Review of the Retrospective Analysis done by the Texas Commission on Environmental Quality for U.S. Environmental Protection Agency Region 6 Regional Technical Advisory Group (RTAG) on January 18, 2006

And

A Subsequent Reanalysis Based on Recalculating the Criteria

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Tables

Figures

Errata

The correlations published for Tables 3, 4 and 5 were incorrect. We had stated that the correlations between the TPWD criteria and the TCEQ criteria were 0.49 in Table 3 (TCEQ all years and 99th percent CI vs. TPWD), 0.70 in Table 4 (TCEQ w/ 10 yr time horizon vs. TPWD) and 0.76 in Table 5 (TCEQ w/ 10 yr time horizon and 90th percent CI vs. TPWD). The revised numbers for the 3 table are 0.33, 0.50, and 0.55, respectively. These values have been corrected in the text.

Upon reflection, however, the correlation is likely not the best way to describe the amount of agreement between the two methods because the correlation measure does not segregate non-compliance from compliance. Instead, we now recommend using a pair of calculations that produce the proportion of agreement for both compliance and non-compliance (Spitzer and Fleiss 1974). Using such a method, we find that in Table 3, the percent agreement for compliance is 82.7% and the percent agreement for non-compliance is 35.4%. For Table 4, the percent agreement for compliance is 85.2% and the percent agreement for non-compliance is 63.3%, and for Table 5, the percent agreement for compliance is 86.2% and the percent agreement for non-compliance is 68.8%.

We also found errors in the colors of the cells within the Tables. In Table 3, for Caddo, subset 6 should be yellow. And in Table 4, for Stillhouse Hollow, subsets 1 and 2 should be green. The figures have not been corrected.

Spitzer R, and J. Fleiss. 1974. A re-analysis of the reliability of psychiatric diagnosis. *British Journal on Psychiatry*: 341-47.

Executive Summary

The Environmental Protection Agency (EPA) has tasked the states with developing numeric criteria for nutrients in surface water. Both the Texas Commission on Environmental Quality (TCEQ) and Texas Parks and Wildlife Department (TPWD) have presented proposals for calculating reservoir nutrient criteria based on anti-degradation approaches using different methodologies.

At the annual meeting of the EPA Region 6 Regional Technical Advisory (RTAG) meeting on January 18, 2006, TCEQ presented a comparison between the TCEQ and TPWD approaches. TCEQ conducted a *retrospective*[1] analysis to determine how well nutrient criteria based on the TPWD and TCEQ methods would work using historical data. Because we found there were several minor errors in the TCEQ analysis, we conducted our own *retrospective* analysis to review their results.

As currently constructed, nutrient criteria based on the TPWD method tended to indicate more reservoirs would have been declared degraded than would nutrient criteria based on the TCEQ method. Primarily, this was because the TCEQ method utilizes the entire historic time series to construct its criterion, whereas the TPWD method uses only the last 10 years. Because many of the reservoirs used in this simulation have experienced changes in their nutrient levels during their historical record, the TCEQ method set criteria that did not accurately reflect the most recent water quality data.

A second reason the TPWD method tended to indicate more reservoirs would have been declared degraded than would the TCEQ method is that the TPWD method uses the 90th *percentile* of the actual data as the criterion, whereas the TCEQ method uses the 99th *percentile* of the *mean* of a subset of the data (*outliers* have been removed).

When both methods used the last 10 years of data and the 90th *percentile*, very similar results were obtained for both TPWD and TCEQ methods. However, differences still exist because the TPWD method uses the actual data to set its criterion, whereas the TCEQ method estimates the criterion based on an assumed theoretical *distribution* for the data.

Both methods can be refined to detect levels of nutrient degradation deemed appropriate. However, the use of a *retrospective* approach is a poor approach to use for that refinement. A better approach for refining either method would be to use simulated time series that have been strategically altered to test each method's *sensitivity* and *specificity*.

[1] Italicized words appear in the Glossary at the end of the document.

Introduction

Under the authority of the Clean Water Act, EPA has tasked the states with developing numeric criteria for nutrients in surface water. The TCEQ is the agency in Texas charged with carrying out the requirements of the Clean Water Act, such as setting water quality standards, assessing state waters, and issuing permits. Currently, the state has only a narrative standard for nutrients, at 30 TAC §307.4(e), which states that *"Nutrients from permitted discharges or other controllable sources shall not cause excessive growth of aquatic vegetation which impairs an existing, attainable, or designated use."* Based on EPA's directive, TCEQ will ultimately need to establish numeric criteria for nutrients for all state waters – rivers, streams, reservoirs, and estuaries. For now, TCEQ is approaching this task in stages, beginning with reservoirs.

