COOPERATIVE LAKES MONITORING PROGRAM

Michigan's Citizen Volunteer Lakes Monitoring Program

ANNUAL SUMMARY REPORT

1998

a partnership for michigan's lakes

Michigan Lake & Stream Associations, Inc.
Michigan Department of Environmental Quality
Michigan's Citizen Volunteers

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INTRODUCTION

Michigan's unique geographical location provides its citizens with a wealth of freshwater resources including over 11,000 inland lakes. In addition to being valuable ecological resources, lakes provide tremendous aesthetic and recreational value for the people of Michigan and neighboring states. A great Michigan summer pastime is going to a cottage on an inland lake to fish, water-ski, swim, and relax.

As more and more people use the lakes and surrounding watersheds, the potential for pollution problems and use impairment increases dramatically. Although many of Michigan's inland lakes have a tremendous capacity to accommodate the burden of man's activities in the short term, continuing stress on the lakes and lake watersheds over time will ultimately lead to adverse water quality impacts.

Reliable information, including water quality data, levels of use, and use impairment are essential for determining the health of a lake and for developing a management plan to protect the lake. As the users and primary beneficiaries of Michigan's lake resources, citizens must take an active role in obtaining this information and managing their lakes.

Michigan's abundant water resources...

..includes over 11,000 inland lakes.

The Cooperative Lakes Monitoring Program (CLMP) is a partnership between the Land and Water Management Division of the Michigan Department of Environmental Quality (DEQ) and the Michigan Lake and Stream Associations, Inc. (ML&SA). The primary purpose of this cooperative program is to help citizen volunteers monitor indicators of water quality in their lake and document changes in lake quality over time. The CLMP provides sampling methods, training, workshops, technical support, quality control, and laboratory assistance for volunteers to monitor their lake for the basic indicators of lake productivity.

THE SELF-HELP LEGACY

Originally known as the Self-Help Program, the CLMP continues a long time tradition of citizen volunteer monitoring on Michigan's inland lakes. Michigan has maintained a volunteer lake monitoring program since 1974 which makes it the second oldest volunteer monitoring program for lakes in the nation. The original program was designed for lake property owners to monitor water quality by measuring water clarity with a Secchi disk. In 1992, the DEQ Land and Water Management Division (then part of the Department of Natural Resources) and the ML&SA entered into a cooperative

"working together
to protect lakes"

Michigan Department of
Environmental Quality

John Engler, Governor
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agreement to expand the basic program. An advanced Self-Help program was initiated in 1993 that included a monitoring component for the plant nutrient phosphorus. In 1994, a side-by-side sampling component was added to the program to assure the quality of the data being collected.

The CLMP continues the "self-help" legacy by providing Michigan's citizens an opportunity to participate in environmental management and learn more about their lakes. Currently, the CLMP supports monitoring components for basic indicators of primary productivity in lakes, including: Secchi disk transparency, total phosphorus, chlorophyll *a*, and aquatic plants.

The CLMP is a cost-effective process for the DEQ to increase the baseline data available for Michigan's inland lakes as well as to establish a continuous data record for determining water quality trends in lakes. The CLMP continues the DEQ/citizen volunteer partnership critical to lake management in Michigan.

LAKE QUALITY

Lake quality is influenced by many factors such as the amount of recreational use it receives, shoreline development, and water quality. Lake *water quality* is a general term covering many aspects of lake chemistry and

CLMP Goals

- provide baseline information and document trends in water quality for individual lakes.
- educate lake residents, users, and interested citizens in the collection of water quality data, lake ecology, and lake management practices.
- build a constituency of citizens to practice sound lake management at the local level and to build public support for lake quality protection.
- provide a cost-effective process for the DEQ to increase baseline data for lakes state-wide.

CLMP Measurements

- Secchi disk transparency
- spring total phosphorus
- summer total phosphorus
- chlorophyll *a*
- aquatic plants

biology. The health of a lake is determined by its water quality.

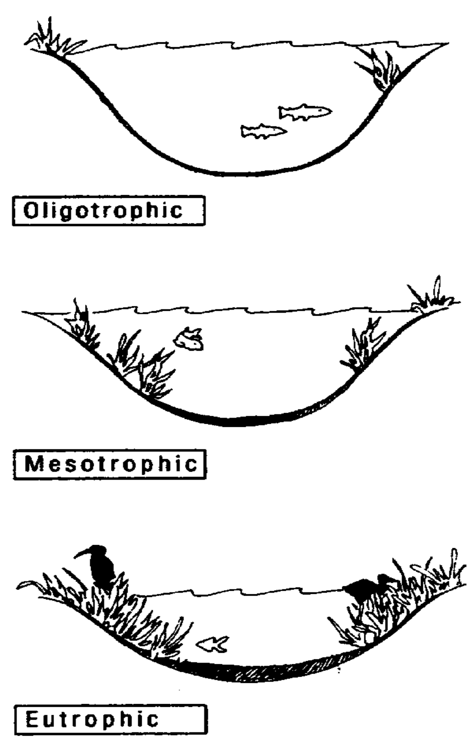
Problems most commonly cited by lake residents, such as excessive weed growth, algal blooms and mucky bottom sediments, are caused by water quality factors that lead to increased lake fertility or productivity. *Productivity* refers to the amount of plant and animal life that can be produced within the lake.

Plant *nutrients* are a major factor that cause increased productivity in lakes. In Michigan, *phosphorus* is the nutrient most responsible for plant and algae growth (*primary productivity*) in inland lakes.

The CLMP is designed to specifically monitor changes in lake productivity. The current program enlists citizen volunteers to monitor water clarity and the algal plant pigment chlorophyll *a* throughout the summer months and total phosphorus is measured during the spring and late summer. These parameters are indicators of primary productivity and, if measured over many years, these data may document changes, or trends, in the lake's productivity.

CLASSIFYING LAKES

A lake's ability to support plant and animal life defines its level of productivity, or *trophic state*. Lakes are commonly classified based on their productivity. Low productive *oligotrophic* lakes are generally deep and clear with little aquatic plant growth. These lakes maintain sufficient *dissolved oxygen* in the cool, deep bottom waters during late summer to support cold water fish such as trout and whitefish. By contrast, high productive *eutrophic* lakes are generally shallow, turbid, and support abundant aquatic plant growth. In deep eutrophic lakes, the cool bottom waters usually contain little or no dissolved oxygen. Therefore, these lakes can only support warm water fish such as bass and pike. Lakes that fall between these two classifications



(Source: Hamlin Lake Improvement Board)

are called *mesotrophic* lakes. Lakes that exhibit extremely high productivity such as nuisance algae and weed growth are called *hypereutrophic* lakes.

