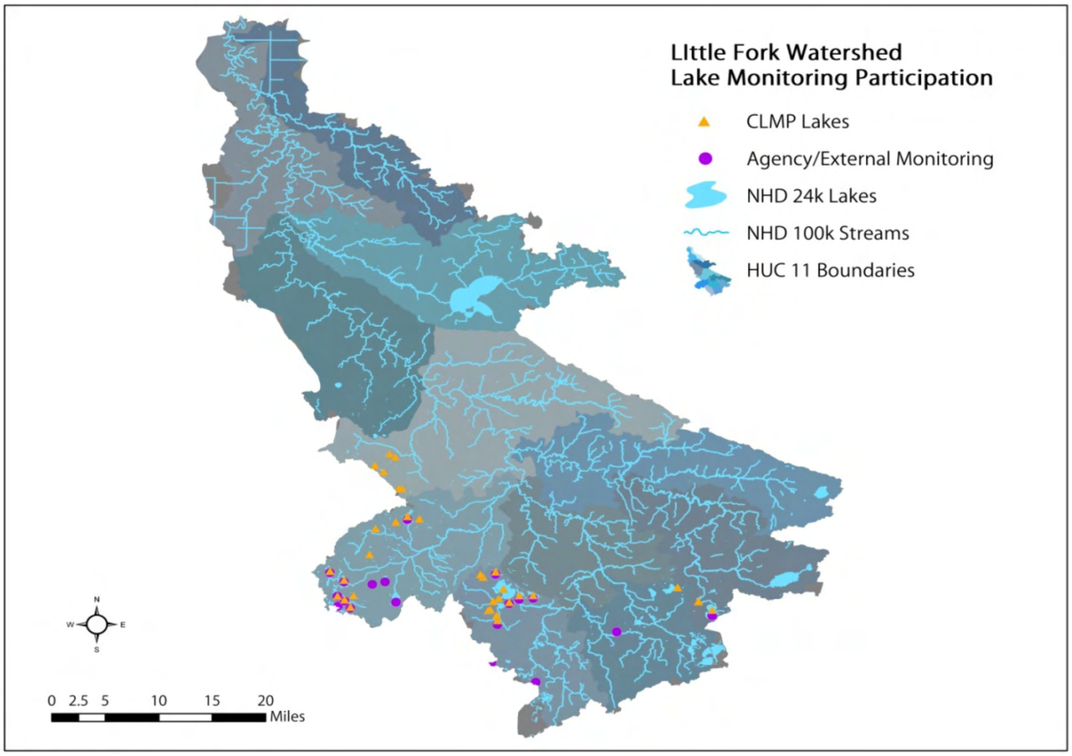
Water Quality Assessment of Select Lakes within the Little Fork River Watershed



Rainy River Basin
St. Louis, Itasca, and Koochiching Counties, Minnesota

Minnesota Pollution Control Agency

Water Monitoring Section

Lakes and Streams Monitoring Unit

August, 2010

Minnesota Pollution Control Agency

Author

Jesse Anderson

Editing

Steve Heiskary

Dana Vanderbosch

Data Provided By

Itasca County Soil and Water Conservation District, Itasca Community College, MN DNR Fisheries (Rian Reed) and Volunteers from the Sturgeon Chain of Lakes

Assessment Report of Selected Lakes

Within the Little Fork River Watershed

Rainy River Basin

Intensive Watershed Monitoring 2008

Minnesota Pollution Control Agency
Water Monitoring Section
Lakes and Streams Monitoring Unit

wq-ws3-09030005

Minnesota Pollution Control Agency
520 Lafayette Road North
Saint Paul, MN 55155-4194
http://www.pca.state.mn.us
651-296-6300 or 800-657-3864 toll free
TTY 651-282-5332 or 800-657-3864 toll free
Available in alternative formats

Table of Contents

List of Tables

List of Figures

Executive Summary

This report is a summary of available water quality data for lakes within the Little Fork River watershed. The watershed approach is a ten-year rotation for assessing waters of the state on the level of Minnesota's 81 major watersheds. The primary feature of the watershed approach is that it provides a unifying focus on the water resources within a watershed as the starting point for water quality assessment, planning, and results measures. The major benefit of this approach is the integration of monitoring resources to provide a more complete and systematic assessment of water quality at a geographic scale useful for the development and implementation of effective restoration and protection strategies. The Minnesota Pollution Control Agency (MPCA) is in the process of aligning its lake monitoring efforts with the major watershed monitoring schedule. Though the MPCA began its ten-year monitoring cycle in 2008, lake monitoring activities were not aligned to this ten-year cycle until 2009. As such, we have limited lake data on which to report at this time. MPCA monitoring of large lakes within the Little Fork watershed will be conducted in 2010-2011. This report will describe all data available at this time. It will be updated in 2012 to include 2010-2011 lake monitoring results.

The Little Fork River watershed drains an area of 4,773 square kilometers (1,843 square miles) in northeast Minnesota. A total of 11 sub-watersheds (HUC-11) comprise the entire watershed. The headwaters start on the north side of the Laurentian divide in Itasca and St. Louis Counties. Forest and wetlands (principally peatlands) are the major land cover classifications in the watershed. The Little Fork River watershed lies within the Northern Lakes and Forest (NLF) and Northern Minnesota Wetland ecoregions. There are approximately 125 natural lakes greater than four hectares (ten acres) in the watershed, with most located in the Bear River and Sturgeon Lake sub-watersheds. In general, lake water quality data are sparse in the watershed, with most lakes having little or no historical water quality data collected. Only 14 lakes have assessment level data. The University of Minnesota has estimated Secchi disk (SD) transparency on all Minnesota lakes greater than four hectares (ten acres), using satellite imagery. Approximately 95 percent of Little Fork watershed lakes have estimated transparences between 1.4 – 4.5 meters (m), with a mean of 3.0 m. In general, estimated SD values indicate good water clarity in the basin, particularly the lakes of the Sturgeon chain and the headwater lakes of the Bear River on the western border of the watershed. Large, shallow wild rice lakes, such as Nett and Big Rice, were estimated to have lower transparencies due to natural bog staining originating from their wetland dominated watersheds.

Lake water quality data in five of the basin's HUC-11 sub-watersheds are described (Sturgeon Lake, Bear River, Middle Little Fork, Rice, and Dark Rivers). The remaining watersheds have insufficient information, or do not contain natural lakes. Results focus on those lakes with assessment level data, or with sufficient Citizen Lake Monitoring Program (CLMP) SD data for trend determinations. The Sturgeon Chain of lakes (Sturgeon, Little Sturgeon, Beatrice, Perch, South Sturgeon, and Side) are the most developed lakes in the Little Fork watershed. Local property owners worked with Minnesota Department of Natural Resources (DNR) Fisheries staff to collect water quality samples in 2007 and 2008. These data provide the basis of water quality assessment. Lakes within the Sturgeon Chain have excellent water quality overall. Headwater and seepage lakes with very small drainage areas have lower total phosphorus (TP) and chlorophyll a (chl-a) concentrations (and higher SD transparencies) because watershed sources of nutrients are low. Flowage lakes with much larger drainage areas have higher TP and chl-a concentrations (and lower transparencies) but results are within NLF criteria and reflective of natural watershed characteristics. Transparency trends vary among the Sturgeon Chain. South Sturgeon has the longest record, with yearly monitoring since 1988. South Sturgeon has a slight (i.e. possible) improvement in transparency since 1988. Since the lake has a very short residence time (0.4 years, or ~ 150 days) it's likely that annual precipitation and climate trends have a strong influence on clarity. The long term mean is about 1.2 meters, and annual averages have varied from 0.8 to 1.6 m. Side Lake was the only lake with a declining trend in transparency. Based on data from 1994-2008 SD declined by one meter; however a data gap from 1997-2001 reduces the predictive power of the trend.

The Bear River watershed drains 435 km^2 (168 mi^2) in the south-west portion of the Little Fork watershed. Lakes are relatively numerous in this HUC-11 and compose the headwaters of the Bear River, the largest tributary to the Sturgeon River. The majority of lakes are undeveloped seepage lakes within George Washington State Forest. Seven lakes in this HUC-11 have assessment level data (Horsehead, Little Bear,

Bear, Raddison, Napoleon, Walters, and Kelly). The assessed lakes were sampled by Itasca County Community College in 2008 and 2009 via a Surface Water Assessment Grant with the MPCA. Overall the data indicate excellent, stable water quality (oligotrophic to mesotrophic conditions), well below NLF nutrient criteria.

Little Fork Watershed lakes were assessed relative to the NLF Class 2B ecoregion standards. The assessment cycle mean TP concentrations for all lakes are below this value (30 µg/L). Likewise, chl-a is below the standard for all lakes except Bear. Based on these results, all assessed lakes are meeting eutrophication criteria for NLF 2B waters (i.e. those waters that support a cool and warm water fishery). The Secchi standard in four lakes (Bear, Little Sturgeon, West Sturgeon, and South Sturgeon) is not being met, but this is due to natural bog staining, as discussed previously, and is not in response to elevated chl-a concentrations.

Introduction to Monitoring Strategy and Sources of Lake Monitoring Data

The MPCA conducts and supports lake monitoring for a variety of objectives. One of our key responsibilities per the federal Clean Water Act 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 Water Conservation Districts, watershed districts, etc.) and citizens 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 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-eight of them annually. With this strategy, we will cycle through all 81 watersheds every ten 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 ten-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 results measures. 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 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 ≥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 ten 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.

MPCA lake monitoring activities were not yet in sync with the watershed approach in 2008, the year MPCA intensively monitored streams in the Little Fork watershed to assess their condition. MPCA monitoring of large lakes within the Little Fork watershed will be conducted in 2010-2011. This report will describe all available lake data collected by partner agencies, grantees, and citizen volunteers for the Little Fork watershed to date, and it will be updated upon completion of MPCA lake monitoring.

Data analyzed and described in this report will include all available data in Storage and Retrieval Water Data Repository (STORET), the federal repository for water quality data. Under the Clean Water Act, Minnesota is required to assess all waters of the state to determine if they meet water quality standards. Specifically, for formal assessment purposes, STORET data collected from 2000-2009 will be described. Historical STORET data collected before 2000, if available, will be used to describe water quality trends on those lakes with sufficient assessment information.

Further detail on concepts and technical terms in this report can be found in the Guide to Lake Protection and Management: (http://www.pca.state.mn.us/water/lakeprotection.html).

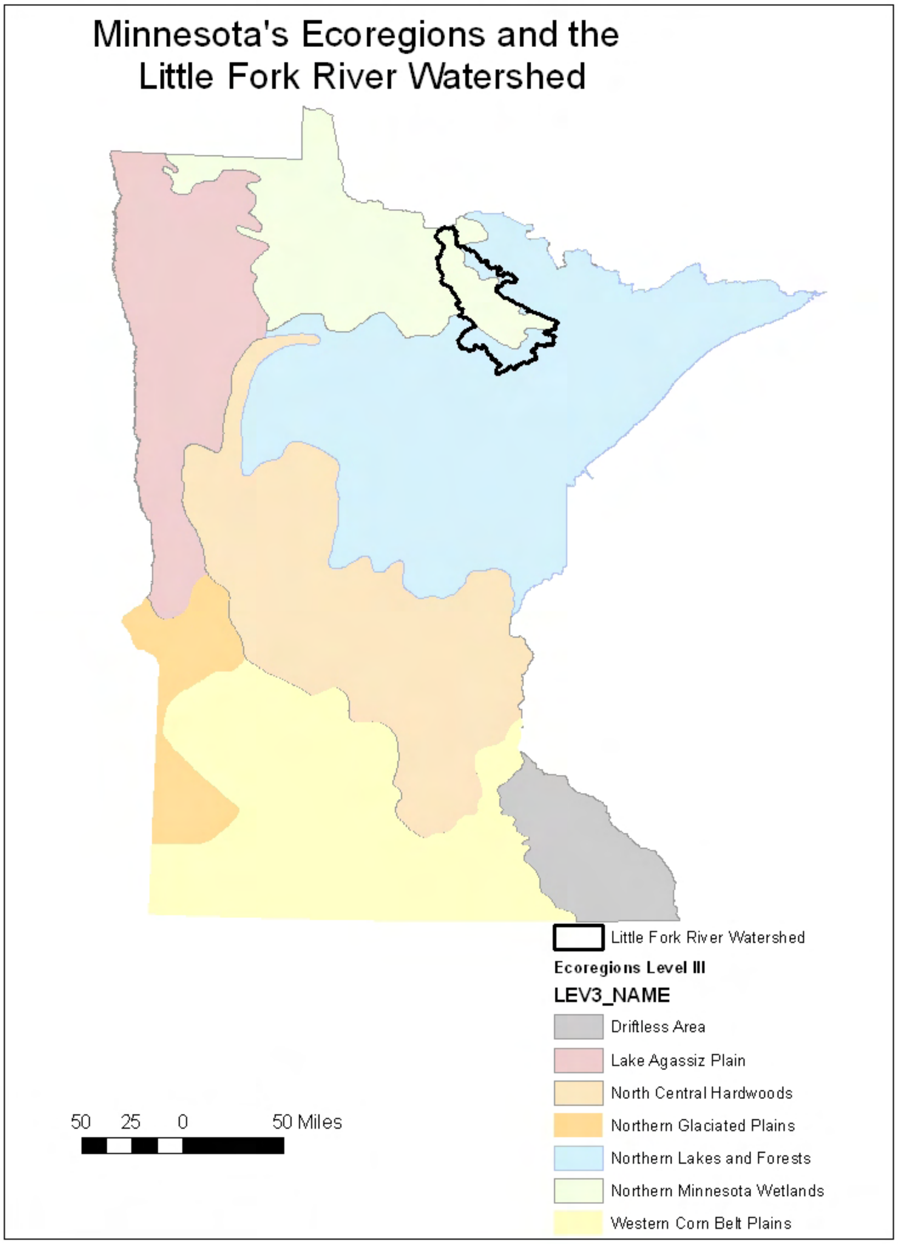
Environmental Setting and Distribution of Lakes

The Little Fork River watershed drains an area of 4,773 square kilometers (1,843 square miles) in northeast Minnesota. The headwaters start on the north side of the Laurentian divide in Itasca and St. Louis Counties. Streams within the watershed generally drain northwest through Koochiching County and the basin of Glacial Lake Agassiz. The Little Fork River reaches its confluence with the Rainy River approximately 17 kilometers (11 miles) west of International Falls, Minnesota. Forest and wetlands (principally peatlands) are the major land cover classifications in the watershed. Some lakes and streams in the basin have high color or turbidity; this natural staining originates from tannin compounds (incompletely dissolved organic matter) that arise from wetland and forest runoff within the watershed. Major tributaries along the length of the river are the Rice, Sturgeon, Willow, Bear, and Nett Lake Rivers, and Beaver Brook. Gauged streams in the watershed have similar flow-frequency and duration characteristics (Helgeson and Lindholm, 1976).

Major industries in the watershed include forest products harvesting and manufacturing, and tourism. Agricultural landuse is minimal and is located primarily along the lower portions of the watershed and is principally pastureland (MPCA, 2001). The communities of Cook and Littlefork are located along the banks of the Little Fork River, the reminder of the watershed can be classified as sparsely populated and remote (Anderson, et. al, 2006). Land ownership in the watershed is 47.7 percent state, 21.4 percent private, 18 percent tribal, 10 percent private industrial (forest industry), and 3.1 percent federal (Anderson, 2001).

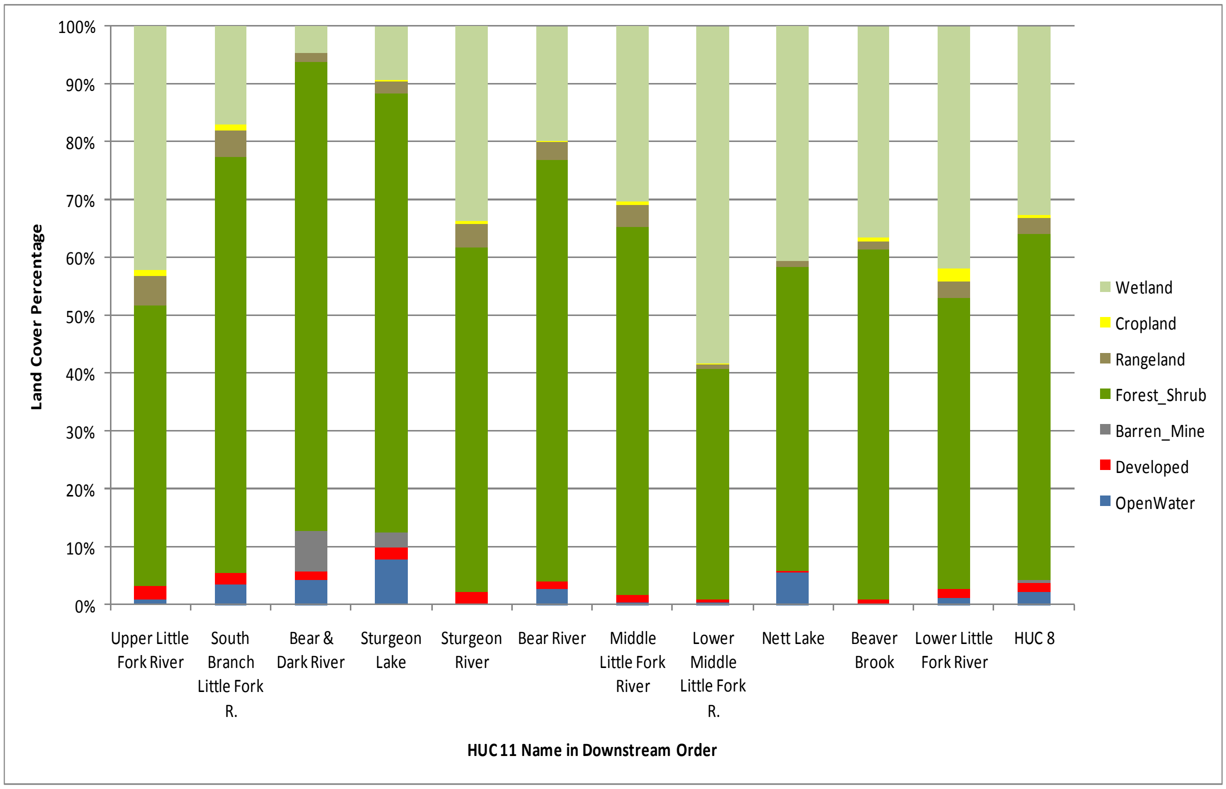
Minnesota is divided into seven regions, referred to as ecoregions, as defined by soils, land surface form, potential natural vegetation and land use (Omernik 1987). Data gathered from representative, minimally impacted (reference) lakes within each ecoregion serve as a basis for comparing the water quality and characteristics of other lakes. The Little Fork River watershed lies within the Northern Lakes and Forest and Northern Minnesota Wetland (NLF / NMW; Figure 1) ecoregions. NLF water quality standards will be used for summer-mean water quality comparisons since there are no water quality standards specific to the NMW ecoregion and most lakes with the watershed are located within the NLF ecoregion. Additionally, the NLF ecoregion will be used for model applications, since it has the largest historical dataset and there are few lakes in the NMW.

Figure 1. Minnesota's ecoregions and the Little Fork River watershed (US EPA Level III Ecoregions)



The Little Fork River is one of Minnesota's 81 major watersheds. Each major watershed has its own Hydrologic Unit Code (HUC-8) for catalog purposes. Nested within each HUC-8 is smaller contributing sub-watersheds, termed HUC-11 watersheds. The Little Fork River has eleven HUC-11 sub-watersheds. Landuse at the Little Fork watershed (HUC-8) scale and in all HUC-11 sub-watersheds is dominated by forest and wetlands (Figure 2). Agriculture and urban land use are low, 3.4 and 1.3 percent, respectfully. Headwater sub-watersheds such as the South Branch Little Fork River (Rice River), Bear and Dark Rivers, and Sturgeon Lake have greater than 70 percent forest land and are principally within the NLF ecoregion. Wetlands (principally peatlands) make up a greater portion of land cover in the lower sub-watersheds reflecting the influence of Glacial Lake Agassiz, and are in the NMW ecoregion.

Figure 2. Landuse in HUC 11 sub-watersheds within the Little Fork River watershed



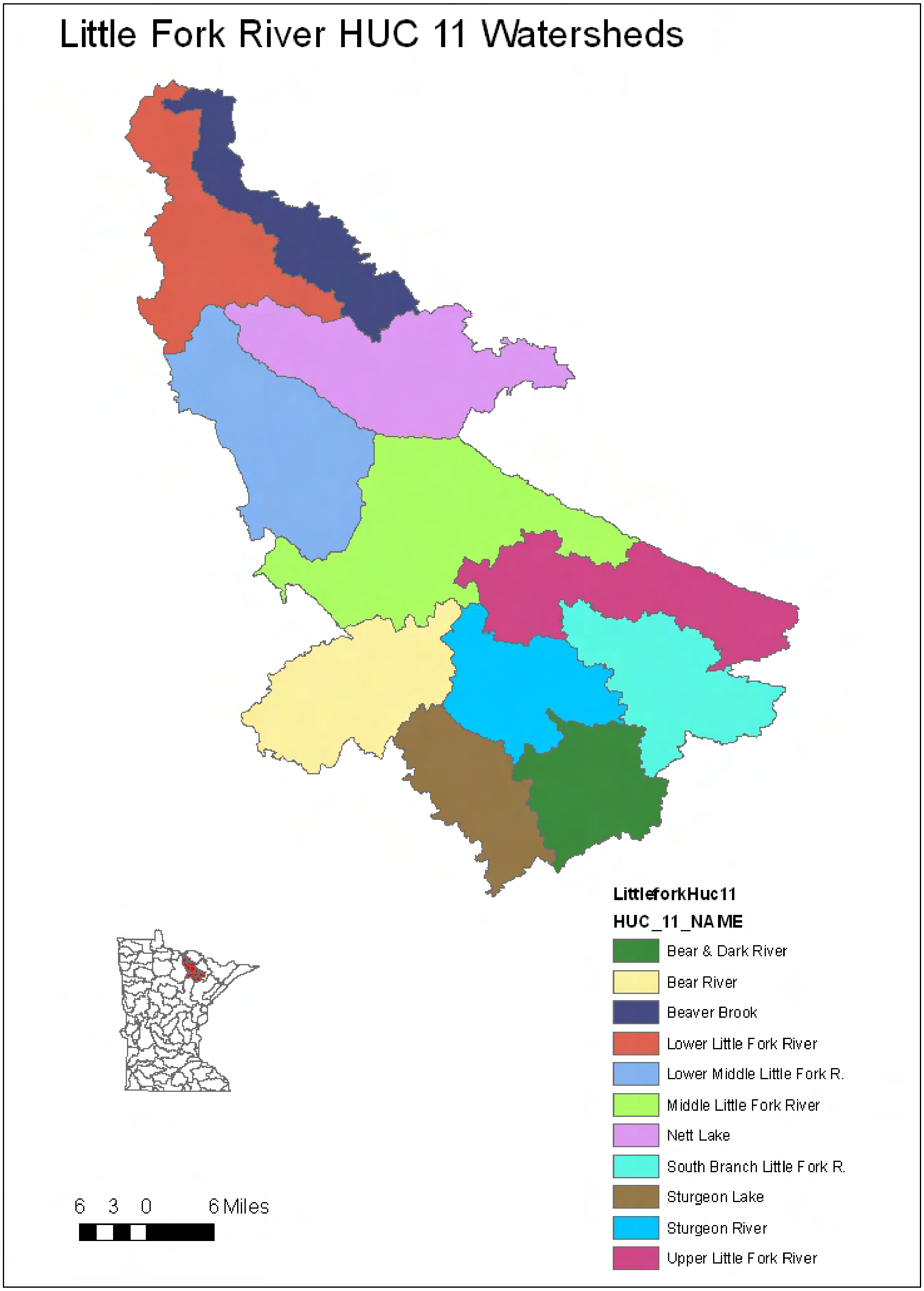
A total of eleven HUC-11 subwatersheds comprise the Little Fork River watershed (Table 1, Figure 3). They range in size from 296 – 698 km^2 (114 – 269 mi^2). Lakes within the watershed are predominantly in the upstream glacial moraine (i.e. NLF) portions of the basin and form the headwaters of the Little Fork River and its tributaries. There are very few lakes in the low gradient Glacial Lake Agassiz peatland plain downstream of the glacial till area. There are approximately 125 natural lakes greater than four hectares (ha) (ten acres; ac) in the watershed, with most located in the Bear River and Sturgeon Lake HUC 11 watersheds (Table 1). The largest lake is Nett Lake at 2,941 ha (7,269 ac), and only six lakes are greater than 202 ha (500 ac) (Table 2). Two HUC-11 watersheds have no lakes, Beaver Brook and the Lower Little Fork River. Morphometric summary data for all lakes within the Little Fork watershed are listed in Appendix A.

