Development of Lake-specific Numerical Nutrient Criteria for Water Quality Standards in Reservation Lakes

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Fond du Lac Reservation Office of Water Protection

and

Grand Portage Reservation Water Quality

Prepared by:
Patricia Soranno, Associate Professor
Department of Fisheries and Wildlife
Michigan State University
East Lansing, MI 48824
soranno@msu.edu

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Preface

This technical report describes the approach for establishing lake-specific numeric nutrient criteria in tribal lakes in the Fond du Lac and Grand Portage reservations. Fond du Lac and Grand Portage Reservations (hereafter FDL and GP) have federally approved Water Quality Standards. Presently, both reservations are working towards USEPA's request to replace narrative nutrient criteria with numeric nutrient criteria. This report describes the approach for the 9 fisheries lakes of FDL and all 15 of the GP lakes. I also include data and analyses for comparison purposes from the 29-lake reference lake database from the Northern Lakes and Forests Ecoregion (the ecoregion for which both reservations are located within) sampled by the MN Water Pollution Control Agency and provided to me in August 2010 by Steve Heiskary.

Introduction

Background: Developing nutrients criteria in lakes

The USEPA has requested that scientifically defensible numerical nutrient criteria be developed to protect designated uses of water bodies (USEPA 2000). Because designated uses themselves are difficult to directly measure, nutrient levels of water bodies have been suggested to be important indicators of designated uses. However, nutrient concentrations alone do not directly measure designated uses. For example, for the designated use of 'supporting aquatic life' in lakes, it is not clear what concentration of phosphorus or nitrogen would indicate that this use is or is not being supported. This result occurs, in part, because 'healthy' biological communities have been found to exist in lakes with total phosphorus concentrations of 5 ug/L or 50 ug/L depending on the type of lake, the landscape setting, the lake depth, etc. To address this issue, practitioners have recommended that biological responses be used to measure the 'aquatic life' designated use such that if the biological response changes when nutrients increase, then it is an indication that the designated use is being threatened or not being supported (Stevenson et al. 2004, Reckhow et al. 2005, Heiskary and Wilson 2008, Soranno et al. 2008). However, it has also been noted that it is critical to consider the natural hydrogeomorphic setting of the lakes and use some sort of quantitative classification to ensure natural lake to lake variation is taken into account when determining whether an important biological change has occurred (Heiskary and Wilson 2008, Soranno et al. 2008, Bachmann et al. *in press*).

An important step in establishing nutrient criteria is to relate nutrient concentrations to biological responses in lakes. Much research that has been conducted in this area for purposes other than nutrient criteria development can inform any criteria development program (see citations in Soranno et al. 2008). However, the vast majority of such studies have been conducted in relatively large, deep, stratified, clear lakes. There certainly are studies conducted on shallow lakes, but such studies often contain lakes with relatively low to only moderate levels of water color, although water color is not always reported (e.g., Jeppesen et al. 2000). I would argue, that even the relationship between nutrients and algae, arguably one of the most well-studied relationships in limnology, has not been well studied in highly stained deep, or highly stained shallow lakes (but see Nurnberg and Shaw 1999 and Bachmann et al 2003). In addition, much less research related to nutrient criteria development has occurred for lakes that are not deep, stratified, and clear (but see Bachmann et al. (a,b,c) *in press*). The fundamental nature of the hydrologic, chemical and physical characteristics of lakes that are shallow, unstratified, and colored is so different from deep, stratified lakes (Nurnberg and Shaw 1999; Webster et al. 2008). As a result, many of our commonly held assumptions regarding the basic limnological relationships need to be evaluated for such lakes.

Another critical factor to consider is the natural hydrogeomorphic setting of lakes because it sets the stage for establishing the natural, or ‘expected conditions’ of nutrients. ‘Expected conditions’ are defined as the concentrations of nutrients in a lake in its least disturbed condition given the state of today’s landscape (Stoddard et al. 2006, Soranno et al. 2008). Quantifying the expected conditions in water bodies is complicated for lakes that are currently subjected to human disturbance, in which case, the expected condition cannot simply be measured by taking samples in present-day. Several possible approaches have been proposed to address this challenge (summarized in Soranno et al. 2008). However, for the situation where lakes are presently experiencing relatively low human impacts and have not changed significantly from historical levels, then measurements taken from present-day can be used as a measure of expected condition (Lafrancois et al. 2009, Bachmann et al. *in press*).

Establishing criteria in tribal waters

The fundamental scientific underpinnings, approaches, and assumptions for establishing nutrient criteria should be no different in tribal waters compared to state waters. Thus, strategies from other states or countries can be applied to establishing nutrient criteria in tribal waters. However, there are two critical differences between establishing numerical nutrient criteria in state waters compared to tribal waters is: (1) the difference in the number of water bodies for which the criteria will be applied, and (2) the type and availability of data to robustly quantify numerical criteria. In a perfect world, we would have and use the exact same data for both state and tribal waters. The reality is that because reservations typically have fewer water bodies, they can devote greater resources per water body and sample each one (or the majority of them) on a regular basis to be able to measure how they change through time. This wealth of data is rarely if ever available for state waters, although certainly some states with fewer lakes have data that are available on any given lake through time to varying degrees. However, for states that have thousands of lakes, an even greater challenge is to effectively capture the large lake-to-lake variation that exists across the state, which may in fact swamp the changes in nutrients that occur from year to year. This fundamental difference in data availability and numbers of water bodies to be managed calls for a different approach for establishing nutrient criteria in tribal waters compared to state approaches, and consideration of how these data can be most effectively used to support the protection of these waters under the Clean Water Act.

In this report, I will describe an approach to quantify numeric nutrient criteria in tribal lands that incorporates some components of existing approaches, but that recognizes the above critical issues. I apply this strategy to lakes in two reservations: the Fond du Lac Reservation (hereafter FDL) and the Grand Portage Reservation (hereafter GP). The approach requires long-term lake data for nutrients and water color or dissolved organic carbon (to assess inter-annual variability), which is rarely available for all state lakes that must be managed and protected under the Clean Water Act.

Comparison and Analysis of the Available Approaches to Develop Numeric Nutrient Criteria

There have been several recent efforts to develop approaches for establishing numerical nutrient criteria (e.g., Dodds and Oakes 2004, Reckhow et al. 2005, Heiskary et al. 2008, Soranno et al. 2008, Bachmann et al. (c) *in press*). In Table 1, I summarize three of the approaches developed to date, as well as the approach I describe in this report. I explore the relative strengths and weaknesses of each approach to help inform the approach that I developed for these tribal waters. The three U.S. states for which criteria have been developed are large in area (incorporating 3-5 Omernik ecoregions within their boundaries), have > 6,500 lakes, and wide ranges of lake sizes (Table 1). Two of the states (MI and MN) have large numbers of different types of lakes ranging from shallow to deep, clear to colored, although the majority are clear-water; the other state (FL) has more similar lakes (shallow, colored, and seepage), but with still large variation in nutrients across the state (Table 1).

States address the challenge of managing thousands of lakes by sampling as many of their often thousands of lakes that they are responsible for at least one time (typically during the same index period). There are two main ways that such data have been then used to establish nutrient criteria: (a) by using or creating ecoregions or nutrient zones (Heiskary and Wilson 2008, Bachmann et al. (c) *in press*) that assume all lakes within a given ecoregion or zone are more similar to each other than to lakes in other zones, (b) use statistical modeling of the local or regional landscape features that are hypothesized to be most related to lake nutrients (Soranno et al. 2008). These approaches are briefly described in Table 5, as are the pros and cons of each approach. They have been developed to try to effectively capture as much variation in nutrients across lakes within the large, heterogeneous states and to establish criteria for different lake types or regions. The advantages of these approaches are that they can be applied at large spatial scales, they can be used for states that have data from many lakes, but with limited temporal sampling, and the approaches use a variety of strategies to incorporate biological condition to inform or relate to criteria and ultimately designated uses (Table 1).

The implicit assumption in these approaches is that a single-time sample during an ‘index’ period captures the ‘average’ conditions of the lakes and that variation among individual lakes and different lake types is greater than temporal variation. In other words, temporal variation is assumed negligible. Although most practitioners recognize that this assumption is not always met, if at all, it is the best that can be done with present data. In fact, the integration of spatial and temporal variation is an important research gap that is needed to be addressed to help inform nutrient criteria development across the nation.

Although these approaches are all well-thought out and appear to work effectively for the states for which they were developed, there are weaknesses with any approach, especially when considering their use in tribes or states with few lakes and extensive long-term monitoring data. For example, for both the Michigan and Florida approaches, the models that explain TP variation across the states only account for ~40% of variation in TP among lakes. Thus, much unexplained variation in lake TP remains that likely leads to errors in applying estimated criteria to individual lakes. For the Minnesota approach, the amount of variation accounted for by their approach cannot be explicitly calculated because their criteria are not based on a single model as the other two approaches are. However, we can evaluate the variation in nutrients in lakes in the reference lake database used to develop the criteria for the Northern Lakes and Forest Ecoregion (NLF, Heiskary and Wilson 2008) and compare those values to the current nutrient concentrations in the tribal waters for the GP reservation (Lafrancios et al. 2009), there are large differences. Nutrient concentrations in GP are much higher than the reference lake database. Considering both groups of lakes are in a minimally-disturbed state, then there would be large errors in applying the NLF ecoregion criteria to GP lakes (Lafrancois et al. 2009).

