Assessment Report of Selected Lakes within the Buffalo River Watershed Red River of the North Basin

Minnesota Pollution Control Agency

December 2012

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Buffalo River Watershed
Red River of the North Basin
Intensive Watershed Monitoring 2009

Minnesota Pollution Control Agency
Water Monitoring and North Watershed Sections
Lakes and Streams Monitoring and Northwest
Watershed Units

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This report is available in alternative formats upon request, and online at www.pca.state.mn.us

Document number: wq-ws3-09020106

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Executive Summary

The Minnesota Pollution Control Agency (MPCA) conducts and supports lake monitoring for a variety of objectives. Staff within the MPCA's Lakes and Streams Monitoring Unit sample approximately 100 lakes per year, coordinate citizen volunteer monitoring through the Citizen Lake Monitoring Program, and manage Surface Water Assessment Grants given to local groups to monitor lake and stream water quality. Watershed-based monitoring emphasizes large lakes (500 acres or greater) whenever possible. All water quality data from these activities are compared to state water quality standards to determine if a given lake is fully supporting or not supporting standards set for recreational use (e.g., swimming, wading, etc.). Lakes not supporting aquatic recreational use are termed "impaired" and are placed on a list biennially. This list is formally termed the 303(d) list (referencing the section within the federal Clean Water Act (CWA) that requires us to assess for condition); it is also commonly called the "Impaired Waters List." A lake placed on the Impaired Waters List is required to be intensively researched through a Total Maximum Daily Load (TMDL) study to determine the source and extent of the pollution problem. The study also requires the development of a restoration plan. For un-impaired waters, a protection plan will be developed following the assessment process. It should be noted that a great deal of lake monitoring is also carried out by various other MPCA staff and local groups who are undertaking TMDL studies, condition monitoring or other special projects.

This report details the assessment of selected lakes within the Buffalo River Hydrologic Unit Code (HUC)-8 watershed. The Buffalo River Watershed is made up of nine HUC-11 intensively monitored watersheds. A general description at the eight-digit HUC level is provided, followed by discussions for each 11-digit HUC that has lakes identified as impaired. A full list of the assessed lakes within the Buffalo River Watershed, including their morphometric characteristics, is located in Appendix A.

Approximately one quarter of the lakes in the watershed had assessment level data; of these, half were determined to be not supporting recreational use. Of the 43 lakes that had complete datasets available for assessment, 16 were considered to be supporting aquatic recreation use and 18 were not supporting aquatic recreation use. Because of the high number of lakes in the Buffalo River, an in depth discussion for all 43 lakes was not possible; however a subset of impaired or otherwise prominent lakes were discussed further.

Introduction

Intensive watershed monitoring approach

The MPCA conducts and supports lake monitoring for a variety of objectives. One of our key responsibilities per the federal CWA is to monitor and assess lakes in Minnesota to determine whether or not these lakes support their designated uses. This type of monitoring is commonly referred to as condition monitoring. While the MPCA conducts its own lake monitoring, local partners (soil and water conservation districts, counties, watershed districts, etc.) and citizens (individuals, lake associations and coalitions of lake associations) play a critical role in helping us because their efforts greatly expand our overall capacity to conduct condition monitoring. To this end, the MPCA coordinates citizen volunteer monitoring through the Citizen Lake Monitoring Program (CLMP), and manages Surface Water Assessment Grants given to local groups to monitor lake water quality. All of the data from these activities are combined with our own lake monitoring data to assess the condition of Minnesota lakes. Lake condition monitoring activities are focused on assessing the recreational use-support of lakes and identifying trends over time. The MPCA also assesses lakes for aquatic consumption and life use-support, based on fish-tissue and water-column concentrations of toxic pollutants.

The primary organizing approach to MPCA's condition monitoring is the "major" watershed (eight-digit hydrologic unit code). There are 81 major watersheds in Minnesota, and the MPCA has established a schedule for intensively monitoring six to eight of them annually. With this strategy, the MPCA and its partners will cycle through all 81 watersheds every 10 years. The MPCA began aligning its stream condition monitoring to this watershed approach in 2007. Lake monitoring was brought into this framework in 2009. The year 2017 will mark the final year of the first 10-year cycle. The watershed approach provides a unifying focus on the water resources within a watershed as the starting point for water quality assessment, planning, and measuring results. By intensively monitoring lakes and streams within a given watershed at the same time, the lake and stream data can be considered together to provide a comprehensive picture of water quality status and a determination can be made regarding how best to proceed with development of regional or watershed–wide restoration and protection strategies.

Even when pooling MPCA, local group and citizen resources, we are not able to monitor all lakes in Minnesota. The primary focus of MPCA monitoring is lakes $\geq$500 acres in size ("large lakes"). These resources typically have public access points, they generally provide the greatest aquatic recreational opportunity to Minnesota's citizens, and these lakes collectively represent 72 percent of the total lake area (greater than 10 acres) within Minnesota. Though our primary focus is on monitoring larger lakes, we are also committed to directly monitoring, or supporting the monitoring of, at least 25 percent of Minnesota's lakes between 100-499 acres ("small lakes"). In most years, we monitor a mix of large and small lakes, and provide grant funding to local groups to monitor lakes that fall in the 10-499 acre range. Currently, we are fully meeting the "large" lake goal, and we are greatly exceeding the "small" lake monitoring goal, largely due to the tremendous commitment by citizen groups to monitor lake conditions.

This report will describe all available lake data collected within the past ten years by partner agencies, grantees, and citizen volunteers found in EQuIS for the Buffalo River watershed. Trophic status, thermal stratification, temporal trends, model-predicted phosphorus and assessment status are noted for all lakes where assessments of support or not support were made. Further detail on concepts and terms in this report can be found in the Guide to Lake Protection and Management: (http://www.pca.state.mn.us/water/lakeprotection.html).

Lake monitoring and data storage

The MPCA collects water quality data for lakes from May through September for each of the applicable years. Data collected from June through September is used to assess the lake's condition while May data is collected to observe lake conditions following the spring melt and near the spring turn over and compare this with the remaining seasonal data. Lake surface samples were collected with an integrated sampler, a polyvinyl chloride (PVC) tube two meters (6.6 feet) in length with an inside diameter of 3.2 centimeters (1.24 inches). Deep total phosphorous (TP) samples were collected near the lake bottom with a Kemmerer sampler.

For lakes sampled by the MPCA, sampling procedures were employed as described in the MPCA Standard Operating Procedure for Lake Water Quality document, which can be found at: http://www.pca.state.mn.us/publications/wq-s1-16.pdf. Samples collected by the MPCA were sent to the Minnesota Department of Health using U. S. Environmental Protection Agency (EPA)approved methods for laboratory analysis. Samples were analyzed for nutrients, color, solids, pH, alkalinity, conductivity, and chlorophyll-*a* (chl-*a*). Temperature and dissolved oxygen (DO) profiles and Secchi disk transparency measurements were also taken. Historical DO and temperature profiles were used for water column analysis in the absence of more recent data.

Data collected by MPCA and submitted to MPCA by external partners is placed in the EPA's data warehouse, STORET. MPCA makes this data available to the public through the Environment Data Access webpage (http://www.pca.state.mn.us/index.php/topics/environmental-data/eda-environmental-data-access/eda-surface-water-searches/eda-surface-water-data-home.html). Individual lake summaries are also available via the MPCA webpage at: http://cf.pca.state.mn.us/water/watershedweb/datasearch/waterSearch.cfm.

Lake morphometry and mixing

Lake area, depth, and mixing have a significant influence on lake processes and water quality. Lake depths of 4.5 meters (15 feet) or less are often well suited for macrophyte (rooted plant) growth and this portion of the lake is referred to as the *littoral* area. This depth of 15 feet is typically the depth that light penetration is sufficient to allow for photosynthesis. Beyond this depth there is usually insufficient light for plant growth, with the exception being lakes with the highest clarity. As such, shallow lakes are often well-suited for macrophyte growth and it is not uncommon for emergent and submergent plants to be found across much of the lake. These plant beds are a natural part of the ecology of these lakes and are important to protect.

The size (area) of the lake as compared to the size of its watershed can be an important factor as well; whereby lakes with small watershed areas relative to their surface area often receive low water and nutrient loading and absent significant sources of nutrients in their watershed, often have good water quality. In contrast, lakes that have large watersheds relative to their surface area often receive high water and nutrient loading, which may result in poor water quality. Modeling, as described in the next section, can help predict the response of the lake.

Thermal stratification (formation of distinct temperature layers), in which deep lakes (maximum depths of nine meters or more) often stratify (form layers) during the summer months and are referred to as *dimictic* (Figure 1). These lakes fully mix or turn over twice per year; typically in spring and fall. Lakes with large surface area and shallow depth (maximum depths of five meters or less) in contrast, typically do not stratify and are often referred to as *polymictic*. Lakes, with moderate depths, may stratify intermittently during calm periods, but mix during heavy winds and during spring and fall. Measurement of temperature throughout the water column (surface to bottom) at selected intervals (e.g. every meter) can be used to determine whether the lake is well-mixed or stratified. The depth of the thermocline (zone of maximum change in temperature over the depth interval) can also be determined. In general, dimictic lakes have an upper, well-mixed layer (epilimnion) that is warm and has high oxygen concentrations. In contrast, the lower layer (hypolimnion) is much cooler and often has little or no oxygen. This low oxygen environment in the hypolimnion is conducive to phosphorus being released from the lake sediments. During stratification, dense colder hypolimnion waters are separated from the nutrient-hungry algae in the epilimnion. Intermittently (weakly) stratified polymictic lakes are mixed in high winds and during spring and fall. Mixing events allow the hypolimnetic nutrient rich water to spread evenly throughout the lake where it is available to algae.

Minnesota's lake standards differentiate among deep and shallow lakes. Shallow lakes are defined as those with maximum depths of 4.5 meters (15 feet) or less or where 80 percent or more of the lake is littoral (≤ 4.5 meters). As noted above shallow lakes are often well mixed and may have extensive growths of macrophytes. In contrast, deep lakes will often stratify during the summer and often have a lower percentage of surface area that can support macrophyte growth.

Polymictic Lake
shallow, no layers,
mixes continuously
Spring, summer and fall

Dimictic Lake
deep, form layers,
mixes spring/fall

Intermittently stratified
moderately deep
mixes during high winds
spring, summer, and fall

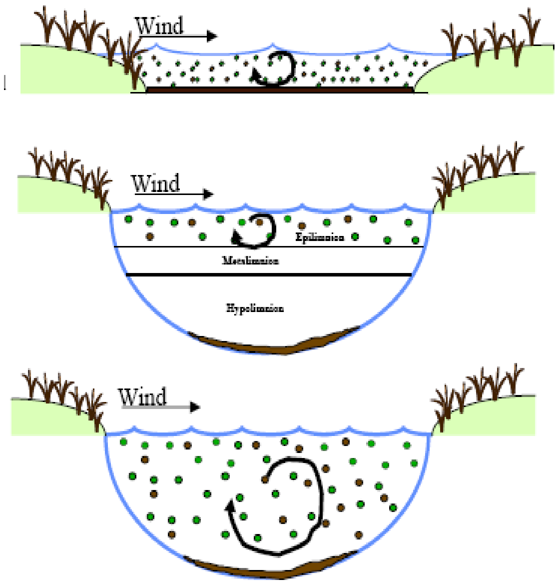


Figure 1. Lake stratification

Data analysis and modeling

A standard approach to data analysis is applied to all fully assessed lakes. The major steps are as follows:

1. Dissolved oxygen and temperature data from the most recent one or two years is reviewed. Profile data are used to determine whether the lake stratifies, depth of thermocline and presence or absence of oxygen in the bottom waters. This step is essential for characterizing the lake and aids in determining whether internal recycling (loading) of phosphorus may be a significant contributor to phosphorus loading during summer months. This evaluation also helps determine the proportion of the water column that may be available for fish habitation during the summer.

2. Total phosphorus (TP), chlorophyll-a (chl-*a*) and Secchi transparency data from the two most recent summers are evaluated. In most instances monthly data will be charted to look for correspondence among the TP, chl-*a*, and Secchi measures (also referred to as trophic status measures). Charting the data also allows for patterns to be observed that may help indicate whether internal recycling and/or shifts in the biology of the lake (macrophyte growth/senescence, zooplankton cropping of algae etc.) may be important factors in moderating the trophic status of the lake.

3. Long-term trends based on available summer-mean TP, chl-*a*, and Secchi are assessed when possible. These data are typically charted and analyzed for trends. If statistically-based CLMP trend analysis was conducted that will be noted as well. If a trend is noted and the investigator is aware of potential causes for the trend that will be noted as well.

4. Numerous complex mathematical models are available for estimating nutrient and water budgets for lakes. These models can be used to relate the flow of water and nutrients from a lake's watershed to observed conditions in the lake. Alternatively, they may be used for estimating changes in the quality of the lake as a result of altering nutrient inputs to the lake (e.g., changing land uses in the watershed) or altering the flow or amount of water that enters the lake. To analyze the most recent water quality of lakes within the Buffalo River watershed, the Minnesota Lake Eutrophication Analysis Procedures (MINLEAP) model (Wilson and Walker, 1989) was used. MINLEAP was developed by MPCA staff based on an analysis of data collected from the ecoregion reference lakes. It is intended to be used as a screening tool for estimating lake conditions with

minimal input data and is described in detail in Wilson and Walker (1989). For the analysis of lakes within the Buffalo River Watershed, MINLEAP was applied as a basis for comparing the observed TP, chl-*a,* and Secchi values with those predicted by the model based on the lake depth and size and the size of the watershed. Individual results for each of the assessed lakes will be discussed in the lake summary portion of the HUC-11 watershed sections within this report. Complete MINLEAP results can be found in Appendix B.

In addition to fully assessed lakes there are often numerous lakes that do not have sufficient data for assessment. In these instances existing data (TP, chl-a, and Secchi) will be summarized and noted in summary tables. In most instances there will be little or no discussion of lakes that are not fully assessed; however summary data will be compiled so that more comprehensive characterizations of lake condition at the HUC-11 and HUC-8 scales can be made.

303 (d) Assessment

The federal CWA requires states to adopt water quality standards to protect waters from pollution. These standards define how much of a pollutant can be in the water and still allow it to meet designated uses, such as drinking water, fishing and swimming. The standards are set on a wide range of pollutants, including bacteria, nutrients, turbidity and mercury. A water body is "impaired" if it fails to meet one or more water quality standards.

Under Section 303(d) Impaired Waters List of the CWA, the state is required to asses all waters of the state to determine if they meet water quality standards. Waters that do not meet standards are added to the 303(d) Impaired Waters List and updated every even-numbered year. If a water resource is listed, an investigative study termed a TMDL is conducted to determine the sources and magnitude of the pollution problem, and to set pollutant reduction goals needed to restore the waters. The MPCA is responsible for monitoring surface waters, assessing condition of lakes and streams, creating the 303(d) Impaired Waters List, and conducting or overseeing TMDL studies in Minnesota.

TP, chl-*a*, and Secchi transparency are used to determine if a lake meets aquatic recreational use standards(ARUS). Minnesota's ecoregion-based eutrophication standards are listed in Table 1. For a lake tobe assessed as impaired it must exceed the causative variable (TP) and one or more of the response variables: chl-*a* and Secchi transparency. The Northern Lakes and Forests (NLF), North Central Hardwood Forests (NCHF) and Northern Glaciated Plains (NGP) ecoregion standards were used for assessing lakes in the Buffalo River watershed. The appropriate standards are based on which ecoregion the lake is located in and whether the lake is considered deep or shallow. Individual assessments for each of the lakes will be discussed in the lake summary portion of the HUC-11 watershed sections within this report.

Table 1. Minnesota lake eutrophication standards by ecoregion and lake type

(Heiskary and Wilson, 2005) and 2010 303 (d) assessment value

Ecoregion	TP	Chl-*a*	Secchi
	ppb	ppb	meters
NLF – Lake trout (Class 2A)	< 12	< 3	> 4.8
NLF – Stream trout (Class 2A)	< 20	< 6	> 2.5
NLF – Aquatic Rec. Use (Class 2B)	< 30	< 9	> 2.0
NCHF – Stream trout (Class 2a)	< 20	< 6	> 2.5
NCHF – Aquatic Rec. Use (Class 2b)	< 40	< 14	> 1.4
NCHF – Aquatic Rec. Use (Class 2b) Shallow lakes	< 60	< 20	> 1.0
WCBP & NGP – Aquatic Rec. Use (Class 2B)	< 65	< 22	> 0.9
WCBP & NGP – Aquatic Rec. Use (Class 2b) Shallow lakes	< 90	< 30	> 0.7

Buffalo River Watershed Background

The major watersheds in Minnesota are classified with the eight-digit HUC system. This is a standardized watershed classification system developed by United States Geological Survey (USGS) in the mid-1970s. Hydrologic units are watershed boundaries organized in a nested hierarchy by size. An eight-digit code uniquely identifies each of the four levels of classification within four two-digit fields. The first two digits identify the water-resources region; the first four digits identify the sub-region; the first six digits identify the accounting unit, and the addition of two more digits for the cataloging unit completes the 8-digit code (Seaber, P.R., et al. 1987).

HUC-8 watershed characteristics

From its source at Tamarack Lake, the Buffalo River flows 88 miles to its confluence with the Red River of the North one mile west of Georgetown. Beginning shortly downstream of the headwaters, a major transition occurs from the Northern Lakes and Forests ecoregion (NLF) dominated by hardwood forests with many wetlands and lakes to the North Central Hardwood Forests ecoregion (NCHF) more influenced by cultivated land and finally to the Lake Agassiz Plains Ecoregion (LAP), a very flat prairie landscape with few wetlands and lakes. The Buffalo River Watershed covers 287,083 hectares (ha; 709,399 acres) (MDNR 2003). The main portion of the Buffalo River Watershed begins in eastern Becker County and encompasses portions of Clay, Otter Tail, and Wilkin Counties.

Land in the Buffalo River Watershed is dominated by agriculture, comprising nearly 70 percent of the total watershed acres (MDNR 2003). Due to the high percentage of agriculture (conversion of prairie and wetland to row crop), an excessive drainage network for agriculture, flat topography in the far western portion of the watershed, and poorly drained clay-based soils, the watershed is prone to severe flooding. Much of the landscape has been altered to aid in rapid water drainage from fields to support increased agricultural production. The drainage of these lands has transformed nutrient and hydrologic dynamics, structure, function, quantity, and configuration of stream and wetland ecosystems (Blann 2009). In addition to drainage and tiling, other human activities, such as dam and road construction and converting land cover from native vegetation to cropland, have changed the landscape significantly.

