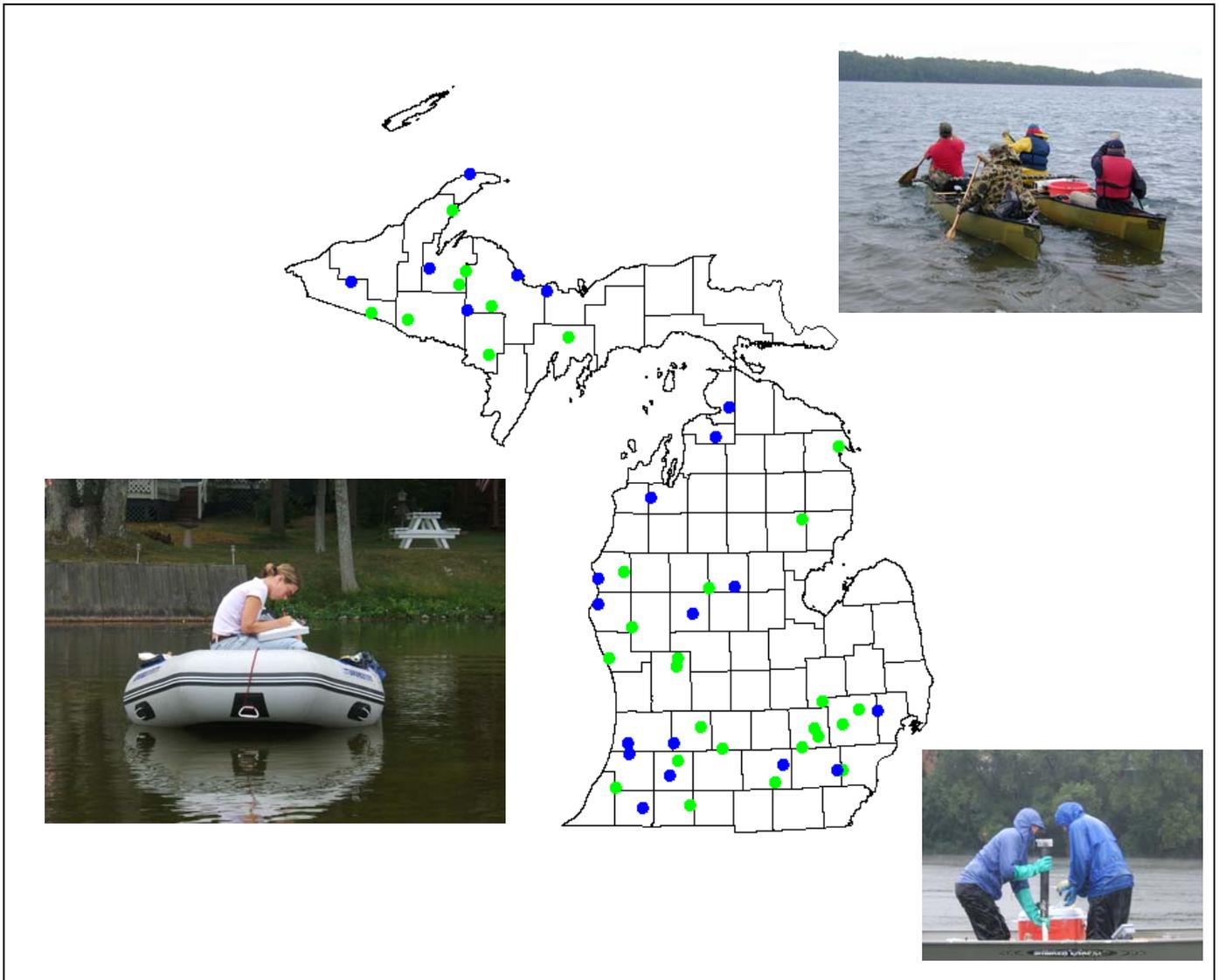


# Michigan National Lakes Assessment Project 2007



## Summary of Results

## **Acknowledgements**

This report was prepared by Ralph Bednarz, Michigan Department of Environmental Quality (Retired) on assignment as a United States Environmental Protection Agency, Senior Environmental Employment Program, enrollee. The author would like to thank management and staff of the Michigan Department of Environmental Quality, Water Resources Division, and the United States Environmental Protection Agency, National Lake Assessment, program collaborators who contributed to this project. The author is especially appreciative to John Kiddon, United States Environmental Protection Agency, who developed the National Lake Assessment tools (LakeTool and Lake Condition Calculator) used in this project.

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Appendix 1b. NLA-Michigan Lakes: Organic carbon, Color, pH, ANC, Secchi, and Turbidity

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Appendix 1d. NLA-Michigan Lakes: Conductivity, Cations, and Anions

## List of Acronyms

ANC	Acid neutralizing capacity
CLMP	Cooperative Lakes Monitoring Program
CMI	Clean Michigan Initiative
DOC	Dissolved Organic Carbon
GLEC	Great Lakes Environmental Center
IBI	Index of Biotic Integrity
LDCI	Lake Diatom Condition Index
LWQA	Lake Water Quality Assessment
MDEQ	Michigan Department of Environmental Quality
MDNR	Michigan Department of Natural Resources
mg/L	Milligrams per liter
NES	National Eutrophication Study
NLA	National Lakes Assessment
NTU	Nessler Turbidity Units
O/E	Observed/Expected
PCU	Platinum-cobalt units
STP	Status and Trends Program
S.U.	Standard units
TOC	Total Organic Carbon
TN	Total Nitrogen
TP	Total Phosphorus
TSI	Trophic State Index
ug/L	Micrograms per liter
UMW	Upper Midwest
USEPA	United States Environmental Protection Agency
WWTP	Wastewater Treatment Plant

## Introduction

The United States Environmental Protection Agency (USEPA) is implementing a series of National Aquatic Resource surveys to assess the quality of the nation's waters. In 2007, the USEPA and its state and tribal partners conducted the first national survey of the nation's lakes, ponds, and reservoirs. This National Lakes Assessment (NLA) Survey is designed to provide statistically valid regional and national estimates of the condition of lakes as well as statewide assessments for those states who participated in the NLA Survey. Consistent sampling and analytical procedures ensure that the results can be compared across the nation.

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

- What percentage 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, bacteria, and lakeshore development?

The sampling design for the NLA Survey is a probability-based sampling site network that provides statistically valid estimates of the condition of about 50,000 lakes nationwide, with a known degree of confidence. A total of 1,028 lakes in the conterminous United States were included in the 2007 NLA Survey. The sample set was comprised of natural and built freshwater lakes and reservoirs greater than 4 hectares (10 acres) and at least one meter in depth. The lake selection process provided for five size class categories, as well as spatial distribution across the nation and nine aggregated ecoregions. Sample sites were selected at random to represent the condition of the larger population of lakes across the nation and each ecoregion. The design also incorporated a representative subset of the lakes that were included in the lake National Eutrophication Study (NES), conducted by the USEPA in 1972 (USEPA, 1974).

Michigan received 29 lakes as part of the original draw of lakes for the national survey and added 21 lakes to the survey design for the state-scale assessment. Four lakes from the suite of national reference lakes selected by the USEPA were also located in Michigan.

The typical sampling effort at each site included a variety of samples and measurements collected at a mid-lake index site, which was often at the deepest point in the lake. Samples included 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 (TP) (based on top and bottom slices from the core) and surface sediment sample for mercury. Michigan added discrete surface and hypolimnetic (sub-themoclone) water samples for mercury analysis to the survey indicators. In addition, ten random nearshore sites were qualitatively assessed for various littoral (nearshore) and riparian (shoreline) habitat-related measures. A bacterial indicator (enterococci) sample was collected at one of the nearshore sites.

This report presents the findings of the state-scale assessment for Michigan's lakes. The structure of this report is patterned after the NLA Survey national report (USEPA, 2009) and Minnesota's NLA Survey state-specific assessment report (Heiskary and Lindon, 2010), which provide a basis for comparing regional and state-level NLA Survey results. More information on

the overall NLA Survey, field methods, and the assessment process, as well as the final national report, can be found at: <https://www.epa.gov/national-aquatic-resource-surveys/nla>.

## **Michigan's NLA Survey Overview and Report Focus**

Michigan's 2007 NLA effort was led by the Michigan Department of Environmental Quality (MDEQ). The project was implemented under contract by the Great Lakes Environmental Center (GLEC) (<https://www.glec.com>) with assistance from the USEPA Senior Environment Employment Program enrollees working for the MDEQ. The project was funded with USEPA Section 106 grant resources and Clean Michigan Initiative funds.

Initially, 29 randomly selected lakes in Michigan were included as part of the national survey. Michigan included 21 additional lakes from the national draw to provide for the statistically-based estimates of condition statewide (Figure 1). Based on the NLA survey design, 50 randomly selected and sampled lakes was the minimum number needed to apply the results statewide with  $\pm 15\%$  margin of error and 95% confidence. In addition to the 50 randomly selected lakes, 4 lakes in Michigan were selected as part of the suite of national reference sites and sampled by the USEPA for the NLA. Appendix 1 includes a listing of all 54 Michigan lakes sampled during the NLA Survey.

The purpose of this report is to provide a summary of the findings for trophic status indicators and related water chemistry, ecological integrity indicators, and recreational indicators for Michigan's lakes based on the NLA Survey data collected during the summer of 2007. Given the NLA Survey statistically-based design, this dataset provides a good basis for describing the typical range of, and interrelationships among, constituents in Michigan's lakes on a statewide basis. The state-scale assessment is compared with the national and regional findings and there is additional analysis of the subset of eight NES lakes for Michigan included in the sample design. These results also are compared to selected results from the MDEQ Lake Water Quality Assessment (LWQA) monitoring project, the Michigan Department of Natural Resource's (MDNR) Status and Trends Program (STP), and Michigan's Cooperative Lakes Monitoring Program (CLMP) volunteer monitoring network.

## **Methods**

All lakes were sampled once and four lakes were revisited for a second sampling: Bogie Lake (Lake ID: NLA06608-0010), Lake Keewaydin (Lake ID: NLA06608-1998); Crooked Lake (Lake ID: NLA06608-1334); and Lake Gogebic (Lake ID: NLA06608-1358). The results of revisit sampling from these four lakes were excluded from statistical analysis so that all lakes were represented by a single sample event collected in July-September of 2007. The randomly selected 50 lakes were sampled by the GLEC (Michigan Lower Peninsula lakes) and MDEQ Senior Environment Employment enrollees (Michigan Upper Peninsula lakes). The four reference lakes were sampled by USEPA staff.

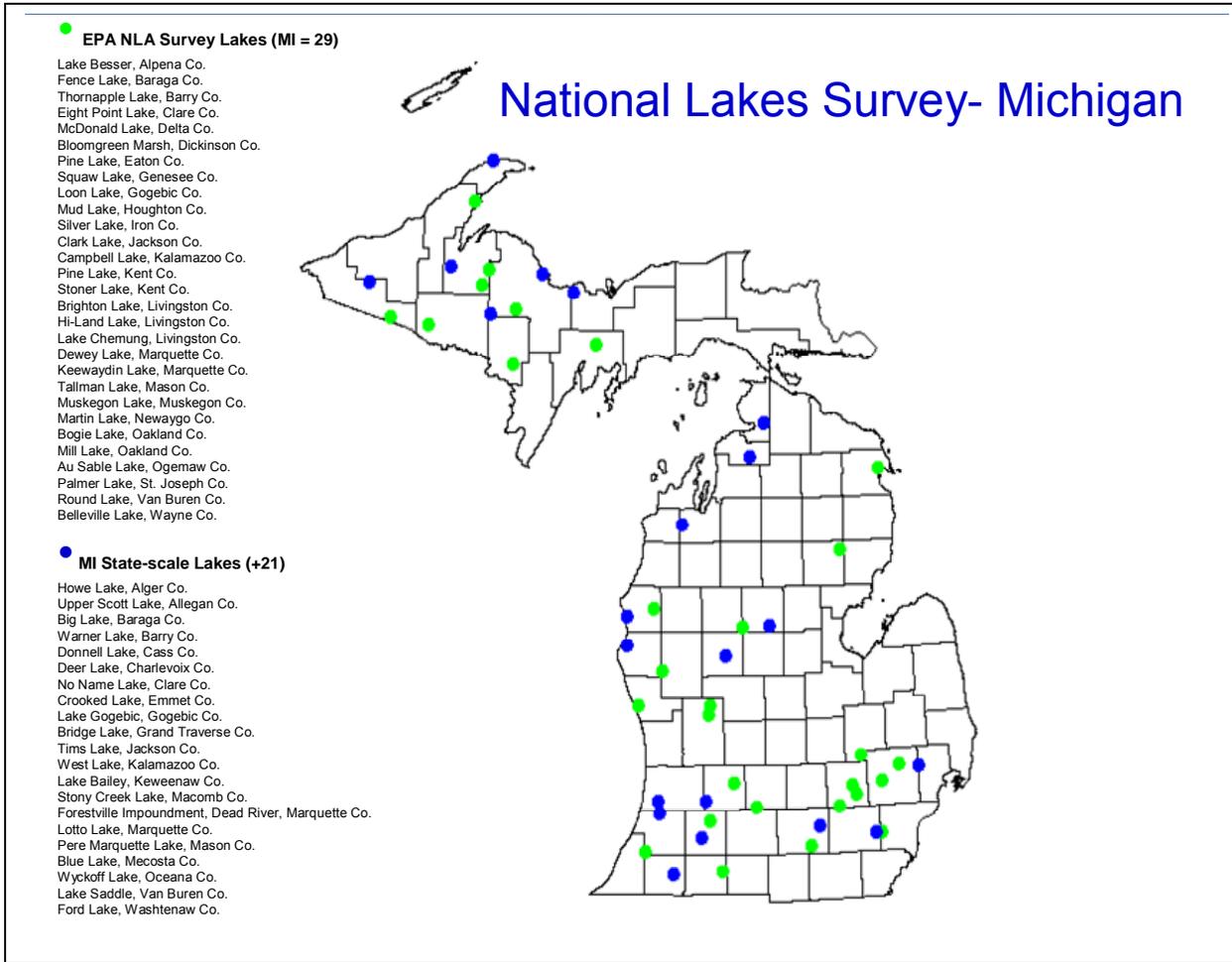


Figure 1. NLA Survey – Michigan Lakes.

All laboratory analyses were conducted by the USEPA, or other federal or private laboratories contracted by the USEPA to analyze the various NLA Survey indicator samples. Details on methods and quality assurance may be found at:

<https://www.epa.gov/national-aquatic-resource-surveys/nla>.

The MDEQ LWQA monitoring program and CLMP volunteer monitoring network results referred to in this report were from samples analyzed by the MDEQ Environmental Laboratory. Relevant details on methods and quality assurance may be found in Bednarz et al. (2008) and Bednarz et al. (2007), respectively. The MDNR STP results were from samples analyzed by the MDEQ Environmental Laboratory; or from TriMatrix Laboratories ([www.trimatrixlabs.com](http://www.trimatrixlabs.com)), White Water Associates, Inc. ([www.white-water-associates.com/](http://www.white-water-associates.com/)), Central Michigan University Michigan Water Resource Center (*The link provided was broken and has been removed*) or GLEC (<https://www.glec.com/>) laboratories. Relevant details on methods and quality assurance for the MDNR STP may be found in Wehrly et al. (2012a).

The 2007 NLA data are summarized at the state level and compared to the national and regional results. The USEPA NLA Survey results are compared geographically based on aggregated Level 3 ecoregions (Figure 2). All three mapping levels (state, aggregated ecoregion, and nation) are incorporated in this report. Microsoft Excel-based mapping and

analysis tools (NLA LakeTool data viewer, NLA Condition Calculator), developed by the USEPA (Kiddon, 2010; 2011a; and 2011b) were used to assist with the data analysis and presentation. These tools provide for NLA data analysis and comparison at the national, ecoregion, and state levels. The tools also allow for user-defined regions (e.g., USEPA Regions or Subregions). The tools let the user select for a weighted or unweighted data analysis, define the scale at which to analyze and present the data, and define three or four thresholds for analyzing each parameter. State-specific trophic status criteria and actual water quality standards are used for the analysis thresholds when available. Otherwise, ecoregion derived thresholds, in particular interquartile ranges (25<sup>th</sup> and 75<sup>th</sup> percentiles), are used for data presentation and mapping purposes.

Tabulated percentile distributions of the weighted physical and chemical constituent data and graphical illustrations of select ecological, trophic, and recreation condition indicators are used to describe parameter distributions for Michigan, the Upper Midwest (UMW) ecoregion, and the nation based on the sampled lakes. Each lake is weighted to reflect its surface area and proportion in the size-class assessment unit and it provides a balanced estimate of all lakes in the state or region (USEPA, 2009; Kiddon, 2011c).

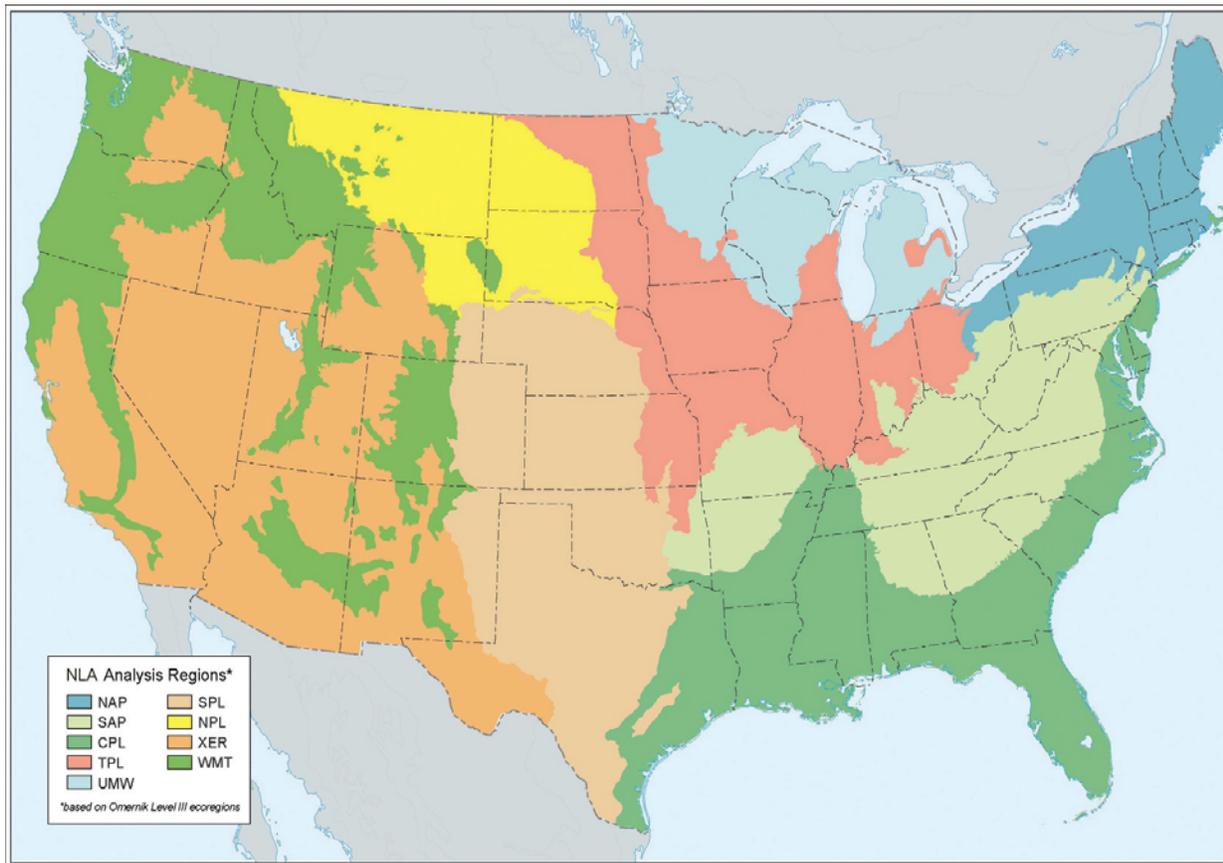


Figure 2. Ecoregions used in the NLA (based on Omernik Level III ecoregions).  
(Source: USEPA)

## Results and Discussion

### *The Condition of Michigan Inland Lakes*

The NLA Survey data analysis used three approaches to assess lake condition (USEPA, 2009). The first approach evaluated whether lakes are able to support healthy aquatic plant and animal communities. The NLA team evaluated key stressors to lake biota, such as chemical and physical habitat attributes, and ranked the stressors in order of importance. The second approach evaluated recreational suitability by assessing the risk of exposure to algal toxins. The third approach evaluated trophic state based on chlorophyll-*a* levels. This report incorporates these three approaches to assess the condition of Michigan's lakes and it extends the trophic condition assessment by analyzing Secchi transparency and TP trophic status indicators along with chlorophyll-*a*. A summary of the water chemistry and related variables for Michigan lakes based on the 2007 NLA data is also presented.

#### Biological Condition of Michigan Lakes

A healthy lake generally contains a varied and abundant biological community that is well balanced in terms of species numbers and diversity. The presence, number, and diversity of fish, insects, algae, macrophytes, and other organisms in and around the lake characterize the health and biological productivity of the lake ecosystem. The number and kinds of plant and animal species present in a lake system are a direct measure of the lake's health.

The 2007 NLA Survey's biological condition assessment is based on information from two biological communities – the phytoplankton and zooplankton assemblages (USEPA, 2009). For the 2007 survey, the primary gauge of biological health is an index of taxa loss, which is applied to the phytoplankton and zooplankton data. The planktonic taxa loss indicator is used as the main measure of overall lake condition since it is based on both plant and animal data. A second method for assessing lake health uses an index of biotic integrity (IBI) based on the sediment diatom data.

Both approaches use the biological reference conditions developed from constructed sets of reference lakes as described in the NLA Survey report technical appendix (USEPA, 2010). Since only a portion of the initial reference lakes selected for the NLA survey were found to be of reference quality, the USEPA used the results from these lakes as well as high quality lakes from the random site selection process to establish "least disturbed" condition benchmarks based on statistically derived reference screening criteria. These benchmarks were established for lakes in the aggregate ecoregions as well as nation's lakes overall.

#### *Index of Taxa Loss*

The 2007 NLA Survey uses a planktonic observed/expected (O/E) taxa loss model to assess the condition of the primary producers (phytoplankton community) and consumers (zooplankton community) in the lake. The O/E model compares taxa found in individual lake samples with those expected to be present in reference lakes. The O/E method is widely used nationally and internationally to assess the condition of aquatic communities.

The O/E values are commonly interpreted as the percentage of the expected taxa present based on reference lake assemblages compiled from a regional basis. The higher the percentage of expected taxa present, the healthier the biological condition of the lake. As with all indicators, the O/E values must be interpreted relative to the quality of reference sites

because the quality of reference sites available in a region sets the bar for what taxa may be expected. For the 2007 NLA, reference condition was established as the least disturbed condition for each region. Regional-specific O/E models to predict the extent of phytoplankton and zooplankton taxa loss across lakes of the United States were developed (USEPA, 2010). Three categories of plankton taxa loss were established: good (<20% taxa loss), fair (20-40% taxa loss), and poor (>40% taxa loss).