EUTROPHICATION

The gradual increase of lake productivity from oligotrophy to eutrophy is called lake aging or *eutrophication*. Lake eutrophication is a natural process resulting from the gradual accumulation of nutrients, increased productivity, and a slow filling in of the lake basin with accumulated sediments, silt and muck. Human activities can greatly speed up this process by dramatically increasing nutrient, soil, or organic matter input to the lake. This human influenced, accelerated lake aging process is known as *cultural eutrophication*. A primary objective of most lake management plans is to slow down cultural eutrophication by reducing the input of nutrients and sediments to the lake.

MEASURING EUTROPHICATION

Measuring a lake's water quality and eutrophication is not an easy task. Lakes are a complex ecosystem made up of physical, chemical and biological components in a constant state of action and interaction.

As on land, plant growth in lakes is not constant throughout the summer months. Some species mature early in the season, die back, and are replaced by other species in a regular succession.

While overall population levels often reach a maximum in mid-summer, this pattern may be influenced or altered by numerous temporal factors such as temperature, rainfall, and aquatic animals. For the same reasons lakes are different from week to week, lake water quality can fluctuate from year to year.

Given these factors, observers of lake water quality must train themselves to recognize the difference between short-term, normal population fluctuations and long-term changes in lake productivity (eutrophication). Many years of reliable data collected on a consistent and regular basis are required to separate true long term changes in lake productivity from seasonal and annual fluctuations.

Important Measures of Eutrophication

Nutrients are the leading cause of eutrophication. Nitrogen and *phosphorus* both stimulate plant growth. Both are measured from samples of water and reported in units of ug/l (micrograms per liter), or ppb (parts per billion). *Phosphorus* is the most important nutrient, and is often used directly as a measure of eutrophication.

Plants are the primary users of nutrients. *Chlorophyll a* is a component of the cells of most plants, and can be used to measure the concentration of small plants in the water, such as algae. *Chlorophyll a* is measured from samples of water and reported in units of ug/l. Macrophytes are aquatic plants with stems and leaves. The location of different species of plants can be mapped, and the density can be measured in pounds of plants per acre of lake.

Transparency or the clarity of water is measured using a device known as a *Secchi disk*. This is an eight inch diameter target painted black and white in alternate quadrants. The disk is attached to a marked line, or measuring tape, and lowered from a boat into the lake. The distance into the water column the disk can be seen is the transparency, measured in feet or meters. A short distance of visibility means that there are suspended particles or algae cells in the water, an indication of nutrient enrichment.

Dissolved Oxygen (DO) which is oxygen dissolved in the water, is necessary to sustain fish populations. Fish such as trout require more DO than warm water species. Eutrophic lakes occasionally have levels of DO below the minimum for fish to survive, and fish kills can result.

Sediments can be measured to determine how fast material is depositing on the bottom. This may indicate watershed erosion, or large die-off of aquatic plants.

Fish can be sampled using nets. In an oligotrophic lake there are likely to be cold water species such as trout. A sample of warm water fish such as sunfish, bass, bullheads, and carp is more typical of a eutrophic lake.

Temperature affects the growth of plants, the release of nutrients, and the mixing of layers of water in the lake. Temperature measurements can determine if mixing occurs, moving nutrients and algal cells from the bottom up into the lake.

LAKE PRODUCTIVITY INDEX

The general lake classification scheme described above is convenient but somewhat misleading in that it places all lakes into a few distinct trophic categories. In reality, lake water quality is a continuum progressing from very good to very poor conditions. A more precise method of describing the productivity of a lake is to use a numerical index which can be calculated directly from water quality data. A variety of indexes are available with Carlson's (1977) *Trophic State Index*, or TSI, being the most widely used.

Carlson's TSI was developed to compare lake data on water clarity, as measured by a Secchi disk, chlorophyll *a* and total phosphorus. These parameters are good indirect measures of a lake's productivity. The TSI expresses lake productivity on a continuous numerical scale from 0 to 100 with increasing numbers indicating more eutrophic conditions. The zero point on the TSI scale was set to correlate with a Secchi transparency of 64 meters (210 feet).

Carlson developed mathematical relationships for calculating the TSI from measurements of Secchi depth transparency, chlorophyll *a*, and total phosphorus in lakes during the summer season. The

Carlson's TSI Equations

$$TSI_{SD} = 60 - 33.2 \log_{10} SD$$

$$TSI_{TP} = 4.2 + 33.2 \log_{10} TP$$

$$TSI_{CHL} = 30.6 + 22.6 \log_{10} CHL$$

where,
SD = Secchi depth transparency (m)
TP = total phosphorus concentration (ug/l)
CHL = chlorophyll *a* concentration (ug/l)

computed TSI values for an individual lake can be used to compare with other lakes, to evaluate changes within the lake over time, and to estimate other water quality parameters within the lake.

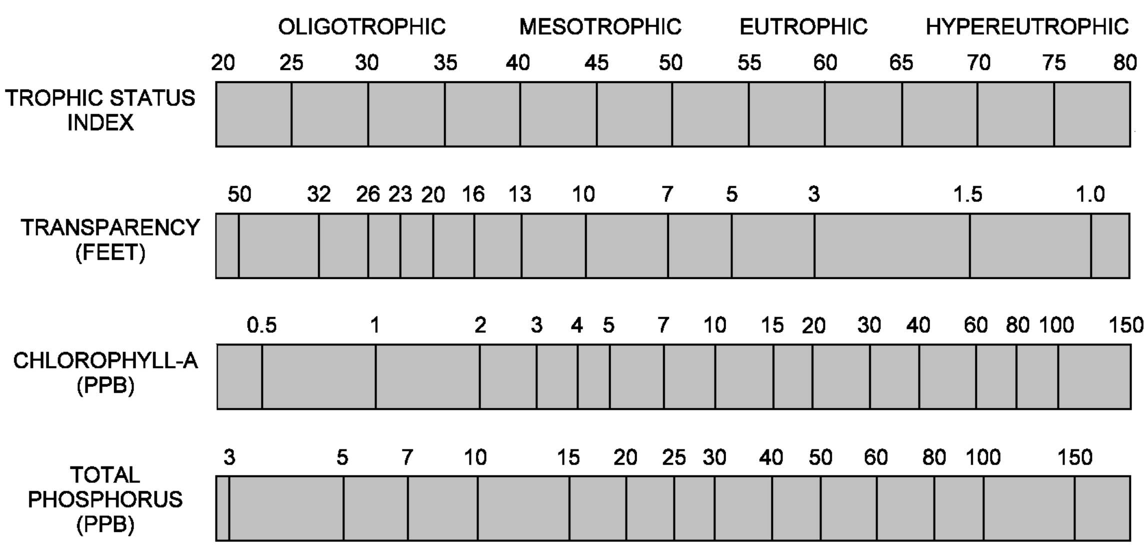
For those preferring to use the general lake classification scheme, the TSI values which correspond approximately with the trophic state terms are illustrated in the figure below. However, the dividing lines between these categories are somewhat arbitrary since lake water quality is a continuum and there is no broad agreement among lake scientists as to the precise point of change between each of these classifications.