For the above reasons, the approaches for establishing nutrient criteria in tribal waters must be different from the approaches that have been developed for states with large spatial extents (e.g., 3-5 Omernik ecoregions) and large numbers of different types of lakes. In developing an approach to establish nutrient criteria in tribal waters, I have incorporated some of the ideas, concepts, and steps from past approaches, because most of the basic ideas apply. However, strategies that take into account temporal variation must be incorporated. It is hoped that the approach developed here can serve as a template for other tribal waters or states that have comparable data and small numbers of lakes to be managed.

Overview: A New Approach for Establishing Numeric Criteria for Sites with Small Numbers of Lakes and Long-term Monitoring Data

There are 8 main steps in this approach to quantify numeric nutrient criteria (Table 2). I first describe the approach in general in this section. In later sections, I describe the application of this approach to the FDL and GP lakes.

Step 1. The first step with any approach to quantify nutrient criteria is an assessment of designated uses for each water body. The most restrictive designated use is then identified and noted for each lake. This approach assumes that the lakes are currently in a minimally-impacted state. If lakes are currently experiencing significant human impacts, then an alternative approach needs to be developed. The most restrictive designated use is then used to guide the criteria development.

Step 2. All available nutrient data are compiled from as many lakes within the area to be managed. Preferred data include: lake nutrients such as total phosphorus (TP) and total nitrogen (TN), any measure of organic carbon (such as water color or dissolved organic carbon (DOC)), additional measures of water clarity such as Secchi depth, and algal measures (such as chlorophyll concentrations or algal biomass).

Step 3: The data in the database should be plotted to identify any outliers and determine if trends are present in the data. If trends are present then the likely causes should be explored. However, the remaining steps assume that there are few if any quantifiable trends in the data. Because shallow lakes mix more frequently, they may be subject to larger numbers of outlier data points in which a sample taken during a mixing event could be substantially different than a sample taken during a short-term stratification event. Outliers should be noted and monitored in the future. However, they are removed from the remaining analyses to estimate expected condition of the lakes. Because there are no universally accepted mathematical definitions of outliers, I used a variety of approaches to identify and remove outliers. First, I plot the data through time to identify candidate outliers that are greatly different from most data points. Then, I plot well-known relationships among the variables to identify data points that fail to fit common limnological relationships. I removed data points from further analyses only after a data point appeared as an outlier from both plots. Evaluation of common limnological relationships allows an assessment of the underlying processes that control lake nutrients and algal communities. This step is important because it determines which published studies can be used to evaluate the lakes. However, often, such relationships have been primarily developed for either spring, or summer periods, and so the seasonality needs to be considered in this step as well.

Step 4. Because the lakes are currently in a minimally impacted state, then the current biological conditions can be assumed to be indicative of lakes meeting designated uses. Biological data from such lakes cannot be used to quantify thresholds in human disturbance, because there would be no lakes that are the high end of the gradient of human use; therefore if a gradient approach were to be taken, data from other sites would have to be used. However, biological data can be treated similar to the nutrient data and be used to set recommended values to support designated uses.

Step 5. Because of large seasonality for water bodies, criteria need to be determined by season (either one or more). Therefore, if samples are taken more than one time per season, or across seasons, then these data need to be accounted for. In addition, the season of most importance for establishing criteria needs to be established and decided.

Step 6. Using the nutrient database for each lake, the 'expected condition' of the lakes for nutrients, clarity and algae can be calculated as the full range of expected concentrations for each variable and each lake. At this point, another examination of outliers should be conducted on a lake-by-lake basis.

Step 7. The final step is to use the above expected conditions to calculate numeric nutrient criteria for each lake to protect designated uses. The nutrient criterion for each nutrient in each lake is calculated to be the upper 90^{th} percentile of the samples within a season across all years.

Lake Descriptions and Designated Uses

Fond du Lac and Grand Portage Lakes

FDL has nine lakes for which criteria are being established in this report. These lakes are the 'primary fisheries' lakes that range in surface area from 6 – 212 ha, and maximum depth from 3.4 – 23.5 (Table FDL1). The lakes have high amounts of natural land cover in their watersheds including forest, grassland/shrubland or wetlands (Table FDL1). The lakes have the designated uses described in Table FDL2, the most restrictive being aquatic life uses.

GP has 15 lakes for which criteria are being established in this report. These include most of the major lakes in GP and they range in surface area from 1 – 144 ha, and they range in maximum depth from .9 – 7.6. The lakes have high amounts of natural land cover in their watersheds (Lafrancois et al. 2009), and have designated uses as described in Table GP2, with aquatic life being the most restrictive.

Using several lines of evidence, I assume that the lakes in both reservations are for the most part in minimally-impacted condition. Edlund et al. (2007, 2009) show results from lake sediment cores taken in two of the GP lakes and found no difference between historic and present-day diatoms and in diatom-inferred TP. In addition, human land use/cover in both reservations is very low, with the maximum % cover of human-dominated land use/cover of 12% in the Big Lake watershed in FDL, although most lakes have human land use/cover < 5% in FDL (Table FDL1), and even lower levels in GP (Lafrancois et al. 2009). The acknowledgement of these lakes being in a minimally-impacted state is important because they presently have relatively high nutrient concentrations relative to lakes in the NLF ecoregion (Lafrancois et al. 2009). However, these high nutrient levels can be attributed to shallow depth of the water bodies, and high DOC concentrations in the lakes (Lafrancois et al. 2009). Other recent efforts to develop criteria for shallow, colored lakes have also arrived at high values for both TP and TN criteria (FL, Table 1).

Comparison of reservation lakes to reference lakes in the NLF ecoregion

There are important similarities AND differences among the three groups of lakes. In comparing the sites, I focus on differences that appear to be ecologically important rather than statistically important because the NLF dataset medians are calculated across lakes with individual data points, and the GP and FDL dataset medians are calculated across lakes and across time. Thus, error estimates would be biased due to the different nature of the dataset structures.

First, I discuss the characteristics across the sites that are similar. Based on median values from 1998-2009 for FDL and GP (Table 3), it appears that FDL lakes are similar to the NLF lakes in the reference database for: TP, chlorophyll *a* (although not at the 90th percentile level), and chl *a*:TP ratio (although not at the 90th percentile level). For GP lakes, there are similar ranges to NLF lakes for TP at all percentiles except the 75th and 90%. In addition, chlorophyll *a* is similar for all percentiles except the 90th, with GP lakes having lower chlorophyll than NLF lakes. The chl *a*:TP ratio is also similar for the 25th and median percentiles, but the ratio is higher in GP lakes for the 75th and 90th percentiles.

Second, I discuss the characteristics across the sites that differ. Both FDL and GP lakes differ from these NLF lakes in both Secchi depth and color – both measures of water clarity such that water clarity is much lower in FDL, and even lower still in GP compared to the NLF lakes. There are differences between GP and NLF lakes for TP at the 75th and 90th percentiles (Table 3), which means the lakes that have high TP in GP have higher TP than the lakes in the NLF that have the highest values. In addition, TN is higher in both FDL and GP than NLF at all levels, with GP being higher than FDL as well.

There is an interesting pattern with chlorophyll *a*. In general, past studies have found that chlorophyll concentrations are often higher in lakes with high color (Nurnberg and Shaw 1999, Webster et al. 2008). Examining the medians across all lakes at FDL and GP, it does not appear that these more highly colored lakes have higher chlorophyll than the NLF lakes (Table 3). Perhaps the fact that lakes in both sites (especially GP) are mostly shallow, especially compared to the NLF dataset as well as the datasets cited above. In shallow lakes in Florida, for example, lakes with macrophyte cover have somewhat lower chlorophyll than laeks without macrophytes, although the relationship was noisy (Bachmann et al. 2002). Thus, the effect of higher chlorophyll in colored lakes that typically occurs could be offset by shallow depths in these lakes (and plant cover) that limits phytoplankton growth and keeps chlorophyll in some of the lakes relatively low.

Applying This Approach to Tribal Waters

Development of numeric nutrient criteria in the 9 FDL fisheries lakes

Steps 1-3: For the FDL fisheries lakes, nutrient, chlorophyll, and clarity data were collected monthly from 1999-2009 during the open-water season (typically May to October). Designated uses for each lake are described in Table FDL2 and the most restrictive use (Aquatic life) was used for criteria development for all lakes. I plotted the data through time for each lake and found no evidence for significant trends in the datasets (Appendix 1A). I plotted nutrients, clarity, and algal variations against each other to help to identify outliers in the data. A few outliers were removed based on evaluation of these common limnological relationships.

