Mille Lacs Lake 48-0002-00 AITKIN, MILLE LACS, & CROW WING COUNTY

Lake Water Quality

Summary

Lake Mille Lacs is located near Garrison, MN and covers portions of both Aitkin and Mille Lacs Counties. With a surface area of 128,223 acres, it is the second largest lake in Minnesota. As a fishery, it produces more walleye than all the state's hatcheries combined. This excellent resource is a significant contributor to the state economy.

Lake Mille Lacs has 14 perennial inlets and one outlet, which classifies it as a drainage lake. It also has over 100 intermittent ditches and culverts draining to it. The Rum River flows out of the southwest region of the lake and eventually drains into the Mississippi.

Water quality data has been collected for Lake Mille Lacs off and on since 1971. These data were collected by a number of organizations including the Minnesota Pollution Control Agency (MPCA), Department of Natural Resources (DNR), the Lake Mille Lacs Property Owners Association, and the Mille Lacs Band of Chippewa. These data show that Lake Mille Lacs is mesotrophic.

The Lake Mille Lacs Property Owners Association and the Mille Lacs Lake Watershed Group are involved in many aspects of the lake. They have participated in lake monitoring and stream inlet/outlet monitoring, shoreline restoration, spring clean-ups, and ice fishing information.

Table 1. Mille Lacs Lake location and key physical characteristics.

Location Data	
MN Lake ID:	48-0002-00
County:	Aitkin, Mille Lacs, & Crow Wing
Ecoregion:	Northern Lakes and Forest
Major Drainage Basin:	Upper Mississippi River
Latitude/Longitude:	46.23333333/-93.64194444
Invasive Species:	Eurasian watermilfoil Zebra mussels Spiny Water Flea

Physical Characteristics	
Surface area (acres):	128,223
Littoral area (acres):	33,129
% Littoral area:	26%
Max depth (ft), (m):	43 (f), 13.1 (m)
Inlets:	14 perennial and over 100 intermittent ditches, culvert, and tributaries
Outlets:	1
Public Accesses:	12

Table 2. Availability of primary data types for Mille Lacs Lake.

Data Availability

Transparency data		Excellent data source from 1993 and 1997-2012.
Chemical data		Excellent data source from 2005-2012.
Inlet/Outlet data		Scattered data available through multiple programs.

Recommendations **For recommendations refer to page 19.**

Lake Map

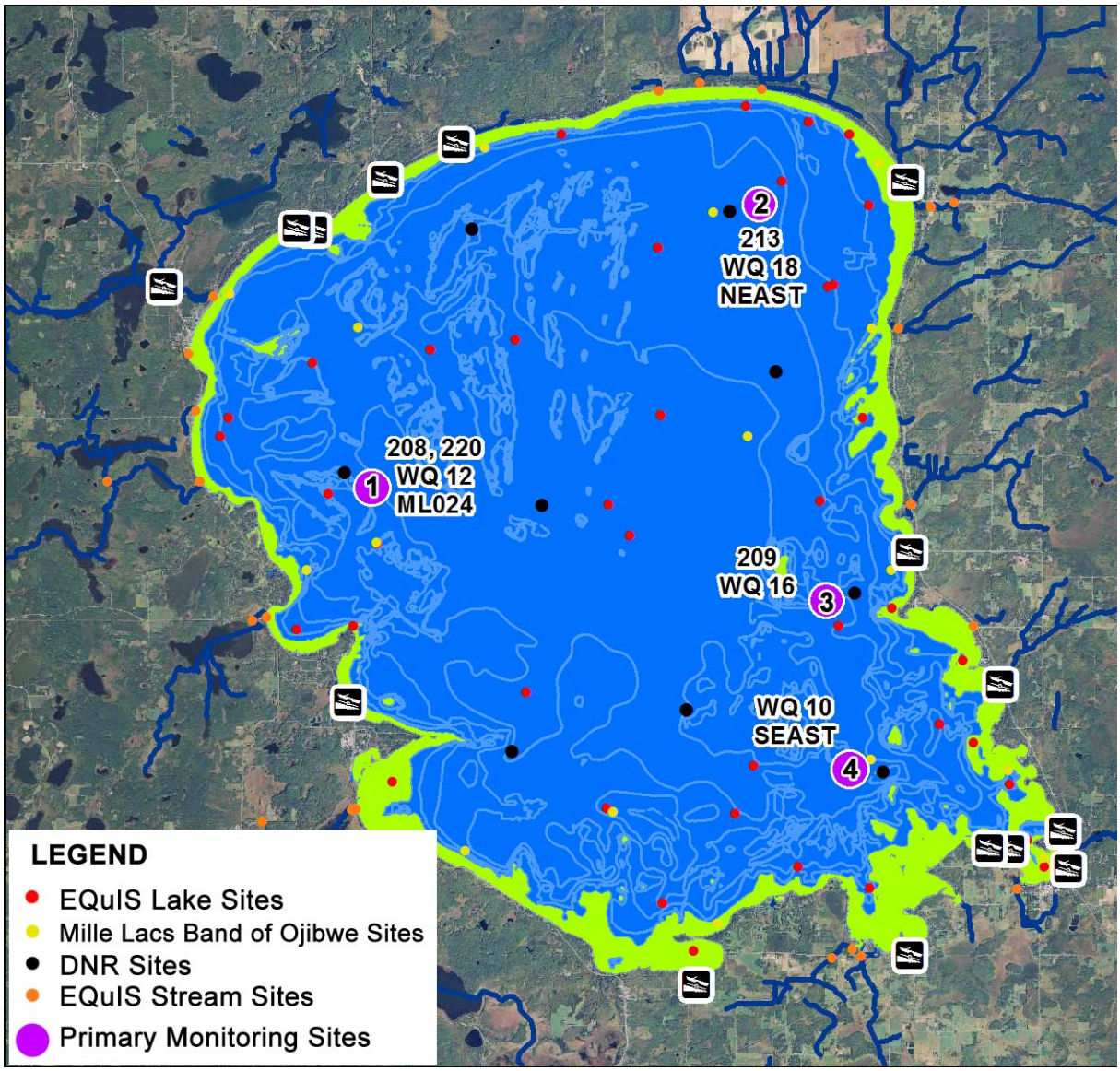


Figure 1. Map of Mille Lacs Lake with 2010 aerial imagery and illustrations of lake depth contour lines, sample site locations, inlets and outlets, and public access points. The light green areas in the lake illustrate the littoral zone, where the sunlight can usually reach the lake bottom, allowing aquatic plants to grow.

Table 3. Monitoring programs and associated monitoring sites. MLBO: Mille Lacs Band of Ojibwe, EQuIS:EQuIS submitted Data, MNDNR: Minnesota Department of Natural Resources.

Lake Site	Depth (ft)	Monitoring Programs
1	32	MLBO: 2005-2012; EQuIS: 1993, 2000-2001, 2007; MNDNR: 2005-2012
2	28	MLBO: 2005-2012; EQuIS: 1997-2012; MNDNR: 2005-2012
3	25	EQuIS: 1993, 2002-2006, 2009-2010; MNDNR: 2005-2012
4	34	MLBO: 2005-2012; MNDNR: 2009-2012

Average Water Quality Statistics

The information below describes available chemical data for Mille Lacs Lake through 2012 (Table 4). The data is from combined site 2.

Minnesota is divided into 7 ecoregions based on land use, vegetation, precipitation and geology. The MPCA has developed a way to determine the "average range" of water quality expected for lakes in each ecoregion. For more information on ecoregions and expected water quality ranges, see page 11.

Table 4. Water quality means compared to ecoregion ranges and impaired waters standard.

Parameter	Mean	Ecoregion Range[1]	Impaired Waters Standard[2]	Interpretation
Total phosphorus (ug/L)	21.9	14 – 27	> 30	Results are within the expected range for the ecoregion.
[3]Chlorophyll *a* (ug/L)	5.7	4 – 10	> 9	
Chlorophyll *a* max (ug/L)	17.5	< 15		
Secchi depth (ft)	11.3	8 – 15	< 6.5	
Dissolved oxygen	Dimictic *see page 8*			Dissolved oxygen depth profiles show that the deep areas of the lake are anoxic in late summer.
Total Kjeldahl Nitrogen (mg/L)	0.50	<0.4 – 0.75		Indicates insufficient nitrogen to support summer nitrogen-induced algae blooms.
Alkalinity (mg/L)	92	40 – 140		Indicates a low sensitivity to acid rain and a good buffering capacity.
Color (Pt-Co Units)	11.6	10 – 35		Indicates clear water with little to no tannins (brown stain).
pH	8.2	7.2 – 8.3		Indicates a hardwater lake. Lake water pH less than 6.5 can affect fish spawning and the solubility of metals in the water.
Chloride (mg/L)	3.2	0.6 – 1.2		Above the expected range for the ecoregion, but still considered low level.
Total Suspended Solids (mg/L)	6.0	<1 – 2		Above the expected range for the ecoregion.
Conductivity (umhos/cm)	185	50 – 250		Above the expected range for the ecoregion.
Total Nitrogen : Total Phosphorus	23:1	25:1 – 35:1		Indicates the lake is phosphorus limited, which means that algae growth is limited by the amount of phosphorus in the lake.

[1]The ecoregion range is the 25th-75th percentile of summer means from ecoregion reference lakes
[2]For further information regarding the Impaired Waters Assessment program, refer to http://www.pca.state.mn.us/water/tmdl/index.html
[3]Chlorophyll *a* measurements have been corrected for pheophytin
Units: 1 mg/L (ppm) = 1,000 ug/L (ppb)

Water Quality Characteristics - Historical Means and Ranges

Table 5. Water quality means and ranges for primary sites.