The planktonic O/E taxa loss model shows that 86% of Michigan lakes are in good biological condition compared with 56% of lakes nationally and 91% for the UMW ecoregion (Figure 3). Approximately 10% of Michigan lakes are in fair biological condition and only 3% of Michigan lakes are in poor biological condition using this indicator.

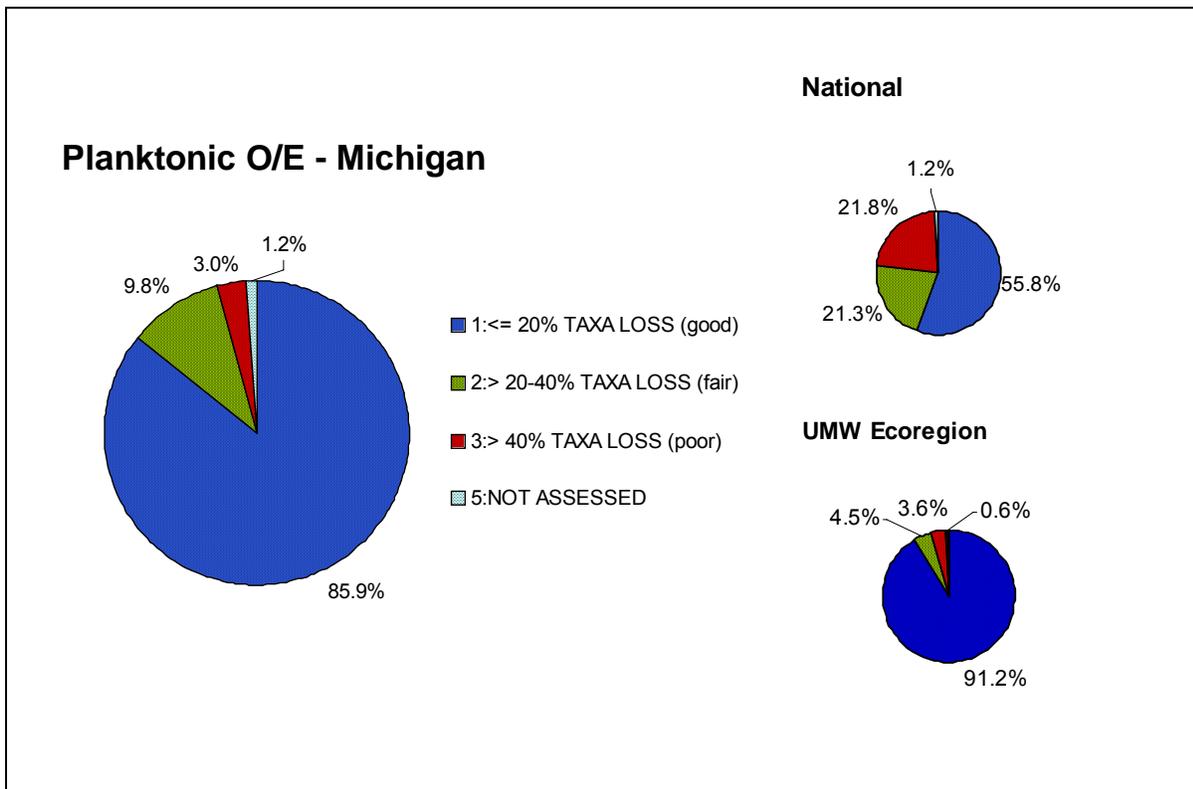


Figure 3. Biological Condition – The Index of Taxa Loss (Planktonic O/E).

#### Index of Biological Integrity

Diatom reconstruction using lake sediment cores can provide valuable information on water quality and biological integrity. The Lake Diatom Condition Index (LDCI), or the Diatom IBI, is a multi-metric indicator used to assess the health of a lake based on the sum of scores for a variety of individual metrics. For the NLA, the metrics used to develop the LDCI include five characteristics of diatom assemblages that are routinely used to evaluate biological integrity: (1) taxonomic richness; (2) taxonomic composition; (3) taxonomic diversity; (4) morphology; and (5) pollution tolerance. Regional-specific disturbance thresholds (i.e., good, fair, poor) were established based on percentages of reference lake distributions of LDCI (USEPA, 2010).

The biological condition of Michigan’s lakes using the LDCI indicates that 86% of the lakes are in least disturbed (good) or intermediate disturbed (fair) condition compared with 74% of lakes nationally and 78% for the UMW ecoregion (Figure 4). Nearly 13% of Michigan lakes are considered to be of poor biological condition using the LDCI.

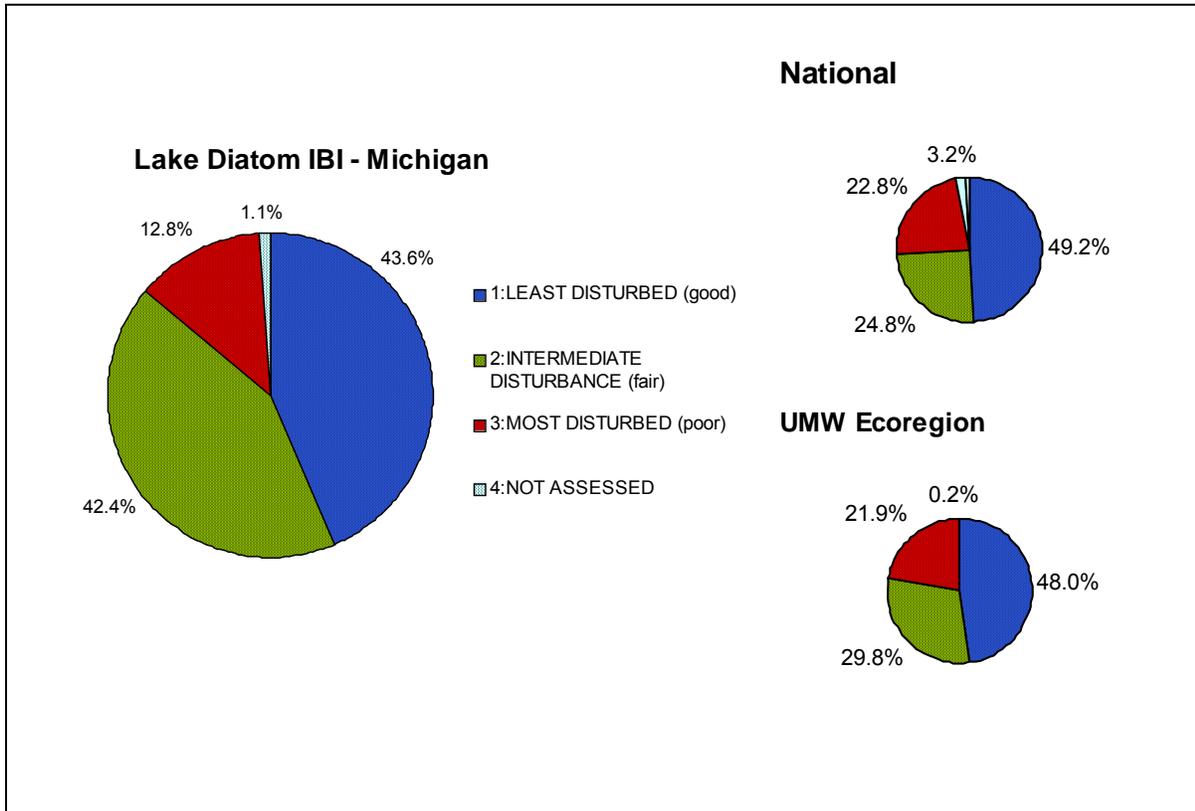


Figure 4. Biological Condition – LDCI.

The national results of the planktonic O/E analysis are similar to the national results of the diatom LDCI analysis. This agreement is not the same for lakes in the UMW ecoregion, including Michigan lakes, where a smaller proportion of lakes are assessed as good and a larger proportion of lakes are assessed as fair using the lake diatom IBI, or LDCI. A possible explanation of these differences is that the taxa loss index examines a specific aspect of biological condition, biodiversity loss, for the total phytoplankton and zooplankton community of the lake whereas the IBI analysis combines multiple characteristics of a specific algal assemblage (diatoms) to evaluate overall biological condition (USEPA, 2010). For this instance, the two groups may be responding differently to the stresses impacting lakes or to different stresses.

#### Stressors of Lake Condition

In natural environments such as lake ecosystems, a stressor can be anything chemical, biological, or physical that has the potential to alter an organism’s ability to thrive. Drought or rapid draw-down, contaminants (e.g., metals, pesticides, excessive nutrients), and human activities can be stressors. An important dimension of the NLA is to evaluate key chemical and physical stressors of lake quality that have the potential to impact lake biota (USEPA, 2009).

## Chemical Stressors

Eight chemical indicators of lake stress were measured in the NLA. Five of the chemical indicators were evaluated for inclusion in the national report including: (1) TP concentration; (2) total nitrogen (TN) concentration; (3) turbidity; (4) acid neutralizing capacity (ANC); and (5) dissolved oxygen concentration. These five indicators along with conductivity (salinity) and chloride are included in the statewide assessment for Michigan and the UMW ecoregion lakes. Mercury data for sediment and water are still under evaluation and are not included in this report.

## Physical Stressors

Physical impacts to lakeshore and littoral habitats can have a profound effect on lake biological health. Physical habitat condition was assessed based on observations of four indicators: (1) lakeshore habitat; (2) shallow water habitat; (3) physical habitat complexity; and (4) human disturbance, based on extent and intensity of human activity.

The lakeshore habitat indicator examines the amount and type of riparian vegetation. This metric is based on observations of three layers of coverage (understory grasses and forbs, mid-story non-woody and woody shrubs, and over-story trees). In general, lakeshores are in better condition when shoreline vegetation cover is lush in all three layers (USEPA, 2010).

The shallow water habitat indicator examines the quality of the shallow edge of the lake (littoral zone) by utilizing data on the presence of living and non-living features such as overhanging vegetation, aquatic plants, large woody snags, brush, boulders, and rock ledges. Lakes with greater and more varied shallow water habitat are typically able to more effectively support aquatic life because they have more complex ecological niches (USEPA, 2010).

The physical habitat complexity indicator integrates data from the riparian and littoral zones to estimate the amount and variety of all cover types at the water's edge, providing an index of habitat condition at the land-water interface of lakes (USEPA, 2010).

All three of the habitat indicators mentioned above are related to conditions in reference lakes. The values are modified regionally to account for differing expectations of natural condition in reference lakes for a particular region.

The lakeshore human disturbance indicator incorporates the extent and intensity of human land use activities that were observed within and adjacent to each physical habitat station. It reflects direct human alteration of the lakeshore ranging from minor changes (such as the removal of trees to develop a picnic area) to major alterations (such as the construction of a large lakeshore residential complex complete with concrete seawalls and artificial beaches) (USEPA, 2010).

For the NLA, each of the above indicators or stressors for a lake was classified as either "good," "fair," or "poor" relative to the conditions found in the set of reference lakes established for the survey. Specifically, lake results above 25% of the reference range values are considered good; those below 5% of the reference range value are poor; and those between the 5% and 25% range are considered fair (USEPA, 2009).

Riparian and nearshore habitat degradation and excess nutrients were the most widespread stressors measured in the NLA nationally (USEPA, 2009). The most wide-spread stressors

measured in Michigan lakes are related to habitat. Figure 5 shows the percent of lakes in Michigan that assessed as poor, fair, and good for each of the key stressors collected during the NLA Survey.

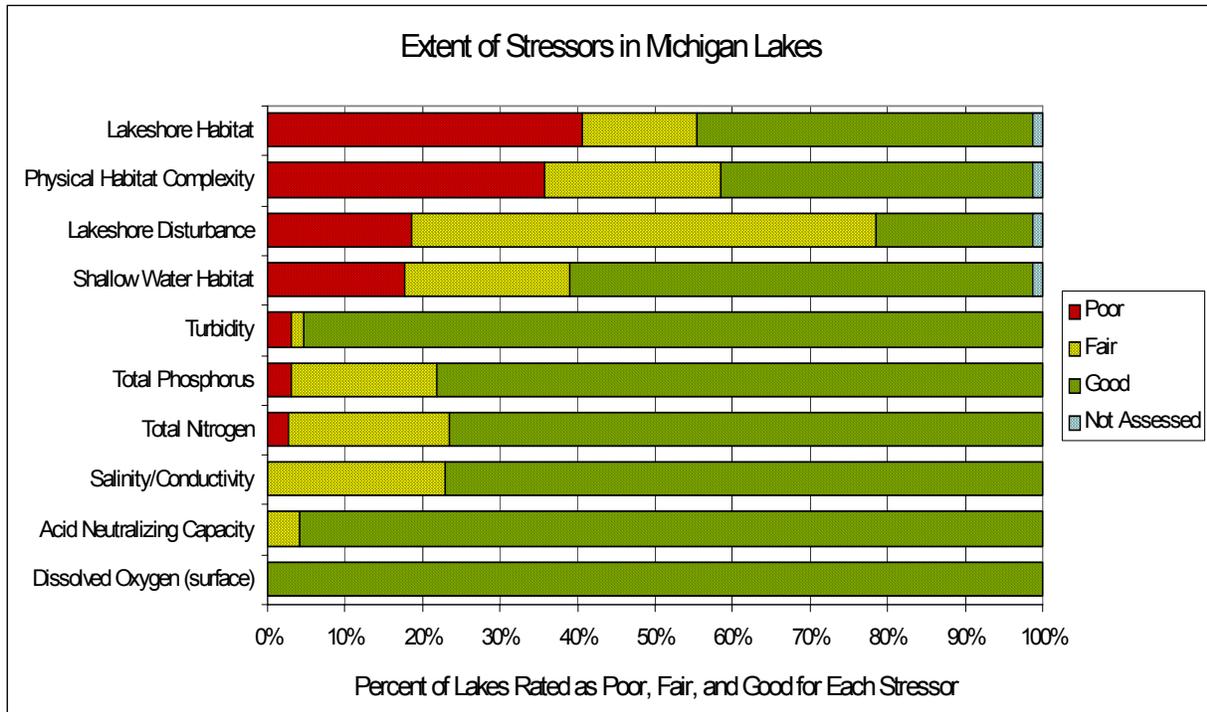


Figure 5. Extent of Stressors in Michigan Lakes, NLA 2007.

According to the survey, loss of lakeshore habitat and physical lakeshore complexity are major stressors for Michigan lakes with nearly 40% of lakes in poor condition for each of these stressors. Nutrients and turbidity account for 3% to 4% of lakes in poor condition for these stressors. Salinity/conductivity, ANC, and dissolved oxygen as measured in the NLA Survey did not account for poor conditions for these stressors in the Michigan lakes measured statewide.

Figures 6 and 7 compare the extent of the habitat and chemical stressors in Michigan's lakes with the results for the lakes in the UMW ecoregion and across the country. The lakeshore habitat and physical lakeshore complexity stressors are higher in Michigan lakes as compared to the nation and the UMW ecoregion. Conversely, a larger percentage of the nation's lakes and lakes in the UMW ecoregion are in poor condition for nutrients, and to a lesser extent for turbidity stressors as compared to Michigan's lakes.

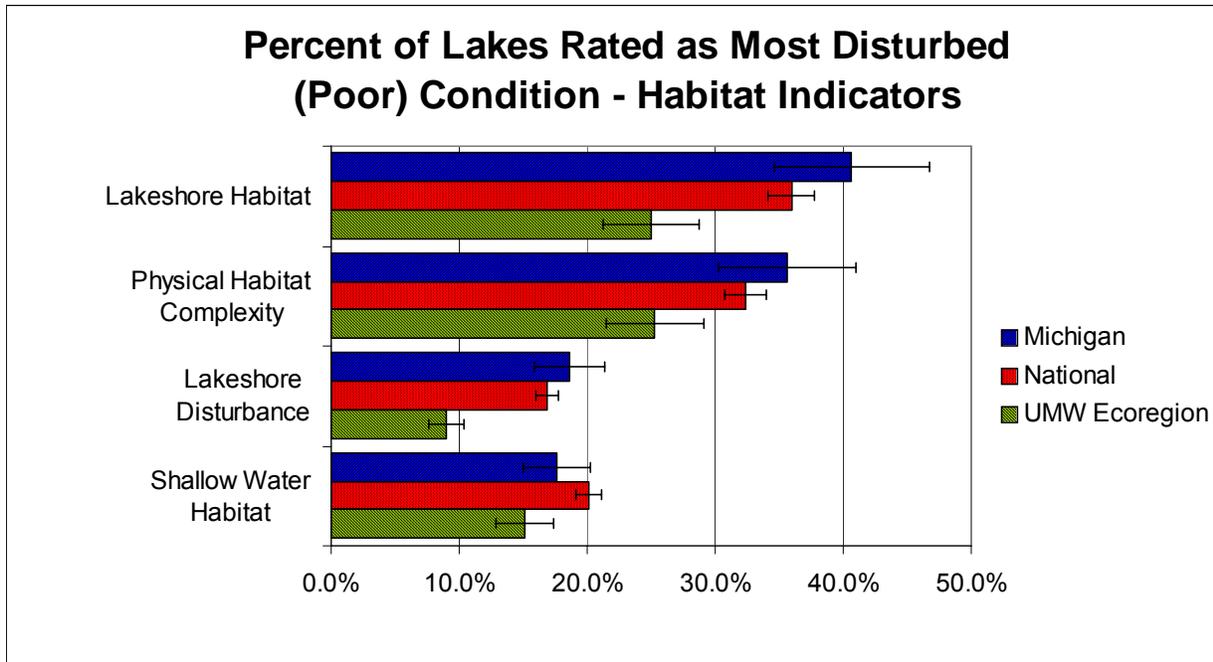


Figure 6. Comparison of Michigan, National and UMW Ecoregion Results for Habitat, NLA 2007.

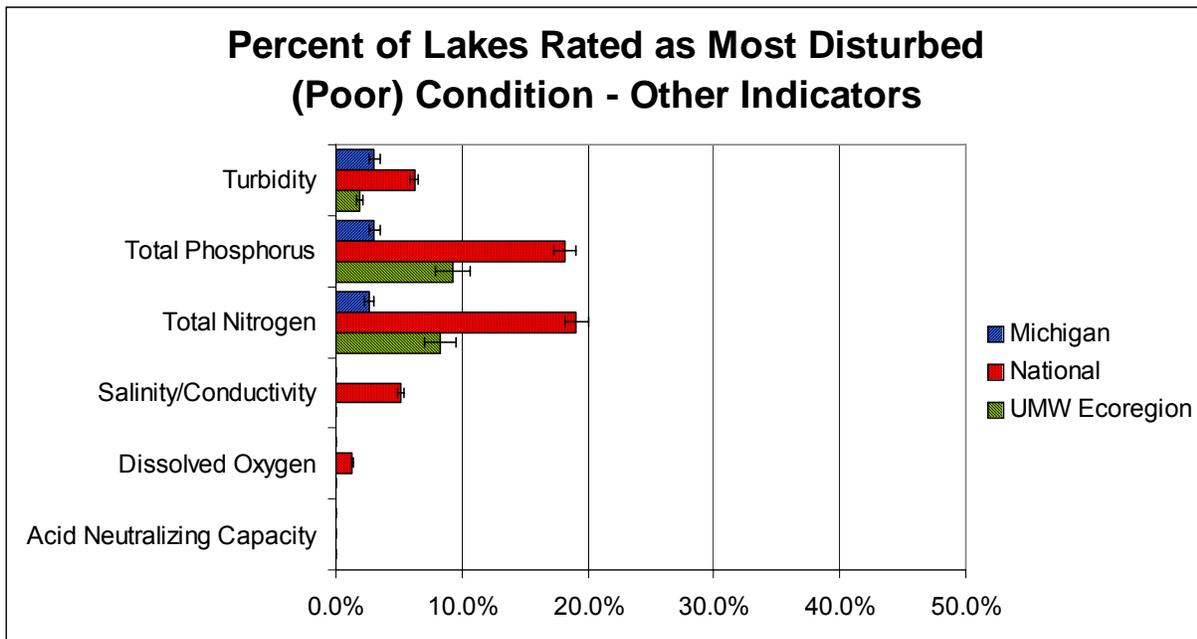


Figure 7. Comparison of Michigan, National and UMW Ecoregion Results for Nutrients and Other Chemical Stressors, NLA 2007.

The ecoregion-specific reference condition thresholds (good/fair/poor) for turbidity, TP, and TN are listed in Table 1.

Table 1. Nutrient Ecoregion VIII – Northern Glaciated Reference Condition Thresholds (Good/Fair/Poor) for Turbidity, TP and TN.

Parameter	Reference Condition Thresholds	
	Good-Fair	Fair-Poor
Turbidity (NTU)	2.75	5.41
Total Phosphorus (ug/L)	16.5	36
Total Nitrogen (ug/L)	674	1174

### Recreational Condition of Michigan Lakes

An important aspect of lake health includes suitability for public use and recreation. Some microbial organisms, or algal toxins, can adversely impact human health. The second approach to evaluate the health of the nation’s lakes included an assessment of exposure to algal toxins. As part of the NLA, three indicators of potential risk to public use and recreation were evaluated including: (1) microcystins, an algal toxin; (2) cyanobacteria, a type of bluegreen algae that can produce algal toxins; and (3) chlorophyll-a, a measure of all algae present (USEPA, 2009). Results for the bacterial pathogen indicator (enterococci) and for sediment and water mercury are still under evaluation and are not included this report.

Results for Michigan show that microcystin levels were present in about the same percent of lakes as they are nationally (approximately 30% for all lakes), but slightly greater than found in the UMW ecoregion lakes (Figure 8). However, for each of the indicators of risk, Michigan lakes showed a lower percentage of lakes in the moderate risk category when compared to the national and UMW ecoregion results (Figure 8) and no lakes in the high risk category.

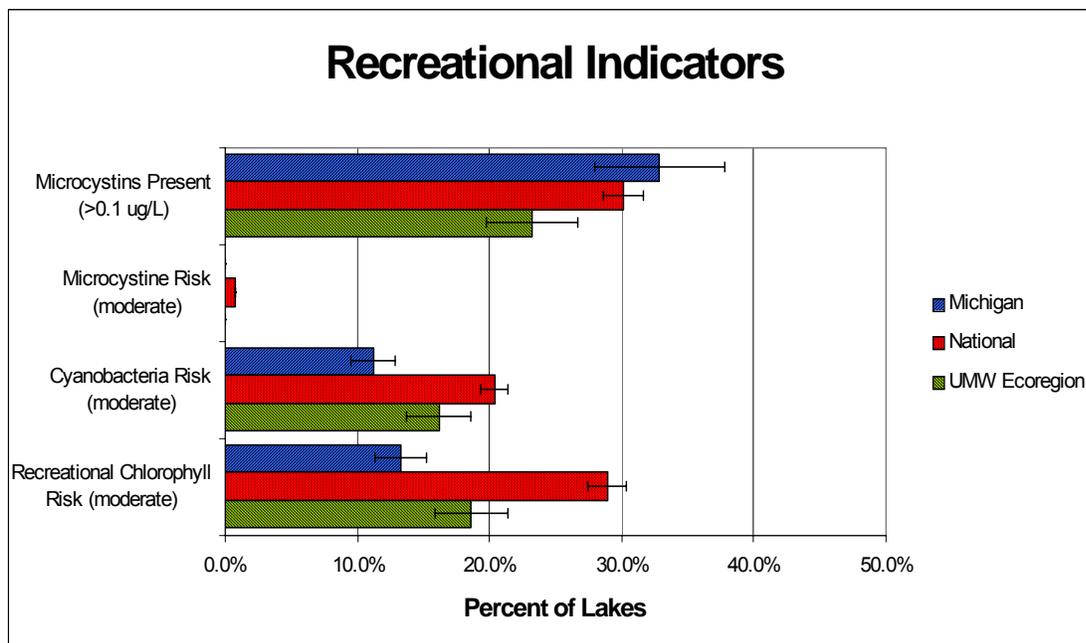


Figure 8. Comparison of Michigan, National and UMW Ecoregion Results for Recreational Condition, NLA 2007.

