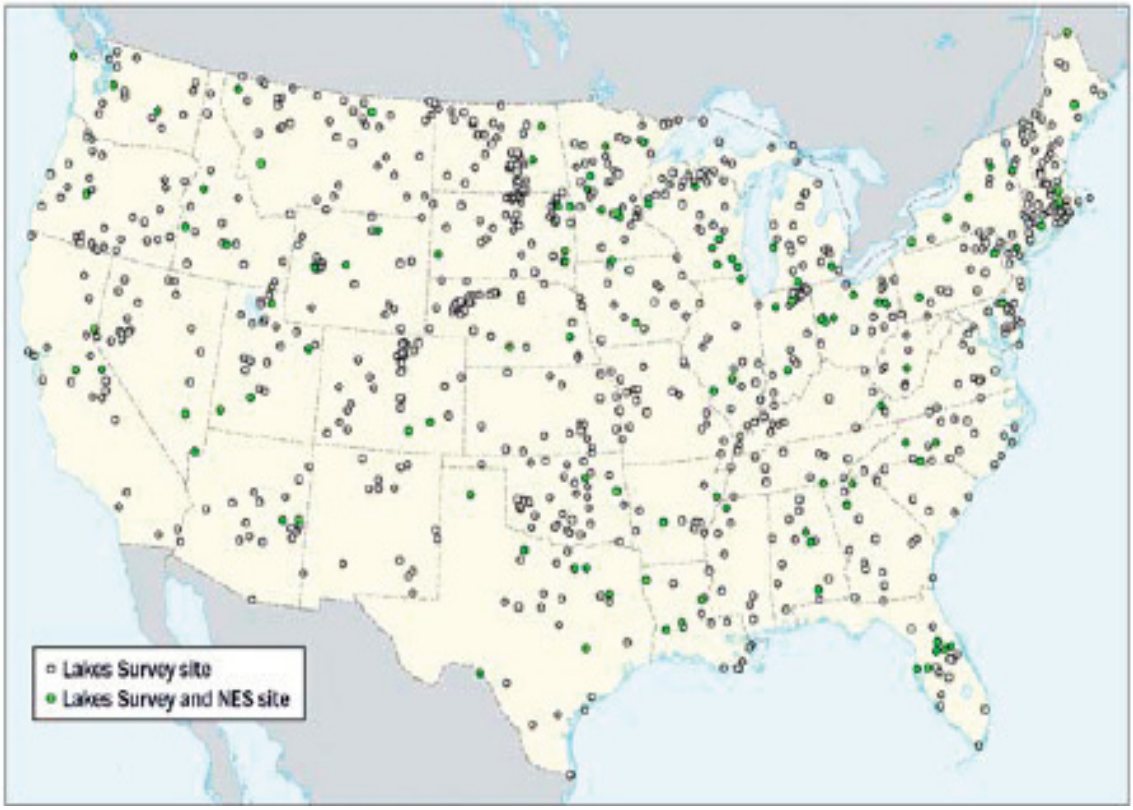

Minnesota National Lakes Assessment Project:

An overview of water chemistry in Minnesota lakes

This report is part of a series based on Minnesota's participation in U.S. EPA's 2007 National Lake Assessment

October 2010

Minnesota Pollution Control Agency

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

Authors and Contributors

Steve Heiskary and Matt Lindon

Environmental Analysis and Outcomes Division

Report review

Michael Duval, Minnesota Department of Natural Resources Division of Fish and Wildlife,

John Kiddon, USEPA, National Health and Environmental Effects Research Laboratory, Atlantic Ecology Division

Bruce Monson, MPCA, Environmental Analysis and Outcomes Division,

Dana Vanderbosch, MPCA Environmental Analysis and Outcomes Division

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Introduction

National Lakes Assessment Project (NLA) Overview

The U.S. Environmental Protection Agency (EPA) has a responsibility to assess the health of the nation's water resources. One of the methods for assessment is a statistically based survey. The Survey of the Nation's Lakes, conducted in 2007, is one of a series of water surveys being conducted by states, tribes, EPA, and other partners. In addition to lakes, partners will also study coastal waters, wadeable streams, rivers, and wetlands in a revolving sequence. The purpose of these surveys is to generate statistically valid and environmentally relevant reports on the condition of the nation's streams, lakes, wetlands, and estuaries at nation-wide and regional scales.

The goal of the Lakes Survey is to address two key questions about the quality of the Nation's lakes, ponds, and reservoirs:

- What percent of the Nation's lakes are in good, fair, and poor condition for key indicators of trophic state, ecological health, and recreation?
- What is the relative importance of key stressors such as nutrients and pathogens?

The sampling design for this survey is a probability-based network that provides statistically valid estimates of the condition of all lakes, with a known degree of confidence. Sample sites are selected at random to represent the condition of all lakes across the nation and each region. A total of 909 lakes in the conterminous U.S. are included in the Lakes Survey. The sample set is comprised of natural and built freshwater lakes, ponds, and reservoirs greater than 10 acres and at least one meter in depth located in the conterminous United States.

The typical sampling effort at each site includes a variety of samples and measurements collected at a mid-lake index site, which is often at the deepest point in the lake. Samples include a two meter integrated sample for water chemistry, chlorophyll-a, microcystin and algal identification; oxygen and temperature profiles; zooplankton tow; and sediment core sample for diatom reconstruction of total phosphorus (based on top and bottom slices from the core) and surface sediment sample for mercury. In addition, 10 random near-shore sites are qualitatively assessed for various littoral and riparian habitat-related measures and a sample for a bacterial indicator was collected. Further details on the survey including methods, parameters measured, and statistical design may be found on the EPA NLA web page at: http://www.epa.gov/owow/lakes/lakessurvey/.

Minnesota's NLA Overview and Report Focus

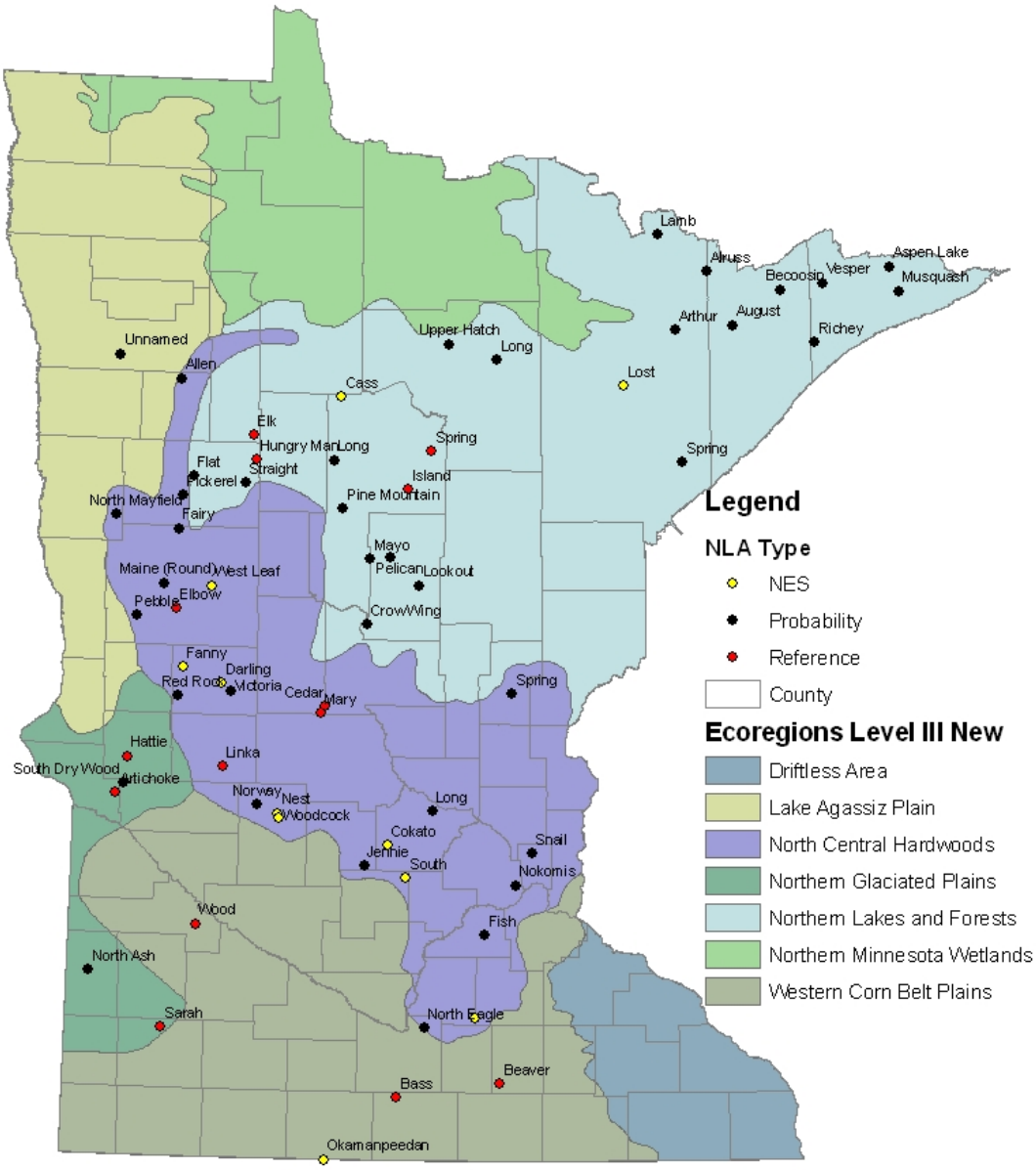
Minnesota's 2007 NLA effort was led by the Minnesota Pollution Control Agency (MPCA) and Minnesota Department of Natural Resources (MDNR). Various other collaborators were engaged in this study as well including the U.S. Forest Service (USFS), Minnesota Department of Agriculture (MDA), and U.S. Geological Survey (USGS). MPCA and MDNR cooperated on initial planning of the survey and conducted a vast majority of the sampling, which took place in July and August for most lakes. USFS staff sampled remote lakes in the Boundary Waters Canoe Area Wilderness (BWCAW).

Minnesota received 41 lakes as a part of the original draw of lakes for the national survey–the most of any of the lower 48 states. Minnesota added nine lakes to the survey to yield the 50 lakes needed for statistically-based statewide estimates of condition (Figure 1). In addition to the 50 lakes, 14 reference lakes were later selected and sampled by USEPA as a part of the overall NLA effort. Data from the reference lakes provide an additional basis for assessing lake condition as a part of NLA.

The purpose of this report is to provide a summary of the water chemistry and related variables for Minnesota's lakes based on the NLA data collected in summer 2007. Because of its statistically-based nature this data set provides a good basis for describing the typical range of constituents and interrelationships in Minnesota's lakes on a statewide basis. Ecoregion-based comparisons and descriptions will be made as well, acknowledging that these data sets, while not statistically valid at the ecoregion level, can provide useful insights into regional patterns. These data will also be

compared, when appropriate, to the previously published typical ranges based on ecoregion reference lake data (Heiskary and Wilson 2008).

Figure 1 Location of Minnesota's NLA lakes as surveyed in 2007. Overlain on EPA ecoregion level III map with lakes coded as follows: NES=National Eutrophication Study (random), Probability (random) and Reference.



MPCA also submitted water quality samples to MDH for analysis on a subset of the NLA lakes. This provides a basis for making inter-laboratory comparisons based on the MDH and EPA data. This will be done to assure that datasets are comparable and that there is no significant bias or differences that need be taken into account when using the NLA data.

The NLA data also provide an opportunity to review status and trends for select National Eutrophication Survey (NES) lakes that were included in the 2007 NLA survey. The NES survey of select lakes across the Nation was conducted by the USEPA in the early 1970s. The NES lakes were often prominent lakes and many received point source discharges of wastewater, either directly or from elsewhere in the watershed. Many of these point sources have been addressed (e.g. diversion or elimination of the discharge, phosphorus limits, etc.) since the NES survey.

Methods

All lakes were sampled once, except Pebble (Lake ID: 56082900) and South (Lake ID: 43001400). The second sampling from these two lakes was excluded for statistical analysis so that all lakes were represented by a single sample event collected in July or August of 2007. The original 50 lakes were sampled by MPCA and MDNR staff with the exception of Cass Lake, which was sampled by the Cass Lake Band. The 14 reference lakes were sampled by USEPA staff.

The NLA also included 200 lakes that had been a part of the National Eutrophication Study (NES). The NES was a targeted survey conducted in the early 1970s that included about 800 wastewater impacted lakes from across the nation. This was an extremely ambitious survey and provided extensive datasets that were used for several purposes. Including a subset of the NES lakes allowed for a statistically-based assessment of trends in this specific population of lakes. Of Minnesota's 50 random lakes – 11 were NES lakes and are included in the statistical summaries and maps. Some additional analysis of the NES lakes will be conducted later in this report.

All laboratory analyses referenced in this report, unless otherwise noted, were conducted by the USEPA laboratory(s) that analyzed all NLA samples for the survey. Details on methods and quality assurance may be found at: http://water.epa.gov/type/lakes/lakessurvey_index.cfm . MPCA data referenced in this report were analyzed by the Minnesota Department of Health (MDH). Relevant details on methods and quality assurance may be found in Heiskary and Wilson (2008). A subset of the NLA lakes had samples analyzed by both the USEPA and MDH laboratories, which allows for a comparison of these two datasets.

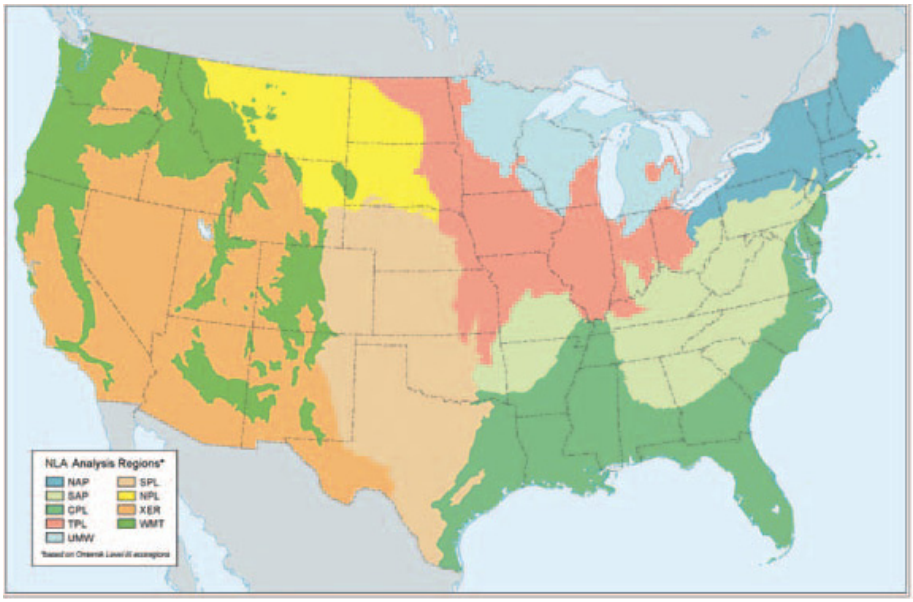
The 2007 NLA data were summarized at the state and ecoregion level. USEPA national NLA assessments and nutrient criteria development focus on aggregated Level 3 ecoregions (USEPA 2010). All three mapping levels (state, ecoregion and aggregated ecoregion) are referred to in the context of this report. Descriptive and inferential statistics were performed with Excel. A mapping and analysis tool (NLA Data Viewer), developed by EPA (Kiddon 2009) was used to assist with the data analysis and presentation. This tool allows for summarization and depiction of NLA data at the national, ecoregion, EPA regional and state levels. It also allows for user-defined regions. The tool allows the user to define the scale at which to analyze and present the data and to define three-four thresholds for analyzing each parameter. Statewide parameter distributions, in particular the 25th and 75th percentiles (Table 2 Table 3 Table 4) were used in selection of "thresholds" for mapping purposes (absent actual water quality standards or other relevant thresholds). For this report the mapping "region" includes Minnesota and its neighboring states: Wisconsin, Iowa, South Dakota and North Dakota (Figure 3). This allows for a much larger data set and provides an improved basis for observing regional patterns in the variables analyzed, since the neighboring states are an extension of Minnesota's ecoregions (Table 3).

Weighted cumulative distribution functions (CDF) are used to describe parameter distributions for Minnesota and the five-state region based on the sampled lakes. For a weighted CDF, each lake is weighted to reflect its surface area and ubiquity in one of nine ecoregions (Kiddon 2010). A weighted CDF provides a balanced estimate of all lakes in a region. The CDF also includes the overall distribution for the "region" and provides an additional basis of comparison for Minnesota's data. A more detailed explanation of weighted vs. un-weighted and CDF construction is provided in Appendix III.

Figure 2 EPA ecoregion maps: a) Aggregated nutrient ecoregions as used in NLA (U.S. EPA 2009) and b) Aggregated level 3 ecoregions as used for nutrient criteria development.

(http://water.epa.gov/scitech/swguidance/waterquality/sandards/criteria/aqlife/pollutants/nutrient/ecomap.cfm).

a)



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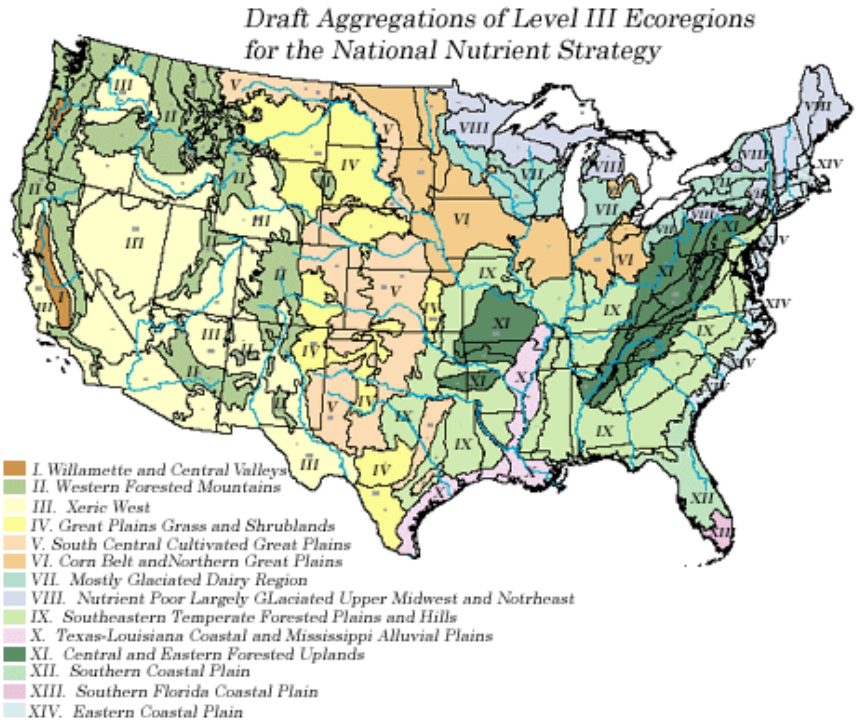
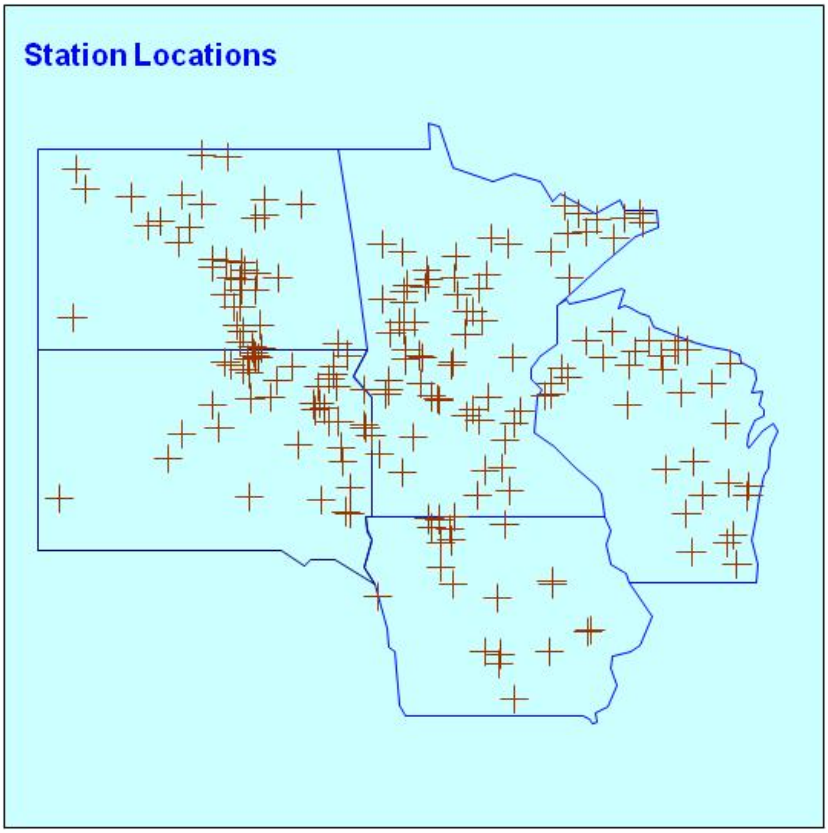


Figure 3 Minnesota and adjacent states 2007 NLA lakes. Data from these lakes represent "region" described herein.



Results and Discussion

Data and Literature Overview

Patterns in lake water chemistry in Minnesota have been described in previous efforts and a couple of relevant studies are noted here. Moyle (1945) described chemical factors influencing the distribution of aquatic plants in Minnesota. As a part of that he makes several observations on regional patterns and describes concentrations that have relevance to aquatic plant growth. In a follow-up article Moyle (1946) addressed some indices of lake productivity with an emphasis on fish production. Again several useful observations were made. Gorham et al. (1983) provided a rather pertinent analysis of the chemical composition of lakes in a four-state region that included Wisconsin, Minnesota, North Dakota and South Dakota. This detailed work describes distinct regional patterns that were largely felt to be a function of underlying geology and transitions in climate (rainfall, runoff and evaporation) across the region. Eilers et al. (1988) provided a description of the water chemistry of northeastern Minnesota, north central Wisconsin, and the upper peninsula of Michigan as a part of the statistically-based Eastern Lake Survey, which was conducted to assess acid rain impacts and sensitivity.

More recently regional patterns have been described using the ecoregion framework (Heiskary and Wilson 1989 and 2008). These characterizations provide a basis for evaluating water chemistry and lake trophic status in a regional context. These data summaries have been based on statewide retrievals of data from STORET (Table 1) and summaries based on ecoregion reference lakes (Table 2). These summaries are used in conjunction with the NLA data to provide perspective on water chemistry, trophic status and regional patterns for Minnesota's lakes. Results from all the

aforementioned studies will be weaved into the discussion of the NLA data as it applies to Minnesota, its ecoregions and the surrounding states.

Percentile distributions, based on un-weighted data, were developed for the various chemical and physical parameters measured in the 2007 NLA survey. These have been done on both a statewide basis as well as an ecoregion basis. While the ecoregion databases are not sufficiently large to provide statistically valid estimates for the specific region they do, nonetheless, provide an indication of the range of concentrations encountered in the survey and provide an indication of what might be considered typical for each ecoregion. "Typical" as described previously (Heiskary and Wilson 2008) refers to the interquartile (IQ) range (25th-75th percentiles). The 14 reference lakes were included in the NLA summaries to keep the number of observations sufficiently large for each ecoregion and from a practical standpoint they may serve to "balance" some of the 11 NES lakes (many of which are or were point source impacted) that were included in the NLA survey. The statistical summaries have been grouped to include similar parameters to allow for review and comparison of the data.

Percentile distributions include both the random and the reference 2007 NLA lakes. Inclusion of the reference lakes allowed for a larger number of observations at the ecoregion level and hopefully an improved estimate of the typical chemical composition as reflected by the interquartile range. For discussion purposes parameters were sorted into three "groups" and data summarized as follows:

a) lake morphometry, transparency, color and organic carbon (Table 3);
b) nutrients and chlorophyll-a (Table 4); and
c) cations and anions (Table 5)

Table 1. Statewide database summary by ecoregion. Percentile values and number of lakes assessed for lake surface area, maximum depth and summer-mean total phosphorus by ecoregion (Heiskary and Wilson 2008).

		Percentile					
Ecoregion	**Parameter**	**10**	**25**	**50**	**75**	**90**	**N**
NLF	Area (ha)	9	20	52	139	334	1,809
NLF	Depth-max. (m)	3.0	5.8	10.0	16.4	24.3	1,519
NLF	TP (µg/L)	9	13	21	30	45	863
CHF	Area (ha)	9	23	66	160	394	976
CHF	Depth-max. (m)	2.4	4.9	8.5	14.0	20.7	829
CHF	TP (µg/L)	18	28	51	112	229	691
WCP	Area (ha)	24	57	129	278	710	110
WCP	Depth-max. (m)	1.8	2.1	3.0	4.9	7.6	87
WCP	TP (µg/L)	62	99	159	234	404	89
NGP	Area (ha)	43	60	146	263	836	38
NGP	Depth-max. (m)	1.5	2.4	3.0	4.6	5.5	28
NGP	TP (µg/L)	54	104	148	194	396	30

Table 2 Ecoregion reference lake database summary. Typical (interquartile) range of summer-mean water quality, morphometric or watershed characteristic based on the reference lakes for each ecoregion (Heiskary and Wilson 2008).

	Ecoregion			
Parameter	**NLF**	**CHF**	**WCP**	**NGP**
# of lakes	32	43	16	13
Area (ha)	61 – 208	74 – 297	75 - 168	198 - 258
Depth-mean (m)	2.5 – 10.5	4.8 – 7.9	1.9 – 3.4	1.5 – 1.8
Depth-max. (m)	9.1 – 24.1	13.0 – 22.0	3.0 – 8.2	2.0 – 3.0
Watershed land use				
% forested	54 - 81%	6 – 25%	0 – 15%	0 – 1%
% wetland	14 – 31%	14 – 30%	3 – 26%	8 – 26%
% cultivated	0 - 1%	22 – 50%	42 – 75%	60 – 82%
% pasture	0 – 6%	11 – 25%	0 – 7%	5 – 15%
Total P (µg/L)	14 - 27	23 - 50	65 - 150	122 - 160
Chl-a mean (µg/L)	4 - 10	5 - 22	30 - 80	36 - 61
Chl-a max. (µg/L)	10 - 15	7 - 37	60 - 140	66 - 88
Secchi disk (m)	2.4 - 4.6	1.5 - 3.2	0.5 - 1.0	0.4 – 0.8
T.Kjeldahl N(mg/L)	0.4 – 0.75	< 0.60 - 1.2	1.3 - 2.7	1.8 - 2.3
NO2+NO3-N (mg/L)	<0.01	<0.01	0.01 - 0.02	0.01 - 0.1
TN:TP ratio	25:1 - 35:1	25:1 - 35:1	17:1 - 27:1	13:1 - 17:1
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
T Suspended. Sed. (mg/L)	< 1 – 2	2 - 6	7 - 18	10 - 30
Sus. Inorganic Sed. (mg/L)	< 1 – 2	1 - 2	3 - 9	5 - 15
Turbidity (NTU)	1- 2	1 - 2	3 - 8	6 - 17
Cond. (umhos/cm)	50 – 250	300 - 400	300 - 650	640 - 900

Table 3. Lake morphometry, pH, transparency, water coloration and organic carbon summary. Based on 50 random and 14 reference lakes from Minnesota NLA survey (un-weighted).

	%ile	*Lake Area*	*Mean Depth*	*Index Site Depth*	*pH - Field*	*pH - Lab*	*Secchi*	*Turb.*	*Color*	*TOC*	*DOC*
		(HA)	m	m			m	NTU	PCU	mg/L	mg/L
State	min	4	0.3	1.0	6.4	6.7	0.1	1	0	3.6	3.2
n=64	5th	8	0.4	1.1	7.2	7.3	0.3	1	4	5.0	4.9
	10th	19	0.5	1.6	7.3	7.4	0.4	1	4	5.6	5.4
	25th	**40**	**1.1**	**3.2**	**8.0**	**8.3**	**0.9**	**1**	**7**	**7.3**	**6.6**
	50th	**78**	**2.0**	**5.9**	**8.5**	**8.5**	**1.7**	**3**	**12**	**9.2**	**8.6**
	75th	**228**	**4.5**	**13.4**	**8.8**	**8.7**	**2.5**	**7**	**21**	**14.2**	**12.9**
	90th	590	6.0	17.9	9.2	8.8	3.9	21	34	18.1	16.8
	95th	872	8.7	26.1	9.4	9.0	4.0	65	40	20.2	18.0
	max	6,605	11.4	34.1	9.6	9.8	6.4	193	93	36.2	27.3
NLF	25th	34	1.8	5.5	7.3	7.5	1.6	1	7	5.9	5.7
n=27	50th	75	2.2	6.7	8.2	8.3	2.4	2	14	8.5	8.3
	75th	145	4.5	13.4	8.5	8.5	3.8	3	27	10.7	10.3
NCHF	25th	51	1.0	3.0	8.3	8.4	0.9	2	6	7.2	6.6
n=26	50th	70	2.8	8.5	8.6	8.6	1.7	4	12	9.1	8.5
	75th	207	4.7	14.0	9.2	8.8	2.3	8.6	18	13.7	12.3
WCP/NGP	25th	90	0.7	2.0	8.5	8.5	0.3	13	9	10.2	8.6
n=11	50th	190	0.8	2.5	8.5	8.6	0.3	20	15	15.1	13.3
	75th	388	1.5	4.4	8.7	8.7	0.6	38	19	17.6	16.8

Table 4. Minnesota NLA summaries for nutrients and chlorophyll-a.

Based on 50 random and 14 reference lakes from Minnesota NLA survey (un-weighted).