Parameters	Site 1	Site 2	Site 3	Site 4
Total Phosphorus Mean (ug/L):	**22.8**	**21.9**	**24.4**	**21.4**
Total Phosphorus Min:	4.9	4.9	15	6
Total Phosphorus Max:	54	54	44	62
Number of Observations:	49	49	23	44
Chlorophyll *a* Mean (ug/L):	**6.3**	**5.7**	**7.4**	**4.7**
Chlorophyll-a Min:	<1	<1	1.7	<1
Chlorophyll-a Max:	21.6	17.5	16.9	14.4
Number of Observations:	55	45	21	39
Secchi Depth Mean (ft):	**10.4**	**11.3**	**10.6**	**11.4**
Secchi Depth Min:	4.5	4.9	5	4.9
Secchi Depth Max:	25.4	24.8	21	24.1
Number of Observations:	76	219	93	48

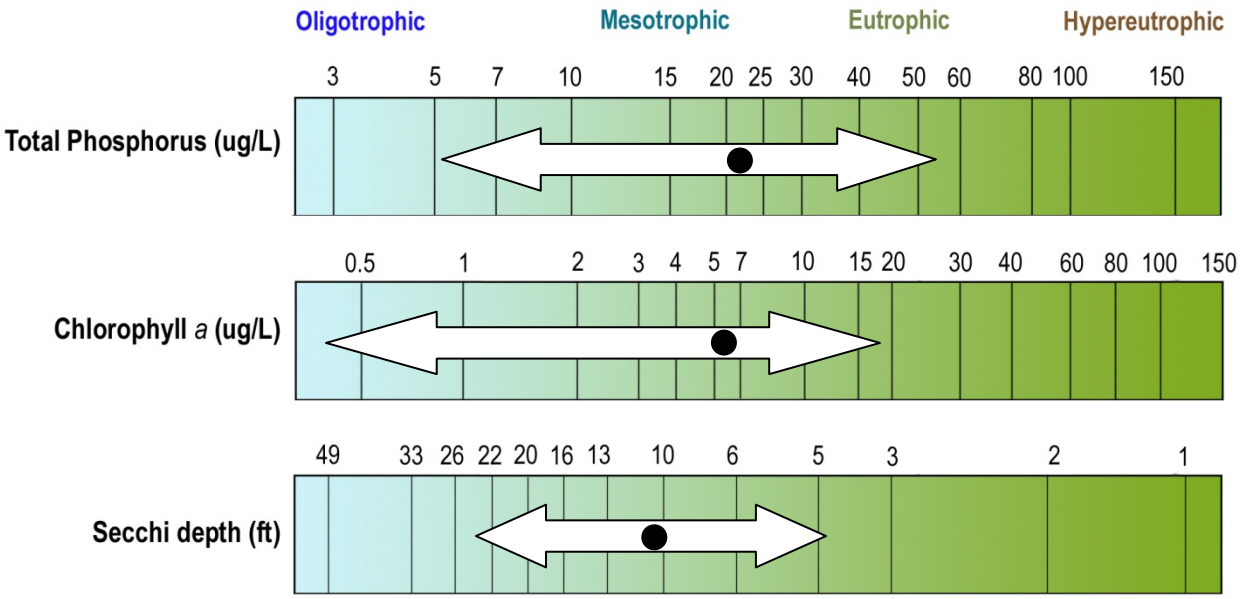


Figure 2. Mille Lacs Lake total phosphorus, chlorophyll a and transparency historical ranges. The arrow represents the range and the black dot represents the historical mean (Primary Site 2). Figure adapted after Moore and Thornton, [Ed.]. 1988. Lake and Reservoir Restoration Guidance Manual. (Doc. No. EPA 440/5-88-002)

Transparency (Secchi Depth)

Transparency is how easily light can pass through a substance. In lakes it is how deep sunlight penetrates through the water. Plants and algae need sunlight to grow, so they are only able to grow in areas of lakes where the sun penetrates. Water transparency depends on the amount of particles in the water. An increase in particulates results in a decrease in transparency. The transparency varies year to year due to changes in weather, precipitation, lake use, flooding, temperature, lake levels, etc.

The annual mean transparency in Mille Lacs Lake ranges from 6.7 to 16.5 feet (Figure 3). All the sites have relatively similar transparency, which makes sense because most of the lake is at similar depth. Each site follows the same ups and downs, which shows year-to-year variability. Monitoring should be continued at all four sites to track future trends in water quality.

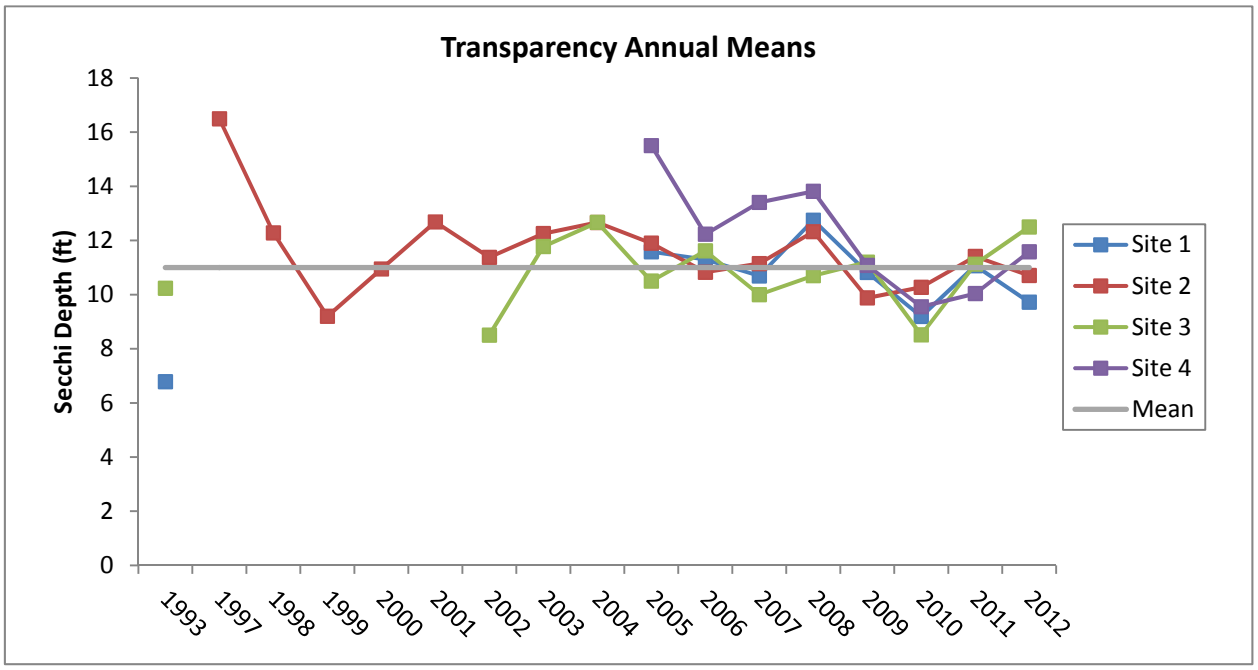


Figure 3. Annual mean transparency compared to long-term mean transparency.

Mille Lacs Lake transparency ranges from 5 to 24 ft at the primary site (2). Figure 4 shows the seasonal transparency dynamics. The maximum Secchi reading is usually obtained in early summer. Mille Lacs Lake transparency is high in May and June, and then declines through August. If the transparency were monitored into October, it would most likely rebound after fall turnover. This transparency dynamic is typical of a Minnesota lake. The dynamics have to do with algae and zooplankton population dynamics, and lake turnover.

It is important for lake residents to understand the seasonal transparency dynamics in their lake so that they are not worried about why their transparency is lower in August than it is in June. It is typical for a lake to vary in transparency throughout the summer.

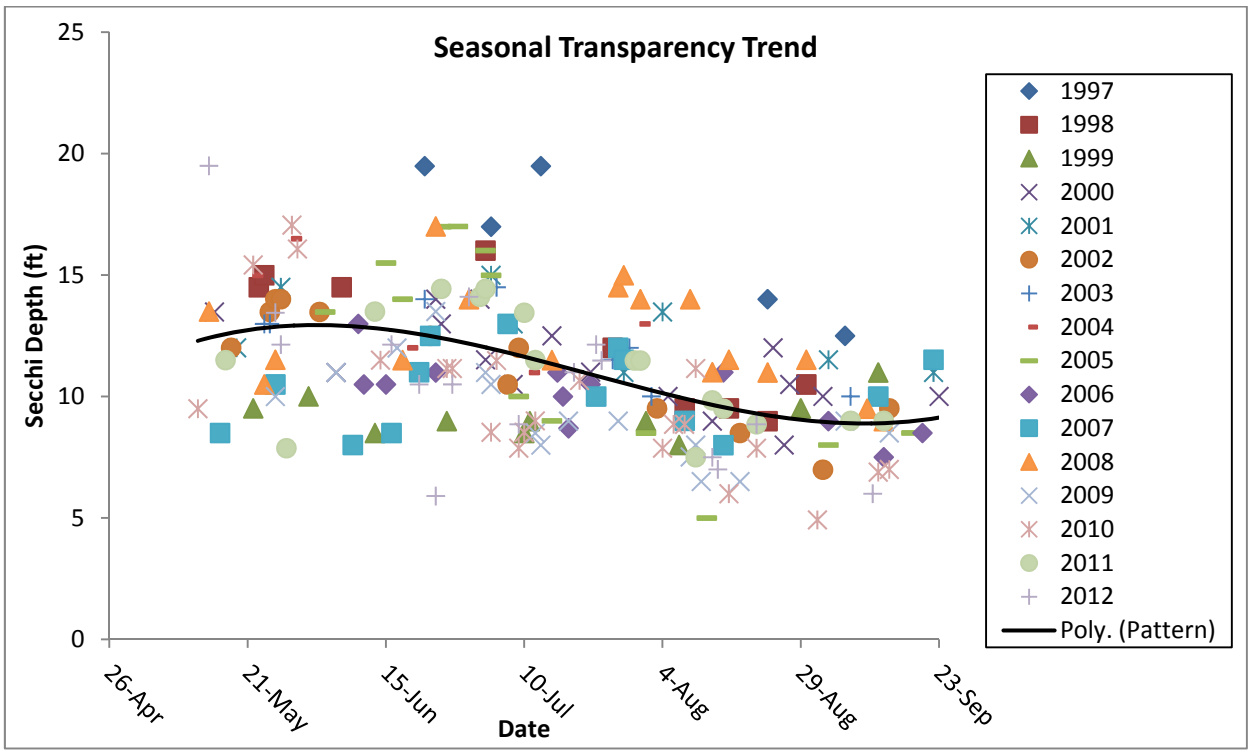


Figure 4. Seasonal transparency dynamics and year to year comparison (Site 2). The black line represents the pattern in the data.

