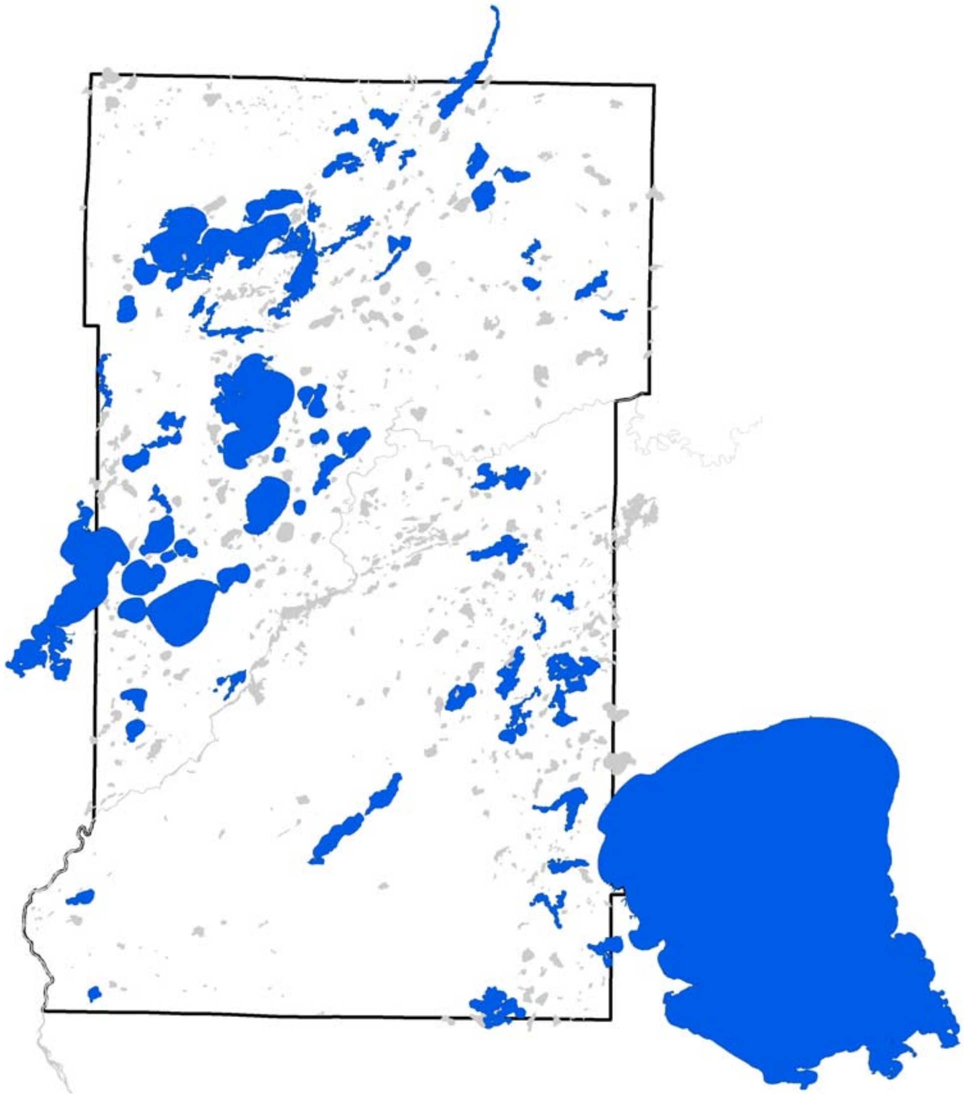
Crow Wing County Lakes Prioritization and Screening



2015

Crow Wing County
Minnesota Board of Soil and Water Resources

List of Abbreviations

BWSR: Board of Soil and Water Resources

CHLA: Chlorophyll *a*

CLMP: Citizens Lake Monitoring Program – transparency data collection

CLMP+: Citizens Lake Monitoring Program – transparency and chemical data collection

CSMP: Citizens Stream Monitoring Program

DNR: Minnesota Department of Natural Resources

LAP: Lake Assessment Program

MPCA: Minnesota Pollution Control Agency

SWCD: Soil and Water Conservation District

TMDL: Total Maximum Daily Load

TP: Total phosphorus

Acknowledgements

Organization and oversight
Mitch Brinks, Crow Wing County
Melissa Barrick, Crow Wing SWCD
Dan Steward, BWSR
Jeff Hrubes, BWSR

Funding provided by
Board of Water and Soil Resources

Organizations contributing data and information
Minnesota Department of Natural Resources (DNR)
Minnesota Pollution Control Agency (MPCA)
Outdoor Corps program (Water Resources Center, University of Minnesota)
Mille Lacs Band of Ojibwe
Thirty Lakes Watershed District
Army Corps of Engineers
Whitefish Area Property Owners Association
Gull Chain of Lakes Association

Report compilation and data assessment
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Introduction

Crow Wing County is located in the lakes country of northern Minnesota. Scenic lakes, rivers and streams cover 14% of the surface area of Crow Wing County - and an additional 14% of the county is covered by wetlands. These resources are valued for their excellent recreation opportunities and water quality.

In 2008, for the purpose of future water planning, the Crow Wing Soil and Water Conservation District (SWCD) decided to evaluate the water quality of the large lakes (>1,000 acres) in Crow Wing County. In 2011, 2013, and 2015 additional lakes were evaluated using the same process. This report contains results from all lake studies, evaluating a total of 73 lakes. Lakes evaluated in this report are indicated in dark blue in Figure 1 and listed in Table 1.

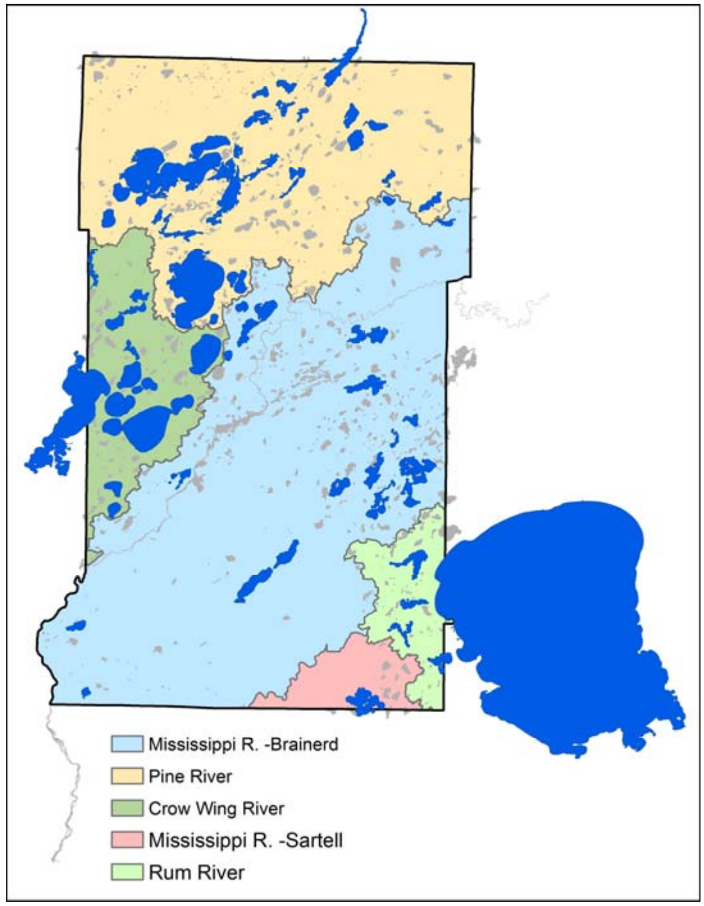


Figure 1. Lakes of Crow Wing County. Lakes evaluated in this report are in dark blue, while each major basin is highlighted in a different color.

Crow Wing County lakes have been monitored off and on between 1970 and 2014. This monitoring has been completed by numerous organizations including Lake Associations, Minnesota Pollution Control Agency, Minnesota Department of Natural Resources, Mille Lacs Band of Ojibwe, Crow Wing SWCD, Thirty Lakes Watershed District, and the Outdoor Corps program (University of Minnesota).

The purpose of this report was to compile all available data for these lakes from all the different sources, evaluate the data quality, identify data gaps, assess the data, and look for water quality trends. This report contains a summary of the current state of large Crow Wing County lakes and recommendations for future monitoring.

Individual lake reports follow with more in-depth assessments and recommendations.

Table 1. Data availability for Crow Wing County Lakes.

Data Availability

Transparency data		Secchi disk data have been collected extensively and should continue yearly since it is relatively easy and inexpensive.
Chemical data		Most large Crow Wing County lakes have at least two years of water quality data in the past 10 years.
Inlet/Outlet data		Inlet/outlet data are sparse, and could be collected on lakes with declining transparency trends to investigate the cause in water quality decline.

Table 2. Lakes assessed in the 2010-2015 lakes assessments (alphabetical order).

Lake Name	Lake ID	Lake Size (acres)
Bass	18-0256-00	309
Bay	18-0034-00	2,320
Bertha	18-0355-00	335
Big Trout	18-0315-00	1,363
Borden	18-0020-00	1,012
Butterfield	18-0231-00	194
Camp	18-0018-00	569
Cedar	01-0209-00	1,745
Clamshell	18-0356-00	204
Clark	18-0374-00	305
Clear	18-0364-00	222
Clearwater	18-0038-00	1,002
Crooked	18-0041-00	385
Cross Lake	18-0312-00	1,813
Crow Wing	18-0155-00	373
Daggett	18-0271-00	231
Eagle	18-0296-01	350
East Fox	18-0298-00	238
Edward	11-0305-00	2,576
Emily	18-0203-00	728
Gilbert	18-0320-01	484
Gladstone	18-0338-00	437
Goodrich	18-0226-00	382
Gull	18-0305-00	9,947
Hamlet	18-0070-00	276
Hanks	18-0044-00	263
Horseshoe	18-0251-00	922
Hubert	18-0375-00	1,288
Island	18-0183-00	240
Kego	18-0293-00	295
Little Hubert	18-0340-00	194
Little Pine	18-0266-00	352
Lougee	18-0342-00	212
Lower Cullen	18-0403-00	569
Lower Hay	18-0378-00	722
Lower Mission	18-0243-00	819
Mary	18-0185-00	399
Middle Cullen	18-0377-00	397
Mille Lacs	48-0002-00	128,223
Mitchell	18-0294-00	429
Nokay	18-0104-00	759
North Long	18-0372-00	6,144
O'Brien (Northeast Bay)	18-0227-02	86
Ossawinnamakee	18-0352-00	690
Ox	18-0288-00	242
Pelican	18-0308-00	8,367
Pig	18-0354-00	182
Placid	18-0076-00	214
Platte	18-0088-00	1,662
Portage	18-0050-00	284
Rabbit	18-0093-02	1,198

Table continued on next page

Table 2 continued. Lakes assessed in the 2010-2015 lakes assessments (alphabetical order).

Lake Name	Lake ID	Lake Size (acres)
Red Sand	18-0386-00	556
Rogers	18-0184-00	235
Roosevelt	11-0043-00	1,511
Ross	18-0165-00	492
Round	18-0373-00	1,650
Rush Hen	18-0311-00	733
Ruth	18-0212-00	603
Sebie	18-0161-00	185
Serpent	18-0090-00	1,103
Sibley	18-0404-00	433
Silver	18-0239-00	214
Smith	18-0028-00	586
South Long	18-0136-00	1,295
Stark	18-0169-00	217
Upper Cullen	18-0376-00	434
Upper Hay	18-0412-00	606
Upper Mission	18-0242-00	882
Upper South Long	18-0096-00	827
West Fox	18-0297-00	449
White Sand	18-0379-00	410
Whitefish	18-0001-00	709
Whitefish	18-0310-00	7,715

Trophic State Index (TSI)

Trophic State Index (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 biological material (*biomass*) in a waterbody at a specific location and time.

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.

Trophic states are defined divisions of a continuum in water quality. The continuum is total phosphorus concentration, chlorophyll a concentration and Secchi depth. Scientists define certain ranges in the above lake measures as different trophic states so they can be easily referred to.