	%ile	*TP*	*TN*	*NO2+NO3*	*NO3-N*	*NH4-N*	*Chl-a*
		µg/L	µg/L	mg/L	mg/L	mg/L	µg/L
State	min	4	230	<0.005	<0.005	0.006	1.1
n=64	5th	5	288	<0.005	<0.005	0.008	1.8
	10th	7	417	<0.005	<0.005	0.011	2.6
	25th	12	537	<0.005	<0.005	0.015	4.3
	50th	20	807	<0.005	<0.005	0.024	7.6
	75th	68	1341	0.002	<0.005	0.045	23.0
	90th	225	2435	0.012	0.086	0.182	50.1
	95th	400	4026	0.110	0.182	0.276	132.2
	max	1,184	15,625	0.430	0.574	0.918	936.0
NLF	25th	9	445	<0.005	<0.005	0.011	2.9
n=27	50th	12	529	<0.005	<0.005	0.015	5.1
	75th	20	694	<0.005	<0.005	0.020	9.2
NCHF	25th	15	631	<0.005	<0.005	0.021	5.4
n=26	50th	22	1039	<0.005	<0.005	0.029	7.4
	75th	69	1357	<0.005	<0.005	0.100	20.6
WCP/NGP	25th	104	1338	<0.005	<0.005	0.032	20.3
n=11	50th	193	2,341	0.009	0.011	0.047	42.3
	75th	316	3,400	0.024	0.081	0.216	87.1

Table 5 Cations, anions and related constituents. Concentrations expressed in mg/L.

Based on 50 random and 14 reference lakes from Minnesota NLA survey (un-weighted).

%ile	*Spc. Cond*	*Ca*	*Mg*	*Na*	*K*	*Si*	*SO4*	*Cl*
State	uS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
min	25	2.3	0.8	0.5	0.3	0.3	0.0	0.1
5th	37	3.1	1.7	1.0	0.3	0.8	0.3	0.2
10th	54	5.1	2.1	1.2	0.5	1.1	1.2	0.3
25th	**177**	**19.1**	**6.7**	**2.2**	**0.9**	**3.1**	**2.2**	**1.5**
50th	**321**	**26.0**	**18.7**	**4.4**	**2.3**	**8.2**	**6.2**	**6.7**
75th	**405**	**33.7**	**26.9**	**9.0**	**4.8**	**13.5**	**14.1**	**18.4**
90th	757	50.3	59.6	20.5	10.0	31.2	114.5	35.2
95th	1030	73.5	73.2	42.1	14.1	34.5	238.6	65.6
max	1523	120.6	92.1	233.3	20.1	52.1	417.4	338.3
NLF								
25th	55	5.2	2.2	1.2	0.6	1.4	1.4	0.3
50th	151	19.9	5.0	2.3	0.8	6.5	2.7	1.2
75th	247	26.0	12.6	3.4	1.3	9.1	3.5	2.5
CHF								
25th	332	22.7	21.3	4.2	2.8	4.0	6.2	6.8
50th	391	27.6	24.8	5.6	3.8	10.2	9.6	14.9
75th	418	33.4	28.6	12.4	5.2	13.8	14.7	26.0
WCP/NGP								
25th	381	30.4	24.9	8.5	4.5	10.6	15.8	16.8
50th	762	57.0	66.0	11.8	8.1	22.0	189.1	18.2
75th	1,005	79.1	73.8	14.3	13.9	35.9	268.1	22.1

Table 6 Cations and anions expressed in µeq/L. Cation and anion balance based on major cations: Ca, Mg, Na & K and anions: ANC, SO_4, & Cl. Balance expressed as the sum of cations-anions and percent calculated based on balance as a function of cations.

%ile	*Ca*	*Mg*	*Na*	*K*	*ANC*	*Cl*	*SO4*	*Cation*	*Anion*	*Bal.*	*Bal/C*
State	ueq/L	ueq/L	ueq/L	ueq/L	ueq/L	ueq/L	ueq/L	ueq/L	ueq/L	C-A	%
min	116	65	22	7	87	3	0	230	215	-693	93
5th	152	136	44	8	240	6	6	366	313	-310	94
10th	256	172	51	14	352	9	26	540	463	-259	95
25th	952	549	96	23	1799	42	47	2031	2015	-134	97
50th	1296	1542	190	59	2900	190	130	3455	3543	-37	99
75th	1679	2216	393	122	3495	520	294	4185	4301	28	101
90th	2511	4903	890	255	4035	993	2383	8420	8766	66	108
95th	3667	6020	1830	359	4865	1851	4968	11493	11462	91	115
max	6018	7579	10148	513	6534	9541	8690	13557	14250	110	123
NLF											
25th	262	183	53	15	354	10	28	546	478	-56	98
50th	993	410	98	19	1474	33	57	1549	1551	17	101
75th	1296	1039	149	34	2540	71	73	2659	2637	45	108
CHF											
25th	1134	1750	181	71	3002	192	128	3793	3813	-149	96
50th	1379	2040	242	98	3414	421	200	4060	4185	-81	98
75th	1668	2350	540	132	3729	735	307	4472	4716	-6.7	100
WCP/NGP											
25th	1518	2046	371	115	3060	473	329	3855	4020	-287	96
50th	2844	5429	514	207	3718	514	3938	8609	8956	-116	97
75th	3948	6070	622	355	4508	624	5582	11334	11272	-12	100

Table 7 Cations and anions expressed as a percent of total cations and anions.

Based on statewide sample.

	Ca	*Mg*	*Na*	*K*	*ANC*	*SO4*	*Cl*
mean	43%	44%	11%	3%	78%	12%	10%
min	7%	11%	2%	1%	28%	0%	1%
max	65%	74%	75%	20%	99%	65%	67%

Comparison of USEPA and MDH Data

A subset of the NLA lakes had samples analyzed for select parameters by both the USEPA and MDH laboratories. This allowed for a comparison among laboratories and provides a basis to determine if there are any significant differences that need be accounted for in the data analysis. Comparisons will be made for the following parameters based on data from about 22 lakes: field and lab pH, TP, TKN vs. TN, chlorophyll-a, chloride, and alkalinity and ANC. Paired data for these parameters and summary of MDH methods is included in Appendix I. A summary of those results are presented in Table 8

Table 8 Comparison of USEPA and MDH NLA data for select lakes and parameters. Absolute difference and percent difference is relative to the USEPA data. Based on comparisons for ~21 lakes.

Parameter	*TP µg/L*	*TN/TKN µg/L*	*Chl-a µg/L*	*Cl mg/L*	*pH*	*Color PCU*
Mean diff.[1]	7	336	10	1	0.3	7
% diff.	63%	26%	22%	5%	3%	77%
Mean diff.[2]	5		3			
% diff.	19%		15%			

[1.] All data comparisons [2.] "Outliers" removed

In general, there was reasonable agreement among USEPA and MDH TP samples (Figure 4), which is good considering that USEPA TP samples were not acidified upon collection, while MPCA (MDH) samples were. The statistical comparison (Table 8) suggests a large percent difference; however this is driven largely by three "outlier" values for: Pine Mountain [23 µg/L (MDH) & 4 µg/L (EPA)], Nokomis [36 µg/L (MDH) & 13 µg/L (EPA)], and Long (22 µg/L (MDH) & 5 µg/L (EPA)] Lakes (Figure 4 Appendix II). In each instance the USEPA value was found to be much lower than any previously reported minimum TP for these lakes. When these three values are removed the mean difference is fairly respectable (Figure 4). These values (if indeed incorrect) could have some influence on subsequent data presentations (e.g. trophic status relationships) and will be noted where that may be the case.

Total nitrogen (TN) was measured directly by USEPA, rather than calculated as a function of total Kjeldahl nitrogen (TKN) and nitrate-N as is the case in many state lake programs. In most Minnesota lakes nitrate-N is generally at or below detection so TKN is essentially equivalent to TN. Based on Figure 4 there is reasonably good agreement among TN and TKN; however MDH TKN values appear to be biased high relative to USEPA TN values. In general USEPA TN values should provide a decent basis for describing TN and its relationship to other variables.

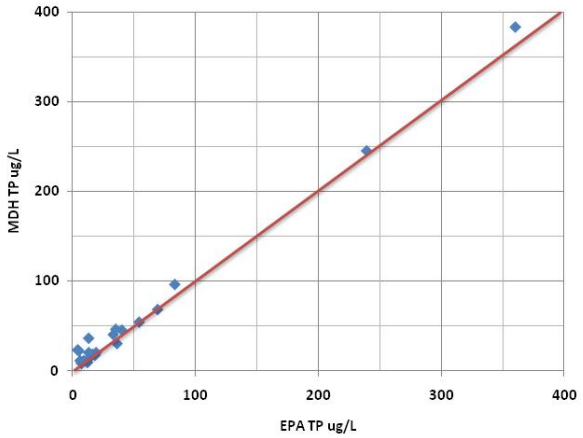
Chlorophyll-a measurements were in reasonable agreement among the two laboratories (Table 8 and Figure 4). Okamanpeedan and Pine Mountain Lakes exhibited very high percent difference among the two laboratories and could be considered "outliers." In the case of Okamanpeedan Chl-a is very high [313 µg/L (MDH) & 185 µg/L (EPA)], which can make precise measurement difficult.

Chloride was in excellent agreement among the two labs (Figure 4 and Table 8) and suggests NLA cation and anion data should be quite comparable with other MDH cation and anion analysis for Minnesota lakes. A comparison of USEPA lab pH and MPCA field pH indicated there was a difference among these two measures; however no distinct bias was evident (Figure 4). The average and percent difference (Table 8) was fairly typical for this type of comparison. Fish Lake with a field pH of 9.2 and lab pH of 7.9 had the largest difference. A comparison of EPA ANC and MDH total alkalinity as $CaCO_3$ indicates 99 % of the variation in ANC can be explained by alkalinity (Figure 4).

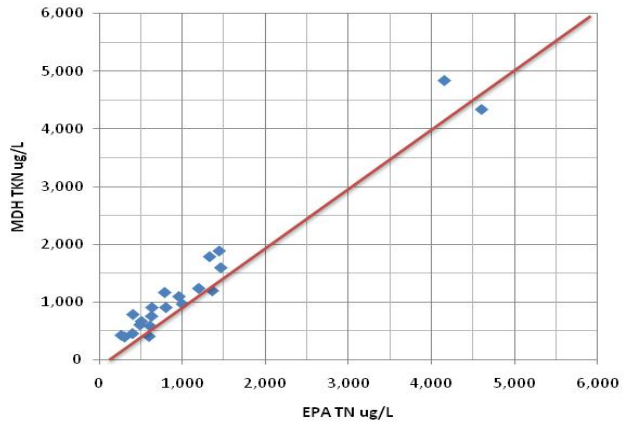
Agreement among color values was relatively poor and is in part an artifact of how color is measured and scales (detection) used in the two laboratories. MDH data are reported in increments of 5 PCU; whereas USEPA used increments of 1 PCU. The range in data analyzed was very small with most measurements ≤20 PCU, which may also contribute to the poor comparison. In general, if the color data are used to indicate a relative "class" of color, e.g. clear, moderate or dark, the laboratory differences should not be an issue.

Figure 4 Comparison of USEPA and MDH measurements for select parameters. 1:1 line included for visual comparison. Charts scaled to allow resolution for majority of data.

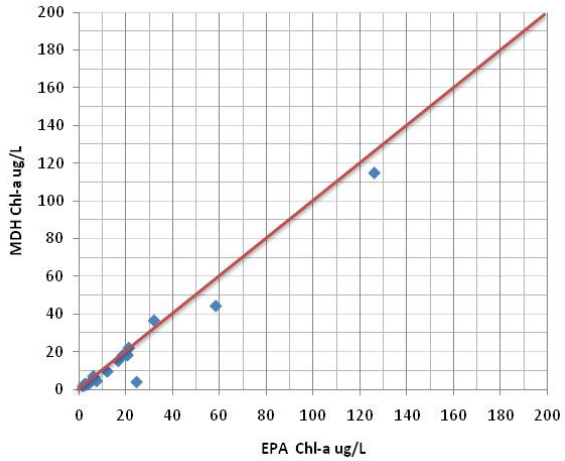
a) Total Phosphorus



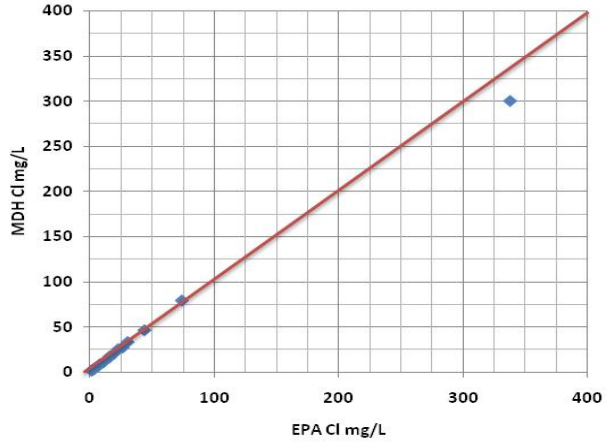
b) TKN



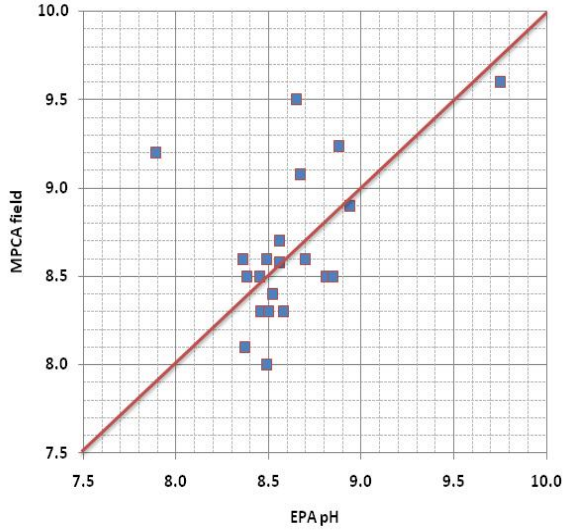
c) Chl-a



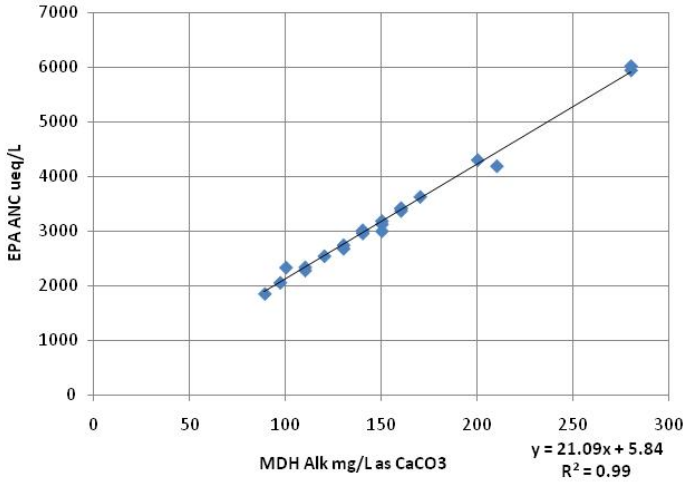
d) Chloride



e) pH



f) Alkalinity & ANC



Morphometric characteristics of NLA as compared to statewide datasets

The NLA stratified random design allowed for lakes in a range of size classes to be selected for the survey. Absent stratification the NLA would have been represented primarily by very small lakes. The percentile distribution of surface area for the 50 random lakes is somewhat similar to the over 2,000 lakes that have been monitored statewide at the lower end (10th-50th %tile; Figure 5), however the NLA lakes are somewhat larger relative to monitored above the 50th percentile. Both datasets are biased toward larger lakes as compared to the overall population of Minnesota lakes. For example, the 75th percentile for the state is on the order of 100 acres (40 ha) as compared to about 325 acres (132 ha) for monitored and 375 acres (152 ha) for NLA. In terms of maximum depth the NLA lakes are slightly shallower as compared to the monitored lakes (Figure 6). The interquartile (IQ) range for the 50 random NLA is ~15-40 feet (4.5-12.1 m) as compared to ~18-52 feet (5.5-15.8 m) for the monitored lakes. However, the ecoregion-based IQ ranges of NLA lake maximum depth (Table 3) is rather similar to the ecoregion-based IQ summary for the monitored lakes (Table 1) and suggests the NLA lakes are fairly representative of the various ecoregions in terms of lake depth.

Figure 5 NLA lake surface area frequency distribution as compared to monitored (2,976) and statewide (11,800) population.

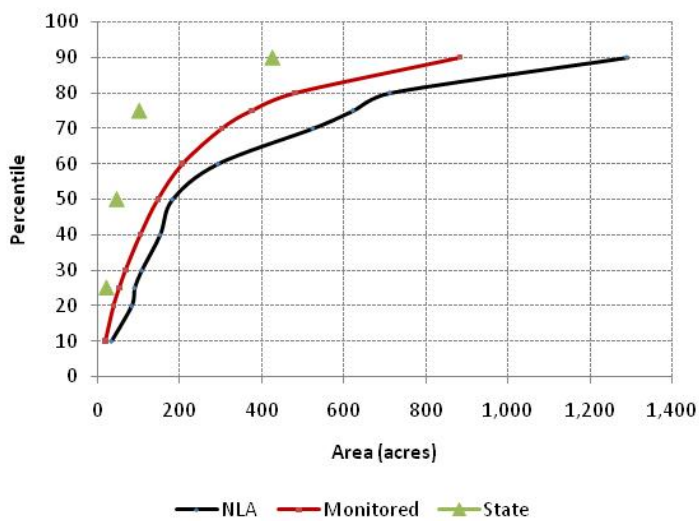
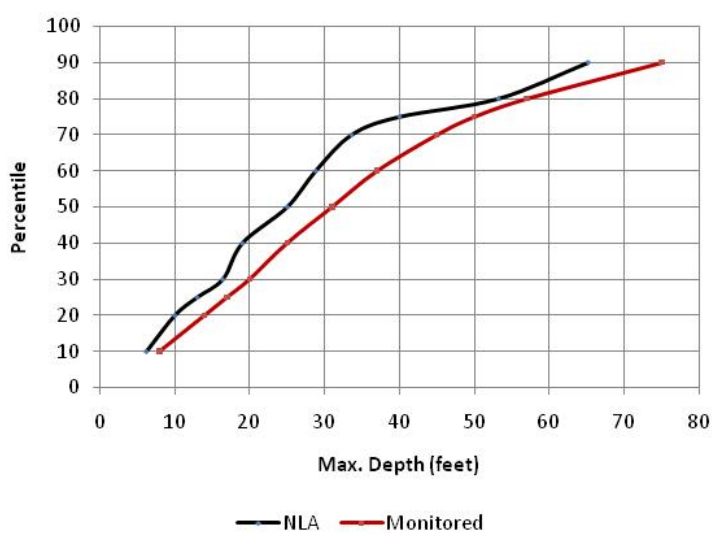


Figure 6 NLA lake maximum depth frequency distribution as compared to monitored (2,309) population



Organic carbon, color and Secchi transparency

Total organic carbon (TOC) consists of a variety of organic (plant and animal) matter in various states of decomposition and includes both dissolved (DOC) and particulate forms (POC). Organic matter may be imported from watershed soils, leaf litter and various other sources or produced within the lake itself from decomposing algae, plants, microbes, and other sources. Organic carbon arising in runoff from wetlands and forested lands is often high in humic substances, which are formed largely as a result of microbial activity on plant material (Wetzel 2001). These humic substances are often dark-colored and lend the "coffee" or "tea" stain to waters. Color, measured in platinum-cobalt units (PCU) provides an indirect estimate of the relative amounts of humic substances in the water. A relative scale we have used in Minnesota is: <20 PCU ~clear, 20-50 PCU ~moderate and >50 PCU ~dark coloration. At very high levels of coloration (above ~100 PCU) the coloration may sufficiently reduce the amount of light available for algal and even macrophyte photosynthesis.

The range and relationship between TOC and DOC for all three ecoregions was quite comparable (Table 3) with the exception of two outliers: South (CHF) and North Eagle Lakes Both lakes had extremely high chlorophyll-a: 936 and 126 µg/L respectively, which contributes to the elevated TOC in both lakes. A typical range for summer TOC in Minnesota lakes is on the order of 7-14 mg/L and the majority is in the DOC form (Figure 7). The NLA data indicate that DOC and TOC are strongly related and that DOC may be reliably estimated based on TOC (92 percent of the variation in DOC can be explained by TOC based on the NLF ecoregion lakes). This concurs with Monson (2007), in a study of stormwater wetlands, where he found that 94% of the measured TOC in the water samples was in the dissolved form. Using log transformed NLA data and all 64 MN lakes the relationship yields a R^2=0.96 and the following equation: Log TOC=1.073 Log DOC-0.037.

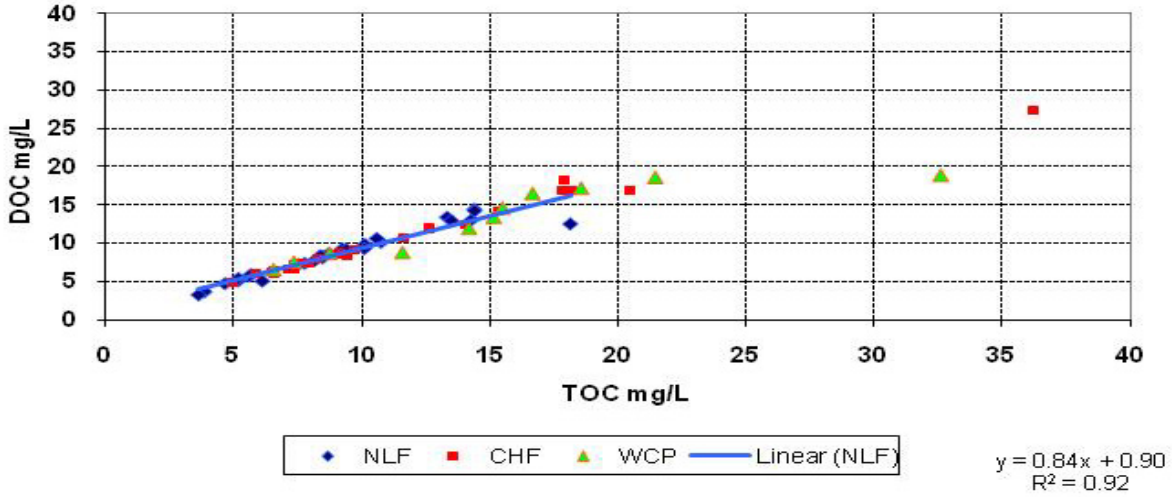
No distinct regional patterns are evident for TOC (Figure 8) or DOC (Figure 9) for Minnesota; however there are some broader regional trends whereby South Dakota and North Dakota are characterized by higher TOC and DOC while Wisconsin and Iowa are characterized by low to mid-range values. Minnesota's CDF is similar to the five-state region over much of the range though the influence of the high TOC/DOC lakes in North and South Dakota are evident in the region-wide CDF. The median DOC for the NLF ecoregion (Table 1) is quite comparable to that found by Eilers et al. (1988) for NE Minnesota lakes.

A majority of the NLA lakes were clear to moderately colored and <10 percent would be considered "highly colored" (Table 3). The weighted CDF estimates that ~60% of Minnesota's lakes have low color while <10% have color >50 PCU (Figure 10). No distinct regional patterns are evident for color in Minnesota or the five state region; though moderate to dark colored lakes are uncommon through central and southern Minnesota, Iowa and southern Wisconsin (Figure 10). The relationship between TOC/DOC and color is marginal with R^2=0.45 and 0.52 respectively, based on the NLF lakes (Figure 7). Log transformation and use of all 64 lakes does not improve the R^2 for DOC and color: 0.47 or TOC and color: 0.44. This suggests color can provide an estimate of TOC or DOC; but there is much variability in the relationships and one should measure these parameters directly if precise concentrations are required. However, given the strong relationship between TOC and DOC, it would be reasonable to monitor TOC and estimate DOC (or vice versa) based on the regression equation (Figure 7) unless a very precise measurement was required.

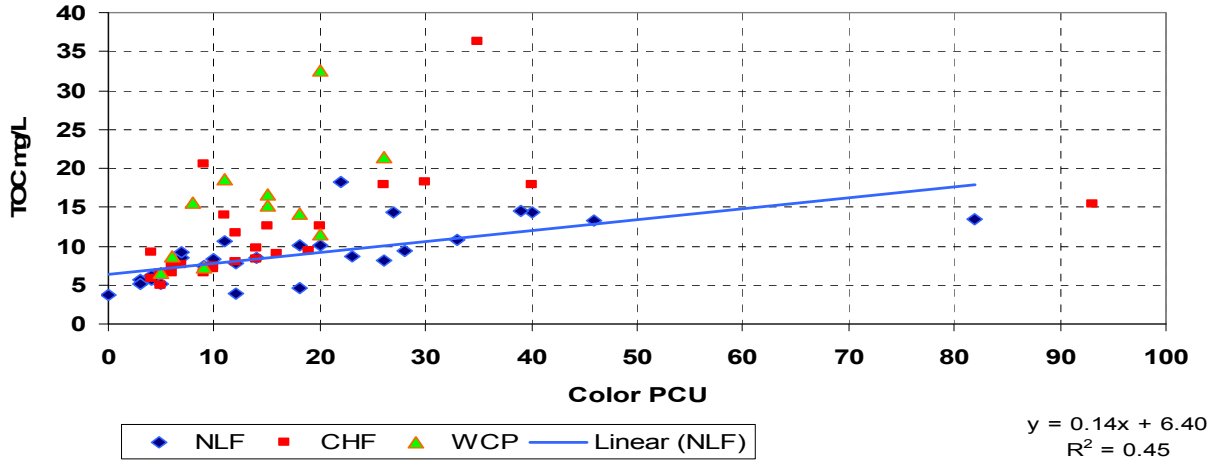
Algal biomass (as measured by chlorophyll-a) is most often the primary determinant of Secchi transparency in Minnesota lakes. However, water color and organic carbon are felt to play a role as well and the NLA data provide an opportunity to examine the influence of organic carbon and color on Secchi transparency. No distinct linear relationship is apparent for color and Secchi; however as color increases above 30 PCU Secchi values fall below 2.0 m (and remain low) (Figure 7). Likewise, there is no distinct linear relationship among TOC/DOC and color; however as DOC or TOC increase the range of observed Secchi measures declines and at DOC or TOC >15 mg/L Secchi is generally <2.0 m (Figure 7). Log transformation and use of all 64 lakes does not appreciably improve the relationships and R^2 remains rather low for TOC and Secchi R^2=0.44 and DOC and Secchi R^2=0.34. Based on these data, organic carbon and color have a minimal influence on transparency at low to moderate levels; however as TOC/DOC increases above 10-15 mg/L and color increases above 30-50 PCU the influence of dissolved and incompletely dissolved organic matter is more pronounced and begins to limit transparency. This, in turn, can affect interrelationships among TP, chlorophyll-a and Secchi, which is addressed in the next section.

Figure 7 Interrelationship of dissolved organic carbon, total organic carbon, color and Secchi. Data expressed by ecoregion. Regression equations based on NLF ecoregion lakes.

