Lake and Reservoir Management, 28:84–91, 2012

ISSN: 0743-8141 print / 1040-2381 online
DOI: 10.1080/07438141.2012.667053

A strategy for establishing numeric nutrient criteria for Florida lakes

Roger W. Bachmann,* Dana L. Bigham, Mark V. Hoyer, and Daniel E. Canfield, Jr.
Florida LAKEWATCH, School of Forest Resources and Conservation, University of Florida,
7922 NW 71 St, Gainesville, FL 32653

Abstract

Bachmann RW, Bigham DL, Hoyer MV, Canfield DE Jr. 2012. A strategy for establishing numeric nutrient criteria for Florida lakes. Lake Reserv Manage. 28:84–91.

We used our knowledge of the factors that determine the nutrient concentrations in Florida lakes to develop a strategy for establishing numeric nutrient criteria for lakes in the State of Florida. Based on previous findings that natural factors were most important in determining the current nutrient concentrations in Florida lakes, we used current distributions of nutrients as a basis for setting criteria. We started with the US Environmental Protection Agency's Florida Lake Regions and grouped similar regions into 6 total phosphorus (TP) zones and 5 total nitrogen (TN) zones that were used to set numeric nutrient criteria for each zone. We propose criteria that will identify the lakes in each zone with the highest concentrations of TP and TN for subsequent investigation to determine the degree anthropogenic sources or natural backgrounds are responsible for their trophic status. To provide special protection to Florida's oligotrophic lakes, site-specific criteria are proposed, with oligotrophic lakes defined as those lakes that have (1) a long-term average of not more than 6 μg/L of chlorophyll and (2) less than 30% coverage by surface area of submersed aquatic macrophytes. The site-specific criteria for TP and TN will be the long-term (7 year) average concentrations. These proposed criteria are protective of the designated uses of Florida lakes and prevent the misclassification of many naturally eutrophic lakes as impaired when they are not undergoing cultural eutrophication. The proposed numeric standards can be implemented immediately in the State of Florida.

Key words: criteria, eutrophication, Florida, nitrogen, nutrient regulation, phosphorus

In November 2010, the US Environmental Protection Agency (USEPA 2010) set numeric nutrient criteria for total phosphorus (TP), total nitrogen (TN), and chlorophyll *a* (Chl-*a*) for lakes in the State of Florida after the state did not establish them on its own. In previous work, we have examined the USEPA criteria in light of our research on the factors determining trophic states (Bachmann et al. 2012a) and discussed how nutrient criteria might be related to the designated uses (Bachmann et al. 2012b) of Florida lakes. The purpose of this study is to examine how other states have set nutrient criteria for their lakes and to propose an alternative process for setting criteria for Florida lakes.

Previous work

We found (Bachmann et al. 2012a) a wide range in the concentrations of TP, TN, and Chl-*a* in Florida lakes, and that edaphic factors as outlined by the USEPA's Florida Lake Regions (Griffith et al. 1997) were dominant in determining the concentrations of plant nutrients in the state's lakes. Natural deposits of phosphatic rocks are responsible for some of the naturally eutrophic lakes in Florida. For some lakes, point-source nutrient pollution from wastewater effluents was a problem in the past, but that problem has since been resolved. We tested and rejected the major assumption of the USEPA (2010) nutrient criteria that any eutrophic lakes in Florida without known point source pollution were the result of nonpoint source nutrient pollution. We found no correlation between measurements of human development around Florida lakes and their concentrations of TP, TN, and Chl-*a*. Several of Florida's 30 benchmark lakes (lakes with minimal human impact and meeting designated uses) were eutrophic, and there was no significant difference between the mean concentrations of TP and TN in these benchmark lakes and all the remaining nonbenchmark Florida lakes. In addition, paleolimnological studies showed that several lakes were

*Corresponding author: rbach@ufl.edu

eutrophic to hypereutrophic prior to 1900, a time preceding significant population growth in the State of Florida.

To assist in the development of numeric nutrient criteria for Florida lakes that will take regional differences into account, we started with the 47 Florida Lake Regions (Griffith et al. 1997) established by the USEPA in collaboration with the Florida Department of Environmental Protection (FDEP) and the University of Florida's LAKEWATCH program. The lakes within a specific region were grouped together because there is homogeneity in the types and quality of lakes and their associations with landscape characteristics, or there is a particular mosaic of lake types and quality (Griffith et al. 1997). The boundaries between the regions also generally followed those on soil maps. Thus, the different regions represented a manifestation of the differences in geology, soils, and hydrology from one part of the state to another, resulting in a patchwork appearance when the lake regions are represented on a map (Griffith et al. 1997).

