

MINNESOTA
LAKE WATER QUALITY
ASSESSMENT DATA: 2004



An update to data presented in the
Minnesota Lake Water Quality Assessment Report: 1990

Environmental Outcomes Division
Environmental Standards and Analysis Section



Minnesota Pollution Control Agency

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APPENDIX 1
MINNESOTA LAKE WATER QUALITY ASSESSMENT DATA: 2004

The Minnesota Lake Water Quality Assessment (MLWQA) report was first written in 1988 and revised in 1990 (Heiskary and Wilson, 1988 and 1990). The MLWQA report was intended to not only fulfill the requirements of Section 314 (Clean Lakes Program) of the Clean Water Act of 1987, but also serve as a useful reference for lake managers statewide. The 1988 and 1990 MLWQA reports provided:

- a basis for assessing the trophic status of Minnesota’s lakes;
- a detailed review of our use of the ecoregion framework and approach to in-lake phosphorus criteria development;
- a review of lake pollution control programs in Minnesota; and
- an appendix with summary data for all assessed lakes at that time.

This current data appendix and accompanying explanations, tables, and figures are intended as an update to data presented in the 1988 and 1990 MLWQA Reports. The current report uses STORET data from 1970 through 2002 as a basis for the lake assessments. Details on methods and procedures used in the assessments are provided in this document. A glossary is provided at the end of this document and includes definitions for many lake-related terms. The Web version of this document includes links to pictures, maps, and figures intended to clarify explanations of terms and concepts referred to in this report. The Web version may be accessed at <http://www.state.pca.mn.us/water/lakequality.html>.

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LAKES ASSESSMENT PROCESS AND DEVELOPMENT: 2004 ASSESSMENT

Thirty two years of data (1970-2002) from USEPA's STORET have been used for the lake assessments. The focus of lake assessments is on trophic state and its relation to support and nonsupport of designated uses, specifically aquatic recreation uses, which includes swimming, wading, aesthetics and other related uses. The parameters used to assess trophic state and aquatic recreational use were epilimnetic TP, chlorophyll-a (chl-a) and Secchi Disk (SD) transparency.

DATA ANALYSIS PROCEDURES

A. Data Age and Quality for Assessments

Monitored Data

Lakes with summer data (defined as the time period from June through September) collected between calendar years 1993-2002 were considered monitored. Summer data are preferred for assessments to better represent the maximum productivity of a lake and yield the best agreement among trophic variables. This time period also reflects the primary season when the resource is used for aquatic recreation. Summer-means were calculated for each variable and used in the assessment. In addition the number of observations (N), standard error (SE) of the mean, maximum (max) and minimum (min) values were calculated as well. These additional statistics can be used to place the mean values in perspective and improve the ability to make comparisons of values among lakes.

Evaluated Data

Lakes without data meeting monitored criteria, but with TP, chl-a or SD transparency measurements collected from 1970-1992 were treated as evaluated. Summer data were used for calculating mean chl-a and SD transparency. All available TP data were used to calculate mean TP. Expanding the season for TP allows for inclusion of a larger number of lakes in northern Minnesota. These lakes were often sampled only during spring or fall turnover as part of the MPCA Acid Rain Lake Monitoring Program in the early 1980's.

Data Quality

Assessing the "quality" of data used in the assessment is a new feature of the 305(b) assessment. Since the data used in these assessments was derived from STORET we assume that certain "quality control" thresholds were already established for the data. Hence our definition of "quality" will focus on the relative amount of information available for the assessment. In the case of our aquatic recreational use assessments TP is the primary variable used so we place the greatest emphasis on the amount of TP data available for the assessment. The "quality" terms used in Table 1 were drawn from USEPA guidance. In general we feel that assessments based on multiple measurements

are more reliable than those based on only a few measurements. The rationale for assigning the respective “quality” definitions corresponds roughly to typical lake-monitoring regimens (e.g. monthly sampling during the summer season), whereby four TP samples often represent one summer; eight samples two summers and 12 samples two-three summers. In the case of 303(d) assessments 12 or more TP, chlorophyll-a and Secchi measurements are required to determine if a lake should be placed on the 303(d) list and was considered “excellent” quality data for assessment. In general the thresholds were similar for the “monitored” (recent) and the “evaluated” (old) data with the exception that there would be no “excellent” evaluated data as these data are more than ten years old.

Table 1. Data quality characterizations for 305(b) and 303(d) assessments.

Quality	“Monitored data”	“Evaluated data”
Poor	< 4 TP measurements	< 4 TP measurements
Fair	$4 \leq TP < 8$, some chl-a & Secchi	$4 \leq TP < 8$, some chl-a & Secchi
Good	$8 < TP < 12$, some chl-a & Secchi	$8 < TP < 12$, some chl-a & Secchi
Excellent	12 TP, 12 chlorophyll-a & 12 Secchi	NA

B. Trophic Status Assessment

Trophic Status was determined for each lake using Carlson’s Trophic State Index (TSI). This index was developed using the relationship among summer Secchi transparency, epilimnetic concentrations of chlorophyll-a, and TP (Figure 1).

The TSI values are calculated as follows:

- * *Secchi disk* (SD) TSI (TSIS) = $60 - 14.41 \ln(\text{SD})$;
 - * *Total phosphorus* (TP) TSI (TSIP) = $14.42 \ln(\text{TP}) + 4.15$;
 - * *Chlorophyll-a* (chl-a) TSI (TSIC) = $9.81 \ln(\text{chl-a}) + 30.6$;
- (chl-a and TP in micrograms per liter ($\mu\text{g/L}$) and SD transparency in meters).

The index ranges from 0 to 100 with higher values indicating more eutrophic conditions. The TSI values were calculated for each variable; however trophic status will be based on total phosphorus when data are available. If no TP data are available for a lake, the Secchi TSI value will be used to estimate trophic status. Ideally, chlorophyll-a would be used for this purpose; however chlorophyll-a (corrected) is measured much less frequently than Secchi or TP so we chose to focus on TP. The following breakpoints were used to define the trophic status of the lake: $TSI \leq 40$ “oligotrophic (O)”, $41 \leq TSI < 50$ “mesotrophic (M)”, $50 \leq TSI < 70$ “eutrophic (E)”, and $TSI \geq 70$ “hypereutrophic (H)”. This index and the interrelationships among TP, chlorophyll-a, and Secchi figure prominently in definition of use-support categories to be addressed later.

Figure 1. Carlson's Trophic State Index

Carlson's Trophic State Index
RE Carlson

- TSI < 30** Classic Oligotrophy: Clear water, oxygen throughout the year in the hypolimnion, salmonid fisheries in deep lakes.
- TSI 30 - 40** Deeper lakes still exhibit classical oligotrophy, but some shallower lakes will become anoxic in the hypolimnion during the summer.
- TSI 40 - 50** Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.
- TSI 50 - 60** Lower boundary of classical eutrophy: Decreased transparency, anoxic hypolimnia during the summer, macrophyte problems evident, warm-water fisheries only.
- TSI 60 - 70** Dominance of blue-green algae, algal scums probable, extensive macrophyte problems.
- TSI 70 - 80** Heavy algal blooms possible throughout the summer, dense macrophyte beds, but extent limited by light penetration. Often would be classified as hypereutrophic.
- TSI > 80** Algal scums, summer fish kills, few macrophytes, dominance of rough fish.

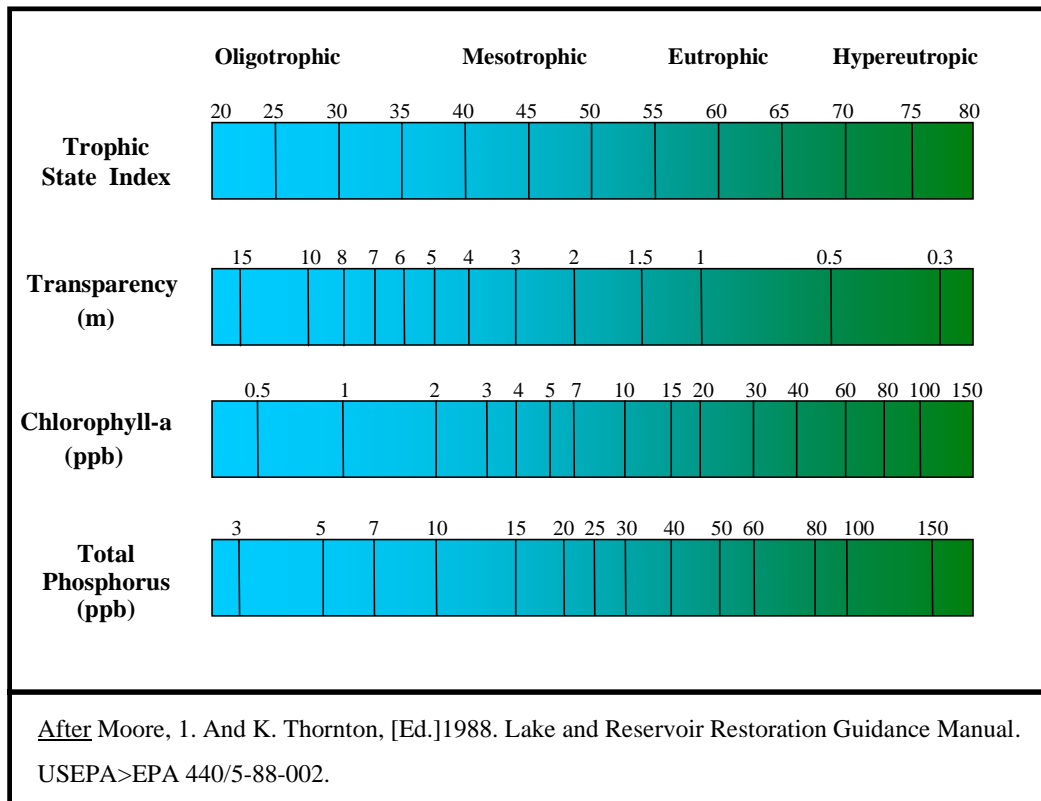


Figure 2. Minnesota's Ecoregions as mapped by USEPA.

