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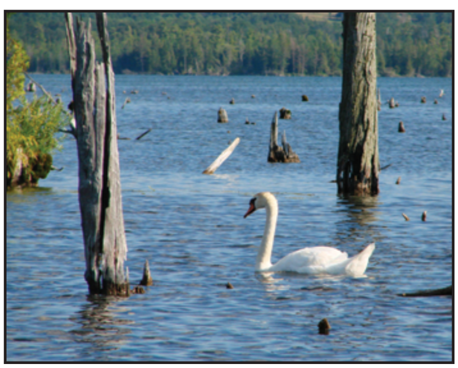
State and Regional Water-Quality Characteristics and Trophic Conditions of Michigan's Inland Lakes, 2001–2005



Scientific Investigations Report 2008–5188

U.S. Department of the Interior
U.S. Geological Survey

Cover. Photographs, left to right: Twinwood Lake, Michigan; Ducks on Little Blue Lake, Michigan; Boaters on Round Lake, Michigan; Swans on Torch Lake Outlet, Michigan (photographs by R.J. Minnerick, U.S. Geological Survey), Children on beach at Lake Lansing, Michigan; and Nicholas Lake, Michigan (photographs by L.M. Fuller, U.S. Geological Survey).

State and Regional Water-Quality Characteristics and Trophic Conditions of Michigan's Inland Lakes, 2001–2005

By L.M. Fuller and R.J. Minnerick

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Conversion Factors

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
	Area	
acre	4,047	square meter (m^2)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	640	acre

Vertical coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

State and Regional Water-Quality Characteristics and Trophic Conditions of Michigan's Inland Lakes, 2001–2005

By L.M. Fuller and R.J. Minnerick

Abstract

The U.S. Geological Survey and the Michigan Department of Environmental Quality are jointly monitoring selected water-quality constituents of inland lakes through 2015 as part of Michigan's Lake Water Quality Assessment program. During 2001–2005, 433 lake basins from 364 inland lakes were monitored for baseline water-quality conditions and trophic status. This report summarizes the water-quality characteristics and trophic conditions of those monitored lake basins throughout the State.

Regional variation of water quality in lake basins was examined by grouping on the basis of the five Omernik level III ecoregions within Michigan. Concentrations of most constituents measured were significantly different between ecoregions. Less regional variation of phosphorus concentrations was noted between Northern Lakes and Forests (50) and North Central Hardwoods (51) ecoregions during summer possibly because water samples were collected when lake productivity was high; hence the utilization of the limited amount of phosphorus by algae and macrophytes may have resulted in the more uniform concentrations between these two ecoregions.

Concentrations of common ions (calcium, magnesium, potassium, sodium, chloride, and sulfate) measured in the spring typically were higher in the Michigan southern Lower Peninsula in the Eastern Corn Belt Plains (55), Southern Michigan/Northern Indiana Drift Plains (56), and Huron/Erie Lake Plains (57) ecoregions. Most ions whose concentrations were less than the minimum reporting levels or were nondetectable were from lakes in the Michigan northern Lower Peninsula and the Upper Peninsula in the Northern Lakes and Forests (50) and North Central Hardwoods (51) ecoregions. Chlorophyll *a* concentrations followed a similar distribution pattern. Measured properties such as pH and specific conductance (indicative of dissolved solids) also showed a regional relation. The lakes with the lowest pH and specific conductance were generally in the western Upper Peninsula (Northern Lakes and Forests (50) ecoregion).

The Michigan Department of Environmental Quality classifies Michigan lakes on the basis of their primary biological productivity or trophic characteristics using the Carlson Trophic State Index. Trophic evaluations based on data collected from 2001 through 2005 indicate 17 percent of the lakes are oligotrophic, 53 percent are mesotrophic, 22 percent are eutrophic, 4 percent are hypereutrophic, and less than 5 percent are classified into transition classes between each major class. Although the distribution of lakes throughout Michigan or between Omernik level III ecoregions is not uniform, about 85 percent of the lakes classified as oligotrophic are in the Northern Lakes and Forests (50) or North Central Hardwoods (51) ecoregions. Nearly 28 percent of all the lakes in each of these two ecoregions were classified as oligotrophic.

Historical trophic-state classes were compared to the current (2001 through 2005) trophic-state classes. Approximately 72 percent of lakes remained in the same trophic-state class, 11 percent moved up a partial or full class (indicating a decrease in water clarity) and 18 percent moved down a partial or full class (indicating an increase in water clarity).

Introduction

Michigan has more than 11,000 inland lakes. These resources provide numerous recreational opportunities and are a major tourist and recreation attraction that supports a recreational industry in Michigan valued at 15 billion per year (Stynes, 2002). Knowledge of water-quality characteristics in these lakes is essential for the effective management of this resource.

Historically, the U.S. Geological Survey (USGS) and the Michigan Department of Environmental Quality (MDEQ) have jointly monitored water quality in Michigan's lakes and rivers. During the 1990s, however, funding for surface-water-quality monitoring was greatly reduced, and funds devoted to monitoring inland lakes through the Federal Clean Water Act (CWA) Clean Lakes Program (Section 314) were eliminated. In 1998, citizens of Michigan passed the Clean Michigan Initiative (CMI) to clean up, protect, and enhance Michigan's environmental infrastructure. Because of expanding water-quality data needs, resulting in part from the new CMI program, MDEQ and USGS jointly re designed and implemented the Lake Water-Quality Assessment (LWQA) monitoring program (Michigan Department of Environmental Quality, 2001).

Through the LWQA monitoring program, all Michigan lakes larger than 25 acres and with public boat launch access will be monitored by 2015 (fig. 1A and 1B). New field studies and data-acquisition activities were developed in accordance with current MDEQ water-quality monitoring activities. The LWQA monitoring-program design incorporates the watershed-management units and 5-year rotational cycle currently being used by the MDEQ Ambient Surface Water Chemistry Monitoring Program (Michigan Department of Environmental Quality, 2000) to assess Michigan's rivers, Great Lakes connecting channels, and bays (fig. 2).

The 5-year basin-monitoring cycle identifies 45 watershed-management units on the basis of statewide drainage to the Great Lakes. Each year, 7 to 10 of the major watersheds in Michigan are monitored and assessed. This is done to ensure that specific watersheds are monitored in the 5-year cycle to assist in (1) statewide water-quality assessments, (2) the National Pollutant Discharge Elimination System (NPDES) permitting process, and (3) resource-management decisions. The monitoring emphasizes data collection to classify each lake by its primary biological productivity and document its general chemical characteristics.

History of Monitoring on Inland Lakes

In 1973, the Michigan Department of Natural Resources (currently MDEQ) began systematically monitoring the quality of Michigan inland lakes under Section 314 of the CWA. In previous years, few water-chemistry data had been collected on Michigan lakes, which hampered documentation of changes in lake water quality. Initially, it was expected that the "significant" lakes, defined as public lakes greater or equal to 50 acres, could be sampled every 5 years. However, by 1979, more than half of the significant lakes were not yet sampled. The U.S. Environmental Protection Agency (USEPA) increased funding under the CWA to assist states in assessing the quality of lakes. Also, a one-time grant from the USEPA was awarded to the State of Michigan in June 1980 for the purpose of inventorying and classifying unsampled lakes.

Carlson's Trophic State Index (TSI) was chosen to classify lakes, for five reasons: (1) the index works well over a broad range of trophic conditions; (2) lakes can be classified by total phosphorus, transparency, and chlorophyll *a*; (3) the index is well suited for Michigan because it was developed by use of using data from Michigan and Minnesota lakes; (4) the index is a continuum with divisions to distinguish general categories; and (5) total phosphorus, transparency, or chlorophyll *a* data previously collected could be evaluated. Because TSI may underestimate the trophic condition in lakes dominated by macrophytes, the relative abundance of submergent macrophytes were observed and noted in the lakes to assist with the TSI classification.

Data evaluated for the classification project were collected by the USEPA National Eutrophication Survey (1972), the Northeast Michigan Council of Governments (1979), and the Michigan Department of Natural Resources (1973–81) (Michigan Department of Natural Resources, 1982). Sampling during this period was generally done in August or September in the deepest basins of each lake. Lakes were classified into three trophic classes on the basis of TSI values of 0 to 100: less than 39 was oligotrophic, 39 to 52 was mesotrophic, and greater than 52 was eutrophic.

Starting around the 1980s, classification techniques were enhanced by noting whether dense macrophytes were present in lakes, and if present, the trophic class was adjusted one class to account for the increase of water clarity resulting from the utilization of available nutrients. Many lakes sampled before 1980 (Michigan Department of Natural Resources, 1982) did not include a macrophytes assessment, and trophic classification for some lakes may be underestimated by Carlson's TSI. The Michigan Department of Natural Resources (1988) reported newly sampled lakes, resampled lakes mainly from pre-1975, and all other lake data through 1987 (including data from the Michigan Department of Natural Resources 1982 assessment). The department subsequently published data from 1988 through 1991 (Michigan Department of Natural Resources, 1992) and the remaining historical data used in this report were published by the MDEQ (2002) and are listed in appendix 1. The historical assessment date in appendix 1 notes the date of the report when the assessment was made, which is an indicator of the range of years when the field measurements were made. For the 1988 assessment, the TSI classification criteria were reevaluated and modified to less than 39 oligotrophic, 39 to 48 mesotrophic, and greater than 48 eutrophic. The hypereutrophic classification (greater than 61) was added for the 1994 assessment, and a slight change in the oligotrophic/mesotrophic boundary value (shift from 39 to 38) was made starting with the 1996 assessment.

Purpose and Scope

This report summarizes the results of the initial 5 years (2001–05) of the Michigan LWQA program. An explanation of sampled constituents is provided, and sample-collection methods used for the analysis are described. These constituents are summarized as a statewide dataset and split into the level III ecoregions delineated by Omernik (1987) to determine whether spatial patterns exist and whether baseline water-quality conditions correlate with the geographic settings as defined by Omernik. Current TSI classifications are compared to historical data to determine change. Omernik level III ecoregions are used to determine whether spatial patterns exist. Maximum lake depth and lake area also were analyzed to determine whether these physical factors influence trophic conditions.

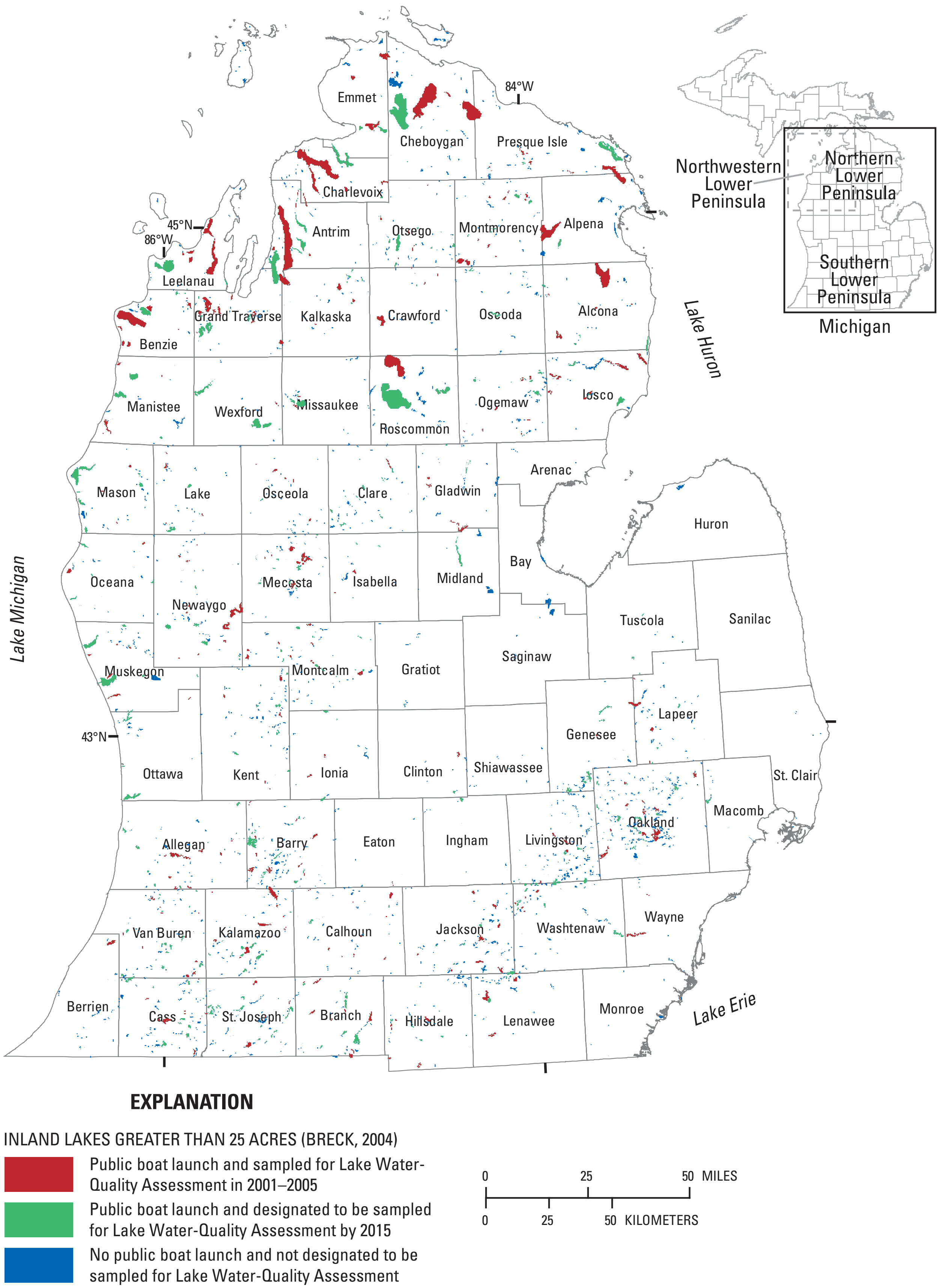

Figure 1A. Inland lakes greater than 25 acres in the Lower Peninsula of Michigan.

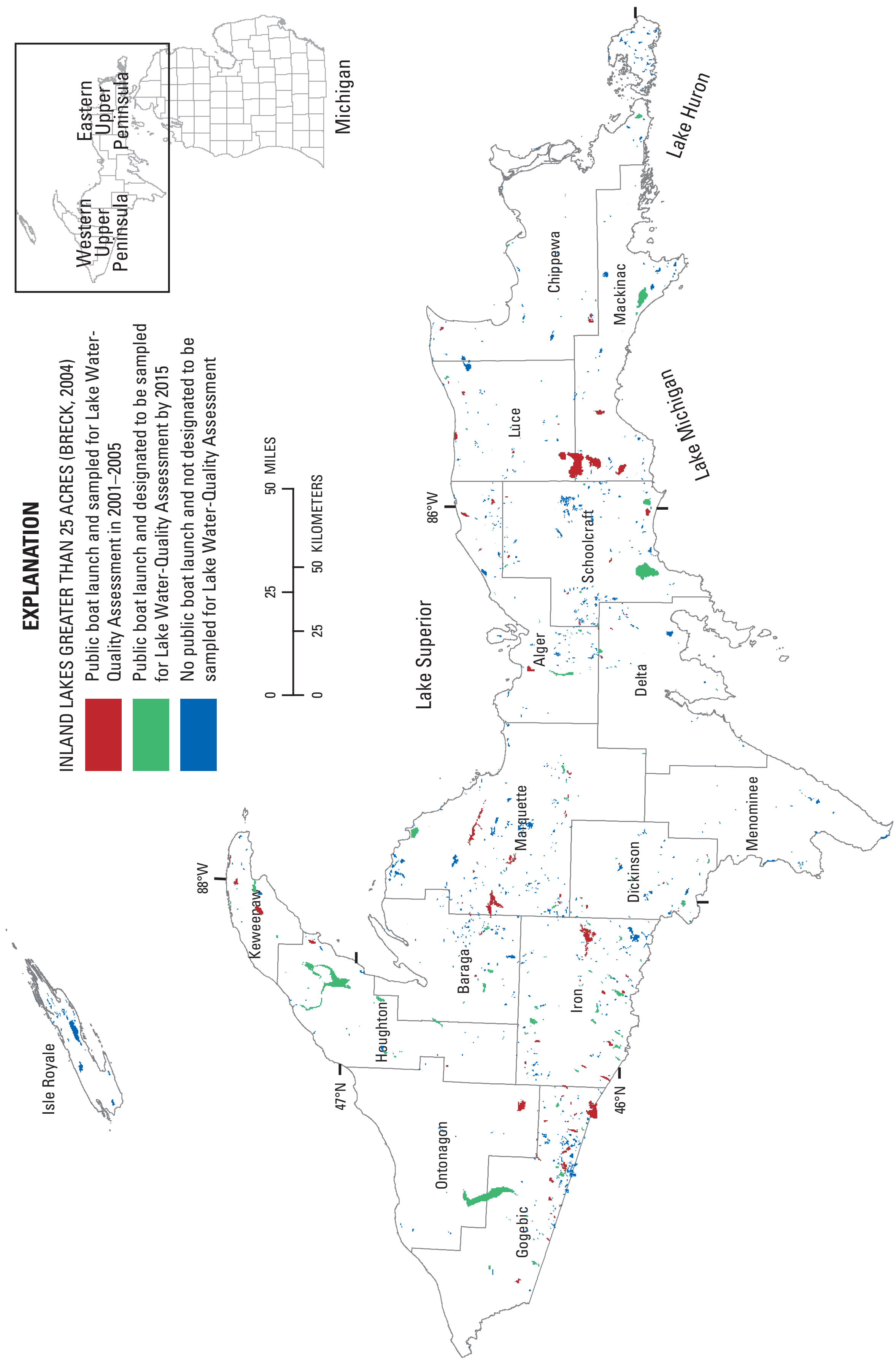

Figure 1B. Inland lakes greater than 25 acres in the Upper Peninsula of Michigan.

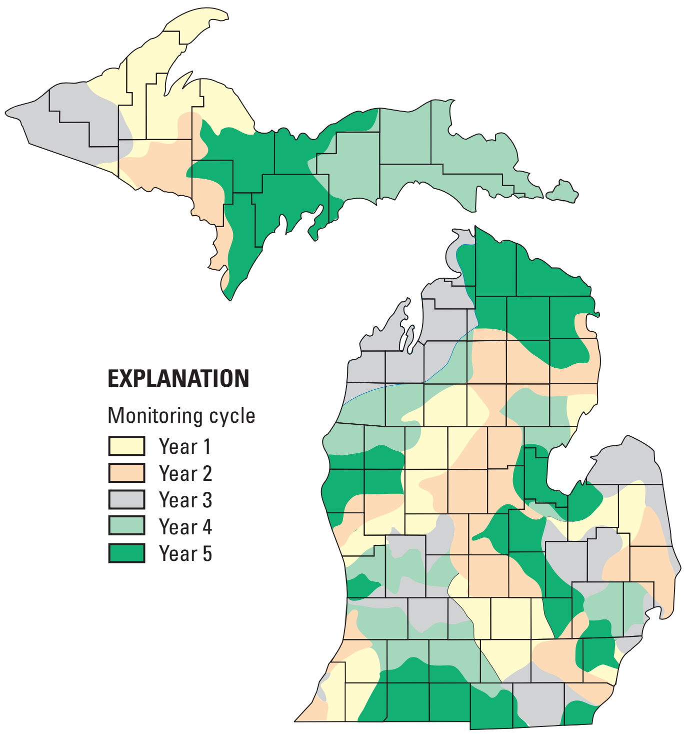

Figure 2. Watershed-management units and 5-year rotational cycle for Lake Water-Quality Assessment in Michigan.

Physical Setting

Michigan's geographic setting, which includes the geology, hydrology, vegetation, climate, soils, and land use, influences the water-quality characteristics of Michigan lakes. Bedrock geology of the western Upper Peninsula is different from that in the remainder of the State, being dominated by Precambrian and Cambrian rock, much the same as the Canadian Shield region to the north. Bedrock geology of the eastern part of the Upper Peninsula and the entire Lower Peninsula (as well as parts of southern Ontario, Ohio, Indiana, Illinois, and Wisconsin) are dominated by formations that are much younger, ranging in age from Ordovician to Jurassic. Bedrock of the western Upper Peninsula is largely metamorphic, although igneous and sedimentary rocks also are present. All of Michigan's metallic mineral resources are hosted in Precambrian rocks. Collectively, these formations are known as the Michigan Basin, which is roughly bowl-shaped and dips gently toward the center, resulting in younger deposits toward the center and older rock units toward the margins. Exposed limestone, dolomite, and gypsum are found and mined in parts of the Lower Peninsula and eastern Upper Peninsula. Although bedrock outcrops are sporadic, most of Michigan is covered by glacial- and lacustrine-derived sediments including clay, silt, sand, gravel, and boulders. Glaciers covered all of Michigan several times during the relatively recent glacial period, although only sediments attributed to the most recent episode are known to exist at the surface. Most of the geographic and topographic features—including Michigan's 11,000 inland lakes—were shaped by glaciers and glacial meltwater.

The Upper Peninsula and the northern Lower Peninsula are forested, with coniferous and northern hardwoods growing on nutrient-poor glacial soils. The northwest Lower Peninsula consists of mostly forest; the southern Lower Peninsula is predominantly agriculture with more organically rich soils. The major manufacturing and population centers are in the southern Lower Peninsula. Lakes in the northern regions are a major source for Michigan's recreational industry.

Five ecoregions make up Michigan, as shown in figure 3 (Omernik, 1987). Omernik level III ecoregions were created on the basis of land use, geology, physiography, vegetation, climate, soils, wildlife, and hydrology.

Northern Lakes and Forests (ecoregion 50), which is the largest ecoregion in Michigan, covers approximately 28,000 mi^2, including part of the northern Lower Peninsula and all of the Upper Peninsula. This ecoregion is made up of nutrient-poor glacial soils, coniferous and northern hardwood forests, undulating till plains, morainal hills, broad lacustrine basins, and extensive sandy outwash plains.

North Central Hardwoods (ecoregion 51) covers approximately 1,650 mi^2 in the northwest Lower Peninsula. This ecoregion is a transitional zone between the forested region to the north and the agricultural region to the south. The main land uses/land covers in this region are forest, wetlands and lakes, and agriculture.

Eastern Corn Belt Plains (ecoregion 55) is the smallest ecoregion in Michigan, covering approximately 550 mi^2 in the southern Lower Peninsula. The ecoregion is mainly a rolling till plain with local end moraines. In the late 1980s, the main land use/land cover for the region was agriculture, which has affected stream chemistry and turbidity.

Southern Michigan/Northern Indiana Drift Plains (ecoregion 56) is the second largest ecoregion in Michigan. It covers approximately 22,600 mi^2 and is bordered by Lake Michigan to the west. The ecoregion has many lakes and marshes, with numerous landforms, soil types and textures, and land uses. Land-use/land-cover types in this region are forests, swamp forests, agriculture, quarries, recreational use, and urban areas.

Huron/Erie Lake Plain (ecoregion 57) is split into two areas in the eastern Lower Peninsula and combines to cover approximately 4,900 mi^2. This ecoregion is a fairly flat plain with sand dunes, beach ridges, and end moraines. Most of this region had been cleared and drained for agriculture and urban and industrial use. Stream quality has been degraded by channelization, ditching, and agricultural activities (Omernik, 1987).

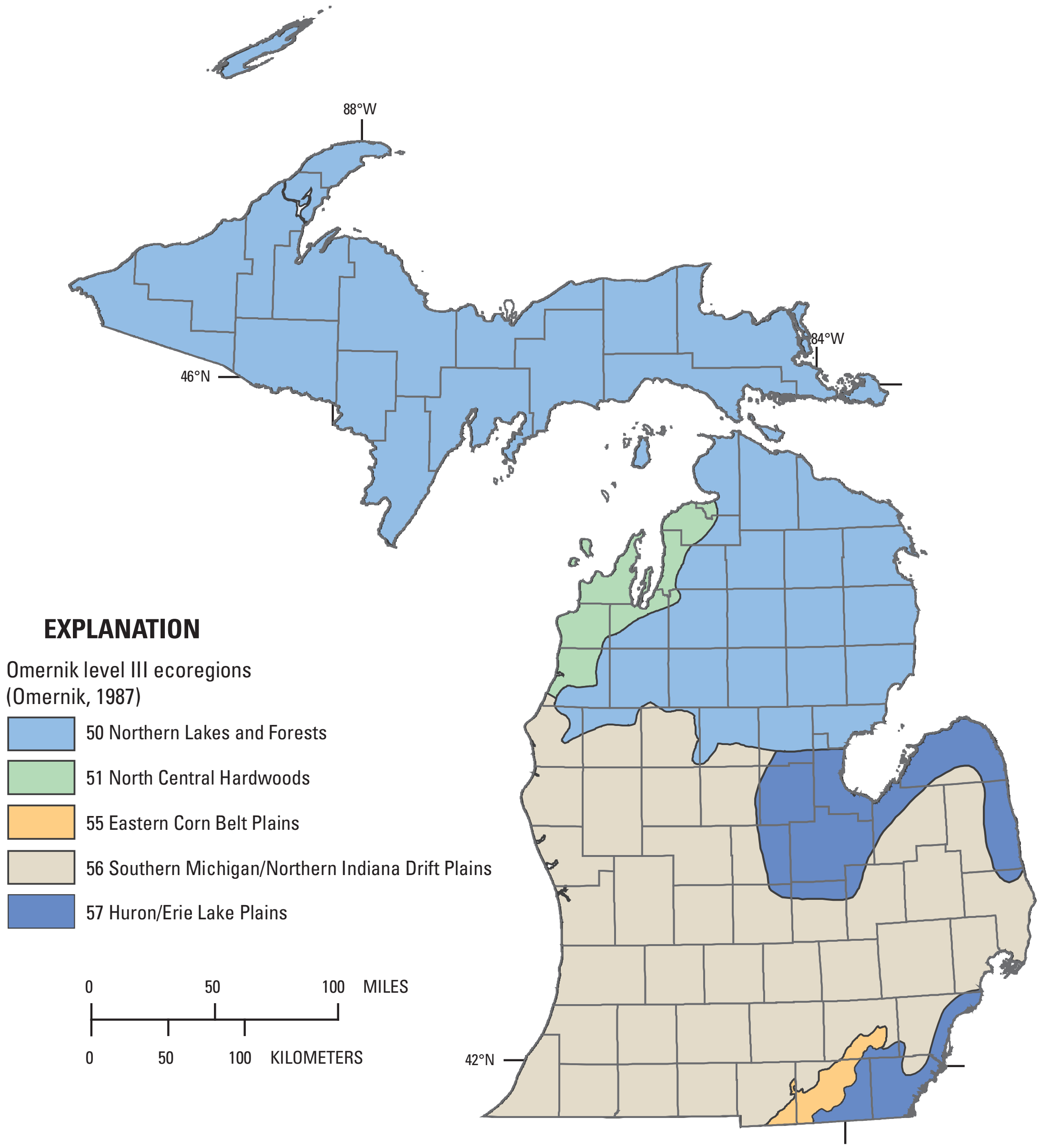

Figure 3. Omernik level III ecoregions for Michigan.

Water-Quality Data-Collection Methods

The sampling methodology was designed to replicate the methods and techniques used historically by MDEQ to sample inland lakes. Care was taken to minimize deviation from past sampling methods, locations, or laboratory-analysis methods that could create variability in the data due to change in techniques or methods rather than an actual change in lake water quality.

Lake and Site Selection

Lakes sampled in a given year were selected randomly from 7 to 10 major watersheds throughout Michigan. Specific watersheds were monitored in a 5-year cycle in conjunction with current MDEQ water-quality activities to help support (1) statewide water-quality assessments, (2) the NPDES permitting process, and (3) resource-management decisions (Michigan Department of Environmental Quality, 1997). The LWQA monitoring program incorporated the watershed-management units and 5-year rotational cycle currently being used by the MDEQ Ambient Surface Water Chemistry Monitoring Program (Michigan Department of Environmental Quality, 2000) to assess Michigan's rivers, Great Lakes connecting channels, and bays.

Lakes targeted for monitoring under the LWQA monitoring program were 25 acres or larger with public boat access. Each watershed is sampled on a 5-year rotation until all lakes meeting these criteria are sampled. After the first 5-year rotation (2001 through 2005), all 45 major watersheds in Michigan had a selection of lakes sampled.

The sampling site in each major lake basin was as close as possible to the known historical sampling location in the deepest basin of each lake. Geographic coordinates for each sampling site was established with a handheld Global Positioning System (GPS) unit. Once the sample site was located with a GPS unit, the site was verified by comparing the depth measured with a electronic depth finder to depths from previous visits.

Site Identification

All previously sampled lake basins were identified with a USEPA Storage and Retrieval (STORET) number. Data storage in the USGS National Water Information System (NWIS) are referenced with a USGS station number, which is the latitude-longitude (Lat-Long) of the location where the sample was collected. A sequence number, indicating the depth at which a sample was collected, was then incorporated in the station number as the last two digits. The lake station numbering system is summarized below:

Lat-Long-01 Vertical profile data.

