

## Wisconsin Phosphorus Water Quality Standards Criteria:

### Technical Support Document

#### Purpose

As required by s. 281.15(2), Wis. Stats., in adopting any water quality criteria for waters of the state, the Department is required to develop a technical support document. That document must include a description of the scientific data used; the margin of safety applied; the persistence, degradability and nature of the pollutant; and the nature and effects on the designated use.

This document is divided into four parts:

- Federal and state requirements;
- Criteria for rivers and streams;
- Criteria for lakes and reservoirs; and
- Criteria for Great Lakes.

Each part contains a summary of the scientific knowledge, a discussion of EPA's guidance and a description of the Department's process for arriving at the proposed criteria.

#### Part 1: Federal and State Requirements

Water quality standards criteria must meet a number of federal and state requirements, and under s. 303(c)(2)(B) of the Clean Water Act, must be approved by EPA. Federal Regulations require states to adopt water quality standards that are protective of designated uses. Specifically, 40 CFR s. 131.11, states:

“(a) Inclusion of pollutants: (1) States must adopt those water quality criteria that protect the designated use. Such criteria must be based on sound scientific rationale and must contain sufficient parameters or constituents to protect the designated use. For waters with multiple use designations, the criteria shall support the most sensitive use.

“(b) Form of criteria: In establishing criteria, States should:

- (1) Establish numerical values based on:
  - (i) 304(a) Guidance; or
  - (ii) 304(a) Guidance modified to reflect site-specific conditions; or
  - (iii) Other scientifically defensible methods; ...”

In addition, 40 CFR section 131.10(b) requires,

“In designating uses of a water body and the appropriate criteria for those uses, the State shall take into consideration the water quality standards of downstream waters and shall ensure that its water quality standards provide for the attainment and maintenance of the water quality standards of downstream waters.”

S. 281.15(2) of Wisconsin Statutes contains the following requirements:

“In adopting or revising any water quality criteria for the waters of the state or any designated portion thereof, the department shall do all of the following:

- (a) At least annually publish and provide public notice of water quality criteria to be adopted, revised or reviewed in the following year.
- (b) Consider information reasonably available to the department on the likely social, economic, energy usage and environmental costs associated with attaining the criteria and provide a description of the economic and social considerations used in the establishment of the criteria.
- (c) Establish criteria which are no more stringent than reasonably necessary to assure attainment of the designated use for the water bodies in question.”

## Part 2: Phosphorus Criteria for Rivers and Streams

### A. Background

Phosphorus, along with nitrogen, is a major nutrient for plant growth both on land and in water. With few nutrients there is little aquatic plant growth that is needed to sustain fish and aquatic life. Often these conditions are referred to as “oligotrophic” (meaning low in nutrients and high in dissolved oxygen). However, as the amount or concentration of phosphorus increases, the plant growth increases. The point where the plant growth is perceived as a nuisance is often referred to as “eutrophic”. Conditions in between are referred to as “mesotrophic”. At least for inland lakes, phosphorus is often the limiting nutrient. That is, if you limit the amount of phosphorus, you will limit the plant growth; regardless of the amount of nitrogen.

While these concepts are relatively easy to apply to inland lakes, they are not as easy to apply to flowing waters. Flowing waters cover a wide range of situations and the relations between phosphorus, plants and bacteria are more complex. Deep, slow flowing rivers may act similar to lakes, while small fast flowing headwater streams may respond in a very different manner.

Factors that influence biomass growth are nutrients, light and temperature. The amount of light may be limited by overhanging grasses in small streams or overhanging trees in larger streams. Suspended sediment in a stream may limit the light penetration. Flow velocity and unstable substrate in a stream increase disturbance. In an overly simplistic way, unless shaded, light tends to penetrate to the bottom of small streams, favoring algal growth on the beds. In contrast, light does not penetrate to the bottom of larger streams and rivers, favoring growth of algae in the water column. In reality, plant growth in streams can be found on the bottom as macrophytes or as benthic algae; as filamentous algae, such as *Cladophora*, anchored to the bottom, but flowing in the water column; as epiphytic algae attached to plants; as suspended algae; or as floating plants, such as duck weed.

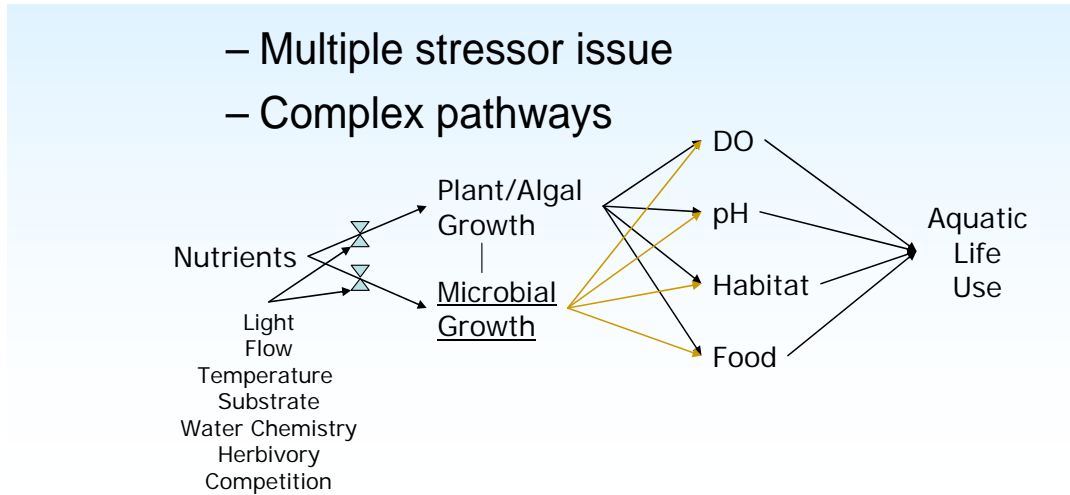
Many people think of the phosphorus-related phenomenon as phosphorus and light promotes algae growth; which causes dissolved oxygen to become decreased in pre-dawn hours. However, Figure 1. illustrates a much more complex picture where phosphorus not only promotes plant growth, but bacteria growth which adds to the dissolved oxygen stress. In addition, there are impacts, such as increases in pH, degradation in habitat and changes in the availability of food. Habitat degradation may be in the form of dense filamentous algae growth inhibiting fish movement or the ability of sight feeding fish to find food. It may also be in the form of increased in macrophyte growth on the stream bed which in



South Fork Jump River near Prentice

turn traps sediment and degrades stream substrate habitat. In some cases, excessive plant growth may inhibit flow and increase flooding. Too much benthic algae growth may eliminate habitat necessary for certain aquatic insects; which in turn reduces food for fish communities.

Figure 1.



Source: Mike Paul, TetraTech

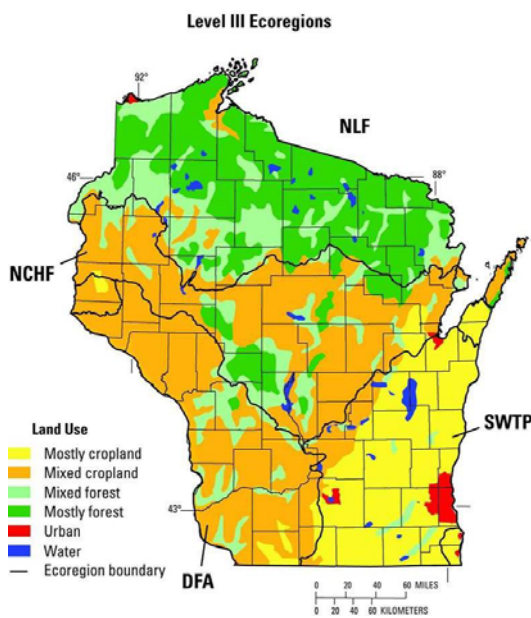
## B. EPA 2000 Nutrient Criteria Technical Guidance Manual: Rivers and Streams

In 2000, EPA published the, “Nutrient Criteria Technical Guidance Manual” that included a summary of the scientific information available at the time of production.<sup>1</sup> Table 1, below contain trophic classification boundaries for stream using a cumulative frequency distribution derived from studies conducted by Dodds, et.al; Van Nieuwenhuysse and Jones; and Omernik.

<sup>1</sup> “Nutrient Criteria Technical Guidance Manual: River and Streams”, EPA-822-B-00-002, July 2000.

Variable	Oligotrophic-mesotrophic boundary	Mesotrophic-eutrophic boundary
Mean benthic chlorophyll (mg/m <sup>2</sup> )	20	70
Maximum benthic chlorophyll (mg/m <sup>2</sup> )	60	200
Sestonic chlorophyll (ug/l)	10	30
Total Phosphorus	25	75

In 2000, EPA published supplemental guidance suggesting phosphorus levels for different multi-state eco-regions for Wisconsin as follows:



- Northern lakes and forests (NLF) -- 12 ug/l
- Northcentral hardwood forests (NCHF) – 29 ug/l
- Driftless area (DFA) – 70 ug/l
- Southeastern Wisconsin till plain (SWTP)– 80 ug/l

The eco-regions are generally based on land cover, rather than features, such as soils, stream gradient, etc. So, for example, the values for the northern lakes and forests are based on clayey soils near Lake Superior as well as sandy soils in the northern part of the lower peninsula of the state of Michigan. All values are based on the 25<sup>th</sup> percentile of available data (25 percent of the data has lower values and 75 percent has higher values).

**EPA Eco-regions for Wisconsin (Source USGS)**

<sup>2</sup> Page 27, “Nutrient Criteria Technical Guidance Manual: River and Streams”, EPA-822-B-00-002, July 2000. Data from:

Dodds, W. K., J. R. Jones, and E. B. Welch. 1998. Suggested classification of stream trophic state: Distributions of temperate stream types by chlorophyll, total nitrogen, and phosphorus. *Water Resources*, 32:1455-1462

Van Nieuwenhuysse, E. E. and J. R. Jones. 1996. Phosphorus-chlorophyll relationship in temperate streams and its variation with stream catchment area. *Can. J. Fish. Aquatic Sci.* 53:99-105.

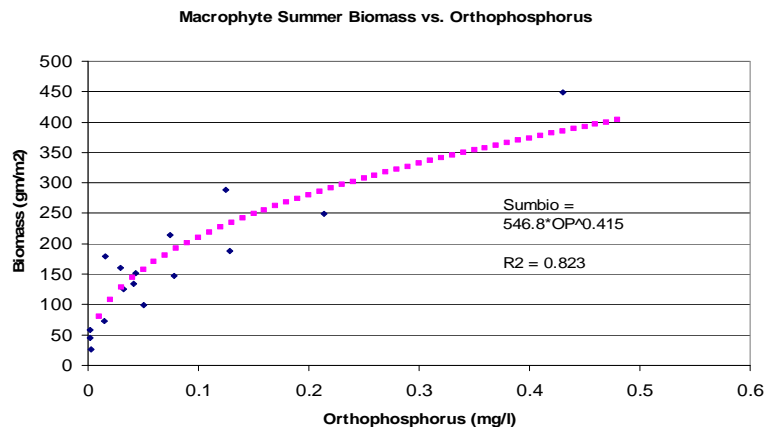
Omernick, J. A., 1977. “Nonpoint Source-Stream Nutrient Level Relationships: A Nationwide Study”. U. S. EPA, Corvallis, OR, 151 pp. EPA 600/3-77-105.