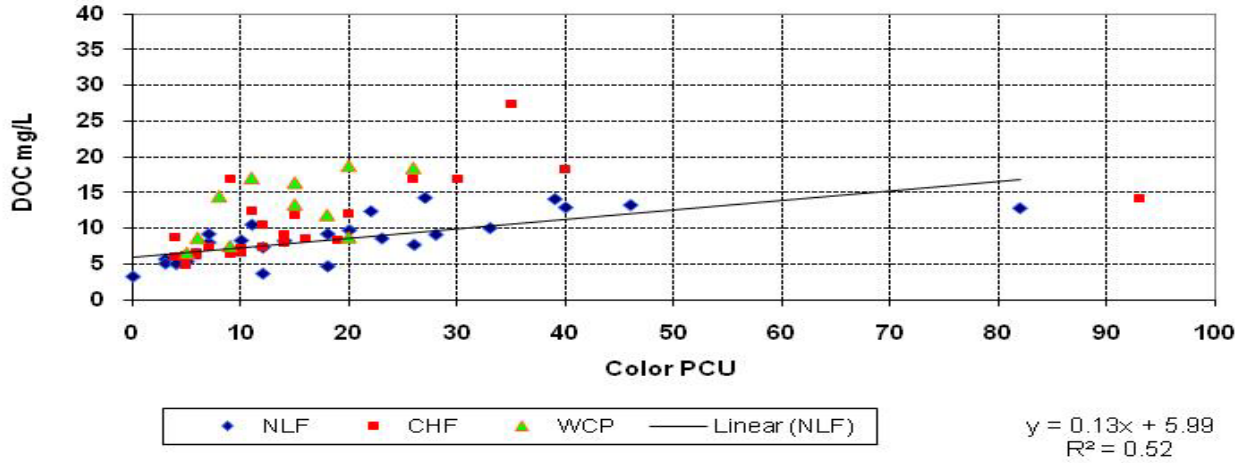
a) DOC as a Function of TOC



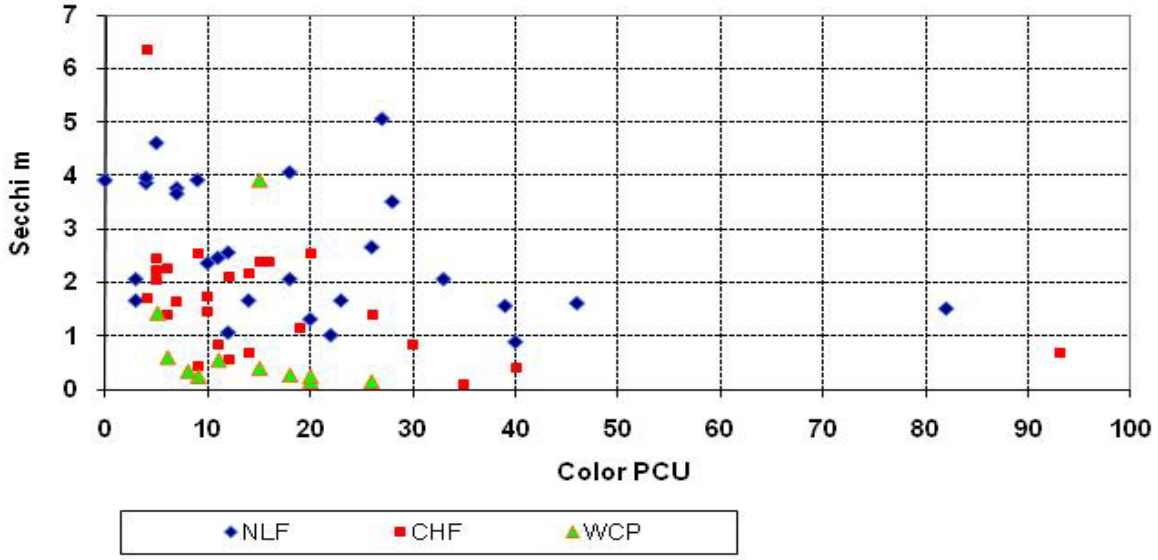
b) TOC as a function of Color



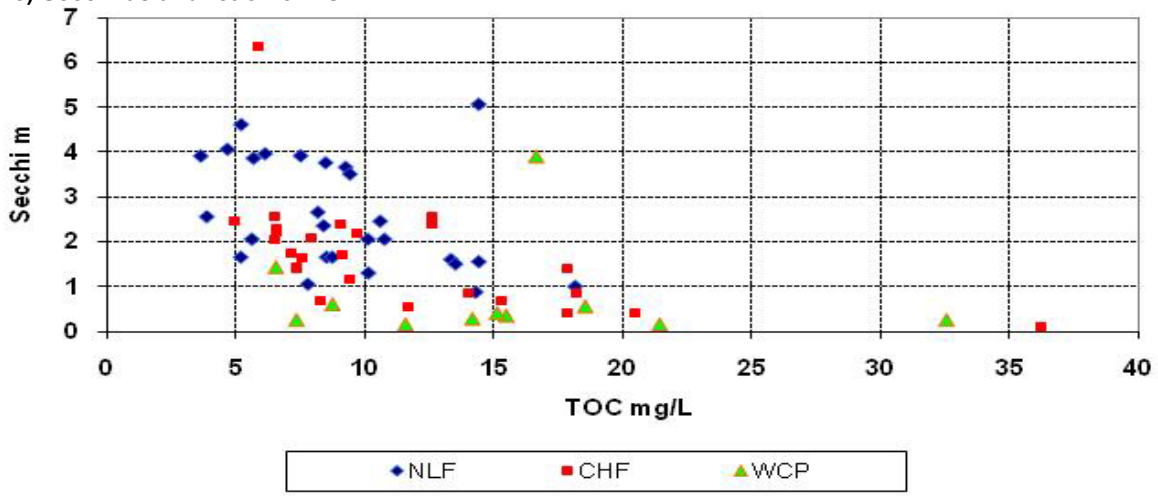
c) DOC as a function of Color



d) Secchi as a function of Color



e) Secchi as a function of TOC



f) Secchi as a function of DOC

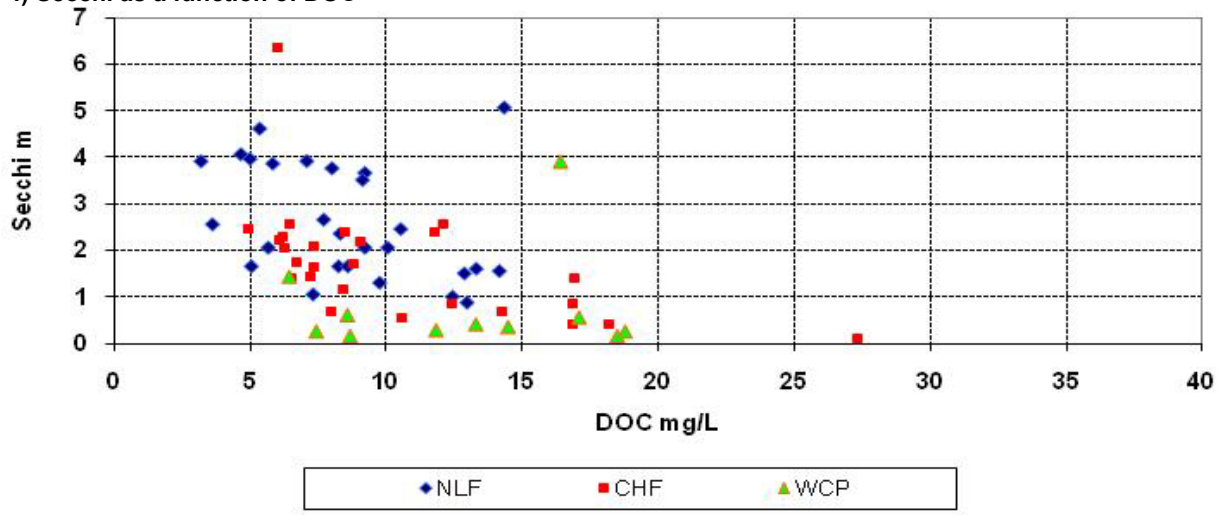
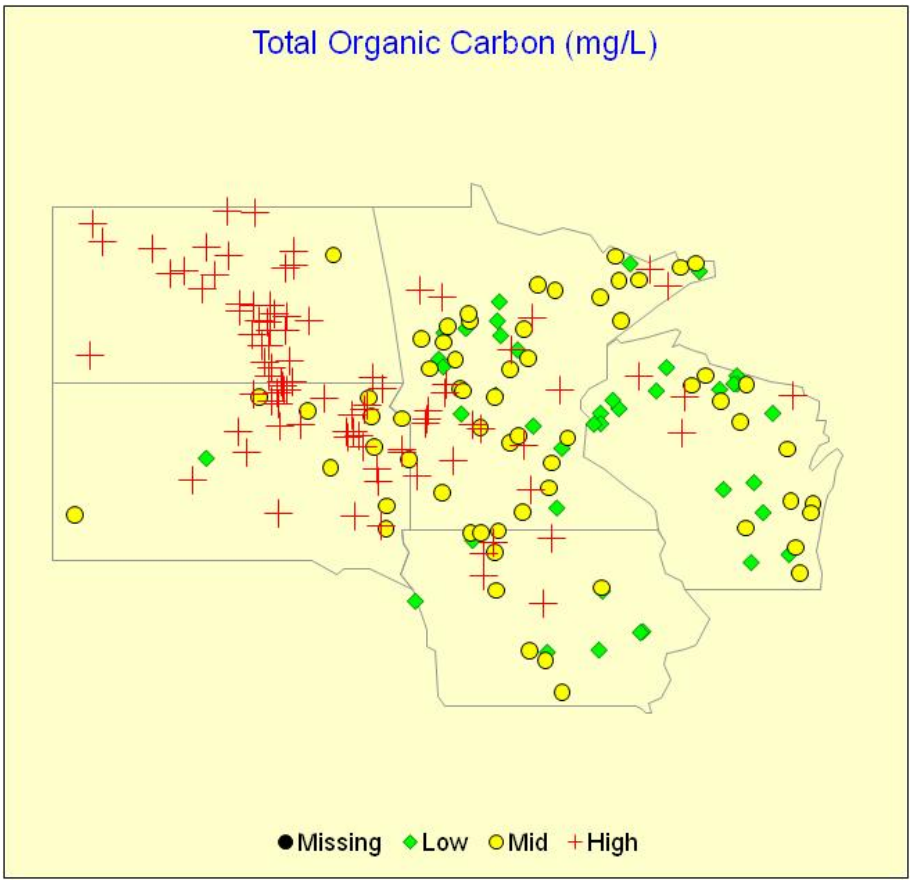


Figure 8 Total Organic Carbon (TOC) map and CDF.

a. TOC map: Low <7 mg/L, Mid. 7-14 mg/L and High >14 mg/L



b. TOC CDF

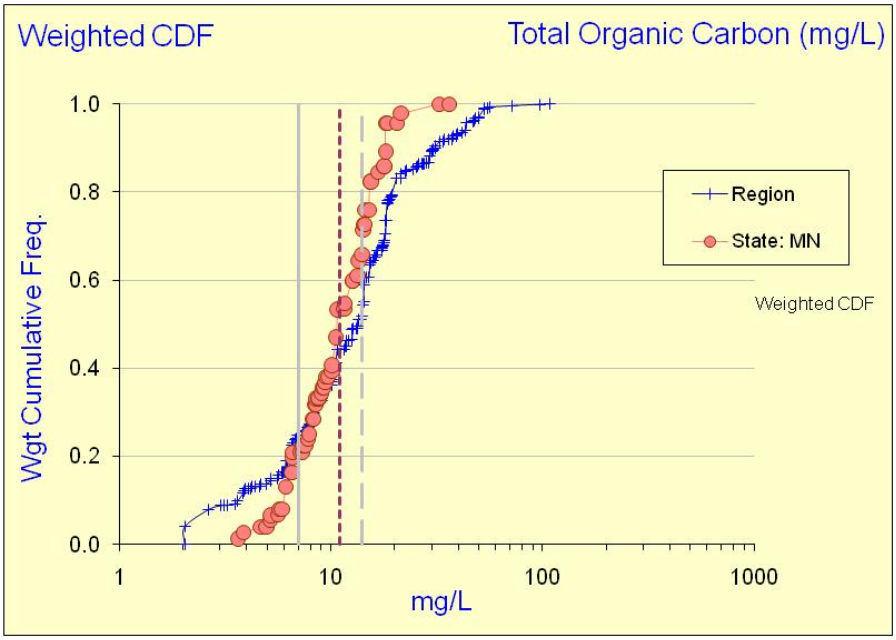
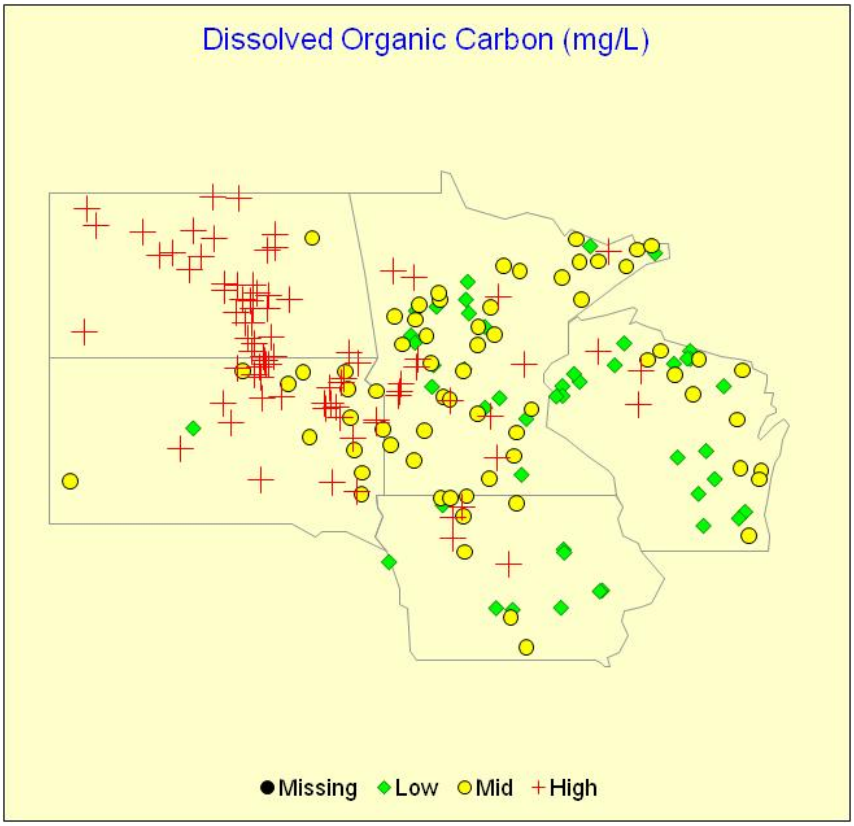


Figure 9 **Dissolved organic carbon (DOC) map and CDF.**

a) DOC map: Low <7.0, Mid 7.0-14.0, High >14.0



b) DOC CDF

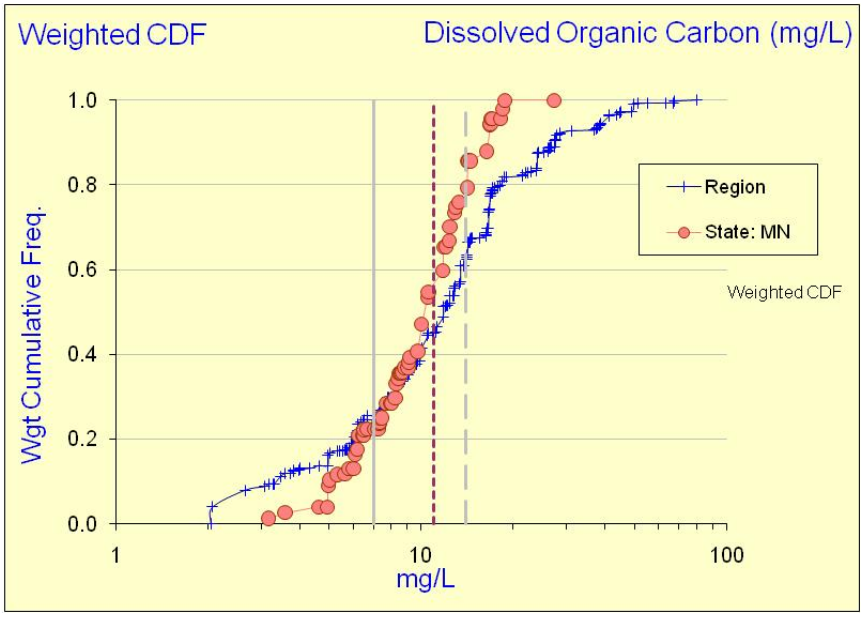
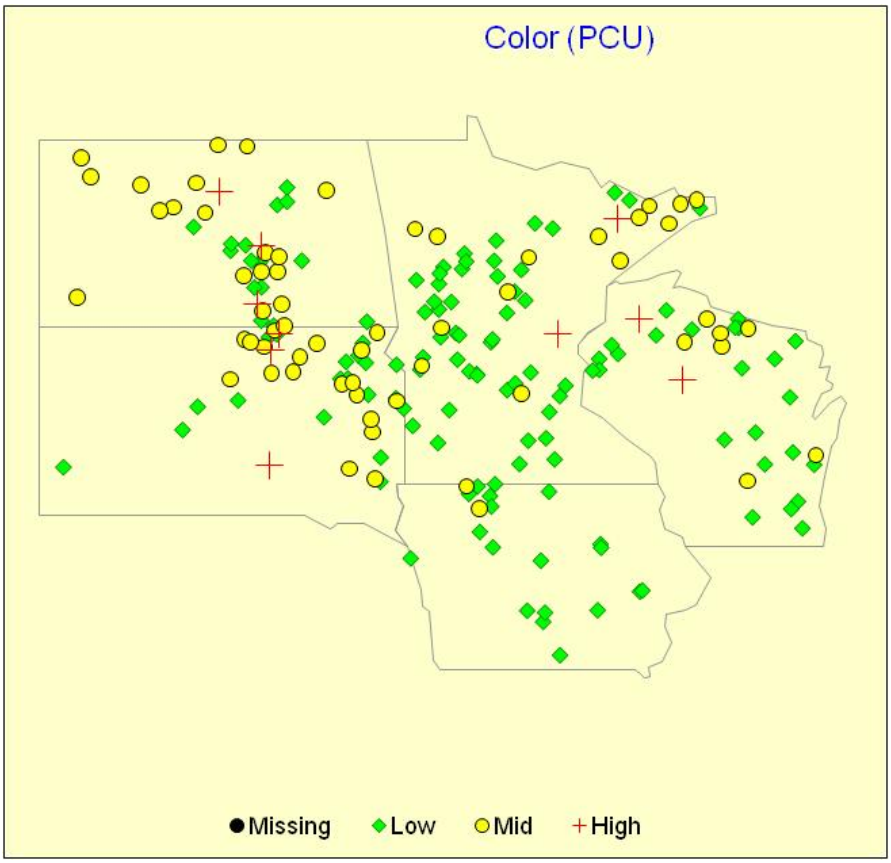
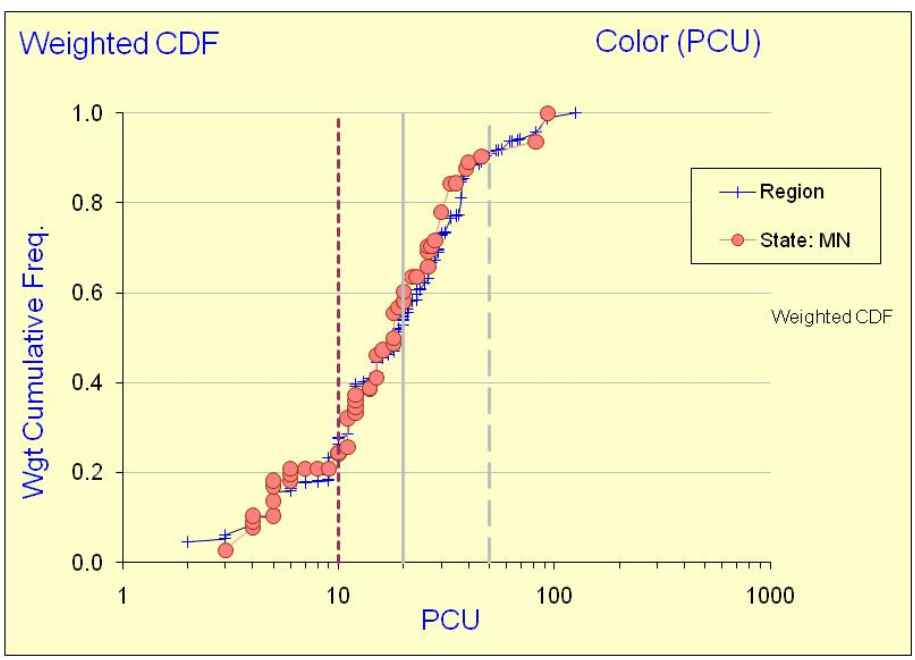


Figure 10 **Color map and CDF**

a) Color map: Low <20 PCU, Mid. 20-50 PCU and High >50 PCU



b. Color CDF



Nutrients and Trophic Status Indicators

Regional patterns in nutrients, chlorophyll and Secchi have long been recognized for Minnesota (e.g. Heiskary and Wilson 1989). The NLA data serve to reinforce these patterns and the interrelationships among these variables. The transition from nutrient-poor to nutrient-rich from NE to SW Minnesota is evident in the NLA data as well. Lakes in NE Minnesota are oligo-mesotrophic, central Minnesota meso-eutrophic and southern Minnesota eutrophic to hypereutrophic (Figure 12). These patterns, which are a reflection of the underlying ecoregions, extend into the adjacent states as well. Minnesota's CDF for TP is similar to the five-state region up to the 50th percentile (Figure 12), which is at 30 µg/L, beyond this point Minnesota's TP concentrations are lower with 75% <40 µg/L and 80% <90 µg/L. Of those >90 µg/L (MN standard for shallow WCP/NGP lakes) the majority are in the WCP and NGP ecoregions. In terms of trophic status 36% would be considered oligotrophic (TP<12 µg/L), 28% mesotrophic (12-30 µg/L), and 17% eutrophic (TP 30-100 µg/L) and 19% hypereutrophic (Figure 12). The maximum observed TP was 1,184 µg/L in South Lake, which is a NES lake that continues to receive wastewater effluent.

Using previously established chlorophyll-a thresholds: <10 µg/L "no bloom," 10-20 "mild bloom" and >20 µg/L "nuisance bloom" (Heiskary and Walker 1988) the NLA data provide an indication as to the extent and magnitude of mid- to late-summer blooms. Lakes in northern Minnesota were characterized by either no blooms or mild blooms, whereas those in southern Minnesota were characterized by nuisance blooms (Figure 13). A mix of conditions was evident across central MN. The CDF for Minnesota was identical to that for the overall five-state region and ~65% had chlorophyll-a <10 µg/L, while ~25% had Chl-a > 30 µg/L – indicative of severe nuisance blooms. The majority of the lakes with severe nuisance blooms were in the NGP and WCP ecoregions and these high Chl-a levels extend through Iowa, South and North Dakota (Figure 13). The maximum MN Chl-a was 936 µg/L in South Lake. This is an extremely high value and likely exceeds the "theoretical maximum" Chl-a, which assumes algal production would eventually be light limited. South Lake's extreme shallowness (mean depth ~0.3 m) may allow for frequent mixing, which may minimize algal "self-shading."

Several forms of nitrogen (N) were measured in the NLA lakes including: total N (TN), ammonia-N, nitrite+nitrate N and nitrate N. Only TN and nitrate N are addressed in this report. TN includes organic N (e.g. algal bound) and inorganic N (ammonia, nitrate and nitrate). Minnesota (and many other states) typically measure total Kjeldahl N, which includes organic-N and ammonia N, and then add nitrate-N to yield TN. A comparison of "calculated" to "measured" TN is made later in this report. A majority of TN is in the organic (algal-bound) form and in general TN increases in a NE to SW pattern (Figure 15). These patterns extend into the adjacent states as well. Based on NLA default thresholds, about 20% of Minnesota's lakes would be considered hypereutrophic based on TN (Figure 15), which is similar to the percentage based on TP (Figure 12). Nitrate-N is dissolved and is readily used by algae and macrophytes. Consistent with our ecoregion-based assessments (Table 2) nitrate-N is typically at or below detection. Based on NLA data over 90% of the Minnesota lakes and overall region lakes were at or below detection (Figure 16).

The relationships among TP, Chl-a and Secchi (Figure 11) are surprisingly good given these are single "point in time" measurements (in contrast to summer means that are typically used to establish relationships). For example the R^2 for TP & Chl-a and Chl-a & Secchi are 0.66 and 0.69 respectively based on the CHF ecoregion lakes (Figure 11). The R^2 for TP & Chl-a can be improved to 0.77 if data for all regions is used with four lakes with TP >400 µg/L and two outlier Chl-a values for Fanny and Red Rock being omitted. These linear R^2 values compare very favorably with log-log relationships based on summer mean data for the ecoregion reference lakes: TP & Chl-a: R^2=0.88 and Secchi & Chl-a: R^2= 0.85 (Heiskary and Wilson 2008).

The value in Figure 11 is not necessarily the correlation among these trophic status measures but rather information on threshold responses among these measurements. Mid to late summer Chl-a tracks rather closely with TP and provides some indication of "bloom risk." When TP <30 µg/L the risk of nuisance blooms (Chl-a > 20 µg/L) is minimal and when TP < 60 µg/L the risk of severe nuisance blooms (Chl-a >30 µg/L) is very low as well (Figure 11). Steady declines in Secchi are evident as Chl-a increases over a range from ~1 to 20 µg/L (Figure 11). As Chl-a increases above 20 µg/L Secchi generally remains below 1.0 m. Likewise, when TP increases above 60 µg/L Secchi remains below 1.0 m (Figure

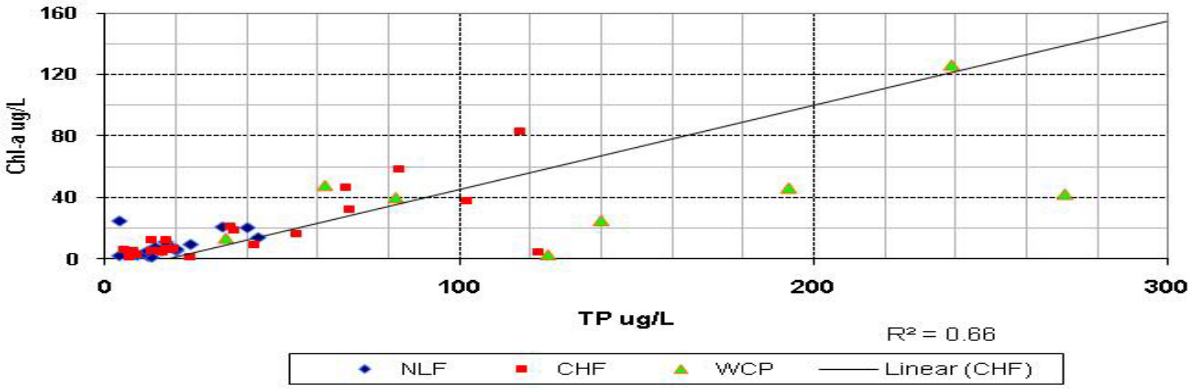
11). Thus to minimize the risk of nuisance blooms and Secchi below 1.0 m, mid-summer TP should remain below 60 µg/L based on these data.

TN: TP ratios have been used as a means for estimating which nutrient may be limiting algal production and provides a relative comparison among TP and TN supply. Ratios <10:1 (concentration-based) have often been used to indicate potential for "N-limitation" while >17:1 has been used as a threshold for "P-limitation." Ratios in between suggest that either P or N could be limiting. Minnesota's lakes are strongly P-limited with ~80% >17:1 and ~5% less than 10:1 (Figure 17). About 35% <29:1 a level suggested by Smith (1983) to be indicative of dominance by blue-greens. Lakes with low-intermediate TN: TP are generally found in the central and southern portion of Minnesota and based on lake assessments in this portion of the state blue-greens are often dominant in mid to late summer.

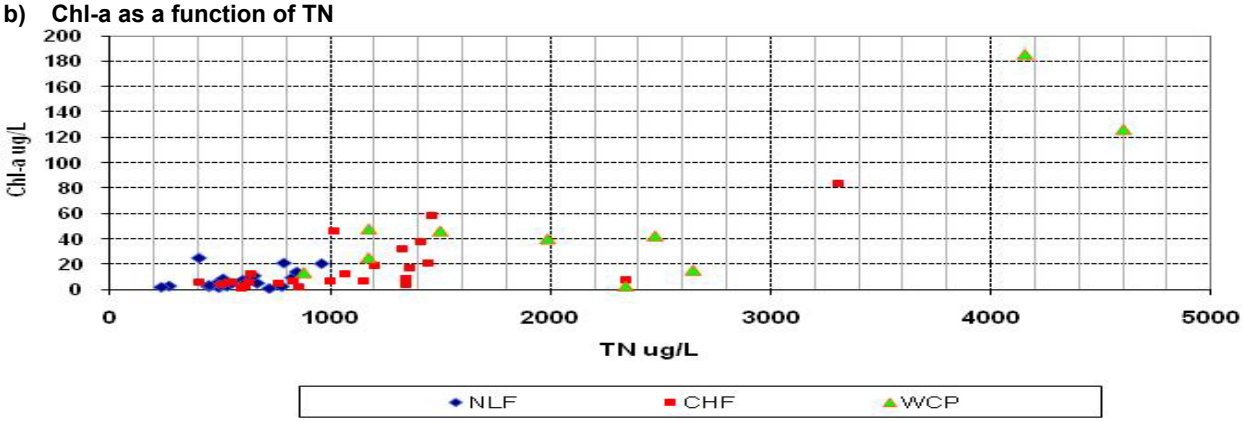
Figure 11 Interrelationships among total phosphorus (TP), total nitrogen (TN), chlorophyll-a (Chl-a) and Secchi.

Graphs scaled to allow resolution for majority of data points (i.e. some extreme values not shown).

