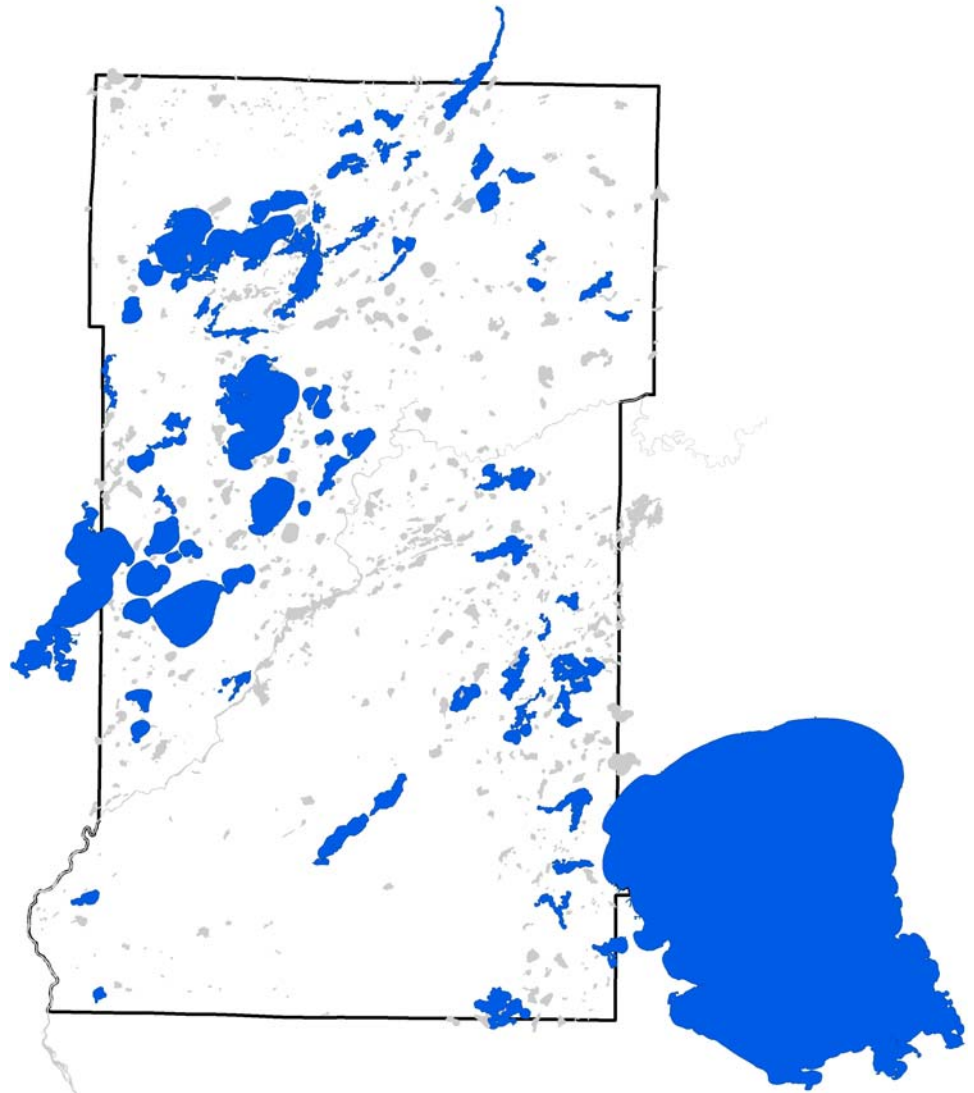


# **Crow Wing County Lakes Prioritization and Screening**



**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

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Thirty Lakes Watershed District  
Army Corps of Engineers  
Whitefish Area Property Owners Association  
Gull Chain of Lakes Association

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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.

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.