In developing nutrient criteria, EPA allows states to use any of a variety of methods to derive criteria, including:

- The EPA eco-region guidance values;
- The 25<sup>th</sup> percentile of available data within the state, either on a statewide basis or on a geographic basis;
- The 75<sup>th</sup> percentile of reference site data;
- Effects-based stressor-response analysis;
- Effects-based information reported in scientific literature;
- Any other method that can be demonstrated to be protective of the designated uses; and
- Multiple lines of evidence, using any combination of the above.

### C. Earlier Wisconsin Stream Studies

In the early 1980s, the Department conducted a number of “mechanistic” studies on the impacts of phosphorus on streams.<sup>3</sup> These studies showed a strong correlation between phosphorus and late-summer macrophyte and benthic algae biomass. The studies also developed a series of models or submodels that could be used in small stream modeling. The studies did not look at the effect on aquatic communities nor did the researchers recommend specific criteria. However in recent discussions with some of the researchers, they believed that the water quality criterion for dissolved oxygen was not met at concentrations of orthophosphorus of about 0.6 mg/l.



### D. Recent Wisconsin Stream Studies

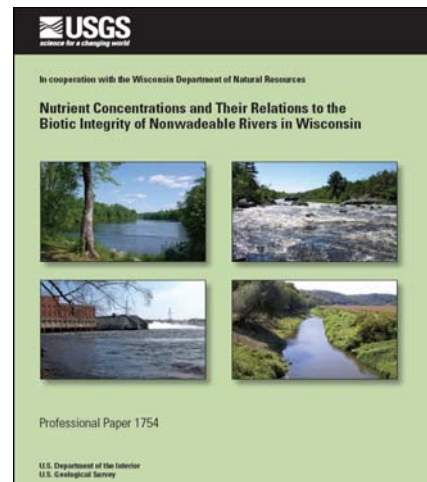
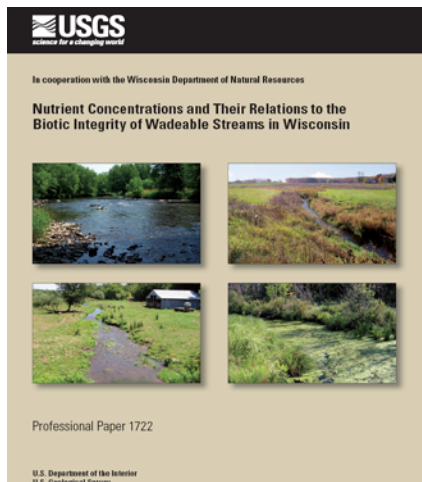
After reviewing EPA’s guidance for streams and rivers, the Department decided to enter into a research project with the US Geological Survey (USGS) on Wisconsin streams and

<sup>3</sup> “Impacts of Phosphorus on Streams”, 1984, Wisconsin Department of Natural Resources.

rivers to develop a statewide data base and scientific information needed to determine nutrient criteria. The parameters selected and the sampling protocols were developed consistent with EPA guidance. Specifically, the studies were developed and conducted do the following:

1. Describe how nutrient – both phosphorus and nitrogen – concentrations and the biotic community vary throughout Wisconsin.
2. Determine which environmental characteristics are most strongly related to the distribution of nutrient concentrations.
3. Determine reference water quality and biotic conditions for different geographic areas across the state.
4. Determine how the stream biotic communities respond to changes in nutrient concentrations.
5. Determine the best regionalization scheme to describe the patterns in reference conditions and responses in water quality and in the biotic community.
6. Develop new indices or algorithms to estimate nutrient concentrations in streams from a combination of biotic indices.

The study results are reported in two documents jointly prepared by Department research staff and USGS staff. The first report, “Nutrient Concentrations and Their Relations to the Biotic Integrity of Wadeable Streams in Wisconsin”, was based on analyzing data



from 240 smaller and larger streams collected in 2001, 2002 or 2003.<sup>4</sup> The second report, “Nutrient Concentrations and Their Relations to the Biotic Integrity of Nonwadeable Rivers in Wisconsin”, was based on analyzing data from 42 rivers collected in 2003.<sup>5</sup> For most of the 282 study sites, fish and aquatic insect information was collected up to a few years in advance of the water quality information. Since the

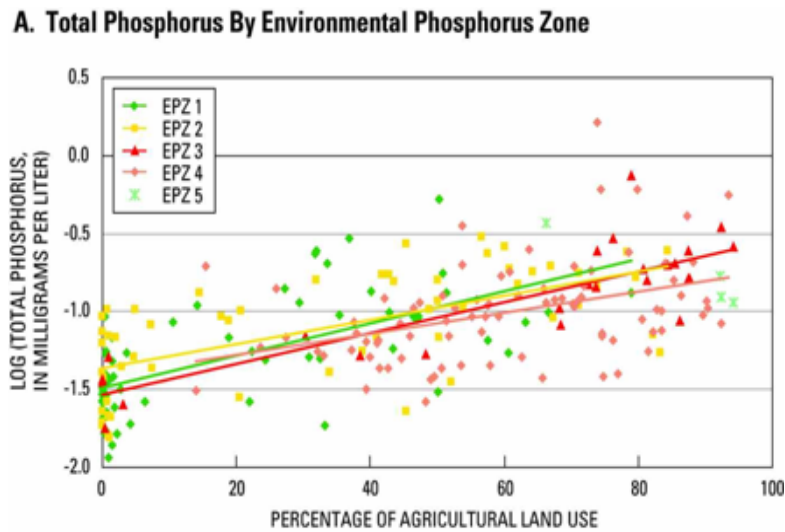
<sup>4</sup> Robertson, D. M., Graczyk, D. J., Garrison, P. J., Wang, L., LaLiberte, G., and Bannerman, R., “Nutrient Concentrations and Their Relations to the Biotic Integrity of Wadeable Streams in Wisconsin”, USGS Professional Paper 1722, 2006.

<sup>5</sup> Robertson, D. M., Weigel, B. M., Graczyk, D. J., “Nutrient Concentrations and Their Relations to the Biotic Integrity of Nonwadeable Rivers in Wisconsin”, USGS Professional Paper 1754, 2008.

results of the studies are described in detail in these reports, they are only summarized in this report.

### Geographic Regions

The first study on wadeable streams analyzed EPA's level III eco-regions and phosphorus zones defined based on information from the 240 streams. Although the developed phosphorus zones better described the regional characteristics of the phosphorus concentrations, the derived correlations explained very little of the variation between zones. Therefore, for purposes of developing phosphorus criteria, geographic regions were not warranted.<sup>6</sup> This does not mean that the potential for achieving the water quality criterion will be the same for each, but that the stream system responds to phosphorus inputs in a very similar manner in all of the phosphorus zones.



From Figure 12A. Robertson, et. al. USGS Professional Paper 1722

### Responses to Total Phosphorus

Researchers within the Department and USGS used a variety of statistical methods to analyze the data from both the wadeable and non-wadeable streams and rivers. A key product of these analyses is the development of response thresholds or breakpoints. For non-wadeable streams and rivers, a breakpoint of 0.064 mg/l total phosphorus was derived, while for wadeable streams the breakpoint was 0.070 mg/l total phosphorus.

The report on non-wadeable streams and rivers contains the following summary explanation on the analysis conducted:

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<sup>6</sup> Robertson, D. M, et. al., 2006

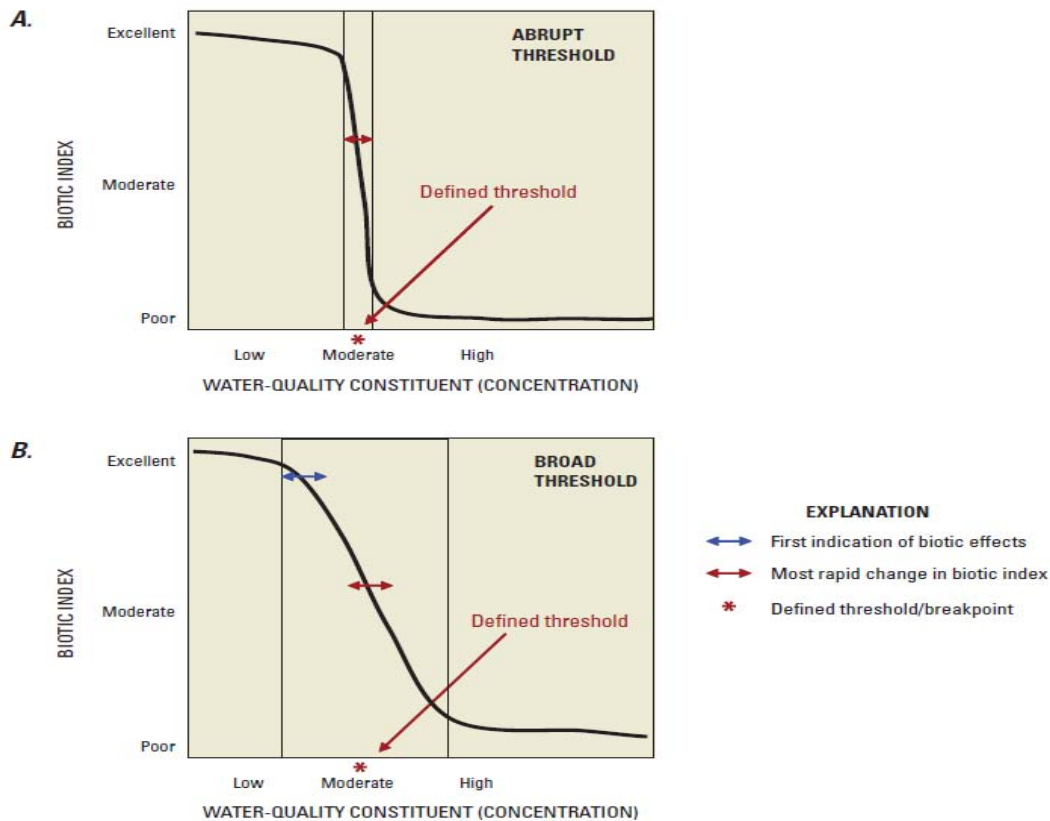


## “Regression-Tree Analysis to Define Thresholds of Breakpoints

“One approach to defining nutrient criteria is to identify thresholds or breakpoints in the response between nutrient concentrations and biotic indices (U.S. Environmental Protection Agency, 2000a). Defining a specific threshold or breakpoint in a response curve of a specific biotic index is straightforward if the curve is well defined and has an abrupt breakpoint (fig. 3A); however, the response curves in many biotic indices are poorly defined and have broad breakpoints (fig. 3B). In the case of indices with broad thresholds, it is very difficult to define the concentration at which the index first begins to change. For the biotic indices, the thresholds or breakpoints were defined as the concentrations at which the rate of response is greatest and, therefore, represents a critical concentration with ecological significance. Regression-tree analyses (Breiman and others, 1984) were used to determine thresholds or breakpoints (most abrupt responses) in the relations between nutrient concentrations and a biotic index. Regression-tree analysis sequentially partitions the data for each independent variable into two groups and examines the differences in the mean values of the dependent variable on the basis of the least-square-error criterion. The least-square-error criterion allows identification of breakpoints that maximize intergroup means relative to the intragroup variance. Only one independent variable (for example, TP or TN) and one dependent variable (for example, IBI) were used at a time; thus, the regression-tree analysis was forced to divide the data for the dependent variable into two groups with highly contrasting means relative to intragroup variances. To determine whether the intergroup means identified by the breakpoints in TP and TN concentrations were statistically different, two-sample student t-tests were done on the basis of assumed equal and unequal variances.”<sup>7</sup>