The USEPA (2010) considered using the Florida Lake Regions to establish numeric nutrient criteria but rejected this approach because of the high number of regions and the low number of lakes in some regions. Our solution was to group together lake regions with similar chemical characteristics into a smaller number of nutrient zones for TP and TN (Table 1). To establish the TP zones, we ran an analysis of variance (ANOVA) using the JMP statistical package to find the geometric mean concentrations of TP in each of the lake regions. We then compared all lake region means with each other using the Tukey-Kramer HSD test. The results of these comparisons were used to group the lake regions into 6 trial TP zones. We then used an ANOVA and a Tukey-Kramer HSD to determine if the geometric mean values for TP in each of the trial TP zones were significantly different from each other and also to determine if the geometric mean values for TP in the lake regions within each trial TP zone were different from each other. In an iterative process, lake regions were moved from one trial TP zone to another until we developed 6 phosphorus zones where the distributions of TP in each lake zone were significantly different from the distributions in each of the other zones. The same process resulted in 5 TN zones that were very similar to but not the same as the phosphorus zones, thus providing a statistical basis for zone establishment. Because the original lake regions were delimited in part in conjunction with information on soils, physiography, geology, vegetation, climate, and land use/land cover, as well as relying on the expert judgment of local limnologists (Griffin et al. 1997), these factors would carry over to the larger nutrient zones.

We reviewed published information on the biology of Florida lakes to determine what concentrations of TP and TN might lead to impairment of their designated uses (Bachmann et al. 2012b). For the designated use of swimming, lake users preferred oligotrophic to mesotrophic lakes (Hoyer et al. 2004). Eutrophic lakes in Florida generally meet their designated use of the "propagation and maintenance of a healthy, well-balanced population of fish and wildlife" (FDEP 2009). Fish standing crops in Florida lakes increased as the concentrations of TP increased from 1 to 1000 μg/L. Florida lakes did not show the kind of changes in fish species with trophic state as might be found in northern lakes. Populations of aquatic birds and alligators also increased with increases in lake trophic state. We found no evidence that the concentrations of TP and TN in the water were responsible for excessive populations of aquatic macrophytes. A study of open-water concentrations of the cyanobacterial toxin microcystin in 187 Florida lakes found only 3 individual water samples collected from 2 lakes exceeded the World Health Organization guidance level of 20 μg/L for swimming,

Table 1.-The constituent USEPA Lake Region numbers for the proposed nutrient zones.

Zones	Constituent USEPA Lake Regions
Total Phosphorus zones	
TP1	65-03, 65-05
TP2	75-04, 75-09, 75-14, 75-15, 75-33
TP3	65-01, 65-02, 75-01, 75-03, 75-05, 75-11, 75-12, 75-16, 75-19, 75-20, 75-23, 75-24, 75-27, 75-32, 76-03
TP4	65-04, 75-02, 75-06, 75-08, 75-10, 75-13, 75-17, 75-21, 75-22, 75-26, 75-29, 75-31, 75-34, 76-01, 76-02
TP5	75-18, 75-25, 75-35, 75-36, 76-04
TP6	65-06, 75-07, 75-28, 75-30, 75-37
Total Nitrogen zones	
TN1	65-03
TN2	65-05, 75-04
TN3	65-01, 65-02, 65-04, 75-01, 75-02, 75-03, 75-09, 75-11, 75-15, 75-20, 75-23, 75-33, 76-03
TN4	65-06, 75-05, 75-06, 75-10, 75-12, 75-13, 75-14, 75-16, 75-17, 75-18, 75-19, 75-21, 75-22, 75-24, 75-26, 75-27, 75-29, 75-31, 75-32, 75-34, 76-02
TN5	75-07, 75-08, 75-25, 75-28, 75-30, 75-35, 75-36, 75-37, 76-01, 76-04

although high levels of microcystin are sometimes found in some lakes in surface accumulations of cyanobacteria.

How criteria are used

Under the nutrient criteria proposed by the USEPA (2010) and the Florida Administrative Code (62–302 and 62–303), a lake would need 3 years of data with at least 10 data points for both alkalinity and water color to place it in a regulatory classification based on color and alkalinity. In addition, it would need 3 consecutive years of data on TP, TN, and Chl-*a*. For each year, the lake would have to be sampled at least 4 times, with at least one sample collected during the May through September period and at least one sample collected during the other months. Geometric means of the 3 variables would be calculated for each of the 3 years. The USEPA criteria for TP and TN have a base value for lakes where the Chl-*a* exceeds its criterion and a range of values for lakes where the Chl-*a* criterion is not exceeded. If the annual geometric mean of one or more of the 3 variables exceeds its criterion for 2 or more years in a 3-year period, the lake is placed on a Planning List. If the Chl-*a* criterion is met each year, but either the TP or TN criterion is exceeded, there is a provision for Lake-Specific Ambient Condition-Based Modified TN and TP Criteria for that lake (USEPA 2010). With approval from the USEPA, the state can use the ambient concentrations of TP and TN as the lake specific criteria, provided they do not exceed the maximum value shown in the USEPA (2010) table. Lakes are also placed on the Planning List if there is a statistically significant increasing trend in the annual geometric means at the 95% confidence level in TN, TP, or Chl-*a* over a 7-year period using a Mann's one-sided, upper-tail test for trend.