The thresholds (low, moderate, and high risk) associated with each indicator of potential risk are based on the World Health Organization criteria as indicated in Table 2.

Table 2. World Health Organization thresholds of risk associated with potential exposure to cyanotoxins.

Indicator (units)	Low Risk of Exposure	Moderate Risk of Exposure	High Risk of Exposure
Chlorophyll-a (ug/L)	< 10	10 - < 50	> 50
Cyanobacteria cell counts (#/L)	< 20,000	20,000 – < 100,000	≥ 100,000
Microcystin (ug/L)	< 10	10 - ≤ 20	> 20

### Trophic Condition of Michigan Lakes

The third approach the NLA used to evaluate the condition of lakes was with respect to primary production. Trophic state depicts biological productivity, representing the total weight of living biological material (biomass) in a water body. Lakes with high nutrient levels, high plant production rates, and an abundance of plant life are generally considered eutrophic (high productivity), whereas lakes that have low concentrations of nutrients, low rates of productivity, and generally low biomass are termed oligotrophic (low productivity). Lakes that fall in between are mesotrophic (moderate productivity), and those on the extreme ends of the scale are termed hypereutrophic (excessive productivity) and ultra-oligotrophic (very low productivity). Lakes exist across all trophic categories naturally. However, hypereutrophic lakes are usually the result of excessive human activity and can be an indicator of stress conditions, which may result in impaired biological communities and recreational use.

There is no preferred trophic state for lakes as a whole since lakes naturally fall in all of these categories. Additionally, the determination of “ideal” trophic state depends on how the lake is used or managed. For example, an oligotrophic lake is a better source of drinking water than a eutrophic lake because the water is easier or less expensive to treat. Swimmers and recreational users also prefer oligotrophic lakes because of their clarity and aesthetic quality. Property values on lakes generally increase with water clarity and aesthetic quality (Boyle and Bouchard, 2003; Krysel et al., 2003). Eutrophic lakes can be biologically diverse with abundant fish, plants, and wildlife. Anglers typically prefer more eutrophic lakes since increased concentrations of nutrients, algae, or aquatic plant life generally result in higher fish production. However, eutrophic lakes do not support a coldwater fishery that requires high levels of dissolved oxygen below the lake’s thermocline.

Eutrophication resulting from nutrient input is a slow, natural part of lake aging. However, human influences today are significantly increasing the amount and rate at which nutrients enter lakes. Human activities such as poorly managed agriculture or septic systems and suburbanization of lakeshores can result in excessive nutrient concentrations reaching lakes. This can lead to accelerated eutrophication and related undesirable effects including nuisance algae, excessive plant growth, decreased water transparency, odor, and fish kills.

Many states classify their lakes by trophic state using a variety of thresholds for nutrients (phosphorus or nitrogen), Secchi disk transparency, or chlorophyll-a, depending on the data available. For the NLA, the trophic state is characterized using chlorophyll-a concentration as

measured in a composite water sample from the upper two meters of the lake (USEPA, 2009). The NLA analysts consider this indicator as the most relevant and straightforward estimate of trophic state because it is based on direct measurements of live organisms, yet acknowledges that other indicators could be used.

For the Michigan assessment, three indicators - Secchi transparency, TP, and chlorophyll-a are used to estimate trophic condition and compare Michigan results to the regional and national results. The trophic status classifications were determined based on Michigan's trophic state index thresholds for these parameters (Table 3). The chlorophyll thresholds for Michigan differ slightly from those used in the NLA but were applied to the national and regional data for this analysis.

Table 3. Michigan Inland Lakes Trophic Status Classification Thresholds.

Trophic State	Carlson TSI	TP (ug/L)	SD-Trans. (ft)	SD-Trans. (m)	Chl-a (ug/L)
Oligotrophic	≤38	≤10	≥15	≥4.6	≤2.2
Mesotrophic	38-48	10-20	7.5-15	2.3-4.6	2.2-6
Eutrophic	48-61	20-50	3-7.5	0.9-2.3	6-22
Hypereutrophic	>61	>50	<3	<0.9	>22

Figures 9, 10, and 11 show the results for each indicator based on these thresholds for Michigan lakes and compares them to the lakes in the nation and UMW ecoregion.

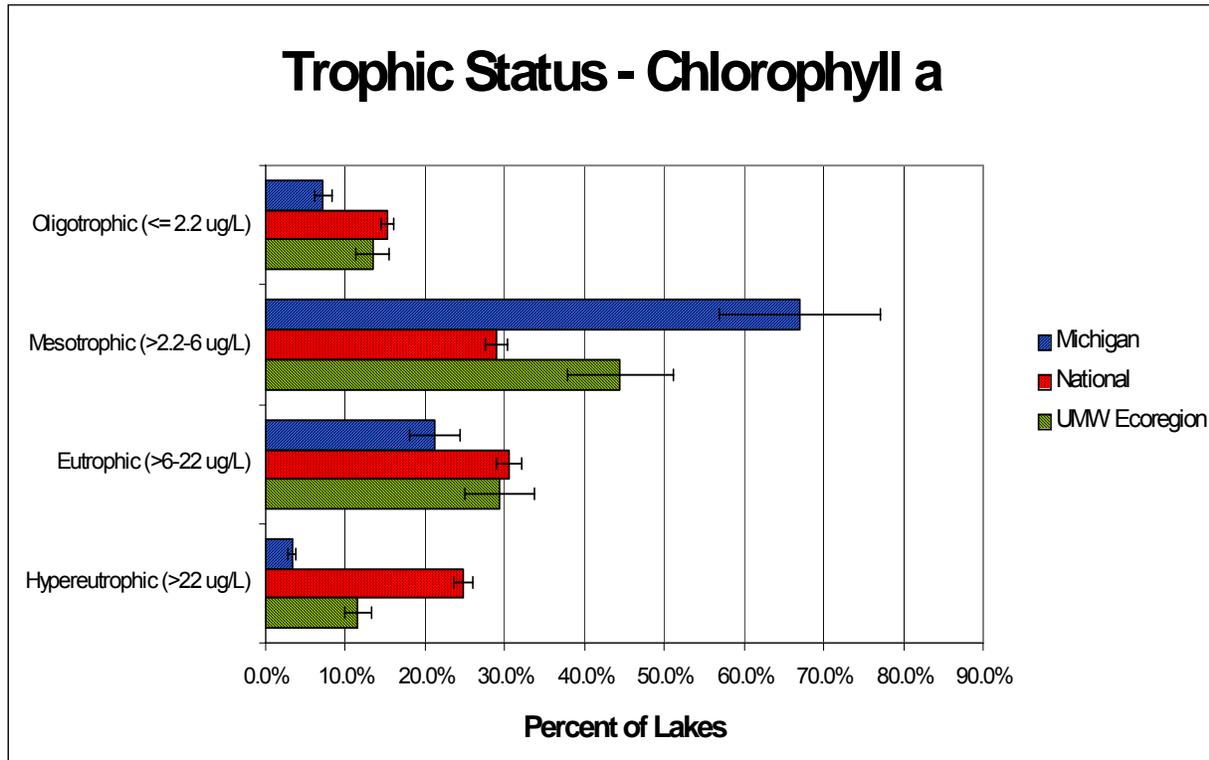


Figure 9. Trophic Status – Chlorophyll-a, NLA 2007.

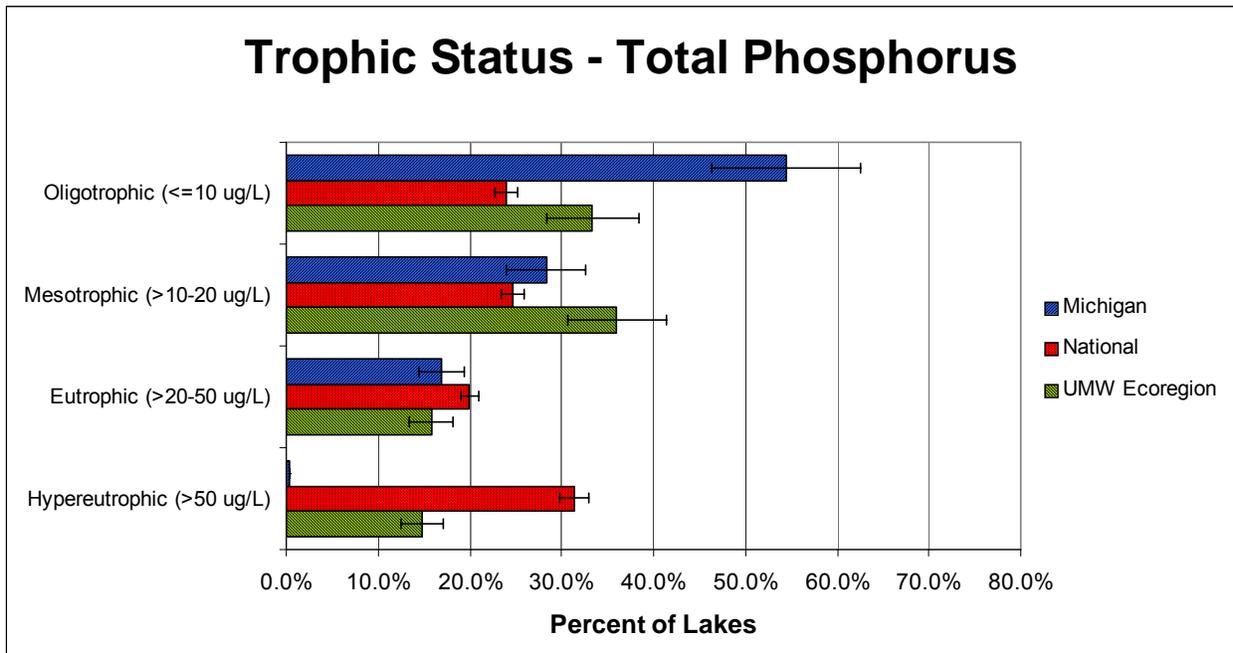


Figure 10. Trophic Status – TP, NLA 2007.

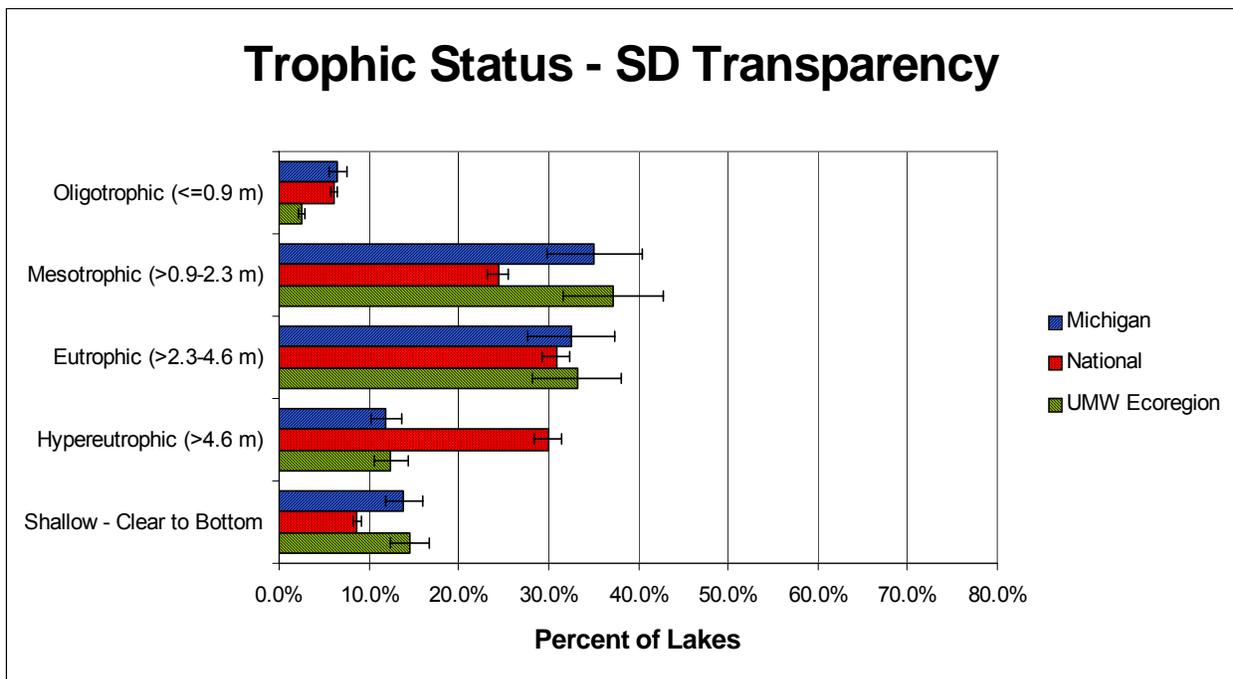


Figure 11. Trophic Status – Secchi Disk Transparency, NLA 2007.

The trophic status distributions are inconsistent based on the individual indicators. For the chlorophyll-*a* indicator, Michigan's lake trophic condition distribution is 7% oligotrophic, 67% mesotrophic, 21% eutrophic, and 3% hypereutrophic. Based on TP, the trophic distribution is 54% oligotrophic, 28% mesotrophic, 17% eutrophic, and 0.4% hypereutrophic. The trophic status split based on Secchi transparency is 6.5% oligotrophic, 35% mesotrophic, 32.5% eutrophic, 12% hypereutrophic, and 14% undetermined (shallow-clear to bottom).

The TP derived trophic condition distribution for Michigan lakes is greatly skewed to the oligotrophic side of the trophic continuum. This pattern is also found in the TP derived trophic status for the UMW ecoregion lakes but to a lesser degree. These results may be a consequence of the differences in the sampling and sample handling methodology incorporated in the NLA Survey as compared to Michigan's and other UMW state's lake sampling protocols. The NLA TP samples were not acidified upon collection and the results for many of these samples (50%) were flagged with holding time codes in the dataset.

### Chemical Condition of Michigan Lakes

Patterns of lake water chemistry have been described in previous monitoring efforts but only for targeted inland lake subpopulations, such as public access lakes (MDNR, 1982; Fuller and Taricska, 2012). The 2007 NLA statistical survey design provides a good basis for describing the typical range of constituents and interrelationships statewide in all Michigan lakes 4 hectares (10 acres) or larger in size and allows for ecoregion-based comparison and descriptions. Percentile distributions, based on weighted data, were developed for the various physical and chemical parameters measured at the mid-lake (deep basin) index site in the 2007 NLA survey. The distributions are presented in tabular format on a statewide, UWM ecoregion, and national basis and distribution patterns are illustrated below.

The statistical summary tables are grouped to include: (a) lake morphometry, pH, transparency, color, and organic carbon (Table 4); (b) nutrients and chlorophyll-*a* (Table 5); and (c) cations and anions (Table 6).

Table 4. Michigan NLA data summary – lake morphometry (unweighted) and pH, ANC, transparency, water coloration, and organic carbon (weighted).

Region	Stats	Est. Mean Depth (m)	Index Site Depth (m)	pH- Field (SU)	ANC (ueq/L)	Secchi (m)	Turbidity (NTU)	Color (PCU)	TOC (mg/L)	DOC (mg/L)
Michigan	mean	2.8	8.3	7.92	1990	2.3	1.95	17.1	8.26	8.01
(n=50)	std dev	1.7	5.2	0.71	1150	1.67	1.46	15.6	4.37	4.22
	max	7.0	21.1	9.43	4310	7.95	9.38	65	20.2	19.4
	75th	3.9	11.6	8.3	2850	3.52	2.39	20	9.44	9.4
	50th	2.5	7.4	8	2250	2.14	1.33	12	6.78	6.34
	25th	1.4	4.2	7.6	865	0.8	1.02	7.13	5.43	5.41
	min	0.3	1.0	6	12.7	0.58	0.60	0.1	2.38	2.17
UMW	mean	3.2	9.5	7.84	1820	1.96	3.53	21.5	9.7	9.07
(n=148)	std dev	2.26	6.79	1.1	1370	1.4	9.3	24.3	5.32	4.85
	max	11.4	34.1	9.6	5940	7.95	193	125	36.2	27.4
	75th	4.4	13.2	8.5	2960	2.61	3.47	26	13.5	12.4
	50th	2.6	7.7	8	1640	2.05	1.74	12	8.81	8.29
	25th	1.5	4.5	7.3	469	0.85	1.16	9	5.87	5.65
	min	0.3	1.0	5.35	12.7	0.1	0.60	0.1	2.04	2.05
Nation	mean	3.1	9.4	7.76	2280	1.81	7.98	21.7	10.2	9.29
(n=1028)	std dev	3.51	10.53	1.32	3910	1.71	19.5	23	10.7	9.61
	max	32.3	97.0	10.3	91600	36.7	574	165	325	291
	75th	3.9	11.6	8.52	2860	2.49	8.27	26	13.4	11.8
	50th	1.9	5.8	8	1210	1.21	3.05	14.8	6.99	6.51
	25th	0.9	2.8	7.2	295	0.674	1.41	8.89	4.32	4.08
	min	0.2	0.5	4.1	-63	0.04	0.24	0.1	0.37	0.34

Table 5. NLA Michigan data summary – nutrients and chlorophyll-a (weighted).

Region	Stats	TP (ug/L)	TN (ug/L)	NO <sub>2</sub> +NO <sub>3</sub> (mg/L)	NO <sub>3</sub> -N (mg/L)	NH <sub>4</sub> -N (mg/L)	CHL-a (ug/L)
Michigan	mean	13.1	660	0.095	0.093	0.021	5.38
(n=50)	std dev	10.5	508	0.504	0.465	0.014	4.92
	max	82	3440	3.100	2.860	0.184	30.7
	75th	16	721	0.005	0.005	0.026	5.05
	50th	8	563	0.005	0.005	0.019	3.32
	25th	6	468	0.005	0.005	0.013	2.31
	min	3	101	0.005	0.005	0.005	1.1
UMW	mean	23.8	759	0.061	0.073	0.029	9.77
(n=148)	std dev	35.8	497	0.247	0.246	0.038	21.5
	max	1180	15600	3.100	2.860	0.918	936
	75th	33	1010	0.005	0.005	0.032	9.44
	50th	15	650	0.005	0.005	0.021	4.48
	25th	7	492	0.005	0.005	0.013	2.88
	min	1	101	0.005	0.005	0.005	1.1
Nation	mean	78.7	1010	0.043	0.049	0.038	23.8
(n=1028)	std dev	171	1270	0.213	0.205	0.080	47.6
	max	4680	25700	6.190	5.410	1.710	936
	75th	77.1	1160	0.005	0.005	0.033	20.9
	50th	20	586	0.005	0.005	0.019	7.1
	25th	10	383	0.005	0.005	0.011	3.17
	min	1	5	0.005	0.005	0.005	0.067

Table 6. Michigan NLA data summary – cations, anions, and related constituents (weighted).

Region	Stats	Sp. Cond (uS/cm)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Si (mg/L)	SO4 (mg/L)	Cl (mg/L)
Michigan	mean	309	26.8	12.6	13.9	1.0	4.5	12.9	28.5
(n=50)	std dev	215	16.2	8.4	18.4	0.7	3.9	11.1	36.8
	max	738	66.6	26.9	63.9	3.5	27.8	61.4	129
	75th	449	35.2	19.1	17.7	1.5	7.7	20.5	32.5
	50th	280	29.2	12.2	5.5	0.9	3.4	8.8	10.6
	25th	110	13.7	4.6	1.5	0.4	1.5	4.3	2.7
	min	14.3	0.9	0.3	0.2	0.1	0.0	0.9	0.2
UMW	mean	220	20.6	11.2	5.8	1.5	6.0	7.6	10.7
(n=148)	std dev	173	14.7	10.4	11.6	1.6	6.8	10.1	22.3
	max	1520	72.3	70.0	233	16.5	34.1	76.8	338
	75th	327	30.4	20.0	4.5	1.6	7.7	9.3	8.8
	50th	189	19.4	6.7	2.1	0.9	3.6	4.9	2.4
	25th	61.2	6.3	2.2	1.1	0.5	0.8	1.9	0.4
	min	13.9	0.9	0.3	0.2	0.1	0.0	0.1	0.1
Nation	mean	757	24.3	27.7	106.0	8.3	7.7	128	153
(n=1028)	std dev	3400	34.9	98.5	681	32.5	9.3	623	1420
	max	50600	486	2470	16700	1410	65.3	40100	15800
	75th	407	31.3	20.0	13.4	4.2	10.1	17.6	16.7
	50th	171	14.5	4.7	4.6	1.6	4.5	5.2	5.7
	25th	60.4	5.0	1.6	2.0	0.7	1.3	2.5	1.6
	min	4.35	0.2	0.1	0.2	0.1	0.0	0.1	0.1

### *Morphometric Characteristics of Michigan Inland Lakes*

The NLA stratified random design allowed for lakes in five size class categories, as well as spatial distribution across the lower 48 states and 9 aggregated Omernik Level 3 ecoregions to be randomly selected for the survey (USEPA, 2006). Absent this stratification process the NLA would have been represented primarily by very small lakes in lake-rich areas of the country, including Michigan. The percentile distribution of surface area and maximum depth for Michigan's 50 random lakes as part of the NLA survey are similar to all lakes in the UMW ecoregion (Table 7). When compared to the targeted public access lakes sampled in the MDEQ LWQA monitoring program and the stratified random-selected lakes in the MDNR STP, Michigan's NLA lakes are generally smaller in surface area and shallower in terms of maximum depth. Both datasets are biased toward larger lakes as compared to the overall population of Michigan lakes 4 hectares (10 acres) or larger in size.

Table 7. Morphometric Characteristics for Michigan Inland Lakes Surveys.