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<sup>7</sup> P. 15, Robertson, et. al. 2008



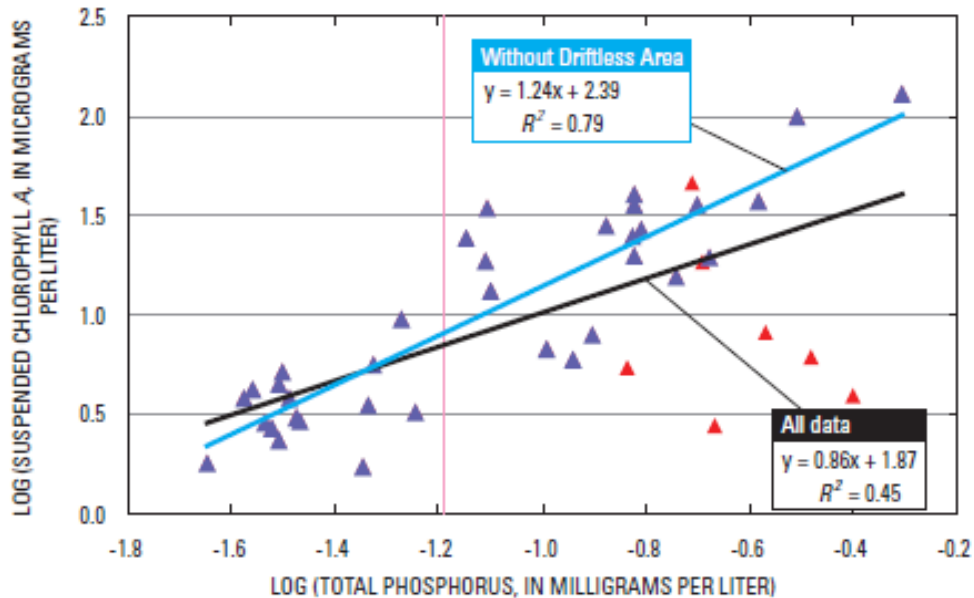
**Figure 3.** Definition of water-quality thresholds in responses of biotic indices to changes in water quality: **A**, biotic indicator with an abrupt threshold and **B**, biotic indicator with a broad threshold.

Source: USGS Professional Paper 1754

## 1. Suspended Chlorophyll

Suspended (sestonic) algae samples were collected monthly between May and October for all wadeable and non-wadeable stream and river sites. As anticipated, the non-wadeable sites would be more “lake-like” and result in a strong correlation between total phosphorus and the amount of suspended algae as measured as chlorophyll *a*. The median suspended chlorophyll concentrations in non-wadeable streams and rivers ranged from 1.74 to 130 ug/l; covering the full range of oligotrophic to eutrophic conditions in the EPA guidance of rivers and streams. The Spearman correlation coefficient between total phosphorus and suspended chlorophyll *a* was 0.89. The ratio of dissolved phosphorus to total phosphorus was lower than for wadeable streams; indicating that more of the dissolved phosphorus was being taken up in the suspended algae.

The relation between total phosphorus and suspended chlorophyll *a* can be masked by shading from suspended sediment. For example, in turbid streams there may not be a positive correlation between total phosphorus and suspended chlorophyll *a*. As shown in Figure 10 a., of the USGS Professional Paper 1754, there is a substantially stronger correlation, if turbid streams and rivers are excluded from the analysis. For example, the r-squared for the equation excluding the driftless area of 0.79 is much greater than the r-squared value for the entire stateside data set.



Source: Figure 10a., USGS Professional Paper 1754

The equation in the above figure where driftless area streams and rivers are excluded is virtually the same as the equation developed by the Department using its long-term trends data set and very similar to an equation based on river studies in Minnesota.<sup>8,9</sup> However, the equation is virtually linear; raising questions on the appropriateness of the breakpoint.

Using the entire data set, the total phosphorus breakpoint reported for non-wadeable stream and rivers was 0.064 mg/l.<sup>10</sup> However, using the equation that excludes driftless area streams and rivers, a suspended chlorophyll *a* concentration of about 8 ug/l is predicted; an oligotrophic condition as indicated in the EPA guidance for streams and rivers. This indicates that a phosphorus criterion for rivers could be a higher concentration than the breakpoint identified in the analysis.

<sup>8</sup> P. 35, “Wisconsin’s Long Term Trend Water Quality Monitoring Program for Rivers”, Wisconsin Department of Natural Resources, November 2006

<sup>9</sup> P. 44, “Establishing Relationships Among In-stream Nutrient Concentrations, Phytoplankton and Periphyton Abundance and Composition, Fish and Macroinvertebrate Indices, and Biochemical Oxygen Demand in Minnesota USA Rivers” Minnesota Pollution Control Agency, 2003

<sup>10</sup> P. 71, Robertson, et. al, 2008

For wadeable streams, the correlation between total phosphorus and suspended chlorophyll a was one of the stronger correlations as indicated by the Spearman correlation coefficient of 0.44. However, only 10 of the 240 streams had suspended chlorophyll a concentrations that exceeded the EPA guidance document oligotrophic-mesotrophic boundary of 10 ug/l and only two of 240 sites exceeded the mesotrophic-eutrophic boundary of 30 ug/l. The low suspended chlorophyll a values in the shallow streams is not unexpected since, unless shaded or masked by turbid conditions, light penetrates to the bed of the stream and favors the growth of macrophytes or benthic algae. The low concentrations of suspended chlorophyll a for wadeable streams also indicate that the correlation with total phosphorus may not be the best or primary correlation for use in developing criteria for streams.

## 2. Turbidity

Since EPA guidance includes some measure of clarity or turbidity as a nutrient response variable, measurement of clarity using a 120 centimeter Secchi tube was one of the parameters measured and analyzed for Wisconsin streams and rivers. The inclusion of a measure of turbidity as a response variable for nutrients is generally based on the growth of suspended algae decreasing clarity. However, for many of the Wisconsin streams a lack of clarity is also a response to suspended sediment that is not a nutrient response parameter. Often it has the opposite effect of shading stream beds and inhibiting or restricting algal growth. This duality makes interpretation of the Secchi tube depth results more difficult. In addition, it should be noted that turbidity or clarity is not a biotic response in streams.

For wadeable streams, the Secchi tube depth decreased with increased phosphorus concentrations. The readings ranged from 20 centimeters to 120 centimeters with a corresponding total phosphorus breakpoint of 0.106 mg/l (106 ug/l). Many of the sites had median Secchi depth values that met or exceeded the maximum depth of 120 centimeters. The correlation was one of the strongest for the wadeable streams.

For non-wadeable streams, a similar general trend was apparent. Again, the Secchi tube depth decreased with with increasing total phosphorus. However, this trend was not evident for driftless area streams. The derived breakpoint for total phosphorus based on Secchi depth was 0.091 mg/l (91 ug/l).

## 3. Benthic Chlorophyll a

In general, the EPA guidance for smaller, shallower streams is based on the concept that when light is adequate to reach the bed of a stream, the impact of phosphorus will be growth of algae on rocks and debris on the bed of the stream. However, much of the impact may be in the form of filamentous algae



anchored to the bed of the stream but growing up into the water column. In some past research, benthic algae measurements explicitly excluded the filamentous algal growth. Generally, non-wadeable streams are considered as too deep to support substantial benthic algal growth. Benthic algae growth is also often very subject to scour. Neither the EPA guidance nor the Wisconsin stream studies developed correlations with macrophyte growth; although many of the Wisconsin streams have substantial portions of their beds covered with macrophytes.

The correlation between total phosphorus and benthic chlorophyll a as not found to be a strong correlation with a Spearman correlation coefficient of 0.33. Nor did the benthic chlorophyll a concentrations correspond well with stream habitat studies that included measurements of the percent of the bottom covered with algae. The derived breakpoint was 0.039 mg/l for total phosphorus. The places the breakpoint for benthic chlorophyll a within the range of pre-western European settlement reference conditions for much of the state.<sup>11</sup>

#### 4. Diatom Indices

Diatoms are a form of algae with a silicate shell with many species that tend to be found on stream beds or clinging as a brown substance to filamentous algae, such as Cladophora. They are found in both freshwater and marine waters and in many environments play a very substantial role in primary productivity within the system. Analysis of diatoms has been used for water quality analysis around the world. Various species have been identified as tolerant or sensitive to various stressors, such as tolerant to low dissolved oxygen conditions or sensitive to low dissolved oxygen conditions. As part of the wadeable stream analysis, diatoms were collected and assessed using three indices: a diatom-nutrient index; a diatom-siltation index; and a diatom-biotic index.

For wadeable streams, the correlation between total phosphorus and the various diatom indices were moderate (Spearman correlation coefficient of 0.46 or 0.47) to high (0.60) for the diatom siltation index. The derived breakpoints for the three indices tended to be relatively consistent and were as follows:

Index <sup>12</sup>	Total Phosphorus Breakpoint (mg/l)
Diatom Nutrient Index	0.057
Diatom Siltation Index	0.074
Diatom Biotic Index	0.072

<sup>11</sup> Page 87, Robertson, et. al., 2006

<sup>12</sup> Page 55, Robertson, et. al., 2006

## 5. Macroinvertebrates

Macroinvertebrates were collected at all wadeable and non-wadeable streams and rivers; either during the year of the water chemistry sampling or in a few years prior to the sampling. Most of the macroinvertebrate metrics are responsive to stresses, such as low dissolved oxygen, but the organisms are also responsive to toxics, flow disruption and thermal stressors. Certain groups of macroinvertebrates may also respond in other manners. Scrapers, such as mayflies, graze on periphyton (benthic sources), particularly diatoms, so their numbers increase with an abundance of periphyton. But increased filamentous algae tend to interfere with their feeding. Filterers, often use filamentous algae as attachment sites, so a preponderance of filterers may be an indication of nutrient rich conditions.<sup>13</sup>

The wadeable and non-wadeable stream and river studies used a variety of metrics to interpret the macroinvertebrate information. For wadeable streams, three community indices out of the eight metrics analyzed had stronger correlations for macroinvertebrates: The Hilsenhoff Biotic Index (HBI); the percent of individuals that were Ephemeroptera, Plecoptera or Trichoptera (EPTN%); and the percent of the taxa that were Ephemeroptera, Plecoptera or Trichoptera (EPTTX%). Overall, the HBI had one of the stronger correlations for all parameters based on the Spearman rank correlation coefficient. The derived total phosphorus breakpoints for the three community indices were 0.088, 0.087 and 0.091 mg/l, respectively<sup>14</sup>

For non-wadeable streams and rivers, 14 metrics were analyzed, and four were determined to be statistically significant and have a stronger Spearman rank correlation coefficient as listed below:<sup>15</sup>

Metric	Total Phosphorus Breakpoint (mg/l)
Species Richness	0.150
Mean Pollution Tolerance Value	0.064
% Individuals Ephemeroptera	0.040
Hilsenhoff Biotic Index	0.150

Unlike the three community indices for wadeable streams, the non-wadeable stream breakpoints show a very wide range. Based on the general depth of non-wadeable waters and the wide range of breakpoints, macroinvertebrates are not necessarily the best biotic indicator for developing phosphorus criteria.