User Perceptions

When volunteers collect Secchi depth readings, they record their perceptions of the water based on the physical appearance and the recreational suitability. These perceptions can be compared to water quality parameters to see how the lake "user" would experience the lake at that time. Looking at transparency data, as the Secchi depth decreases the perception of the lake's physical appearance rating decreases. Mille Lacs Lake was rated as being "crystal clear" 42% of the time by samplers at site 213 between 1997 and 2012 (Figure 5).

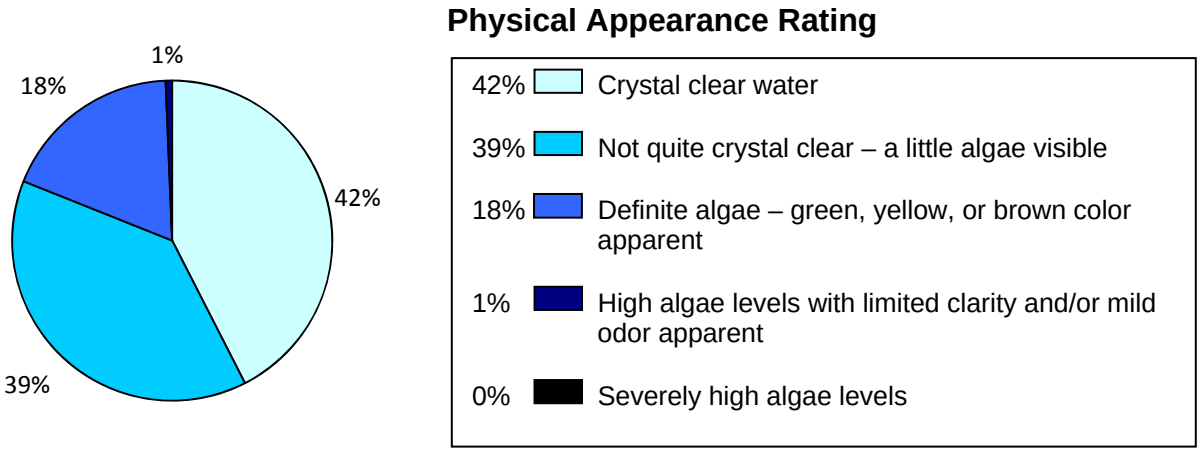


Figure 5. Mille Lacs Lake physical appearance ratings by samplers.

As the Secchi depth decreases, the perception of recreational suitability of the lake decreases. Mille Lacs Lake was rated as having "very minor aesthetic problems" 44% of the time from 1997-2012 (Figure 6).

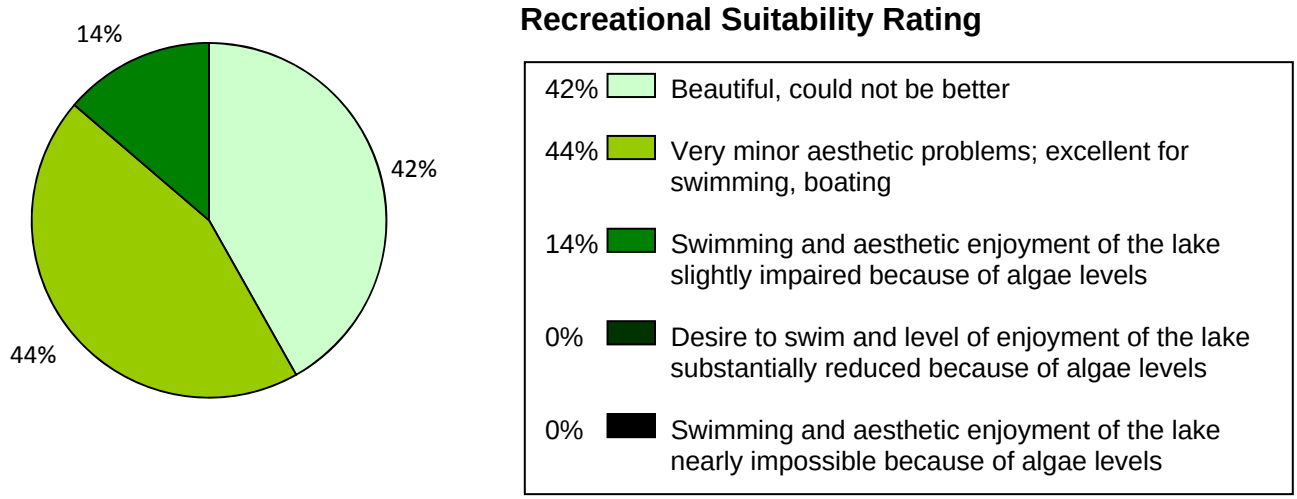


Figure 6. Recreational suitability rating, as rated by the volunteer monitor.

Total Phosphorus

Mille Lacs Lake is phosphorus limited, which means that algae and aquatic plant growth is dependent upon available phosphorus.

Total phosphorus was evaluated in Mille Lacs Lake at site 2 in 2005-2012. Although the data have a wide range, they do not indicate much seasonal variability. The majority of the data points fall into the mesotrophic and eutrophic ranges (Figure 7).

Phosphorus should continue to be monitored to track any future changes in water quality.

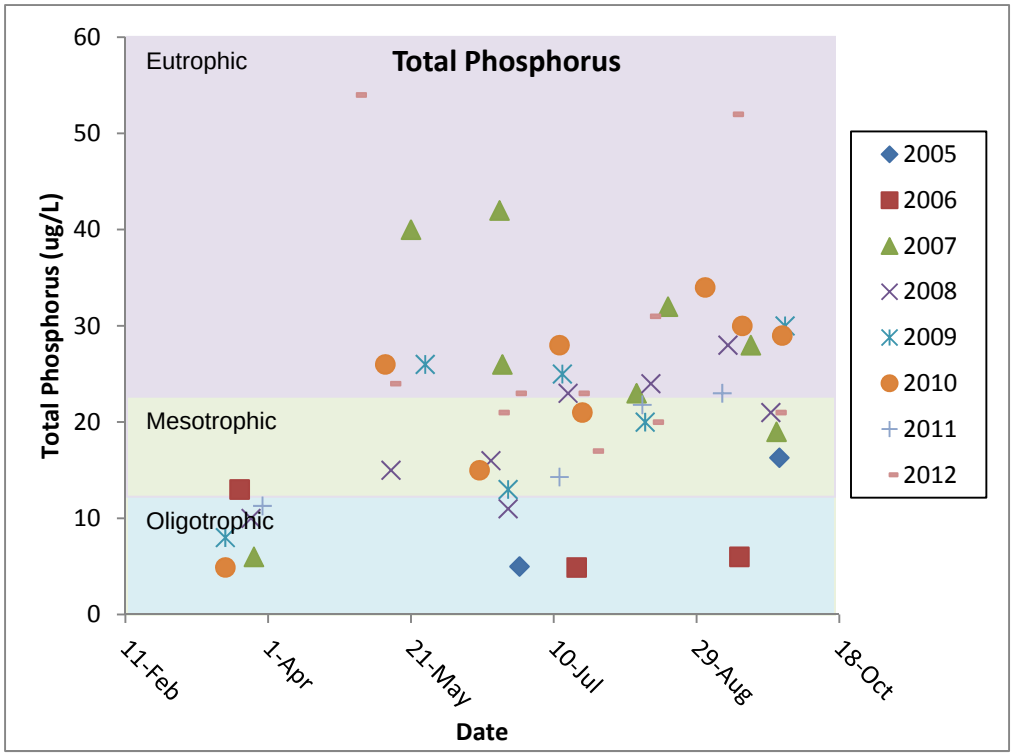


Figure 7. Historical total phosphorus concentrations (ug/L) for Mille Lacs Lake at site 2.

Chlorophyll *a*

Chlorophyll *a* is the pigment that makes plants and algae green. Chlorophyll *a* is tested in lakes to deter mine the algae concentration or how "green" the water is. Chlorophyll *a* concentrations greater than 10 ug/L are perceived as a mild algae bloom, while concentrations greater than 20 ug/L are perceived as a nuisance.

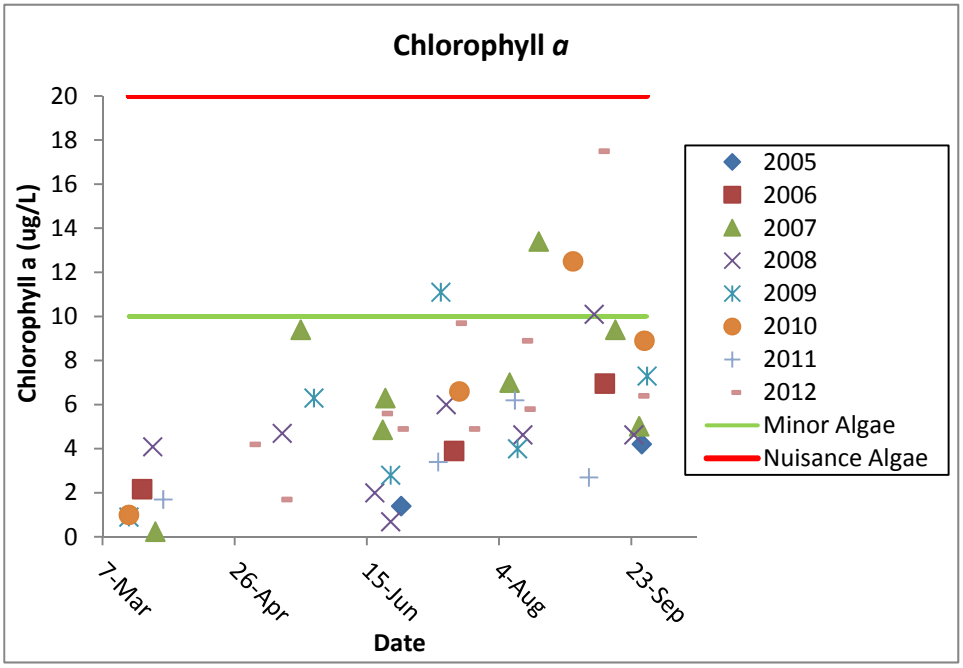
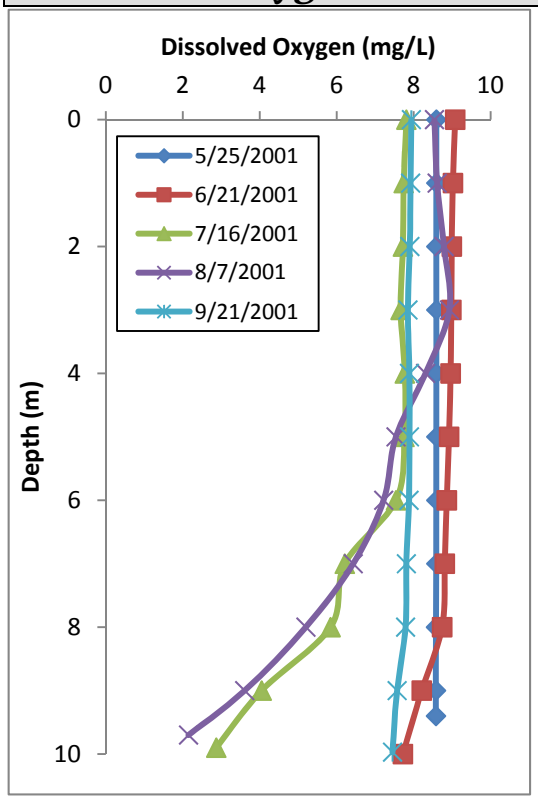


Figure 8. Chlorophyll *a* concentrations (ug/L) for Mille Lacs Lake at site 2.