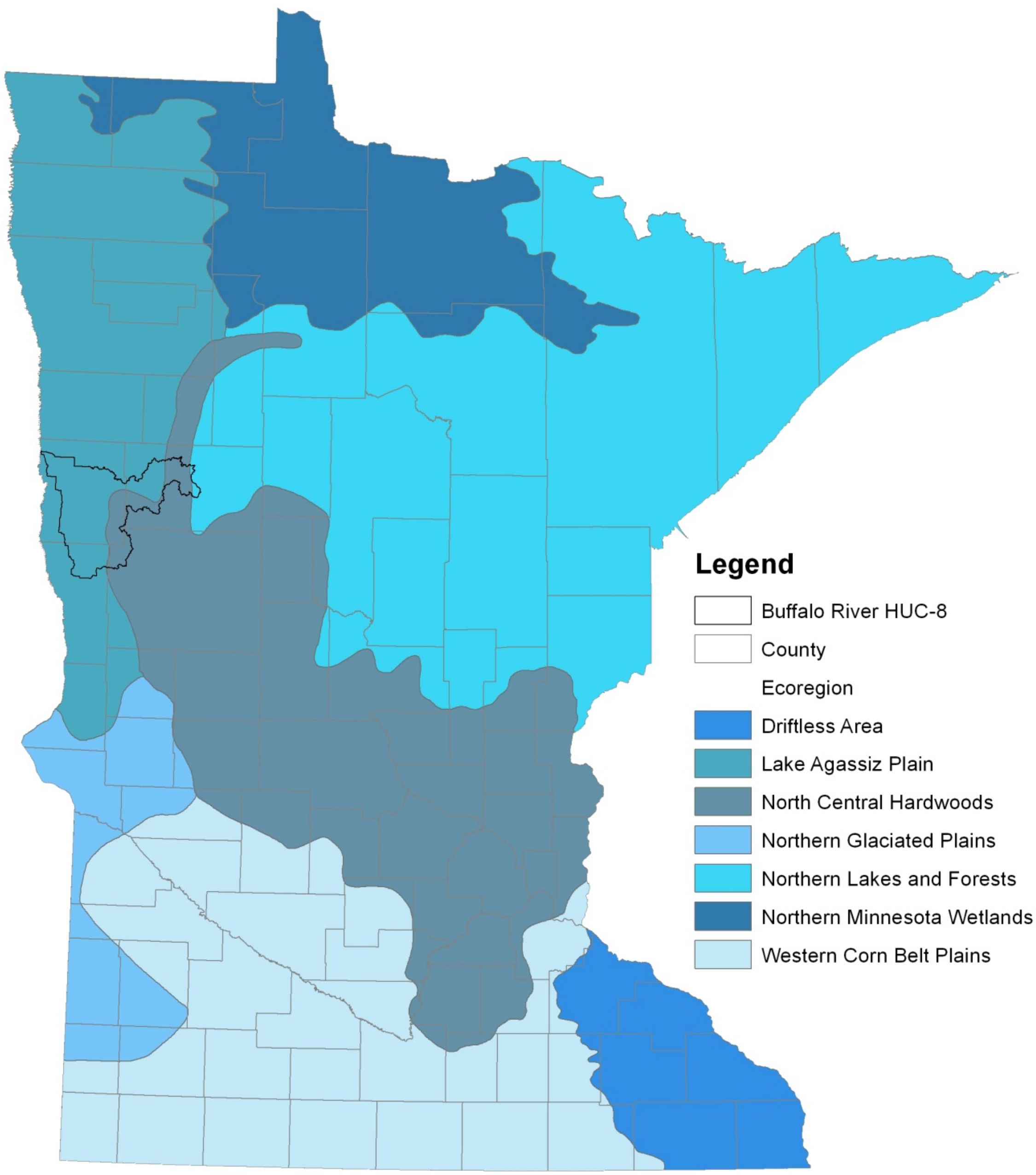


Figure 2. Minnesota's EPA mapped ecoregions and Buffalo River Watershed location

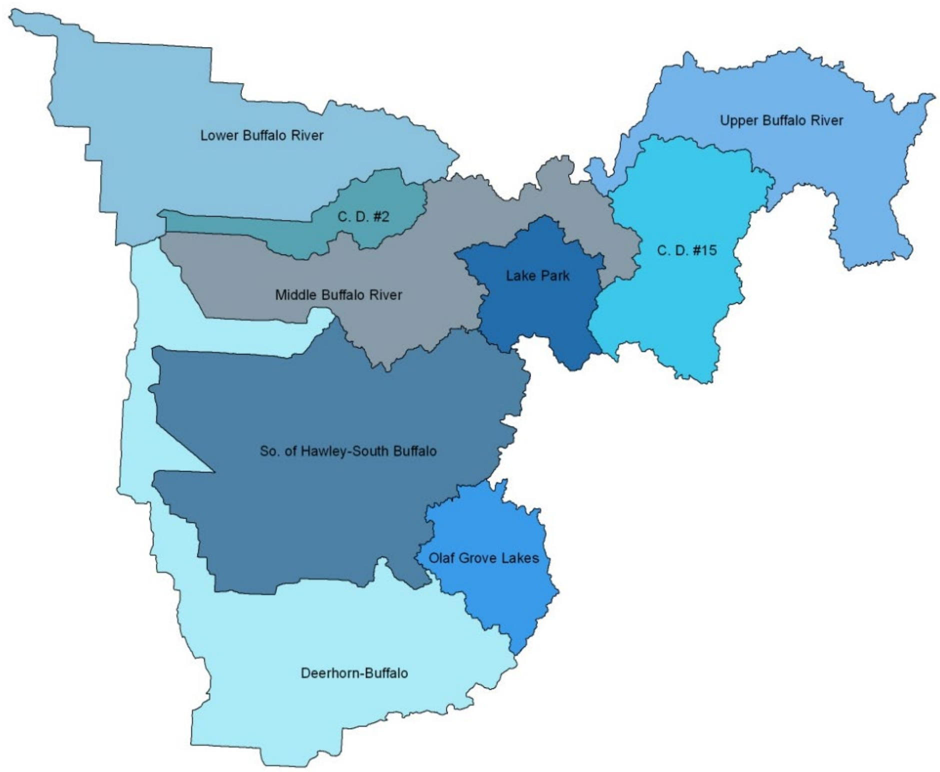


Figure 3. Buffalo River HUC-11 watershed boundaries

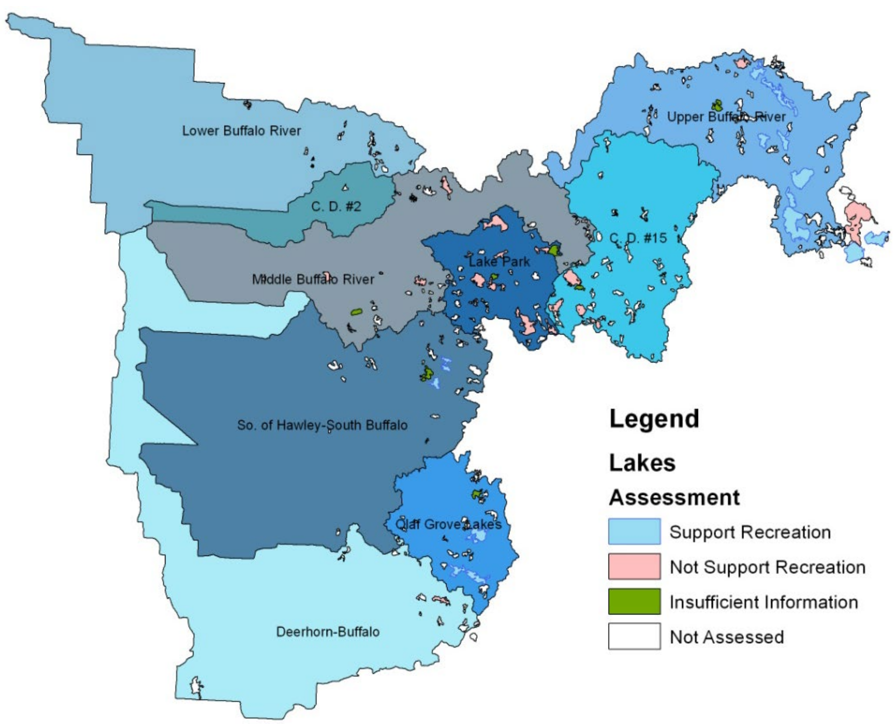


Figure 4. Buffalo River HUC-11 watershed boundaries, surface water and monitoring coverage

Climatic and hydrologic conditions

Much of the data from this report was collected between 2008 and 2012. Based on a review of the water year departure from normal maps produced by the State Climatological Office – DNR Division of Ecological and Water Resources, the Buffalo River Watershed has experienced elevated precipitation in 2008, through 2010, with the western portions of the watershed receiving in excess of 10 additional inches of rain in 2009 and 2010. Normal precipitation levels were recorded in 2011 and 2012 is on track to be one of the driest years on record. Based on the 2012 August 1st to October 1st preliminary drought information, less than two inches of rainfall have been recorded during that two month span.

It is significant to note that this region of the state experienced high precipitation in the 1990s resulting in considerable changes to lake elevation, often resulting in altered drainage from previous conditions. Two events that are noteworthy include: the mid July 1993 storm that dropped 7.1 inches in 24 hours near Lake Park, a town centrally located in the north part of the Buffalo River Watershed. In 1997, the area received record snowfall levels and had record spring flooding that imposed heavy flood damages within the Red River Valley, most notable in Grand Forks, North Dakota. This will be detailed further in specific lake discussions.

HUC-11 Lake Assessment

The Buffalo River HUC-8 watershed is comprised of nine HUC-11 watershed units (Figure 3). Each individual watershed has had varying amounts of surface water monitoring. Lake assessment results are presented for the HUC-11 watershed units within the Buffalo River watershed where an assessment of not support was made or where a chain of local significance resides (five of the nine HUC-11s). The discussion will proceed from the upper most HUC-11 (Upper Buffalo River) to the Middle Buffalo River HUC-11, which all drain to the main stem Buffalo River. In addition, the Deerhorn-Buffalo HUC-11 will also be discussed, which drains to the South Branch of the Buffalo River. Lakes less than four ha (10 acres) will not be included in the discussion or tables provided.

Upper Buffalo River 11-HUC Watershed

The Upper Buffalo River (09020106010) HUC-11 watershed is the headwaters of the Buffalo River, originating in Tamarack Lake. It drains from west to southwest and spans three ecoregions: NLF, NCHF, and LAP. Forested and cultivated land uses dominate the watershed with the eastern portion being more heavily forested. Fourteen of the 39 lakes in the watershed have been assessed against aquatic recreation use standards (ARUS; Table 2).

Table 2. Lakes within the Upper Buffalo River HUC-11 watershed

Lake Name	Lake ID	Lake Area (ha)	% Littoral	Max Depth (m)	Mean Depth (m)	Mean TP (ug/L)	Mean Chl-a (ug/L)	Secchi Mean (m)	Aquatic Recreation Use Support[4]
Pine	[1]03-0200-00	218.5	89.5	5.5	2.7	24	8	2.1	FS
South Tamarac	[1]03-0241-01	222.6	100	4.9	1.5	20	4	1.9	FS
North Tamarac	[1]03-0241-02	579.9	95.5	5.2	2.4	36	13	1.7	NS[5]
Rice	03-0291-00	90.8	72.9	7	2.3	28	7	2.2	FS
Rock	03-0293-00	485.7	95.5	5.5	2.4	27	7	1.8	FS
Little Round	[1]03-0302-00	219.9	100	1.7	0.8	25	3	0.8	FS
Big Sugar Bush	03-0304-00	177.4	63.1	12.8	3.4	13	3	5.6	FS
Little Sugar Bush	03-0313-00	85.7	49	8.8	3.9	22	11	3	FS
Buffalo	03-0350-00	180	51	11.2	4.4	23	9	3	FS
Island	03-0351-00	85.6	100	3	1.6	23	6	2.5	FS
Birch	03-0352-00	88.2	82.3	7.6	2	37	16	2.8	FS
O-Me-Mee	03-0428-00	54.9	100	3	1.5	68	21	1.7	IF
St. Clair	03-0430-00	43.1	88.6	5.8	1.4	24	8	3.1	FS
Mission	03-0471-00	98.6	100	2.4	1.6	120	76	0.6	NS

1. Mean depths estimated.
2. Watershed area estimated from MDNR lake catchment file
3. Due to available maps and sampling location, only the north basin was used to calculate mean depth and lake area for Lake Eleven.
4. NS = not supporting, FS = supporting, IF = insufficient information to determine support, NA = not assessed (too small or wetland-like)
5. Lake is not supporting aquatic recreation use due to natural conditions; no TMDL is required.

North Tamarack 03-0241-02

North Tamarack Lake is a shallow, 580 hectare (ha) lake with a maximum depth of 5.2 meters (m; 17 feet) located northeast of Detroit Lakes, Minnesota. The lake has a 3,659 ha watershed (6:1 watershed to lake ratio) dominated by forested land uses. The lake was listed for excess nutrients in 2010 and reviewed for natural background impairment in 2011 and removed from the Impaired Waters List in 2012. The lake is not developed; with the Tamarack National Wildlife Refuge making up the majority of the watershed with very limited road and residential development. A previous lake report was completed on the basin and is available from MPCA.

Profile data was available from 2005, 2009, and 2010. The lake does not exhibit stratification; the lake is susceptible to wind mixing.

Water chemistry data was collected in 2005, and from 2007, through 2010 (Figure 5). Seasonally, TP and chl-*a* concentrations are varied, likely due to the shallow nature of the lake and the influence that wind mixing will have on phosphorus concentrations and algal production. The chl-*a* response matches well to the changes in TP. Secchi follows a pattern of high clarity in the spring, declining across the summer, and improving in the fall.

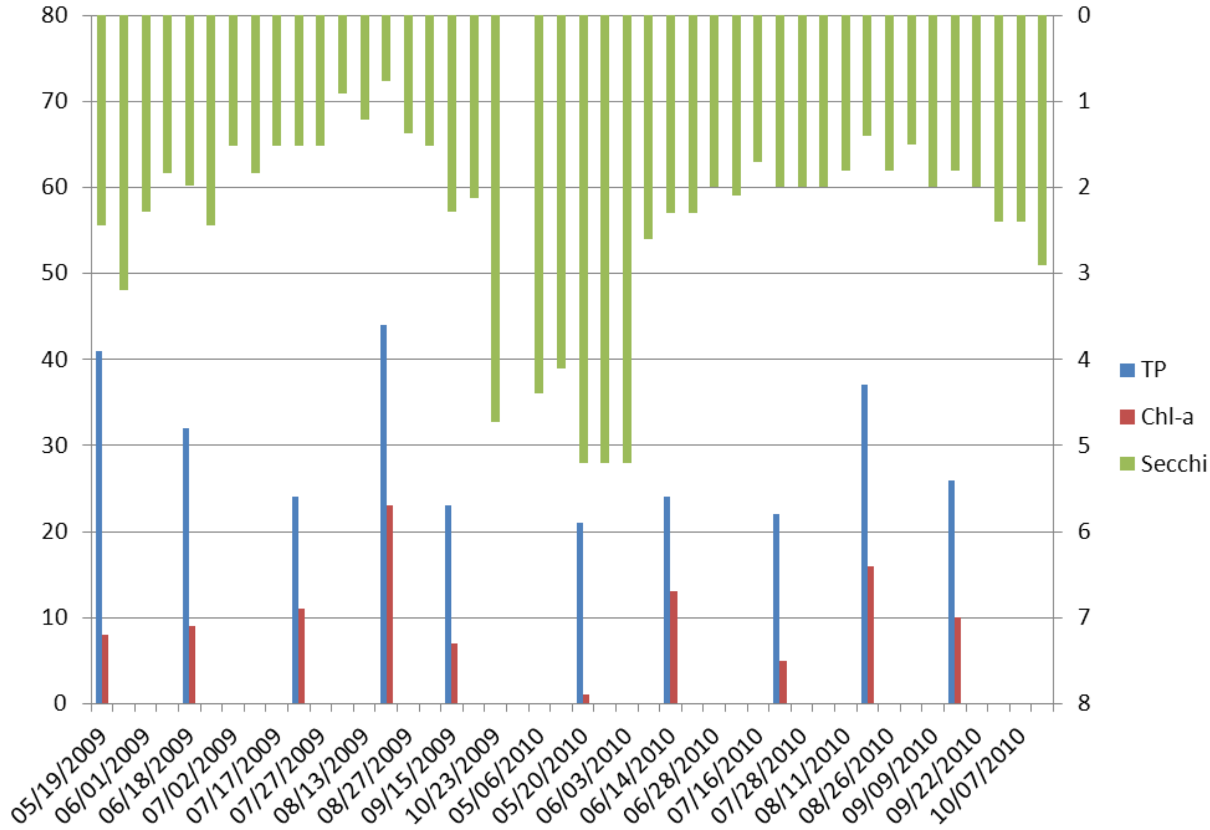


Figure 5. North Tamarack Lake water quality data

Phosphorus levels appear to be declining in recent years, although a matching decline in chlorophyll-*a* is less evident (Figure 6). 2010, is the first year where phosphorus levels were below the criteria for the eutrophication standard.

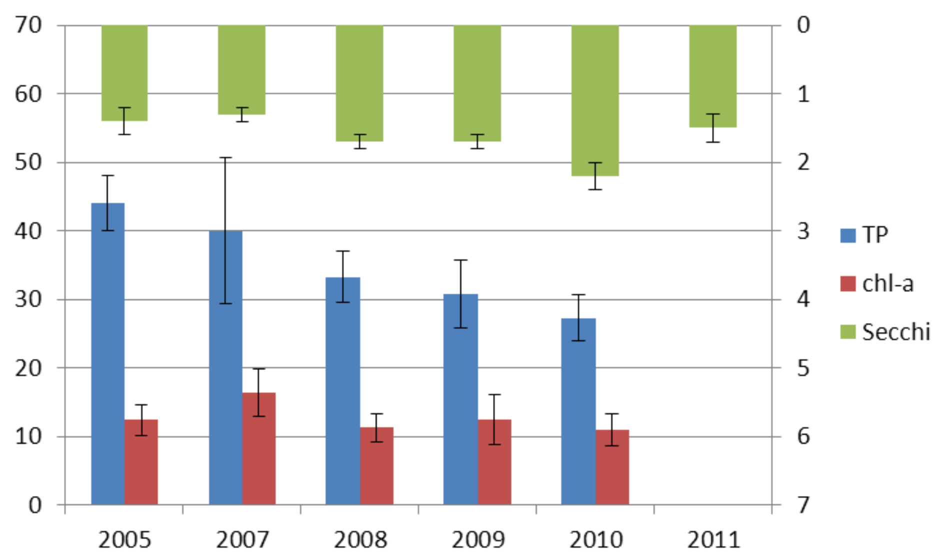


Figure 6. North Tamarack Lake long-term water quality data

MINLEAP was run for North Tamarack Lake as a basis for comparing observed data with that predicted by the model based on lake depth and size, watershed size, and ecoregion location. The model was run for the NLF ecoregion. The observed TP, chl-*a* and Secchi were worse than modeled results. The lake retains approximately 56 percent of the phosphorus that enters it and has a residence time on the order of one and a half years. Complete modeling results can be found in Appendix B.

Mission 03-0471-00

Mission Lake is a shallow, 99 hectare (ha) lake with a maximum depth of 2.4 meters (m; 7.8 feet) located southeast of White Earth, Minnesota. The lake has a 350 ha watershed (3.5:1 watershed to lake ratio) dominated by forested and water/wetland land uses. The lake was listed for excess nutrients in 2011. The lake is not heavily developed; a residence is on the southwest shore and a gravel operation is on the northern shore; the land to the west of the lake is cultivated.

Surface temperature readings were available from the 2009 and 2010 sampling seasons. Temperatures as high as 28^{o}C were recorded.

Water chemistry data were collected in 2009 and 2010 (Figure 7). Phosphorus levels remain high across both seasons, varying only about 20 ug/L each year across the season and never dropping below 100 ug/L. In 2010, chl-*a* concentrations increased across the season while Secchi improved; a likely scenario for this would be the presence of aphanizomenon, an algal species that allows for greater transparency during high concentrations. In 2010, there was a less pronounced change in chlorophyll-*a* and Secchi.

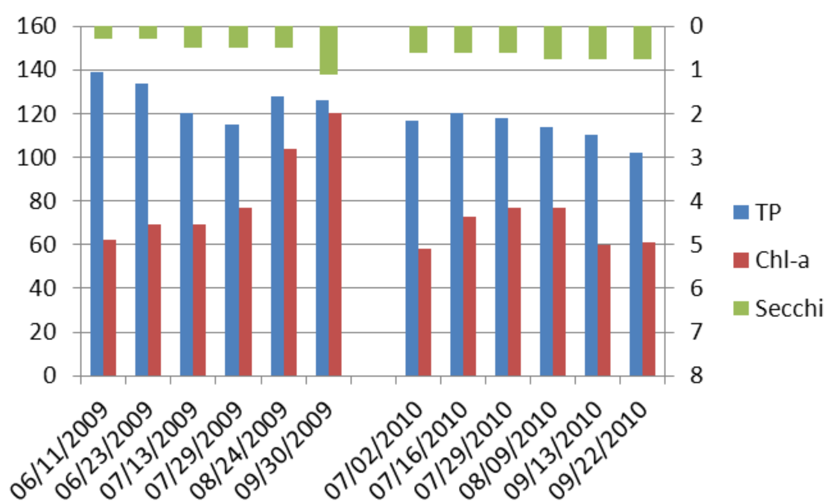


Figure 7. Mission Lake water quality data

MINLEAP was run for Mission Lake as a basis for comparing observed data with that predicted by the model based on lake depth and size, watershed size, and ecoregion location. The model was run for the NCHF ecoregion. The observed TP, chl-*a* and Secchi were considerably worse than the modeled results. The lake retains approximately 77 percent of the phosphorus that enters it and has a residence time on the order of three years. Complete modeling results can be found in Appendix B.

This is a very shallow basin and is susceptible to wind mixing. The mixing, in addition to elevated temperature levels, are likely leading to phosphorus release from the sediments and driving internal loading. Without measures to address this source of phosphorus, it is unlikely that standards will be met.