<sup>13</sup> Pages 8 to 27, Lillie, R. A., Szczytko, S. W., Miller, M. A., "Macroinvertebrate Data Interpretation Guidance Manual", Wisconsin Department of Natural Resources, 2003.

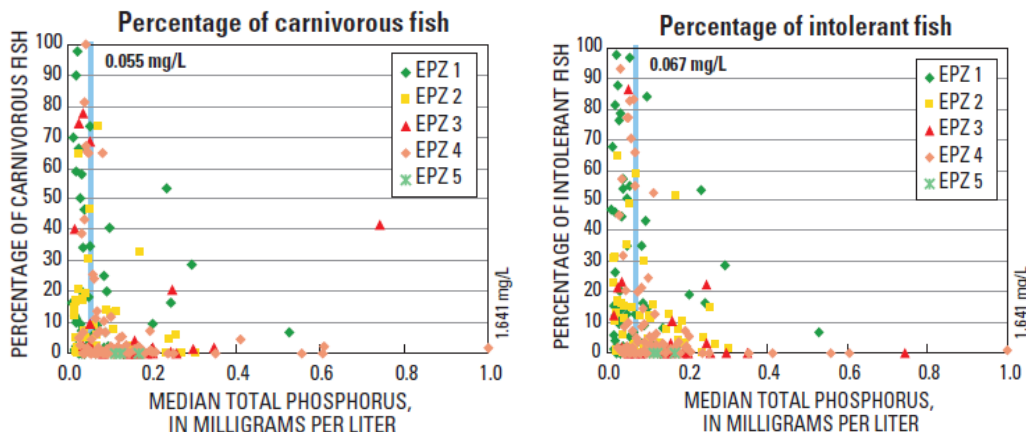
<sup>14</sup> Page 69, Robertson, et. al., 2006.

<sup>15</sup> Page 48, Robertson, et. al., 2008.

## 6. Fish Indices

Fish often represent the overall aquatic community health. If one or more critical parts of the community is impacted, such as spawning beds covered with silt, lack of water column clarity or low dissolved oxygen, it will likely show up as a deficiency in the fish community. Metrics commonly evaluated include the broad spectrum Fish Index of Biotic Integrity (Fish IBI) and more focused metrics such as the percent of intolerant fish. Lithophilic spawners, for example, need fairly clean, hard substrate, somewhere within a reasonable spawning migration distance and relatively high dissolved oxygen levels. In contrast, nest guarders fan the eggs to keep them oxygenated and clean. The percent suckers generally include redhorses, the intolerant blue sucker, intolerant northern hog sucker, and occasionally the (sporadic) intolerant spotted sucker; all requiring good water clarity and clean substrate.

For wadeable streams eight metrics were analyzed, with the stronger correlations with total phosphorus were with the percent carnivores, intolerant species, the percent carnivores and the Fish IBI, in decreasing order of their Spearman rank correlation coefficients.<sup>16</sup> In addition, as shown below, the graphs of total phosphorus and percent carnivores and percent intolerant fish more than any other chart show an abrupt threshold.



Source: From Figure 29, USGS Professional Paper 1722

For non-wadeable streams and rivers, eleven fish indices were analyzed. Of the eleven, six had stronger correlations. In general, the correlations, based on the Spearman rank correlation coefficient are stronger than those for wadeable streams. Those six indices are shown below roughly in decreasing order of the strength of the correlation.

Indicator	Total Phosphorus Breakpoint (mg/l) <sup>17</sup>
No. of intolerant species	0.139
% of suckers by weight	0.091

<sup>16</sup> Page 74, Robertson, et. al, 2006.

<sup>17</sup> Page 71, Robertson, et. al. 2008.

Large river fish IBI	0.139
% individuals that are river species	0.079
No. of river species	0.147
% individuals that are lithophilic spawners	0.055

## E. Use of Breakpoints and Thresholds in Calculating Criteria

### 1. Original Analysis

Given the suite of breakpoints for the wadeable and non-wadeable streams and rivers from the USGS/DNR studies described above, the Department convened a multi-agency work group of scientists to recommend phosphorus criteria values. The work group recommended separate concentrations for streams (wadeable) and rivers (non-wadeable).

#### Streams

For streams, the work group suggested a procedure where each of the four groups: water chemistry, benthic indices, macroinvertebrates and fish, be included in a community-type analysis and that each group be given equal weight. Further, the work group recommended that the average of the strongest indices for each group be calculated. Thus, the procedure became an “average of average” as shown in the table below.

<b>Water Chemistry</b>	<b>ug/l</b>
Secchi Depth	106
Suspended Chlorophyll a	70
<i>Average for category</i>	<b>88</b>
<b>Benthic</b>	
Benthic Chlorophyll a	39
Diatom Nutrient Index	57
Diatom Siltation Index	74
Diatom Biotic Index	72
<i>Average for category</i>	<b>61</b>
<b>Macroinvertebrates</b>	
Hilsenhoff Biotic Index	88
Percent EPT Individuals	87
Percent EPT Taxa	91
<i>Average for category</i>	<b>89</b>



<b>Fish</b>	
Fish IBI	55
Percent Carnivores	55
Percent Intolerant	67
<i>Average for category</i>	<b>59</b>
<i>Average of category averages</i>	<b>74</b>
<i>Rounded</i>	<b>75</b>

The “average of average” is an approach that identifies a value near the middle of the cluster. The work group also considered using the lowest breakpoint, such as 55 ug/l for fish or 59 ug/l for the category of fish, but the work group believed that the strength of the analysis was in the “weight of all of the evidence” and not in a single correlation. Weighted averages were also considered, using the Spearman rank as the weighting factor.

A mini-sensitivity analysis was conducted where benthic chlorophyll a was excluded due to its relatively weak correlation and Secchi depth was excluded due to the sediment turbidity aspect. Then similar analyses were done using two or three indices per category, where appropriate. The results ranged from 69 to 75 ug/l.

### Rivers

A similar analysis was conducted for rivers (non-wadeable) with the results shown in the table below.

<b>Water Chemistry</b>	<b>ug/l</b>
Secchi Depth	91
Suspended Chlorophyll a	64
<i>Average for category</i>	<b>78</b>
<b>Macroinvertebrates</b>	
Species Richness	150
Hilsenhoff Biotic Index	150
Pollution Tolerance	64
Percent Ephemeroptera	40
<i>Average for category</i>	<b>101</b>
<b>Fish</b>	
Large River Fish IBI	139
% of weight that is suckers	91
No. of intolerant species	139

% of individuals that are river species.	79 <sup>18</sup>
<i>Average for category</i>	<i>112</i>
<i>Average of category averages</i>	<i>97<sup>19</sup></i>
<i>Rounded</i>	<i>100</i>

## 2. 2010 Review

In early 2010 EPA released additional guidance to states on use of empirical methods to derive criteria values. The guidance was developed with involvement of a committee convened by EPA's Science Advisory Board. In early 2010, the Department, with the advice and assistance of EPA, conducted a review of the original analysis using key elements on the new advisory guidance. This review is described below.

Wadeable streams. As discussed above, there is a suite of breakpoints and thresholds from the study of wadeable streams with varying correlation strengths. For wadeable streams, no single correlation is significantly stronger than that others and no single biotic response parameter is uniquely more applicable than the others. The table below compiles a number of factors considered in reviewing and selecting correlations to use.

Screening and Weighting of Correlations with Response Factors for Wadeable Streams						
Characteristic/Index (1)	Breakpoint (ug/l)	Statistical Correlation (2)	Response Curve (3)	Focused Index (4)	Other (5)	Total Points
Water Chemistry						
<i>Secchi depth</i>	<i>106</i>	<i>-1</i>				<i>-1</i>
Benthic						
<i>Benthic chlorophyll a</i>	<i>39</i>	<i>0</i>		<i>1</i>	<i>-1</i>	<i>0</i>
Diatom Nutrient Index	57	2		1		3
Diatom Siltation Index	74	3				3
Diatom Biotic Index	72	2				2
Macroinvertebrates						
Hilsenhoff Biotic Index	88	2		1		3
% EPT Individuals	87	0		1		1
%EPT Taxa	91	2		1		3
<i>% Scrapers</i>	<i>NR</i>	<i>-1</i>		<i>1</i>		<i>0</i>
Fish						
<i>Fish IBI</i>	<i>55</i>	<i>0</i>				<i>0</i>
% Carnivores	55	1	1	1		3
<i>% Omnivores</i>	<i>NR</i>	<i>-1</i>		<i>1</i>		<i>0</i>

<sup>18</sup> This is the corrected value. This decreases the average for the category from 129 ug/l to 112 ug/l and the overall average from 103 ug/l to 97 ug/l.

<sup>19</sup> A variety of weighted averages were calculated using different combinations of indices from the same data set with the results ranging from 97 to 105 ug/l.

% Intolerant Species	67	0	1	1		2
% Tolerant Species	NR	-1		1		0
NR = not reported						

Explanation of Factors

1. Only those determined to be significantly significant ( $p < 0.05$ ) are listed. See Tables 5, 11, 15 and 18 in Professional Paper 1722
2. Based on Spearman rank correlation coefficients from tables 5, 11, 15 and 18 in Professional Paper 1722, as follows:

< 0.3 (absolute value)	-1
0.30 to 0.39	0
0.40 to 0.49	1
0.50 to 0.59	2
> 0.60	3

3. Abrupt response curves given an additional point
4. Focused indices are given additional weight. Broad spectrum indices are not.
5. Quality concerns associated with benthic chlorophyll values. Secchi depth may reflect suspended sediment, which masks effects of nutrients. But, a negative factor was not applied.

The breakpoints for all correlations with positive points were averaged by category. The rationale for the averaging is that there is a great similarity between some of the indices and some of the indices are sub-indices of others. For example, the percent EPT individuals is a component of the Hilsenhoff biotic index. The subcategory averages are:

Benthic indices – 67 ug/l  
 Macroinvertebrate indices – 89 ug/l  
 Fish Indices – 61 ug/l

The average of the three category values is 72 ug/l. However, these values could be looked upon as defining a range for the criterion for streams.

To better interpret this information two other pieces of information were also used. Using natural reproduction of trout as an indicator of meeting designated uses, all of the Class I trout streams in the wadeable stream study had median total phosphorus concentrations of 74 ug/l or less. This does not mean that a class I trout stream could not have a total phosphorus concentration of greater than 74 ug/l. But it does suggest that a criterion can be as high as 74 ug/l and be protective of fish and aquatic designated use.

As another line of evidence, through a study of reference streams in southwestern Wisconsin, Miller and others found a 75<sup>th</sup> percentile total phosphorus value of 70 ug/l.<sup>20</sup>

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<sup>20</sup> P. 49, Miller, M. A., Colby, A.C.C., Kanehl, P., “Report on the Regional Environmental Monitoring and Assessment Program Study of Wadeable Streams in the Driftless Area Ecoregion in Western Wisconsin, Wisconsin Department of Natural Resources, 2006.

EPA has identified the 75<sup>th</sup> percentile of reference streams as an acceptable method for nutrient criteria development.

Based on the information from the wadeable stream study, the review of streams clearly meeting the fish and aquatic life designated use and the information on reference streams in southwest Wisconsin, the Department continued to propose a total phosphorus criterion concentration of 75 ug/l for Wisconsin streams.

