of implementation actions; for the next 25 years. Monitoring data will be evaluated and decisions will be made as to how to proceed for the next five years. The management approach to achieving the goals should be adapted as new information is collected and evaluated.

15.2 Stormwater Ordinances and Low Impact Development

The communities within the Chisago Lakes Chain of Lakes Watershed are currently not defined as Municipal Separate Storm Sewer System communities (MS4 - the state's municipal stormwater permit) which means that they are not required to have strong ordinances to protect impaired and unimpaired waters. The communities of Chisago City, Lindstrom, and Center City within the Chisago Chain of Lakes were chosen as a St. Croix Minimal Impact Design Standard (MIDS) Pilot Community. This program will provide assistance with reviewing and updating existing stormwater-related ordinances to better protect and restore water resources. The local communities will then be able to enhance new development and redevelopment ordinances, and allow the integration of Low Impact Development concepts into local codes and procedures.

15.3 Subwatershed Assessments

Urban subwatershed assessments are completed for the developed portions of Center City, Lindstrom, and Chisago City. The urban subwatershed assessments were completed in 2011 and 2012 by the Chisago SWCD. Rural subwatershed assessments are set to be completed by the SWCD in the rural portions of the watershed in 2013. These assessments help guide implementation activities by determining the potential runoff load as well as identifying the most logical locations to start with Best Management Practice (BMP) implementation. Local decision makers and the SWCD use the subwatershed assessments to prioritize implementation activities and apply for funding. Visit www.chisagoswcd.org for more information.

15.4 Prioritization

Prioritization of implementation activities is going to be key in achieving the necessary reductions with the current level of funds and staff time available. Examples of prioritizing BMPs will include focusing on watershed loading reductions before implementing any major in-lake treatment efforts. This does not mean that efforts, such as vegetation management, should stop; but the primary focus of work should look at reducing external sources.

Other efforts for prioritization include prioritizing work on upstream lakes before working on the downstream lakes, or starting work on lakes with lower reduction goals before working on higher reduction lakes. These are all things that will be looked in the development of the Restoration Plan, and discussed with local citizens.

15.5 Education and Outreach

A crucial part in the success of the Restoration and Protection plan that will be designed to clean up the impaired lakes and protect the non-impaired lakes will be participation from local citizens. In order to gain support from these citizens, education and civic engagement opportunities will be necessary. A variety of educational avenues can and will be used throughout the watershed. These include (but are not limited to): press releases, meetings, workshops, focus groups, trainings, websites, etc. CLLID and Chisago SWCD staff and board members work to educate the residents of the watersheds about ways to clean up their lakes on a regular basis. Education will continue throughout the watershed.

15.6 Technical Assistance

The Chisago SWCD provides assistance to landowners for a variety of projects that benefit water quality throughout Chisago County. Assistance provided to landowners varies from agricultural and rural best management practices to urban and lakeshore best management practices. This technical assistance includes education and one-on-one training. Many opportunities for technical assistance are as a result of educational workshops of trainings. It is important that these outreach opportunities for Chisago County residents continue. Marketing is necessary to motivate landowners to participate in voluntary cost-share assistance programs.

Technical assistance is provided by a variety of entities, including but not limited to the Chisago SWCD and NRCS. Programs such as State cost-share, Clean Water Legacy funding, Environmental Quality Incentives Program (EQIP), Conservation Reserve Program (CRP) are available to help implement the best conservation practices that each parcel of land is eligible for to target the best conservation practices per site. Conservation practices may include, but are not limited to: stormwater bioretention, septic system upgrades, feedlot improvements, invasive species control, wastewater treatment practices, agricultural and rural best management practices and internal loading reduction. More information about types of practices and implementation of BMPs will be discussed in the Chisago Lakes Chain of Lakes Watershed Restoration and Protection Plan.

15.7 Partnerships

Partnerships with counties, cities, townships, citizens, businesses, and lake associations are one mechanism through which the CLLID and the Chisago SWCD protect and improve water quality. The CLLID and the Chisago SWCD will continue its strong tradition of partnering with state and local government to protect and improve water resources and to bring waters within the Chisago Lakes Chain of Lakes Watershed into compliance with State standards. A partnership with local government units and regulatory agencies such as Chisago City, Lindstrom, Center City, townships and Chisago County may be formed to develop and update ordinances to protect the areas water resources.

15.8 Cost

The Clean Water Legacy Act requires that a TMDL include an overall approximation of the cost to implement a TMDL [MN Statutes 2007, section 114D.25]. The initial estimate for implementing the Chisago Lakes Watershed TMDL is approximately $2,000,000 to $5,500,000. This estimate will be refined when the more detailed implementation plan is developed.

15.9 Strategies for Individual Lakes

North Center Lake

To meet the TMDL, taking into account the MOS, total loading to the lake needs to be reduced by 1,108 lb/yr, or 18% (Table 71). If the upstream lakes (Little, Pioneer, and South Center Lakes) all meet their water quality goals, the load to North Center Lake would be reduced by 520 lb/yr. The remaining 588 lb/yr reduction should come from watershed BMPs. Watershed load reduction practices will include urban stormwater reduction practices, lakeshore and streambank buffers, and a wide variety of agricultural Best Management Practices (BMPs). Internal loading is not excessively high in North Center Lake and is not a primary focus of restoration efforts.

Table 71 – North Center Lake Phosphorus Reduction Summary

PHOSPHORUS SOURCE	EXISTING ANNUAL TP LOAD (LB/YR)	IMPLEMENTATION SCENARIO ANNUAL TP LOAD (LB/YR)	LOAD REDUCTION NEEDED (LB/YR)	PERCENT REDUCTION (%)
Watershed	2,813	1,705	1,108	39%
Atmospheric Deposition	200	200	0	0%
Internal	3,000	3,000	0	0%
Total	**6,013**	**4,905**	**1,108**	**18%**

South Center Lake

To meet the TMDL, taking into account the MOS, total loading to the lake needs to be reduced by 1,260 lb/yr, or 21% (Table 72). If the upstream lakes (Linn and Ogren Lakes) all meet their water quality goals, the load to South Center Lake would be reduced by 210 lb/yr. Of the remaining load reduction needed, approximately 842 lb/yr should come from the watershed load and approximately 208 lb/yr should come from internal load. Watershed load reduction practices will include urban stormwater reduction practices, lakeshore and streambank buffers, and a wide variety of agricultural Best Management Practices (BMPs). Due to the small amount of internal load reduction needed for South Center Lake, internal load reduction practices should not be a primary focus of restoration efforts. As watershed loads to the lake are reduced, over the long term the lake should respond with lower internal loading rates.

Table 72 – South Center Lake Phosphorus Reduction Summary

PHOSPHORUS SOURCE	EXISTING ANNUAL TP LOAD (LB/YR)	IMPLEMENTATION SCENARIO ANNUAL TP LOAD (LB/YR)	LOAD REDUCTION NEEDED (LB/YR)	PERCENT REDUCTION (%)
Watershed	2,385	1,333	1,052	44%
Atmospheric Deposition	240	240	0	0%
Internal	3,500	3,292	208	6%
Total	**6,125**	**4,865**	**1,260**	**21%**

Lake Emily

To meet the TMDL, taking into account the MOS, total loading to the lake needs to be reduced by 362 lb/yr, or 93% (Table 73). Approximately 100 lb/yr should come from the watershed load and approximately 262 lb/yr should come from internal load. Watershed load reduction practices will include stormwater reduction practices, lakeshore buffers, and a wide variety of agricultural Best Management Practices (BMPs). In-lake practices may consist of fish and aquatic plant management and management of internal nutrient cycling.

Table 73– Lake Emily Phosphorus Reduction Summary

PHOSPHORUS SOURCE	EXISTING ANNUAL TP LOAD (LB/YR)	IMPLEMENTATION SCENARIO ANNUAL TP LOAD (LB/YR)	LOAD REDUCTION NEEDED (LB/YR)	PERCENT REDUCTION (%)
Watershed	106	6.2	100	94%
Atmospheric Deposition	4.6	4.6	0	0%
Internal	278	16	262	94%
Total	**389**	**27**	**362**	**93%**

Linn Lake

To meet the TMDL, taking into account the MOS, total loading to the lake needs to be reduced by 2,395 lb/yr, or 88% (Table 74). Approximately 848 lb/yr should come from the watershed load and approximately 1,547 lb/yr should come from internal load. Watershed load reduction practices will include stormwater reduction practices, lakeshore and streambank buffers, and a wide variety of agricultural Best Management Practices (BMPs). In-lake practices may consist of fish and aquatic plant management and management of internal nutrient cycling.

Table 74 – Linn Lake Phosphorus Reduction Summary

PHOSPHORUS SOURCE	EXISTING ANNUAL TP LOAD (LB/YR)	IMPLEMENTATION SCENARIO ANNUAL TP LOAD (LB/YR)	LOAD REDUCTION NEEDED (LB/YR)	PERCENT REDUCTION (%)
Watershed	945	97	848	90%
Atmospheric Deposition	49	49	0	0%
Internal	1,725	178	1,547	90%
Total	**2,719**	**324**	**2,395**	**88%**

Little Lake

To meet the TMDL, taking into account the MOS, total loading to the lake needs to be reduced by 2,658 lb/yr, or 90% (Table 75). Approximately 1,562 lb/yr should come from the watershed load and approximately 1,096 lb/yr should come from internal load. Watershed load reduction practices will include a wide variety of agricultural Best Management Practices (BMPs) and lakeshore and streambank buffers. In-lake practices may consist of fish and aquatic plant management and management of internal nutrient cycling.