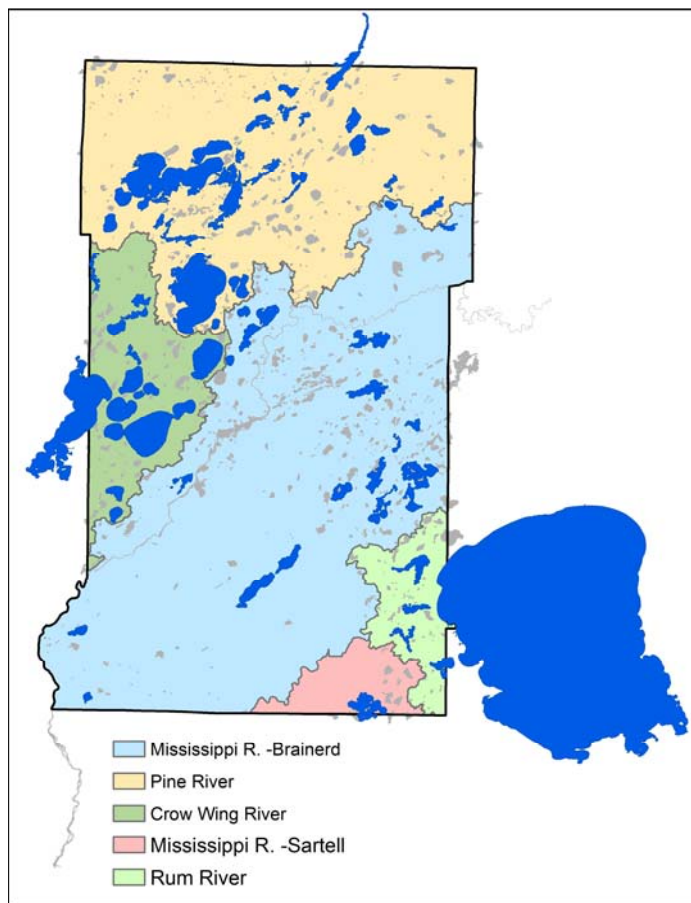


Figure 1. Lakes of Crow Wing County. Lakes evaluated in this report are in dark blue, while each major basin is highlighted in a different color.

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).

| <b>Lake Name</b> | <b>Lake ID</b> | <b>Lake Size (acres)</b> |
|------------------|----------------|--------------------------|
| 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).

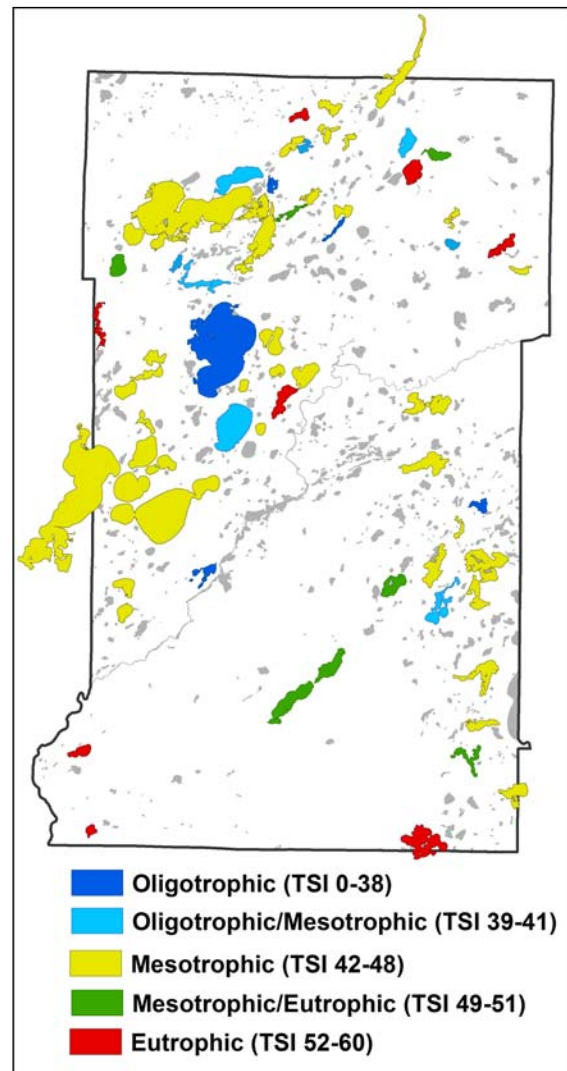


Figure 2. Crow Wing County large lakes illustrating trophic states.