Non-wadeable Streams and Rivers. In general and as anticipated, the correlations between total phosphorus and the suite of biotic indices were stronger than those for wadeable streams and rivers. On the other hand, the spread of breakpoints for biotic indices is broader and there are no abrupt thresholds in the response curves. There is no indication that any single correlation is more meaningful than another from those identified as stronger or medium. The table below shows the results of the same screening and weighting analysis as conducted for wadeable streams.

Screening and Weighting of Correlations with Response Factors for Non-Wadeable Streams and Rivers						
Characteristic/Index (1)	Breakpoint (ug/l)	Statistical Correlation (2)	Response Curve (3)	Focused Index (4)	Other (5)	Total Points
Water Chemistry						
Suspended chlorophyll a	64	3	-1	1	1	4
Secchi depth	91	3				3
Macroinvertebrates						
Species Richness	150	2				2
% <i>Ephemeroptera</i>	40	0				0
% <i>Plecoptera</i>	148	0				0
Mean Pollution Tolerance Index	64	1		1		2
Hilsenhoff Biotic Index	150	0		1		1
Fish						
Fish IBI	139	2				2
# River species	79	1				1
# <i>Suckers</i>	NR	0				0
# Intolerant Species	139	3		1		3
% River Species	NR	1				1
% Lithophilic spawners	55	1				1
% Sucker	91	2		1		3
% Insectivores	NR	1				1
% <i>with Disease</i>	NR	0				
NR = not reported						

Averaging within a category results in 76 ug/l, 121 ug/l and 101 ug/l for water chemistry, macroinvertebrates and fish, respectively. The average of the three categories is 99 ug/l.

There is a need however, to delve deeper into the results. It is not surprising that the fish indices are stronger than the macroinvertebrates. Giving both the same weight raises some concern. Looking only at the strongest for fish and macroinvertebrates, those with two points or more, the breakpoints from low to high are 64, 91, 139, 139 and 150. The average of only those is 116 ug/l.

The water chemistry breakpoints also merit further discussion and analysis. To some degree and in some locations, the turbidity as measured by Secchi tube depth results in the effects of phosphorus being masked. In other locations, it is a measurement of nutrient related turbidity. Suspended chlorophyll a with the turbid driftless area excluded, provides a very strong correlation. However, the total phosphorus – suspended chlorophyll a relation is linear; making the usefulness of the breakpoint questionable. As an additional analysis, the equation of this relation can be used to predict chlorophyll a concentrations as shown in the table below.

Total phosphorus concentration (ug/l)	Calculated suspended chlorophyll a concentration	Comment
64 ug/l	8 ug/l	Oligotrophic condition in EPA's guidance
80 ug/	10 ug/l	Mesotrophic condition
105 ug/l	15 ug/l	Mesotrophic condition
120 ug/l	18 ug/l	
130 ug/l	20 ug/l	Considered a nuisance condition in lakes

An acceptable range for suspended chlorophyll a is like in the range of 10 to 15 ug/l, which corresponds to total phosphorus concentrations of about 80 ug/l to 105 ug/l. Using this analysis, a phosphorus concentration of 105 ug/l is likely an upper boundary.

Using an upper boundary of 105 ug/l based on suspended chlorophyll a, and giving greater emphasis to the fish category value of 101 ug/l, there is merit in a proposed criterion for rivers of 100 to 105 ug/l. The Department continued to propose 100 ug/l as the criterion.

### Part 3. Proposed Phosphorus Criteria for Lakes and Reservoirs

Phosphorus, an essential element for plant and animal growth, is generally considered the key element in controlling algae and macrophyte growth in lakes. Although a certain amount of phosphorus is considered necessary to support aquatic life, too much phosphorus fosters a number of concerns associated with eutrophic conditions. In general, the U. S. Environmental Protection Agency states that eutrophication effects the composition of fisheries, including shifting the population to less desirable species; inhibits recreational enjoyment, including swimming and scenic beauty; and restricts use for drinking water supply. Very severe eutrophic conditions may also cause human health concerns, such as toxic conditions associated with blooms of cyanobacteria (blue-green algae). Consistent with Justus von Leibig's Law of the Minimum expressed more than 170 years ago, where growth is controlled not by the total of resources available, but by the scarcest resource, most often phosphorus is the "scarcest" nutrient and the one that controls plant growth in lakes and streams. This was confirmed in the 1970's when Vollenweider concluded that in deeper (stratified) lakes algal growth is directly related to phosphorus inputs. In the past few decades there have been a number of refinements to these major concepts.

To describe the conditions in lakes, a number of classification systems and terms have been used. For the "trophic" status of lakes, oligotrophic (few nutrients), mesotrophic, eutrophic (many nutrients) and hypereutrophic are terms commonly used. The Carlson Trophic Status Index is one of the most commonly used systems to describe the trophic status of lakes. Carlson describes ranges within the lake trophic status continuum as follows (with transition zones included):

- Oligotrophic – Clear water, oxygen throughout the year in the hypolimnion (bottom waters), salmonid (e.g. lake trout or cisco) in deep lakes. Phosphorus concentrations 6 ug/l or less. Chlorophyll a concentrations of 1 ug/l or less.
- Oligotrophic – Mesotrophic – Deeper lakes still exhibit classic oligotrophy, but some shallower lakes will become anoxic (no oxygen) in the hypolimnion during the summer. Phosphorus concentrations of 6 to 12 ug/l. Chlorophyll a concentrations of 1 to 3 ug/l.
- Mesotrophic – Water moderately clear, but increasing probability of anoxia in hypolimnion during summer. Phosphorus concentrations of 12 to 25 ug/l. Chlorophyll a concentrations of 3 to 8 ug/l.
- Mesotrophic – Eutrophic – Lower boundary of eutrophy; decreased transparency, anoxic hypolimnia during the summer, macrophyte problems evident, warm-water fisheries only. Phosphorus concentrations of 25 to 50 ug/l. Chlorophyll a concentrations of 8 to 25ug/l.

- Eutrophic – Dominance of blue green algae, algal scums probable, extensive macrophyte problems. Phosphorus concentrations of 50 to 100 ug/l. Chlorophyll a concentrations of 25 to 60 ug/l.
- Eutrophic – Hypereutrophic – Heavy algal blooms possible throughout summer, dense macrophyte beds, but extent limited by light penetration. Often classified as hypereutrophic. Phosphorus concentrations of 100 to 150 ug/l. Chlorophyll a concentrations of 60 to 150 ug/l.
- Hypereutrophic – Algal scums, summer fish kills, few macrophytes, dominance of rough fish. Phosphorus concentrations exceeding 175 ug/. Chlorophyll a concentrations exceeding 150 ug/l.

It should be noted that other factors, such as physical characteristics do cause lakes to not exactly fit these descriptions. For example, a deeper lake with a large volume in the hypolimnion may show oligotrophic conditions at higher phosphorus concentrations than a deeper lake with a small hypolimnion.

### **Proposed Phosphorus Criteria**

#### Objectives.

In reviewing the scientific information, five objectives were considered.

1. Minimize the frequency of nuisance algal blooms caused by cultural sources;
2. In shallow lakes, minimize the shift from macrophyte domination to algae domination;
3. Provide for safe swimming conditions;
4. Sustain sport fisheries; and
5. Minimize the potential for “toxic” algae conditions.

Of the five objectives, information on three objectives seemed adequate for phosphorus criteria development: minimizing the frequency of nuisance algal conditions, minimizing shifts in aquatic plant communities and sustaining fish communities. For the toxic algae conditions, scientific information is lacking on the correlation between specific phosphorus concentrations and “toxic” conditions.

Lake Types. Criteria are proposed for various lake types generally based on depth, whether they have a surface outlet or not and whether they support a coldwater fishery in deeper waters. Many deeper lakes tend to stratify seasonally. That is, an upper water

layer and a lower water layer tend to form based on temperature and other factors and there is little mixing between the two. These lake types are an aggregate of the lake types identified by the lake assessment work group. They are as follows:

- Shallow – Drainage lakes

These lakes tend not to stratify. They have a maximum depth of less than about 18 feet with more than 50 percent of the area potentially supporting submerged aquatic vegetation and have a surface outlet. They generally support a natural community consisting of a single game species and panfish.

- Deep – drainage lakes

These lakes tend to stratify. They have a lake depth of greater than about 18 feet with less than 50 percent of the lake having the potential to support submerged aquatic vegetation, a water column that tends to have temperature stratification, and a surface outlet. They support a natural fish community with two or more game fish species, and panfish are common.

- Deep two-story lakes

These lakes are a subset of the deeper lakes, but have a greater than 50 foot maximum depth. The key element of this group is that they either support or have the potential to support a coldwater fishery in the lower strata of the lake. Given the relatively small number of these lakes, it is possible that a list of the specific two-story lakes may be used to define the group.

- Shallow – seepage lakes

These lakes tend not to stratify. They have a maximum depth of less than about 18 feet with more than 50 percent of the area potentially supporting submerged aquatic vegetation and lack a surface outlet. They generally support a natural community consisting of a single game species and panfish.

- Deep – seepage lakes

These lakes tend to stratify. They have a lake depth of greater than 18 feet with less than 50 percent of the lake having the potential to support submerged aquatic vegetation, a water column that tends to have temperature stratification, and a lack of surface outlet. They support a natural fish community with two or more game fish species and panfish are common.

- Reservoir – shallow

Reservoirs are man-made impoundments and exhibit both lake and riverine characteristics and generally have a hydraulic residence time of 14 days or more



based on a summer 120 day Q 10 flow. To differentiate reservoirs from lakes with level controls, the outlet control structure of a reservoir generally increased the water depth by a factor of four or greater. Shallow reservoirs are otherwise defined the same as shallow – drainage lakes.

- Reservoir – deep

Reservoirs are man-made impoundments and exhibit both lake and riverine characteristics and generally have a hydraulic residence time of 14 days or more based on a mean residence time. To differentiate reservoirs from lakes with level controls, the outlet control structure of a reservoir generally increased the water depth by a factor of two or greater. Shallow reservoirs are otherwise defined the same as the deep – drainage lakes.

- Impoundments

Impoundments are small lakes created by constructing dams on streams or rivers that have a short residence time, less than 14 days.

#### Criteria.

**For deep – drainage lakes and deep reservoirs, a total phosphorus concentration of 30 ug/l.**

A primary piece of information used to determine phosphorus concentrations for deeper lakes was the frequency of algal blooms based on in-lake phosphorus concentrations (see Figure 1). A chlorophyll a value of 20 ug/l is commonly used to represent a nuisance algal bloom. A frequency of 5 percent, about 6 days out of the “summer” was used as a goal. The curve corresponding to 20 ug/l is highlighted and arrows show the 5 percent frequency and the corresponding phosphorus value of 27 to 28 ug/l. That value, when rounded to the nearest 5 or 0 results in a value of 30 ug/l. A total phosphorus concentration of 30 ug/l would decrease the risk of a “severe” algal nuisance to less than 1 percent.