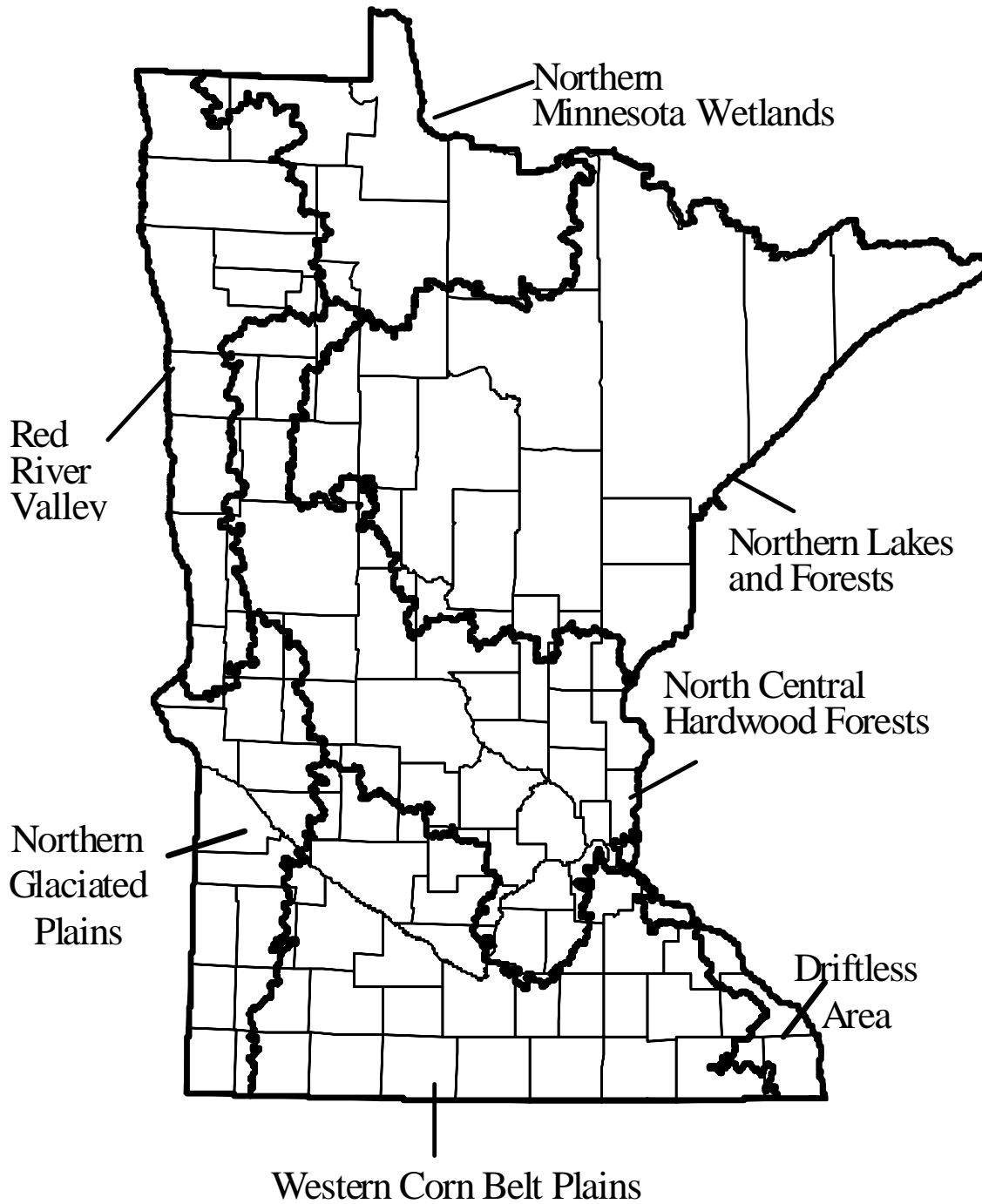
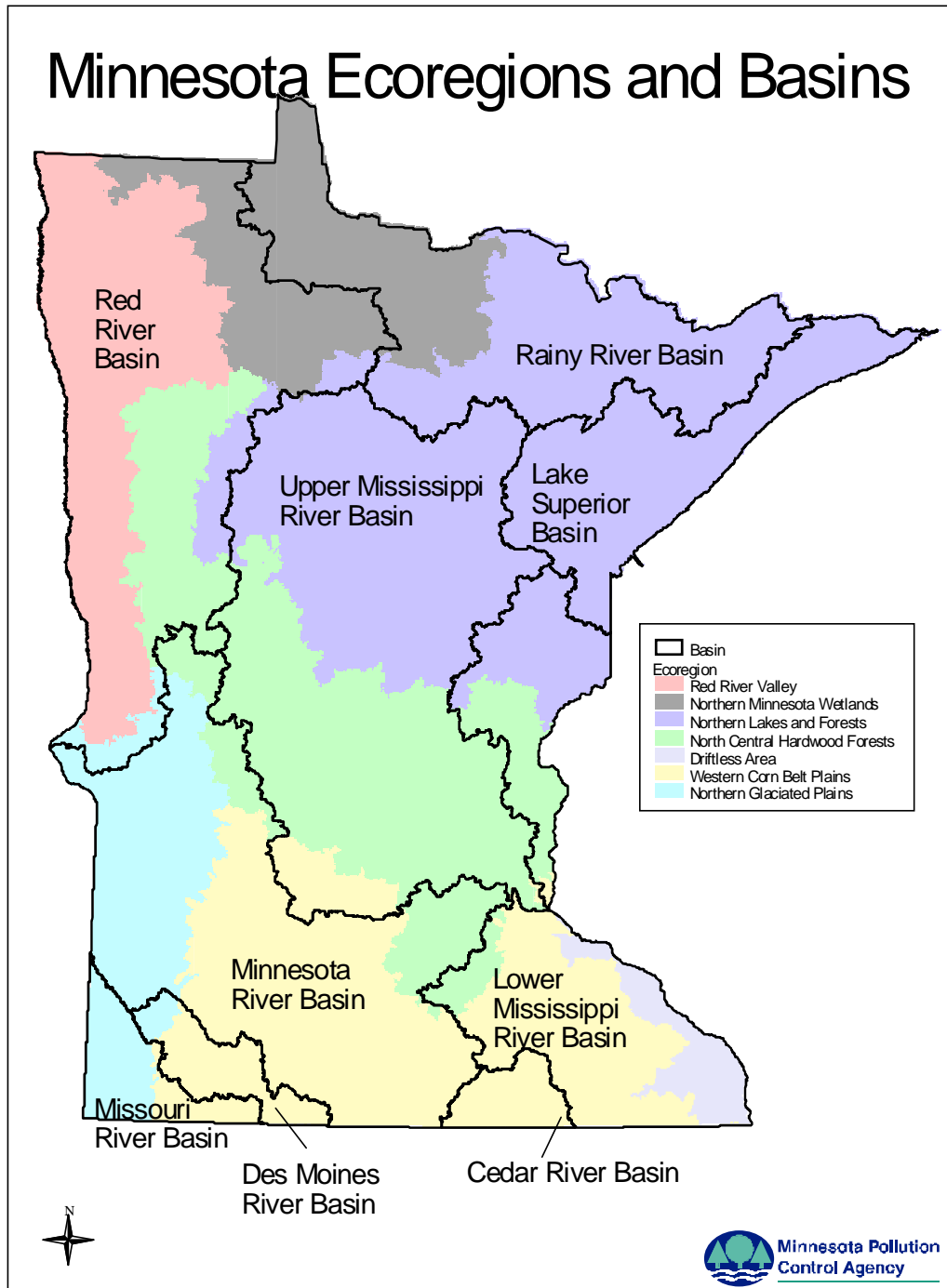


Figure 3. Minnesota's Ecoregions and Major Drainage Basins.



C. Aquatic Recreation Use Assessment

Assessing whether lakes “support” or “do not support” aquatic recreation is required as a part of Section 305(b) of the Clean Water Act. Minnesota has long used an ecoregion-based approach for these assessments. Previously developed ecoregion-based phosphorus (TP) criteria (Figure 2 and Table 2) have long been used in conjunction with Carlson’s TSI scale to establish use support thresholds (Table 3). These thresholds are described in more detail in MPCA’s “Guidance Manual for Assessing the Quality of Minnesota Surface Water (www.pcs.state.mn.us/) and were used to determine nutrient-impaired waters for the 2002 303(d) list and they help guide the 305(b) assessments as well.

The phosphorus “criteria” we refer to were originally derived based on an analysis of reference lake data (Table 4) and various ecoregion-specific considerations such as lake-morphometry, attainability and lake user perceptions (Heiskary and Wilson, 1988). Determining use support by ecoregion provides a more reflective picture of the condition of Minnesota lakes, as opposed to assessing all lakes by a single scale that ignores important regional differences such as lake morphometry and lake user perceptions. The MPCA is currently in the process of developing total phosphorus, chlorophyll-a and Secchi criteria as a part of the water quality standards revision process.

The thresholds used for 305(b) have been modified slightly (from previous assessments) so they are more consistent with use support definitions developed for 303(d) assessment (Table 3). For 305(b) purposes we will use three “levels” of support: full, partial, and non support. In general, full support thresholds for the Northern Lakes and Forests (NLF) and North Central Hardwood Forests (CHF) ecoregions are the same as in previous 305(b) assessments (30 and 40 µg/L respectively); while those for the Western Corn Belt Plains (WCP) and Northern Glaciated Plains (NGP) are somewhat less restrictive (70 µg/L). Differences in lake-user perceptions of “impaired swimming” and what constitutes nuisance algal blooms, along with differences in lake-morphometry and attainability are primary reasons for the regional differences. As with assessment of trophic status, TP will be used as the basis for assessing use support. If TP data are not available Secchi (based on TSI thresholds described below) will be used.

The Northern Lakes and Forests and North Central Hardwood Forests ecoregions phosphorus criteria levels, 30 ug/L and 40 ug/L, respectively, serve as the upper thresholds for full support of aquatic recreational use. Those concentrations correspond to Carlson’s TSI values of 53 and 57, respectively. Phosphorus concentrations above criteria levels would result in greater frequencies of nuisance algal blooms and increased frequencies of “impaired swimming.” The upper threshold for partial support of aquatic recreational use was set at 56 and 59 Carlson’s TSI units, respectively, for these two regions. As phosphorus concentrations increase from about 30 ug/L to 60 ug/L, summer-mean chlorophyll-a concentrations increase from about ten ug/L to 30 ug/L, and Secchi transparency decreases from about 2.5 meters to 1.5 meters (Figure 4). Over this range, the frequency of nuisance algal blooms (greater than 20 ug/L chl-a) increases from about five percent of the summer to about 70 percent of the summer (Figure 5). The increased frequency of nuisance algal blooms and reduced Secchi transparency results in a high percentage of the summer (26-50 percent) perceived as “impaired swimming.”