For many lakes in Michigan, Carlson's TSI equations can be used to roughly predict values of one variable from measurements of another in the surface water of the lake during the summer season as shown in the figure below.

Lake scientists have also developed relationships to predict summer productivity indicators from water quality variables measured during lake turnover in the spring. One such relationship was developed by Dillon and Rigler (1974) which predicts mean (average) summer chlorophyll *a* from spring total phosphorus measurements.

These relationships must be used carefully when predicting water quality variables and productivity.

CARLSON'S TROPHIC STATE INDEX



(Source: Minnesota Pollution Control Agency)

CLMP RESULTS

Secchi Disk Transparency

Citizen volunteers measure Secchi disk transparency from late spring to the end of the summer. Ideally, eighteen weekly measurements are made from mid May through mid September. As a minimum, eight equally spaced measurements from the end of May to the beginning of September are accepted to provide a good summer transparency mean (average) for the lake. Frequent transparency measurements are necessary throughout the growing season since algal species composition in lakes can change significantly during the spring and summer months, which can dramatically affect overall water clarity.

A summary of the transparency data collected by the lake volunteers during 1998 is included in Appendix 1. The number of measurements, or readings, made between mid May and mid September and the minimum and maximum Secchi disk transparency values are included for each lake that participated in the program. For those lakes with eight or more evenly spaced readings over this time period, the mean, median, standard deviation and Carlson TSI_{SD} values were calculated and listed.

The mean, or average, is simply the sum of the measurements divided by the number of measurements. The median is the middle value when the set of measurements is ordered from lowest to highest value. The standard deviation is a common statistical determination of the dispersion, or variability, in a set of data.

The data range and standard deviation gives an indication of seasonal variability in transparency in the lake. Lakes with highly variable Secchi disk readings need to be sampled frequently to provide a representative mean summer transparency value. Few measurements and inconsistent sampling periods for these lakes will result in unreliable data for annual comparisons.

The TSI_{SD} values were calculated using Carlson's equations (see page seven) and the mean summer transparency values. (Note: the mean transparency value is converted from feet to meters for the TSI_{SD} calculation) The graphical relationship on page eight can be used to relate the TSI_{SD} value to the general trophic status classification for the lake (i.e. oligotrophic, mesotrophic, eutrophic) as well as to provide a rough estimate of summer chlorophyll *a* and total phosphorus levels in the lake. If the transparency measurements are made properly and consistently year after year the annual TSI_{SD} values can be compared to evaluate changes, or trends, in trophic status of the lake over time.

During 1998, Secchi disk transparency data were reported for 129 lakes (192 basins). Over 2500 transparency measurements were reported which ranged from 0 to 54 feet. For the lakes with eight or more equally spaced readings between mid May and mid September, the overall mean, or average, Secchi disk transparency was 10.9 feet. The Carlson TSI_{SD} values ranged from 26 to 62 for these lakes with a mean value of 43. A Carlson TSI value of 43 is generally indicative of a good quality mesotrophic lake (see page eight).

Total Phosphorus

Phosphorus is one of several essential nutrients that algae need to grow and reproduce. For most lakes in Michigan, phosphorus is the most important nutrient, the limiting factor, for algae growth. The total amount of phosphorus in the water is typically used to predict the level of productivity in a lake. An increase in phosphorus over time is a measure of nutrient enrichment in a lake.

The CLMP volunteers monitor for total phosphorus during spring overturn, when the lake is generally well mixed from top to bottom, and during late summer, when the lake is at maximum temperature stratification from the surface to the bottom. Spring overturn is an opportune time of the year to sample just the surface of a lake to obtain a representative sample for estimating the total amount of phosphorus in the lake. A surface sample collected during late summer represents only the upper water layer of the lake, the epilimnion, where most algal productivity occurs. The late summer total phosphorus results, along with the Secchi disk transparency and chlorophyll measurements, are used to determine the trophic status of the lake. The spring overturn total phosphorus data, collected year after year, are useful for evaluating nutrient enrichment in the lake.

Total phosphorus results for the 1998 CLMP are included in Appendix 2. The spring total phosphorus data are listed first, followed by the late summer data. The TSI_{TP} values were calculated using Carlson's equations (see page seven) and the late summer total phosphorus data. Results from replicate and side-by-side sampling are also provided. Approximately 10% of the replicate samples collected by the volunteers were analyzed as part of the data quality control process for the CLMP. Also, the DEQ participated in side-by-side sampling on approximately 10% of the enrolled lakes.

During 1998, samples for total phosphorus measurements were collected on 98 lakes (105 basins). The spring overturn total phosphorus results ranged from <5 to 79 ug/l with a mean (average) of 13.8 ug/l. The late summer total phosphorus results ranged from 7 to 69 ug/l with 15.6 ug/l as the mean. The Carlson TSI_{TP} values ranged from 32 to 65 for these lakes with a mean value of 42. A Carlson TSI value of 42 is generally indicative of a good quality mesotrophic lake (see page eight).

Chlorophyll *a*

Chlorophyll is the green photosynthetic pigment in the cells of plants. The relative amount of algae in a lake can be estimated by measuring the chlorophyll *a* concentration in the water. As an algal productivity indicator, chlorophyll *a* is often used to determine the trophic status of a lake.

Chlorophyll monitoring was added to the CLMP in 1998 as a pilot study. Forty lakes were included in the pilot study. For each lake, the volunteers collected and processed five sets of chlorophyll *a* samples, one set per month from May through September.

Results from the chlorophyll monitoring pilot study are included in Appendix 3. Results for each monthly sampling event are listed as well as the mean, median, and standard deviation of the monthly data for each lake. The TSI_{CHL} values were calculated using Carlson's equations (see page seven) and the median summer chlorophyll values. Results from the replicate and side-by-side sampling are also provided. Side-by-side and replicate samples were collected and analyzed for nearly half of the lakes that participated in the 1998 chlorophyll pilot study.