Table 75 – Little Lake Phosphorus Reduction Summary

Phosphorus Source	Existing Annual TP Load (lb/yr)	Implementation Scenario Annual TP Load (lb/yr)	Load Reduction Needed (lb/yr)	Percent Reduction (%)
Watershed	1,710	148	1,562	91%
Atmospheric Deposition	44	44	0	0%
Internal	1,200	104	1,096	91%
Total	**2,954**	**296**	**2,658**	**90%**

Ogren Lake

To meet the TMDL, taking into account the MOS, total loading to the lake needs to be reduced by 467 lb/yr, or 45% (Table 76). Approximately 430 lb/yr should come from the watershed load and approximately 37 lb/yr should come from internal load. Watershed load reduction practices will include a wide variety of agricultural Best Management Practices (BMPs) and lakeshore and streambank buffers. In-lake practices may consist of fish and aquatic plant management and management of internal nutrient cycling.

Table 76 – Ogren Lake Phosphorus Reduction Summary

Phosphorus Source	Existing Annual TP Load (lb/yr)	Implementation Scenario Annual TP Load (lb/yr)	Load Reduction Needed (lb/yr)	Percent Reduction (%)
Watershed	860	430	430	50%
Atmospheric Deposition	13	13	0	0%
Internal	170	133	37	22%
Total	**1,043**	**576**	**467**	**45%**

Pioneer Lake

To meet the TMDL, taking into account the MOS, total loading to the lake needs to be reduced by 1,771 lb/yr, or 96% (Table 77). Approximately 21 lb/yr should come from the watershed load and approximately 1,750 lb/yr should come from internal load. Watershed load reduction practices will include urban stormwater reduction practices, lakeshore and streambank buffers, and a wide variety of agricultural Best Management Practices (BMPs). In-lake practices may consist of fish and aquatic plant management and management of internal nutrient cycling.

Table 77 – Pioneer Lake Phosphorus Reduction Summary

Phosphorus Source	Existing Annual TP Load (lb/yr)	Implementation Scenario Annual TP Load (lb/yr)	Load Reduction Needed (lb/yr)	Percent Reduction (%)
Watershed	22	0.61	21	95%
Atmospheric Deposition	21	21	0	0%
Internal	1,800	50	1,750	97%
Total	**1,843**	**72**	**1,771**	**96%**

School Lake

To meet the TMDL, taking into account the MOS, total loading to the lake needs to be reduced by 1,591 lb/yr, or 88% (Table 78). Approximately 818 lb/yr should come from the watershed load and approximately 773 lb/yr should come from internal load. Watershed load reduction practices will include urban stormwater reduction practices, lakeshore and streambank buffers, and a wide variety of agricultural Best Management Practices (BMPs). In-lake practices may consist of fish and aquatic plant management and management of internal nutrient cycling.

Table 78 – School Lake Phosphorus Reduction Summary

PHOSPHORUS SOURCE	EXISTING ANNUAL TP LOAD (LB/YR)	IMPLEMENTATION SCENARIO ANNUAL TP LOAD (LB/YR)	LOAD REDUCTION NEEDED (LB/YR)	PERCENT REDUCTION (%)
Watershed	918	100	818	89%
Atmospheric Deposition	39	39	0	0%
Internal	850	77	773	91%
Total	**1,807**	**216**	**1,591**	**88%**

Wallmark Lake

To meet the TMDL, taking into account the MOS, total loading to the lake needs to be reduced by 3,997 lb/yr, or 95% (Table 79). Approximately 1,052 lb/yr should come from the watershed load and approximately 2,945 lb/yr should come from internal load. Watershed load reduction practices will include urban stormwater reduction practices, lakeshore and streambank buffers, and a wide variety of agricultural Best Management Practices (BMPs). In-lake practices may consist of fish and aquatic plant management and management of internal nutrient cycling.

Table 79 – Wallmark Lake Phosphorus Reduction Summary

PHOSPHORUS SOURCE	EXISTING ANNUAL TP LOAD (LB/YR)	IMPLEMENTATION SCENARIO ANNUAL TP LOAD (LB/YR)	LOAD REDUCTION NEEDED (LB/YR)	PERCENT REDUCTION (%)
Watershed	1,098	46	1,052	96%
Atmospheric Deposition	40	40	0	0%
Internal	3,075	130	2,945	96%
Total	**4,213**	**216**	**3,997**	**95%**

16 REASONABLE ASSURANCES

As part of an implementation strategy, reasonable assurances provide a level of confidence that the TMDL allocations will be implemented by federal, state, or local authorities. Implementation of the Chisago Lakes Chain of Lakes TMDL will be accomplished by both state and local action on many fronts, both regulatory and non-regulatory. Multiple entities in the watershed already work towards improving the lakes' water quality. Water quality restoration efforts will be led by the CLLID and the Chisago SWCD along with assistance from the local communities.

16.1 Non-Regulatory

At the local level, CLLID and Chisago SWCD currently implement programs targeted at water quality improvement and have been actively involved in projects to improve water quality in the past. It is anticipated that their involvement will continue. Potential state funding of TMDL implementation projects includes the Clean Water Fund grants. At the federal level, funding can be provided through Section 319 grants that provide cost share dollars to implement activities in the watershed. Various other funding and cost-share sources exist, which will be listed in the Chisago Lakes Chain of Lakes TMDL Implementation Plan.

The implementation strategies described in this TMDL have demonstrated to be effective in reducing nutrient loadings to lakes. CLLID and Chisago SWCD have programs in place to continue many of the recommended activities. Monitoring will continue and adaptive management will be in place to evaluate progress made towards achieving the beneficial use of each lake.

16.2 Regulatory

State implementation of the TMDL will be through action on NPDES permits for regulated construction stormwater. To meet the WLA for construction stormwater, construction stormwater 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.

To meet the WLA for industrial stormwater, industrial stormwater activities are required to meet the conditions of the industrial stormwater general permit or Nonmetallic Mining & Associated Activities general permit (MNG49) under the NPDES program and properly select, install and maintain all BMPs required under the permit.

Chisago County's current septic system ordinance is based on septic system inspection at the time of property transfer or installation of any new or replacement on-site sewage disposal system. From 2004 to 2009 Chisago County participated in the Three County Septic Pilot Program to inspect all septic systems within their jurisdiction (not including Chisago City or the City of Lindstrom) to identify and upgrade systems determined to be an imminent threat to public health threat. In 2010 Chisago County received another grant from the "Clean Water Legacy Fund" to offer free compliance inspections and pay a portion of the pumping cost within the shoreland. This grant is to find and fix all imminent threat to public health and failing to protect ground water septic systems. In 2010 and 2011 financial assistance was awarded for the sole purpose of aiding low income property owner on septic system replacement cost.

Chisago County is not an MPCA delegated partner with the State Feedlot Program and does not employ a County Feedlot Officer; MPCA provides field staff for feedlot permitting and compliance checks on all registered animal operations.

16.3 Chisago County Water Plan

Past and current versions of the Chisago County water plan have identified impaired waters and TMDLs as a priority for county efforts. The water plan priorities are based on public input process; which has identified water quality and quantity as priority concerns throughout the county. Based on these concerns Chisago County and the Chisago SWCD have been focusing their past and current efforts on addressing these issues, and will likely continue this into the future.

This TMDL report and Final Restoration Plan will be incorporated in the county water plan once they are approved.

17 STAKEHOLDER PARTICIPATION

17.1 Steering Committee

Steering Committee meetings were held on the following dates:
September 19, 2011
A second meeting will be scheduled in 2012.

Meeting minutes are included in Appendix C – Meeting Minutes.

17.2 Public Meetings

Public Meetings were held on the following dates:
September 19, 2011
A second meeting will be scheduled in 2012

September 19, 2011 meeting – Fifteen area citizens attended an open house to answer questions about the TMDL as a whole. Specific questions per lake were answered. The biggest concern was for the non-impaired lakes and how to protect them from becoming impaired in the future. The Restoration and Protection Plan will identify measures to restore the impaired lakes and protect the non-impaired lakes.

The Public Comment period was October 22, 2012 – November 21, 2012.

17.3 Farmer Focus Group Meeting

Farmer Focus Group meetings were held on March 28, 2011 and April 3, 2012 with a group of influential agricultural producers within Chisago County, local Agronomists, along with Chisago Soil & Water Conservation District and USDA Natural Resources Conservation Service staff. The focus of the meeting was the local TMDL studies currently happening in Chisago County. Statistics were shared with the group that included pollutant runoff potentials from different land uses; this showed that due to the large amount of land in agricultural production, there is the potential to reduce pollutant runoff in large quantities. The producers are interested in maximizing their production while preventing soil and nutrient loss.

17.4 Regular Updates

Regular updates about the TMDL process are given at the Chisago Lakes Lake Improvement District Board meetings. These meetings are held the first Monday of each month at 6:30 pm in the Chisago County Government Center. Another update on the process is also given each year at the Chisago Lakes Lake Improvement District Annual Meeting held in February. Board members are also given chance to review the documents and provide comments along the way. The board members on the CLLID each represent different lakes and their associated watersheds. These board members are often members of their individual Lake Associations, in those cases, the board members give updates at Lake Association meetings. Similar updates are also given by the SWCD to the area Lake Associations for newsletters, and annual meetings.