Chlorophyll *a* was evaluated in Mille Lacs Lake at site 2 from 2005-2012 (Figure 8). Chlorophyll *a* concentrations remained below 20 ug/L on all sample dates indicating no nuisance algae blooms. During 4 sample dates in late summer chlorophyll a results were greater than 10 ug/L indicating minor algae blooms. The chlorophyll a tends to increase as the summer progresses, but that is common in lakes.

Dissolved Oxygen



Dissolved Oxygen (DO) is the amount of oxygen dissolved in lake water. Oxygen is necessary for all living organisms to survive except for some bacteria. Living organisms breathe in oxygen that is dissolved in the water. Dissolved oxygen levels of <5 mg/L are typically avoided by game fisheries.

Mille Lacs Lake is a relatively shallow lake, with a maximum depth of 43 ft. Dissolved oxygen profiles from data collected in 2001 at site 1 (actual site 208) show stratification developing mid-summer. The thermocline in July and August occurs at approximately 10 meters (33 feet), which means that gamefish will be scarce below this depth. Figure 9 is a representative DO profile for Mille Lacs Lake and it illustrates stratification in the summer of 2010 at site 101.

Figure 9. Dissolved oxygen profile for Mille Lacs Lake at site 1 (actual site is 208).

Trophic State Index (TSI)

TSI is a standard measure or means for calculating the trophic status or productivity of a lake. More specifically, it is the total weight of living algae (algae biomass) in a waterbody at a specific location and time. Three variables, chlorophyll a, Secchi depth, and total phosphorus, independently estimate algal biomass.

Phosphorus (nutrients), chlorophyll *a* (algae concentration) and Secchi depth (transparency) are related. As phosphorus increases, there is more food available for algae, resulting in increased algal concentrations. When algal concentrations increase, the water becomes less transparent and the Secchi depth decreases. If all three TSI numbers are within a few points of each other, they are strongly related. If they are different, there are other dynamics influencing the lake's productivity, and TSI mean should not be reported for the lake.

The mean TSI for Mille Lacs Lake falls into the mesotrophic range (Figure 10). There is good agreement between the TSI for phosphorus and chlorophyll *a*, indicating that these variables are strongly related (Table 6). The TSI for transparency is slightly lower, which could be due to large algal particles dominating the algal community, or selective grazing by zooplankton on the smaller algal cells.

Mesotrophic lakes (TSI 40-50) are characterized by moderately clear water most of the summer. Mesotrophic lakes are commonly found in central Minnesota and have clear water with algal blooms in late summer (Table 7). They are also good for walleye fishing.

Table 6. Trophic State Index for site 2.

Trophic State Index	Site 2
TSI Total Phosphorus	42
TSI Chlorophyll-a	48
TSI Secchi	49
TSI Mean	46
Trophic State:	Mesotrophic

Numbers represent the mean TSI for each parameter.

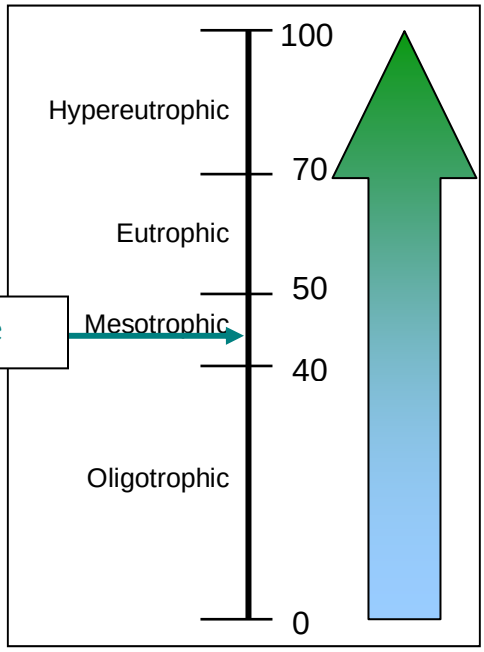


Figure 10. Trophic state index chart with corresponding trophic status.

Table 7. Trophic state index attributes and their corresponding fisheries and recreation characteristics.

TSI	Attributes	Fisheries & Recreation
<30	Oligotrophy: Clear water, oxygen throughout the year at the bottom of the lake, very deep cold water.	Trout fisheries dominate
30-40	Bottom of shallower lakes may become anoxic (no oxygen).	Trout fisheries in deep lakes only. Walleye, Cisco present.
40-50	Mesotrophy: Water moderately clear most of the summer. May be "greener" in late summer.	No oxygen at the bottom of the lake results in loss of trout. Walleye may predominate.
50-60	Eutrophy: Algae and aquatic plant problems possible. "Green" water most of the year.	Warm-water fisheries only. Bass may dominate.
60-70	Blue-green algae dominate, algal scums and aquatic plant problems.	Dense algae and aquatic plants. Low water clarity may discourage swimming and boating.
70-80	Hypereutrophy: Dense algae and aquatic plants.	Water is not suitable for recreation.
>80	Algal scums, few aquatic plants	Rough fish (carp) dominate; summer fish kills possible

Source: Carlson, R.E. 1997. A trophic state index for lakes. *Limnology and Oceanography*. 22:361-369.

Trend Analysis

For detecting trends, a minimum of 8-10 years of data with 4 or more readings per season are recommended. Minimum confidence accepted by the MPCA is 90%. This means that there is a 90% chance that the data are showing a true trend and a 10% chance that the trend is a random result of the data. Only short-term trends can be determined with just a few years of data, because there can be different wet years and dry years, water levels, weather, etc, that affect the water quality naturally.

Mille Lacs Lake had enough data to perform a trend analysis on all three parameters (Table 8). The data was analyzed using the Mann Kendall Trend Analysis.

Table 8. Trend analysis for site Mille Lacs Lake.

Lake Site	Parameter	Date Range	Trend
3 - east	Transparency	2002-2012	No Trend
3 - east	TP, CHLA	2005-2012	No Trend
2 - northeast	Transparency	1997-2012	No Trend
2 - northeast	TP, CHLA	2005-2012	No Trend

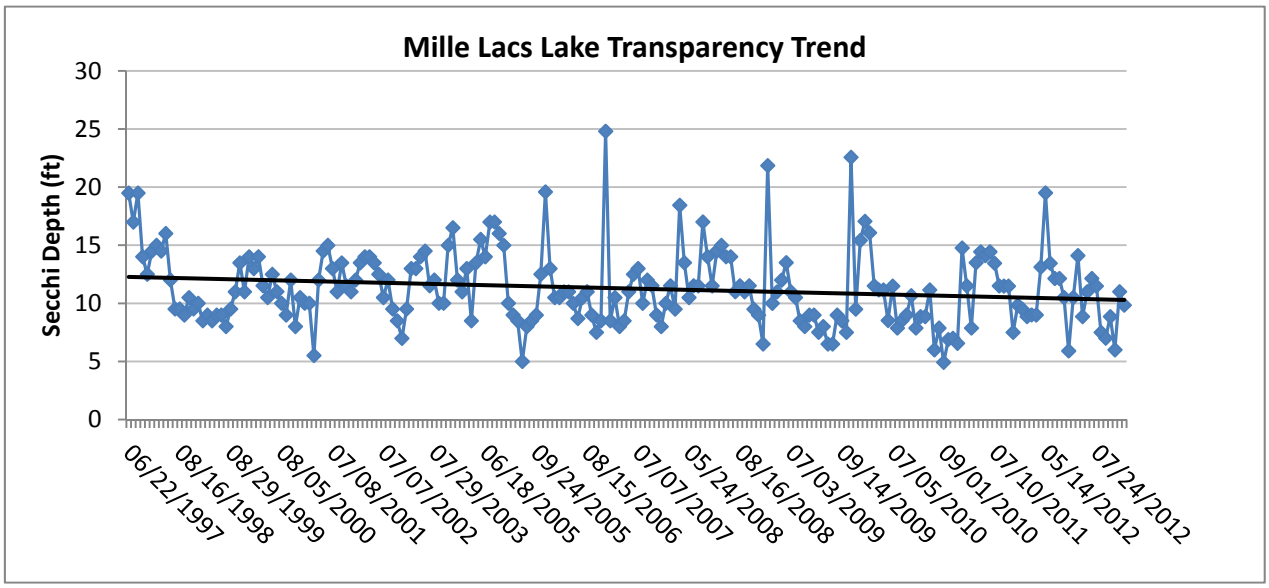


Figure 11. Transparency (feet) trend for site 2 from 1997-2012.

Mille Lacs Lake shows no evidence of water quality trends (Figure 11). That means that the water quality is stable. Transparency monitoring should continue so that this trend can be tracked in future years.

Ecoregion Comparisons

Minnesota is divided into 7 ecoregions based on land use, vegetation, precipitation and geology (Figure 12). The MPCA has developed a way to determine the "average range" of water quality expected for lakes in each ecoregion. From 1985-1988, the MPCA evaluated the lake water quality for reference lakes. These reference lakes are not considered pristine, but are considered to have little human impact and therefore are representative of the typical lakes within the ecoregion. The "average range" refers to the 25th - 75th percentile range for data within each ecoregion. For the purpose of this graphical representation, the means of the reference lake data sets were used.