Most of the large Crow Wing County lakes fall into the mesotrophic category (Table 3, Figure 2).

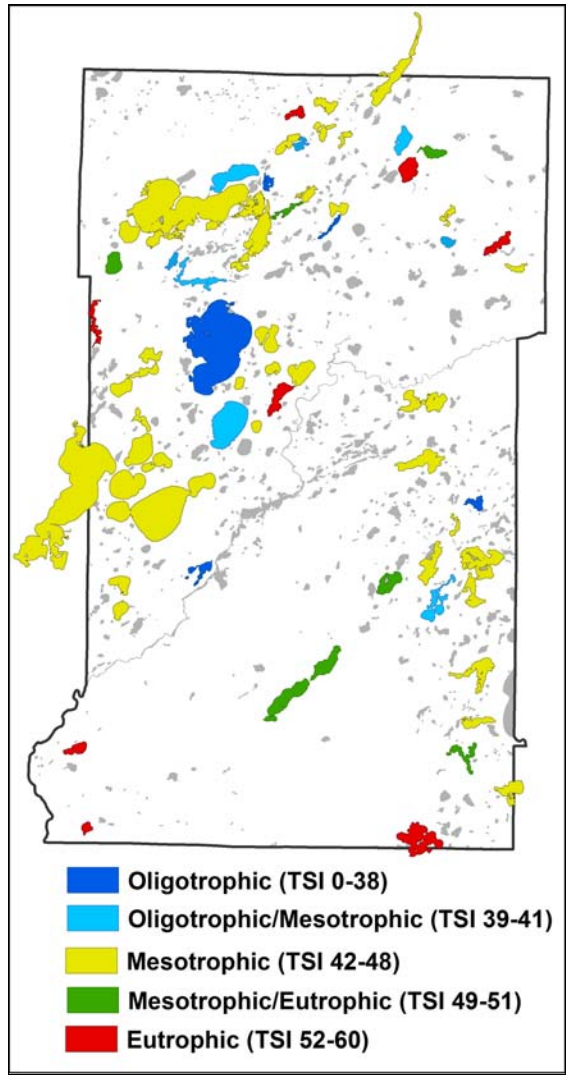


Figure 2. Crow Wing County large lakes illustrating trophic states.

Table 3. Trophic state and trophic state index for large lakes in Crow Wing County.

Lake	Mean TSI	Trophic State	Mean TSI Secchi	Mean TSI Phosphorus	Mean TSI Chlorophyll *a*
Hamlet	--	Oligotrophic	35	No Data	No Data
Gilbert	37	Oligotrophic	36	37	39
O'Brien	37	Oligotrophic	35	40	37
Ox	37	Oligotrophic	33	40	38
Pelican	38	Oligotrophic	36	37	39
Ossawinnamakee	39	Oligotrophic/Mesotrophic	35	43	40
Big Trout	40	Oligotrophic/Mesotrophic	38	40	41
Clear	40	Oligotrophic/Mesotrophic	40	37	44

Table continued on the next page.

Table 3. Continued Trophic state and trophic state index for large lakes in Crow Wing County.

Lake	Mean TSI	Trophic State	Mean TSI Secchi	Mean TSI Phosphorus	Mean TSI Chlorophyll *a*
Crooked	40	Oligotrophic/Mesotrophic	38	39	43
Hanks	40	Oligotrophic/Mesotrophic	42	38	41
Rogers	40	Oligotrophic/Mesotrophic	37	40	42
Sugar Bay	40	Oligotrophic/Mesotrophic	39	40	43
Portage	41	Oligotrophic/Mesotrophic	40	40	44
Ruth	41	Oligotrophic/Mesotrophic	35	46	43
Bay	41	Mesotrophic	38	43	43
East Fox	41	Mesotrophic	36	43	43
Butterfield	42	Mesotrophic	39	45	43
Island	42	Mesotrophic	38	41	46
North Long	42	Mesotrophic	40	41	46
Placid	42	Mesotrophic	37	45	45
Rush	42	Mesotrophic	40	42	43
Serpent	42	Mesotrophic	37	43	44
Silver	42	Mesotrophic	39	45	42
Whitefish (Lower)	42	Mesotrophic	40	42	44
Bertha	43	Mesotrophic	41	44	45
Clamshell	43	Mesotrophic	39	46	45
Clearwater	43	Mesotrophic	39	43	46
Cross	43	Mesotrophic	42	44	44
Edward	43	Mesotrophic	43	43	44
Goodrich	43	Mesotrophic	40	47	42
Horseshoe	43	Mesotrophic	38	44	47
Hubert	43	Mesotrophic	40	45	43
Little Hubert	43	Mesotrophic	40	44	43
Lougee	43	Mesotrophic	41	44	44
Lower Hay	43	Mesotrophic	41	44	44
Pig	43	Mesotrophic	40	44	45
Rabbit	43	Mesotrophic	41	43	44
Roosevelt	43	Mesotrophic	44	42	45
West Fox	43	Mesotrophic	39	45	46
Gladstone	44	Mesotrophic	41	45	46
Lower Cullen	44	Mesotrophic	40	45	46

Table continued on the next page.

Table 3. Continued Trophic state and trophic state index for large lakes in Crow Wing County.

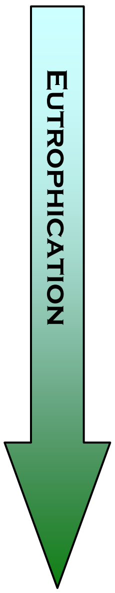
Lake	Mean TSI	Trophic State	Mean TSI Secchi	Mean TSI Phosphorus	Mean TSI Chlorophyll *a*
Middle Cullen	44	Mesotrophic	40	45	47
Red Sand	44	Mesotrophic	44	48	40
White Sand	44	Mesotrophic	42	47	43
Cedar	45	Mesotrophic	45	44	49
Borden	46	Mesotrophic	45	46	47
Gull	46	Mesotrophic	45	45	49
Mille Lacs	46	Mesotrophic	49	42	48
Smith	46	Mesotrophic	43	46	48
Stark	46	Mesotrophic	48	44	46
Whitefish	46	Mesotrophic	41	47	49
Bass	47	Mesotrophic	44	48	48
Clark	47	Mesotrophic	45	48	48
Eagle	47	Mesotrophic	45	49	48
Mitchell	47	Mesotrophic	46	46	49
Whitefish (Upper)	47	Mesotrophic	43	50	48
Bass	47	Mesotrophic	44	48	48
Little Pine	48	Mesotrophic	46	51	47
Upper Cullen	48	Mesotrophic	45	59	51
Upper Mission	48	Mesotrophic	43	51	51
Camp	49	Mesotrophic/Eutrophic	48	45	53
Daggett	49	Mesotrophic/Eutrophic	49	51	48
Nokay	49	Mesotrophic/Eutrophic	47	45	55
Round	50	Mesotrophic/Eutrophic	45	50	55
Upper South Long	50	Mesotrophic/Eutrophic	49	47	55
Mary	51	Eutrophic	52	52	48
Upper Hay	51	Eutrophic	48	56	50
Kego	52	Eutrophic	49	55	53
Platte	52	Eutrophic	49	54	52
Emily	53	Eutrophic	53	57	50
Lower Mission	54	Eutrophic	48	57	55
Lower South Long	54	Eutrophic	52	57	55
Sebie	56	Eutrophic	53	58	58

Table continued on the next page.

Table 3. Continued Trophic state and trophic state index for large lakes in Crow Wing County.

Lake	Mean TSI	Trophic State	Mean TSI Secchi	Mean TSI Phosphorus	Mean TSI Chlorophyll *a*
Sibley	56	Eutrophic	52	55	60
Crow Wing	57	Eutrophic	52	58	62
Ross	59	Eutrophic	59	51	59

Table 4. Trophic states and corresponding lake and fisheries conditions.



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, Tullibee 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.

Water Quality Trends

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.

All of the lakes evaluated had sufficient transparency data to perform a statistical trend analysis. There was enough historical data to perform trend analysis for total phosphorus or chlorophyll *a* on 30 lakes or bays. The data were analyzed using the Mann Kendall Trend Analysis (Tables 5-7).

Table 5. Crow Wing County Lakes with improving water quality trends (TP=Total phosphorus, CHLA= Chlorophyll a).

Lake	Parameter	Date Range	Trend	Probability
Bay	Transparency	1998-2012	Weak Improving	80%
Butterfield	Transparency	2006-2014	Improving	90%
Crooked	Transparency	2001, 2004-2010	Improving	95%
Daggett	TP	2003-2011	Improving	90%
Eagle (Main Basin)	TP	2003-2005, 2007-2011	Improving	90%
Hanks	Transparency	1980-1989, 1991, 2008, 2009, 2010	Improving	95%
Kego	TP	2004-2005, 2007-2011	Improving	90%
Little Hubert	Transparency	1992-2014	Improving	99.9%
Little Pine (204)	TP	2003, 2005, 2007-2011	Improving	90%
Little Pine (203)	Transparency	1984, 1986-1996, 1998, 2004-2011	Improving	99%
Lougee	Transparency	1997-2014	Improving	99%
Lower Mission	Transparency	1990-1992, 1994-2011	Improving	90%
North Long (East Bay)	Transparency	1998-2010	Improving	99.9%
O'Brien	Transparency	1994-2014	Improving	99%
Ossawinnamakee	Transparency	1985-2011	Improving	95%
Ox	Transparency	1999, 2001-2005, 2007-2011	Improving	95%
Portage	Transparency	1991-1997, 1999-2011	Improving	95%
Rabbit (East Bay)	Transparency	1998-1999, 2001-2011	Improving	95%
Rabbit (West Bay)	Transparency	1998-1999, 2001-2011	Improving	95%
Roosevelt (South Bay)	Transparency	1999-2011	Improving	95%
Smith	Transparency	2000-2011	Improving	95%
Sugar Bay	Transparency	2003-2011	Improving	95%
Whitefish (18-0001)	Transparency	1993-2010	Improving	99%

Table 6. Crow Wing County Lakes with declining water quality trends. For chlorophyll a and phosphorus parameters, a declining trend means that their concentrations are increasing. For transparency, a declining trend means that the clarity is decreasing (TP=Total phosphorus, CHLA= Chlorophyll a).

Lake	Parameter	Date Range	Trend	Probability
Big Trout	Transparency	1992-2010	Declining	99.9%
Crow Wing	Transparency	2000-2014	Declining	90%
Eagle (West Basin)	Transparency	2007-2014	Declining	90%
Emily	Transparency	2001-2005, 2007-2009	Declining	90%
Gull (Booming Out Bay)	Transparency	1987-2011	Declining	99%
Island	Transparency	2004-2014	Declining	95%
Lower Cullen	Transparency	1994-2011	No Trend	--
Lower Cullen	TP	1995-2008	Declining	95%
Lower Cullen	CHLA	1995, 1997-2008	Declining	90%
Mary	Transparency	2002-2014	Declining	95%
Middle Cullen	Transparency	1998-2012	Declining	95%
Middle Cullen	TP, CHLA	2003-2005	No Trend	--
North Long (Main Bay)	Transparency	2000-2011	Declining	90%
North Long (West Bay)	Transparency	2000-2011	Declining	90%
Platte	Transparency	1995-2012	Declining	95%
Sebie	TP	2008-2014	Declining	99%
Sebie	Transparency	2007-2014	Declining	95%
Serpent	Transparency	1977-1981, 2002-2011	Declining	95%
Sibley	Transparency	1989-2004	Declining	99 %
Silver	Transparency	2005-2014	Declining	95%
Stark	Transparency	2007-2014	Declining	95%
Upper Mission	Transparency	2003-2011	Declining	99%
White Sand	Transparency	1997-2011	Declining	95%
Whitefish (Lower)	Transparency	1989-2002. 2004-2005, 2007-2010	Declining	99%

Table 7. Crow Wing County Lakes with no evidence of water quality trends (TP=Total phosphorus, CHLA= Chlorophyll a).