Survey	Stats	Area (acres)	Area (hectares)	Max. Depth (feet)	Max. Depth (meters)
NLA-MI (n=50)	mean	631.8	255.7	27.4	8.3
	std dev	1960.57	793.43	17.04	5.20
	max.	13047.8	5280.4	69	21.1
	75th	359	145.3	38	11.6
	50th	152.4	61.7	24	7.4
	25th	75.8	30.7	14	4.2
NLA-UMW (n=148)	min.	10.4	4.2	3	1.0
	mean	617.0	249.7	10.3	3.2
	std dev	1912.96	774.16	7.42	2.26
	max.	16321.3	6605.1	112	34.1
	75th	357	144.5	43	13.2
	50th	135.9	55.0	25	7.7
LWQA (n=730)	25th	64.5	26.1	15	4.5
	min.	10.4	4.2	3	1.0
	mean	688.9	278.8	43.4	13.2
	std dev	1965.82	795.57	27.36	8.34
	max.	20044	8111.8	285	86.9
	75th	449.5	181.9	57	17.4
LWQA-2007 (n=85)	50th	188.5	76.3	39	11.9
	25th	95	38.4	25	7.6
	min.	22.5	9.1	3	0.9
	mean	346.9	140.4	42.8	13.1
	std dev	470.61	190.46	24.59	7.50
	max.	2571	1040.5	115	35.1
STP (n=233)	75th	333	134.8	57	17.4
	50th	171	69.2	39	11.9
	25th	100	40.5	25	7.6
	min.	35	14.2	3	0.9
	mean	701.1	283.74	40.5	12.34
	max.	17268	6988.36	120	36.58
STP-2007 (n=28)	75th	379.3	153.50	52	15.85
	50th	172	69.61	35	10.67
	25th	77	31.16	24	7.32
	min.	10	4.05	5	1.52
	mean	360.1	145.7	36.3	11.1
	std dev	595.08	240.83	19.27	5.87
STP-2007 (n=28)	max.	2571	1040.5	87	26.5
	75th	271	109.7	48	14.6
	50th	171	69.2	35	10.5
	25th	103.8	42.0	24	7.2
	min.	10	4.0	3	0.9

*Organic carbon, color, turbidity, 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 organic carbon (DOC) and particulate forms. 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 organisms. 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 “tea stained” appearance to lake waters. Color, measured in platinum-cobalt units (PCU), provides an indirect estimate of the relative amounts of humic substances in water.

Median values for TOC, DOC, and color in Michigan lakes are 6.78 milligrams per liter (mg/L), 6.34 mg/L, and 12 PCU respectively (Table 3). The majority of the TOC is in the DOC form. Organic carbon in Michigan lakes is relatively low compared to all lakes in the UMW ecoregion with median values of TOC at 8.81 mg/L and DOC at 8.29 mg/L. Median color values are equivalent. The distribution of lakes in low, moderate, and high concentration ranges and the regional patterns for these parameters in the UMW ecoregion lakes, including Michigan lakes, are illustrated in Figures 12-14. The concentration ranges (low, moderate, high) for each parameter correspond to the lower-quartile (<25<sup>th</sup> percentile), inter-quartile (25<sup>th</sup>-75<sup>th</sup> percentile), and upper-quartile (> 75<sup>th</sup> percentile).

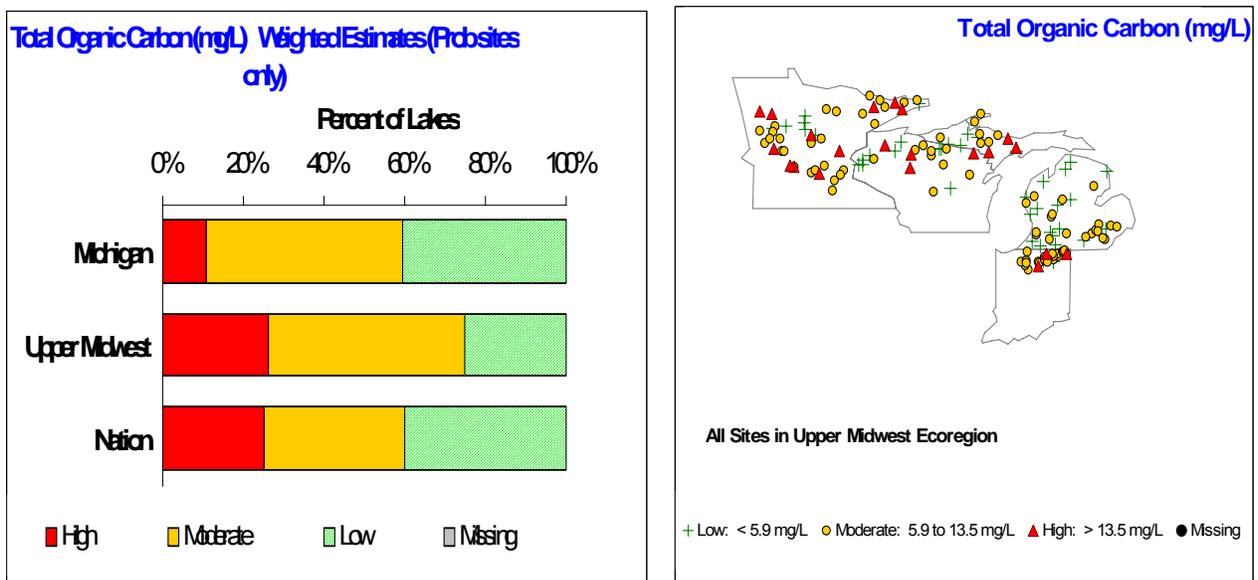


Figure 12. UMW ecoregion concentration range distribution and pattern for TOC.

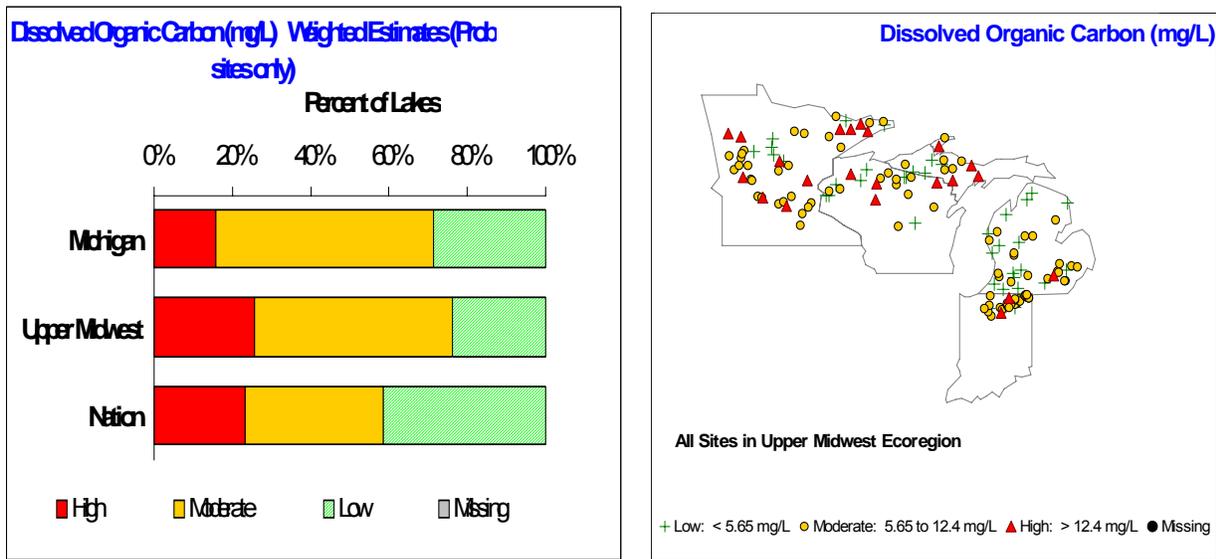


Figure 13. UMW ecoregion concentration range distribution and pattern for DOC.

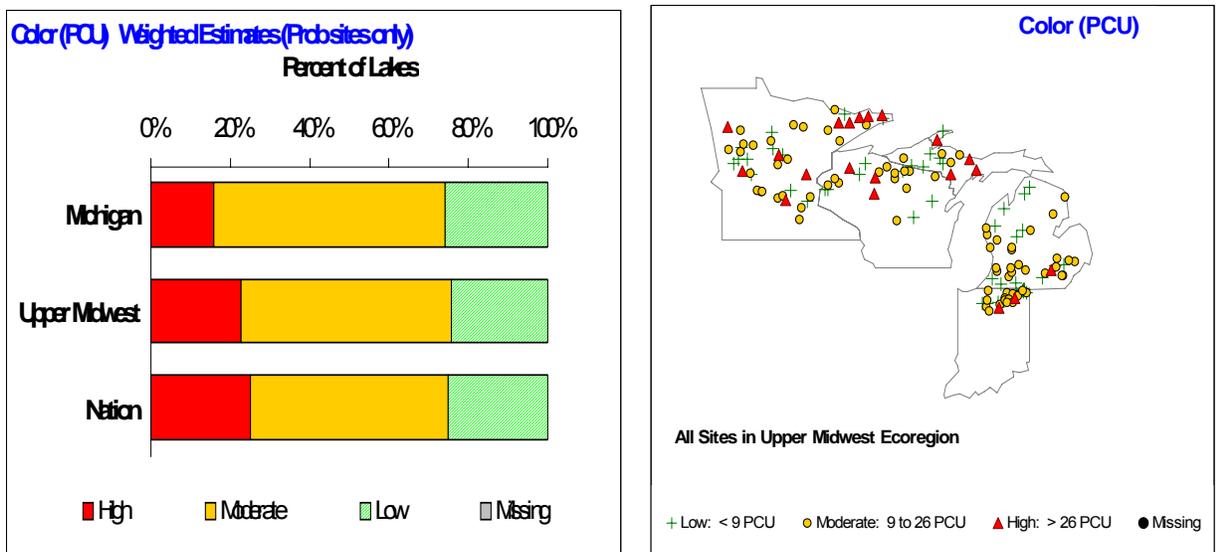


Figure 14. UMW ecoregion concentration range distribution and pattern for Color.

Algal biomass (as measured by chlorophyll-*a*) is most often the primary determinant of Secchi transparency in lakes in the UMW ecoregion, including Michigan lakes. However, water color and organic carbon can play a role at high color levels (i.e., > 30 PCU) and TOC/DOC (i.e., > 15 mg/L) (Heiskary and Lindon, 2010). The median value for Secchi transparency in Michigan lakes is 2.14 meters, which is similar to the median transparency of all lakes in the UMW ecoregion (median = 2.05 meters). However, the interquartile range (25<sup>th</sup>-75<sup>th</sup> percentile) is less, with a greater percentage of Michigan lakes with higher transparency compared to all lakes in the UMW ecoregion. Turbidity is generally less in Michigan lakes (median = 1.33 Nessler Turbidity Units [NTU]) as compared to all UMW ecoregion lakes (median = 1.74 NTU). The distribution of lakes in low, moderate, and high concentration ranges and the

regional patterns for these parameters in the UMW ecoregion lakes, including Michigan lakes, are illustrated in Figures 15-16.

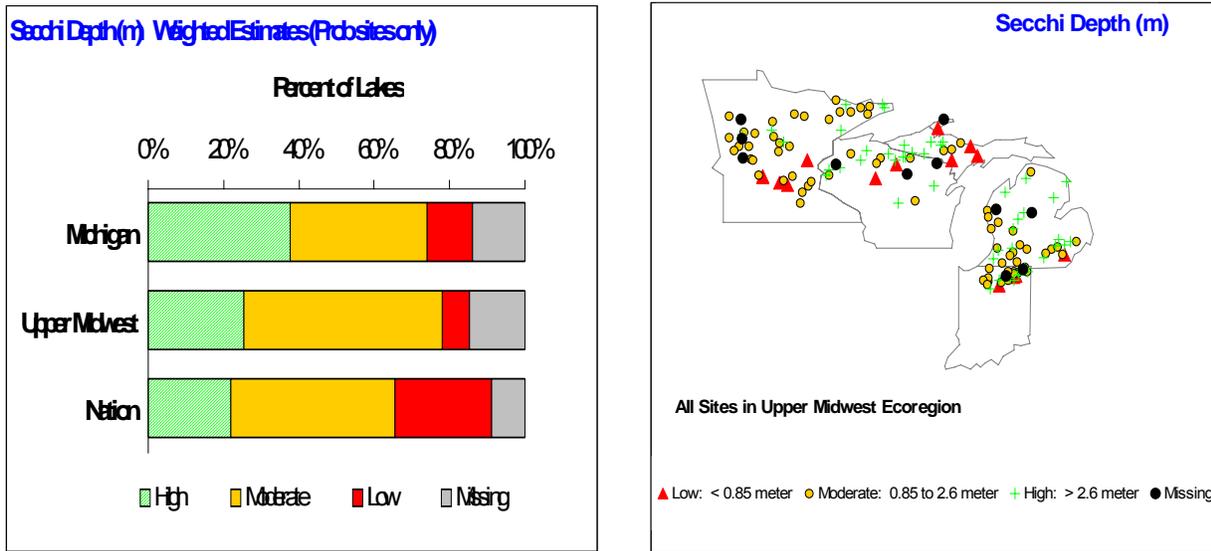


Figure 15. UMW ecoregion water clarity range distribution and pattern for Secchi Transparency.

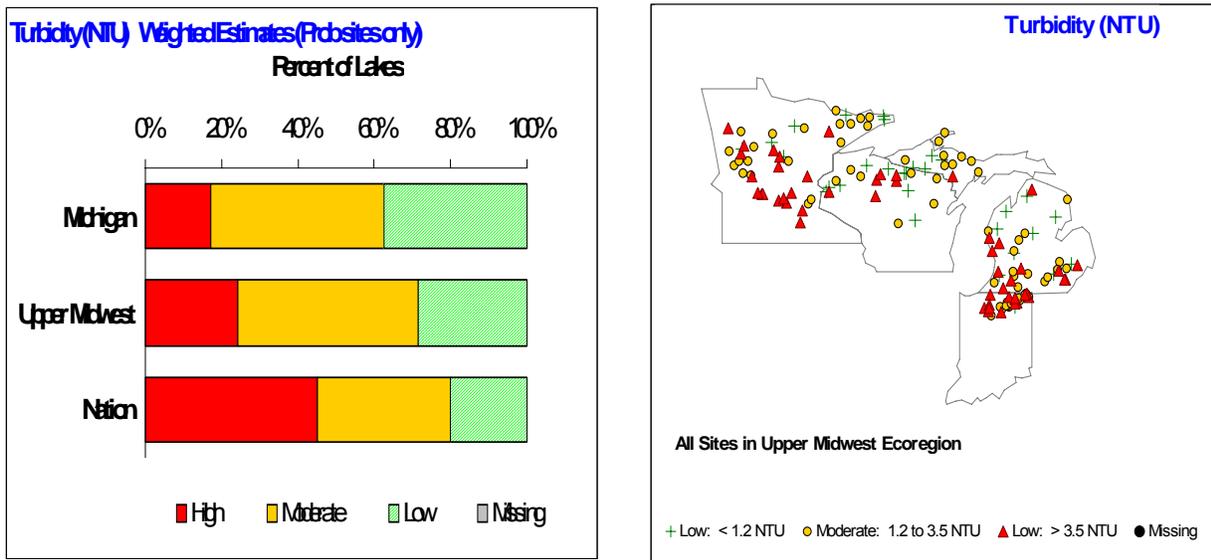


Figure 16. UMW ecoregion concentration range distribution and pattern for Turbidity.

### Nutrients and chlorophyll-a

Water concentrations for TP (median = 8 micrograms per liter [ug/L]) and TN (median = 563 ug/L) in Michigan lakes are low compared to all UMW ecoregion lakes (TP median = 15 ug/L; TN median = 650 ug/L). The interquartile (25<sup>th</sup>-75<sup>th</sup> percentile) range for TP in Michigan lakes is 6-16 ug/L and for TN the range is 468-721 ug/L (Table 4).

Chlorophyll-*a* concentrations are also lower in Michigan lakes (median = 3.32 ug/L) as compared to all UMW ecoregion lakes (median = 4.48 ug/L). The interquartile range for chlorophyll-*a* in Michigan lakes is small, 2.31-5.05 ug/L (Table 4).

Regional patterns in nutrients and chlorophyll-*a* have long been recognized for Michigan lakes (MDNR, 1982). The NLA data serve to reinforce these patterns and the interrelationships among these variables. The transition for more phosphorus-rich to phosphorus-poor lakes from southern to northern Michigan's Lower Peninsula is evident in the NLA data as well. Michigan's Upper Peninsula lakes show a more variable nutrient pattern. The concentration range distributions and regional patterns for TP, TN, and chlorophyll-*a* in the UMW ecoregion lakes, including Michigan lakes, are illustrated in Figures 17-19. The concentration ranges (low, moderate, high) for these parameters correspond to the Michigan inland lakes trophic state index thresholds (Table 2).

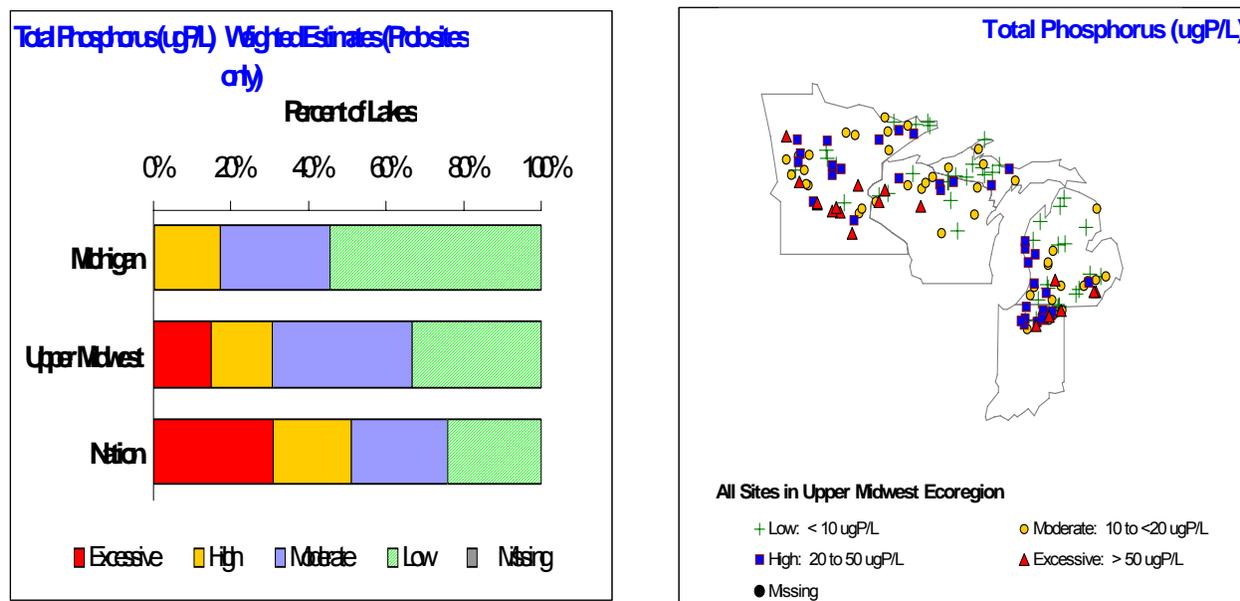


Figure 17. UMW ecoregion concentration range distribution and pattern for TP.

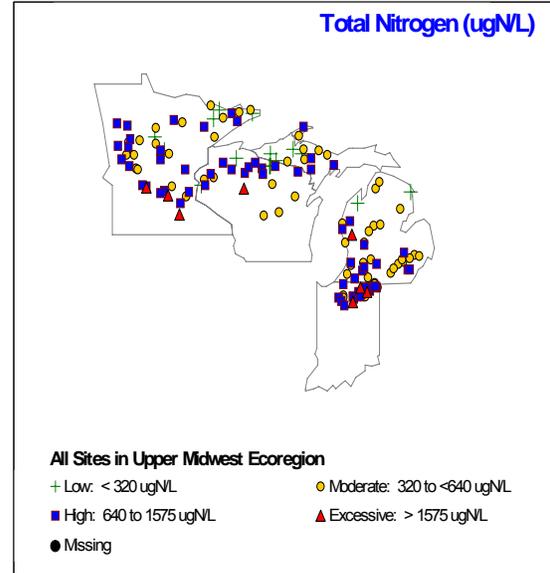
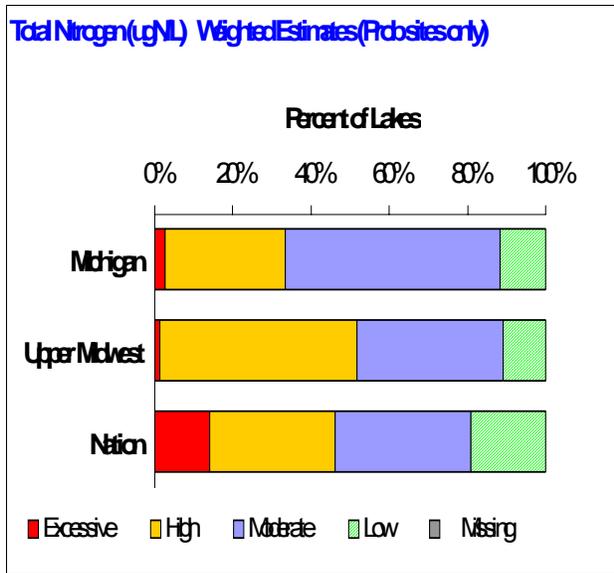


Figure 18. UMW ecoregion trophic concentration range distribution and pattern for TN.

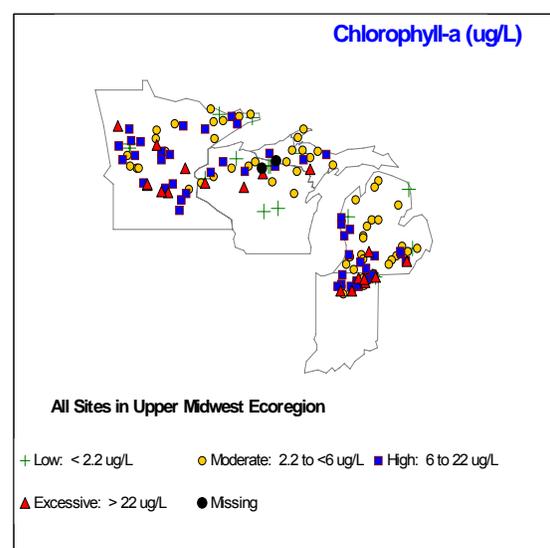
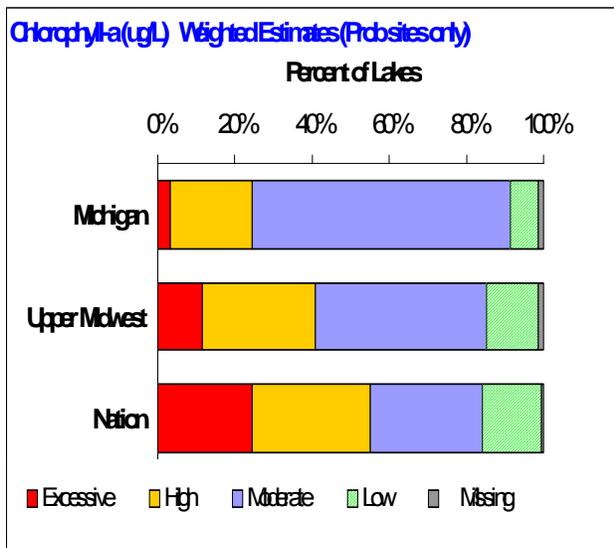


Figure 19. UMW ecoregion trophic concentration range distribution and pattern for Chlorophyll-a.