Summary

Fourteen of the 39 lakes greater than four hectares (10 acres) were reviewed for aquatic recreation use in the watershed (Table 2). The lakes are a mix of deep and shallow basins. Mission Lake is considered to be not supporting aquatic recreation use due to excess nutrients. North Tamarack, the headwaters of the Buffalo River (NRCS 2011), is also impaired for aquatic recreation use (excess nutrients), but an extensive review determined that the source of this impairment is natural (i.e., no TMDL will be required) (Table 3). Lake O-Me-Mee is right at the standards; more information will be necessary to determine if the lake is improving or declining and should be impaired. The remainder of the lakes meet aquatic recreation use standards. Most of these lakes are in a headwaters region with relatively intact watersheds. As forest is converted to cropland and developed land uses, increased runoff may cause nutrient levels in the lakes to rise. Shallow lakes have limited ability to assimilate nutrients. Efforts to keep phosphorus out of the lakes will be necessary to preserve the high quality of the lakes in this watershed.

Table 3. Comparison to standards for discussed lakes in the Upper Buffalo Watershed HUC-11

Ecoregion	TP	Chl-*a*	Secchi
	ppb	ppb	meters
NLF – Aquatic Rec. Use (Class 2B)	**< 30**	**< 9**	**> 2.0**
North Tamarack 03-0241-02	36	13	1.7
NCHF – Aquatic Rec. Use (Class 2b) Shallow lakes	**< 60**	**< 20**	**> 1.0**
Mission	120	76	0.6

County Ditch 15 HUC-11 Watershed

The County Ditch 15 (09020106020) HUC-11 watershed drains County Ditch 15 and numerous wetlands, small creeks and ditches. It drains from east to west and crosses the NCHF and LAP ecoregions. Cultivated and pasture land uses dominate this watershed. Four of the 28 lakes in the watershed have been assessed against aquatic recreation use standards (ARUS; Table 4).

Table 4. Lakes within the County Ditch #15 HUC-11 Watershed

Lake Name	Lake ID	Lake Area (ha)	% Littoral	Max Depth (m)	Mean Depth (m)	Mean TP (ug/L)	Mean Chl-a (ug/L)	Secchi Mean (m)	Aquatic Recreation Use Support[4]
Canary	[1,2]03-0516-00	27.3	65	7.6	3.4			1.6	IF
Marshall	03-0526-00	75	66	6.1	3.2	42	21	1.9	NS
Gottenberg	[1]03-0528-00	46.7	100	3.4	1	68	34	0.8	NS
Boyer	03-0579-00	130.6	65.8	7.9	2.8	54	24	2.4	NS
Forget-Me-Not	03-0624-00	95.4	100	2.1	1.0	82	27	0.9	NS

1. Mean depths estimated.
2. Watershed area estimated from MDNR lake catchment file
3. Due to available maps and sampling location, only the north basin was used to calculate mean depth and lake area for Lake Eleven.
4. NS = not supporting, FS = supporting, IF = insufficient information to determine support, NA = not assessed (too small or wetland-like)
5. Lake is not supporting aquatic recreation use due to natural conditions; no TMDL is required.

Marshall 03-0526-00

Marshall Lake is a 75 hectare (ha) lake with a maximum depth of 6.1 meters (m; 19.7 feet) located near Audubon, Minnesota. The lake has a 215 ha watershed (2.8:1 watershed to lake ratio) dominated by cultivated and water/wetland land uses. The lake was listed for excess nutrients in 2011. The lake has few residences, but is surrounded by cultivated land typically with a narrow forested riparian area. Considering the size of the littoral area (~66 percent) and the maximum depth, this lake will be considered deep for the purposes of assessment.

Water chemistry data was collected in 2008 and 2009 (Figure 8). In both years of sampling, phosphorus and chlorophyll-*a* concentrations increased across the sampling season and then declined in the fall. Secchi followed a similar pattern, with declining transparency observed as the season progresses.

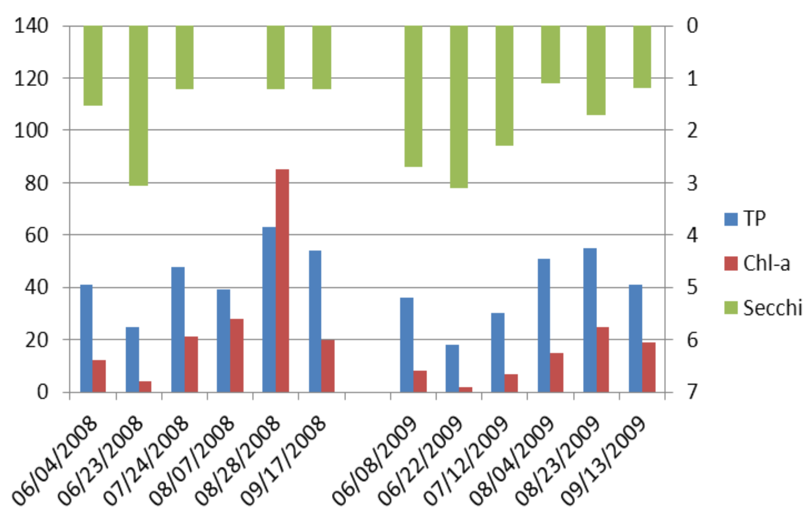


Figure 8. Marshall Lake water quality data

MINLEAP was run for Marshall Lake as a basis for comparing observed data with that predicted by the model based on lake depth and size, watershed size, and ecoregion location. The model was run for the NCHF ecoregion. The observed TP and Secchi were worse than, but not significantly different from the modeled results. The chl-*a* observed values were significantly worse than predicted in the modeled results. The lake retains approximately 85 percent of the phosphorus that enters it and has a residence time on the order of eight years. Complete modeling results can be found in Appendix B.

With Marshall Lake having some depth and the exceedences being close to the standard, the lake should respond to reductions in phosphorus in the watershed. Internal loading should be considered, but does not appear to be driving huge shifts in water quality across the season.

Gottenberg 03-0528-00

Gottenberg Lake is a shallow, 47 hectare (ha) lake with a maximum depth of 3.4 meters (m; 11 feet) located southwest of Audubon, Minnesota. The lake has a 502 ha watershed (11:1 watershed to lake ratio) dominated by forested and cultivated land uses. The lake was listed for excess nutrients in 2011. The lake is surrounded by cultivated land, typically with a narrow forested riparian area.

Water chemistry data was collected in 2009 and 2010 (Figure 9). Maximum surface temperature observed was 26°C. In both years of sampling, phosphorus and chlorophyll-*a* concentrations increased across the sampling season, indicative of shallow lake conditions. Secchi was low both years, rarely reaching depths greater than one meter.

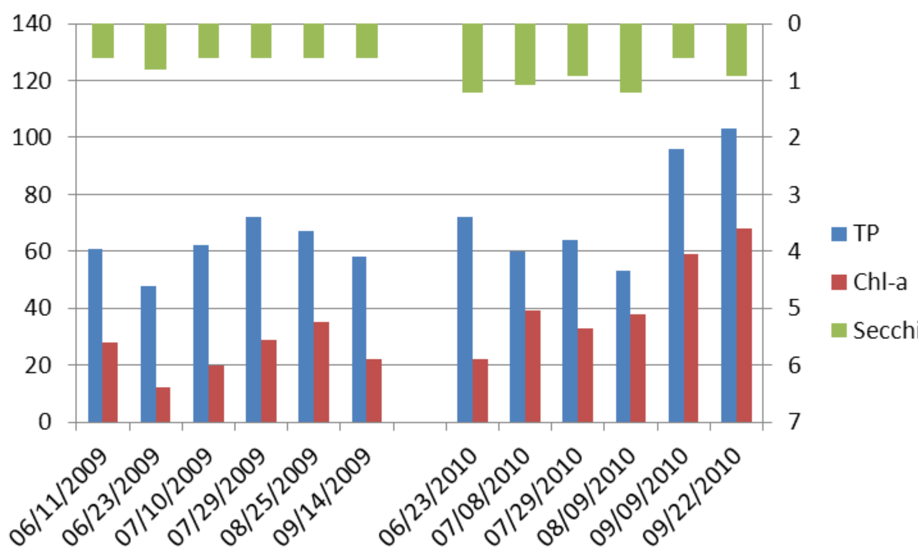


Figure 9. Gottenberg Lake water quality data

MINLEAP was run for Gottenberg Lake as a basis for comparing observed data with that predicted by the model based on lake depth and size, watershed size, and ecoregion location. The model was run for the NCHF ecoregion. The observed values matched the predictions in the model for this lake. The lake retains approximately 58 percent of the phosphorus that enters it and has a residence time on the order of eight months. Complete modeling results can be found in Appendix B.

Concentrations on most dates exceed the shallow lake standard for both the phosphorus and chlorophyll-*a*. In 2010 especially, it appears that internal loading is causing a significant increase in phosphorus concentrations (~40 ug/L increase across the season) and will need to be addressed to meet the recreation use criteria for Gottenberg Lake.

Boyer 03-0579-00

Boyer Lake is a deep, 130 hectare (ha) lake with a maximum depth of 7.9 meters (m; 26 feet) located east of Lake Park, Minnesota. The lake has an 843 ha watershed (6.5:1 watershed to lake ratio) dominated by cultivated and water/wetland land uses. The lake was listed for excess nutrients in 2011. The lake is lightly developed and predominantly surrounded by cultivated land, typically with a narrow forested riparian area. The lake increased in water level during the high precipitation in the late 1990s. This rise in water levels resulted in significant shoreline erosion in areas of steep shoreline, most notably on the east side of the lake. An artificial outlet was installed under US HWY 10 in 2011 to reduce and stabilize the rising water levels. The outlet lowered the lake level roughly four feet in order to return the lake to the relatively stable lake level that existed prior to the recent 18-year period of greater than normal precipitation.

Water chemistry data was collected in 2008 and 2009 (Figure 10). Phosphorus generally increased across the season; a response in chl-*a* and Secchi was more pronounced in 2008, in 2009 the chl-*a* did not increase as much as expected. A review of temperature and rainfall data did not provide any clues to the change in chlorophyll-*a* response in the second year of sampling.

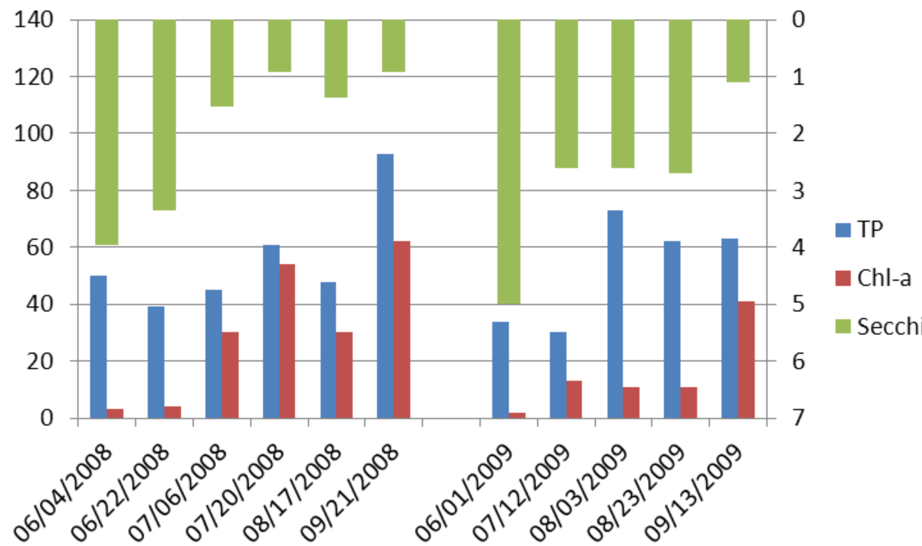


Figure 10. Boyer Lake water quality data

MINLEAP was run for Boyer Lake as a basis for comparing observed data with that predicted by the model based on lake depth and size, watershed size, and ecoregion location. The model was run for the NCHF ecoregion. The observed values were worse than but not significantly different than the modeled values. The lake retains approximately 76 percent of the phosphorus that enters it and has a residence time on the order of three years. Complete modeling results can be found in Appendix B.

Forget-Me-Not 03-0624-00

Forget-Me-Not Lake is a shallow, 95 hectare (ha) lake with a maximum depth of 2.1 meters (m; seven feet) located near Lake Park, Minnesota. The lake has an 859 ha watershed (9:1 watershed to lake ratio) dominated by cultivated land uses. The lake was listed for excess nutrients in 2011. The lake has two residences and is predominantly surrounded by cultivated land, typically with a narrow forested riparian area.

Water chemistry data was collected in 2009 and 2010 (Figure 11). Phosphorus and chlorophyll-*a* increased across the season with a corresponding decline in Secchi transparency; this is typical of shallow lakes in Minnesota where internal loading plays a large role.

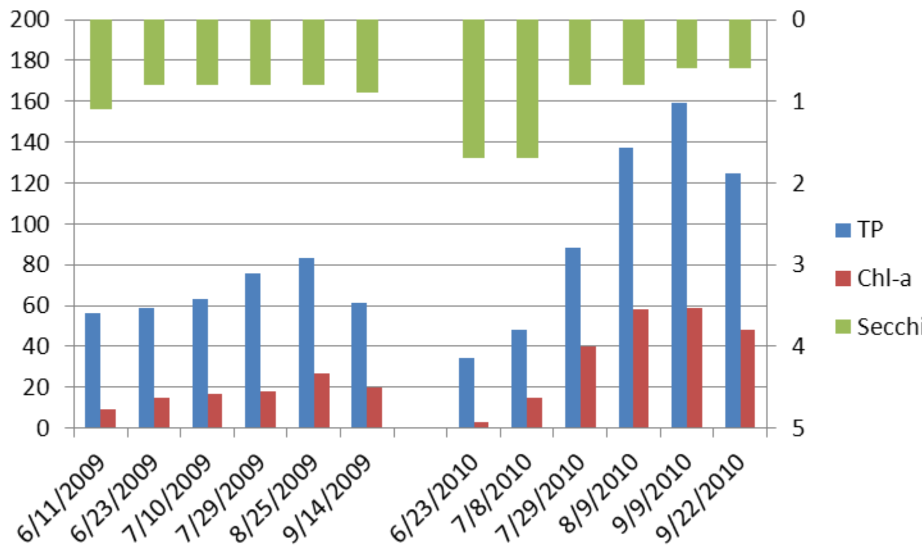


Figure 11. Forget-Me-Not Lake water quality data

MINLEAP was run for Forget-Me-Not Lake as a basis for comparing observed data with that predicted by the model based on lake depth and size, watershed size, and ecoregion location. The model was run for the NCHF ecoregion. The observed values were in line with the modeled values. The lake retains approximately 60 percent of the phosphorus that enters it and has a residence time on the order of seven months. Complete modeling results can be found in Appendix B.

Summary

Four of the 28 lakes greater than four hectares (10 acres) in this watershed were assessed in the watershed (Table 4). Again, a mix of deep and shallow lakes dominates this area; however, these lakes have significantly more developed watersheds than upstream lakes. Marshall, Boyer, Gottenberg, and Forget-Me-Not are all exceeding aquatic recreation use eutrophication standards (excess nutrients) (Table 5). Reduction in overland runoff and management of internal loading of phosphorus in shallow lakes will need to be addressed to see water quality improvements in these basins. Row-crop agriculture and the resultant intensive drainage play an important part in these lakes eutrophication problems. Protection and restoration strategies will, in part, need to address these concerns with agricultural best management practices.

Table 5. Comparison to standards for discussed lakes in the County Ditch 15 Watershed HUC-11

Ecoregion	TP	Chl-*a*	Secchi
	ppb	ppb	meters
NCHF – Aquatic Rec. Use (Class 2B) **Deep lakes**	**< 40**	**< 14**	**> 1.4**
Marshall	42	21	1.9
Boyer	54	24	2.4
NCHF – Aquatic Rec. Use (Class 2b) **Shallow lakes**	**< 60**	**< 20**	**> 1.0**
Gottenberg	68	34	0.8
Forget-Me-Not	82	27	0.9

Lake Park HUC-11 Watershed

The Lake Park (09020106030) HUC-11 watershed is located in the Clay and Becker counties draining Hay Creek and a number of smaller tributaries to the Buffalo River. The watershed drains NCHF and LAP ecoregions, with cultivated and forested land uses dominating the landscape. Eight of the 32 lakes in the watershed have been assessed against aquatic recreation use standards (ARUS; Table 6).

In addition to the lake summaries below, a more in depth conversation regarding the lakes in the Sand Lake Chain (Sand, Talac, Sorenson, Sand (Yort), and Axberg lakes) is included due to historical concerns about pollutant loading, and dramatic changes in lake elevation and flow pattern.

Table 6. Lakes within the Lake Park HUC-11 watershed

Lake Name	Lake ID	Lake Area (ha)	% Littoral	Max Depth (m) pre-1997	Max Depth (m) post -1997	Mean Depth (m)	Mean TP (ug/L)	Mean Chl-a (ug/L)	Secchi Mean (m)	Aquatic Recreation Use Support[4]
Sand	[1,2]03-0618-00	23.6	100	2.7	4.0	1.5	83	9	1.1	IF
Talac	[1]03-0619-00	39.7		4	6.0	2.8	93	29	1.9	NS
Sorenson	[1,2]03-0625-00	17.1	100	2.4	3.0	1.7	177	41	1.7	NS
Stakke	03-0631-00	194.5	99.3	4.6		2.1	65	30	1.5	NS
Gourd	03-0635-00	48.8	100	1.8		1.2	113	54	0.6	NS
West LaBelle	03-0645-00	40.9		5.8		1.3	89	41	1.3	NS
Lime	03-0646-00	43.4	100	2.4		1.4	138	63	0.9	NS
Stinking	03-0647-00	153.3	100	2.4		1.5	309	96	0.7	NS
East LaBelle	03-0648-00	77.8	53			3.2	38	15	2.2	IF
Sand	03-0659-00	81.4	52.3	8.5	11.0	4.3	125	28	2	NS
Axberg (Main Basin)	03-0660-01	13.2	100	4.0	4.0					NA
Axberg (West Basin)	03-0660-02	4.8	100	1.8	1.8					NA
Chicken Drop Marsh	14-0214-00	6.8	100	1.8	1.8					NA

1. Mean depths estimated.
2. Watershed area estimated from MDNR lake catchment file
3. Due to available maps and sampling location, only the north basin was used to calculate mean depth and lake area for Lake Eleven.
4. NS = not supporting, FS = supporting, IF = insufficient information to determine support, NA = not assessed (too small or wetland-like)
5. Lake is not supporting aquatic recreation use due to natural conditions; no TMDL is required.

The Sand Lake Watershed

The subwatershed that contains Sand, Talac, Sorenson, Yort (aka Sand) and Axberg Lakes has been locally controversial since the early 1990's. Concern about high phosphorus concentrations flowing from Axberg Lake into Sand Lake were first brought to the attention of the MPCA in the fall of 1993. Samples collected in 1993 and 1995 from the outlet of Axberg Lake had phosphorus concentrations that exceeded 2.5 mg/l on two occasions. The northwest bay of Axberg Lake was diked off from the remainder of the lake in the early to mid-1960's and used as a chicken manure lagoon for an egg production facility. Discharge from Axberg Lake had been channeled through this lagoon and then north through several wetlands and ponds and into the south east corner of Sand Lake. After assessing the situation, the MPCA hired a contractor in 1997, to install a 24 inch corrugated metal pipe to bypass the flow of Axberg Lake around the chicken manure pond. This effort resulted in significant reductions of phosphorus loading from Axberg Lake to the downstream receiving lakes.

The long-term average phosphorus concentration in Axberg Lake is 224 ug/l. The elevated level may be the result of manure spills or from runoff of farm land near the lake that had received excessive manure application throughout the years (some portions of the land had a history of being too nitrogen rich for crop production). Although the chicken manure pond has been isolated, for the most part, from the downstream lake system, the surface discharge from Axberg Lake with its elevated phosphorus concentration remains a source of concern for downstream lake phosphorus loading and eutrophication.

Another contributing factor in the impairment of these lakes concerns the extensive wet weather period this watershed experienced from 1993 to 2010. This area received higher than normal precipitation during this period that resulted in the lake levels rising and a shift in the hydrologic flow pattern. Snow accumulation during the winter of 1996/1997 resulted in the historic 1997, Red River Flood and a significant rise in lake levels within the Sand Lake Watershed (Figure 12).