The fisheries lakes in FDL fall well within common patterns observed in other north temperate lakes, although some of the relationships are not as strong as observed in other studies. For example, TP is positively related to chlorophyll (Figure 1), however, the strength of the relationship is somewhat lower than other studies. The less strong relationship is most likely due to the fact that FDL lakes tend to be shallower and more colored relative to most lakes that are part of studies examining TP vs CHL relationships. FDL lakes appear to be more limited by phosphorus compared to nitrogen as the relationships between chlorophyll and TP is stronger than the relationship between chlorophyll and TN (Figure 1). Importantly, water color is also positively related to chlorophyll, although the slope is shallow and the amount of variation explained is low, but significant. Other studies have found that chlorophyll concentration is in fact higher in colored lakes compared to clearer lakes for the same TP levels (Webster et al. 2008). The reason for this pattern has not been conclusively identified, but some have argued that high color forces phytoplankton into a smaller volume of water near the surface. The fact that chlorophyll is not elevated compared to NLF lakes, suggests that this effect is not large (see Table 3). However, because shallow lakes can have lower chlorophyll concentrations, perhaps the water color effect is being offset by the shallow depths of these lakes. Nutrients themselves are correlated in these lakes. Plots of TP vs TN are similar to other studies. TP and water color are also positively correlated, as is TN and water color, both of which have been found elsewhere.

Step 4: COMING SOON. I will use the biological data that have been collected by the tribes to assess the current biological condition of the lakes. Similar to the nutrients, given that it is assumed the lakes are in minimally-impacted state, the biological condition should reflect that condition as well. The biological conditions measured to date could be used as a benchmark for achieving the aquatic life designated uses given the nutrient concentrations during the same time period. Metrics to be quantified for FDL include: LIST METRICS HERE.

Step 5: Because most research and nutrient criteria development has been conducted using data from the summer index period, I selected the summer months of July, August, and September as the index period to more easily compare to other studies. In addition, this period is the time of maximum primary and secondary production in lakes. I calculated a range of percentiles for the data (including the median, the 50th percentile) to compare the two reservation sites to each other and to the 29-lake reference lake database for lakes within the Northern Lakes and Forest ecoregion (NLF) compiled by S. Heiskary for MN's nutrient criteria development (Table 3). I used this dataset for comparison because these NLF lakes were considered to be in a minimally-impacted state and because both FDL and GP are within the NLF ecoregion. FDL lakes are relatively similar to NLF lakes for TP at all percentiles. On the other hand, TN is higher in FDL lakes relative to NLF lakes for all percentiles. Chlorophyll is remarkably similar across all three sites. In addition, the Chl *a*:TP ratio is very similar between NLF and FDL lakes except for the 90th percentile lakes where FDL lakes that have the highest ratio are higher than the highest observed ratios in NLF lakes. Because for a given TP concentration, more highly stained lakes have somewhat higher chlorophyll, some of this difference may be due to the higher water color in the FDL lakes compared to the NLF lakes, especially in the upper percentiles (Table 3). This overall higher water color in FDL also leads to overall shallower Secchi depths in FDL compared to NLF lakes.

FDL and GP lakes have some similarity, but also important differences. The hydrogeomorphic settings of the two reservations differs substantially, which may be the reason for the fairly large differences in nutrient concentrations and water color. TP is higher in general in GP, primarily in the higher percentiles (Table 3). Whereas, TN is consistently higher at all percentiles, as is water color. Interestingly, despite such differences, the chlorophyll concentrations are remarkably similar across FDL and GP, as well as NLF lakes. However, given the large differences among the three groups of lakes, I would argue that chlorophyll may be limited by different factors in the different groups of lakes.

Step 6: The box plots show that both interannual variability within the lakes, and variability across the lakes is quite large in FDL and must be taken into account when setting nutrient criteria (Figure 3a-b). A single criterion that applies to all lakes would not be recommended due to the diversity of lakes in FDL. When examining the conditions of the lakes individually, there is very large inter-lake variability in most variables except perhaps chlorophyll. The medians of TP range from between 10 and 20 ug/L to greater than 30 ug/L in a couple lakes (Figure 3a). TN has a wider range across the lakes, which chlorophyll is actually consistently below 10 ug/L except for Third Lake, which has been noted to be partially supporting its designated uses in the past due to the presence of algal blooms. Further examination of this lake is needed and is ongoing (N. Schuldt, personal comm.). Secchi depths are relatively shallow reflecting the high water color in these lakes and these two variables are inversely related as is commonly the case (Figure 3b).

To determine the expected conditions of the lakes for each nutrient, I removed any remaining outliers in the dataset (ones that were not selected using the above approaches). For this step, I defined the outliers statistically as the ‘far outside values’ that are beyond 3.5 times the interquartile range of the data (Systat 11.0 software). These points are shown as open circles in Figure 3a-b. I removed these outliers because they represent extremely high values that are rare across the 10 year sampling period so would be likely to bias the nutrient criteria calculations in the next step. In FDL, I deleted 2 values for TP, 3 values for TN and 3 values for chlorophyll as shown in Figure 3a.

Step 7: I then took the TP, TN and chlorophyll datasets for each lake for the samples in July, August, and September from 1999-2009 (with outliers removed) and calculated the 90th percentile value for each lake. This value is the lake-specific nutrient or chlorophyll criterion. In Table 4b, the criteria are shown for all lakes with the outliers removed as per Step 6. In brackets, I show the number of samples that were used to estimate the criterion. At the bottom of the table, I calculated the median criterion (e.g., the median of all the lake TP criteria from FDL lakes only) to compare it to the median criterion in GP lakes as well as to the criterion that has been recommended for NLF ecoregion lakes. For TP, the median FDL criterion is less than the NLF criterion, by 7 ug/L. However, an important point is that the lake to lake variation within FDL is very high such that if just the median value was used (i.e., 23) for all lakes, there are lakes with ‘expected conditions’ well ABOVE or BELOW that value by ecologically relevant amounts (e.g., one lake is 24 ug/L over the median, and another lake is 8 ug/L below the median). These results highlight the importance of capturing lake-to-lake variation in setting nutrient criteria.

The values for TN cannot be compared to NLF because TN criterion were not estimated. However, the chlorophyll criterion is identical to the NLF criterion. However, again, the lake-to-lake variation within FDL is large such that some lakes are 6 ug/L less than the median criterion, or 35 units above it. The very large chlorophyll criterion for Third Lake suggests that perhaps it is experiencing human impact that has not been quantified yet. Finally, to more easily compare across FDL, GP and NLF lakes, I plotted the data from Table 4b (Figure 5). The plots show that the FDL lakes fall above and below the NLF criterion, but are lower in general than the GP criteria for nutrients.

Table 4b represents the recommended nutrient criteria for the FDL lakes. However, I include Table 4a to show the effect of removal of the outlier points. In Table 4b, I highlighted in yellow, those criteria that changed once the outliers were removed. Criteria decreased after removal of outliers for no lakes for TP, for only 3 lakes for TN, and for 1 lake for chlorophyll. The differences were ecologically relevant in some cases, and not large in others. However, as the outliers that were removed were relatively rare data points, I think the dataset with outliers removed is a better reflection of expected conditions. Nevertheless, it would be worth examining the outliers in relation to other conditions (such as sampling conditions, lack of stratification, etc.) that might explain these occasional high values.

Development of numeric nutrient criteria in 15 GP lakes

Steps 1-3: For the GP lakes, nutrient, chlorophyll, and clarity data were collected monthly from 1999-2009 every other year during the open-water season (typically May to October). Designated uses for each lake are described in Table GP2 and the most restrictive use (Aquatic life) was used for criteria development for all lakes. I plotted the data through time for each lake and found no evidence for significant trends in the datasets (Appendix 1**B**). I plotted nutrients, clarity, and algal variations against each other to help to identify outliers in the data. A few outliers were removed based on evaluation of these common limnological relationships.

The GP do not seem to follow patterns observed in other north temperate lakes. For example, TP is only very weakly positively related to chlorophyll (Figure 2). The lack of a relationship is most likely due to the fact that GP lakes are even shallower and more colored than FDL lakes and much more so than most lakes that are part of studies examining TP vs CHL relationships. There is little evidence that GP lake chlorophyll is limited by either phosphorus or nitrogen (Figure 2), as the relationships between TP or TN and chlorophyll are significant, but with extremely low R^2. And, similar to FDL, GP lake chlorophyll is only weakly, but positively related to water color (as measured by DOC). Other studies have found that chlorophyll concentration is in fact higher in colored lakes compared to clearer lakes for the same TP levels (Webster et al. 2008). The reason for this pattern has not been conclusively identified, but some have argued that high color forces phytoplankton into a smaller volume of water near the surface. The fact that chlorophyll is not elevated compared to NLF lakes, suggests that this effect is not large (see Table 3). However, because shallow lakes can have lower chlorophyll concentrations, perhaps the water color effect is being offset by the shallow depths of these lakes. Nutrients themselves are correlated in these lakes, but again, much weaker than other north temperate lakes and weaker than FDL lakes.

Step 4: COMING SOON. I will use the biological data that have been collected by the tribes to assess the current biological condition of the lakes. Similar to the nutrients, given that it is assumed the lakes are in minimally-impacted state, the biological condition should reflect that condition as well. The biological conditions measured to date could be used as a benchmark for achieving the aquatic life designated uses given the nutrient concentrations during the same time period. Metrics to be quantified for FDL include: LIST METRICS HERE.