*Chemical cations and anions*

The chemical composition of a lake is fundamentally a function of its climate and its basin geology (<http://waterontheweb.org/>). The ion balance for typical freshwater lakes is usually dominated by four major cations (in order of dominance): calcium ( $Ca^{+2}$ ), magnesium ( $Mg^{+2}$ ), sodium ( $Na^{+}$ ), and potassium ( $K^{+}$ ) and the major balancing anions (in order of dominance): carbonates ( $CO_3^{-2}$  and  $HCO_3^{-}$ ), sulfate ( $SO_4^{-2}$ ), and chloride ( $Cl^{-}$ ). The concentrations of these ions generally constitute over 99% of the total salinity (Wetzel, 2001). Silica occurs in lesser abundance in natural waters and along with sulfate and iron is greatly influenced by biotic

processes. Chloride is usually not dominant in open lake systems, but pollution sources of chlorides can modify natural concentrations greatly (Wetzel, 2001).

The specific conductance of lake water is the measure of the resistance of a solution to electronic flow and in typical carbonate/bicarbonate-type lake water is closely proportional to concentrations of the major ions. Concentrations and forms of Ca, K, SO<sub>4</sub>, and inorganic carbon are highly dynamic and are influenced markedly by metabolic activities (Wetzel, 2001). Calcium influences growth and population dynamics of freshwater biota, with Ca-deficient soft-water (<10 mg/L) and Ca-rich hard-water (>20 mg/L) species often being referenced. In contrast, concentrations of Mg, Na, and K are relatively conservative and undergo relatively minor changes from biotic utilization (Wetzel, 2001). Magnesium is essential for chlorophyll-bearing plants and algae but Mg demand is often minor compared to its general availability (Wetzel, 2001). Sodium 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 ion balance for freshwater lakes is: HCO<sub>3</sub><sup>-</sup> - 73%, Ca<sup>+2</sup> - 63%, Mg<sup>+2</sup> - 17%, SO<sub>4</sub><sup>-2</sup> - 16%, Na<sup>+</sup> - 15%, Cl<sup>-</sup> - 10%, and K<sup>+</sup> - 4% (<http://waterontheweb.org/>). Based on the NLA data, Ca<sup>+2</sup> and Mg<sup>+2</sup> are the dominant cations and SO<sub>4</sub><sup>-2</sup> and Cl<sup>-</sup> along with HCO<sub>3</sub><sup>-</sup> are the dominant anions in Michigan lakes (Table 4). The distribution of lakes in low, moderate, and high concentration ranges and the regional patterns for specific conductance and the major cations and anions in the UMW ecoregion lakes, including Michigan lakes, are illustrated in Figures 20-27. The concentration ranges (low, moderate, high) for each parameter correspond to the lower-quartile (<25<sup>th</sup> percentile), inter-quartile (25<sup>th</sup>-75<sup>th</sup> percentile), and upper-quartile (> 75<sup>th</sup> percentile).

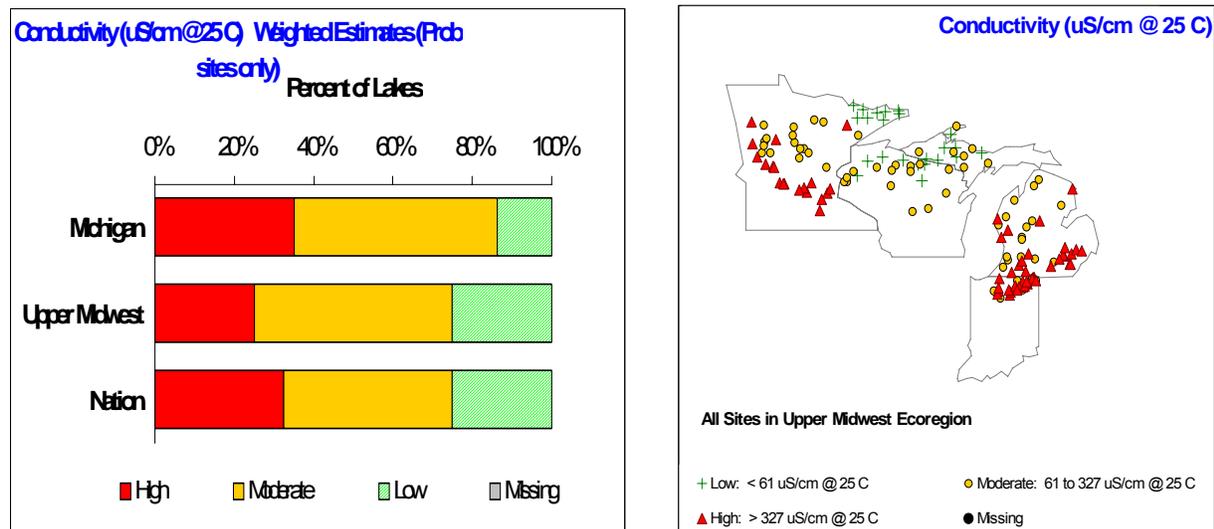


Figure 20. UMW ecoregion concentration range distribution and pattern for Specific Conductance.

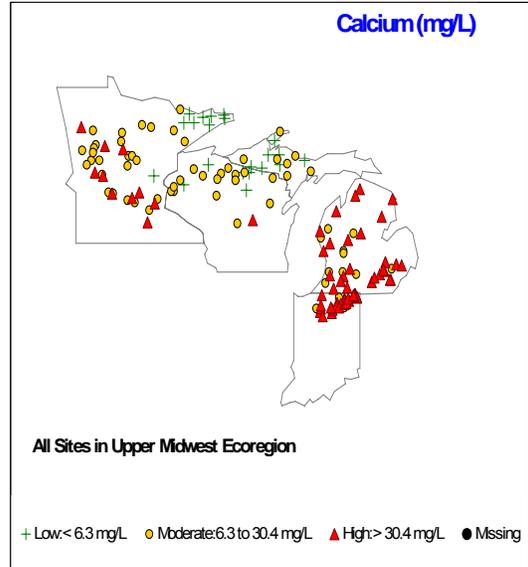
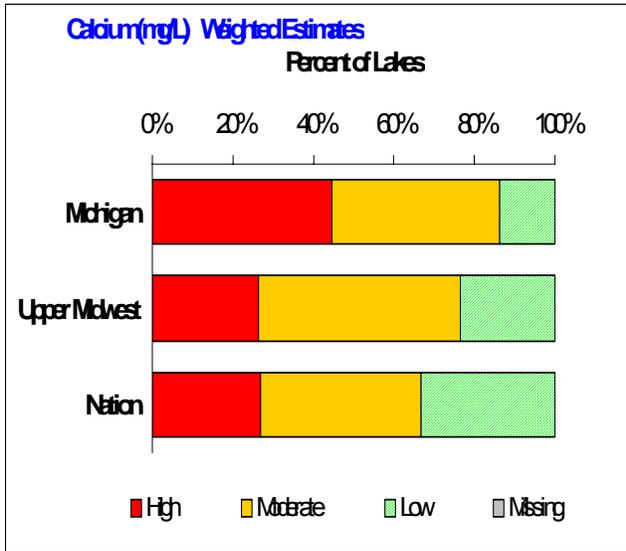


Figure 21. UMW ecoregion concentration range distribution and pattern for Calcium.

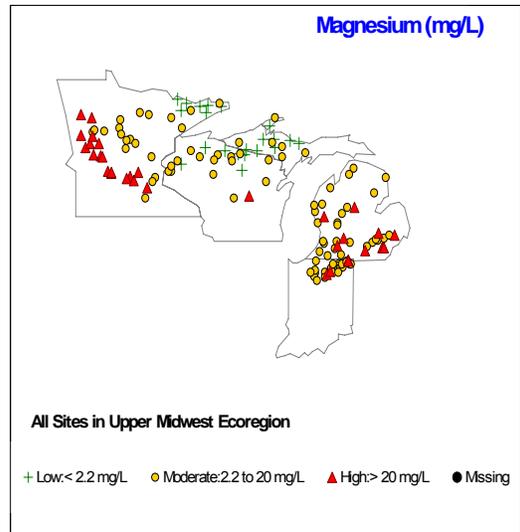
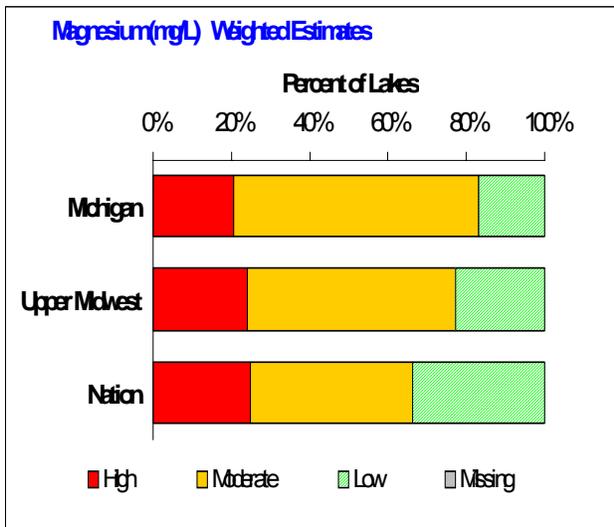


Figure 22. UMW ecoregion concentration range distribution and pattern for Magnesium.

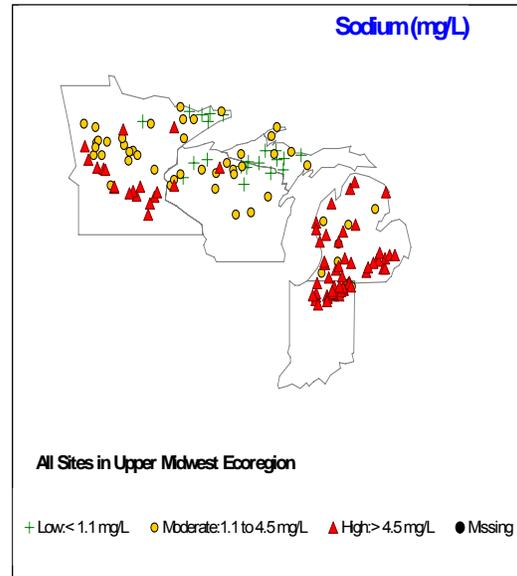
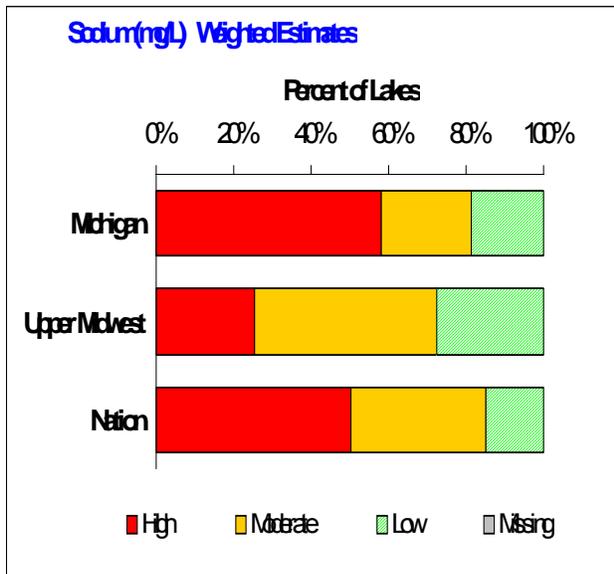


Figure 23. UMW ecoregion concentration range distribution and pattern for Sodium.

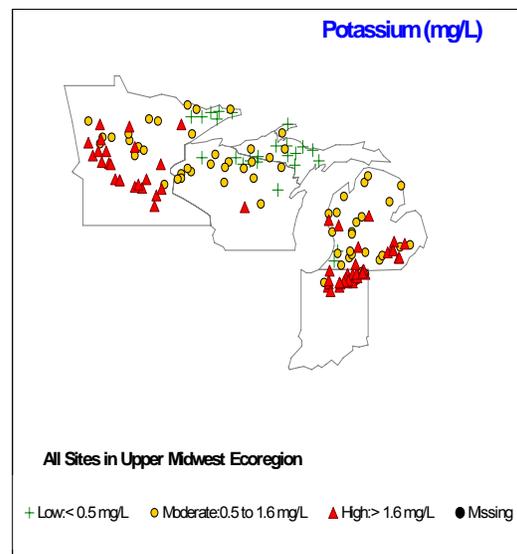
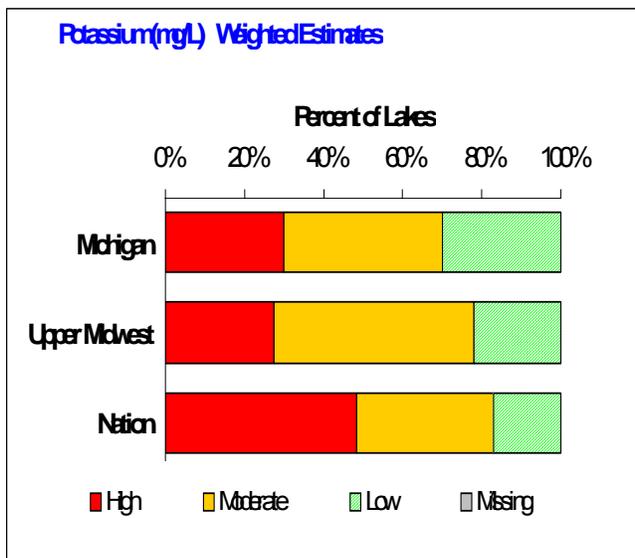


Figure 24. UMW ecoregion concentration range distribution and pattern for Potassium.

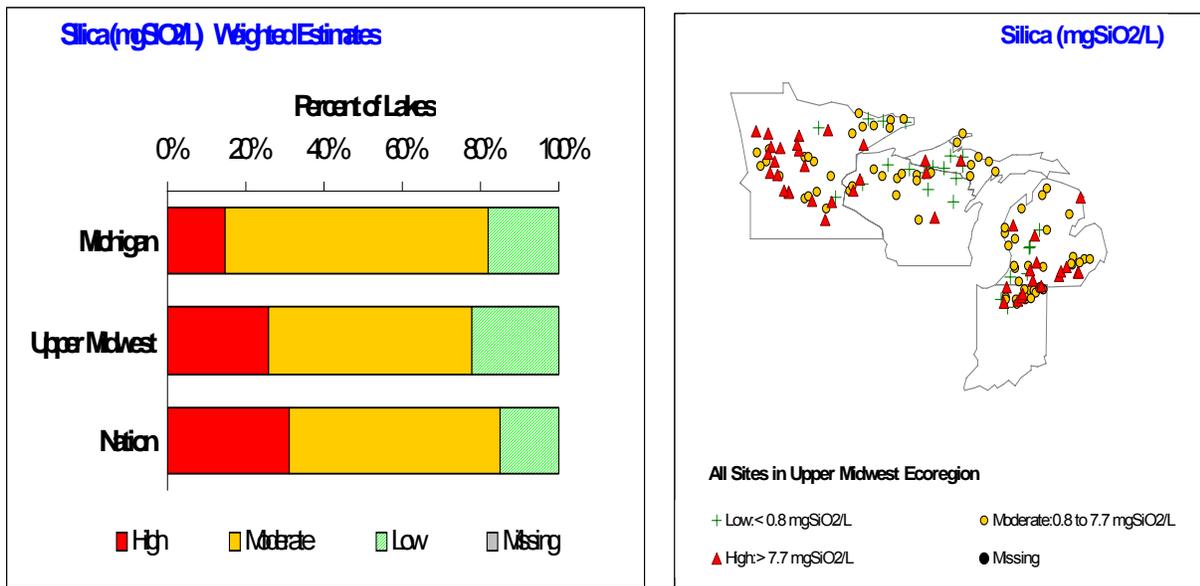


Figure 25. UMW ecoregion concentration range distribution and pattern for Silica.

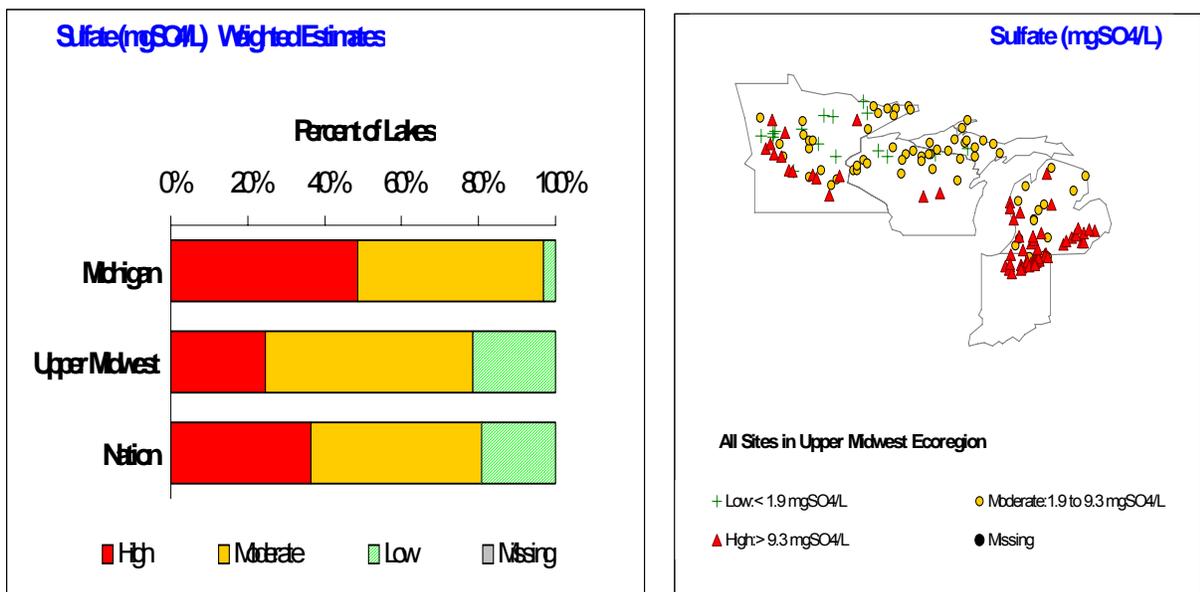


Figure 26. UMW ecoregion concentration range distribution and pattern for Sulfate.

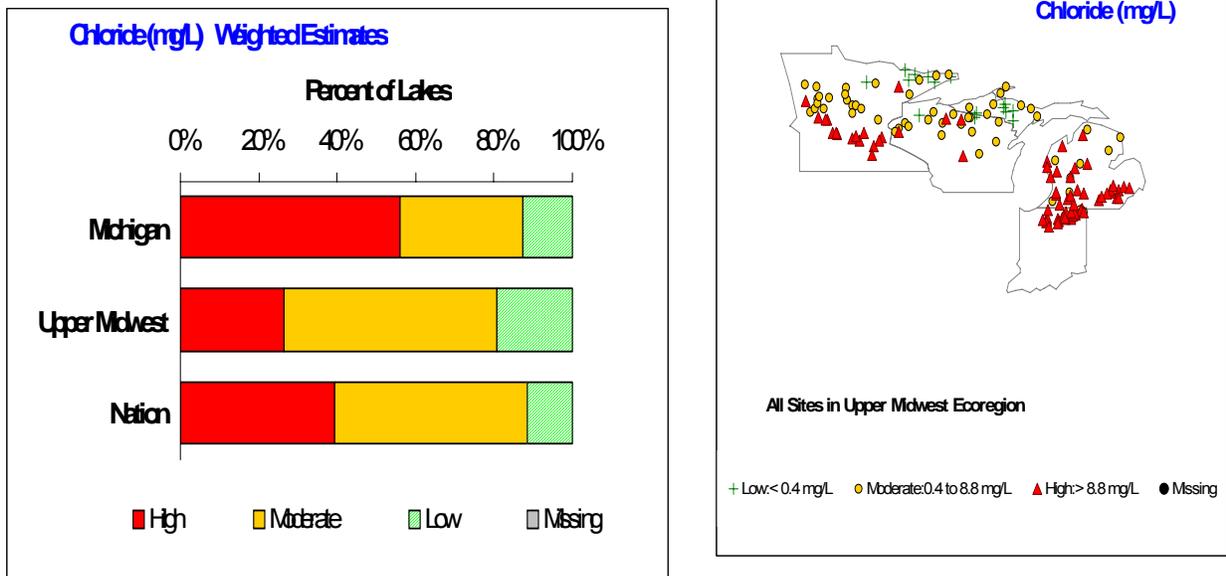


Figure 27. UMW ecoregion interquartile distribution and pattern for Chloride.

Water concentrations for chloride (median = 10.6 ug/L), sodium (medium = 5.5 ug/L) and sulfate (median = 8.8 ug/L) in Michigan lakes are elevated as compared to all UMW ecoregion lakes (Cl median = 2.4 ug/L; Na median = 2.1 ug/L; SO<sub>4</sub> median = 4.9 ug/L). The interquartile (25<sup>th</sup>-75<sup>th</sup> percentile) range for chloride in Michigan lakes is 2.7-32.5 ug/L while the interquartile ranges for sodium and sulfate are 1.5-17.7 ug/L and 4.3-20.5 ug/L, respectively (Table 5). Elevated concentrations for these ions are associated with areas of higher population densities, especially in southern Michigan.

#### ANC and pH

Alkalinity is traditionally the term that referred to the buffering capacity of the carbonate-bicarbonate system in water and is now used interchangeably with ANC (Wetzel, 2001). Bicarbonates and carbonates provide most of this buffering capacity in Michigan waters. Alkalinity is often expressed as mg/L CaCO<sub>3</sub> but is more accurately expressed as equivalents per liter (1 mg/L = 20 microequivalence per liter [ueq/L] or 0.02 milliequivalence per liter [meq/L]). Michigan's dominant limestone geology in the Lower Peninsula and the eastern Upper Peninsula contributes to the vast majority of Michigan lakes being carbonate-bicarbonate dominant and lakes in the western Upper Peninsula having lower alkalinity and thus lesser buffering capacity. The carbonate-bicarbonate buffering system highly influences the pH in Michigan's lakes. The concentration range (low, moderate, high) distribution and regional pattern for ANC is illustrated in Figure 28. The concentration ranges (low, moderate, high) for each parameter correspond to the lower-quartile (<25<sup>th</sup> percentile), inter-quartile (25<sup>th</sup>-75<sup>th</sup> percentile), and upper-quartile (> 75<sup>th</sup> percentile). The distribution and regional pattern for pH is illustrated in Figure 29 with the threshold values set at 6.5 and 9.0 standard units (S.U.); the Michigan water quality standard range for pH (hydrogen ion concentration range).