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.

| <b>Lake</b>       | <b>Mean TSI</b> | <b>Trophic State</b>     | <b>Mean TSI Secchi</b> | <b>Mean TSI Phosphorus</b> | <b>Mean TSI Chlorophyll a</b> |
|-------------------|-----------------|--------------------------|------------------------|----------------------------|-------------------------------|
| 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.

| <b>Lake</b>       | <b>Mean TSI</b> | <b>Trophic State</b>  | <b>Mean TSI<br/>Secchi</b> | <b>Mean TSI<br/>Phosphorus</b> | <b>Mean TSI<br/>Chlorophyll a</b> |
|-------------------|-----------------|-----------------------|----------------------------|--------------------------------|-----------------------------------|
| 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.

| EUTROPHICATION | TSI                              | Attributes   | Fisheries & Recreation   |
|----------------|----------------------------------|--|--|
|                | <30                              | <b>Oligotrophy:</b> 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                            | <b>Mesotrophy:</b> 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                            | <b>Eutrophy:</b> 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                            | <b>Hypereutrophy:</b> 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).

| <b>Lake</b>            | <b>Parameter</b> | <b>Date Range</b>               | <b>Trend</b> | <b>Probability</b> |
|------------------------|------------------|---------------------------------|--------------|--------------------|
| 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).

| <b>Lake</b>            | <b>Parameter</b> | <b>Date Range</b>                           | <b>Trend</b> |
|------------------------|------------------|---|--------------|
| 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 25<sup>th</sup> - 75<sup>th</sup> percentile range for data within each ecoregion.

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.

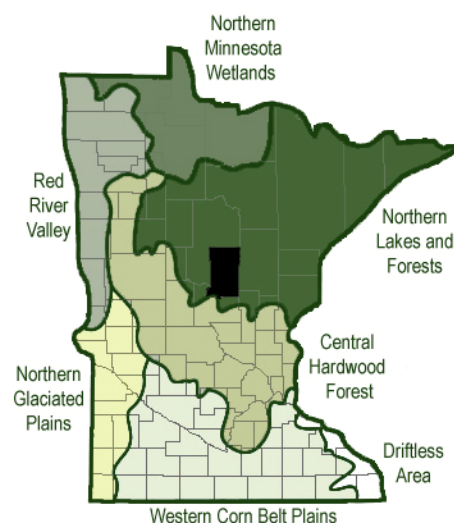


Figure 3. Minnesota Ecoregions. Crow Wing County is indicated in black.