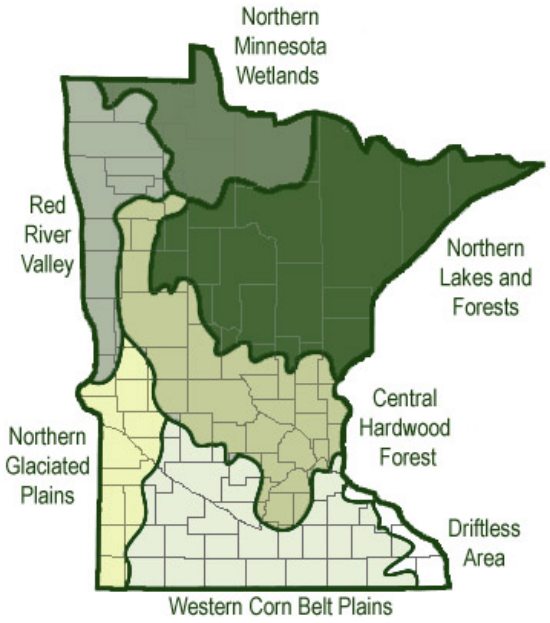
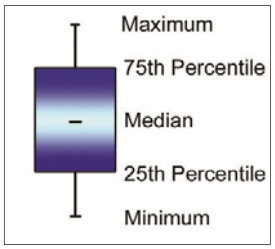


Figure 12. Minnesota Ecoregions.

Mille Lacs Lake is in the Northern Lakes and Forest Ecoregion. The mean total phosphorus, chlorophyll *a* and transparency (Secchi depth) for Mille Lacs Lake are within the ecoregion ranges (Figure 13).



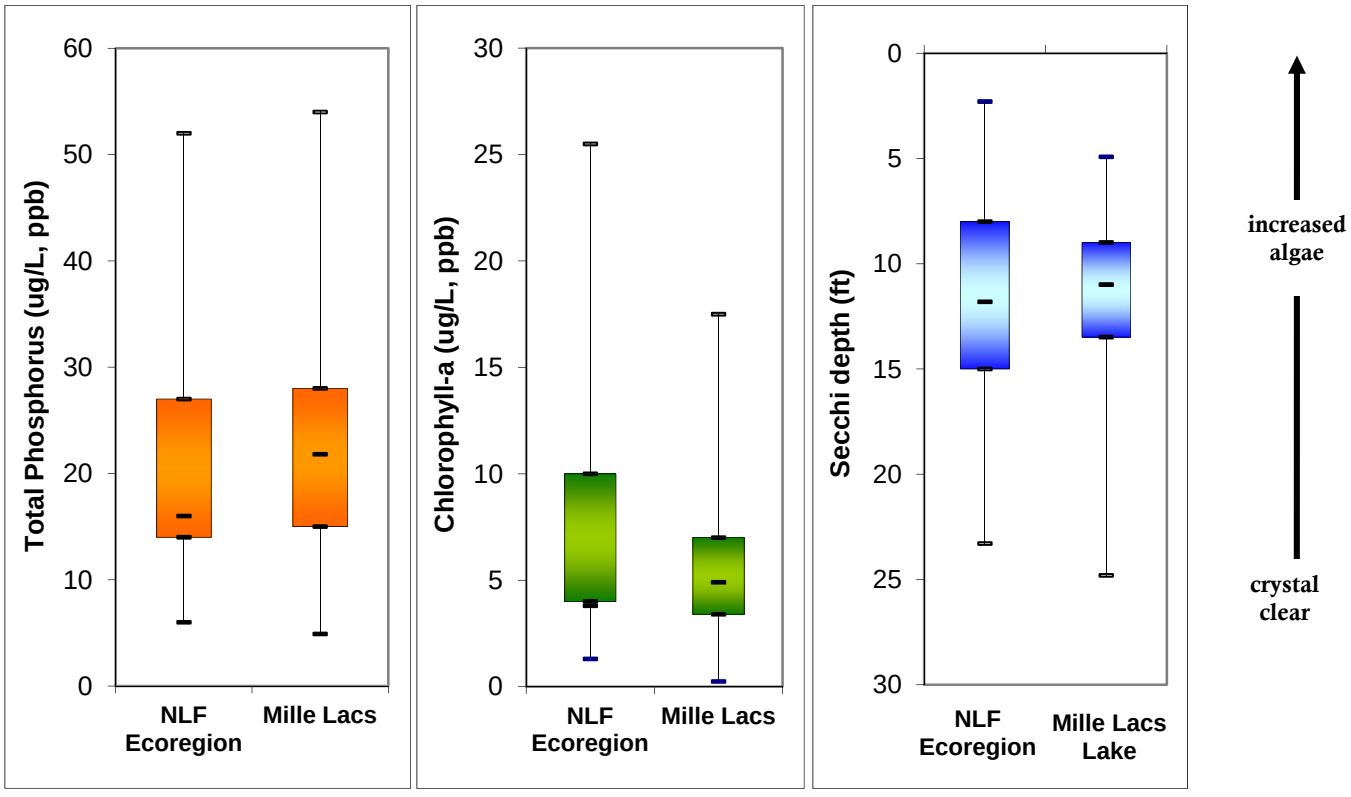


Figure 13. Mille Lacs Lake ranges from Site 2 compared to Northern Lakes and Forest Ecoregion ranges. The Mille Lacs Lake total phosphorus is from 49 data points and chlorophyll *a* ranges are from 45 data points collected in May-September of 2005-2012. The Mille Lacs Lake Secchi depth range is from 216 data points collected in May-October of 1997-2012.

Lakeshed Data and Interpretations

Lakeshed

Understanding a lakeshed requires an understanding of basic hydrology. A watershed is defined as all land and water surface area that contribute excess water to a defined point. The MN DNR has delineated three basic scales of watersheds (from large to small): 1) basins, 2) major watersheds, and 3) minor watersheds.

The Rum River Major Watershed is one of the watersheds that make up the Upper Mississippi River Basin, which drains south to the Gulf of Mexico (Figure 14). This major watershed is made up of 101 minor watersheds. Mille Lacs Lake is located in minor watershed 21002 (Figure 15).

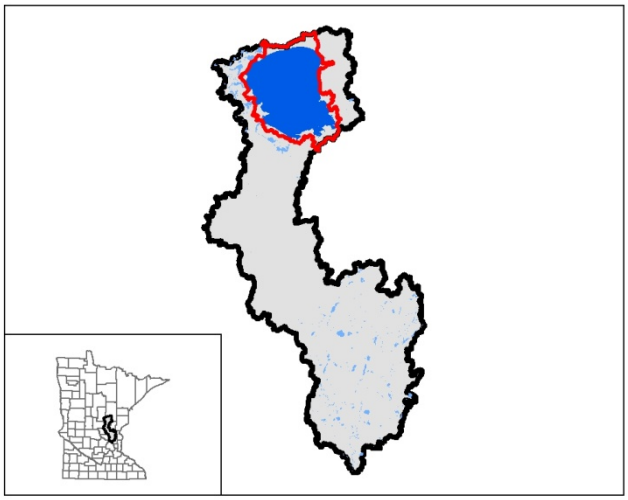


Figure 14. Rum River Watershed.

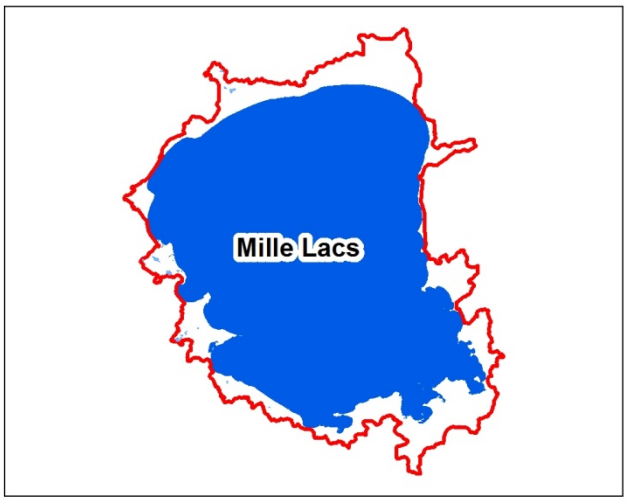


Figure 15. Minor Watershed 21002.

The MN DNR also has evaluated catchments for each individual lake with greater than 100 acres surface area. These lakesheds (catchments) are the "building blocks" for the larger scale watersheds. Mille Lacs Lake falls within lakeshed 2100200 (Figure 16). Though very useful for displaying the land and water that contribute directly to a lake, lakesheds are not always true watersheds because they may not show the water flowing into a lake from upstream streams or rivers. While some lakes may have only one or two upstream lakesheds draining into them, others may be connected to a large number of lakesheds, reflecting a larger drainage area via stream or river networks. For further discussion of Mille Lacs Lake's watershed, containing all the lakesheds upstream of the Mille Lacs Lake lakeshed, see page 17. The data

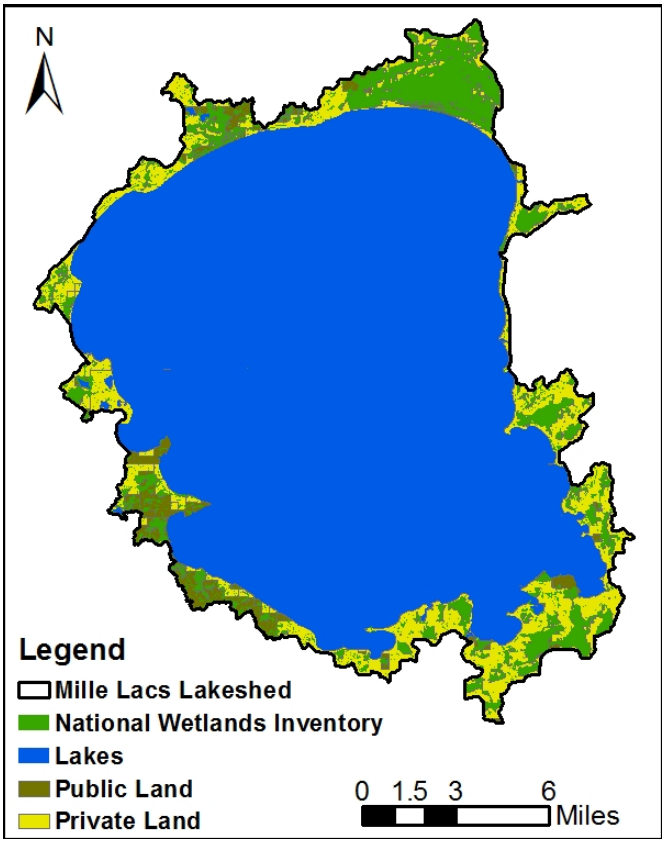


Figure 16. Mille Lacs Lake lakeshed (2100200) with land ownership, lakes, wetlands, and rivers illustrated.

interpretation of the Mille Lacs Lake lakeshed includes only the immediate lakeshed as this area is the land surface that flows directly into Mille Lacs Lake.