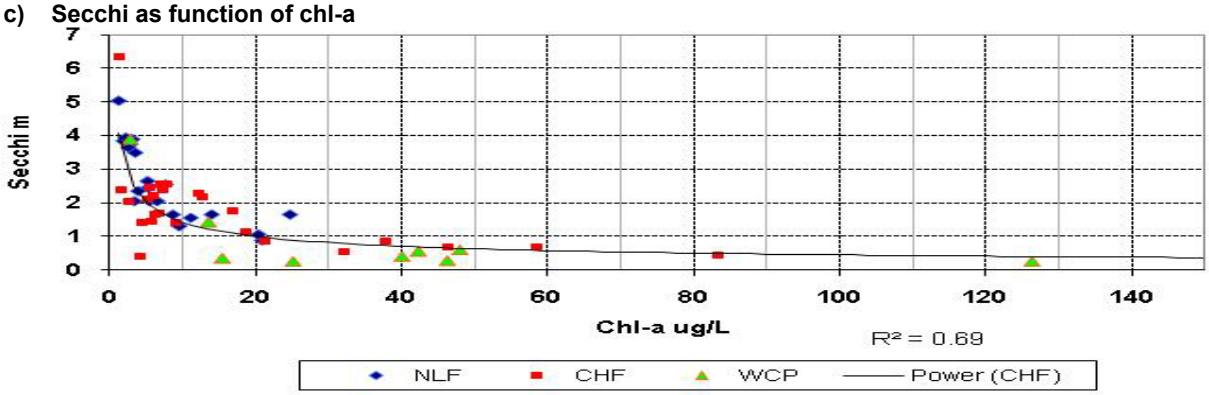
a) Chl-a as a function of TP



b) Chl-a as a function of TN



c) **Secchi as function of chl-a**



d) **Secchi as a function of TP**

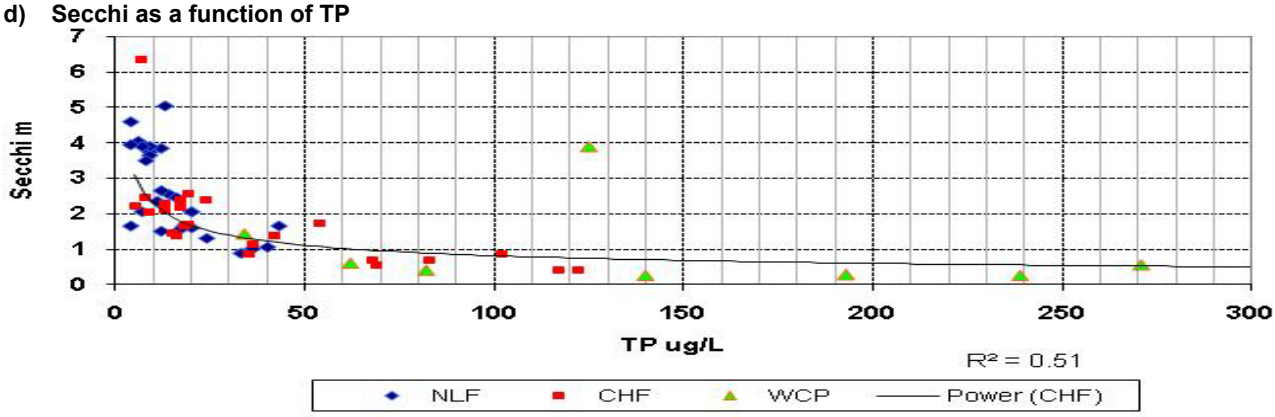
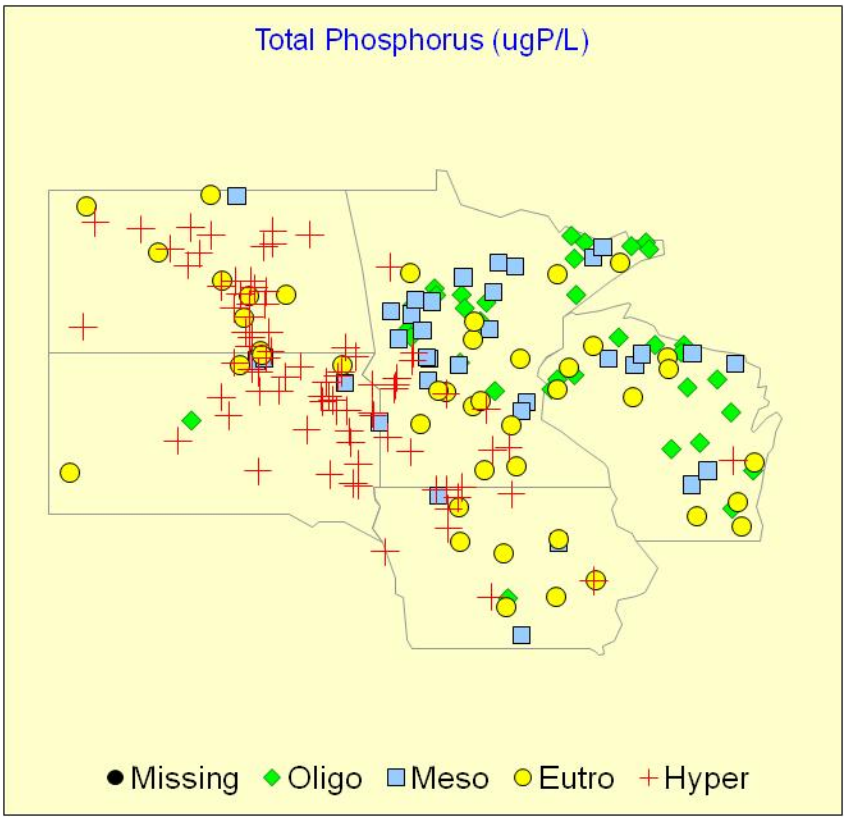


Figure 12 **Total phosphorus map a) trophic status classes and b) CDF**

a) Trophic status map. MN-based thresholds: Oligo <12 µg/L, Meso 12-30 µg/L, Eutro 30-100 µg/L Hyper >100 µg/L



b) TP CDF with TSI thresholds

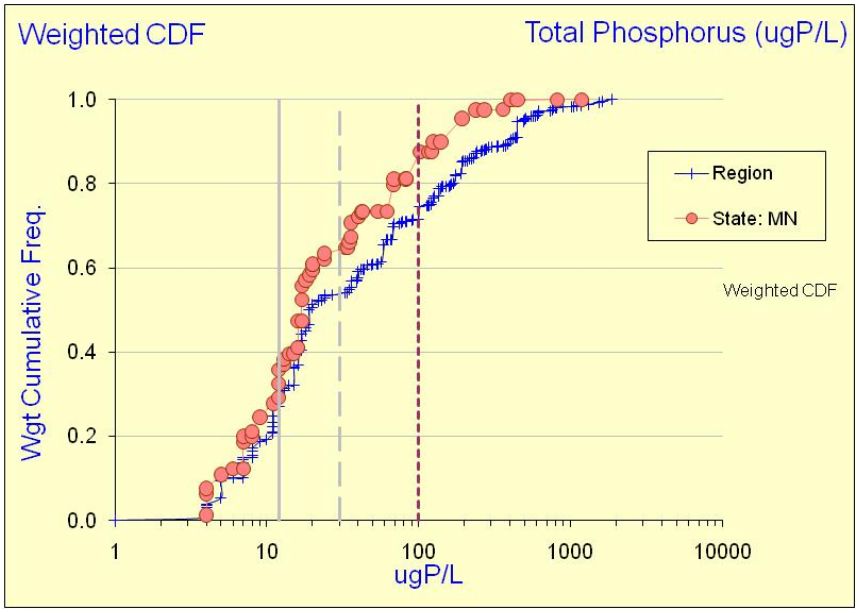
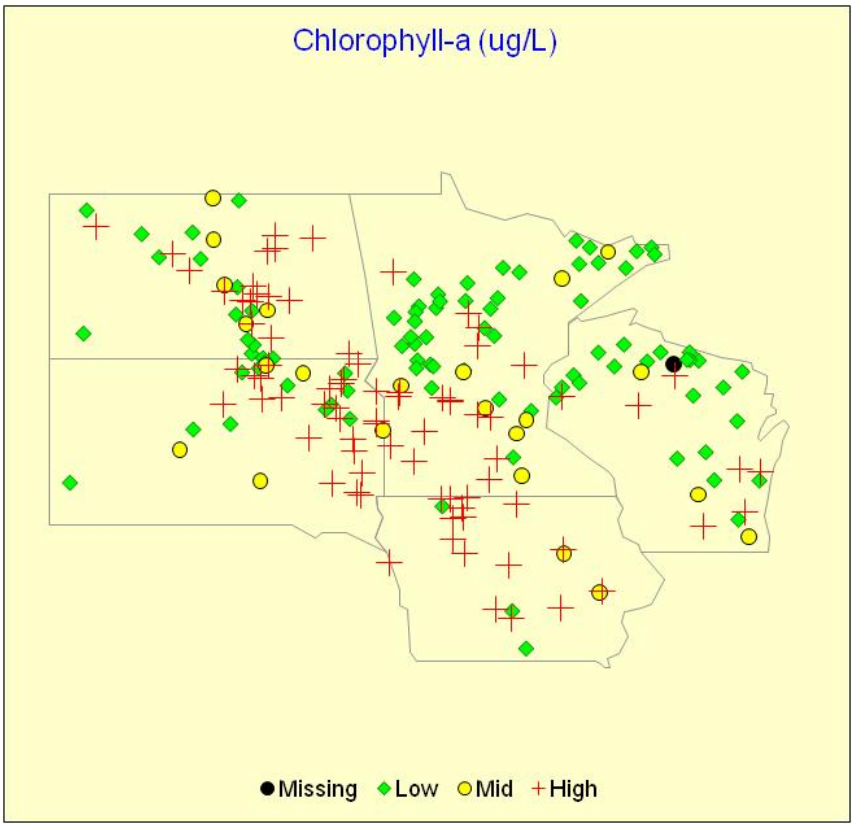
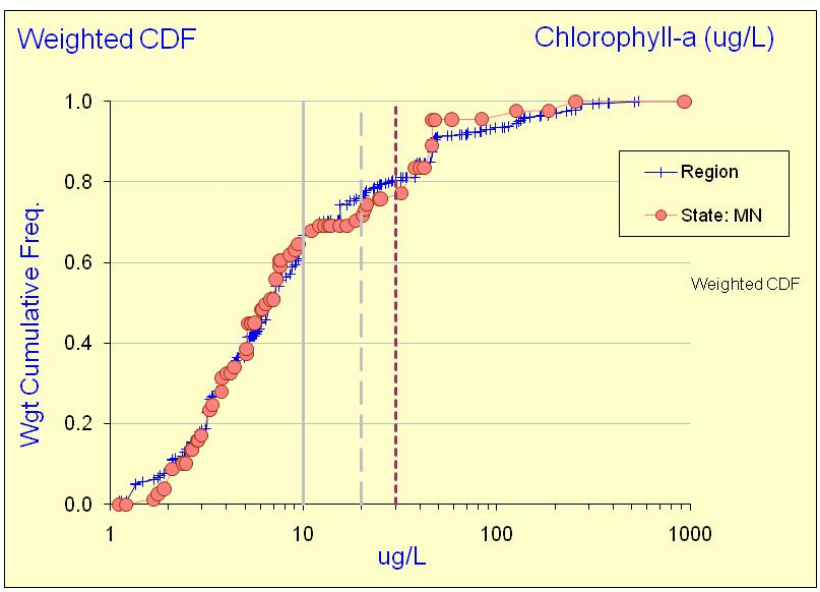


Figure 13 **Chlorophyll-a maps & CDF: a) nuisance bloom map, b) Chl-a CDF c) trophic status map**

a) Chl-a map with nuisance bloom classes: Thresholds based on Heiskary and Wilson (2008): Low <10 µg/L (no bloom), Mid 10-20 µg/L (mild bloom) and High >20 µg/L (nuisance)



b) Chl-a CDF with bloom class. thresholds



c) Chl-a map. MN-based thresholds: Oligo <3 Meso 3-10 µg/L, Eutro 10-30 µg/L and Hyper >30 µg/L

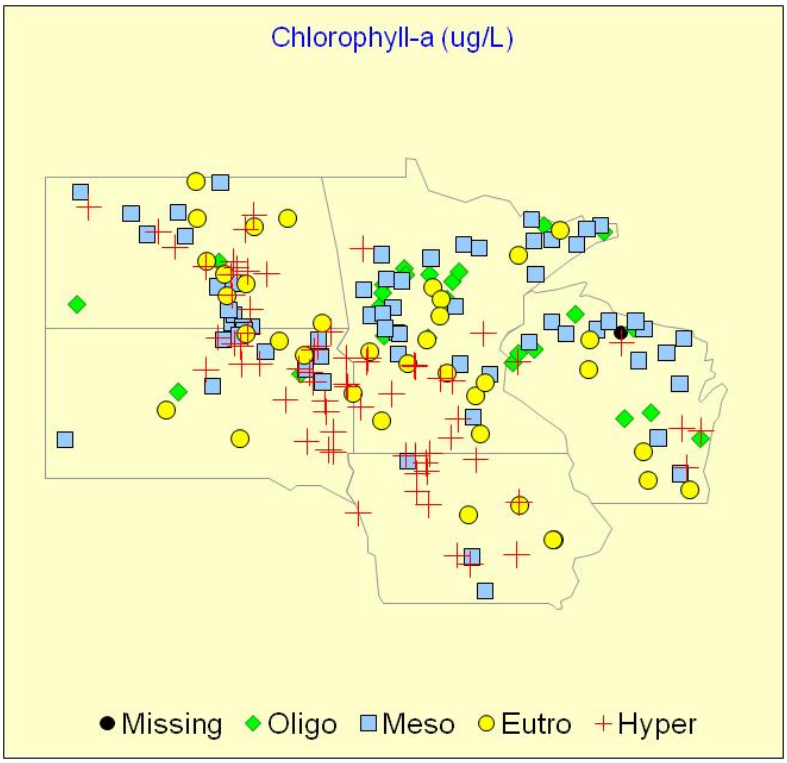
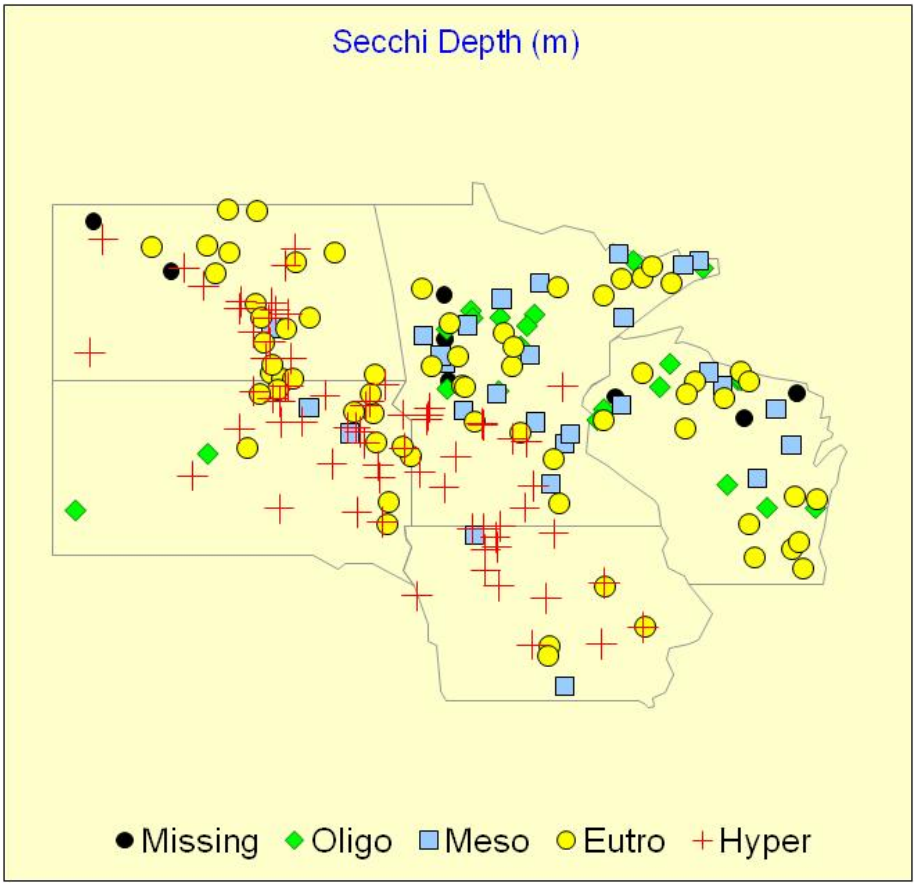


Figure 14 Secchi transparency a) trophic status map and b) CDF.

a) Secchi trophic status map. USEPA and MN-based TSI thresholds: Oligo >3.5 m, Meso 2.0-3.5 m, Eutro 0.7-2.0 m and Hyper <0.7 m



b) Secchi CDF. User-defined at 3.5 m represents transition from mesotrophy to oligotrophy.

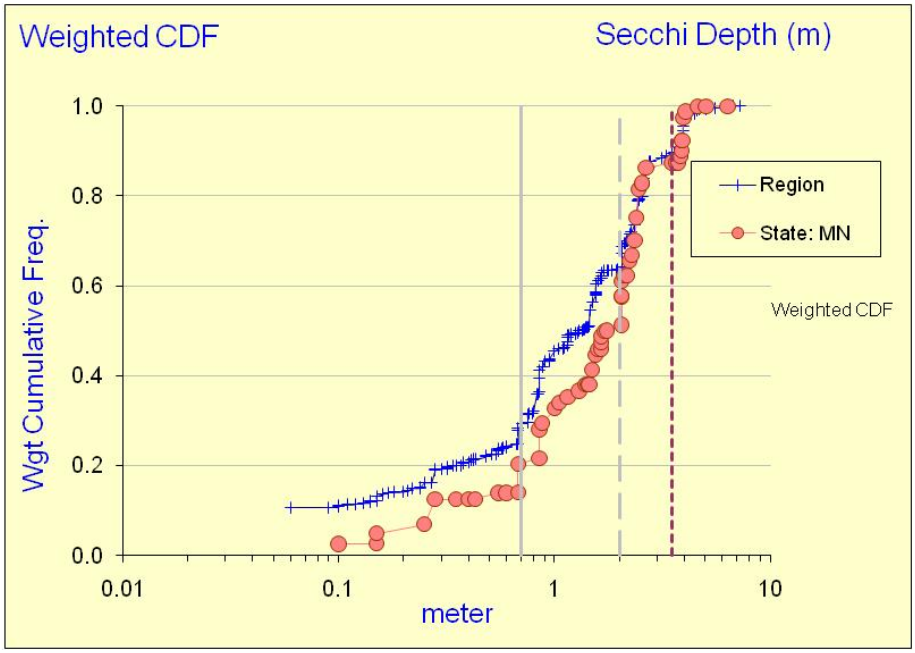
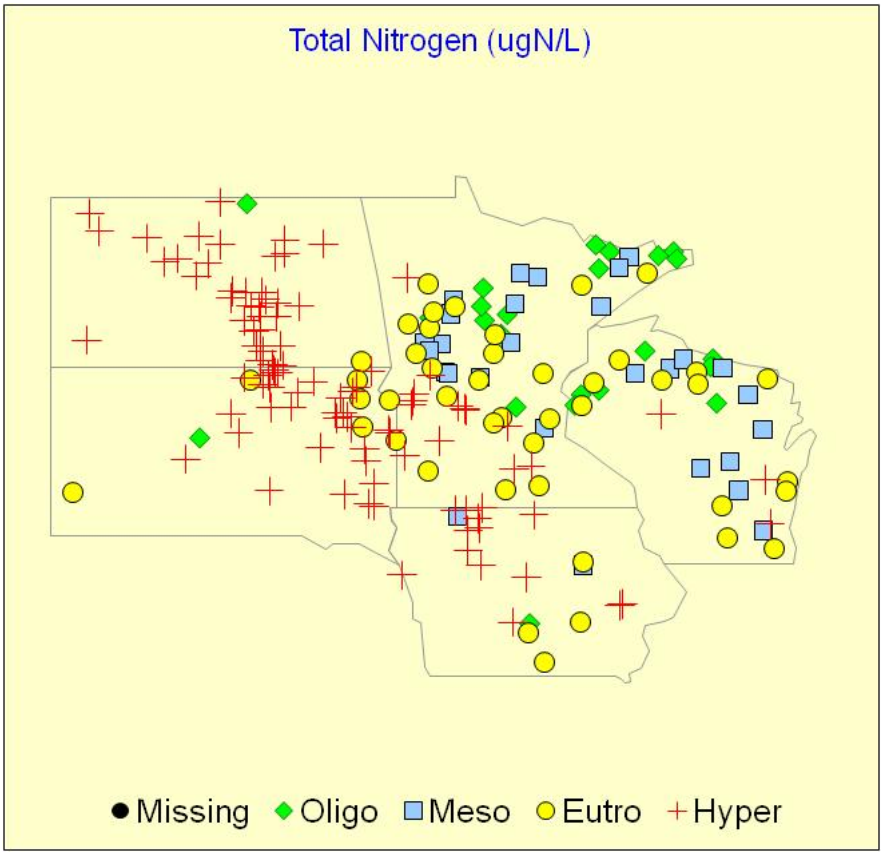


Figure 15 Total Nitrogen map and CDF

a) TN trophic status map. USEPA-based thresholds: Oligo <500 µg/L, Meso 500-750 µg/L, Eutro 750-1,400, Hyper >1,400 µg/L



b) TN CDF. User-defined threshold MN statewide 75th percentile (Table 4)

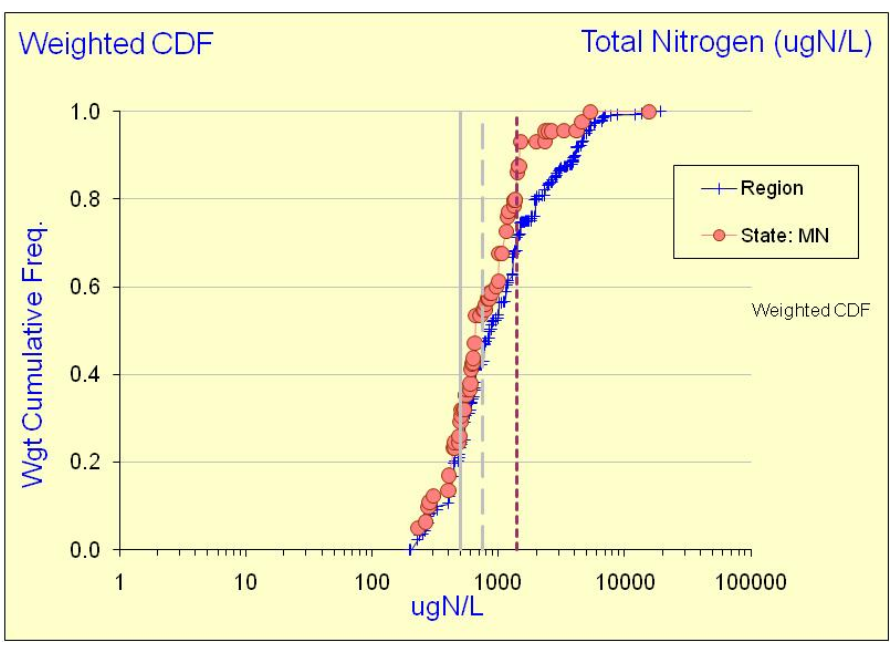
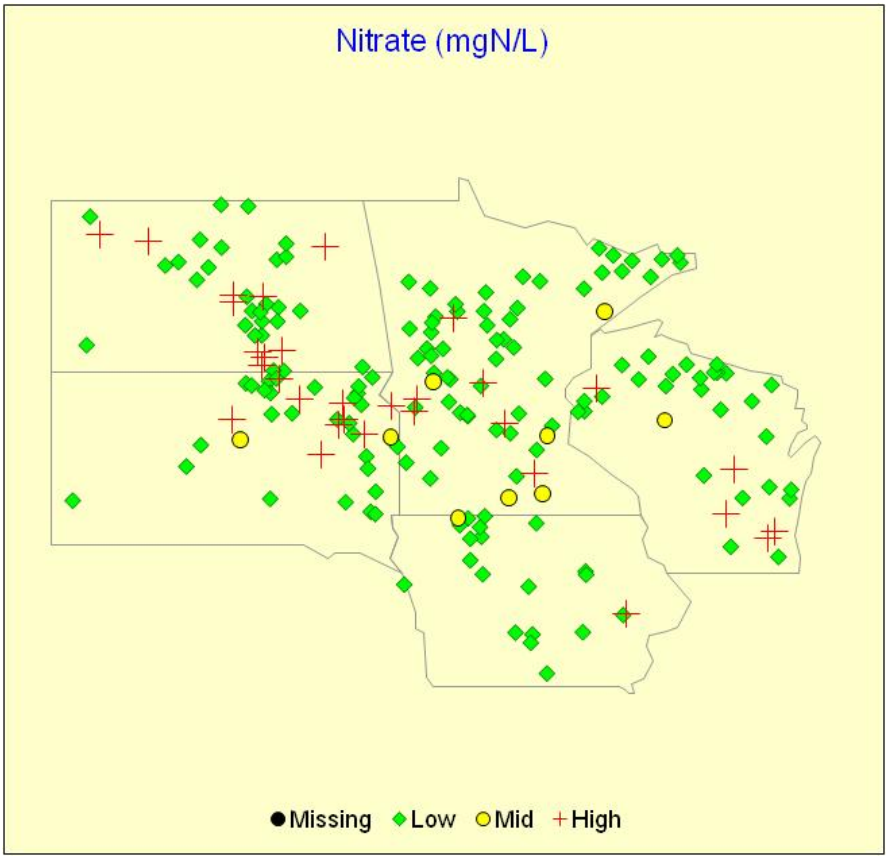


Figure 16 Nitrate-N map and CDF

a) NO^3 map. USEPA-based thresholds: Low <0.01, Mid 0.01-0.1, High >0.1



b) NO^3 CDF. User-defined threshold ~95th percentile MN statewide (Table 4)

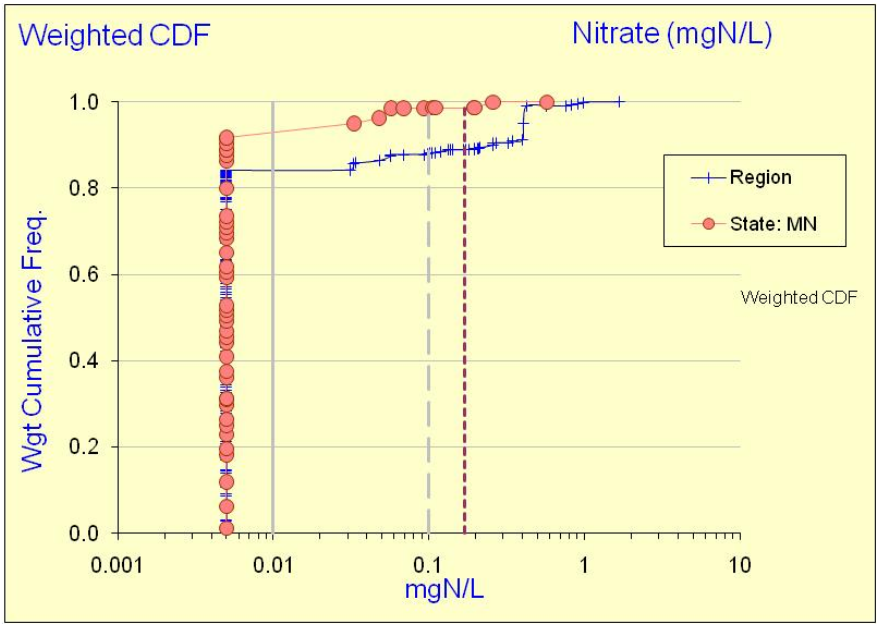
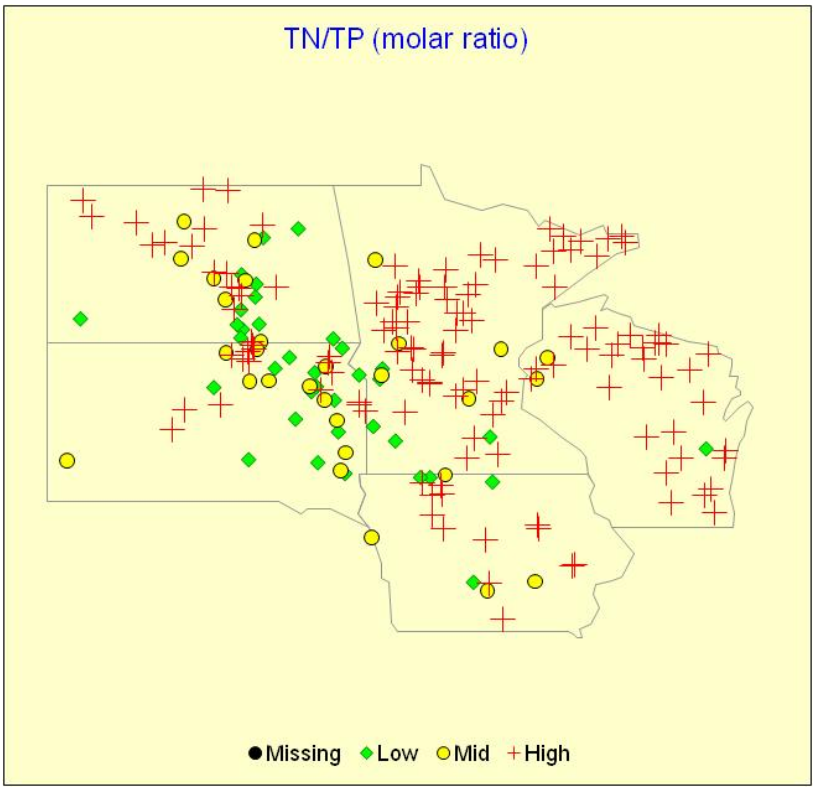
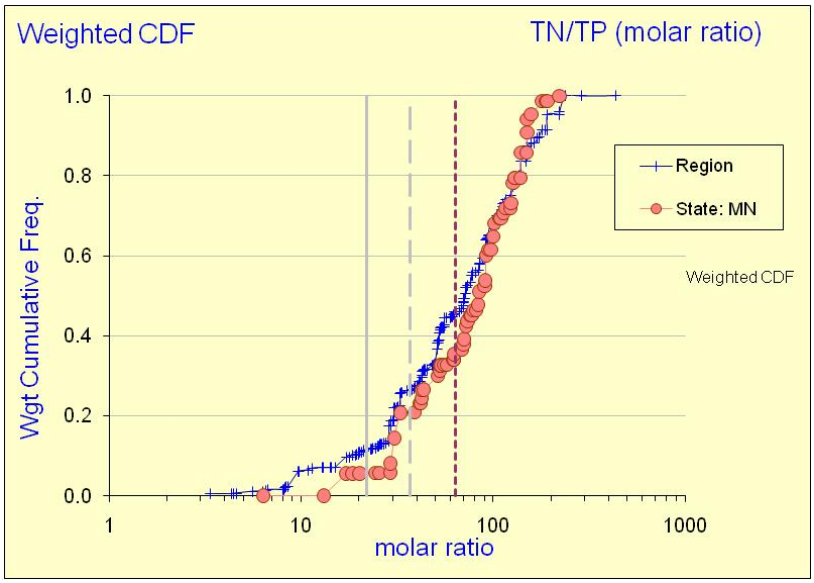


Figure 17 TN: TP ratio map and CDF

a) TN: TP map - Low <10:1(22:1 molar) "N-limited," Mid 10-17 (22-37:1 molar) either P or N; High >17:1(37:1 molar); Very high >29:1 (64:1 molar)



b) TN: TP ratios, thresholds noted above.