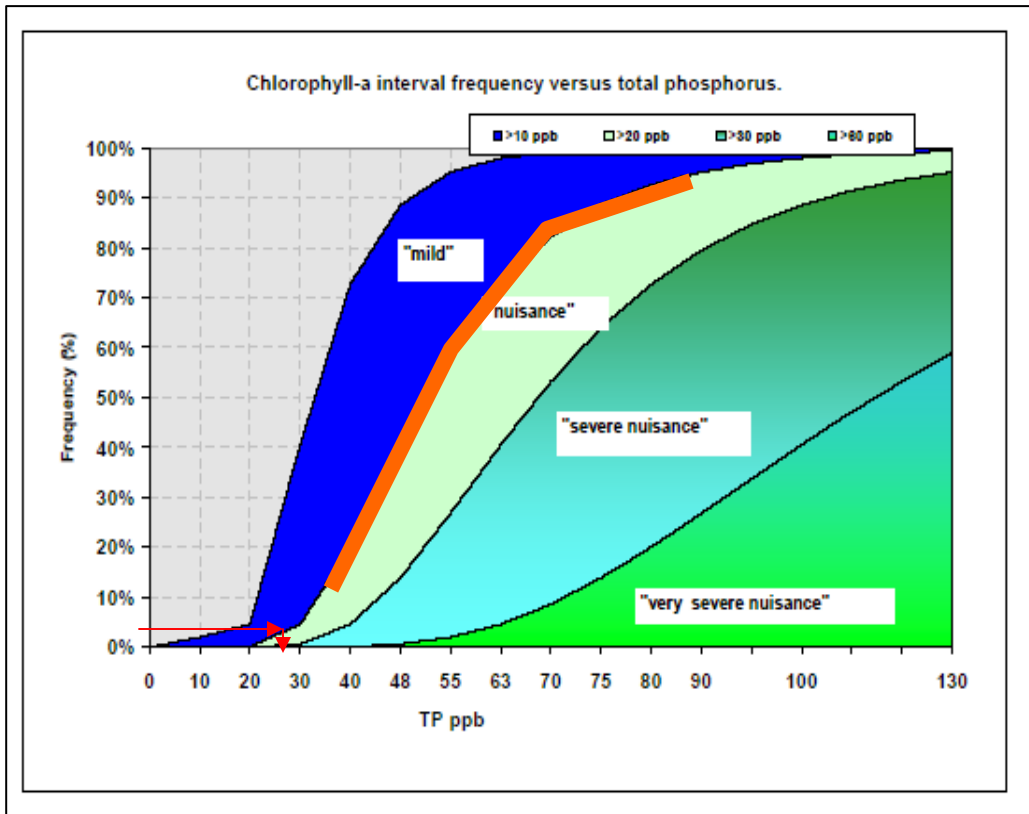
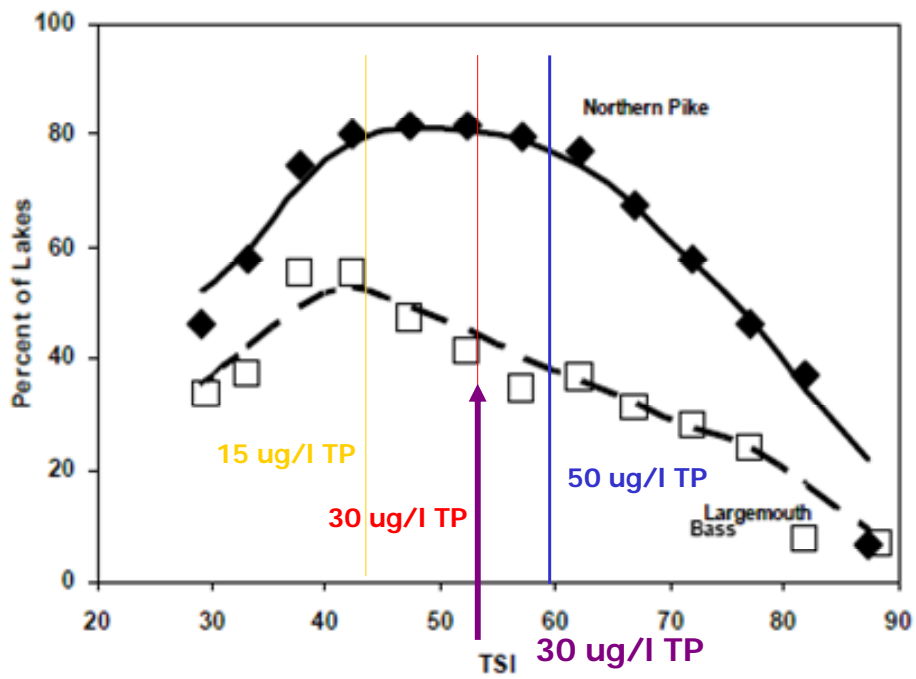
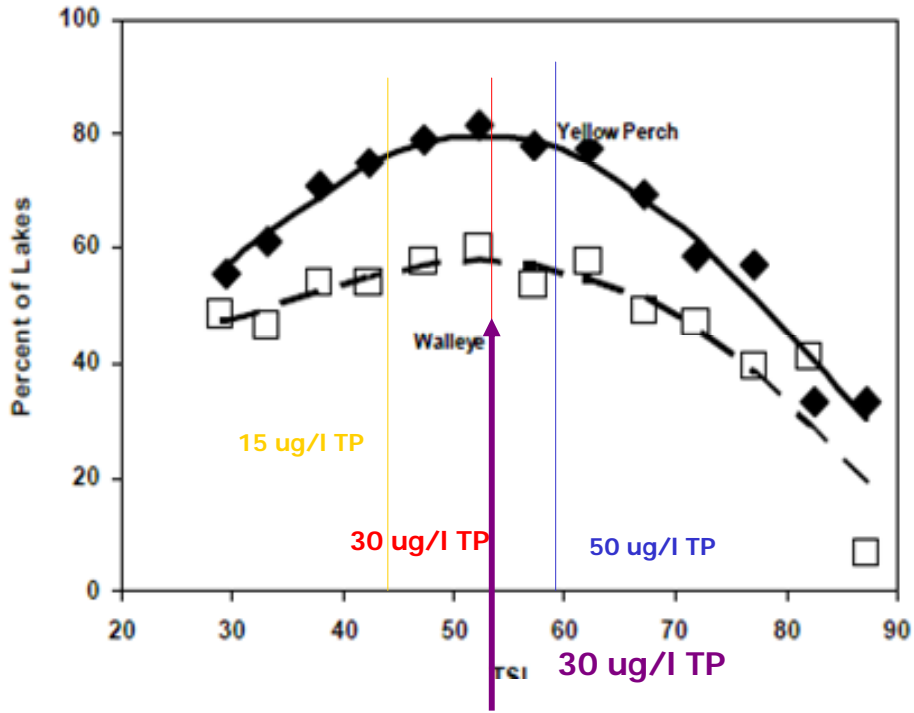


Figure 1. Frequency of nuisance algal conditions relative to total phosphorus concentrations.

Source: Paired phosphorus and chlorophyll a measurements from 641 lakes as presented on page 25 of “Minnesota Lake Water Quality Assessment Report: Developing Nutrient Criteria”, Third Edition, September 2005, Minnesota Pollution Control Agency. The development of the chart is described in the article by Heiskary and Walker, titled “Developing nutrient criteria for Minnesota lakes” and published in Lake and Reservoir Management 4:1-9, 1988.

While the above chart deals with recreational uses, such as boating and viewing, the Department also desired to assess how this concentration of phosphorus protects fish communities. Information tends to be very limited overall and limited to sport fisheries. As shown in Figures 2a and 2b, a total phosphorus concentration of 30 ug/l should be protective of sport fisheries as illustrated in the following figures from “Minnesota Lake Water Quality Assessment Report: Developing Nutrient Criteria” Third Edition with lines for values inserted.<sup>21</sup>

<sup>21</sup> Corresponding information on the presence of sport fish relative to trophic state in lakes in Wisconsin is not available due to the extensive stocking of fish in lakes.



Figures 2a and 2b. Presence of sport fish relative to trophic state in lakes.

Source "Minnesota Lake Water Quality Assessment Report: Developing Nutrient Criteria", Third Edition, September 2005, Minnesota Pollution Control Agency; based on work by Schupp (MDNR) and Wilson (MPCA), 1992 and Schupp (MDNR) unpublished data.

This total phosphorus concentration should result in transparency of 1.2 to 2.3 meters; adequate for life guards to see into swimming waters. Such values have been promulgated by some states and Canadian provinces. At one point in time, the predecessor to the Wisconsin Department of Health and Family Services had a recommended value of 1.2 meters.

**For 2-story lakes a total phosphorus concentration of 15 ug/l.**

In Wisconsin, 2-story lakes represent a relatively small percent of the inland lakes. A key goal for these lakes is to attain and maintain a minimum of 6 mg/l of dissolved oxygen in the hypolimnion, the lowest layer in these stratified lakes. The total phosphorus concentration needed to maintain 6 mg/l of dissolved oxygen varies with the volume of the hypolimnion. That is, lakes with a large volume of water in the hypolimnion could have a higher total phosphorus concentration than those lakes with a small volume of water in the hypolimnion.

The proposed criterion of 15 ug/l is based on the mean concentration of reference lakes plus one standard deviation. Reference lakes were selected based on a minimum of human impact, and the phosphorus concentrations were derived through interpretation of sediment cores. In all cases, the bottom of the core was used to present pre-settlement conditions. The Department recognizes that the concentration of 15 ug/l is higher than the 10 ug/l associated with classic oligotrophic lakes and the 12 ug/l promulgated by the Minnesota Pollution Control Agency. Also, the concentration would seem to result in a concentration too high to support a lake trout fishery as depicted on Figure 3 below.

Given the apparent conflict and the relatively small number of these lakes, 2-story lakes may be candidates for site-specific criteria development.

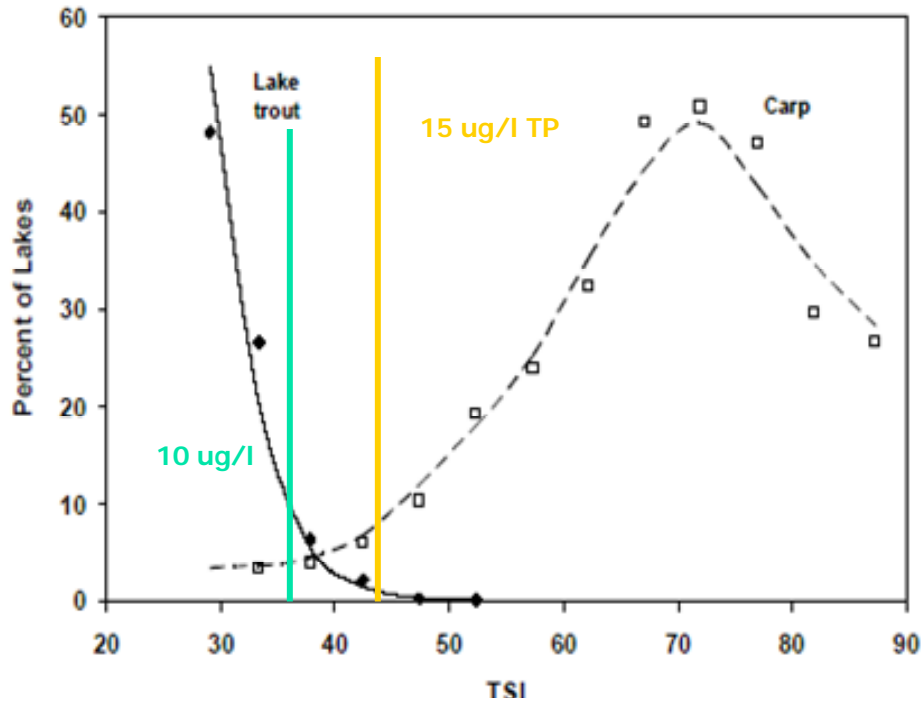


Figure 3. Presence of lake trout and carp relative to lake trophic status.