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19 APPENDIX A – WATERS FOR PROTECTION

19.1 Waters for Protection

Many waters within the Chisago Lakes Chain of Lakes Watershed are currently meeting water quality standards set by the State of Minnesota. These waters will require protection measures including but not limited to best management practices, ordinances, and education. These unimpaired and unassessed waters are listed in Table 80.

Table 80 - Waters for Protection

Lake Name	DNR Lake ID
North Lindstrom Lake	13-0035
South Lindstrom Lake	13-0028
Little Green Lake	13-0041-01
Green Lake	13-0041-02
Mattson Lake	13-0043
Spider Lake	13-0019
Bloom Lake	13-0001
Ellen Lake	13-0047
Kroon Lake	13-0013
Swamp Lake	13-0016
Chisago Lake	13-0012
Lake Martha	13-0040

Section 19.2 Physical Characteristics through section 19.7 Phosphorus Source Inventory is an example of the type of information that may be gathered (Kroon Lake information is more detailed than the other protection lakes due to information gathered before Kroon was deemed to be no longer impaired) and used for the Restoration and Protection Plan that will follow in the Chisago Lakes Chain of Lakes Watershed TMDL report. This information will then be used to determine the best options for implementation.

19.2 Physical Characteristics

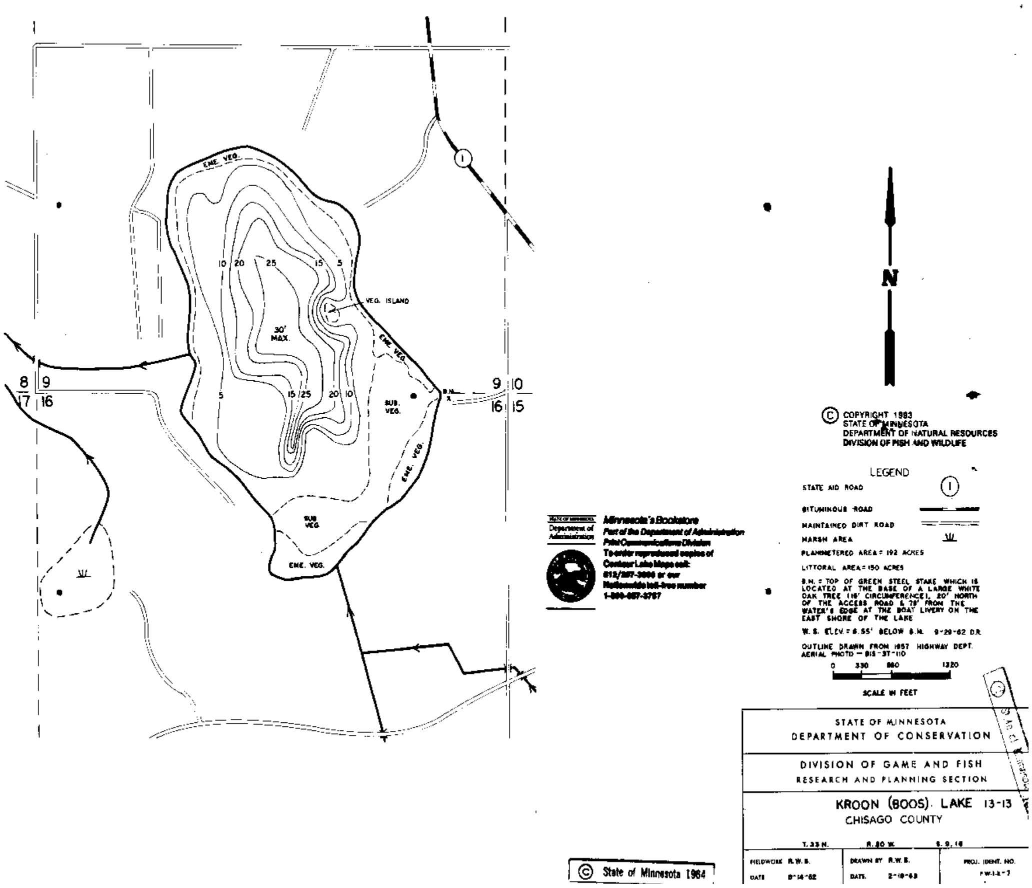
Kroon Lake (MN DNR Lake ID 13-0013) is a lake located in southern Chisago County, two miles south of Lindstrom. Table 81 summarizes the lake's physical characteristics, Figure 63 displays aerial photography from 2007, and Figure 64 illustrates the available bathymetry. Much of the lakeshore has clay, muck overlying sand substrate.

Table 81 – Kroon Lake Physical Characteristics

Characteristic	Value	Source
Lake total surface area (ac)	181	MN DNR bathymetric data – 0 m depth contour digitized from 1991-92 aerial photography
Percent lake littoral surface area (%)	83	MN DNR Lake Finder
Lake volume (ac-ft)	1,388	Calculated from MN DNR bathymetric data using 2010 surface contour (aerial photo) and 1991-92 depth contours
Mean depth (ft)	7.7	Lake volume ÷ surface area
Maximum depth (ft)	30	MN DNR Lake Finder
Drainage area (ac)	960	SWAT model (HDR 2008)
Watershed area: Lake area	5.3	Calculated

Figure 63 – Kroon Lake 2007 Aerial Photography

Figure 64 – Kroon Lake Bathymetry



19.3 Land Cover

Table 82 – Kroon Lake Watershed Land Cover

Land Use	Direct Drainage		Entire Drainage	
	Total Acres	% of Watershed	Total Acres	% of Watershed
Developed	1.2	0.2	19.6	1.7
Cropland	242.1	43.5	635.2	55.7
Grassland	19.0	3.4	57.4	5.0
Wetland	32.0	5.7	128.5	11.3
Woodland	81.8	14.7	119.3	10.5
Lake Surface Area	181.0	32.5	181.0	15.9
Total	**557.1**	**100%**	**1,141.0**	**100%**

19.4 Existing Studies, Monitoring, and Management

Kroon Lake has been monitored for water level and water quality through the CLLID and volunteers for many years. Data in the MPCA's water quality database dates back to 1994. A MPCA Citizen Lake Monitoring Program report shows that Kroon Lake Water quality hovers very near the state standards (2001). Severe algae blooms were noted in August of 2001.

19.5 Lake Uses

Aquatic recreation is the designated use for Kroon Lake, which incorporates swimming, wading, aesthetics, and other related uses. Kroon Lake experiences fishing pressure in the summer and to a less extent in the winter. Several ice fishing houses are present on the lake throughout the winter. During the summer months both residents and visitors use the lake for fishing and recreation.

19.6 Lake Assessment

Water Quality

Water quality monitoring data for Kroon Lake are available from 1994 to 2010. Only data from within the most recent 10 years (2001-2010) were used to determine whether Kroon Lake meets lake water quality standards. The lake does not meet lake water quality standards for chlorophyll-*a*. The lake just meets lake water quality standards for total phosphorus and Secchi transparency (Table 83).

Table 83 – 10-year Growing Season Mean TP, Chl-*a*, and Secchi for Kroon Lake, 2001 – 2010.

Parameter	Growing Season Mean (June – September)	Growing Season CV (June – September)	Lake Standard
Total phosphorus (µg/L)	36	± 5	≤ 40
Chlorophyll-*a* (µg/L)	25	± 22	≤ 14
Secchi transparency (m)	1.5	± 10	≥ 1.4

The 10-year growing season mean of Chl-*a* in Kroon Lake exceeded lake water quality standards between 2001 and 2010. Between 2001 and 2010, the growing season mean annual TP, Chl-*a*, and Secchi transparency were variable with no visible long-term trend (Figure 65, Figure 66 and Figure 67). The 2010 growing season mean TP and Secchi transparency met the lake water quality standards (Figure 65 and Figure 67) while Chl-*a* violated the lake water quality standard

(Figure 66). In 2010, maximum TP and Chl-*a* and minimum transparency occurred throughout August and September (Figure 68).

Figure 65 – Growing Season Means ± SE of Total Phosphorus for Kroon Lake by Year. The dashed line represents the lake water quality standard for TP (40 µg/L).