Over 230 chlorophyll samples were collected and processed for the 40 lakes included in the pilot study. The chlorophyll *a* levels in these lakes ranged from <1 to 170 ug/l over the five-month sampling period. The overall mean (average) was 6.6 ug/l and the median was 4 ug/l. The Carlson TSI_{CHL} values ranged from <31 to 65 with a mean value of 44. A Carlson TSI value of 44 is generally indicative of a good quality mesotrophic lake (see page eight).

The TSI_{CHL}, TSI_{SD}, and TSI_{TP} values for the pilot study lakes can be compared to provide useful information about the factors controlling the overall trophic status in these lakes (Carlson and Simpson, 1996). For lakes where phosphorus is the limiting factor for algae growth, all three TSI values should be nearly equal. However, this may not always be the case. For example, the TSI_{SD} may be significantly larger than the TSI_{TP} and TSI_{CHL} values for lakes that precipitate calcium carbonate, or marl, during the summer. The marl particles in the water column would scatter light and reduce transparency in these lakes, which would increase the

TSI_{SD}. Also, phosphorus may adsorb to the marl and become unavailable for algae growth which would reduce the TSI_{CHL}. For lakes where zooplankton grazing or some factor other than phosphorus limits algal biomass, the TSI_{TP} may be significantly larger than the TSI_{SD} and TSI_{CHL}.

Data from the CLMP provide citizens with basic information on their lakes which can be used as indicators of the lake's productivity. If measured over many years, these data may be useful in documenting changes and trends in water quality.

Although CLMP data provide very useful water quality information, anyone who is involved in making decisions on lake management will want to assemble more information on a lake's condition. The DEQ and ML&SA may be able to help you obtain additional information on your lake.

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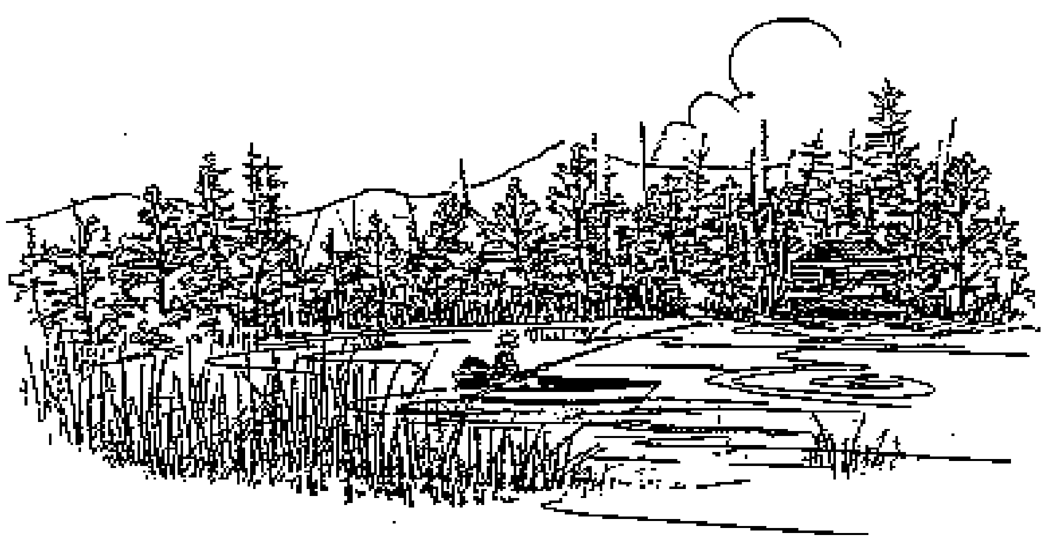

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Special thank you is extended to the dedicated volunteers who have made the CLMP one of the nation's most successful citizen volunteer lakes monitoring programs.

APPENDIXES

Appendix 1

1998 Secchi Disk Transparency Results

Appendix 2

1998 Total Phosphorus Results

Appendix 3

1998 Chlorophyll Pilot Study Results

APPENDIX 1
1998 COOPERATIVE LAKES MONITORING PROGRAM
SECCHI DISK TRANSPARENCY RESULTS

Lake	County	Number of Readings	Range Min.	Range Max.	Mean	Median	Standard Deviation	Carlson TSI SD (transparency)
Arbutus 1	Grand Traverse	15	13.5	14.5	14.2	14.3	0.31	39
Arbutus 2	Grand Traverse	15	17.0	20.0	18.3	18.0	1.02	35
Arbutus 3	Grand Traverse	15	17.0	19.0	17.7	18.0	0.59	36
Arbutus 4	Grand Traverse	15	16.5	18.0	17.4	17.5	0.57	36
Arbutus 5	Grand Traverse	15	14.5	17.0	15.5	15.0	0.79	38
Arnold	Clare	17	13.0	27.0	19.9	19.0	3.31	34
Avalon	Montmorency	11	15.0	30.0	22.1	21.0	4.48	32
Baldwin	Montcalm	18	9.5	18.0	13.2	13.5	2.35	40
Baldwin 1	Cass	8	6.9	9.9	8.7	9.1	1.16	46
Baldwin 2	Cass	8	6.4	11.0	9.1	9.7	1.59	45
Baldwin 3	Cass	8	6.7	9.2	8.3	8.6	0.89	47
Baldwin 4	Cass	8	6.4	8.2	7.3	7.4	0.65	48
Barlow	Barry	13	5.0	18.5	8.8	6.5	4.03	46
Bass	Kent	18	8.5	15.5	10.7	10.5	2.07	43
Bear	Manistee	12	8.0	13.0	9.5	9.0	1.45	45
Bear 1	Kalkaska	14	26.0	46.0	34.0	32.3	6.71	26
Bear 2	Kalkaska	14	26.5	44.0	33.4	32.0	5.44	27
Beaver	Alpena	17	9.3	16.3	12.8	12.3	2.00	40
Big Bradford	Otsego	16	13.0	21.5	18.4	18.5	2.63	35
Big Pine Island	Kent	18	6.0	16.0	10.2	9.8	2.69	44
Big Pleasant	St. Joseph	17	11.0	23.0	14.9	13.0	4.37	38
Bills	Newaygo	16	8.0	20.0	12.4	11.5	4.27	41
Blue	Mason	15	18.0	34.0	27.1	27.0	5.25	30
Blue 1	Mecosta	18	12.0	17.0	14.6	14.8	1.25	39
Blue 2	Mecosta	17	12.0	18.0	14.8	14.5	1.52	38
Burkhart	Washtenaw	18	9.5	17.0	12.2	12.0	1.90	41
Byram 1	Genesee	18	11.0	21.0	15.7	14.5	2.59	37
Byram 2	Genesee	18	13.0	20.0	15.3	14.0	2.54	38
Byram 3	Genesee	18	11.0	20.0	14.3	13.0	3.18	39
Camp	Kent	11	11.0	17.0	13.6	13.0	1.77	39
Campau & Kettle	Kent	18	8.0	15.0	10.6	9.5	2.48	43
Cedar	Van Buren	17	9.0	23.0	15.4	15.5	4.69	38
Chain	Iosco	14	9.0	14.0	10.8	10.0	1.67	43
Chemung	Livingston	16	10.5	15.5	12.1	12.0	1.15	41
Christiana	Cass	18	4.0	10.0	6.6	6.3	1.81	50
Clear	Jackson	18	7.0	14.5	11.8	13.0	2.49	42
Clear 1	St. Joseph	4	10.0	15.5				
Clear 2	St. Joseph	4	10.5	16.0				
Clifford 1	Montcalm	17	10.0	19.0	13.5	14.0	2.76	40
Clifford 2	Montcalm	17	11.0	17.0	13.6	14.0	1.77	39
Coldwater	Branch	8	7.0	21.0	12.9	10.0	5.33	40
Corey	St. Joseph	16	8.0	18.5	10.8	9.5	3.36	43
Crockery	Ottawa	15	3.0	11.5	5.9	5.8	2.56	51
Crooked 1	Clare	14	8.6	11.8	10.4	10.3	0.82	43