Step 5: Because most research and nutrient criteria development has been conducted using data from the summer index period, I selected the summer months of July, August, and September as the index period to more easily compare to other studies. In addition, this period is the time of maximum primary and secondary production in lakes. I calculated a range of percentiles for the data (including the median, the 50^{th} percentile) to compare the two reservation sites to each other and to the 29-lake reference lake database for lakes within the Northern Lakes and Forest ecoregion (NLF) compiled by S. Heiskary for MN’s nutrient criteria development (Table 3). I used this dataset for comparison because these NLF lakes were considered to be in a minimally-impacted state and because both FDL and GP are within the NLF ecoregion. GP lakes differ from the NLF lakes for almost all variables except chlorophyll. In fact, GP is more different to the NLF dataset than the FDL are (Table 3). TP is generally higher than NLF lakes, but only by small amounts in the higher percentile ranges. TN is much larger in GP lakes than both NLF and FDL lakes. Whereas, chlorophyll is similar across all sites. Finally, both Secchi depth and DOC are very different in GP lakes compared to NLF lakes, with FDL lakes being intermediate between NLF and GP lakes for both. The hydrogeomorphic settings of the two reservations differs substantially, which may be the reason for the fairly large differences in nutrient concentrations and water color. Interestingly, despite such differences, the chlorophyll concentrations are remarkably similar across FDL and GP, as well as NLF lakes. However, given the large differences among the three groups of lakes, I would argue that chlorophyll may be limited by different factors in the different groups of lakes.

Step 6: The box plots show that both interannual variability within the lakes, and variability across the lakes is quite large in GP and must be taken into account when setting nutrient criteria (Figure 4a-b). GP lakes have larger ranges in TP compared to FDL, but about the same ranges for CHL and TN (although the absolute levels of TN is higher in GP). A single criterion that applies to all lakes would not be recommended due to the diversity of lakes in GP. When examining the conditions of the lakes individually, there is very large inter-lake variability in most variables except perhaps chlorophyll. The medians of TP range more across the 15 lakes than the FDL lakes (Figure 4a). Secchi depths are relatively shallow reflecting the high water color in these lakes and these two variables are inversely related as is commonly the case (Figure 4b). Although Secchi depth is relatively deep in two lakes – Trout and Taylor, and DOC concentrations are also low in these lakes (Figure 4b).

To determine the expected conditions of the lakes for each nutrient, I removed any remaining outliers in the dataset (ones that were not selected using the above approaches). For this step, I defined the outliers statistically as the ‘far outside values’ that are beyond 3.5 times the interquartile range of the data (Systat 11.0 software). These points are shown as open circles in Figure 4a-b. I removed these outliers because they represent extremely high values that are rare across the 10 year sampling period so would be likely to bias the nutrient criteria calculations in the next step. In GP, I deleted 14 values for TP, 4 values for TN and 5 values for chlorophyll as shown in Figure 4a. It appears that GP had more datapoints that were classified as outliers compared to FDL. One possible explanation for this result is that because GP lakes in general are more shallow than FDL lakes, they may mix more frequently leading to more events of sediment resuspension that can lead to higher pulses of nutrients and possibly algal cells that have settled to low light areas. This idea could be tested by looking at temperature profiles during these sampling events and total suspended solids to see if it is elevated on days that these outliers were present. If you remove the two deepest lakes from GP and the one deep lake in

FDL and calculate the averages of the lake depths, the average of the maximum depths for GP is 2.6 m and for FDL is 4.9 m. Nevertheless, these GP data points still met the criteria for outliers and were removed from further analyses.

Step 7: I then took the TP, TN and chlorophyll datasets for each lake for the samples in July, August, and September from 1999-2009 (with outliers removed) and calculated the 90th percentile value for each lake. This value is the lake-specific nutrient or chlorophyll criterion. In Table 4b, the criteria are shown for all lakes with the outliers removed as per Step 6. In brackets, I show the number of samples that were used to estimate the criterion. At the bottom of the table, I calculated the median criterion (e.g., the median of all the lake TP criteria from GP lakes only) to compare it to the median criterion in FDL lakes as well as to the criterion that has been recommended for NLF ecoregion lakes.

For TP, the median GP criterion is nearly identical to the NLF criterion. However, an important point is that the lake to lake variation within GP is very high such that if just the median value was used (i.e., 31) for all lakes, there are lakes with 'expected conditions' well ABOVE or BELOW that value by ecologically relevant amounts (e.g., one lake is 59 ug/L over the median amount, and another lake is 18 ug/L below the median value). These results highlight the importance of capturing lake-to-lake variation in setting nutrient criteria. The values for TN cannot be compared to NLF because TN criterion were not estimated. However, the chlorophyll criterion is identical to the NLF criterion. However, again, the lake-to-lake variation within FDL is large such that some lakes are 4 ug/L less than the median criterion, or 12 ug/L above it. Finally, to more easily compare across GP, FDL and NLF lakes, I plotted the data from Table 4b (Figure 5). The plots show that the GP lakes fall almost equally above and below the NLF median for chlorophyll, they have a much wider range in TP than in chlorophyll around the NLF median, and have higher TN 90th percentiles (and median) compared to FDL lakes.

Table 4b represents the recommended nutrient criteria for the GP lakes. However, I include Table 4a to show the effect of removal of the outlier points. In Table 4b, I highlighted in yellow, those criteria that changed once the outliers were removed. Criteria decreased after removal of outliers for 11 lakes for TP, for only 2 lakes for TN, and for 3 lakes for chlorophyll. Again, given that GP has more outliers than FDL, it is not surprising that more of the criteria changed once outliers were removed. The differences were ecologically relevant in some cases, and not in others. However, as the outliers that were removed were relatively rare data points, I think the dataset with outliers removed is a better reflection of expected conditions. Nevertheless, it would be worth examining the outliers in relation to other conditions (such as sampling conditions, lack of stratification, etc.) that might explain these occasional high values.

Assumptions for this approach and evidence supporting these assumptions

There are several important assumptions in this approach to develop numeric nutrient criteria. First, I assume that the lakes are at minimal levels of human impact and exist in some form of 'reference' state (see above for evidence). Second, I assume that the condition of the lakes from the period of collection of the nutrient database (e.g.. for the lakes in this report, 1998-2009) is indicative of both past and future conditions of minimal human impact. Third, I assume that the nutrients in the lakes from the sampling period are at a level to support the 'Aquatic life' designated use, which is the most restrictive of the uses for the lakes. Unfortunately, the point at which an increase in nutrients will cause this use to not be supported is not known precisely or even in general because too little research has been conducted on such lakes with high color and that are very shallow. Therefore, I use the frequent sampling of nutrients from a 10 year time period for each lake to set the criterion for the nutrient level that incorporates interannual variability, as well as the biological sampling that shows communities of high biological integrity. Fourth, I assume that the climate that the lakes experienced during the time period of nutrient sampling is representative of future climate. Thus, the nutrient criteria should be valid as long as climate does not change dramatically from this period of record.

The role of projected climate change is a concern that applies to any approach for quantifying nutrient criteria. If climate does change significantly, there could be important changes in both hydrology and DOC in these lakes that likely will influence both nutrients and algal communities. For example, it is possible to develop scenarios that lead to increases OR decreases in DOC depending on changes in climate, which would likely have important effects on lake nutrients and ultimately chlorophyll. For example, it could be that with declining DOC, nutrients might also decrease, which in lakes with current minimal human disturbance is not a desired endpoint. Because DOC levels in lakes in both reservations is moderate to high, the relationship between climate, DOC, nutrients and algal response is important in these lakes.

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Edlund e tal. 2009

Bachmann et al. 2002

APPENDIX 1. I can add plots for the variables below. Takes up lots of space to do for each lake, but can easily be made if it would help.

(A) FDL Nutrient, chlorophyll, and clarity data by lake, through time.
(B) GP Nutrient, chlorophyll, and clarity data by lake, through time.

Table 1. Comparison of different approaches for estimating nutrient criteria from published studies.

Citation	Location & calculated TP criteria ranges (ug/L)	# Omernik ecoreg's	# Lakes applied to*	Max. lake area (ha)	Types of lakes	Approach	Pros	Cons
Soranno et al. 2008	Michigan **8 - 34**	5	6,595	8,000	-Most deep -Most clear -Drainage & seepage	**BTPM**: Multiple regression using landscape variables to predict expected condition; and, biological gradient analysis to determine benchmarks (ie. criteria)	-Quantifis expected condition from any lake using landscape variables -Uses biological condition to set benchmarks to inform criteria	-The model accounts for relatively low amount of variation in TP (~60% remains unexplained)
Heiskary & Wilson 2008	Minnesota **12 - 90**	4	11,842^	116,000	-Most deep -Most clear -Drainage & seepage	**Ecoregion, plus lake type & use classification:** Also factored in gradient analysis of chl, bloom frequency, and user perception.	-Predicts criterion based on ecoregion and lake type -Uses biological condition to inform criteria	-Much lake-to-lake variation within ecoregions and lake types not taken into account
Bachmann et al. *in press*	Florida **9 - 359**	3	7,700[t]	189,000	-Shallow -Colored -Seepage, 70%	**Six phosphorus zones (regions):** Clustered the lakes based on TP concentrations. Set criteria based on 90% percentile of TP within each [P] zone. -And, site-specific criteria for oligo. lakes	-Predicts criterion for any lake based on [P] zone it is in *NOTE:* Could not find obvious biological thresholds, so did not use them.	-The zones account for relatively low amount of variation in TP (~60% unexplained).
This report	Fond du Lac Res'n. **15 - 47**	<1	9	212 (median lake area = 33 ha)	-Shallow (1 deep) -Clear & colored -Drainage and some seepage	**Lake-specific temporal variation of minimally-disturbed lakes:** Use 10 yrs of monitoring data for nutrient and chlorophyll from the summer index period to calculate the criteria as the 90th percentiles for each lake for TP, TN, Chl.	-Accounts for interannual variability for individual lakes -These large datasets could be used to inform efforts at the state-scale with less data	-Need sustained long-term monitoring data for each lake
This report	G. Portage Res'n. **13 - 90**	< 1	15	144 (median lake area = 9 ha)	-Shallow -Most colored -Drainage, 100%	Same as above	Same as above	Same as above

* Lakes > 4 ha (~10 acres)
^ http://www.dnr.state.mn.us/faq/mnfacts/water.html
[t] http://www.stateofflorida.com/Portal/DesktopDefault.aspx?tabid=95

Table 2. Overview of the major steps for developing nutrient criteria for sites with interannual and seasonal water body data, and for which are presently in a minimally-impacted state. Note that this approach could be applied to lakes, wetlands or streams with minor modifications specific to each water body type. The text below is written specifically for lakes.