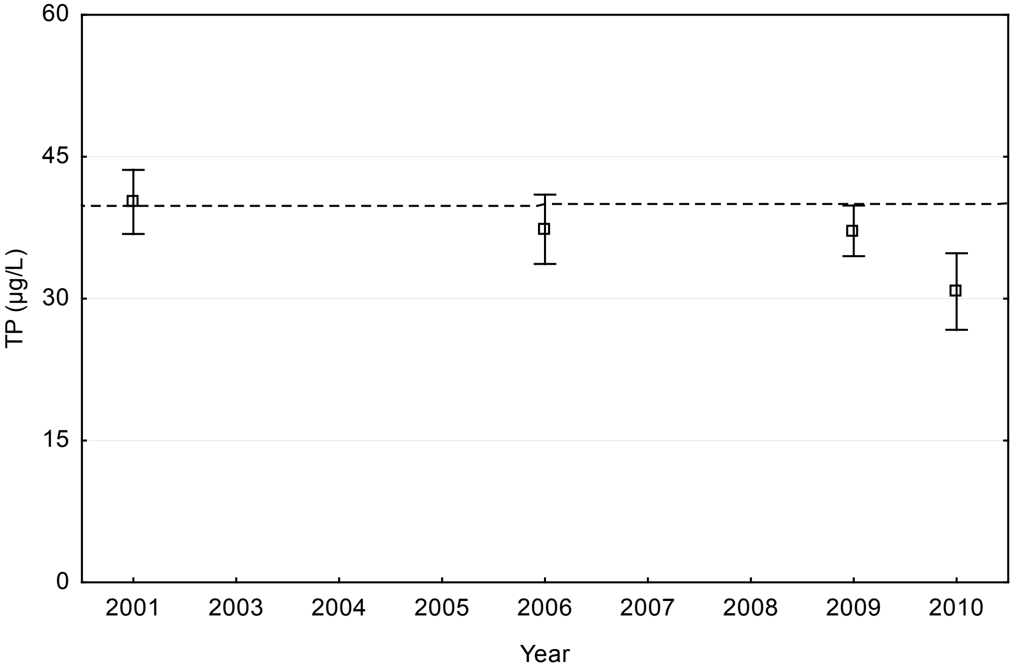


Figure 66 – Growing Season Means ± SE of Chlorophyll-*a* for Kroon Lake by Year. The dashed line represents the lake water quality standard for Chl-*a* (14 µg/L).

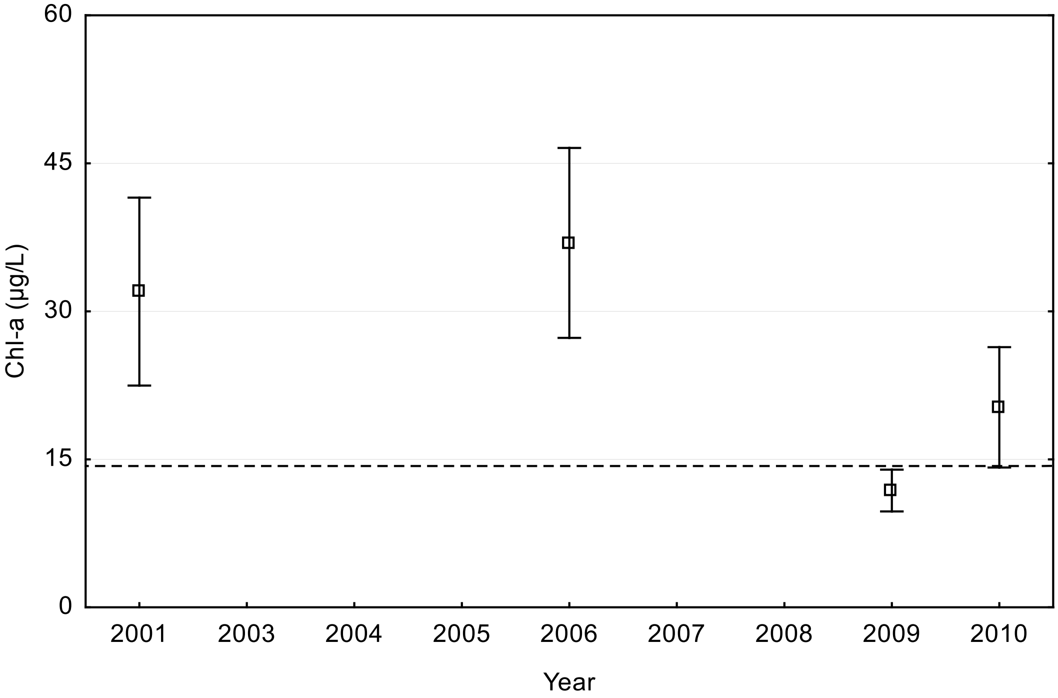


Figure 67 – Growing Season Means ± SE of Secchi Transparency for Kroon Lake by Year. The dashed line represents the lake water quality standard for transparency (1.4 m).

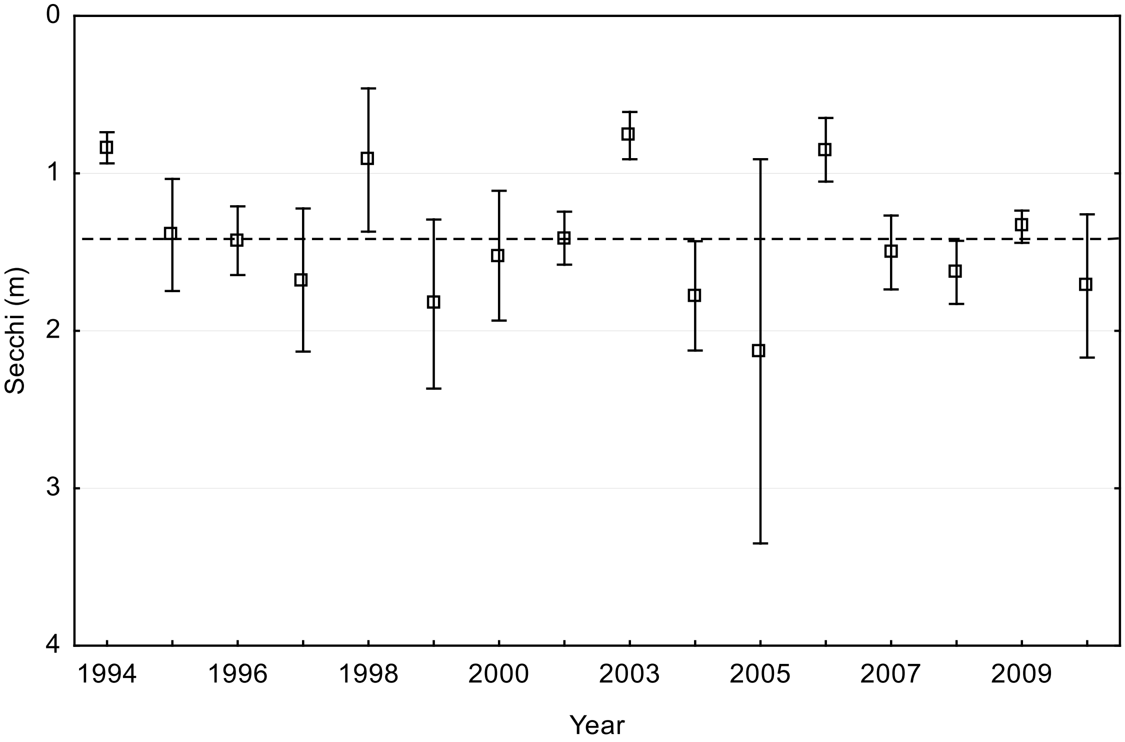
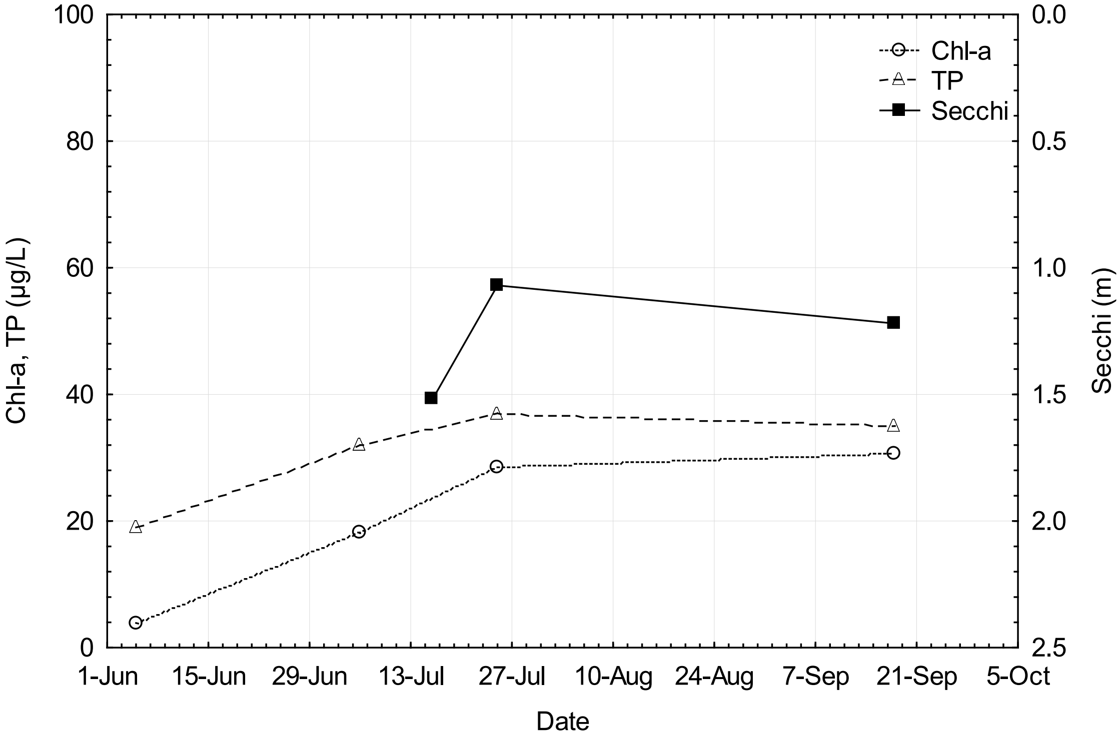


Figure 68 – Growing Season Trends of Chl-a, TP, and Secchi Depth 2010 for Kroon Lake, 2010.