Lat-Long-02 Sample collected 3 ft above lake bottom.

Lat-Long-03 Depth-integrated sample through the photic zone.

Lat-Long-05 Sample collected 3 ft below lake surface.

Lat-Long-06 Sample collected at mid-depth or metalimnion.

Sampling Strategy

All lakes selected for monitoring within a given year were sampled once during spring turnover (usually April) and again in late summer (August or September), when they typically are thermally stratified. Samples collected during spring turnover, when water is well mixed, represent average water quality in the lake. Samples collected in late summer, when water is warmest and aquatic plant growth is at its peak, represent water-quality characteristics when productivity is the greatest.

Discrete lake-water samples were collected at several depths from a single vertical water column at the deepest basin of each lake. Additional sample locations were used for those lakes that had multiple deep basins where complete interbasin mixing was unlikely.

Before sample collection, vertical profiles of dissolved-oxygen concentration, water temperature, specific conductance, and pH were measured to determine stratification. Water clarity was measured with a Secchi disk. During late-summer sampling, a qualitative macrophyte evaluation was made in the littoral zone of each lake, to refine the trophic-state evaluation.

Field and Laboratory Methods

Standard MDEQ and USGS field methods were used to collect and preserve samples. During spring sampling, three discrete samples were collected. One sample was collected 3 ft below the surface, another 3 ft above the bottom, and the third at mid-depth. Summer sampling used the same sample depths except in stratified lakes, where the mid-depth sample was collected from the center of the metalimnion. Water samples collected near bottom, near surface, and mid-depth were analyzed for nutrients; samples to analyze for all other water-quality characteristics were collected only from mid-depth in the spring. All water samples except for the chlorophyll *a* sample were collected with a Van Dorn-style sampler. Water samples for chlorophyll *a* analysis were depth-integrated samples collected by lowering a bottle sampler through the photic zone (considered twice the depth of the Secchi disk measurement for this study). On those lakes where the photic zone extended to the lake bottom, the bottle sampler was lowered to about 1 ft above the lake bottom with care taken to not disturb bottom sediments.

During spring sampling, only mid-depth samples were collected on shallow lakes when depth prohibited collection of three discrete samples. Samples were collected 3 ft below the lake surface at these same shallow lakes during the summer. The data collected from spring and summer sampling for shallow lakes were associated with the appropriate lake stratum that would allow for data analysis and lake-assessment calculations.

Water samples for nutrients were preserved with sulfuric acid (H_2SO_4) to a pH of less than 2, and water samples for selected ions (calcium, magnesium, sodium, potassium) were preserved with nitric acid (HNO_3) to a pH of less than 2. Chlorophyll *a* samples were filtered onsite through a 0.45-µm combination acetate, nitrate cellulose filter (filter type HAWP 047 00). The filter was then placed in a vial containing 10 mL of 90 percent acetone. All samples were then shipped chilled to the MDEQ laboratory for analysis of chlorophyll *a* and ions. Nutrient analyses were completed either by the MDEQ or their contract laboratory. Properties and constituents, laboratory analytical methods, and reporting levels are listed in table 1.

Trophic-Status Evaluation

A biologically productive lake is desirable for many activities such as fishing and maintaining a healthy wildlife population; however, a lake can be overly productive (hypereutrophic). Eventually, if excessive plant and algal growth goes unchecked, the lake may become impaired.

Table 1. Properties and constituents of water-quality data collected from Michigan’s lakes sampled 2001–2005.

[MRL, Minimum Reporting Level; mg/L, milligrams per liter; µg/L, micrograms per liter; USEPA, U.S. Environmental Protection Agency]

Property or constituent	Units	MRL1	Method	Reference
Alkalinity, water, unfiltered (acid neutraling capacity)	mg/L as $CaCO_3$	20	310.1	USEPA, 1983
Calcium, total recoverable	mg/L	1	7140/215.1	USEPA, 1983
Chloride, dissolved	mg/L	1	325	USEPA, 1983
Hardness, total	mg/L as $CaCO_3$	5	Calculated SM 2340 B	Clesceri and others, 1998
Magnesium, total recoverable	mg/L	1	7450/242.1	USEPA, 1983
Sodium, total recoverable	mg/L	1	7770/273.1	USEPA, 1983
Sulfate,	mg/L	2	375.1	USEPA, 1983
Potassium, total recoverable	mg/L	0.1	7610/258.1	USEPA, 1983
Nitrogen, ammonia + organic total	mg/L	.1	351.2	USEPA, 1983
Nitrogen, ammonia total	mg/L	.01	350.1	USEPA, 1983
Nitrogen, nitrate plus nitrite, total	mg/L	.01	353.2	USEPA, 1983
Phosphorus, total	mg/L	.005	365.4	USEPA, 1983
Chlorophyll *a*	µg/L	1	SM 10200 H	Clesceri and others, 1998

[1]Established reporting levels for various analytical procedures from Oblinger-Childress and others (1999).

MDEQ classifies lakes on their level of primary biological productivity or trophic state. A lake with low productivity is classified as oligotrophic. A lake moderate in productivity is classified as mesotrophic. A biologically productive lake is classified as eutrophic, and an excessive biologically productive lake is classified as hypereutrophic. The trophic state of lakes can be compared and tracked over time to help evaluate eutrophication resulting from nutrient enrichment that may reflect changes in land-use practices.

The primary biological productivity in each lake basin was evaluated by MDEQ with Carlson’s TSI (Carlson, 1977). Carlson’s TSI was developed for use with lakes that have few rooted aquatic plants and little non-algal turbidity (U.S. Environmental Protection Agency, 2007). Late-summer sample data were used in this evaluation because primary biological productivity was assumed to be near its peak. Carlson’s TSI as modified by MDEQ was computed from the total phosphorus (collected near the surface), chlorophyll *a* concentrations (collected in the photic zone; fig. 4), and Secchi-disk measurements (fig. 5).

The Carlson’s TSI is a numerical scale ranging from 0 to 100. The low end of the scale represents low primary biological productivity (oligotrophy). The middle of the scale represents moderate biological productivity (mesotrophy). The high end represents a very biologically active lake (eutrophy), and the highest end of the scale represents excessive biological productivity (hypereutrophy). Carlson and Simpson (1996) suggest TSI ranges for north temperate lakes where a TSI value less than 40 represents oligotrophic conditions; 40–50, mesotrophic; 50–70, eutrophic; and greater than 70, hypereutrophic.

Although the concept of TSI ranges is simple, the interpretation can be complex because of their interdependency. The TSI values computed from any of the three indicators (chlorophyll *a*, total phosphorus, and Secchi-disk transparency (SDT)) will not necessarily be the same. There is a chemical and physical environment that can influence particular indicators and the interrelation with one another (Wetzel, 2001).

The MDEQ has adopted a modified scale and interpretation of the three indicators to account for regional characteristics (Michigan Department of Natural Resources, 1982). TSI values less than 38 represent oligotrophic conditions; 38–48, mesotrophic; 49–61, eutrophic; and greater than 61, hypereutrophic.

Walker (1979) proposed that averaging the TSI values from all three indicators would provide a means of reducing the effects of individual sampling and measurement errors, thus developing a robust estimate of the index. Carlson’s TSI may underestimate the trophic state of lakes dominated by macrophytes. The relative abundance of submergent macrophytes was used to indicate more productive conditions than indicated by TSI values. Walker assumed that “moderate” and “dense” growths of macrophytes were indicative of mesotrophic and eutrophic conditions, respectively. Therefore, if the TSI indicated mesotrophic conditions but “dense” growths of macrophytes were present, the lake would then be classified as eutrophic. For lakes with multiple basins, the TSI values from the primary sampling station (deepest basin) were used to determine the trophic state of these lakes.

Figure 4. U.S. Geological Survey technician filtering water for chlorophyll *a* analysis.

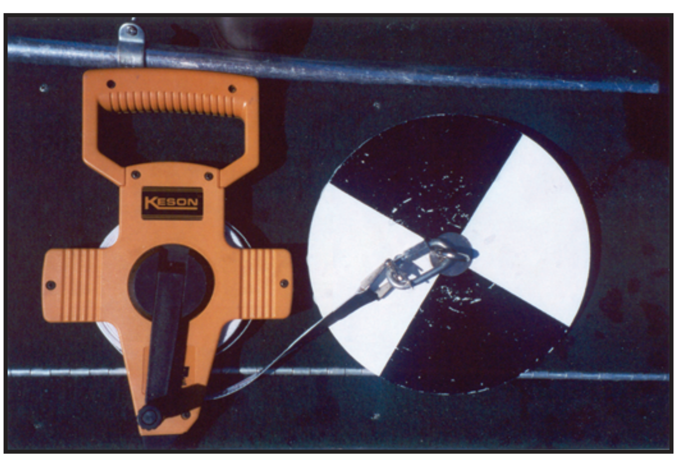

Figure 5. Secchi disk, which is lowered into the water attached to a measuring tape to determine the Secchi-disk depth (depth at which the Secchi disk disappears).

The following equations were used to calculate the TSI value for lakes presented in appendix 1 and summarized in table 2:

$$\text{TSI secchi} = 60 - 14.41 * \ln(\text{Secchi-disk depth, in meters}) \quad (1)$$

$$\text{TSI chlorophyll } a = 9.81 * \ln(\text{chlorophyll } a\text{, in micrograms per liter}) + 30.6 \quad (2)$$

$$\text{TSI total phosphorus} = 14.42 * \ln(\text{total phosphorus, in micrograms per liter}) + 4.15 \quad (3)$$

Table 2. Lake trophic state and classification ranges for Trophic State Index for total phosphorus, Secchi-disk transparency, and cholorophyll *a*.

[Based on Michigan Department of Natural Resources (1982) and modified by the State of Michigan to account for regional characteristics. TSI, Trophic State Index; SDT, Secchi-disk transparency; Chl-*a*, chlorophyll *a*; TP, total phosphorus; m, meters; µg/L, micrograms per liter; mg/L, milligrams per liter; <, less than; >, greater than].

Lake trophic state	Carlson TSI	SDT (m)	Chl-*a* (µg/L)	TP (mg/L)
Oligotrophic	< 38	> 4.6	< 2.2	< 0.010
Mesotrophic	38–48	2.3–4.6	2.2–6	.010–.020
Eutrophic	49–61	.9–2.2	6.1–22	.021–.050
Hypereutrophic	> 61	< .9	> 22	> .050

Data Quality Assurance, Treatment of Censored Data, and Data Access

Per USGS policy, analytical laboratories that provide chemical, radiochemical, and biological analyses are regularly reviewed and evaluated to ensure that data quality is appropriately maintained (U.S. Geological Survey, 1998). During the review process for the Michigan lake-sample analyses, any samples that did not follow prescribed processing protocol were excluded from the database. In a few instances, sample bottles leaked and were not processed. For these reasons, some samples from various constituents were removed. The tables in this report note the number of samples analyzed for the respective constituents.

In addition to the laboratories' actual measurement for each constituent, some data were also censored—that is, reported as "nondetect" or "less than (<)"—or estimated (E). Nondetects result when analysis for a specific constituent yields no evidence of the constituent's being present in the sample. Less-than data result when a constituent is detected but the concentration is less than the minimum reporting level for that constituent; for example, less than 0.01 milligrams per liter (< 0.01 mg/L). This occurs when an exact value cannot be assigned to a constituent but can be assigned various ranges less than reported detection limits. Estimated values are assigned for a variety of reasons where the analysis deviates from strict protocol or ideal analytical conditions (extrapolation, minor loss of sample during preparation, and so forth).

The MDEQ laboratory and their private contract laboratory provided analytical results with associated data-qualifier descriptions. All analytical methods used were matched with the appropriate USGS constituent codes and methods, in addition to the remark codes for less-than and estimated data, before the data were stored in NWIS. Both laboratories participated in the USGS Standard Reference Sample program. The laboratories were evaluated by using performance evaluation samples, called Standard Reference Samples (SRS). The SRS were submitted to the laboratories semiannually for performance-comparison purposes. Statistical evaluation of the results provides information to compare the analytical performance between laboratories and to determine possible analytical deficiencies and problems. Although the SRS project is not a certification program, participation is required for all laboratories that provide water-quality data for the USGS. Any analyte measured by an individual laboratory that did not receive marginal or higher ratings during the evaluation period was not used in the data analysis for this report. Laboratory-evaluation results can be found at *http://bqs.usgs.gov/srs/* .

With regard to treatment of censored data, the Helsel and Cohn (1988) method of adjusted maximum likelihood was used to create the summary statistics for constituent datasets that contained more than 5 percent nondetect or less-than data values. For all other constituents, zero was entered for nondetects, and the detection limit was entered for less-than data. This approach was chosen to minimize skewed summary statistics when a large percentage of values for particular constituents were nondetects or less-than data values. The rationale for this approach is given in appendix 2.

All LWQA monitoring data were archived in the USEPA data-management system (STORET), as well as in the USGS National Water Information System (NWIS) database. These data are available to the public at *http://mi.waterdata.usgs.gov/nwis/qw* and at *http://www.michigan.gov/miswims*.

Statewide Water Quality of Inland Lakes

From 2001 through 2005, selected lakes were sampled in all of Michigan's 45 watershed management units and 5 ecoregions. Of the 364 lakes sampled, 52 were lakes with more than one major basin. In all, 433 lake basins were assessed and used in the analysis for this report. A summary of the number of lakes, basins, and lakes with multiple basins monitored by sample year is given in table 3.

A statistical summary of statewide lake-basin water-quality data collected during the study period from selected sample depths is presented in table 4. The data used for analysis were collected from sample depths and during the seasonal period that would be used for trophic classification and characterization of baseline water-quality conditions. Summary data were created for (1) chlorophyll *a* (depth-integrated water sample collected from the photic zone during late summer), (2) nutrient constituents—ammonia plus organic nitrogen, ammonia, nitrite plus nitrate, and total phosphorus (collected from the epilimnion during late summer about 3 ft below the lake surface), (3) Secchi-disk measurements made in late summer, and (4) selected chemical properties—hardness, calcium, magnesium, potassium, sodium, alkalinity, chloride, sulfate, and nutrients, ammonia plus organic nitrogen, ammonia, nitrite plus nitrate, and total phosphorus (collected during the spring, before thermal stratification, from mid-depth).

Table 3. Number of Michigan lakes, basins, and lakes with multiple basins sampled from 2001 through 2005.

Year	Number of lakes sampled	Number of basins sampled	Number of lakes with multiple basins
2001	56	67	9
2002	64	75	7
2003	77	91	11
2004	83	103	14
2005	84	97	11

In about 75 percent of the lake basins sampled in Michigan, trophic characteristics are associated with oligotrophic or mesotrophic conditions. However, 13 percent of those lakes would be characterized as oligotrophic if Secchi-disk transparency were used as the sole trophic indicator, 33 percent if only summer near-surface total phosphorus were used, and 29 percent if chlorophyll *a* were the sole indicator, on the basis of ranges of constituents presented in table 2. Also noted was that the total nitrogen to total phosphorus ratio was greater than 15 to 1 in 92 percent of the lake basins in ecoregion 50, 97 percent in ecoregion 51, and 90 percent in ecoregion 56. This finding indicates that most lake basins sampled in Michigan are phosphorus limited (Lillie and Mason, 1983). The concentrations of common ions ranged noticeably statewide. Some constituents were non detectable in many lake basins, and others exceeded their statewide average by several magnitudes. Notably, the maximum reported concentrations for chloride and sulfate were more than 28 times the state median value, but the same constituents were reported at non detects in some lakes. Alkalinity, which is a measure of the capacity of lake water to neutralize acid and an indicator of its ability to buffer the adverse effects of acid rain, ranged from less than the minimum reporting limit (20 mg/L) to 246 mg/L. In more than half the lakes, alkalinity was greater than 116 mg/L.

Table 4. Statistical summary of Michigan lake basins sampled from 2001 through 2005 by season and lake. (The Helsel and Cohn (1988) adjusted maximum likelihood method was used to create summary statistics for constituents with greater than 5 percent of the data as nondetects or less-than values; otherwise, zero was used for all nondetect values, and the detection limit was used for all less-than values.)

[µg/L, micrograms per liter; mg/L, milligrams per liter; N, number of lake basin samples; Min, minimum; Qu., quartile; Max, maximum; Std, Standard; Dev, deviation; <, less than]

Constituent	Unit	N	Min	1st Qu.	Mean	Median	3rd Qu.	Max	Std Dev.
Summer photic zone									
Chlorophyll *a*	µg/L	432	0.0	2.0	6.9	3.6	6.0	120.0	12.3
Summer near surface									
Secchi-disk transparency	meters	421	.3	2.1	3.1	3.0	3.8	11.3	1.5
Ammonia + Organic Nitrogen	mg/L	433	.08	.37	.63	.53	.75	2.64	.41
Ammonia	mg/L	348	< 1	.01	.03	.01	.04	.64	.05
Nitrite + Nitrate	mg/L	433	< .01	.00	.03	.00	.01	3.10	.24
Phosphorus	mg/L	431	.000	.010	.019	.011	.020	.290	.026
Spring mid-depth									
Hardness	mg/L	432	.0	82.5	133.8	139.0	179.0	337.0	74.0
Calcium	mg/L	432	1.1	22.8	35.0	35.7	45.7	98.6	19.2
Magnesium	mg/L	432	.0	6.1	11.4	11.2	16.6	28.7	6.8
Potassium	mg/L	432	.2	.6	1.2	1.0	1.6	5.4	.9
Sodium	mg/L	431	< 1	2.2	8.6	4.8	8.1	136.0	14.6
Alkalinity	mg/L	430	< 20	67.0	116.7	116.0	148.0	246.0	98.5
Chloride	mg/L	429	.0	4.0	17.8	8.0	18.0	246.0	28.1
Sulfate	mg/L	430	< 2.0	2.0	11.2	5.0	15.0	142.0	17.6
Ammonia + Organic Nitrogen	mg/L	432	.06	.33	.55	.49	.68	2.89	.31
Ammonia	mg/L	387	.00	.01	.08	.04	.08	.67	.11
Nitrite + Nitrate	mg/L	431	.00	.06	.28	.10	.21	6.70	.60
Phosphorus	mg/L	432	.000	.009	.018	.013	.021	.203	.020

Inland Lake Water Quality and Ecoregions

Water-quality data were separated into the five Omernik level III ecoregions mentioned previously. Lake-basin summary statistics by ecoregion are presented in table 5. The majority of the measured constituents were within ecoregion 56; ecoregion 50 was a close second. Ecoegion 51 had about a third as many measurements as ecoregions 56 and 50. Ecoregions 55 and 57 had two and one measurements, respectively, and thus were excluded from further analysis because of an inadequate number of measurements.

The Kruskal-Wallis rank-sum test (Schlotzhauer and Littell, 1997) was used to determine whether there was a statistically significant difference among the three tested ecoregions, by constituent, at a p-value equal or less than 0.05 (indicating statistically significant difference at the 95-percent confidence level). To identify *which* ecoregions were statistically different from each other, the Wilcoxon rank-sum test (Schlotzhauer and Littell, 1997) was used, again with a p-value equal or less than 0.05 (to indicate statistically significance differences at the 95-percent confidence interval). Differences between each combination of ecoregions are summarized in table 6.

The Kruskal-Wallis rank-sum test showed that all constituents except ammonia were significantly different at the 95-percent level among all ecoregions. (Ammonia could not be analyzed because of the low number of samples from ecoregion 51.) The Wilcoxon rank-sum test showed that all constituents were significantly different at the 95-percent level between ecoregions 50 and 56, and most constituents were significantly different between ecoregions 50 and 51, and 51 and 56.

The summer chlorophyll *a* and nutrients, along with summer Secchi-disk transparency, spring ions, nutrients, and other chemical properties, are summarized by ecoregion in table 5. Appendix 3 (figs. 3–1 through 3–18) presents boxplots showing percentiles by ecoregions and statewide summary, and appendix 4 (figs. 4–1 through 4–18) shows statewide spatial distribution by ecoregions.

The median summer chlorophyll *a* concentration was the lowest in the northwest Lower Peninsula ecoregion 51, followed by the northern Lower Peninsula and the Upper Peninsula, ecoregion 50. Water clarity measured with a Secchi disk had a similar regional distribution; the greatest transparency was in ecoregion 51, followed by ecoregion 50.

Comparison of spring mid-depth data (assuming that mixing occurred and that values were similar to the near surface value) to the summer near-surface data, there was a slight increase in concentrations of ammonia plus organic nitrogen from spring to summer in ecoregions 51 and 56. Ammonia and nitrite plus nitrate decreased in concentration from spring to summer uniformly throughout Michigan. The median phosphorus concentration changed little from spring to summer in ecoregions 50 and 51 and decreased slightly in ecoregion 56. Ecoregions show the greatest range in concentration of phosphorus during the summer, notably in southern Michigan ecoregion 56, whereas lake basins in northwest Michigan ecoregion 51 showed the greatest variation in concentration of phosphorus during the spring (appendix 3).

Concentrations of common ions generally were higher in the southern Lower Peninsula in ecoregions 55 and 56. Most measurements that were less than the minimum reporting level or were nondetectable were from lake basins in the northern Lower and the Upper Peninsula ecoregions 50 and 51. The highest median concentration for most common ions by ecoregion was in southern Michigan ecoregion 56. The highest measured concentration in a given lake basin for a common-ion constituent was also in ecoregion 56, except for potassium and sulfate, which were highest in ecoregion 50. A limnological explanation of the importance of water-quality characteristics and constituents examined in this report is given in appendix 5.

Specific Conductance and pH

The ranges of pH and specific conductance shown in figures 6 and 7, respectively, were measured at approximately mid-depth during spring sampling. Lake water during spring turnover is generally well mixed and fairly uniform throughout the water column and is used to define baseline water-quality characteristics. Although the water column is generally well mixed in the spring, slight variations of measured properties can exist throughout the column and may vary slightly from the data presented in these figures. These figures show the geographic distribution of the measured properties of pH and specific conductance in relation to the level III ecoregions.

In 14 lakes (noted in appendix 1) pH was less than 6.5, and in no lake was pH greater than 9.0. Twelve lakes with pH less than 6.5 were in ecoregion 50, and two were in ecoregion 56. Ten lakes with a pH of less than 6.5 were in the western Upper Peninsula, one was in the eastern Upper Peninsula, and three were in the Lower Peninsula. Generally, lakes with a pH greater than 6.5 and less than 9.0 were distributed somewhat evenly throughout the State and ecoregions.

The specific conductance of waters (indicative of dissolved solids) in inland lakes in Michigan varied greatly. In several lakes in the western part of the Upper Peninsula, recorded specific conductance was less than 25 µS/cm; in some lakes in southeast Michigan, values exceeded 1,000 µS/cm. Specific conductance generally was highest in the southern part of the Lower Peninsula, (ecoregions 55, 56, and 57) decreasing farther north (ecoregions 50 and 51) and especially toward the western Upper Peninsula.

Table 5. Statistical summary of Michigan lake basins sampled from 2001 through 2005 by Omernik level III ecoregions. (The Helsel and Cohn (1988) adjusted maximum likelihood method was used to create summary statistics for constituents with greater than 5 percent of the data as less-than or nondetect values; otherwise, zero was used for all nondetect values, and the detection limit was used for all less-than values.)

[µg/L, micrograms per liter; mg/L, milligrams per liter; N, number of basin samples; Min, minimum; Med, median; Max, maximum; <, less than]

Constituent	Unit	Omernik level III ecoregion														
		50					51					56				
Summer photic zone		N	Min	Med	Mean	Max	N	Min	Med	Mean	Max	N	Min	Med	Mean	Max
Chlorophyll *a*	µg/L	172	0.0	2.9	3.9	44.0	44	0.0	2.6	2.9	7.8	213	1.0	4.6	9.7	120.0
Summer near surface																
Secchi-disk transparency	meters	165	1.1	3.2	3.7	11.3	43	.6	3.3	3.4	8.2	210	.3	2.7	2.7	5.5
Ammonia + Organic Nitrogen	mg/L	172	.09	.40	.47	1.5	44	.10	.52	.71	2.60	214	.08	.61	.73	2.60
Ammonia	mg/L	153	< 1	.01	.03	.56	9	< 1	.01	.01	.03	185	< 1	.01	.03	.64
Nitrite + Nitrate	mg/L	172	< .01	.01	.01	.11	44	< .01	.01	.06	.33	214	< .01	.01	.10	3.10
Phosphorus	mg/L	172	.001	.010	.013	.100	44	.000	.010	.011	.040	212	.004	.014	.025	.290
Spring mid-depth																
Hardness	mg/L	172	.0	82	79.8	229.0	44	7.0	150	131.9	184.0	213	23.0	175	177.4	337.0
Calcium	mg/L	172	1.1	24.3	22.1	74.3	44	2.7	40.2	36.7	53.8	213	5.2	43.1	44.9	98.6
Magnesium	mg/L	172	1	6.3	7.1	19.2	44	.0	10.4	9.7	16.7	213	2.2	16.6	15.8	28.7
Potassium	mg/L	172	.2	.6	.7	5.4	44	.2	.7	.7	1.4	213	.4	1.6	1.8	4.8
Sodium	mg/L	171	< 1	2.1	3.1	27.1	44	< 1	4.1	4.4	15.5	213	< 1	7.8	14.4	136.0
Alkalinity	mg/L	171	< 20	69	75.2	202.0	44	< 20	120	109.8	162.0	212	21.0	143	139.4	246.0
Chloride	mg/L	171	1	3	5.2	70.0	43	1.0	6	7.3	28.0	212	2.0	17	30.2	246. 0
Sulfate	mg/L	172	< 2	3	4.5	142.0	43	< 2	4	7.2	46.0	212	< 2	14	17.2	76.0
Ammonia + Organic Nitrogen	mg/L	172	.10	.40	.46	1.35	44	.06	.48	.52	1.40	213	.10	.57	.61	1.96
Ammonia	mg/L	168	.01	.03	.08	.67	24	.01	.06	.08	.32	194	.00	.04	.08	.49
Nitrite + Nitrate	mg/L	171	.00	.07	.08	.24	44	.01	.16	.21	.82	213	.00	.15	.44	6.70
Phosphorus	mg/L	172	.000	.011	.013	.050	44	.000	.009	.019	.203	213	.004	.018	.022	.176

Table 6. Results of statistical tests comparing constituents between Omernik level III ecoregions.

[*, statistically significant at the 95-percent confidence interval; NA, not available because of the lack of samples in one or both categories; zero was used for nondetect values, and the detection limit was used for less-than values]

Constituent		Omernik level III ecoregion		
		50 & 51	50 & 56	51 & 56
Summer photic zone	**Kruskal-Wallis rank-sum test p-value**	**Wilcoxon rank-sum test p-value**		
Chlorophyll *a*	0.00 *	0.33	0.00 *	0.00 *
Summer near surface				
Secchi-disk transparency	.00 *	.52	.00 *	.00 *
Ammonia + organic nitrogen	.00 *	.01 *	.00 *	.19
Ammonia	NA	NA	.00 *	NA
Nitrite + nitrate	.00 *	.00 *	.00 *	.00 *
Phosphorus	.00 *	.13	.00 *	.00 *
Spring mid-depth				
Hardness	.00 *	.00 *	.00 *	.28
Calcium	.00 *	.00 *	.00 *	.09 *
Magnesium	.00 *	.00 *	.00 *	.37
Potassium	.00 *	.03 *	.00 *	.02 *
Sodium	.00 *	.00 *	.00 *	.29
Alkalinity	.00 *	.00 *	.00 *	.69
Chloride	.00 *	.00 *	.00 *	.05 *
Sulfate	.00 *	.00 *	.00 *	.03 *
Ammonia + organic nitrogen	.00 *	.16	.00 *	.02 *
Ammonia	NA	NA	.02 *	NA
Nitrite + nitrate	.00 *	.00 *	.00 *	.02 *
Phosphorus	.00 *	.02 *	.00 *	.04 *

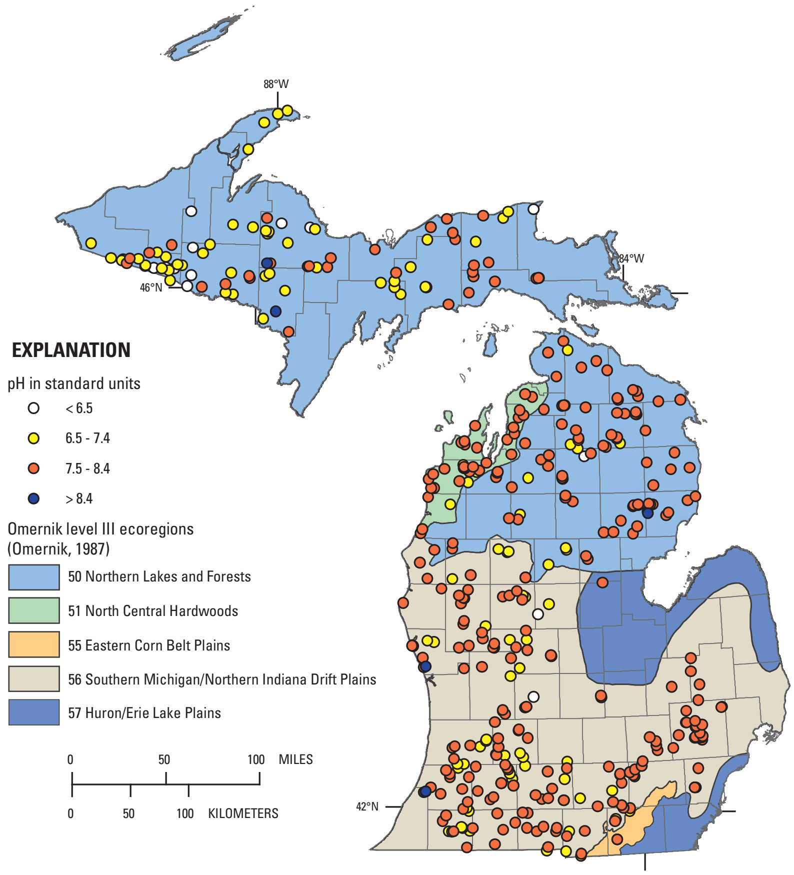

Figure 6. pH in Michigan lake basins during spring turnover for 2001 through 2005, lain on Omernik level III ecoregions.