Lakes placed on the Planning List are assessed to determine whether the water body is impaired (i.e., not meeting its designated use) and whether the impairment is due to pollutant discharges. In cases where a lake on the Planning List is determined to be impaired but the cause of the impairment cannot be determined, the lake is placed on a Study List for futher analysis to determine the causative pollutant or other factors contributing to impairment.

Lakes on the Planning List and the Study List are examined to determine if their failure to meet one or more of the criteria for TP, TN, or Chl-*a* is due to pollutant loading or concentrations that cause or contribute to nonattainment of water quality standards. When a lake is determined to be impaired by nutrients due to excess loading, it is placed on the Verified List of lakes for studies that will determine a total maximum daily load (TMDL) for the nutrient(s) causing the impairment. Lakes that fail the nutrient criteria due to natural background conditons are not included in the Verified List and are removed from the Planning List or the Study List. In the regulations, natural background is interpreted as the condition of waters in the absence of man-induced alterations based on the best available scientific information.

Examination of approaches that might be used to set criteria

It is our understanding that the overall objective for setting numeric nutrient criteria in Florida lakes is to identify lakes where changes in trophic state are due to increases in nutrient loading from anthropogenic activities. A set of numeric criteria for the plant nutrients phosphorus and nitrogen for a lake allows lake managers to determine if a lake has become culturally eutrophied. If it has, the criteria provide target concentrations for nutrient reduction programs. It is important to emphasize that we are looking at changes in the state of trophic state and not absolute values; thus, the nutrient standards should reflect what we might expect the lake to be like without anthropogenic acceleration of nutrient inputs. A lake that is naturally eutrophic would have nutrient criteria that reflect that natural state.

USEPA approach classifying lakes using alkalinity and water color

Rather than group Florida lakes by geographic regions as many states like Minnesota (Heiskary and Wilson 2008) have done, the USEPA (2010) used 3 groupings based on alkalinity and color. Lakes with color values of >40 PCU had one set of criteria, clear lakes with an alkalinity >20 mg/L as $CaCO_3$ were treated as mesotrophic lakes and had another set of criteria, and the remaining clear acid lakes were considered oligotrophic with yet another set of criteria. There were also some site-specific criteria that would allow somewhat higher TP and TN concentrations for colored lakes and clear alkaline lakes that had Chl-*a* values that met a 20 μg/L Chl-*a* criterion.

Impact of USEPA criteria

To examine the probable consequences of these criteria, we used our data on Florida lakes from the previous study (Bachmann et al. 2012a) to determine which lakes would fail one or more of the numeric nutrient criteria as established by the USEPA (2010). We placed 390 lakes with data on alkalinity and color into the three groups specified by USEPA. To identify impaired lakes, we followed the procedures of the USEPA (2010) and the Florida Statutes and found that 173 (44%) of these lakes had concentrations of TP, TN, or Chl-*a* that exceeded their respective numeric nutrient criteria.

Our previous study (Bachmann et al. 2012a) showed that many Florida lakes are naturally eutrophic and should not be classified as impaired. The result is an uneven distribution of lakes that exceeded the criteria, depending upon the nutrient zone. For example, the percent of lakes failing the TP criteria ranged from none in zone TP1 to 43% in zone TP4 and 90% in zone TP6. The explanation is that alkalinity is not as precise in delineating expected phosphorus and nitrogen concentrations as a geographic grouping, such as our nutrient zones.

The USEPA (2010) determined that lakes in Florida with an alkalinity $\leq$20 mg/L as $CaCO_3$ were oligotrophic and should have a Chl-*a* concentration $\leq$6 μg/L. We examined our dataset for Florida lakes (Bachmann et al. 2012a) and found that it included 314 oligotrophic lakes (Chl-*a*$\leq$ 6 μg/L) that also had alkalinity data. Of these oligotrophic lakes, only 193 had an alkalinity $\leq$20 mg/L as $CaCO_3$, and 121 lakes had higher alkalinities. The implication is that 39% of the oligotrophic lakes will not be identified by the alkalinity test and under the USEPA (2010) criteria will not have numeric nutrient criteria that will protect their oligotrophic status.