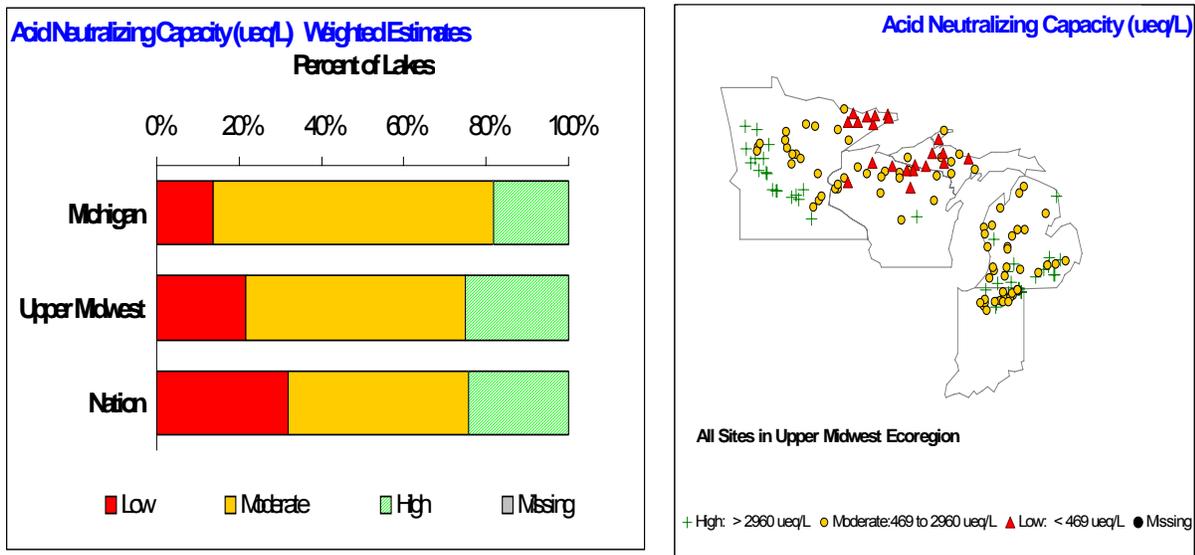


Figure 28. UMW ecoregion concentration range distribution and pattern for ANC.

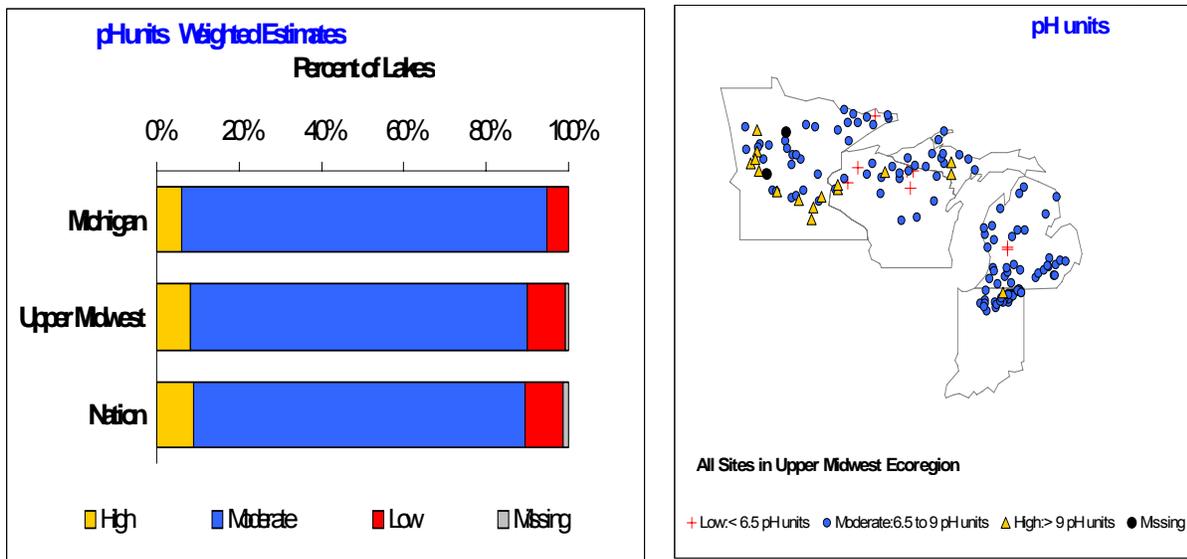


Figure 29. UMW ecoregion trophic status criteria distribution and pattern for pH.

### NES Lake Summary

Between 1972 and 1976, the USEPA conducted the NES (USEPA, 1974). This study was designed to assess the trophic condition (defined as nutrient enrichment) of lakes influenced by domestic wastewater treatment plants (WWTPs). While national in scope, the NES lake selection design was unlike the NLA in that it was not probability-based; rather it targeted a specific set of 800 wastewater impacted lakes.

As part of the 2007 NLA, a subset of 200 randomly selected NES lakes was resampled to allow for a statistical assessment for that specific population of lakes. Although some design

differences between the two studies are recognized, the NLA analysts looked at changes in the NES lakes over the 30-plus years by comparing concentration levels of key indicators and by examining trophic status. Comparing historical (circa 1972) to current (2007) TP levels in the NES lakes, they found 50% decreased, 26% increased, and 24% had no change. Trophic status based on chlorophyll-a also changed with trophic status improving in 26% (184) of the lakes, remaining unchanged in over half (51% or 408 lakes), and degrading in 23% (208) of the NES lakes (USEPA, 2009).

Michigan had eight NES lakes included in the 2007 NLA. Pertinent water quality data for these lakes from the NLA are summarized in Table 8. Changes in point source discharges and TP levels since the NES are noted in Table 9.

Table 8. Michigan's NES lakes included in 2007 NLA.

NLA Site ID	Lake Name	County	Ecoregion	Lake Area (hectars)	Sample Date	Mean Depth (meters)	TP (ug/L)	TN (ug/L)	Chl-a (ug/L)	Secchi Depth (meters)	Spec Cond (umhos)	Na (mg/L)	SO4 (mg/L)	Cl (mg/L)
NLA06608-0363	Palmer Lake	ST JOSEPH	SMNIDP	291.7	7/21/2007	4.3	18	567	11.7	1.70	475	6.8	61.4	22.4
NLA06608-0463	Belleville Lake	WAYNE	SMNIDP	272.8	8/19/2007	1.9	82	1031	30.7	0.58	716.6	41.9	39.1	101.7
NLA06608-0938	Muskegon Lake	MUSKEGON	SMNIDP	1889.3	8/7/2007	6.3	34	519	11.9	1.46	387.7	17.6	20.3	24.4
NLA06608-1014	Lake Chemung	LIVINGSTON	SMNIDP	120.1	9/13/2007	7.0	15	568	9.8	4.20	683.3	58.0	19.3	108.2
NLA06608-1130	Thornapple Lake	BARRY	SMNIDP	177.5	8/21/2007	3.1	65	634	23.7	1.08	555	9.4	42.9	24.6
NLA06608-1487	Ford Lake	WASHTENAW	SMNIDP	384.9	8/20/2007	3.3	61	1071	14.6	1.93	737.5	44.4	43.1	111.6
NLA06608-1626	Pere Marquette Lake	MASON	SMNIDP	238.2	8/8/2007	4.3	30	623	14.8	1.95	390.6	10.6	20.4	22.9
NLA06608-1782	Lake Brighton	LIVINGSTON	SMNIDP	63.8	9/13/2007	1.0	32	606	17.4	0.95	696	54.6	15.3	110.4

Table 9. Michigan NES lakes WWTP discharge status and in-lake TP changes.

NLA Site ID	Lake Name	County	NES TP ug/L (1972)	NLA TP ug/L (2007)	Point Source Discharge Status
NLA06608-0363	Palmer Lake	ST JOSEPH	123	18	Discharge from Bronson WWTP, secondary treatment upgrade in 1973, advanced treatment in 1994
NLA06608-0463	Belleville Lake	WAYNE	118	82	Discharge from Ypsilanti Township WWTP removed. Indirect input from Ann Arbor, Ypsilanti, Scio-Webster, and Dexter WWTP; TMDL established in 2004
NLA06608-0938	Muskegon Lake	MUSKEGON	48	34	Muskegon and Roosevelt Park WWSL and land disposal system within watershed
NLA06608-1014	Lake Chemung	LIVINGSTON	15	15	No WWTP discharge to lake, riparian property septic tank/drainfield treatment systems
NLA06608-1130	Thornapple Lake	BARRY	46	65	Discharge from Nashville WWTP, WWSL and spray irrigation replacement system in 1981
NLA06608-1487	Ford Lake	WASHTENAW	71	61	Discharge from Ann Arbor, Dexter, Scio-Webster, and Ypsilanti WWTP; TMDL established in 2004
NLA06608-1626	Pere Marquette Lake	MASON	23	30	Discharge from Ludington WWTP and Scottville and Custer WWSL
NLA06608-1782	Lake Brighton	LIVINGSTON	642	32	Discharge from Brighton WWTP, phosphorus removal since 1970, point source discharge elimination in 1988

Based on a simple comparison of trophic state indicators (TP, chlorophyll-a, and transparency) represented as Carlson Trophic State Index (TSI) values, two of the eight lakes (Palmer and Brighton) exhibited trophic condition improvement for two of the indicators (Figures 30-32). The

other six lakes did not show a shift in trophic conditions. Belleville, Ford, and Thornapple are man-made lake reservoirs with large watersheds. Muskegon and Pere Marquette are drowned river mouth lakes with outlets to Lake Michigan. Chemung is a natural lake with no WWTP discharge, but may be influenced by the individual septic tanks of the shoreline dwellings. It should be noted that the 1972 NES chlorophyll-a data may have an error up to  $\pm 20\%$  because of instrumentation problems during the 1972 sampling.

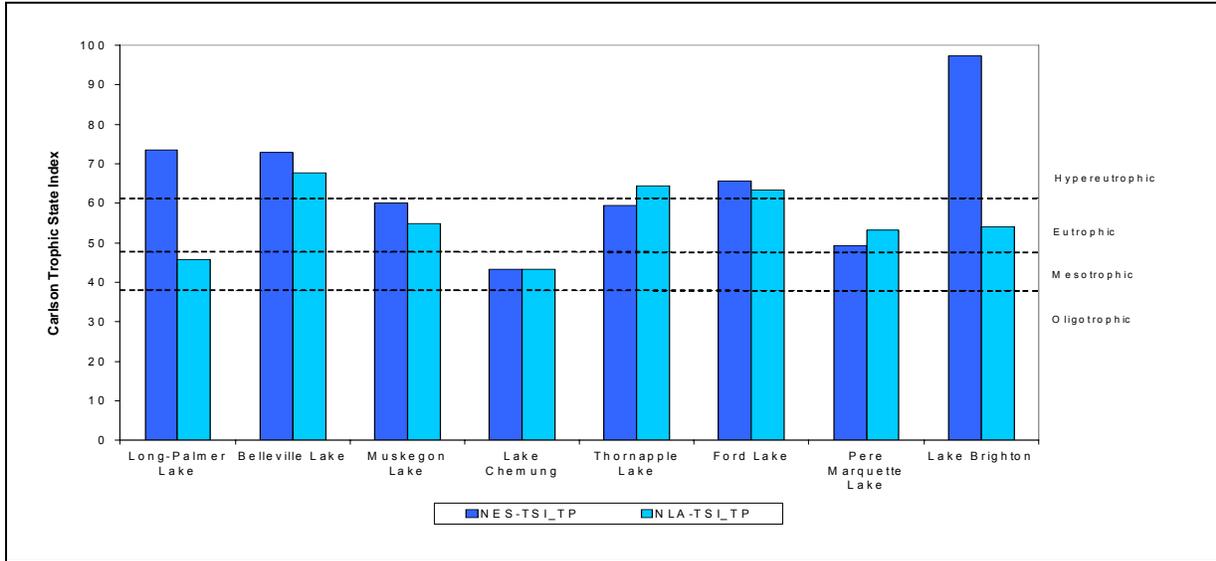


Figure 30. Long-term Trophic Condition Changes in Michigan NLA/NES Lakes: Carlson TSI-TP.

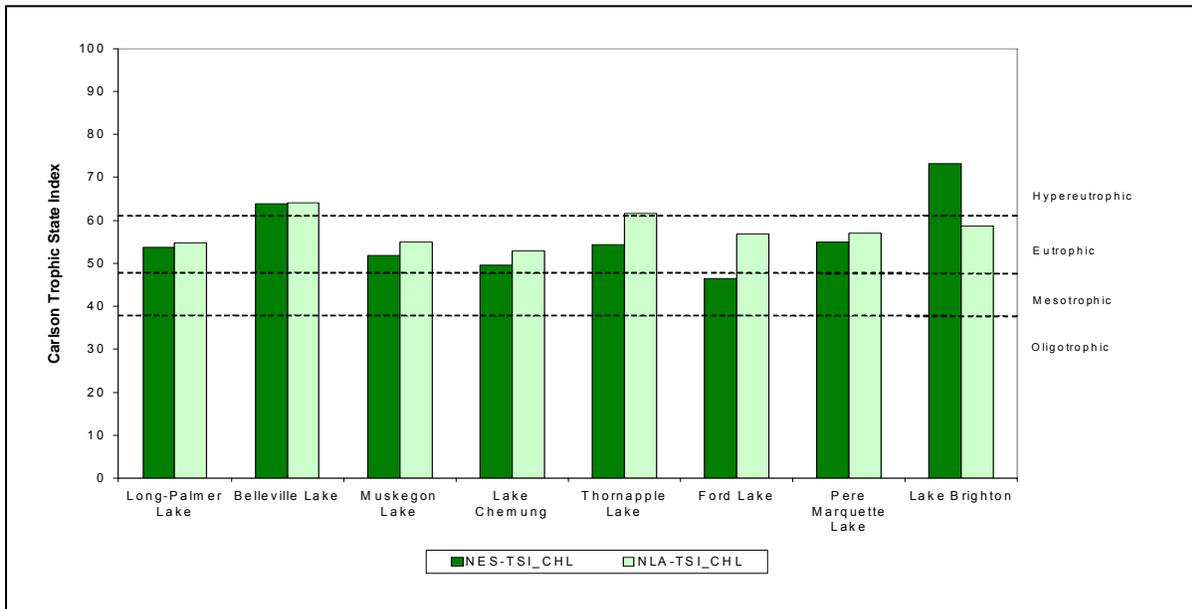


Figure 31. Long-term Trophic Condition Changes in Michigan NLA/NES Lakes – Carlson TSI-Chlorophyll-a.

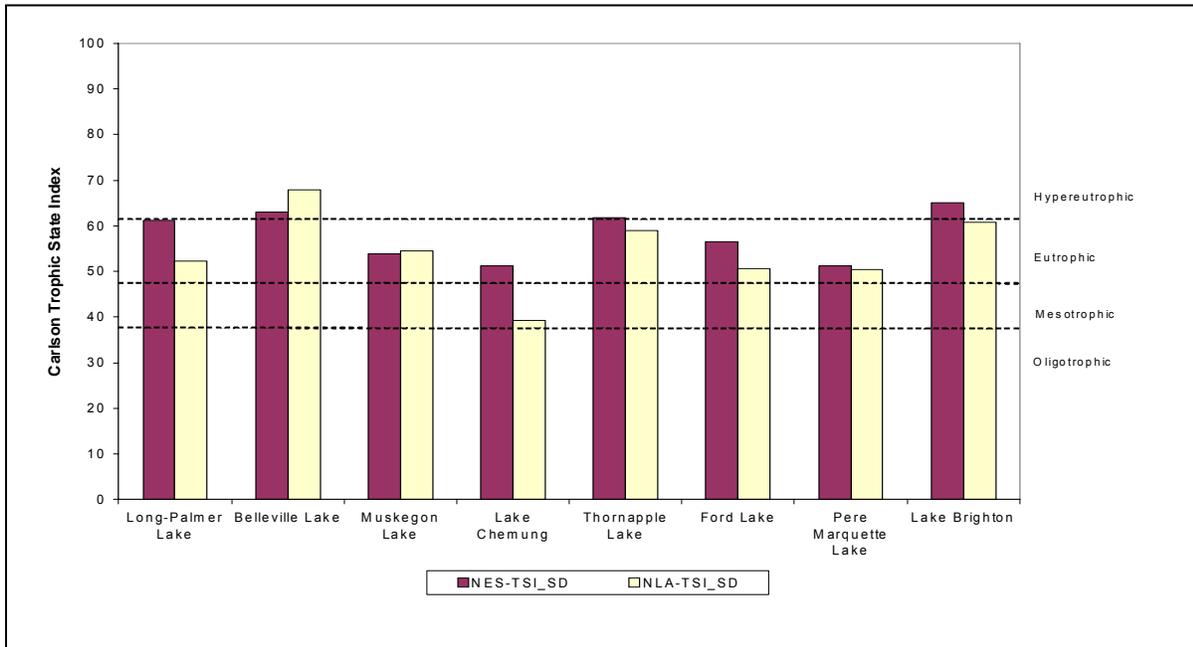


Figure 32. Long-term Trophic Condition Changes in Michigan NLA/NES Lakes – Carlson TSI-Transparency.

Figure 33 illustrates historical phosphorus levels for Brighton, Palmer, Thornapple, and Chemung as examples of long-term changes or trends in the NES lakes. Palmer Lake exhibited significant reduction in TP after the Bronson WWTP secondary treatment upgrade in 1973. Lake Brighton TP levels dropped substantially after phosphorus removal was established at the Brighton WWTP in 1970 and the outfall was removed and relocated downstream in 1988. Lake Chemung does not receive direct treated domestic wastewater input and it exhibits consistent low TP levels over time. Thornapple Lake, a reservoir lake with a large watershed, shows variable TP levels but a decreasing trend since the Nashville WWTP was replaced with a Wastewater Sewage Lagoon (WWSL) and spray irrigation system in 1981. These examples demonstrate the value of a long-term data record to assess changes or trends and the lake-specific response to point source nutrient load reductions.

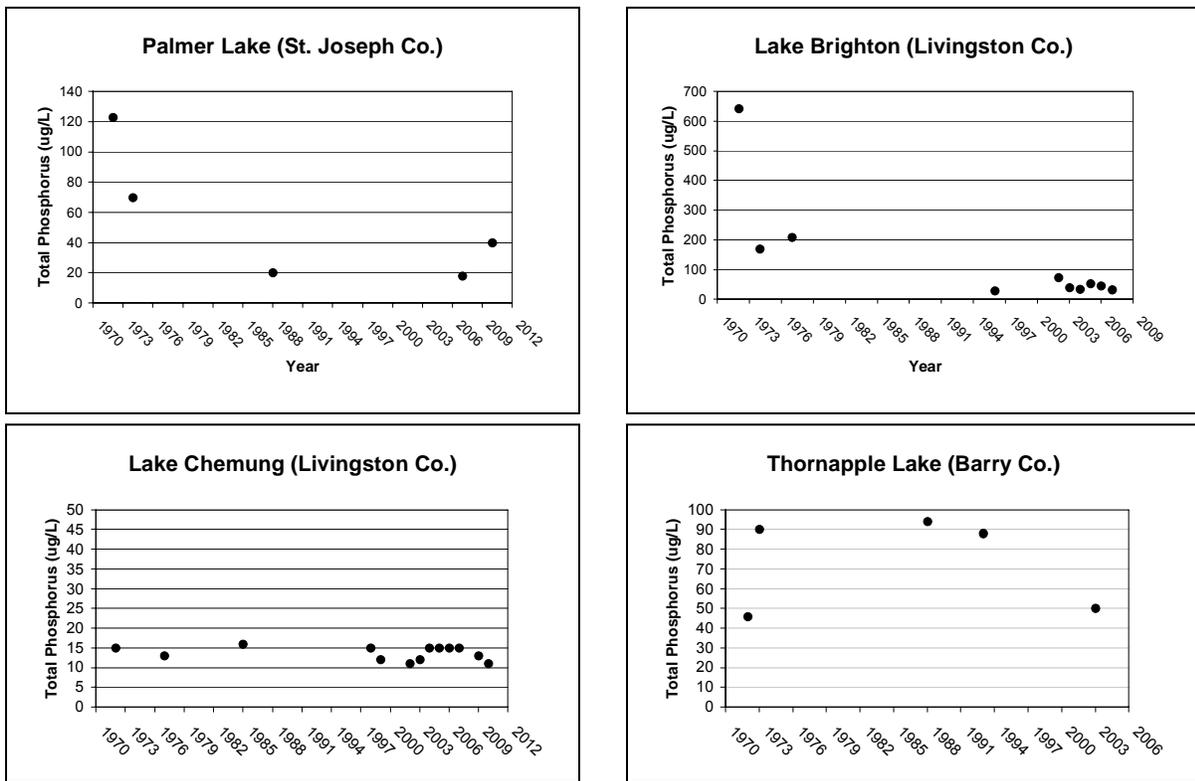


Figure 33. Long-term TP levels in Palmer, Brighton, Chemung, and Thornapple Lakes (note: different scales used for Total Phosphorus [y-axis])

#### Comparison of 2007 NLA Data with MDEQ and MDNR Data

As indicated previously, Michigan’s state lake monitoring programs were ongoing at the time of the 2007 NLA Survey, specifically the MDEQ LWQA monitoring program and the MDNR STP. Additionally, the MDEQ CLMP, Michigan’s statewide volunteer lakes monitoring program, annually collects trophic state indicator data on over 200 lakes.

The MDEQ and U.S. Geological Survey-Michigan Water Science Center jointly redesigned and implemented the LWQA monitoring program in 2001 (MDEQ, 2001). Under the current program, a set of 730 public access lakes larger than 25 acres in surface area were targeted for sampling by 2010. During 2007, 85 lakes were sampled as part of the LWQA monitoring program. An interim five-year project report was published in 2008 (Fuller and Minnerick, 2008) with a final report targeted for early 2012 (Fuller and Taricska, 2012).

The MDNR, Fisheries Division, implemented the STP in 2002 (Hayes et al., 2003). The objective of the STP is to collect and synthesize data needed by fisheries managers, policy-makers, and the public to maintain an inventory of inland habitat and fish community characteristics statewide; develop reference points for local, regional, and statewide management needs; and assess the status of, and detect changes to, aquatic habitats and fish communities across Michigan. The STP uses a stratified random design to determine what lakes to survey. This design ensures that sampling effort is distributed across the state and across a range of lake types, including all public lakes ten acres and larger in size. The initial

STP report covering the first six years, 2002-2007, and a total of 233 lakes sampled, is targeted for early 2012 (Wehrly et al., 2012b). Twenty-eight lakes were sampled for the STP in 2007.

The CLMP has been an important component of Michigan's inland lakes monitoring program for over 38 years (<https://micorps.net/>). The primary purpose of this cooperative program is to help citizen volunteers monitor indicators of water quality in their lake and document changes in lake quality over time. During 2007, 91 lakes enrolled in the CLMP were sampled for the primary trophic status indicators.

Table 10 summarizes the trophic condition indicator (Secchi transparency, TP, and chlorophyll-a) data that were collected independently in 2007 as part of the four statewide monitoring programs. These data (unweighted) are presented graphically as box and whiskers plots in Figures 34-36.