Lake	Parameter	Date Range	Trend
Bass	Transparency	1997-2002, 2004, 2007-2009, 2011-2014	No Trend
Bertha	TP, CHLA	2003-2005, 2007-2011	No Trend
Bertha	Transparency	1993-1998, 2002, 2004-2011	No Trend
Borden	Transparency	2003-2009, 2012-2014	No Trend
Camp	Transparency	2004-2011	No Trend
Cedar	Transparency	1995-2012	No Trend
Clamshell	Transparency	1993-2005, 2007-2011	No Trend
Clamshell	TP, CHLA	2003-2005, 2007-2011	No Trend
Clark	Transparency	1994-2014	No Trend
Clark	TP, CHLA	2000-2004, 2007-2011, 2013	No Trend
Clear	Transparency	1999-2003, 2007-2011	No Trend
Clearwater	Transparency	1989-2011	No Trend
Cross	Transparency	1984-1996, 2004, 2007-2010	No Trend
Daggett	CHLA	2003-2011	No Trend
Daggett	Transparency	1993-2011	No Trend
Eagle (Main Basin)	CHLA	2003-2005, 2007-2011	No Trend
Eagle (Main Basin)	Transparency	2001, 2003-2005, 2007-2014	No Trend
Eagle (East Basin)	Transparency	2007-2014	No Trend
East Fox	Transparency	2002-2014	No Trend
East Fox	TP, CHLA	2003, 2005, 2007-2011	No Trend
Edward	Transparency	2000-2012	No Trend
Edward	TP, CHLA	2000-2004, 2006, 2008-2012	No Trend
Gilbert	Transparency	1989-2011	No Trend
Gilbert	TP, CHLA	1999-2011	No Trend
Gladstone	Transparency	1993-2004	No Trend
Goodrich	TP, CHLA	2003-2011	No Trend
Goodrich	Transparency	2003-2005, 2007-2011	No Trend
Gull (Main Lake)	Transparency	1986-2011	No Trend
Hamlet	Transparency	2001-2014	No Trend
Horseshoe (East Bay)	Transparency	2003-2012	No Trend
Horseshoe (East Bay)	TP, CHLA	2003-2012	No Trend
Horseshoe (West Bay)	Transparency	1991-2012	No Trend
Horseshoe (West Bay)	TP, CHLA	2003-2012	No Trend
Hubert	Transparency	2003-2012	No Trend
Kego	CHLA	2004-2005, 2007-2011	No Trend
Kego	Transparency	2001-2011	No Trend
Little Pine (204)	CHLA	2003, 2005, 2007-2011	No Trend
Little Pine (202)	Transparency	2005-2014	No Trend
Lougee	TP, CHLA	2000-2004, 2006, 2010-2012	No Trend
Lower Hay	Transparency	1984-1989, 1991-2005, 2007-2009	No Trend
Lower South Long	Transparency	1995-2004	No Trend
Mary	TP, CHLA	2002-2011	No Trend

Table continues on the next page.

Table 7 continued. Crow Wing County Lakes with no evidence of water quality trends (TP=Total phosphorus, CHLA= Chlorophyll a).

Lake	Parameter	Date Range	Trend
Mille Lacs - east	Transparency	2002-2012	No Trend
Mille Lacs - northeast	Transparency	1997-2012	No Trend
Mitchell	Transparency	2004-2011	No Trend
Nokay	Transparency	2006-2013	No trend
O'Brien	TP, CHLA	2003-2011	No Trend
Ox	TP, CHLA	2003-2005, 2007-2011	No Trend
Pelican	Transparency	2000-2012	No Trend
Pelican	TP, CHLA	2000-2012	No Trend
Pig	Transparency	1999-2014	No Trend
Pig	TP, CHLA	2003, 2005, 2007-2011	No Trend
Placid	Transparency	2000-2014	No Trend
Red Sand	Transparency	2001-2010	No Trend
Rogers	TP, CHLA	2001-2006, 2009-2010	No Trend
Rogers	Transparency	1998-2014	No Trend
Roosevelt (North Bay)	Transparency	1996-2011	No Trend
Ross	Transparency	1998-2012	No Trend
Round	Transparency	1993-2012	No Trend
Rush	Transparency	2002-2010	No Trend
Ruth	Transparency	2005-2013	No trend
Sebie	CHLA	2008-2014	No Trend
South Long	Transparency	1995-2010	No Trend
Upper Cullen	Transparency	1988-2012	No Trend
Upper Cullen	TP, CHLA	1988-2012	No Trend
Upper Hay	Transparency	1992-2003, 2005-2011	No Trend
Upper South Long	Transparency	1986-2010	No Trend
West Fox	Transparency	2001-2009	No Trend
West Fox	TP, CHLA	2003-2011	No Trend
Whitefish (Upper)	Transparency	1986-1989, 1991, 1998, 2002-2005, 2007-2010	No Trend

Ecoregion Comparisons

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. 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.

Figure 3. Minnesota Ecoregions. Crow Wing County is indicated in black.

All of Crow Wing County is in the Northern Lakes and Forests (NLF) Ecoregion (Figure 3). This heavily forested ecoregion is made up of steep, rolling hills interspersed with pockets of wetlands, bogs, lakes and ponds. Lakes are typically deep and clear, with good gamefish populations. These lakes are very sensitive to damage from atmospheric deposition of pollutants (mercury), storm water runoff from logging operations, urban and shoreland development, mining, inadequate wastewater treatment, and failing septic systems. Agriculture is somewhat limited by the hilly terrain and lack of nutrients in the soil, though there are some beef and dairy cattle farms.

Most of the lakes evaluated in this report fall within the expected ecoregion ranges. Crow Wing, Sebie, Platte, Lower South Long, Upper South Long, Lower Mission, Sibley, Ross, and Emily Lakes are slightly poorer than the expected ecoregion ranges. Most of these lakes are shallow, which means they don't compare to the ecoregion ranges as well. Pelican, Gilbert and Ossawinnamakee Lakes are better than the expected ecoregion average.

Statewide Assessments

Lake monitoring should be designed and accomplished for achieving specific goals. There are two main purposes for lake monitoring in Minnesota. The first is the MPCA statewide 303(d) and 305(b) assessments that occur every two years. Statewide MPCA Assessments are performed with a minimum data set of 10 data points each of total phosphorus, chlorophyll *a*, and secchi depth over a two-year period in the past 10 years. This assessment can be considered the first step to understanding a lake.

The second purpose for lake monitoring is ongoing education, awareness and lake condition. After the lake's current condition is determined, associations can monitor water quality each year to learn about seasonal variability, year-to-year variability, and if the water quality is improving, declining or staying the same (trend analysis). Condition monitoring involves collecting at least 5 samples during the growing season (the typical program involves monitoring once a month May-September) each year.

Impaired Waters Assessment 303(d) List
There are two main types of Impaired Waters Assessment for lakes: eutrophication (phosphorus) for aquatic recreation and mercury in fish tissue for aquatic consumption.

Many of the Crow Wing County Lakes are listed as impaired for mercury; however, they are part of the statewide mercury TMDL (Figure 4). The remaining lakes in the county most likely are not listed due to lack of fish tissue data. There are statewide fish consumption guidelines available from the Minnesota Department of Health: http://www.health.state.mn.us/divs/eh/fish/index.html.

Most Mercury comes from the air. Mercury gets into the air through emissions from coal-burning plants and taconite processing and moves long distances in the wind currents. From there, it settles into our lakes and streams and bacteria convert it to a toxic form, methylmercury. The problem is that 90% of the mercury in our waters comes from other states and countries, which is why it is so hard to regulate. In turn, 90% of the mercury emitted in Minnesota goes to other states and countries.

The mercury that settles into our lakes and streams gets filtered by zooplankton, the tiny animals that get eaten by small fish. The larger the small fish gets, the more mercury builds up in its tissue from all the zooplankton eaten. Mercury bioaccumulates, which means that at each step in the food chain the mercury builds to higher levels, especially in large predatory fish such as walleye, northern pike and muskies.

Crow Wing, Jail, Kego, Mayo, Platte and Sibley Lakes in Crow Wing County are currently listed as impaired for eutrophication as of the 2014 Impaired Waters List (Figure 4). Margaret Lake in Cass County is listed as impaired for eutrophication as of the 2014 Impaired Waters List, and is connected to Gull Lake.

Many of the large lakes in Crow County have been involved in Surface Water Assessment Grants (SWAG) that cover the cost of collecting data. This data will be used to complete the state assessments on these lakes.

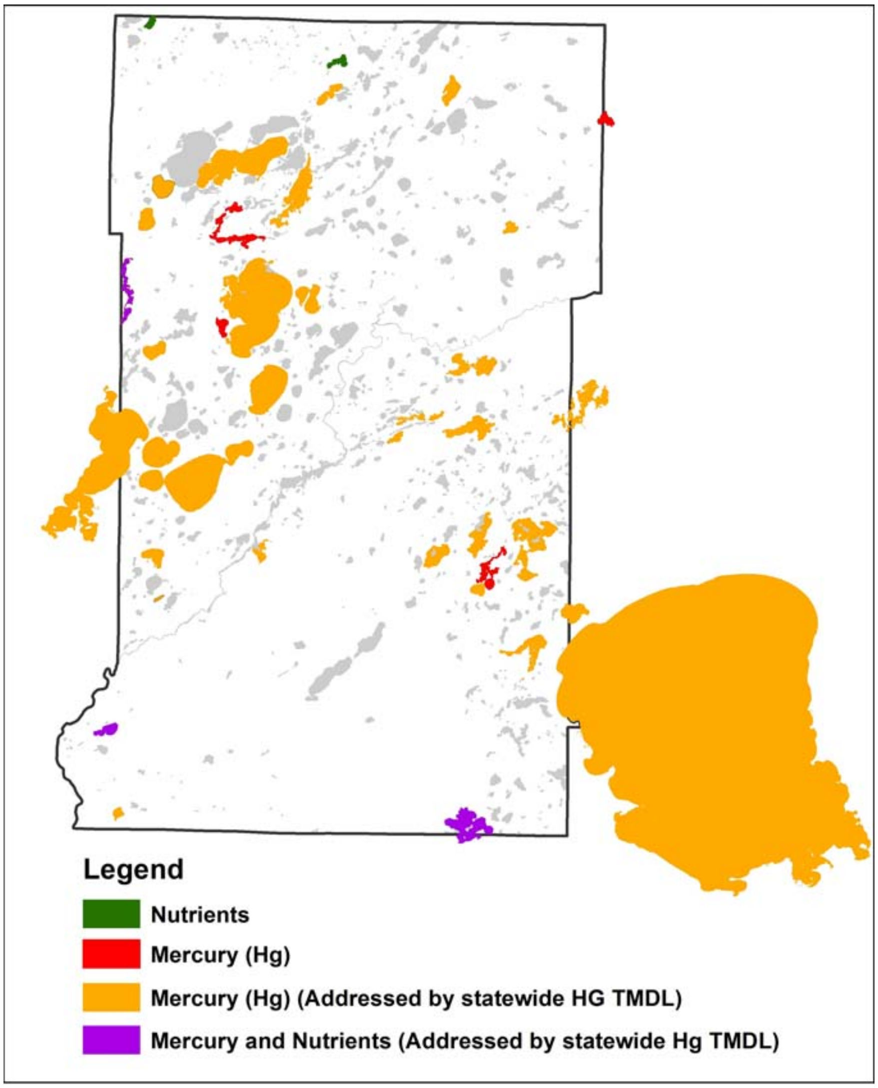


Figure 4. Crow Wing County lakes illustrating impaired waters status.

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 8). Watershed disturbance was defined as having urban, agricultural and mining land uses. Watershed protection is defined as publicly owned land or conservation easement.

Table 8. 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.