Step 1. Compile the designated uses for each water body: Determine the designated uses for each water body, identify the most restrictive use for relating to the criteria. Decide if the lakes are currently in the minimally-impacted state. If they are, then proceed to step 2. If not, then alternate approach required.

Step 2. Create the nutrient and algal database: Compile the nutrient criteria database that includes data on all available nutrient, clarity, and algal data for each lake through seasons and years.

Step 3. Evaluate the dataset and the controlling factors of the lakes: Make plots of all nutrient, clarity, and algal data through time to identify outliers and determine if any trends are present in the data. If trends are present, then the likely causes of the trends should be investigated. For either case, proceed to the next step. In addition, quantify common limnological relationships among water bodies (e.g., total phosphorus vs chlorophyll) using values for all lakes. At this step, data points that are clearly outliers that fall beyond common relationships or fall extremely far outside of the rest of the dataset should be removed.

Step 4. Quantify biological condition: Using available biological data, quantify the biological condition of the lakes to determine the range of acceptable condition for meeting designated uses.

Step 5. Identify the index period: Select the period within each year from which samples will be used for remaining steps that are deemed most appropriate for nutrient criteria development. Calculate the median level for the index period and compare to any other available data within the region for comparison purposes.

Step 6. Calculate lake-specific ‘expected conditions’ for nutrients and chlorophyll through time for the index period: Using monitoring data for the index period, determine what the ‘expected condition’ should be for each lake for each variable. The expected conditions includes the full range of concentrations for each variable for each lake, but with careful consideration of outliers.

Step 7. Derive lake-specific nutrient criteria: Using the expected conditions from the previous step to quantify lake-specific nutrient criteria for each nutrient, clarity, or algal variable using the 90^{th} percentile of the samples from the index period across the entire sampling period.

Table 3. Nutrient, clarity, and organic carbon characteristics of lakes in GP, the fisheries lakes in FDL, and the Northern Lakes and Forest (NLF) ecoregion reference database of 29 lakes provided by S. Heiskary (August 2010). Data from GP and FDL are calculated as medians of samples from July, August, and September from all years the lakes were sampled for each variable. Note, this table was created after removing outliers as defined by points being 'far outside values' (beyond 3 times the inter-quartile ranges (Systat, inc.) [c], and the Cleveland method for quantifying percentiles was used.

Variable	Location	25th	Median	75th	90th
TP (ug/L)	GP	10	20	30	52
	FDL	15	19	25	37
	NLF	14	17	26	38
TN (ug/L)	GP	700	900	1200	1600
	FDL	530	720	868	1130
	NLF	412	550	748	986
Chl *a* (ug/L)	GP	2.0	4.0	7.0	10.0
	FDL	2.9	4.9	7.8	13.0
	NLF	3.0	4.1	7.0	13.7
Chl *a*:TP	GP	0.10	0.20	0.40	0.67
	FDL	0.18	0.25	0.38	0.51
	NLF	0.19	0.25	0.34	0.37
Secchi (m) [a]	GP	1.3	0.8	0.7	0.5
	FDL	2.4	1.7	1.3	0.9
	NLF	4.4	3.3	2.8	1.6
Color (ptCo)	GP[b]	66	138	184	277
	FDL	22	41	72	129
	NLF	10	17	34	55

[a] The axis for Secchi depth was reversed such that the 25th percentile represents the values for which Secchi are deeper and the 90% percentile are for values in which Secchi depth is shallow to line up with the other parameters, such as nutrients.
[b] DOC data was converted to color using a regression equation derived from concurrent samples taken for DOC and water color in 2009 in all GP lakes (M. Watkins). The regression resulted in a R^2 of 0.925.
[c] The Cleveland method was used to calculate the percentiles.

Table FDL1. Lake and watershed descriptions including lake and catchment morphometry and land use/cover in lake watersheds of FDL lakes.

	Watershed and lake characteristics:				**Land use/cover:**					**Dominant human uses:**	
Lake Name	Watershed area (ha)	Lake area (ha)	WS area: LK area	Max depth (m)	All forest types	Human use	All wetlands	Grassland and shrubland	Open water	Forest cut-overs	Other rural devl.
Big Lake	507	212	2	6.1	36.0%	12.1%	6.4%	4.1%	41.4%	0.0%	11.8%
Lost Lake	122	55	2	3.4	38.6%	3.1%	6.9%	4.4%	47.1%	2.8%	0.3%
Joe Martin Lk.	1808	27	66	23.5	50.6%	0.9%	9.7%	36.5%	2.2%	0.8%	0.1%
Pat Martin Lk.	5314	14	369	4.6	35.6%	2.7%	34.3%	25.0%	2.3%	1.6%	0.2%
Perch Lake-No.	1832	89	21	5.2	46.8%	0.5%	31.5%	6.0%	15.3%	0.0%	0.3%
Simian Lake	5314	33	162	3.7	35.6%	2.7%	34.3%	25.0%	2.3%	1.6%	0.2%
Sofie Lake	85	14	6	4.9	79.0%	0.4%	0.0%	2.0%	19.0%	0.0%	0.4%
Third Lake	50	6	8	6.1	28.0%	2.0%	3.0%	58.0%	10.0%	0.0%	0.0%
West Twin Lk.	245	49	5	5.5	48.9%	4.7%	17.9%	6.1%	22.3%	3.2%	1.5%

Table FDL2. Designated uses of water bodies in FDL. All lakes are deemed to be fully supporting designated uses at this time except for Third Lake, which is classified as partially supporting due to the presence of algal blooms in the summer.

Lake Name	Aqu. Life, Cold water fisheries	Aqu. Life, Warm water fisheries	Wildlife	Recreation, primary contact	Recreation, secondary contact	Cultural, Wild rice areas	Cultural, Aesthetic waters	Agricultural	Navigation	Commercial
Big Lake		1	1	1	1	1		1	1	1
Lost Lake		1	1	1	1			1	1	1
Joe Martin Lake	1	1	1	1	1		1	1	1	1
Pat Martin Lake		1	1	1		1		1	1	1
Perch Lake-No.		1	1	1		1	1	1	1	1
Simian Lake		1	1	1		1		1	1	1
Sofie Lake		1	1	1				1	1	1
Third Lake		1	1	1	1			1	1	1
West Twin Lake		1	1	1	1	1		1	1	1

Table GP1. Lake and watershed morphometry of lakes in GP. Due to a lack of GIS coverages of lake watersheds, land use/cover percentages by lake are not available. GP is representative of the Boreal Shield landscape and is characterized by rugged topography, nutrient poor glacial soils, extensive forests, and abundant lakes and wetlands (Lafrancois et al. 2009). There is minimal human disturbance around lakes, except for forest logging that occurs to varying degrees.

Lake Name	Watershed area (ha)	Lake area (ha)	WS area: LK area	Max depth (m)
Center Lake	587	14	41	3.4
Chevans Lake	1839	4	472	1.2
Cuffs Lake	587	6	101	1.5
Dutchman Lake	335	19	18	4.3
Helmer Nelson Lake	587	9	65	2.4
Little Lake	430	1	717	0.9
Loon Lake	184	14	13	2.4
Mt. Maud Lake	550	3	162	2.4
North Lake	45	2	20	2.1
Swamp Lake	1458	144	10	5.8
Swede Lake	32	2	20	1.8
Taylor Lake	673	13	52	7.6
Teal Lake	344	29	12	2.1
Trout Lake	114	26	4	6.4
Turtle Lake	41	3	16	3.7

Table GP2. Designated uses of water bodies in GP. All lakes are deemed to be fully supporting designated uses at this time.