Macrophytes

Macrophytes are abundant in Kroon Lake. Curly leaf pondweed has been identified in this lake. The curly-leaf pondweed covers a majority of the littoral area of the lake. In the shallow areas large populations of cattails and other macrophytes are present.

Fish

Species present in 2009 included northern pike, largemouth bass, bluegill, black crappie, yellow perch, brown bullhead, bowfin (dogfish), golden shiner, hybrid sunfish, and pumpkinseed sunfish. Kroon Lake is largely managed for northern pike.

19.7 Phosphorus Source Inventory

Watershed + Shallow Groundwater Phosphorus Sources

The SWAT model estimated that Kroon Lake receives 140 pounds of phosphorus annually from watershed runoff and shallow groundwater flow (Table 84). The 2030 phosphorus load from watershed runoff and shallow groundwater is estimated to be 150 lb/yr based on projected population estimates and resulting development. This represents a 7% increase in phosphorus loading from existing conditions. Due to the changed economic climate, development is slower than projections; the total additional load may not be realized until 2040 or later.

Table 84 – Kroon Lake Watershed Runoff and Shallow Groundwater Phosphorus Source Summary

Phosphorus Source	Annual P Load (lb/yr)	Flow Volume[1] (AF/yr)	Area (ac)	Equiv. Depth of Flow (in/yr)	Average Areal P Load (lb/ac-yr)[2]	Average P Conc. (µg/L)[3]
Direct Loading	140	576	960	7.2	0.15	90

[1] Watershed runoff plus shallow groundwater flow
[2] Annual TP load (lb/yr) divided by drainage area (ac)
[3] Annual TP load (lb/yr) divided by average annual flow volume

A very small portion of the North West corner of the Kroon Lake watershed is serviced by city sanitary sewer. The majority of the homes have private on-site septic systems, which are estimated to have a 25% failure rate. Four imminent threat to public health septic systems have been recently upgraded, one of these is within the shoreland area. One small feedlot exists within the contributing watershed area. In the 1950s, there was a hog operator in the watershed, who allowed the hogs access to the lake. The operator has since left the watershed.

Atmospheric Phosphorus Sources

Atmospheric deposition is estimated to be 50 lb/yr (see *Atmospheric Deposition* in Section 2.2 for more information).

Internal Phosphorus Sources

The modeled internal load based on sediment phosphorus content indicates that internal loading accounts for an additional 1,900 to 2,600 lb/yr of phosphorus loading to the lake. These rates of internal loading are relatively high for a lake that does not exhibit symptoms of excessive internal loading. The internal loading rate from Ogren Lake was applied to the surface area of Kroon Lake, for a total of 630 lb/yr internal loading to Kroon Lake.

Phosphorus Load Summary

The total modeled phosphorus load to Kroon Lake is 820 lb/yr (Table 85).

Table 85 – Kroon Lake Phosphorus Source Summary

Phosphorus Source	Phosphorus Load (lb/yr)
Watershed + Shallow Groundwater	140
Atmospheric	50
Internal Load	630
Total	**820**

20 APPENDIX B – SUPPORTING DATA FOR BATHTUB MODELS

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 and chlorophyll-*a* concentrations (µg/L) and to the nearest tenth of a meter for Secchi transparency (see Model Calibration in Section 2.3).

The loading goals in the individual lake sections take into account the 10% MOS and are therefore lower than the tributary goals in the Bathtub model output, which do not take into account the MOS.

The loads labeled as "internal loads" in the Bathtub input and output tables were the loads added for model calibration that were divided between internal and external loads. The load summary and allocation tables in the individual TMDL report sections should be referenced for the final modeling results.

North Center Lake

Table 86 – Calibrated (benchmark) Bathtub model case data (input) for North Center Lake

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.75	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	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	N Center	0	1	3.051	1.78	1.85	1.78	0.12	0	0	0.33	0.33	0	0	0.62	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	70	0.08	0	0	45	0.15	1	0.04	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	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	Watershed runoff + Little + Pi	1	1	64.9	12.8	0	0	0	73	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)	0.015	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 87 – Calibrated (benchmark) Bathtub model diagnostics (model results) for North Center Lake

Segment: 1 N Center

		Predicted Values--->			Observed Values--->		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	70	0.22	66%	70	0.08	66%

Table 88 – Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for North Center Lake

Component: TOTAL P **Segment: 1 N Center**

Trib	**Type**	**Location**	**Flow** hm^3/yr	**Flow** %Total	**Load** kg/yr	**Load** %Total	**Conc** mg/m^3
1	1	Watershed runoff + Little +	12.8	84.8%	934.4	54.4%	73
PRECIPITATION			2.3	15.2%	91.5	5.3%	40
INTERNAL LOAD			0.0	0.0%	690.9	40.2%	
TRIBUTARY INFLOW			12.8	84.8%	934.4	54.4%	73
***TOTAL INFLOW			15.1	100.0%	1716.8	100.0%	114
ADVECTIVE OUTFLOW			12.4	82.2%	862.6	50.2%	70
***TOTAL OUTFLOW			12.4	82.2%	862.6	50.2%	70
***EVAPORATION			2.7	17.8%	0.0	0.0%	
***RETENTION			0.0	0.0%	854.2	49.8%	

Hyd. Residence Time =	0.4378	yrs
Overflow Rate =	4.1	m/yr
Mean Depth =	1.8	m

Table 89 – TMDL scenario Bathtub model case data (input) for North Center Lake

Internal Load TP was the only input that was revised from the calibrated (benchmark) model.

Segment Morphometry		Internal Loads (mg/m2-day)	
		Total P	
Seg	**Name**	**Mean**	**CV**
1	N Center	0.36	0

Table 90 – TMDL scenario Bathtub model diagnostics (model results) for North Center Lake

Segment: 1 N Center

		Predicted Values--->			Observed Values--->		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	60	0.21	60.1%	70	0.08	66.3%

Table 91 – TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for North Center Lake

Component: TOTAL P **Segment: 1 N Center**

			Flow	Flow	Load	Load	Conc
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
1	1	Watershed runoff + Little +	12.8	84.8%	934.4	65.5%	73
PRECIPITATION			2.3	15.2%	91.5	6.4%	40
INTERNAL LOAD			0.0	0.0%	401.2	28.1%	
TRIBUTARY INFLOW			12.8	84.8%	934.4	65.5%	73
***TOTAL INFLOW			15.1	100.0%	1427.1	100.0%	95
ADVECTIVE OUTFLOW			12.4	82.2%	747.2	52.4%	60
***TOTAL OUTFLOW			12.4	82.2%	747.2	52.4%	60
***EVAPORATION			2.7	17.8%	0.0	0.0%	
***RETENTION			0.0	0.0%	679.9	47.6%	

Hyd. Residence Time = 0.4378 yrs
Overflow Rate = 4.1 m/yr
Mean Depth = 1.8 m

South Center Lake

Table 92 – Calibrated (benchmark) Bathtub model case data (input) for South Center Lake

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.75	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	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	S Center	0	1	3.598	3.84	2.33	3.8	0.12	0	0	0.17	0.76	0	0	0.27	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	50	0.09	0	0	40	0.18	1.3	0.09	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	1.53	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	Watershed runoff + Ogrens	1	1	40.9	7.88	0	0	0	101	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)	0.015	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 93 – Calibrated (benchmark) Bathtub model diagnostics (model results) for South Center Lake

Segment: 1 S Center

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	50	0.31	52%	50	0.09	52%

Table 94 – Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for South Center Lake

Component: TOTAL P Segment: 1 S Center

Trib	**Type**	**Location**	**Flow hm³/yr**	**Flow %Total**	**Load kg/yr**	**Load %Total**	**Conc mg/m³**
1	1	Watershed runoff + Ogre	7.9	74.5%	795.9	63.2%	101
PRECIPITATION			2.7	25.5%	107.9	8.6%	40
INTERNAL LOAD			0.0	0.0%	354.8	28.2%	
TRIBUTARY INFLOW			7.9	74.5%	795.9	63.2%	101
***TOTAL INFLOW			10.6	100.0%	1258.6	100.0%	119
ADVECTIVE OUTFLOW			7.4	70.1%	371.9	29.5%	50
***TOTAL OUTFLOW			7.4	70.1%	371.9	29.5%	50
***EVAPORATION			3.2	29.9%	0.0	0.0%	
***RETENTION			0.0	0.0%	886.8	70.5%	

Hyd. Residence Time = 1.8640 yrs

Overflow Rate = 2.1 m/yr

Mean Depth = 3.8 m

Table 95 – TMDL scenario Bathtub model case data (input) for South Center Lake

Internal Load TP was the only input that was revised from the calibrated (benchmark) model.