## 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.

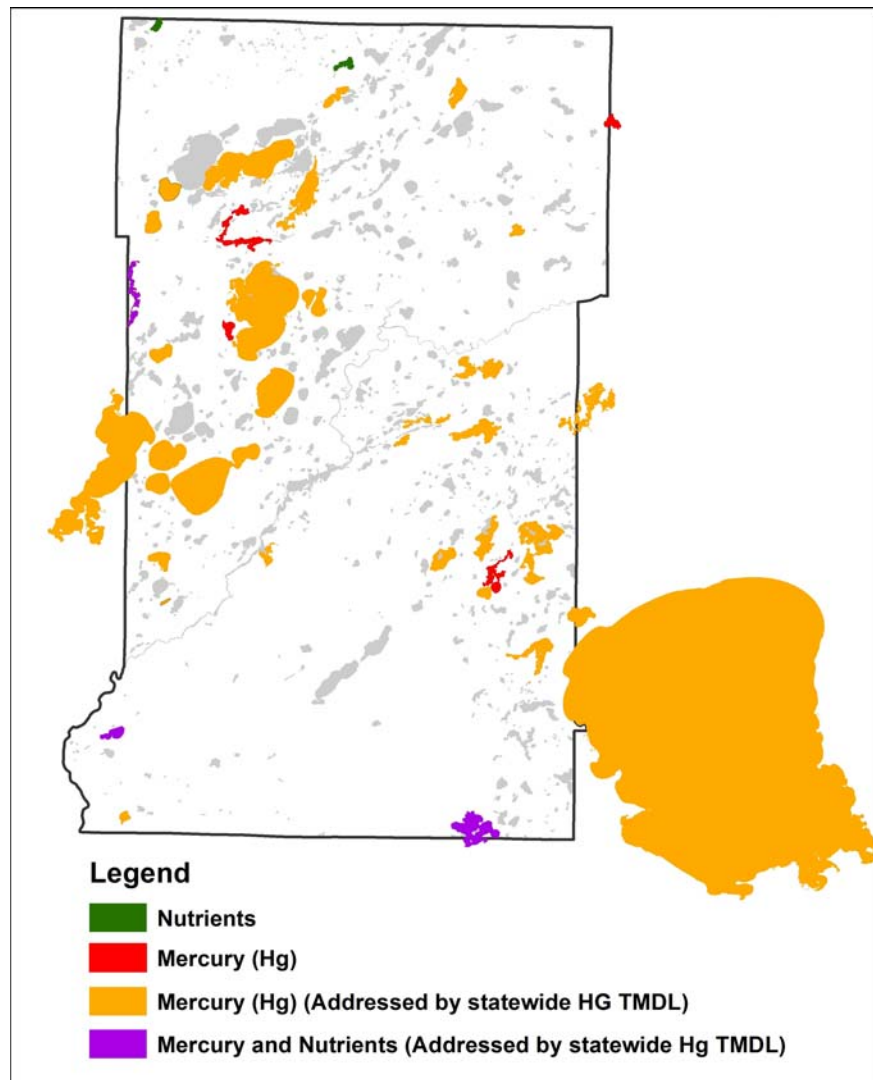


Figure 4. Crow Wing County lakes illustrating impaired waters status.



## 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. |

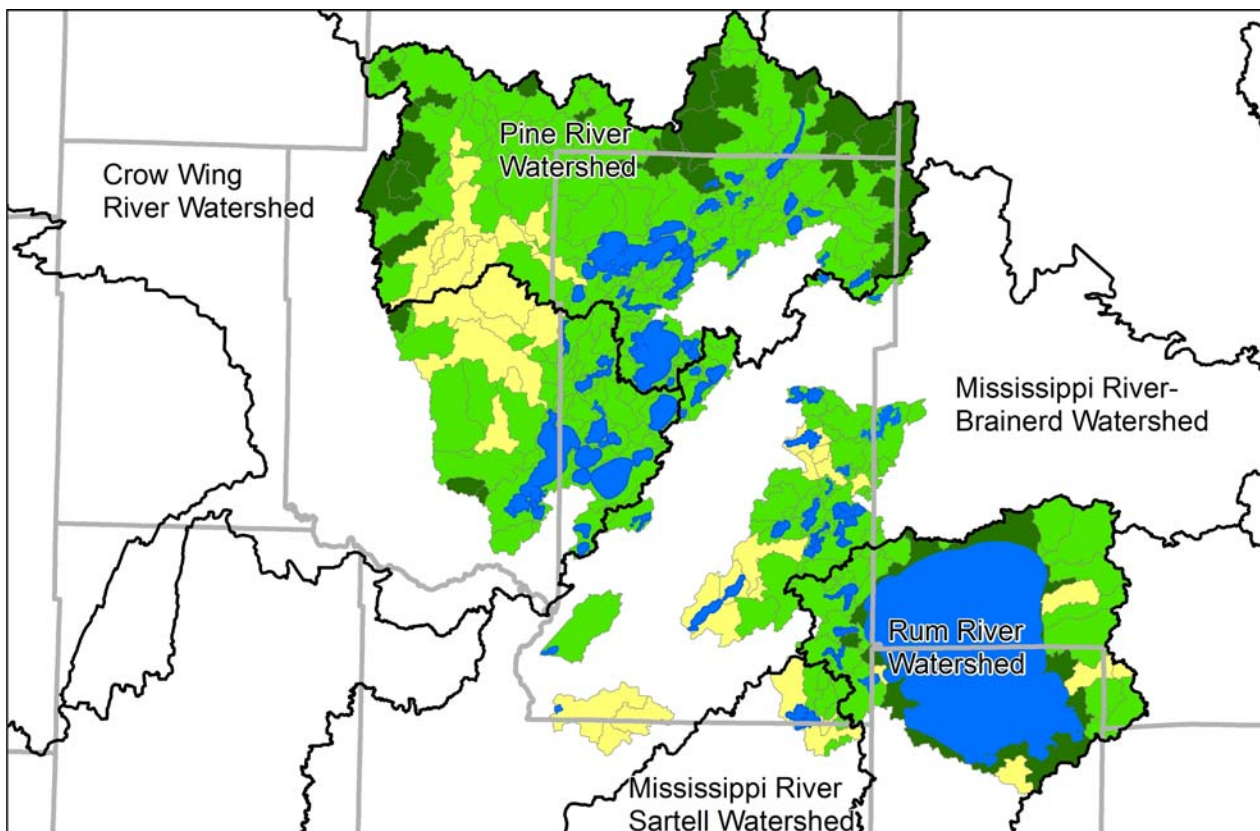


Figure 5. Map of lakesheds color-coded with management focus (Table 9).