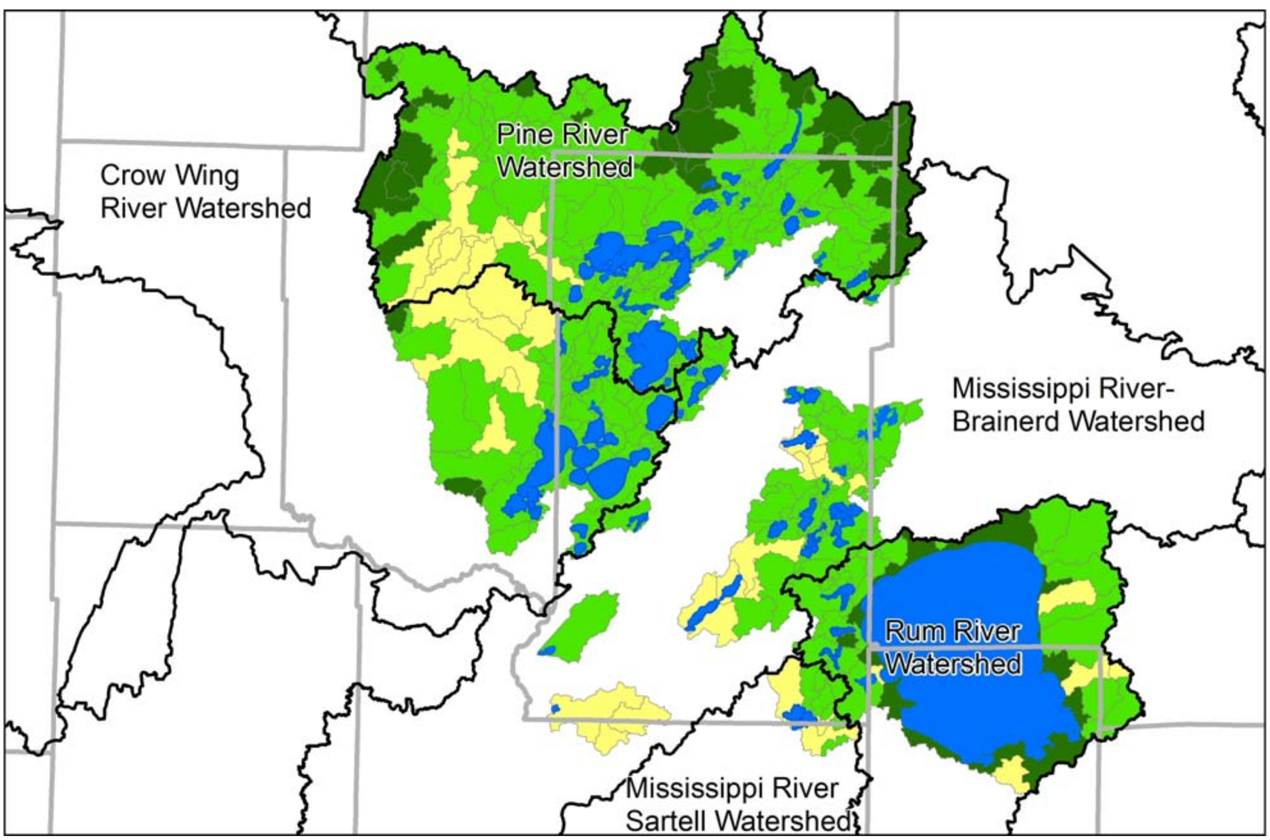


Figure 5. Map of lakesheds color-coded with management focus (Table 9).

Most of the lakes evaluated in this report have a protection management focus (light green, Figure 5, Table 9). The lakesheds around Upper and Lower South Long, Serpent, Sebie and Platte Lakes are listed in the full restoration (yellow, Figure 5, Table 9), which means they are more than 25% disturbed.

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. There are fourteen Crow Wing County Lakes that are listed as Cisco refuge lakes (Table 9).

Table 9. Crow Wing County Lakes evaluation of watershed protection and disturbance.

Lake Name	Management Focus	Cisco Refuge Lakes
Kego	Vigilance	
Mille Lacs	Vigilance	
Bass	Protection	
Bay	Protection	
Bertha	Protection	x
Big Trout	Protection	x
Borden	Protection	x
Butterfield	Protection	
Camp	Protection	
Cedar	Protection	
Clamshell	Protection	
Clark	Protection	
Clear	Protection	x
Clearwater	Protection	
Crooked & Sugar Bay	Protection	x
Cross	Protection	
Crow Wing	Protection	
Daggett	Protection	
Eagle	Protection	
East Fox	Protection	x
Edward	Protection	
Emily	Protection	
Gilbert	Protection	
Gladstone	Protection	
Goodrich	Protection	
Gull	Protection	
Hamlet	Protection	
Hanks	Protection	
Hubert	Protection	
Island	Protection	
Little Hubert	Protection	
Little Pine	Protection	
Lougee	Protection	
Lower Cullen	Protection	
Lower Hay	Protection	x
Lower Mission	Protection	
Mary	Protection	
Middle Cullen	Protection	

Table continued on next page.

Table 9 continued. Crow Wing County Lakes evaluation of watershed protection and disturbance.

Lake Name	Management Focus	Cisco Refuge Lakes
Mitchell	Protection	
Nokay	Protection	
North Long	Protection	
O'Brien	Protection	
Ossawinnamakee	Protection	x
Ox	Protection	
Pelican	Protection	x
Pig	Protection	x
Placid	Protection	
Portage	Protection	x
Rabbit	Protection	
Red Sand	Protection	
Rogers	Protection	
Roosevelt	Protection	
Ross	Protection	
Round	Protection	
Rush-Hen	Protection	x
Ruth	Protection	
Sibley	Protection	
Silver	Protection	
Smith	Protection	
Stark	Protection	
Upper Cullen	Protection	
Upper Hay	Protection	
Upper Mission	Protection	
West Fox	Protection	x
White Sand	Protection	
Whitefish	Protection	x
Platte	Full Restoration	
Sebie	Full Restoration	
Serpent	Full Restoration	
South Long	Full Restoration	
Upper South Long	Full Restoration	

Aquatic Invasive Species

Invasive species are a large threat to Minnesota's lakes. Invasive species can get out of control because there is nothing in the ecosystem naturally to keep the population in check. They can also replace native beneficial species and change the lake's ecosystem.

As of 2015, Crow County has numerous infestations (Figure 6). The most difficult infestation to deal with is zebra mussels, since there is currently no method of controlling them.

At boat landings, there are usually DNR signs telling which invasive species are present in the waterbody and how to prevent their spread. Boaters should be educated about how to check for invasive species before moving from lake to lake. Care should be taken to protect Crow Wing County's water resources from future aquatic invasive species infestations.

For a current list of the infested waters in Minnesota, visit the DNR's website:
http://www.dnr.state.mn.us/invasives/index_aquatic.html.

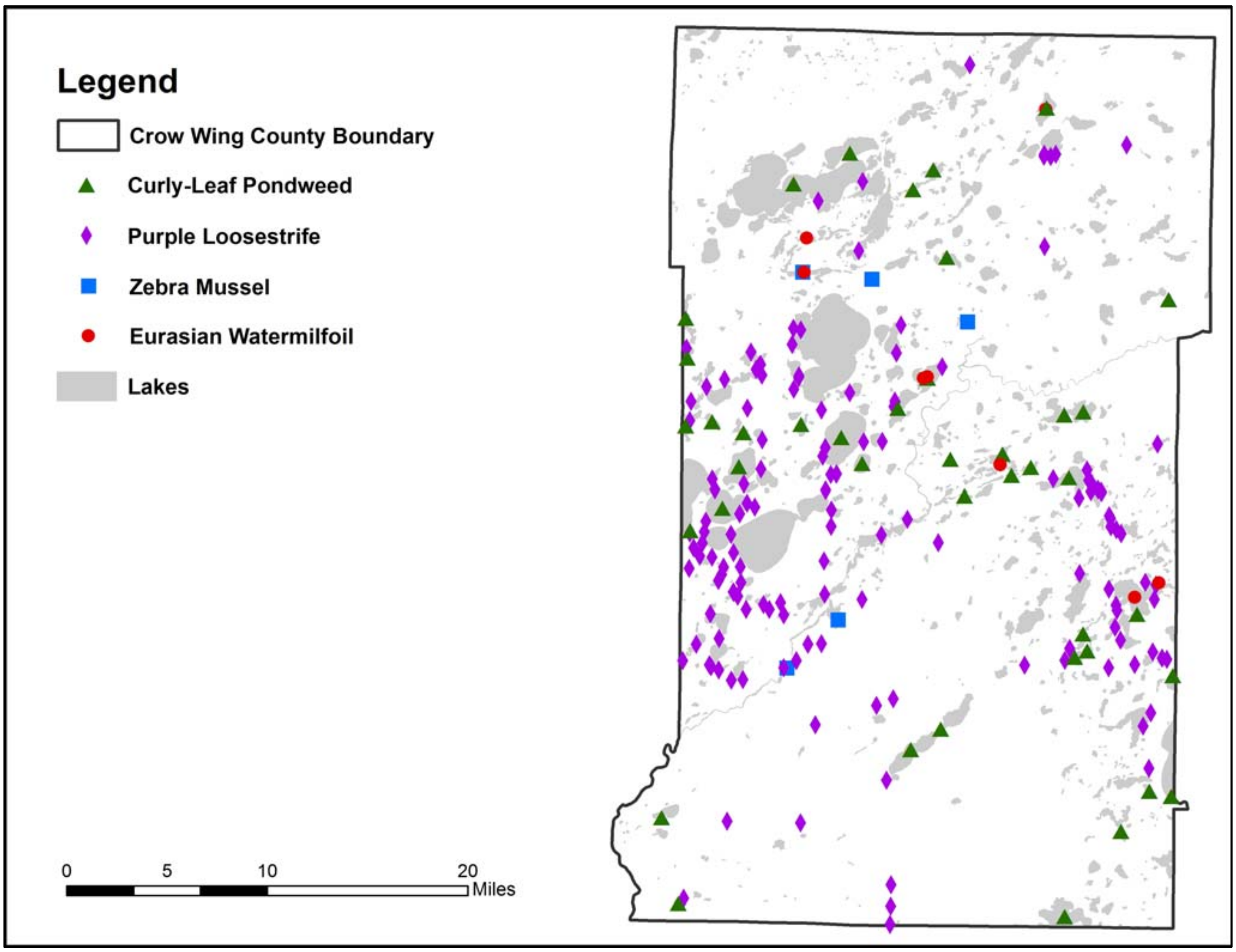


Figure 6. Crow Wing County lakes with invasive species.

Matrix of Potential Lake Impacts

Table 10. Definitions of potential lake impacts from Tables 11-15.

Potential Lake Impact*	Definition
Agriculture	Agriculture is present near the lakeshore and there may not be sufficient buffers to protect the lake from runoff.
Development	Development has occurred around the lakeshore (impervious surface, septic systems), and additional development is possible.
Shallow	The majority of the lake is 25 feet deep or less. Aquatic plants and sediments must be protected to prevent a switch to the turbid state.
Internal Loading	Internal loading could be occurring due to lake depth and frequent mixing in the summer. The internal loading shows as increasing phosphorus toward the end of the summer and nuisance algae blooms.
Inlet Loading	Phosphorus could be impacting the lake through inlet loading.
Large Watershed	The large watershed of the lake contributes nutrients cumulatively to the lake.
City Stormwater	There is a city located on the lake shore and city stormwater can carry nutrients into the lake that fuels plant and algae growth.

These lake impacts are not quantified as to how much loading they are providing to the lake.

Prioritization Methods

The lakes were first considered in one large matrix. Potential lake impacts were summed, and 4-6 impacts were labeled in red, while 1-2 impacts were labeled in green. Declining trends were labeled in red and improving trends were labeled in green. Then the lakes were sorted by trend. Categories were formed by comparing water quality trends with the number of lake impacts. For details see Tables 11-15. For more explanation and interpretation see page 26.

Table 11. Matrix showing which potential impacts apply to the assessed lakes in Crow Wing County. These lakes are considered high priority for restoration and protection.