Table 1. Lake distribution in the Little Fork River HUC-11 watersheds

HUC 11 Name	Area km^2 (mi^2)	Total Lakes	All P Lakes [1]	Lakes <4 ha (10 ac.)	Lakes 4 - 40 ha (10-100 ac.)	Lakes 40 – 202 ha (100-500 ac.)	Lakes > 202 ha (>500 ac.)	FS [2]	NS [3]	Insufficient Data [4]
Upper Little Fork River	464.9 (179.5)	2	2		1		1			
South Branch Little Fork R. (Rice R.)	390.0 (150.6)	14	10	4	7	1	2			2
Bear & Dark River	296.8 (114.6)	25	17	2	11	4	0			2
Sturgeon Lake	296.0 (114.3)	46	31	2	14	13	1	8		4
Sturgeon River	335.6 (129.6)	6	2	0	2	0	0			
Bear River	436.6 (168.6)	46	29	3	17	9	0	7		15
Middle Little Fork River	698.7 (269.8)	19	12	4	8	0	0			5
Lower Middle Little Fork R.	549.8 (212.3)	4	3	1	1	2	0			
Nett Lake	549.3 (212.1)	1	1	0	0	0	1			
Beaver Brook	318.5 (123.0)	0								
Lower Little Fork River	435.8 (168.3)	0								

1. Lakes identified as protected waters by MN DNR
2. Full Support, FS, number of lakes meeting MPCA nutrient criteria
3. Not Support, NS, number of lakes not meeting MPCA nutrient criteria
4. Number of lakes with insufficient data available for a water quality assessment

Figure 3. Little Fork River HUC-11 watersheds



A summary of lake distribution within the Little Fork watershed is as follows:

- Small flow-through and seepage lakes that form the headwaters of the Bear River, in the southwest corner of the basin. Examples include Thistledew, Raddison, Owen, and Bear lakes.
- The large lakes of the Sturgeon Chain, and its tributaries, which form the headwaters of the Sturgeon River. Examples include Sturgeon, Side, Shannon, and Long Lake.
- Headwater lakes of the Dark River, including Dark, Clear, Fourteen, and Leander Lakes
- Headwater lakes of Johnson Creek and the Rice River, including Sand, Auto, and Little Rice
- Large, shallow headwater wild rice lakes. Examples include Nett and Big Rice.

Table 2. Lakes within the Little Fork watershed summarized by acreage class

Lake Class (Size Range in Hectares)	Number of Lakes
4 - 8	42
8 – 20	28
20-40	19
40- 202	29
> 202	6

Lakes make up a small portion of the total area (3.1 percent) within the Little Fork River watershed. In general, lake water quality data are sparse in the watershed, with most lakes having little or no historical water quality data collected. For most lakes in the Little Fork watershed, CLMP Secchi disk (SD) transparency data made up the majority of available data.

A total of 42 lakes have some historical data, but insufficient amounts for a formal water quality assessment (Table 3). Only 14 lakes have assessment level data; this is defined by the MPCA as at least eight paired total phosphorus (TP), chlorophyll-a (Chl-a), and SD transparency measurements within the most recent ten years (MPCA, 2010).

Table 3. Little Fork River watershed lake summary

Total drainage area	4,773 km^2
Number of HUC 11 watersheds	11
Lake area as percentage of total HUC 8	3.1 %
Total number of Lakes	163
Number of lakes over 4 hectares	124
Number of lakes with assessment level data	14
Number of lakes with insufficent data	42
Number of lakes with no water qualty data in STORET	67

Summary of 2008 Climate and Hydrological Data

The summer of 2008 was near the historical average in terms of precipitation (Figure 4). Average annual precipitation varies from 58-73 centimeters (23-29 inches) across the watershed, and is greatest in the southeastern portion of the basin (NRCS, 2008). Calendar year 2008 precipitation totaled about 72.6 centimeters (28.6 inches) at the climate station in Littlefork, Minnesota (Figure 5; State Climatology office data; http://www.climate.umn.edu/hidradius/radius.asp).

Annual run-off for the 2008 water year (October 2007 – September 2008) for the two U.S. Geological Survey streamflow gages in the watershed, the Little Fork River at Littlefork and the Sturgeon River near Chisholm, were about 10-20 percent wetter than historic averages. 2008 daily streamflows at the Littlefork gage, which integrates climate conditions in the entire watershed, were correspondingly slightly above average as well. The 2008 spring peak discharge was over 322 cubic meters per second (11,400 cubic feet per second; Figure 6), nearly double the 1.5 year flood frequency streamflow of 195 cubic meters per second (6,900 cubic feet per second; Anderson et. al, 2006). Long term lake elevation data have been collected on very few lakes in the watershed. Two lakes with elevation data from 2001-2009, Sand and Sturgeon, are shown in Figure 7. Calendar year 2008 lake elevations where above average as well- reflecting the influence of above average runoff in the watershed. Both lakes exceeded their ordinary high water elevations in 2008, as defined by the Minnesota Department of Natural Resources (DNR).

Figure 4. 2008 and 2009 water year precipitation departure from normal

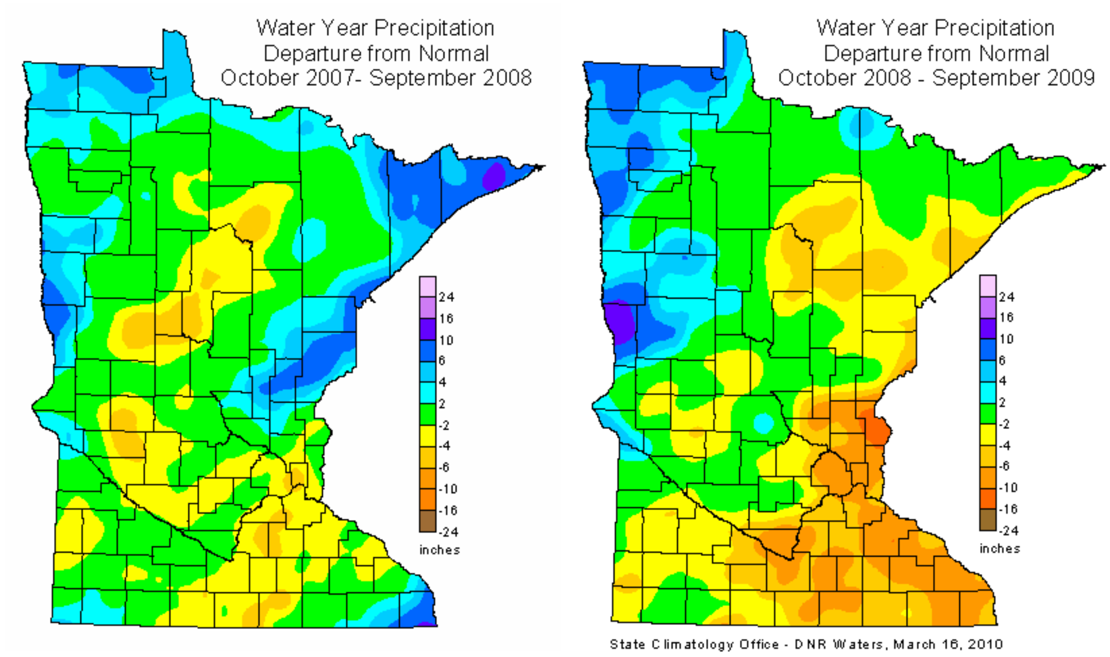


Figure 5. 2008 precipitation data; Littlefork, Minnesota (State Climatology Office)

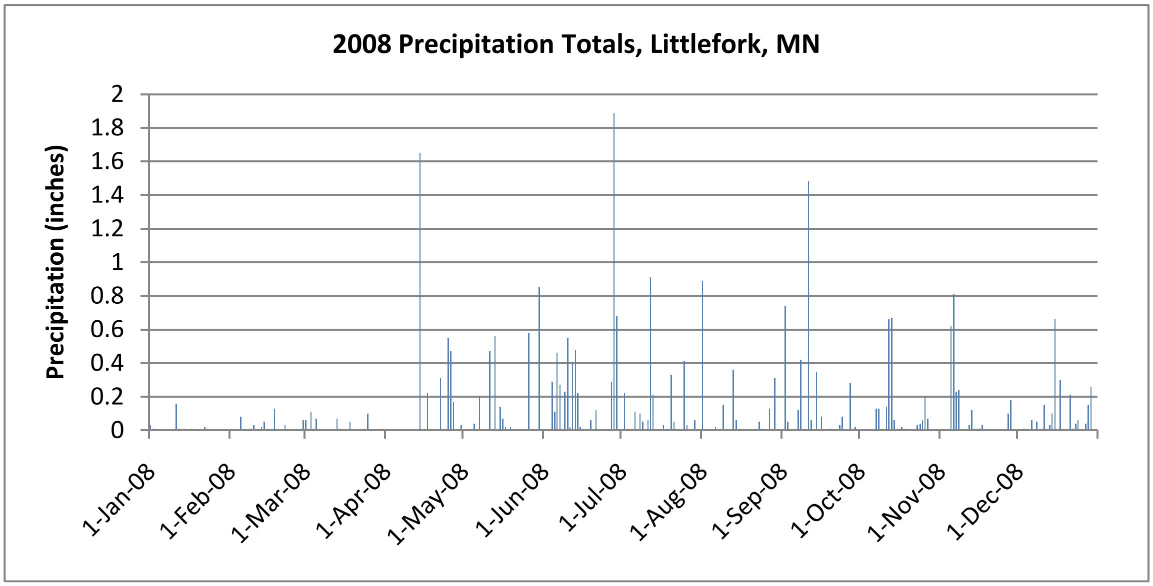


Figure 6. 2008 monitoring season streamflow data, USGS data from the Little Fork River at Littlefork, MN.

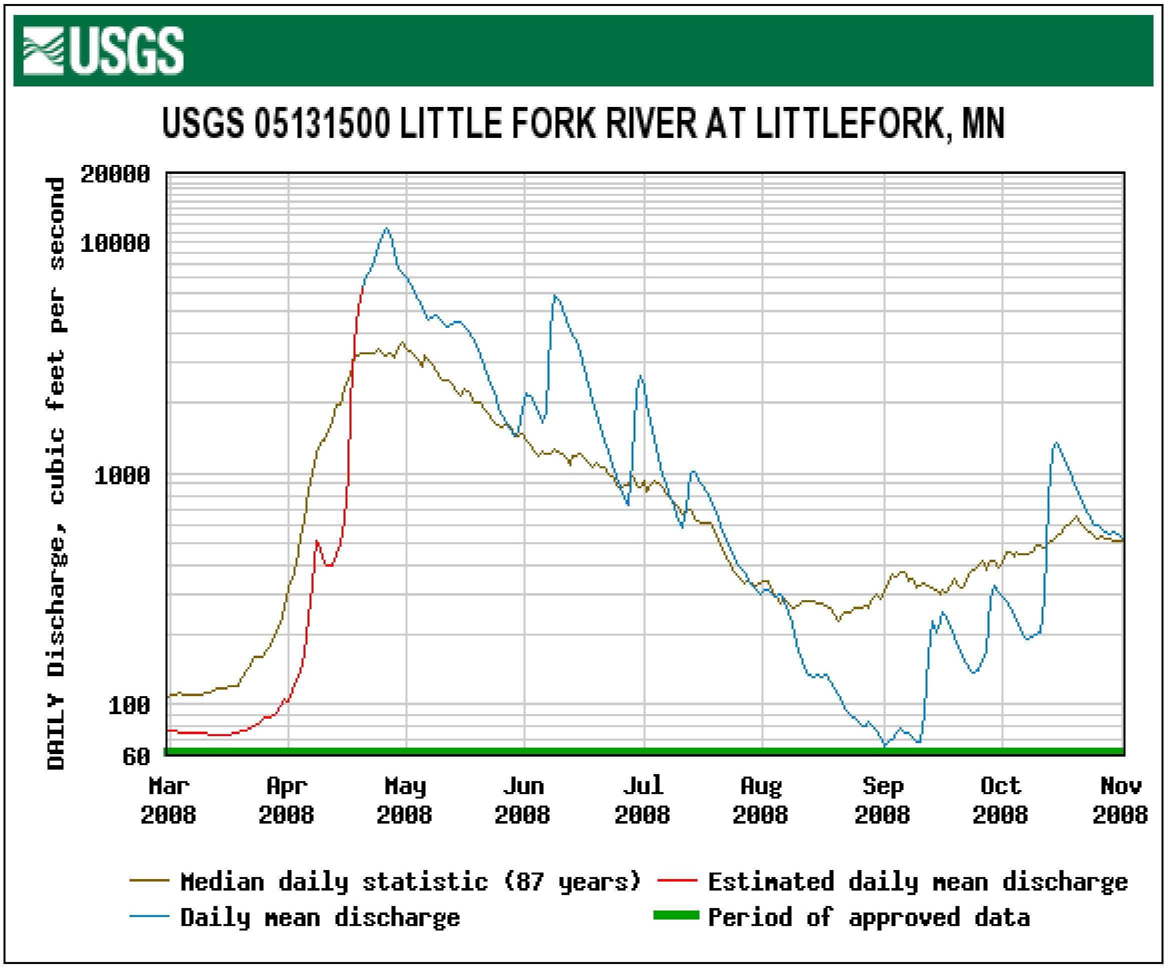
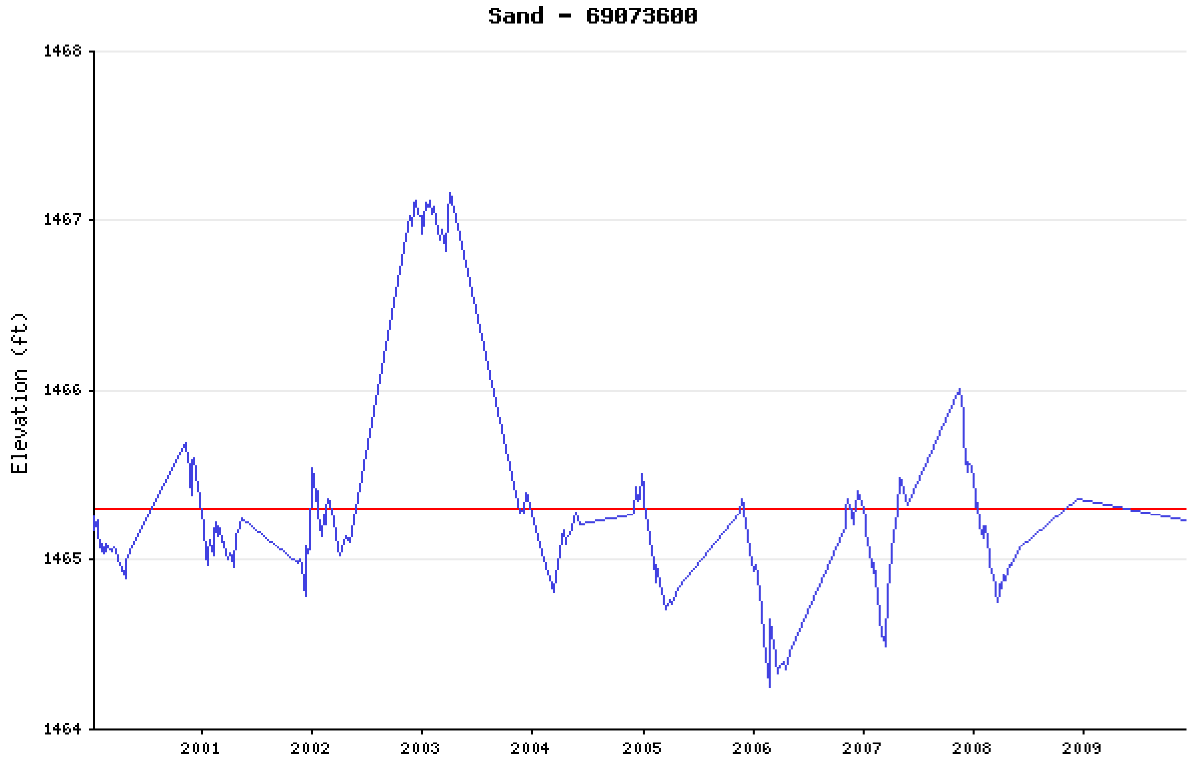
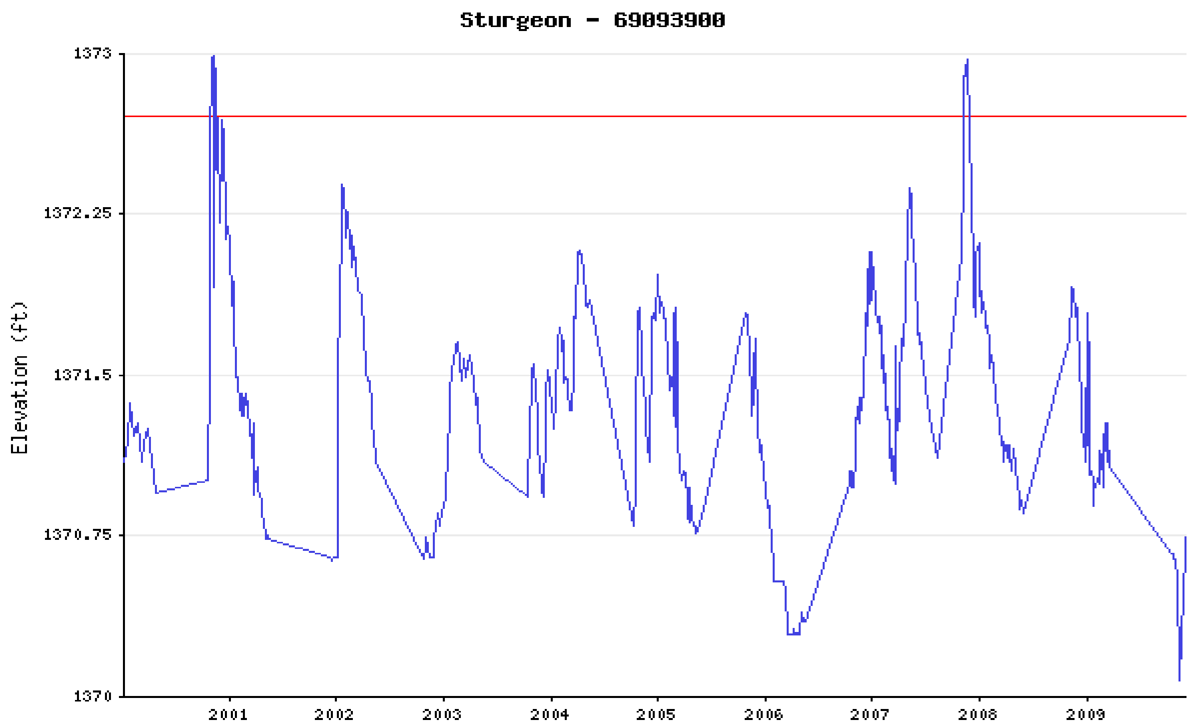


Figure 7. Lake elevations for Sand and Sturgeon lakes, MN DNR ordinary high water elevation shown in red (MN DNR data)





Methods

Data described and analyzed in this report include water samples collected by MPCA cooperators and grantees, SD data collected by citizen volunteers in the CLMP, and estimates of water clarity from analysis of satellite imagery. Water samples were often collected at the lake's maximum depth. Lake surface samples were collected with an integrated sampler, a poly vinyl chloride (PVC) tube two meters (6.6 feet) in length, with an inside diameter of 3.2 centimeters (1.24 inches); or a surface grab sample. Field measurements of dissolved oxygen and temperature were collected by MN DNR staff and citizen volunteers on select lakes, instrumentation was calibrated according to DNR standard operating procedures. Sampling procedures by grantees were employed as described in the MPCA Standard Operating Procedure for Lake Water Quality document, which can be found here: http://www.pca.state.mn.us/publications/wq-s1-16.pdf .

CLMP volunteers collect SD transparency data on their lakes. Details on the program can be found in MPCA (2008), in summary:

CLMP is a cooperative program that combines the technical resources of the MPCA and the efforts of citizen volunteers statewide that collect water quality data on their lakes. The participation of citizen volunteer monitors in the CLMP effectively increases the monitoring capabilities of the MPCA. The CLMP is a cost-effective way to obtain good, basic, water quality data on many of Minnesota's lakes. A Secchi disk is a circular metal plate attached to a calibrated rope. It is probably the least expensive and easiest to use tool in water quality monitoring. One of the best aspects of the Secchi disk is that the information provided by the Secchi disk is easily interpreted by volunteers and can be used to detect water quality trends in lakes.

To determine Secchi transparency trend results, all available Secchi data were extracted from STORET, the U.S. EPA's national water quality database. For lakes, a minimum of eight–ten years of data (with four or more readings per season) are typically required to detect trends. The statistical software package Systat was used to perform the Seasonal Kendall test to determine whether the data for each lake exhibit increasing or decreasing trends, as well as other non-parametric statistical tests. As of 2008, CLMP data was used to determine trends on over 1,200 lakes in Minnesota.

Water sample analysis was performed by the laboratory of the Minnesota Department of Health, or other certified labs, using United States Environmental Protection Agency-approved methods.

MPCA contracted with the University of Minnesota to estimate water clarity statewide using 2005 Landsat satellite imagery. MPCA uses satellite estimates of water clarity to augment field-collected water chemistry and SD data; satellite estimates of clarity are not solely used for water quality assessment purposes. For most lakes in the Little Fork watershed, these estimates are the only data available, and are used to describe clarity on the HUC-8 scale. Remote-sensing methods can be found in Olmanson (2008) and http://www.water.umn.edu/.

Modeling

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 water quality of assessed lakes within the Little Fork watershed, the Minnesota Lake Eutrophication Analysis Procedures (MINLEAP) model (Wilson and Walker, 1989) was used.