Source “Minnesota Lake Water Quality Assessment Report: Developing Nutrient Criteria”, Third Edition, September 2005, Minnesota Pollution Control Agency; based on work by Schupp (MDNR) and Wilson (MPCA), 1992 and Schupp (MDNR) unpublished data.

**For deep – seepage lakes a total phosphorus concentration of 20 ug/l**

Deep seepage lakes are a significant concern in that they tend to have long water residence times and are very difficult to restore; much more difficult than deep drainage lakes. In the professional judgment of Department lake management staff and university experts, a lower criteria concentration than the 30 ug/l concentration for deep drainage lakes was warranted. Analysis of lake bed core data for these lakes indicated a mean value based on pre-settlement conditions plus one standard deviation of 15 ug/l. Department staff believed a higher value than the pre-settlement mean value would be protective of these lakes, but not substantially higher. Thus, a concentration of 20 ug/l was selected.

**For shallow lakes (drainage, seepage and reservoirs), a total phosphorus concentration of 40 ug/l.**

Similar to the deeper lakes, the Department looked at the frequency of nuisance algal blooms and protecting the fishery. In addition, the Department looked at preventing a

shift in the shallow lakes from macrophyte domination to algae domination during the summer.

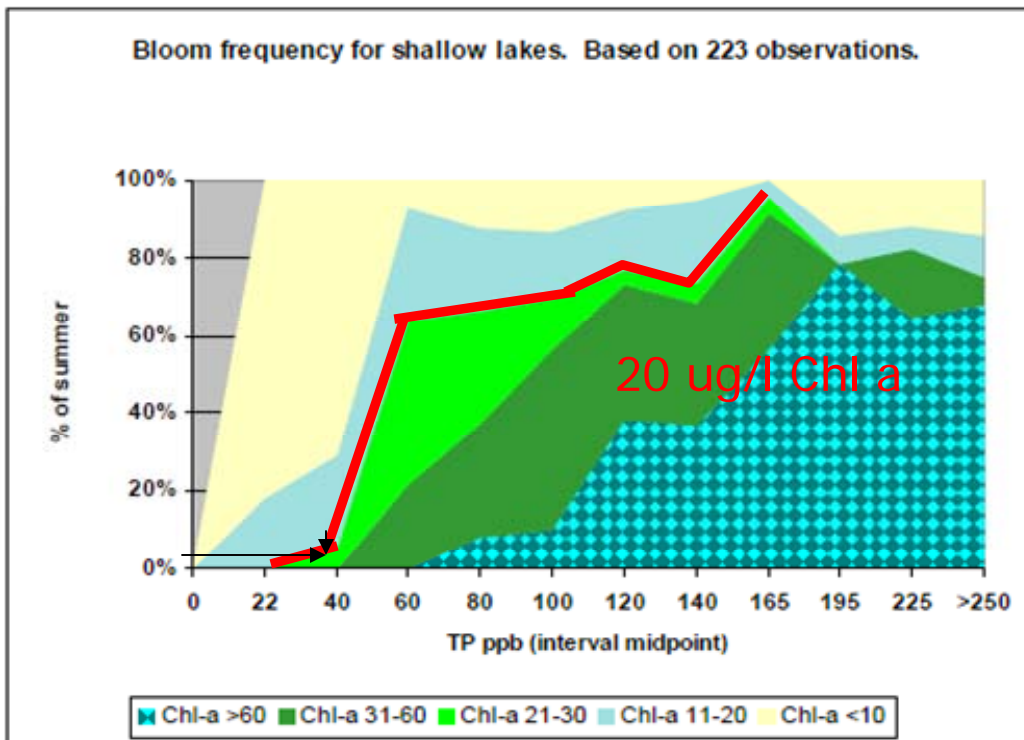


Figure 4. Frequency of nuisance algal blooms relative to total phosphorus concentrations.

Source: Based on 223 observations in shallow lakes in southwest and west central Minnesota. From page 25 of “Minnesota Lake Water Quality Assessment Report: Developing Nutrient Criteria”, Third Edition, September 2005, Minnesota Pollution Control Agency.

Recent studies in Minnesota have shown that shallow lakes can shift from macrophyte dominated to algal dominated during the summer if there are high concentrations of phosphorus in the lake. Figure 5 shows that the start of this shift is apparent at about 40 ug/l total phosphorus.

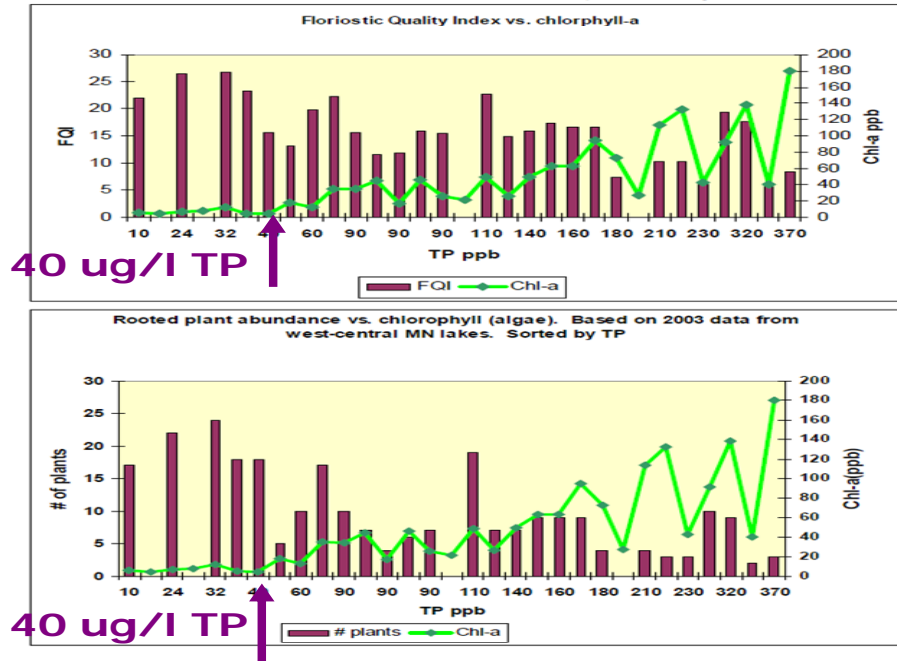
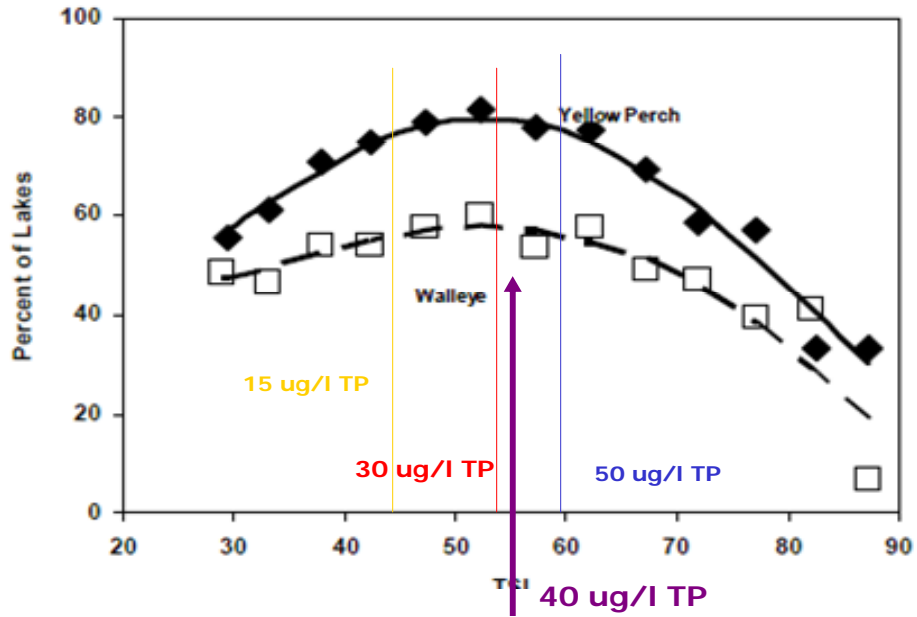


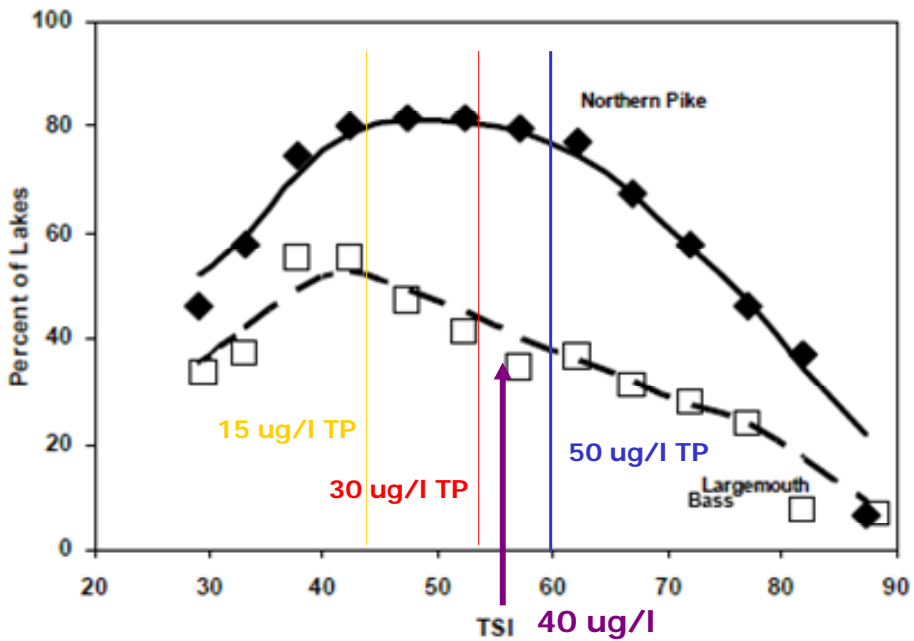
Figure 5. Comparison among rooted plant metrics and TP, chlorophyll-a and Secchi. Based on 27 shallow west-central MN lakes.

Source “Minnesota Lake Water Quality Assessment Report: Developing Nutrient Criteria”, Third Edition, September 2005, Minnesota Pollution Control Agency.

As shown in Figures 6a and 6b, a total phosphorus concentration of 40 ug/l should be protective of sport fisheries as illustrated in the figures below from “Minnesota Lake Water Quality Assessment Report: Developing Nutrient Criteria” Third Edition with lines for values inserted.



Note: Purple arrow should be slightly to the right on both the figure above and below..



Figures 6a and 6b. Presence of sport fish relative to trophic state in lakes.

Source “Minnesota Lake Water Quality Assessment Report: Developing Nutrient Criteria”, Third Edition, September 2005, Minnesota Pollution Control Agency.