High Priority Restoration/Protection

Lake	Agriculture	Development	Shallow	Internal Loading, Algae Blooms	Inlet loading	Large Watershed	City Stormwater	Total Impacts*	Trend	Prioritization Notes
Big Trout		x						1	Declining	High Priority
Island (18-0183-00)		x				x		2	Declining	High Priority
Serpent		x					x	2	Declining	High Priority

These lake impacts are not quantified as to how much loading they are providing to the lake.

Table 12. Matrix showing which potential impacts apply to the assessed lakes in Crow Wing County. These lakes are considered priority for determining nutrient sources and then implementing restoration projects.

Priority Lakes

Lake	Agriculture	Development	Shallow	Internal Loading, Algae Blooms	Inlet loading	Large Watershed	City Stormwater	Total Impacts*	Trend	Prioritization Notes
Lower Cullen		x		x	x			3	Declining	See future studies section
Middle Cullen		x		x	x			3	Declining	See future studies section
North Long		x			x		x	3	Declining	See future studies section
Silver	x	x	x					3	Declining	See future studies section
Stark		x			x			2	Declining	See future studies section
Upper Mission		x		x				2	Declining	See future studies section
White Sand		x	x				x	3	Declining	See future studies section
Whitefish (18-0310-00)		x			x	x		3	Declining	See future studies section

These lake impacts are not quantified as to how much loading they are providing to the lake.

Table 13. Matrix showing which potential impacts apply to the assessed lakes in Crow Wing County. These lakes are considered flow-through lakes.

Many Impacts, But Flow-Through Lakes

Lake	Agriculture	Development	Shallow	Internal Loading, Algae Blooms	Inlet loading	Large Watershed	City Stormwater	Total Impacts*	Trend	Prioritization Notes
Daggett		x	x	x	x	x		5	Stable	Nutrients flowing through
Lower South Long	x	x		x	x			4	Stable	Nutrients flowing through
Upper South Long	x	x		x	x	x		5	Stable	Nutrients flowing through

These lake impacts are not quantified as to how much loading they are providing to the lake.

Table 14. Matrix showing which potential impacts apply to the assessed lakes in Crow Wing County. These lakes are Impaired for excess nutrients.

Impaired Waters - Restoration potential can be determined by TMDL

Lake	Agriculture	Development	Shallow	Internal Loading, Algae Blooms	Inlet loading	Large Watershed	City Stormwater	Total Impacts*	Trend	Prioritization Notes
Crow Wing	x	x	x	x	x			5	Declining	Restoration potential?
Emily**		x	x	x	x	x	x	6	Declining	Restoration potential?
Mary**		x		x	x	x		4	Declining	Restoration potential?
Platte	x	x	x	x	x			5	Declining	Restoration potential?
Sebie**	x	x	x	x	x	x		6	Declining	Restoration potential?
Sibley		x		x	x	x		4	Declining	Restoration potential?

**These lake impacts are not quantified as to how much loading they are providing to the lake.*
***These lakes are not on the 2014 Impaired Waters List, but are over the Impaired Waters Standard, so should be considered on future lists.*

Table 15. Matrix showing which potential impacts apply to the assessed lakes in Crow Wing County. These lakes are stable or improving.

Low Concern

Lake	Agriculture	Development	Shallow	Internal Loading, Algae Blooms	Inlet loading	Large Watershed	City Stormwater	Total Impacts*	Trend	Prioritization Notes
Bass (18-0256-00)		x	x					2	Stable	
Bay		x			x			2	Improving	
Bertha		x						1	Stable	
Borden		x			x			2	Stable	
Butterfield		x	x					2	Improving	
Camp		x						1	Stable	
Cedar (01-0209-00)		x			x			2	Stable	
Clamshell		x						1	Stable	
Clark		x			x			2	Stable	

Table continued on next page…

Table 15 continued. Matrix showing which potential impacts apply to the assessed lakes in Crow Wing County. These lakes are stable or improving.

Low Concern

Lake	Agriculture	Development	Shallow	Internal Loading, Algae Blooms	Inlet loading	Large Watershed	City Stormwater	Total Impacts*	Trend	Prioritization Notes
Clear		x						1	Stable	
Clearwater		x						1	Stable	
Crooked		x						1	Improving	
Cross		x			x	x		3	Stable	
Eagle		x			x	x		3	Improving	
East Fox		x			x	x		3	Stable	
Edward		x						1	Stable	
Gilbert		x						1	Stable	
Gladstone		x						1	Stable	
Goodrich		x						1	Stable	
Gull		x			x	x		3	Stable	
Hamlet		x						1	Stable	
Hanks		x						1	Improving	
Horseshoe		x						1	Stable	
Hubert		x						1	Stable	
Kego		x	x	x	x			4	Improving	Improving from past
Little Hubert		x						1	Improving	
Little Pine		x			x	x		3	Improving	
Lougee		x						1	Improving	
Lower Hay		x			x			2	Stable	
Lower Mission	x	x	x	x	x			5	Improving	Improving from past
Mille Lacs		x			x			2	Stable	
Mitchell		x			x	x		3	Stable	
Nokay	x	x			x			3	Stable	
O'Brien (Northeast Bay)		x						1	Improving	

Table continued on next page…

Table 15 continued. Matrix showing which potential impacts apply to the assessed lakes in Crow Wing County. These lakes are stable or improving.

Low Concern

Lake	Agriculture	Development	Shallow	Internal Loading, Algae Blooms	Inlet loading	Large Watershed	City Stormwater	Total Impacts*	Trend	Prioritization Notes
Ossawinnamakee		x			x			2	Improving	
Ox		x						1	Improving	
Pelican		x						2	Stable	
Pig		x						1	Stable	
Placid		x	x					2	Stable	
Portage		x						1	Improving	
Rabbit		x			x			2	Improving	
Red Sand		x	x				x	3	Stable	
Rogers		x						1	Stable	
Roosevelt		x			x			2	Improving	
Ross		x		x	x			3	Stable	
Round (18-0373-00)		x			x			2	Stable	
Rush Hen		x			x	x		3	Stable	
Ruth		x					x	2	Stable	
Smith		x			x			2	Improving	
Upper Cullen		x		x	x			3	Stable	
Upper Hay		x			x			2	Stable	
West Fox		x			x			2	Stable	
Whitefish (18-0001-00)		x						1	Improving	

These lake impacts are not quantified as to how much loading they are providing to the lake.

Summary and Recommendations

Specific Summary (Tables 11-15)
Tables 11-15 are a way to prioritize where projects are needed in the county. High Priority lakes included Big Trout, Serpent, and Island (18-0183) (Table 11). These lakes have excellent water quality and only one or two main impacts but are declining. These lakes are good grant application candidates lakes since some specific projects could really help restore water quality. Crow Wing County already has been working on Big Trout and Serpent. Island was included because it had excellent water quality, and then a big flood in 2012 caused a decline. Hopefully this lake could get back on track with some erosion control projects.

There are some lakes that have mainly good water quality but declining trends (Table 12). These lakes would benefit from more study/monitoring to see what projects can help them: Lower Cullen, Middle Cullen, North Long, Silver, Stark, Upper Mission, White Sand, Whitefish. Whitefish is in the Pine River Watershed Restoration and Protection Strategy process (WRAPS) – so is already being studied. See more information about the Pine River WRAPS here: http://www.pca.state.mn.us/tchydce. See the Future Studies section on page 30 for project ideas for the other lakes.

There are some lakes that have a lot of potential impacts, but they don't have declining trends (Table 13). A possible explanation could be that because they are major flow-through lakes a lot of the nutrients that flow in, flow back out: Daggett, Upper South Long, Lower South Long.

There are some lakes that have many potential impacts, declining trends, and are on the Impaired Waters List (Table 14). A full TMDL is needed to figure out how to fix these lakes. These lakes include: Crow Wing, Emily, Mary, Platte, Sebie and Sibley. Emily, Mary and Sebie are not on the 2014 Impaired Waters List, but are over the state impaired waters standards, so they would likely be included on future lists.

The remaining lakes have stable or improving trends (Figure 15). These lakes can continue monitoring to watch for any future water quality changes.

Overall Conclusions
Many of the lakes evaluated in this report had similar conditions: mesotrophic lakes between 40-70 feet deep at the maximum. This seems to be the natural state of these lakes after the glaciers receded.

All of the lakes had enough transparency data to perform a trend analysis. Thirty lakes had enough phosphorus and chlorophyll a data to perform trends. Overall, 23 lakes (or bays) had improving water quality trends (Table 5), 20 lakes (or bays) had declining trends (Table 6), and 52 lakes (or bays) had no trends (Table 7). Some of the declining trends could be due to adjacent towns, and some could be from heavy development and a disturbed lakeshed.

Crow Wing, Jail, Kego, Mayo, Platte and Sibley Lakes in Crow Wing County are currently listed as impaired for eutrophication as of the 2014 Impaired Waters List (Figure 4). A Total Maximum Daily Load (TMDL) study will be conducted on these lakes to determine how to reduce phosphorus levels.

Fourteen of the lakes evaluated in this report are designated as Cisco refuge lakes by the DNR: Bertha, Big Trout, Borden, Clear, Crooked, East Fox, Lower Hay, Ossaminnawakee, Pelican, Pig, Roosevelt, Rush-Hen, West Fox and Whitefish. Ciscos (*Coregonus artedi)* can be an early indicator of eutrophication in a lake because they require cold hypolimnetic temperatures and high dissolved oxygen levels. Cisco refuge lakes are usually deep and have good oxygen levels. Protecting the water quality and lakesheds of these lakes will help ensure the Cisco's survival.

Second tier development and the conversions of small seasonal cabins to large year-round homes seems to be the largest overall impacts and risk to the lakes in Crow Wing County. From looking at GIS mapping layers over time, it appears that development on lakes in Crow Wing County has increased significantly since 1990. Crow Wing County has a high pressure for development due to the high quality water resources. Once the second tier is developed, the drainage in the lakeshed changes and more runoff reaches the lake from impervious surface and lawns. Project ideas include protecting land with conservation easements, enforcing county shoreline ordinances, smart development, shoreline restoration, rain gardens, and septic system maintenance. Proper vegetative buffers, wetland restoration and conservation farming practices would decrease the impact by agriculture.

Monitoring Recommendations
Some of the lakes in Crow Wing County had disjointed data with many gaps. Monitoring is most effective when done at one primary site in the lake over many consecutive years. Some of the lakes in this report jumped around and monitored one site one year and a different site the next year, which makes it hard to compare conditions year-to-year.

At a minimum, every lake should have one primary site (recommended in each individual report) that should be monitored for transparency with a Secchi disk weekly or bimonthly every summer. This monitoring is free and is tracked through the Minnesota Pollution Control Agency's Citizen Lake Monitoring Program (CLMP, http://www.pca.state.mn.us/wfhyac7). After 8-10 years of consecutive data, a trend analysis can be completed for each lake.

Hamlet Lake is the only one considered in this report that had no phosphorus or chlorophyll a data. It does have a good transparency data set. Two years of phosphorus and chlorophyll a data collection on this lake would help to understand it better and to be assessed by the Minnesota Pollution Control Agency.

Lakes that have declining trends and nuisance algae blooms should be monitored for internal loading and inlet loading. To confirm if internal loading is occurring, hypolimnion water samples (water samples taken 1 foot above the lake's bottom) and corresponding dissolved oxygen profiles could be monitored for a summer or two. To determine the phosphorus loading from the watershed, the inlets could be monitored during baseline and peak flow events (spring thaw and heavy rains).

Mille Lacs Lake
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.

Whitefish Area Lakes (Pine River Watershed)
The lakes in the Whitefish Area Property Owners Association (WAPOA) are near the end of the large Pine River watershed. Of these lakes, about half of them are directly connected to the Whitefish Chain of Lakes. The Pine River enters Upper Whitefish from the west, and flows through Whitefish, Rush and Cross Lakes before exiting to the south. Lower Hay and Big Trout are also connected to this chain. A dam at Crosslake regulates water levels in the Whitefish Chain of Lakes. An enormous amount of water moves through this system, which has its advantages and disadvantages. The disadvantage is that a lot of nutrients enter the lakes from the Pine River Watershed, while the advantage is that the system is flushed regularly. Upper Whitefish Lake is mesotrophic, and is the first lake to receive all the nutrients from the Pine River Watershed. Lakes lower in the watershed

have lower TSIs (Rush=41, Cross=42). Lower Whitefish and Rush lakes have declining transparency trends in the past decade, which could be due to the cumulative nutrients flowing through the Chain of Lakes.