APPENDIX 1
1998 COOPERATIVE LAKES MONITORING PROGRAM
SECCHI DISK TRANSPARENCY RESULTS

Lake	County	Number of Readings	Range Min.	Range Max.	Mean	Median	Standard Deviation	Carlson TSI_{SD} (transparency)
		Secchi Disk Transparency (feet)						
Crooked 2	Clare	14	8.8	11.5	10.5	10.5	0.79	43
Crooked (Big)	Van Buren	18	12.5	18.0	15.1	15.3	1.42	38
Crooked (Little)	Van Buren	8	16.5	20.3	18.8	19.2	1.61	35
Crystal	Benzie	5	17.2	22.0				
Cub	Kalkaska	17	15.0	21.0	17.7	17.0	1.83	36
Dewey	Cass	18	5.0	9.0	7.4	7.3	1.18	48
Diamond	Cass	18	5.0	29.0	11.6	8.5	7.05	42
Donnell	Cass	15	7.8	22.0	11.6	9.5	4.41	42
Duck 1	Grand Traverse	17	7.0	12.0	9.6	9.0	1.32	44
Duck 2	Grand Traverse	17	7.0	12.0	9.8	10.0	1.39	44
East 1	Kalkaska	17	6.0	9.0	7.7	8.0	0.92	48
East 2	Kalkaska	17	5.0	8.0	6.5	6.0	0.94	50
East Twin	Montmorency	15	9.0	16.5	11.9	10.5	2.55	41
Emerald	Newaygo	16	4.0	14.0	8.9	10.0	2.74	46
Farwell	Jackson	7	7.3	12.0				
Fenton	Genesee	5	12.5	15.0				
Fish	Van Buren	18	6.3	12.6	8.8	8.5	2.06	46
Ford	Mason	17	9.5	15.1	12.5	13.1	2.11	41
Forest	Oakland	13	8.0	15.0	10.8	10.5	2.01	43
George 1	Clare	18	8.0	12.0	9.8	9.5	1.19	44
George 2	Clare	18	8.0	12.0	10.0	10.0	1.23	44
George 3	Clare	18	8.0	12.0	9.8	9.5	1.33	44
Glen (Big)	Leelanau	14	13.0	23.0	17.2	16.5	2.99	36
Glen (Little)	Leelanau	17	5.0	10.0	8.1	8.0	1.32	47
Gravel	Van Buren	18	8.0	21.0	15.6	14.0	3.71	38
Hackert	Mason	17	11.0	19.0	13.7	13.0	1.96	39
Hamilton	Dickinson	18	10.0	17.0	14.4	14.0	1.69	39
Hamlin 1	Mason	6	6.0	10.0				
Hamlin 2	Mason	6	11.0	14.5				
Harper	Lake	10	11.7	19.0	14.5	13.9	2.24	39
Hawk	Oakland	14	5.0	10.5	7.3	7.3	1.66	49
Higgins 1	Roscommon	3	17.0	31.0				
Higgins 2	Roscommon	7	19.0	33.0				
Horsehead	Mecosta	12	7.0	14.0	10.6	10.3	2.58	43
Hubbard	Alcona	17	9.0	22.5	12.9	12.5	3.50	40
Hunter's	Alcona	2	19.5	20.0				
Hutchins	Allegan	14	4.1	7.1	6.1	6.3	0.87	51
Indian	Montcalm	15	5.0	11.0	7.4	7.0	2.02	48
Indiana	Cass	15	9.0	25.0	12.3	11.0	4.23	41
Jeptha (Upper)	Van Buren	16	7.2	16.7	12.7	13.0	3.43	41
Juno	Cass	18	4.0	9.5	6.3	6.3	1.83	51
Keeler 1	Van Buren	18	9.5	11.0	10.2	10.0	0.49	44
Kirkwood	Oakland	18	1.7	6.5	2.9	2.8	1.10	62
Klinger	St. Joseph	17	9.0	21.0	13.4	12.0	3.36	40