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 artedii*) 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 Wing 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](http://www.dnr.state.mn.us/invasives/index_aquatic.html).

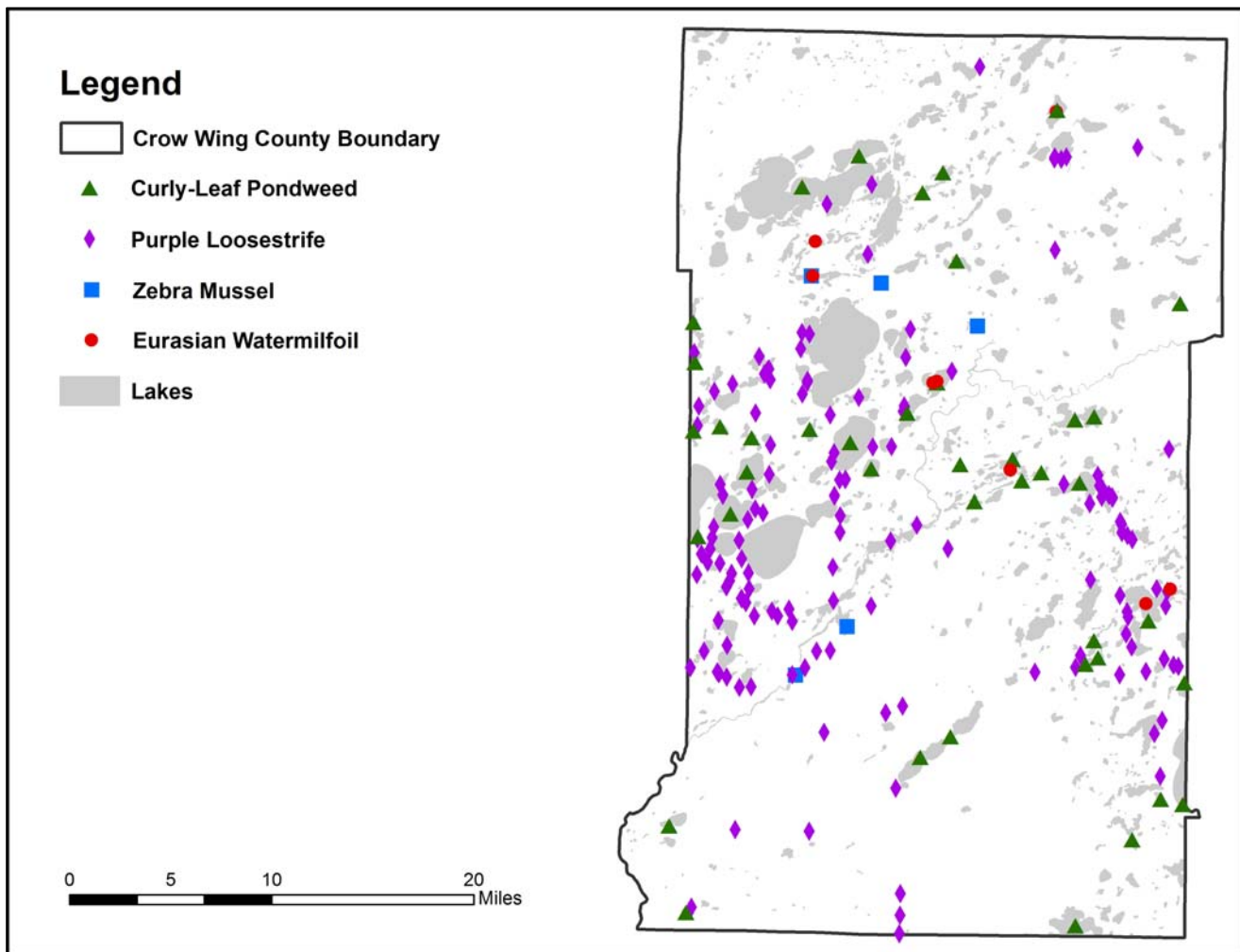


Figure 6. Crow Wing County lakes with invasive species.