Big Trout Lake is oligotrophic, and is connected to Lower Whitefish, but the Pine River doesn't flow through it. It is also very deep and has a very small watershed. This lake has a declining trend, which is more likely to be due to land practices around the lake than its connection with the Whitefish Chain.

East of Whitefish Lake is another chain of lakes along Daggett Brook that flow into Cross Lake. These lakes include Daggett, Little Pine, East and West Fox, Kego, Eagle, Mitchell and Roosevelt. These lakes have heavy development immediately around their lakeshore, but the watershed is well protected (Figure 5).

It's a little more difficult to manage the water quality in the Whitefish Chain of Lakes because the large watershed cumulatively impacts the lakes. The main impacts to these lakes are the large watershed and the heavy development. The Pine River Watershed is participating in a Watershed Restoration and Protection Plan through the Minnesota Pollution Control Agency. Once that report is completed, it could show areas to focus improvement projects in the watershed: http://www.pca.state.mn.us/tchydce.

Projects that would have the best chance of improving the water quality of these lakes and lakes downstream include runoff and sedimentation reduction in the Pine River Watershed and buffer strips along the whole Pine River, especially in the area directly downstream of cities. In addition, managing heavy development by enforcing county ordinances, restoring shorelines, and installing rain gardens can contribute to water quality improvements.

The other WAPOA lakes include Ossawinnamakee, Roosevelt, Ruth, and Emily lakes. Ruth and Emily Lakes sit to the north and south of the town of Emily. Lake Emily has a declining transparency trend. It receives the main impact from the town of Emily, as the town is in its lakeshed and Ruth and Mary Lakes flow into it. The nutrients from all these lakes and the town of Emily cumulatively impact Lake Emily. In addition, Lake Emily is shallow, so there is not much volume to dilute what's running into it. Ruth Lake doesn't appear to be as affected by the town of Emily, because it is a headwaters catchment. Ruth Lake has insufficient data for a trend analysis, but it doesn't appear to be declining. Managing stormwater in the town of Emily and maintaining proper buffers between the town and the lakes will help protect water quality.

Ossawinnamakee and the southern bay of Roosevelt are improving in transparency, while the northern bay of Roosevelt has no trend. These two lakes have great water quality and a lot of shoreline due to their long, narrow shapes. This shape makes them vulnerable to impacts from development.

Portage Crooked Hanks Chain of Lakes

The Portage, Crooked, Sugar Bay, and Hanks Chain of Lakes have outstanding water quality. These lakes are on the border of oligotrophic and mesotrophic (TSI=40), and all of them have improving trends in transparency. Only one other lakeshed flows into these lakes, so they are at an advantage that they don't have a large watershed. Currently, the lakeshed is well-forested (75% of land area, excluding water), which provides good water quality protection. The management focus for these lakes should be to protect their water quality by managing the impacts from current development and minimizing impact from future development through county ordinances.

Brainerd – Baxter, Highway 371 Area Lakes
The two lakes in this report located within Brainerd/Baxter, Gilbert and Red Sand, are in good condition because they have good drainage and they don't have large watersheds that include a lot of the city area. White Sand has a declining trend in transparency, so the projects in the future studies section on the following page could be applied.

North Long, Round, and Gull Lakes are all connected to each other. They all have slightly elevated chloride levels, which is most likely due to runoff from Highway 371. Currently, the northern bay of Gull, and the western and main bays of North Long have declining trends in transparency. Impervious surface from Hwy 371 and development have affected the drainage in this area. Managing the runoff by installing rain gardens and sediment basins, restoring wetlands, and restoring shorelines could help the water quality in this area.

Hubert, Edward, and Pelican Lakes are different in that they have small watersheds and are not connected to any lake chains. For these lakes, the land practices around the lakeshore such as septic systems and unnatural lawns are the main impact on water quality. Currently, Pelican, Hubert and Edward Lakes have no trends in transparency.

Eastern Crow Wing County Lakes
Serpent Lake has a declining trend in transparency. This trend could be due to the adjacent cities of Crosby and Deerwood. The Crow Wing SWCD is participating in a Clean Water Partnership project on Serpent Lake, which has a goal to identify areas for improvement in the lakeshed. Managing runoff from these cities is very important for improving water quality in Serpent Lake.

Rabbit, Smith, Lower Mission, and Bay Lakes have improving trends in transparency. It is not always easy to determine why lakes are improving. It can be due to natural causes or the conditions in the watershed such as low available nutrients and low development density.

Lower Cullen and Upper Mission Lakes are declining in transparency. Both lakes have second tier development, and Lower Cullen is the last lake in the chain from Upper and Middle Cullen. See the Future Studies section below for projects that could help track why these lakes are declining.

Camp, Clearwater, South Long, and Upper South Long have no trends in transparency. Camp and Clearwater currently have low development densities and are extensively forested. A major change or additional subdivisions in these lakesheds could affect the water quality of these lakes. Upper and Lower South Long have some agriculture in their lakesheds. These lakes should be managed for the impacts from agriculture and development.

Shallow Lakes
Shallow lakes usually have a maximum depth around 25 feet deep or less and don't completely stratify all summer. A healthy shallow lake should have clear water and abundant aquatic plants. Native aquatic plants stabilize the lake's sediments and tie up phosphorus in their tissues. When aquatic plants are uprooted from a shallow lake, the lake bottom is disturbed, and the phosphorus in the water column gets used by algae instead of plants. This contributes to "greener" water and more algae blooms. Protecting native aquatic plant beds will ensure a healthy lake and healthy fishery.

Studies have shown that large boat motors can re-suspend the phosphorus from the lake's sediment and cause algae blooms. Boaters should be encouraged to drive slowly through areas shallower than 10 feet.

The shallow lakes evaluated in this report include Emily, Gilbert's southern bay, Lower Mission, Ross, White Sand, Red Sand, Kego, Crow Wing, Sebie, Silver, Placid, Butterfield, and Bass (18-0256).

Stormwater Management.
Stormwater management is an issue anywhere there is development, therefore all the lakes in this report. Any impervious surface, including driveways, roads, roofs and patios cause the rain to run off of them instead of soaking into the ground. Turf grass does not sufficiently infiltrate rainwater either. Rain gardens and wetlands can be good areas for storm water storage and infiltration.

For lakes that have a town or city on their shoreline, investigate specifically where storm water drains so that it is not impacting the lake. Towns have a high density of impervious surface. Lakes with potential city stormwater impacts include Serpent, White Sand, Red Sand, Emily, Ruth, and North Long.

Future Studies
For lakes with declining water quality trends, future studies that would better pinpoint the impacts on the lake include

1. Shoreline inventory
2. Monitoring stream inlets
3. Monitoring for internal loading
4. A watershed flow analysis.

Look in Tables 11-15 for which potential impacts apply to which lakes.

The shoreline inventory would consist of driving around the lake and rating each parcel as to how much of the frontage has a vegetative buffer. This study would identify areas to target with shoreline buffer installation and rain gardens.

To determine the phosphorus loading from the watershed, the inlets could be monitored during baseline and peak flow events (spring thaw and heavy rains). The inlets could also be ground-truthed, which entails walking them to look for erosion and insufficient vegetative buffers.

Monitoring for internal loading involves collecting hypolimnion water samples (water samples taken 1 foot above the lake's bottom) and corresponding dissolved oxygen profiles. This monitoring shows whether phosphorus is being released from the sediments and fueling algae blooms.

A watershed flow analysis would be done using GIS software to see the areas of heaviest runoff into the lake. This analysis would also help where stormwater mitigation, rain gardens and shoreline restoration would have the most positive impact on the lake.

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)

Lake Associations

- Lake condition monitoring
- Ground truthing – visual inspection upstream on stream inlets
- Shoreline inventory study by a consultant

Soil and Water Conservation District (SWCD) and Natural Resources Conservation Service (NRCS)

- Shoreline restoration
- Stream buffers
- 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.

Aquatic Invasive Species
As of 2015, there are a growing number of Crow Wing County Lakes infested with zebra mussels. Great care should be taken to protect Crow Wing County's excellent water resources from any future infestations. Protection projects could include lake access boat inspections and educational campaigns.

Grant Possibilities
MPCA Clean Water Partnership Grants: These grants are available for nonpoint source water pollution projects such as diagnostic studies or implementation projects to protect water bodies. This grant would apply well to a large chain of lakes.
http://www.pca.state.mn.us/aj0rb37

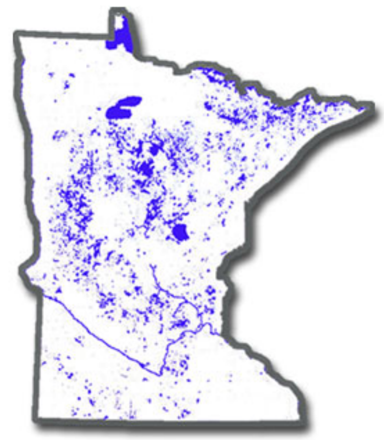
BWSR Clean Water Grants: These grants can be used for a variety of "on-the-ground" projects, where citizens and local governments are installing conservation practices to improve the quality in lakes, rivers and wetlands.
http://www.bwsr.state.mn.us/grants/index.html

DNR Conservation Partners Legacy Grant Program: These grants can be used for projects that restore, enhance and/or protect habitats for MN's fish, game, and wildlife.
http://www.dnr.state.mn.us/grants/habitat/cpl/index.html

DNR Shoreline Habitat Restoration Grants: Shoreland and Aquatic Habitat Block Grants are designed to provide cost share funding to counties, cities, watershed districts, other local units of government, conservation groups, and lake associations. It allows participants to conduct shoreline and watershed enhancement projects with native plants, while improving aquatic habitat and water quality for fish and wildlife.
http://www.dnr.state.mn.us/grants/habitat/shoreland.html

Appendix I: Limnology Educational Summary

Lake Water Quality: the natural factors and the human factors



There are many factors that contribute to a lake's current condition, including natural factors and human factors. Once these factors are understood, a better understanding of past, present and future lake water quality is possible.

Most of the lakes in Minnesota were formed as glaciers receded during the last ice age. Approximately 15,000 years ago to about 9,000 years ago, glaciers alternately retreated and advanced over the landscape, carving out holes and leaving behind ice chunks. As these ice chunks melted in the holes left behind, lakes were formed. Northern Minnesota was scraped fairly clean down to the bedrock, with boulders, sand and clay left behind, while southern Minnesota was left with a rich, fine prairie (now agricultural) soil.

The first thing that goes into understanding a lake is what sort of geological area it is in. Northern Minnesota lakes are commonly very deep, rocky lakes in forested areas. These lakes have very clear water and characteristically low phosphorus and algae concentrations due to the abundance of sandy, relatively infertile soil. The lakes in southwestern Minnesota are shallower prairie lakes surrounded by fertile soil. Lakes in this area tend to have more nutrients available for plants and algae to grow, and therefore get "greener" in the summer.

The geology and glacial formation of a lake usually determines its shape, size and depth. These factors contribute to nearly all physical, chemical and biological properties of a lake. Lake users such as fishermen are probably aware of these characteristics already because they also determine where the fish are. A lake that is one large round hole is different than a lake that has a lot of bays, points and bottom structure. A long narrow lake is more affected by wind (which mixes the lake) than a round lake. Deep lakes have different dynamics than shallow lakes, and most of all, deep lakes have more water. The more water a lake has (volume), the better it is able to dilute what runs into it.