Segment Morphometry		Internal Loads (mg/m2-day)	
		Total P	
Seg	**Name**	**Mean**	**CV**
1	S Center	0.27	0

Table 96 – TMDL scenario Bathtub model diagnostics (model results) for South Center Lake

Segment:	1	S Center				
	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	40	0.30	42.5%	50	0.09	51.9%

Table 97 – TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for South Center Lake

Component:		TOTAL P		Segment:	1	S Center	
			Flow	Flow	Load	Load	Conc
Trib	**Type**	**Location**	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Watershed runoff + Ogre	7.9	74.5%	795.9	86.8%	101
PRECIPITATION			2.7	25.5%	107.9	11.8%	40
INTERNAL LOAD			0.0	0.0%	13.1	1.4%	
TRIBUTARY INFLOW			7.9	74.5%	795.9	86.8%	101
***TOTAL INFLOW			10.6	100.0%	917.0	100.0%	87
ADVECTIVE OUTFLOW			7.4	70.1%	299.4	32.7%	40
***TOTAL OUTFLOW			7.4	70.1%	299.4	32.7%	40
***EVAPORATION			3.2	29.9%	0.0	0.0%	
***RETENTION			0.0	0.0%	617.6	67.3%	

Hyd. Residence Time =	1.8640	yrs
Overflow Rate =	2.1	m/yr
Mean Depth =	3.8	m

Lake Emily

Table 98 – Calibrated (benchmark) Bathtub model case data (input) for Lake Emily

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.75	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	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	Segname 1	0	1	0.069	1.1	0.58	1.1	0.12	0	0	0.08	20	0	0	6.73	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	341	0.02	0	0	152	0.4	0.3	0.15	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	0.755	0	0.8	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	Trib 1	1	1	0.445	0.1	0	0	0	58.8	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)	0.015	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 99 – Calibrated (benchmark) Bathtub model diagnostics (model results) for Lake Emily

Segment: 1 Segname 1

		Predicted Values--->			Observed Values--->		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	341	0.36	98.5%	341	0.02	98.5%

Table 100 – Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for Lake Emily

Component: TOTAL P **Segment: 1 Segname 1**

Trib	**Type**	**Location**	**Flow hm^3/yr**	**Flow %Total**	**Load kg/yr**	**Load %Total**	**Conc mg/m^3**
1	1	Trib 1	0.1	65.9%	5.9	3.3%	59
PRECIPITATION			0.1	34.1%	2.1	1.2%	40
INTERNAL LOAD			0.0	0.0%	169.6	95.5%	
TRIBUTARY INFLOW			0.1	65.9%	5.9	3.3%	59
***TOTAL INFLOW			0.2	100.0%	177.6	100.0%	1170
ADVECTIVE OUTFLOW			0.1	60.0%	31.1	17.5%	341
***TOTAL OUTFLOW			0.1	60.0%	31.1	17.5%	341
***EVAPORATION			0.1	40.0%	0.0	0.0%	
***RETENTION			0.0	0.0%	146.5	82.5%	

Hyd. Residence Time =	0.8338	yrs
Overflow Rate =	1.3	m/yr
Mean Depth =	1.1	m

Table 101 – TMDL scenario Bathtub model case data (input) for Lake Emily

Internal Load TP was the only input that was revised from the calibrated (benchmark) model.

Segment Morphometry		**Internal Loads (mg/m2-day)**	
		Total P	
Seg	**Name**	**Mean**	**CV**
1	Segname 1	0.21	0

Table 102 – TMDL scenario Bathtub model diagnostics (model results) for Lake Emily

Segment:		**1**	**Segname 1**				
		Predicted Values--->			**Observed Values--->**		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	60	0.27	59.7%	341	0.02	98.5%

Table 103 – TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for Lake Emily

Component:		**TOTAL P**		**Segment:**	**1**	**Segname 1**	
			Flow	**Flow**	**Load**	**Load**	**Conc**
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
1	1	Trib 1	0.1	65.9%	5.9	44.4%	59
PRECIPITATION			0.1	34.1%	2.1	15.6%	40
INTERNAL LOAD			0.0	0.0%	5.3	40.0%	
TRIBUTARY INFLOW			0.1	65.9%	5.9	44.4%	59
***TOTAL INFLOW			0.2	100.0%	13.2	100.0%	87
ADVECTIVE OUTFLOW			0.1	60.0%	5.4	41.0%	60
***TOTAL OUTFLOW			0.1	60.0%	5.4	41.0%	60
***EVAPORATION			0.1	40.0%	0.0	0.0%	
***RETENTION			0.0	0.0%	7.8	59.0%	

Hyd. Residence Time =	0.8338	yrs
Overflow Rate =	1.3	m/yr
Mean Depth =	1.1	m

Linn Lake

Table 104 – Calibrated (benchmark) Bathtub model case data (input) for Linn Lake

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.75	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	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

													Internal Loads (mg/m2-day)					
		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		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	Linn Lake	0	1	0.716	1.83	1.55	1.8	0.12	0	0	1.07	0.54	0	0	3.95	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	217	0.03	0	0	87.6	0.33	0.42	0.16	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	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	Trib 1	1	1	4.65	0.85	0	0	0	197	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)	0.015	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 105 – Calibrated (benchmark) Bathtub model diagnostics (model results) for Linn Lake

Segment: 1 Linn Lake

		Predicted Values--->			Observed Values--->		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	217	0.38	95%	217	0.03	95%

Table 106 – Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for Linn Lake

Component: TOTAL P **Segment: 1 Linn Lake**

Trib	Type	Location	Flow hm^3/yr	Flow %Total	Load kg/yr	Load %Total	Conc mg/m^3
1	1	Trib 1	0.9	61.3%	167.5	13.7%	197
PRECIPITATION			0.5	38.7%	21.5	1.8%	40
INTERNAL LOAD			0.0	0.0%	1033.0	84.5%	
TRIBUTARY INFLOW			0.9	61.3%	167.5	13.7%	197
***TOTAL INFLOW			1.4	100.0%	1221.9	100.0%	881
ADVECTIVE OUTFLOW			0.8	54.6%	164.5	13.5%	217
***TOTAL OUTFLOW			0.8	54.6%	164.5	13.5%	217
***EVAPORATION			0.6	45.4%	0.0	0.0%	
***RETENTION			0.0	0.0%	1057.4	86.5%	

Hyd. Residence Time = 1.7311 yrs
Overflow Rate = 1.1 m/yr
Mean Depth = 1.8 m

Table 107 – TMDL scenario Bathtub model case data (input) for Linn Lake
Internal Loads TP and Tributary TP were the only inputs that were revised from the calibrated (benchmark) model.

Segment Morphometry		**Internal Loads (mg/m2-day)**	
		Total P	
Seg	**Name**	**Mean**	**CV**
1	Linn Lake	0	0

Tributary Data		**Total P (ppb)**	
Trib	**Trib Name**	**Mean**	**CV**
1	Trib 1	166	0

Table 108 – TMDL scenario Bathtub model diagnostics (model results) for Linn Lake

Segment: 1 Linn Lake

		Predicted Values--->			**Observed Values--->**		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	60	0.32	60.2%	217	0.03	95.3%

Table 109 – TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for Linn Lake

Component: TOTAL P **Segment: 1 Linn Lake**

			Flow	**Flow**	**Load**	**Load**	**Conc**
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
1	1	Trib 1	0.9	61.3%	141.1	86.8%	166
PRECIPITATION			0.5	38.7%	21.5	13.2%	40
TRIBUTARY INFLOW			0.9	61.3%	141.1	86.8%	166
***TOTAL INFLOW			1.4	100.0%	162.6	100.0%	117
ADVECTIVE OUTFLOW			0.8	54.6%	45.8	28.2%	60
***TOTAL OUTFLOW			0.8	54.6%	45.8	28.2%	60
***EVAPORATION			0.6	45.4%	0.0	0.0%	
***RETENTION			0.0	0.0%	116.8	71.8%	

Hyd. Residence Time =	1.7311	yrs
Overflow Rate =	1.1	m/yr
Mean Depth =	1.8	m

Little Lake

Table 110 – Calibrated (benchmark) Bathtub model case data (input) for Little Lake

Global Variables	**Mean**	**CV**
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.75	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	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

													Internal Loads (mg/m2-day)					
		Outflow		**Area**	**Depth**	**Length**	**Mixed Depth (m)**		**Hypol Depth**		**Non-Algal Turb (m^{-1})**		**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	Little	0	1	0.664	2.9	1.19	2.9	0.12	0	0	0.35	0.63	0	0	4.4	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	173	0.11	0	0	70.6	0.2	0.71	0.04	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	1.07	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	Watershed runoff	1	1	8.15	1.49	0	0	0	154	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)	0.015	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 111 – Calibrated (benchmark) Bathtub model diagnostics (model results) for Little Lake

Segment: 1 Little

		Predicted Values--->			Observed Values--->		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	173	0.36	92.3%	173	0.11	92.3%

Table 112 – Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for Little Lake

Component: TOTAL P **Segment: 1 Little**

Trib	Type	Location	Flow hm^3/yr	Flow %Total	Load kg/yr	Load %Total	Conc mg/m^3
1	1	Watershed runoff	1.5	74.9%	229.5	17.4%	154
PRECIPITATION			0.5	25.1%	19.9	1.5%	40
INTERNAL LOAD			0.0	0.0%	1067.1	81.1%	
TRIBUTARY INFLOW			1.5	74.9%	229.5	17.4%	154
***TOTAL INFLOW			2.0	100.0%	1316.5	100.0%	662
ADVECTIVE OUTFLOW			1.4	70.6%	243.0	18.5%	173
***TOTAL OUTFLOW			1.4	70.6%	243.0	18.5%	173
***EVAPORATION			0.6	29.4%	0.0	0.0%	
***RETENTION			0.0	0.0%	1073.5	81.5%	

Hyd. Residence Time = 1.3718 yrs
Overflow Rate = 2.1 m/yr
Mean Depth = 2.9 m

Table 113 – TMDL scenario Bathtub model case data (input) for Little Lake

Internal Loads TP and Tributary TP were the only inputs that were revised from the calibrated (benchmark) model.