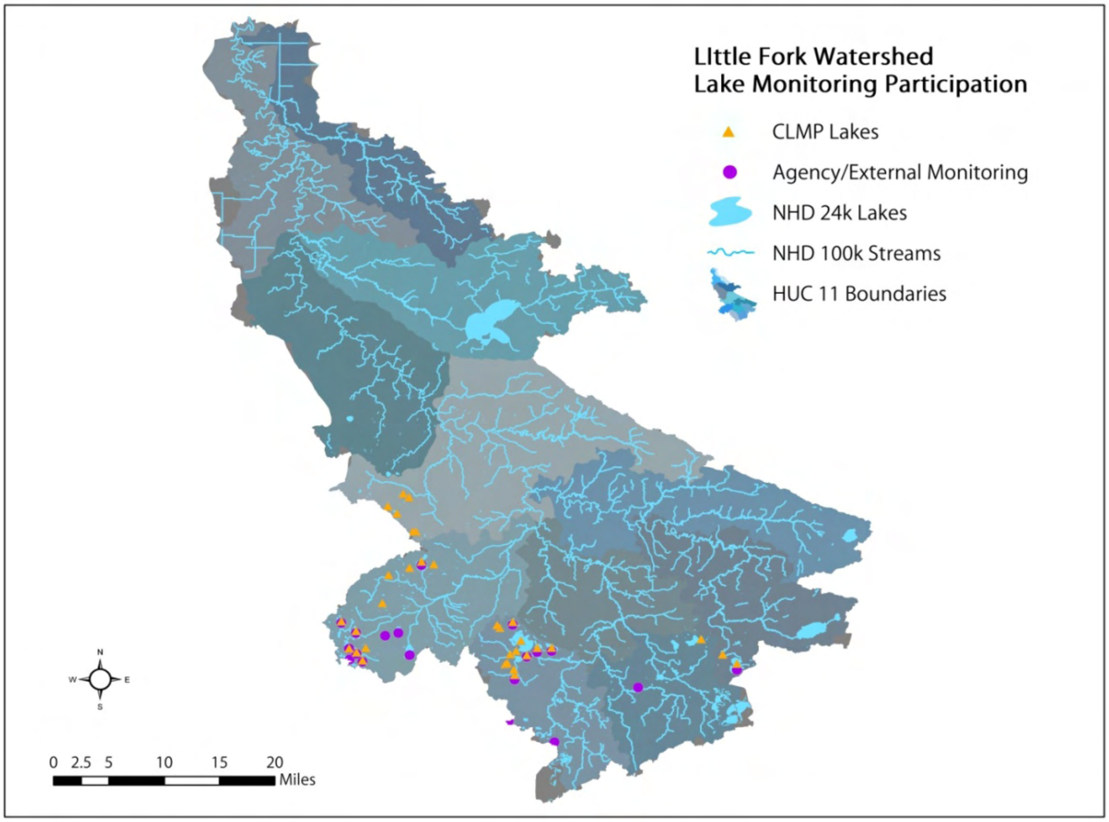
MINLEAP was developed by MPCA staff based on an analysis of data collected from the ecoregion reference lakes. It is intended to be used as a screening tool for estimating lake conditions with minimal input data and is described in greater detail in Wilson and Walker (1989). For the analysis of assessed lakes within the Little Fork 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 of the watershed. The MINLEAP model was only applied to those lakes with assessment level water quality data- a minimum of eight samples collected over two or more years in the ten-year assessment cycle. Individual results for each of the assessed lakes will be discussed in the lake summary portion of the HUC-11 watershed sections of this report.

Results

Because water quality data collected by the MPCA are not yet available for lakes within the Little Fork watershed, results in this report will focus on other sources of available data- CLMP SD transparency data, TP and chl-a data from STORET collected by partner organizations, and basin-wide remotely-sensed (i.e. estimated) SD transparency. As discussed previously, water quality data are generally sparse in the Little Fork watershed (Table 3), likely due to the remote nature of many lakes in the HUC-8 watershed. Only 14 lakes have sufficient data for a formal water quality assessment. Figure 8 shows the location of lakes with historical water quality data. More prominent lakes in the basin, such as the Sturgeon Lake Chain, and those with established volunteer monitoring, such as Beatrice and Sand Lake, have more comprehensive datasets.

SD data on un-assessed lakes, either monitored or estimated by satellite imagery, will be discussed at the HUC-8 scale. The remainder of the report will be organized by the HUC-11 sub-watersheds and focus on those lakes with assessment level data, or with sufficient CLMP data for trend determinations. Lake water quality data in five of the watershed's HUC-11 sub-watersheds will be described (Sturgeon Lake, Bear River, Middle Little Fork, Rice, and Dark Rivers). The remaining HUC 11 watersheds have insufficient information, or do not contain natural lakes.

Figure 8. Monitored lakes within the Little Fork watershed



Sechchi Transparency Summary – monitoring and remote sensing estimates at the HUC 8 scale

A cumulative frequency plot of estimated remotely-sensed SD transparency data for lakes within the Little Fork watershed is shown in Figure 9. Estimated transparency values are shown in Figures 10 and 11 (close up of upper basin). Estimated SD transparencies ranged from 1.0 to 5.0 meters (m) (3-17 feet). Approximately 95 percent of lakes have estimated transparences between 1.4 – 4.5 m (4.5 – 15 feet; Figure 9), with a mean of 3.0 m (10 feet). In general, remotely-sensed SD values indicate good water clarity, particularly the lakes of the Sturgeon chain and the headwater lakes of the Bear River on the southwestern border of the basin. Large, shallow wild rice lakes, such as Nett and Big Rice, were estimated to have lower transparencies due to natural bog staining originating from their wetland dominated watersheds. The large taconite tailings basins on the southern portion of watershed divide have low transparencies (Figure 11). They will not be discussed in detail because they are not natural lake basins (their data were also excluded from statistical analyses); however, these basins do contribute water to downstream lakes and rivers via seepages and permitted discharge points. Suspended sediment concentrations in these discharges are low, ranging from 1-5 mg/L (MPCA Delta database). A total of 51 lakes in the HUC 8 watershed have at least 1 SD measurement collected in the 2000-2009 assessment cycle; however, only 18 of these lakes have at least 10 SD measurements collected since 2000. Since the majority of monitored lakes have only one SD measurement, watershed-wide conclusions on water clarity are not possible. Average monitored transparency ranged from 4.55 m (15 feet) on Napoleon Lake to 0.46 m (1.5 feet) on Johnson Lake- a small, undeveloped lake in the Sturgeon Lake sub-watershed. The mean SD of all monitored lakes was 2.35 m (7.5 feet), slightly below the average of the MPCA's larger NLF dataset (Table 4) and the 2008 CLMP state-wide seasonal mean transparency of 2.95 m (9.5 feet; Schussler and Nichols, 2009). The monitored and remotely- sensed SD estimates were compared on the HUC 8 scale. A statistical regression of the 46 lakes with paired monitored and remotely-sensed SD indicated that, on average, the satellite estimate was higher than the measured SD transparency. This is likely due to a combination of factors - the natural bog stain common to many lakes in the watershed that may interfere with satellite reflectance, and limited monitored data- specifically a lack of SD measurements collected near the late summer 2005 image date. Olmanson's statewide dataset (Olmanson et. al., 2008) had an R^2 value of about 0.80 (indicating strong agreement) when comparing monitored versus satellite estimated Secchi transparency, both converted to trophic state index (TSI; Carlson, 1977). On the 18 lakes with at least ten SD measurements, the non-parametric Kruskal-Wallis test statistic was calculated on the paired data. Results indicated stronger correlation (i.e. the variables were not statistically different).

Table 4. Comparison of monitored versus satellite estimated Secchi transparency data in Little Fork Watershed lakes, and lakes within the NLF / NMW ecoregions

Summary Statistic	Little Fork Monitored Lakes [1]	Little Fork 2005 Remote Sensing Estimates	MPCA's Assessed Lakes in NLF & NMW Ecoregions [2]
Number of lakes	51	103	1,674
Mean transparency (m)	2.35	3.0	3.07
Median transparency (m)	2.44	3.02	2.91
Maximum transparency (m)	4.55	5.00	15.2
Minimum transparency (m)	0.46	1.00	0.30

1. Lakes with at least 1 SD reading in STORET from 2000-2009
2. MPCA Lake Assessment Database

Figure 9. Cumulative frequency plot of remotely-sensed SD for 103 lakes within the Little Fork watershed

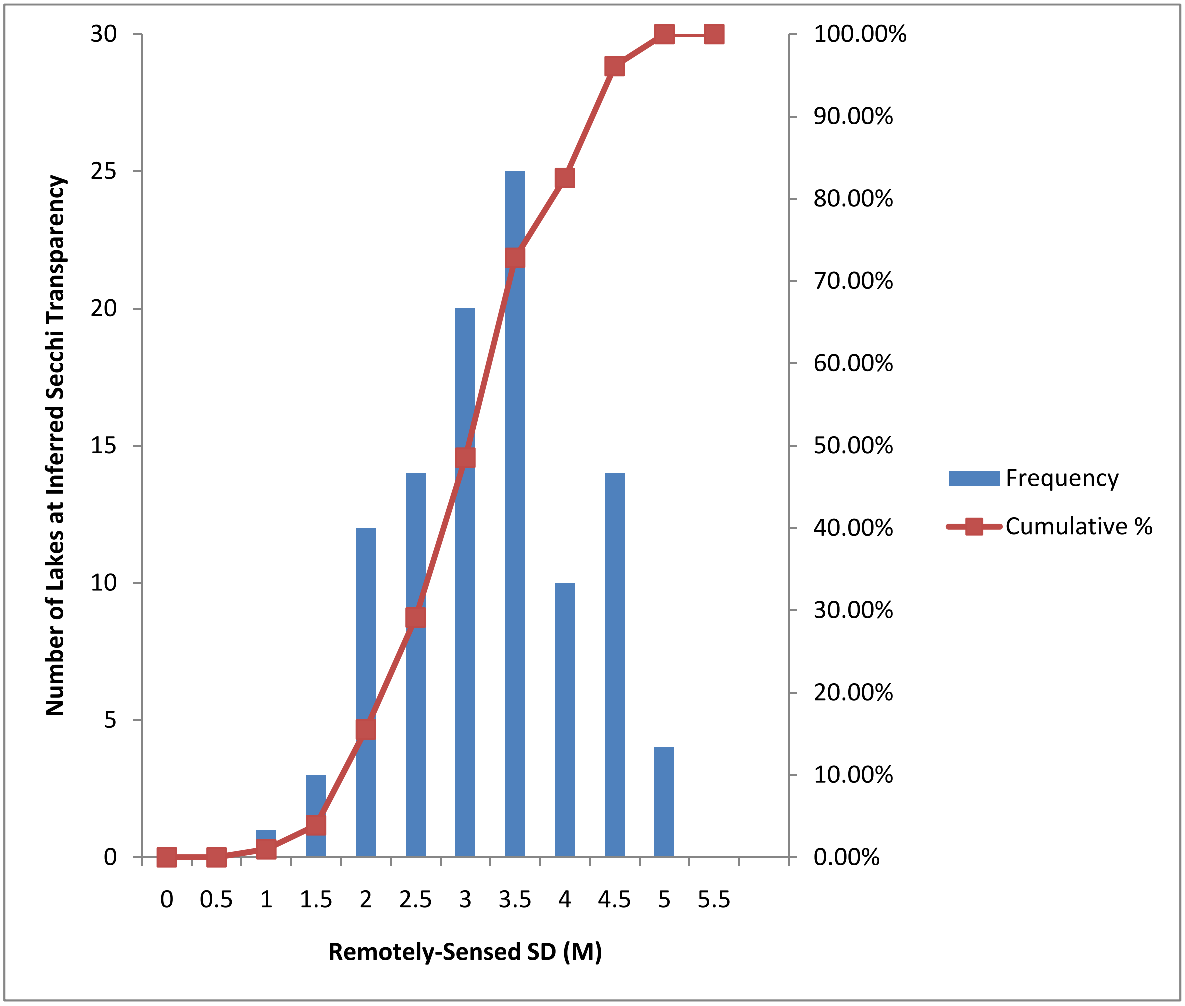


Figure 10. Satellite estimated Secchi transparency for lakes within the Little Fork Watershed

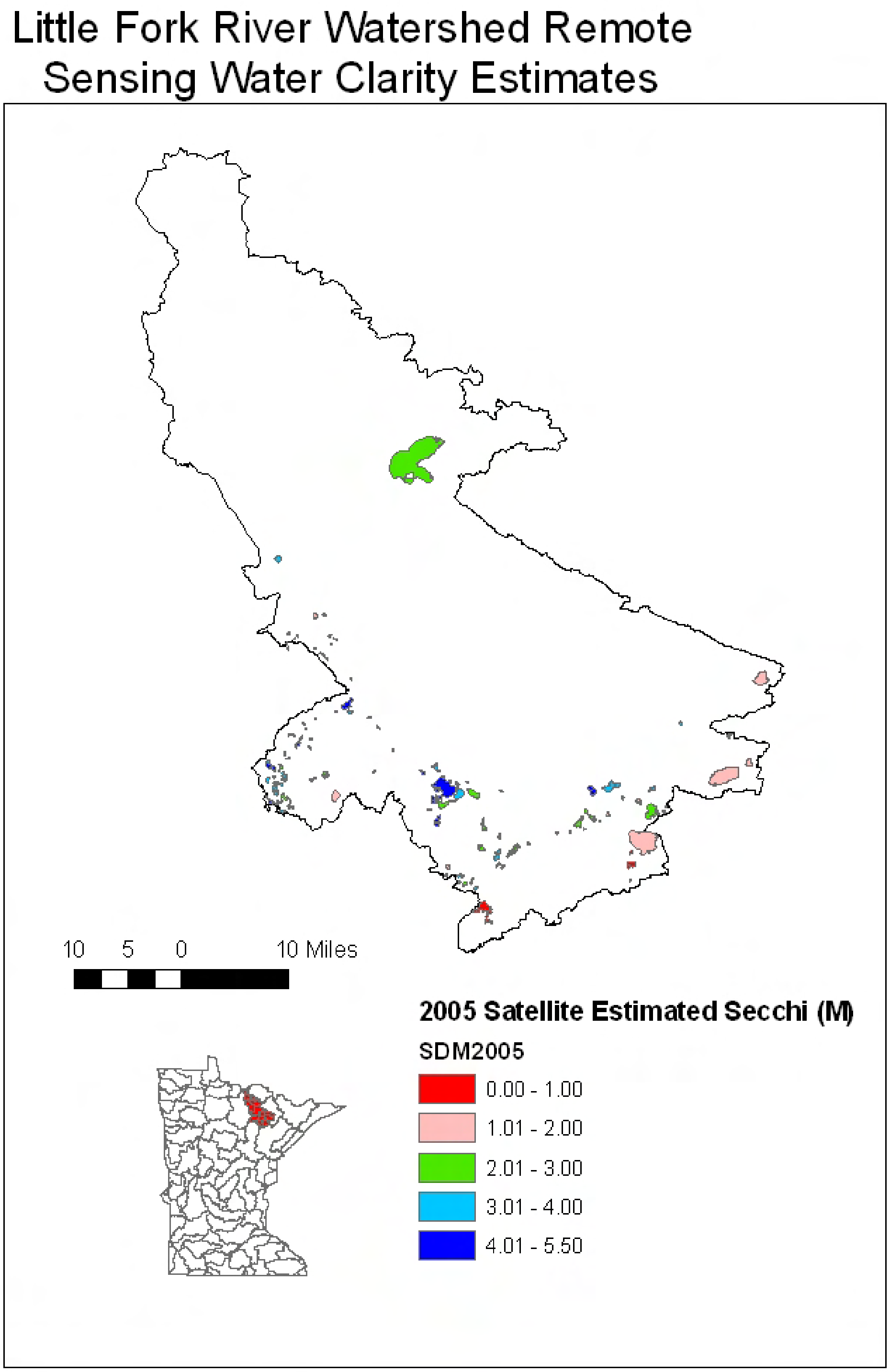
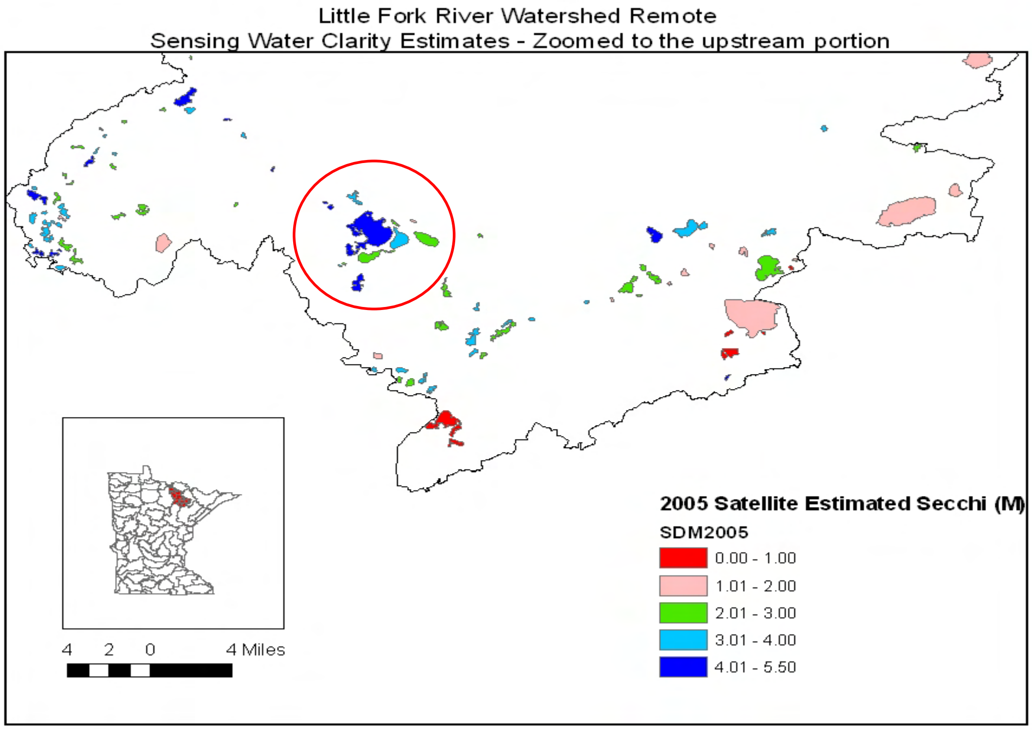


Figure 11. Upstream portion of the watershed. Sturgeon Chain of Lakes noted in red circle. Side Lake is SE of Sturgeon Lake



South Branch Little Fork River (Rice River) HUC 11 - 09030005020

The South Branch Little Fork River HUC-11 drains the 390 km^2 (150 mi^2) Rice River watershed. Lakes are located in the watershed's southern border (Figure 12). Sand (69-0736) and Little Sand (69-0732) are the only lakes with sufficient CLMP data for trend determination, and no lakes in the HUC-11 have sufficient data for a formal assessment. Sand and Little Sand lakes are hydrologically connected and form the headwaters of Johnson Creek, a designated trout stream and tributary to the Rice River. Both lakes have higher levels of lakeshore development when compared to other area lakes.

Figure 12. South Branch Little Fork River HUC-11 watershed

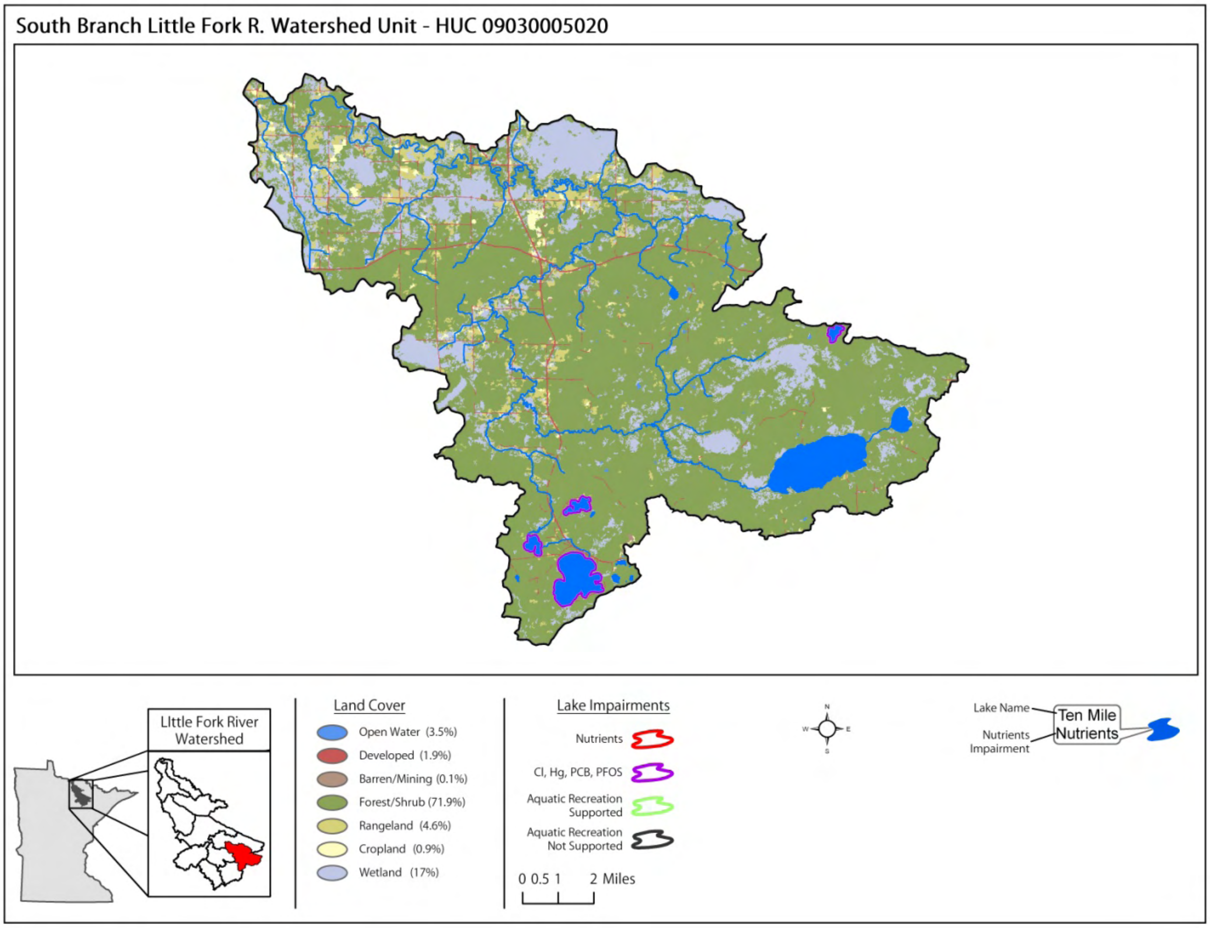
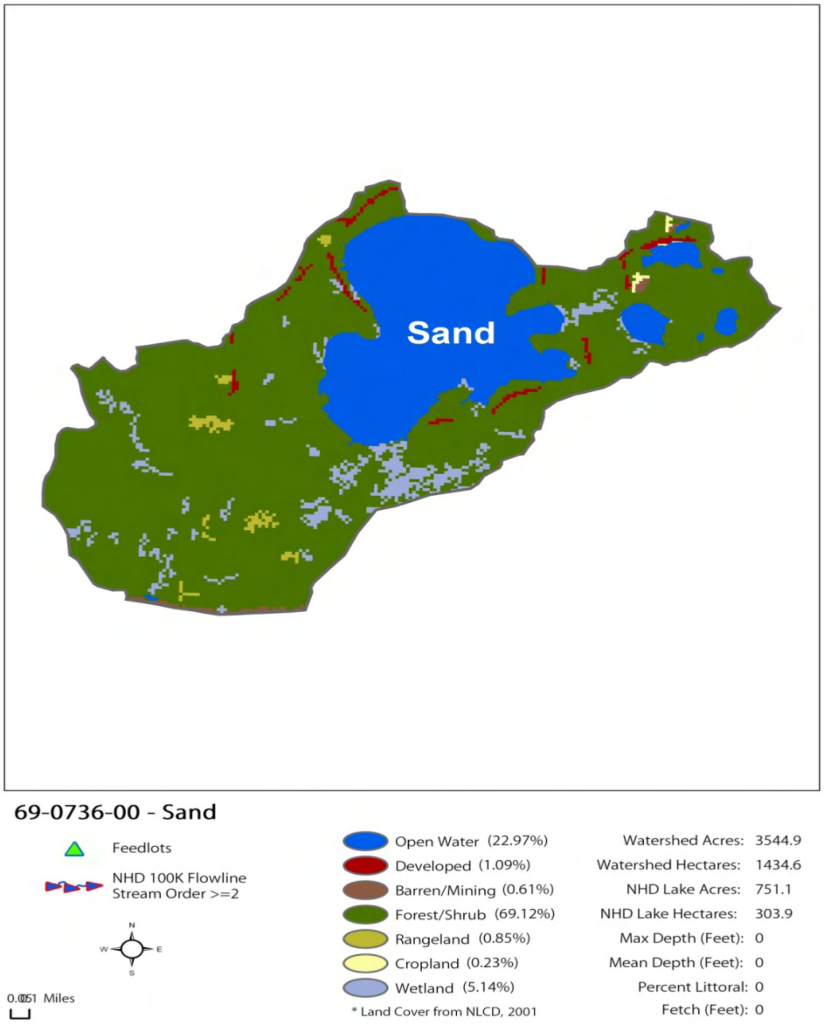