## 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.

| 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 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 artedii*) 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.

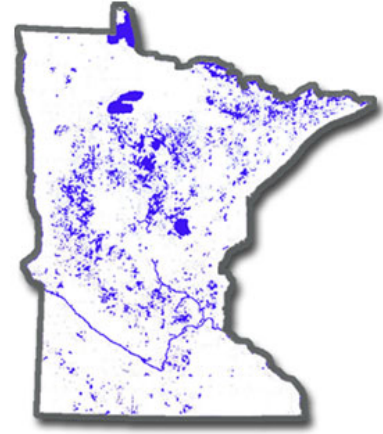
<http://www.dnr.state.mn.us/grants/habitat/shoreland.html>

# 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.

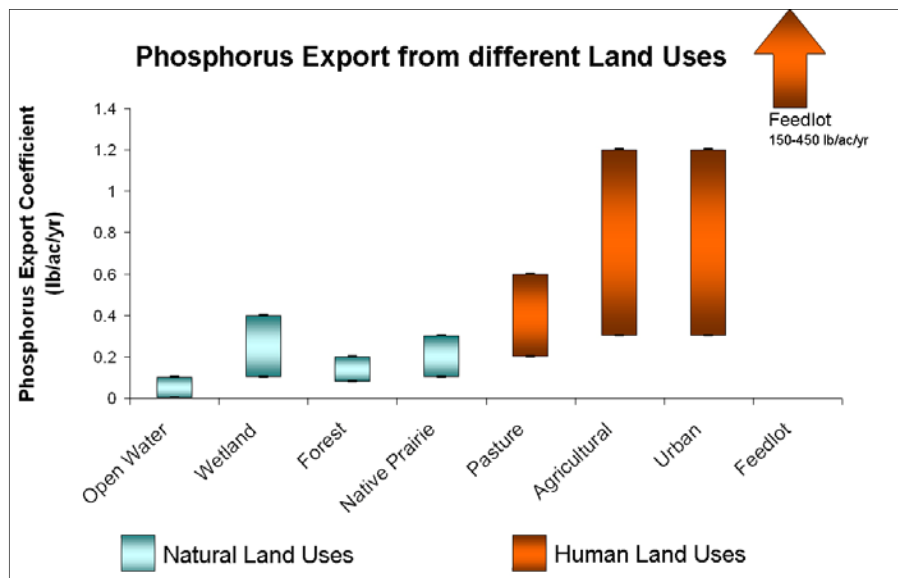
Humans can speed up the process of eutrophication by adding excess nutrients and sediment quickly, where the lake will change trophic states in a matter of decades instead of centuries. This type of eutrophication is called cultural eutrophication because humans cause it. We have changed the landscape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

**Total Phosphorus (ppb) related to Lake Trophic State**

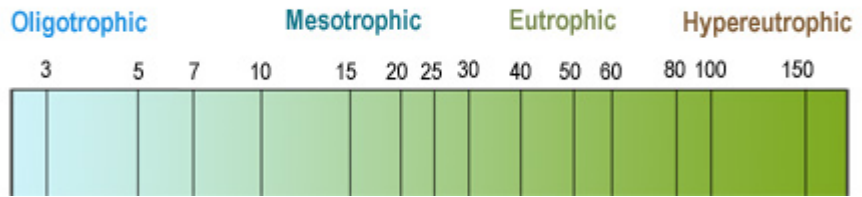


Figure 1. Phosphorus concentration (ppb) related to lake trophic state.

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.