Segment Morphometry		**Internal Loads (mg**	
		Total P	
Seg	**Name**	**Mean**	**CV**
1	Little	0	0

Tributary Data		**Total P (ppb)**	
Trib	**Trib Name**	**Mean**	**CV**
1	Watershed runoff	87	0

Table 114 – TMDL scenario Bathtub model diagnostics (model results) for Little Lake

Segment:	**1**	**Little**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	40	0.28	42.6%	173	0.11	92.3%

Table 115 – TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for Little Lake

Component:		**TOTAL P**		**Segment:**	**1**	**Little**	
			Flow	**Flow**	**Load**	**Load**	**Conc**
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
1	1	Watershed runoff	1.5	74.9%	129.6	86.7%	87
PRECIPITATION			0.5	25.1%	19.9	13.3%	40
TRIBUTARY INFLOW			1.5	74.9%	129.6	86.7%	87
***TOTAL INFLOW			2.0	100.0%	149.6	100.0%	75
ADVECTIVE OUTFLOW			1.4	70.6%	56.8	38.0%	40
***TOTAL OUTFLOW			1.4	70.6%	56.8	38.0%	40
***EVAPORATION			0.6	29.4%	0.0	0.0%	
***RETENTION			0.0	0.0%	92.7	62.0%	

Hyd. Residence Time =	1.3718	yrs
Overflow Rate =	2.1	m/yr
Mean Depth =	2.9	m

Ogren Lake

Table 116 – Calibrated (benchmark) Bathtub model case data (input) for Ogren Lake

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.75	0.0
Evaporation (m)	0.88	0.0
Storage Increase (m)	0	0.0

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

Atmos. Loads (kg/km^2-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	30	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Segment Morphometry

													Internal Loads (mg/m2-day)					
		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		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	Segname 1	0	1	0.198	4.6	0.35	4.3	0.12	0	0	0.08	2.9	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	64	0.14	0	0	29	0	2.5	0.58	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	1.5	0	1	0	1.17	0	2	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	Trib 1	1	1	16.6	2.65	0	0	0	147	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 117 – Calibrated (benchmark) Bathtub model diagnostics (model results) for Ogren Lake

Segment: 1 Segname 1

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	64	0.26	63%	64	0.14	63%

Table 118 – Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for Ogren Lake

Component: TOTAL P **Segment: 1 Segname 1**

Trib	**Type**	**Location**	**Flow** hm^3/yr	**Flow** %Total	**Load** kg/yr	**Load** %Total	**Conc** mg/m^3
1	1	Trib 1	2.7	94.7%	389.6	98.5%	147
PRECIPITATION			0.1	5.3%	5.9	1.5%	40
TRIBUTARY INFLOW			2.7	94.7%	389.6	98.5%	147
***TOTAL INFLOW			2.8	100.0%	395.5	100.0%	141
ADVECTIVE OUTFLOW			2.6	93.8%	167.5	42.3%	64
***TOTAL OUTFLOW			2.6	93.8%	167.5	42.3%	64
***EVAPORATION			0.2	6.2%	0.0	0.0%	
***RETENTION			0.0	0.0%	228.0	57.7%	

Hyd. Residence Time =	0.3471	yrs
Overflow Rate =	13.3	m/yr
Mean Depth =	4.6	m

Table 119 – TMDL scenario Bathtub model case data (input) for Ogren Lake

Tributary TP concentration was the only input that was revised from the calibrated (benchmark) model.

Tributary Data		**Total P (ppb)**	
Trib	**Trib Name**	**Mean**	**CV**
1	Trib 1	79	0

Table 120 – TMDL scenario Bathtub model diagnostics (model results) for Ogren Lake

Segment: **1** **Segname 1**

		Predicted Values--->			**Observed Values--->**		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	40	0.23	42.5%	64	0.14	62.6%

Table 121 – TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for Ogren Lake

Component: **TOTAL P** **Segment:** **1** **Segname 1**

Trib	**Type**	**Location**	**Flow hm^3/yr**	**Flow %Total**	**Load kg/yr**	**Load %Total**	**Conc mg/m^3**
1	1	Trib 1	2.7	94.7%	209.4	97.2%	79
PRECIPITATION			0.1	5.3%	5.9	2.8%	40
TRIBUTARY INFLOW			2.7	94.7%	209.4	97.2%	79
***TOTAL INFLOW			2.8	100.0%	215.3	100.0%	77
ADVECTIVE OUTFLOW			2.6	93.8%	106.0	49.2%	40
***TOTAL OUTFLOW			2.6	93.8%	106.0	49.2%	40
***EVAPORATION			0.2	6.2%	0.0	0.0%	
***RETENTION			0.0	0.0%	109.3	50.8%	

Hyd. Residence Time = 0.3471 yrs
Overflow Rate = 13.3 m/yr
Mean Depth = 4.6 m

Pioneer Lake

Table 122 – Calibrated (benchmark) Bathtub model case data (input) for Pioneer Lake

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.75	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	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	Pioneer	0	1	0.312	1.52	0.285	1.5	0.12	0	0	0.84	0.48	0	0	7.03	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	345	0	0	0	103	0	0.42	0.17	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	0.755	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	Watershed runoff	1	1	0.368	0.08	0	0	0	120	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)	0.015	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 123 – Calibrated (benchmark) Bathtub model diagnostics (model results) for Pioneer Lake

Segment: 1 Pioneer

		Predicted Values--->			**Observed Values--->**		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	345	0.43	98.6%	345		98.6%

Table 124 – Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for Pioneer Lake

Component: TOTAL P **Segment: 1 Pioneer**

Trib	**Type**	**Location**	**Flow hm^3/yr**	**Flow %Total**	**Load kg/yr**	**Load %Total**	**Conc mg/m^3**
1	1	Watershed runoff	0.1	25.5%	9.6	1.2%	120
PRECIPITATION			0.2	74.5%	9.4	1.1%	40
INTERNAL LOAD			0.0	0.0%	801.1	97.7%	
TRIBUTARY INFLOW			0.1	25.5%	9.6	1.2%	120
***TOTAL INFLOW			0.3	100.0%	820.1	100.0%	2612
ADVECTIVE OUTFLOW			0.0	12.6%	13.6	1.7%	345
***TOTAL OUTFLOW			0.0	12.6%	13.6	1.7%	345
***EVAPORATION			0.3	87.4%	0.0	0.0%	
***RETENTION			0.0	0.0%	806.5	98.3%	

Hyd. Residence Time =	12.0243	yrs
Overflow Rate =	0.1	m/yr
Mean Depth =	1.5	m

Table 125 – TMDL scenario Bathtub model case data (input) for Pioneer Lake

Internal Load TP was the only input that was revised from the calibrated (benchmark) model.

Segment Morphometry		Internal Loads (mg/m2-day)	
		Total P	
Seg	**Name**	**Mean**	**CV**
1	Pioneer	0.15	0

Table 126 – TMDL scenario Bathtub model diagnostics (model results) for Pioneer Lake

Segment:		1	Pioneer				
		Predicted Values--->			Observed Values--->		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	60	0.42	60.1%	345		98.6%

Table 127 – TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for Pioneer Lake

Component:		TOTAL P		Segment:	1	Pioneer	
			Flow	Flow	Load	Load	Conc
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
1	1	Watershed runoff	0.1	25.5%	9.6	26.6%	120
PRECIPITATION			0.2	74.5%	9.4	26.0%	40
INTERNAL LOAD			0.0	0.0%	17.1	47.4%	
TRIBUTARY INFLOW			0.1	25.5%	9.6	26.6%	120
***TOTAL INFLOW			0.3	100.0%	36.1	100.0%	115
ADVECTIVE OUTFLOW			0.0	12.6%	2.4	6.6%	60
***TOTAL OUTFLOW			0.0	12.6%	2.4	6.6%	60
***EVAPORATION			0.3	87.4%	0.0	0.0%	
***RETENTION			0.0	0.0%	33.7	93.4%	

Hyd. Residence Time = 12.0243 yrs
Overflow Rate = 0.1 m/yr
Mean Depth = 1.5 m

School Lake

Table 128 – Calibrated (benchmark) Bathtub model case data (input) for School Lake

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.75	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	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	School	0	1	0.587	1.52	1.24	1.5	0.12	0	0	1.27	0.11	0	0	3.6	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	216	0.11	0	0	82	0.11	0.4	0.02	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	0.83	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	Watershed runoff + Mattson L	1	1	3.84	0.58	0	0	0	53	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)	0.015	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 129 – Calibrated (benchmark) Bathtub model diagnostics (model results) for School Lake

Segment: 1 School

		Predicted Values--->			Observed Values--->		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	216	0.38	95.3%	216	0.11	95.3%

Table 130 – Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for School Lake

Component: TOTAL P **Segment: 1 School**

Trib	**Type**	**Location**	**Flow** hm^3/yr	**Flow** %Total	**Load** kg/yr	**Load** %Total	**Conc** mg/m^3
1	1	Watershed runoff + Mattso	0.6	56.8%	30.7	3.7%	53
PRECIPITATION			0.4	43.2%	17.6	2.1%	40
INTERNAL LOAD			0.0	0.0%	771.8	94.1%	
TRIBUTARY INFLOW			0.6	56.8%	30.7	3.7%	53
***TOTAL INFLOW			1.0	100.0%	820.2	100.0%	804
ADVECTIVE OUTFLOW			0.5	49.4%	108.9	13.3%	216
***TOTAL OUTFLOW			0.5	49.4%	108.9	13.3%	216
***EVAPORATION			0.5	50.6%	0.0	0.0%	
***RETENTION			0.0	0.0%	711.3	86.7%	

Hyd. Residence Time =	1.7714	yrs
Overflow Rate =	0.9	m/yr
Mean Depth =	1.5	m

Table 131 – TMDL scenario Bathtub model case data (input) for School Lake

Internal Load TP was the only input that was revised from the calibrated (benchmark) model.