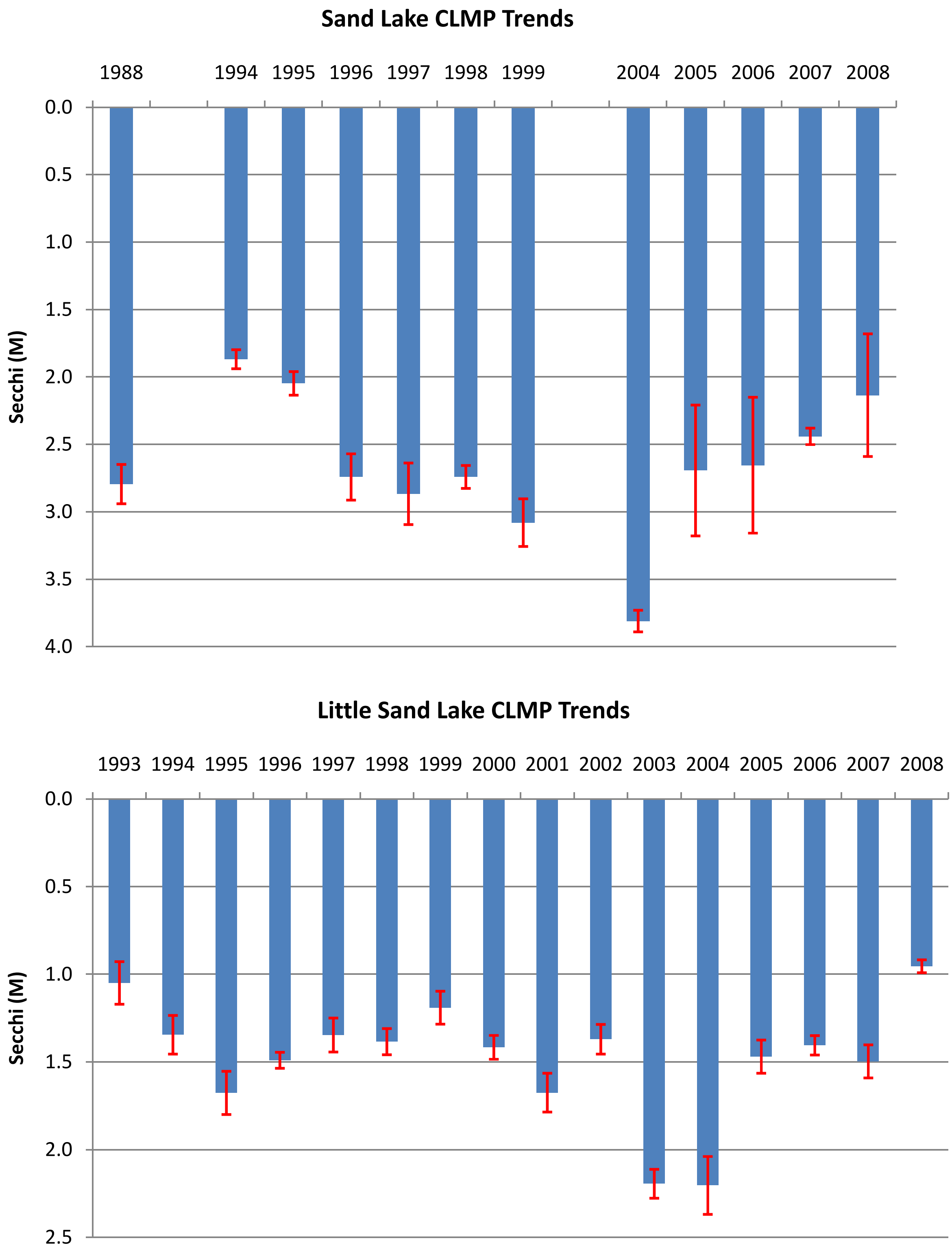
Figure 13. Sand Lake watershed.



Sand Lake covers an area of 303 ha (751 acres) and is located approximately 12 kilometers (eight miles) north of Virginia, Minnesota. Sand Lake has a relatively high density of lake shore development, particularly along its north shore; however forest remains the dominant land cover within the watershed (Figure 13). CLMP transparency data has been collected for 12 years (1988, 1994-1999, and 2004-2008). The long-term mean transparency is 2.65 m (8.5 feet). Available data indicate an increase in transparency through 2005; however recent measures suggest a slight decline (Figure 14). With the break in the CLMP Secchi record it is difficult to discern whether there is a distinct long-term trend or if Sand Lake transparency simply cycles over the course of several years in response to climate (e.g. rainfall and temperature), biology (e.g. fish and zooplankton) or watershed runoff.

Little Sand Lake covers an area of 34 ha (86 acres), and is also moderately developed. It is located downstream of Sand Lake. CLMP data have been collected since 1993 and the long-term mean transparency is 1.47 m (4.9 feet). There is no distinct linear trend over time; however Secchi does fluctuate over the course of several years with patterns somewhat similar to Sand Lake. It is interesting to note that both lakes exhibited peak transparency in 2004 and declined thereafter. A closer inspection of factors noted above may provide insight into causes of these fluctuations.

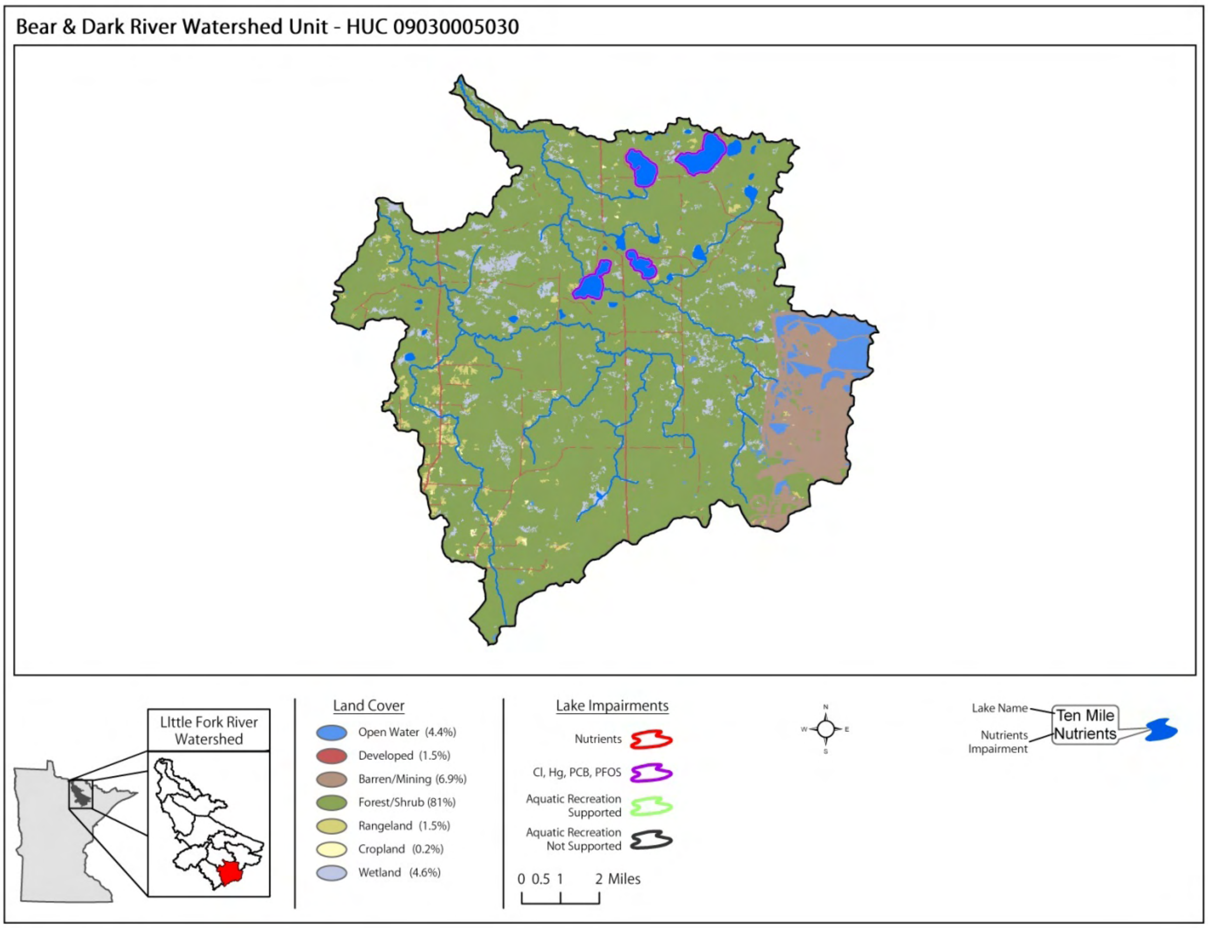
Figure 14. Summer-mean Secchi for Sand and Little Sand Lakes. Based on CLMP data. Standard error of the mean noted in red



Dark River HUC 11 - 09030005030

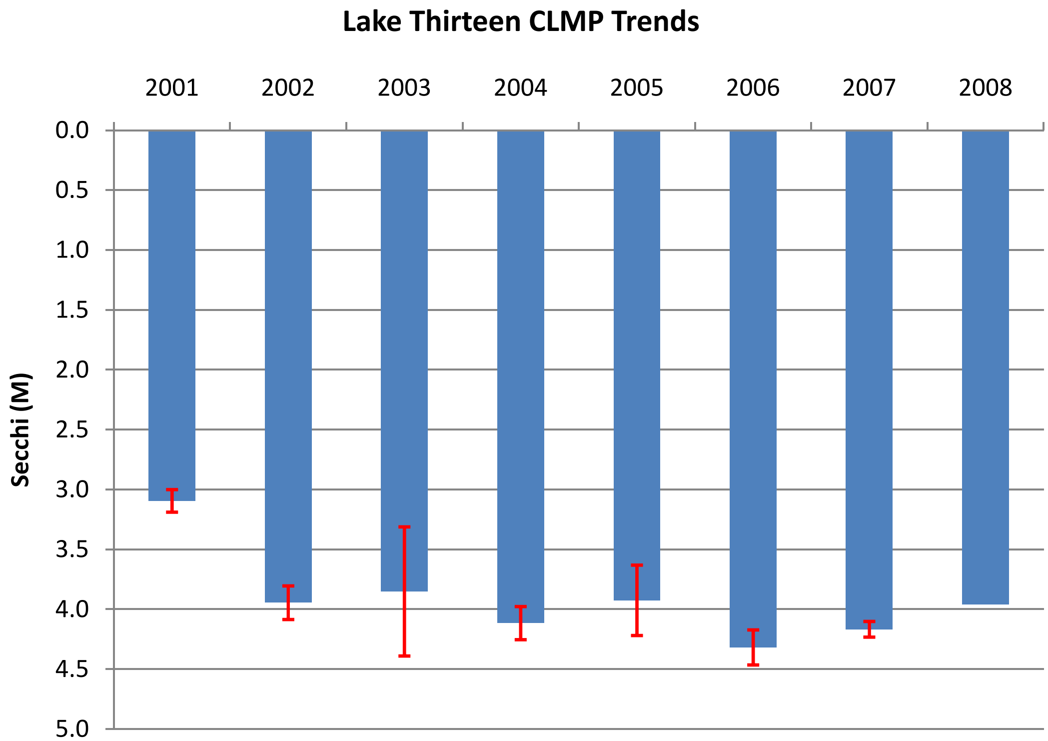
The Dark River and the East Branch Sturgeon River sub-watershed drains 296 km^2 (114 mi^2). Lakes in the HUC-11 are located near the center of the watershed and all are within the Dark River sub-watershed (Figure 15). Taconite tailings basins at the SE corner of the watershed form the headwaters of the Dark River. The East Branch of the Sturgeon River begins in relatively undeveloped land within Superior National Forest.

Figure 15. Bear and Dark River watershed



Lake Thirteen (69-0794) is the only lake in this HUC-11 with sufficient CLMP data for trend determination; no lakes in this sub-watershed have assessment level data. Lake Thirteen is adjacent to the larger Lake Fourteen on the NE portion of the sub-watershed. CLMP data have been collected since 2001. Overall mean transparency is 3.92 m (13 feet). SD transparency has been relatively stable and no trends were detected (Figure 16).

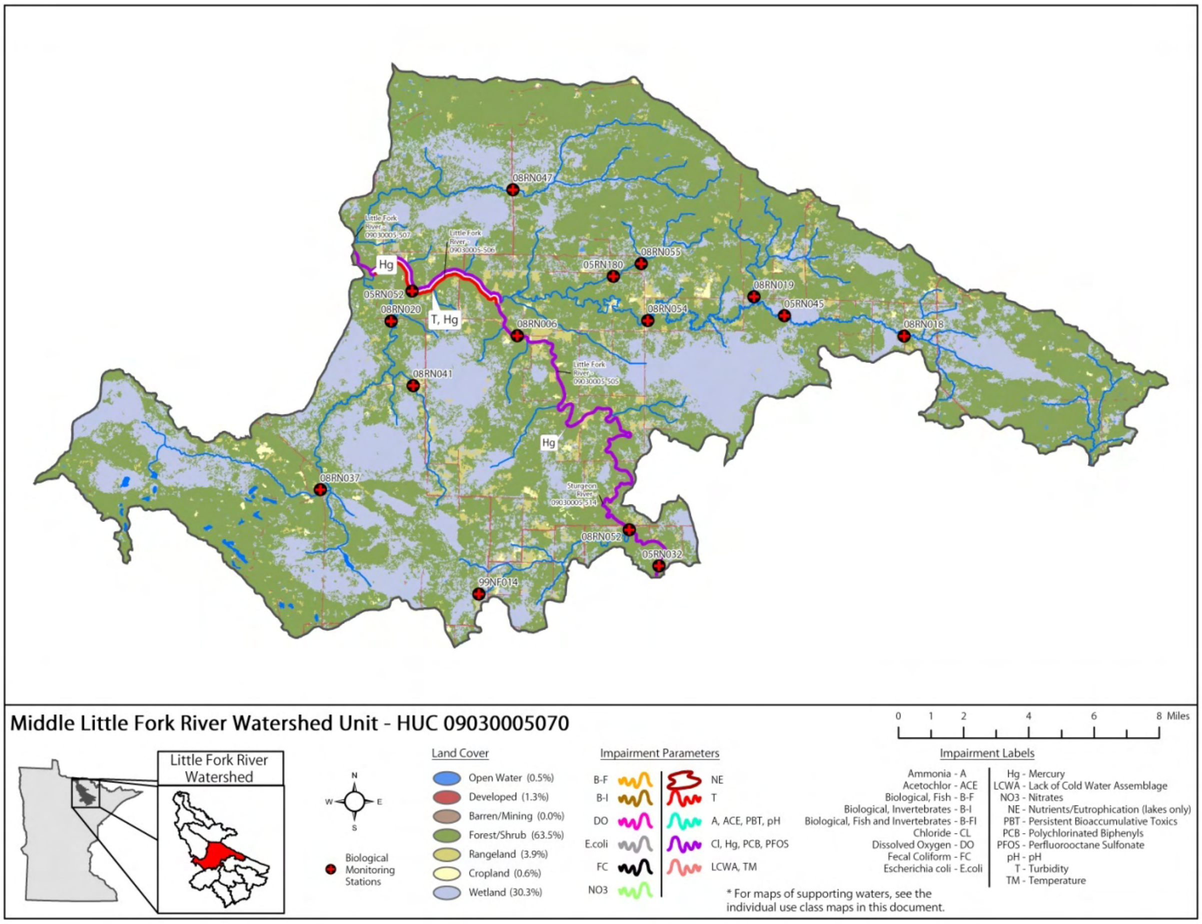
Figure 16. Summer-mean Secchi for Lake Thirteen. Based on CLMP data. Standard error of the mean noted in red



Middle Little Fork River HUC 11 - 09030005070

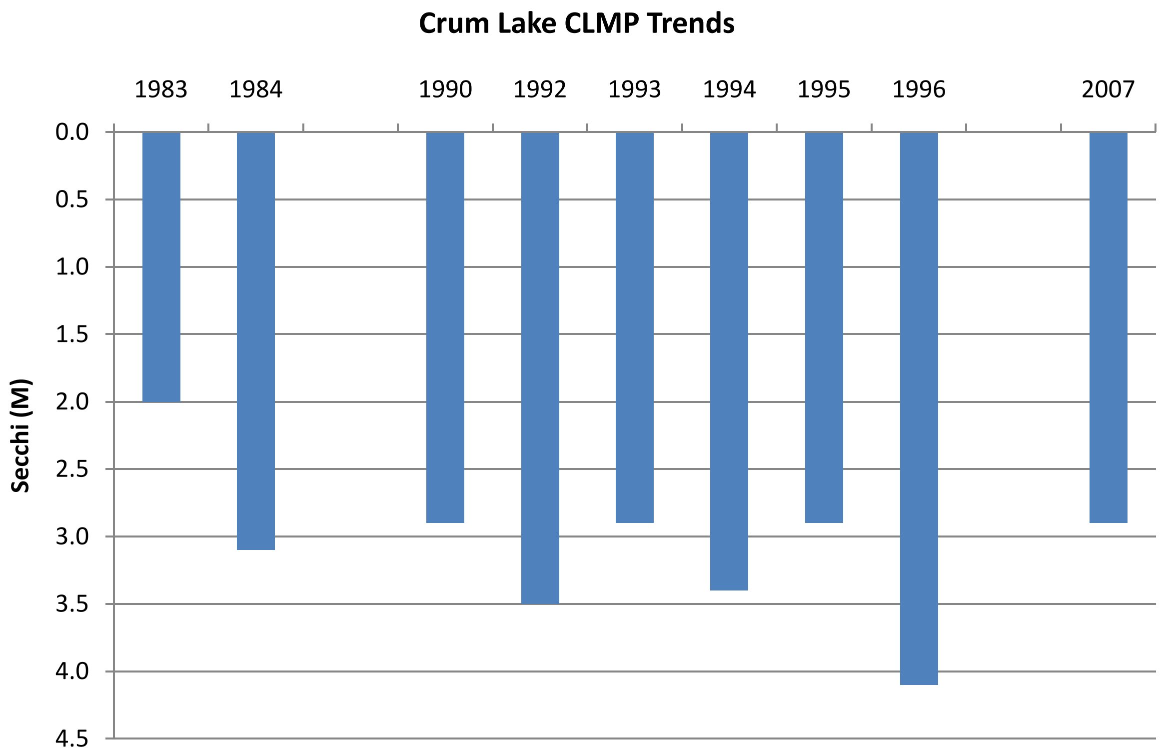
The Middle Little Fork is the largest HUC-11 in the Little Fork watershed, draining 698 km^2 (269 mi^2). It includes about 32 km (20 miles) of the Little Fork River and two major tributaries- the Valley River along the SW portion of the HUC-11 and the Willow River in the east. Lakes in the HUC-11 are limited to the SW portion of the basin and are nearly all small, isolated seepage lakes (Figure 17).

Figure 17. Middle Little Fork River HUC-11 watershed



No lakes in the Middle Little Fork have assessment level data, and only 1 lake (Crum Lake – 31-0171) has sufficient CLMP data for trend determinations. Crum Lake is located approximately 24 km (15 miles) east of Effie. It covers 7 ha (18 acres) in an undeveloped area within George Washington State Forest. It has been sampled once or twice per year periodically since 1983 and was the subject of acid rain research in the 1980s. Crum Lake has nine years of discontinuous Secchi data, which does not allow for an analysis of trends. The long-term mean is 3.1 m (ten feet), and summer-mean Secchi varies between 3 - 4 m (10 – 13 feet) in most years (Figure 18). Since the watershed and lakeshore are undeveloped forest land, it's likely that water quality is stable.

Figure 18. Summer-mean Secchi for Crum Lake. Based on CLMP data.



Sturgeon Lake HUC 11 - 09030005040

The Sturgeon Lake watershed (Figure 19) covers an area of 296 km^2 (114 mi^2) and forms the headwaters of the Sturgeon River, the Little Fork River's largest tributary. The large lakes of the Sturgeon Chain (Sturgeon, Little Sturgeon, Beatrice, Perch, South Sturgeon, and Side) are prominent features of the sub-watershed. Beatrice and Perch are seepage lakes; stream channels connect the remaining lakes of the Sturgeon Chain. Other lakes within this watershed include numerous small seepage lakes that form the headwaters of the Shannon River, which flows into the Sturgeon River just east of Perch Lake. McCarthy Beach State Park, a popular recreation area, includes portions of Sturgeon, Side, and Beatrice Lakes.

Forests and wetlands make up about 85 percent of the watershed. Developed and mining (taconite tailings basins) each make up about 2 percent of the landuse. The Sturgeon Chain of Lakes are likely the most developed lakes in the Little Fork watershed. Local property owners have worked with MN DNR Fisheries (Rian Reed) and Itasca County to model shore land development sensitivity and proper citing of septic systems. As part of this effort, volunteers and the DNR worked cooperatively to collect water quality samples in 2007 and 2008. These data are summarized here and provide the basis of the water quality assessment. Excluding the Sturgeon Chain, only one additional lake in this HUC-11 has assessment level data - Hobson Lake (69-0923) a seepage lake in the headwaters of the Shannon River that was included in acid rain monitoring in the early 1980s.

Assessed lakes in the Sturgeon Chain will be discussed together as a case study, given their hydrologic connectively and recent monitoring. Lake data will be displayed in ‘downstream order’. In summary, Sturgeon, West Sturgeon, and South Sturgeon lakes flow into Little Sturgeon (Figure 20); Side and Perch lakes flow into the Sturgeon River downstream of all other lakes (Beatrice lake is located near the height of land and although it has no surface outlet it is assumed to flow south to Sturgeon Lake). Morphometry, watershed areas, and residence times vary among the lakes. These variables have a strong influence on lake water quality. Little Sturgeon Lake (Figure 20) has the largest drainage area (42 percent of the entire HUC-11), receiving water from all lakes except for Side and Perch. Side and Perch Lakes (Table 5) have very small drainage areas, < 2.5 km^2 (< 1 mi^2). The surface area of these lakes makes up a large percentage of the lake’s total drainage area. Conversely, smaller, shallower lakes with large watershed areas have faster residence times. Estimated residence times range from 0.1 years on Little Sturgeon to 20 years on Side Lake (Table 5).