The Sand Lake Watershed prior to the 1997 flood flowed into and terminated at Sand Lake 03-0659-00, a large, deep lake. Sand Lake appeared to have a significant groundwater discharge because its lake level appeared to decline faster than Talac during the summers prior to 1997 (when the lakes became connected at the same elevation). After the 1997 flood and the resulting increase in lake levels, the drainage pattern changed and flowed from Sand Lake into Talac Lake and then north into Yort (aka Sand) Lake 03-0618-00. Figures 13 and 14 show the pre and post 1997, drainage pattern shift. Both Talac and Yort Lakes are shallow and have much less ability to assimilate nutrients than deeper lakes such as Sand.

The increase in precipitation and runoff that affected lake levels within this watershed resulted in significant phosphorus loading to the lake system. In addition, a previously isolated portion of the watershed west of Clay County Road 118 began discharging into a pond (Chicken Drop Marsh) located immediately west of Axberg Lake. This pond was piped into the West Bay of Axberg Lake (location of spill) and this excess flow and phosphorus was discharged downstream into Sand, Talac and Yort Lakes. In addition, the rise in lake levels in Sand and Talac Lakes has resulted in significant shoreline erosion.

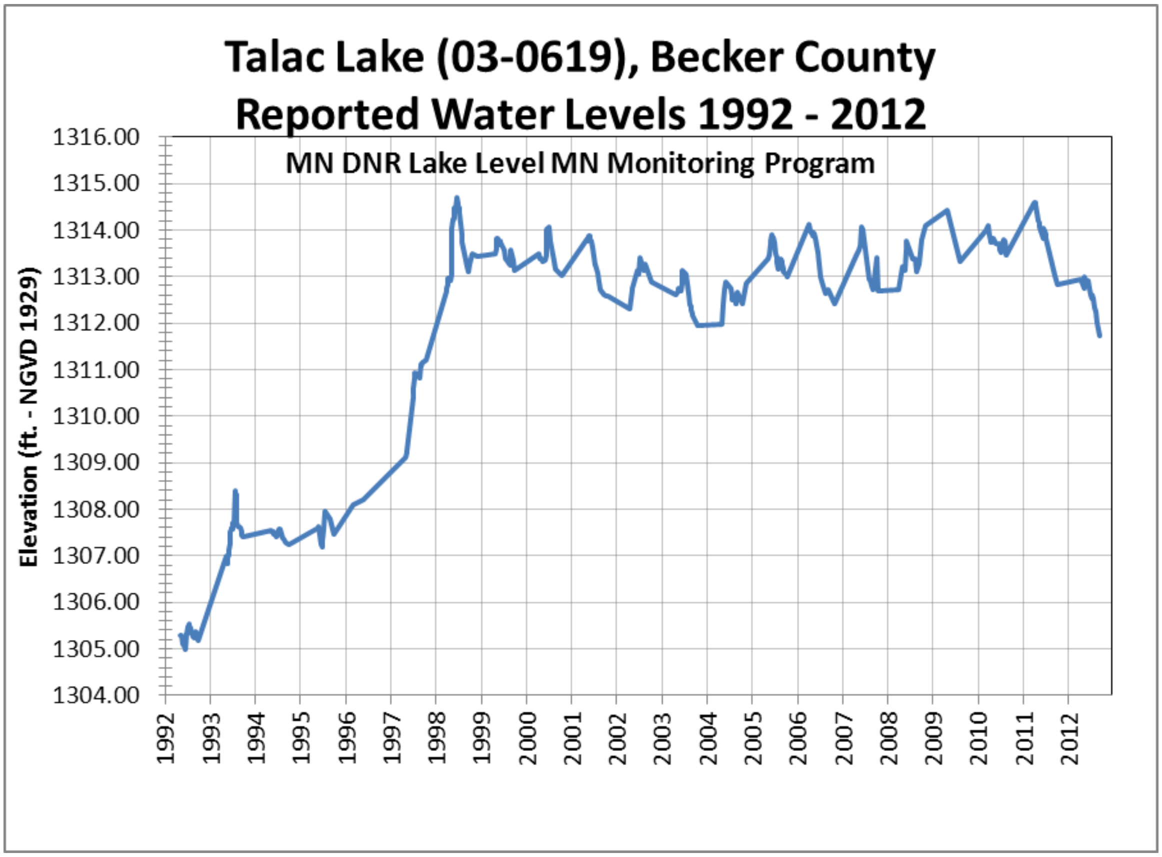


Figure 12. Talac Lake-level results 1992to 2012

Another threat to the future health of the lakes in this watershed is the potential for the introduction of carp. Carp are present in the Buffalo River and if they made their way into these shallow lakes they could contribute to the release of phosphorus with their bottom feeding activity that tends to disturb bottom sediments and re-suspend nutrients into the water column. One of the protective measures for this system should be to make sure there are migration barriers to prevent carp from swimming upstream into these lakes.

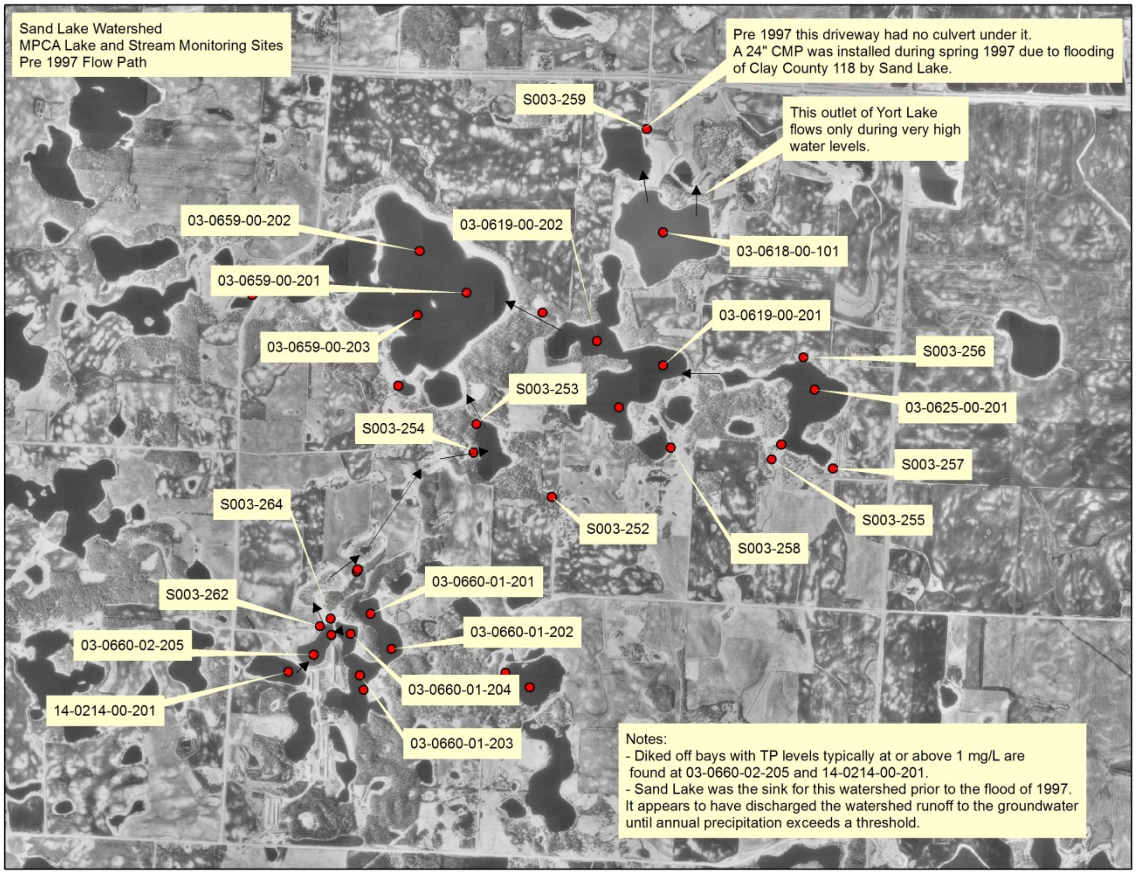


Figure 13. Sand Lake Watershed pre-1997 flow paths

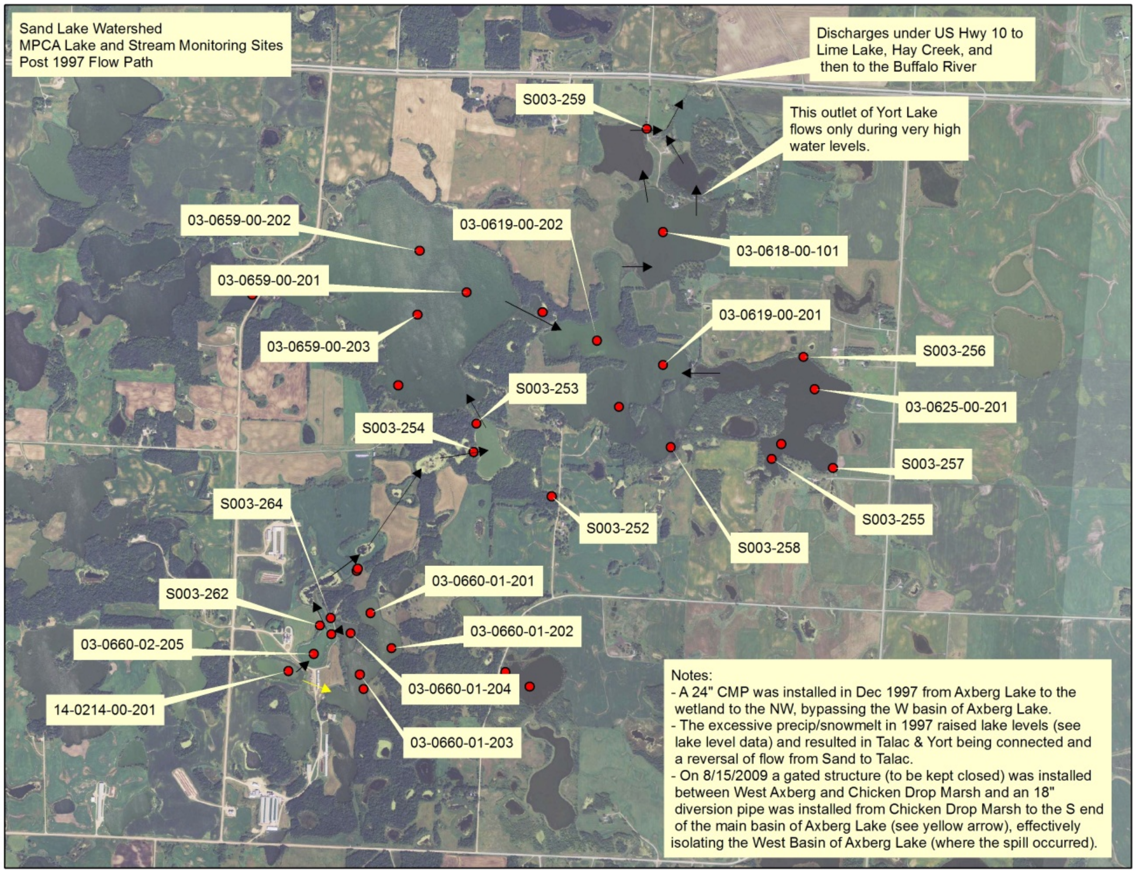


Figure 14. Sand Lake Watershed post 1997 flow paths

Sand (Stump) 03-0659-00

Sand (Stump) Lake is a deep, 81 hectare (ha) lake with a maximum depth of 11 meters (m; 36 feet) located southwest of Lake Park, Minnesota. This lake underwent a large change in water elevation in the floods of the late 1990s; originally an 8.5 meter deep lake that drained Axberg, Talac, and Sorenson Lakes, now it receives water only from Axberg and drains to Talac, reducing the watershed to 1,483 ha from an original drainage area of 2,193 ha. The lake has a 614 ha watershed dominated by cultivated and forested land uses. The lakeshore is very lightly developed, with the majority being a forested riparian area surrounded by cultivated land. The lake was determined to be impaired for aquatic recreation use in 2008, based on the deep lake NCHF standard.

The most recent water quality data collected on Sand Lake was from 2008 and 2012 (Figure 15). Profile data was available from 2008; the lake does stratify with a thermocline developing between a depth of five and seven meters. Water below this level did not contain sufficient oxygen to sustain game fish (greater than 5 mg/L). Hypolimnetic values from 2008, indicate that high concentrations of phosphorus (300 to 400 ug/L) are being released from the sediment, but the stratification is keeping this phosphorus from playing a role in summer surface concentrations. It is very likely that during fall (September-October) turnover an algal bloom would develop with the addition of the phosphorus to the surface, as observed in 2008. The data follows a pattern typical of deep lakes, elevated concentrations in the spring as a result of turnover, declining concentrations as the summer goes on and watershed contributions are limited, and a peak in the fall during turnover.

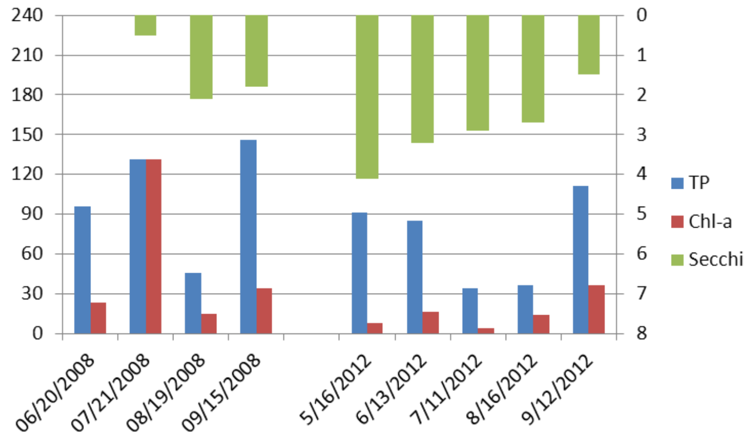


Figure 15. Sand Lake water quality data

In the most recent analysis of Secchi disk transparency trends, Sand Lake was not exhibiting a trend (Figure 16). The lake varies from year to year in phosphorus concentrations, no clear tie to weather patterns – the area was exhibiting very wet conditions in 1999, and drought conditions in 2003 and 2012, the remainder of the years was considered to be plus four inches of the long-term average precipitation. The fall turnover was captured in the sampling events in 2005 and 2008 and is likely influencing the higher concentrations observed (Figure 17).

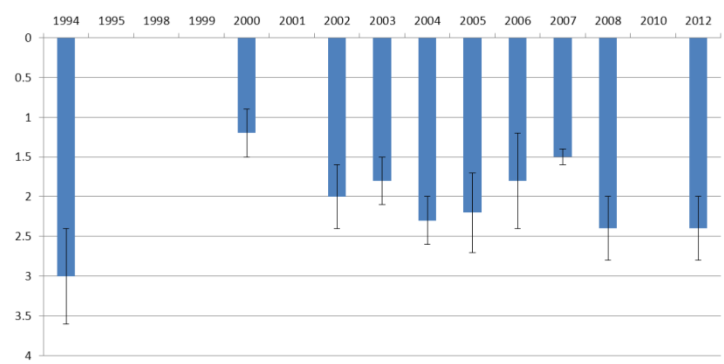


Figure 16. Sand Lake long-term Secchi transparency

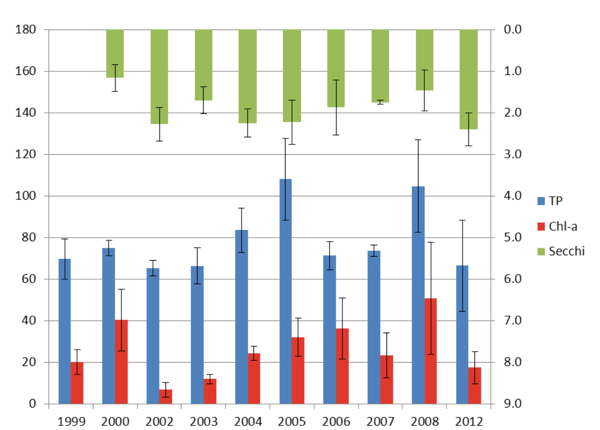


Figure 17. Sand Lake long-term water quality data

MINLEAP was run for Sand (Stump) Lake as a basis for comparing observed data with that predicted by the model based on lake depth and size, watershed size, and ecoregion location. The model was run for the NCHF ecoregion. The model was originally run with the default stream input of 148 ug/L phosphorus, which is consistent with ecoregion expectations. However, due to the contamination of Axberg Lake by chicken manure waste in the 60s and 70s, inflow concentrations upstream of Sand (Stump) Lake averaged 658 ug/L phosphorus (average of 2000, through 2006 data). Once calibrated for the average inflow value, the standard error of the modeled values included the range of the observed values for phosphorus and chlorophyll-a. In all, the model predicted worse water conditions that were observed. The lake retains approximately 81 percent of the phosphorus it receives. The residence time is on the order of two years. Complete modeling results can be found in Appendix B.

Axberg 03-0660-00

Axberg Lake is a shallow, 18 hectare (ha) lake located southwest of Lake Park, Minnesota. The lake is made up of two basins, the 13.2 ha main lake (03-0660-01) and the 4.8 ha west basin (03-0660-02). The west basin was created with a dike that was constructed in the early to mid-1960's. This basin was used as a chicken manure lagoon for an egg producing farm. The lake has a 614 ha watershed dominated by cultivated and forested land uses. The lakeshore is a mix of row crop and forested land and contains a large poultry feedlot. Both basins of Axberg Lake will be assessed as shallow lakes in the NCHF ecoregion.

The west basin of Axberg Lake was contaminated by waste from a poultry feedlot during the 1960s and 1970s. To attempt to contain the contamination, which was adversely affecting downstream waters, an outlet was constructed draining the main basin of Axberg lake to the wetland northwest of the lake in 1997. This outlet eliminated the need for the main basin from first draining through the contaminated west basin to outlet the lake. In 2009, a gated culvert was installed between the west basin and the main lake and a diversion was constructed to route water from Chicken Drop Marsh through the main basin of Axberg Lake, to isolate the west basin and prevent any further discharge to the downstream lakes (Figure 18).

Figure 18. Map of Axberg Lake area

The most recent water quality data collected on Axberg (main and west basins) and Chicken Drop Marsh was from 2012 (Figure 19). The main basin has elevated phosphorus and chlorophyll-*a* concentrations consistently over the period of record with values averaging 224 ug/L and 99 ug/L, respectively (Figure 19a). The west basin, which received the poultry waste, had average concentrations of 1239 ug/L for phosphorus and 130 ug/L for chlorophyll-*a* (Figure 19b). Chicken Drop Marsh, which originally drained into the west basin, had 2012 concentrations of 747 ug/L for phosphorus and 57 ug/L of chlorophyll-*a* (Figure 19c). These are all highly eutrophic systems and Sand (Stump) Lake is being negatively impacted by the discharge from this chain of lakes. With the contaminated basin isolated, internal loading will likely drive continued elevated concentrations of phosphorus in this system.