If the state does not act, authority to set numeric nutrient criteria will revert to EPA. Stakeholders in Texas are united in their dislike of EPA's stated approach to setting criteria, which would result likely in many Texas reservoirs being placed on the state list of impaired waters (also called the "303(d) list"). It is important to ensure that waterbodies added to the list are actually impaired, and not listed due to inappropriate standards, since considerable state and stakeholder resources are expended in studying and modeling waterbodies on the list.

Development of nutrient criteria is an area of critical importance to TPWD because the department is responsible for protecting aquatic systems for a variety of uses. TPWD has historically worked closely with TCEQ biologists in developing and evaluating the scientific research used in establishing water quality standards. TPWD's Inland Fisheries Division is responsible for managing the state's diverse freshwater fisheries resources, which includes approximately 800 public impoundments covering 1.7 million acres and 80,000 miles of rivers and streams. TPWD's State Parks Division oversees more than 600,000 acres of land owned or leased by the department, including 123 state parks, historic sites and natural areas, many of which provide a venue for swimming, boating and other outdoor recreational opportunities, as well as operating public water supply systems and/or wastewater treatment systems.

In 2001, TCEQ contracted with U. S. Geological Survey (USGS) to begin assembling nutrient data for reservoirs. In May 2002, they convened the first meeting of the Nutrient Criteria Development Advisory Work Group. TCEQ has favored an anti-degradation approach and has presented draft criteria at recent stakeholder meetings.

In June 2004, TPWD put forward its own recommendations for calculating reservoir nutrient criteria. TPWD noted that it could manage Texas reservoirs for multiple uses under a diversity of nutrient levels; however, it could not work effectively with a hypereutrophic situation. In hypereutrophic environments there can be a loss of diversity of fish species and a loss of sport fish populations. TPWD thus seeks to avert any situation that leads to a deterioration in water quality.

Both the TCEQ and TPWD proposals are based on anti-degradation approaches, although the statistical methodologies differ. In establishing criteria, it is important to consider how compliance with the criteria will be assessed. At the annual meeting of the EPA Regional Technical Advisory (RTAG) meeting on January 18, 2006, TCEQ presented a comparison between the TCEQ and TPWD approaches using historical data for several reservoirs to illustrate what stakeholders might expect from each approach.

TPWD staff have reviewed the calculations presented by TCEQ at the RTAG meeting. This document provides a detailed explanation of this review and a subsequent reanalysis based on recalculation of the criteria.

General Comments on the Methodologies

Parametric vs. Nonparametric statistics

TCEQ has proposed an approach that is based on parametric statistics, calculating the upper confidence level about the *mean* of an assumed *normal distribution*. When the data deviate from a *normal distribution*, such an approach is subject to inherent error which increases as the data deviate farther from the *normal distribution*. When the *skewness* is extreme, both the *mean* and the variance are poor descriptors of the skewed *distribution*. It is known that environmental data, such as chlorophyll-a, are generally not well described by a *normal distribution*. These data exhibit only positive values and typically exhibit considerable *skewness*. In calculating reservoir criteria, the TPWD approach accounts for this by calculating the bounds of the actual data *distribution*, and does not oblige the data to fit an assumed *distribution* for which bounds are estimated. Under the TPWD approach, the actual data are used to establish the reservoir criteria. The TPWD approach avoids errors that are associated with use of an assumed *distribution* that does not accurately represent the data.

The procedures recommended by TPWD utilize *nonparametric* methodologies to set the criterion (i.e. they do not rely on an assumption that the data are normally distributed). With the TPWD approach, the actual individual sample data are used to set the criterion and to determine compliance. The observed data are sorted and ranked, and the 90^{th} *percentile* of the historic data is set as the criterion. In the assessment period, TPWD recommends that a waterbody be considered to fully support its use if $\leq$ 10% of samples exceed the criteria. The TCEQ approach is different in that it uses an assumed theoretical *normal distribution* to establish the criterion. Further, both the criterion and the assessment are based on the average of all the data, not the individual observations. Because the actual individual sample data are used to set the TPWD criterion, but the average is used to set the TCEQ criterion, the TPWD criterion is typically higher than the TCEQ criterion.