The lakeshed vitals table identifies where to focus organizational and management efforts for each lake (Table 9). Criteria were developed using limnological concepts to determine the effect to lake water quality.

KEY
Possibly detrimental to the lake
Warrants attention
Beneficial to the lake

Table 9. Mille Lacs Lake lakeshed vitals table.

Lakeshed Vitals		**Rating**
Lake Area	128123 acres	descriptive
Littoral Zone Area	14760 acres	descriptive
Lake Max Depth	40 feet	descriptive
Lake Mean Depth	28.5 feet	
Water Residence Time	7.4 years	
Miles of Stream	32.3	descriptive
Inlets	14 perennial and over 100 intermittent ditches, culvert, and tributaries	
Outlets	1	
Major Watershed	21 – Rum River	descriptive
Minor Watershed	21002	descriptive
Lakeshed	2100200	descriptive
Ecoregion	Northern Lakes and Forests	descriptive
Total Lakeshed to Lake Area Ratio (total lakeshed includes lake area)	1:1	
Standard Watershed to Lake Basin Ratio (standard watershed includes lake areas)	2:1	
Wetland Coverage (NWI)	8.2%	
Aquatic Invasive Species	Eurasian watermilfoil, Zebra mussels, Common carp, Spiny waterflea, Chinese mysterysnail, Banded mystery snail, Curly-leaf pondweed, Eurasian watermilfoil	
Public Drainage Ditches	Yes	
Public Lake Accesses	12	
Miles of Shoreline	92.0	descriptive
Shoreline Development Index	2.11	
Public Land to Private Land Ratio	0.2:1	
Development Classification	General Development	
Miles of Road	160 (this figure only includes major roads, there are many more miles of local roads around Mille Lacs Lake)	descriptive
Municipalities in lakeshed	Garrison, Wahkon, Isle	
Forestry Practices	County Forest Management: http://www.co.crow-wing.mn.us/index.aspx?NID=261	
Feedlots	3	
Sewage Management	Individual Subsurface Sewage Treatment Systems (Inspection and assessment required for all permits and property transfers within the Shoreland Protection Zone)	
Lake Management Plan	None	
Lake Vegetation Survey/Plan	None	

Land Cover / Land Use

The activities that occur on the land within the lakeshed can greatly impact a lake. Land use planning helps ensure the use of land resources in an organized fashion so that the needs of the present and future generations can be best addressed. The basic purpose of land use planning is to ensure that each area of land will be used in a manner that provides maximum social benefits without degradation of the land resource.

Changes in land use, and ultimately land cover, impact the hydrology of a lakeshed. Land cover is also directly related to the land's ability to absorb and store water rather than cause it to flow overland (gathering nutrients and sediment as it moves) towards the lowest point, typically the lake. Impervious intensity describes the land's inability to absorb water, the higher the % impervious intensity the more area that water cannot penetrate in to the soils. Monitoring the changes in land use can assist in future planning procedures to address the needs of future generations.

Phosphorus export, which is the main cause of lake eutrophication, depends on the type of land cover occurring in the lakeshed. Figure 17 depicts the land cover in Mille Lacs Lake's lakeshed.

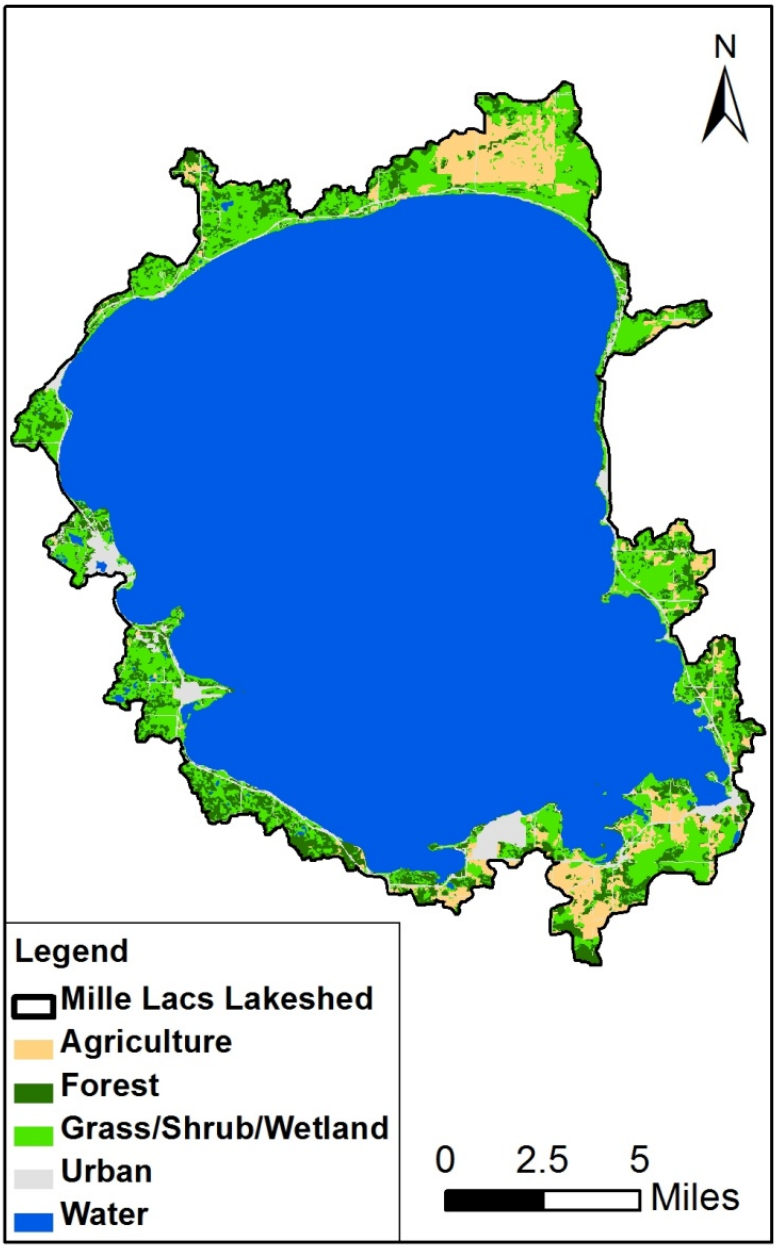


Figure 17. Mille Lacs Lake lakeshed (2100200) land cover (http://mrlc.gov).

The National Land Cover Dataset has online records of land cover statistics from years 2001 and 2006. Although some of this data is 12 years old, it is the most recent data set that is comparable. Table 10 describes the Mille Lacs lakeshed land cover statistics and percent change from 2001 to 2006. Due to the many factors that influence demographics, one cannot determine with certainty the projected statistics over the next 10, 20, 30+ years, but one can see the transitions occurring within the last 12 years within the lakeshed.

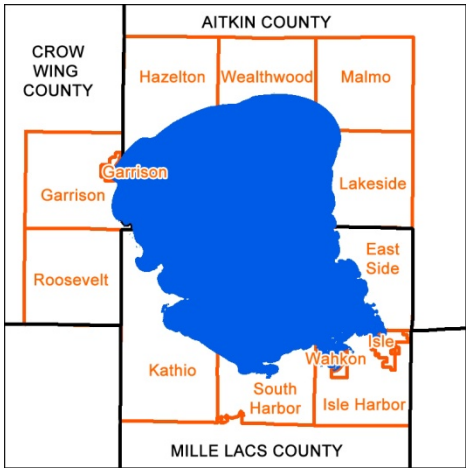
Table 10. Mille Lacs Lake's lakeshed land cover statistics and % change from 2001 to 2006 (http://mrlc.gov).

Land Cover	2001 Acres	Percent	2006 Acres	Percent	% Change 2001 to 2006
Agriculture	6134	3.73	6341	3.85	3.4% Increase
Forest	8439	5.13	8300	5.04	1.6% Decrease
Grass/Shrub/Wetland	16767	10.19	16611	10.09	0.9% Decrease
Water	128623	78.16	128518	78.09	0.1% Decrease
Urban	4731	2.87	4802	2.92	1.5% Increase
Impervious Intensity %					
0-19	4233	2.57	4256	2.59	0.5% Increase
20-49	315	0.19	360	0.22	14.1% Increase
50-79	107	0.06	110	0.07	3.1% Increase
80-100	76	0.05	76	0.05	No Change
Total Area	164572		164572		
Total Impervious Area (Percent Impervious Area Excludes Water Area)	4731	2.87	4802	2.92	1.5% Increase

Demographics

Mille Lacs Lake is classified as a general development lake. General development lakes usually have more than 225 acres of water per mile of shoreline and 25 dwellings per mile of shoreline, and are more than 15 feet deep.

The Minnesota Department of Administration Geographic and Demographic Analysis Division extrapolated future population in 5-year increments out to 2035. These projections are shown in Figure 18 below. Wahkon City and South Harbor Township have the highest extrapolated growth projections over the next 30 years.