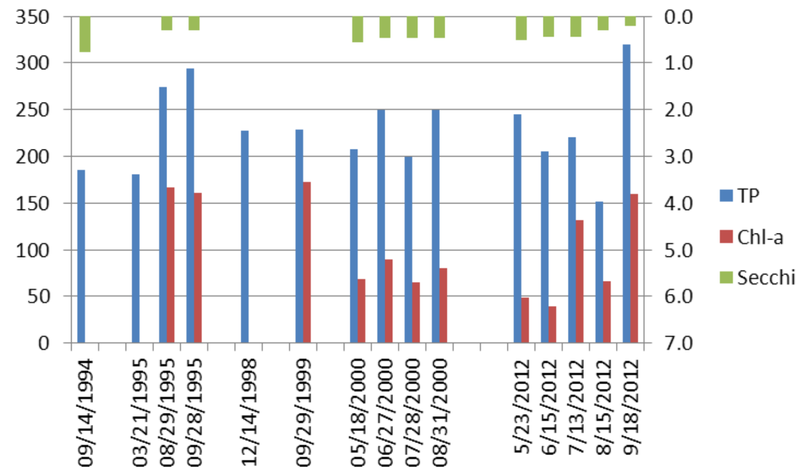
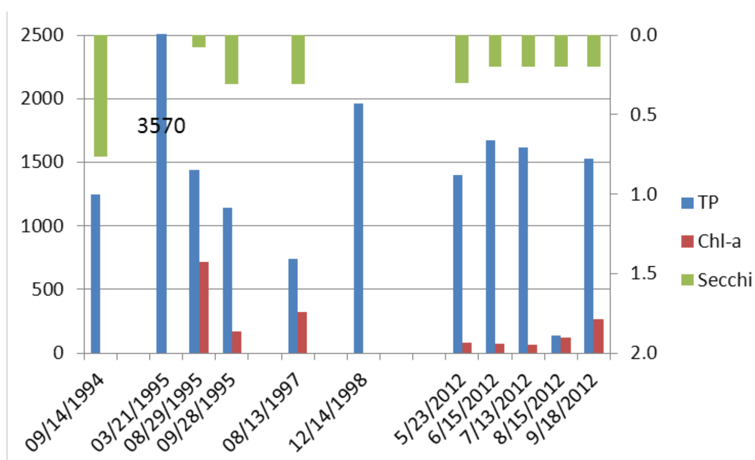
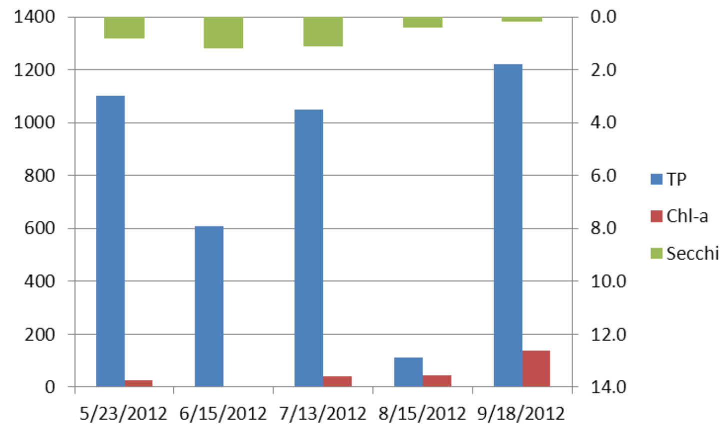


Figure 19. Axberg Lake water quality data, **a). Axberg (Main Basin) Lake 03-0660-01 water chemistry**



b). Axberg (West Basin) Lake 03-0660-02 water chemistry



c). Chicken Drop Marsh 14-0214-00 water chemistry

MINLEAP was run for both basins of Axberg Lake as a basis for comparing observed data with that predicted by the model based on lake depth and size, watershed size, and ecoregion location. The model was run for the NCHF ecoregion. The model under predicted observed values; stream inflow had to be calibrated up from 148 ug/L to 600 ug/L to get the model to match observed values. This is expected considering the impact of contaminated basin and internal loading that will continue to elevate concentrations in the basin. The main basin of the lake retains approximately 50 percent of the phosphorus it receives. The residence time is on the order of five months. Complete modeling results can be found in Appendix B.

Sand (Yort) 03-0618-00

Sand Lake is a shallow, 24 hectare (ha) lake with a maximum depth of 2.7 meters (m; nine feet) located southwest of Lake Park, Minnesota. The lake had a 79 ha watershed prior to elevated water levels in the 1990s. The current watershed area, which drains Sand, Talac, Sorenson, and Axberg Lakes, is 2,311 (96:1 watershed to lake ratio) dominated by cultivated and water/wetland land uses. The lake has insufficient data to review for recreation use support during the 2011 assessments.

Water chemistry data was collected in 2002 and 2012 (Figure 20). Originally the lake was 2.7 m deep; during the elevated water levels in the 1990s, the maximum depth rose to 4.0 m. The lake is still considered to be shallow in terms of assessment. Phosphorus levels appeared to increase across the season. Chlorophyll-*a* levels appeared to be higher in late 2012, than in other sampling dates; it was very dry in 2012, and those conditions would have provided conditions favorable to algal growth.

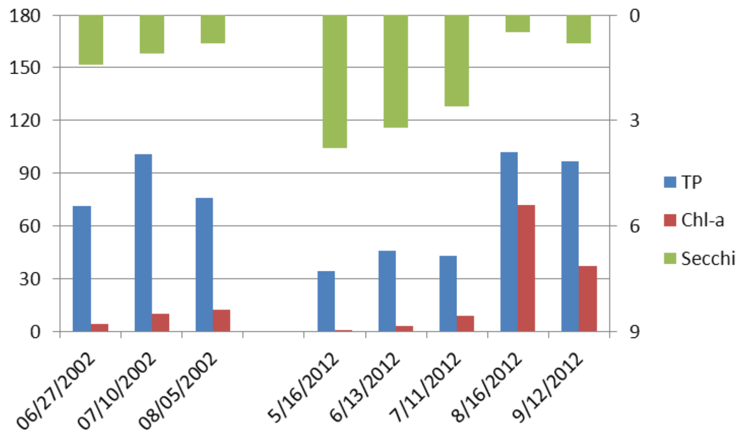


Figure 20. Sand (Yort) Lake water quality data

MINLEAP was run for Sand (Yort) Lake as a basis for comparing observed data with that predicted by the model based on lake depth and size, watershed size, and ecoregion location. The model was run for the NCHF ecoregion. The observed TP and Secchi agreed with modeled results; the model predicted significantly worse chlorophyll-a concentrations to be present in the basin. The lake retains approximately 37 percent of the phosphorus that enters it and has a residence time on the order of three months. Complete modeling results can be found in Appendix B.

Talac 03-0619-00

Talac Lake is a shallow, 40 hectare (ha) lake with a maximum depth of 6.0 meters (m; 20 feet) located southwest of Lake Park, Minnesota. The lake had a 711 ha watershed prior to rise in water level in 1997. The current watershed area, which drains Sand, Sorenson, and Axberg Lakes, is 2,193 (54:1 watershed to lake ratio) dominated by cultivated and forested land uses. The lake was listed for excess nutrients in 2002. Originally the lake was 4.0 m deep; during the rise in water levels in 1997s, the maximum depth rose to 6.0 m (Figure 12). Talac Lake is still considered to be shallow in terms of assessment.

Phosphorus levels appeared to increase across the season as typical of shallow lakes; internal loading can provide an additional source of phosphorus and runoff declines (Figure 21). Chlorophyll-*a* levels appeared to be higher in late 2012, than in other sampling dates; it was very dry in 2012, and those conditions would have provided conditions favorable to algal growth.

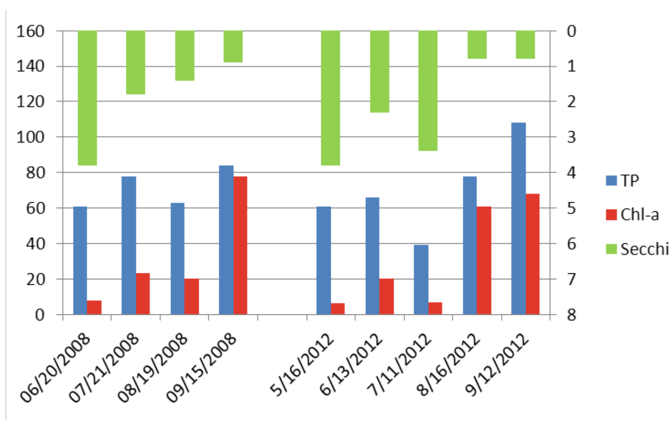


Figure 21. Talac (Lee) Lake water quality data

Water chemistry data was collected in 11 years from 1993 through 2012 (Figure 22). Since the change in the watershed flow patterns, Talac Lake has consistently exceeded the 60 ug/L threshold for TP in the eutrophication standard. Similar patterns have been observed with the chlorophyll-a concentrations, consistently higher average concentrations since the increased watershed size (Figure 22). Secchi does appear better than expected. Aphanizomenon plays a role in increased clarity and a strong spring time zooplankton community is often present to graze down the algae biomass providing for some early season lake clarity. The Secchi record for Talac Lake is quite extensive, spanning from 1987 through the present (Figure 23). A weak improving trend in Secchi transparency was noted during the last trend analysis completed.

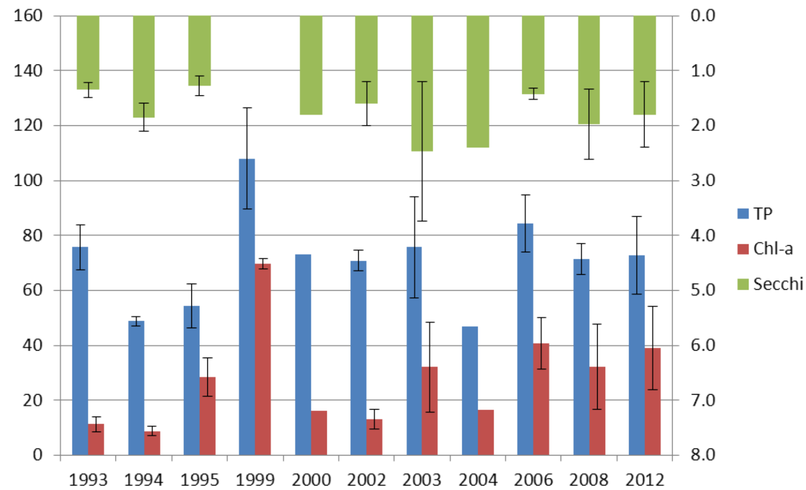


Figure 22. Long-term water quality data for Talac Lake

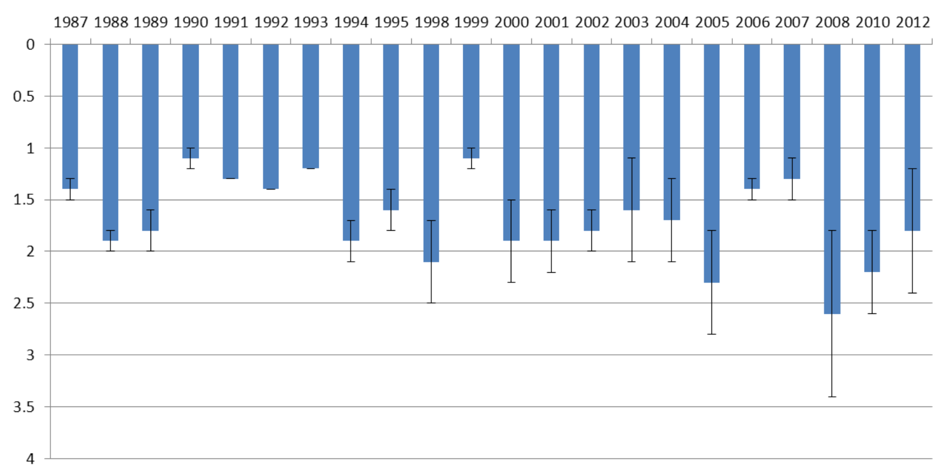


Figure 23. Long-term Secchi transparency for Talac Lake

MINLEAP was run for Talac Lake as a basis for comparing observed data with that predicted by the model based on lake depth and size, watershed size, and ecoregion location. The model was run for the NCHF ecoregion; two runs were completed, one for pre 1997 flood conditions and one post. The observed TP, chl-*a* and Secchi matched modeled predictions well. Only Secchi deviated from the model, with much higher clarity than the model anticipate (1.0 meter). The lake retained approximately 64 percent of the phosphorus that enters its pre-1997 and 52 percent post-1997. The residence time has shifted from just over a year to six months since the flooding. Complete modeling results can be found in Appendix B.

Sorenson 03-0625--00

Sorenson Lake is a shallow, 17 hectare (ha) lake with a maximum depth of 3.0 meters (m; 10 feet) located southwest of Lake Park, Minnesota. The lake has a 382 ha watershed dominated by cultivated and forested land uses. The lake was listed for excess nutrients in 2010. Originally the lake was 2.4 m deep; during the elevated water levels in the 1990s, the maximum depth rose to 3.0 m. The lake is still considered to be shallow in terms of assessment.

A full season of data is only available for 2012; based on that data, it appears that the lake functions similar to expected for shallow lakes with an increase in nutrients and algae during the season and a decline in Secchi transparency (Figure 24). Considering the elevated nature of the phosphorus concentrations, one would expect more response in chl-*a* and Secchi is earlier sampling events. In late 2012, the chl-*a* did increase considerably from previous years.

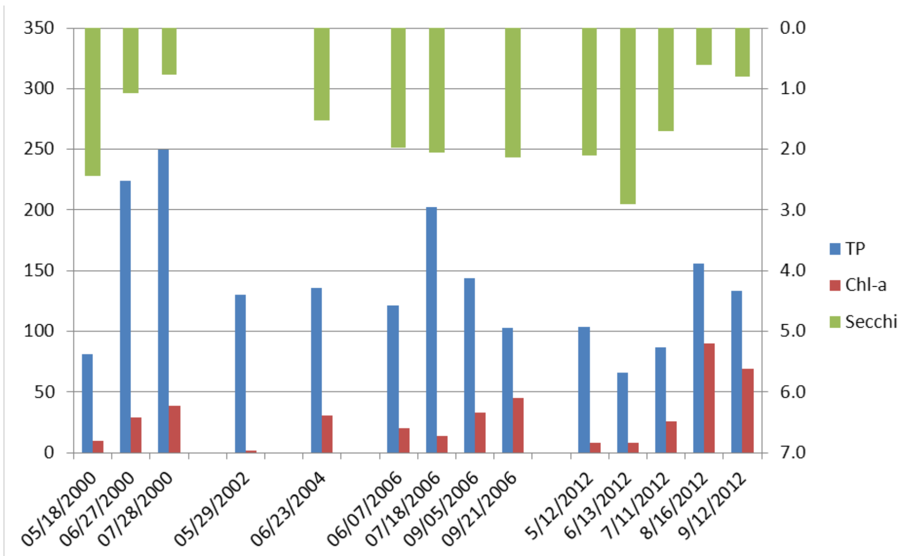


Figure 24. Sorenson Lake water quality data

MINLEAP was run for Sorenson Lake as a basis for comparing observed data with that predicted by the model based on lake depth and size, watershed size, and ecoregion location. The model was run for the NCHF ecoregion. Observed TP and Secchi were significantly different than the modeled values; the model predicted lower TP concentrations and lower Secchi transparency. Chl-*a* matched the modeled value; this indicates that the lake likely has the capacity to produce more algae than currently present. Aphanizomenon often plays a role in allowing for better than expected clarity. The lake retains approximately 55 percent of the phosphorus it receives. The residence time is on the order of seven months. Complete modeling results can be found in Appendix B.

Stakke 03-0631-00

Stakke Lake is a shallow, 195 hectare (ha) lake with a maximum depth of 4.6 meters (m; 15 feet) located south of Lake Park, Minnesota. The lake has a 1,230 ha watershed dominated by cultivated and forested land uses. The fringe of the lake is narrow and forested; much of the western shore is being developed into residential lots. The lake was listed for excess nutrients in 2011. With 100 percent of the lake considered littoral, the lake will be assessed as a shallow lake.

The lake was sampled for chemistry in 2008 and 2009 and has Secchi data from 2011, (Figure 25). The lake appears to have increasing nutrient and algal concentrations across the season, combined with declining transparency; common to shallow lakes in Minnesota. The lake is quite large and would be susceptible to wind mixing, which would aid in the re-suspension of phosphorus into the water column.

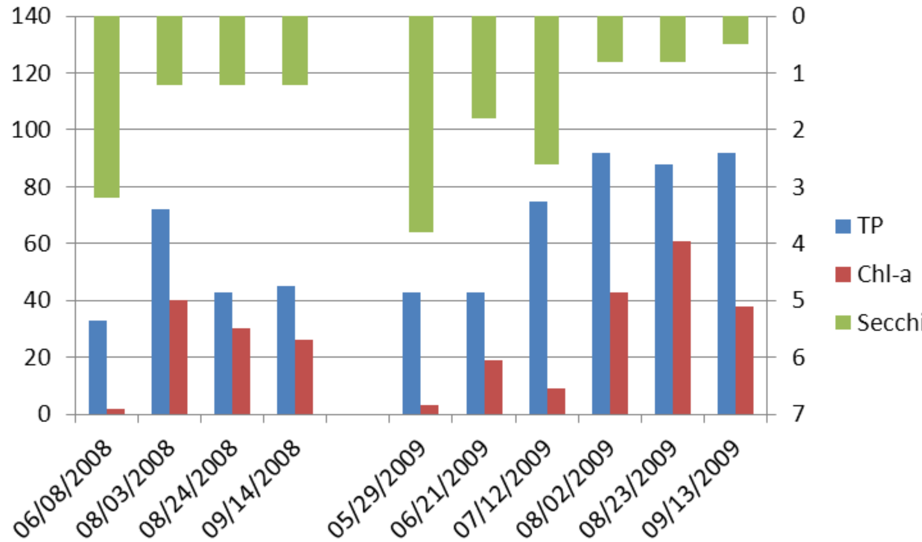


Figure 25. Stakke Lake water quality data

MINLEAP was run for Stakke Lake as a basis for comparing observed data with that predicted by the model based on lake depth and size, watershed size, and ecoregion location. The model was run for the NCHF ecoregion. Observed TP and chl-*a* were much higher than the model predicted. Considering the pattern of phosphorus increase during the time of the least runoff that internal loading is playing a key role in this basin, something the model is not equipped to depict. The Secchi transparency matched modeled values; this could indicate that aphanizomenon was present (algae that allows greater transparency). The lake retains approximately 74 percent of the phosphorus it receives. The residence time is on the order of two and a half years. Complete modeling results can be found in Appendix B.

Gourd 03-0635-00

Gourd Lake is a shallow, 49 hectare (ha) lake with a maximum depth of 1.8 meters (m; six feet) located south of Lake Park, Minnesota. The lake has a 146 ha watershed dominated by cultivated and water/wetland land uses. There are a couple of residences on the lake; the majority of the shoreline is a narrow forested riparian area that abuts agricultural land. The lake was listed for excess nutrients in 2011. With 100 percent of the lake considered littoral, the lake will be assessed as a shallow lake.

The lake was sampled for chemistry in 2009 and 2010 (Figure 26). The lake appears to have increasing nutrient and algal concentrations across the season. Secchi transparency is quite low, at its best (less than one meter), but it does appear to respond to the increase in algae with decreasing transparency.

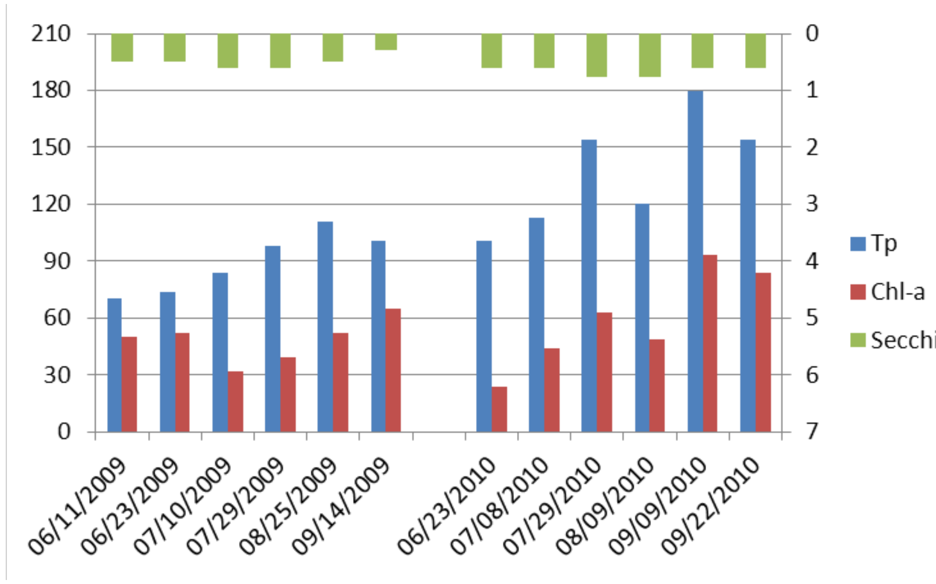


Figure 26. Gourd Lake water quality data

MINLEAP was run for Gourd Lake as a basis for comparing observed data with that predicted by the model based on lake depth and size, watershed size, and ecoregion location. The model was run for the NCHF ecoregion. Observed water quality conditions were considerably worse than predicted in the model. Considering the pattern of phosphorus increase during the time of the least runoff that internal loading is playing a key role in this basin, something the model is not equipped to depict. The lake retains approximately 76 percent of the phosphorus it receives. The residence time is on the order of three years. Complete modeling results can be found in Appendix B.