Table 2. Minnesota Lakes Total Phosphorus Criteria (Heiskary and Wilson 1988).

Ecoregion	Use and Level of Support	TP Criterion
Northern Lakes and Forests	Cold water fishery Full support	< 15 µg/liter
Northern Lakes and Forests	Primary-contact recreation and aesthetics Full support	< 30 µg/liter
North Central Hardwood Forests	Primary-contact recreation and aesthetics Full support	< 40 µg/liter
Western Corn Belt Plains and Northern Glaciated Pains	Primary-contact recreation, Full support	< 40 µg/liter
Western Corn Belt Plains and Northern Glaciated Pains	Primary-contact recreation, Partial support	< 90 µg/liter

Table 3. Trophic Status Thresholds for Determination of Use Support for Lakes: Comparison of 305(b) and 303(d). (Carlson’s TSI noted for each threshold.)

Ecoregion (TSI)	TP ppb	Chl ppb	Secchi m	TP Range ppb	TP ppb	Chl ppb	Secchi m
305(b):	Full Support			Partial Support	Non-Support		
303(d):	Not Listed			Review	Listed		
NLF	< 30	<10	≥ 1.6	30 – 35	> 35	> 12	< 1.4
(TSI)	(< 53)	(< 53)	(< 53)	(53-56)	(> 56)	(> 55)	(> 55)
CHF	< 40	< 15	≥ 1.2	40 - 45	> 45	> 18	< 1.1
(TSI)	(< 57)	(< 57)	(< 57)	(57 – 59)	(> 59)	(> 59)	(> 59)
WCP & NGP	< 70	< 24	> 1.0	70 - 90	> 90	> 32	< 0.7
(TSI)	(< 66)	(< 61)	(< 61)	(66 – 69)	(> 69)	(> 65)	(> 65)

TSI = Carlson trophic state index; Chl = Chlorophyll-a; ppb = parts per billion or µg/L, m = meters

For the NLF ecoregion summer-mean TP concentrations above 35 ug/L were associated with nonsupport of aquatic recreational use. At TP concentrations above 35 ug/L, mild algal blooms (greater than 10 ug/L chl-a) may occur over 50 percent of the summer and nuisance blooms (> 20 ug/L chl-a) about 15 percent of the summer. Secchi transparency will typically average 1.6 m or less. The combination of frequent blooms and reduced transparency will result in a high frequency of impaired swimming (perhaps 50 percent of summer) and greater than 25 percent as “no swimming.”

For the CHF ecoregion summer-mean TP concentrations above 45 ug/L were associated with nonsupport of aquatic recreational use. At TP concentrations above about 45 ug/L mild blooms occur over 80 percent of the summer, nuisance blooms about 40 percent of the summer, and severe nuisance blooms about 15 percent of the summer. Secchi transparency typically averages 1.1 m or less over this range of TP. Transparencies less than 1.4 m are typically associated with impaired swimming, while those less than 1.1 m are typically associated with no swimming (Heiskary and Wilson, 1988).

For the Western Corn Belt Plains and Northern Glaciated Plains the upper TP thresholds for fully supporting is 70 ug/L, which is consistent with the level used for 303(d) assessment (Table 3). This corresponds to a TSI of 66. At a TP concentration of 70 ug/L, summer mean chlorophyll-a averages about 24 ug/L and Secchi transparency is about 0.8 meter. Nuisance algal blooms (greater than 30 ug/L chl-a for these regions) would occur for approximately 50 percent of the summer. Few lakes in these two ecoregions have TP concentrations of 70 ug/L or less. Partial support, which corresponds to a TP concentration of 70 - 90 ug/L (Carlson's TSI = 69), is again consistent with the 303(d) assessment (Table 3). Total phosphorus concentrations greater than 90 ug/L are considered not supporting of aquatic recreational use. At TP concentrations greater than 90 ug/L, Secchi transparency averages 0.5 meters or less and nuisance algal blooms may occur over 75 percent of the summer.

Lakes in the Red River Valley (RRV) and Northern Minnesota Wetlands (NMW) ecoregions were assessed using the North Central Hardwood Forests and Northern Lakes and Forests criteria, respectively. This is because there were too few lakes to establish reference conditions in the Red River Valley or Northern Minnesota Wetlands ecoregions.

Table 4. Ecoregion reference lake data summary. Based on the interquartile (25th – 75th percentile) range for reference lakes in each ecoregion. Also referred to as “typical range.”

Parameter	Northern Lakes and Forests	North Central Hardwood Forests	Western Corn Belt Plains	Northern Glaciated Plains
# of reference lakes	30	35	12	10
Total Phosphorus (µg/L)	14 - 27	23 - 50	65 - 150	122 - 160
Chlorophyll mean (ug/l)	4 - 10	5 - 22	30 - 80	36 - 61
Chlorophyll maximum (ug/l)	< 15	7 - 37	60 - 140	66 - 88
Secchi Disk (feet) (meters)	8 - 15 (2.4 - 4.6)	4.9 - 10.5 (1.5 - 3.2)	1.6 - 3.3 (0.5 - 1.0)	1.3 - 2.6 (0.4 - 0.8)
Total Kjeldahl Nitrogen (mg/l)	0.4 - 0.75	< 0.60 - 1.2	1.3 - 2.7	1.8 - 2.3
Nitrite + Nitrate-N (mg/l)	<0.01	<0.01	0.01 - 0.02	0.01 - 0.1
Alkalinity (mg/l)	40 - 140	75 - 150	125 - 165	160 - 260
Color (Pt-Co Units)	10 - 35	10 - 20	15 - 25	20 - 30
pH (SU)	7.2 - 8.3	8.6 - 8.8	8.2 - 9.0	8.3 - 8.6
Chloride (mg/l)	0.6 - 1.2	4 - 10	13 - 22	11 - 18
Total Suspended Solids (mg/l)	< 1 - 2	2 - 6	7 - 18	10 - 30
Total Suspended Inorganic Solids (mg/l)	< 1 - 2	1 - 2	3 - 9	5 - 15
Turbidity (NTU)	< 2	1 - 2	3 - 8	6 - 17
Conductivity (umhos/cm)	50 - 250	300 - 400	300 - 650	640 - 900
TN:TP ratio	25:1 - 35:1	25:1 - 35:1	17:1 - 27:1	7:1 - 18:1

Figure 4. Total Phosphorus, Chlorophyll-a, and Secchi Scatterplots and Regressions. Based on ecoregion reference lake data.