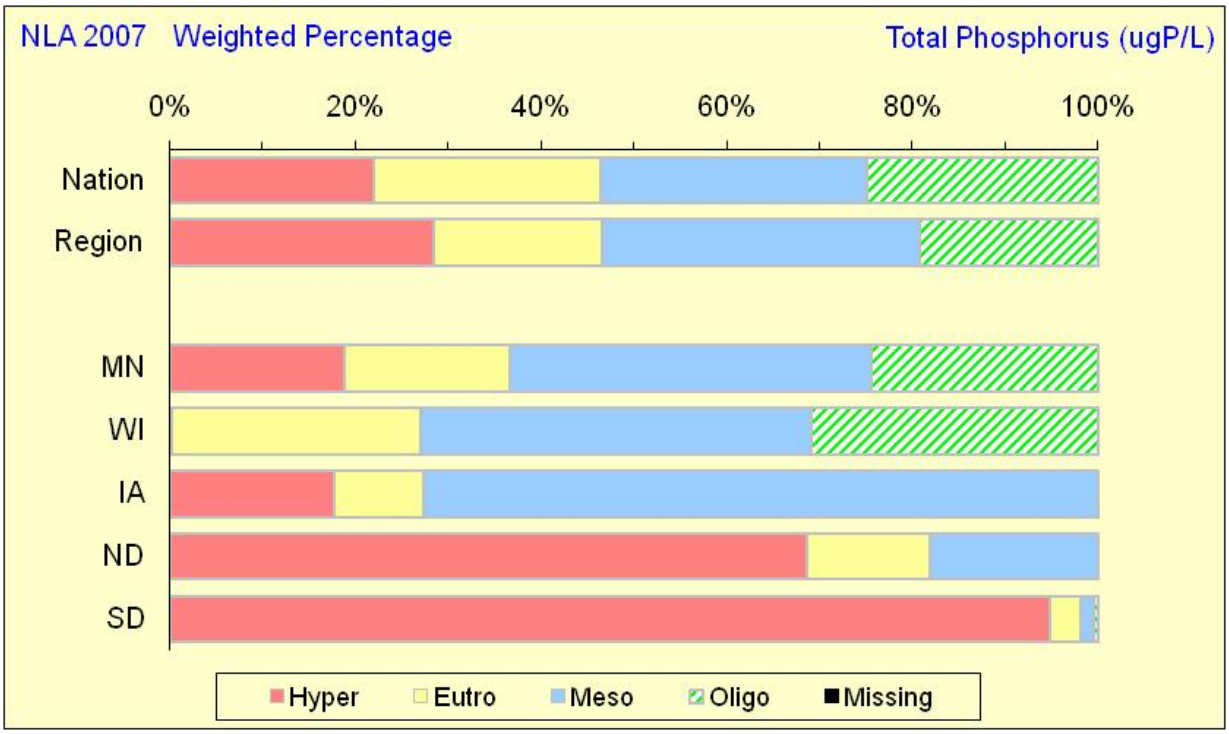
Trophic status summary

In the NLA report EPA characterized the trophic status of the Nation's lakes based on nationally-consistent thresholds (USEPA 2010). These same thresholds were used for the Minnesota NLA data to allow for a comparison between Minnesota's lakes and the overall lakes represented by the NLA. The percentage of Minnesota's lakes in the various trophic status classes is somewhat comparable to that of the overall Nation (Figure 18). This is not too surprising given the distinct regional patterns in Minnesota (Figure 2) and diversity in lake condition (Table 2). Based on the four indicators Minnesota generally has a lower percentage characterized as oligotrophic but a higher percentage classified as mesotrophic as compared to the Nation (Table 9). The proportion of highly eutrophic (hypereutrophic) lakes in Minnesota is quite similar to the Nation. A comparison for the nation, five-state region and the individual states is provided in Figure 18.

Table 9 Percent of U.S. lakes and Minnesota lakes by trophic status, based on four alternative trophic indicators (derived from USEPA 2010).

Indicator	Oligotrophic		Mesotrophic		Eutrophic		Hypereutrophic	
	Nation	Minn.	Nation	Minn.	Nation	Minn.	Nation	Minn.
Chl-a	13	4	37	47	30	25	20	24
Secchi	11	3	23	47	40	30	18	18
TN	22	12	37	47	22	26	18	20
TP	25	24	29	39	25	18	21	19

Figure 18 NLA trophic status comparison for nation, five-state region and individual states.



Ion Chemistry

The chemical composition of a lake is fundamentally a function of its climate and its basin geology (http://wateronthweb.org/). The ion balance for most freshwater lakes can be summed up based on four cations (in order of typical dominance): calcium (Ca^{+2}), magnesium (Mg^{+2}), sodium (Na^{+}) and potassium (K^{+}). The major balancing anions (in order of typical dominance): bicarbonate (HCO_3^{-}), sulfate (SO_4^{-2}) and chloride (Cl^{-}). In the data summary the typical (interquartile) range and overall range for each of these parameters is expressed in terms of mg/L (Table 5) and in terms of microequivalents (µeq/L), which is based on the molecular weight and charge of the ion (Table 6).

Ca influences growth and population dynamics of freshwater flora and fauna and is considered a dynamic ion (Wetzel 2001). Freshwater organism distribution has been often associated with Ca, with Ca-poor waters (<10 mg/L) and hard waters (>20 mg/L) often being referenced. In contrast Mg, Na and K are relatively conservative and undergo relatively minor changes from biotic utilization (Wetzel 2001). Mg is essential for chlorophyll-bearing plants and algae but Mg demand is often minor compared to its general availability (Wetzel 2001). Na has been noted to be important for blue-green algal growth with reference to 4 mg/L as required for near optimal growth in several species and maximal growth at concentrations up to 40 mg/L (Wetzel 2001). A typical cation balance for fresh water is: Ca - 63%, Mg – 17%, Na – 15% and K – 4% (http://wateronthweb.org/). Based on the NLA data Ca and Mg are the dominant cations in Minnesota lakes and are equally dominant on average (Table 5). The relative amounts of Na and K, based on the NLA data (Table 5), are comparable to the typical range noted above. While Ca or Mg were the dominant cations in the vast majority of the lakes there were a couple lakes with extremely high Na. South Lake, a wastewater impacted lake, exhibited the highest Na concentration at 233 mg/L (10,148 µeq/L) which was balanced by Cl at 338 mg/L (9,541 µeq/L). The lake with the next highest Na (46.7 mg/L or 2,085 µeq/L) was Nokomis, which lies in a highly urbanized watershed and receives extensive road runoff. Its Cl content was quite high as well at 73.9 mg/L.

Ionic strength, as reflected by conductivity, alkalinity (ANC), Ca etc. increases from northeast to southwest Minnesota and the typical ranges for the ecoregions reflect this spatial trend (Table 5). This is also apparent in the reference lake data (Table 2) and has been the subject of various studies by Moyle (1946), Gorham et al. (1983) and others. About 40% of Minnesota's lakes would be considered Ca "poor" (Ca <10 mg/L) and about 50% "hardwater" based on Wetzel (2001) and Moyle (1946) classifications. Northeastern portion of the NLF ecoregion lakes are Ca poor and Ca steadily increases to the west and south (Figure 22). The patterns follow into the adjacent states as well. Mg exhibits a similar pattern to Ca with the highest values in SW Minnesota (Figure 23). On an equivalent basis Mg replaces Ca as the dominant cation in the CHF, WCP and NGP ecoregions (Table 6).

Na increases as well in a NE to SW pattern (Figure 24). About 65% of Minnesota's lakes have Na <4.0 mg/L, below a level suggested as being "optimal" for blue-green growth. Lakes with high Na that are "outliers" from the "regional pattern:" are either point-source impacted (e.g. Lost, South and Cokato) or have highly urbanized watersheds (Snail, Nokomis and Fish). In most instances, elevated Na is balanced by elevated Cl (Appendix). Minnesota's Na distribution is somewhat similar to that of WI or IA but concentrations are generally lower than those found in ND and SD (Figure 24). K exhibits a similar NE to SW pattern of increasing concentration in MN (Figure 25). Again lakes that are outliers from the regional pattern are often in wastewater impacted or in urbanized watersheds. Spring Lake, near Mora, is an exception with a K of 5.2 mg/L, which ranks near the 80th percentile based on the statewide CDF (Figure 25).

Silica (Si) is moderately abundant in freshwater and is used by diatom, chrysophytes and higher plants (Wetzel 2001). Diatoms commonly grow abundantly in Si-rich waters in the spring and it is often a shortage of Si that eventually contributes to a crash in the diatoms in late spring in MN lakes. Si does not exhibit a strong regional gradient though it is somewhat higher in the WCP/NGP ecoregions as compared to the NLF & CHF ecoregions (Table 5). Minnesota's Si distribution is similar to that of the region (Figure 26).

Alkalinity is historically the term that referred to the buffering capacity of the carbonate system in water and is now used interchangeably with acid neutralizing capacity (ANC) (Wetzel 2001). Bicarbonates and carbonates provide most of this buffering capacity in Minnesota waters (Figure 4). Alkalinity is often expressed as mg/L $CaCO_3$ but is more accurately expressed as equivalents per liter (1 mg/L=20 µeq/L or 0.02 meq/L). The vast majority of lakes are bicarbonate dominated (Table 6) and as previously described in Moyle (1951), Gorham et al. (1983) and others there is a general NE

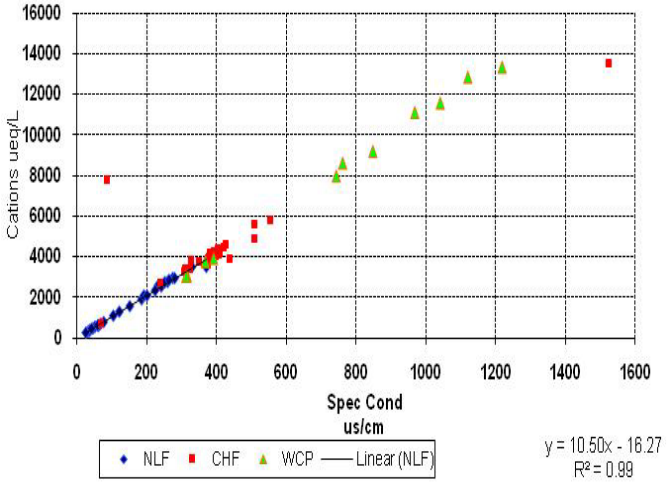
to SW increase in ANC (alkalinity) (Figure 27). If one drew isopleths maps from the NLA data they would look similar to those drafted by Moyle (1951).

Sulfate is typically the next most dominant ion and a distinct regional pattern is evident for MN with increasing concentrations in a NE to SW direction (Figure 28). This pattern is similar to that reported by Moyle (1951). The sulfate-rich lakes correspond to Region IV as described in Gorham et al. (1983) where they note the lakes occur on calcareous substrates rich in sulfur-bearing minerals; which is in contrast to the non-calcareous substrates in NE MN. Wetzel (2001) describes a usual range of 5-30 mg/L, with an average of 11 mg/L for freshwaters world-wide. The thresholds used in Figure 28 were based on characterizations by Moyle (1946) where <10 mg/L was considered soft water, while >50 mg/L was hard to alkali.

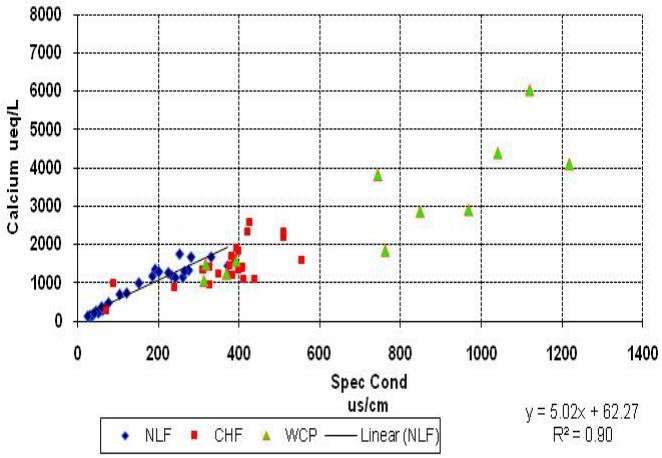
Borrowing from a graphical technique used in Gorham et al. (1983), the direct relationship among specific conductivity and total cations is demonstrated based on the NLA data (Figure 19). The distinct regional patterns in conductivity, Ca and Mg are further reinforced in Figure 20 and conductivity can be used to estimate Ca and Mg. The increasing significance of Mg as the major cation as one moves from NE Minnesota (NLF ecoregion) to SW Minnesota (NGP & WCP ecoregions) is evident as well (Figure 23).

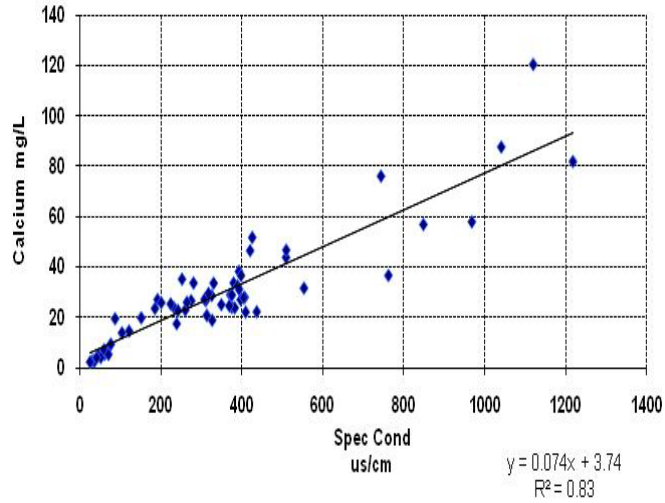
Figure 19. Cations expressed as a function of specific conductivity.

a) Total Cations as a function of Conductivity

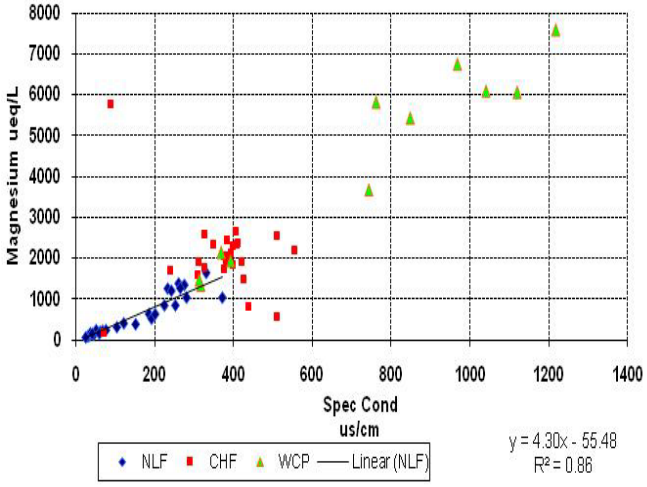


b) Calcium in µeq/L (by ecoregion) and in mg/L





c. Magnesium in µeq/L by ecoregion and mg/L



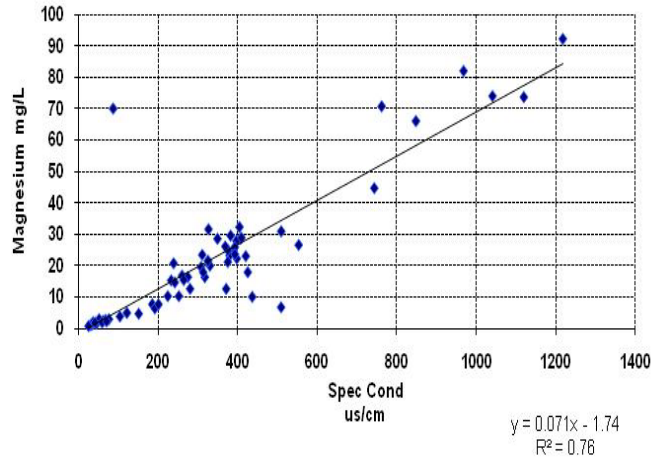
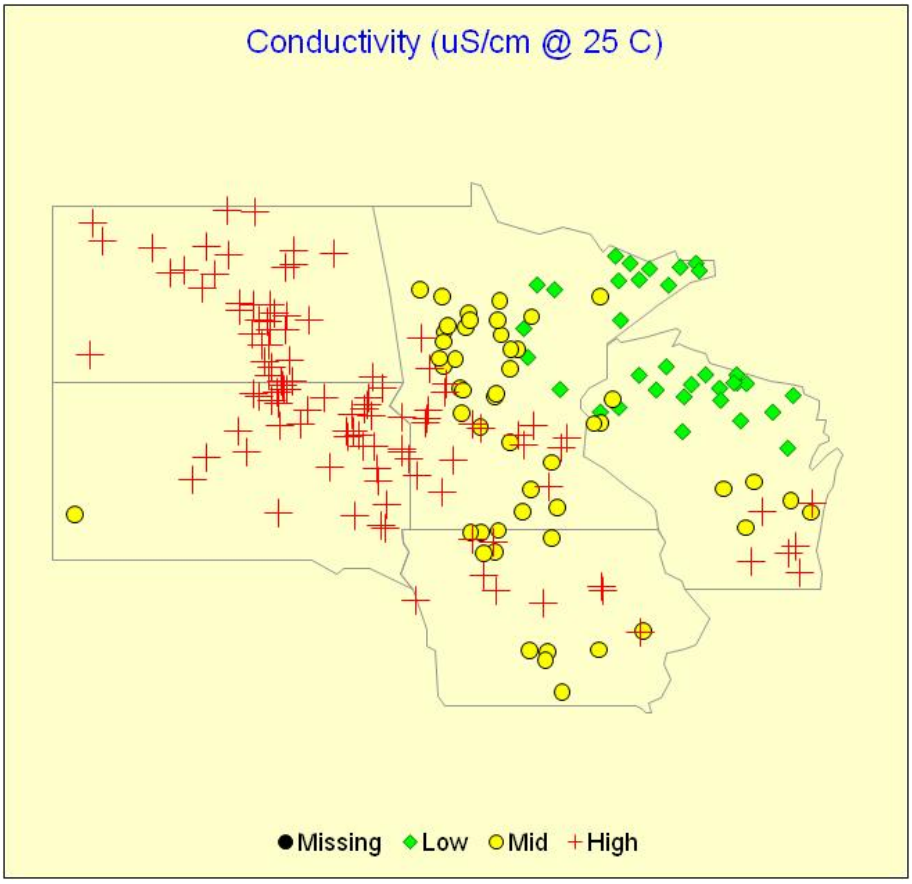


Figure 20 Specific conductivity map and CDF

a) Conductivity map. MN-based thresholds statewide IQ (Table 5): Low <175 µS/cm, Mid 175-400 µS/cm, High >400 µS/cm



b) Conductivity CDF. User-defined threshold near 90th percentile for MN (Table 5)

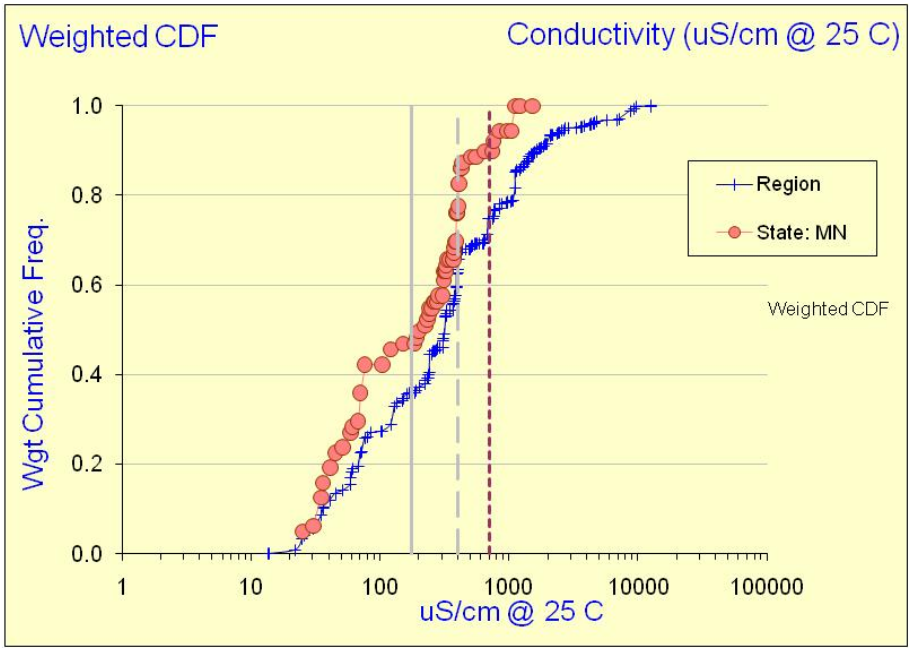
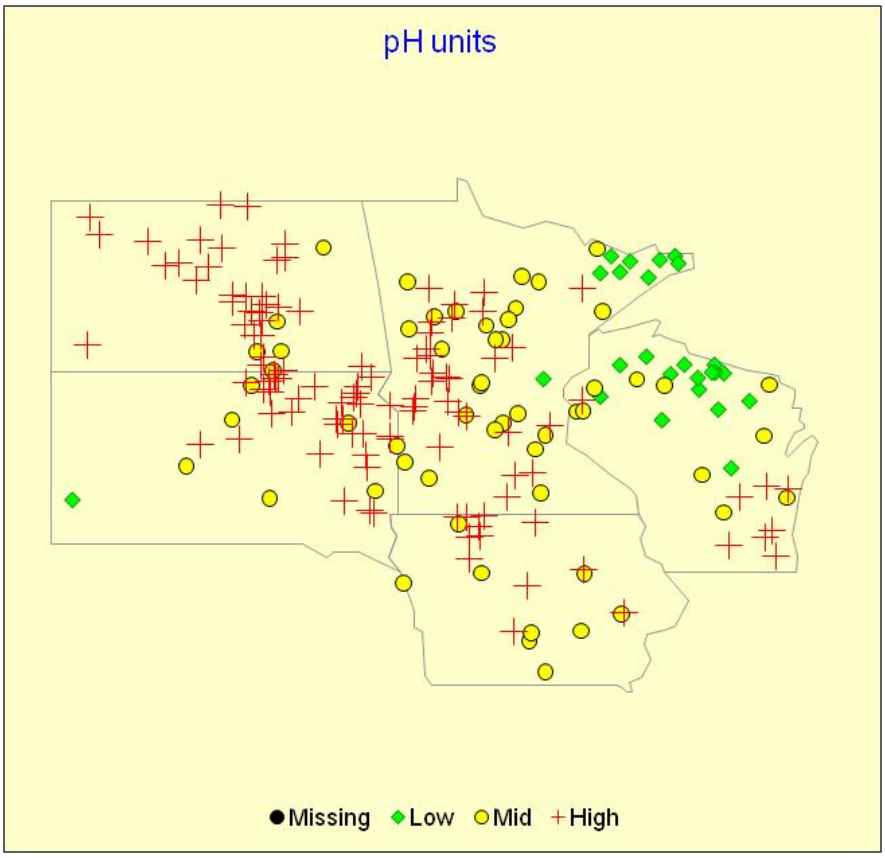


Figure 21 **pH map and CDF.**

a) pH map: USEPA thresholds: Low <7.5, Mid 7.5-8.5, High >8.5



b) pH CDF. User-defined threshold pH 9.0 is MN water quality standard

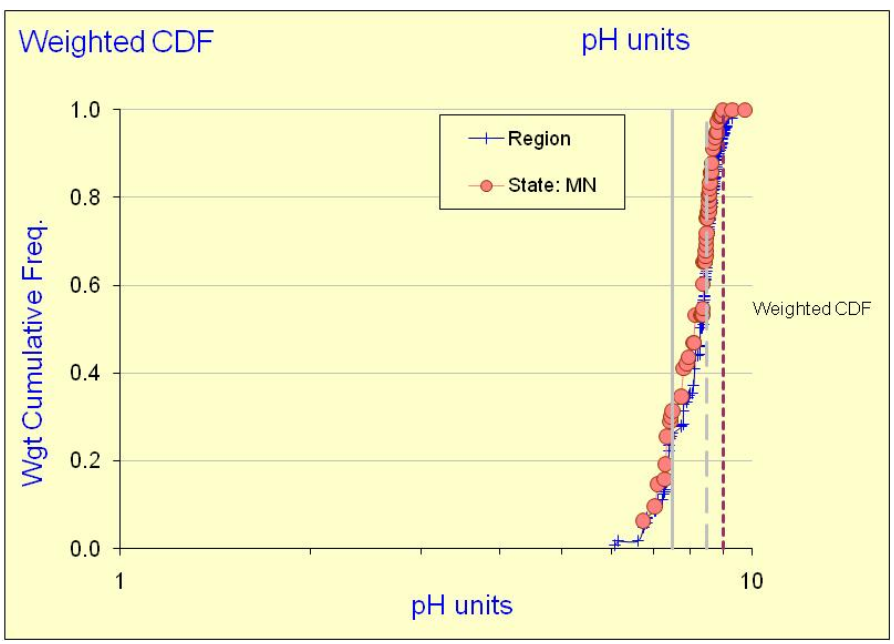
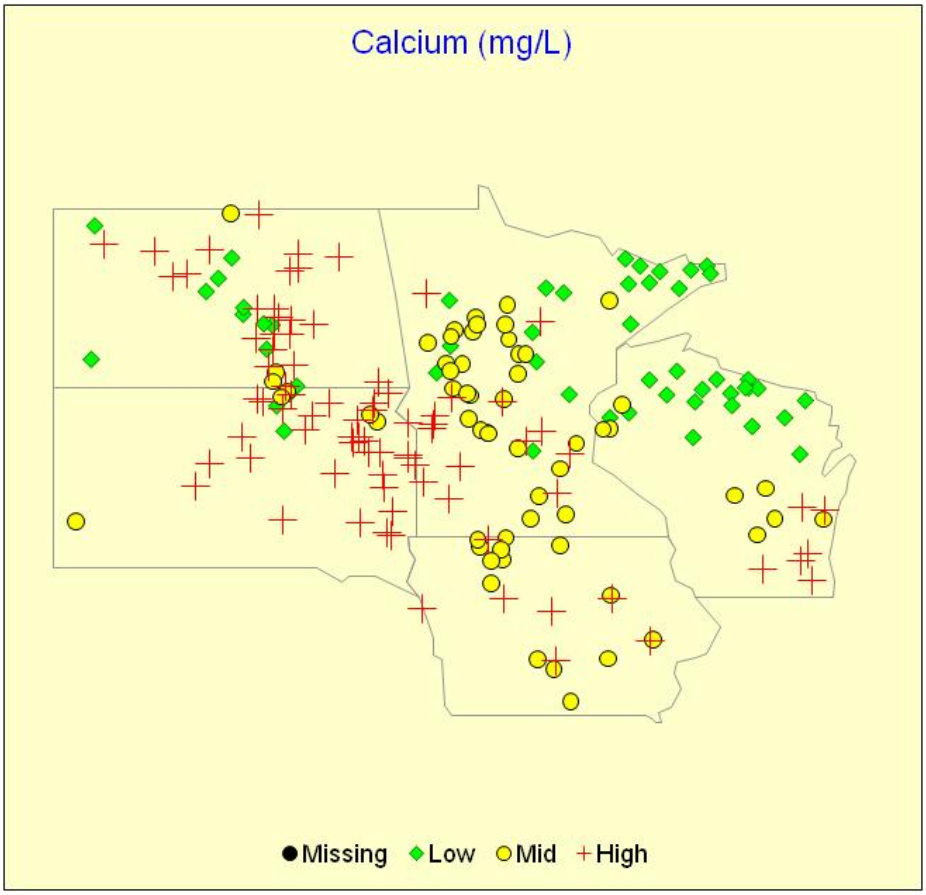


Figure 22 Calcium map and CDF

a) Ca map: MN-based thresholds IQ range (Table 5): Low <20 mg/L, Mid 20-35 mg/L, High >35 mg/L



b) Ca CDF. User-defined threshold (10 mg/L) based on Moyle for "soft" water

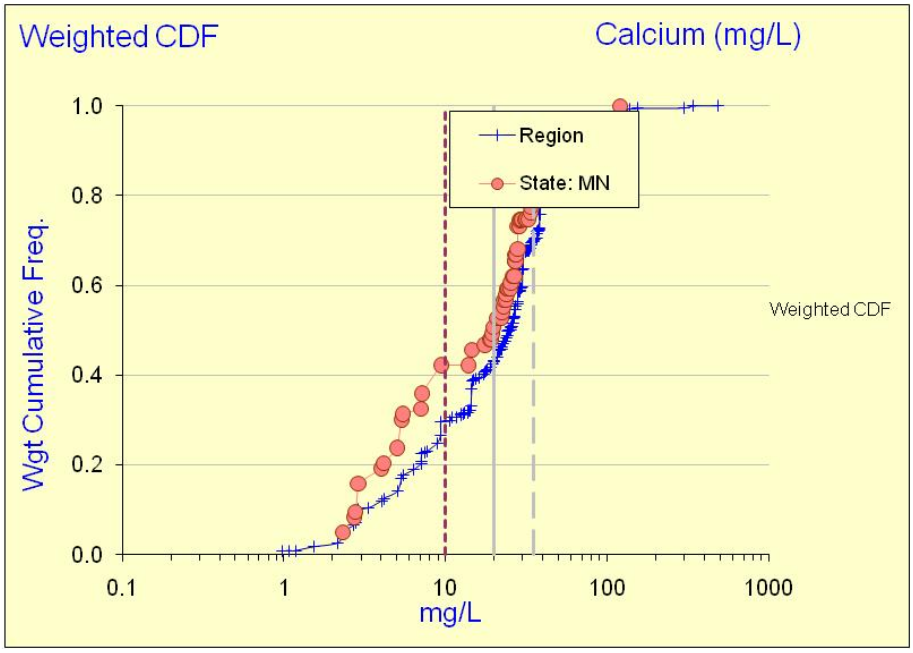
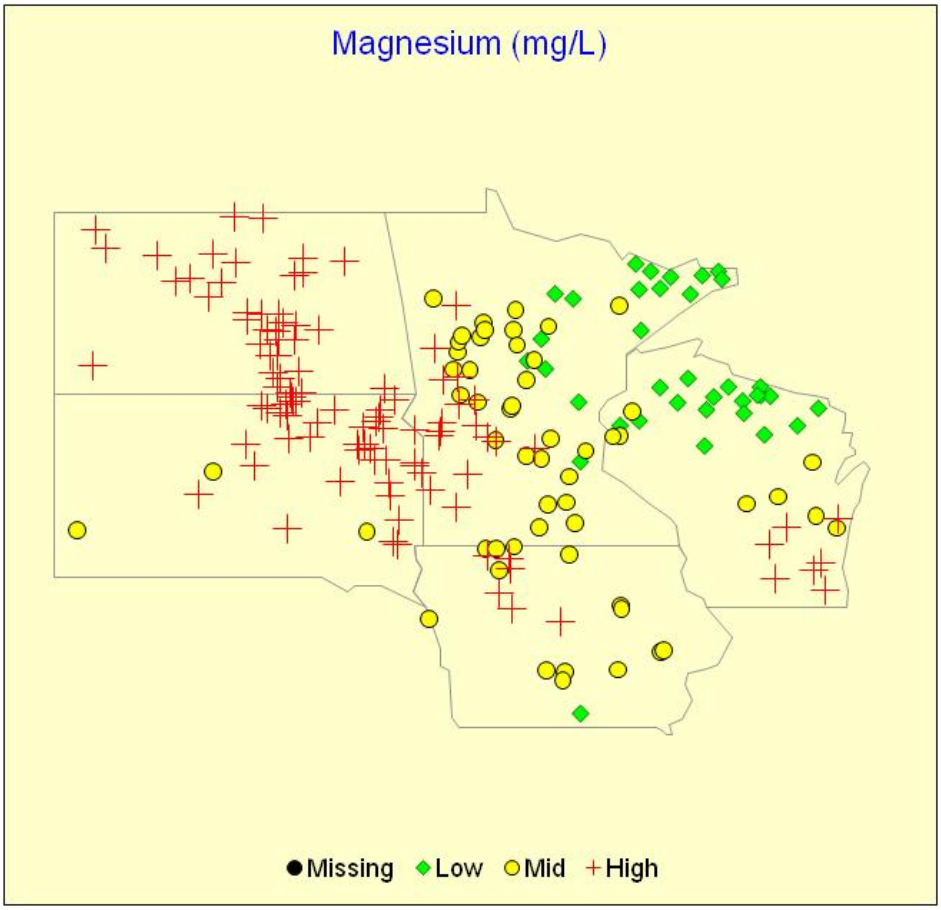