West LaBelle (Duck) 03-0645-00

West LaBelle Lake is a shallow, 41 hectare (ha) lake with a maximum depth of 5.8 meters (m; 19 feet) located in Lake Park, Minnesota. The lake has a 780 ha watershed dominated by cultivated and water/wetland land uses. The southern shore of the lake has residential development; the northern shore is cultivated up to the shoreline and the eastern shore abuts County Highway 9. The lake was listed for excess nutrients in 2011. With 100 percent of the lake considered littoral, the lake will be assessed as a shallow lake.

The lake was sampled for chemistry in 2009 and 2010 (Figure 27). In 2009, West LaBelle Lake followed a pattern common to shallow lakes, increasing nutrient and algal concentrations across the season paired with decreases in transparency. In 2010 the pattern was less evident; in addition, the chl-a concentrations increased and Secchi transparencies decreased considerably from those observed in 2009.

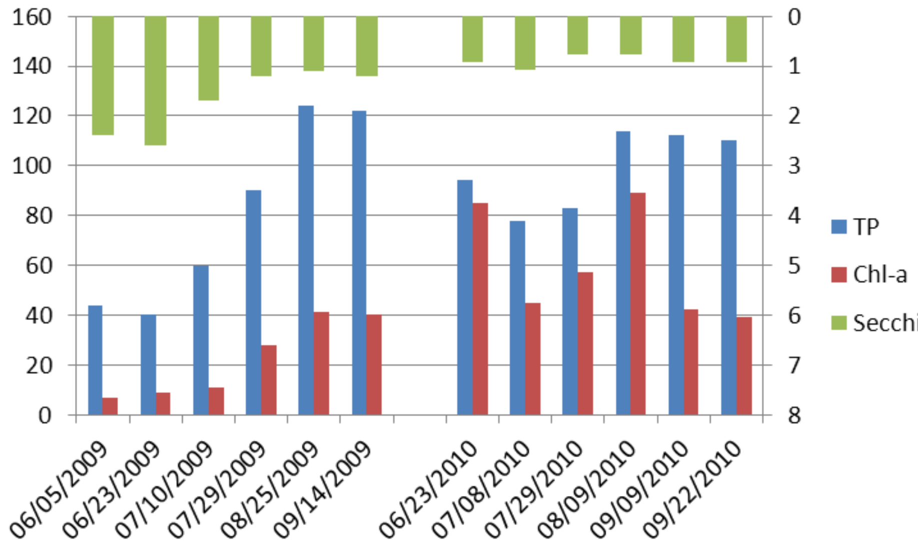


Figure 27. West LaBelle Lake water quality data

MINLEAP was run for West LaBelle Lake as a basis for comparing observed data with that predicted by the model based on lake depth and size, watershed size, and ecoregion location. The model was run for the NCHF ecoregion. Modeled and observed water quality conditions were similar. The lake retains approximately 53 percent of the phosphorus it receives. The residence time is on the order of six months. Complete modeling results can be found in Appendix B.

Lime 03-0646-00

Lime Lake is a shallow, 43 hectare (ha) lake with a maximum depth of 2.4 meters (m; eight feet) located west of Lake Park, Minnesota. The lake has a 2,785 ha watershed dominated by cultivated and water/wetland land uses. The lakeshore has a few residences, but primarily is bordered by cultivated land with little to no forested riparian fringe. The lake was listed for excess nutrients in 2011. With 100 percent of the lake considered littoral, the lake will be assessed as a shallow lake.

The lake was sampled for chemistry in 2009 and 2010 (Figure 28). In 2009, Lime Lake followed a pattern common to shallow lakes, increasing nutrient and algal concentrations across the season paired with decreases in transparency. In 2010 the pattern was less evident, but elevated levels were present from mid-July through September.

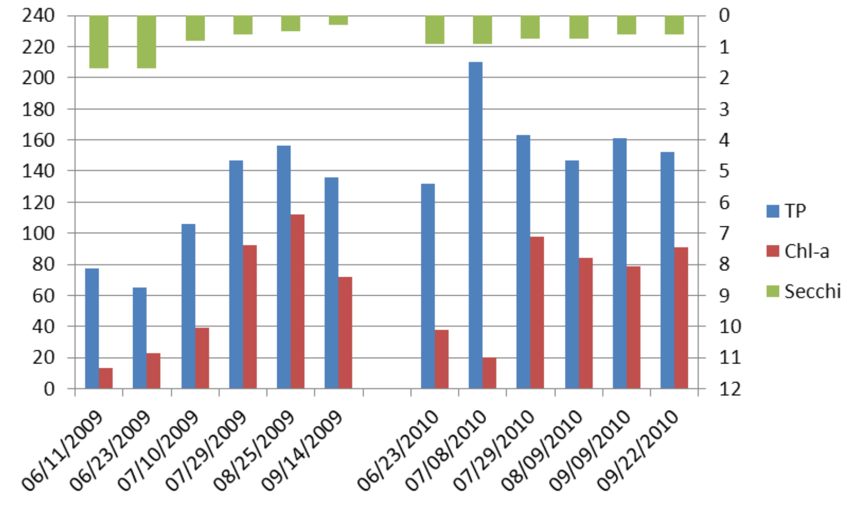


Figure 28. Lime Lake water quality data

MINLEAP was run for Lime Lake as a basis for comparing observed data with that predicted by the model based on lake depth and size, watershed size, and ecoregion location. The model was run for the NCHF ecoregion. Phosphorus concentrations were considerably higher than predicted values. The model does not take into account internal loading. The lake retains approximately 38 percent of the phosphorus it receives. The residence time is on the order of three months. Complete modeling results can be found in Appendix B.

Lime Lake has a history of a mink farm on the west shore and cattle on the south shore. These animal operations along with the intensive drainage and agriculture in the watershed are likely, in part, responsible for the high phosphorus concentrations. In addition, Lime Lake is immediately downstream of Yort (Sand) Lake and receives the discharge from the Sand Lake Watershed that is phosphorus enriched from Axberg Lake and the basin used as a chicken manure pond. The nutrient enrichment conditions in a shallow lake such as Lime will result in increased chlorophyll levels and decreased clarity. The shallow nature of the lake and susceptibility to wind mixing would likely stimulate phosphorus release from the sediments even during years of low precipitation (and subsequent low external loading) and this is likely driving the poor water quality conditions in the lake.

Stinking 03-0647-00

Stinking Lake is a shallow, 153 hectare (ha) lake with a maximum depth of 2.4 meters (m; eight feet) located northwest of Lake Park, Minnesota. The lake has a 6,263 ha watershed dominated by cultivated land use. The lakeshore is bordered by cultivated land with little to no forested riparian fringe. The lake was listed for excess nutrients in 2011. Land use in the watershed was dominated by cultivated agriculture (65 percent), followed by water/wetland (15 percent), and forest (10 percent); urban and pasture/grassland land uses made up five percent each; while transitional between NCHF and NGP ecoregions, it was determined the lake should be held to the NGP shallow lake eutrophication standard.

Stinking Lake historically and currently receives the wastewater effluent from the City of Lake Park. Wastewater effluent from Lake Park's pond system discharges to Hay Creek which flows northwest of the city for about three miles before discharging into Stinking Lake. The Stinking Lake outlet has a control structure constructed so that it can be used for flood storage. When in operation, the water level of the lake can bounce several feet in order to impound flood water. Both of these situations can have an impact of the water quality of the lake.

The lake was sampled for chemistry in 2009 and 2010 (Figure 29). Stinking Lake exhibits a pattern common to shallow lakes; nutrients start out relatively low in the spring and increase across the season, remaining high even during the periods of little runoff/external contribution in the late summer and fall. Secchi responds well to the changes in chlorophyll-*a*. Overall, the phosphorus has a huge annual range, with concentrations shifting 400 ug/L in the span of six weeks. Wind mixing and internal loading are likely driving the conditions in this basin.

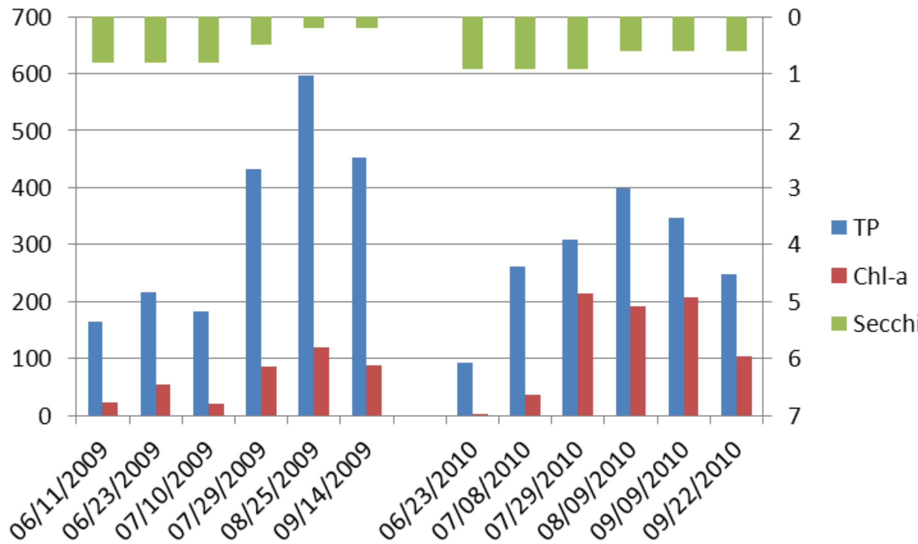


Figure 29. Stinking Lake water quality data

MINLEAP was run for Stinking Lake as a basis for comparing observed data with that predicted by the model based on lake depth and size, watershed size, and ecoregion location. The model was run for the NGP ecoregion. The model predicted similar phosphorus concentrations to those observed in 2009 and 2010. The range on the chlorophyll-*a* data suggests that the lake likely has the capacity to produce more algae; it is possible that sediment in the water column or rooted vegetation is tempering the algal growth on some dates. The lake retains approximately 81 percent of the phosphorus it receives. The residence time is on the order of 10 months. Complete modeling results can be found in Appendix B.

East LaBelle 03-0648-00

East LaBelle Lake is a moderately deep, 78 hectare (ha) lake with a maximum depth of 5.8 meters (m; 19 feet) located on the north edge of Lake Park, Minnesota. The lake has a 614 ha watershed dominated by cultivated and water/wetland land uses. The lakeshore is bordered County Road 9 to the north and west, and lightly developed on the east and southern shores. With 53 percent of the lake considered littoral, the lake will be assessed as a deep lake in the NCHF ecoregion.

The lake was sampled for chemistry in 2009 and 2010 (Figure 30). East LaBelle Lake does exhibit some of the pattern expected in shallower basins; the nutrient levels increase across the season. While deeper than many of the lakes in the area, the lake still has little protection from wind and possibly mixes intermittently throughout the summer. This likely indicates that internal loading is playing a role in East LaBelle Lake and should be considered in protection efforts.

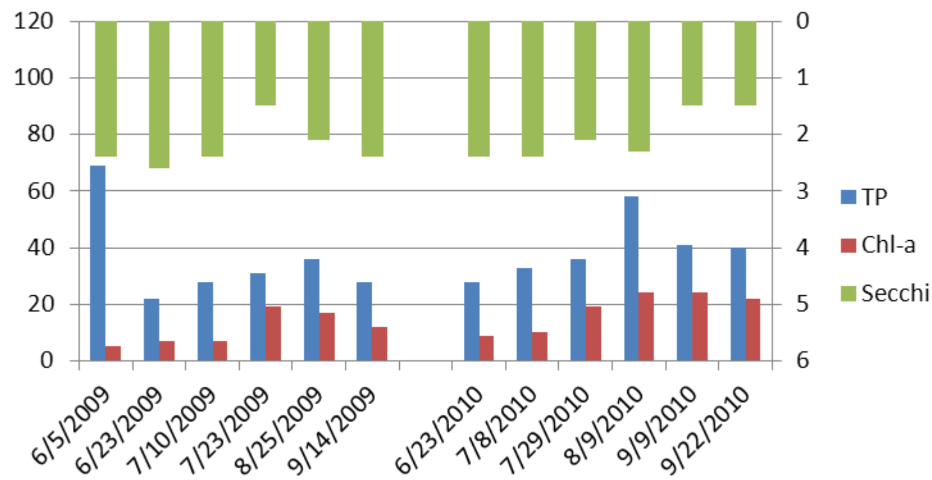


Figure 30. East LaBelle Lake water quality data

MINLEAP was run for East LaBelle Lake as a basis for comparing observed data with that predicted by the model based on lake depth and size, watershed size, and ecoregion location. The model was run for the NCHF ecoregion. The model predictions matched those of the observed values. The lake retains approximately 76 percent of the phosphorus it receives. The residence time is on the order of three years. Complete modeling results can be found in Appendix B.

LaBelle Lake has seen rising water levels as a result of increases in annual precipitation during the past 15 years. In 2011, the Buffalo River Watershed District implemented a lake drawdown project that involved Boyer and Labelle Lakes. The Boyer Lake outlet was constructed to flow north under

US HWY 10 and through LaBelle Lake and north into the Buffalo River. In excess of four feet of water was removed from Boyer Lake and the elevation of LaBelle was lowered about two feet. This project would significantly affect the detention time in LaBelle during the period of time Boyer Lake was discharging and could have other implications for water quality. Both of the lakes were undergoing excessive shoreline erosion as a result of the high water.

Summary

Eight of the 32 lakes greater than four hectares (10 acres) were reviewed for aquatic recreation use in the watershed (Table 6). Of those, six were exceeding eutrophication standards and are listed as impaired for aquatic recreation use; East LaBelle is approaching the standard, a small increase in phosphorus would push the lake above the eutrophication standards (Table 7). All of the lakes in this watershed are shallow except for Sand Lake (03-0659-00) and East LaBelle (03-0648-00). Shallow lakes are particularly sensitive to watershed inputs of phosphorus; wind mixing paired with high temperatures allows sediment in the lake to release additional phosphorus (internal loading) which accelerates the increase in algae and decrease in transparency.

Table 7. Comparison to standards for discussed lakes in the Lake Park Watershed HUC-11

Ecoregion	TP	Chl-*a*	Secchi
	ppb	ppb	meters
NCHF – Aquatic Rec. Use (Class 2b) Deep Lakes	**< 40**	**< 14**	**> 1.4**
East LaBelle	35	16	2.1
Sand (Stump)	78	26.3	1.8
NCHF – Aquatic Rec. Use (Class 2b) Shallow lakes	**< 60**	**< 20**	**> 1.0**
Sand (Yort)	77	21	1.1
Talac	77	32.6	1.9
Sorenson	127	37	1.9
Stakke	65	30	1.5
Gourd	113	54	0.6
West LaBelle	89	41	1.3
Lime	138	63	0.9
Axberg (Main Basin)	224	99	0.4
Axberg (West Basin)	1239	130	0.3
NGP – Aquatic Rec. Use (Class 2b) Shallow lakes	**< 90**	**< 30**	**> 0.7**
Stinking	309	96	0.7

Middle Buffalo River HUC-11 Watershed

The Middle Buffalo River Watershed Unit, immediately downstream of the Upper Buffalo River Watershed Unit, drains an area of 136 square miles and is located in western Becker and east-central Clay Counties. The watershed is dominated by cultivated land uses and contains both the NCHF and LAP ecoregions. Four of the 16 lakes greater than four hectares (10 acres) were reviewed for aquatic recreation use (Table 8).

Table 8. Lakes within the Middle Buffalo River HUC-11 Watershed

Lake Name	Lake ID	Lake Area (ha)	% Littoral	Max Depth (m)	Mean Depth (m)	Mean TP (ug/L)	Mean Chl-a (ug/L)	Secchi Mean (m)	Aquatic Recreation Use Support[4]
Lee	14-0049-00	55.4	64.2	11	4.2	43	18	1.1	NS
Swede Grove	[1]14-0078-00	63	100	2.4	1.2	77	30	1.6	FS
Maria	[1]14-0099-00	43.6	100	2.7	1.4	199	56	1.1	NS
Silver	14-0100-00	46.5	31.6	11.9	6.8	50	17	1.8	IF

1. Mean depths estimated.
2. Watershed area estimated from MDNR lake catchment file
3. Due to available maps and sampling location, only the north basin was used to calculate mean depth and lake area for Lake Eleven.
4. NS = not supporting, FS = supporting, IF = insufficient information to determine support, NA = not assessed (too small or wetland-like)
5. Lake is not supporting aquatic recreation use due to natural conditions; no TMDL is required.

Lee 14-0049-00

Lee Lake is a deep, 55 hectare (ha) lake with a maximum depth of 11 meters (m; 36 feet) located near Hawley, Minnesota. The lake has a 1,904 ha watershed (35:1 watershed to lake ratio) dominated by cultivated and forested land uses. The lake was listed for excess nutrients in 2012. The lake is undergoing development with the northwestern shore being divided into lots and a fair amount of existing residences on the northeast shore. Outside of the forested riparian area, the lake is surrounded by cultivated land. Compared to other lakes in the watershed, the forested riparian area is quite large.

Water chemistry data was collected in 2010 and 2011 (Figure 31). At strong thermocline develops between four and five meters during the summer months, with oxygen levels dropping below the 5 mg/L necessary to support game fish below that depth. Phosphorus and chlorophyll-*a* decline across the season and then peak in the fall; this is consistent with patterns seen in deep lakes where the phosphorus release during turnover leads to elevated concentrations in the spring and fall. Hypolimnetic phosphorus concentrations ranged from 70, to over, 400 ug/L, over the two years of sampling.

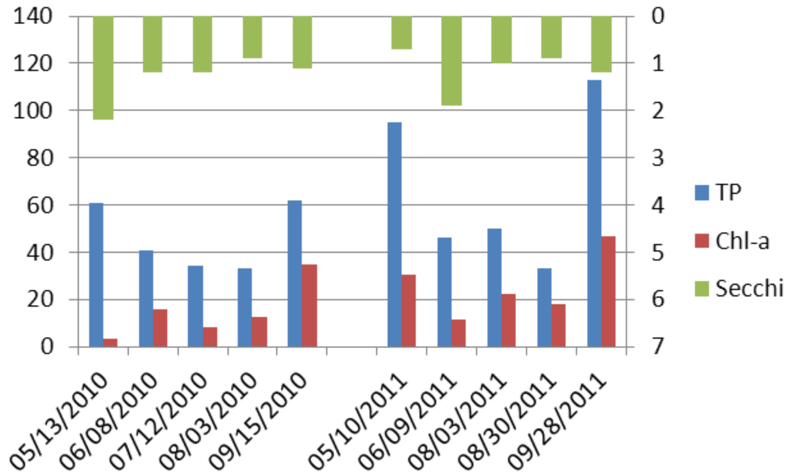


Figure 31. Lee Lake water quality data

MINLEAP was run for Lee Lake as a basis for comparing observed data with that predicted by the model based on lake depth and size, watershed size, and ecoregion location. The model was run for the NCHF ecoregion. The observed values were in line with the modeled values. The lake retains approximately 61 percent of the phosphorus that enters it and has a residence time on the order of a year. Background phosphorus concentrations, as predicted by the model, indicate that average concentrations prior to the conversion of land to development and agriculture would have been approximately 27 ug/L. Current averages are near 51 ug/L. Complete modeling results can be found in Appendix B.

Steps should be taken to reduce watershed contributions of runoff. Deep lakes have a better ability to deal with phosphorus already in the sediments, due to the stratification of the lake. However, the phosphorus release was quite high compared to surface values and this internal load will likely lead to late season (September or October) algal blooms.

Swede Grove 14-0078-00

Swede Grove Lake is a shallow, 63 hectare (ha) lake with a maximum depth of 2.4 meters (m; eight feet) located near Hitterdal, Minnesota. The lake has a 619 ha watershed (10:1 watershed to lake ratio) dominated by cultivated land uses. The lake was considered fully supporting aquatic recreation use in 2011. The lake does not have any shoreline residences; there is a waterfowl production area on the south end of the lake and the remaining shoreline is cultivated with a very narrow forested fringe.

Water chemistry data was collected in 2009 and 2010 (Figure 32). Surface temperatures reached a maximum of 27^{o}C during the two year sampling window. Phosphorus and chlorophyll-*a* increase across the season with a corresponding decline in transparency; this is consistent with patterns seen in shallow lakes internal loading drives the nutrient cycling.