Use biological conditions to set standards

Previously, Bachmann et al. (2012b) found that there were no logical nutrient thresholds for the propagation of fish and wildlife. Throughout the course of biological evolution there have probably always been water bodies with trophic states that range from oligotrophic to hypereutrophic, and aquatic species that make up the biological communities of lakes would have evolved to take advantage of the full range of lake trophic states. Therefore, we expect to find adjustments in the species composition of the flora and fauna with changes in trophic state, so there should be no absolute standard in Florida that says one type of community is "healthy" and another "unhealthy." For recreation and enjoyment, some people prefer oligotrophic lakes with unproductive, clear waters; others prefer more eutrophic lakes with more abundant populations of fish, aquatic birds, and alligators. Wagner and Oglesby (1984) discussed the incompatibility of fishery optimization and other management objectives such as water supply, contact recreation, and aesthetics. While individuals may have personal preferences for lakes of one trophic state over another, if the trophic state is natural rather than due to cultural eutrophication, there is nothing that can be done through regulation to change it.

Designated uses

Many states have narrative standards whereby their waters are classified according to a single designated use, and substances cannot be introduced into them that would interfere with that use. In Virginia, this approach was proposed (VWRRC 2005) to set numeric nutrient standards for their artificial reservoirs (the state has only 2 natural lakes). Virginia proposed sport fishing as the designated use for their reservoirs. For each ecoregion in the state, the water bodies were classified as coldwater fish, warmwater fish, and fertilized lakes. The proposed criteria for each subregion were based on the current nutrient concentrations in the reservoirs with the best fisheries. Because there were no natural conditions to preserve, this was a logical way to set their criteria. The State of Iowa (IEPC 2011) has also proposed a single use standard in which most public lakes are designated as swimming lakes. The Chl-*a* concentration must be <25 μg/L in 75% or more of samples collected during the recreational season (May–Sep), and the Secchi depth must be $\geq$1 m in 75% or more of samples collected during the recreational season. The State of Kansas (KDHE 2011) has designated several water bodies for drinking water and has proposed a Chl-*a* criterion of 10 μg/L with site-specific TP and TN criteria to meet that goal. The State of Oklahoma (OWRB 2005) has proposed a Chl-*a* criterion of 10 μg/L for several water supply reservoirs.

The State of Maine (Danielson 2009) has proposed a decision framework to determine if a given designated use for a lake (i.e., recreation in and on the water, aquatic life, trophic state, and habitat) is impaired. Environmental responses measured include Secchi disk depths, Chl-*a* concentrations, and aquatic biological communities. If there is an impairment, it would be determined if phosphorus or some other nutrient were responsible, and appropriate limits would be established for that water body. This approach has not yet been accepted by the USEPA.

The situation, however, is more complex in Florida. Most Florida lakes have a multiple use classification for "Recreation, propagation of a healthy, well-balanced population of fish and wildlife" (FDEP 2009). Many people in Florida prefer clear oligotrophic lakes for recreational uses like swimming (Hoyer et al. 2004), yet we found that the populations of fish and wildlife were highest in the lakes with the highest concentrations of TP, TN, and Chl-*a* (Bachmann et al. 2012b). No set of plant nutrient criteria would be optimum for all the designated uses in Florida lakes.

Regionalization

Minnesota used a regionalization approach to set nutrient criteria in that state (Heiskary and Wilson 2008). They took advantage of well-known ecological gradients from the northeast to the southwest corners of that state (Moyle 1945, 1956) and used the 4 USEPA Level III Ecoregions plus lake types and use classifications within the ecoregions to develop variable nutrient standards across Minnesota. As a result, their phosphorus criteria range from 12 to 90 μg/L, reflecting the natural differences from one region to another.

The State of South Carolina has also used a regionalized approach in setting numeric nutrient criteria (SCDHEC 2008). For the Blue Ridge Mountains ecoregion of the state, TP shall not exceed 20 μg/L, Chl-*a* shall not exceed 10 μg/L, and TN shall not exceed 350 μg/L. For the Piedmont and Southeastern Plains ecoregions of the state, TP shall not exceed 60 μg/L, Chl-*a* shall not exceed 40 μg/L, and TN shall not exceed 1500 μg/L. For the Middle Atlantic Coastal Plains ecoregion of the state, TP shall not exceed 90 μg/L, Chl-*a* shall not exceed 40 μg/L, and TN shall not exceed 1500 μg/L. The proposed numeric nutrient criteria for the State of Virginia (VWRRC 2005), as discussed earlier, are different for each of the 3 ecoregions found in this state.