Secchi transparency is lower for the NLA results with an unweighted median of 2.31 meters (2.14 meters - weighted data) compared to 3.2, 3.2, and 3.5 meters for the LWQA, STP, and CLMP, respectively. Conversely, the chlorophyll-a results for the NLA are higher with an unweighted median of 3.82 ug/L (3.32 ug/L – weighted data) compared to 2.8, 2.65, and 2.9 ug/L for the LWQA, STP, and CLMP, respectively. The epilimnetic TP results for the state agency monitoring programs are similar to the unweighted NLA results with median values of 11, 10, and 10 ug/L for the LWQA, STP, and CLMP, respectively, compared to 10.5 ug/L for the NLA. However, when the NLA results are adjusted for the lake size distribution categories and weighted accordingly, the statewide median TP concentration is 8 ug/L.

Table 10. Statistical summary of the trophic state parameters collected in 2007 as part of the NLA survey, LWQA monitoring program, STP, and CLMP monitoring network.

Survey (2007)	Stats	Total Phosphorus (ug/L)	Secchi Transparency (m)	Chlorophyll-a (ug/L)
NLA (weighted) (n=50)	mean	13.1	2.3	5.38
	std dev	10.5	1.67	4.92
	max	82	7.95	30.7
	75th	16	3.52	5.05
	50th	8	2.14	3.32
	25th	6	0.8	2.31
	min	3	0.58	1.1
NLA (unweighted) (n=50)	mean	17	2.65	7
	std dev	16.5	1.54	6.61
	max	82	7.95	30.7
	75th	19.5	3.64	9.97
	50th	10.5	2.31	3.82
	25th	7	1.43	2.98
	min	3	0.58	1.1
LWQA (n=85)	mean	14.4	3.5	4.98
	std dev	11.06	1.51	9.93
	max	73	7.3	90
	75th	16	4.3	5.25
	50th	11	3.2	2.8
	25th	8	2.4	1.8
	min	<5	0.3	<1
STP (n=28)	mean	11.9	3.37	3.35
	std dev	6.13	1.28	2.35
	max	26	6.1	11
	75th	15.5	4.22	3.7
	50th	10	3.2	2.65
	25th	7	2.29	2.1
	min	4	1.52	<1
CLMP (n=91)	mean	12.4	3.69	3.91
	std dev	8.23	1.5	3.36
	max	48	8.7	19
	75th	16	4.5	4.5
	50th	10	3.5	2.9
	25th	7	2.7	1.9
	min	<5	0.6	<1

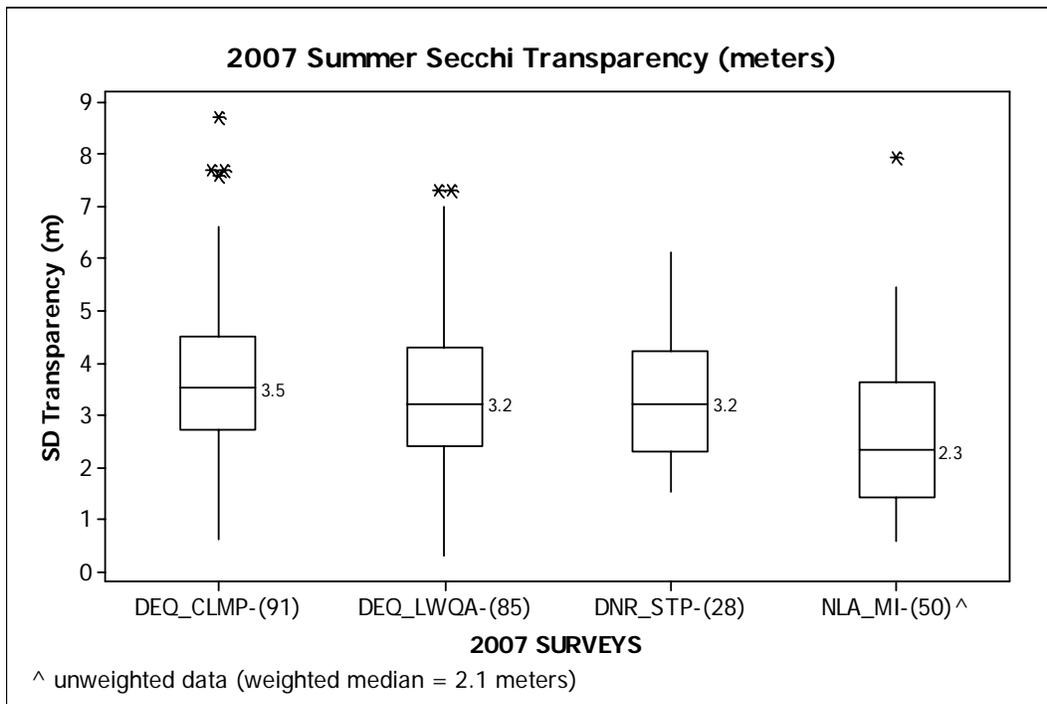


Figure 34. Multiple surveys comparison – 2007 summer Secchi transparency.

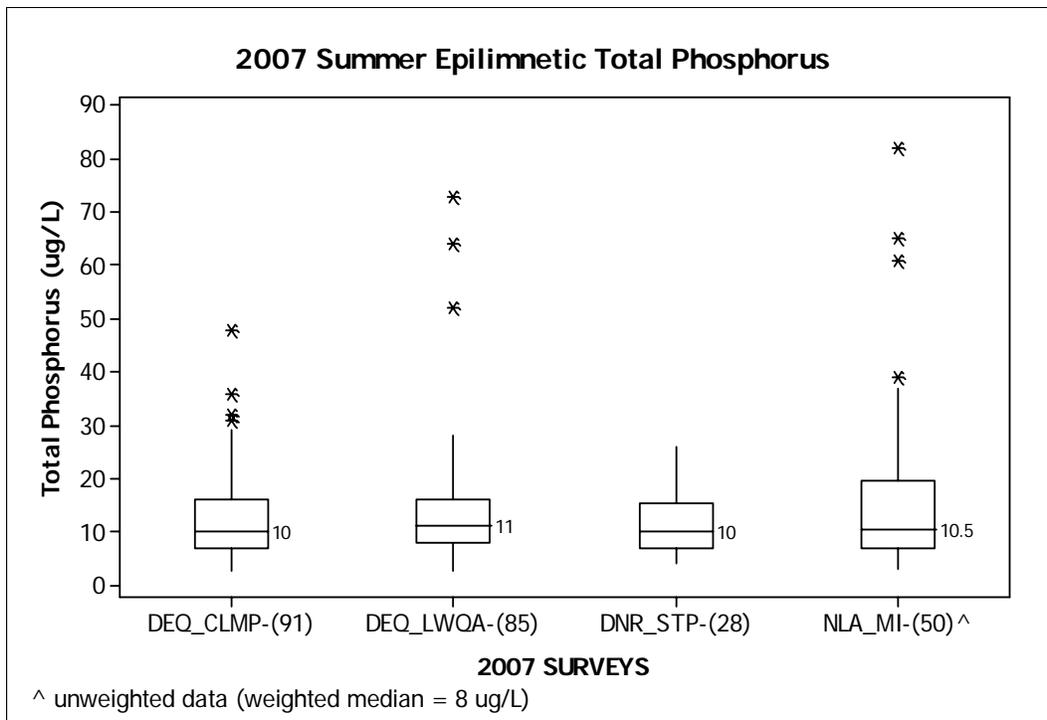


Figure 35. Multiple surveys comparison – 2007 summer epilimnetic TP.

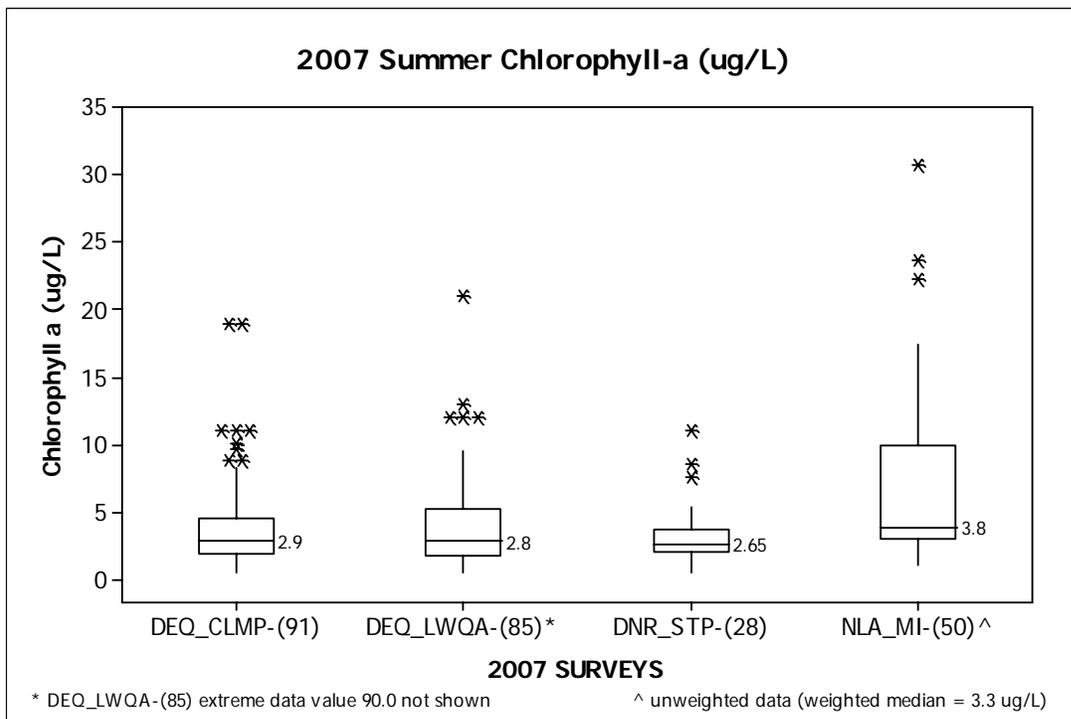


Figure 36. Multiple surveys comparison – 2007 summer chlorophyll-a.

### Summary and Conclusions

Michigan’s 2007 NLA Survey effort was led by the MDEQ with contractual support from the GLEC. The MDEQ and GLEC cooperated on the initial planning of the survey and GLEC staff conducted the sampling of Michigan’s Lower Peninsula lakes included in the survey and coordinated sample processing and shipping. The MDEQ Senior Environment Employment staff sampled Michigan’s Upper Peninsula lakes.

Michigan received 29 lakes as a part of the original NLA draw of lakes and added 21 lakes to the survey to achieve the 50 lakes minimum needed for statistically-based statewide estimates of condition (Figure 1). Four lakes from the suite of national reference lakes selected by the USEPA were also located in Michigan. Applying the appropriate weighting factors to the data collected from this random set of lakes provides for a robust dataset for evaluating ecological and recreational condition of Michigan’s lakes and for examining statewide and regional patterns in trophic status indicators and related water chemistry parameters included in the NLA.

The biological condition of Michigan’s lakes is good based on the assessment of the zooplankton and phytoplankton assemblages. The planktonic O/E taxa loss analysis shows that 86% of the lakes are in good condition ( $\leq 20\%$  taxa loss), which is similar to all lakes in the UMW ecoregion at 91%. Only 3% of Michigan lakes are considered poor ( $> 40\%$  taxa loss) for these two biological communities. Based on the LDCI, 86% of Michigan’s lakes are in least disturbed (good) or intermediate disturbed (fair) condition as compared to 78% for the UMW ecoregion.

Physical impacts to lakeshore and littoral habitats were found to be the greatest stressors for lakes in Michigan as well as the UMW ecoregion and the nation's lakes. Loss of lakeshore habitat and physical lakeshore complexity are the major stressors for Michigan lakes with nearly 40% of lakes in poor condition for each of these stressors. Shallow water habitat is in poor condition in nearly 18% of Michigan's lakes. The lakeshore and littoral habitat stressors are more significant in Michigan lakes as compared to all lakes in the UMW ecoregion. Nutrients and turbidity account for 3% to 4% of lakes in poor condition for these stressors. Nutrient levels (TP and TN) are lower in Michigan lakes as compared to all lakes in the UMW ecoregion. Salinity/conductivity, ANC, and dissolved oxygen (epilimnetic) stressors as measured in the NLA Survey are minor in Michigan lakes statewide.

For the NLA, recreational health was evaluated based on three indicators of potential risk including microcystins levels, cyanobacteria (bluegreen algae) abundance, and chlorophyll-a concentrations. Microcystin is detected in approximately one-third of Michigan lakes, which is slightly higher than for all lakes in the UMW ecoregion. However, for the indicators of risk, less than 15% of Michigan lakes exhibit moderate potential for cyanobacteria and recreational chlorophyll risk, which is lower than for all lakes in the UMW ecoregion. No lakes exhibited high risk.

The 2007 NLA opted to use chlorophyll-a as the primary indicator for assessing the trophic condition of the nation's lakes. Michigan employs chlorophyll-a as well as TP and Secchi transparency to determine lake trophic status. Based on the NLA chlorophyll-a results, Michigan's lake trophic condition distribution is 7% oligotrophic, 67% mesotrophic, 21% eutrophic, and 3% hypereutrophic. This is compared to 13% oligotrophic, 45% mesotrophic, 29% eutrophic, and 12% hypereutrophic for all lakes in the UMW ecoregion.

Michigan's lake trophic condition distribution based on the NLA TP results is much different with 54% oligotrophic, 28% mesotrophic, 17% eutrophic, and 0.4% hypereutrophic, which may be skewed as a result of sample handling and sample holding time disparity. Based on the recently completed LWQA monitoring program results for all 730 public access lakes sampled statewide, the trophic condition distribution is 17.5% oligotrophic, 55% mesotrophic, 24% eutrophic, and 3.5% hypereutrophic using an integrated trophic indicators assessment (Bednarz, 2011).

The chemical condition of Michigan and UMW ecoregion lakes is a consequence of their glacial origin and Great Lakes basin geology. The dominant limestone geology and thick glacial deposits in Michigan's Lower Peninsula and eastern Upper Peninsula establishes the base chemistry and buffering capacity for the mostly hard-water lakes in this region while the Canadian Shield igneous and sandstone bedrock geology of the western Upper Peninsula creates a much different water chemistry pattern with a greater percentage of soft-water lakes.

Michigan lakes generally have more ANC as compared to all lakes in the UMW ecoregion. However, lakes in the western Upper Peninsula tend to have lower ANC and thus they are more vulnerable to acidification, both from natural and human-based pH stressors. The NLA Survey found two Michigan lakes below Michigan's Water Quality Standard for hydrogen ion concentration expressed as pH range (6.5-9.0 S.U.), which on a weighted basis represent 5.3% of Michigan's lakes statewide. Unpredictably, both of these lakes were located in the Lower Peninsula, which is inconsistent with the results of the LWQA monitoring program, which found 14 of the 730 lakes sampled (1.9%) had spring turnover or summer epilimnetic pH below 6.5 S.U. and 19 lakes (2.6%) were threatened for low pH (Bednarz, 2011). All but two of these lakes are located in the western Upper Peninsula. These results suggest that more lakes may

need to be added to the NLA state-scale survey design to accurately determine distribution patterns for these parameters in Michigan lakes given the dissimilar water chemistry characteristics of the western Upper Peninsula lakes compared to the Lower Peninsula lakes.

Calcium and sodium are the dominant cations and sulfate and chloride, along with carbonate-bicarbonate, are the dominant anions. Concentrations of these ions in Michigan lakes are higher as compared to all lakes in the UMW ecoregion. The highest chloride and sulfate concentrations are generally associated with areas of higher population density and transportation corridors in southeast Michigan.

Organic carbon in Michigan lakes is relatively low compared to all lakes in the UMW ecoregion. Platinum-cobalt color levels are similar for Michigan lakes compared to lakes in the UMW ecoregion. The median value for Secchi transparency in Michigan lakes is similar to all lakes in the UMW ecoregion although a greater percentage of Michigan lakes are in the higher transparency category (75<sup>th</sup> percentile) when compared to all lakes in the UMW ecoregion. Turbidity is generally less in Michigan lakes as compared to all UMW ecoregion lakes.

Water concentration of TP in Michigan lakes is low as compared to all UMW ecoregion lakes while TN concentration is similar but slightly higher. Chlorophyll-a levels are also lower for Michigan lakes as compared to all lakes in the UMW ecoregion. The relative phosphorus-rich to phosphorus-poor south to north lakes distribution pattern previously reported for the Lower Peninsula is reinforced by the NLA Survey results. Michigan's Upper Peninsula lakes show a more variable pattern for nutrients. These patterns are mirrored by the chlorophyll-a results.

Michigan's subset of NES lakes exhibited trophic condition improvement in two of the eight lakes sampled. The improved conditions in these lakes resulted from treatment upgrades or removal of WWTP discharges to the lakes. The six NES lakes that showed little or no improvement are either man-made reservoir lakes on large watersheds, drowned river mouth lakes to Lake Michigan, or a lake with individual septic systems for the shoreline dwellings but no WWTP discharge.

When comparing NLA results to the LWQA, STP, and CLMP results for the 2007 monitoring cycle, the NLA findings for Secchi transparency was lower and chlorophyll-a higher than measured in the agency monitoring programs. For TP, the unweighted NLA value was similar but the weighted value was lower as compared to the LWQA, STP, and CLMP results.

The NLA randomly selected lake dataset provides a valuable complement to data collected from the MDEQ targeted lake monitoring programs and the MDNR fishery condition-based lake STP. The NLA state-scale assessment allows for extrapolation to the entire state, and defined regions, for all lakes 4 hectares (10 acres) or larger. This can provide context for data collected from other monitoring programs, help identify the most significant statewide lake management needs, and provide a basis for assessing effectiveness of lake management and pollution control activities on Michigan's inland lakes. It also allows management agencies to target resources and additional monitoring where they may be needed to protect, preserve, and restore water quality.

The NLA ecoregional assessments reveal broad-scale patterns in lake condition across state lines. The UMW ecoregion assessment and state-scale results for Michigan, Wisconsin, and Minnesota provide a basis for comparing and evaluating lake management strategies and outcomes across jurisdictional boundaries.

The NLA biological condition indicators and the quantitative physical habitat metrics added an additional dimension to Michigan's lake quality assessment process. The 2007 NLA-Michigan found that 86% of Michigan's lakes support healthy planktonic communities when compared to least disturbed reference sites. But lakeshore habitats and physical lakeshore complexity are found to be the major stressors for Michigan lakes, which may impact overall lake condition long-term. These results point to the importance of expanding and establishing protective lakes management programs, such as the Michigan Natural Shoreline Partnership (<http://www.shorelinepartnership.org/>), and supporting "grass-root" lake protection and preservation initiatives in Michigan.

The state-scale results establish a baseline for future monitoring efforts on Michigan lakes, which may be used to track statewide trends in lake condition. Continued state-scale participation in the NLA will allow for more detailed assessment of temporal differences in the data and trend analysis for Michigan's lakes. Adding more lakes to the state-scale assessments is recommended to allow for more refined analysis of the distribution patterns for the water quality parameters.

### **Next Steps**

The next round of the NLA Survey is scheduled for summer 2012. The MDEQ will again participate in the Survey and conduct a state-scale assessment to add to the 2007 NLA-Michigan findings.

Future direction for Michigan's lake monitoring and assessment programs is being discussed by a joint MDEQ-MDNR water collaboration team. The directive of this team is to explore opportunities for collaboration between the MDNR, Fisheries Division, and the MDEQ, Water Resources Division, monitoring programs. The NLA statistical survey design and assessment process likely will be part of future collaborative lake monitoring and assessment initiatives in Michigan.

## References

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# Appendix 1a. NLA-Michigan Lakes: Lake Morphometry.