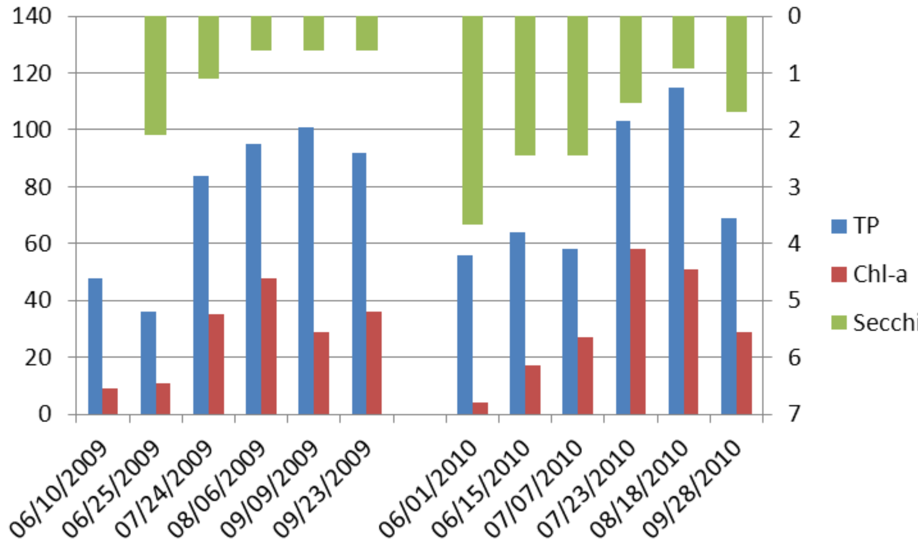


Figure 32. Swede Grove Lake water quality data

MINLEAP was run for Swede Grove Lake as a basis for comparing observed data with that predicted by the model based on lake depth and size, watershed size, and ecoregion location. The model was run for the NGP and NCHF ecoregions, since the lake resides in the LAP. The observed values were in line with the modeled values for the NCHF and significantly better than the modeled values for the NGP. A review of the land use for this basin indicates the lake is in transition – high cultivated land use, but not quite as much as one would expect in the NGP, but more forest and wetland than expected in that ecoregion as well. The lake retains approximately 62 percent of the phosphorus that enters it and has a residence time on the order of a year based on the NCHF inputs and 91 percent retention of phosphorus and a residence time estimated at three years. Complete modeling results can be found in Appendix B.

Maria 14-0099-00

Maria Lake is a shallow, 44 hectare (ha) lake with a maximum depth of 2.4 meters (m; eight feet) located southwest of Hawley, Minnesota. The lake has a 542 ha watershed (12:1 watershed to lake ratio) dominated by cultivated land uses. The lake was listed for excess nutrients in 2011. The lake has one residence and is surrounded by cultivated land with little riparian fringe. Land use in the watershed is consistent with the NGP ecoregion.

Water chemistry data was collected in 2009 and 2010 (Figure 33). Lake surface temperatures as high as 26°C were recorded. Phosphorus increases across the season, as typical with shallow lakes that experience internal loading. The chlorophyll-a response was similar, but not as consistent as the increase in phosphorus; weather conditions or high sediment levels could have led to a lessened response.

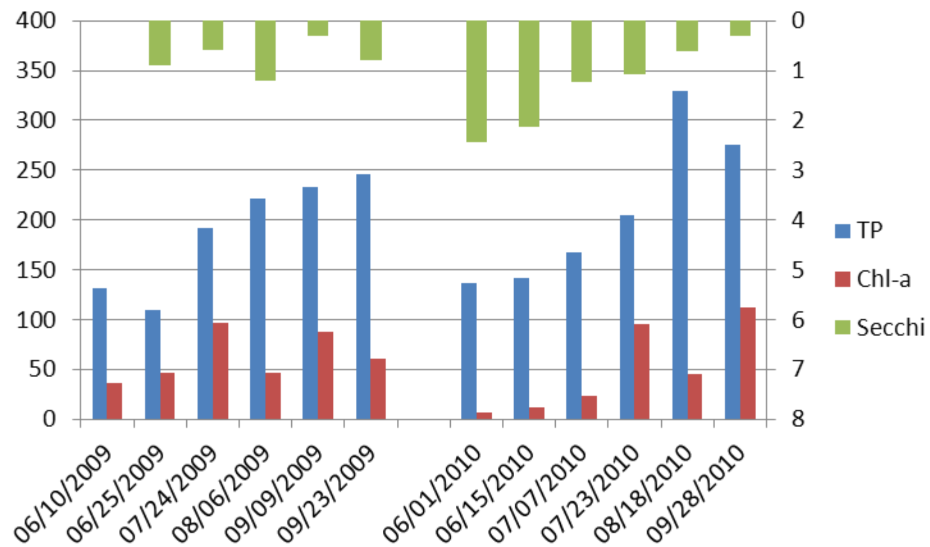


Figure 33. Maria Lake water quality data

MINLEAP was run for Maria Lake as a basis for comparing observed data with that predicted by the model based on lake depth and size, watershed size, and ecoregion location. The model was run for the NGP ecoregion. The observed values were in line with the modeled values for phosphorus, however, the model predicted significantly worse chl-*a* and Secchi values. The lake has the potential for much higher algal concentrations. The lake retains approximately 90 percent of the phosphorus that enters it and has a residence time on the order of a three years. Complete modeling results can be found in Appendix B.

Silver 14-0100-00

Silver Lake is a deep, 46.5 hectare (ha) lake with a maximum depth of 11.9 meters (m; 39 feet) located south of Hawley, Minnesota. The lake has a 1,791 ha watershed (38:1 watershed to lake ratio) dominated by cultivated land uses. During the 2011 assessments, it was noted that phosphorus exceeds the eutrophication standard, but a corresponding response in chlorophyll-*a* or Secchi was not found, so the lake was not listed as impaired. The lake has a number of residences and had a cattle feedlot; it is surrounded by cultivated land with little riparian fringe. In the late 1980s/early 1990s, the cattle manure pond was overtopped and the manure flowed over the bank and into Silver Lake.

The lake is located in the Lake Agassiz Plain ecoregion; land use in the watershed is transitional; more agriculture than expected for the North Central Hardwood Forest ecoregion but too much developed and forested land to fit well with the Northern Glaciated Plains ecoregion. Considering the depth of the lake and the transitional land use, the decision was made to hold Silver Lake to the North Central Hardwood Forest ecoregion eutrophication standard.

Water chemistry data was collected in 2010 and 2011 (Figure 34). Phosphorus decreases across the season, as typical with deep lakes with an increase in the fall as turnover occurs. Hypolimnetic phosphorus was as high as 894 ug/L in 2011; with such high concentrations in the anoxic water, during fall turnover a late season algae bloom would be expected (October) as the waters mix. Chlorophyll-*a* and Secchi responded predictably to the changes in phosphorus. Pesticide sampling was conducted in August of 2011; Metolachlor and Atrazine were both present in Silver Lake.

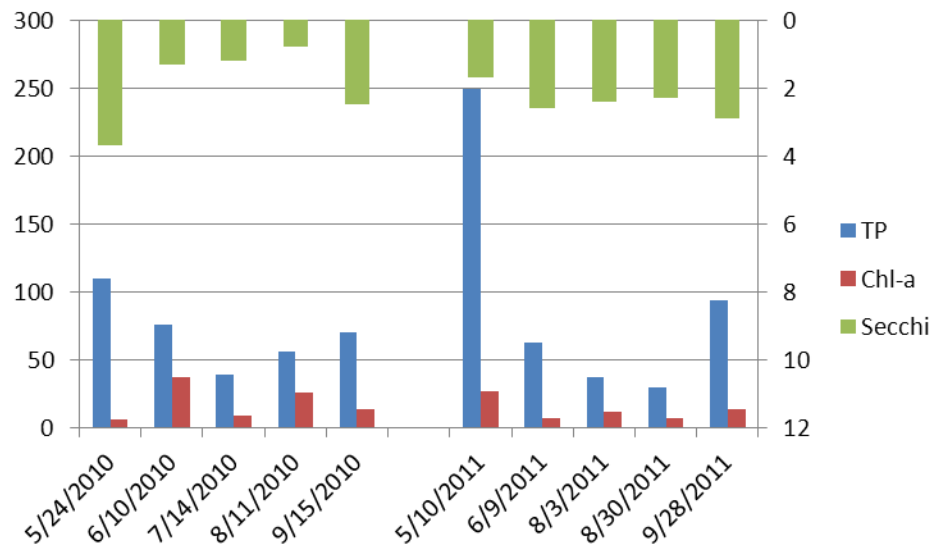


Figure 34. Silver Lake water quality data

MINLEAP was run for Silver Lake as a basis for comparing observed data with that predicted by the model based on lake depth and size, watershed size, and ecoregion location. The model was run for the NCHF ecoregion. The observed values were in line with the modeled values. The lake retains approximately 66 percent of the phosphorus that enters it and has a residence time on the order a year and a half. Complete modeling results can be found in Appendix B.

Summary

Four of the 16 lakes greater than four hectares (10 acres) were reviewed for aquatic recreation use (Table 8). Silver Lake exceeds only the phosphorus criteria; since the lake is not responding negatively to this increase (decreased transparency, increased algal blooms), the lake has not be listed as impaired. Maria and Lee Lake exceed the eutrophication standards and are impaired for aquatic recreation use (Table 9). Swede Grove was determined to be meeting recreation standards for the NGP ecoregion. Maria and Swede Grove are shallow lakes that will need attention to internal loading in addition to reductions in nutrient runoff in the watershed. Lee Lake is seeing increased development pressure and is close to the standards; the lake should be protected from further increases in phosphorus laden runoff.

Table 9. Comparison to standards for discussed lakes in the Middle Buffalo River Watershed HUC-11

Ecoregion	**TP**	**Chl-*a***	**Secchi**
	ppb	**ppb**	**meters**
NCHF – Aquatic Rec. Use (Class 2b) Deep Lakes	**< 40**	**< 14**	**> 1.4**
Lee	43	18	1.1
Silver	56	15	2.0
NGP – Aquatic Rec. Use (Class 2b) Shallow lakes	**< 90**	**< 30**	**> 0.7**
Swede Grove	77	30	1.6
Maria	199	56	1.1

Deerhorn-Buffalo HUC-11 Watershed

The Deerhorn-Buffalo Watershed unit is located in northwestern Otter Tail, northeastern Wilkin, and south-central Clay Counties and encompasses an area of 222.6 square miles. The Buffalo River, South Branch is the major waterway within the watershed and originates in northwest Ottertail County and flows northwest. The watershed is dominated by row crop cultivation and crosses the NCHF and LAP ecoregions.

Only one of the six lakes greater than four hectares (ten acres) had sufficient data to review for aquatic recreation use in this watershed, Jacobs Lake (Table 10). This shallow lake exceeded the eutrophication standards and is considered impaired for aquatic recreation use (Table 11). Phosphorus contributions from watershed runoff and internal loading will need to be addressed to improve the recreational use of this basin.

Table 10. Lake morphometric and assessment data for the Deerhorn-Buffalo River HUC-11 Watershed

Lake Name	Lake ID	Lake Area (ha)	% Littoral	Max Depth (m)	Mean Depth (m)	Mean TP (ug/L)	Mean Chl-a (ug/L)	Secchi Mean (m)	Aquatic Recreation Use Support[4]
Jacobs	56-1039-00	48.6	100	5.2	1.1	87	38	1.9	NS

1. Mean depths estimated.
2. Watershed area estimated from MDNR lake catchment file
3. Due to available maps and sampling location, only the north basin was used to calculate mean depth and lake area for Lake Eleven.
4. NS = not supporting, FS = supporting, IF = insufficient information to determine support, NA = not assessed (too small or wetland-like)
5. Lake is not supporting aquatic recreation use due to natural conditions; no TMDL is required.

Table 11. Summer-mean values compared to NCHF eutrophication standards

Ecoregion	TP	Chl-a	Secchi
	ug/L	ug/L	meters
NCHF – Aquatic Rec. Use (Class 2B) Shallow Lakes	**< 60**	**< 20**	**> 1.0**
Jacobs	87	38	1.9

Jacobs 56-1039-00

Jacobs Lake is a shallow, 49 hectare (ha) lake with a maximum depth of 5.2 meters (m; 17 feet) located west of Pelican Rapids, Minnesota. The lake has a 2,345 ha watershed (48:1 watershed to lake ratio) dominated by cultivated and forested land uses. The lake was listed for excess nutrients in 2011. The lake has a few residences and is surrounded by a forested fringe and cultivated land.

Water chemistry data was collected in 2009 and 2010 (Figure 35). Lake surface temperatures as high as 26^{o}C were recorded. In 2009, the lake followed a typical shallow lake pattern, increasing concentrations of TP and chl-*a* with a corresponding decline in Secchi. In 2010, the data was much more variable; strong wind mixing likely lead to the large swings in TP.

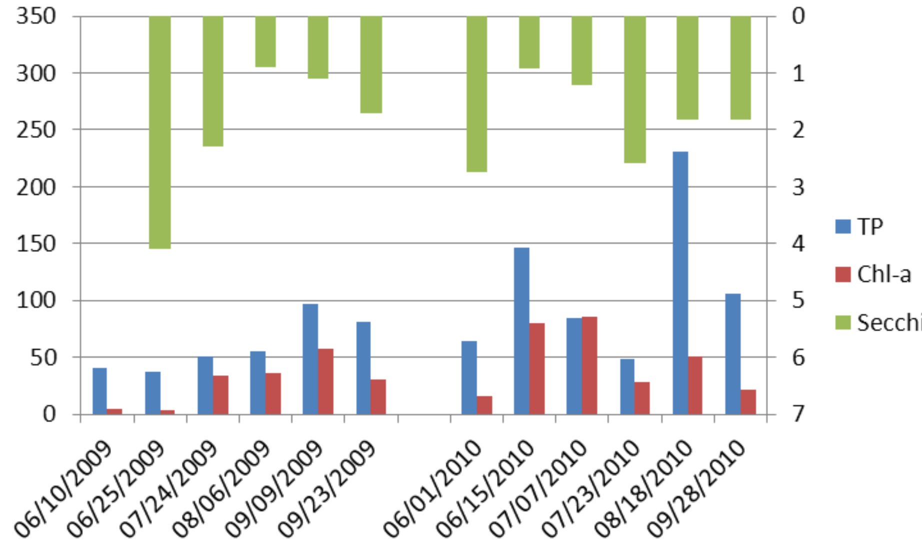


Figure 35. Jacobs Lake water quality data

MINLEAP was run for Jacobs Lake as a basis for comparing observed data with that predicted by the model based on lake depth and size, watershed size, and ecoregion location. The model was run for the NCHF ecoregion. Observed and modeled values were in agreement. The lake retains approximately 40 percent of the phosphorus that enters it and has a residence time on the order of three years. Complete modeling results can be found in Appendix B.

Watershed Summary

Buffalo River watershed lakes were assessed against the Northern Lakes and Forests, North Central Hardwood Forest or Northern Glaciated Plains ecoregions Class 2B standards for deep and shallow lakes (Appendix A). Based on recent monitoring, more than one-third of all monitored lakes (16 of 43) exceed the eutrophication standard and are impaired for aquatic recreation use, and several more are very close to the standard.

According to Table 1, the TP and chl-*a* standards for the support of aquatic recreation in lakes within the NCHF ecoregion are less than 40 µg/L and 14 µg/L respectively for deep lakes and less than 60 µg/L and 20 µg/L respectively for shallow lakes. The TP and chl-*a* standards for the support of aquatic recreation in lakes within the NGP ecoregion are less than 65 µg/L and 22 µg/L respectively for deep lakes and less than 90 µg/L and 30 µg/L respectively for shallow lakes. For chl-*a* levels at or below 30 µg/L, “nuisance algal blooms” (chl-*a* > 20 µg/L) should occur less than 10 percent of the summer and transparency should remain at or above three meters (9.8 feet) over 85 percent of the summer.

Impairments are found across the watershed, with the exception of the two eastern sub-watersheds that are headwaters in nature, with more intact (forested) watersheds than the rest of the agriculturally dominated watersheds. As expected in transitional watersheds, a mix of deep and shallow lakes occurs naturally in this part of Minnesota. Shallow lakes are particularly sensitive to disturbances in the watershed as they have little ability to assimilate external inputs of phosphorus. In addition, shallow lakes are susceptible to internal loading of phosphorus, with wind mixing causing the continual re-suspension of sediments and release of phosphorus into the water column. With the intensive land alteration in this watershed, and the shallow nature of the lakes, extra care should be taken to reduce watershed loading of phosphorus.

The impact from animal feedlots on these lakes is also significant. Seven of the 16 impaired lakes have been enriched from the wastes from livestock operations. In addition, Stinking Lake is impacted from the wastewater discharge from the City of Lake Park.

The wet weather that this area has experienced during the past 15 plus years has had a significant impact of runoff rates and volumes flowing into these lakes. Nutrient loading from the watershed increases significantly when precipitation rates regularly exceed the average annual rate. In addition to increased flows across the watershed and into the lakes, the intensity of the precipitation events have increased as evidenced with the 7.1 inch 24–hour event that occurred on July 15 and 16, 1993. These factors have also lead to significant rises in lake elevations as experienced in the Sand Lake chain of lakes, LaBelle and Boyer Lakes. Shoreline erosion rates during high water have greatly accelerated. In addition, extensive beds of emergent aquatic plants have been drowned out due to high water. Newly flooded land, rich with organic matter and nutrients also contribute to the phosphorus loading during the time of high water.

A most significant contribution to nutrient impairment of these lakes is the intensive row-crop agriculture that this region experiences. Soils in this area are generally fertile and clay based. They hold moisture well and are highly productive for agricultural crop use. Lakes in this watershed have become degraded with the loss of watershed storage (both surface and groundwater) through the extensive system of surface and subsurface drainage. The change from a natural hydrograph to a flashy hydrograph increases the flow rate and pushes pollutants rapidly through the system until they are able to settle out in a wetland or lake. Wetlands in the watershed are typically degraded from both being hydraulically overloaded as well as becoming sinks for the soil/sediment that is rapidly flushed from the land surface as a result of a general lack of adequate agricultural best management practices. As commodity prices have risen, so has the intensity of agricultural development on the landscape. The natural system of streams that once carried the flow of surface and groundwater across the landscape is now an intricate system of laser graded ditches that transport water, nutrients and sediment downstream into the receiving wetland, lake or stream. This transition to a more highly intensive agricultural landscape will make protection and restoration of these lakes challenging.