APPENDIX 1
1998 COOPERATIVE LAKES MONITORING PROGRAM
SECCHI DISK TRANSPARENCY RESULTS

Lake	County	Secchi Disk Transparency (feet) Number of Readings	Range Min.	Range Max.	Mean	Median	Standard Deviation	Carlson TSI_{SD} (transparency)
Lake of the Woods	Van Buren	18	8.2	15.2	11.0	10.8	2.11	43
Lakeville	Oakland	16	0.0	17.0	11.1	15.0	6.72	42
Lancelot 1	Gladwin	5	5.0	10.0				
Lancelot 2	Gladwin	5	4.2	7.0				
Lancelot 3	Gladwin	5	4.0	9.5				
Lancer 1	Gladwin	5	6.0	8.0				
Lancer 2	Gladwin	5	7.0	12.3				
Lancer 3	Gladwin	5	5.0	8.0				
Lancer 4	Gladwin	5	2.5	4.0				
Lancer 5	Gladwin	5	3.0	6.0				
Lansing	Ingham	16	5.2	10.0	5.9	5.5	1.15	51
Leelanau (North)	Leelanau	17	10.0	17.0	13.1	14.0	2.33	40
Leelanau (South)	Leelanau	18	5.0	12.5	9.2	9.5	2.61	45
Leisure	Shiawassee	18	9.2	19.2	14.1	14.2	2.70	39
Lily	Clare	18	8.5	10.0	9.1	9.0	0.48	45
Little Blue	Kent	13	13.0	20.0	15.3	14.8	2.34	38
Little Bradford	Otsego	8	14.0	26.0	18.3	17.0	4.33	35
Little Paw Paw 1	Berrien	15	4.0	8.5	6.6	6.8	1.21	50
Little Paw Paw 2	Berrien	15	4.0	8.5	6.7	7.0	1.22	50
Little Paw Paw 3	Berrien	15	4.0	7.6	6.5	6.8	1.02	50
Little Twin	Cass	17	1.4	19.0	14.0	14.4	4.10	39
Londo 1	Iosco	5	8.0	11.0				
Londo 2	Iosco	5	8.0	9.0				
Londo 3	Iosco	5	8.0	10.0				
Londo 4	Iosco	3	11.0	12.0				
Long	Branch	9	3.0	8.0	5.4	5.0	1.50	53
Long	Grand Traverse	18	17.0	54.0	31.4	31.0	11.23	27
Long	Ionia	17	8.0	13.4	10.8	10.5	1.78	43
Long	Iosco	16	8.5	15.3	9.9	9.5	1.68	44
Long	Washtenaw	9	8.0	10.7	9.7	10.0	1.03	44
Louise	Dickinson	18	14.0	19.0	16.1	16.0	1.28	37
Mary	Dickinson	18	14.0	22.0	16.9	17.0	2.05	36
McGilvery 1	Gladwin	8	7.5	11.0	8.3	8.0	1.13	47
McGilvery 2	Gladwin	8	7.0	11.0	8.6	8.3	1.18	46
McGilvery 3	Gladwin	8	8.0	11.0	8.4	8.0	1.05	46
Mecosta	Mecosta	15	12.0	18.0	14.6	14.0	1.88	38
Mill	Van Buren	13	10.0	20.5	14.5	14.0	2.91	39
Missaukee 1	Missaukee	11	6.0	11.5	9.2	9.0	1.43	45
Missaukee 2	Missaukee	11	4.9	7.5	6.1	6.0	1.05	51
Missaukee 3	Missaukee	11	5.1	7.2	6.1	5.9	0.75	51
Missaukee 4	Missaukee	11	5.6	7.8	6.5	6.2	0.69	50
Missaukee 5	Missaukee	11	4.2	7.5	6.1	6.0	1.07	51
Missaukee 6	Missaukee	11	4.8	6.5	5.5	5.3	0.57	53
Missaukee 7	Missaukee	11	5.0	7.9	6.6	6.5	0.82	50

APPENDIX 1
1998 COOPERATIVE LAKES MONITORING PROGRAM
SECCHI DISK TRANSPARENCY RESULTS

Lake	County	Secchi Disk Transparency (feet) Number of Readings	Range Min.	Range Max.	Mean	Median	Standard Deviation	Carlson TSI_{SD} (transparency)
Missaukee 8	Missaukee	11	6.8	11.5	9.3	9.8	1.62	45
Moon	Gogebic	15	16.0	24.0	19.1	19.0	2.37	35
Nevins	Montcalm	16	10.0	22.0	14.3	12.8	4.17	39
Oxford	Oakland	18	16.0	33.0	22.3	21.5	4.61	32
Painter	Cass	18	3.0	9.0	5.9	5.8	1.81	52
Paw Paw 1	Berrien	13	5.2	16.8	9.5	7.8	3.77	45
Paw Paw 2	Berrien	13	4.8	15.4	9.0	7.2	3.38	45
Paw Paw 3	Berrien	13	5.4	13.8	8.6	7.4	3.02	46
Payne	Barry	8	7.0	13.0	9.0	8.8	2.05	45
Pentwater (Center)	Oceana	5	4.9	9.8				
Pentwater (East)	Oceana	5	4.9	11.5				
Pentwater (West)	Oceana	5	5.7	11.2				
Platte	Benzie	18	3.0	16.0	9.9	11.0	3.94	44
Pleasant 1	Washtenaw	16	6.5	13.4	9.6	9.5	1.93	44
Pleasant 2	Washtenaw	16	6.8	12.3	9.7	9.5	1.56	44
Pleasant 3	Washtenaw	16	6.8	13.6	10.1	10.1	1.71	44
Pleasant 1	Wexford	3	9.5	10.8				
Pleasant 2	Wexford	3	9.0	9.3				
Reynolds (Lower)	Van Buren	10	11.0	14.5	13.1	13.5	1.28	40
Reynolds (Upper)	Van Buren	11	14.0	19.0	16.1	16.0	1.78	37
Robinson	Newaygo	15	5.0	12.0	9.3	9.0	1.91	45
Round	Kent	7	11.0	17.0				
Round 1	Mecosta	18	9.0	17.0	12.5	12.0	2.25	41
Round 2	Mecosta	18	9.0	17.0	12.6	12.0	2.20	41
Sanford	Benzie	13	15.0	22.0	16.3	16.0	1.80	37
Sapphire	Missaukee	15	4.0	9.0	6.3	6.0	1.93	51
School Section 1	Mecosta	18	11.4	14.3	12.9	12.9	0.86	40
School Section 2	Mecosta	18	11.8	14.2	13.1	13.1	0.72	40
School Section 3	Mecosta	18	11.6	14.4	13.2	13.2	0.83	40
Scram	Kent	17	13.1	20.7	17.2	17.4	1.74	36
Secord 1	Gladwin	9	6.0	11.0	7.8	7.0	1.64	48
Secord 2	Gladwin	9	4.0	6.8	5.5	5.4	0.79	53
Secord 3	Gladwin	9	4.0	6.3	4.9	5.0	0.92	54
Selkirk	Allegan	7	4.0	17.5				
Sherwood	Oakland	18	5.5	12.0	9.1	9.5	1.95	45
Shingle	Clare	18	8.0	18.0	12.4	11.8	3.27	41
Silver 1	Genesee	18	4.5	11.0	7.4	7.3	1.83	48
Silver 2	Genesee	18	4.3	9.5	7.0	7.3	1.38	49
Silver 3	Genesee	18	4.7	11.0	8.0	8.0	1.76	47
Spider 1	Grand Traverse	18	13.0	29.5	17.0	15.5	4.81	36
Spider 2	Grand Traverse	18	13.0	26.0	16.1	15.0	3.34	37
Spider 3	Grand Traverse	17	11.5	25.5	14.8	14.0	3.49	38
Stone Ledge	Wexford	18	6.0	12.0	9.2	9.5	2.02	45
Strawberry 1	Livingston	12	4.0	9.0	6.1	6.0	1.37	51