Figure 23 **Magnesium map and CDF.**

a) Mg map. MN-based thresholds for statewide IQ range (Table 5): Low <7 mg/L, Mid 7 – 27 mg/L, High >27 mg/L



b) Mg CDF. User-defined threshold based on Moyle for "soft" water

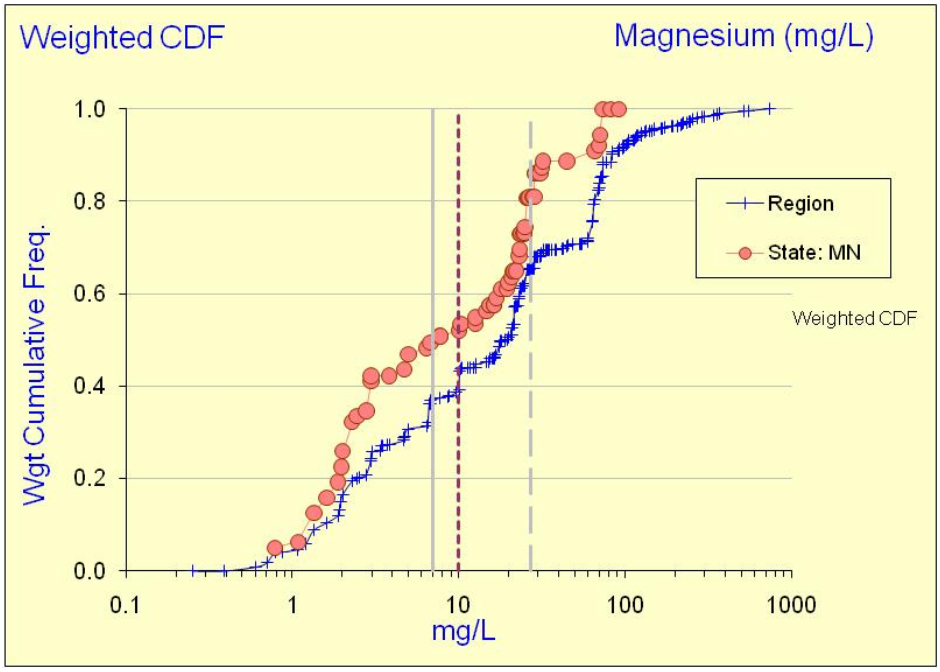
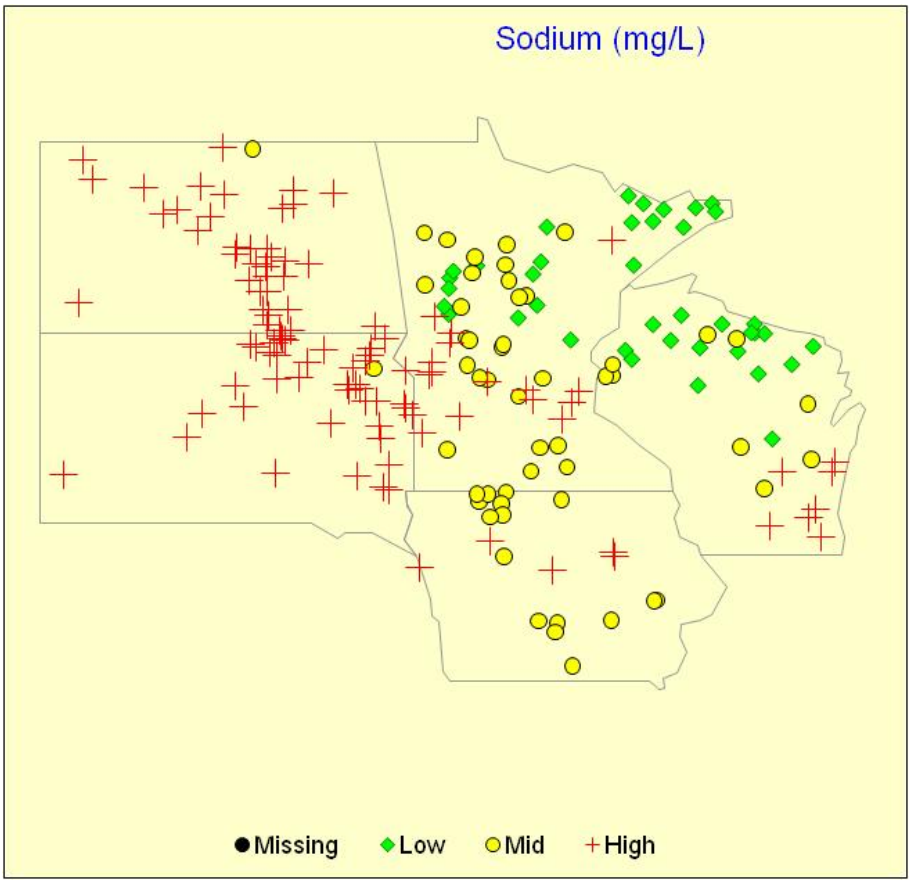


Figure 24 **Sodium map and CDF.**

a) Na map. USEPA & MN-based thresholds (Table 5): Low <3 mg/L, Mid 3-10 mg/L, High >10 mg/L



b) Na CDF. User defined threshold at 20 mg/LMN statewide 90th percentile (Table 5)

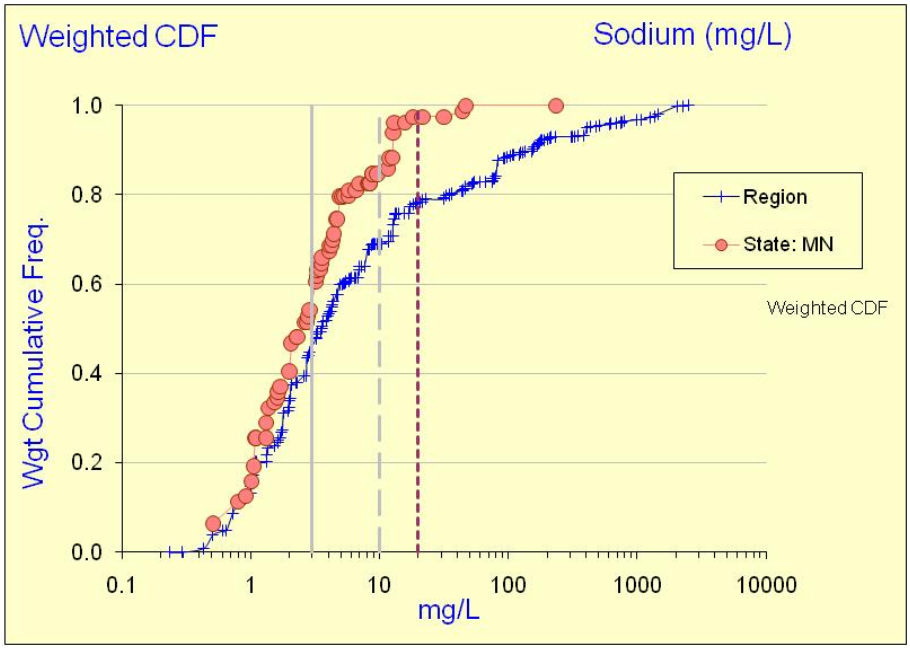
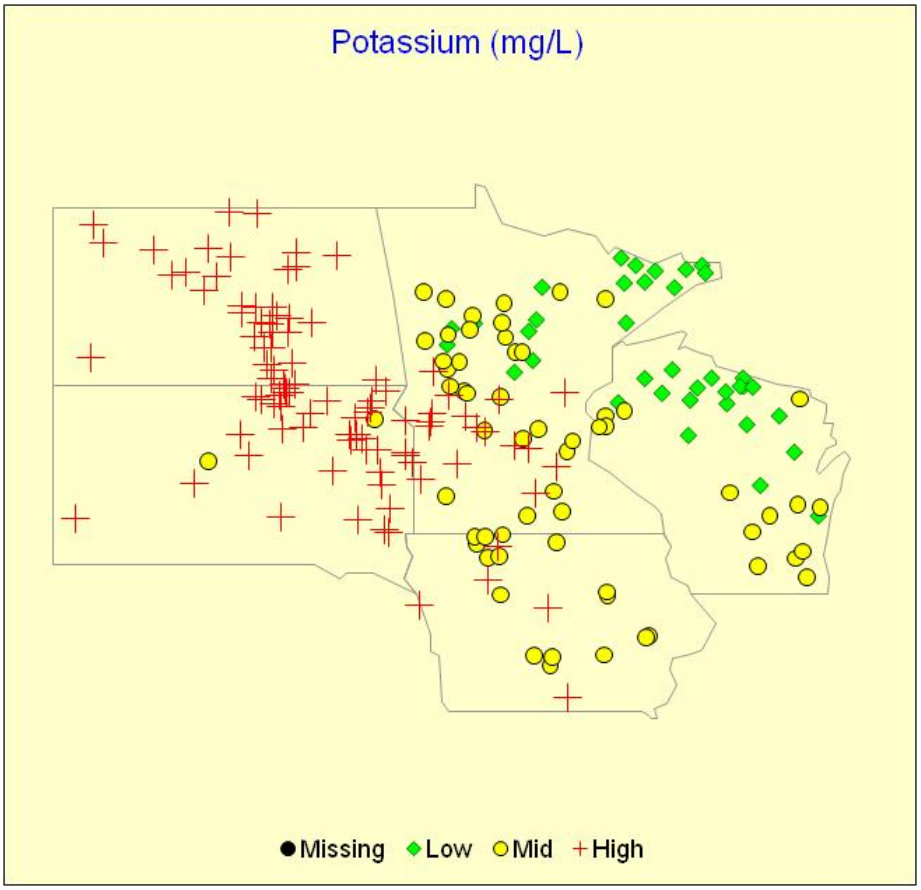


Figure 25 Potassium map and CDF.

a) K map. USEPA thresholds used: Low <1 mg/L, Mid 1-5 mg/L, High >5 mg/L



b) K CDF. User-defined threshold (10 mg/L) statewide 90th percentile (Table 5)

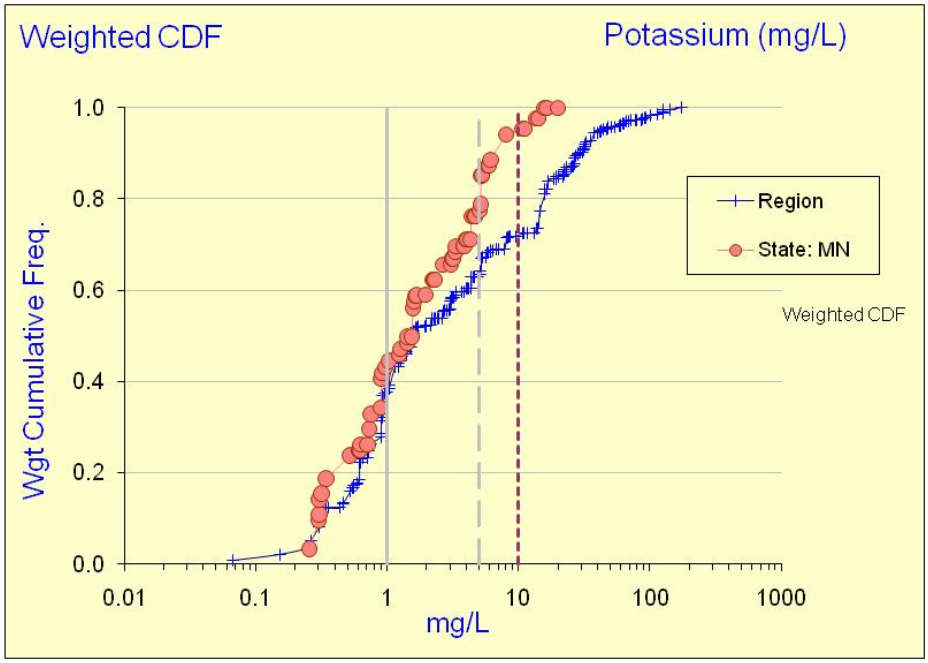
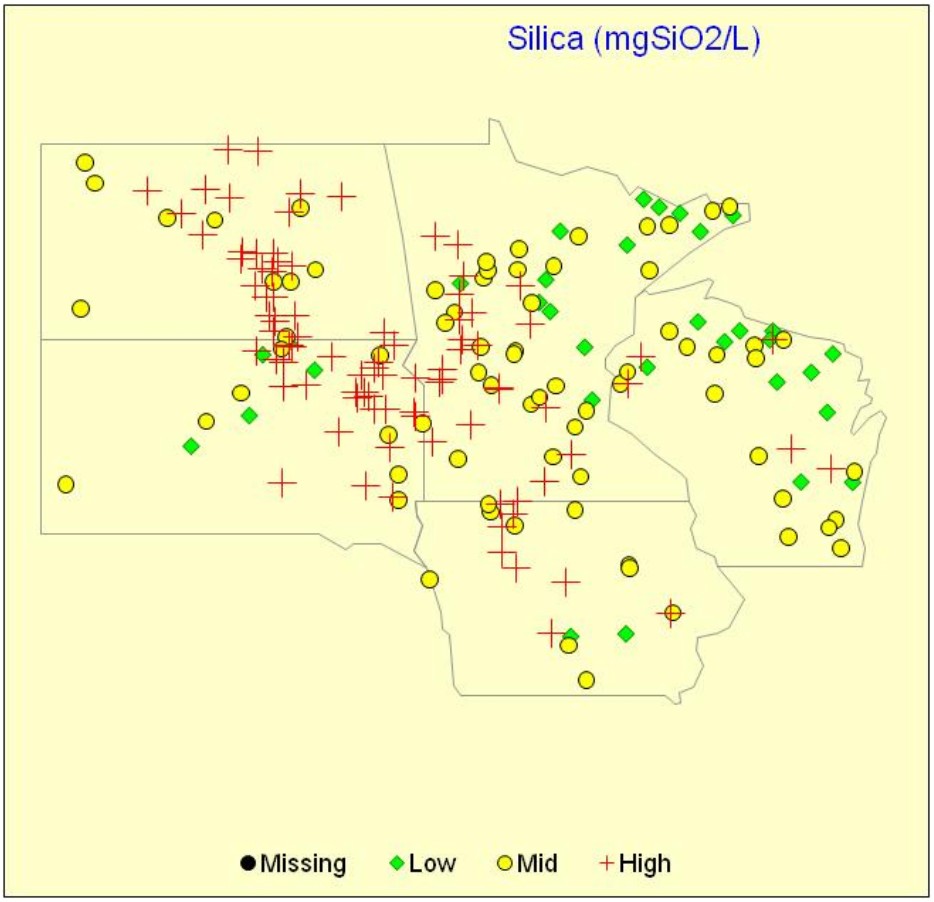


Figure 26 Silica map and CDF

a) Si map. USEPA thresholds used: Low <2 mg/L, Mid 2-11 mg/L, High >11 mg/L



b) Si CDF

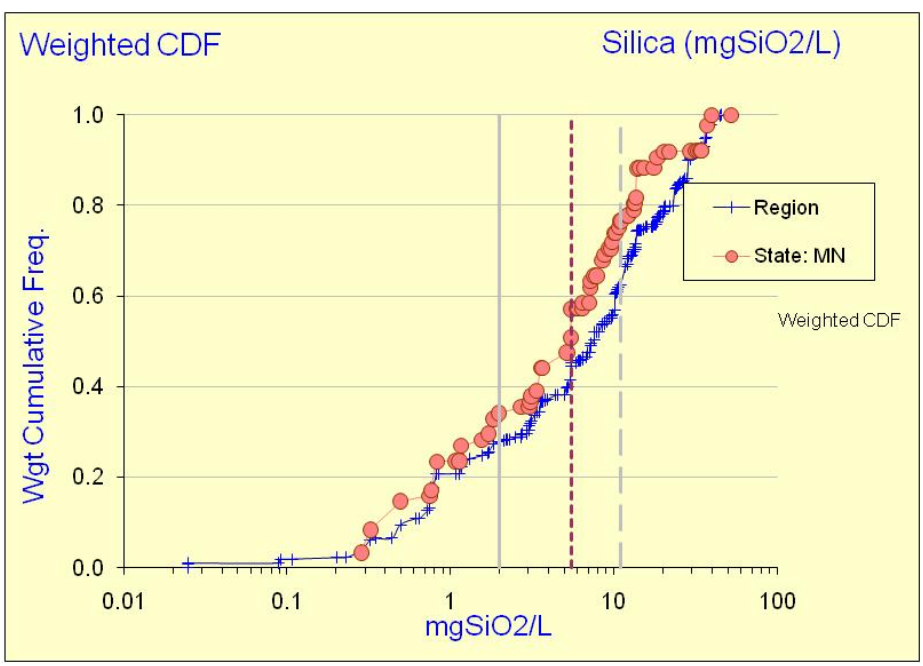
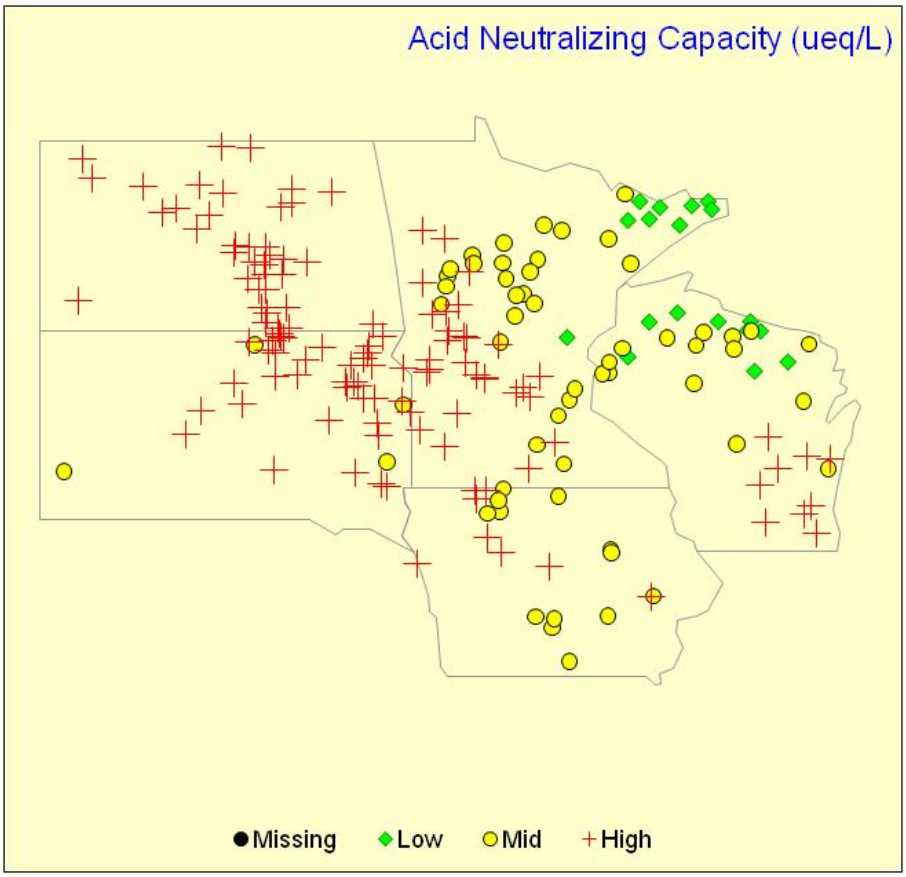


Figure 27 **Acid neutralizing capacity map and CDF.**

a) ANC map. USEPA thresholds used: Low < 500 µeq/L, Mid. 500-3,000 µeq/L and High >3,000 µeq/L



b) ANC CDF

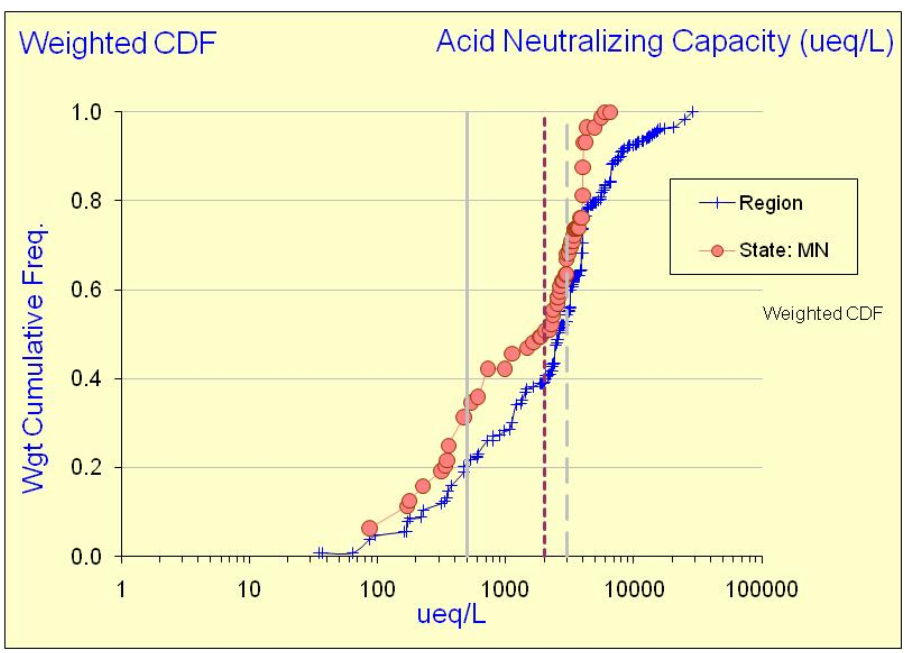
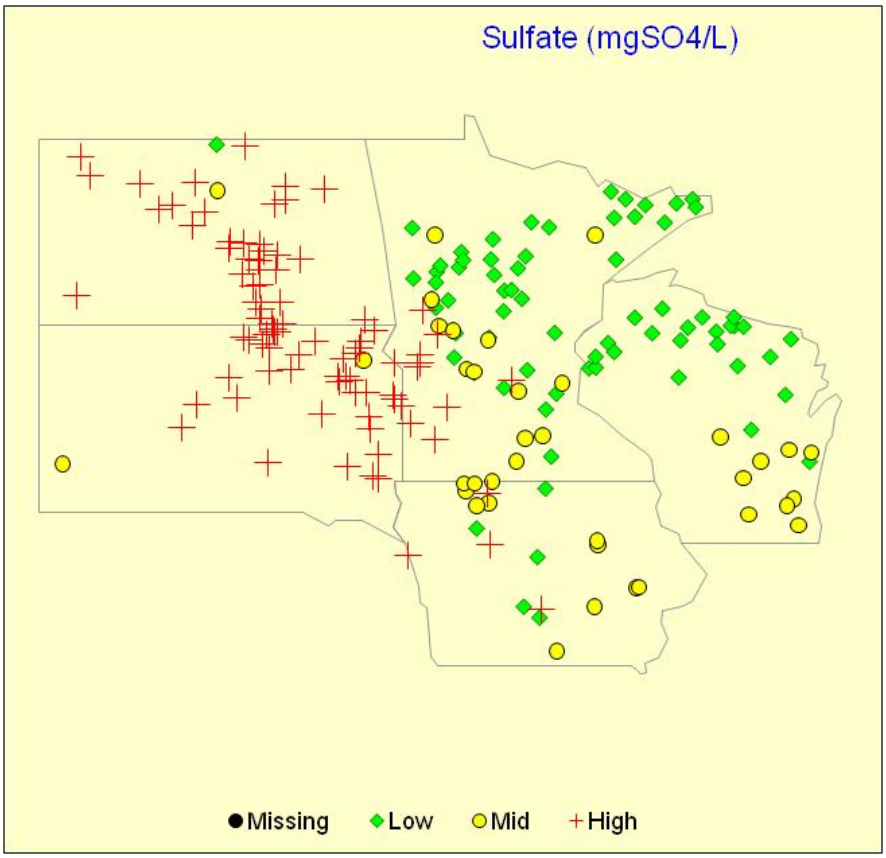


Figure 28 Sulfate map and CDF.

a) SO_4 map: low <10 mg/L, mid 10-50 mg/L and high >50 mg/L.

(Minnesota standard is 10 mg/L for waters with wild rice**)**



b. SO_4 CDF

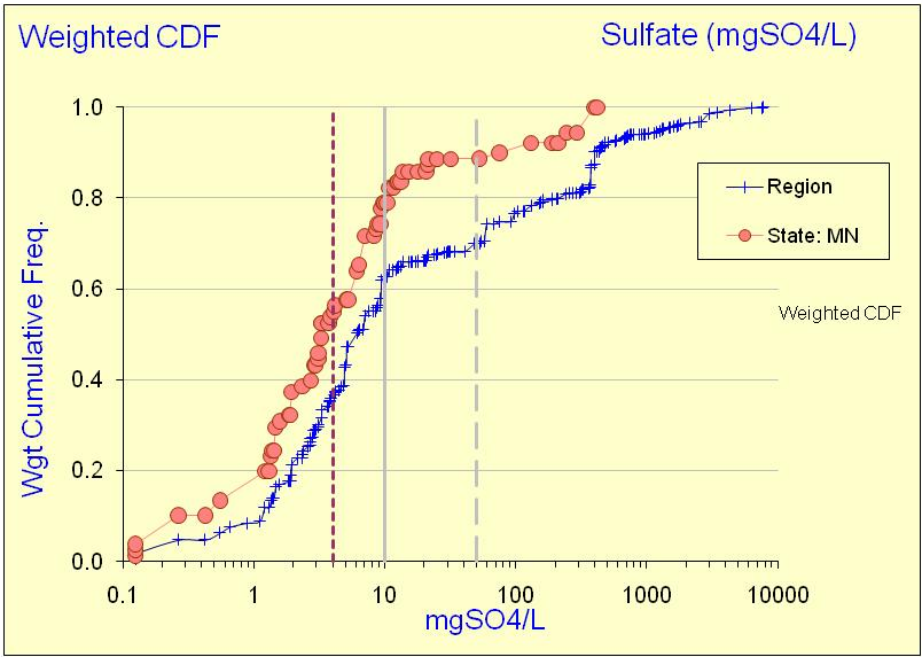
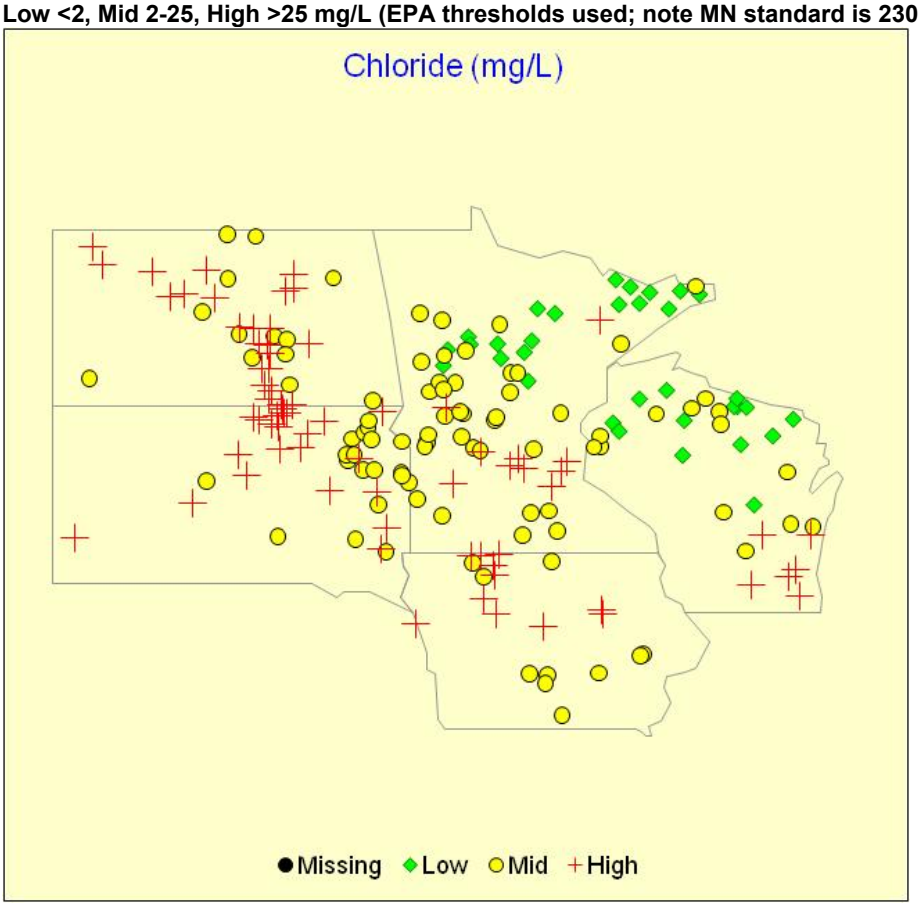
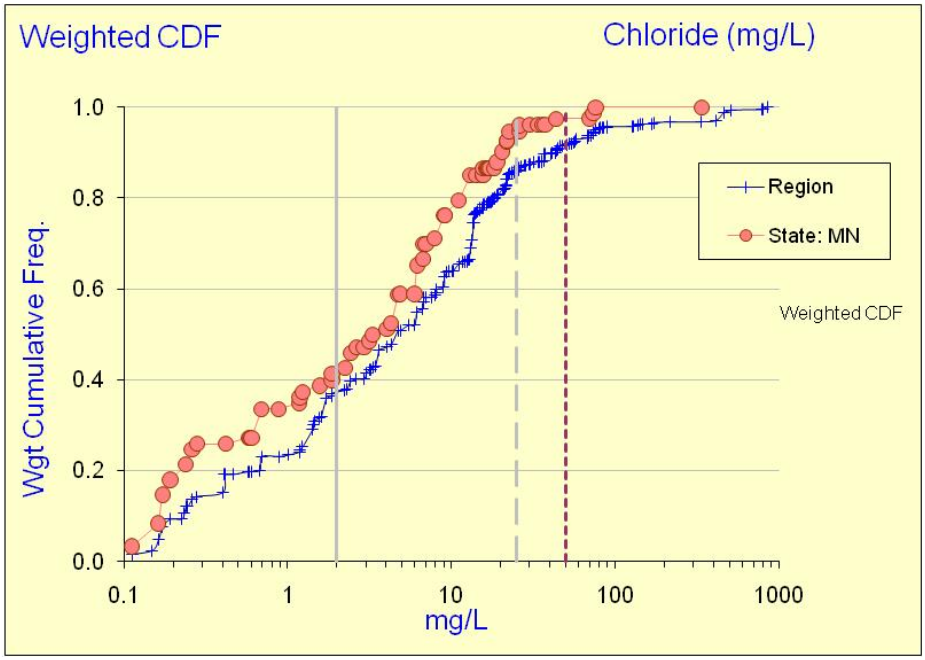


Figure 29 Chloride map and CDF

Low <2, Mid 2-25, High >25 mg/L (EPA thresholds used; note MN standard is 230 mg/L)



b. Cl CDF



NES Lake Summary

As a part of the 2007 NLA a subset of the original National Eutrophication Survey (NES) lakes were re-sampled to allow for a statistical assessment of that specific population of lakes. The NES was a targeted survey of 800 wastewater impacted lakes conducted from 1972-1976. For the NLA, 200 lakes from the NES were randomly selected using the same probability design used in the broader survey (USEPA 2010). Based on a comparison of NES TP (c1972) and NLA TP (2007) USEPA found that 50% decreased, 26% increased and 24% had no change in TP – on a nation-wide basis.