Lake Name	Aqu. Life, Cold water fisheries	Aqu. Life, Warm water fisheries	Aqu. Life, Wetland (e.g., wildlife, biodiv.)	Wildlife	Recreation, primary contact, moderate use	Recreation, primary contact, infrequent use	Cultural, Wild rice areas	Forestry	Navigation	Industrial
Center Lake	1		1	1		1	1	1	1	1
Chevans Lake		1	1	1		1		1	1	1
Cuffs Lake		1	1	1		1	1	1	1	1
Dutchman Lake		1	1	1		1		1	1	1
Helmer Nelson Lake		1	1	1		1	1	1	1	1
Little Lake	1		1	1		1		1	1	1
Loon Lake		1	1	1		1	1	1	1	1
Mt. Maud Lake		1	1	1		1	1	1	1	1
North Lake		1	1	1		1	1	1	1	1
Swamp Lake	1		1	1	1		1	1	1	1
Swede Lake		1	1	1		1		1	1	1
Taylor Lake	1		1	1	1			1	1	1
Teal Lake		1	1	1		1	1	1	1	1
Trout Lake	1	1	1	1	1			1	1	1
Turtle Lake		1	1	1	1			1	1	1

Table 4. Estimated lake-specific criteria for TP, TN and chlorophyll *a* (Chl) in GP and FDL, and criteria for the NLF ecoregion lakes developed by the state of Minnesota (Heiskary and Wilson 2008). The criteria are calculated as the 90th percentiles of the summer samples (July-September) any samples taken from 1999-2009 in each lake. Note, these criteria have been calculated without removal of outlier points, except for the extreme points detected from plots of the common limnological relationships. This table is provided for comparison purposes only. I recommend that **Table 4a** be used to establish nutrient criteria.

		Criteria (90th Percentile)		
Location	Lake Name	TP (ug/L)	TN (ug/L)	Chl (ug/L)
FDL	Big Lake - North	18	770	6
	Big Lake - South	21	830	7
	Lost Lake	23	1025	13
	Joe Martin Lake	15	618	3
	Pat Martin Lake	21	739	7
	Perch Lake - North	32	944	18
	Perch Lake - South	44	1686	8
	Simian Lake	47	1352	16
	Sofie Lake	36	854	33
	Third Lake	44	1548	44
	West Twin Lake - North	22	830	10
	West Twin Lake - South	24	812	11
GP	Center Lake	76	1540	67
	Chevans Lake	67	2041	9
	Cuffs Lake	70	1780	9
	Dutchman Lake	31	1820	11
	Helmer Nelson Lake	97	2180	55
	Little Lake	29	1905	8
	Loon Lake	60	1400	10
	Mt. Maud Lake	78	2070	13
	North Lake	40	1000	4
	Swamp Lake	40	1624	10
	Swede Lake	40	1440	12
	Taylor Lake	50	1220	6
	Teal Lake	40	1600	8
	Trout Lake	30	1400	7
	Turtle Lake	90	1820	9
	Median GP criteria	50	1624	9
	Median FDL criteria	23	842	10
	NLF criterion	30	--	9

Table 4b. With outliers removed (See table 3 for description of outlier removal)**.** Estimated lake-specific criteria for TP, TN and chlorophyll *a* (Chl) in GP and FDL, and criteria for the NLF ecoregion lakes developed by the state of Minnesota (Heiskary and Wilson 2008). The criteria are calculated as the 90th percentiles of the summer samples (July-September) any samples taken from 1999-2009 in each lake. The values in brackets are the number of samples for which the percentiles are calculated. The values highlighted in yellow are the values that have changed once outliers were removed (see Table 4a for what the previous values were).

		Criteria (90th Percentile)					
Location	Lake Name	TP (ug/L)		TN (ug/L)		Chl (ug/L)	
FDL	Big Lake - North	18	*[17]*	770	*[17]*	6	*[9]*
	Big Lake - South	21	*[17]*	830	*[17]*	7	*[9]*
	Lost Lake	23	*[17]*	1025	*[16]*	13	*[9]*
	Joe Martin Lake	15	*[17]*	520	*[16]*	3	*[9]*
	Pat Martin Lake	21	*[17]*	739	*[16]*	7	*[9]*
	Perch Lake - North	32	*[17]*	944	*[17]*	18	*[9]*
	Perch Lake - South	44	*[17]*	1686	*[17]*	8	*[2]*
	Simian Lake	47	*[17]*	1314	*[16]*	16	*[9]*
	Sofie Lake	36	*[17]*	830	*[16]*	9	*[8]*
	Third Lake	44	*[17]*	1548	*[17]*	44	*[9]*
	West Twin Lake - North	22	*[17]*	830	*[17]*	10	*[9]*
	West Twin Lake - South	24	*[17]*	812	*[17]*	11	*[9]*
GP	Center Lake	66	*[17]*	1540	*[18]*	21	*[16]*
	Chevans Lake	56	*[17]*	2041	*[18]*	9	*[18]*
	Cuffs Lake	52	*[14]*	1348	*[14]*	9	*[15]*
	Dutchman Lake	31	*[18]*	1820	*[18]*	11	*[16]*
	Helmer Nelson Lake	89	*[17]*	2180	*[18]*	15	*[13]*
	Little Lake	20	*[15]*	1905	*[16]*	5	*[15]*
	Loon Lake	31	*[13]*	1400	*[15]*	10	*[14]*
	Mt. Maud Lake	68	*[16]*	2070	*[18]*	13	*[18]*
	North Lake	18	*[13]*	1000	*[15]*	4	*[15]*
	Swamp Lake	40	*[14]*	1624	*[13]*	10	*[15]*
	Swede Lake	28	*[14]*	1422	*[14]*	12	*[15]*
	Taylor Lake	13	*[13]*	1220	*[14]*	6	*[15]*
	Teal Lake	14	*[13]*	1600	*[15]*	8	*[15]*
	Trout Lake	30	*[14]*	1400	*[15]*	7	*[15]*
	Turtle Lake	90	*[17]*	1820	*[17]*	9	*[16]*
	Median GP criteria	31	*[15]*	1600	*[15]*	9	*[15]*
	Median FDL criteria	23	*[12]*	830	*[12]*	9	*[12]*
	NLF criterion	30		--		9	

Figure 1. Relationships between nutrients, chlorophyll, and water color in FDL fisheries lakes. Data points are individual sampling events from all open-water months and all years sampled from 1999-2009.

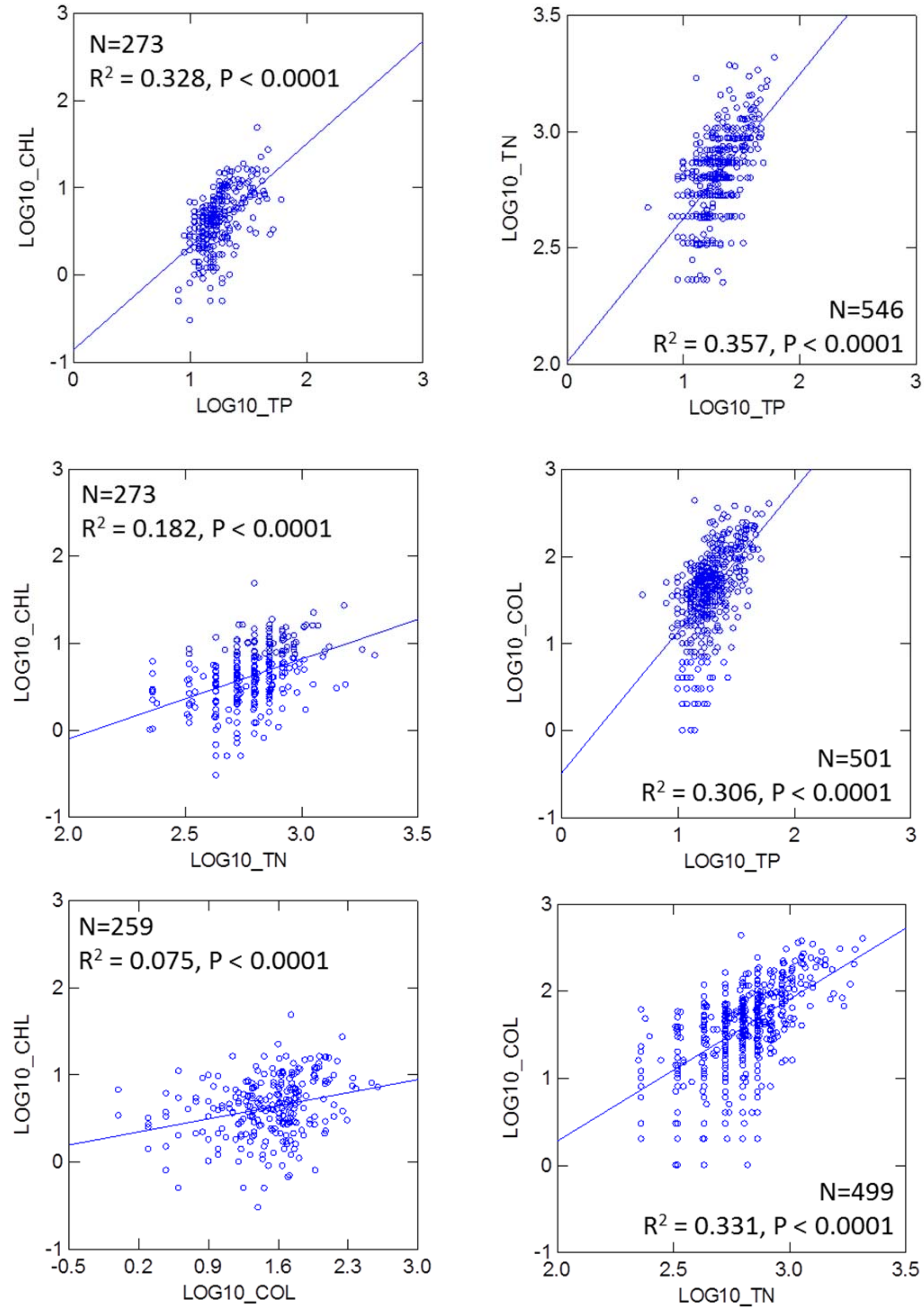


Figure 2. Relationships between nutrients, chlorophyll, and water color in GP lakes. Data points are individual sampling events from all open-water months and all years sampled from 1999-2009.