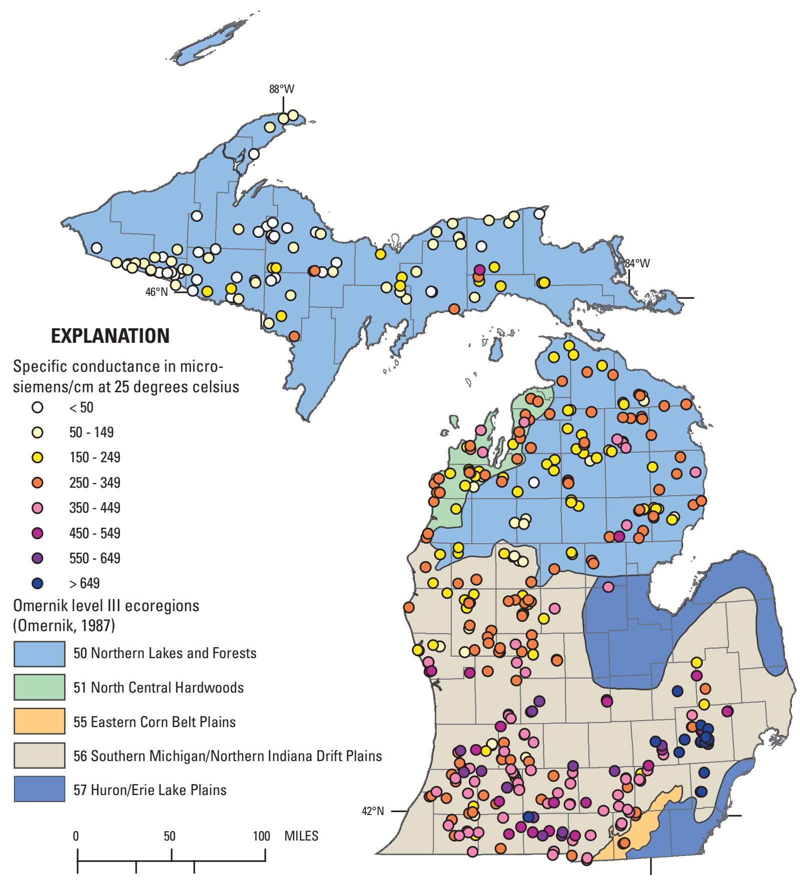

Figure 7. Specific conductance in Michigan lake basins during spring turnover for 2001 through 2005, lain on Omernik level III ecoregions.

Trophic State Index Class Compared to Maximum Lake Depth and Lake Area

Maximum lake depth and area were compared across TSI classes to determine whether a relation exists between these physiographic characteristics and trophic conditions. The Kruskal-Wallis rank-sum test determined a statistically significant difference at the 95-percent confidence interval between maximum lake depth and TSI classes but not between lake area and TSI classes. The distribution of lake depths and areas within each TSI class is shown in figures 8 and 9, respectively. The figures indicate that lake depth seems to vary between TSI classes; lake area remains fairly constant across classes.

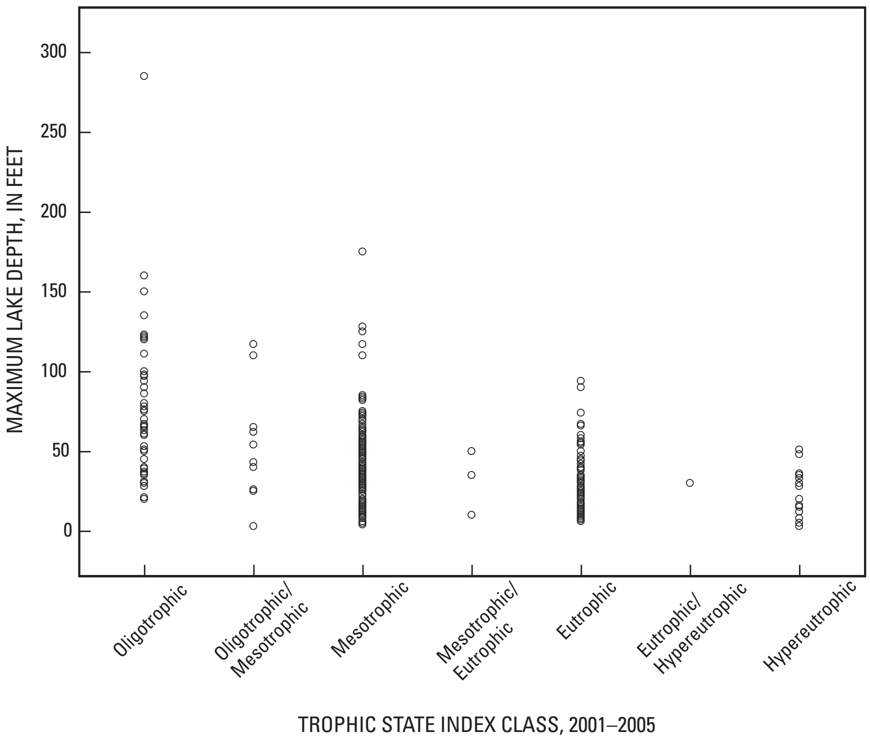

Figure 8. Relation of Trophic State Index class to lake depth in Michigan lake basins, 2001–2005.

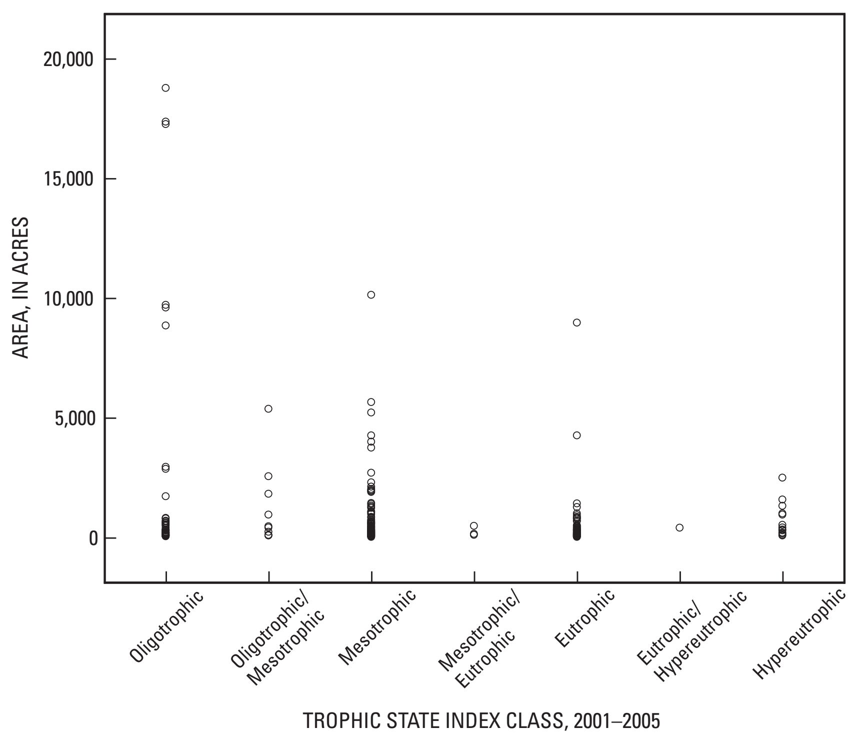

Figure 9. Relation of Trophic State Index class to lake area in Michigan lake basins, 2001–2005.

Comparison of Current Trophic Assessment with Historical Assessments

Current trophic evaluations by lake made by the MDEQ reveal that nearly 17 percent are oligotrophic, 53 percent are mesotrophic, 22 percent are eutrophic, 4 percent are hypereutrophic, and less than 5 percent are classified into mixed classes between each major class. About 85 percent of the oligotrophic lakes are in ecoregions 50 and 51, where they constitute nearly 28 percent of the lakes. Statewide, about 10 percent of all lakes evaluated from 2001 through 2005 were adjusted up one trophic classification to account for nutrient uptake by macrophytes (Walker, 1979).

Historical trophic evaluations made by the MDEQ reveal that 16 percent are oligotrophic, 54 percent are mesotrophic, 24 percent are eutrophic, and 6 percent are hypereutrophic. Even though the percentage of lakes classified in each trophic class between current and historical data are similar, they are not indicative of individual lakes. Seventy-two percent did not change trophic class, 18 percent decreased a partial or whole trophic class (indicating improved water clarity), and 11 percent increased a partial or whole trophic class (indicating decreased water clarity). None of the trophic evaluations for lakes increased or decreased more than one trophic class.

Direct comparison between historical and current trophic classifications are difficult to make because of changes to the evaluation process and classification boundaries that evolved with time. Trophic evaluations by the MDEQ evolved during the collection of historical data with experience, knowledge, and training. During the 1980s, the trophic class for a lake was adjusted up one class if dense macrophytes were present. For lakes assessed in 1993, the eutrophic class was split into two classes, adding the hypereutrohpic class with a TSI value greater than 61. For lakes starting in the 1995 assessment, the TSI class ranges separating the oligotrophic and mesotrophic classes were adjusted down one TSI unit. Although all historical lakes were reclassified, if necessary, using current trophic class ranges (table 2) in appendix 1, not all lakes from the 1982, 1988, 1989 assessments (noted in appendix 1) had a record of macrophytes being present or their density. Because approximately 40 percent of the data are from these early-assessment dates, it is difficult to draw exact comparisons between historical and current data for lakes.

Summary and Conclusions

This 5-year compilation report summarizes the first years (2001–2005) of lake water-quality data collected by the USGS and MDEQ through the LWQA program. From 2001 through 2005, a total of 433 lake basins from 364 lakes 25 acres or greater in size with public boat launches was sampled. Current and historical lake trophic assessments provided by MDEQ are also presented. Variation of water-quality characteristics in lake basins, spatial variations related to geographic influences, and changes in trophic classifications were statistically evaluated using the Kruskal-Wallis rank-sum test and the Wilcoxon signed-ranks test. Data summarized in this report are used to establish baseline water-quality characteristics and are used for trophic classification.

The ratio between total nitrogen to total phosphorus was greater than 15 to 1 in more than 90 percent of the lakes, an indication that most lake basins sampled in Michigan are phosphorus limited. Concentration of many common ions and nutrients varied considerably throughout Michigan. Some constituents (magnesium, chloride, sulfate, ammonia, nitrite plus nitrate, and phosphorus) were nondetectable in many lakes but exceeded their statewide median by several orders of magnitude in other lakes. Maximum reported concentrations of chloride and sulfate were about 28 times the statewide median. Regional variation of water quality was noted statewide.

Omernik (1987) level III ecoregions were used to separate the water-quality data into groups on the basis of their origin of collection from regions with similar ecosystems. Geographic setting, climate, geology, hydrology, vegetation, and land use all influence water-quality characteristics. Concentrations of measured ions generally were higher in the southern Lower Peninsula in Omernik ecoregions 55, 56, and 57 (Eastern Corn Belt Plains, Southern Michigan/Northern Indiana Drift Plains, and Huron/Erie Lake Plains). Concentrations of most ions that were less than the minimum reporting levels or were nondetectable were from lakes in the northern Lower Peninsula and Upper Peninsula in Omernik ecoregions 50 and 51 (Northern Lakes and Forests and North Central Hardwoods). Chlorophyll *a* concentrations followed a similar distribution pattern. The lowest chlorophyll *a* concentrations were in ecoregions 50 and 51. Measured properties such as pH and specific conductance (indicative of dissolved solids) also showed a regional relation. The lakes with the lowest pH and specific conductance were generally in the western Upper Peninsula, in ecoregion 50 (Northern Lakes and Forests). The lowest concentrations of most nutrients were also in ecoregions 50 and 51.

Data indicate that a slightly greater variation in nutrients, particularly phosphorus, occurs in the spring between ecoregions. Less variation was noted during the summer, when lake productivity is high and nutrient uptake by algae and macrophytes is the greatest. Lakes with dense macrophytes tend to utilize most of the available phosphorus, which results in more uniform concentrations among ecoregions and lake basins.

MDEQ classifies lakes on the basis of their primary biological productivity or trophic characteristics and uses the Carlson Trophic State Index to classify Michigan lakes. However, MDEQ has adopted a modified scale and interpretation to account for regional characteristics. In the analysis of the 2001–2005 lake data, the MDEQ trophic index was adjusted for nutrient uptake when substantial amounts of macrophytes are present.

Trophic evaluations made by the MDEQ of lakes sampled from 2001 through 2005 reveal that nearly 17 percent are oligotrophic, 53 percent are mesotrophic, 22 percent are eutrophic, 4 percent are hypereutrophic, and less than 5 percent are classified into mixed classes between each major class. Historical trophic evaluations (appendix 1) made by the MDEQ reveal that 16 percent are oligotrophic, 54 percent are mesotrophic, 24 percent are eutrophic, and 6 percent are hypereutrophic. Seventy-two percent of lakes did not change trophic class, 18 percent decreased a partial or whole trophic class (indicating improved water clarity), and 11 percent increased a partial or whole trophic class (indicating decreased water clarity). No lakes increased or decreased more than one trophic class of the comparable current and historical lakes. For approximately 40 percent of the historical data from early MDEQ assessment dates (1982, 1988, and 1989), notation of dense macrophyte presence may have been omitted; thus, for these data, it is unknown whether dense macrophytes were indeed present and whether the lake assessments should have been moved up a trophic class. For this reason, it is difficult to make comparisons between historical and 2001–2005 lake trophic class.

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Appendixes 1 through 5

Appendix 1. List of Michigan lake basins sampled from 2001 through 2005.

[USEPA, U.S. Environmental Protection Agency; USGS, U.S. Geological Survey; TSI, Trophic state index; *, classification adjusted because of dense macrophytes; <, less than; **, pH value less than 6.5; N. E. B., northeast basin; S. E. B., southeast basin; N. B., north basin; S. B., south basin.; E. C. B., east-central basin; S. W. B., southwest basin; E. B., east basin; W. B., west basin; C. B., central basin; S. C. B., south-central basin; 50, Northern Lakes and Forest; 51, North Central Hardwood Forest; Eastern Corn Belt Plains; 56, Southern Michigan/Northern Indiana Drift Plains; 57, Huron/lake Erie Plains; O, oligotrophic; M, mesotrophic; E, eutrophic; H, hypereutrophic; –, multiple basin (multiple basin lakes were averaged)]

County	Omernik level III ecoregion	USEPA STORET number	USGS station number	Lake Basin name	Lake area (acres)	Maximum lake depth (feet)	Year sampled	pH < 6.5	2001–2005 TSI class	Adjusted TSI class	Historical TSI class	Historical assessment date
Alcona	50	MI010040	443347083481701	Alcona Dam Pond near Curtisville, Mich.	953	43	2002		O/M		M	1995
Alcona	50	MI010051	444120083243101	Brownlee Lake at Lincoln, Mich.	87	25	2002		M		E	1997
Alcona	50	MI010050	444414083520601	Crooked Lake near Curran, Mich.	89	28	2005		M		M	1991
Alcona	50	MI010020	444836083335101	Hubbard Lake near Hubbard Lake, Mich.	8,850	75	2005		O		O	1991
Alcona	50	MI010041	444045083363801	Jewell Lake at Barton City, Mich.	193	34	2002		M		M	1995
Alger	50	MI020038	462400086504101	Au Train Lake near Au Train, Mich.	830	25	2005		M		E	1993
Alger	50	MI020039	463826086023401	Grand Sable Lake near Grand Marais, Mich.	630	60	2005		M		M	1993
Alger	50	MI020054	463445086131001	Kingston Lake near Green Haven, Mich.	250	20	2005		M		M	1982
Alger	50	MI020040	463218085575701	Nawakwa Lake near Green Haven, Mich. (N. E. B)	399	26	2005		M		E	1982
Alger	50	MI020041	463202085582901	Nawakwa Lake near Green Haven, Mich. (S. E. B)	–	–	2005		–	–	–	–
Allegan	56	MI030256	422530085512301	Base Line Lake near Merson, Mich.	187	44	2004		E		E	1995
Allegan	56	MI030257	423336085412001	Big Lake near Martin, Mich.	137	30	2004		E		M	1995
Allegan	56	MI030259	422532085555001	Eagle Lake near Cheshire, Mich.	225	69	2004		M		M	1982
Allegan	56	MI030472	423347085571001	Lake Allegan near Mich.llgrove, Mich.	1587	20	2004		H		H	1993
Allegan	56	MI030260	423410085474301	Mich.ner Lake near Allegan, Mich.	325	83	2004		M		M	1995
Allegan	56	MI030223	423652085372501	Selkirk Lake near Shelbyville, Mich. (N. B.)	–	–	2004		–	–	–	–
Allegan	56	MI030224	423625085374001	Selkirk Lake near Shelbyville, Mich. (S. B.)	94	94	2004		E	*	E	1995
Allegan	56	MI030262	423303085585401	Swan Creek Pond near Fennville, Mich.	140	6	2004		E		E	1982
Allegan	56	MI030261	422752085574201	Swan Lake near Cheshire, Mich.	200	28	2004		H		H	1995
Alpena	50	MI040064	445900083522901	Fletcher Pond near Hillman, Mich.	8,970	8	2005		E		E	1991
Antrim	51	MI050093	450600085153001	Ben-Way Lake near Eastport, Mich.	131	42	2003		M		M	1982
Antrim	51	MI050090	445600085225401	Birch Lake near Kewadin, Mich.	326	53	2003		O		M	1988
Antrim	51	MI050056	450943085143601	Ellsworth lake at Ellsworth, Mich.	120	42	2003		M		M	1982
Antrim	51	MI050103	445418085112101	Lake Of The Woods near Mancelona, Mich.	141	14	2003		M		M	1982
Antrim	51	MI050055	450140085185601	Torch Lake near Creswell, Mich. (N. B.)	–	–	2003		–	–	–	–
Antrim	51	MI050054	445850085180401	Torch Lake near Creswell, Mich. (S. B.)	18,770	285	2003		O		O	1997
Baraga	50	MI070038	463559088071201	Keewaydin Lake near Michigamme, Mich.	151	25	2002		M		M	1982
Baraga	50	MI070044	463422088260501	Parent Lake near Covington, Mich.	182	4	2001		M		M	2001
Baraga	50	MI070039	463328088125401	Ruth Lake at Three Lakes, Mich.	192	36	2002		M		M	1982
Barry	56	MI080094	423030085162301	Clear Lake near Hastings, Mich.	184	16	2003		E	*	E	1982

Appendix 1. List of Michigan lake basins sampled from 2001 through 2005. —Continued

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County	Omernik level III ecoregion	USEPA STORET number	USGS station number	Lake Basin name	Lake area (acres)	Maximum lake depth (feet)	Year sampled	pH < 6.5	2001–2005 TSI class	Adjusted TSI class	Historical TSI class	Historical assessment date
Barry	56	MI080071	422925085255301	Crooked Lake at Crooked Lake, Mich.	735	48	2004		M		E	1991
Barry	56	MI080096	424458085320401	Duncan Lake near Caledonia, Mich.	130	55	2003		E		E	1982
Barry	56	MI080090	423320085295701	Fish Lake near Orangeville, Mich.	165	56	2004		M		O	1993
Barry	56	MI080089	424128085165501	Leach Lake near Hastings, Mich. (N. B.)	109	52	2003		M		E	1995
Barry	56	MI080088	424107085171201	Leach Lake near Hastings, Mich. (S. B.)	–	–	2003		–	–	–	–
Barry	56	MI080101	423723085301201	Long Lake near Cloverdale, Mich.	146	49	2004		M		O	1982
Barry	56	MI080091	422830085143701	Long Lake near Middleville, Mich.	81	3	2003		O/M		M	1982
Barry	56	MI080104	422937085311501	Pine Lake near Dayton, Mich. (E. C. B)	–	–	2004		–	–	–	–
Barry	56	MI080100	422957085312501	Pine Lake near Dayton, Mich. (N. E. B)	660	34	2004		M		M	1993
Barry	56	MI080064	423733085111701	Thornapple Lake near Caledonia, Mich.	409	30	2003		E/H		H	1993
Benzie	51	MI261001	443745086140601	Betsie Lake near Frankfort, Mich.	250	22	2003		E		H	1993
Benzie	51	MI100066	444007086111001	Crystal Lake near Benzonia, Mich.	9,711	160	2003		O		O	1982
Benzie	51	MI100139	444426085513401	Herendeene Lake near Lake Ann, Mich.	36	37	2003		M		M	1995
Benzie	51	MI100125	444319085511101	Lake Ann near Lake Ann, Mich. (N. B.)	–	–	2003		–	–	–	–
Benzie	51	MI100082	444243085503601	Lake Ann near Lake Ann, Mich. (S. E. B)	527	70	2003		O		O	1991
Benzie	51	MI100083	444253085511901	Lake Ann near Lake Ann, Mich. (S. W. B)	–	–	2003		–	–	–	–
Benzie	51	MI100122	444232086035701	Little Platte Lake near Honor, Mich.	805	8	2003		E		E	1988
Benzie	51	MI100085	443344086123801	Lower Herring Lake near Watervale, Mich.	450	60	2004		M		M	1993
Benzie	51	MI100140	443655085541601	Turtle Lake near Lake Ann, Mich.	38	22	2003		M		E	1995
Benzie	51	MI100084	443340086105001	Upper Herring Lake near Watervale, Mich.	540	25	2004		M		E	1988
Berrien	56	MI110411	421251086152401	Paw Paw Lake at Watervliet, Mich. (E. B.)	–	–	2001		–	–	–	–
Berrien	56	MI110410	421224086163301	Paw Paw Lake at Watervliet, Mich. (W. B.)	857	90	2001		E	*	E	2001
Branch	56	MI120130	415407085062901	Cary Lake near Batavia, Mich.	79	38	2005		M		M	1982
Branch	56	MI120195	420256085150801	Kenyon Lake near Athens, Mich.	73	29	2005		M		E	1993
Branch	56	MI120104	415532084535301	Marble Lake near Quincy, Mich. (N. B.)	780	60	2005		E		M	1988
Branch	56	MI120102	415354084542401	Marble Lake near Quincy, Mich. (S. B.)	–	–	2005		–	–	–	–
Branch	56	MI120123	415549085122501	Matteson Lake near Matteson, Mich.	307	38	2005		E		E	1997
Branch	56	MI120147	414639084594101	Silver Lake near Kinderhook, Mich.	213	40	2005		M		M	1982
Branch	56	MI120139	415616085020601	South Lake near Coldwater, Mich.	118	18	2005		E		H	1993
Branch	56	MI120126	420240085115501	Union Lake near Union City, Mich.	525	16	2005		H		H	1993

Appendix 1. List of Michigan lake basins sampled from 2001 through 2005. —Continued

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County	Omernik level III ecoregion	USEPA STORET number	USGS station number	Lake Basin name	Lake area (acres)	Maximum lake depth (feet)	Year sampled	pH < 6.5	2001–2005 TSI class	Adjusted TSI class	Historical TSI class	Historical assessment date
Branch	56	MI850006	414516085002401	Lake George near Jamestown, Ind.	565	82	2005		M		M	1982
Calhoun	56	MI130172	422315084470201	Duck Lake near Springport, Mich.	629	50	2004		M		M	1995
Calhoun	56	MI130237	420835084490601	Homer Lake near Homer, Mich. (N. E. B.)	74	30	2005		M		M	1997
Calhoun	56	MI130238	420815084492501	Homer Lake near Homer, Mich. (S. C. B.)	–	–	2005		–	–	–	–
Calhoun	56	MI130296	422150084591201	Lane Lake near Marshall, Mich.	24	24	2004		E		E	1997
Calhoun	56	MI130191	421051085070501	Lee Lake near Stanley Corners, Mich.	116	47	2005		M	*	M	1993
Calhoun	56	MI130189	420919084590601	Nottawa Lake near Ellis Corners, Mich.	116	21	2005		E	*	E	1993
Calhoun	56	MI130206	421342084564201	Upper Brace Lake near Marshall, Mich.	70	41	2004		M		M	1993
Calhoun	56	MI130210	422440085132601	Wabascon Lake near Bedford, Mich.	70	45	2004		E		E	1997
Calhoun	56	MI130205	420855085030201	Warners Lake near Ellis Corners, Mich.	59	30	2005		E		M	1997
Calhoun	56	MI130275	421817084483501	Winnipeg Lake near Marengo, Mich.	38	22	2004		E		E	1993
Cass	56	MI140068	414642085494201	Baldwins Lake near Union, Mich.	266	55	2001		M		E	2001
Cass	56	MI140060	415622085532001	Belas Lake near Vandalia, Mich.	58	17	2001		E		E	2001
Cass	56	MI140039	415411085580301	Diamond Lake near Vandalia, Mich. (E. B.)	1,020	64	2001		M		M	2001
Cass	56	MI140040	415405085590901	Diamond Lake near Vandalia, Mich. (W. B.)	–	–	2001		–	–	–	–
Cass	56	MI140104	415425085480001	Driskels Lake near Jones, Mich.	37	28	2005		M		E	1995
Cass	56	MI140063	415544085461301	Harwood Lake near Corey, Mich.	122	55	2005		M		M	1995
Cass	56	MI140053	420345085483001	Hemlock Lake near Marcellus, Mich.	64	75	2005		M		M	1995
Cass	56	MI140087	415544085523801	Kirk Lake near Vandalia, Mich.	42	23	2001		M		M	2001
Cass	56	MI140066	415914086044501	Mill Pond near Dowagiac, Mich.	174	7	2005		E		M	1982
Cass	56	MI140106	420145086025001	South Twin Lake near Dowagiac, Mich.	44	41	2001		M		M	2001
Cass	56	MI140068	415412086010101	Stone Lake at Cassopolis, Mich.	148	56	2001		E		E	2001
Charlevoix	51	MI150082	450949084583901	Deer Lake near Boyne Falls, Mich.	443	20	2003		M		M	1991
Charlevoix	51	MI150062	451549085062201	Lake Charlevoix near Charlevoix, Mich. (E. B.)	17,260	122	2003		O		O	1989
Charlevoix	51	MI150063	451711085110501	Lake Charlevoix near Charlevoix, Mich. (W. B.)	–	–	2003		–	–	–	–
Charlevoix	51	MI150115	450712085120801	Six Mile Lake near Ellsworth, Mich.	407	31	2003		M		E	1988
Charlevoix	51	MI150059	451136084454501	Thumb Lake near Vanderbilt, Mich. (C. B.)	484	150	2005		O		O	1982
Charlevoix	51	MI150058	451132084450401	Thumb Lake near Vanderbilt, Mich. (E. B.)	–	–	2005		–	–	–	–
Charlevoix	51	MI150060	451131084464401	Thumb Lake near Vanderbilt, Mich. (W. B.)	–	–	2005		–	–	–	–
Cheboygan	50	MI160048	452728084163401	Black Lake near Onaway, Mich.	10,130	50	2005		M		M	1991