Minnesota had 11 NES lakes included in the survey and pertinent water quality data are summarized in Table 10 based on the 2007 NLA. Changes in point source discharges since the NES are noted in (Table 11). For those still receiving significant point source discharges: Fanny, South and Lost the influence on in-lake TP and other variables such as Na, SO_4 and Cl are quite evident (Table 11). Based on a simple comparison of NES TP (or other available data) to NLA TP five lakes (45%) exhibited decreased TP: Fanny, Woodcock, South, Lost and Cokato; 3 (27%) exhibited no change: Cass, Darling and West Leaf; and 3 (27%) exhibited increased TP: Nest, Okamanpeedan, and Upper Sakatah (Table 11).

These percentages are rather comparable to the national NES results noted above. Of those lakes that exhibited a change in TP only Lost and Cokato resulted in what might be considered a shift in trophic status with both moving from hypereutrophic to mildly eutrophic conditions. Of the three with "increased" TP – each has a large watershed and is dominated by non-point source loading from the watershed.

A few of the lakes had extended data records and it is instructive to review these records for a cross section of the NES lakes: Cokato with a significant point source reduction, Nest with some point source reduction and Darling without a significant point source discharger in its watershed (Figure 30). Cokato, a lake with a rather small watershed, exhibited a significant reduction in TP with the diversion of the WWTF discharge in the late 1970s. TP in recent years has declined further and would characterize the lake as mildly eutrophic. Nest, a lake with a large watershed, exhibited variable TP over its extensive data record. Based on Figure 30 its TP is relatively unchanged from the 1972 NES value. Darling, a lake with a moderate-sized watershed and no significant point source discharge, exhibited relatively stable TP based on its almost 40-year record. These three examples demonstrate the value of an extended data record to assess trends and how variable lake response can be to point source reductions.

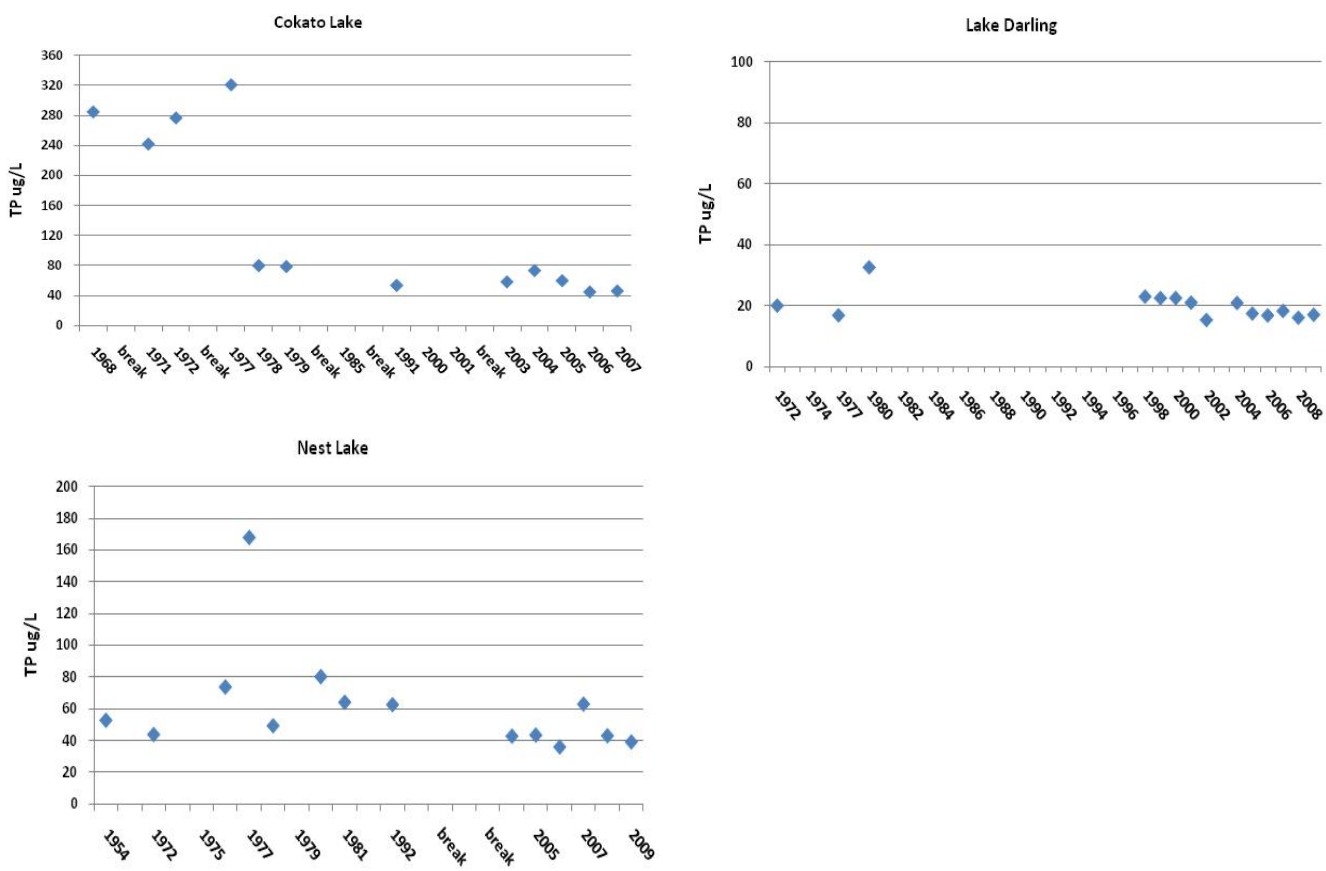
Table 10 Minnesota's NES lakes included in 2007 NLA. Data from 2007 NLA visit.

NLAP Site ID	Lake Name	County	Eco	Lake Area	Sample Date	Mean Depth (m)	TP ug/L	Total N ug/L	Chl-a ug/L	Secchi (m)	Spc Cond (umhos)	Na mg/L	SO4 mg/L	Cl mg/L
NLA06608-0403	Cass Lake	BELTRAMI	NLF	6605	8/6/2007	11.4	20	485	5	2.1	275	5	3	5
NLA06608-0686	Fanny Lake	DOUGLAS	CHF	15	7/11/2007	0.4	122	1,343	4	0.4	553	44	32	69
NLA06608-1390	Darling	DOUGLAS	CHF	468	7/19/2007	5.8	15	553	6	1.5	397	8	12	16
NLA06608-0215	Nest Lake	KANDIYOHI	CHF	385	8/22/2007	3.3	83	1,463	58	0.7	389	5	15	16
NLA06608-1239	Woodcock	KANDIYOHI	CHF	73	7/24/2007	1.0	117	3,309	83	0.4	409	13	2	34
NLA06608-0759	Okamanpeedan	MARTIN	WCP	888	8/7/2007	0.3	360	4,153	185	0.2	393	8	18	30
NLA06608-0167	South Lake	MCLEOD	CHF	70	7/23/2007	0.3	1,184	15,625	936	0.1	1523	233	25	338
NLA06608-0878	West Leaf	OTTER TAIL	CHF	281	8/1/2007	4.9	18	630	6	1.7	325	3	8	7
NLA06608-1303	Upper Sakatah	RICE	CHF	495	8/8/2007	0.9	817	2,338	8	2.6	425	8	13	22
NLA06608-0318	Lost Lake	ST LOUIS	NLF	33	7/20/2007	1.7	43	847	14	1.7	371	21	21	37
NLA06608-0551	Cokato Lake	WRIGHT	CHF	220	8/20/2007	4.5	54	1,361	17	1.8	510	13	53	26

Table 11 Minnesota NES lakes TP comparison based on NES (1972), other, and NLA (2007) data. Includes notes on point source discharges.

NLAP Site ID	Lake Name	County	NES TP mg/L	Other TP mg/L	NLA TP mg/L	Notes
			(1972)	(year)	(2007)	
NLA06608-0403	Cass Lake	BELTRAMI	22		20	Bemidji 0.3 mg/L (0.15 mg P/L in 2010) & Cass Lake WWTF spray irrigation by 1985
NLA06608-0686	Fanny Lake	DOUGLAS	412		122	Discharge from Evansville WWTF, P variance in 1982, variance removed in 2010
NLA06608-1390	Darling	DOUGLAS	20		15	no discharge to lake
NLA06608-0215	Nest Lake	KANDIYOHI	44		83	New London 1 mg/L & Belgrade spray on land 1985 far upstream of Nest. Currently New London & Spicer share facility & dischare to Middle Fork Crow downstream of Nest.
NLA06608-1239	Woodcock	KANDIYOHI	903		117	Spicer WWTF to 1 mg/L (see Nest)
NLA06608-0759	Okamanpeedan	MARTIN		163 (1998)	360	Ceylon WWTF no limit. Extremely small discharge relative to watershed NPS.
NLA06608-0167	South Lake	MCLEOD	3,830		1,184	Winsted variance 1980, upgraded in 1987. Variance recommended for removal.
NLA06608-0878	West Leaf	OTTER TAIL		16 (1996)	18	Henning WWTF discharge to East Leaf, on land by 1985
NLA06608-1303	Upper Sakatah	RICE		419 (1980)	817	State park discharge routed to Waterville.
NLA06608-0318	Lost Lake	ST LOUIS	340		43	Gilbert WWTF to 1 mg/L by 1985; currently at 0.8 mgP/L.
NLA06608-0551	Cokato Lake	WRIGHT	277	80 (1978)	54	Diverted Cokato WWTF to Crow River

Figure 30 Long-term TP trends in three Minnesota NES lakes: Cokato, Nest and Darling. Summer-mean data for most years. Note scale breaks in data record.



Summary and Conclusions

Minnesota's 2007 NLA effort was led by the Minnesota Pollution Control Agency (MPCA) and Minnesota Department of Natural Resources (MDNR). Various other collaborators were engaged in this study as well including the U.S. Forest Service (USFS), Minnesota Department of Agriculture (MDA), and U.S. Geological Survey (USGS). MPCA and MDNR cooperated on initial planning of the survey and conducted a vast majority of the sampling, which took place in July and August for most lakes. USFS staff sampled remote lakes in the Boundary Waters Canoe Area Wilderness (BWCAW).

Minnesota received 41 lakes as a part of the original draw of lakes for the national survey–the most of any of the lower 48 states. Minnesota added nine lakes to the survey to yield the 50 lakes needed for statistically-based statewide estimates of condition (Figure 1). In addition to the 50 lakes, 14 reference lakes were later selected and sampled by USEPA as a part of the overall NLA effort. Data from the reference lakes provide an additional basis for assessing lake condition as a part of NLA. Combined (probability, NES and reference) these lakes provide a robust dataset for examining statewide and regional patterns in water chemistry and other factors included in the NLA.

The purpose of this report is to provide a summary of the water chemistry and related variables for Minnesota's lakes based on the NLA data collected in summer 2007. Because of its statistically-based nature this data set provides a good basis for describing the typical range of constituents and interrelationships in Minnesota's lakes on a statewide basis. Ecoregion-based comparisons and descriptions are made as well and, while not statistically significant, they provide useful insights into regional patterns. These data are compared, when appropriate, to the previously published typical ranges based on ecoregion reference lake data (Heiskary and Wilson 2008). Data presentation includes: basic (un-weighted) distributions of the parameters on a statewide and ecoregion basis, maps by parameter for Minnesota and a five-state region consisting of MN, WI, IA, SD and ND and weighted cumulative distribution functions (CDF) for Minnesota and this five-state region.

Previous studies have described regional patterns in lake trophic status (Moyle 1946 and Heiskary and Wilson 1989). The NLA data reinforce these patterns and provide a basis for statistically describing trophic status on a statewide basis and providing estimates at an ecoregion or other regional basis. In terms of TP-based trophic status the distribution of Minnesota's lakes is rather similar to that of the Nation (Table 9) and about 64% of Minnesota's lakes would be considered oligotrophic or mesotrophic (on a weighted basis). The majority of these lakes are in the NLF and CHF ecoregions (Figure 12). The Minnesota NLA TP, Chl-a and Secchi data exhibit relatively strong correlations that are similar to what is found for summer-mean data (Figure 11) and can be used to describe interrelationships and identify thresholds. With respect to nitrogen the Minnesota and five-state regional data reveal very poor correspondence among TN and Chl-a (Figure 11) and TN:TP ratios (Figure 17) indicate that <10% of the lakes might be considered "N-limited" – both of which support the need to emphasize TP over TN when developing nutrient criteria.

Ionic strength, as reflected by conductivity, alkalinity (ANC), Ca etc. increases from northeast to southwest Minnesota and the typical ranges for the ecoregions reflect this spatial trend (Table 5). This is consistent with patterns described by Moyle (1946) and Gorham et al. (1983). The regional maps (e.g. Figure 20) demonstrate how the patterns continue into the adjacent states and suggest the broader regional nature of the patterns. For parameters with actual water quality standards, e.g. Cl and SO_4, the maps and CDFs indicate where and how many lakes might be anticipated to exceed the standard. For SO_4 80% of the lakes are <10 mg/L (standard) and those that do exceed the standard are generally in SW MN – lakes that are less likely to have wild rice and a few point source impacted lakes (Table 10). The sole lake in NE MN (where wild rice is more commonly found) that exceeded the 10 mg/L standard is Lost Lake, a point source impacted lake. For Cl, over 95% of the lakes are <25 mg/L and <1% exceed the 230 mg/L standard. The sole lake that exceeded 230 mg/L was South Lake, a point-source impacted lake (Table 10). Further the current work indicates that lakes with elevated Cl are generally either point-source impacted (Table 10) or are in more urbanized watersheds (Figure 29). Work to-date on Cl TMDLs (e.g. Wenck 2009) and other studies in the Upper Midwest (Corsi et al. 2010) further reinforces the role of urbanization, extent of impervious area and use of road salt as important factors that contribute to elevated Cl. However, the NLA data and previous ecoregion-based water quality assessments (Table 1) indicate that highly elevated Cl is not a statewide problem.

As a part of the 2007 NLA a subset of the original National Eutrophication Survey (NES) lakes were re-sampled to allow for a statistical assessment of that specific population of lakes. For the NLA, 200 lakes (11 in MN) from the NES were randomly selected using the same probability design used in the broader survey (USEPA 2010). Based on a comparison of NES TP (c1972) and NLA TP (2007) USEPA found that 50% decreased, 26% increased and 24% had no change in TP – on a nation-wide basis. A review of data for Minnesota's 11 NES lakes revealed similar percentages: 46% decreased TP, 27% increased and 27% unchanged. However, of those with decreased TP – only two could be considered to have shifted trophic status (Table 11).

The NLA data provide a valuable complement to data collected from other more targeted MPCA and MDNR programs. This statistically-based dataset allows for extrapolation to the entire state or defined regions. This can provide context for data collected from other programs, estimate numbers or percentages of lakes that meet water quality standards or numbers or percentages of lakes that may have a chemical make-up or other attributes that may be of interest to state or local lake managers. Previous and future NLA reports from Minnesota provide information on other lake attributes that will hopefully be useful to current and future lake managers and scientists.

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Appendix

I. USEPA Data for Minnesota's NLA lakes. Sorted by type: NES, Reference and Draw (Probability)

a) Lake morphometry
b) Organic carbon, color pH and Secchi
c) Nutrients, cations and anions (mg/L)
d) Cations and anions in μeq/L

II. Comparison of USEPA and MPCA (MDH) data for select lakes

III. Legend, abbreviations and units of measurement

NLAP Site ID	Lake Name	Type	County	Eco	Area	Sample Date	Mean Depth	Index Depth
					ha		m	m
NLA06608-0403	Cass Lake	NES	BELTRAMI	NLF	6605	8/6/2007	11.4	34.1
NLA06608-0686	Fanny Lake	NES	DOUGLAS	CHF	15	7/11/2007	0.4	1.1
NLA06608-1390	Darling	NES	DOUGLAS	CHF	468	7/19/2007	5.8	17.5
NLA06608-0215	Nest Lake	NES	KANDIYOHI	CHF	385	8/22/2007	3.3	9.8
NLA06608-1239	Woodcock	NES	KANDIYOHI	CHF	73	7/24/2007	1.0	3.0
NLA06608-0759	Okamanpeedan	NES	MARTIN	WCP	888	8/7/2007	0.3	1.0
NLA06608-0167	South Lake	NES	MCLEOD	CHF	70	7/23/2007	0.3	1.0
NLA06608-0878	West Leaf	NES	OTTER TAIL	CHF	281	8/1/2007	4.9	14.7
NLA06608-1303	Upper Sakatah	NES	RICE	CHF	495	8/8/2007	0.9	2.7
NLA06608-0318	Lost Lake	NES	ST LOUIS	NLF	33	7/20/2007	1.7	5.2
NLA06608-0551	Cokato Lake	NES	WRIGHT	CHF	220	8/20/2007	4.5	13.5
NLA06608-MN:03-0029	Hungry Man	Ref	BECKER	NLF	36	8/8/2007	2.2	6.7
NLA06608-MN:06-0002	Artichoke Lake	Ref	BIG STONE	NGP	780	9/6/2007	1.1	3.2
NLA06608-ELS:2D3-008	Spring Lake	Ref	CASS	NLF	32	8/10/2007	4.5	13.4
NLA06608-MN:11-0102	Island	Ref	CASS	NLF	140	8/11/2007	4.3	12.8
NLA06608-MN:15-0010	Elk	Ref	CLEARWATER	NLF	113	8/9/2007	9.3	28.0
NLA06608-MN:22-0074	Bass Lake	Ref	FARIBAULT	WCP	79	9/11/2007	1.8	5.5
NLA06608-MN:49-0140	Cedar Lake	Ref	MORRISON	CHF	93	9/24/2007	8.8	26.5
NLA06608-MN:51-0063	Sarah	Ref	MURRAY	NGP	475	9/5/2007	0.8	2.5
NLA06608-MN:56-0306	Elbow Lake	Ref	OTTER TAIL	CHF	77	9/17/2007	4.8	14.5
NLA06608-MN:61-0037	Lake Linka	Ref	STEELE	CHF	70	9/25/2007	5.3	15.8
NLA06608-MN:74-0023	Beaver Lake	Ref	STEELE	WCP	39	9/12/2007	2.7	8.0
NLA06608-MN:75-0200	Lake Hattie	Ref	STEVENS	NGP	179	9/7/2007	0.8	2.5
NLA06608-MN:77-0019	Mary Lake	Ref	TODD	CHF	49	9/16/2007	5.8	17.5
NLA06608-0110	Pickerel	Draw	BECKER	NLF	139	7/31/2007	4.1	12.4
NLA06608-0366	Straight Lake	Draw	BECKER	NLF	209	7/31/2007	6.0	18.0
NLA06608-1134	Flat Lake	Draw	BECKER	NLF	743	8/7/2007	1.8	5.5
NLA06608-0279	North Eagle	Draw	BLUE EARTH	WCP	100	8/8/2007	0.9	2.6
NLA06608-0494	Pine Mountain	Draw	CASS	NLF	631	7/11/2007	7.8	23.5
NLA06608-0942	Long Lake	Draw	CASS	NLF	105	7/10/2007	7.7	23.0
NLA06608-1262	Mayo Lake	Draw	CASS	NLF	252	7/9/2007	1.4	4.2
NLA06608-0558	North Mayfield	Draw	CLAY	CHF	14	8/9/2007	1.2	3.7
NLA06608-0782	Vesper Lake	Draw	COOK	NLF	6	7/31/2007	3.1	9.4
NLA06608-0890	Aspen Lake	Draw	COOK	NLF	59	7/30/2007	2.8	8.5
NLA06608-1018	Richey Lake	Draw	COOK	NLF	42	8/2/2007	0.4	1.1
NLA06608-1274	Musquash	Draw	COOK	NLF	54	8/1/2007	2.5	7.6
NLA06608-0238	Pelican Lake	Draw	CROW WING	NLF	3376	7/11/2007	9.3	28.0
NLA06608-0771	Lookout Lake	Draw	CROW WING	NLF	92	8/13/2007	1.5	4.6
NLA06608-0990	Crow Wing	Draw	CROW WING	NLF	144	7/30/2007	1.9	5.7
NLA06608-0622	Victoria	Draw	DOUGLAS	CHF	169	7/24/2007	4.7	14.1
NLA06608-1454	Red Rock	Draw	DOUGLAS	NGP	300	7/25/2007	1.9	5.7
NLA06608-0679	Lake Nokomis	Draw	HENNEPIN	CHF	81	6/27/2007	1.3	4.0
NLA06608-0190	Upper Hatch	Draw	ITASCA	NLF	7	8/14/2007	2.1	6.2
NLA06608-0958	Long	Draw	ITASCA	NLF	146	8/15/2007	2.0	6.0
NLA06608-1283	Spring Lake	Draw	KANABEC	CHF	7	6/27/2007	1.8	5.5
NLA06608-1383	Norway Lake	Draw	KANDIYOHI	CHF	907	8/22/2007	3.1	9.4
NLA06608-0526	Becousin Lake	Draw	LAKE	NLF	43	7/18/2007	1.8	5.5
NLA06608-1038	August Lake	Draw	LAKE	NLF	75	8/3/2007	1.8	5.5
NLA06608-1111	North Ash Lake	Draw	LINCOLN	NGP	34	7/10/2007	0.5	1.5
NLA06608-0211	Allen Lake	Draw	MAHNOMEN	CHF	58	8/7/2007	0.5	1.4
NLA06608-1175	Jennie Lake	Draw	MEEKER	CHF	428	8/21/2007	1.0	3.0
NLA06608-0174	Pebble Lake	Draw	OTTER TAIL	CHF	69	7/25/2007	4.6	13.7
NLA06608-1198	Maine (Round)	Draw	OTTER TAIL	CHF	35	7/25/2007	3.3	10.0
NLA06608-1326	Fairy Lake	Draw	OTTER TAIL	CHF	54	8/6/2007	0.8	2.4
NLA06608-0915	Unnamed	Draw	POLK	CHF	4	8/8/2007	0.6	1.7
NLA06608-1447	Snail Lake	Draw	RAMSEY	CHF	64	7/18/2007	2.4	7.1
NLA06608-0935	Fish Lake	Draw	SCOTT	CHF	70	8/6/2007	2.9	8.6
NLA06608-1102	Alruss	Draw	ST LOUIS	NLF	12	7/16/2007	4.5	13.4
NLA06608-1150	Lamb Lake	Draw	ST LOUIS	NLF	28	7/19/2007	1.7	5.2
NLA06608-1342	Arthur Lake	Draw	ST LOUIS	NLF	31	7/17/2007	1.2	3.7
NLA06608-1347	Sprinq Lake	Draw	ST LOUIS	NLF	40	6/28/2007	1.9	5.8
NLA06608-0871	North Drywood	Draw	STEVENS	NGP	253	7/12/2007	0.4	1.2
NLA06608-0743	Long Lake	Draw	WRIGHT	CHF	35	6/26/2007	2.8	8.4

Lake Name	NES	Eco	pH - F	pH - L	Secchi	Turb.	Color	TOC	DOC
	Ref				m	NTU	PCU	mg/L	mg/L
Cass Lake	NES	NLF		8.7	2.1	3	3	5.6	5.6
Fanny Lake	NES	CHF	9.4	9.3	0.4	1	40	17.9	18.2
Darling	NES	CHF	8.7	8.7	1.5	3	10	7.4	7.2
Nest Lake	NES	CHF	8.6	8.4	0.7	16	14	8.3	8.0
Woodcock	NES	CHF	9.1	9.0	0.4	14	9	20.5	16.9
Okamanpeedan	NES	WCP	8.9	8.9	0.2	74	20	11.6	8.7
South Lake	NES	CHF	9.6	9.8	0.1	193	35	36.2	27.3
West Leaf	NES	CHF	8.5	8.4	1.7	2	7	7.6	7.3
Upper Sakatah	NES	CHF	9.6	8.8	2.6	6	20	12.7	12.1
Lost Lake	NES	NLF	8.9	8.6	1.7	4	23	8.7	8.6
Cokato Lake	NES	CHF	8.3	8.5	1.8	4	10	7.2	6.7
Hungry Man	Ref	NLF	8.4	8.4	3.8	1	7	8.5	8.0
Artichoke Lake	Ref	NGP	8.5	8.7	0.6	12	11	18.6	17.1
Spring Lake	Ref	NLF	8.0	8.3	5.1	1	27	14.4	14.3
Island	Ref	NLF	8.7	8.1	3.7	1	7	9.3	9.2
Elk	Ref	NLF	8.5	8.6	3.9	1	9	7.5	7.1
Bass Lake	Ref	WCP	8.6	8.6	0.6	14	6	8.7	8.6
Cedar Lake	Ref	CHF	8.3	8.4	6.4	1	4	5.9	6.0
Sarah	Ref	NGP	8.4	8.5	0.3	32	9	7.3	7.5
Elbow Lake	Ref	CHF	8.4	8.5	2.5	2	5	5.0	4.9
Lake Linka	Ref	CHF	8.6	8.7	2.6	1	9	6.6	6.5
Beaver Lake	Ref	WCP	7.9	8.3	1.4	5	5	6.5	6.5
Lake Hattie	Ref	NGP	8.5	8.6	0.3	22	8	15.5	14.5
Mary Lake	Ref	CHF	8.1	8.4	2.2	3	14	9.7	9.1
Pickerel	Draw	NLF	8.6	8.6	3.9	1	4	5.7	5.8
Straight Lake	Draw	NLF	8.4	8.5	2.6	2	12	3.9	3.6
Flat Lake	Draw	NLF	8.8	8.5	1.3	5	20	10.1	9.7
North Eagle	Draw	WCP	9.5	8.7	0.3	43	20	32.6	18.8
Pine Mountain	Draw	NLF	8.1	8.4	1.7	4	3	5.2	5.0
Long Lake	Draw	NLF	8.3	8.6	4.1	1	18	4.7	4.6
Mayo Lake	Draw	NLF	8.5	8.5	0.9	5	40	14.3	13.0
North Mayfield	Draw	CHF	7.6	8.4	2.4	2	15	12.7	11.8
Vesper Lake	Draw	NLF	6.4	6.7	2.1	1	33	10.8	10.0
Aspen Lake	Draw	NLF	7.3	7.5	3.5	1	28	9.4	9.1
Richey Lake	Draw	NLF	7.8	7.4	1.0	3	22	18.2	12.4
Musquash	Draw	NLF	7.4	7.3	4.6	1	5	5.2	5.3
Pelican Lake	Draw	NLF	8.3	8.5	3.9	1	0	3.6	3.2
Lookout Lake	Draw	NLF	8.8	8.6	2.1	3	18	10.1	9.2
Crow Wing	Draw	NLF	8.6	8.7	1.1	7	12	7.8	7.3
Victoria	Draw	CHF		8.6	1.4	4	6	7.4	6.5
Red Rock	Draw	NGP	8.5	8.8	3.9	1	15	16.7	16.4
Lake Nokomis	Draw	CHF	8.3	8.5	2.3	2	6	6.6	6.2
Upper Hatch	Draw	NLF	7.3	7.8	2.5	1	11	10.6	10.5
Long	Draw	NLF	8.1	8.0	1.7	3	14	8.5	8.2
Spring Lake	Draw	CHF	6.7	7.3	0.7	9	93	15.3	14.2
Norway Lake	Draw	CHF	8.7	8.6	0.9	9	11	14.0	12.4
Becousin Lake	Draw	NLF	7.1	7.0	1.6	1	39	14.4	14.2
August Lake	Draw	NLF	7.2	7.4	1.6	2	46	13.4	13.3
North Ash Lake	Draw	NGP	8.0	8.4	0.3	20	18	14.2	11.9
Allen Lake	Draw	CHF	9.2	9.0	1.4	3	26	17.9	16.9
Jennie Lake	Draw	CHF	8.6	8.5	0.6	15	12	11.7	10.6
Pebble Lake	Draw	CHF	9.2	8.9	1.7	2	4	9.1	8.8
Maine (Round)	Draw	CHF	9.1	8.7	2.1	2	5	6.5	6.2
Fairy Lake	Draw	CHF	9.2	8.8	2.4	102	16	9.1	8.5
Unnamed	Draw	CHF	8.4	8.1	0.9	5	30	18.2	16.8
Snail Lake	Draw	CHF	9.1	8.7	2.1	1	12	7.9	7.4
Fish Lake	Draw	CHF	9.2	7.9	1.2	5	19	9.5	8.4
Alruss	Draw	NLF	7.2	7.1	4.0	1	4	6.1	5.0
Lamb Lake	Draw	NLF	8.2	7.7	2.4	2	10	8.4	8.3
Arthur Lake	Draw	NLF	7.3	7.3	1.5	3	82	13.5	12.9
Sprinq Lake	Draw	NLF	8.0	8.1	2.7	2	26	8.2	7.7
North Drywood	Draw	NGP	8.6	8.6	0.2	69	26	21.5	18.5
Long Lake	Draw	CHF	8.0	8.5	2.2	7	5	6.6	6.1