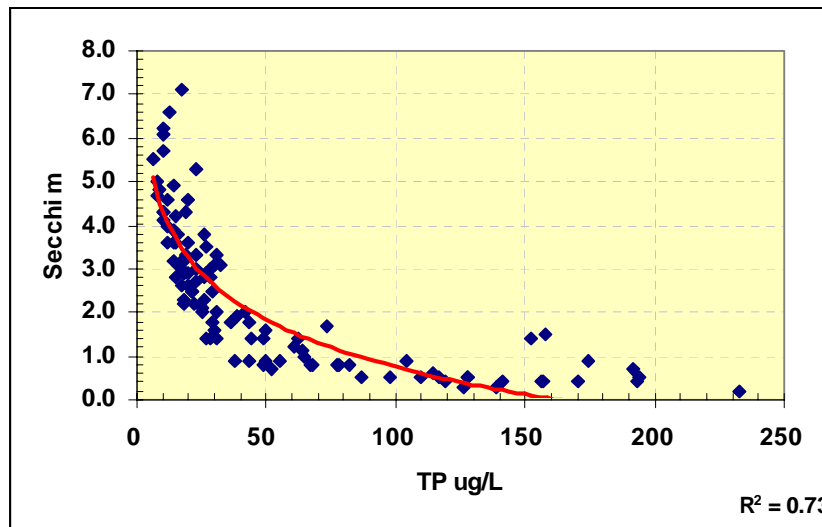
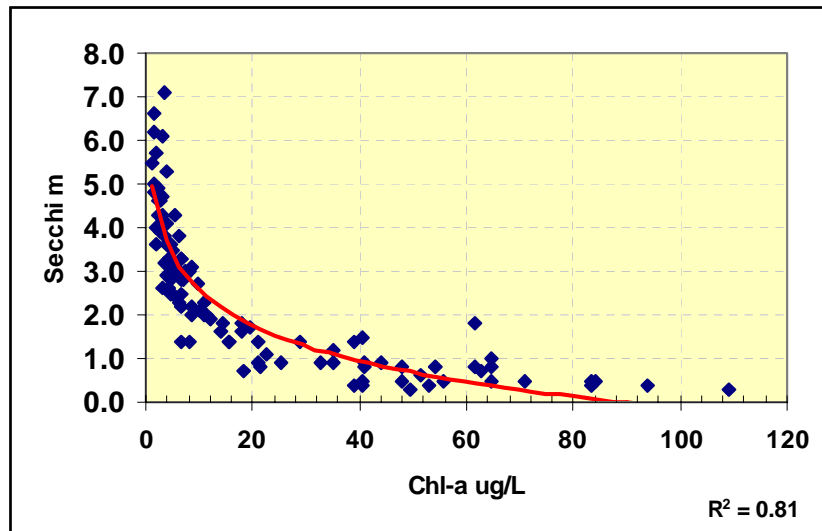
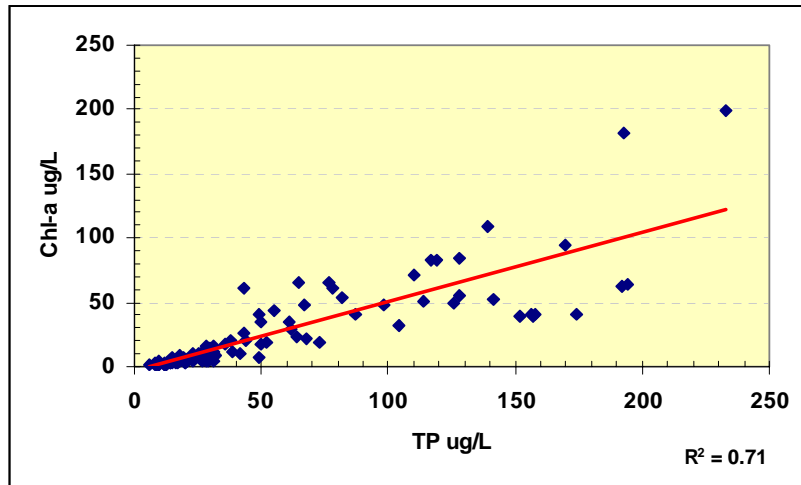
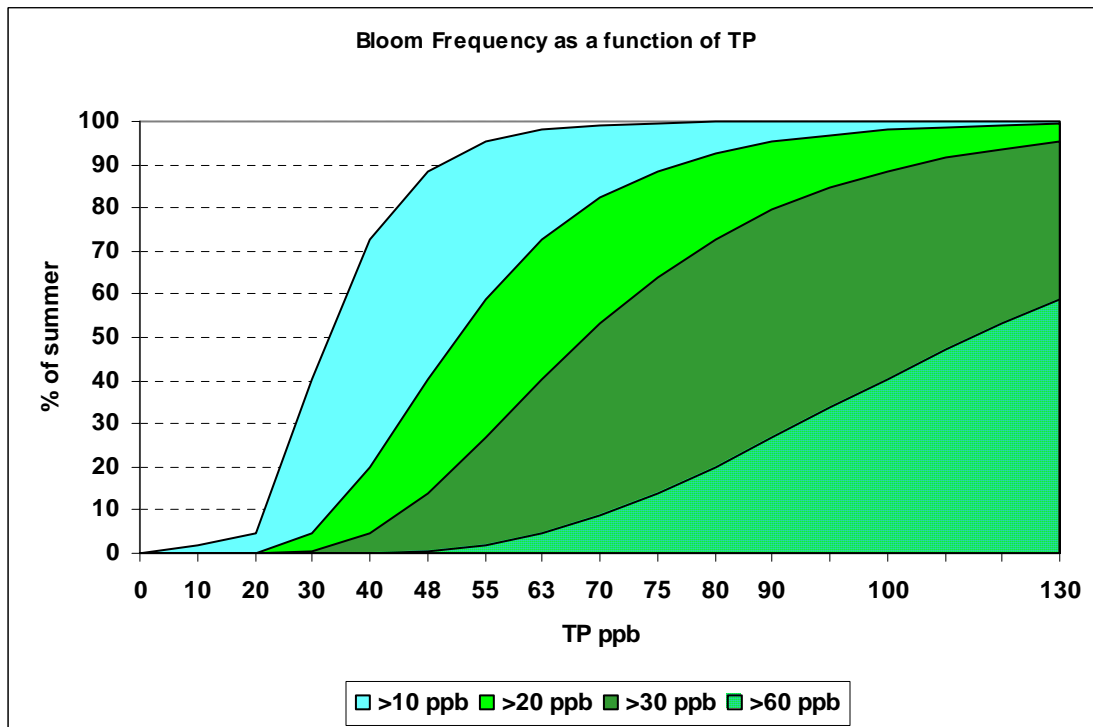
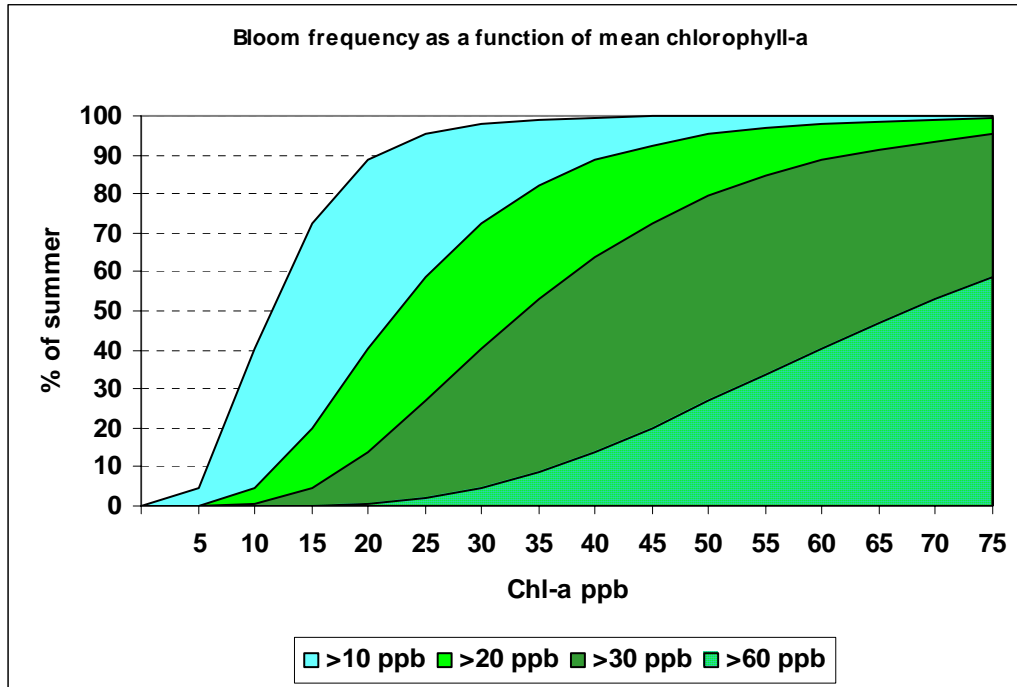


Figure 5. Algal Bloom Frequency as a Function of Mean Chlorophyll-a and Total Phosphorus



RESULTS AND DISCUSSION

Following is a discussion of aquatic recreational use support and associated data used in this assessment. For 305(b) purposes assessments are commonly done on both a statewide and basin-specific basis. Hence our analysis will include results and discussion pertinent to Minnesota's nine major drainage basins (Figure 3). In addition ecoregion-specific results will be shared to offer further insight into the status of lakes, potential causes of support or non-support, quality and sources of data used in the assessment. Where appropriate results are expressed in terms of number of lakes and number of lake acres. An ecoregion-based summary of trophic status measurements (TP, chlorophyll-a and Secchi) and lake morphometry of the assessed lakes is presented (Table 5).

A. Available data and data quality

Trophic status data used in this assessment were available for 2,790 lakes representing approximately 2,572,000 acres. Of this total 63 percent of the lakes (79% acres) were assessed based on monitored data and 37 percent (21 acres) were assessed based on evaluated data (Figure 6a). The higher percentage of monitored lake-acres (as compared to number of lakes) can be attributed to the numerous large lakes assessed in the past ten years including: Mille Lacs, Rainy, Lake of the Woods and Upper Red Lake.

The greatest number of assessed lakes were located in the Upper Mississippi Basin, and of these, over 70 percent were considered monitored (Figure 6b). Active participation in the CLMP, local water plan, Metropolitan Council, and related monitoring efforts contribute to the high number of assessed lakes and the high percentage of monitored lakes in this basin. The Rainy and Lake Superior Basins were the next highest by number, however less than 40 percent were based on monitored data. This is likely because many of the lakes in these basins are located within the Boundary Waters Canoe Area Wilderness (BWCAW) and there has been very limited monitoring of these lakes and lakes in the surrounding Superior National Forest in the past decade. Though there is participation in the CLMP it is not nearly as high as that seen in the Upper Mississippi Basin. Much of the monitored acreage in the Rainy can be attributed to Lake of the Woods (312,070 acres), Rainy (220,800 acres) and Vermilion (40,557 acres) all of which have been monitored by the MPCA in the past ten years. The Lower Mississippi Basin, while being relatively lake poor, had the highest percentage of its assessments based on monitored data. Lake Pepin, at 25,000 acres, accounts for much of the monitored acres in this basin. Other large lakes that have been monitored include Lake Byllesby and Cannon Lake on the Cannon River. The Red River and Minnesota Basins, also had a high percentage of monitored lakes -- about 80 percent. In the Red River Basin active monitoring through local water plans (coalitions of lake associations), watershed districts, other local efforts and CLMP contribute to the high percentage of monitored lakes. Among the larger lakes that have been monitored here are Upper Red Lake (107,800), Otter Tail (14,753 acres) and Lake Traverse (11,525 acres). In the Minnesota Basin local monitoring efforts by counties, municipalities, Metropolitan Council, CLMP and MPCA lake assessments all play a role in the data collected.

Table 5. Minnesota Lake Water Quality Assessment Data Base Summary (2004).

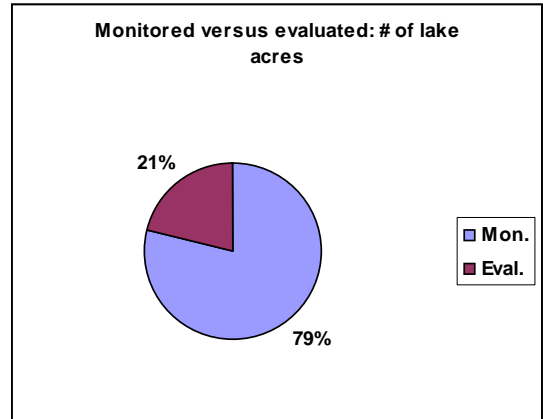
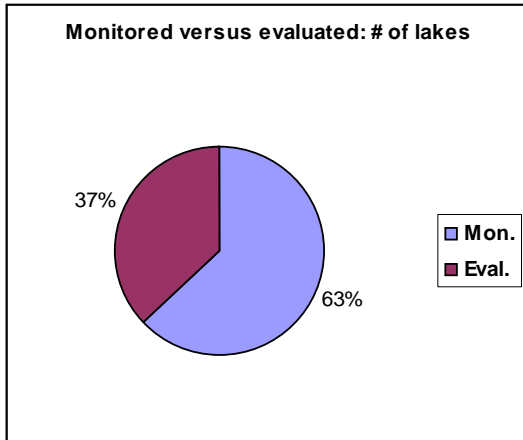
Percentile (%) by ecoregion ¹