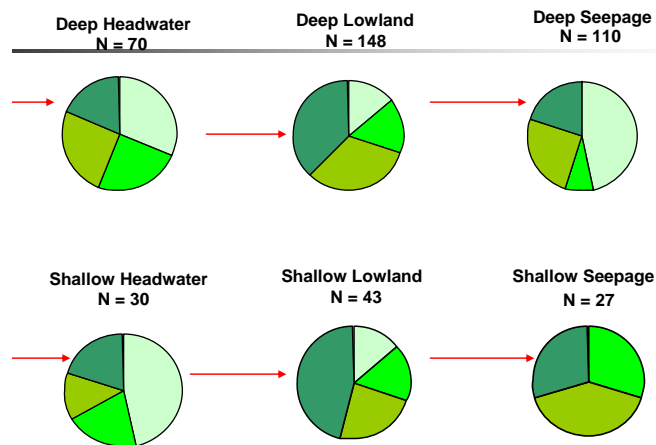
## Impoundments

Given the relatively short water residence time for most impoundments, they often respond as riverine systems. Therefore, no specific lake criteria are proposed. The criteria for the upstream stream or river will apply.

## Attainment

Figure 7 shows the present attainment for the proposed criteria for different types of lakes in different settings within a watershed, based on a review of a recent 400-lake data set. The darkest color or blue-green with the arrow point to the slice shows lakes exceeding the proposed criteria.

Figure 7. Lake Conditions Relative to Criteria Concentrations



## Part 5: Phosphorus Criteria for the Great Lakes

The phosphorus criteria proposed of 7 ug/l for Lake Michigan and 5 ug/l for Lake Superior are from the International Joint Commission guidelines for the Great Lakes.<sup>22</sup> They have been used to develop phosphorus load reduction targets for each of the lakes and have been used in guidance since at least 1980. The 5 ug/l value for Lake Superior is intended to maintain the lake as an oligotrophic body of water. The 7 ug/l value for Lake Michigan is based on maintaining the lake at the breakpoint between an oligotrophic and a mesotrophic body of water.

In their 2009 State of the Great Lakes report<sup>23</sup>, EPA and Environment Canada state that for Lake Superior the open lake water is good quality with average phosphorus concentrations in the open water being at or below the guidance values. The nearshore waters are identified as unassessed. For Lake Michigan the report states that the open waters are in good condition and concentrations are at or below the guidance values. However, for Lake Michigan nearshore waters, the report gives a poor status and states that guidance values may be exceeded for at least part of the growing season.

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<sup>22</sup> Phosphorus Management Strategies Task Force, "Phosphorus Management for the Great Lakes", Final report to the International Joint Commission, Great Lakes Water Quality Board and Great Lakes Science Advisory Board, 1980.

<sup>23</sup> Environment Canada and U. S. Environmental Protection Agency, "State of the Great Lakes 2009", page 77, EPA-905-R-09-031.

## Part 6. Lower Green Bay



### Background

Lower Green Bay, as it is commonly called, is the innermost portion of Green Bay starting at the mouth of the Fox River. Its outer boundary is delineated by an imaginary line from Long Tail Point on the west shore to Point Au Sable on the east shore; encompassing 55 km<sup>2</sup> (21.2 mi<sup>2</sup>). It is generally shallow with water depths ranging from 0.3 meters (1 foot) near the mouth of the Fox River to 3.4 meters (11 feet) at the outer boundary; depending on Lake Michigan water levels and excluding the dredged navigation channel. With this shallow depth, it has an extensive littoral zone that provides habitat for invertebrates, fish and waterfowl and currently supports to a limited degree areas of submerged aquatic vegetation, such as *Vallisneria Americana*, wild celery.

Historically, Lower Green Bay has had a series of water quality problems largely resulting from pollutants carried by the Fox River into the inner bay. Based on these historic water quality problems, it has been designated a Great Lakes Area of Concern and is currently the subject of a Total Maximum Daily Load analysis. The water quality problems include high turbidity levels, high nutrient concentrations, preponderance of blue green algae, and low dissolved oxygen concentrations. These ambient conditions have resulted in loss of submerged aquatic vegetation. These water quality problems have been summarized in a series of State of the Bay reports, including the most recent draft 2008 report (available upon request).

### Narrative Criterion

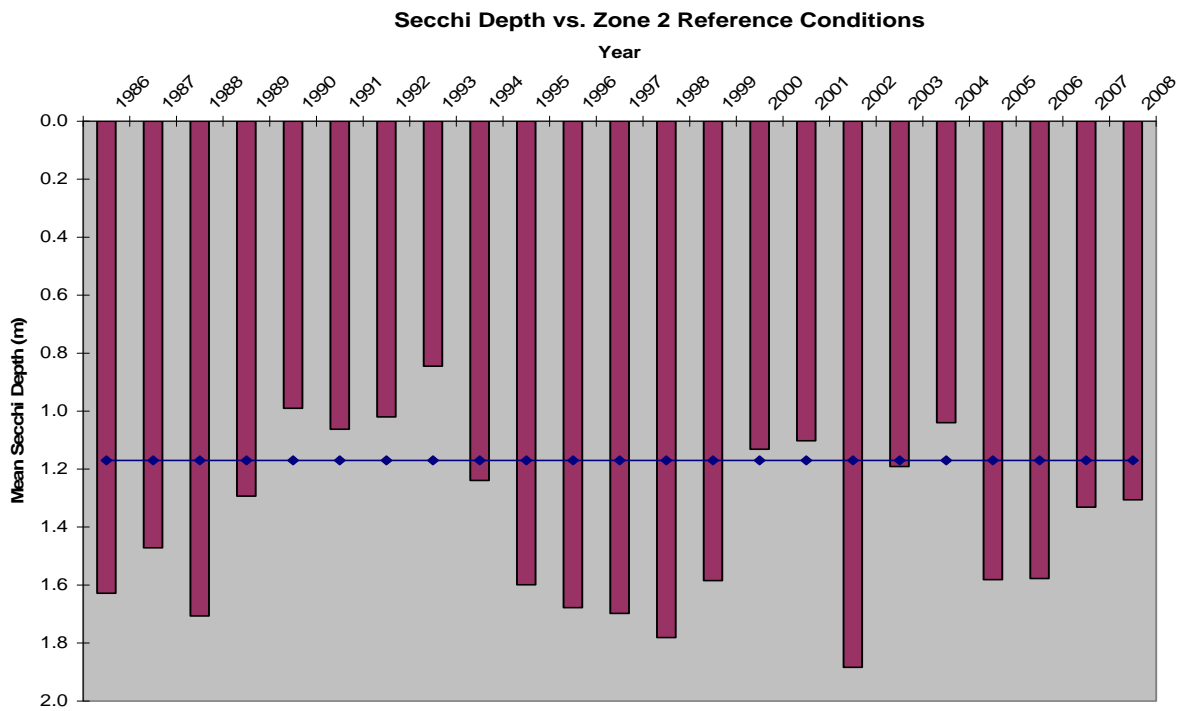
“For the portion of Green Bay from the mouth of the Fox River to a line from Long Tail Point to Point au Sable, the water clarity and other phosphorus – related conditions that are suitable for support of a diverse biological community, including a robust and sustainable area of submersed aquatic vegetation in shallow water areas.” (S. NR 102.06 (5) (c))

## Numeric Translators

Average concentrations of 60 ug/l of total phosphorus and 15 mg/l for total suspended solids are identified as numeric translators for the narrative criterion. They are to be applied as an average for zones for zones 1 and 2.

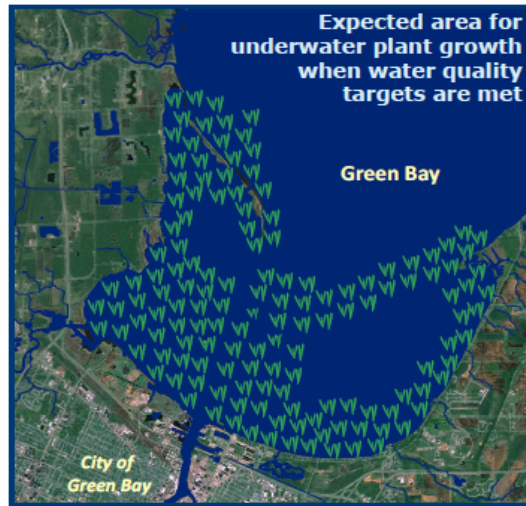
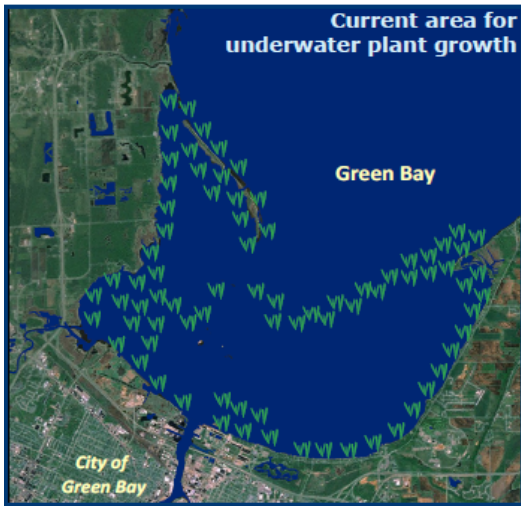
## Technical Support for Numeric Translators

Zone 2 the portion of Green Bay beyond the inner bay can be used as a reference water. Zone 2 doesn't have pristine conditions, but it generally supports its designated uses. Its use as a reference water must be used with care since zone 2 has greater depths and more mixing with the larger part of Green Bay. Ideally, the inner bay, zone 1, should have clarity conditions similar to those found in zone 2. The 75<sup>th</sup> percentile of average annual Secchi depth data from 1986 to present, a Secchi depth is about 1.2 meters.



Bars represent average annual Secchi depths from all stations based on data collected by the Green Bay Metropolitan Sewerage District. The horizontal line is a 1.17 meter depth.

As illustrated in the two images below, attaining a Secchi depth of 1.2 meters will substantially increase the area suitable for growth of submerged aquatic vegetation.



Derived from "Use of GIS to predict Colonization Patterns of Submergent Vegetation in Lower Green Bay with Changes in Light Conditions", Eric Sager, unpublished thesis, Trent University, October 1993, Wisconsin Department of Natural Resources, Total Maximum Daily Load and Watershed Management Plan for Total Phosphorus and Total Suspended Solids in the Lower Fox River Basin and Lower Green Bay

The relationship between total phosphorus (TP), total suspended solids (TSS) and Secchi depth in the inner bay has been derived by Sager (unpublished 2008) as:

$$\text{Secchi depth (m)} = 1.62 - 0.85 \text{ TP (mg/l)} - 0.027 \text{ TSS (mg/l)}; r^2 = 0.439$$

Using this equation, a total phosphorus concentration of 0.060 mg/l and a total suspended solids concentration of 15 mg/l will result in a Secchi depth of 1.2 meters.

### **Relation to Fox River Phosphorus Criterion**

The numeric translator for phosphorus correlates with the phosphorus criteria for the Lower Fox River. This relation has been described by Sager (unpublished, 2008) through the following regression equation:

$$\text{TP}_{\text{bay}} \text{ (ug/l)} = 0.02 + 0.60 \text{ TP}_{\text{river}} \text{ (ug/l)}; r^2 = 0.469$$

Therefore, attainment of the 100 ug/l phosphorus criterion at the mouth of the Fox River should result in attainment of the 60 ug/l numeric phosphorus translator value.