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County	Omernik level III ecoregion	USEPA STORET number	USGS station number	Lake Basin name	Lake area (acres)	Maximum lake depth (feet)	Year sampled	pH < 6.5	2001–2005 TSI class	Adjusted TSI class	Historical TSI class	Historical assessment date
Cheboygan	50	MI160089	453715084423001	Lancaster Lake near Lancaster, Mich.	52	57	2005		M		M	1997
Cheboygan	50	MI160169	453159084234601	Long Lake near Alverno, Mich.	400	61	2005		O		O	1991
Cheboygan	50	MI210151	452904084333701	Mullett Lake near Aloha, Mich.	17,360	120	2005		O		M	1982
Chippewa	50	MI170078	461039085023701	Carp Lake near Trout Lake, Mich.	560	30	2004		M		M	1997
Chippewa	50	MI170079	461055085005601	Frenchmans Lake near Trout Lake, Mich. (C. B.)	174	20	2004		M		E	1982
Chippewa	50	MI170080	461058085012101	Frenchmans Lake near Trout Lake, Mich. (W. B.)	–	–	2004		–	–	–	–
Chippewa	50	MI170137	464241085040001	Shelldrake Pond near Paradise, Mich.	266	5	2004	**	M		M	1982
Clare	50	MI180107	440423084451901	Arnold Lake near Harrison, Mich.	118	80	2002		O		O	1997
Clare	50	MI180067	440528084455001	Big Long Lake near Harrison, Mich.	210	76	2001		O		O	2001
Clare	50	MI180108	435747084570101	Shingle Lake at Lake George, Mich.	35	35	2001		M		M	2001
Clinton	56	MI190093	425635084245401	Lake Ovid near Westchester Heights, Mich. (N. B.)	412	16	2002		H		H	1993
Clinton	56	MI190094	425557084245201	Lake Ovid near Westchester Heights, Mich. (S. B.)	–	–	2002		–	–	–	–
Crawford	50	MI200044	444742084325001	K.P. Lake near Lovells, Mich.	110	25	2002	**	O/M		M	1982
Crawford	50	MI200042	443857084472901	Lake Margrethe near Grayling, Mich. (C. B.)	1,920	65	2004		M		M	1982
Crawford	50	MI200036	443740084471501	Lake Margrethe near Grayling, Mich. (S. B.)	–	–	2004		–	–	–	–
Crawford	50	MI200043	443802084472401	Lake Margrethe near Grayling, Mich. (S. W. B.)	–	–	2004		–	–	–	–
Crawford	50	MI200058	445126084370801	Section One Lake near Waters, Mich.	56	21	2002		O		O	1982
Crawford	50	MI200111	444913084283301	Shupac Lake near Lovells, Mich.	107	97	2002		O		O	1991
Delta	50	MI210114	460328086330401	Camp Seven Lake near Uno, Mich.	60	35	2004		M		M	1997
Delta	50	MI210171	460640086373101	Dana Lake near Steuben, Mich.	98	25	2005		M		E	1982
Delta	50	MI210151	460843086463001	Pole Creek Lake near Trenary, Mich.	87	10	2005		E		E	1982
Delta	50	MI210113	460929086372101	Skeels Lake near Uno, Mich.	91	50	2004		M		M	1982
Dickinson	50	MI220040	455111088041301	Bass Lake near Iron Mountain, Mich.	61	58	2002		M	*	M	1982
Dickinson	50	MI220060	454518087470701	Hamilton Lake near Waucedah, Mich.	75	31	2002		E	*	M	1995
Dickinson	50	MI220061	460413087501501	Norway Lake near Ralph, Mich.	52	26	2005		M		M	1982
Dickinson	50	MI220038	455436087555401	Rock Lake near Merriman, Mich.	84	30	2002		M		M	1982
Dickinson	50	MI220036	461102088034101	Sawyer Lake near Channing, Mich.	241	20	2005		E	*	E	1989
Dickinson	50	MI220063	461213088010201	Silver Lake near Floodwood, Mich.	118	20	2002		M		E	1982
Eaton	56	MI230173	422615084464201	Narrow Lake near Olivet, Mich.	121	48	2004		H		H	1993
Emmet	51	MI240045	452453084500401	Crooked Lake near Conway, Mich.	2,300	50	2005		M		M	1989

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County	Omernik level III ecoregion	USEPA STORET number	USGS station number	Lake Basin name	Lake area (acres)	Maximum lake depth (feet)	Year sampled	pH < 6.5	2001–2005 TSI class	Adjusted TSI class	Historical TSI class	Historical assessment date
Emmet	50	MI240043	454127084452001	Lake Paradise near Carp Lake, Mich.	1,900	15	2003		M		E	1988
Emmet	50	MI240078	453615084553301	Larks Lake near Marsh Corner, Mich.	605	9	2005		M		M	1982
Genesee	56	MI250444	430645083274601	Holloway Reservoir near Columbiaville, Mich.	954	15	2003		H		H	1993
Genesee	56	MI250417	430001083401001	Thread Lake near Flint, Mich.	80	5	2003		H		H	1993
Gladwin	56	MI260032	440128084325701	Pratt Lake near Podunk, Mich.	180	28	2002		O		O	1982
Gladwin	56	MI260025	440010084315401	Wiggins Lake near Gladwin, Mich.	345	25	2002		M		M	1989
Gladwin	57	MI260034	434906084223001	Wixom Lake near Edenville, Mich.	1,980	40	2002		M		E	1982
Gogebic	50	MI270123	461326089102001	Allen Lake near Watersmeet, Mich.	79	40	2003	**	M		M	1995
Gogebic	50	MI270124	461813089103001	Bass Lake near Watersmeet, Mich.	191	18	2003		M		M	1995
Gogebic	50	MI270105	461942089215001	Beatons Lake near Watersmeet, Mich.	302	90	2003		O		O	1995
Gogebic	50	MI270125	461258089182001	Clark Lake near Watersmeet, Mich.	820	75	2003	**	O		O	1993
Gogebic	50	MI270126	461206089080301	Dinner Lake near Watersmeet, Mich.	110	19	2003		M		M	1995
Gogebic	50	MI270127	461253089125201	Duck Lake near Watersmeet, Mich.	610	25	2003		M		O	1995
Gogebic	50	MI270110	461303089044001	Imp Lake near Watersmeet, Mich.	84	86	2003	**	O		O	1995
Gogebic	50	MI270065	461639089285601	Langford Lake near Thayer, Mich.	481	10	2003		M/E		M	1993
Gogebic	50	MI270047	461534089394801	Little Oxbow Lake near Marenisco, Mich.	95	85	2003		M		M	1997
Gogebic	50	MI270111	462258090005001	McDonald Lake near Bessemer, Mich.	485	10	2003		E	*	E	1995
Gogebic	50	MI270112	461426089363201	Moosehead Lake near Marenisco, Mich.	54	39	2003		E	*	M	1995
Gogebic	50	MI270113	461636089470401	Moraine Lake near Marenisco, Mich.	67	20	2003		O		M	1995
Gogebic	50	MI270114	461615089385901	Ormes Lake near Marenisco, Mich.	50	65	2003	**	O		M	1995
Gogebic	50	MI270066	461643089343001	Pomeroy Lake near Marenisco, Mich.	314	15	2003		E		E	1991
Gogebic	50	MI270122	461449089022601	Taylor Lake near Watersmeet, Mich.	109	35	2003		M/E		M	1995
Gogebic	50	MI270046	461331089235701	Thousand Island Lake near Stickley, Mich. (S. B.)	1,020	47	2003		M		M	1995
Gogebic	50	MI270045	461358089234801	Thousand Island Lake near Watersmeet, Mich. (N. B.)	–	–	2003		–	–	–	–
Gogebic	50	MI860017	460726089065001	Lac Vieux Desert near Phelps, Wisc.	4,260	38	2003		E		M	1995
Grand Traverse	51	MI280131	444137085425201	Bass Lake near Grawn, Mich. (N. B.)	349	19	2003		M		M	1989
Grand Traverse	51	MI280132	444100085425301	Bass Lake near Grawn, Mich. (S. B.)	–	–	2003		–	–	–	–
Grand Traverse	51	MI280133	443623085482501	Bass Lake South near Karlin, Mich.	89	29	2003		M		M	1989
Grand Traverse	51	MI280142	444510085364501	Boardman Lake at Traverse City, Mich.	339	73	2003		M	*	E	1995

Appendix 1. List of Michigan lake basins sampled from 2001 through 2005. —Continued

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County	Omernik level III ecoregion	USEPA STORET number	USGS station number	Lake Basin name	Lake area (acres)	Maximum lake depth (feet)	Year sampled	pH < 6.5	2001–2005 TSI class	Adjusted TSI class	Historical TSI class	Historical assessment date
Grand Traverse	51	MI280143	443840085303001	Brown Bridge Pond near Mayfield, Mich.	180	29	2003		M		M	1995
Grand Traverse	50	MI280080	443359085201501	Fife Lake near Fife Lake, Mich.	617	60	2004		O		O	1989
Grand Traverse	51	MI280145	444105085474001	Lake Dubonnet near Interlochen, Mich.	182	6	2003		M		M	1995
Grand Traverse	51	MI280084	444329085452201	Long Lake near Traverse City, Mich.	2,860	80	2003		O		O	1989
Grand Traverse	51	MI280116	444146085411101	Silver Lake near Grawn, Mich. (N.C.B.)	600	98	2003		O		O	1989
Grand Traverse	51	MI280119	444910085202601	Skegemog Lake near Rapid City, Mich.	2,560	26	2003		M/O		M	1988
Grand Traverse	51	MI280136	444106085292001	Spider Lake near Mayfield, Mich. (N. C. B.)	–	–	2003		–	–	–	–
Grand Traverse	51	MI280137	444035085293501	Spider Lake near Mayfield, Mich. (S. W. B)	459	32	2003		M		M	1989
Hillsdale	56	MI300152	415357084363201	Baw Beese Lake near Hillsdale, Mich.	414	70	2005		M		M	1982
Hillsdale	56	MI300174	414327084385001	Lake Diane near Austin, Mich. (N. B.)	295	51	2005		H		H	1993
Hillsdale	56	MI300173	414237084391301	Lake Diane near Austin, Mich. (S. B.)	–	–	2005		–	–	–	–
Hillsdale	56	MI850005	414447084482701	Long Lake near Camden, Mich.	146	35	2005		E		E	1982
Hillsdale	56	MI300112	415136084473901	Long Lake near Reading, Mich.	210	40	2005		M		M	1988
Hillsdale	56	MI300155	415348084460801	Round Lake near Reading, Mich.	72	35	2005		M		M	1982
Houghton	50	MI310120	463946088544101	Bob Lake near Pori, Mich.	133	15	2003	**	M		M	1997
Houghton	50	MI310195	470924088172001	Rice Lake near Lake Linden, Mich.	675	9	2001		M		M	2001
Ionia	56	MI340090	425150085120701	Morrison Lake near Clarksville, Mich. (E. B.)	330	36	2004		H		H	1993
Ionia	56	MI340182	425200085122001	Morrison Lake near Clarksville, Mich. (N. E. B.)	–	–	2004		–	–	–	–
Ionia	56	MI340181	425134085125501	Morrison Lake near Clarksville, Mich. (W. B.)	–	–	2004		–	–	–	–
Ionia	56	MI340179	425638085073801	Sessions Lake near Saranac, Mich.	135	55	2004	**	E		E	1982
Iosco	50	MI350108	442606083263501	Foote Dam Pond near Au Sable, Mich.	1,824	40	2002		O/M		O	1995
Iosco	50	MI350139	442051083385801	Indian Lake near Tawas City, Mich.	218	15	2001		E	*	E	2001
Iosco	50	MI350106	442047083521001	Londo Lake near Hale, Mich.	176	14	2001		M		M	2001
Iosco	50	MI350076	442516083513501	Long Lake near Hale, Mich. (C. B.)	493	62	2001		M		M	2001
Iosco	50	MI350075	442520083521301	Long Lake near Hale, Mich. (N. W. B)	–	–	2001		–	–	–	–
Iosco	50	MI350077	442451083504201	Long Lake near Hale, Mich. (S. E. B.)	–	–	2001		–	–	–	–
Iosco	50	MI350078	442443083490901	Loon Lake near Hale, Mich.	417	128	2001		M	*	M	2001
Iosco	50	MI350111	441938083403501	Sand Lake near Tawas City, Mich.	248	25	2001		M		M	2001
Iosco	50	MI350074	442751083211401	Van Etten Lake near Oscoda, Mich.	1,320	33	2002		H	*	H	1993
Iosco	50	MI350107	442124083523601	West Londo near Hale, Mich.	190	15	2001		M		M	2001

Appendix 1. List of Michigan lake basins sampled from 2001 through 2005. —Continued

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County	Omernik level III ecoregion	USEPA STORET number	USGS station number	Lake Basin name	Lake area (acres)	Maximum lake depth (feet)	Year sampled	pH < 6.5	2001–2005 TSI class	Adjusted TSI class	Historical TSI class	Historical assessment date
Iron	50	MI360072	460158088244701	Buck Lake near Alpha, Mich.	153	39	2002		M		M	1993
Iron	50	MI360081	461155088263301	Gibson Lake near Amasa, Mich.	78	23	2002		M		M	1982
Iron	50	MI360082	461020088531501	Golden Lake near Basswood, Mich.	285	100	2002	**	O		O	1995
Iron	50	MI360053	460233088294701	Indian Lake near Alpha, Mich.	196	36	2002		O		M	1993
Iron	50	MI360051	460646088300301	Lake Emily near Chicagon, Mich.	320	32	2002		E		H	1993
Iron	50	MI360033	460500088454901	Lake Ottawa near Stambaugh, Mich.	551	90	2002		O		M	1993
Iron	50	MI360088	460506088553701	Little Smoky Lake near Beechwood, Mich.	78	20	2002	**	O		M	1982
Iron	50	MI360043	461043088141601	Michigamme Reservoir near Kelso Junction, Mich. (N. W. B.)	5,220	30	2002		M		M	1993
Iron	50	MI360102	460952088134801	Michigamme Reservoir near Kelso Junction, Mich. (S. W. B.)	–	–	2002		–	–	–	–
Iron	50	MI360087	462450088411001	Norway Lake near Kenton, Mich.	53	20	2003		M		O	1993
Iron	50	MI360092	461436088592001	Tamarack Lake near Watersmeet, Mich.	335	18	2003		E		E	1982
Iron	50	MI360090	462304088524001	Tepee Lake near Kenton, Mich.	124	35	2003	**	M		M	1993
Iron	50	MI360091	462038088454901	Winslow Lake near Gibbs City, Mich.	255	25	2002		M		M	1993
Isabella	56	MI370063	433925084570101	Coldwater lake near Two Rivers, Mich.	294	65	2002		M		M	1993
Isabella	56	MI370068	433454085040401	Halls Lake near Millbrook, Mich.	68	26	2002	**	E	*	E	1993
Jackson	56	MI380287	421226084190501	Center Lake at Michigan Center, Mich.	850	28	2001		E		E	2001
Jackson	56	MI380173	420710084184701	Clark Lake near Brooklyn, Mich.	580	55	2003		M		O	1991
Jackson	56	MI380290	421606084130501	Grass Lake at Grass Lake, Mich.	348	13	2001		E	*	E	2001
Jackson	56	MI380244	422341084204901	Pleasant Lake near Munith, Mich.	269	50	2001		M		M	2001
Jackson	56	MI380246	421951084135601	Portage Lake near Munith, Mich. (S. B.)	360	40	2001		M		M	2001
Jackson	56	MI380245	422009084135801	Portage Lake near Munith,Mich. (C. B.)	–	–	2001		–	–	–	–
Jackson	56	MI350110	420513084282201	Round Lake near Somerset Ct. Mich. (C. B.)	155	40	2001		O		M	1995
Jackson	56	MI380293	420904084390001	Swains Lake near Concord, Mich.	69	64	2004		M		M	1993
Jackson	56	MI380264	420538084132001	Vineyard Lake near Brooklyn, Mich. (N. B.)	–	–	2003		–	–	–	–
Jackson	56	MI380263	420430084121501	Vineyard Lake near Brooklyn, Mich. (S. B.)	505	42	2003		M		M	1988
Kalamazoo	56	MI390208	421004085330201	Austin Lake near Portage, Mich.	1,090	11	2005		M		M	1997
Kalamazoo	56	MI390411	421258085425801	Eagle Lake near Mattawan, Mich.	248	10	2004		M		M	1982
Kalamazoo	56	MI390210	422345085242501	Gull Lake near Gull Lake, Mich. (C. B.)	–	–	2004		–	–	–	–

Appendix 1. List of Michigan lake basins sampled from 2001 through 2005. —Continued

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County	Omernik level III ecoregion	USEPA STORET number	USGS station number	Lake Basin name	Lake area (acres)	Maximum lake depth (feet)	Year sampled	pH < 6.5	2001–2005 TSI class	Adjusted TSI class	Historical TSI class	Historical assessment date
Kalamazoo	56	MI390211	422501085253901	Gull Lake near Gull Lake, Mich. (N. B.)	2,030	110	2004		M		M	1993
Kalamazoo	56	MI390209	422258085235001	Gull Lake near Gull Lake, Mich. (S. B.)	–	–	2004		–	–	–	–
Kalamazoo	56	MI390540	420855085351501	Hogset Lake near Portage, Mich.	81	32	2005		M		M	1997
Kalamazoo	56	MI390264	421644085281401	Morrow Pond near East Comstock, Mich. (C. B.)	–	–	2004		–	–	–	–
Kalamazoo	56	MI390265	421655085292101	Morrow Pond near East Comstock, Mich. (W. B.)	1,001	8	2004		H		H	1993
Kalamazoo	56	MI390478	421524085205001	Portage Lake near Climax , Mich. (S. E. B.)	180	43	2005		M		M	1988
Kalamazoo	56	MI390479	421552085205001	Portage Lake near Climax, Mich. (N. E. B.)	–	–	2005		–	–	–	–
Kalamazoo	56	MI390519	422425085440101	Ruppert Lake near Otsego, Mich.	28	29	2004		M		M	1993
Kalamazoo	56	MI390382	422105085230501	Sherman Lake near Gull Lake, Mich.	153	36	2004		M		M	1993
Kalamazoo	56	MI390520	421836085212601	Whitford Lake near Augusta, Mich.	24	25	2004		M		M	1993
Kalkaska	50	MI400026	444333084562301	Bear Lake near Kalkaska, Mich.	316	60	2004		O		O	1995
Kalkaska	51	MI400032	443810085092601	East Lake near Lodi, Mich.	91	20	2004		E		E	1995
Kalkaska	50	MI400015	444828084554801	Indian Lake near Mancelona, Mich.	70	20	2004		O		O	1995
Kalkaska	50	MI400034	444635085005801	Manistee Lake near Kalkaska, Mich.	860	18	2004		M		M	1989
Kent	56	MI410437	430612085220201	Big Pine Island Lake near Grattan, Mich.	223	45	2003		E		E	1982
Kent	56	MI410436	431036085395801	Camp Lake near Sparta, Mich.	154	50	2003		M/E		M	1982
Kent	56	MI410273	425027085265801	Campau Lake near Alaska, Mich. (N. B.)	–	–	2003		–	–	–	–
Kent	56	MI410274	424958085270001	Campau Lake near Alaska, Mich. (S. B.)	125	50	2003		E		M	1982
Kent	56	MI410439	424839085253201	Campbell Lake near Alto, Mich.	60	60	2003		M		M	1982
Kent	56	MI410267	431432085213501	Lincoln Lake near Gowen, Mich.	411	67	2003		E	*	E	1991
Keweenaw	50	MI420028	472750087512301	Lake Fanny Hooe at Copper Harbor, Mich.	227	40	2001		O		O	2001
Keweenaw	50	MI420030	472156088071201	Lake Gratiot near Central, Mich.	1,438	70	2001		M		M	2001
Keweenaw	50	MI420029	472617087580501	Lake Medora near Copper Harbor, Mich.	696	30	2001		O		O	2001
Lake	50	MI430029	440528085584001	Big Bass Lake near Peacock, Mich.	290	45	2004		M		M	1993
Lake	50	MI430030	440807085583401	Harper Lake near Irons, Mich.	76	59	2004		M		M	1993
Lake	50	MI430032	435319085470101	Idlewild Lake near Idlewild, Mich.	105	22	2005		M		M	1993
Lake	50	MI430050	435127085584301	Reed Lake near Carr, Mich.	45	45	2005		O		O	1993
Lapeer	56	MI440105	425322083233001	Big Fish Lake near Ortonville, Mich.	105	70	2003		M		M	1982
Lapeer	56	MI440094	430044083222801	Lake Nepessing near Lapeer, Mich.	414	25	2003		E	*	E	1982
Lapeer	56	MI440103	431300083273201	Otter Lake at Otter Lake, Mich.	68	117	2003		M	*	E	1982

Appendix 1. List of Michigan lake basins sampled from 2001 through 2005. —Continued

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Leelanau	51	MI450066	445350085503401	Lime Lake near Maple City, Mich.	670	67	2003		O		O	1982
Leelanau	51	MI450070	445523085505501	Little Traverse Lake near Maple City, Mich.	640	54	2003		M		O	1982
Leelanau	51	MI450047	450226085434801	North Lake Leelanau at Leland, Mich.	2,950	121	2003		O		O	1988
Leelanau	51	MI450069	445447085525501	School Lake near Glen Arbor, Mich.	175	175	2003		M		M	1982
Leelanau	51	MI450048	445225085423801	South Lake Leelanau at Bingham, Mich.	5,370	62	2003		O/M		O	1982
Lenawee	56	MI460179	415916084171801	Devils Lake near Devils Lake, Mich. (N. B)	1,330	63	2005		M		M	1982
Lenawee	56	MI460181	415816084174001	Devils Lake near Devils Lake, Mich. (S. B.)	–	–	2005		–	–	–	–
Lenawee	55	MI460247	415002084152701	Lake Hudson near Clayton, Mich. (C. B.)	2,500	30	2003		H		H	1993
Lenawee	55	MI460248	414941084162401	Lake Hudson near Clayton, Mich. (W. B.)	–	–	2003		–	–	–	–
Lenawee	56	MI460249	420415084080001	Round Lake near Oak Shade Park, Mich.	67	67	2005		M		E	1988
Lenawee	56	MI460264	420252084082301	Sand Lake near Onsted, Mich.	440	53	2003		M		O	1982
Livingston	56	MI470204	423037083500701	Appleton Lake near Chilson, Mich.	56	36	2002		O		M	1982
Livingston	56	MI470134	423252083504101	East Crooked Lake near Chilson, Mich.	252	35	2002		M		M	1988
Livingston	56	MI470390	422544083592901	Hi-Land Lake near Pinckney, Mich.	123	12	2002		E		E	1988
Livingston	56	MI470094	423452083510001	Lake Chemung near Howell, Mich.	310	70	2005		M		E	1997
Livingston	56	MI470096	423651083545801	Thompson Lake near Howell, Mich.	262	55	2005		M		M	1993
Luce	50	MI480019	462755085430001	Bass Lake near McMillan, Mich.	145	74	2004		M		M	1982
Luce	50	MI480013	464142085210301	Culhane Lake near Paradise, Mich.	97	49	2004		M		E	1997
Luce	50	MI480020	461806085342401	Kaks Lake near Watsons Corner, Mich.	60	22	2004		E	*	E	1982
Luce	50	MI480011	463954085375601	Muskallonge Lake near Deer Park, Mich.	786	20	2005		E	*	M	1988
Luce	50	MI480010	461651085441701	North Manistique Lake near Carpenter Landing, Mich.	1,722	50	2004		O		O	1988
Luce	50	MI480018	463847085242301	Pike Lake near Deer Park, Mich.	292	43	2004		M		M	1982
Mackinac	50	MI490033	461400085451501	Manistique Lake near Curtis, Mich.	10,131	20	2004		M		M	1988
Mackinac	50	MI490035	460412085474101	Milakokia Lake near Gould City, Mich.	1,956	25	2004		M		M	1988
Mackinac	50	MI490037	460919085302401	Millecoquins Lake near Millecoquins, Mich.	1,062	12	2004		M		M	1993
Mackinac	50	MI490034	461157085443701	South Manistique Lake near Curtis, Mich.	4,001	29	2004		M		E	1993
Manistee	51	MI510174	442921086142501	Arcadia Lake at Arcadia, Mich.	275	31	2004		M		M	1982
Manistee	56	MI510191	441237086191701	Canfield Lake near Manistee, Mich.	29	29	2004		M		M	1997
Manistee	51	MI510189	442606085595701	Healy Lake near Lemon, Mich.	39	50	2004		E		E	1991

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County	Omernik level III ecoregion	USEPA STORET number	USGS station number	Lake Basin name	Lake area (acres)	Maximum lake depth (feet)	Year sampled	pH < 6.5	2001–2005 TSI class	Adjusted TSI class	Historical TSI class	Historical assessment date
Manistee	56	MI510091	441438086181201	Manistee Lake at Manistee, Mich.	930	50	2004		E	*	E	1993
Marquette	50	MI520147	461540087221801	Bass Lake near New Swanzy, Mich.	77	77	2005		O		M	1989
Marquette	50	MI520126	461545087352601	Bass Lake near Princeton, Mich.	271	23	2005		E		M	1989
Marquette	50	MI520205	463357087341801	Dead River Storage Basin near Negaunee, Mich.	2,704	59	2001	**	M		M	2001
Marquette	50	MI520207	462636087485701	Greenwood Reservoir near Greenwood, Mich.	1,400	38	2005		M		M	1993
Marquette	50	MI520208	461645088025001	Horseshoe lake near Witch Lake, Mich.	123	10	2002		M		M	1982
Marquette	50	MI520204	463745088032801	Lake Arfelin near Michigamme, Mich.	66	35	2002		O		O	1993
Marquette	50	MI520094	463131088020501	Lake Michigamme near Champion, Mich. (E. B.)	4,260	70	2002		M		O	1993
Marquette	50	MI520095	463032088025601	Lake Michigamme near Champion, Mich. (S. B)	–	–	2002		–	–	–	–
Marquette	50	MI520150	463154088040301	Lake Michigamme near Champion, Mich. (W. B.)	–	–	2002		–	–	–	–
Marquette	50	MI520212	461529087293601	Little Shag Lake near Princeton, Mich.	103	35	2005		O		O	1982
Marquette	50	MI520217	463308087311201	McClure Storage Basin near Marquette, Mich.	132	48	2001		M		M	2001
Marquette	50	MI520200	461600087342401	Pike Lake near Princeton, Mich.	88	37	2005		O		M	1982
Marquette	50	MI520213	461955087201501	Sporley Lake near Little Lake, Mich.	76	42	2005		M		M	1993
Marquette	50	MI520156	461645088001201	Witch Lake at Witch Lake, Mich.	211	90	2002		O		M	1997
Marquette	50	MI520214	463524087534801	Wolf Lake near Champion, Mich.	124	13	2005	**	M		M	1993
Mason	56	MI530104	440456086102901	Gun Lake near Fountain, Mich.	219	20	2004		M		M	1982
Mason	56	MI530142	435859086194001	Hackert Lake near Scottville, Mich.	125	52	2004		M		M	1997
Mason	56	MI530144	435138086144501	Pleiness Lake near Wiley, Mich.	81	38	2005		E	*	E	1982
Mecosta	56	MI540074	434342085222501	Bergess Lake near Big Rapids, Mich.	60	45	2001		M		M	2001
Mecosta	56	MI540092	433717085165901	Blue Lake near Mecosta, Mich.	235	50	2001		O		O	2001
Mecosta	56	MI540050	434539085173101	Chippewa Lake at Chippewa Lake, Mich.	791	40	2002		E		E	1988
Mecosta	56	MI540072	434205085161301	Jehnsen Lake near Mecosta, Mich.	270	18	2001		M		M	2001
Mecosta	56	MI540057	433700085174701	Lake Mecosta near Mecosta, Mich. (N. B.)	297	37	2001		M		M	2001
Mecosta	56	MI540056	433621085174001	Lake Mecosta near Mecosta, Mich. (S. B.)	–	–	2001		–	–	–	–
Mecosta	56	MI540074	434339085135701	Martiny Lake near Chippewa Lake, Mich. (N. C. B.)	1,420	47	2002		E		M	2001
Mecosta	56	MI540077	434248085122001	Martiny Lake near Chippewa Lake, Mich. (S. E. B.)	–	–	2002		–	–	–	–
Mecosta	56	MI540079	434146085140001	Pretty Lake near Mecosta, Mich.	121	22	2002		M	*	M	1993
Mecosta	56	MI540081	434308085262501	Townline Lake near Big Rapids, Mich.	73	52	2001		M		M	2001
Missaukee	50	MI570017	442113085145301	Goose Lake near Lake City, Mich.	100	14	2001		M		M	2001

Appendix 1. List of Michigan lake basins sampled from 2001 through 2005. —Continued