Ecoregion	Parameter	5	10	25	50	75	90	95	N
NLF & NMW	Area (acres)	15	22	49	129	347	835	1,654	1,809
NLF & NMW	Depth-maximum (feet)	7	10	19	33	54	80	100	1,519
NLF & NMW	TP (ppb)	7	9	13	21	30	45	58	863
NLF & NMW	Chlorophyll-a (ppb)	2	2	3	5	8	14	22	521
NLF & NMW	Secchi (m)	0.9	1.2	1.8	2.8	4.0	5.1	5.9	1,394
CHF & RRV	Surface area (acres)	13	22	58	165	400	984	1,754	976
CHF & RRV	Depth-maximum (feet)	6	8	16	28	46	68	82	829
CHF & RRV	TP (ppb)	15	18	28	51	112	229	351	691
CHF & RRV	Chlorophyll-a (ppb)	3	4	8	21	45	89	131	622
CHF & RRV	Secchi (m)	0.4	0.5	1.0	1.6	2.6	3.5	4.2	968
WCP	Surface area (acres)	32	61	143	322	694	1,776	2,222	110
WCP	Depth-maximum (feet)	4	6	7	10	16	25	33	87
WCP	TP (ppb)	54	62	99	159	234	404	609	89
WCP	Chlorophyll-a (ppb)	11	14	32	50	83	125	173	79
WCP	Secchi (m)	0.2	0.3	0.4	0.6	1.0	1.5	2.2	109
NGP	Surface area (acres)	80	108	150	364	658	2,091	4,700	38
NGP	Depth-maximum (feet)	4	5	8	10	15	18	25	28
NGP	TP (ppb)	46	54	104	148	194	396	405	30
NGP	Chlorophyll-a (ppb)	4	9	25	36	52	64	66	27
NGP	Secchi (m)	0.3	0.4	0.5	0.7	1.6	1.9	2.1	37

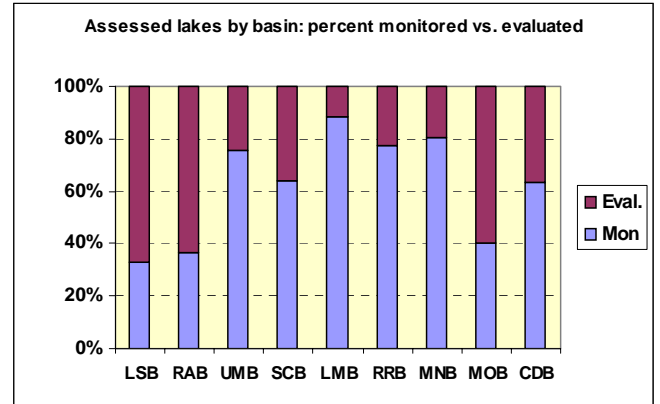
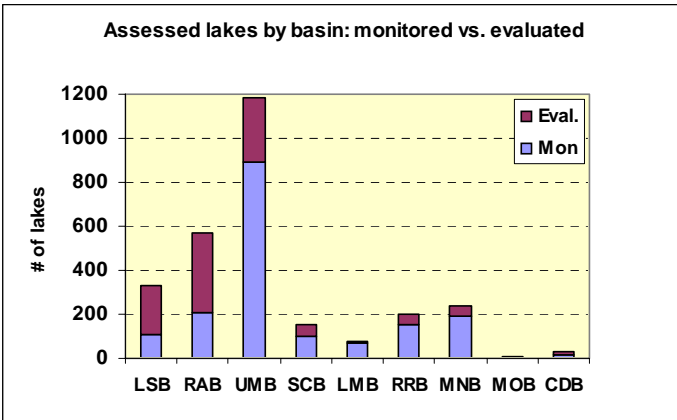
¹ For example, a TP concentration of 13 ppb ranks at the 25th percentile for lakes in the Northern Lakes and Forests and Northern Minnesota Wetlands ecoregions, which implies that 75% of the assessed lakes in these ecoregions have a TP > 13 ppb. N = number of lakes assessed for that parameter.

**Figure 6. Age of data: monitored versus evaluated data by:
a) state, b) basin, and c) ecoregion.**

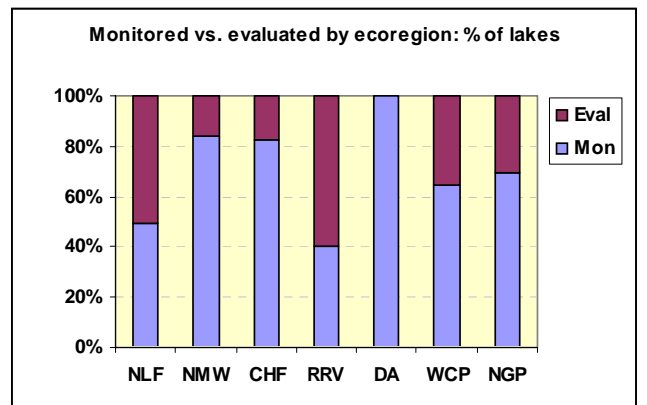
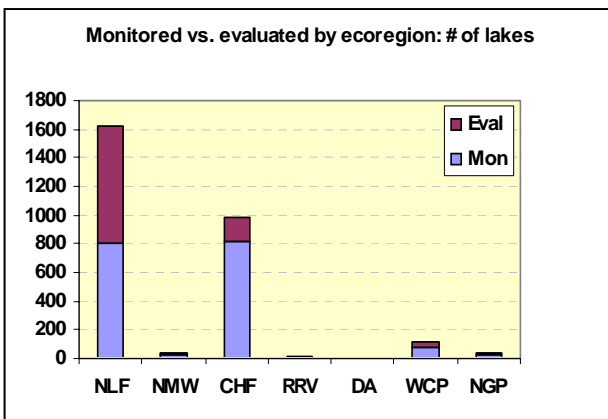
a)



b)



c)



The Missouri and Cedar Des Moines Basin are relatively lake-poor as compared to the other basins and hence the number of assessed lakes (10 and 30 respectively) was quite low (Figure 6). However, 40 and 60 percent respectively, of their assessed lakes were monitored. For the Missouri Basin, Lake Ocheda accounts for about one-third of the assessed lake acres. CLMP participation is low in these two basins and MPCA monitoring, CWP and related projects account for much of the data.

In terms of ecoregions the majority of the assessed lakes are in the NLF and CHF ecoregions, which is not surprising as these two regions contain the majority of the state's lakes. These two ecoregions include much of the Upper Mississippi, Rainy, and Lake Superior Basins. Also, most of the lakes that were assessed in the Red River Basin are found in the CHF portion of the basin with most of the remaining lakes being found in the NMW ecoregion. The NLF, as was the case with the Lake Superior and Rainy Basins, has a relatively low percentage of monitored lakes – for the same reasons stated previously. The CHF has over 80 percent of its assessed lakes as monitored. This, as noted earlier for the Upper Mississippi River Basin, can be attributed to very active monitoring efforts at the county level (typically water plan initiated monitoring) with watershed districts or management organizations, Metropolitan Council, CLMP volunteers, and others making large contributions to the assessed data in this ecoregion. The NMW ecoregion that is centered on Red Lake has a very high percentage of monitored lakes. This is a direct result of local monitoring efforts combined with CLMP. The WCP and NGP ecoregions had a low number of assessed lakes, however both has over 60 percent as monitored. In this case MPCA monitoring, such as the 2002 study of 22 southwest Minnesota lakes (Heiskary et al. 2003) and CWP projects have figured prominently in the collection of data on these lakes.

Data quality considers the relative amount of information used in the assessment (with a primary focus on TP) and to some degree speaks to the confidence we have in the assessment. Overall only nine percent of the assessed lakes had “excellent” quality data (the amount of data that would allow for 303(d) list assessment). Another 10 percent had “good” quality data that might be consistent with one or more full summers of monitoring and 15 percent had “fair” quality data that would be consistent with perhaps one summers worth of monitoring. The remaining 66 percent had “poor” quality data, meaning that less than one full summer of TP data was available. In many of these instances no TP data was available and CLMP Secchi data was the only data for the lake and this assessment.

The data quality in most of the basins could be considered poor to fair (Figure 7). The Upper Mississippi Basin, which had the highest number of assessed lakes, had about 20 percent of the lakes with good-excellent data. Most of the lakes with excellent data are located in the Seven County Metro Area and monitoring by Met. Council and related soil and water and watershed district efforts account for much of the remainder of the data. Volunteers figure prominently in this monitoring. These observations would also apply to the St. Croix and Minnesota Basins as well. The Red River Basin had almost 40 percent of the assessed lakes characterized as having good-excellent data. Again organized monitoring efforts associated with local water plans (coalitions of lake

associations) and watershed districts contribute to the better quality data. In contrast the vast majority of the assessments in the Lake Superior and Rainy Basins were considered to be of poor-fair quality.

Stratifying data quality based on ecoregions shows a similar pattern as described above. For example the vast majority of the assessments for the NLF were based on poor – fair quality data. The CHF ecoregion had almost 40 percent of its assessments based on excellent – good quality data, but again most of these lakes were located in the Metro Area. Though the overall number of assessments was low in the WCP and NGP ecoregions (Figure 7) the percentage of those based on good – fair quality data was much higher than either the NLF or CHF ecoregions. This, as noted previously, is a direct result of MPCA and project-oriented monitoring efforts.

B. Lake trophic status

Lake trophic status was assessed based on Carlson’s Trophic State Index as previously noted. The assessment was based on TP (if data was available) or Secchi transparency. The Lake Superior, Rainy, and Red River Basins are characterized primarily (60 percent or more) by oligotrophic and mesotrophic lakes (Figure 8). In contrast the Minnesota, Cedar Des Moines, and Missouri Basins are characterized primarily by eutrophic to hypereutrophic lakes. The St. Croix Basin is intermediate between these two extremes and is characterized largely by eutrophic lakes.

The ecoregions that comprise the various basins show a similar picture. Whereby the NLF and NMW ecoregions are dominated by oligotrophic to mesotrophic lakes and the WCP and NGP are dominated by eutrophic to hypereutrophic lakes (Figure 8). The CHF ecoregion has the greatest diversity in trophic status with mesotrophic and eutrophic lakes accounting for about 70 percent of the assessed lakes.