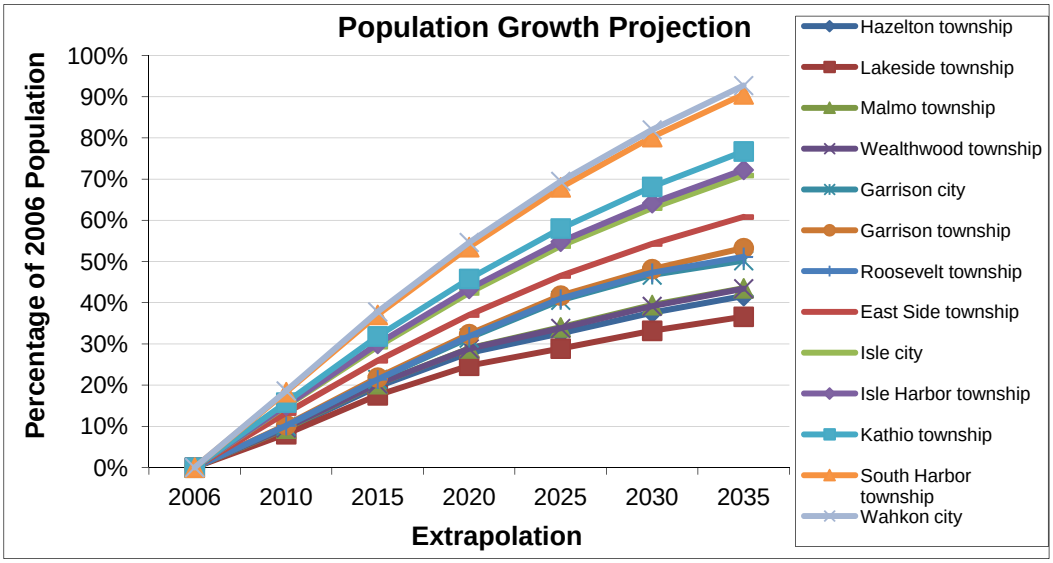


Figure 18. Population growth projection for the townships (Aitkin County only) around Mille Lacs Lake and Aitkin County (source: http://www.demography.state.mn.us/resource.html?Id=19332)

Lakeshed Water Quality Protection Strategy

Each lakeshed has a different makeup of public and private lands. Looking in more detail at the makeup of these lands can give insight on where to focus protection efforts. The protected lands (easements, wetlands, public land) are the future water quality infrastructure for the lake. Developed land and agriculture have the highest phosphorus runoff coefficients, so this land should be minimized for water quality protection.

The majority of the land within Mille Lacs Lake's lakeshed is privately owned and covered with forests or wetlands (Table 11). This land can be the focus of development and protection efforts in the lakeshed.

Table 11. Land ownership, land use/land cover, estimated phosphorus loading, and ideas for protection and restoration in the lakeshed (Sources: Crow Wing County parcel data, National Wetlands Inventory, and the 2006 National Land Cover Dataset).

	Private (18%)					78%	Public (4%)		
	Developed	**Agriculture**	**Forested Uplands**	**Other**	**Wetlands**	**Open Water**	**County**	**State**	**Federal**
Land Use (%)	2.3	2.1	3.4	3.6	6.6	78	0.1	3.2	0.7
Runoff Coefficient Lbs of phosphorus/acre/year	0.45 – 1.5	0.26 – 0.9	0.09		0.09		0.09	0.09	0.09
Estimated Phosphorus Loading Acreage x runoff coefficient	1816 – 6055	1601 – 5541	552		90		4	478	113
Description	Focused on Shoreland	Cropland	Focus of develop-ment and protection efforts	Open, pasture, grass-land, shrub-land	Protected				
Potential Phase 3 Discussion Items	Shoreline restoration	Restore wetlands; CRP	Forest stewardship planning, 3rd party certification, SFIA, local woodland cooperatives		Protected by Wetland Conservation Act		County Tax Forfeit Lands	State Forest	National Forest

DNR Fisheries approach for lake protection and restoration

Credit: Peter Jacobson and Michael Duval, Minnesota DNR Fisheries

In an effort to prioritize protection and restoration efforts of fishery lakes, the MN DNR has developed a ranking system by separating lakes into two categories, those needing protection and those needing restoration. Modeling by the DNR Fisheries Research Unit suggests that total phosphorus concentrations increase significantly over natural concentrations in lakes that have watershed with disturbance greater than 25%. Therefore, lakes with watersheds that have less than 25% disturbance need protection and lakes with more than 25% disturbance need restoration (Table 12). Watershed disturbance was defined as having urban, agricultural and mining land uses. Watershed protection is defined as publicly owned land or conservation easement.

Table 12. Suggested approaches for watershed protection and restoration of DNR-managed fish lakes in Minnesota.

Watershed Disturbance (%)	Watershed Protected (%)	Management Type	Comments
< 25%	> 75%	Vigilance	Sufficiently protected -- Water quality supports healthy and diverse native fish communities. Keep public lands protected.
	< 75%	Protection	Excellent candidates for protection -- Water quality can be maintained in a range that supports healthy and diverse native fish communities. Disturbed lands should be limited to less than 25%.
25-60%	n/a	Full Restoration	Realistic chance for full restoration of water quality and improve quality of fish communities. Disturbed land percentage should be reduced and BMPs implemented.
> 60%	n/a	Partial Restoration	Restoration will be very expensive and probably will not achieve water quality conditions necessary to sustain healthy fish communities. Restoration opportunities must be critically evaluated to assure feasible positive outcomes.

The next step was to prioritize lakes within each of these management categories. DNR Fisheries identified high value fishery lakes, such as cisco refuge lakes. Ciscos (*Coregonus artedi)* can be an early indicator of eutrophication in a lake because they require cold hypolimnetic temperatures and high dissolved oxygen levels. These watersheds with low disturbance and high value fishery lakes are excellent candidates for priority protection measures, especially those that are related to forestry and minimizing the effects of landscape disturbance. Forest stewardship planning, harvest coordination to reduce hydrology impacts and forest conservation easements are some potential tools that can protect these high value resources for the long term.

Mille Lacs Lake's lakeshed is classified with having 85.3% of the watershed protected and 6.1% of the watershed disturbed (Figure 19). Therefore, this lakeshed should have a vigilance focus. Goals for the lake should be to limit any increase in disturbed land use. Figure 20 displays the upstream lakesheds that contribute water to the lakeshed of interest. All of the land and water area in this figure has the potential to contribute water to Mille Lacs Lake, whether through direct overland flow or through a creek or river. There are 45 lakesheds upstream of the Mille Lacs Lake lakeshed.

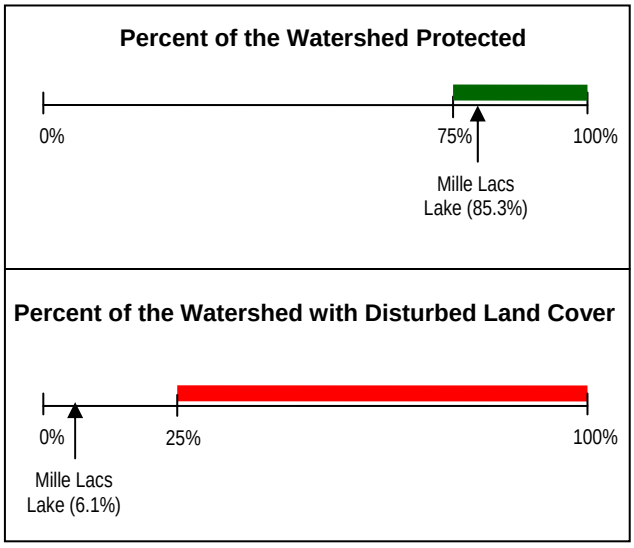


Figure 19. Mille Lacs Lake's lakeshed percentage of watershed protected and disturbed.

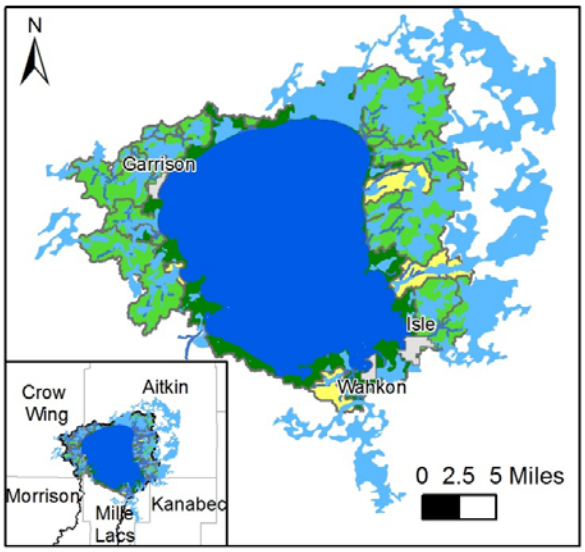


Figure 20. Upstream lakesheds that contribute water to the Mille Lacs Lake lakeshed. Color-coded based on management focus (Table 12).

Status of the Fishery (DNR, as of 09/01/2011)

The Mille Lacs Lake game fish community is primarily composed of walleye, yellow perch, northern pike, muskellunge, and smallmouth bass. Other game fish include largemouth bass, bluegill, pumpkinseed and black crappie. Common minnow species include spottail shiner and mimic shiner. Invasive animal species include common carp, zebra mussel, Chinese mystery-snail, banded mystery-snail, and spiny water flea. Curlyleaf pondweed and Eurasian watermilfoil are well established in the lake.

Creel Survey Fishing effort for the 2010-2011 winter season was 1.78 million angler-hours (ang-hrs), about 3% above average. Open water 2011 fishing effort was 1.16 million ang-hrs, and was about 18% below average. Pressure and catch during the State government shutdown, which went from July 1 through July 20, was estimated based on data from the first seven days prior to the shutdown and the first seven days immediately after the shutdown. Walleye harvest declined slightly from 2010 levels. Harvest was 188,400 lbs and total kill was 230,200 lb, a 15% decrease from 2010. Anglers released an additional 860,000 lb of walleye, which was almost a 40% increase over 2010. Most of the harvested walleye were age 3 and age 4.

Anglers harvested 5,900 lb of northern pike, and released 77,000 lb. Total kill for pike was 9,800 lb. Northern pike regulations changed in 2011 to a 27-40 inch protected slot with one over 40 inches allowed in a possession limit of 3 fish. Yellow perch harvest was 83,400 lb. Cisco harvest was 55,500 lb, which was the highest observed since the bag limits were reduced to 10 fish in 2003. Anglers caught 50,900 smallmouth bass in 2011, which was the highest ever observed for Mille Lacs Lake.

Fall Assessment Walleye catch per effort (CPE) in the inshore gillnets was 9.7 fish/net and 16.1 lb/net, the second lowest historically observed. In offshore nets, walleye CPE was 14.5 fish/net and 28.4 lb/net, which are the second and third lowest, respectively. The CPE of walleye longer than 20 inches, which peaked around 2002, decreased to moderate levels in the offshore nets. In the inshore nets, CPE of larger walleye decreased to around 2 per net, which is well below peak values of close to 5 per net from 2000-2006. As observed in recent years, the 2000, 2001, 2004, and now the 2009 year classes were poorly represented in the gill nets, while 2005 through 2008 appear average. Early indications from electro-fishing suggest that the 2010 and 2011 year classes have the potential to be average to above average. The proportion of mature walleyes that were male in inshore gill nets was nearly 50%. The number of mature males sampled in the inshore gill nets may be stabilizing after several years of decline, but should be watched closely. Walleye growth was below average for female walleye and smaller males, and about average for males ages 4-6. Walleye condition was below average at all sizes.