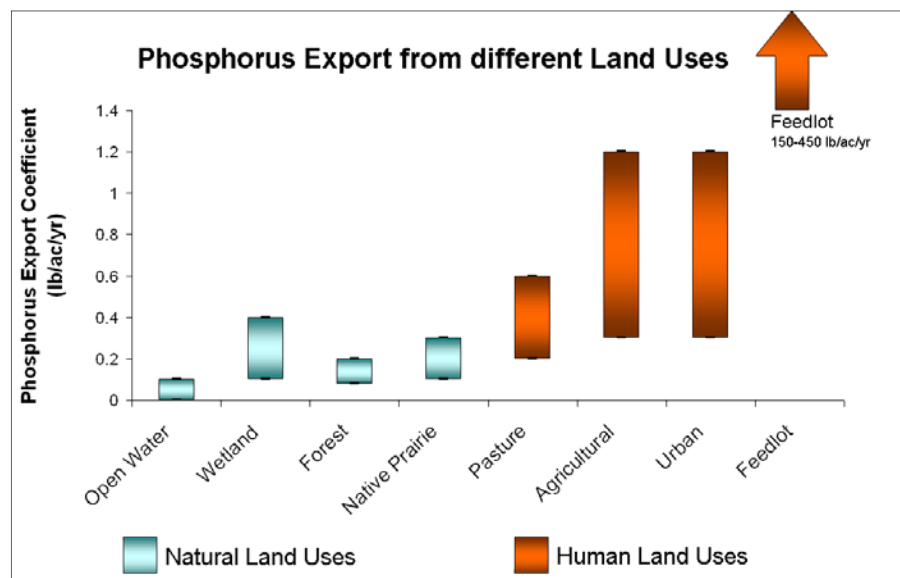


Figure 2. Phosphorus export coefficient for natural vs human land uses.

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).

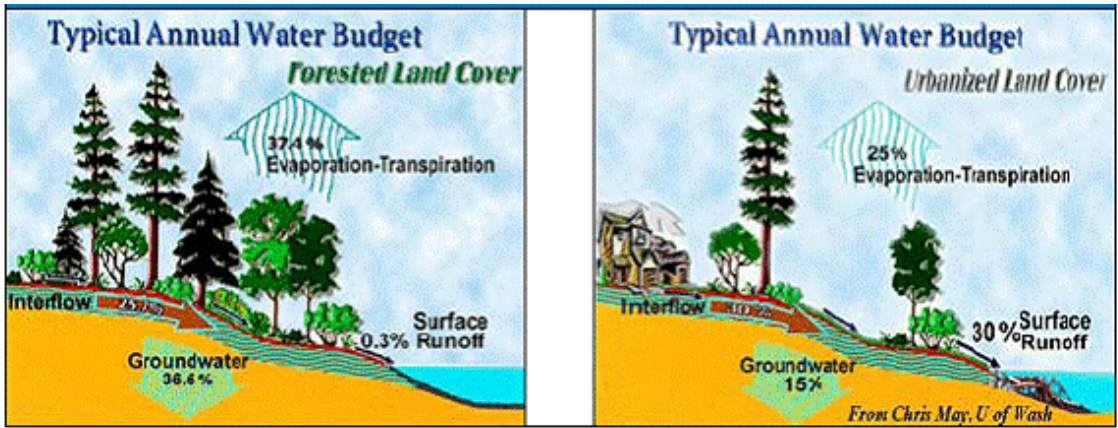
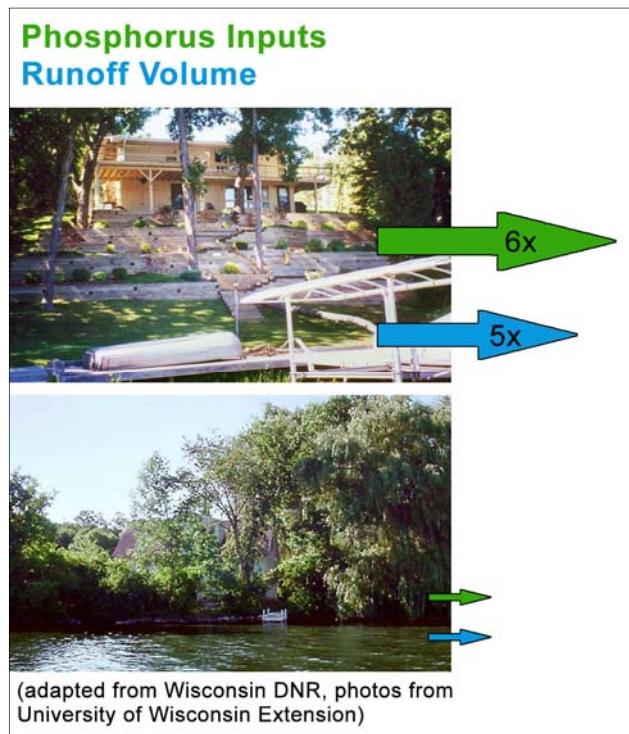


Figure 3. Differences in annual water budget from natural land cover to urbanized land cover (Source: May, University of Washington).

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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# 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.