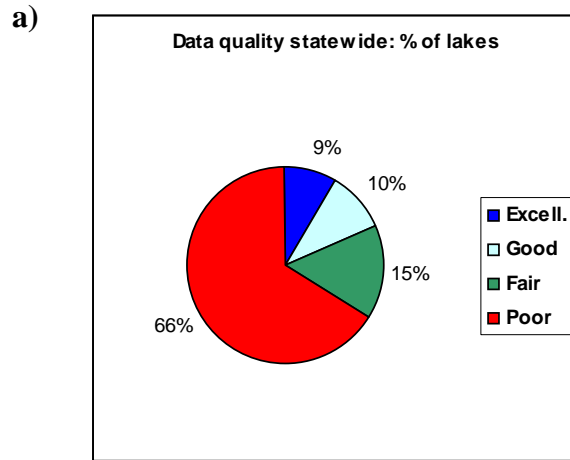
C. Aquatic recreational use support

Of the total of 2,790 assessed lakes 53 percent fully supported aquatic recreational use while 37 percent did not (Figure 9a). The remainder partially supported uses. In terms of lake acres 50 percent fully supported while only 16 percent did not. The primary reason for the difference between these figures (number of lakes vs. lake acres) is that the larger lakes tend to drive the acreage-based assessment and many of these large lakes (e.g. Lake Mille Lacs, Leech, Lake of the Woods) tend to fully or partially support uses. In contrast there are numerous small lakes that do not fully support aquatic recreational uses.

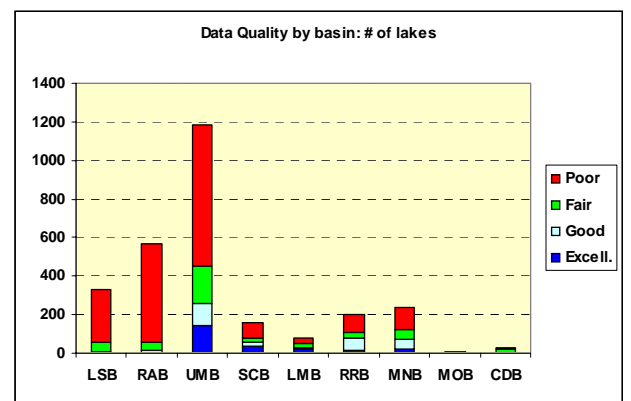
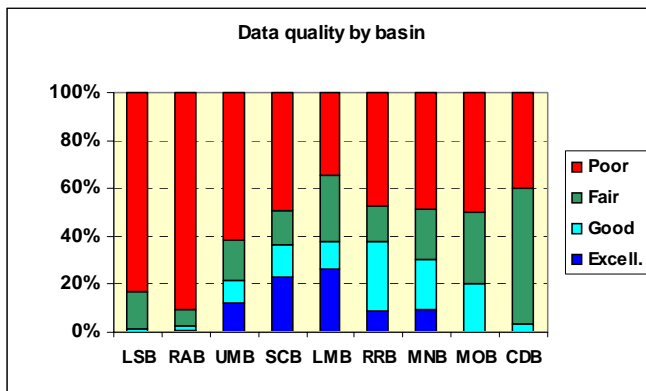
The relative percentage of lakes in each use class varies by basin. The Lake Superior, Rainy, and Red River Basins all have relatively high percentages of fully or partially supporting lakes (Figure 9b). In contrast the Minnesota, Cedar-Des Moines, and Missouri lakes are predominately considered non supporting. The St. Croix Basin lakes are intermediate between these two extremes. A fairly similar (among basin) picture is conveyed if we look at the percent of lake acres (Figure 9b).

The examination of use support by ecoregion may provide more insight than the basin-based comparisons, since the thresholds used in the assessment are ecoregion-based and the underlying characteristics that comprise the ecoregions: land use, soil type, potential natural vegetation and landform can strongly influence the delivery of nutrients to the lake. The majority of the assessed lakes of the NLF and NMW ecoregions either fully or partially support aquatic recreation uses (Figure 9). These two ecoregions are characterized by moderately deep lakes (Table 5) and watersheds dominated by forest and wetland uses. In contrast the majority of the lakes in the CHF, WCP and NGP ecoregions are non supporting of aquatic recreational uses. The reasons for non-support of swimmable use vary between regions. NLF ecoregion lakes which do not support swimmable use are often smaller and shallower than the norm and often have some past or present source of excess P loading in their watershed such as a wastewater treatment plant discharge. CHF ecoregion lakes that do not support swimmable use are often shallower than the norm. Also they often have a source (or multiple sources) of excessive P loading such as: wastewater treatment plant discharge, numerous feedlots, excessive land application of bio-solids, high percentage of agricultural land use, or high percentage of impervious area (receive large amounts of storm water runoff) in their watershed. All of these sources can contribute high P loading to a lake. In the WCP and NGP ecoregions the vast majority of lakes are quite shallow (Table 5) and have highly agricultural watersheds. Runoff from these agricultural lands is typically very high in P. This high P loading from the watershed and shallowness of the lakes (which promotes poor retention of P by lake sediments and internal recycling of P) typically lead to high in-lake P concentrations and subsequently nuisance algal blooms and low transparency. The combination of high watershed P loading and the limited assimilative capacity of shallow lakes often limit the degree to which water quality of these lakes might be improved.

Figure 7. Data quality: a) statewide, b) by basin, and c) by ecoregion



b)



c)

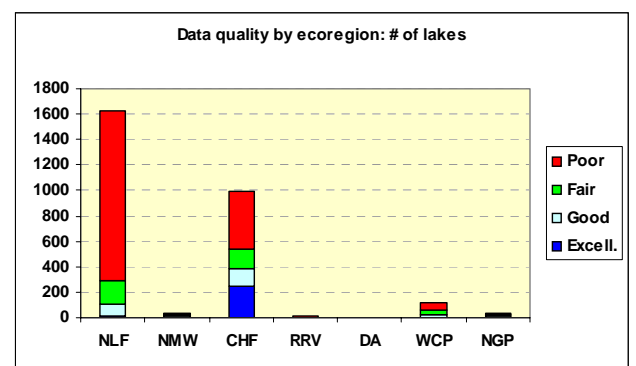
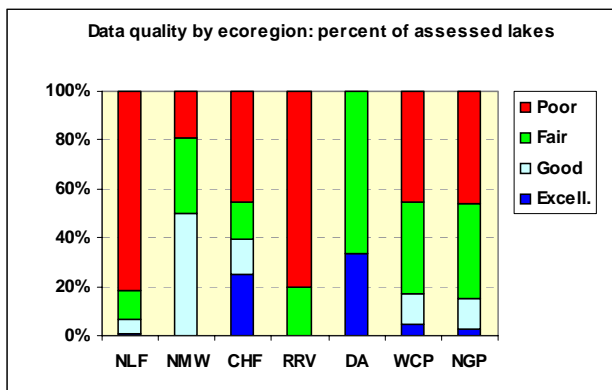
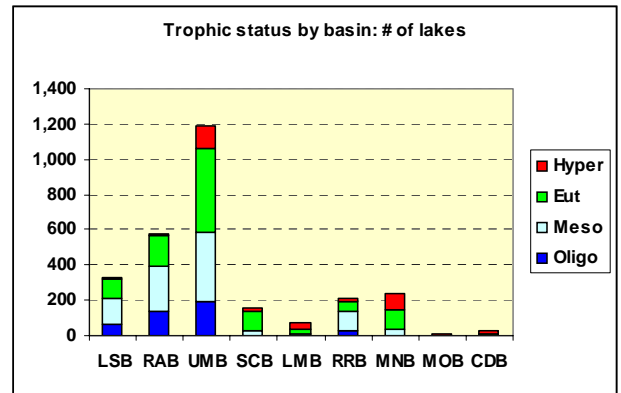
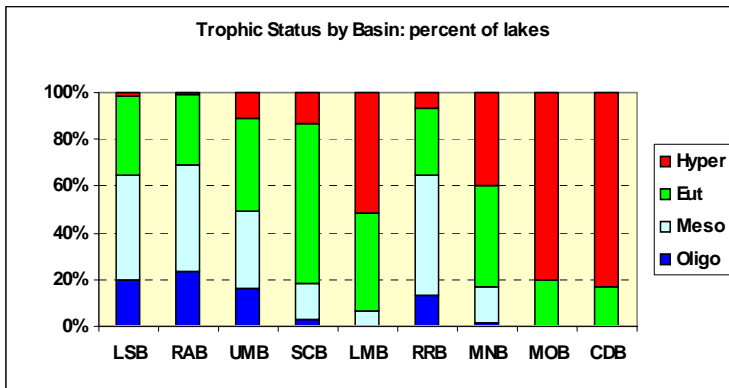


Figure 8. Lake trophic status by a) basin and b) ecoregion

a)



b)