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Appendix A-Lake Morphometric Data

Lake ID	Lake Name	County	HUC-11	Ecoregion	Lake Area (ha)	Max Depth (m)	Mean Depth (m)	Watershed Area (ha)	% Littoral	Aquatic Recreation Use Support[4]
[1]03-0200-00	Pine	Becker	09020106010	NLF	218.5	5.5	2.7	521	89.5	FS
[1]03-0241-01	South Tamarack	Becker	09020106010	NLF	222.6	4.9	1.5	829	100	FS
[1]03-0241-02	North Tamarack	Becker	09020106010	NLF	579.9	5.2	2.4	3659	95.5	NS[5]
03-0243-00	Mary Yellowhead	Becker	09020106010	NLF	13.8					
03-0290-00	Spring	Becker	09020106010	NCHF	21.9	18.3			40	
03-0291-00	Rice	Becker	09020106010	NCHF	90.8	7.0	2.3	8154	72.9	FS
03-0293-00	Rock	Becker	09020106010	NCHF	485.7	5.5	2.4	7868	95.5	FS
03-0294-00	Momb	Becker	09020106010	NCHF	18.5	8.2			62.4	
03-0295-00	North Twin	Becker	09020106010	NCHF	8.5					
03-0298-00	Werk	Becker	09020106010	NCHF	38.5					
03-0299-00	Rochert	Becker	09020106010	NCHF	8.3					
03-0301-00	North Momb	Becker	09020106010	NCHF	11.6					
[1]03-0302-00	Little Round	Becker	09020106010	NCHF	219.9	1.7	0.8	4398	100	FS
03-0304-00	Big Sugar Bush	Becker	09020106010	NCHF	177.4	12.8	3.4	1344	63.1	FS
03-0312-00	Bullhead	Becker	09020106010	NCHF	13.4					
03-0313-00	Little Sugar Bush	Becker	09020106010	NCHF	85.7	8.8	3.9	2370	49	FS
03-0314-00	Fish	Becker	09020106010	NCHF	32.8	18.0			51.4	
03-0316-00	Mud	Becker	09020106010	NCHF	20.2	2.4			100	
03-0318-00	Eagen	Becker	09020106010	NCHF	30.9	4.9			97.5	
03-0319-00	Blackberry	Becker	09020106010	NCHF	25.2					
03-0325-00	Cranberry	Becker	09020106010	NCHF	14.3					
03-0344-00	Unnamed	Becker	09020106010	NCHF	6.6					
03-0350-00	Buffalo	Becker	09020106010	NCHF	180	11.2	4.4	13969	51	FS
03-0351-00	Island	Becker	09020106010	NCHF	85.6	3.0	1.6	739	100	FS

Lake ID	Lake Name	County	HUC-11	Ecoregion	Lake Area (ha)	Max Depth (m)	Mean Depth (m)	Watershed Area (ha)	% Littoral	Aquatic Recreation Use Support[4]
03-0352-00	Birch	Becker	09020106010	NCHF	88.2	7.6	2.0	724	82.3	FS
03-0406-00	Houg	Becker	09020106010	NCHF	18.1					
03-0427-00	Unnamed	Becker	09020106010	NCHF	4.9					
03-0428-00	O-Me-Mee	Becker	09020106010	NCHF	54.9	3.0	1.5	2287	100	IF
03-0429-00	Fairbank's	Becker	09020106010	NCHF	39.1					
03-0430-00	St. Clair	Becker	09020106010	NCHF	43.1	5.8	1.4	3254	88.6	FS
03-0432-00	Anderson	Becker	09020106010	NCHF	15.3					
03-0436-00	Unnamed (Kutz)	Becker	09020106010	NCHF	7.6	4.9			94	
03-0438-00	Unnamed	Becker	09020106010	NCHF	8.3					
03-0439-00	Carrott	Becker	09020106010	NCHF	16.6					
03-0440-00	Squash	Becker	09020106010	NCHF	11.3					
03-0442-00	Unnamed	Becker	09020106010	NCHF	7.1					
03-0471-00	Mission	Becker	09020106010	NCHF	98.6	2.4	1.6	350	100	NS
03-0558-00	Unnamed	Becker	09020106010	LAP	8.2					
03-0559-00	Unnamed (Skaeim)	Becker	09020106010	LAP	15.7					
03-0562-00	Trotochaud	Becker	09020106010	LAP	37.0					
03-0390-00	Wheeler	Becker	09020106020	NCHF	25.0	13.1			81.6	
03-0393-00	Unnamed	Becker	09020106020	NCHF	4.3					
03-0414-00	Gandrud	Becker	09020106020	NCHF	10.0					
03-0508-00	Unnamed	Becker	09020106020	LAP	12.7					
03-0513-00	Reep	Becker	09020106020	LAP	19.3					
[1,2]03-0516-00	Canary	Becker	09020106020	NCHF	27.3	7.6	3.4	143	65	IF
03-0517-00	Gilbertson	Becker	09020106020	NCHF	17.9					
03-0519-00	Bluebird	Becker	09020106020	LAP	6.4					

Lake ID	Lake Name	County	HUC-11	Ecoregion	Lake Area (ha)	Max Depth (m)	Mean Depth (m)	Watershed Area (ha)	% Littoral	Aquatic Recreation Use Support[4]
03-0521-00	Audubon	Becker	09020106020	NCHF	31.6					
03-0524-00	North Barnes	Becker	09020106020	NCHF	17.0	5.5			93.8	
03-0525-00	South Barnes	Becker	09020106020	NCHF	31.8	3.0			100	
03-0526-00	Marshall	Becker	09020106020	NCHF	75.0	6.1	3.2	215	66	NS
[1]03-0528-00	Gottenberg	Becker	09020106020	NCHF	46.7	3.4	1.0	502	100	NS
03-0529-00	South McKinstry	Becker	09020106020	NCHF	4.7	1.8			100	
03-0531-00	Minnetonka	Becker	09020106020	NCHF	16.5	6.7			81.8	
03-0532-00	Jay	Becker	09020106020	NCHF	9.6					
03-0533-00	Unnamed	Becker	09020106020	NCHF	6.0					
03-0535-00	Berseth	Becker	09020106020	NCHF	8.9					
03-0536-00	Pierce	Becker	09020106020	LAP	35.8					
03-0550-00	Seabold	Becker	09020106020	LAP	39.6					
03-0578-00	Unnamed	Becker	09020106020	LAP	9.6					
03-0579-00	Boyer	Becker	09020106020	NCHF	130.6	7.9	2.8	843	65.8	NS
[1]03-0624-00	Forget-Me-Not	Becker	09020106020	NCHF	95.4	2.1	1.0	859	100	
03-0634-00	Orange	Becker	09020106020	NCHF	24.2					
03-0767-00	Unnamed	Becker	09020106020	LAP	9.6					
03-0768-00	Unnamed	Becker	09020106020	LAP	4.2					
03-0948-00	Unnamed	Becker	09020106020	NCHF	7.2					
[1,2]03-0618-00	Sand	Becker	09020106030	NCHF	23.6	2.7	1.5	5,711	100	IF
[1]03-0619-00	Talac	Becker	09020106030	NCHF	39.7	4.0	2.8	2,193		NS
03-0621-00	Lund Brothers Marsh	Becker	09020106030	NCHF	12.1					
03-0622-00	Unnamed	Becker	09020106030	NCHF	11.4					
[1,2]03-0625-00	Sorenson	Becker	09020106030	NCHF	17.1	2.4	1.7	382	100	NS

Lake ID	Lake Name	County	HUC-11	Ecoregion	Lake Area (ha)	Max Depth (m)	Mean Depth (m)	Watershed Area (ha)	% Littoral	Aquatic Recreation Use Support[4]
03-0627-00	Unnamed	Becker	09020106030	NCHF	7.7					
03-0628-00	Unnamed	Becker	09020106030	NCHF	6.8					
03-0631-00	Stakke	Becker	09020106030	NCHF	194.5	4.6	2.1	1230	99.3	NS
03-0632-00	Prune	Becker	09020106030	NCHF	13.0					
03-0633-00	Horan	Becker	09020106030	NCHF	30.8					
03-0635-00	Gourd	Becker	09020106030	NCHF	48.8	1.8	1.2	146	100	NS
03-0636-00	Engebretson	Becker	09020106030	NCHF	12.4	2.6				
03-0638-00	Beseau	Becker	09020106030	NCHF	88.8	8.2	3.1		53.1	
03-0643-00	Brannigan	Becker	09020106030	NCHF	19.8					
03-0645-00	West LaBelle	Becker	09020106030	NCHF	40.9	5.8	1.3	780		NS
03-0646-00	Lime	Becker	09020106030	NCHF	43.4	2.4	1.4	2785	100	NS
03-0647-00	Stinking	Becker	09020106030	NGP	153.3	2.4	1.5	6263	100	NS
03-0648-00	East LaBelle	Becker	09020106030	LAP	77.8		3.2	614	53	IF
03-0651-00	Unnamed	Becker	09020106030	LAP	5.6					
03-0659-00	Sand	Becker	09020106030	NCHF	81.4	8.5	4.3	1483	52.3	NS
[1]03-0660-01	Axberg (Main Basin)	Becker	09020106030	NCHF	13.2	3.7	1.5	377		NA
[1]03-0660-02	Axberg (West Basin)	Becker	09020106030	NCHF	4.8	1.8	1	247		NA
03-0662-00	Cuba	Becker	09020106030	NCHF	21.1					
03-0920-00	Unnamed	Becker	09020106030	NCHF	5.7					
14-0003-00	Anderson	Clay	09020106030	NCHF	8.9					
14-0045-00	Unnamed	Clay	09020106030	NCHF	14.0					
14-0047-00	Moe	Clay	09020106030	NCHF	18.4					
14-0052-00	Solum	Clay	09020106030	NCHF	10.3					
14-0053-00	Christ Olson	Clay	09020106030	NCHF	27.4					

Lake ID	Lake Name	County	HUC-11	Ecoregion	Lake Area (ha)	Max Depth (m)	Mean Depth (m)	Watershed Area (ha)	% Littoral	Aquatic Recreation Use Support[4]
14-0054-00	Hoe	Clay	09020106030	NCHF	21.0					
14-0061-00	Erickson	Clay	09020106030	NCHF	22.2					
14-0062-00	Jergenson	Clay	09020106030	NCHF	24.8	2.1			100	
03-0514-00	Unnamed	Becker	09020106040	LAP	4.8					
03-0545-00	Lee Marshes	Becker	09020106040	LAP	8.9					
03-0552-00	Unnamed	Becker	09020106040	LAP	9.1					
03-0612-00	Little Boyer	Becker	09020106040	NCHF	6.9					
03-0650-00	Unnamed	Becker	09020106040	LAP	21.8					
03-1118-00	Unnamed	Becker	09020106040	LAP	5.5					
14-0049-00	Lee	Clay	09020106040	NCHF	55.4	11.0	4.2	1904	64.2	NS
14-0050-00	Unnamed	Clay	09020106040	NCHF	6.5					
14-0056-00	Knudson	Clay	09020106040	NCHF	13.2					
14-0058-00	Perch	Clay	09020106040	NCHF	16.0	5.2			83.9	
14-0059-00	Unnamed	Clay	09020106040	NCHF	5.2					
[1]14-0078-00	Swede Grove	Clay	09020106040	NGP	63.0	2.4	1.2	619	100	FS
14-0079-00	Meyer	Clay	09020106040	NCHF	27.5					
14-0089-00	Doran	Clay	09020106040	NCHF	31.4					
[1]14-0099-00	Maria	Clay	09020106040	NGP	43.6	2.7	1.4	542	100	NS
14-0100-00	Silver	Clay	09020106040	NCHF	46.5	11.9	6.8	1791	31.6	IF
56-1019-01	Grena	Otter Tail	09020106050	NCHF	38.3					
56-1026-00	Sands	Otter Tail	09020106050	NCHF	22.7					
56-1037-00	Colness	Otter Tail	09020106050	NCHF	34.3	1.8			100	
56-1039-00	Jacobs	Otter Tail	09020106050	NCHF	48.6	5.2	1.1	2345	100	NS
56-1046-00	Unnamed	Otter Tail	09020106050	NCHF	17.9					

Lake ID	Lake Name	County	HUC-11	Ecoregion	Lake Area (ha)	Max Depth (m)	Mean Depth (m)	Watershed Area (ha)	% Littoral	Aquatic Recreation Use Support[4]
84-0012-00	Unnamed	Wilkin	09020106050	NCHF	6.9					
[2]03-0657-00	Turtle	Becker	09020106060	NCHF	74.4	22.3	8.2	366	38	
03-0658-00	Long	Becker	09020106060	NCHF	40.0	4.0			100	
03-0661-00	Pump	Becker	09020106060	NCHF	26.3					
[1,3]14-0018-00	Eleven	Clay	09020106060	NCHF	60.0	2.4	1.4	2647	100	FS
14-0019-00	Three	Clay	09020106060	NCHF	37.8					
14-0020-00	Unnamed	Clay	09020106060	NCHF	6.8					
14-0021-00	Ten	Clay	09020106060	NCHF	62.1	5.2	1.7	4686	90.1	IF
14-0026-00	Thirteen	Clay	09020106060	NCHF	20.2					
[1]14-0029-00	Unnamed (North Mayfield)	Clay	09020106060	NCHF	9.3	4.0	2.4	19094	100	IF
14-0030-00	Fifteen	Clay	09020106060	NCHF	58.6	6.7	3.1	4309	70.5	FS
14-0038-00	Laura	Clay	09020106060	NCHF	23.0					
14-0063-00	Overson	Clay	09020106060	NCHF	21.8	3.7			100	
14-0065-00	Burke	Clay	09020106060	NCHF	14.7					
14-0068-00	Unnamed (Jetvig)	Clay	09020106060	NCHF	9.7	3.7				
14-0069-00	Abrahamson	Clay	09020106060	NCHF	5.9					
14-0071-00	Ness	Clay	09020106060	NCHF	32.1					
14-0096-00	Bjorndahl	LAP	09020106060	NCHF	5.7					
14-0143-00	Unnamed	LAP	09020106060	NCHF	9.2					
14-0001-00	Maple	Clay	09020106070	NCHF	15.8					
14-0009-00	Solem	Clay	09020106070	NCHF	27.9					
14-0012-00	Whiskey	Clay	09020106070	NCHF	13.8					
14-0014-00	Unnamed	Clay	09020106070	NCHF	5.3					
56-0933-00	Unnamed	Otter Tail	09020106070	NCHF	7.7					

Lake ID	Lake Name	County	HUC-11	Ecoregion	Lake Area (ha)	Max Depth (m)	Mean Depth (m)	Watershed Area (ha)	% Littoral	Aquatic Recreation Use Support[4]
[1]56-0934-00	Harrison (Helgeson)	Otter Tail	09020106070	NCHF	44.1	3.7	1.9	752	100	IF
56-0935-00	Rankle	Otter Tail	09020106070	NCHF	14.1					
56-0936-00	Businger	Otter Tail	09020106070	NCHF	18.4					
56-0941-00	Pete	Otter Tail	09020106070	NCHF	40.3	4.9	0.9	1802	100	FS
56-0950-01	West Olaf	Otter Tail	09020106070	NCHF	58.2	18.6	3.7	2227		FS
56-0950-02	East Olaf	Otter Tail	09020106070	NCHF	93.1					
56-0951-00	Deadman	Otter Tail	09020106070	NCHF	9.1					
56-0952-00	Grove	Otter Tail	09020106070	NCHF	165.9	4.6	1.2	3486	99.5	FS
56-1021-00	Unnamed	Otter Tail	09020106070	NCHF	4.9					
56-1022-00	Alfred	Otter Tail	09020106070	NCHF	13.5					
56-1030-00	Gaards	Otter Tail	09020106070	NCHF	23.1					
56-1031-00	Unnamed	Otter Tail	09020106070	NCHF	12.6					
56-1033-00	Unnamed	Otter Tail	09020106070	NCHF	6.6					
56-1600-00	Unnamed	Otter Tail	09020106070	NCHF	8.5					
14-0090-00	Solwald	Clay	09020106090	LAP	24.6					
14-0091-00	Buhaug	Clay	09020106090	LAP	8.3					
14-0092-00	Tatlie	Clay	09020106090	LAP	24.2					
14-0102-00	Unnamed	Clay	09020106090	LAP	10.0					
14-0103-00	Cromwell	Clay	09020106090	LAP	11.6					
14-0106-00	Hotsie	Clay	09020106090	LAP	12.5					
14-0107-00	Unnamed	Clay	09020106090	LAP	5.1					
14-0336-00	Hartke	Clay	09020106090	LAP	6.8					

1. Mean depths estimated.
2. Watershed area estimated from DNR lake catchment file
3. NS = not supporting, FS = supporting, IF = insufficient information to determine support, NA = not assessed (too small or wetland-like)
4. Wetland that is not assessed as a lake; included for comparison purposes.

Appendix B-MINLEAP Modeling Results

Lake ID	Lake Name	Obs TP	MINLEAP TP	Obs Chl-a	MINLEAP Chl-a	Obs Secchi	MINLEAP Secchi	Average TP Inflow	TP Load	Background TP	P Retention	Outflow	Residence Time	Areal Load
		ug/L	ug/L	ug/L	ug/L	m	m	ug/L	kg/yr	ug/L	%	hm3/yr	years	m/yr
03-0200-00	Pine	24	19	8	5	2.1	3.0	64	95	30.3	70	1.48	4.0	0.68
03-0241-01	South Tamarack	20	26	4	8	1.9	2.3	60	133	36.0	57	2.2	1.5	0.99
03-0241-02	North Tamarack	36	25	13	7	1.7	2.4	57	525	31.3	56	9.17	1.5	1.58
03-0291-00	Rice	28	90	7	47	2.2	0.8	150	1596	-	40	10.64	0.2	11.71
03-0293-00	Rock	27	58	7	25	1.8	1.2	159	1660	-	64	10.42	1.1	2.15
03-0302-00	Little Round	25	80	3	40	0.8*	0.9	157	912	41.0	49	5.81	0.4	2.64
03-0304-00	Big Sugar Bush	13	40	3	14	5.6	1.6	171	312	-	77	1.82	3.3	1.02
03-0313-00	Little Sugar Bush	22	57	11	24	3.0	1.2	155	482	-	63	3.12	1.1	3.64
03-0350-00	Buffalo	23	74	9	36	3.0	0.9	150	2742	-	51	18.23	0.4	10.13
03-0351-00	Island	23	56	6	24	2.5	1.2	169	168	-	67	0.99	1.4	1.16
03-0352-00	Birch	37	51	16	20	2.8	1.3	170	166	-	70	0.98	1.8	1.11
03-0428-00	O-Me-Mee	68	84	21	43	1.7	0.8	152	456	-	45	3.00	0.3	5.46
03-0430-00	St. Clair	24	97	8	52	3.1	0.8	150	639	-	36	4.25	0.1	9.85
03-0471-00	Mission	120	44	76	17	0.6	1.5	196	97	-	77	0.49	3.2	0.50
03-0516-00	Canary					1.6		181	36	-	-	0.20	4.7	0.72
03-0526-00	Marshall	42	31	21	10	1.9	2.0	206	64	-	85	0.31	7.8	0.41
03-0528-00	Gottenberg	68	69	34	32	0.8	1.0	165	111	-	58	0.67	0.7	1.44
03-0579-00	Boyer	54	41	24	15	2.4	1.6	175	201	-	76	1.15	3.2	0.88
03-0624-00	Forget-Me-Not	82	66	27	30	0.9	1.0	168	194	-	60	1.15	0.8	1.21
03-0618-00	Sand	83	45	9	17	1.1	1.5	199	22	-	77	0.11	3.2	0.48
03-0619-00	Talac	93	77	29	38	1.9	0.9	151	434	-	49	2.87	0.4	7.22

Lake ID	Lake Name	Obs TP	MINLEAP TP	Obs Chl-a	MINLEAP Chl-a	Obs Secchi	MINLEAP Secchi	Average TP Inflow	TP Load	Background TP	P Retention	Outflow	Residence Time
03-0625-00	Sorenson	177	70	41	33	1.7	1.0	156	79	-	55	0.50	0.6
03-0631-00	Stakke	65	46	30	18	1.5	1.4	179	295	-	0.74	1.68	2.4
03-0635-00	Gourd	113	48	54	19	0.6	1.4	204	43	-	76	0.21	2.8
03-0645-00	West LaBelle	89	73	41	35	1.3	1.0	158	162	-	53	1.03	0.5
03-0646-00	Lime	138	94	63	50	0.9	0.8	151	549	-	38	3.64	0.2
03-0647-00	Stinking	309	312	96	289	0.7	0.3	1609	4743	-	81	2.95	0.8
03-0648-00	East LaBelle	38	42	15	15	2.2	1.6	171	141	-	76	0.83	3.0
03-0659-00	Sand	125	49	28	19	2.0	1.4	158	310	-	69	1.96	1.8
14-0049-00	Lee	43	60	18	26	1.1	1.1	153	383	27.2	61	2.5	0.9
14-0078-00	Swede Grove	77	186	30	136	1.6	0.4	2066	483	-	91	0.23	3.2
14-0099-00	Maria	199	192	56	142	1.1	0.4	1919	420	-	90	0.22	2.8
14-0100-00	Silver	50	53	17	22	1.8	1.3	153	369	25	66	2.35	1.3
56-1039-00	Jacobs	87	93	38	50	1.9	0.8	152	466	-	39	3.07	0.2
03-0657-00	Turtle	12	24	4	7	6.6	2.5	183	93	-	87	0.51	12.1
14-0018-00	Eleven	26	103	6	57	2.2	0.7	150	517	-	31	3.45	0.1
14-0021-00	Ten	57	93	27	49	1.7	0.8	150	920	-	38	6.12	0.2
14-0029-00	Unnamed	17	132	7	82	2.5	0.6	148	3676	-	11	24.83	-
14-0030-00	Fifteen	33	80	14	40	2.2	0.9	151	847	-	47	5.63	0.3
56-0934-00	Harrison (Helgeson)	54	63	33	28	1.4	1.1	159	158	-	60	1.00	0.8
56-0941-00	Pete	54	96	12	52	3.0	0.8	152	359	-	37	2.36	0.2
56-0950-01	West Olaf	30	64	11	29	2.4	1.1	153	446	-	58	2.92	0.7
56-0952-00	Grove	41	77	14	37	3.1	0.9	157	720	-	51	4.6	0.4