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County	Omernik level III ecoregion	USEPA STORET number	USGS station number	Lake Basin name	Lake area (acres)	Maximum lake depth (feet)	Year sampled	pH < 6.5	2001–2005 TSI class	Adjusted TSI class	Historical TSI class	Historical assessment date
Missaukee	50	MI570015	441900085160801	Lake Sapphire near Lake City, Mich.	264	8	2001		M		M	2001
Montcalm	56	MI590171	430952085160201	Baldwin Lake at Greenville, Mich.	72	35	2003		M		M	1982
Montcalm	56	MI590142	431844085114501	Clifford Lake near Langston, Mich. (N. B.)	200	45	2003		M		M	1989
Montcalm	56	MI590141	431818085110201	Clifford Lake near Langston, Mich. (S. B.)	–	–	2003		–	–	–	–
Montcalm	56	MI590105	431547084561801	Crystal Lake at Crystal, Mich. (C. B.)	724	70	2002		M		M	1997
Montcalm	56	MI590106	431521084560101	Crystal Lake at Crystal, Mich. (S. B.)	–	–	2002		–	–	–	–
Montcalm	56	MI590179	432259085113001	Lake Montcalm near Six Lakes, Mich.	68	67	2003		M		M	1982
Montcalm	56	MI590146	432125085320701	Little Whitefish Lake near Pierson, Mich.	181	40	2001		E	*	E	2001
Montcalm	56	MI590172	431940085181401	Rainbow Lake near Trufant, Mich.	155	22	2003		M		E	1982
Montcalm	56	MI590107	432715085120601	Townline Lake near Six Lakes, Mich.	247	49	2003		M		E	1982
Montcalm	56	MI590131	431929085321201	Whitefish Lake near Pierson, Mich. (S. E. B.)	501	54	2001		M		M	2001
Montcalm	56	MI590132	431938085325201	Whitefish Lake near Pierson, Mich. (S. W.)	–	–	2001		–	–	–	–
Montcalm	56	MI590130	432301085221401	Winfield Lake near Howard City, Mich.	121	50	2001		M		M	2001
Montmorency	50	MI600023	445621084111901	Avery Lake near Lewiston, Mich. (N .B.)	180	78	2005		O		O	1982
Montmorency	50	MI600024	445547084113501	Avery Lake near Lewiston, Mich. (S. B.)	–	–	2005		–	–	–	–
Montmorency	50	MI600020	450734084104901	Clear Lake near Atlanta, Mich.	133	90	2005		O		M	1982
Montmorency	50	MI600013	445157084183601	East Twin Lake at Lewiston, Mich.	974	20	2002		M		M	2001
Montmorency	50	MI600019	450651083585201	Ess Lake near Hillman, Mich.	113	51	2005		O		O	1982
Montmorency	50	MI600025	450750083583001	Long Lake near Hillman, Mich. (C. B.)	294	80	2005		O		O	1991
Montmorency	50	MI600026	450640083582001	Long Lake near Hillman, Mich. (S. B.)	–	–	2005		–	–	–	–
Montmorency	50	MI600031	445735084145801	McCormick Lake near Bigelow, Mich.	100	78	2005		O		O	1982
Montmorency	50	MI600029	450711084054801	Rush Lake near Hillman, Mich.	224	18	2005		M		M	1982
Montmorency	50	MI600030	445330084090901	Sage Lake near Lewiston, Mich.	51	36	2005		M	*	M	1982
Montmorency	50	MI600014	445235084201001	West Twin Lake at Vienna Junction, Mich.	1,327	30	2002		M		M	1991
Muskegon	56	MI610358	431452086173501	Bear Lake at North Muskegon, Mich.	415	12	2001		H		H	2001
Muskegon	56	MI610253	432015086233001	Duck Lake near Whitehall, Mich. (E. B.)	313	65	2001		M		M	2001
Muskegon	56	MI610278	432028086241801	Duck Lake near Whitehall, Mich. (W. B.)	–	–	2001		–	–	–	–
Muskegon	56	MI610407	432208086103101	East Twin lake at Twin Lake, Mich.	111	19	2001		M		E	1988
Muskegon	56	MI610321	432247086143301	Fox Lake at Lakewood, Mich.	80	3	2002		H		E	1982
Muskegon	56	MI610225	431045086153701	Mona Lake near Norton Shores, Mich. (C. B.)	695	42	2004		E		H	1993

Appendix 1. List of Michigan lake basins sampled from 2001 through 2005. —Continued

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County	Omernik level III ecoregion	USEPA STORET number	USGS station number	Lake Basin name	Lake area (acres)	Maximum lake depth (feet)	Year sampled	pH < 6.5	2001–2005 TSI class	Adjusted TSI class	Historical TSI class	Historical assessment date
Muskegon	56	MI610226	431025086165101	Mona Lake near Norton Shores, Mich. (W. B.)	–	–	2004		–	–	–	–
Newaygo	56	MI620188	434014085532301	Benton Lake near Woodland Park, Mich.	33	14	2005		E		M	1995
Newaygo	56	MI620062	432338085393501	Bills Lake near Newaygo, Mich.	204	90	2003		O		O	1995
Newaygo	56	MI620058	432028085481201	Blanch Lake at Grant, Mich.	63	18	2001		E		E	2001
Newaygo	56	MI620064	432631085395801	Croton Dam Pond at Croton, Mich.	1,235	40	2001		M		M	2001
Newaygo	56	MI620106	433026085515001	Crystal Lake near Wooster, Mich.	125	61	2002		O		M	1982
Newaygo	56	MI620065	432925085373901	Hardy Dam Pond near Oxbow, Mich.	3,750	110	2001		M		M	2001
Newaygo	50	MI620060	434344085543001	Nichols Lake near Woodland Park, Mich.	160	55	2005		M		O	1997
Newaygo	50	MI620189	434621085483801	Pettibone Lake near Lilley, Mich.	44	40	2005		M		M	1995
Newaygo	56	MI620061	433155085512201	Robinson Lake at Jugville, Mich.	137	30	2002		E		M	1995
Newaygo	56	MI620040	431934085543801	Sand Lake near Bridgeton, Mich.	58	15	2001		M		M	2001
Newaygo	50	MI620190	434229085510701	Woodland Lake near Woodland Park, Mich. (E. B.)	203	51	2005		M		M	1995
Newaygo	50	MI620192	434232085515001	Woodland Lake near Woodland Park, Mich. (N. B.)	–	–	2005		–	–	–	–
Newaygo	50	MI620191	434218085515301	Woodland Lake near Woodland Park, Mich. (S. B.)	–	–	2005		–	–	–	–
Oakland	56	MI630746	424306083314201	Big Lake at Andersonville, Mich. (W. B.)	215	14	2002		E		E	1989
Oakland	56	MI630745	424313083312001	Big Lake at Andersonville, Mich. (W. C. B.)	–	–	2002		–	–	–	–
Oakland	56	MI630543	423643083213801	Cass Lake near Pontiac, Mich. (C. B.)	–	–	2004		–	–	–	–
Oakland	56	MI630547	423716083213501	Cass Lake near Pontiac, Mich. (N. E. B.)	–	–	2004		–	–	–	–
Oakland	56	MI630542	423611083221601	Cass Lake near Pontiac, Mich. (S. C. B.)	1,281	125	2004		M		M	1993
Oakland	56	MI630537	423559083233801	Cass Lake near Pontiac, Mich. (W. B.)	–	–	2004		–	–	–	–
Oakland	56	MI630563	423843083232601	Crescent Lake near Pontiac, Mich. (N. B.)	90	40	2004		E	*	E	1982
Oakland	56	MI630562	423822083230601	Crescent Lake near Pontiac, Mich. (S. B.)	–	–	2004		–	–	–	–
Oakland	56	MI630708	424350083255101	Deer Lake near Clarkston, Mich.	137	63	2004		O		M	1982
Oakland	56	MI630842	424830083311801	Heron Lake near Holly, Mich.	132	40	2003		M		E	1989
Oakland	56	MI630534	423133083400101	Kent Lake near New Hudson, Mich.	1,000	35	2002		E		H	1991
Oakland	56	MI630681	424202083213701	Lake Oakland near Drayton Plains, Mich.	255	64	2004		M		E	1982
Oakland	56	MI630670	424945083090701	Lakeville Lake near Lakeville, Mich. (C. B.)	460	66	2004		E	*	E	1988
Oakland	56	MI630671	424952083084301	Lakeville Lake near Lakeville, Mich. (E. B.)	–	–	2004		–	–	–	–
Oakland	56	MI630414	424134083251101	Lotus Lake near Waterford, Mich.	419	65	2004		O/M	*	M	1997
Oakland	56	MI630706	423730083363401	Lower Pettibone Lake near Highland, Mich.	89	41	2002		M		M	1997

Appendix 1. List of Michigan lake basins sampled from 2001 through 2005. —Continued

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County	Omernik level III ecoregion	USEPA STORET number	USGS station number	Lake Basin name	Lake area (acres)	Maximum lake depth (feet)	Year sampled	pH < 6.5	2001–2005 TSI class	Adjusted TSI class	Historical TSI class	Historical assessment date
Oakland	56	MI630415	424114083254801	Maceday Lake near Waterford, Mich.	234	117	2004		O/M	*	M	1993
Oakland	56	MI630583	423500083215701	Orchard Lake near Orchard Lake Village, Mich.	788	111	2004		O		M	1991
Oakland	56	MI630421	423626083260201	Union Lake at Union Lake, Mich. (C .B.)	465	110	2002		O/M		M	1988
Oakland	56	MI630423	423607083252601	Union Lake at Union Lake, Mich. (S. E. B.)	–	–	2002		–	–	–	–
Oakland	56	MI630422	423609083263001	Union Lake at Union Lake, Mich. (S. W. B.)	–	–	2002		–	–	–	–
Oceana	56	MI540065	434652086054501	School Section Lake near Colfax, Mich.	182	26	2005		M		M	1982
Oceana	56	MI640034	434022086301001	Silver Lake near Mears, Mich.	690	22	2005		E		E	1989
Ogemaw	56	MI650054	441133084020701	Bush Lake near Skidway Lake, Mich.	51	35	2004		M		M	1982
Ogemaw	50	MI650044	442409084012701	Devoe Lake near Lupton, Mich. (C. B.)	130	53	2004		M		O	1997
Ogemaw	50	MI650043	442404084014601	Devoe Lake near Lupton, Mich. (W. B.)	–	–	2004		–	–	–	–
Ogemaw	50	MI650046	442439084011401	Grousehaven Lake near Lupton, Mich.	95	54	2004		O/M		O	1997
Ogemaw	56	MI650032	441447083593201	Hardwood Lake near Prescott, Mich.	172	35	2004		H		H	1993
Ogemaw	56	MI650053	441229084144901	Lake George near West Branch, Mich.	89	70	2002		M		O	1982
Ogemaw	56	MI650033	441742084095501	Peach Lake near West Branch, Mich.	208	74	2004		E	*	M	1982
Ogemaw	50	MI650023	442430083584301	Rifle Lake near Shady Shores, Mich. (S. B.)	183	70	2004		O		M	1993
Ogemaw	50	MI650022	442458083584401	Rifle Lake near Shady Shores, Mich. (N .B.)	–	–	2004		–	–	–	–
Ogemaw	56	MI650062	441224084210301	Tee Lake near West Branch, Mich.	33	62	2002		M		M	1993
Ontonagon	50	MI660076	462358089065001	Bond Falls Flowage near Paulding, Mich.	2,118	28	2003		M		M	1982
Ontonagon	50	MI660077	462002089162101	County Line Lake near Paulding, Mich.	65	51	2003		O		M	1995
Osceola	56	MI670056	435201085115701	Big Lake near Evart, Mich. (C. B.)	204	85	2001		M		M	2001
Osceola	56	MI670057	435154085115801	Big Lake near Evart, Mich. (S.W. B.)	–	–	2001		–	–	–	–
Osceola	56	MI670066	440513085290701	Diamond Lake near Tustin, Mich.	61	60	2004		M		E	1993
Osceola	56	MI670062	440123085170301	Hicks Lake near Leroy, Mich.	155	33	2001		E		E	2001
Osceola	56	MI670058	440356085224201	Rose Lake near Tustin, Mich. (E. B.)	370	30	2004		E		E	1989
Osceola	56	MI670059	440340085233201	Rose Lake near Tustin, Mich. (W. B.)	–	–	2004		–	–	–	–
Osceola	56	MI670067	440146085193801	Sunrise Lake near Leroy, Mich.	80	66	2001		O		O	2001
Otsego	50	MI690049	445955084380601	Dixon Lake near Gaylord, Mich.	80	35	2002		O		M	1982
Otsego	50	MI690051	445622084361601	Emerald Lake near Arbutus Beach, Mich.	63	35	2002		M		M	1982
Otsego	50	MI690065	445328084413201	Heart Lake near Waters, Mich.	63	123	2002		O		M	1982
Otsego	51	MI690131	450252084470701	Lake 27 near Elmira, Mich.	112	22	2003		M		M	1991

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County	Omernik level III ecoregion	USEPA STORET number	USGS station number	Lake Basin name	Lake area (acres)	Maximum lake depth (feet)	Year sampled	pH < 6.5	2001–2005 TSI class	Adjusted TSI class	Historical TSI class	Historical assessment date
Otsego	50	MI690129	445531084363801	Opal Lake near Otsego Lake, Mich.	122	39	2002		O		O	1991
Otsego	50	MI690132	451035084312201	Pickerel Lake near Vanderbilt, Mich.	43	33	2005		M		O	1991
Ottawa	56	MI700422	430957085512301	Crockery Lake near Gooding, Mich.	108	54	2004		E		E	1997
Presque Isle	50	MIZ10074	451519083565801	Lake May near Hawks, Mich.	161	161	2005		E		M	1991
Presque Isle	50	MI710057	451728083591301	Lake Nettie near Millersburg, Mich. (E. B.)	278	46	2005		M		M	1982
Presque Isle	50	MI710056	451801083595201	Lake Nettie near Millersburg, Mich. (W. B.)	–	–	2005		–	–	–	–
Presque Isle	50	MI710034	451303083290201	Long Lake near Leroy, Mich.	5,652	25	2005		M		M	1982
Presque Isle	50	MI710058	451733083575801	Lost Lake near Hawks, Mich.	104	17	2005		M		M	1982
Presque Isle	50	MI710075	451432084102801	Shoepac Lake near Millersburg, Mich.	45	94	2005		O		O	1997
Presque Isle	50	MI710060	451237083432301	Sunken Lake near Posen, Mich.	50	21	2005		E		E	1982
Presque Isle	50	MI710076	451346084094801	Tomahawk Lake near Millersburg, Mich.	40	32	2005		M		O	1991
Roscommon	50	MI720028	442655084405601	Higgins Lake near Roscommon, Mich. (E. B.)	9,600	135	2001		O		O	2001
Roscommon	50	MI720057	442939084453801	Higgins Lake near Roscommon, Mich. (N. W. B.)	–	–	2001		–	–	–	–
Roscommon	50	MI720026	442832084453401	Higgins Lake near Roscommon, Mich. (S. W. B.)	–	–	2001		–	–	–	–
Schoolcraft	50	MI770059	461604086264301	Boot Lake near Shingleton, Mich.	108	30	2004		E		M	1982
Schoolcraft	50	MI770037	460649086155501	Dodge Lake near Hiawatha, Mich. (E .B.)	88	51	2004		M		O	1982
Schoolcraft	50	MI770036	460648086162101	Dodge Lake near Hiawatha, Mich. (W. B.)	–	–	2004		–	–	–	–
Schoolcraft	50	MI770033	455850086012601	Gulliver Lake near Gulliver, Mich.	836	22	2004		M		M	1988
Schoolcraft	50	MI770060	460701086163801	Island Lake near Hiawatha, Mich.	106	30	2004		O		O	1982
Schoolcraft	50	MI770070	461324086361501	Petes Lake near Wetmore, Mich.	194	37	2004		O		M	1982
Schoolcraft	50	MI770038	462851086153301	Ross Lake near Seney, Mich.	196	19	2004		M		M	1982
Schoolcraft	50	MI770071	462909085565201	Snyder Lake near Seney, Mich.	60	17	2004		M		M	1982
St Joseph	56	MI750136	414810085323801	Klinger Lake near Klingers, Mich.	830	72	2005		M		M	1982
St Joseph	56	MI750245	420241085305701	Portage Lake near Mendon, Mich.	510	60	2005		E		E	1997
St Joseph	56	MI750161	415454085271601	Sand Lake near Nottawa, Mich.	120	22	2005		E		E	1995
St Joseph	56	MI750162	415810085194301	Sturgeon Lake near Colon, Mich.	250	24	2005		E		E	1989
Van Buren	56	MI800269	421356085524001	Ackley Lake near Paw Paw, Mich.	65	16	2001		M		M	2001
Van Buren	56	MI800241	420520085494201	Cedar Lake near Marcellus, Mich.	269	84	2001		M		M	2001
Van Buren	56	MI800461	421928085482601	Fish Lake near Pine Grove, Mich.	34	27	2001		E	*	E	2001
Van Buren	56	MI800271	420442085515901	Gravel Lake near Marcellus, Mich.	296	31	2001		O		O	2001

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County	Omernik level III ecoregion	USEPA STORET number	USGS station number	Lake Basin name	Lake area (acres)	Maximum lake depth (feet)	Year sampled	pH < 6.5	2001–2005 TSI class	Adjusted TSI class	Historical TSI class	Historical assessment date
Van Buren	56	MI800272	420800085492001	Huzzy Lake near Lawton, Mich.	80	34	2005		E		E	1982
Van Buren	56	MI800253	421437086122201	Rush Lake near Hartford, Mich.	118	58	2001		E	*	E	2001
Van Buren	56	MI800150	422241086025201	Saddle Lake near Breedsville, Mich.	298	32	2002		E		M	1982
Van Buren	56	MI800256	421139086061101	Shafer Lake near Hartford, Mich.	81	72	2001		M		M	2001
Van Buren	56	MI800255	421927086001701	South Scott Lake near Bangor, Mich.	124	55	2002		M		M	1988
Van Buren	56	MI800460	422355085550801	Three Legged Lake near Paw Paw, Mich.	40	20	2004		E		E	1997
Van Buren	56	MI800273	422058086003801	Upper Jeptha Lake near Breedsville, Mich.	57	42	2002		M		M	1982
Washtenaw	56	MI810330	421855084045001	Cedar Lake near Guthrie, Mich.	73	27	2002		M		E	1982
Washtenaw	56	MI810339	422201084042101	Green Lake near Lyndon Center, Mich.	90	11	2002		E	*	E	1982
Washtenaw	56	MI810337	421931084052601	Mill Lake near Guthrie, Mich.	142	25	2002		E	*	M	1982
Washtenaw	56	MI810335	422053084073901	Mud Lake near Brooklyn, Mich.	92	7	2001		E	*	E	2001
Washtenaw	56	MI810276	422336084002901	North Lake near Chalkerville, Mich.	227	58	2002		M	*	M	1982
Wayne	56	MI821086	421257083272401	Belleville Lake near French Landing, Mich. (2nd E. B.)	1,270	16	2002		E		H	1993
Wayne	56	MI821409	421253083263801	Belleville Lake near French Landing, Mich. (E. B.)	–	–	2002		–	–	–	–
Wayne	56	MI820790	421252083273501	Belleville Lake near French Landing, Mich. (East)	–	–	2002		–	–	–	–
Wayne	56	MI821228	422154083244701	Newburgh Lake near Livonia, Mich.	100	9	2005		E		H	1993
Wexford	50	MI830074	441930085221001	Long Lake near Cadillac, Mich.	190	8	2001		E		E	2001

Appendix 2. Rationale for treatment of censored data

Censored data—those reported as “nondetect” or “less than (<)”—are problematic for statistical analyses because they do not represent reliable quantitative measurements. An inventory of the nondetect and less-than values for each constituent examined in the datasets for this report is presented in table 2–1. Various methods of handling censored data have been developed to enable computation of summary statistics, among which is the adjusted maximum likelihood described by Helsel and Cohn (1988).

Even though summary statistics could be estimated with the adjusted maximum likelihood method, some of the additional statistical comparisons presented in this report require exact values to be entered for the nondetect and less-than data. Two approaches for substituting values for censored data are (1) entering zero or (2) entering the detection limit. Neither approach is ideal because each can affect the resulting statistical distribution in different ways; specifically, if zero is entered for nondetect and less-than data, the median and mean will be lower than if the detection limit is entered.

To examine the magnitude of differences in using one approach or the other with the Michigan inland-lake datasets, both approaches were tried and comparable sets of basic summary statistics computed for constituents where more than 5 percent of the data were nondetects or less-than values. Results of the comparison are given in table 2–2. For each constituent, variations in summary statistics for the two approaches were noted, especially between the mean values; but generally, the differences in the summary statistics were slight. It was ultimately decided to use a compromise approach, entering zero for nondetect data and the detection limit for less-than data.

Table 2–1. Percentages of values for each constituent in the 2001–2005 Michigan lakes dataset that were nondetects and less-than values.

[N, number of lake-basin samples; ND, number of lake-basin samples with nondetect values; <, number of lake basin samples with less-than values]

Constituent	N	ND	<	Percent
Summer photic zone				
Chlorophyll *a*	432	12	9	4.9
Summer near surface				
Secchi-disk transparency	421	0	0	.0
Ammonia + Organic Nitrogen	433	0	5	1.2
Ammonia	348	3	45	13.8
Nitrite + Nitrate	433	37	168	47.3
Phosphorus	431	2	13	3.5
Spring mid-depth				
Hardness	432	6	2	1.9
Calcium	432	0	0	.0
Magnesium	432	12	7	4.4
Potassium	432	0	0	.0
Sodium	431	37	13	11.6
Alkalinity	430	19	9	6.5
Chloride	429	17	0	4.0
Sulfate	430	29	14	10.0
Ammonia + Organic Nitrogen	432	0	9	2.1
Ammonia	387	1	18	4.9
Nitrite + Nitrate	431	9	5	3.2
Phosphorus	432	7	13	4.6

Table 2-2. Comparative statistical summaries of Michigan lake-basin data resulting from two censored-data treatments.

[mg/L, milligrams per liter; N, number of lake-basin samples; Min, minimum; Qu., quartile; Max, maximum; Std, Standard; Dev, deviation; *, zero entered for all nondetect and less-than values; **, detection limit entered for all nondetect and less-than values]

Constituent	Unit	N	Min	1st Qu.	Mean	Median	3rd Qu.	Max	Std Dev
Summer near surface									
Ammonia*	mg/L	348	0.000	0.004	0.027	0.010	0.034	0.640	0.062
Ammonia**	mg/L	348	.001	.006	.028	.010	.034	.640	.061
Nitrite + Nitrate*	mg/L	433	.000	.000	.054	.001	.007	3.100	.242
Nitrite + Nitrate**	mg/L	433	.001	.006	.059	.010	.010	3.100	.241
Spring mid-depth									
Sodium*	mg/L	431	.0	2.3	8.7	4.8	8.1	136.0	14.4
Sodium**	mg/L	431	1.0	2.3	8.8	4.8	8.1	136.0	14.3
Alkalinity*	mg/L	430	.0	67.5	107.9	116.0	147.5	246.0	56.5
Alkalinity**	mg/L	430	20.0	67.5	109.2	116.0	147.5	246.0	54.2
Sulfate*	mg/L	432	.0	2.0	11.13	5.0	15.0	142.0	14.7
Sulfate**	mg/L	432	2.0	2.0	11.33	5.0	15.0	142.0	14.6

References Cited

Helsel, D.R., and Cohn, T.A., 1988, Estimation of descriptive statistics for multiply censored water quality data: Water Resources Research, v. 24, no. 12, p. 1997–2004.

Appendix 3. Water-quality constituents in Michigan lake basins from 2001 through 2005

(Helsel and Cohn (1988) adjusted maximum likelihood was used to create summary statistics for constituents with greater than 5 percent of the data with nondetect and less-than values; otherwise, zero was used for all nondetect values, and the detection limit was used for all less-than values.)

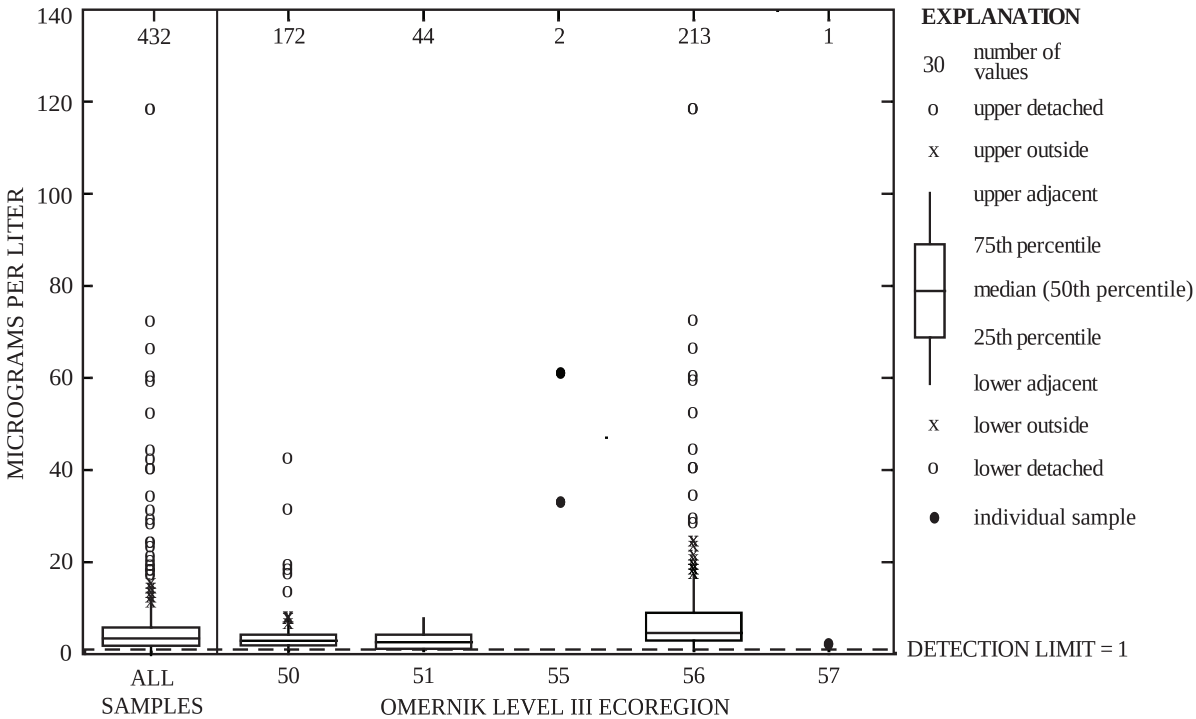

Figure 3–1. Distribution of chlorophyll *a* from the summer photic zone in Michigan lake basins for years 2001 through 2005.

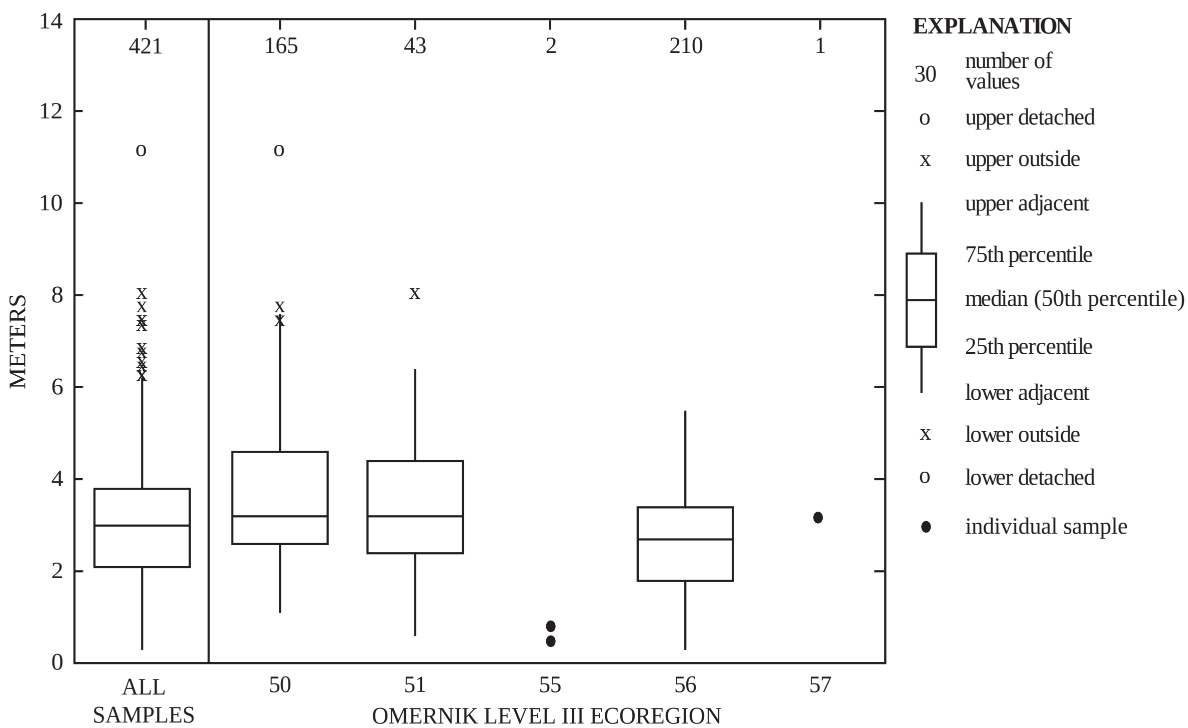

Figure 3–2. Distribution of Secchi-disk transparency from the summer near surface in Michigan lake basins for years 2001 through 2005.