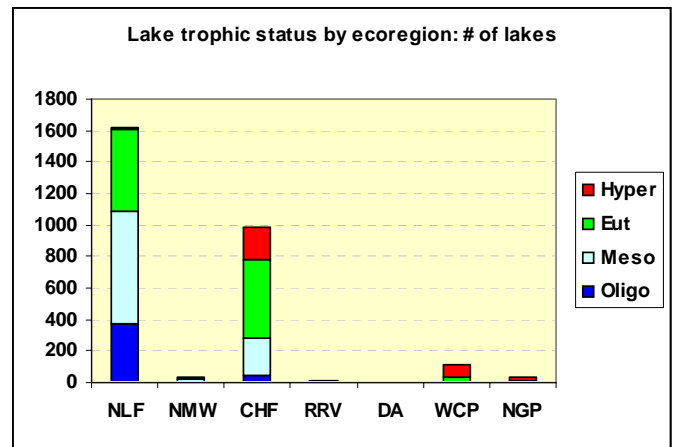
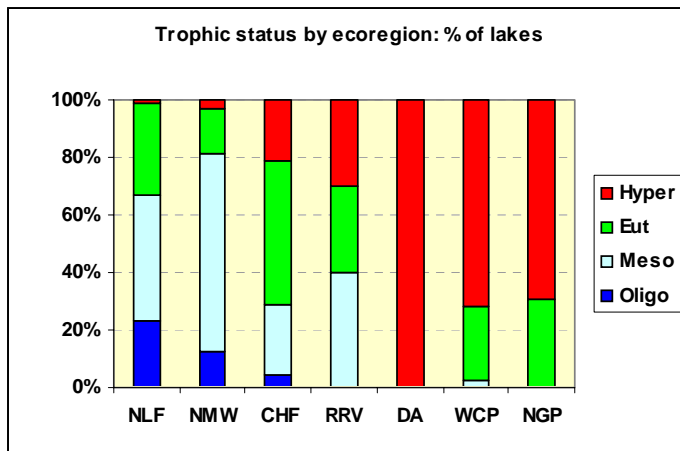
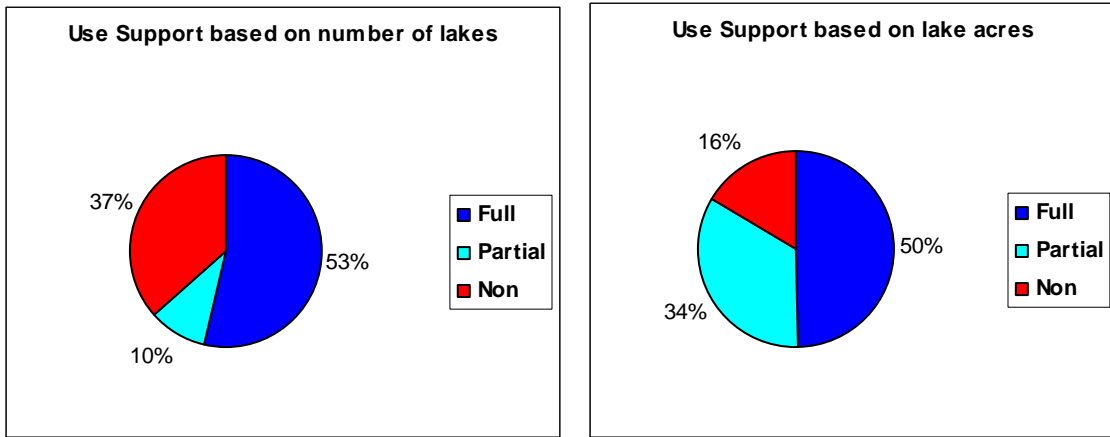


Figure 9. Aquatic recreational use support by a) state, b) basin, and c) ecoregion

a)



b)

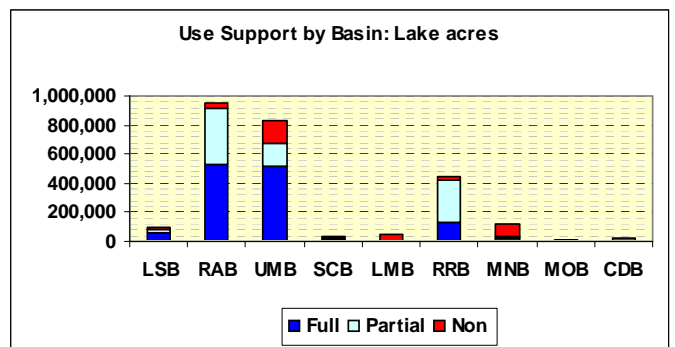
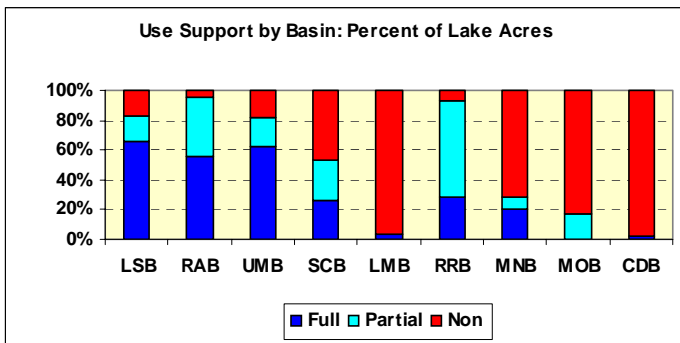
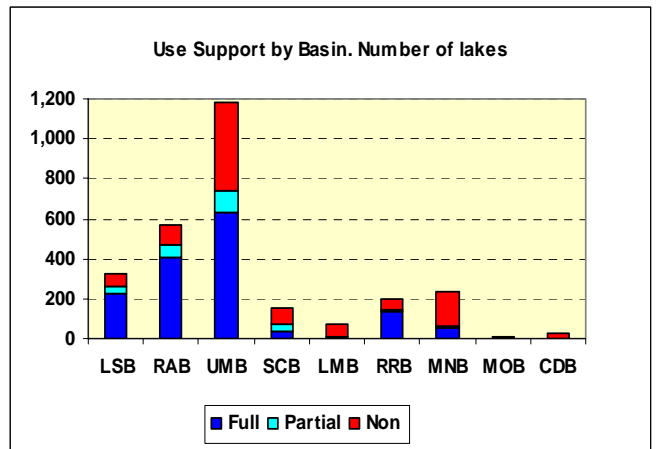
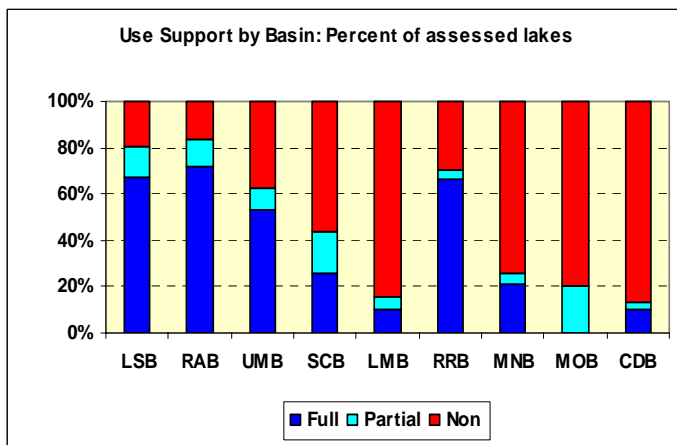
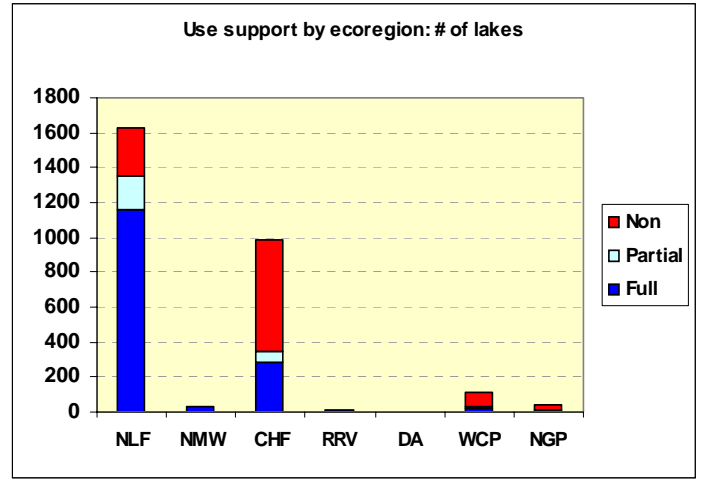
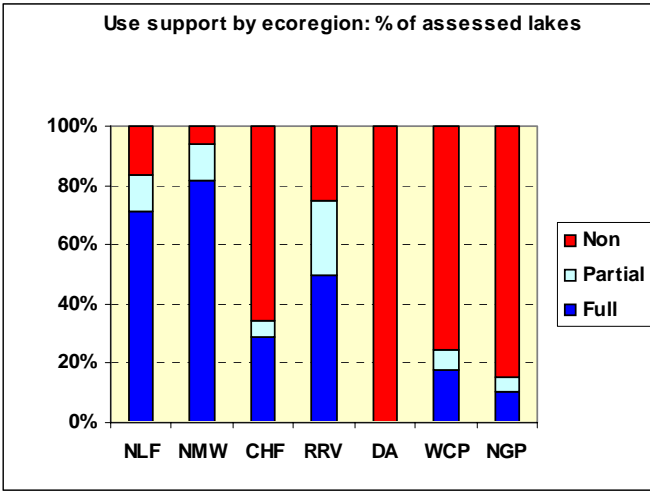


Figure 9 continued

c)



Data Base Legend

UNITS - The following are pertinent units and conversion factors used in this data base:

- ppm = parts per million equivalent to mg/L = milligrams per liter
- ppb = parts per billion equivalent to ug/L = micrograms per liter
- acres - divide by 2.47 to get hectares; feet - divide by 3.28 to get meters

Lake ID# = MN Department of Natural Resources identification number (see note 1)

Lake = common name of lake

Location= location from nearest town

WBT = water body type as per PWI (see note 2)

Area = surface area (acres)

D max = maximum depth (feet)

ME = monitored or evaluated (see note 3)

Qual = quality or amount of data available for the assessment (see note 4)

TS = trophic status; O=oligotrophic, M=mesotrophic, E=eutrophic, and H=hypereutrophic (see note 6)

TP = mean total phosphorus (ppb) (see note 5)

SEP = standard error of the mean TP (see note 5)

NP = number of TP measurements used to calculate mean

P Min = minimum TP

P Max = maximum TP

CHL = mean chlorophyll-a (ppb)

SEC = standard error of the mean chlorophyll-a

NC = number of chlorophyll-a measurements used to calculate mean

C Min = minimum chlorophyll-a

C Max = maximum chlorophyll-a

SDM = mean Secchi disk (meters)

SES = standard error of the mean Secchi

NS = number of Secchi measurements used to calculate mean

S Min = minimum Secchi

S Max = maximum Secchi

TSP = Carlson's trophic state index based on TP = $14.42 \ln(\text{TP}) + 4.15$ (see note 6)

TSC = Carlson's trophic state index based on CHLA = $9.81 \ln(\text{CHLA}) + 30.6$

TSS = Carlson's trophic state index based on SDM = $60 - 14.41 \ln(\text{SDM})$

ALK = alkalinity (ppm) (see note 8)

N Alk = number of alkalinity measurements used to calculate the mean

COL = color (Platinum-cobalt Units) (see note 7)

N Col = number of color measurements used to calculate the mean

Use = aquatic recreation use support classification whereby *FS* = "full-support", *PS* = "partial-support", and *NS* = "non-support" (see note 11)

Bas = Basin: major river basin the lake is located in: *UMB*=Upper Mississippi, *LMB*=Lower Mississippi, *MNB*=Minnesota River, *RRB*=Red River, *RAB*=Rainy River, *LSB*=Lake Superior, *CDB*=Cedar and Des Moines, *MOB*=Missouri, *SCB*=St. Croix (see note 10)

Eco = **Ecoregion:** *NLF*=Northern Lakes and Forests, *CHF*=North Central Hardwood Forests, *NGP*=Northern Glaciated Plains, *WCP*=Western Corn Belt Plains, *RRV*=Red River Valley, *DA*=Driftless Area, *NMW*=Northern Minnesota Wetlands

Data Base Summary and Notes

The following notes are included to clarify how this data base was assembled, how to interpret the information, and cautions for its use.