A group in Canada (Gartner Lee Ltd. 2009) has examined the feasibility of using an ecoregion approach for setting phosphorus guidelines in Canada by using the Province of Ontario as a case study. They found a significant variance in phosphorus concentrations could be explained by classifying the lakes and rivers into 1 of 3 ecozones. They found the ecoregion concept was a feasible means of classifying the natural trophic states of their lakes, but that the use of additional factors might be needed to provide sufficient resolution of background conditions for nutrient management. A suggested goal was to limit increases in lake phosphorus concentrations to 50% above the natural background levels.

The European Community has developed an ambitious program called the European Water Framework Directive (EC 2000) to protect and improve all of their surface water resources. It is regional in nature, as each member state will identify a typology for their water bodies based on fundamental ecological drivers such as altitude and geology; their ecological quality is then compared with a “type-specific reference condition” (Hatton-Ellis 2008). The ecological quality is assessed using a variety of biotic variables (phytoplankton, macrophytes, invertebrates, and fish) as well as chemical measurements including TP and TN. These metrics are used to place each lake into 1 of 5 different ecological classes (high, good, moderate, poor, and bad) with a goal of achieving a minimum of good ecological status by 2015 (Sondergaad et al. 2005).

The regionalization approach is more complicated in Florida because our natural lake regions represent more of a patchwork, and the Level III Ecoregions account for only a small fraction of the variance in phosphorus and nitrogen (1 and 3%, respectively) concentrations among lakes (Bachmann et al. 2012a). For this reason we used a modified regional approach in our proposed criteria.

Proposed nutrient criteria for Florida lakes

We found that when we take the phosphorus and nitrogen nutrient zones into account, most Florida lakes are no different in their concentrations of TP and TN from those in the benchmark lakes selected by the FDEP (2009) to represent undisturbed lakes in Florida (Bachmann et al. 2012a), likely because Florida has a permit program to control point sources of pollution and has strong stormwater regulations for new development. In addition, the Florida Department of Agriculture and Consumer Services has a program of Best Management Practices for agricultural activities, designed to protect both water quality and quantity. As a result, average Florida lake trophic states have not changed during a period of intense human population growth (Terrell et al. 2000), which means that as a starting point we can consider most Florida lakes at this time to be the same as the benchmark lakes. They represent lakes with a minimum of anthropogenic nutrient inputs and are not going to be improved with regulation. The best we can do is to maintain them in their current state and concentrate on picking out the smaller number of lakes with potential nutrient pollution problems.

Numeric criteria for nonoligotrophic lakes

Using the data from 1387 Florida lakes in the Bachmann et al. (2012a) study, we prepared cumulative frequency distributions for TP and TN for each of the respective TP and TN zones (Fig. 1) and tabulated the respective TP and TN concentrations for the 75th, 80th, 85th, and 90th percentiles for each nutrient zone (Table 2). Because we did not find evidence of widespread cultural eutrophication for Florida lakes (Bachmann et al. 2012a), we propose that for each of the 6 phosphorus zones, the 90th percentile of phosphorus concentrations for lakes within that zone be used as the preliminary criterion to identify lakes that might be affected due to anthropogenic causes (Figure 2). We would do the same for the 5 nitrogen zones (Table 2). We used the 90th percentile as the preliminary criterion, because most of the lakes were not different from the reference state. We note that USEPA (2010) used the 90th percentile of nutrient concentrations of reference streams as a part of their process for setting numeric nutrient criteria for flowing waters in Florida. Through a program of adaptive management that we discuss later, the percentile can be adjusted up or down as experience is gained with these criteria.

This approach is in line with the intention of the FDEP (FDEP 2009) to use the “the upper end of nitrogen and phosphorus frequency distributions from benchmark sites to define nutrient thresholds that FDEP expects to be both defensible and reliable for protection of aquatic life in Florida