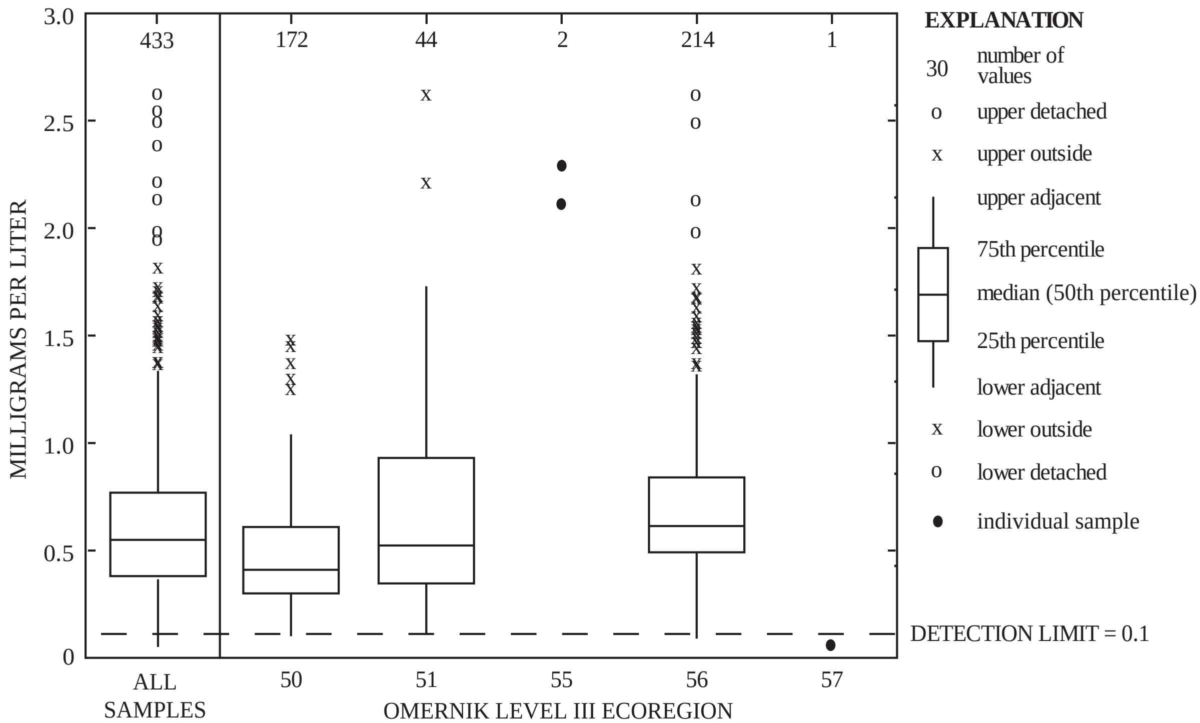

Figure 3–3. Distribution of ammonia plus organic nitrogen from the summer near surface in Michigan lake basins for years 2001 through 2005.

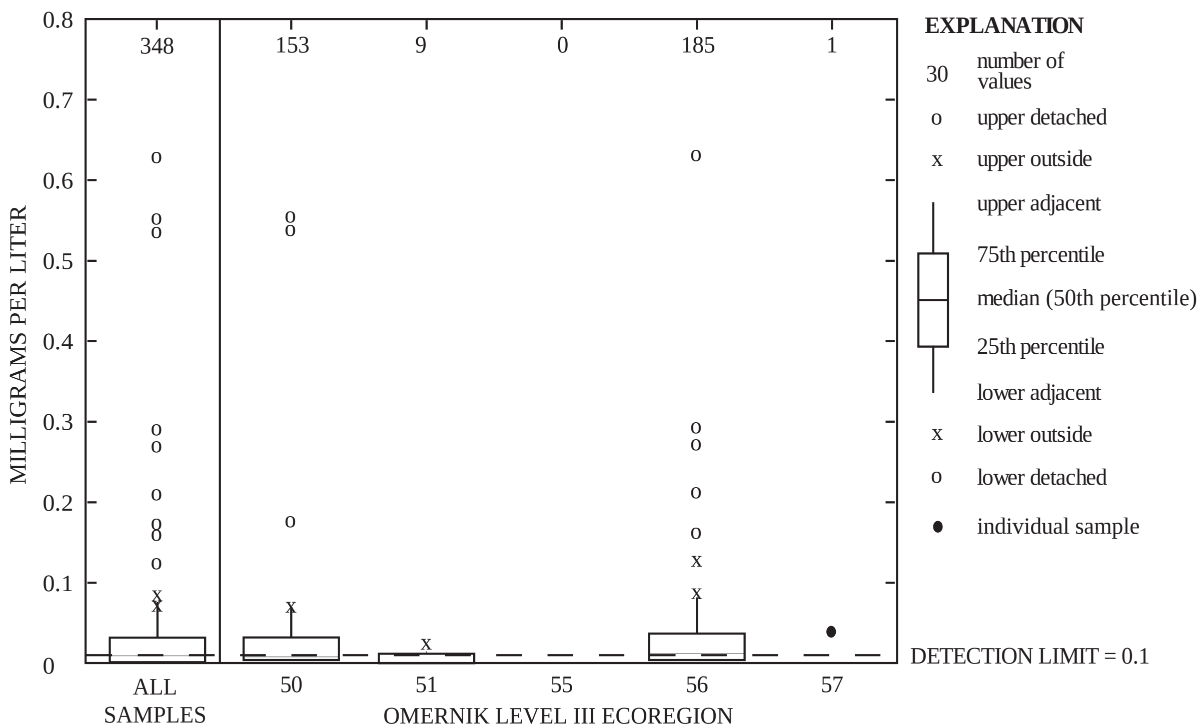

Figure 3–4. Distribution of ammonia from the summer near surface in Michigan lake basins for years 2001 through 2005.

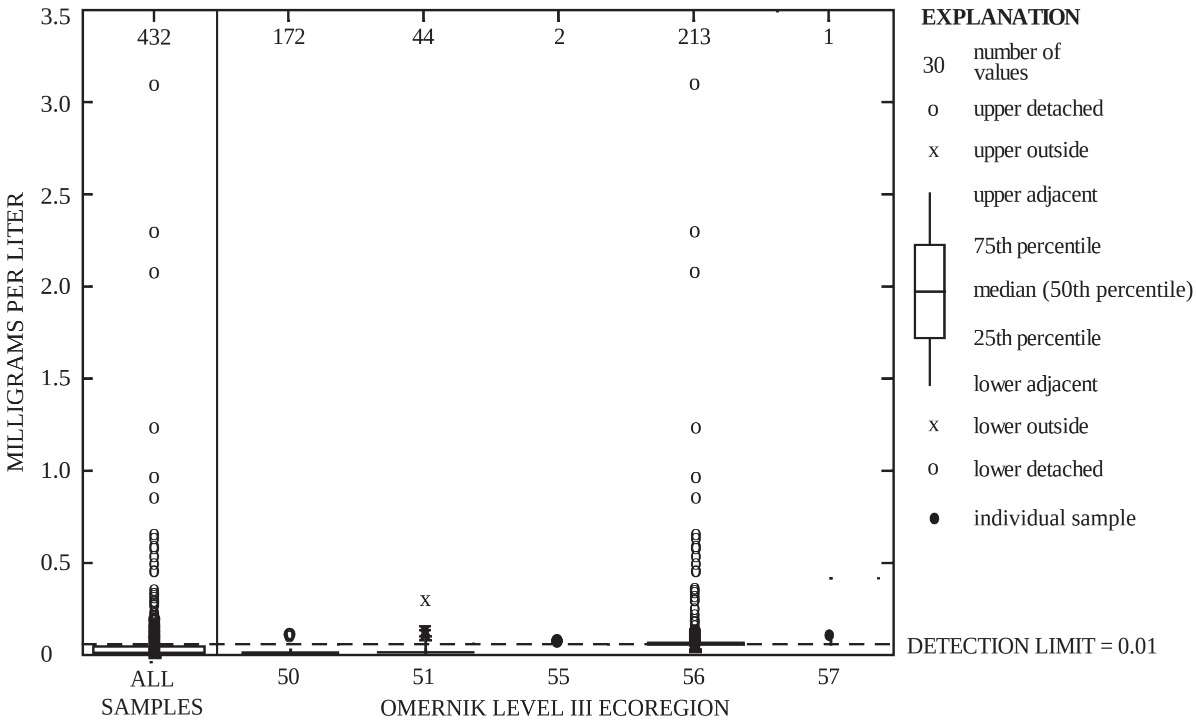

Figure 3–5. Distribution of nitrite plus nitrate from the summer near surface in Michigan lake basins for years 2001 through 2005.

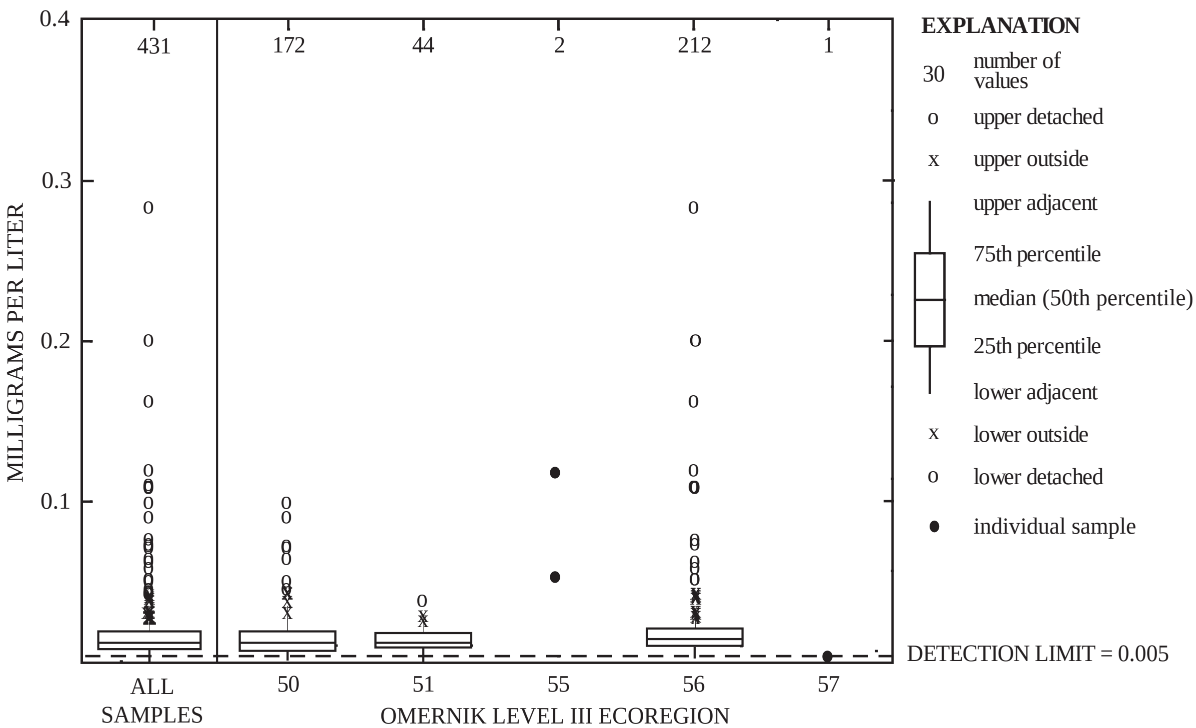

Figure 3–6. Distribution of phosphorus from the summer near surface in Michigan lake basins for years 2001 through 2005.

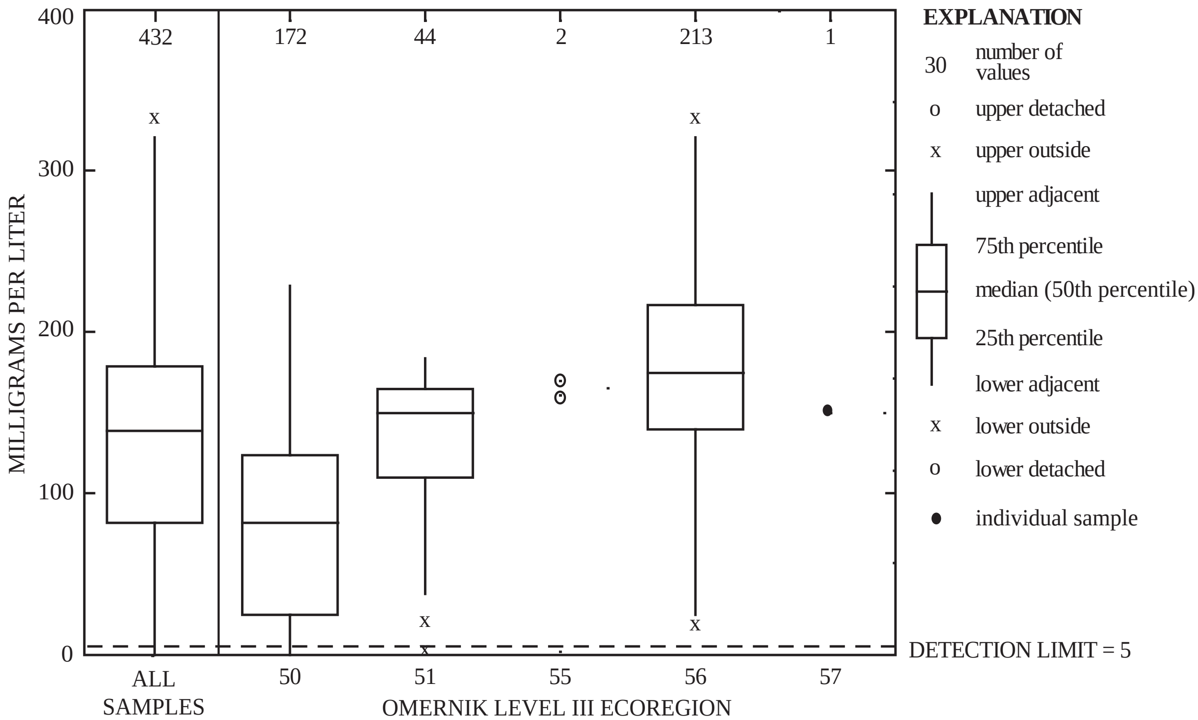

Figure 3–7. Distribution of hardness from the spring mid-depth in Michigan lake basins for years 2001 through 2005.

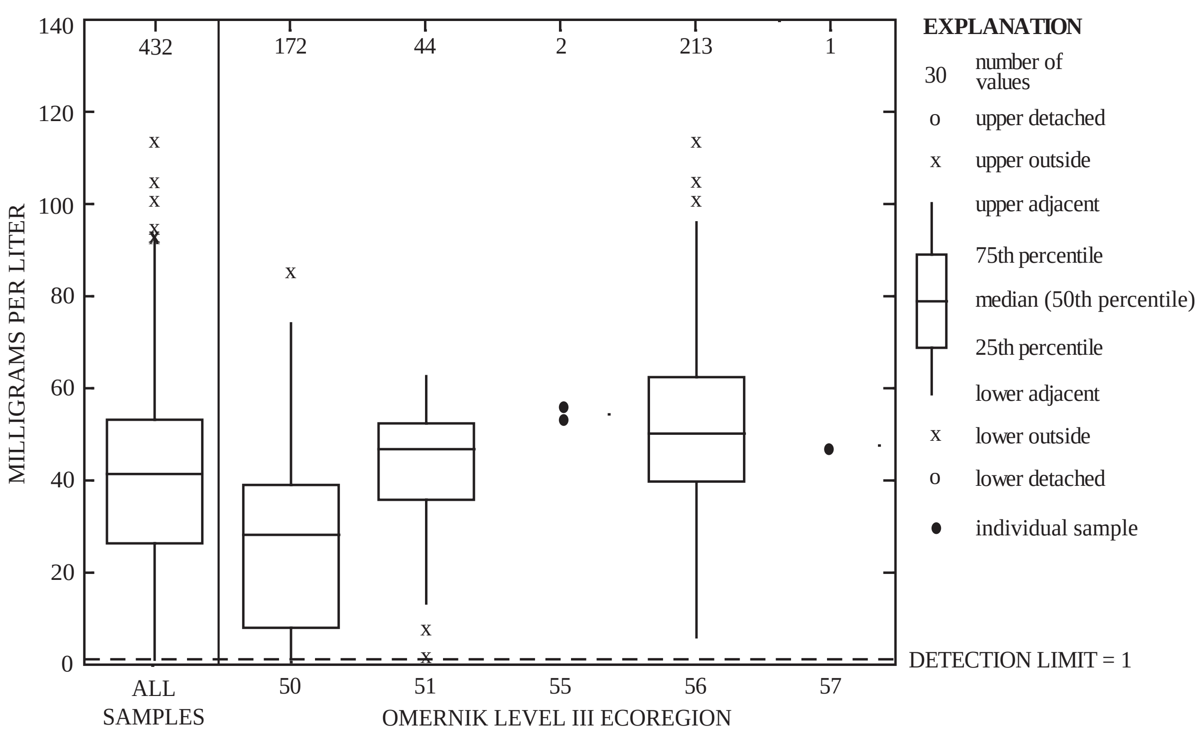

Figure 3–8. Distribution of calcium from the spring mid-depth in Michigan lake basins for years 2001 through 2005.

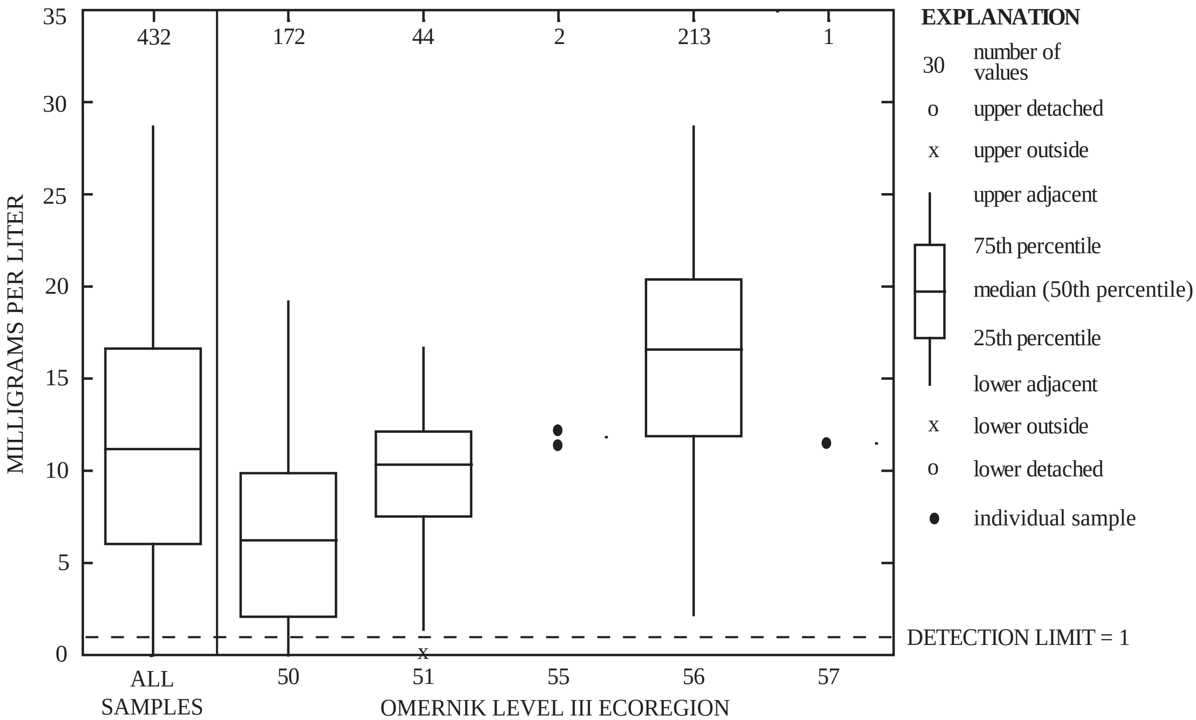

Figure 3–9. Distribution of magnesium from the spring mid-depth in Michigan lake basins for years 2001 through 2005.

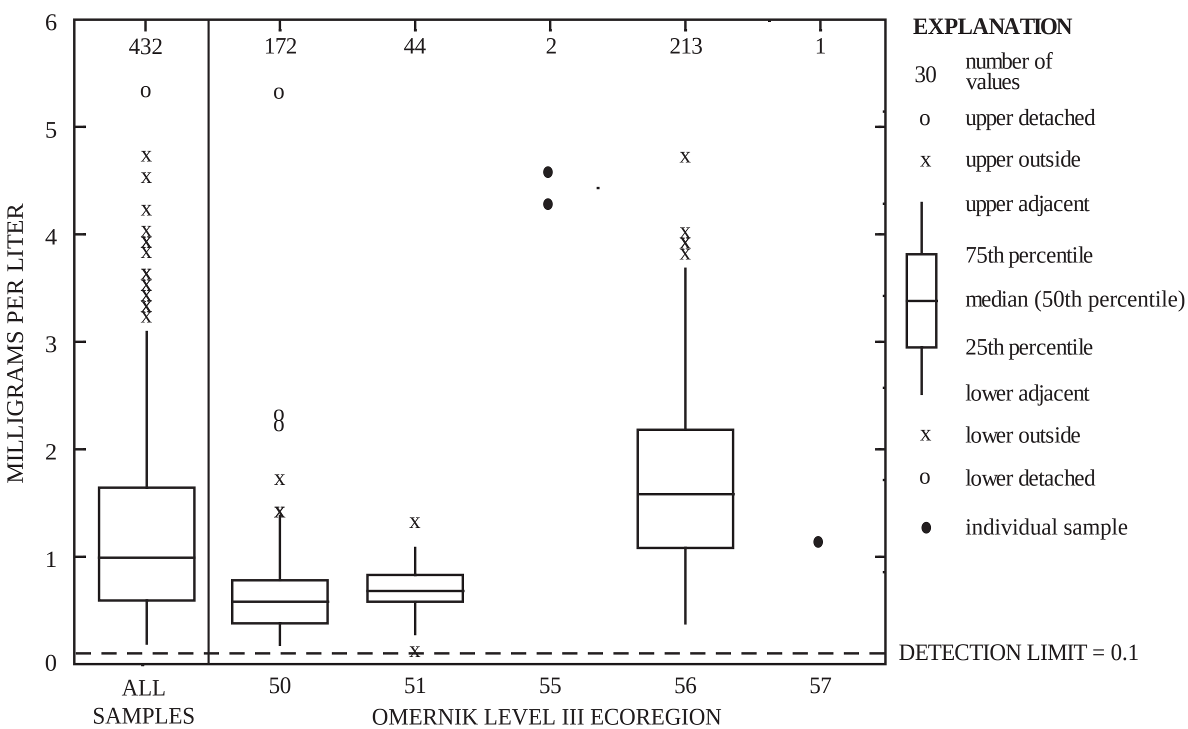

Figure 3–10. Distribution of potassium from the spring mid-depth in Michigan lake basins for years 2001 through 2005.

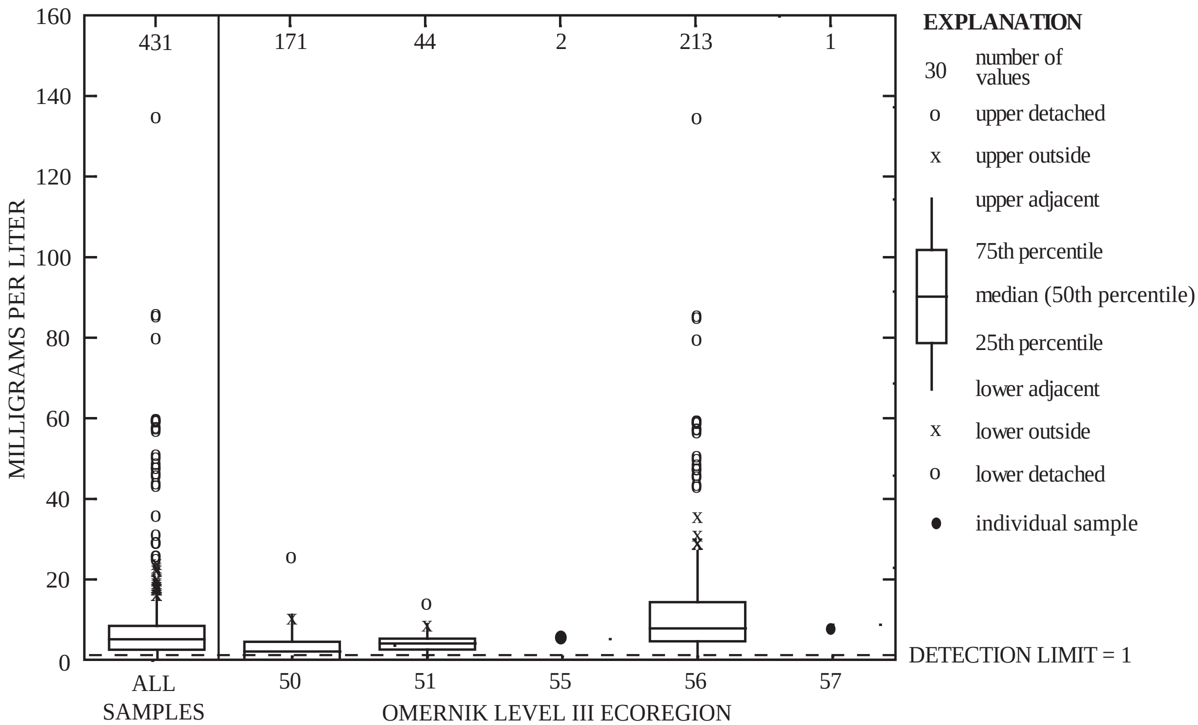

Figure 3–11. Distribution of sodium from the spring mid-depth in Michigan lake basins for years 2001 through 2005.

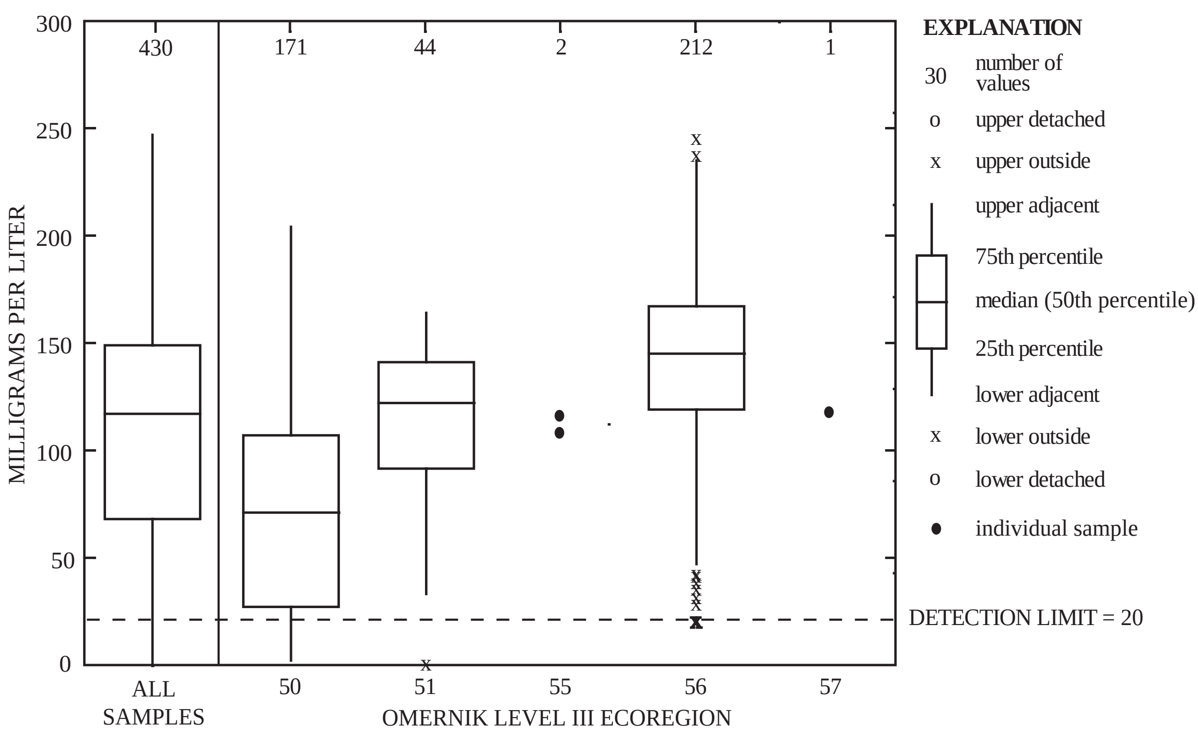

Figure 3–12. Distribution of alkalinity from the spring mid-depth in Michigan lake basins for years 2001 through 2005.