1. **Lake ID** numbers are taken from the Minnesota Department of Natural Resources, 1968 publication "Bulletin 25: An Inventory of Minnesota Lakes" or its current equivalent "Public Waters Inventory (PWI)". It is a six-digit code with the first two digits indicating the county and the next four the lake number. These numbers are used for storing/retrieving data in STORET. Lakes with a 01, 02, etc., suffix indicates that the lake has been divided into "bays" for data storage and assessment purposes. The noted surface area and depth is an estimate for that bay (Example: Lake ID = 01-0123-01 indicates - Anoka County, Cedar Lake, main basin.).
2. **WBT** – Refers to water body type as indicated in MDNR's PWI. PWI serves to document all public waters (lakes and wetlands) and assign individual ID numbers. (consistent with Bulletin 25). However some lakes in Bulletin 25 are really wetlands and are coded as "LW" whereas lakes have the codes "LP" or "L" in the PWI. Lakes that are "wetlands" based on the PWI were not assessed for the 303(d) list, however this differentiation was not made for the 305(b) assessments noted herein.
3. **ME** - Any lake with total phosphorus (TP), chlorophyll-a, or Secchi transparency data collected between 1970-2002, and stored under MPCA's agency code 21 MINNL in STORET is included in this assessment. Lakes were classified into one of two categories for this data assessment. "M" implies *monitored* (recent) and indicates that summer (June through September) data collected between 1993 and 2002 was available for that lake. "E" implies *evaluated* (old). This indicates that data for this lake was collected between 1970-1990. Non-summer total phosphorus measurements may also be included in this category.
4. **Qual** – This refers to the "quality" of the data used in the assessment and refers to the number and extent of observations available for the assessment. The terms used were derived from USEPA guidance but actual classifications were developed by MPCA as follows: Poor - < 4 TP observations; Fair – 4 ≤ TP < 8, some chlorophyll-a and Secchi; Good – 8 < TP < 12, some chlorophyll-a and Secchi; and Excellent – 12 TP, 12 chlorophyll-a and 12 Secchi observations.
5. **Statistics** – Summer-mean TP, chlorophyll-a, and Secchi was calculated for each lake where data was available. "Summer" includes any observations collected from June

through September. The number of observations (N) represents the individual sample dates used to calculate the summer-mean. The standard error of the mean (SE) is calculated as the standard deviation divided by the square root of the number of observations. In addition, the minimum and maximum values for the assessment period are included to assist in the data assessment. Considering the N and SE values, in conjunction with the mean, provides a basis for assessing the “confidence” we have that the mean value accurately characterizes the trophic status of the lake. Likewise the minimum and maximum values provide an indication of how variable the particular parameter may be for a given lake. In general, means calculated from a small number of observations, or highly variable observations, often have a large standard error. Alternately, means calculated from a large number of observations, or relatively uniform observations, often have a small standard error. These statistics (SE in particular) can also be used as a basis for comparing summer-mean values among lakes to determine if the means are significantly different.

6. **Trophic State Index** – *Carlson’s Trophic State Index* (TSI) is used as the basis for estimating the trophic status of Minnesota lakes (Figure 1). Trophic status ranges from oligotrophic to hypereutrophic (and is viewed as a continuum) on this scale. Carlson’s TSI is based on the interrelationships of TP, chlorophyll-a, and Secchi transparency. The *individual* TSIs are very useful for understanding the relationship of TP, chlorophyll, and transparency for a given lake and provide *the best information on the trophic condition* of the lake. If the individual TSI values for a lake do not correspond fairly closely (e.g., within 5 TSI units), then the individual values should be inspected and particular attention should be paid to the number of observations used to calculate the mean values and to determine which parameter might be the more accurate predictor of trophic state. The following notes may be helpful in this regard:
 - a. If one index value is based on numerous measures while the others are based on a single measure, then the former is probably the better indicator of trophic state.
 - b. If there is only a single measurement for each index value, the phosphorus TSI should be favored as it provides an estimate of the "potential" trophic status of a lake.
 - c. Secchi or chlorophyll-a TSIs based on single observations should be viewed with caution.
 - d. Secchi TSI values in highly colored waters (see note 7) or waters high in inorganic suspended solids (e.g., clay) may provide a poor estimate of trophic state. This is because the dark coloration or high suspended sediments may limit the amount of algae produced and often will be the primary factor limiting transparency.
 - e. Lakes dominated by large colonial algae, such as Aphanizomenon sp. (look like clumps of grass clippings), may have high transparencies (low TSI) relative to the

- phosphorus concentration. This is because these colonies of algae may form “rafts” or scums at the surface of the water which are easily displaced by wind or lowering of a Secchi disk and hence Secchi readings may be deeper than if the algae were dispersed evenly throughout the water column. This is very common in hypereutrophic lakes and hence Secchi may not be the best indicator of trophic status in highly nutrient-rich lakes.
- f. Lakes with extensive macrophyte (rooted submergent and emergent plants) growth may have higher transparency and lower chlorophyll-a (lower TSIs) than expected based on the phosphorus concentration. These plants may compete with algae for available nutrients like phosphorus.
 - g. Ecoregion patterns may also give an indication as to which TSI value is a better reflection of the trophic status of a lake.
 - h. This data base may not provide an accurate estimate of the current trophic status of a given lake because of the number of observations or the age of the data. In particular, those labeled as "evaluated" should be viewed with caution since the data may be over ten years old.
 - i. If more current data is available for a lake, or if data is available for a lake that is not included in the appendix, then the appendix data and Table 5 can be used to place the condition of the lake in perspective relative to other lakes in a given ecoregion.
7. **Color** - as measured against a platinum-cobalt standard (PCU or Pt-Co units), can give an indication of the relative amount of dissolved organic matter in the water. High coloration, or "bog stain" as it is referred to, is usually caused by runoff from wetlands or forested lands. At high values, color may interfere with the expected phosphorus - chlorophyll - Secchi relationship of a lake. In general, values between 0-20 are considered clear, 21-50 are considered moderately colored, 51-100 are considered highly colored, and values greater than 100 can be considered very highly colored. Based on data from the ecoregion reference lakes color begins to influence the phosphorus - chlorophyll - Secchi relationships above about 50 Pt-Co units, and may strongly influence the relationship above 100 Pt-Co units. In highly colored lakes, transparency and chlorophyll values are often lower than expected based on the phosphorus values.
8. **Alkalinity** - is measured in mg/l as calcium carbonate (CaCO_3). It represents a measure of a solution's ability to buffer or neutralize acids. Lakes located in areas of calcareous glacial till (common throughout central and southern Minnesota) will have higher alkalinity than lakes formed on non-calcareous bedrock (common in northeastern Minnesota). Water with alkalinity less than about 75 mg/L could be considered soft, 76-150 moderately hard, 151-300 hard, and greater than 300 very hard. Alkalinity has also been used as a basis for estimating sensitivity to acid precipitation. For this purpose, lakes with alkalinity values less than 5 to 10 mg/L

could be considered potentially sensitive to acid precipitation based on current levels of deposition across Minnesota. At this point we have identified no “culturally acidified” lakes in Minnesota.

9. **Ecoregion Reference Lakes** - One means for placing lake water quality information in perspective is to compare summer mean values to those found in reference lakes from the same ecoregion in which the lake is located in. The U.S. Environmental Protection Agency mapped ecoregions for the United States from information on soils, landform, potential natural vegetation, and land use. For Minnesota, within-ecoregion similarities in lake chemistry and lake morphometry (depth and surface area) have been noted. Reference lakes, deemed to be representative and minimally impacted by man (e.g., no point source wastewater discharges, no large urban areas in the watershed, etc.), were sampled in each ecoregion by the MPCA from 1985 through 1988. These lakes are not necessarily the most “pristine” for the region, as is evident from the data in Table 4. The reference lake data base consists of approximately 90 lakes distributed as follows among the four ecoregions with the majority of Minnesota's lakes: Northern Lakes and Forests (NLF)- 30, North Central Hardwood Forest (CHF)- 38, Western Corn Belt Plains (WCP) - 12, and Northern Glaciated Plains (NGP)- 10. Data from the reference lakes can be used as a "yardstick" to compare other data against. Table 4 provides a range of summer-mean values for each parameter and each ecoregion. These values were taken from the "inter-quartile range" (25th to 75th percentile) of the reference lakes for each region. By using these values, we have excluded the very low values (lower 25 percent) and the very high values (upper 25 percent) and thus, have a range of values that represent the central tendency of the reference lake's water quality. If your lake is near the transition zone of two ecoregions it is often useful to make comparisons to reference lakes from both ecoregions.
10. **Major Drainage Basins** - Minnesota is characterized by nine major drainage basins (Figure 3). The MPCA is using the major river basins as a basis for focusing permitting, monitoring, and other water quality activities. Basin information documents (BID's) and plans will be developed for each basin over the next several years. The ecoregion framework will be used in conjunction with the basin approach to evaluate lake condition.
11. **Use Support (Aquatic recreation)** - Formerly referred to as “swimmable use “ support, this use support classification considers not only swimming, but also wading, aesthetics, and other related uses. The various classes of full, partial and non support are defined in the text of this report.
12. **Further Reading** - The following papers/reports are suggested for further information on the following topics: trophic state index, use of ecoregion framework, and lake water quality assessment in Minnesota. Several of these may be found on the MPCA lake water quality assessment web page at:
<http://www.pca.state.mn.us/water/lakequality.html#reports>

13. Hydrologic Unit Code The 8-character federal code identifying the Cataloguing Unit, the smallest of the different hydrologic units. The coding is hierarchical with a 2-character region, a 4-character subregion, a 6-character accounting unit and an 8-character cataloguing unit.

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