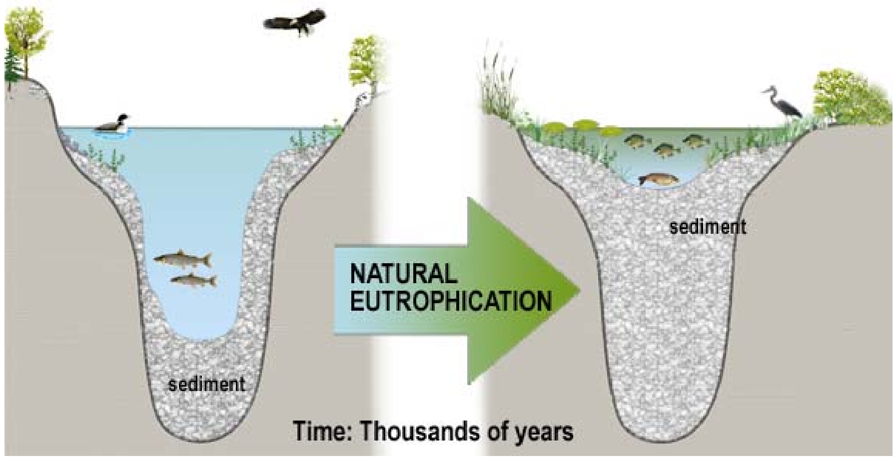
Shallow lakes are lakes where the sunlight can reach the entire bottom. Generally, this corresponds to about 15 feet deep or less. Since the sunlight can reach the bottom, aquatic plants are able to grow there. In deep lakes, the bottom does not receive sunlight, so no plants grow there and it stays dark and cold.

Another major factor affecting lake condition is the size of its watershed and where the lake sits within the watershed. A watershed is an area of land where all the water drains into the same river system. These watershed areas are defined by topography, or ridges of elevation. Therefore, watersheds are mainly driven by gravity – water runs down hill.

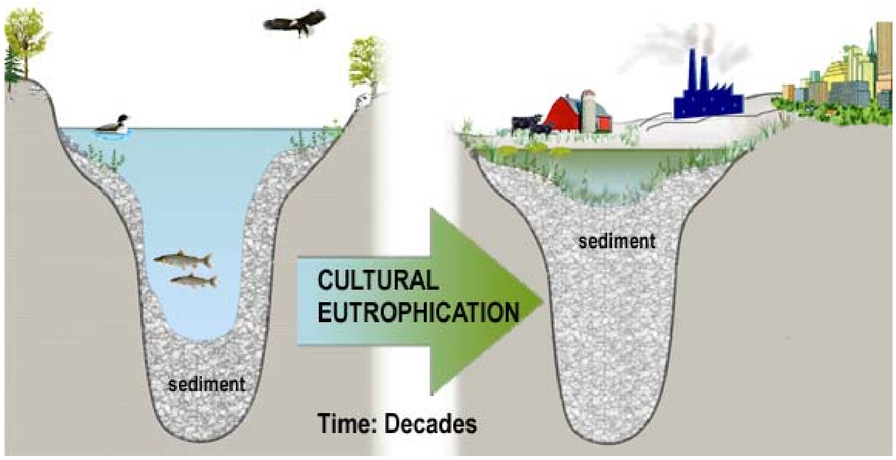
If a lake has a very small watershed or is at the top of a watershed (in topography terms), the lake usually has better water clarity than a lake at the bottom of a large watershed. As water flows downhill through a watershed it picks up sediment from erosion and nutrients from runoff. This sediment and nutrients can feed algae and cause the lake to become "greener".

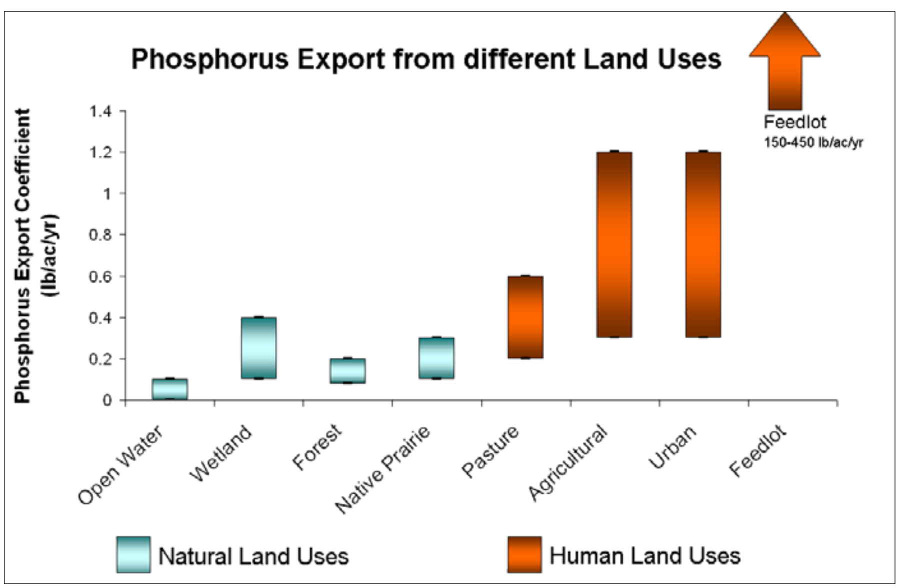
Lakes go through a natural ageing process where they gradually receive nutrients (phosphorus and nitrogen) and sediment from erosion in the surrounding watershed and become more fertile and shallow. This process is called eutrophication. Eutrophication is a natural process that a lake goes through over thousands of years.

Humans can speed up the process of eutrophication by adding excess nutrients and sediment quickly, where the lake will change trophic states in a matter of decades instead of centuries. This type of eutrophication is called cultural eutrophication because humans cause it. We have changed the landscape around lakes, which changes their water quality and speeds up eutrophication.



Around lakes, we have added a lot of impervious surface. Impervious surface is any surface on land that is impenetrable to water and prevents its absorption into the ground. Examples include rooftops, sidewalks, parking lots, and roads. The more impervious surface in a concentrated area, the less surface there is for rain to be absorbed into the ground. Instead, it ends up running into lakes and streams and carrying nutrients and sediment from the land it flows over.





Land practices such as urban areas, factories, agriculture, animal feedlots contain very concentrated amounts of nutrients. These nutrients wash into lakes and streams during heavy rains or through storm sewers. The additional nutrients that run into lakes and streams cause algal blooms and additional plant growth.

When erosion occurs along a lakeshore or a stream bank of a lake inlet, that extra soil can get washed into the lake. The extra soil particles cause cloudier water and eventually settle on the bottom of the lake making it mucky and less stable. The soil also carries with it nutrients such as phosphorus and nitrogen.

Eutrophication can be slowed if the inputs of nutrients (especially phosphorus) and sediment are slowed. Creating natural vegetation buffers along lakeshores and streams soak up nutrients and filter runoff. When planning new construction near water, make sure erosion is prevented by silt fences and minimize creating more impervious surface.

So how can one tell if the lake's water quality is declining or improving? The best way to determine long-term trends is to have 8-10 years of lake water quality data such as clarity (secchi disk), phosphorus, and chlorophyll-a (algae concentration). Only short-term trends can be determined with just a few years of data, because there can be different wet years, dry years, weather, water levels, etc. that affect the water quality naturally. The data needs to be analyzed with a statistical test (i.e.: Mann Kendall Trend Analysis) to be confident in a true trend.

In summary, lakes start out with a certain natural condition that depends on their location, their watershed size, and their area, depth and shape. Then we humans add to that by what type of land practices we implement near the lake and upstream from the lake. Lakes that are in more heavily populated areas usually have had more cultural eutrophication than lakes that are in sparsely populated areas.

When it comes to protecting our lakes, stewardship is an attitude. It is the understanding that what we do on land and in the water affects the lake. It is recognition that lakes are vulnerable and that in order to make them thrive, citizens, both individually and collectively, must assume responsibility for their care. Once you learn more about all the factors that potentially affect your lake, you can practice preventative care of your lake, and hopefully avoid costly problems.

"In the end, we will conserve only what we love; we will love only what we understand; and we will understand only what we have been taught." - Baba Dioum, a Senegalese ecologist.

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Appendix II: Phosphorus Export Educational Summary

Introduction

The purpose of lakeshed assessment is to develop an inventory and assess the resources within each lakeshed. The assessment can then be used as a tool to evaluate issues and create a framework of goals and strategies for citizens, as well as representatives from local units of government and resources agencies in the region. This information helps support the continued commitment to a collaborative effort to protect and improve water quality of Minnesota lakes and manage our limited resources.

Understanding a lakeshed requires the understanding of basic hydrology. A watershed is the area of land that drains into a surface water body such as a stream, river, or lake and contributes to the recharge of groundwater. There are three categories of watersheds: 1) basins, 2) major watersheds, and 3) minor watersheds.

Within this watershed hierarchy, lakesheds also exist. A lakeshed is defined simply as the land area that drains to a lake. While some lakes may have only one or two minor watersheds draining into them, others may be connected to a large number of minor watersheds, reflecting a larger drainage area via stream or river networks.

This summary includes educational information about phosphorus and nutrient transport in watersheds and lakesheds. For each individual lakeshed assessment, conclusions can be drawn as to the best way to protect and conserve land within the lakeshed. See individual lake reports for specific recommendations. Overall recommendations include:

- Continue to follow BMPs (Best Management Practices) in the lakeshed:
  - Plant natural vegetation along the shoreline
  - Protect and extend low phosphorus land covers wherever possible (forest/wetland)
  - Surface water onsite management (rain gardens, drainage, etc.)

- For lakes located near a town, investigate where storm water drains so that it is not impacting the lake. Rain gardens and wetlands can be good areas for storm water storage and infiltration.

Phosphorus

Phosphorus is a nutrient important for plant growth. In most lakes, phosphorus is the limiting nutrient, which means that everything that plants and algae need to grow is available in excess (sunlight, warmth, water, nitrogen, etc.), except phosphorus. This means that phosphorus has a direct effect on plant and algal growth in lakes – the more phosphorus that is available, the more plants and algae there are in the lake. Phosphorus originates from a variety of sources, many of which are related to human activities. Major sources include human and animal wastes, soil erosion, detergents, septic systems and runoff from farmland or fertilized lawns.

Phosphorus is usually measured in two ways in lakes, ortho-phosphate (soluble reactive phosphorus) and total phosphorus. Ortho-phosphate (soluble reactive phosphorus) is the chemically active, dissolved form of phosphorus that is taken up directly by plants. Ortho-phosphate levels fluctuate daily, and in lakes there usually isn't a lot of ortho-phosphate because it is incorporated into plants quickly. Total phosphorus (TP) is a better way to measure phosphorus in lakes because it includes both ortho-phosphate and the phosphorus in plant and animal fragments suspended in lake water. TP levels are more stable and an annual mean can tell you a lot about the lake's water quality and trophic state, as shown in Figure 1.

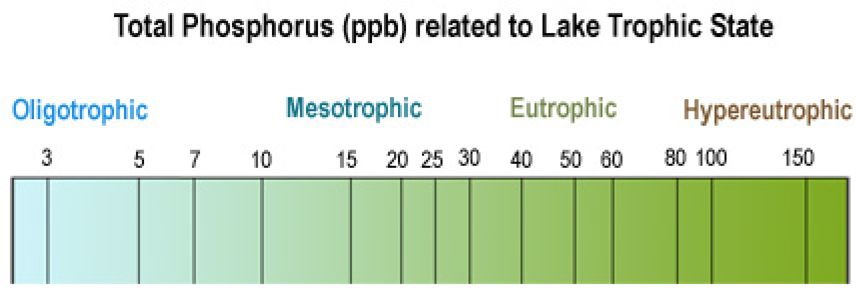

Figure 1. Phosphorus concentration (ppb) related to lake trophic state.

If phosphorus inputs are decreased or eliminated, less plants and algae are able to grow and water quality can improve.

Nutrient export to lakes

Phosphorus export, which is the main cause of lake eutrophication, depends on the type of land use occurring in the lakeshed. Phosphorus export (in lbs/acre/year) can be estimated from different land uses using the phosphorus export coefficient. Figure 2 shows the phosphorus export from the natural landscape versus human land uses. Humans alter the landscape, thereby adding more phosphorus to the lake than would occur naturally.