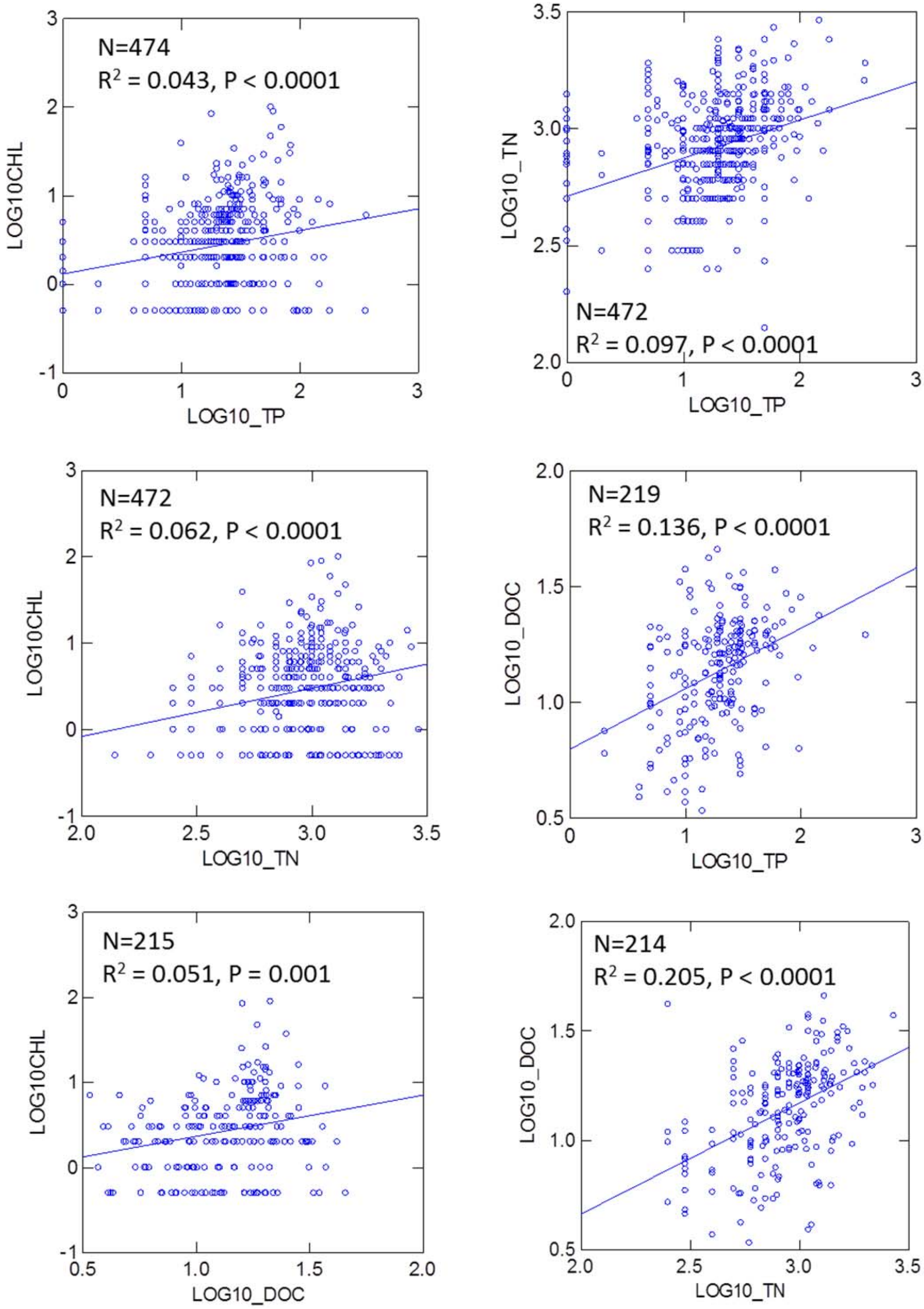


Figure 3a. Box plots of all data points for all months and all sampled years for each lake in FDL for TP, TN and chlorophyll concentrations. Note, the open circle points were defined as 'far outside values' and removed from the analysis to calculate percentiles for all tables and nutrient criteria calculation.

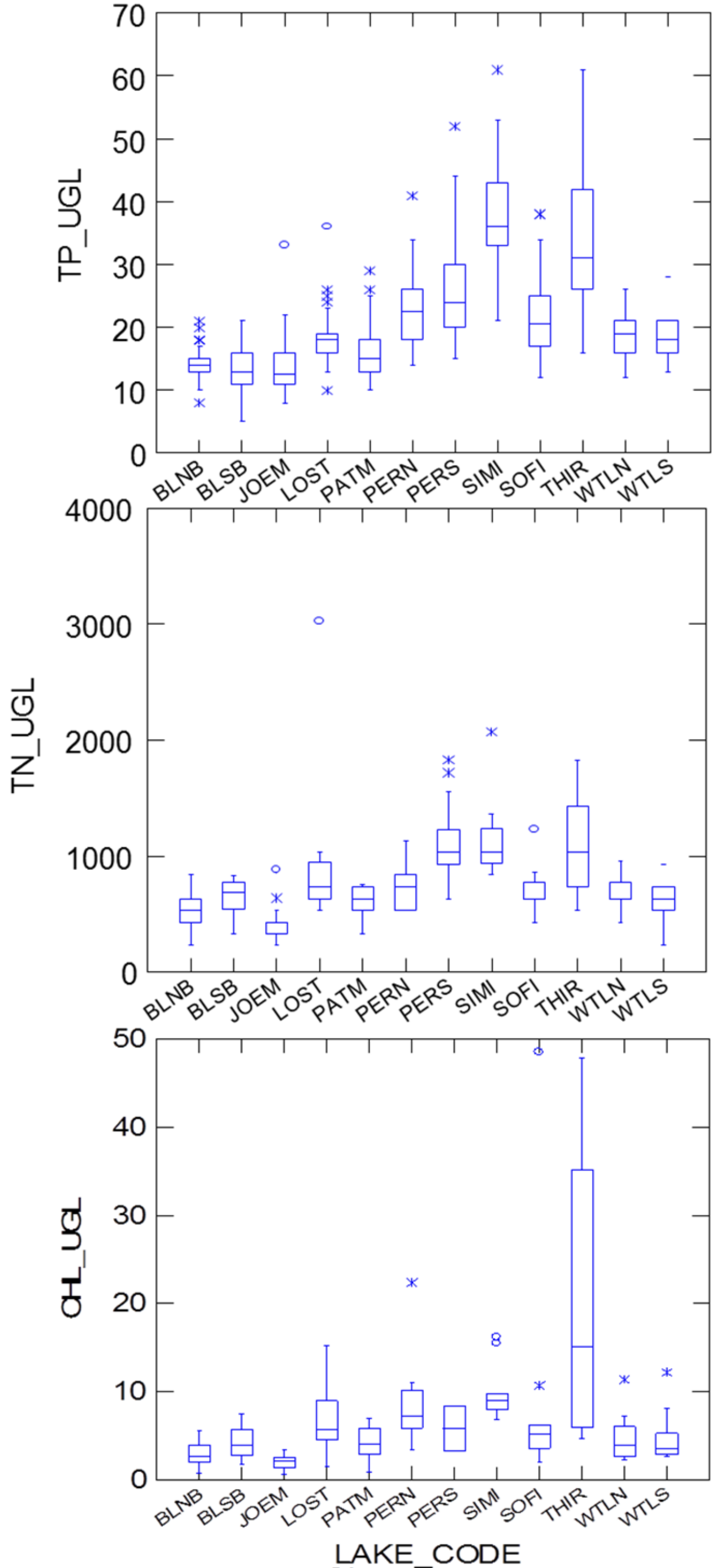
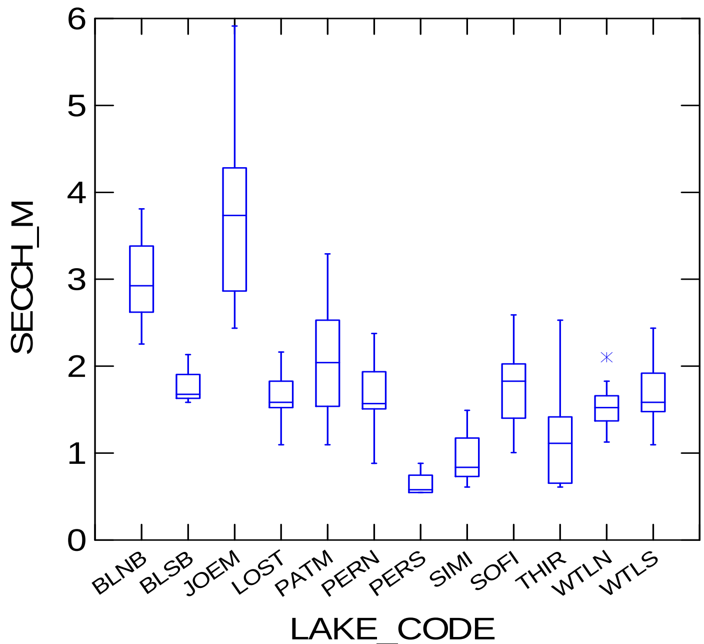


Figure 3b. Box plots of all data points for all months and all sampled years for each lake in FDL for Secchi depth and water color. Outliers were not removed for these two variables.