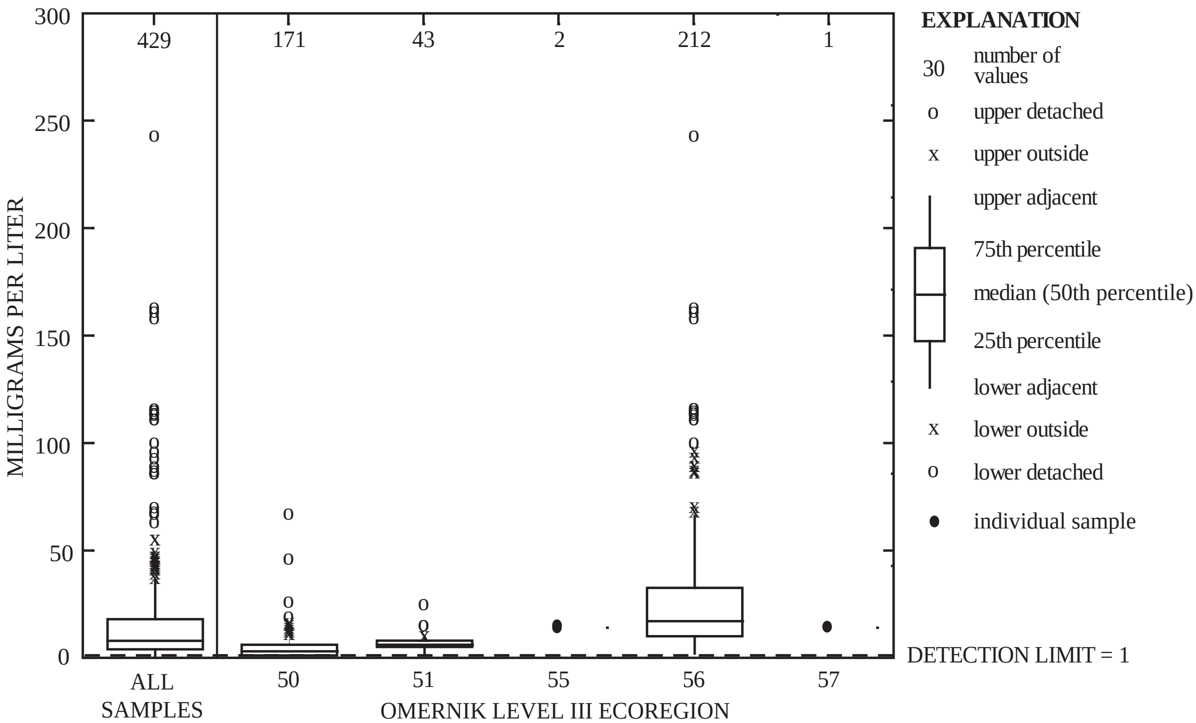

Figure 3–13. Distribution of chloride from the spring mid-depth in Michigan lake basins for years 2001 through 2005.

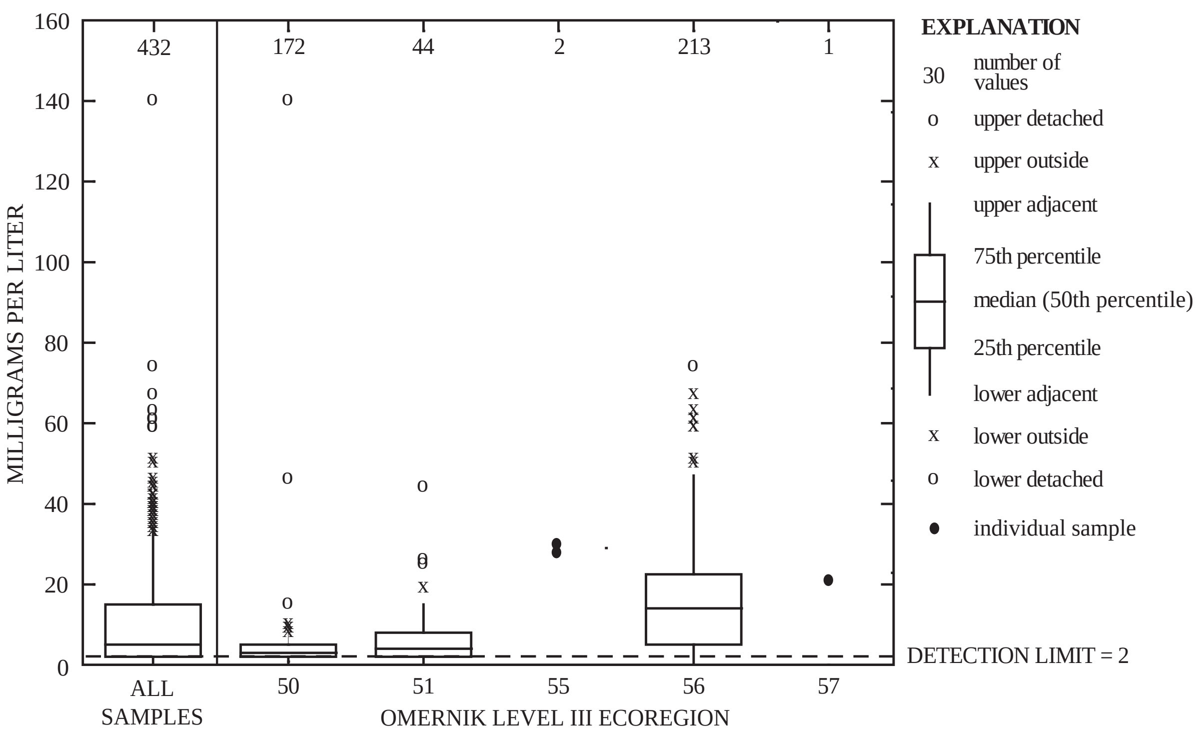

Figure 3–14. Distribution of sulfate from the spring mid-depth in Michigan lake basins for years 2001 through 2005.

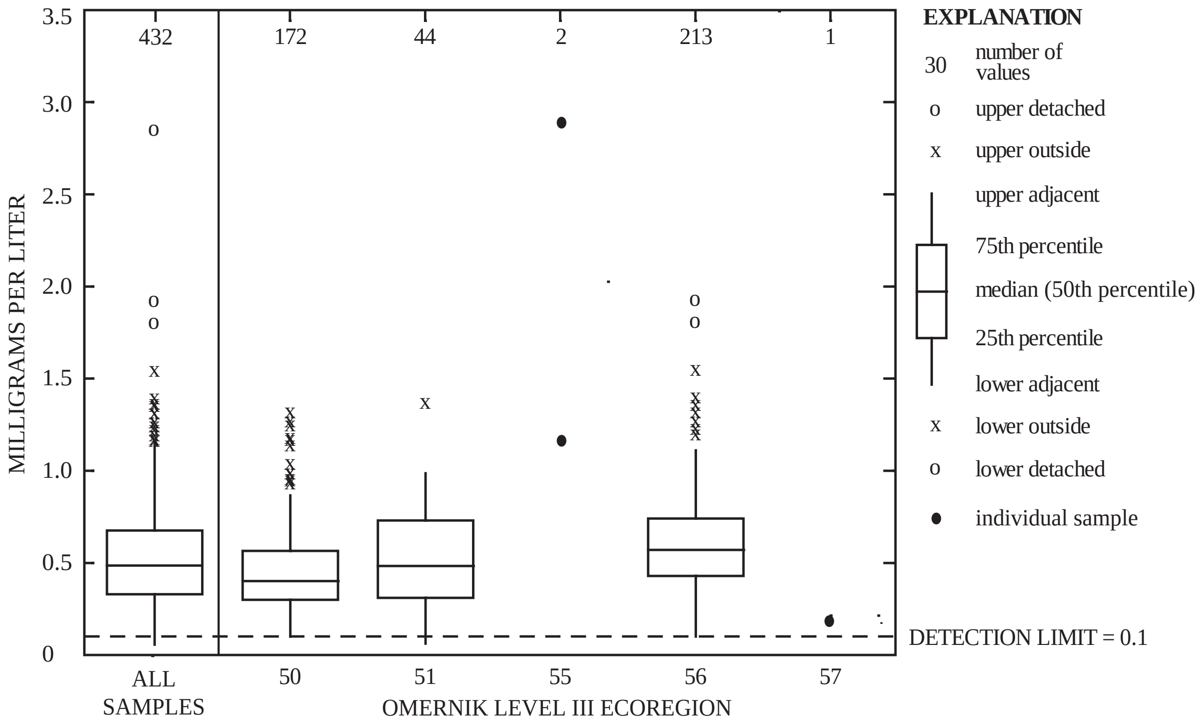

Figure 3–15. Distribution of ammonia plus organic nitrogen from the spring mid-depth in Michigan lake basins for years 2001 through 2005.

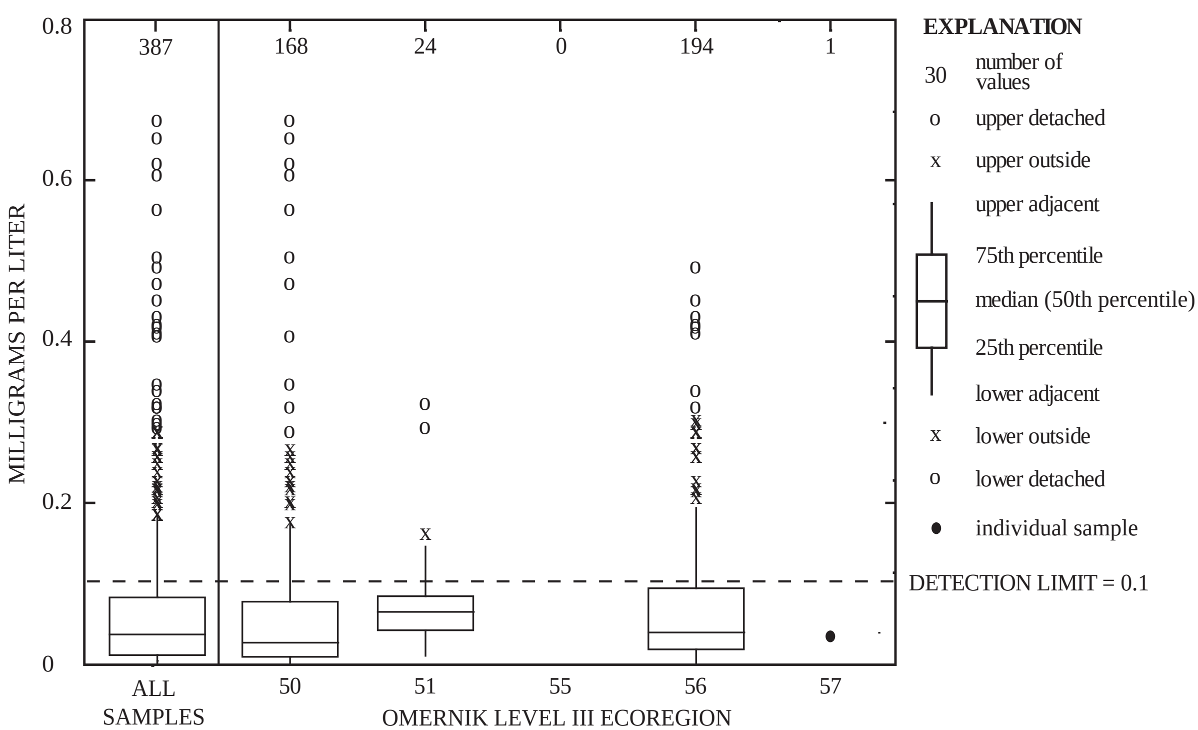

Figure 3–16. Distribution of ammonia from the spring mid-depth in Michigan lake basins for years 2001 through 2005.

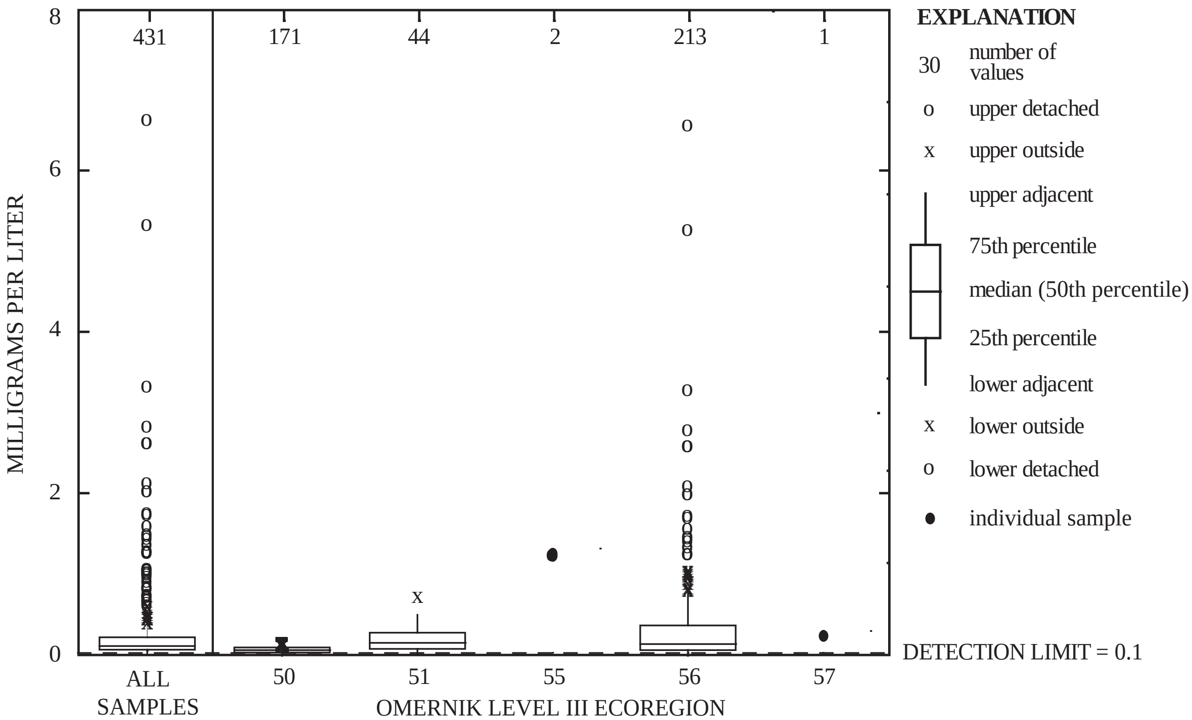

Figure 3–17. Distribution of nitrite plus nitrate from the spring mid-depth in Michigan lake basins for years 2001 through 2005.

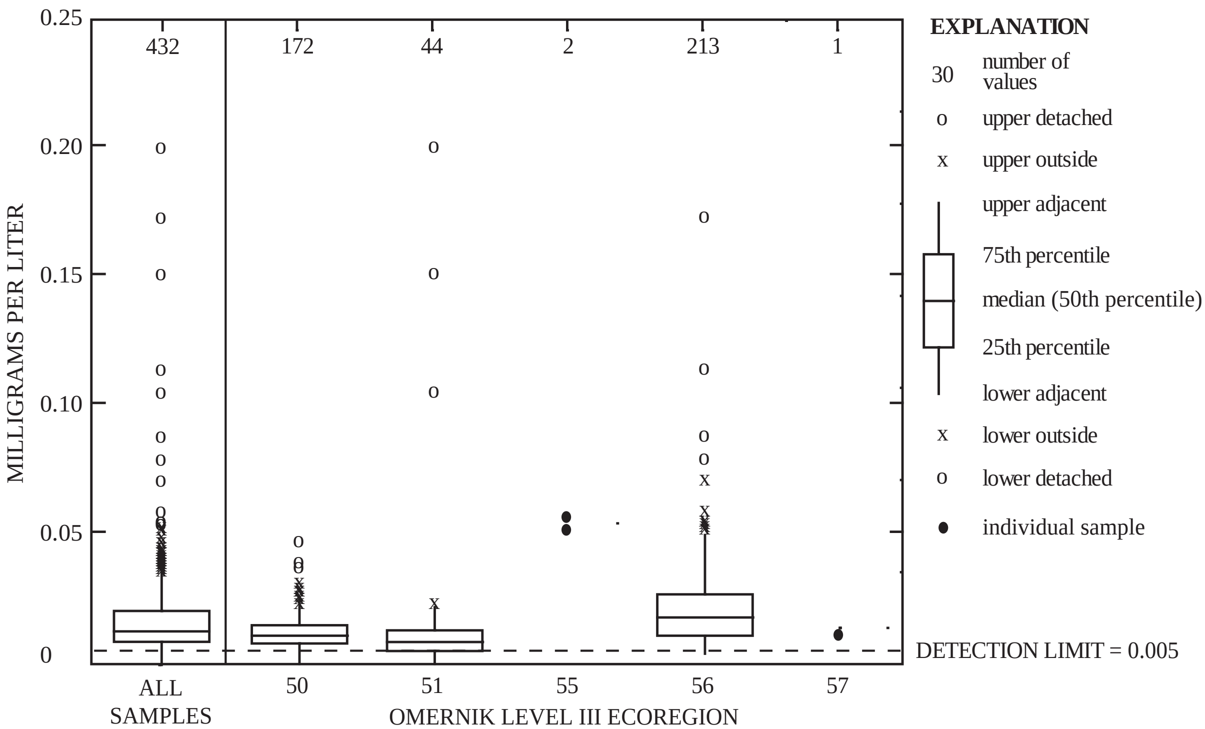

Figure 3–18. Distribution of phosphorus from the spring mid-depth in Michigan lake basins for years 2001 through 2005.

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Appendix 4. Spatial distribution of water-quality constituents in Michigan lake basins from 2001 through 2005

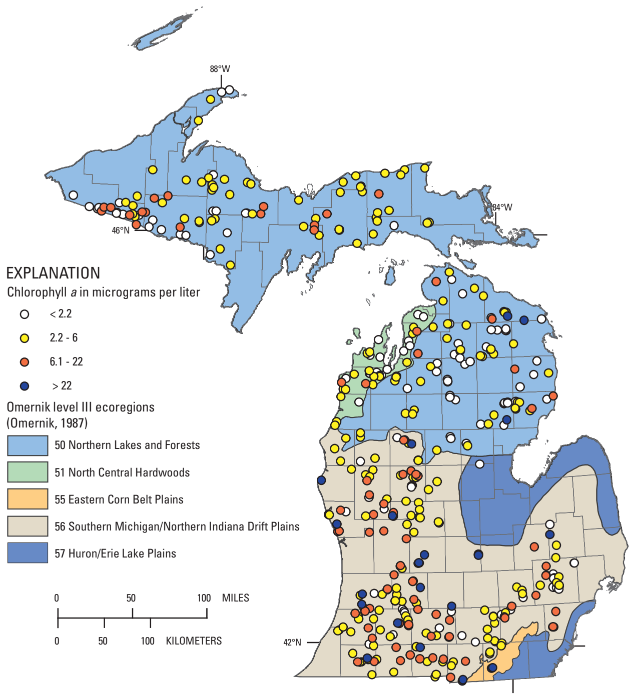

Figure 4–1. Concentration of chlorophyll *a* from summer photic zone in Michigan lake basins from 2001 through 2005.

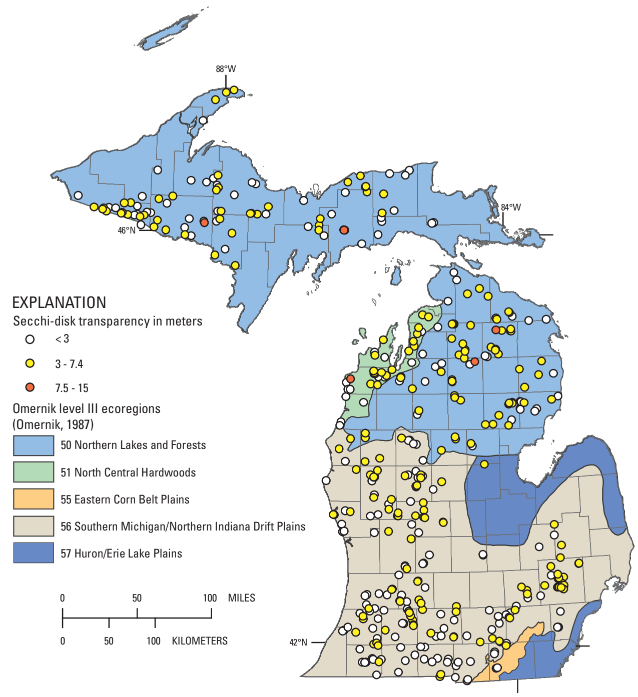

Figure 4–2. Secchi-disk transparency from summer near surface in Michigan lake basins from 2001 through 2005.

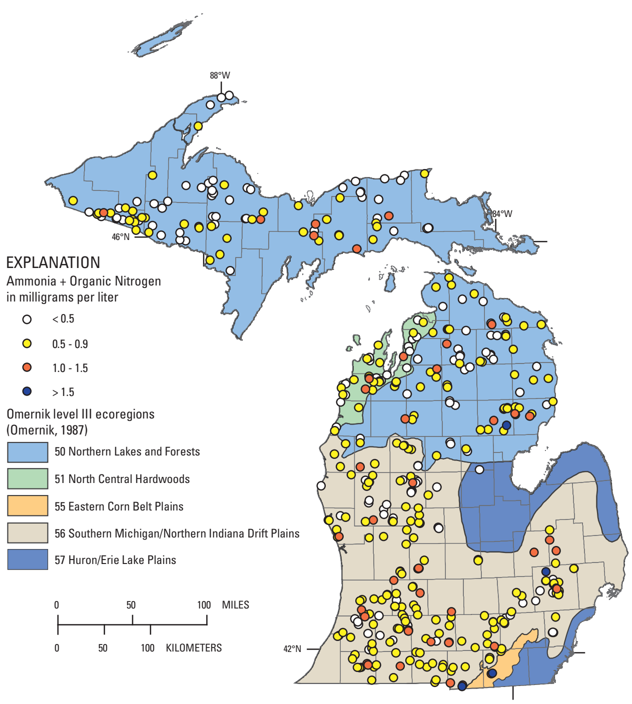

Figure 4–3. Concentration of ammonia plus organic nitrogen from spring mid-depth in Michigan lake basins from 2001 through 2005.

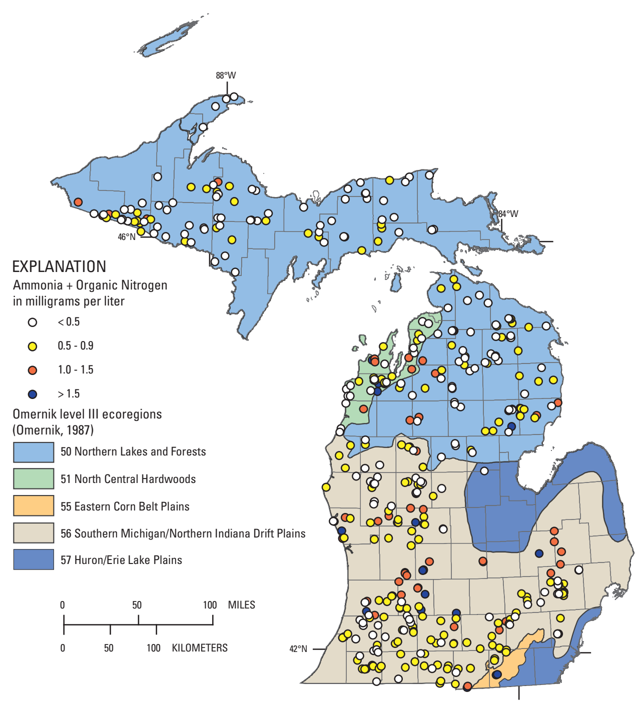

Figure 4–4. Concentration of ammonia plus organic nitrogen in Michigan lake basins from summer near surface from 2001 through 2005.

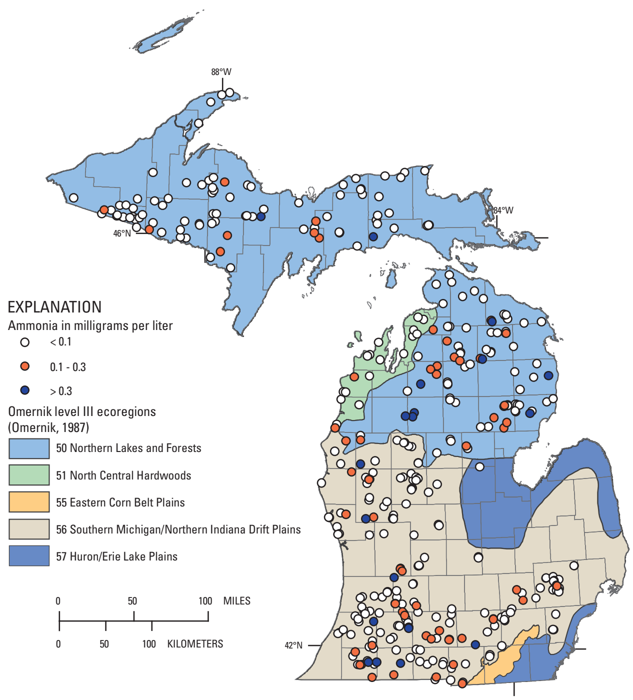

Figure 4–5. Concentration of ammonia from spring mid-depth in Michigan lake basins from 2001 through 2005.

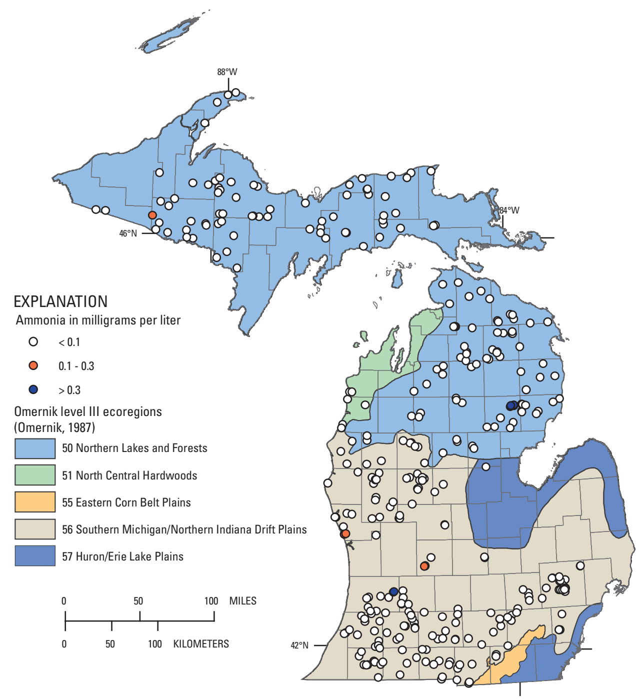

Figure 4–6. Concentration of ammonia from summer near surface in Michigan lake basins from 2001 through 2005.

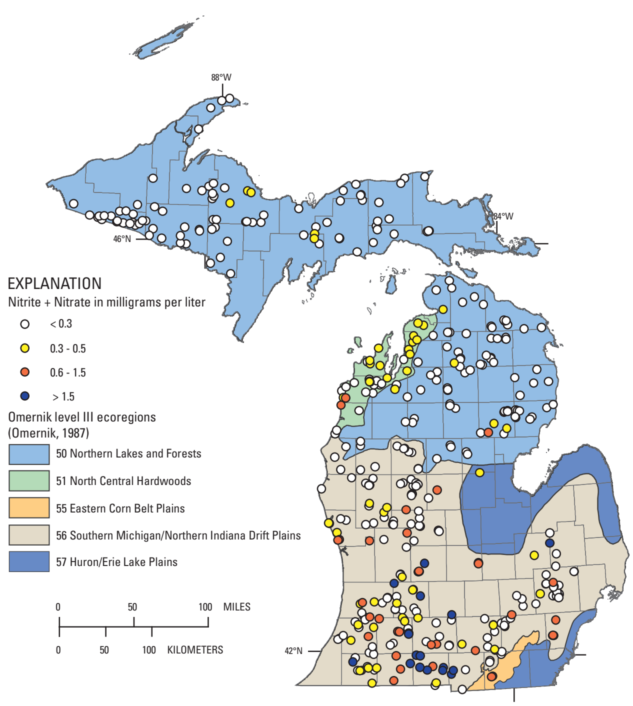

Figure 4–7. Concentration of nitrite plus nitrate from spring mid-depth in Michigan lake basins from 2001 through 2005.