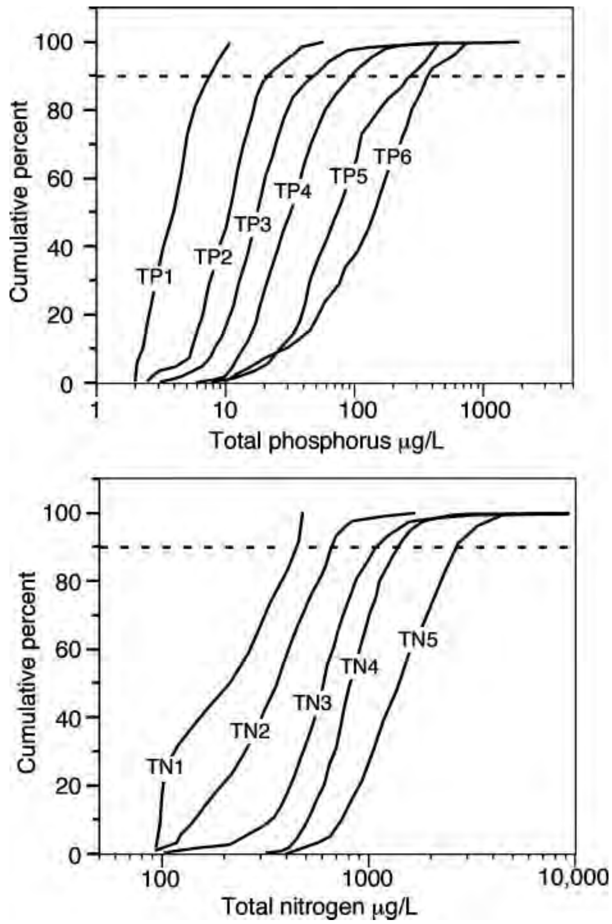

Figure 1.-Cumulative distributions of total phosphorus for each of the phosphorus zones and total nitrogen for each of the nitrogen zones. The dashed line indicates the 90th percentile that was used to find the proposed criteria for phosphorus and nitrogen.

Table 2.-Concentrations of total phosphorus (TP) and total nitrogen (TN) (μg/L) for selected percentiles of their cumulative distributions in their respective TP zones and TN zones.

	Percentiles			
	75th	**80th**	**85th**	**90th**
Total phosphorus concentrations by TP zones				
TP1	5	5	6	7
TP2	15	16	18	21
TP3	26	30	34	45
TP4	53	59	72	93
TP5	132	156	213	252
TP6	248	281	328	355
Total nitrogen concentrations by TN zones				
TN1	309	382	435	450
TN2	532	565	612	642
TN3	820	876	967	1087
TN4	1083	1140	1231	1369
TN5	1975	2216	2397	2701

waters." The agency proposed that these thresholds would be used to identify waters that are potentially impaired for nutrients. In our proposal, lakes with concentrations above these criteria would be placed on the Planning List for additional monitoring. If subsequent investigations cannot demonstrate a source of anthropogenic nutrient pollution, those lakes would not be placed on the Verified List of impaired lakes for additional regulation.

Numeric criteria for oligotrophic lakes

To give special protection to the oligotrophic lakes of Florida, we also propose identifying them using site-specific

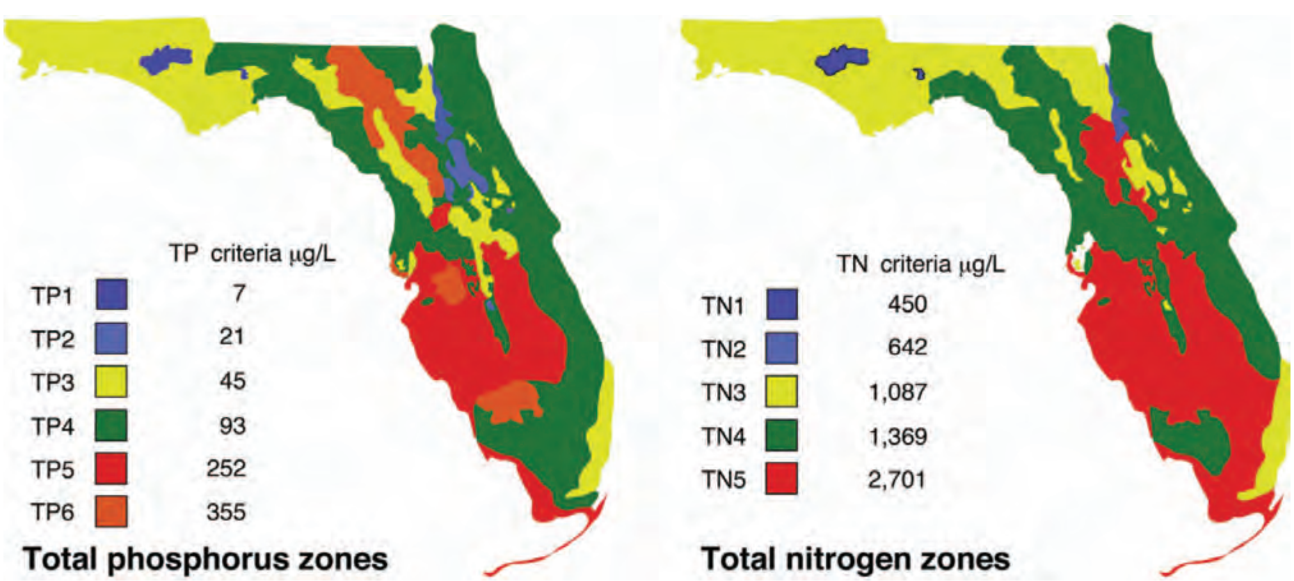

Figure 2.-Maps showing the phosphorus and nitrogen zones and the proposed numeric criteria for TP and TN.