APPENDIX 1

1998 COOPERATIVE LAKES MONITORING PROGRAM

SECCHI DISK TRANSPARENCY RESULTS

Lake	County	Secchi Disk Transparency (feet)						Carlson
		Number of Readings	Range		Mean	Median	Standard Deviation	TSI_{SD} (transparency)
			Min.	Max.				
Strawberry 2	Livingston	4	6.4	8.4				
Sylvan	Newaygo	16	4.0	10.0	6.7	7.0	1.70	50
Taylor	Oakland	18	12.0	18.0	14.9	14.5	1.98	38
Twin Lakes North	Cass	18	10.0	19.0	13.6	13.0	2.73	39
Van Ettan	Iosco	18	3.0	6.0	4.3	4.0	1.10	56
Vaughn	Alcona	11	5.3	10.0	7.9	8.0	1.47	47
Vineyard	Jackson	18	5.0	25.0	12.0	10.0	5.26	41
West Twin	Montmorency	15	8.7	12.0	10.0	10.0	1.08	44
White 1	Oakland	15	17.0	22.3	20.3	20.5	1.87	34
White 2	Oakland	15	14.0	23.5	19.1	19.3	2.10	35
White 3	Oakland	15	9.0	16.0	13.7	14.3	1.90	39
Windover 2	Clare	8	13.0	19.0	15.3	14.8	1.81	38
Windover 3	Clare	8	13.0	18.0	14.9	14.5	1.73	38
Wolf	Lake	10	9.0	10.0	9.5	9.3	0.42	45
Woods	Kalamazoo	16	10.0	15.0	12.4	12.3	1.79	41
Zukey	Livingston	8	5.0	12.0	8.5	9.0	2.62	46

APPENDIX 2

1998 COOPERATIVE LAKES MONITORING PROGRAM

TOTAL PHOSPHOROUS RESULTS

Lake	County	Total Phosphorus (ug/l) Spring -Overturn (Volunteer)	Spring -Overturn (DEQ)	Late - Summer (Volunteer)	Late - Summer (DEQ)	Carlson TSI_{TP} (summer TP)
Arbutus	Gr. Traverse	3 T		10		37
Arnold	Clare	7		7		32
Avalon	Montmorency	1 T		7		32
		(4 T)				
Baldwin	Cass	7				
Baldwin	Montcalm	15		18		46
				(16)		
Barlow	Barry	10	12	11		39
		(10)				
Bass	Kent	16		12		40
Bear	Kalkaska	3 T		8		34
Big Crooked	Van Buren	9		*		
Big Pine Island	Kent	16		17		45
Big Pleasant	St. Joseph			10		37
Blue	Mason	10		10		37
Blue	Mecosta	10	10	10		37
		(7)				
Burkhart	Washtenaw	10		15		43
Cedar	Van Buren	10		13		41
Chain	Iosco	10	15	15		43
		(9)	(13)			
Chemung	Livingston	19		15		43
Christiana	Cass	20		22		49
Clear	Jackson	8		15		43
		(5)				
Clifford	Montcalm	11		*		
Corey	St. Joseph	9		8	12	34
				(8)		
Crockery	Ottawa	79		21		48
Crystal 1	Benzie	4 T				
Crystal 2	Benzie	5		8		34
Cub	Kalkaska	6		9		36
Dewey	Cass	16		18		46
Devils (North)	Lenawee	8		10		37
Devils (South)	Lenawee	7		15		43
Diamond	Cass	5		8		34
Doc and Tom	Clare	14		15		43
Donnell	Cass	*		9		36
E. Twin	Montmorency	4 T		9		36
				(11)		
East	Kalkaska	9				

APPENDIX 2
1998 COOPERATIVE LAKES MONITORING PROGRAM
TOTAL PHOSPHOROUS RESULTS

Lake	County	Total Phosphorus (ug/l) Spring -Overturn (Volunteer)	(DEQ)	Late - Summer (Volunteer)	(DEQ)	Carlson TSI_{TP} (summer TP)
Fenton	Genesee	11		*		
		(15)				
Fish	Van Buren	*		20		47
				(18)		
Gravel	Van Buren	12				
Gulliver	Schoolcraft	9		11		39
		(11)				
Hackert	Mason	8		10	11	37
				(10)		
Hamilton	Dickinson	9		10		37
		(11)				
Hamlin (Upper)	Mason	20		59		63
Hamlin (Lower)	Mason	13		35		55
Hammond	Oakland	*		9		36
Harper	Lake	8		11		39
Higgins	Roscommon	4 T				
		(6)				
Horsehead	Mecosta	16		15		43
Hubbard	Alcona	9		9		36
Hunter's	Alcona	*		15		43
Jeptha (Upper)	Van Buren	15				
Juno	Cass	20		25		51
Keeler	Van Buren	16		14		42
Lake George	Clare	17		12		40
		(16)				
Lancelt	Gladwin	*				
Lancer	Gladwin	*				
Lansing	Ingham	22		20		47
				(32)		
Lily (Mouth)	Clare	19		19		47
Lily (Basin)	Clare	19		16		44
Little Blue	Kent	*		*		
Little Crooked	Van Buren	10		*		
Little Paw Paw	Berrien			21		48
Long	Gr. Traverse	5		9		36
Long	Iosco	14	19	13		41
Long	Washtenaw	11		19		47
Louise	Dickinson	7		7		32
Mary	Dickinson	18		9		36
				(9)		