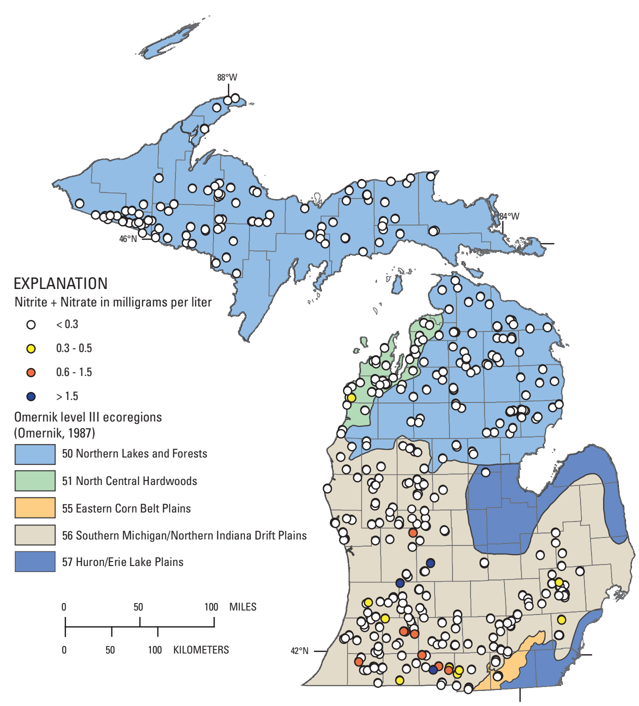

Figure 4–8. Concentration of nitrite plus nitrate from summer near surface in Michigan lake basins from 2001 through 2005.

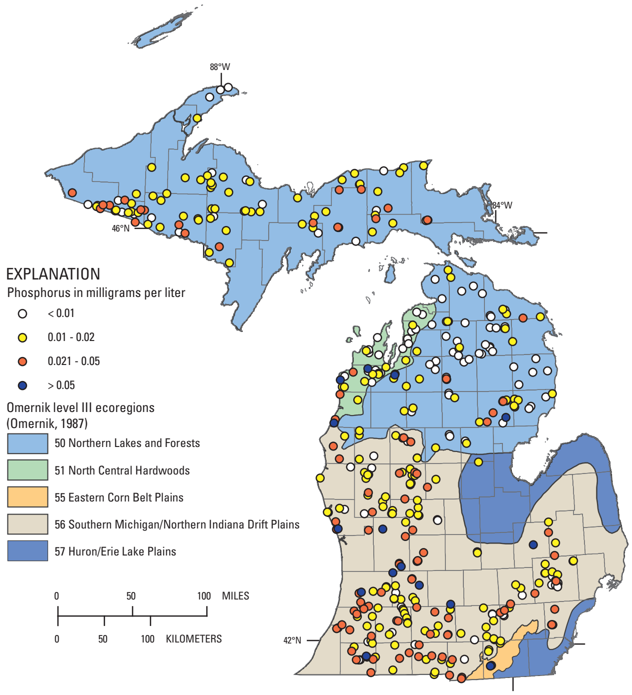

Figure 4–9. Concentration of phosphorus from spring mid-depth in Michigan lake basins from 2001 through 2005.

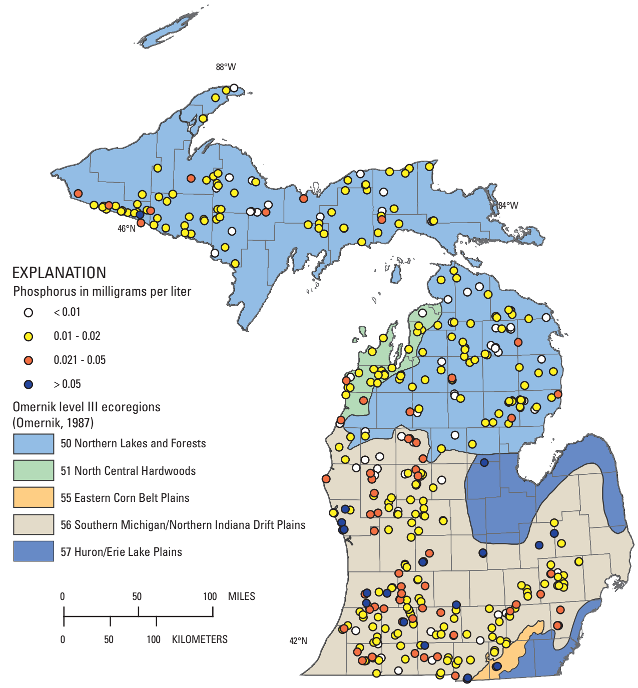

Figure 4–10. Concentration of phosphorus from summer near surface in Michigan lake basins from 2001 through 2005.

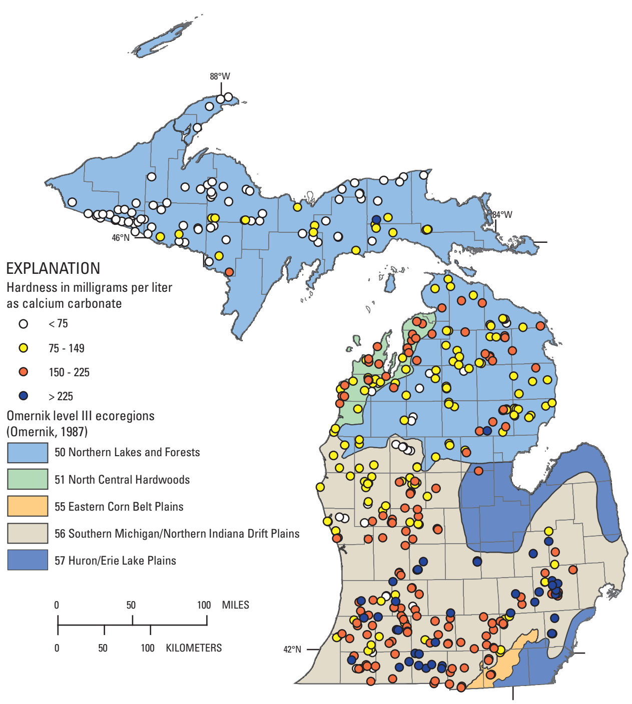

Figure 4–11. Concentration of hardness from spring mid-depth in Michigan lake basins from 2001 through 2005.

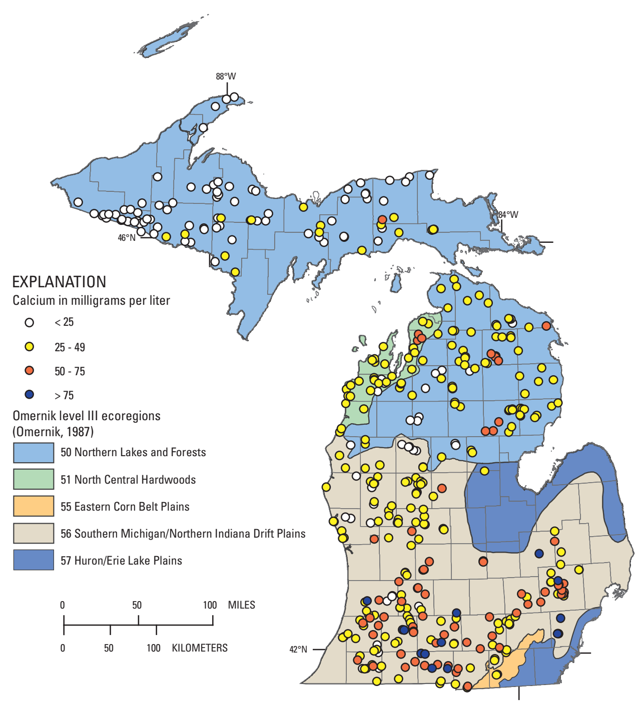

Figure 4–12. Concentration of calcium from spring mid-depth in Michigan lake basins from 2001 through 2005.

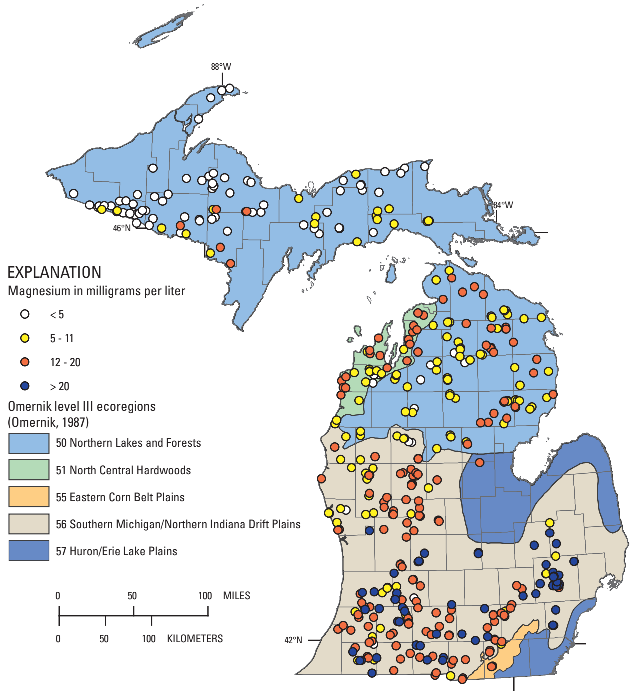

Figure 4–13. Concentration of magnesium from spring mid-depth in Michigan lake basins from 2001 through 2005.

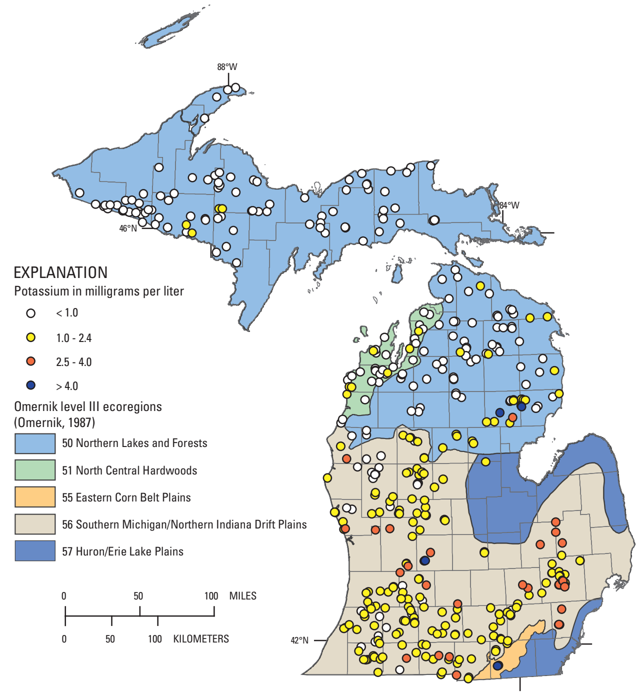

Figure 4–14. Concentration of potassium from spring mid-depth in Michigan lake basins from 2001through 2005.

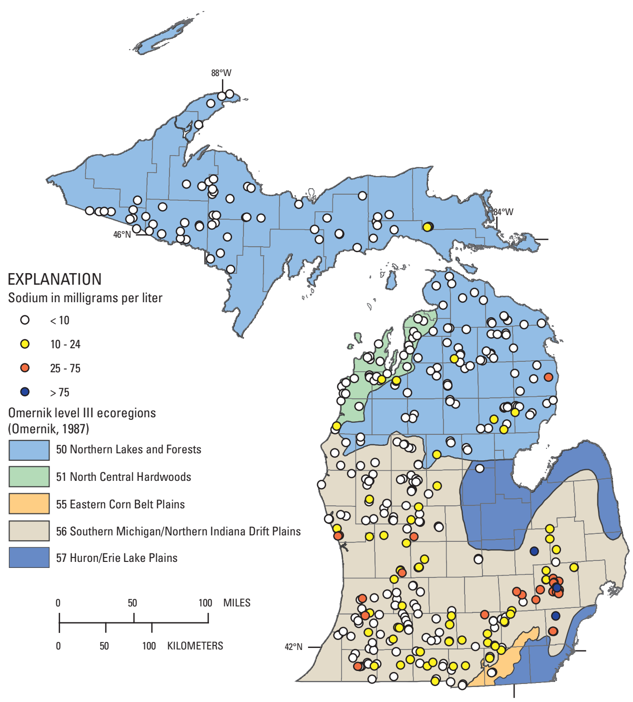

Figure 4–15. Concentration of sodium from spring mid-depth in Michigan lake basins from 2001 2005.

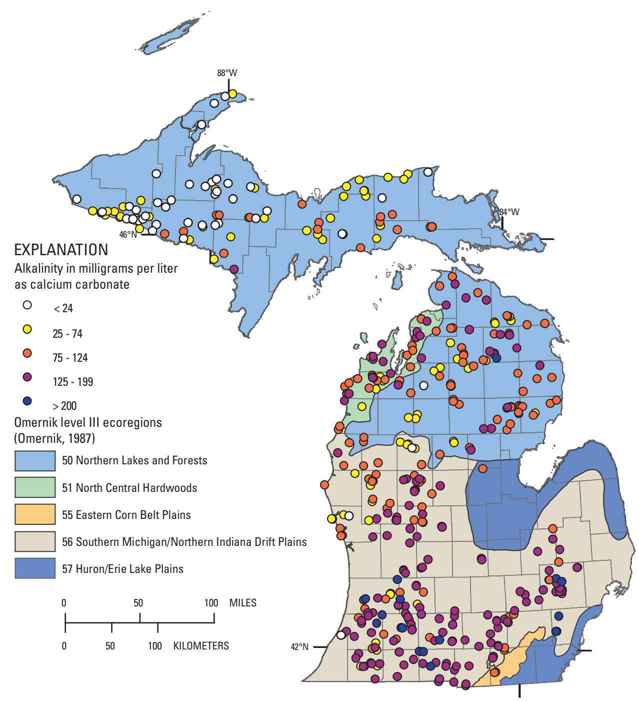

Figure 4–16. Concentration of alkalinity from spring mid-depth in Michigan lake basins from 2001 through 2005.

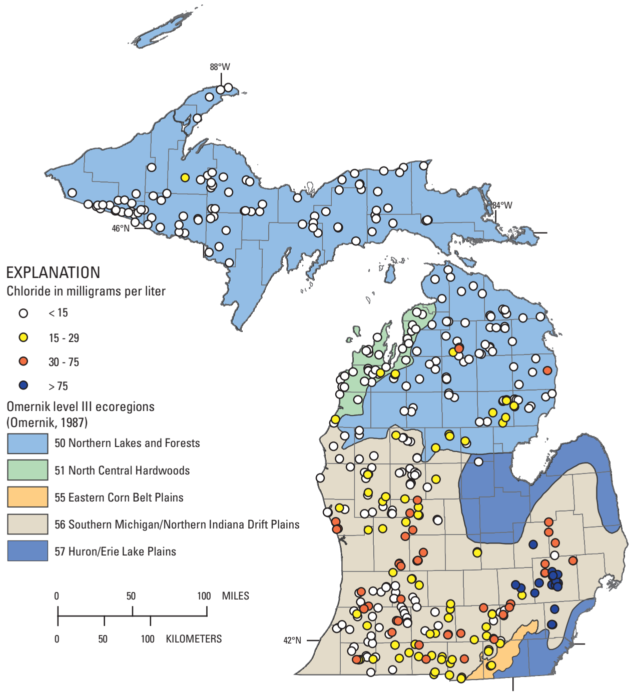

Figure 4–17. Concentration of chloride from spring mid-depth in Michigan lake basins from 2001 through 2005.

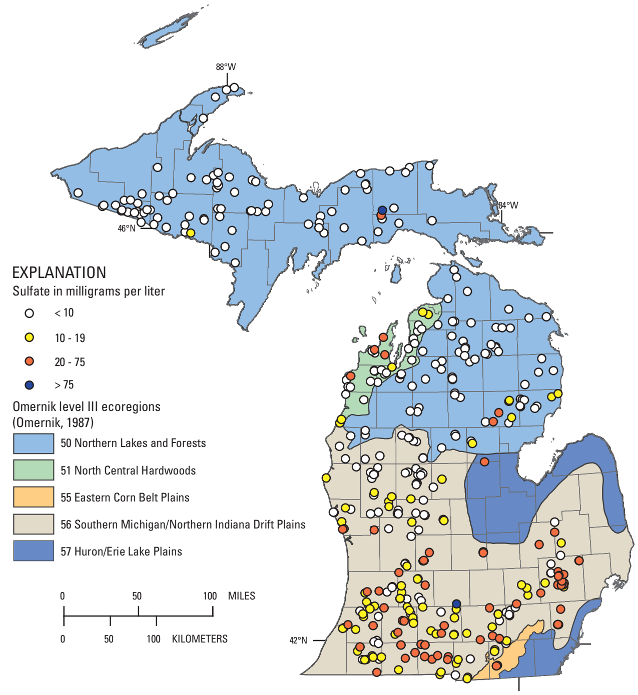

Figure 4–18. Concentration of sulfate from spring mid-depth in Michigan lake basins from 2001 through 2005.

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Appendix 5. A limnologic explanation of water-quality characteristics and constituents sampled in Michigan lakes, 2001–2005

Water-Quality Characteristics of Ponds, Lakes, and Impoundments

The water-quality characteristics of ponds, lakes, and impoundments are determined by a dynamic interaction of physical, chemical, and biological factors. A lake is an ecosystem comprising of living organisms that interact with each other and the physical and chemical properties in that aquatic system. Because of this interaction, physical, chemical, and biological properties can affect other properties. For example, if the water temperature (physical property) of a lake increases, the ability of the lake to contain dissolved gases such as oxygen (chemical property) will decrease, thus restricting the type of fish and other organisms (biological property) that can survive in that environment. The shape and size of a lake basin can affect physical, chemical, and biological constituents of lakes. Shallow lakes allow light penetration to the bottom, which can promote plant growth; sunlight may not reach the bottom in deep lakes.

The source of water to a lake and its retention time in the lake are important in determining the water-quality characteristics. If precipitation is the major source of water, the lake may be acidic and low in nutrients and can be susceptible to acid rain. If ground water is the major source of water, the lake is usually well buffered against acid rain and generally contains low to moderate amounts of nutrients. Ground-water-fed lakes may be susceptible to increased nutrient loading by way of ground-water inflow from local septic systems, lawn fertilization, or agriculture in the watershed. Lakes without inlet streams, with their major source of water coming from precipitation and/or ground water, have longer retention times that allow nutrients to accumulate over a number of years; these nutrients commonly are recycled with spring and fall mixing. If streams are the major source of water to a lake, nutrient levels commonly are influenced by the amount of runoff and human activity in the watershed; these lakes generally have the most variable water-quality characteristics. Rapid water-exchange rates allow nutrients to be flushed out of a lake quickly but also allow for accelerated nutrient loading if streams and rivers flow into the lake.

Interactions between physical, chemical, and biological properties are numerous, generally complex, and in some cases not fully understood. The following is a brief discussion of some of these factors and their interactions and how they are important in the understanding of lake-water quality.

Lake Productivity

A biologically productive lake is desirable for many activities such as fishing and maintaining a healthy wildlife population; however, a lake can be overly productive, which can lead to eutrophication. Eventually, if the excessive plant and algal growth goes unchecked, the overabundance of aquatic growth may impair the lake. Dense aquatic plant growth is shown in figure 5–1.

Figure 5–1. Dense aquatic plant growth (photograph by R.J. Minnerick, U.S. Geological Survey).

Lakes commonly are classified on their level of biological productivity, which is referred to as trophic level. A biologically productive lake is classified as “eutrophic,” and a lake with low productivity is classified as “oligotrophic.” A lake moderate in productivity is classified as “mesotrophic,” and excessive biological productivity is classified as “hypereutrophic.” The trophic status of lakes can be compared and tracked over a time to help evaluate changes in land-use practices and their effects on water quality.

In Michigan, phosphorus is commonly the nutrient in shortest supply and has a substantial effect on productivity; it is considered the limiting element in many lakes. Phosphorus can theoretically generate 500 times its weight in algal matter; nitrogen can generate 71 times its weight (Wetzel, 2001). Excessive phosphorus in a lake commonly is associated with increased loading from septic systems, fertilization of lawns, and agriculture. Excess phosphorus stimulates plant growth and is used by the plants and algae. Lakes with abundant rooted aquatic plants and attached algae may have measured nutrient levels during the summer months that are lower than other productive lakes with less aquatic plant growth (Walker, 1979). These plants use large amounts of nutrients from the water during the growing season. As these plants mature and die, they sink and become part of the organic matter on the lake bottom, which then begins to decompose. If lake-bottom water becomes anoxic, the phosphorus stored in the decomposing plant matter is released at a greater rate and becomes soluble. During spring and fall turnover, the phosphorus that is released from the bottom sediment becomes mixed throughout the lake, where it becomes available again for plant and algal growth. The recycling of these nutrients into the lake water creates a potential for additional algal blooms, particularly as additional nutrients continue to load the system.

How responsive the productivity of a lake is to the introduction of excessive nutrients depends on many factors. The geologic, hydrologic, and biologic components that make up the watershed of a lake all interact and can affect how the water quality may change with the introduction of nutrients. The source of water for a lake and whether it has an outflow will affect the retention or flushing time of the basin. The size and depth of a lake will also determine how the chemical and biological processes will respond to an increase of nutrients. A deep lake with a steep shoreline gradient will limit light penetration, which is needed for plant production and growth. Shallow lakes that allow sunlight to reach their entire bottom are susceptible to algal blooms and plant growth and usually have eutrophic characteristics. Lakes with deep basins generally have oligotrophic characteristics (Cole, 1983).

Water Temperature and Thermal Stratification

Water temperature in lakes is important because of the role it plays in lake stratification and its relation to chemical and biological processes. Thermal stratification is a phenomenon found in many Michigan lakes where a layer of less dense warm water is isolated from mixing with a more dense colder layer. The extent of thermal stratification in lakes depends on the interaction between the size and depth of the lake basin, water clarity, solar heating, and local wind characteristics.

In many lakes, the dominant cause of mixing or circulation is wind. Wind-derived circulation is limited by the water depth; thus, shallow lakes are usually well mixed by the wind. In deeper lakes, only the upper part of the water column may be affected by wind. The extent of wind-derived mixing is also affected by the morphometry of the lake, orientation of the lake to the prevailing wind, and the topography and land cover of the surrounding area.

Once stratification occurs, the warmer upper layer of water, the “epilimnion,” is isolated by a “thermocline” from the colder deeper ”hypolimnion.” The transition zone of rapid temperature change at the thermocline is the “metalimnion.” Water quality can vary substantially between thermal layers. The thermal barrier will allow unique physical and chemical processes to occur within each zone that will influence the cycling of nutrients and other elements within the lake. These layers can remain distinct until fall when the surface-water temperature begins to cool and, assisted by wind action, the lake water will mix (fall overturn). In the spring, this process occurs again (spring overturn) when the ice first leaves the lake and the cold surface water begins to warm to about 4.0ºC. As denser water sinks, aided again by wind, the lake water mixes. The thermal layers develop again through the summer, and the cycle continues.

Specific Conductance

Specific conductance is a measure of the ability of water to conduct an electrical current and is an indicator of the concentration of dissolved solids in water. Pure water is a poor conductor of electricity; however, pure water has the ability to dissolve many substances that dissociate into ions, thus increasing the capability of the water to conduct electricity. Conductance is temperature related so reported values are normalized to 25.0ºC and reported as specific conductance. As the concentration of dissolved minerals increases, specific conductance also increases. While a lake is stratified, specific conductance generally is higher near the bottom because of the release of dissolved materials (such as iron, manganese, and phosphorus) from the bottom sediments under anoxic conditions.

Water Clarity

Water clarity, or transparency, has two main components: true color (materials dissolved in the water) and turbidity (materials suspended in the water, such as algae and silt). The color of lake water reflects the type and amount of dissolved organic chemicals it contains (Lillie and Mason, 1983). Many lakes possess natural, tan-colored compounds (mainly humic and tannic acids) from decomposing plant material in the watershed. Brown water can result from bogs draining into a lake. Algae population is usually the largest and most variable component that affects water clarity.

Water clarity is commonly measured with a Secchi disk. Water clarity, in addition to atmospheric conditions, determines the depth to which sunlight will penetrate the lake. Light is essential for the photosynthesis process by plants. The slope of the lake basin, soils, bottom substrate, and available nutrients, coupled with the maximum depth that light will penetrate, will help determine the composition of rooted plants and free-floating algae. Water clarity can be reduced by the presence of suspended sediment, organics, free-floating algae, and zooplankton. Algae are commonly the dominant influence on the clarity of lake water. Therefore, Secchi-disk measurements relate to free-floating algae concentrations in lake water and are an important tool in determining the biological productivity of a lake.

pH

The pH of a lake is a measure of the hydrogen-ion activity in the lake water. It is defined as the negative logarithm of the hydrogen-ion concentration and varies over a 14-unit log scale; a pH of 7.0 is neutral. Values less than 7.0 indicate acidic conditions, and values greater than 7.0 indicate alkaline conditions. The pH in most natural surface water ranges from 6.5 to 8.5, but pH values outside this range do occur. Many chemical and biological processes, including photosynthesis, nitrification, and calcium-carbonate dissolution, control pH in lake water. Algae and aquatic plants produce oxygen and consume carbon dioxide by the photosynthesis process during the day and produce carbon dioxide when they respire at night. Carbon dioxide then combines with water to form carbonic acid, therefore creating a daily diurnal fluctuation of pH. This fluctuation is important because it affects the solubility of many chemical constituents and because aquatic organisms have limited pH tolerances. It has been shown that pH values greater than 8.5 will accelerate the release of phosphorus from lake-bottom sediment (James and Barko, 1991).

Dissolved Oxygen

Dissolved oxygen (DO) concentration is a critical factor in lake ecosystems and is a component of many chemical and biological processes. It is critical to many organisms for respiration and is an important controlling factor on the diversity of fish and other living organisms that a lake will support. DO enters the lake water from the atmosphere and from production by aquatic plants (photosynthesis). The concentration of DO is dependent on water temperature. As water warms, it has less ability to naturally absorb oxygen. Even though the deeper water in lakes during the summer is typically colder than the surface water, it usually holds less oxygen. This is because in thermally stratified lakes, oxygen that enters the surface does not reach the deeper levels of the lake because of the thermocline. This barrier prevents circulation of water throughout the lake. As a result, the consumption of oxygen in the hypolimnion by chemical processes and the decomposition of organics found in the bottom sediments exceed the rate of replenishment. If this condition continues, the demand for oxygen will deplete all available oxygen near the lake bottom and can cause a condition known as anoxia. If the oxygen demand continues unabated, more oxygen will be used, and the anoxic zone will increase in size and progress upwards through the hypolimnion. Anoxic conditions can trigger another process that will accelerate the release of phosphorus bound up in the bottom sediments. This phosphorus then is circulated throughout the lake when overturn occurs.

Nutrients

Phosphorus and nitrogen are required for plant growth. The concentration of these nutrients will determine the quantity of plants that a lake can support. The quantity and diversity of the plant community in turn plays an important role in the quantity and diversity of fish and other living organisms in this environment. However, if excessive amounts of nutrients are present, algal blooms and excessive growth of other aquatic plants can occur. Accelerated introduction of nutrients into a lake is usually a result of human activities in the watershed. Poor agriculture practices, failing septic systems, and increased runoff associated with residential development are leading contributors to eutrophication.

Commonly, it requires only small additional quantities of nutrients above those that are present naturally to increase the productivity of a lake to the point where eutrophication becomes a concern. The nutrient in shortest supply will tend to be the limiting control on production of shoreline plants, phytoplankton, and other algae (Hem, 1985). In Michigan, concentrations of total phosphorus greater than 0.020 mg/L are considered indicative of eutrophic conditions (Ralph Bednarz, Michigan Department of Environmental Quality, oral commun., 2003). Typically, phosphorus is considered the limiting nutrient in lakes in this region, although increased phosphorus and nitrogen concentrations can have a greater combined effect on plant growth than either nutrient alone in some lakes (Elser and others, 1990). Lakes with a total nitrogen to total phosphorus ratio greater than 15 to 1 near the surface are generally considered phosphorus limited; ratios ranging from 10 to 1 to 15 to 1 indicate a transition situation; and a ratio less than 10 to 1 indicates nitrogen limitation (Lillie and Mason, 1983).

Chlorophyll *a*

Chlorophyll a is photosynthetic pigment found in algae (Wetzel, 2001). Its concentration, therefore, is commonly used as a measure of density of algal population in a lake. The highest concentrations usually are measured during summer, when the lake is the warmest. Algae are the primary food producers in the food chain. A moderate concentration of algae is necessary for a lake to be biologically productive; however, excessive populations or algal blooms are undesirable and can have profound effects on the water quality.

Acid Neutralizing Capacity (ANC)

Also sometimes referred to as alkalinity, ANC is a measure of the capacity of water to neutralize acid. Alkalinity usually is measured by titrating a water sample with an acid to a predetermined pH value (fixed endpoint) or to a point where the change in pH per unit of acid is greatest (incremental). Alkalinity is a generalized measurement in that it does not identify individual compounds; rather, it measures their total effect. The lower the alkalinity of a lake, the more susceptible it is to the influences of acid rain.

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