criteria. Our previous study (Bachmann et al. 2012a) showed that, while the oligotrophic lakes tended to be concentrated in a few phosphorus and nitrogen zones, some oligotrophic lakes could also be found in any of the zones. We also have shown that many oligotrophic lakes have high alkalinities and would be missed under the USEPA (2010) criteria. Under our proposal, lakes with current Chl-*a* concentrations of ≤ 6 μg/L would be classified as oligotrophic lakes regardless of where they are located. We would exclude those lakes with high populations of aquatic macrophytes. Canfield et al. (1983) found that in lakes with more than 30% of the surface area covered with submersed aquatic macrophytes, the plants reduced the nutrient levels in the open water, but the lakes were still biologically rich. If the plants were removed, the nutrient levels and Chl-*a* would increase and Secchi depths would decrease. In our proposal, oligotrophic lakes would be defined as lakes that have (1) a long-term (7 year) average of no more than 6 μg/L of Chl-*a*, and (2) less than 30% coverage by surface area of submersed aquatic macrophytes. The site-specific criteria for TP and TN for each lake would be the long-term average concentrations in that lake.

Protection for lakes with nutrients significantly lower than criteria

The majority of the lakes being regulated will be neither culturally eutrophied lakes nor oligotrophic lakes; however, many would have TP and TN concentrations considerably less than the 90th percentile levels. Because the goal of the proposed criteria is to protect lakes from anthropogenic changes in trophic state, we propose to use the anti-degradation clause currently in the state statutes to hold those lakes to current levels of plant nutrients. Under current Florida laws, a lake will be placed on the Planning List if TP, TN, or Chl-*a* shows a statistically significant increase over a 7-year period. In all cases, allowance has to be made for changes in nutrient concentrations due to natural causes such as seasonal cycles, longer cycles of wet years and dry years, changes in water levels, and changes in macrophyte biomass.

Advantages of this approach

Our approach takes into account the natural variability of Florida lakes by building on the USEPA Florida Lake Regions as represented by the geographic zones for TP and TN (Bachmann et al. 2012a). It recognizes that in their natural states Florida lakes can be oligotrophic, mesotrophic, or eutrophic; thus, regulatory resources will not be wasted attempting to regulate a natural phenomenon.

Our approach would allow baseline criteria to be established upon adoption rather than waiting several years to set the criteria for individual lakes because there are a limited number of Florida lakes with a 3-year dataset on TP, TN, color, and alkalinity (a major requirement of the USEPA approach). The shapefiles of the USEPA lake regions and the nutrient zones are available in ARCGIS format from the authors, so it is relatively easy to find the nutrient zone for an individual lake that has not yet been examined.

Our proposal would allow the protection of all oligotrophic lakes regardless of their alkalinity status by using a site-specific procedure. If the anti-degradation procedure were used, all other lakes would have protection as well. If regulations cause the large number of naturally eutrophic lakes to be in violation, the resources of FDEP and local governments will be wasted in attempts to change them. Our plan will result in a smaller list of lakes with potential significant enrichment from human activities. This will permit the FDEP to focus on the lakes most likely to have a nutrient problem.

Use of adaptive management

We view our proposal as a blueprint for the process of setting numeric nutrient criteria for each of the 7700 lakes in Florida. It provides a set of criteria that can be implemented in a short period of time based on our current state of knowledge, but recognizes that changes will have to be made to the criteria for some lakes as new information on controllable sources of nutrients becomes available. As the lakes exceeding the 90th percentile are investigated, the criteria may have to be adjusted to reflect the amounts of documented anthropogenic nutrient loads. After more information becomes available, the percentile may have to be adjusted upward or downward from the 90th percentile to characterize more accurately the lakes most likely to be culturally eutrophied. In the same way, potentially oligotrophic lakes that currently have significant anthropogenic sources of nutrients might be identified and their criteria adjusted. There should be an ongoing process of adaptive management that would eventually arrive at the best numeric nutrient criteria for Florida lakes that reflect their diversity.

References

Bachmann RW, Bigham DL, Hoyer MV, Canfield DE Jr. 2012a. Factors determining the distributions of total phosphorus, total nitrogen and chlorophyll *a* in Florida lakes. Lake Reserv Manage. 28 (1): 10–26.

Bachmann RW, Bigham DL, Hoyer MV, Canfield DE Jr. 2012b. Phosphorus, nitrogen and the designated uses of Florida lakes. Lake Reserv Manage. 46–58.