Segment Morphometry		**Internal Loads (mg/m2-day)**	
		Total P	
Seg	**Name**	**Mean**	**CV**
1	School	0.28	0

Table 132 – TMDL scenario Bathtub model diagnostics (model results) for School Lake

Segment: **1** **School**

		Predicted Values--->			**Observed Values--->**		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	60	0.32	59.9%	216	0.11	95.3%

Table 133 – TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for School Lake

Component: **TOTAL P** **Segment:** **1** **School**

			Flow	**Flow**	**Load**	**Load**	**Conc**
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
1	1	Watershed runoff + Mattso	0.6	56.8%	30.7	28.4%	53
PRECIPITATION			0.4	43.2%	17.6	16.2%	40
INTERNAL LOAD			0.0	0.0%	60.0	55.4%	
TRIBUTARY INFLOW			0.6	56.8%	30.7	28.4%	53
***TOTAL INFLOW			1.0	100.0%	108.4	100.0%	106
ADVECTIVE OUTFLOW			0.5	49.4%	30.2	27.9%	60
***TOTAL OUTFLOW			0.5	49.4%	30.2	27.9%	60
***EVAPORATION			0.5	50.6%	0.0	0.0%	
***RETENTION			0.0	0.0%	78.2	72.1%	

Hyd. Residence Time =	1.7714	yrs
Overflow Rate =	0.9	m/yr
Mean Depth =	1.5	m

Wallmark Lake

Table 134 – Calibrated (benchmark) Bathtub model case data (input) for Wallmark Lake

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.75	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	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

													Internal Loads (mg/m2-day)					
		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		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	Wallmark	0	1	0.587	2.01	1.52	2	0.12	0	0	0.08	12.61	0	0	8.63	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	322	0.21	0	0	165	0.3	0.6	0.41	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	1.28	0	1.5	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	Watershed runoff	1	1	1.61	0.36	0	0	0	91	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)	0.015	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 135 – Calibrated (benchmark) Bathtub model diagnostics (model results) for Wallmark Lake

Segment:		1	Wallmark				
		Predicted Values--->			Observed Values--->		
Variable		Mean	CV	Rank	Mean	CV	Rank
TOTAL P	MG/M3	322	0.42	98.3%	322	0.21	98.3%

Table 136 – Calibrated (benchmark) Bathtub model segment balances (water and phosphorus budgets) for Wallmark Lake

Component:		TOTAL P		Segment:	1	Wallmark	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Watershed runoff	0.4	45.0%	32.8	1.7%	91
PRECIPITATION			0.4	55.0%	17.6	0.9%	40
INTERNAL LOAD			0.0	0.0%	1850.3	97.3%	
TRIBUTARY INFLOW			0.4	45.0%	32.8	1.7%	91
***TOTAL INFLOW			0.8	100.0%	1900.7	100.0%	2375
ADVECTIVE OUTFLOW			0.3	35.5%	91.2	4.8%	322
***TOTAL OUTFLOW			0.3	35.5%	91.2	4.8%	322
***EVAPORATION			0.5	64.5%	0.0	0.0%	
***RETENTION			0.0	0.0%	1809.4	95.2%	

Hyd. Residence Time =	4.1590	yrs
Overflow Rate =	0.5	m/yr
Mean Depth =	2.0	m

Table 137 – TMDL scenario Bathtub model case data (input) for Wallmark Lake

Internal Load TP was the only input that was revised from the calibrated (benchmark) model.

Segment Morphometry		Internal Loads (mg/m2-day)	
		Total P	
Seg	**Name**	**Mean**	**CV**
1	Wallmark	0.27	0

Table 138 – TMDL scenario Bathtub model diagnostics (model results) for Wallmark Lake

Segment:		1	Wallmark				
		Predicted Values--->			Observed Values--->		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	60	0.37	60.0%	322	0.21	98.3%

Table 139 – TMDL scenario Bathtub model segment balances (water and phosphorus budgets) for Wallmark Lake

Component:		TOTAL P		Segment:	1	Wallmark	
			Flow	Flow	Load	Load	Conc
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
1	1	Watershed runoff	0.4	45.0%	32.8	30.3%	91
PRECIPITATION			0.4	55.0%	17.6	16.3%	40
INTERNAL LOAD			0.0	0.0%	57.9	53.5%	
TRIBUTARY INFLOW			0.4	45.0%	32.8	30.3%	91
***TOTAL INFLOW			0.8	100.0%	108.3	100.0%	135
ADVECTIVE OUTFLOW			0.3	35.5%	17.1	15.8%	60
***TOTAL OUTFLOW			0.3	35.5%	17.1	15.8%	60
***EVAPORATION			0.5	64.5%	0.0	0.0%	
***RETENTION			0.0	0.0%	91.2	84.2%	

Hyd. Residence Time =	4.1590	yrs
Overflow Rate =	0.5	m/yr
Mean Depth =	2.0	m

21 APPENDIX C – MEETING MINUTES

Chisago Lakes Chain of Lakes Watershed TMDL

Steering Committee Meeting – 9/19/2011

Meeting Attendees: Andrea Plevan (EOR), Nancy-Jeanne LeFevre (EOR), Chris Klucas (MPCA), John Erdmann (MPCA), Jerry Spetzman (Chisago County), Jim Almendinger (SCWRS), Deb Sewell (MN DNR Fisheries), Barb Loida (MnDOT), Lou Sibik (LID), Bud Kapell (LID), Jill Behnke (Center City), John Pechman (Chisago City), John Olinger (Lindstrom), Craig Mell (SWCD), Casey Thiel (SWCD)

1) **TMDL Background**
   - a. Discussion on the TMDL for 10 impaired lakes within the Chisago Lakes Chain of Lakes Watershed: steps, monitoring, restoration and protection, sources, implementation, land cover
   - b. Macrophytes and Fish: carp numbers were questioned – Deb Sewell, MN DNR confirmed that there are carp present in the lakes but that their numbers are not above what is to be expected. CLPW and milfoil are present in many lakes. CLPW is a phosphorus source.
2) **Regulatory**
   - a. No Wasteload Allocations will be given to the cities.
3) **Bathtub Model Information**
   - a. There is a distinction between the quality of the lakes.
     - i. 3 lakes are moderately impaired – Most of these are the deeper/larger lakes
     - ii. 5 lakes are extremely impaired – Most of these are shallow and small. Many of them do not have a flowing outlet.
4) **Kroon Lake**
   - a. Is Kroon Lake deep or shallow?
     - i. 78% littoral as assessed by MPCA, 83% littoral calculated off of MN DNR Lake finder
     - ii. Meets both water quality standards
   - b. Should it be in the TMDL or in the Protection portion of the report?
     - i. Listed in 2006 – did not meet standards. 2001-2010 – meets standards
     - ii. MPCA is working on finding out if it should be delisted or should remain in the TMDL
     - iii. There was a large hog operation on the south end of Kroon Lake in the 50s or 60s – could have left high P load in the lake sediments.
5) **Groundwater Phosphorus Exchange**
   - a. How much phosphorus moves in the groundwater exchange?
   - b. Is there an impact on lake phosphorus cycling by the dissolved phosphorus exported with groundwater and the particulate P that remains in the lake? This could explain a portion of the unknown and internal load that had to be added to the model to account for the high measured phosphorus samples in the small lakes.

    c. The project team will investigate incorporating groundwater into the lake models.

6) Phosphorus in Sediments
    a. Sediment phosphorus data were presented. High potential release rates exist in many lakes.
    b. The internal loads estimated from the sediment data are not high enough to account for the unknown loading determined by the lake models.

7) Next Steps
    a. Allocations
        i. Wasteload Allocations
            1. The only WLAs will be for construction and industrial stormwater. The TMDL will include transfer loading rates for MnDOT in case it comes under permit coverage in the watershed in the future.
            2. Chisago City – in a separate TMDL approved in 2010, Chisago was considered an MS4 that might come into permit coverage in the near future, and was provided in a WLA in the event that it came under permit coverage. Population growth projections are now lower, and the MPCA has clearer guidelines regarding which MS4s should be given future WLAs. Chisago City is not included and will not be given a future WLA for this TMDL.
            3. Draft report will be completed by spring of 2012.
            4. The next steering committee meeting will be after the draft report and draft implementation plans are completed.