Table 5. Lake morphometry and watershed data for the Sturgeon Chain of Lakes

Lake Name	Watershed Area km^2 (mi^2) [1]	Lake Area hectares (mi^2)	Mean Depth meters (feet) [3]	Residence Time (years) [4]
Beatrice	2.22 (0.86)	44.0 (0.17)	4.5 (15)	3.6
Sturgeon [2]	38.0 (14.68)	732.9 (2.83)	10.6 (35)	8.1
Little Sturgeon	124.3 (48.03)	121.7 (0.47)	3.0 (10)	0.1
South Sturgeon	66.3 (25.62)	80.2 (0.31)	7.6 (25)	0.4
Side	1.6 (0.62)	147.6 (0.57)	7.6 (25)	20.2
Perch	2.14 (0.83)	134.6 (0.52)	4.5 (15)	9.3

1. Excludes lake area
2. Includes West Sturgeon Lake
3. Estimated from MDNR Lake finder Maps
4. Estimated from MINLEAP model

Figure 19. Sturgeon Lake HUC-11 watershed

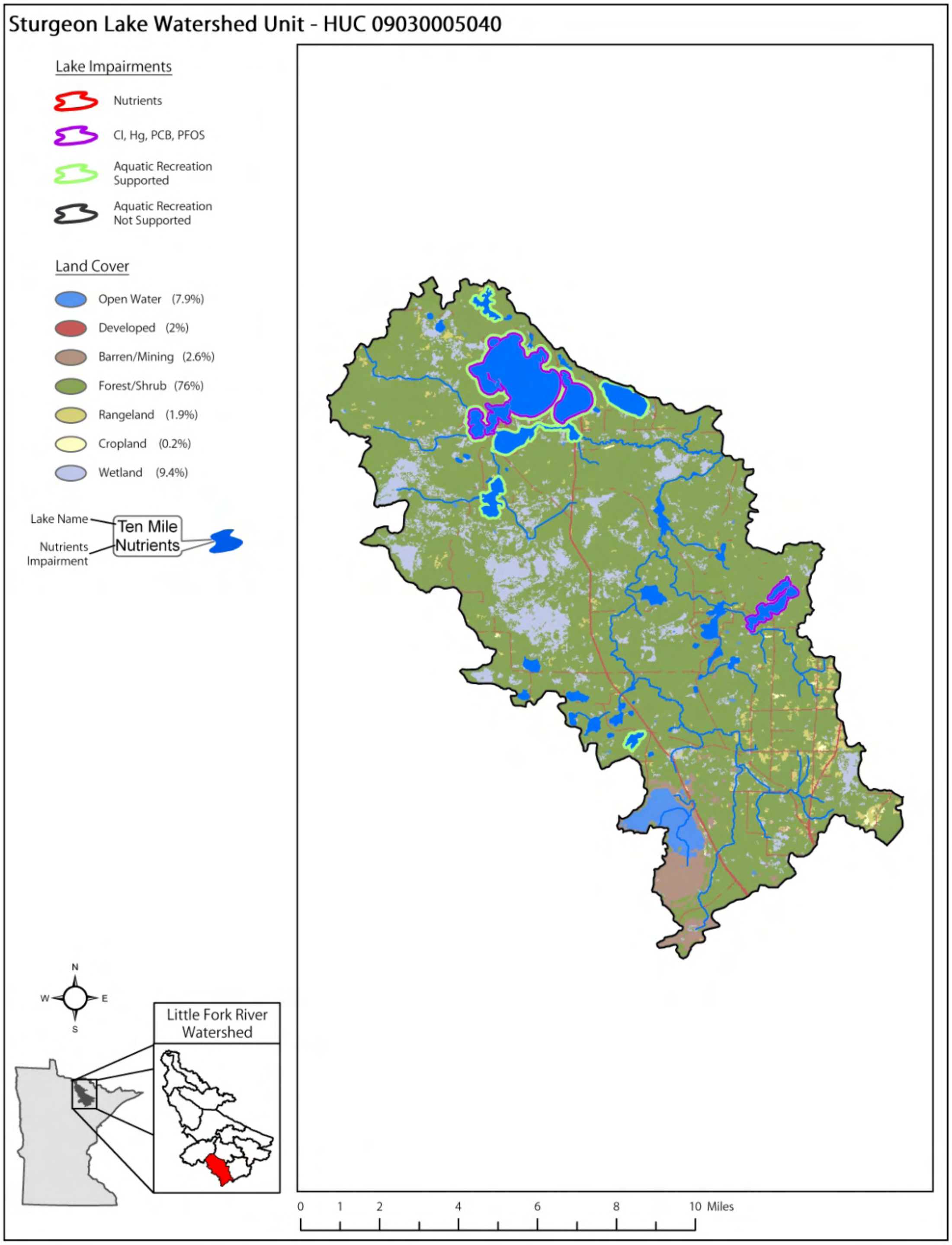
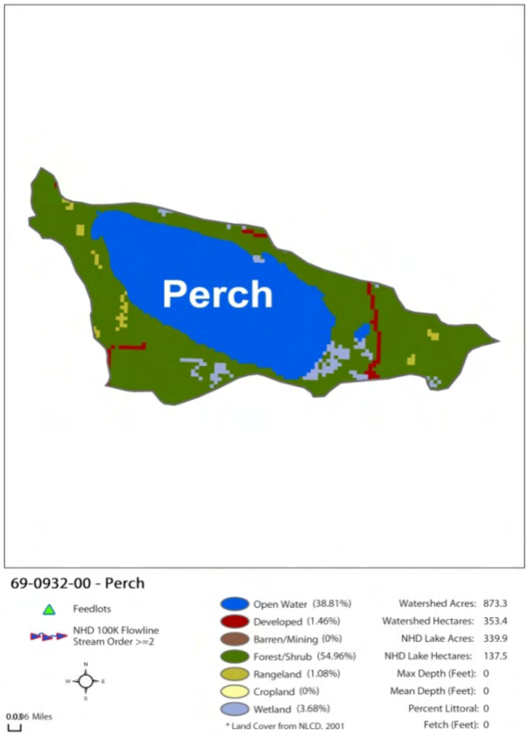
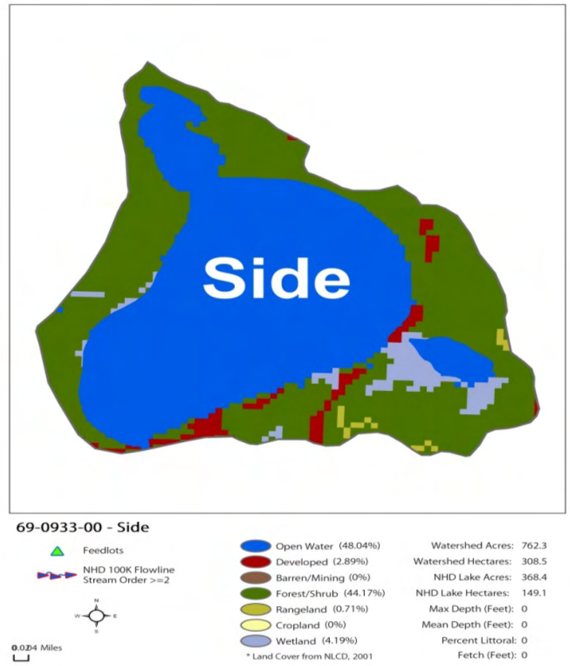
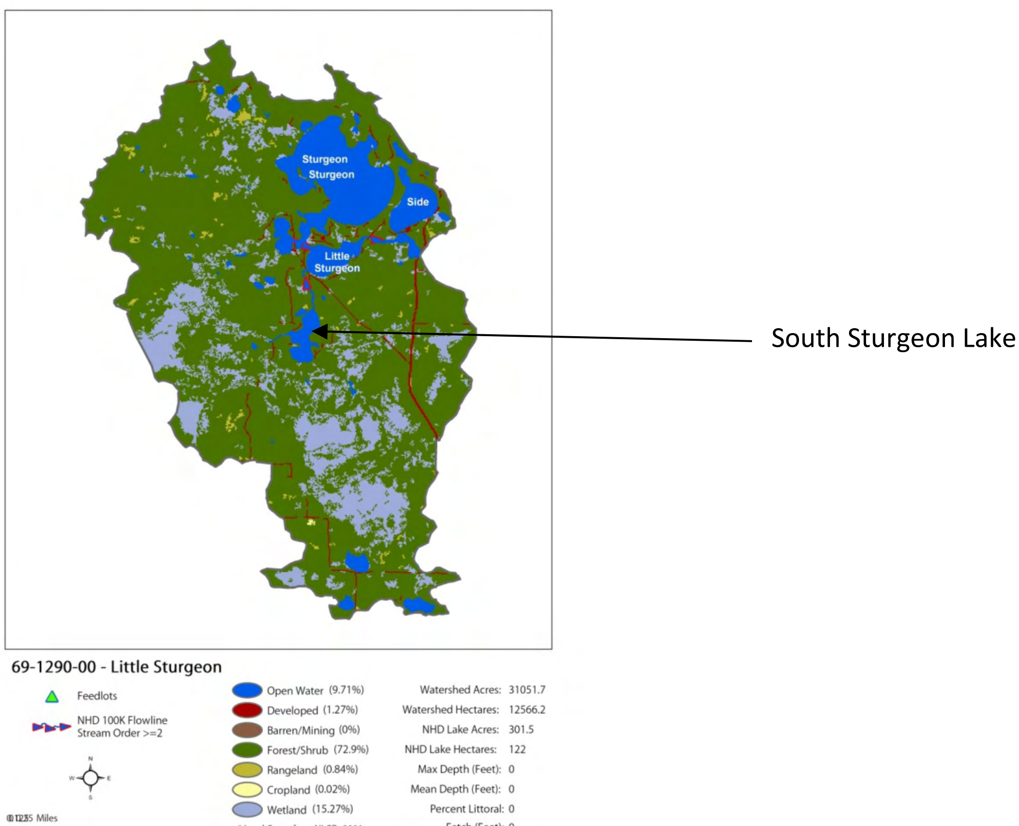


Figure 20. Lakeshed maps of Perch, Side and Little Sturgeon Lakes (South Sturgeon Lake flows into Little Sturgeon and is noted with arrow)

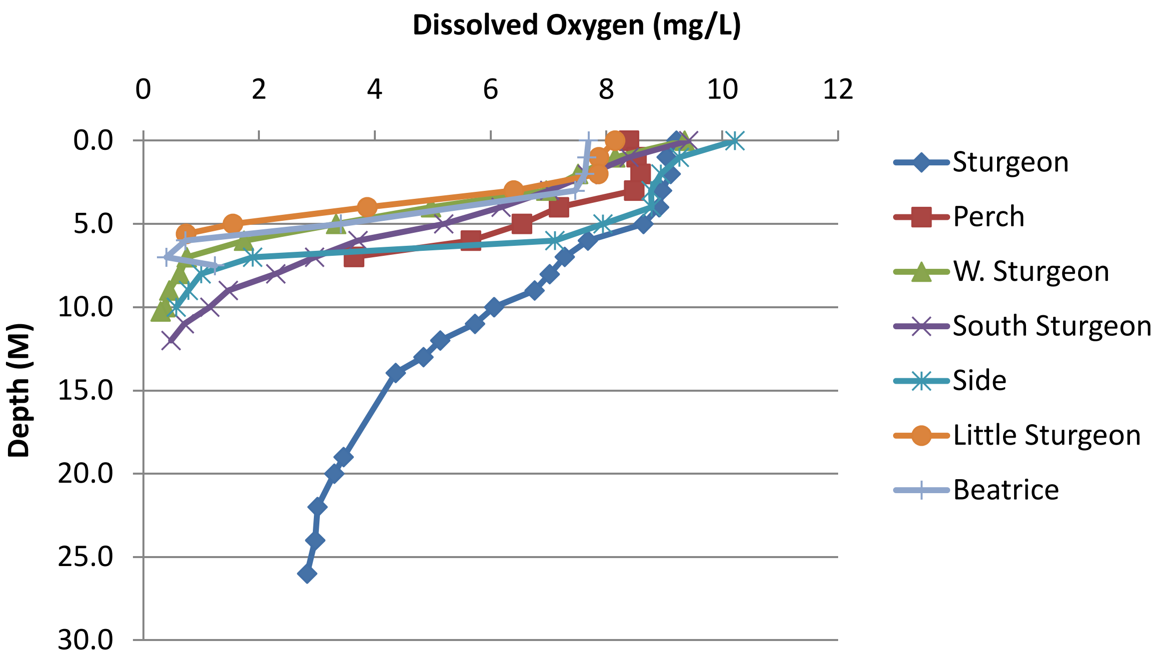


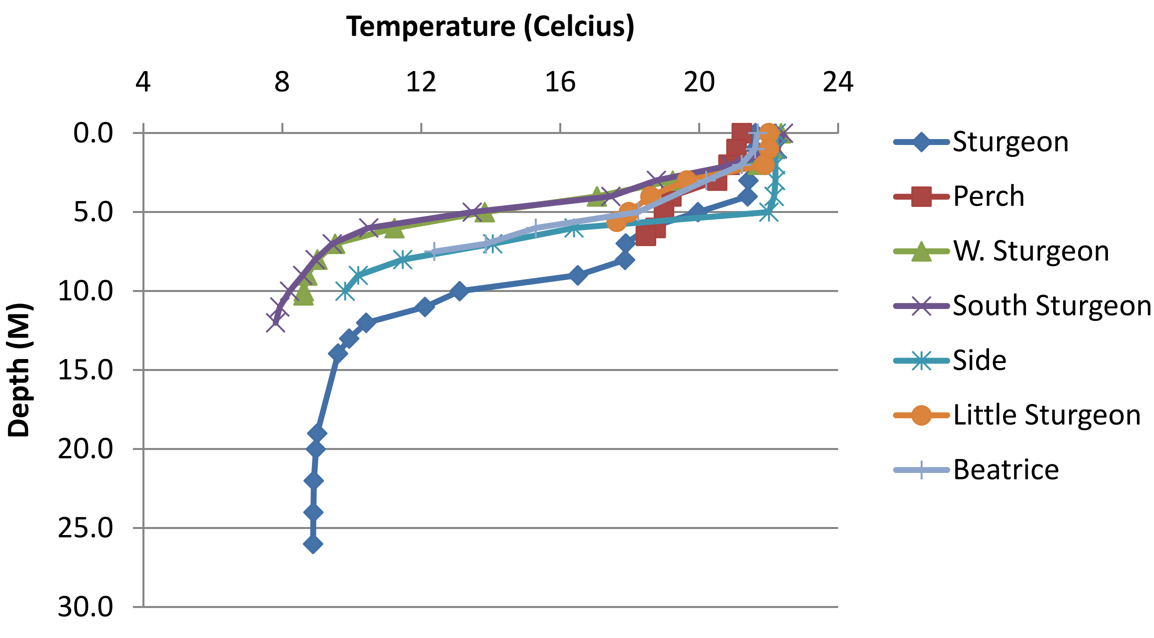




Mid-summer (July) dissolved oxygen (DO) and temperature profiles for the Sturgeon Chain of Lakes are shown in Figure 21. All lakes were thermally stratified in mid-summer, 2008. Surface temperatures were consistent among lakes, approximately 22-23 Celsius. Lakes with comparatively large volumes, such as Sturgeon and Side, had cooler temperatures and higher DO concentrations in the metalimnion. All lakes maintained epilimnetic oxygen concentrations greater than five mg/L, levels needed to support healthy cool and warm water fisheries. DO concentrations dropped to near zero in the hypolimnion for all lakes except Sturgeon, which is normal for lakes with this morphology in the NLF ecoregion.

Figure 21. Sturgeon Chain July 2008 dissolved oxygen and temperature profiles



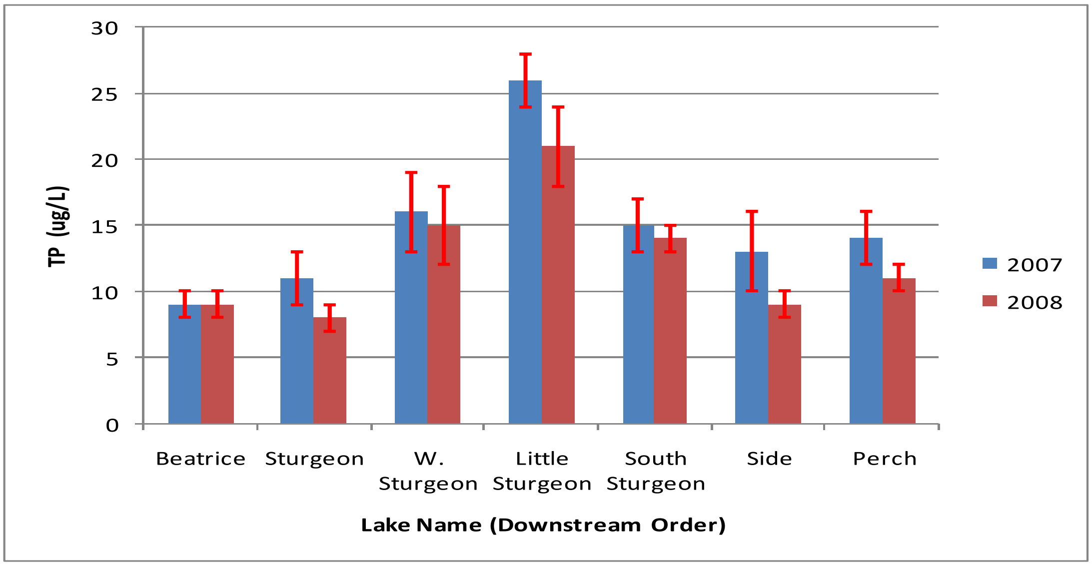


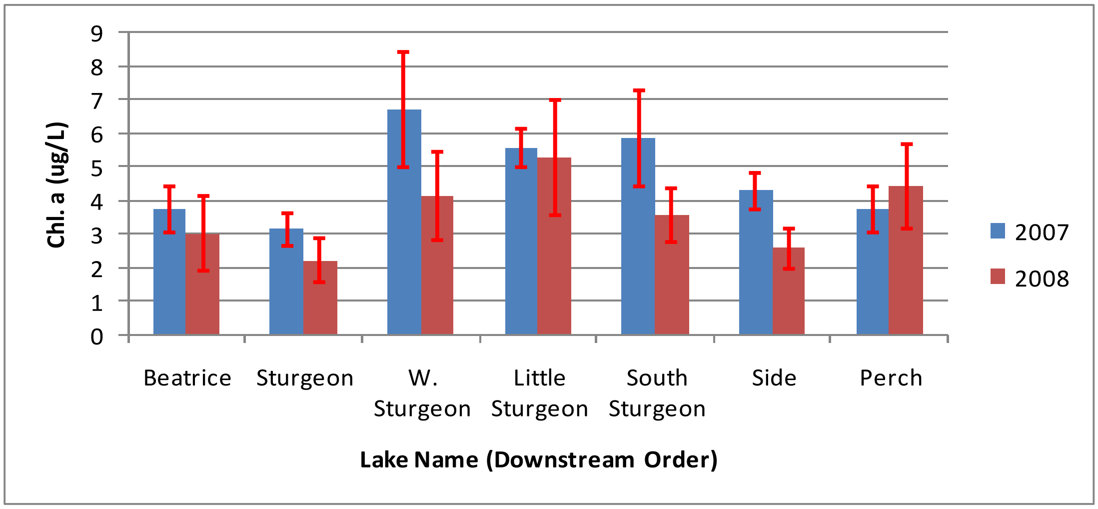
Annual average (2007 and 2008) TP, chl-a, and SD transparency data for the Sturgeon Chain of Lakes are shown in Figure 22. In general, these data indicate excellent water quality. TP concentrations were similar among years. Concentrations ranged from 10-15 µg/L in the headwater lakes with small contributing watersheds (Beatrice, Sturgeon, Side, and Perch). Concentrations were higher (but still below NLF assessment criteria) on lakes with larger drainage areas and rapid residence times – such as South and Little Sturgeon. These lakes with rapid residence times (less than half a year – Table 5) act more like flowages, are naturally more productive and receive runoff from large wetland complexes which can rapidly flow into the lakes. Chl-a concentrations were correlated with TP concentrations, and ranged from 2.5 – 6.5 µg/L. As expected, concentrations were lowest in the headwater lakes and slightly higher in the flowage lakes. Average SD transparency ranged from 1.0 – 4.3 m (3 – 14 feet). The flowage lakes have lower clarity and high color. Lower SD transparency in these lakes is not a response to high chlorophyll (i.e. algae) concentrations. This natural staining originates from tannin compounds drained from wetlands and forests within the watersheds.

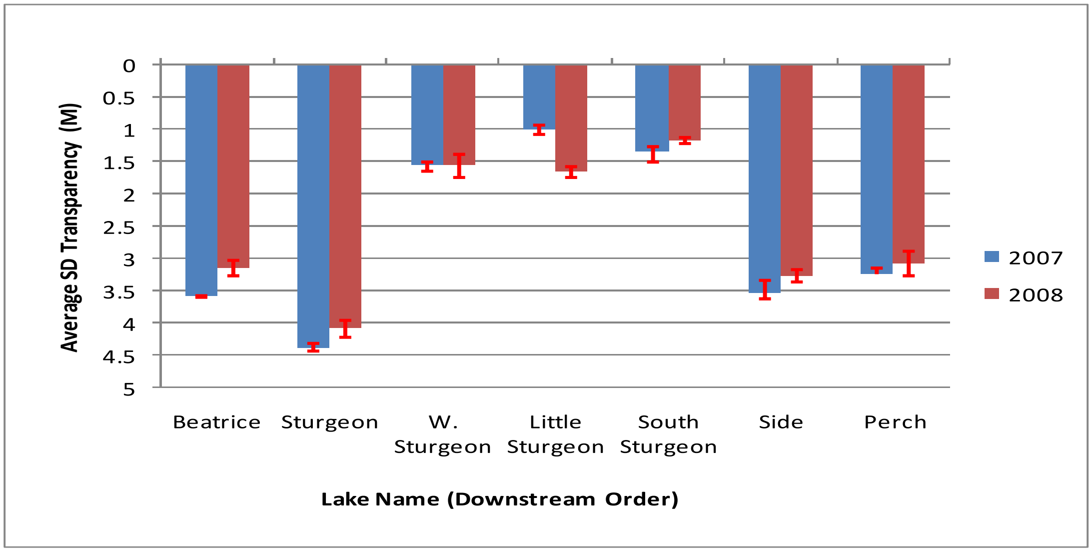
The MINLEAP model was utilized for lakes in the Sturgeon Chain based on the average of 2007 and 2008 TP, chl-a, and SD values. The model comparers observed data with those predicted by the model based on lake depth, and the lake's watershed. Complete modeling results for Beatrice, Sturgeon, S. Sturgeon, Perch, Side, and Little Sturgeon Lakes can be found in Appendix B. For all lakes (except South and Little Sturgeon) MINLEAP's predicted values were very close to observed. On the two flowage lakes, predicted values were higher than the observed. The MINLEAP model does not account for the bog-stained water observed in these lakes, and was not designed to model conditions in lakes with very short residence times. The model predicts a wide range of TP loads, based on lake and watershed characteristics. Estimated annual TP loads range from a minimum of 22 kilograms (48 pounds) on Beatrice Lake to over 1,500 kilograms (3,300 pounds) on Little Sturgeon

In summary, recent water quality monitoring indicate that lakes within the Sturgeon chain have excellent water quality. Headwater and seepage lakes with very small drainage areas have lower TP and chl-a concentrations (and higher SD transparencies) because watershed sources of nutrients are low. Flowage lakes with much larger drainage areas have higher TP and chl-a concentrations (and lower transparencies) but results are within NLF criteria and reflective of natural watershed characteristics.