NLA Site ID	Lake Name	Visit #	Type	County	Ecoregion*	Area (ha)	Sample Date	Est. Mean Depth (m)	Index Site Depth (m)
NLA06608-0010	Bogie Lake	1	PROB_Lake	OAKLAND	SMNIDP	30	7/17/2007	3.9	11.7
NLA06608-0010	Bogie Lake	2	PROB_Lake	OAKLAND	SMNIDP	30	8/18/2007	3.7	11
NLA06608-0170	Tallman Lake	1	PROB_Lake	MASON	NLF	51	9/21/2007	1.1	3.4
NLA06608-0234	Pine Lake	1	PROB_Lake	KENT	SMNIDP	21	8/23/2007	2.3	6.8
NLA06608-0286	Silver Lake	1	PROB_Lake	IRON	NLF	56	8/8/2007	5.9	17.8
NLA06608-0330	Lake Besser	1	PROB_Lake	ALPENA	NLF	115	9/5/2007	1.7	5
NLA06608-0363	Palmer Lake	1	NES_Lake	ST JOSEPH	SMNIDP	292	7/21/2007	4.3	13
NLA06608-0399	Hiland Lake	1	PROB_Lake	LIVINGSTON	SMNIDP	16	7/16/2007	1.2	3.5
NLA06608-0426	Eight Point Lake	1	PROB_Lake	CLARE	NLF	160	9/17/2007	2.6	7.7
NLA06608-0462	Loon Lake	1	PROB_Lake	GOGEBIC	NLF	150	8/20/2007	4.1	12.2
NLA06608-0463	Belleville Lake	1	NES_Lake	WAYNE	SMNIDP	273	8/19/2007	1.9	5.8
NLA06608-0502	Squaw Lake	1	PROB_Lake	GENESEE	SMNIDP	30	8/18/2007	3.6	10.7
NLA06608-0619	Campbell Lake	1	PROB_Lake	KALAMAZOO	SMNIDP	60	7/18/2007	3.7	11.1
NLA06608-0630	Dewey Lake	1	PROB_Lake	MARQUETTE	NLF	21	7/30/2007	0.8	2.5
NLA06608-0734	Mud Lake	1	PROB_Lake	HOUGHTON	NLF	69	7/24/2007	1.1	3.2
NLA06608-0874	Martin Lake	1	PROB_Lake	NEWAYGO	SMNIDP	23	8/30/2007	3.9	11.8
NLA06608-0875	Pine Lake	1	PROB_Lake	EATON	SMNIDP	46	9/14/2007	2.1	6.3
NLA06608-0938	Muskegon Lake	1	NES_Lake	MUSKEGON	SMNIDP	1889	8/7/2007	6.3	19
NLA06608-0974	Fence Lake	1	PROB_Lake	BARAGA	NLF	94	7/16/2007	1.6	4.9
NLA06608-1003	Round Lake	1	PROB_Lake	VAN BUREN	SMNIDP	82	7/23/2007	2.7	8.2
NLA06608-1014	Lake Chemung	1	NES_Lake	LIVINGSTON	SMNIDP	120	9/13/2007	7.0	21.1
NLA06608-1034	Mill Lake	1	PROB_Lake	OAKLAND	SMNIDP	11	8/16/2007	3.0	9
NLA06608-1130	Thornapple Lake	1	NES_Lake	BARRY	SMNIDP	178	8/21/2007	3.1	9.4
NLA06608-1162	Lake Au Sable	1	PROB_Lake	OGEMAW	NLF	106	9/6/2007	5.0	15
NLA06608-1167	Clark Lake	1	PROB_Lake	JACKSON	SMNIDP	233	9/20/2007	5.2	15.5
NLA06608-1206	McDonald	1	PROB_Lake	DELTA	NLF	12	8/2/2007	0.7	2.2
NLA06608-1258	Stoner Lake	1	PROB_Lake	KENT	SMNIDP	30	8/22/2007	0.5	1.5
NLA06608-1334	Crooked Lake	1	PROB_Lake	EMMET	NLF	1396	7/31/2007	5.0	15
NLA06608-1334	Crooked Lake	2	PROB_Lake	EMMET	NLF	1396	8/14/2007	6.0	18
NLA06608-1358	Lake Gogebic	1	PROB_Lake	GOGEBIC	NLF	5280	8/28/2007	2.2	6.7
NLA06608-1358	Lake Gogebic	2	PROB_Lake	GOGEBIC	NLF	5280	9/18/2007	2.2	6.7
NLA06608-1370	Wyckoff Lake	1	PROB_Lake	OCEANA	SMNIDP	15	8/31/2007	2.0	6
NLA06608-1387	West Lake	1	PROB_Lake	KALAMAZOO	SMNIDP	132	7/20/2007	0.9	2.7
NLA06608-1398	Howe Lake	1	PROB_Lake	ALGER	NLF	36	8/17/2007	0.3	1
NLA06608-1434	Deer Lake	1	PROB_Lake	CHARLEVOIX	NLF	184	8/1/2007	1.8	5.5
NLA06608-1450	Blue Lake	1	PROB_Lake	MECOSTA	SMNIDP	89	7/24/2007	5.0	15
NLA06608-1487	Ford Lake	1	NES_Lake	WASHTENAW	SMNIDP	385	8/20/2007	3.3	10
NLA06608-1515	Upper Scott	1	PROB_Lake	ALLEGAN	SMNIDP	38	8/29/2007	0.6	1.8
NLA06608-1626	Pere Marquette Lake	1	NES_Lake	MASON	SMNIDP	238	8/8/2007	4.3	13
NLA06608-1643	Warner Lake	1	PROB_Lake	BARRY	SMNIDP	16	7/19/2007	3.7	11.2
NLA06608-1654	Forestville Basin	1	PROB_Lake	MARQUETTE	NLF	36	7/9/2007	2.4	7.2
NLA06608-1679	Tims Lake	1	PROB_Lake	JACKSON	SMNIDP	41	7/15/2007	2.5	7.5
NLA06608-1690	Bridge Lake	1	PROB_Lake	GRAND TRAVERSE	NCHF	13	9/10/2007	3.7	11
NLA06608-1706	Clark Co. Lake	1	PROB_Lake	CLARE	SMNIDP	4	9/17/2007	1.3	4
NLA06608-1707	Donnell Lake	1	PROB_Lake	CASS	SMNIDP	96	7/22/2007	6.4	19.2
NLA06608-1742	Big Lake	1	PROB_Lake	BARAGA	NLF	50	7/18/2007	3.1	9.2
NLA06608-1758	Bailey Lake	1	PROB_Lake	KEWEENAW	NLF	78	7/23/2007	0.3	1
NLA06608-1771	Saddle Lake	1	PROB_Lake	VAN BUREN	SMNIDP	109	8/28/2007	3.0	9
NLA06608-1782	Lake Brighton	1	NES_Lake	LIVINGSTON	SMNIDP	64	9/13/2007	1.0	3
NLA06608-1802	Stony Creek Lake	1	PROB_Lake	MACOMB	SMNIDP	192	9/12/2007	2.1	6.3
NLA06608-1910	Blomgren	1	PROB_Lake	DICKINSON	NLF	32	7/11/2007	0.6	1.8
NLA06608-1998	Keewaydin Lake	1	PROB_Lake	MARQUETTE	NLF	53	8/6/2007	2.3	6.9
NLA06608-1998	Keewaydin Lake	2	PROB_Lake	MARQUETTE	NLF	53	9/11/2007	2.1	6.2
NLA06608-2078	Lotto Lake	1	PROB_Lake	MARQUETTE	NLF	43	8/24/2007	1.6	4.8
NLA06608-ELS:2B2-008	Hall Lake	1	REF_Lake	HOUGHTON	NLF	6	8/21/2007	4.6	13.7
NLA06608-MI:7007	Sullivan Lake	1	REF_Lake	WASHTENAW	SMNIDP	10	8/1/2007	2.2	6.7
NLA06608-R5:KATHRYN	St. Kathryn	1	REF_Lake	IRON	NLF	65	8/22/2007	3.0	9.1
NLA06608-R5:OTTAWA	Lake Ottawa	1	REF_Lake	IRON	NLF	214	8/23/2007	8.6	25.9

\*Ecoregion Key  
 NCHF – North Central Hardwood Forests  
 NLF – Northern Lakes and Forests  
 SMNIDP – Southern Michigan/Northern Indiana Drift Plains

Appendix 1b. NLA-Michigan Lakes: Organic carbon, Color, pH, ANC, Secchi, and Turbidity.

Lake Name	County	Visit #	pH_Field (SU)	ANC (ueq/L)	Secchi Depth (m)	Turbidity (NTU)	Color (PCU)	TOC (mg/L)	DOC (mg/L)
Bogie Lake	OAKLAND	1	8.4	2090	4.475	3.05	4	4.96	4.94
Bogie Lake	OAKLAND	2	8.5	1927	2.6	1.42	5	4.69	4.55
Tallman Lake	MASON	1	7.6	2069	3.3	0.75	0	7.23	6.94
Pine Lake	KENT	1	6	1346	3.3	1.23	9	6.3	6.21
Silver Lake	IRON	1	8.2	42	5.415	0.76	6	4.74	4.46
Lake Besser	ALPENA	1	7.6	3199	3.95	1.27	14	4.32	4.37
Palmer Lake	ST JOSEPH	1	8	3112	1.7	1.93	5	5.74	5.3
Hiland Lake	LIVINGSTON	1	7.8	3673	2.265	1.08	39	13.17	14.26
Eight Point Lake	CLARE	1	7.6	1690	3.6	1.48	5	6.72	6.2
Loon Lake	GOGEBIC	1	7.9	55	7.95	0.65	0	2.38	2.17
Belleville Lake	WAYNE	1	6.8	3294	0.575	9.38	12	7.1	6.91
Squaw Lake	GENESEE	1	7.9	3103	3.825	1.36	10	7.2	7.37
Campbell Lake	KALAMAZOO	1	8	3289	2.35	2.38	11	4.3	4.58
Dewey Lake	MARQUETTE	1	9.3	1636	2.05	1.34	12	9.14	8.23
Mud Lake	HOUGHTON	1	7.5	368	0.66	1.68	33	13.38	12.5
Martin Lake	NEWAYGO	1	8.1	3489	1.35	4.82	14	4.29	3.97
Pine Lake	EATON	1	7.4	2247	1.75	2.38	15	8.95	8.71
Muskegon Lake	MUSKEGON	1	8.3	2844	1.46	5.41	22	5.79	5.61
Fence Lake	BARAGA	1	8.04	940	5.45	0.64	5	4.28	4.36
Round Lake	VAN BUREN	1	7.2	533	3.55	1.23	5	5.88	5.62
Lake Chemung	LIVINGSTON	1	7.6	2845	4.2	1.33	3	7.75	7.65
Mill Lake	OAKLAND	1	8.2	3646	4.45	1.13	11	8.9	8.91
Thornapple Lake	BARRY	1	6.8	4311	1.075	6.39	14	5.38	4.8
Lake Au Sable	OGEMAW	1	8	2562	3.45	0.85	10	9.58	9.26
Clark Lake	JACKSON	1	7.9	3056	4.4	1.92	4	3.59	3.83
McDonald	DELTA	1	7.2	931	0.8	2.39	58	16.48	15.82
Stoner Lake	KENT	1	6.1	698	1.36	0.86	20	10.13	10.44
Crooked Lake	EMMET	1	8.3	2846	2	3.54	7	3.43	3.5
Crooked Lake	EMMET	2	8.1	2827	1.45	3.93	8	3.52	3.45
Lake Gogebic	GOGEBIC	1	7.8	532	2.75	1.48	12	6.28	6.14
Lake Gogebic	GOGEBIC	2	7.9	557	2.5	1.02	18	5.62	5.42
Wyckoff Lake	OCEANA	1	8.3	2713	1.45	4.27	21	10.57	9.67
West Lake	KALAMAZOO	1	8.2	2014	0.95	5.02	12	7.47	7.03
Howe Lake	ALGER	1	7.4	117	0.8	2.41	65	20.22	19.39
Deer Lake	CHARLEVOIX	1	8.3	2331	3.75	1.01	8	5.76	5.36
Blue Lake	MECOSTA	1	8.2	2659	2.79	1.26	0	4.59	4.65
Ford Lake	WASHTENAW	1	7.9	3084	1.925	5.3	12	6.39	6.22
Upper Scott	ALLEGAN	1	8.6	1157	1.65	4.36	15	7.23	6.58
Pere Marquette Lake	MASON	1	8	2951	1.95	1.62	13	2.84	2.37
Warner Lake	BARRY	1	7.8	2262	3.5	1.25	10	5.45	5.5
Forestville Basin	MARQUETTE	1	8.03	562	2.25	1.65	25	6.92	6.46
Tims Lake	JACKSON	1	7.9	2638	2.25	1.33	17	9.47	10.03
Bridge Lake	GRAND TRAVERSE	1	7.9	2318	3.95	1.13	5	4.38	4.12
Clark Co. Lake	CLARE	1	8.4	2861	3.5	0.72	12	5.77	5.65
Donnell Lake	CASS	1	7.9	3440	1.5	4.36	2	4.87	4.6
Big Lake	BARAGA	1	6.74	13	4.95	0.6	4	3.93	3.48
Bailey Lake	KEWEENAW	1	9	1327	0.9	1.67	7	12.23	12.03
Saddle Lake	VAN BUREN	1	7.3	2659	2.7	1.15	20	8.74	8.29
Lake Brighton	LIVINGSTON	1	8	3149	0.95	6.25	11	6.77	6.34
Stony Creek Lake	MACOMB	1	7.6	2866	1.315	3.82	12	6.34	6.03
Blomgren	DICKINSON	1	9.43	1877	0.8	6.14	35	19.69	18.15
Keewaydin Lake	MARQUETTE	1	7.4	104	2.75	1.51	25	7.86	7.72
Keewaydin Lake	MARQUETTE	2	8.1	97	1.975	1.39	20	7.81	7.3
Lotto Lake	MARQUETTE	1	8.2	276	2.59	1.66	4	6.56	6.04
Hall Lake	HOUGHTON	1	5.9	58	1.39	0.59	65	10.26	10.76
Sullivan Lake	WASHTENAW	1	8.4	3218	2.84	1.24	15	9.48	9.03
St. Kathryn	IRON	1	8.2	780	2.34	1.68	5	5.42	5.28
Lake Ottawa	IRON	1	8.5	2296	7.95	0.37	8	2.56	2.38

Appendix 1c. NLA-Michigan Lakes: Nutrients and Chlorophyll-a.

Lake Name	County	Visit #	TP (ug/L)	TN (ug/L)	NO2+NO3 (ug/L)	NO3-N (ug/L)	NH4-N (ug/L)	CHL-a (ug/L)
Bogie Lake	OAKLAND	1	10	473	0	0	1.2	4.4
Bogie Lake	OAKLAND	2	10	485	0	0	0.3	3.3
Tallman Lake	MASON	1	8	780	0	0	1.9	1.4
Pine Lake	KENT	1	14	584	0.015	0.009	2.6	4.8
Silver Lake	IRON	1	5	413	0	0	0.4	2.2
Lake Besser	ALPENA	1	13	289	0.012	0.008	1.6	1.1
Palmer Lake	ST JOSEPH	1	18	567	0	0	0.9	11.7
Hiland Lake	LIVINGSTON	1	13	586	0.01	0	2.4	3.4
Eight Point Lake	CLARE	1	5	574	0	0	1.1	3.1
Loon Lake	GOGEBIC	1	3	194	0	0	0.1	
Belleville Lake	WAYNE	1	82	1031	0.014	0.01	6.9	30.7
Squaw Lake	GENESEE	1	5	648	0	0	0.4	2.3
Campbell Lake	KALAMAZOO	1	7	733	0.229	0.281	4	3.0
Dewey Lake	MARQUETTE	1	8	771	0	0	1.9	2.6
Mud Lake	HOUGHTON	1	16	364	0	0	1.1	3.2
Martin Lake	NEWAYGO	1	29	3441	3.097	2.855	2.4	14.2
Pine Lake	EATON	1	16	720	0.005	0	4.7	6.1
Muskegon Lake	MUSKEGON	1	34	519	0.028	0.115	2.4	11.9
Fence Lake	BARAGA	1	4	101	0	0	1	1.7
Round Lake	VAN BUREN	1	12	524	0	0	0.9	3.8
Lake Chemung	LIVINGSTON	1	15	568	0.004	0	1	9.8
Mill Lake	OAKLAND	1	5	563	0	0	0.9	2.0
Thornapple Lake	BARRY	1	65	634	0.01	0.007	5.8	23.7
Lake Au Sable	OGEAW	1	8	541	0.007	0.002	1.3	3.1
Clark Lake	JACKSON	1	5	461	0.002	0	1	2.6
McDonald	DELTA	1	17	834	0	0	2.1	3.0
Stoner Lake	KENT	1	16	712	0.006	0.003	2.6	4.3
Crooked Lake	EMMET	1	7	388	0	0	0.4	3.0
Crooked Lake	EMMET	2	7	314	0	0	0.7	2.8
Lake Gogebic	GOGEBIC	1	11	288	0.005	0	0.6	
Lake Gogebic	GOGEBIC	2	7	359	0.011	0.023	1.4	4.6
Wyckoff Lake	OCEANA	1	39	1063	0.008	0.056	1.2	16.2
West Lake	KALAMAZOO	1	25	994	0	0	1.4	10.0
Howe Lake	ALGER	1	24	624	0	0	0.2	7.9
Deer Lake	CHARLEVOIX	1	5	458	0	0	0.6	2.3
Blue Lake	MECOSTA	1	10	469	0.017	0.023	1.3	2.9
Ford Lake	WASHTENAW	1	61	1071	0.107	0.2	13.1	14.6
Upper Scott	ALLEGAN	1	33	845	0	0	0.6	11.6
Pere Marquette Lake	MASON	1	30	623	0.212	0.286	1.6	14.8
Warner Lake	BARRY	1	5	488	0	0	1	3.2
Forestville Basin	MARQUETTE	1	6	354	0.063	0.078	1.6	4.5
Tims Lake	JACKSON	1	8	366	0	0	1.7	3.1
Bridge Lake	GRAND TRAVERSE	1	7	317	0.007	0	0.8	4.6
Clark Co. Lake	CLARE	1	6	563	0	0	1.4	
Donnell Lake	CASS	1	8	723	0.302	0.432	1.6	3.3
Big Lake	BARAGA	1	7	244	0	0	1.6	3.4
Bailey Lake	KEWEENAW	1	8	892	0	0	2.3	3.1
Saddle Lake	VAN BUREN	1	10	603	0	0	0	4.0
Lake Brighton	LIVINGSTON	1	32	606	0	0	0.8	17.4
Stony Creek Lake	MACOMB	1	18	536	0.007	0.02	1.4	5.3
Blomgren	DICKINSON	1	37	830	0	0	2	22.2
Keewaydin Lake	MARQUETTE	1	13	430	0.001	0	1.1	3.3
Keewaydin Lake	MARQUETTE	2	8	326	0.002	0	0.9	5.3
Lotto Lake	MARQUETTE	1	7	569	0	0	1.1	8.6
Hall Lake	HOUGHTON	1	8	299	0	0	0.6	4.0
Sullivan Lake	WASHTENAW	1	9	828	0	0	1.9	2.7
St. Kathryn	IRON	1	7	405	0	0	0.4	4.1
Lake Ottawa	IRON	1	3	148	0	0	0.4	1.0

Appendix 1d. NLA-Michigan Lakes: Conductivity, Cations, and Anions.

Lake Name	County	Visit #	Sp. Cond. (uS/cm)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	SiO2 (mg/L)	SO4 (mg/L)	Cl (mg/L)
Bogie Lake	OAKLAND	1	650.1	25.6	20.0	63.9	1.5	3.1	20.7	128.6
Bogie Lake	OAKLAND	2	648.6	25.5	21.2	60.8	1.6	3.6	19.3	128.8
Tallman Lake	MASON	1	239.1	21.3	14.0	2.3	0.7	7.7	5.0	7.2
Pine Lake	KENT	1	271.5	19.8	5.5	17.8	1.0	0.5	2.4	38.2
Silver Lake	IRON	1	22.17	1.6	0.5	0.6	0.6	0.2	4.4	0.8
Lake Besser	ALPENA	1	333.5	38.9	15.3	5.5	0.5	9.1	9.2	6.9
Palmer Lake	ST JOSEPH	1	475	56.1	19.5	6.8	1.6	16.2	61.4	22.4
Hiland Lake	LIVINGSTON	1	460.7	61.3	17.0	9.7	2.1	7.7	27.4	25.4
Eight Point Lake	CLARE	1	206.2	25.0	6.7	3.5	0.6	0.4	5.3	8.5
Loon Lake	GOGEBIC	1	14.28	1.4	0.4	0.2	0.3	0.0	2.4	0.2
Belleville Lake	WAYNE	1	716.6	56.2	21.2	41.9	3.2	8.9	39.1	101.7
Squaw Lake	GENESEE	1	612.4	41.9	22.2	37.7	2.8	1.8	13.4	92.1
Campbell Lake	KALAMAZOO	1	429.3	38.7	24.3	9.4	1.0	8.3	30.9	20.5
Dewey Lake	MARQUETTE	1	153.1	15.3	10.3	0.6	0.2	3.1	2.4	0.4
Mud Lake	HOUGHTON	1	55.55	5.7	1.9	1.2	0.6	1.7	5.2	0.5
Martin Lake	NEWAYGO	1	421.8	42.1	24.1	5.0	2.6	2.9	22.1	15.3
Pine Lake	EATON	1	294.2	29.5	11.0	9.3	1.0	4.4	4.3	19.0
Muskegon Lake	MUSKEGON	1	387.7	42.1	13.2	17.6	1.3	4.4	20.3	24.4
Fence Lake	BARAGA	1	100.3	13.4	3.7	1.2	1.0	8.4	4.7	0.3
Round Lake	VAN BUREN	1	83.8	7.9	3.2	2.1	0.1	0.3	5.9	4.4
Lake Chemung	LIVINGSTON	1	683.3	41.6	16.1	58.0	3.5	1.7	19.3	108.2
Mill Lake	OAKLAND	1	631.2	60.0	19.2	37.7	2.0	4.5	16.3	81.8
Thornapple Lake	BARRY	1	555	66.6	26.9	9.4	1.8	12.8	42.9	24.6
Lake Au Sable	OGEMAW	1	279	34.8	13.1	3.0	0.7	5.6	8.9	5.5
Clark Lake	JACKSON	1	429.5	35.5	22.2	10.2	1.2	27.8	26.1	23.3
McDonald	DELTA	1	121.8	14.0	4.6	2.1	0.2	1.5	2.5	5.3
Stoner Lake	KENT	1	100.2	9.1	4.6	2.0	0.8	0.2	2.2	6.5
Crooked Lake	EMMET	1	299.1	35.5	13.3	4.8	0.7	7.0	8.5	8.0
Crooked Lake	EMMET	2	302.4	38.5	14.1	4.0	0.5	7.9	9.3	8.2
Lake Gogebic	GOGEBIC	1	79.23	9.2	2.5	2.4	0.6	11.0	4.6	3.4
Lake Gogebic	GOGEBIC	2	80.57	8.7	2.4	2.2	0.5	12.2	4.8	3.5
Wyckoff Lake	OCEANA	1	314.4	30.3	18.4	5.7	1.7	7.7	10.6	15.1
West Lake	KALAMAZOO	1	437.1	33.7	18.4	21.2	1.1	0.4	45.3	47.0
Howe Lake	ALGER	1	38.65	2.8	1.9	1.0	0.3	1.4	6.0	0.4
Deer Lake	CHARLEVOIX	1	287.2	31.7	10.9	7.4	0.8	6.2	11.7	13.7
Blue Lake	MECOSTA	1	301.6	32.3	14.4	5.7	0.7	9.2	8.4	11.9
Ford Lake	WASHTENAW	1	737.5	55.5	22.0	44.4	3.3	8.9	43.1	111.6
Upper Scott	ALLEGAN	1	171.2	17.5	6.6	5.0	0.4	2.5	10.7	10.7
Pere Marquette Lake	MASON	1	390.6	46.4	13.5	10.6	1.1	5.8	20.4	22.9
Warner Lake	BARRY	1	246.6	29.0	12.3	1.5	0.6	1.9	11.2	2.9
Forestville Basin	MARQUETTE	1	76.29	10.7	2.0	1.7	0.5	5.6	5.2	2.7
Tims Lake	JACKSON	1	316.4	33.5	16.8	6.7	0.9	8.0	11.3	18.0
Bridge Lake	GRAND TRAVERSE	1	280.2	34.1	8.8	5.6	0.9	5.9	8.3	10.4
Clark Co. Lake	CLARE	1	640.8	35.4	25.2	47.6	1.6	7.7	32.6	89.7
Donnell Lake	CASS	1	379.5	39.2	19.5	6.1	1.3	7.6	16.2	12.0
Big Lake	BARAGA	1	14.87	0.9	0.3	0.5	0.4	0.1	3.2	0.8
Bailey Lake	KEWEENAW	1	151.7	23.4	2.8	2.3	0.1	2.2	5.4	2.7
Saddle Lake	VAN BUREN	1	302.4	35.4	11.7	6.8	1.0	3.4	8.4	11.8
Lake Brighton	LIVINGSTON	1	696	45.1	19.3	54.6	1.8	6.0	15.3	110.4
Stony Creek Lake	MACOMB	1	533.6	35.9	22.8	28.9	1.4	3.9	21.4	63.3
Blomgren	DICKINSON	1	186.1	20.7	12.9	0.4	0.1	2.7	5.9	0.3
Keewaydin Lake	MARQUETTE	1	23.05	2.2	0.7	0.6	0.4	0.1	2.9	0.3
Keewaydin Lake	MARQUETTE	2	23.79	2.2	0.7	0.5	0.4	0.4	2.9	0.3
Lotto Lake	MARQUETTE	1	33.39	3.2	1.4	0.2	0.5	0.6	0.9	0.4
Hall Lake	HOUGHTON	1	16.88	1.8	0.4	0.3	0.3	0.2	1.8	0.2
Sullivan Lake	WASHTENAW	1	349.5	44.1	13.4	4.6	1.3	8.7	10.9	9.3
St. Kathryn	IRON	1	85.33	11.6	2.7	0.8	0.3	2.5	2.6	0.4
Lake Ottawa	IRON	1	231.1	30.2	10.7	1.5	0.6	7.8	6.0	0.6