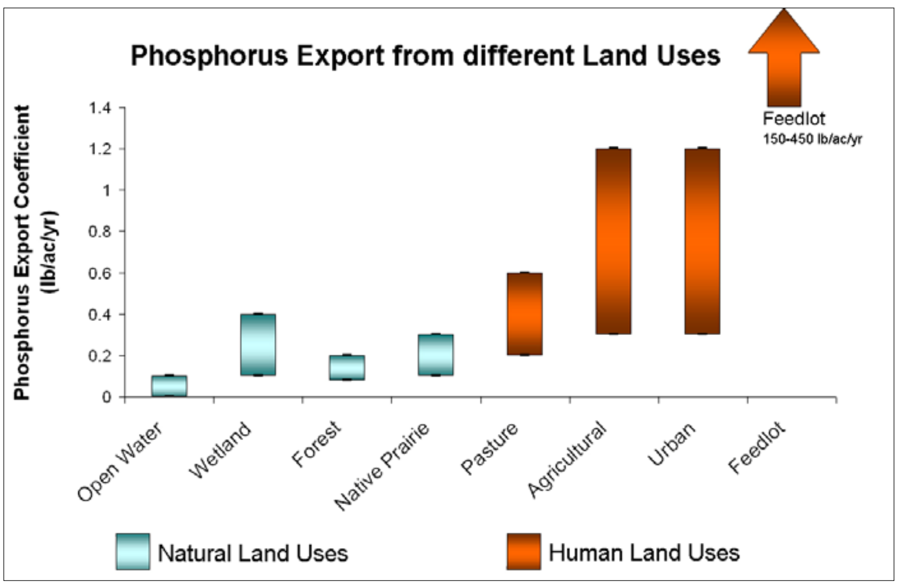

Figure 2. Phosphorus export coefficient for natural vs human land uses.

Stormwater is an all-inclusive term that refers to any of the water running off of the land's surface after a rainfall or snowmelt event. Stormwater carries nutrients and other pollutants, the largest being phosphorus. Around lakes, urban development is one of the largest contributors of phosphorus. Prior to development, stormwater is a small component of the annual water balance. However, as development increases, the paving of pervious surfaces (that is, surfaces able to soak water into the ground) with new roads, shopping centers, driveways and rooftops all adds up to mean less water soaks into the ground and more water runs off. Figure 2 is a variation on a classic diagram that has appeared in many documents describing the effects of urbanization. This adaptation from the University of Washington shows how the relative percentages of water soaking into the ground change once development begins in a forested area. Note that the numbers assigned to the arrows depicting the movement of water will vary depending upon location within Minnesota (MPCA 2008).

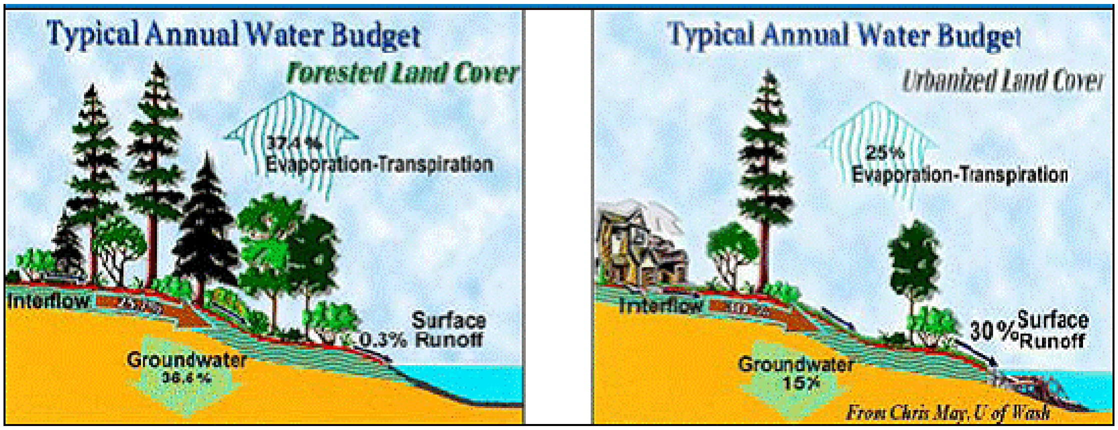

Figure 3. Differences in annual water budget from natural land cover to urbanized land cover (Source: May, University of Washington).

The changes in the landscape that occur during the transition from rural and open space to urbanized land use have a profound effect on the movement of water off of the land. The problems associated with urbanization originate in the changes in landscape, the increased volume of runoff, and the quickened manner in which it moves (Figure 3). Urban development within a watershed has a number of direct impacts on downstream waters and waterways, including changes to stream flow behavior and stream geometry, degradation of aquatic habitat, and extreme water level fluctuation. The cumulative impact of these changes should be recognized as a stormwater management approach is assembled (MPCA 2008).

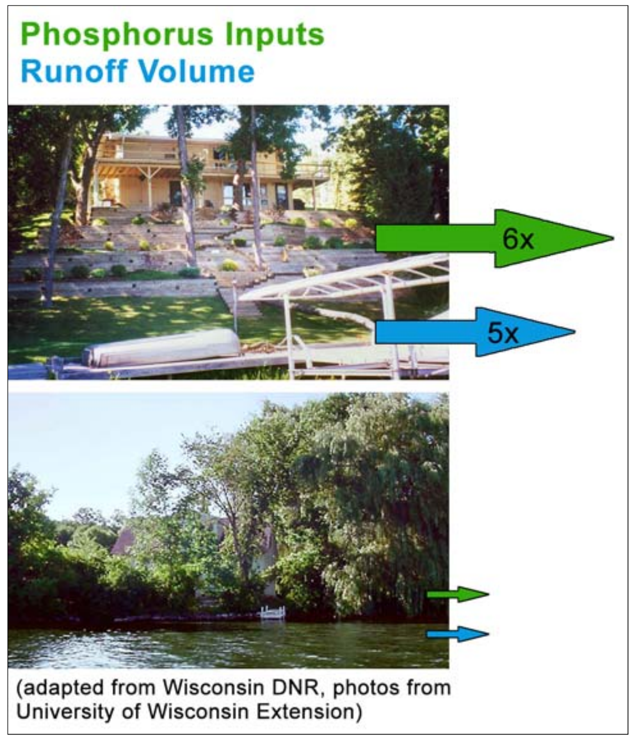

Figure 4. The effects of development on the amount of phosphorus and total runoff from a shoreland property. A large landscaped lot with a manicured lawn, a beach, and a retaining wall can increase total runoff volume by 500% and the phosphorus inputs to the lake by 600% (University of Wisconsin–Extension and Wisconsin Department of Natural Resources. 2002).

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Minnesota Pollution Control Agency (MPCA). 2008. Minnesota Stormwater Manual Version 2. January 2008. Minnesota Pollution Control Agency, St. Paul, MN 55155-4194

University of Wisconsin–Extension and Wisconsin Department of Natural Resources. 2002. A guide to environmentally sound ownership. A publication of the Southeast Wisconsin Fox River Basin Partnership Team, University of Wisconsin–Extension, and Wisconsin Department of Natural Resources.

Appendix 3: Glossary of terms

Glossary

Anoxic: without oxygen. Organisms cannot survive in prolonged periods of anoxia.

Chlorophyll-a: the pigment that makes plants and algae green. Chlorophyll-a is measured in lakes to determine algal concentration.

Dissolved oxygen: oxygen that is dissolved in the water column. Aquatic organisms (zooplankton, aquatic invertebrates and fish) need this oxygen to survive.

Epilimnion: The top layer of a lake where the sunlight penetrates and provides energy for plants and algae to grow.

Eutrophic: A lake that has low water clarity and high productivity (phosphorus and chlorophyll-1). Eutrophic lakes have a Trophic State Index between 50 and 70, an anoxic hypolimnion in the summer, algal and aquatic plants are prevalent, and can only support warm water fish.

Fall turnover: when the summer stratification layers of a lake mix due to the cooling epilimnion (upper layer of the lake). This mixing distributes all the nutrients evenly through the water column.

Fertility: the amount of plant and animal life that can be produced within a lake. Fertility is directly related to the amount of nutrients present in the lake to "feed" plants and animals (phosphorus, nitrogen).

Hypereutrophic: A lake that has very low water clarity and very high productivity (phosphorus and chlorophyll-a). Hypereutrophic lakes have a Trophic State Index over 70, and usually have heavy algal blooms and very dense aquatic plants.

Hypolimnion: The deep part of a lake that is cold and dark due to no sunlight penetration. This area of a lake can be anoxic in the summer due to stratification and decomposition.

Littoral area: the area around a lake that is shallow enough to support plant growth (usually less than 15 feet). This part of the lake also provides the essential spawning habitat for most warm water fishes (e.g. bass, walleye, and panfish).

Mesotrophic: A lake that has moderate water clarity and productivity (phosphorus and chlorophyll-a). Mesotrophic lakes have a Trophic State Index between 30 and 50, and the hypolimnion can become anoxic during the summer.

Nitrogen: a nutrient important for plant growth. Nitrogen can enter a lake through groundwater, surface runoff and manure.

Oligotrophic: A lake that has very clear water and very low productivity (phosphorus and chlorophyll-a). Oligotrophic lakes have a Trophic State Index under 30, the hypolimnion contains oxygen throughout the year and can support trout.

OP (Ortho Phosphate): the amount of inorganic phosphorus within a lake. Inorganic phosphorus is readily usable by algae and plants for growth.

Phosphorus: a nutrient needed for plant growth. Phosphorus can enter a lake through runoff from manure and fertilizer or through seepage from leaking septic and holding tanks.

Productivity: the amount of plant and animal life that can be produced within a lake. Productivity is directly related to the amount of nutrients present in the lake to "feed" plants and animals (phosphorus, nitrogen).

Secchi Depth: a measure of water clarity that can indicate the overall health of a lake. A black and white metal disc is lowered into the water on a rope until it can't be seen anymore and raised to the point it can be seen. The depth of the disk to the surface of the water is the Secchi Depth.

Spring turnover: when the ice melts off the lake in the spring and cold water on the top of the lake sinks. This mixing distributes all the nutrients evenly through the water column.

Stratification: The process in which most Minnesota lakes separate into three layers during the summer. The upper layer (epilimnion) becomes warm and is penetrated by sunlight, the lower layer (hypolimnion) is cold and dark and the middle area (thermocline) separates the top and bottom layers. Warm water is less dense than cold water, which is why the upper layer floats on top of the bottom layer and does not mix in the summer. Minnesota lakes mix in the spring and the fall, when the top layer of the lake cools off.

Thermocline: The area between the warm top layer of a lake and the cold bottom part of the lake. The thermocline is characterized by a sharp drop in temperature.

TP (Total Phosphorus): the total amount of organic and inorganic phosphorus within a lake. Organic phosphorus includes detritus, feces, dead leaves and other organic matter.

TMDL (Total Maximum Daily Load): the amount of a particular pollutant that a body of water can handle without violating state water quality standards.

Trend Analysis (Mann Kendall statistic): a way to test the probability of a trend being real versus just happening by chance. A trend probability of 90% (minimum probability used by MPCA) means that there is a 90% probability that the observed trend is real and a 10% probability that the observed trend is just from random chance.

Trophic State: Trophic states are defined divisions of a continuum in water quality. The continuum is Total Phosphorus concentration, Chlorophyll a concentration and Secchi depth. Scientists define certain ranges in the above lake measures as different trophic states so they can be easily referred to. See Oligotrophic, Mesotrophic, Eutrophic, Hypereutrophic.

TSI: Trophic State Index is a measurement of overall lake productivity (nutrient enrichment). The overall TSI of a lake is the average of the TSI for phosphorus, chlorophyll-a and secchi depth.

Turbidity: refers to how clear the water is. Cloudiness (turbidity) in the water can be due to suspended matter such as silt, clay, plankton and other organic matter. The more turbid the water is, the less sunlight can pass through.

Watershed: the area of land that drains into a lake directly or by way of a stream that flows into the lake. The land use practices of an entire watershed can affect the water quality of a lake.