The northern pike CPE of 1.9 fish/net in the inshore gill nets remained at near historical highs since 32 nets were implemented in 1983. The average weight of northern pike was near average at 5.3 lbs. Inshore nets sampled 10 year classes, with most of the fish from the 2009 and 2008 year classes. Since protected slot regulations went into effect in 1998, the number of pike over 28 inches initially increased, but now appears stable. Thirty-five percent of the northern pike caught in the inshore nets were over 28 inches in length. Mature female pike weight in the inshore nets decreased 40%, from the 2010 historical high of 310 lbs to 187 lbs in 2011, which was still in the top third of weight observed since 1986. Some of the decrease in northern pike observed in 2011 fall gill nets may be due to increased harvest for the year.

Yellow perch CPE in the inshore gillnets was 44 fish/net and 11.0 lb/net. Gill net CPE of perch larger than 9 in has remained about the same for the last five years and was at around 13 fish/net in 2011. In the offshore nets, perch CPE was 34.0 fish/net and 10.4 lb/net.

Cisco CPE declined sharply to 1.6 fish/net and 0.6 lb/net in the inshore nets and declined to a moderate 15.6 fish/net and 12.9 lb/net in the offshore nets. Cisco have experienced several years of good recruitment, believed to be associated with cooler summers and falls. The result has been more cisco in the lake as forage, and increased catches by winter anglers. The difference in

magnitude between the inshore and offshore catches in 2011 may reflect a diminished population that is no longer over-flowing into the less desirable habitat of the near shore region, or a behavioral shift due to other environmental factors.

Other species were also caught in standard gill nets, generally in low numbers. Burbot continue to exhibit declining numbers, and are now only occasionally observed in the assessment nets. Rock bass increased to average levels in 2011. Smallmouth bass catch rose from 0.3 fish/net in 2010 to 1.0 fish/net in 2011, the second highest level observed in the inshore gill nets. It's not likely that the smallmouth bass population actually increased by a factor of three over the course of a year, so most of the increase is likely due to differences in catchability between 2010 and 2011. Trends over the last decade show an increasing smallmouth bass population in the lake.

The forage gill nets showed weak numbers of age 0 cisco and moderate numbers of yellow perch at all ages. Age 1 and age 2 cisco were at moderate levels. Age 0 spottail shiners, and bluntnose minnows were not observed in the forage gill nets. Older spottail shiners were observed at relatively low levels. The size of YOY perch was below average in both the trawl and the forage gill nets. Reduced forage levels help explain the low condition observed in fall walleyes and suggest an increased propensity for a strong walleye bite for recreational anglers until forage stocks are replenished in early summer.

Invasive Species Zebra mussel density increased to 920/ft2, which was about 65 times higher than in 2010 and over ten million times higher than in 2005. Veliger (larval zebra mussels) densities decreased from 2010 levels, however, July counts were not performed due to the State government shutdown. The counts of adult zebra mussels have not peaked and 2012 counts should continue to increase.

The overall abundance of spiny water flea appears to have also increased in 2011, despite no counts during the July State government shutdown. Spiny water flea was found in Mille Lacs for the first time in 2009. Peak density increased from 0.3/liter in September 2009 to 10.3/liter in September 2010 to 11.5/liter in June 2011. Spiny water fleas were observed in samples from June through September. Late May was the only sampling period where spiny water fleas were not observed.

See the link below for specific information on gillnet surveys, stocking information, and fish consumption guidelines. http://www.dnr.state.mn.us/lakefind/showreport.html?downum=48000200

Key Findings / Recommendations

Monitoring Recommendations
Transparency monitoring at sites 1, 2, 3, and 4 should be continued annually. It is important to continue transparency monitoring weekly or at least bimonthly every year to enable year-to-year comparisons and trend analyses. Total Phosphorus and chlorophyll *a* monitoring should continue, as the budget allows, to track trends in water quality.

Mille Lacs Lake is a difficult lake to monitor because there are so many different agencies and groups involved, and because it is so large. Implementing an annual monitoring program on this lake that shares data with all interested groups would greatly benefit the understanding of this lake. This monitoring program could include a few sites of transparency monitoring and one or two sites of chemical monitoring. This monitoring can also help determine if there are any effects on water quality from the Zebra mussel population. Transparency should be monitored weekly or every other week, and chemical monitoring should occur on at least 4-5 dates evenly spread throughout the summer to get a good average.

Overall Summary
Mille Lacs Lake is a mesotrophic lake (TSI = 46) with no evidence of a trend in water quality. The MN DNR water quality modeling shows that 85.3% of the lakeshed is protected, but this is misleading because 78% of that is the lake area itself. Disturbed land uses make up 6.1% of the lakeshed, and the threshold where water quality tends to decline is at 25%.

Four percent (4%) of the lakeshed is public land and most of the private land use is categorized as forested uplands and wetlands (Table 11). These land use categories are generally good for water quality.

Due to its large size (128,223 acres), the volume of water in Mille Lacs Lake is able to dilute a lot of runoff. It could, however, reach a tipping point when the amount of nutrients running into the lake can change the water quality.

Ciscos (Coregonus artedi) can be an early indicator of eutrophication in a lake because they require cold hypolimnetic temperatures and high dissolved oxygen levels. The DNR reports that in 2011 the cisco catch declined sharply to 1.6 fish/net and 0.6 lb/net in the inshore nets and declined to a moderate 15.6 fish/net and 12.9 lb/net in the offshore nets. Cisco have experienced several years of good recruitment, believed to be associated with cooler summers and falls. The result has been more cisco in the lake as forage, and increased catches by winter anglers. The difference in magnitude between the inshore and offshore catches in 2011 may reflect a diminished population that is no longer over-flowing into the less desirable habitat of the near shore region, or a behavioral shift due to other environmental factors.

There are many invasive species in Mille Lacs Lake, and only time will tell what impact these have on the water quality and the fishery.

Priority Impacts to the Lake
Mille Lacs is one of the premier lakes in Minnesota, and development around the lake is continuing at a rapid pace. The shore length is 76 miles with more than 70% of it developed with seasonal and year-round homes, businesses and other commercial interests. The greater majority of these developed parcels are not sewered and rely on on-site treatment systems. The townships around Mille Lacs Lake show 20-30% predicted growth in the next 10 years (Figure 18).

The Mille Lacs Lake Watershed Management Group states that “it is estimated that the lake contributes $150 to $200 million to regional and state economies. More than 2000 recreational-based jobs are maintained by the continued excellence of the area’s resources. There is a local desire to promote further development of this recreation-based economy.”

Best Management Practices Recommendations
The management focus for Mille Lacs Lake should be to protect the current water quality and the lakeshed. Efforts should be focused on managing and/or decreasing the impact caused by additional development, including first and second tier development, and impervious surface area. Project ideas include enforcing county shoreline ordinances, smart development, shoreline restoration, rain gardens, and septic system maintenance.

The Mille Lacs Lake Watershed Management Group states that “long-term sustainable development of the lake will only be possible if the local units of governments create a cohesive watershed development plan detailing issues of management such as setbacks and septic regulation, and wetland protection.”

Maintaining forested and vegetated land cover along the lake is important for protecting the current water quality. When surface runoff flows through native vegetation, which has a much more robust

root system than turf grass, and infiltrates into the soil it acts as a filter, slowing down and removing potential containments in the water.

Any large undeveloped parcels around the lake would be good candidates for conservation easements or wildlife management areas, especially if they are ringed with wetlands, which are good quality fish and wildlife habitat.

Project Implementation
The best management practices above can be implemented by a variety of entities. Some possibilities are listed below.

Individual property owners
- Shoreline restoration
- Rain gardens
- Aquatic plant bed protection (only remove a small area for swimming)
- Conservation easements

Lake Associations
- Lake condition monitoring
- Ground truthing – visual inspection upstream on stream inlets
- Watershed mapping by a consultant
- Shoreline inventory study by a consultant
- Conservation easements

Soil and Water Conservation District (SWCD) and Natural Resources Conservation Service (NRCS)
- Shoreline restoration
- Stream buffers
- Wetland restoration
- Work with farmers to
    - Restore wetlands
    - Implement conservation farming practices
    - Land retirement programs such as Conservation Reserve Program

County-wide Recommendation
In order to better manage the impact of septic systems on lake water quality, it is recommended that the county implement a lake-wide septic inspection program. In a program such as this, the county would focus on one to three lakes a year, pull septic system records on those lakes, and require old systems to be inspected. This program can rotate through the county doing a few lakes each year.

Since conversion of small cabins to large lake homes could be a future issue, strengthening county shoreline ordinances such as set-backs, impervious surface limits and shoreline alteration (installation of retaining walls and removing trees) will help to protect water quality.

Organizational contacts and reference sites

Lake Mille Lacs Watershed Group	130 Southgate Drive, Aitkin, MN 56431 (218) 927-6565 http://www.millelacswatershed.org
Aitkin Soil and Water Conservation District	130 Southgate Drive, Aitkin, MN 56431 (218) 927-6565 http://www.aitkincountyswcd.org
Crow Wing County Land Services Department	322 Laurel Street, Suite 14, Brainerd, MN 56401 218-824-1128 http://crowwing.us/index.aspx?nid=211
Crow Wing Soil and Water Conservation District	322 Laurel Street, Suite 13, Brainerd, MN 56401 (218) 828-6197 http://www2.co.crow-wing.mn.us/swcd/
DNR Fisheries Office	1601 Minnesota Drive, Brainerd, MN 56401 (218) 828-2550 http://www.dnr.state.mn.us/lakefind/index.html
Regional Minnesota Pollution Control Agency Office	7678 College Road, Suite 105, Baxter, MN 56425 (218) 828-2492 http://www.pca.state.mn.us
Regional Board of Soil and Water Resources Office	1601 Minnesota Drive, Brainerd, MN 56401 (218) 828-2383 http://www.bwsr.state.mn.us
Mille Lacs Band of Ojibwe	43408 Oodena Drive, Onamia, MN 56359 (320) 532-4181 http://www.millelacsband.com/