Figure 22. 2007-08 Sturgeon Chain of Lakes total phosphorus, chlorophyll-a and Secchi transparency



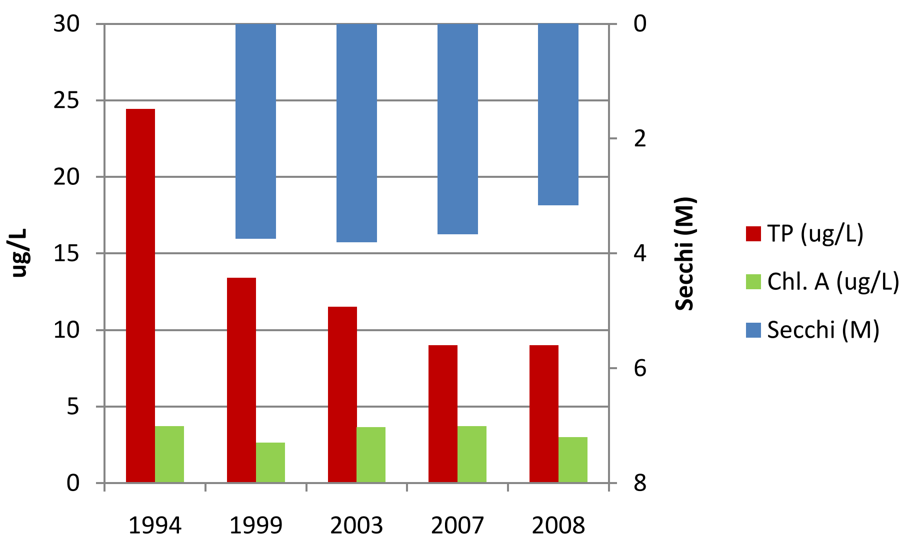




Water quality and CLMP trends

The Itasca County Soil and Water Conservation District has collected water quality data on Beatrice Lake periodically since 1994. Combining these data with available STORET and DNR / volunteer data allows for examination of water quality trends. TP, chl-a and SD transparency data are shown in Figure 23 (only years with at least 3 samples are shown). TP concentrations have been relatively stable around 10 µg/L since 1999. Concentrations were significantly higher in 1994. The area's precipitation was 10 – 15 centimeters (four-six inches) above normal in 1994 (http://www.climate.umn.edu/img/annual/p1994dept.gif) and increased runoff could be a cause of elevated TP concentrations. Chl-a concentrations have been stable around four µg/L in all years. No other lake in this HUC-11 watershed has sufficient data for trend determinations.

Figure 23. Beatrice Lake water quality trends (Itasca Co. SWCD, DNR, and STORET data)

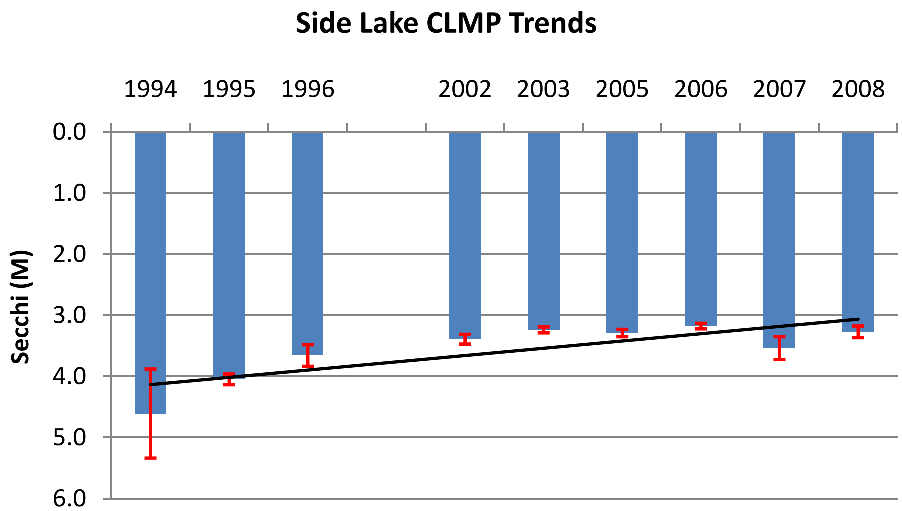


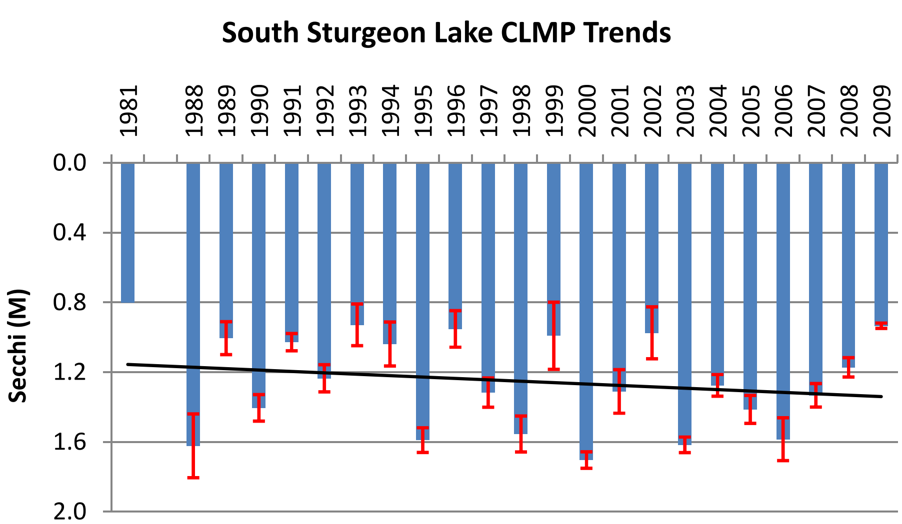
The MPCA has analyzed CLMP SD trends on several lakes in the Sturgeon Chain (Table 6; http://www.pca.state.mn.us/clmp-publications.html). Data have been collected for a number of years, ranging from 6 years on Hobson Lake to 23 years on South Sturgeon Lake. Transparency trends vary among the Sturgeon Chain. Two notable examples, Side and South Sturgeon, are shown in Figure 24. Side Lake is the only lake with a declining trend, and S. Sturgeon has the longest record, with yearly monitoring since 1988. Transparency in Side Lake has declined about one meter (three feet) from 1994-2008, although a data gap from 1997-2001 reduces the predictive power of the trend and the trend line is highly driven by the 1994 mean. The more continuous record from 2002-2008 indicates very stable transparency and no trend. A slight (i.e. possible) improvement in transparency has been detected on S. Sturgeon since 1988. Since the lake has a very short residence time (0.4 years, or ~ 150 days) it's likely that annual precipitation and climate trends have a strong influence on clarity. The long term mean is about 1.2 m (four feet) and annual averages have varied from 0.8 to 1.6 m (2.5 - 5.3 feet).

Table 6. CLMP trends for the Sturgeon Chain of Lakes

Lake Name	Lake ID	2000-2009 Assessment Cycle Mean SD (m)	Overall Mean SD (m)	Years of Data	Transparency Trend
Beatrice	31-0058	3.6	3.69	19	Possible Decline
South Sturgeon	31-0003	1.33	1.25	23	Possible Improvement
Perch	69-0932	3.39	3.41	10	No Trend
Side	69-0933	3.31	3.57	9	Declining
Sturgeon	69-0939	4.09	3.78	15	Possible Decline
Hobson	69-0923	2.98	3.91	6	Declining

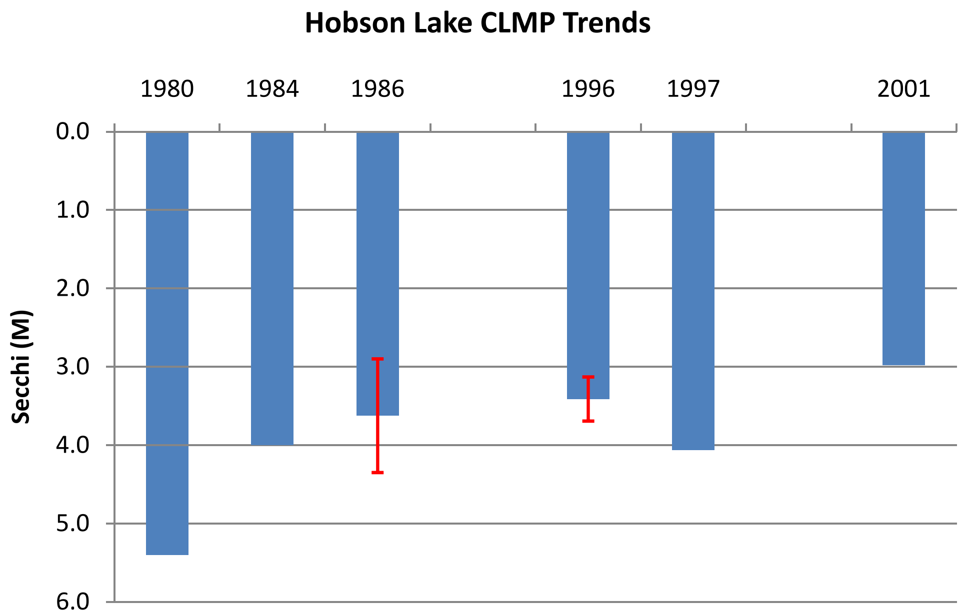
Figure 24. CLMP trends on Side and South Sturgeon Lakes, linear trend lines noted in black





Hobson Lake (69-0923) is the only additional lake in the Sturgeon Lake HUC-11 with assessment level data. Hobson is a small seepage lake, covering 25 ha (62 acres), located in the headwaters of the Shannon River. Lake-shore development is minimal, with most lakeshore owned by Hibbing Taconite. The lake was sampled four times in 2001. TP, chl-a, and SD transparency were all meeting NLF criteria. Since only one year of data was collected in the assessment cycle, assessment thresholds were adjusted by 20 percent (made more stringent), providing additional assurance that the lake is in compliance – per MPCA Assessment Guidance (MPCA, 2010). The limited and discontinuous CLMP SD record does not allow for trend assessment. Based on available data, summer-mean SD ranges from 3-4 m (10 – 13 feet) in most summers (Figure 25).

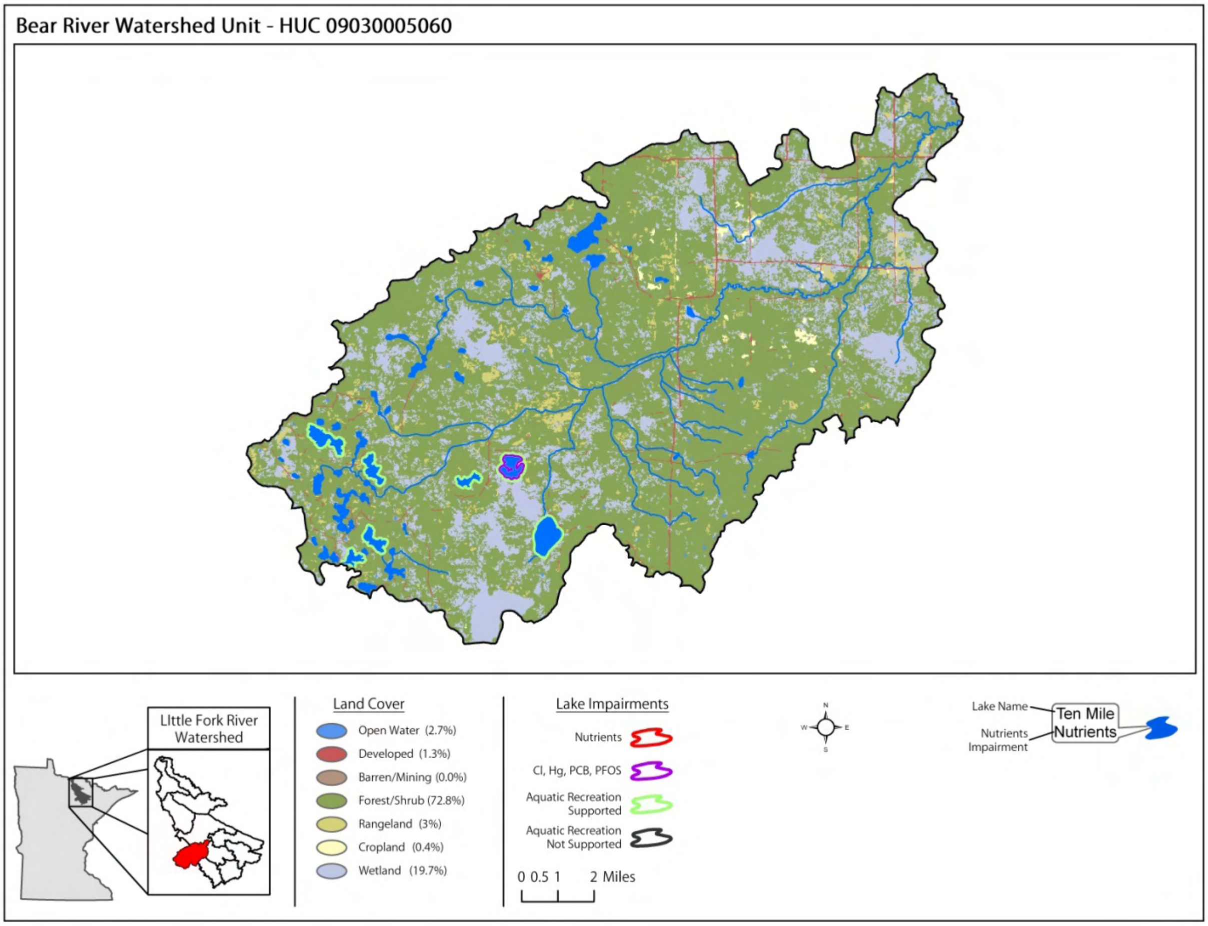
Figure 25. Summer-mean Secchi for Hobson Lake. Based on CLMP data



Bear River HUC 11 - 09030005060

The Bear River HUC-11 drains 435 km^2 (168 mi^2) in the south-west portion of the Little Fork watershed (Figure 26). Lakes are relatively numerous in this HUC-11 and compose the headwaters of the Bear River, the largest tributary to the Sturgeon River. The majority of lakes are undeveloped seepage lakes within George Washington State Forest. Seven lakes in this HUC-11 have assessment level data (Horsehead, Little Bear, Bear, Raddison, Napoleon, Walters, and Kelly) and one additional lake has sufficient CLMP data for trend determination (Owen). The assessed lakes were sampled by Itasca County Community College in 2008 and 2009 via a Surface Water Assessment Grant with the MPCA.

Figure 26. Bear River HUC-11 watershed. Bear River tributary lakes noted in red, headwater seepage lakes noted in orange



Raddison, Napoleon, Walters, and Kelly Lakes are in close proximity and form the headwaters of the Bear River watershed along the southwestern edge of the HUC-11 (Figure 26). The lakes have very small watersheds with small stream or sub-surface outlets. Walters Lake has the largest drainage area 11.3 km^2 (4.39 mi^2), but the smallest volume (and therefore the shortest residence time). Land use within the lake-sheds is > 90 percent forest and water. For example, nearly 50 percent of Napoleon Lake's watershed is composed of the lake itself (Table 7, Figure 28).

Table 7. Morphometry data for Bear River Watershed headwater lakes

Lake Name	Lake ID	Watershed Area km^2 (mi^2) [1]	Lake Area hectares (square miles)	Mean Depth meters (ft) [2]	Residence Time (years) [3]
Raddison	31-0284	2.8 (1.09)	80 (0.31)	7.6 (25)	8.2
Napoleon	31-0290	0.6 (0.23)	49 (0.19)	6.1 (20)	15.4
Kelly	31-0299	1.2 (0.49)	31 (0.12)	6.1 (20)	5.7
Walters	31-0298	11.3 (4.39)	46 (0.18)	2.4 (8)	0.4
Horsehead	31-0155	2.2 (0.85)	25 (0.10)	3.6 (12)	1.9
Little Bear	31-0156	1.9 (0.76)	49 (0.19)	4.5 (15)	4.5
Bear	31-0157	53.1 (20.5)	137 (0.53)	3.0 (10)	0.3

1. Excludes lake area; estimated
2. Estimated from MDNR Lakefinder Maps
3. Estimated from MINLEAP model

TP, chl-a, and SD data for these four lakes are shown in Figure 27. Values did not vary significantly among years. Overall the data indicate excellent, stable water quality (oligotrophic to mesotrophic conditions), well below NLF nutrient criteria. Walters Lake had slightly higher TP and chl-a concentrations, likely because it is naturally the most productive lake (i.e. largest drainage area, and smallest volume).

Horsehead, Little Bear, and Bear lakes are also in close proximity and form the headwaters of the Bear River. Bear Lake has the largest watershed area of the three lakes, draining most lakes in the HUC-11. A large wetland complex separates Bear from the upstream lakes (Figure 26). Horsehead and Little Bear are connected via a wetland complex, and they flow into the Bear River just downstream from its source at the outlet of Bear Lake. These three lakes have more lakeshore development than the previously discussed headwater lakes, although it's well within the range of other NLF lakes (Heiskary and Wilson, 2005). TP, chl-a, and SD data for these three lakes are shown in Figure 29. Bear Lake is the most productive of the three, with average TP concentrations of 27 µg/L; Horsehead and Little Bear lakes had average TP concentrations about 15 µg/L. Chl-a concentrations were relatively high in Bear as well, averaging 14 µg/L in 2009. Chl-a concentrations greater than 20 µg/L will typically be perceived as a nuisance bloom in northern Minnesota lakes (Heiskary and Walker, 1988). Chl-a concentrations peaked at 25µg/L in mid-summer 2009, this sample was likely taken during a mild bloom, and increased the seasonal average concentration and standard error (Figure 29). SD transparencies are lowest in Bear, due to the bog stained water from the wetland and forest dominated watershed. Horsehead and Little Bear lakes have much smaller watershed areas (Figure 30, Table 7) and have lower nutrient concentrations, higher transparencies, and reflect mesotrophic conditions.

Figure 27. 2008-09 Bear River watershed seepage lakes TP, Chl-a, and SD data

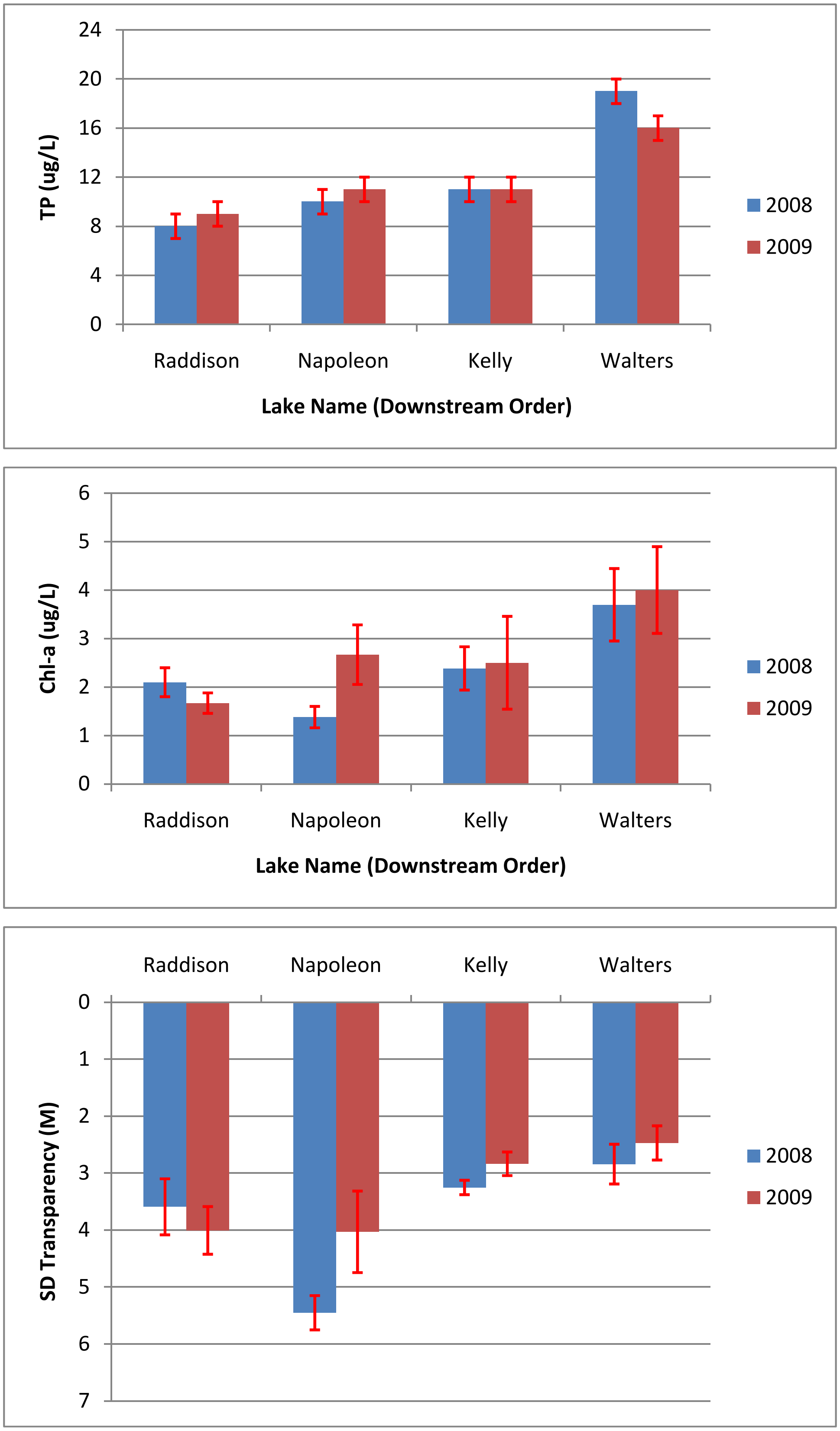


Figure 28. Headwater seepage lakes of the Bear River; Walters and Kelly Lakes are located SE and S of Owen Lake