APPENDIX 2
1998 COOPERATIVE LAKES MONITORING PROGRAM
TOTAL PHOSPHOROUS RESULTS

Lake	County	Total Phosphorus (ug/l) Spring -Overturn (Volunteer)	Spring -Overturn (DEQ)	Late - Summer (Volunteer)	Late - Summer (DEQ)	Carlson TSI TP (summer TP)
McGilvery	Gladwin	*		19		47
				(17)		
Mecosta	Mecosta	16	14	10		37
		(11)				
Miner	Allegan	*				
Missaukee	Missaukee	8				
Moon	Gogebic	7		*		
N. Twin	Cass	7		14		42
Nevins	Montcalm	18		21		48
Oxbow	Oakland	14		8		34
Oxford	Oakland	8		10		37
				(10)		
Painter	Cass	26		69		65
Paw Paw 1	Berrien	26		15		43
Paw Paw 2	Berrien	26		14		42
Paw Paw 3	Berrien	27		15		43
Pentwater	Oceana	37		30		53
Pleasant	Washtenaw	21		22	21	49
				(23)		
Pleasant	Wexford	12				
Robinson	Newaygo	25		20	19	47
Round	Lenawee	9		12		40
Round	Mecosta	14	15	13		41
		(15)				
S. Twin	Cass	6		10		37
Sanford	Benzie	18		11		39
Sapphire	Missaukee	9		17	18	45
				(14)		
School Section 1	Mecosta	4 T		11		39
School Section 2	Mecosta	7		12		40
Secord	Gladwin	34		15		43
Shingle	Clare	18		14		42
Spider	Gr. Traverse	7		12		40
Stone Ledge	Wexford	17		18		46
Strawberry	Livingston	19	18	31	33	54
		(18)			(30)	
Taylor	Oakland	14		11		39
Van Etten	Iosco	28		33		55
Vaughn	Alcona	23		26		51
Vineyard	Jackson	5				
W. Twin	Montmorency	4 T		10		37

APPENDIX 2

1998 COOPERATIVE LAKES MONITORING PROGRAM
TOTAL PHOSPHOROUS RESULTS

Lake	County	Total Phosphorus (ug/l) Spring -Overturn (Volunteer)	Spring -Overturn (DEQ)	Late - Summer (Volunteer)	Late - Summer (DEQ)	Carlson TSI_{TP} (summer TP)
White	Oakland	12		12		40
Wildwood	Cheboygan	17				
Windover	Clare	*		9		36
Wolf	Lake			11		39
Woods	Kalamazoo	28		24	25	50

* no lake sample received, or sample turned in to late to process
T value reported is less than criteria of detection (5 ug/l)
( ) values in parenthesis are replicate sample results for QA/QC program
(note: all late-summer data coded, recommended laboratory holding time was exceeded before analysis)

APPENDIX 3

1998 COOPERATIVE LAKES MONITORING PROGRAM
CHLOROPHYL PILOT STUDY RESULTS

Lake	County	Chlorophyll *a* (ug/l)								Carlson TSI_{CHL} (chlorophyll)
		Sampling Event					Mean	Median	Standard Deviation	
		May	June	July	Aug.	Sept.				
Arbutus	Grand Traverse	3	3	3	4	3	3.2	3	0.45	41
		(0.9 T)								
Arnold	Clare	0.7 T	0.5 T	2	2	2	1.4	2	0.77	37
Avalon	Montmorency	*	*	1	2	2				
				(1), [1T]						
Bass	Kent	0.2 T	2	4	5	1	2.4	2	2.02	37
Blue	Mecosta	0.1 T	2	3	3	2	2.0	2	1.18	37
			[4]							
Burkhart	Washtenaw	4	4	7	5	10	6.0	5	2.55	46
			(4)							
Christiana	Cass	5	13	5	6	15	8.8	6	4.82	48
Corey	St. Joseph	4	2	2	3	3	2.8	3	0.84	41
						(3), [2]				
Diamond	Cass	0.8 T	2	5	3	3	2.8	3	1.55	41
Fenton	Genesee	2	3	2	5	3	3.0	3	1.22	41
		(3)								
Hackert	Mason	3	2	2	2	3	2.4	2	0.55	37
						[2]				
Harper	Lake	2	2	2	2	3	2.2	2	0.45	37
				(2)						
Horsehead	Mecosta	5	4	5	3	7	4.8	5	1.48	46
Hubbard	Alcona	2	0.7 T	3	3	2	2.1	2	0.95	37
				(2), [1]						
Juno	Cass	7	20	8	10	20	13.0	10	6.48	53
Lake George	Clare	3	6	4	4	1	3.6	4	1.82	44
		[2]			(4)					
Lansing	Ingham	0.9 T	7	6	7	7	5.6	7	2.65	50
				(6)						
Long	Iosco	4	9	8	8	7	7.2	8	1.92	51
					(8), [4,(4)]					
Long	Washtenaw	4	20	21	*	*				
McGilvery	Gladwin	8	6	7	4	8	6.6	7	1.67	50
Mecosta	Mecosta	0.9 T	4	5	0.4 T	3	2.7	3	1.97	41
		(2)	[3]							
Moon	Gogebic	3	*	3	2	*				
			(*)							

APPENDIX 3
1998 COOPERATIVE LAKES MONITORING PROGRAM
CHLOROPHYL PILOT STUDY RESULTS

Lake	County	Chlorophyll *a* (ug/l) Sampling Event May	June	July	Aug.	Sept.	Mean	Median	Standard Deviation	Carlson TSI CHL (chlorophyll)
Nevins	Montcalm	2	1 [1]	3	5	5	3.2	3	1.79	41
Oxbow	Oakland	4 (4)	4	6	*	4	4.5	4	1.00	44
Oxford	Oakland	1	1	2	2 (3)	4	2.0	2	1.22	37
Painter	Cass	9	23	33	32	170	53.4	32	65.89	65
Pentwater	Oceana	18	9	18	26	19	18.0	18	6.04	59
Robinson	Newaygo	23	8	8	14	7 (9), [6]	12.0	8	6.75	51
Round	Mecosta	5	0.6 T [1]	3	5	9	4.5	5	3.09	46
Sapphire	Missaukee	*	5	5	7	5 (5), [3]	5.5	5	1.00	46
School Section	Mecosta	0.1 T	2	2	6	8	3.6	2	3.26	37
Secord	Gladwin	4 [4]	2 (2)	6	4	2	3.6	4	1.67	44
Shingle	Clare	6 [6]	17	3	8	19	10.6	8	7.02	51
Spider	Grand Traverse	0.4 T	5	5	7	5	4.5	5	2.44	46
Stone Ledge	Wexford	5	6	4	11	10	7.2	6	3.11	48
Twin (North)	Cass	0.3 T	4	0.1 T (0.3 T)	0.5 T	0.1 T	1.0	< 1	1.69	< 31
Twin (South)	Cass	0.8 T	1	0.3 T	0.9 T	1	< 1	< 1	0.29	< 31
Van Etten	Iosco	13	10	11	3 [13]	10	9.4	10	3.78	53
Windover	Clare	4	3	2	5	4	3.6	4	1.14	44
Woods	Kalamazoo	6	7	8	22	21 (25), [10]	12.8	8	7.98	51

* no sample received, sample turned in to late to process, or sample contaminated
T value reported is less than criteria of detection (1 ug/l)
( ) values in parenthesis are replicate sample results for QA/QC program
[ ] values in brackets are DEQ side-by-side sample results for QA/QC program