Lake Name	NES	TP	Total N	N2N3	Nitrate	NH4-N	Chl-a	Cond	Ca	Mg	Na	K	Si	SO4	Cl
	Ref	ug/L	ug/L	mg/L	mg/L	mg/L	ug/L	uS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Cass Lake	NES	20	485	0.002	0.000	0.011	5.4	275	26.7	16.4	5.3	1.7	10.2	2.9	4.9
Fanny Lake	NES	122	1,343	0.002	0.000	0.067	4.2	553	31.7	26.6	44.2	3.8	31.9	31.7	69.5
Darling	NES	15	553	0.000	0.000	0.022	5.6	397	27.1	27.9	8.2	4.1	12.3	11.6	16.3
Nest Lake	NES	83	1,463	0.013	0.006	0.114	58.5	389	32.6	24.9	5.3	3.1	15.3	15.2	15.7
Woodcock	NES	117	3,309	0.000	0.000	0.028	83.4	409	22.2	28.9	12.7	5.3	14.5	1.9	33.8
Okamanpeedan	NES	360	4,153	0.000	0.000	0.011	185.4	393	31.3	23.6	8.3	2.3	52.1	17.9	30.2
South Lake	NES	1,184	15,625	0.000	0.000	0.069	936.0	1523	19.2	24.6	233.3	16.5	29.6	25.1	338.3
West Leaf	NES	18	630	0.000	0.000	0.023	6.1	325	28.7	21.5	3.5	2.0	13.4	8.2	7.0
Upper Sakatah	NES	817	2,338	0.011	0.105	0.918	7.6	425	51.8	17.9	8.4	3.8	34.1	12.6	21.9
Lost Lake	NES	43	847	0.000	0.000	0.017	13.9	371	29.0	12.6	21.5	3.1	1.1	20.7	37.4
Cokato Lake	NES	54	1,361	0.430	0.574	0.179	16.8	510	46.8	30.9	13.0	4.6	5.9	53.0	26.0
Hungry Man	Ref	9	779	0.000	0.000	0.042	2.7	185	23.6	7.8	1.3	0.6	7.1	0.4	0.4
Artichoke Lake	Ref	271	2,475	0.125	0.195	0.273	42.3	968	58.0	81.9	21.5	20.1	34.6	189.1	18.2
Spring Lake	Ref	13	722	0.000	0.000	0.021	1.1	252	35.3	10.3	2.7	0.7	10.2	3.7	0.9
Island	Ref	9	447	0.000	0.000	0.008	2.5	104	13.9	3.8	1.1	0.6	1.1	1.4	0.6
Elk	Ref	9	529	0.000	0.000	0.008	2.9	264	26.1	15.5	5.7	1.5	6.5	1.3	0.6
Bass Lake	Ref	62	1,175	0.009	0.069	0.044	48.0	369	24.6	26.1	6.5	4.7	11.1	10.4	16.8
Cedar Lake	Ref	7	595	0.011	0.110	0.029	1.2	308	27.3	19.6	4.7	2.3	9.6	9.2	6.0
Sarah	Ref	140	1,174	0.021	0.011	0.056	25.1	744	76.2	44.7	8.9	4.3	7.9	210.2	17.2
Elbow Lake	Ref	8	540	0.000	0.000	0.048	5.4	349	25.1	28.5	2.3	3.2	17.7	3.3	2.9
Lake Linka	Ref	19	835	0.000	0.000	0.019	7.0	382	23.9	29.6	9.6	5.2	6.1	9.9	9.1
Beaver Lake	Ref	34	880	0.009	0.093	0.158	13.5	318	29.6	16.4	4.2	2.3	3.0	5.2	15.5
Lake Hattie	Ref	446	2,647	0.180	0.196	0.8	15.4	1041	87.8	73.9	15.6	14.1	32.7	292.6	16.8
Mary Lake	Ref	17	1,065	0.000	0.000	0.026	12.8	398	36.7	22.3	5.1	5.9	3.6	13.3	14.2
Pickerel	Draw	12	491	0.000	0.000	0.012	1.8	260	23.1	16.8	2.8	4.0	1.6	1.4	3.3
Straight Lake	Draw	14	601	0.188	0.259	0.017	7.6	330	33.6	20.0	3.3	1.4	8.8	9.8	6.7
Flat Lake	Draw	24	826	0.000	0.000	0.031	9.4	233	23.9	15.3	2.3	0.9	20.4	0.0	0.6
North Eagle	Draw	239	4,600	0.000	0.000	0.031	126.3	313	20.9	17.9	8.7	5.8	10.2	13.7	22.5
Pine Mountain	Draw	4	401	0.000	0.000	0.02	24.6	280	33.7	12.6	4.3	1.3	13.7	2.3	1.9
Long Lake	Draw	6	306	0.000	0.000	0.015		242	22.8	14.7	3.5	1.2	9.4	1.8	1.2
Mayo Lake	Draw	33	788	0.000	0.000	0.028	20.8	192	27.1	6.4	3.6	1.6	6.5	3.8	4.3
North Mayfield	Draw	17	1,154	0.000	0.000	0.058	7.2	407	28.0	28.6	4.9	4.4	3.6	1.5	9.0
Vesper Lake	Draw	7	443	0.000	0.000	0.006	3.3	35	2.9	1.4	1.1	0.3	5.5	7.0	0.7
Aspen Lake	Draw	8	449	0.000	0.000	0.011	3.4	61	5.4	2.4	1.6	0.6	7.6	5.1	2.6
Richey Lake	Draw	36	1,174	0.000	0.000	0.013		45	5.0	1.6	1.0	0.3	1.8	2.9	0.1
Musquash	Draw	4	285	0.000	0.000	0.007		30	2.8	1.1	0.9	0.3	0.8	3.1	0.3
Pelican Lake	Draw	7	265	0.000	0.000	0.019	3.0	224	25.4	10.3	4.1	1.6	1.7	3.1	2.2
Lookout Lake	Draw	20	622	0.000	0.000	0.011	6.4	68	7.1	2.8	1.7	0.6	2.0	0.0	1.2
Crow Wing	Draw	40	960	0.000	0.000	0.015	20.3	201	25.9	7.7	2.9	1.0	13.3	4.2	3.1
Victoria	Draw	16	508	0.000	0.000	0.016	4.4	380	33.7	23.2	7.0	3.3	2.7	8.6	19.0
Red Rock	Draw	125	2,341	0.026	0.057	0.573	2.8	762	36.7	70.7	11.8	15.9	18.5	131.3	21.8
Lake Nokomis	Draw	13	635	0.003	0.048	0.038	12.1	509	43.9	6.8	46.7	3.3	10.8	8.8	73.9
Upper Hatch	Draw	16	666	0.000	0.000	0.007	5.2	76	9.4	3.0	0.5	0.9	0.5	0.3	0.2
Long	Draw	18	511	0.000	0.000	0.015	8.6	151	19.9	4.7	3.3	1.0	9.7	1.6	1.6
Spring Lake	Draw	68	1,012	0.000	0.000	0.039	46.4	70	5.4	2.3	2.1	5.2	0.8	1.2	4.7
Norway Lake	Draw	35	1,444	0.009	0.010	0.194	21.3	405	27.9	32.3	4.4	6.1	11.0	21.2	15.7
Becousin Lake	Draw	17	651	0.002	0.000	0.016	11.0	36	2.7	2.0	1.1	0.3	0.3	3.3	0.3
August Lake	Draw	20	561	0.000	0.000	0.013		51	4.1	3.0	1.6	0.3	3.1	2.7	1.2
North Ash Lake	Draw	193	1,500	0.000	0.000	0.032	46.2	1120	120.6	73.6	12.7	8.1	37.2	399.3	13.1
Allen Lake	Draw	42	1,340	0.001	0.000	0.277	9.1	327	18.9	31.6	4.1	3.1	12.1	21.5	4.0
Jennie Lake	Draw	69	1,328	0.010	0.005	0.183	32.1	375	28.9	25.0	5.8	5.1	7.2	6.3	26.0
Pebble Lake	Draw	19	1,002	0.000	0.000	0.018	6.8	87	19.5	70.0	18.2	10.8	3.1	75.1	7.9
Maine (Round)	Draw	9	611	0.000	0.000	0.012	2.6	311	26.8	23.4	2.0	2.2	5.4	10.7	6.7
Fairy Lake	Draw	24	854	0.001	0.000	0.021	1.7	239	17.5	20.7	1.5	0.9	13.3	0.0	1.9
Unnamed	Draw	102	1,410	0.000	0.000	0.021	37.9	393	38.3	25.9	3.2	1.6	13.9	6.1	6.2
Snail Lake	Draw	13	760	0.000	0.000	0.015	5.1	437	22.3	10.1	43.9	1.4	0.8	12.4	76.3
Fish Lake	Draw	36	1,198	0.000	0.000	0.024	18.7	375	24.1	21.2	11.6	5.1	3.4	4.1	43.7
Alruss	Draw	4	230	0.000	0.000	0.01	2.1	25	2.3	0.8	0.8	0.5	0.3	1.9	0.2
Lamb Lake	Draw	11	500	0.000	0.000	0.014	3.8	59	7.2	2.0	1.4	0.8	1.2	1.3	0.2
Arthur Lake	Draw	12	279	0.004	0.000	0.024		41	4.0	1.9	1.3	0.3	7.2	0.6	0.2
Sprinq Lake	Draw	12	551	0.008	0.033	0.034	5.1	121	14.6	5.0	2.6	0.7	8.5	3.3	2.4
North Drywood	Draw	407	5,378	0.000	0.000	0.047	256.3	849	57.0	66.0	13.0	13.7	39.7	243.7	20.5
Long Lake	Draw	5	406	0.000	0.000	0.028	6.0	420	46.6	23.1	4.6	2.7	5.2	9.3	11.1

Lake Name	Region	Ca	Mg	Na	K	NH4-N	ANC	SO4	Cl	No3	Cation	Anion	Balance	Cat/Bal.
		ueq/L	ueq/L	ueq/L	ueq/L	ueq/L	ueq/L	ueq/L	ueq/L	ueq/L	ueq/L	ueq/L	C-A	%
Cass Lake	NLF	1332	1350	229	43	1	2839	61	138	0	2954	3037	-84	97
Fanny Lake	CHF	1581	2188	1924	98	5	3211	660	1960	0	5796	5831	-35	99
Darling	CHF	1351	2299	355	105	2	3547	242	461	0	4112	4250	-138	97
Nest Lake	CHF	1625	2051	232	78	8	3368	317	442	0	3994	4128	-133	97
Woodcock	CHF	1106	2378	552	135	2	3456	39	953	0	4173	4448	-275	94
Okamanpeedan	WCP	1560	1945	362	58	1	2990	373	852	0	3926	4215	-289	93
South Lake	CHF	956	2028	10148	421	5	4186	523	9541	0	13557	14250	-693	95
West Leaf	CHF	1434	1773	151	51	2	3124	172	197	0	3409	3492	-83	98
Upper Sakatah	CHF	2586	1475	365	98	66	3925	262	617	8	4589	4812	-222	95
Lost Lake	NLF	1448	1039	933	80	1	2218	430	1056	0	3500	3704	-204	95
Cokato Lake	CHF	2337	2544	564	119	13	3625	1103	734	41	5576	5503	73	101
Hungry Man	NLF	1178	638	58	16	3	1883	9	12	0	1892	1903	-11	99
Artichoke Lake	NGP	2894	6742	937	513	20	6534	3938	514	14	11106	11000	106	101
Spring Lake	NLF	1760	848	118	18	2	2559	78	25	0	2745	2661	84	103
Island	NLF	695	315	48	16	1	982	30	17	0	1074	1028	46	104
Elk	NLF	1300	1272	250	39	1	2843	27	17	0	2862	2887	-25	99
Bass Lake	WCP	1230	2148	284	119	3	3129	217	474	5	3783	3825	-42	99
Cedar Lake	CHF	1363	1609	205	59	2	2996	192	168	8	3237	3364	-126	96
Sarah	NGP	3804	3675	386	111	4	3460	4376	486	1	7980	8323	-343	96
Elbow Lake	CHF	1253	2348	99	81	3	3660	69	82	0	3785	3811	-27	99
Lake Linka	CHF	1192	2432	416	132	1	3752	207	257	0	4174	4215	-41	99
Beaver Lake	WCP	1475	1346	184	59	11	2638	109	438	7	3075	3191	-116	96
Lake Hattie	NGP	4380	6084	680	361	57	4965	6092	473	14	11562	11543	18	100
Mary Lake	CHF	1832	1833	223	152	2	3477	276	401	0	4042	4154	-113	97
Pickerel	NLF	1151	1385	122	102	1	2677	29	94	0	2760	2800	-40	99
Straight Lake	NLF	1678	1645	143	36	1	3182	204	189	19	3503	3594	-91	97
Flat Lake	NLF	1190	1259	98	23	2	2539	0	16	0	2573	2555	17	101
North Eagle	WCP	1040	1472	380	149	2	2333	286	634	0	3043	3253	-210	94
Pine Mountain	NLF	1683	1039	188	32	1	2957	49	53	0	2944	3058	-114	96
Long Lake	NLF	1137	1206	154	31	1	2541	38	33	0	2530	2612	-82	97
Mayo Lake	NLF	1354	527	156	42	2	1851	80	121	0	2081	2052	29	101
North Mayfield	CHF	1399	2351	213	112	4	3990	31	255	0	4079	4276	-197	95
Vesper Lake	NLF	144	111	47	8	0	87	146	20	0	311	253	58	123
Aspen Lake	NLF	272	202	71	16	1	337	106	74	0	561	517	44	108
Richey Lake	NLF	251	133	44	7	1	315	60	3	0	435	378	57	115
Musquash	NLF	138	89	40	8	1	178	65	8	0	275	250	25	110
Pelican Lake	NLF	1267	848	176	41	1	2279	64	63	0	2333	2406	-73	97
Lookout Lake	NLF	353	230	74	16	1	610	0	35	0	673	644	29	104
Crow Wing	NLF	1293	635	124	25	1	2055	87	89	0	2077	2230	-153	93
Victoria	CHF	1683	1910	303	85	1	3408	179	537	0	3981	4124	-143	97
Red Rock	NGP	1833	5815	514	405	41	5603	2734	615	4	8609	8956	-347	96
Lake Nokomis	CHF	2191	556	2029	86	3	2742	184	2085	3	4864	5015	-151	97
Upper Hatch	NLF	470	244	22	23	1	724	6	5	0	760	735	26	103
Long	NLF	993	388	142	26	1	1474	33	44	0	1549	1551	-2	100
Spring Lake	CHF	268	188	90	134	3	471	25	133	0	682	629	52	108
Norway Lake	CHF	1394	2657	192	156	14	3419	441	443	1	4413	4303	110	103
Becousin Lake	NLF	136	165	46	8	1	227	68	7	0	355	302	53	117
August Lake	NLF	207	245	70	8	1	349	57	34	0	531	439	92	121
North Ash Lake	NGP	6018	6056	553	207	2	4050	8314	369	0	12837	12733	104	101
Allen Lake	CHF	943	2599	178	79	20	3256	447	114	0	3819	3817	1	100
Jennie Lake	CHF	1444	2057	253	132	13	3015	132	735	0	3899	3882	16	100
Pebble Lake	CHF	974	5757	790	275	1	5940	1563	224	0	7797	7728	70	101
Maine (Round)	CHF	1335	1927	86	56	1	2998	224	190	0	3406	3412	-6	100
Fairy Lake	CHF	875	1707	67	24	2	2631	0	53	0	2673	2684	-10	100
Unnamed	CHF	1911	2128	140	40	2	3998	127	174	0	4221	4300	-79	98
Snail Lake	CHF	1115	830	1910	36	1	1646	259	2151	0	3892	4056	-164	96
Fish Lake	CHF	1201	1743	505	130	2	2337	85	1234	0	3581	3656	-75	98
Alruss	NLF	116	65	35	13	1	171	40	5	0	230	215	14	107
Lamb Lake	NLF	357	162	60	19	1	536	28	7	0	599	570	28	105
Arthur Lake	NLF	201	155	58	9	2	358	12	5	0	424	375	49	113
Sprinq Lake	NLF	731	410	114	19	2	1124	68	68	2	1275	1263	12	101
North Drywood	NGP	2844	5429	564	350	3	3825	5073	578	0	9191	9475	-284	97
Long Lake	CHF	2324	1897	201	68	2	4299	194	313	0	4492	4806	-314	93

Appendix II. Water chemistry comparison of EPA and MPCA (MDH) data. South Lake not included in averages.

				pH - Lab EPA	pH - Field	pH diff	diff / %EPA	TP EPA	TP MDH	TP diff	diff / %EPA
NLAP Site ID	Lake Name	County	Sample Date					ug/L	µg/L		
NLA06608-0110	Pickerel	BECKER	7/31/2007	8.6	8.6	0.0	0%	12	9	3	25%
NLA06608-0366	Straight Lake	BECKER	7/31/2007	8.5	8.4	0.1	1%	14	15	-1	7%
NLA06608-0494	Pine Mountain	CASS	7/11/2007	8.4	8.1	0.3	3%	4	23	-19	475%
NLA06608-0942	Long Lake	CASS	7/10/2007	8.6	8.3	0.3	3%	6	11	-5	83%
NLA06608-1262	Mayo Lake	CASS	7/9/2007	8.5	8.5	-0.1	1%	33	40	-7	21%
NLA06608-0238	Pelican Lake	CROW WING	7/11/2007	8.5	8.3	0.2	2%	7	8	-1	14%
NLA06608-0990	Crow Wing	CROW WING	7/30/2007	8.7	8.6	0.1	1%	40	45	-5	13%
NLA06608-0622	Victoria	DOUGLAS	7/24/2007			0.0		16	18	-2	13%
NLA06608-0679	Lake Nokomis	HENNEPIN	6/27/2007	8.5	8.3	0.2	2%	13	36	-23	177%
NLA06608-0215	Nest Lake	KANDIYOHI	8/22/2007	8.4	8.6	-0.2	3%	83	96	-13	16%
NLA06608-1383	Norway Lake	KANDIYOHI	8/22/2007	8.6	8.7	-0.1	2%	35	46	-11	31%
NLA06608-1175	Jennie Lake	MEEKER	8/21/2007	8.5	8.6	-0.1	1%	69	68	1	1%
NLA06608-0174	Pebble Lake	OTTER TAIL	7/25/2007	8.9	9.2	-0.4	4%	19	20	-1	5%
NLA06608-0878	West Leaf	OTTER TAIL	8/1/2007	8.4	8.5	-0.1	1%	18	17	1	6%
NLA06608-1198	Maine (Round)	OTTER TAIL	7/25/2007	8.7	9.1	-0.4	5%	9	11	-2	22%
NLA06608-0935	Fish Lake	SCOTT	8/6/2007	7.9	9.2	-1.3	14%	36	30	6	17%
NLA06608-0551	Cokato Lake	WRIGHT	8/20/2007	8.5	8.3	0.2	2%	54	54	0	0%
NLA06608-0743	Long Lake	WRIGHT	6/26/2007	8.5	8.0	0.5	6%	5	22	-17	340%
NLA06608-0759	Okamanpeedan	MARTIN	8/7/2007	8.9	8.9	0.0	0%	360	383	-23	6%
NLA06608-0279	North Eagle	BLUE EARTH	8/8/2007	8.7	9.5	-0.9	9%	239	245	-6	3%
NLA06608-0174	Pebble Lake	OTTER TAIL	8/28/2010	8.9	8.5	0.4	4%	13	20	-7	54%
average						***0.3***	***3%***			***7***	***63%***
count										***21***	
NLA06608-0167	South Lake	MCLEOD	7/23/2007	9.8	9.6	0.2	2%	1,184	1150	34	3%

	TN EPA	TKN MDH	TN diff	diff / %EPA	Chl-a EPA	Chl-a MDH	Chl-a diff	diff / %EPA	Cl EPA	CL MDH	Cl diff	diff / %EPA	Color EPA	Color MDH	Color diff	diff / %EPA
Lake Name	ug/L	µg/L			ug/L	µg/L			mg/L	mg/L			PCU	PCU		
Pickerel	491	610	-119	24%	1.8	1.66	0.1	6%	3.3	3.3	0.0	1%	4	5	-1.0	25%
Straight Lake	601	410	191	32%	7.6	4.29	3.3	43%	6.7	6.7	0.0	0%	12	5	7.0	58%
Pine Mountain	401	460	-59	15%	24.6	3.79	20.9	85%	1.9	2	-0.1	7%	3	5	-2.0	67%
Long Lake	306	400	-94	31%					1.2	1.3	-0.1	10%	18	5	13.0	72%
Mayo Lake	788	1170	-382	48%	20.8	18.1	2.7	13%	4.3	4.5	-0.2	5%	40	50	-10.0	25%
Pelican Lake	265	430	-165	62%	3.0	2.22	0.8	25%	2.2	2.3	-0.1	3%	0	5	-5.0	
Crow Wing	960	1100	-140	15%	20.3	18.3	2.0	10%	3.1	3.1	0.0	2%	12	5	7.0	58%
Victoria	508	670	-162	32%	4.4	3.02	1.4	31%	19.0	20	-1.0	5%	6	5	1.0	17%
Lake Nokomis	635	910	-275	43%	12.1	9.35	2.8	23%	73.9	79	-5.1	7%	6	10	-4.0	67%
Nest Lake	1,463	1600	-137	9%	58.5	44.2	14.3	24%	15.7	17	-1.3	8%	14	5	9.0	64%
Norway Lake	1,444	1890	-446	31%	21.3	21.9	-0.6	3%	15.7	16	-0.3	2%	11	20	-9.0	82%
Jennie Lake	1,328	1790	-462	35%	32.1	36.5	-4.4	14%	26.0	27	-1.0	4%	12	5	7.0	58%
Pebble Lake	1,002	970	32	3%	6.8	6.09	0.7	10%	7.9	8.2	-0.3	3%	4	10	-6.0	150%
West Leaf	630	760	-130	21%	6.1	6.84	-0.7	12%	7.0	7.1	-0.1	2%	7	5	2.0	29%
Maine (Round)	611	590	21	3%	2.6	2.81	-0.2	6%	6.7	7	-0.3	4%	5	5	0.0	0%
Fish Lake	1,198	1240	-42	4%	18.7	18	0.7	4%	43.7	46	-2.3	5%	19	5	14.0	74%
Cokato Lake	1,361	1200	161	12%	16.8	15	1.8	11%	26.0	27	-1.0	4%	10	20	-10.0	100%
Long Lake	406	790	-384	95%	6.0	5.23	0.8	13%	11.1	11	0.1	1%	5	20	-15.0	300%
Okamanpeedan	4,153	4840	-687	17%	185.4	313	-127.6	69%	30.2	33	-2.8	9%	20	30	-10.0	50%
North Eagle	4,600	4340	260	6%	126.3	115	11.3	9%	22.5	25	-2.5	11%	20	30	-10.0	50%
Pebble Lake	803	910	-107	13%	6.0					8.2			10	5	5.0	50%
			212	***26%***			***10.4***	***22%***			***1***	***5%***			***7***	***70%***
			21				***19***								***21***	
South Lake	15,625	12700	2,925	19%	936.0	696	240.0	26%	338.3	300	38.3	11%	35	60	-25.0	71%

Appendix III. Water quality data legend, notes and CDF construction description.

VARIABLE NAME	VARIABLE LABEL
AREA_HA	Lake area (hectares) from NHD
DATE_COL	Date of site visit
EST_Mean_Z	Estimated Mean Depth in meters calculated from estimated volume, likely biased low
PH_LAB	pH Measured at WRS Laboratory (initial pH of ANC titration)
COND	Conductivity (uS/cm @ 25 C)
ANC	Gran ANC (ueq/L)
TURB	Turbidity (NTU)
COLOR	Color (PCU)
TOC	Total Organic Carbon (mg/L)
DOC	Dissolved Organic Carbon (mg/L)
PTL	Total Phosphorus (µg/L)
NTL	Total Nitrogen (µg/L)
NTL_PPM	Total Nitrogen N (mg/L)
NH4N_PPM	Ammonium (mg N/L)
NH4	Ammonium (ueq/L)
NO3_NO2	Nitrate + Nitrite by Flow Injection Analysis (mg N/L)
NO3N_PPM	Nitrate (mg N/L)
NO3	Nitrate (ueq/L)
CL_PPM	Chloride (mg/L)
CL	Chloride (ueq/L)
SO4_PPM	Sulfate (mg/L)
SO4	Sulfate (ueq/L)
CA_PPM	Calcium (mg/L)
CA	Calcium (ueq/L)
MG_PPM	Magnesium (mg/L)
MG	Magnesium (ueq/L)
NA_PPM	Sodium (mg/L)
NA	Sodium (ueq/L)
K_PPM	Potassium (mg/L)
K	Potassium (ueq/L)
SIO2	Silica (mg/L SiO2)
SITE_ID	ID assigned to each site
CNTYNAME	County name
SITE_TYPE	Site type (PROB=probability lake, REF= candidate reference lake
ECO_L3_NM	Omernik level 3 ecoregion name
NESLAKE	Natl. Eutrophication Survey lake (sampled in 1970s)

Definition of a CDF curve and weighted vs. un-weighted results (Kiddon 2010)

Definition of a CDF curve: A Cumulative Distribution Function (CDF) expresses the relative ranking of a value in a dataset, for example the ranking of one lake's chlorophyll value relative to values in all lakes of a state or region. A CDF curve plots the rank on the Y-axis (values = zero to one) vs. the measured parameter values on the X-axis. The CDF curve is interpreted as the probability (Y axis) that a lake will exhibit a value less than or equal to a given parameter value (read on the X-axis).

Weighted vs. Un-weighted CDF: In an Un-weighted CDF, all lakes have equal weighting; therefore, the probability is simply the percent rank of the lake's value in a list of all values measured in an unbiased manner. The spreadsheet uses the Excel function PERCENTRANK in calculations. The Un-weighted CDF curve is relatively smooth, with uniform vertical spacing between observations. Un-weighted CDFs are appropriate in cases where all lakes in a region have equal probability of being sampled. This is not the case in the NLA design (see below). An Un-weighted CDF of NLA observations gives undue emphasis to larger lakes in lake-poor localities.

For a Weighted CDF, each lake is weighted to reflect its surface area and ubiquity in one of nine ecoregions, Small lakes in lake-rich regions are weighted more heavily because they represent a greater portion of the entire lake population. In other words, lake selection is biased to assure adequate representation of lake size and ubiquity in an ecoregion, and the importance of observations is re-balanced by the weighting factor. Operationally in this spreadsheet, lakes are listed in increasing order of parameter value, a cumulative sum of weights is calculated for each lake (i.e., the sum of all prior weights in the list), and this value is divided by the sum of all weights, thus creating an uneven progression of values ranging from zero to one. The Weighted CDF curve is therefore irregular, with large vertical jumps reflecting enhanced weighting of an observation. A Weighted CDF provides a balanced estimate of all lakes in a region

Tips regarding interpretation of CDF curves: For parameters for which larger values are considered detrimental (e.g., Total P), portions of the CDF plot positioned to the right and below the CDF curve denote poorer conditions. Conversely, portions of the plot positioned to the left and upward of the CDF curve denote better conditions. The opposite relationships hold for parameters for which lower parameter values are detrimental (e.g., Secchi depth or DO). Thus, for example, when comparing State and regional CDF curves for Total P, the case where the State CDF curve is positioned to the right of the regional curve indicates that the State exhibits poorer conditions than the region as a whole. Conversely, a State CDF curve for DO that is displaced to the right relative to the regional curve signifies that that state exhibits better conditions (higher DO values) than the region.