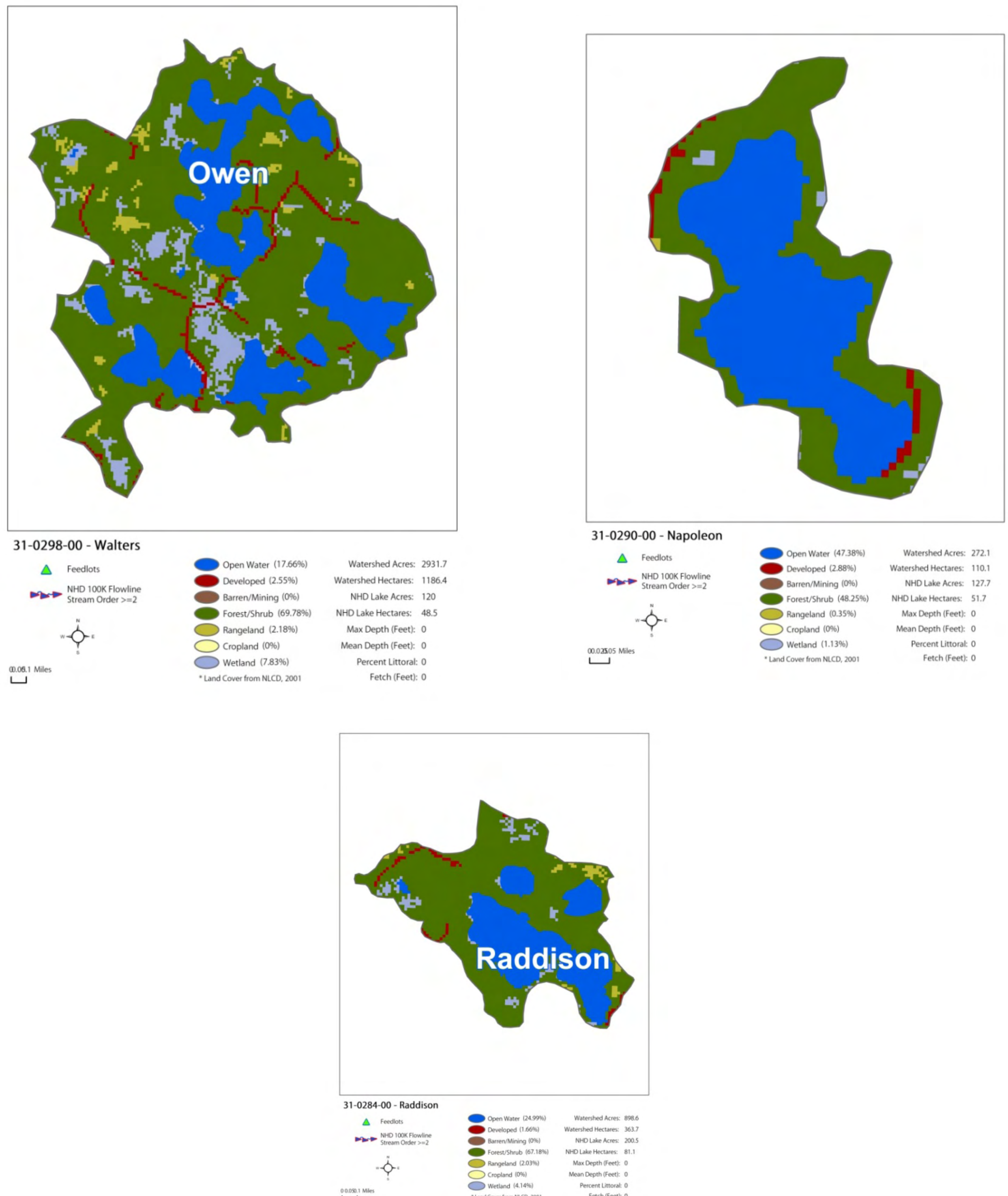


Figure 29. 2008-09 Bear River headwater lakes TP, Chl-a, and SD data

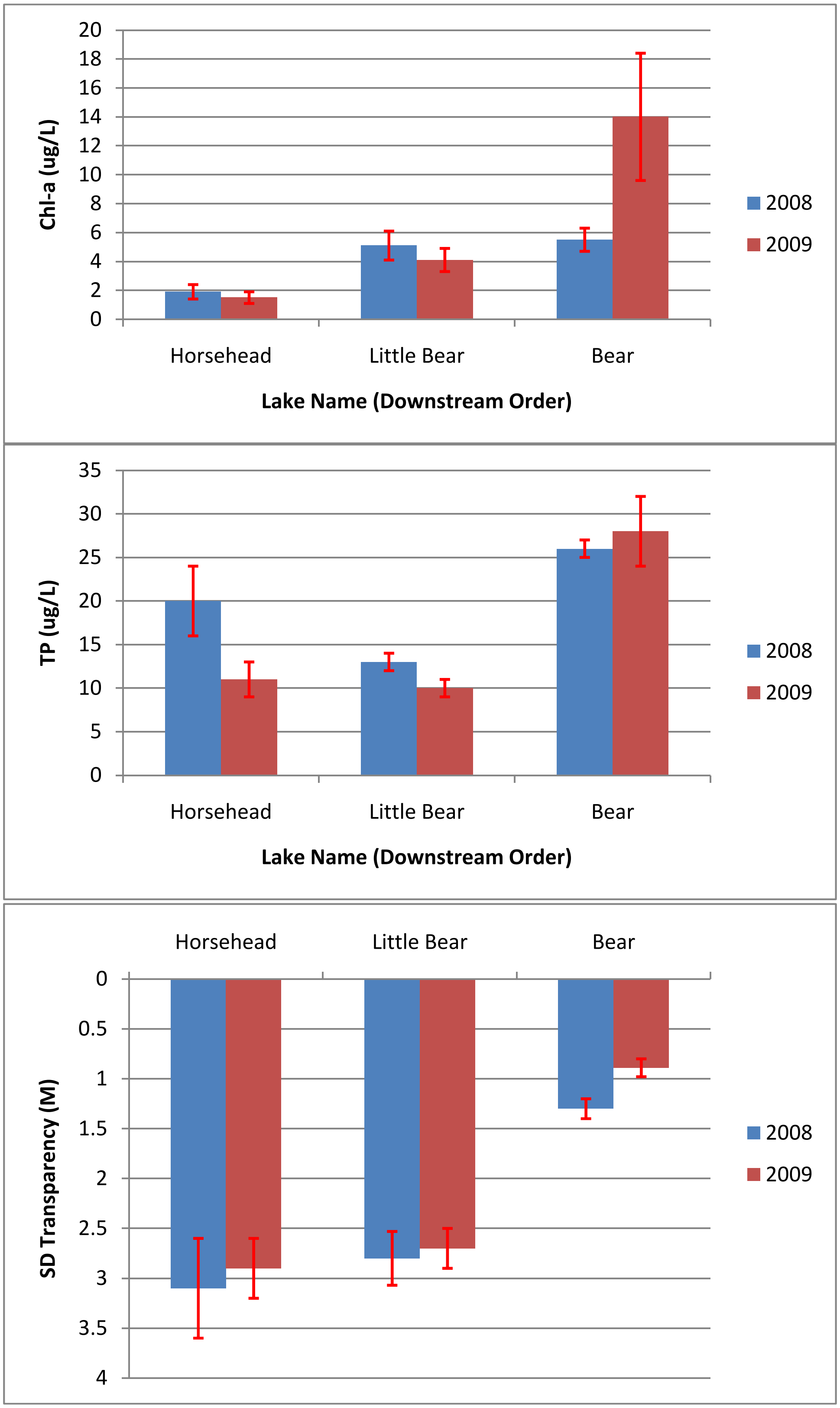
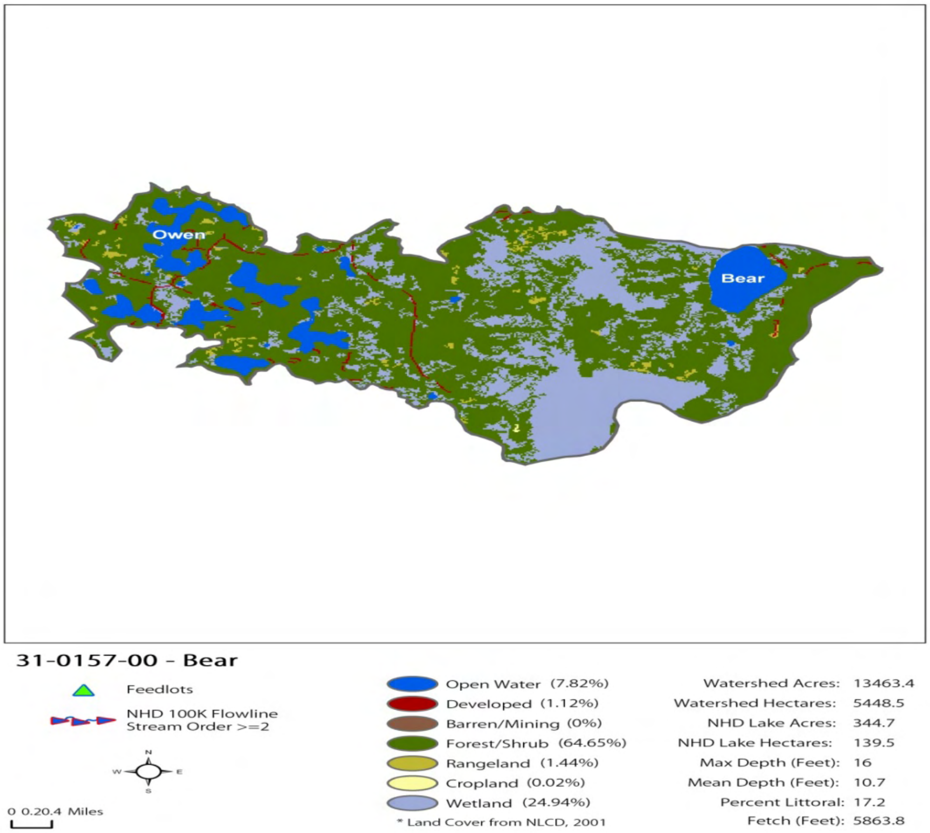
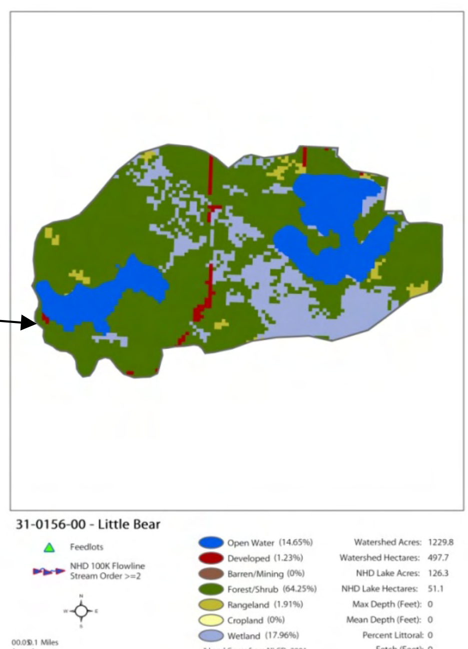


Figure 30. Bear, Little Bear and Horsehead Lakes watershed maps



Horsehead Lake



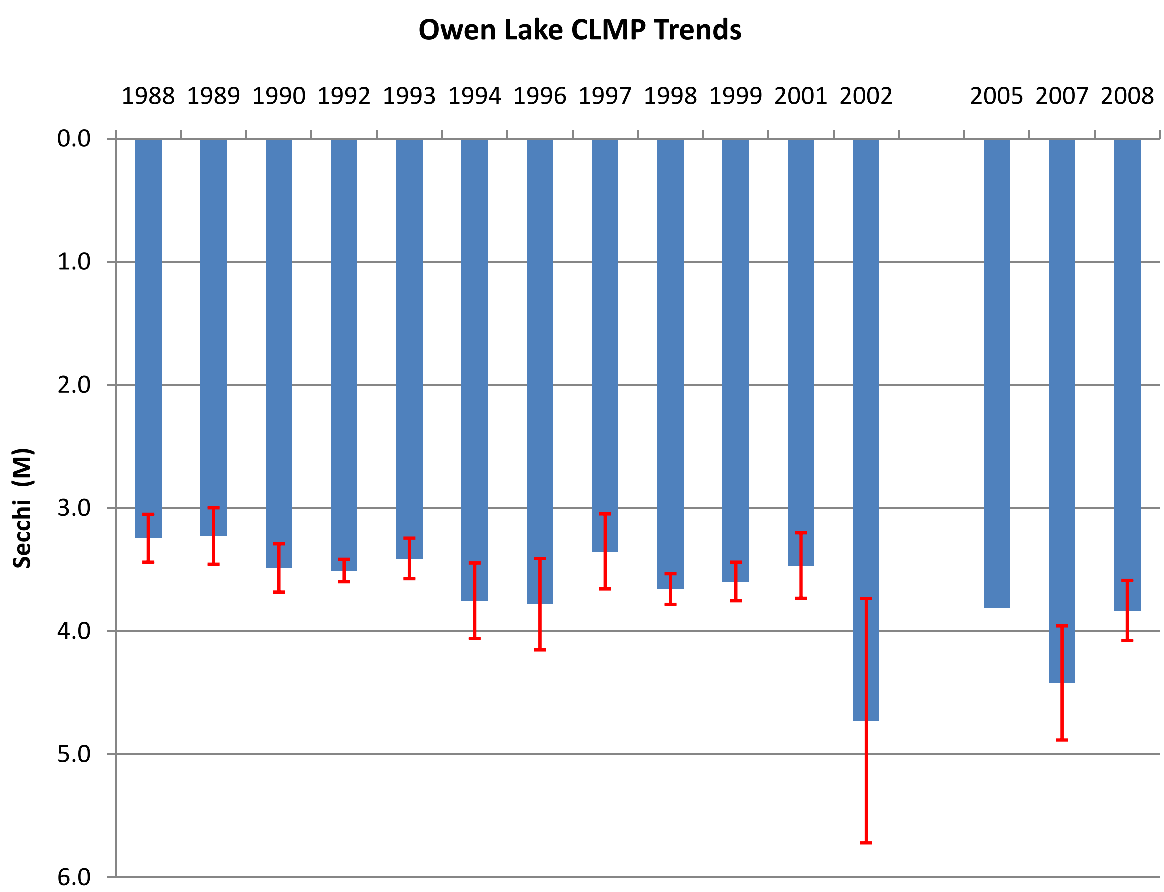
Little Bear Lake

The MINLEAP model was utilized for the assessed lakes in the Bear River watershed on the average of 2008 and 2009 TP, chl-a, and SD values. The model compares observed data with those predicted by the model based on lake depth, and the lake's watershed. Complete modeling results can be found in Appendix B. For all lakes (except Walters) MINLEAP's predicted values were not statistically different to observed. MINLEAP tended to over-predict TP on Walters because the model has difficulty predicting TP in small, flow-through lakes. Estimated TP loading rates ranged from 15 kg/yr (33 pounds/yr) on Napoleon Lake to 656 kg/yr (1,446 pounds/yr) on Bear Lake.

Water Quality Trends

One lake in this HUC-11, Owen (31-0292), has sufficient CLMP data for trend determinations. Owen lake has been monitored periodically since 1988 (Figure 31). It is likely that SD transparency has slightly improved overall, with an estimated increase (improvement) of 0.3 m (1.2 feet) per decade. As Owen is one of the more developed lakes in the HUC-11, it is important that monitoring continue to track annual variability and the effects of watershed landuse changes on lake water quality.

Figure 31. Summer-mean Secchi for Owen Lake. Based on CLMP data.



Trophic State Index

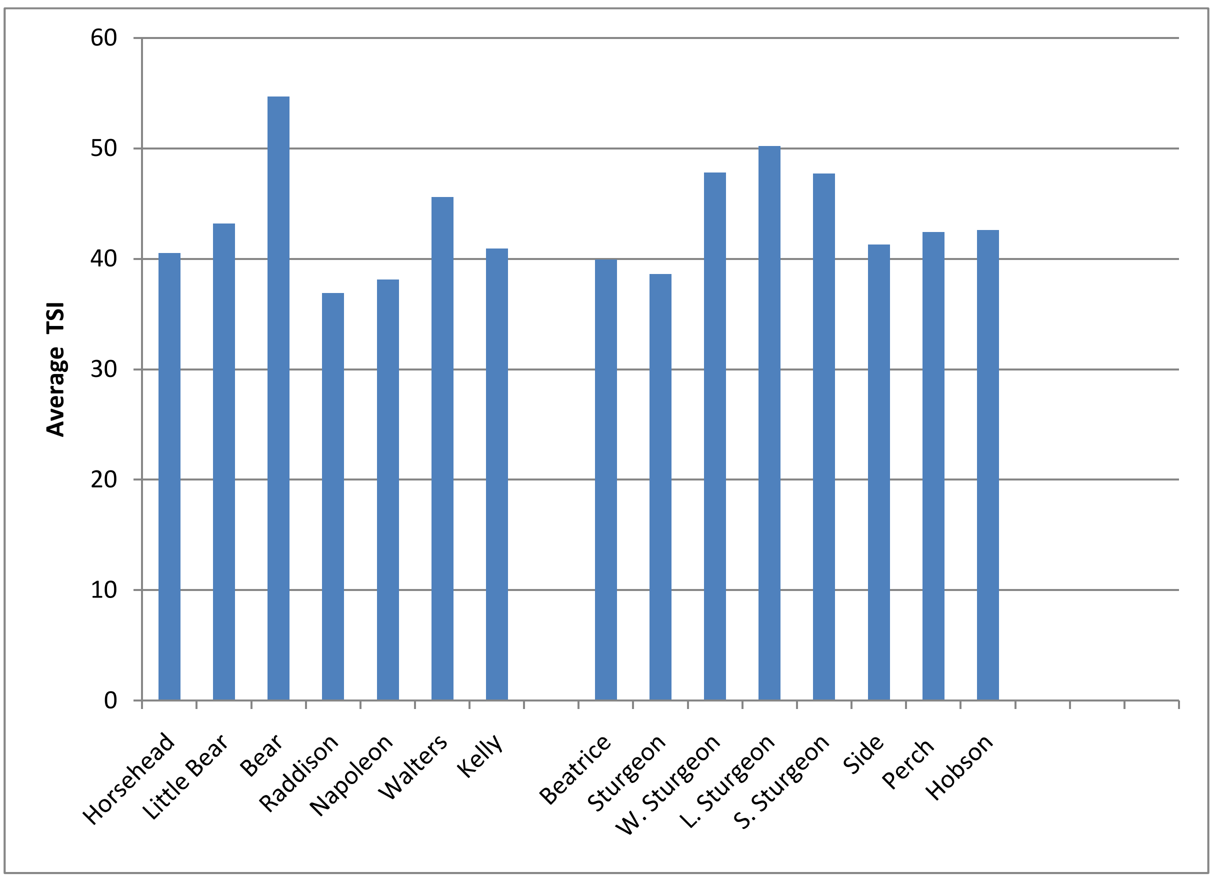
One way to evaluate the trophic status of a lake and to interpret the relationship between TP, chl-a, and Secchi disk transparency is Carlson's Trophic State Index (TSI) (Carlson 1977). TSI values are calculated as follows: Total Phosphorus TSI (TSIP) = 14.42 ln (TP) + 4.15

Chlorophyll-a TSI (TSIC) = 9.81 ln (Chl-*a*) + 30.6

Secchi disk TSI (TSIS) = 60 – 14.41 ln (SD)

TP and chl-a are in µg/L and Secchi disk is in meters. TSI values range from 0 (ultra-oligotrophic) to 100 (hypereutrophic). In this index, each increase of ten units represents a doubling of algal biomass. Comparisons of the individual TSI measures provides a bases for assessing the relationship among TP, chl-a, and Secchi. In general, the TSI values are in fairly close correspondence with each other. Natural bog staining reduces Secchi transparency, and drives up the average TSI in several lakes. The average of the TP, Chl-a, and Secchi TSI values for the assessed lakes in the Bear River and Sturgeon Lake HUC-11 watersheds are shown in Figure 32. All lakes except Bear are classified as mesotrophic. The three lakes with the highest average TSI values (Bear, Little Sturgeon, and South Sturgeon) have the largest watershed areas, and drain through large wetland complexes, where bog-stained runoff can naturally lower SD transparency and raise average TSI values.

Figure 32. Trophic State Index values for assessed lakes in the Bear River and Sturgeon Lake HUC-11 watersheds



Assessment Summary

The federal Clean Water Act 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) of the Clean Water Act, Minnesota is required to asses all waters of the state to determine if they meet water quality standards. Waters that do not meet standards (i.e., impaired waters) are added to the 303(d) list and updated every even-numbered year. In order for a lake to be considered impaired for aquatic recreation use, the average TP concentration must exceed the water quality standard for its ecoregion. In addition, either the chl-a concentration for the lake must exceed the standard or the Secchi data for the lake must be below the standard. A minimum of eight samples collected over two or more years are needed to conduct the assessment. There are numerous other water quality standards for which we assess Minnesota's water resources. An example is mercury found in fish tissue. If a water body is listed, an investigative Total Maximum Daily Load (TMDL) study must be conducted to determine the sources and extent of pollution, and to establish pollutant reduction goals needed to restore the resource to meet the determined water quality standards for its ecoregion. The MPCA is responsible for performing assessment activities, listing impaired waters, and conducting TMDL studies in Minnesota.

Little Fork watershed lakes were assessed relative to the NLF Class 2B ecoregion standards (Table 8). The assessment cycle mean TP concentration for all lakes is below this value (30 µg/L). Likewise, chl-a is below the standard for all lakes except Bear. Based on these results, all assessed lakes are meeting eutrophication criteria for NLF 2B waters (i.e. those waters that support a cool and warm water fishery). The Secchi standard in four lakes (Bear, Little Sturgeon, West Sturgeon, and South Sturgeon) is not being met, but this is due to natural bog staining, as discussed previously, and is not in response to elevated chl-a concentrations. Several lakes and most reaches of the Little Fork and Sturgeon Rivers are listed as impaired for mercury in fish tissue. That impairment was addressed through a statewide mercury TMDL. This TMDL is available here: **http://www.pca.state.mn.us/water/tmdl/tmdl-mercuryplan.html**.

Two lower reaches of the Little Fork River, from the Cross River to the Rainy River confluence (about 35 river miles or 56 km), are currently impaired for turbidity. Sources of the turbidity are primarily suspended sediment likely originating from streambank erosion during high flow events (Anderson et. al., 2006). The TMDL study is not yet underway. Research and monitoring, conducted by the MPCA and local partner agencies, is on-going.

Table 8. Eutrophication criteria by ecoregion and lake type, and assessment cycle mean values

	Ecoregion	TP	Chl-*a*	Secchi
		µg/L	µg/L	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**
Bear River HUC-11	Horsehead Lake (31-0155)	14	1.7	3
Bear River HUC-11	Little Bear Lake (31-0156)	11	4.6	2.8
Bear River HUC-11	Bear Lake (31-0157)	27	10.2	1.1
Bear River HUC-11	Raddison (31-0284)	9	1.8	4.3
Bear River HUC-11	Napoleon (31-0290)	11	2.2	4.6
Bear River HUC-11	Walters Lake (31-0298)	17	3.9	2.3
Bear River HUC-11	Kelly Lake (31-0299)	11	2.6	2.6
Sturgeon Lake HUC-11	Beatrice Lake (31-0158)	8.8	3.4	3.6
Sturgeon Lake HUC-11	Sturgeon Lake (69-0939-01)	9.0	2.6	4.1
Sturgeon Lake HUC-11	West Sturgeon Lake (69-0939-03)	15.7	5.4	1.6
Sturgeon Lake HUC-11	Little Sturgeon Lake (69-1290)	23.8	5.4	1.5
Sturgeon Lake HUC-11	South Sturgeon Lake (31-0003)	14.6	4.3	1.3
Sturgeon Lake HUC-11	Side Lake (69-0933)	11.0	3.4	3.3
Sturgeon Lake HUC-11	Perch Lake (69-0932	12.4	4.0	3.3
Sturgeon Lake HUC-11	Hobson Lake (69-0923)	12.0	3.9	2.9

Literature Cited

Anderson, A. 2001. A Study of the Little Fork River. Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Fisheries.

Anderson, J.A., N. Baratono, A. Streitz, J. Magner, and E.S. Verry, 2006. Effect of Historical Logging on Geomorphology, Hydrology, and Water Quality in the Little Fork River Watershed. Minnesota Pollution Control Agency and Ellen River Partners. 66p.

Carlson, R.E, 1977. A trophic state index for lakes. Limnology and Oceanography, 22:361-369.

Heiskary, S.A., and W.W. Walker, 1988. Developing nutrient criteria for Minnesota lakes. Lake and Res. Manage. 4:1-9.