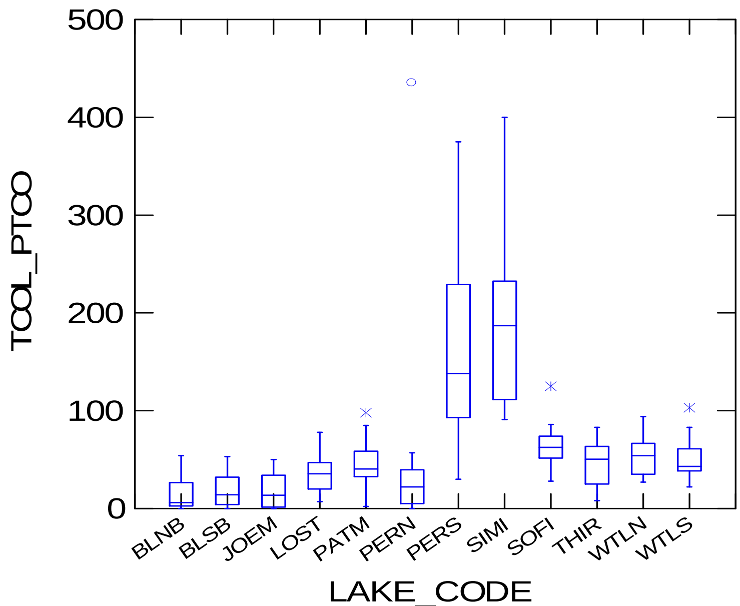


Figure 4a. Box plots of all data points for all months and all sampled years for each lake in GP for TP, TN and chlorophyll concentrations. Note, the open circle points were defined as 'far outside values' and removed from the analysis to calculate percentiles for all tables and nutrient criteria calculation.

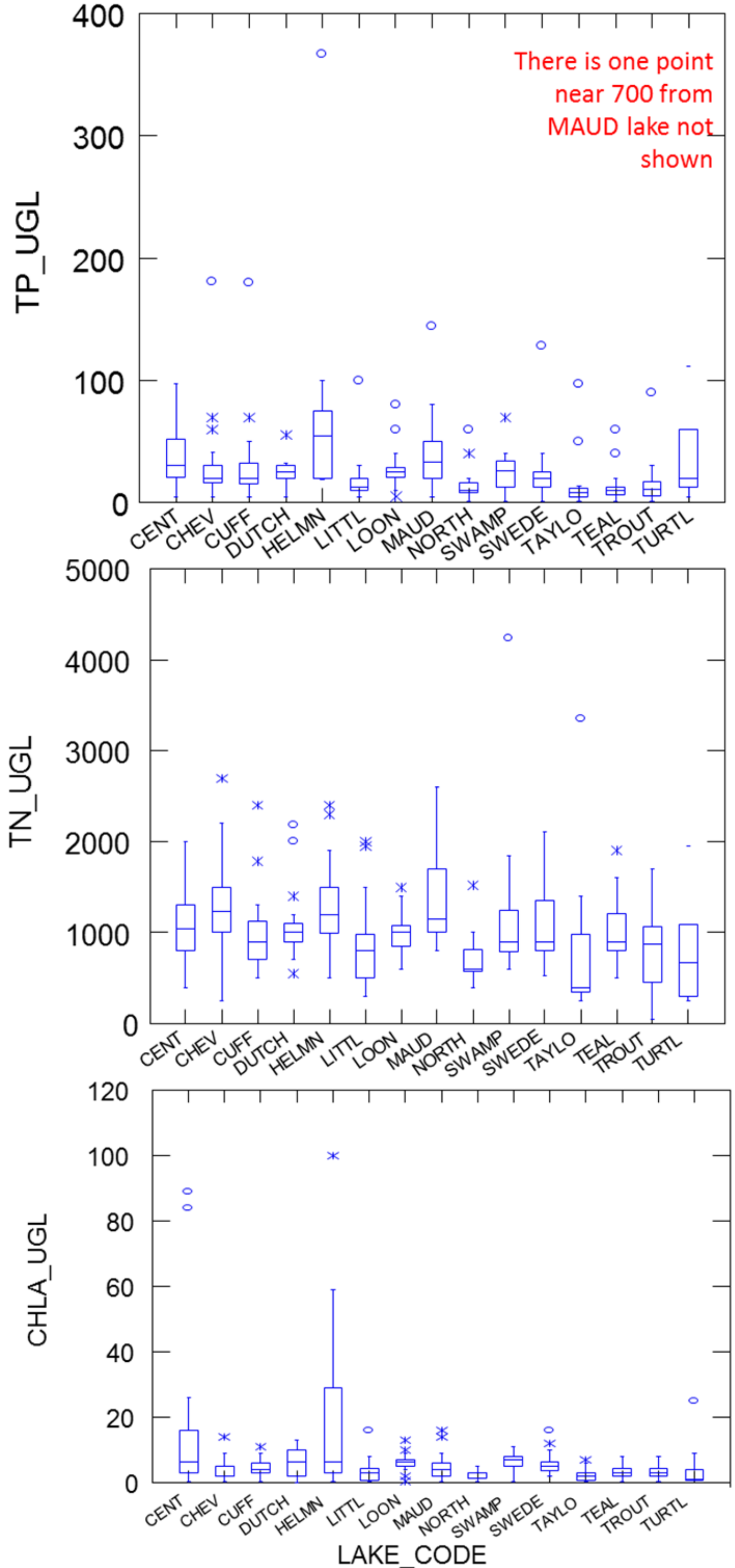


Figure 4b. Box plots of all data points for all months and all sampled years for each lake in GP for Secchi depth and DOC concentration. Outliers were not removed for these two variables.

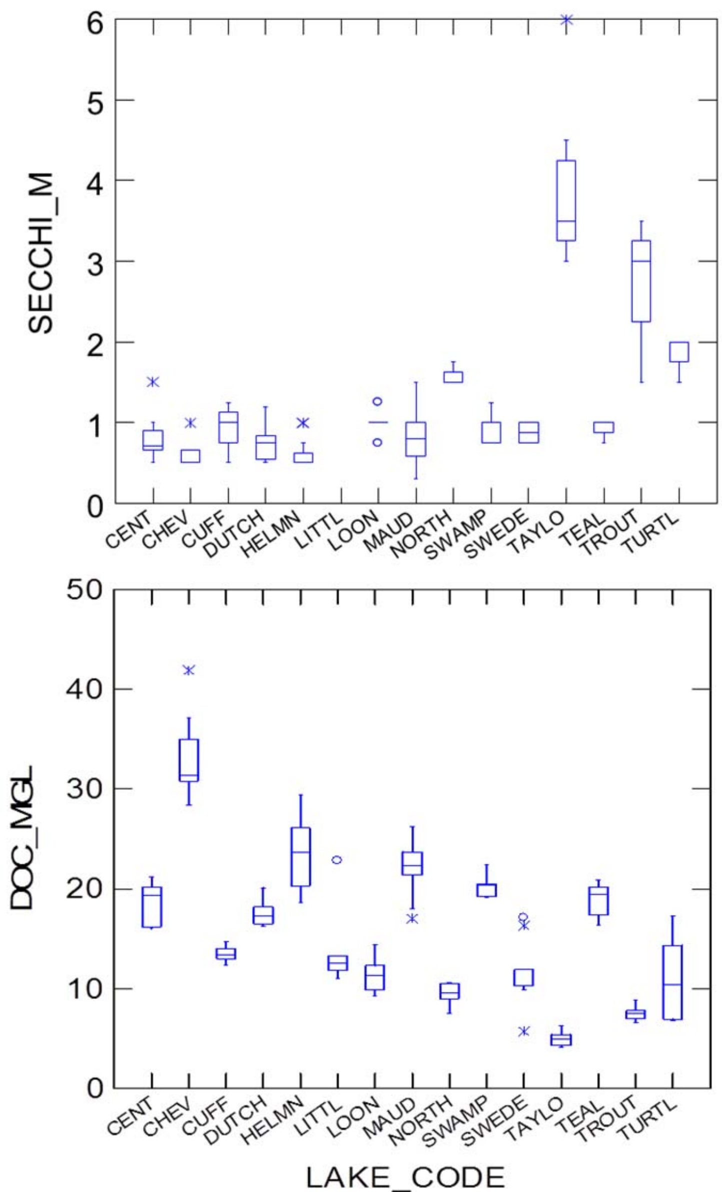


Figure 5. Plots showing the distribution of lake-specific nutrient criteria calculated for each of the lakes in each site (blue diamonds), as well as criteria estimated for the NLF ecoregion for comparison (Heiskary and Wilson 2008). These data are also provided in Table 4. The large black circles are either the median across lakes (for GP and FDL) or the value for the NLF ecoregion.