Canfield DE Jr, Langeland KA, Maceina MJ, Haller WT, Shireman JV, Jones JR. 1983. Trophic state classification of lakes with aquatic macrophytes Can J Fish Aquat Sci. 40:1713–1718.

Danielson T. 2009. Description of nutrient criteria for fresh surface waters (Chapter 583). Maine Department of Environmental

Protection. DEPLW-0974; [cited 1 Feb 2012]. Available from http://www.penobscotnation.org/dnr/water/resources/description_of_nutrient_criteria.pdf

[EC] European Commission. 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. OJEC. L 327:1–72.

[FDEP] Florida Department of Environmental Protection. 2009. State of Florida numeric nutrient criteria development plan; [cited 5 Jul 2010]. Available from http://www.dep.state.fl.us/water/wqssp/nutrients/docs/fl-nutrient-plan-v030309.pdf

Gartner Lee Ltd. 2009. Development of ecoregion based phosphorus guidelines for Canada: Ontario as a case study. Can Counc M Environ; [cited 22 Dec 2011]. Available from http://www.ccme.ca/assets/pdf/phosphorous_ecoregion_rpt_1.0_e.pdf

Griffith GE, Canfield DE Jr, Horsburgh CA, Omernik JM. 1997. Lake Regions of Florida. Corvallis (OR): US Environmental Protection Agency; National Health and Environmental Effects Research Laboratory. EPA/R-97/127; [cited 5 Jul 2010]. Available from http://www.epa.gov/wed/pages/ecoregions/fl_eco.htm

Hatton-Ellis T. 2008. The hitchhiker's guide to the Water Framework Directive. Aquat Conserv. 18:111–116.

Heiskary SA, Wilson CB. 2008. Minnesota's approach to lake nutrient criteria development. Lake Reserv Manage. 24:282–297.

Hoyer MV, Brown CD, Canfield DE Jr. 2004. Relations between water chemistry and water quality as defined by lake users in Florida. Lake Reserv Manage. 20:240–248.

[IEPC] Iowa Environmental Protection Commission. 2011. Notice of intended action to amend Chapter 61, "water quality standards," Iowa Administrative Code; [cited 26 Maqy 2011]. Available from http://www.iowadnr.gov/water/standards/files/noia_nutrients.pdf

[KDHE] Kansas Department of Health and Environment. 2011. Chlorophyll-a criteria for public water supply lakes or reservoirs. Water quality standards white paper; [cited 26 May 2011]. Available from http://www.owrb.ok.gov/util/rules/pdf_rul/nutrient_criteria_sws_jd.pdf

Moyle JB. 1945. Some chemical factors influencing the distribution of aquatic plants in Minnesota. Am Midl Nat. 34:402–420.

Moyle JB. 1956. Relationships between the chemistry of Minnesota surface waters and wildlife. J Wildl Manage. 20:303–320.

[OWRB] Oklahoma Water Resources Board. 2005. Justification for chlorophyll-a criteria to protect the public and private water supply beneficial use of sensitive water supplies; [cited 26 May 2011]. Available from http://www.owrb.ok.gov/util/rules/pdf_rul/nutrient_criteria_sws_jd.pdf

[SCDHEC] South Carolina Department of Health and Environmental Control. 2008. R.61-68. Water classification and standards. Bureau of Water., Columbia, SC; [cited 19 Dec 2011]. Available from http://www.scdhec.gov/environment/water/regs/r61-68.pdf

Sondergaard M, Jeppesen E, Jensen JP, Amsinck SL. 2005. Water Framework Directive: ecological classification of Danish lakes. J. Appl Ecol. 42:616–629.

Terrell JB, Watson DL, Hoyer MV, Allen MS, Canfield DE Jr. 2000. Temporal water chemistry trends (1967–1997) for a sample (127) of Florida waterbodies. Lake Reserv Manage. 16:177–194.

[USEPA] United States Environmental Protection Agency. 2010. Water quality standards for the state of Florida's lakes and flowing waters. Federal Register 75:131 (26 January 2010) 4173–4226; [cited 21 Dec 2011]. Available from edocket.access.gpo.gov/2010/pdf/2010-29943.pdf

[VWRRC] Virginia Water Resources Research Center. 2005. Issues related to freshwater nutrient criteria for lakes and reservoirs in Virginia. Special Report; [cited 27 Aug 2010]. Available from www.vwrrc.vt.edu/pdfs/specialreports/sr272005.pdf

Wagner KJ, Oglesby RT. 1984. Incompatibility of common lake management objectives. Lake Reserv Manage. 1:97–100.