Heiskary, S.A., and Wilson, C.B., 2005. Minnesota lake water quality assessment report: developing nutrient criteria, Minnesota Pollution Control Agency, 176 p.

Helgeson, JO, Lindholm, GF, and Ericson, DW, 1976, Water resources of the Little Fork River watershed, Northeastern Minnesota. U.S. Geological Survey Hydrologic Investigations Atlas HA-551, 2 sheets

Minnesota Pollution Control Agency, 2001. Rainy River, Basin Information Document, Minnesota Pollution Control Agency.

Minnesota Pollution Control Agency, 2008. Citizen Lake Monitoring Program Instruction Manual http://www.pca.state.mn.us/water/water-types-and-programs/surface-water/lakes/citizen-lake-monitoring-program/citizen-lake-monitoring-program.html#volunteers.

Minnesota Pollution Control Agency, 2009. Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List , 2010 Assessment Cycle.

Minnesota Pollution Control Agency, 2010. Guidance Manual for assessing the quality of Minnesota surface waters for determination of impairment: 305(b) report and 303(d) list.

Natural Resources Conservation Service, 2008. Rapid Watershed Assessment, Little Fork, Minnesota HUC 09030005, 19 p. http://www.mn.nrcs.usda.gov/technical/rwa/Assessments/reports/little_fork.pdf .

Olmanson, L.G., M.E. Bauer, and P.L. Brezonik, 2008. A 20-year Landsat water clarity census of Minnesota's 10,000 lakes. Remote Sensing of Environment, 112:4086-4097.

Schussler, J. and M. Nichols. 2009. Citizen lake monitoring program. 2008 report on the transparency of Minnesota Lakes. Minnesota Pollution Control Agency.

Wilson, C.B. and W.W. Walker, 1989. Development of lake assessment methods based upon the aquatic ecoregion concept. Lake and Reserv. Management. 5(2):11-22.

Appendix A

Morphometric characteristics for all lakes within the Little Fork River Watershed

Lake ID	Lake Name	County	HUC 11 Name	Trophic Status	Eco-region	Lake Area	Max Depth	Catchment Area	% Littoral	Assessment Status
						Acres	Feet	Acres		
69-1029	*Little Lost*	*St. Louis*	*Upper Little Fork River*		*NMW*	*18.63*				
69-0581	*Lost*	*St. Louis*	*Upper Little Fork River*		*NMW*	*734.63*	*20.00*		*95.0*	
69-1319	*Little Jammer*	*St. Louis*	*South Branch Little Fork R.*		*NLF*	*0.41*	*4.00*			
69-1308	*Deep Pond*	*St. Louis*	*South Branch Little Fork R.*		*NLF*	*0.61*	*15.00*			
69-0735	*Wheel*	*St. Louis*	*South Branch Little Fork R.*		*NLF*	*10.27*	*12.00*			
69-0734	*James*	*St. Louis*	*South Branch Little Fork R.*		*NLF*	*17.22*			*84.4*	
69-0737	*Jamer*	*St. Louis*	*South Branch Little Fork R.*		*NLF*	*18.16*	*6.50*			
69-0739	*Big Rosendahl*	*St. Louis*	*South Branch Little Fork R.*		*NLF*	*42.53*				
69-0671	*Pfeiffer*	*St. Louis*	*South Branch Little Fork R.*		*NLF*	*55.84*	*26.00*		*62.5*	
69-0732	*Little Sand*	*St. Louis*	*South Branch Little Fork R.*	*E*	*NLF*	*86.35*	*14.00*		*100.0*	*Insufficient Data*
69-0731	*Auto*	*St. Louis*	*South Branch Little Fork R.*		*NLF*	*95.23*	*25.00*		*78.0*	
69-0701	*Aerie*	*St. Louis*	*South Branch Little Fork R.*	*M*	*NLF*	*143.00*	*37.00*		*69.0*	*Insufficient Data*
69-0612	*Little Rice*	*St. Louis*	*South Branch Little Fork R.*		*NLF*	*181.55*	*3.50*			

69-0736	Sand	St. Louis	South Branch Little Fork R.	E	NLF	751.05	15.00			Insufficient Data
69-0669	Big Rice	St. Louis	South Branch Little Fork R.		NLF	1820.62	4.50		100.0	
69-1276	Pickles	St. Louis	South Branch Little Fork R.		NLF	7.46				
69-0733	Minnow	St. Louis	South Branch Little Fork R.			9.96				
69-1328	Pond 2	St. Louis	Bear & Dark River		NLF	2.85	35.00			
69-1385	Tremblon	St. Louis	Bear & Dark River	NLF	NLF	3.56				
69-1323	Louise	St. Louis	Bear & Dark River		NLF	3.84	10.00			
69-1399	Little Round	St. Louis	Bear & Dark River		NLF	5.09				
69-1317	Moska	St. Louis	Bear & Dark River		NLF	8.05	20.00			
69-1327	Pond 1	St. Louis	Bear & Dark River		NLF	8.38	15.00			
69-1320	Jean	St. Louis	Bear & Dark River		NLF	9.05	25.00			
69-1275	Unnamed	St. Louis	Bear & Dark River		NLF	1.78				
69-0792	Candle	St. Louis	Bear & Dark River		NLF	9.94				
69-0795	Gate	St. Louis	Bear & Dark River		NLF	10.48	27.00		84.4	
69-0791	Beaver	St. Louis	Bear & Dark River		NLF	13.36	27.00			
69-1007	McNiven	St. Louis	Bear & Dark River		NLF	13.59				
69-0788	Camp A	St. Louis	Bear & Dark River		NLF	15.77	30.00		82.7	

69-0789	*Lost Man*	*St. Louis*	*Bear & Dark River*		*NLF*	*16.12*				
69-0858	*Deepwater*	*St. Louis*	*Bear & Dark River*	*M*	*NLF*	*19.79*	*30.00*		*59.1*	*Insufficient Data*
69-0797	*Watercress*	*St. Louis*	*Bear & Dark River*		*NLF*	*26.34*	*4.00*			
69-0860	*Balkan*	*St. Louis*	*Bear & Dark River*		*NLF*	*27.82*				
69-0800	*Mud*	*St. Louis*	*Bear & Dark River*		*NLF*	*46.23*	*9.00*			
69-0798	*Moose*	*St. Louis*	*Bear & Dark River*		*NLF*	*61.93*	*5.00*			
69-0799	*Clear*	*St. Louis*	*Bear & Dark River*		*NLF*	*131.92*	*20.00*		*82.9*	
69-0796	*Leander*	*St. Louis*	*Bear & Dark River*		*NLF*	*244.21*	*45.00*		*24.0*	
69-0793	*Fourteen*	*St. Louis*	*Bear & Dark River*		*NLF*	*384.65*	*18.00*		*100.0*	
69-0801	*Jutila*	*St. Louis*	*Bear & Dark River*		*NLF*	*14.44*	*6.00*		*100.0*	
69-0794	*Thirteen*	*St. Louis*	*Bear & Dark River*	*M*	*NLF*	*76.23*	*17.00*		*92.0*	*Insufficient Data*
69-0790	*Dark*	*St. Louis*	*Bear & Dark River*		*NLF*	*221.73*	*31.00*		*59.0*	
69-1409	*Unnamed*	*St. Louis*	*Sturgeon Lake*		*NLF*	*2.49*				
69-1411	*Pothole 1*	*St. Louis*	*Sturgeon Lake*		*NLF*	*2.55*				
69-1398	*Dew*	*St. Louis*	*Sturgeon Lake*		*NLF*	*3.66*				
69-1412	*Pothole2*	*St. Louis*	*Sturgeon Lake*		*NLF*	*4.84*				
69-1413	*Pothole3*	*St. Louis*	*Sturgeon Lake*		*NLF*	*5.15*				

31-1306	Olson	Itasca	Sturgeon Lake	E	NLF	10.10				Insufficient Data
69-1410	Lost Pond	St. Louis	Sturgeon Lake		NLF	7.50				
31-0062	Unnamed	Itasca	Sturgeon Lake	E	NLF	9.21				Insufficient Data
69-0916	Dollar	St. Louis	Sturgeon Lake		NLF	9.81	32.00		75.0	
31-0061	Unnamed	Itasca	Sturgeon Lake	E	NLF	12.59				Insufficient Data
31-0059	Johnson	Itasca	Sturgeon Lake	H	NLF	13.47				Insufficient Data
31-0063	Unnamed	Itasca	Sturgeon Lake		NLF	14.78				
69-0934	Pickerel	St. Louis	Sturgeon Lake		NLF	29.61	47.00		78.5	
31-0060	Section Eleven	Itasca	Sturgeon Lake	E	NLF	33.86				Insufficient Data
69-0919	Loven	St. Louis	Sturgeon Lake		NLF	35.28	20.00			
69-0910	Shoe Pack	St. Louis	Sturgeon Lake		NLF	36.55	30.00		89.8	
69-0877	Stingy	St. Louis	Sturgeon Lake		NLF	37.75				
69-0914	McCormack	St. Louis	Sturgeon Lake		NLF	48.42	25.00		39.0	
69-0917	Rock	St. Louis	Sturgeon Lake		NLF	63.94	50.00			
69-0922	Rat	St. Louis	Sturgeon Lake		NLF	70.89	20.00			
69-0913	Gansey	St. Louis	Sturgeon Lake		NLF	72.06	25.00			
69-0918	Clearwater	St. Louis	Sturgeon Lake		NLF	73.75	30.00		55.0	

31-0058	*Beatrice*	*Itasca*	*Sturgeon Lake*	*O*	*NLF*	*112.52*	*30.00*		*62.2*	*Full Support*
69-0939-03	*West Sturgeon*	*St. Louis*	*Sturgeon Lake*	*M*	*NLF*	*112.55*				*Full Support*
69-0906	*Day*	*St. Louis*	*Sturgeon Lake*		*NLF*	*122.33*	*14.00*		*100.0*	
69-0925	*Shannon*	*St. Louis*	*Sturgeon Lake*		*NLF*	*122.98*	*10.00*		*100.0*	
69-0911	*Island*	*St. Louis*	*Sturgeon Lake*		*NLF*	*127.91*	*15.00*		*100.0*	
69-0939-02	*Middle Sturgeon*	*St. Louis*	*Sturgeon Lake*		*NLF*	*129.14*	*31.00*			
69-0912	*Dewey*	*St. Louis*	*Sturgeon Lake*		*NLF*	*183.50*	*38.00*		*46.2*	
31-0003	*South Sturgeon*	*Itasca*	*Sturgeon Lake*	*M*	*NLF*	*199.29*	*43.00*		*23.0*	*Full Support*
69-0859	*Long*	*St. Louis*	*Sturgeon Lake*		*NLF*	*238.40*	*37.00*		*47.0*	
69-1290	*Little Sturgeon*	*St. Louis*	*Sturgeon Lake*	*M*	*NLF*	*301.55*	*22.00*			*Full Support*
69-0932	*Perch*	*St. Louis*	*Sturgeon Lake*	*M*	*NLF*	*339.89*	*21.00*		*5.7*	*Full Support*
69-0933	*Side*	*St. Louis*	*Sturgeon Lake*	*O*	*NLF*	*368.44*	*31.00*		*41.1*	*Full Support*
69-0939-01	*Sturgeon*	*St. Louis*	*Sturgeon Lake*	*O*	*NLF*	*1576.94*	*80.00*			*Full Support*
69-0939	*Sturgeon*	*St. Louis*	*Sturgeon Lake*		*NLF*	*1819.64*	*75.00*		*4.1*	
69-0915	*Sunset*	*St. Louis*	*Sturgeon Lake*		*NLF*	*7.04*				
69-0909	*Unnamed*	*St. Louis*	*Sturgeon Lake*		*NLF*	*9.30*				
69-1025	*Unnamed*	*St. Louis*	*Sturgeon Lake*		*NLF*	*11.26*				

69-0924	Elk	St. Louis	Sturgeon Lake		NLF	11.97				
69-0929	Unnamed	St. Louis	Sturgeon Lake		NLF	12.10				
69-1024	Unnamed	St. Louis	Sturgeon Lake		NLF	13.72				
69-0920	Stuart	St. Louis	Sturgeon Lake		NLF	27.83	40.00			
69-0923	Hobson	St. Louis	Sturgeon Lake	O	NLF	62.54	40.00		62.0	Full Support
69-0859-02	LONG (NORTH BASIN)	St. Louis	Sturgeon Lake		NLF	49.82				
69-0859-01	LONG (MAIN BASIN)	St. Louis	Sturgeon Lake		NLF	188.66	35.00			
69-1388	Shoe/Osbome	St. Louis	Sturgeon River		NMW	1.80				
69-0931	Luna	St. Louis	Sturgeon River		NMW	19.57	25.00			
69-0930	Elbow	St. Louis	Sturgeon River		NLF	24.30				
69-0927	Bathtub	St. Louis	Sturgeon River		NLF	10.32				
69-0926	Braun	St. Louis	Sturgeon River		NLF	11.89				
69-0928	Near Side	St. Louis	Sturgeon River		NLF	16.58				
31-0283	Unnamed	Itasca	Bear River		NLF	0.18				
31-1170	Unnamed	Itasca	Bear River		NLF	1.80				
31-1172	Unnamed	Itasca	Bear River		NLF	1.86				
31-0066	Unnamed	Itasca	Bear River		NLF	9.36				
31-1175	Unnamed	Itasca	Bear River		NLF	11.03				

31-0163	*Unnamed*	*Itasca*	*Bear River*	*E*	*NLF*	*11.44*				*Insufficient Data*
31-0166	*Piel*	*Itasca*	*Bear River*		*NLF*	*11.78*				
31-0300	*Unnamed*	*Itasca*	*Bear River*		*NLF*	*14.35*				*Insufficient Data*
31-0295	*Bass*	*Itasca*	*Bear River*	*E*	*NLF*	*20.00*				*Insufficient Data*
31-0164	*Unnamed (Seventeen)*	*Itasca*	*Bear River*	*E*	*NLF*	*21.77*				*Insufficient Data*
31-0286	*Beaver*	*Itasca*	*Bear River*	*E*	*NLF*	*22.00*				*Insufficient Data*
31-0194	*Klingendiel*	*Itasca*	*Bear River*	*M*	*NLF*	*30.23*				*Insufficient Data*
31-0291	*Kelly*	*Itasca*	*Bear River*	*E*	*NLF*	*30.53*				*Insufficient Data*
31-0319	*Rat*	*Itasca*	*Bear River*		*NLF*	*52.71*				
31-0302	*May*	*Itasca*	*Bear River*		*NLF*	*62.37*	*15.00*		*100.0*	
31-0155	*Horsehead*	*Itasca*	*Bear River*	*M*	*NLF*	*70.36*	*40.00*		*81.6*	*Full Support*
31-0299	*Kelly*	*Itasca*	*Bear River*	*O*	*NLF*	*77.40*	*37.00*		*5.0*	*Full Support*
31-0289	*Lost*	*Itasca*	*Bear River*	*M*	*NLF*	*85.41*	*25.00*		*52.0*	*Insufficient Data*
31-0320	*Wilson*	*Itasca*	*Bear River*	*M*	*NLF*	*86.10*			*53.1*	*Insufficient Data*
31-0301	*Otter*	*Itasca*	*Bear River*	*M*	*NLF*	*109.47*				*Insufficient Data*
31-0162	*Little Moose*	*Itasca*	*Bear River*		*NLF*	*123.19*	*20.00*			*Insufficient Data*
31-0156	*Little Bear*	*Itasca*	*Bear River*	*O*	*NLF*	*126.28*	*35.00*		*68.3*	*Full Support*
31-0284	*Raddison*	*Itasca*	*Bear River*	*O*	*NLF*	*200.51*	*40.00*		*36.0*	*Full Support*
31-0292	*Owen*	*Itasca*	*Bear River*	*E*	*NLF*	*271.40*	*35.00*		*76.8*	*Insufficient Data*

31-0158	*Thistledew*	*Itasca*	*Bear River*	*M*	*NLF*	*324.19*	*45.00*		*23.3*	*Insufficient Data*
31-0157	*Bear*	*Itasca*	*Bear River*	*E*	*NLF*	*344.70*	*16.00*		*79.1*	*Full Support*
31-1164	*Unnamed*	*Itasca*	*Bear River*		*NLF*	*4.06*				
31-0961	*Unnamed*	*Itasca*	*Bear River*		*NLF*	*6.50*				
31-0962	*Unnamed*	*Itasca*	*Bear River*		*NLF*	*6.62*				
31-0960	*Unnamed*	*Itasca*	*Bear River*		*NLF*	*7.77*				
31-0071	*Wamp*	*Itasca*	*Bear River*	*E*	*NLF*	*14.85*				*Insufficient Data*
31-0297	*Rainbow*	*Itasca*	*Bear River*		*NLF*	*15.70*	*23.00*			*Insufficient Data*
31-0167	*Eve*	*Itasca*	*Bear River*		*NLF*	*16.31*				
31-0165	*Unnamed*	*Itasca*	*Bear River*		*NLF*	*16.78*				
31-0287	*Unnamed*	*Itasca*	*Bear River*	*E*	*NLF*	*17.12*				*Insufficient Data*
31-0310	*Unnamed*	*Itasca*	*Bear River*	*E*	*NLF*	*18.47*				*Insufficient Data*
31-0288	*Unnamed*	*Itasca*	*Bear River*		*NLF*	*25.45*				
31-0064	*Unnamed (Fox)*	*Itasca*	*Bear River*		*NLF*	*25.50*				*Insufficient Data*
31-0065	*Spring*	*Itasca*	*Bear River*	*M*	*NLF*	*29.33*	*15.00*			*Insufficient Data*
31-0322	*Unnamed*	*Itasca*	*Bear River*	*E*	*NLF*	*30.32*				*Insufficient Data*
31-0161	*Little Drew*	*Itasca*	*Bear River*	*M*	*NLF*	*33.87*				*Insufficient Data*
31-0168	*Tuber*	*Itasca*	*Bear River*	*E*	*NLF*	*35.92*				*Insufficient Data*
31-0285	*Blind Pete*	*Itasca*	*Bear River*	*M*	*NLF*	*69.53*	*20.00*		*93.0*	*Insufficient Data*
31-0296	*Long*	*Itasca*	*Bear River*	*O*	*NLF*	*80.11*	*39.00*		*57.1*	*Insufficient Data*

31-0298	Walters	Itasca	Bear River	M	NLF	119.95	19.00		86.8	Full Support
31-0290	Napoleon	Itasca	Bear River	O	NLF	127.72	30.00		33.9	Full Support
31-1307	Unnamed	Itasca	Middle Little Fork River		NLF	1.15				
31-1308	Unnamed	Itasca	Middle Little Fork River		NMW	6.99				
31-0323	Unnamed	Itasca	Middle Little Fork River		NMW	2.78				
31-1177	Unnamed	Itasca	Middle Little Fork River		NMW	3.95				
31-1056	Hope	Itasca	Middle Little Fork River		NMW	6.58				
31-0173	Unnamed	Itasca	Middle Little Fork River		NMW	9.60				
31-0172	Unnamed (Herrigan)	Itasca	Middle Little Fork River		NMW	10.40				
31-0185	Unnamed	Itasca	Middle Little Fork River		NLF	11.81				Insufficient Data
31-0184	Sun	Itasca	Middle Little Fork River		NMW	12.79				Insufficient Data
31-0324	Candy	Itasca	Middle Little Fork River		NMW	13.77				
31-0186	Perch	Itasca	Middle Little Fork River		NLF	16.02				Insufficient Data
31-0171	Crum	Itasca	Middle Little Fork River	M	NMW	18.05	14.00		100.0	Insufficient Data
31-0325	Unnamed	Itasca	Middle Little Fork River		NMW	39.10				
31-0175	Button Bow	Itasca	Middle Little Fork River	M	NMW	79.95	18.00		9.2	Insufficient Data
31-0329	Unnamed(Little Horseshoe)	Itasca	Middle Little Fork River	E	NLF	12.10	37.00			Insufficient Data

31-0330	*Island*	*Itasca*	*Middle Little Fork River*	*E*	*NLF*	*13.72*				*Insufficient Data*
31-0182	*Unnamed (Blue Ridge)*	*Itasca*	*Middle Little Fork River*		*NLF*	*14.02*	*33.00*			
31-0170	*Lost*	*Itasca*	*Middle Little Fork River*	*E*	*NMW*	*24.68*	*24.00*			*Insufficient Data*
31-0174	*Herrigan*	*Itasca*	*Middle Little Fork River*	*M*	*NMW*	*25.89*				*Insufficient Data*
36-0004	*Pocquette*	*Koochiching*	*Lower Middle Little Fork R.*		*NMW*	*41.65*	*65.00*			
36-0005	*Franklin*	*Koochiching*	*Lower Middle Little Fork R.*		*NMW*	*107.49*	*25.00*			
36-0007	*Myrtle*	*Koochiching*	*Lower Middle Little Fork R.*		*NMW*	*165.47*				
36-0003	*Unnamed*	*Koochiching*	*Lower Middle Little Fork R.*		*NMW*	*9.93*				
36-0001	*Nett*	*Koochiching*	*Nett Lake*		*NMW*	*7268.99*	*7.50*			

Appendix B

Lake chemistry and MINLEAP results for assed lakes

Lake ID	Lake Name	TP Mean	TP MINLEAP	Chl –a Mean	Chl-a MINLEAP	Secchi Mean	Secchi MINLEAP	Average TP Inflow	TP Load	Chiadudani/ Vighi [2]	Phos. Retention	Outflow	Residence Time	Areal Load
		ug/L	ug/L	ug/L	ug/L	meters	meters	ug/L	kg/yr	ug/L	%	hm3/yr	years	m/yr
31-0058	Beatrice	8.8	14	3.4	3.2	3.59	3.9	39	22		64	0.57	3.6	1.26
69-0939	Sturgeon [3]	9	14	2.7	3	4.1	4	58	565		76	9.7	8.1	1.32
31-0003	South Sturgeon	14.6	33	4.3	10.7	1.36	1.9	52	806	10.4	38	15.37	0.4	19.08
69-0932	Perch	12.4	14	4.1	3.3	3.37	3.9	69	46		79	0.67	9.3	0.49
69-0933	Side	11	11	3.4	2.1	3.33	5	74	42		86	0.56	20.2	0.38
69-0923	Hobson [1]	11.7	15	3.9	3.5	2.98	3.7	66	10	10.7	77	0.15	7.9	0.58
31-0155	Horsehead [1]	13.8	23	1.7	6.4	3.02	2.6	56	31	10.1	59	0.54	1.9	1.91
31-0299	Kelly [1]	10.9	16	2.6	3.8	2.96	3.5	60	20	8.8	73	0.33	5.7	1.06
31-0156	Little Bear [1]	11.2	18	4.6	4.4	2.76	3.2	60	31	18	70	0.52	4.5	1.02
31-0284	Raddison	8.6	14	1.8	3.1	4.3	4	61	46	17.1	77	0.75	8.2	0.93
31-0157	Bear	27.1	34	10.2	11.4	1.07	1.9	53	656	18.4	36	12.39	0.3	8.88
31-0298	Walters	17.2	33	3.9	10.7	2.33	1.9	53	143	26.1	39	2.68	0.4	5.52
31-0290	Napoleon	10.6	12	2.2	2.5	4.55	4.5	73	15	18.7	84	0.2	15.4	0.4
69-1290	Little Sturgeon	23.8	39	5.4	14.1	1.56	1.6	52	1506		25	28.77	0.1	23.58

1. watershed areas are estimated for these headwater, seepage lakes
2. Only calculated for those lakes with alkalinity data
3. Main basin water quality data