Data for Amistad Reservoir can be used to illustrate these differences. As Figure 1 shows, the *mean* of the data is approximately 2 µg/L (the blue vertical line). The TCEQ criterion would correspond to the computed 99^{th} *percentile* of the *mean*, which for these data is approximately 2.9 µg/L (the red vertical line). The TPWD criterion would correspond to the 90^{th} *percentile* of the actual data, which is approximately 5 µg/L (the pink vertical line). Hypothetical data can be created to represent some other period of time when the reservoir had higher chlorophyll-a values. In this example, the data have been shifted such that the *mean* for these hypothetical data just exceeds the TCEQ criterion. This corresponds to the first occasion when the TCEQ criterion would identify the waterbody as impaired. Using the TCEQ approach and this dataset, 44% of the individual data points would exceed the 2.9 µg/L criterion at the time the impairment was identified. With the TPWD metric, only 10% of the samples would have to exceed the 5.0 µg/L TPWD criterion before the reservoir is no longer fully supportive. In addition, this example illustrates how the skewed nature of the data can present problems with the TCEQ approach. If the data followed a true *normal distribution*, using the TCEQ approach, one would expect 50% of the points to exceed the TCEQ criterion, while in the actual data only 44% exceed the TCEQ criterion.

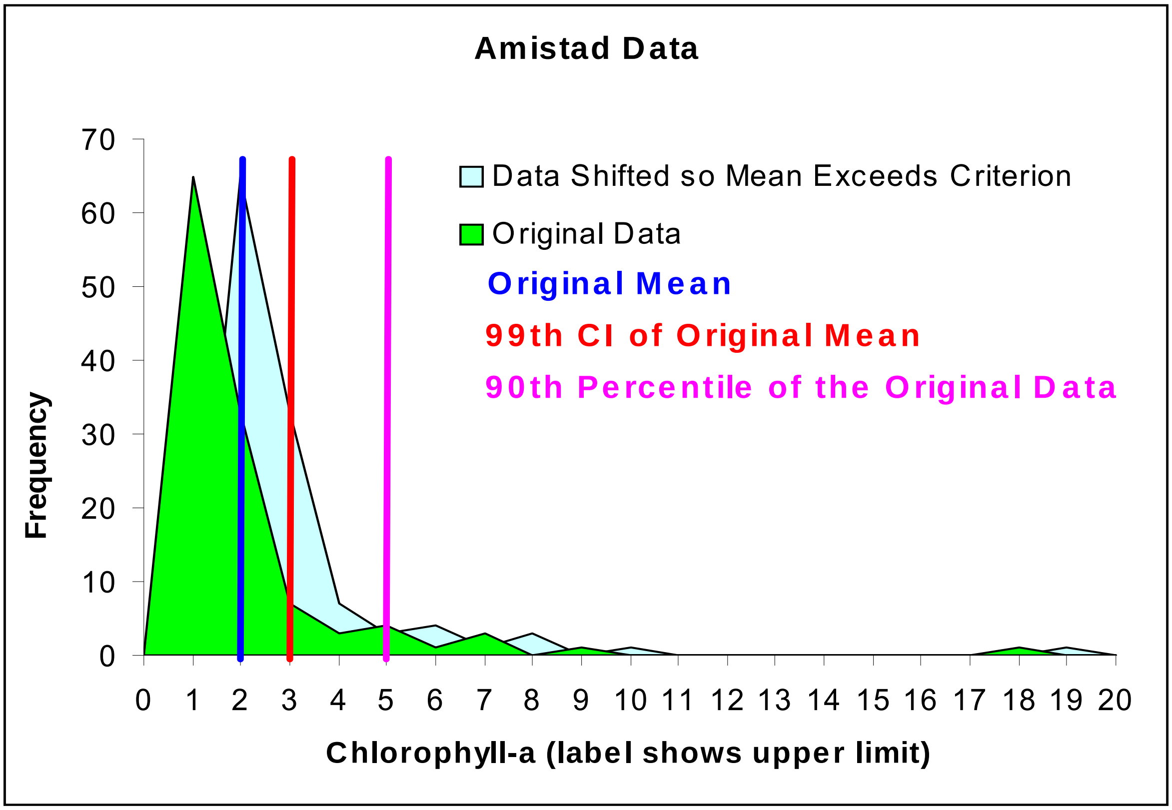

Figure 1. Comparison of TCEQ and TPWD approaches using data from Amistad Reservoir.

Chronic vs. Acute Tendencies

As noted above, comparison of the TPWD and TCEQ methods is somewhat difficult because they are measuring different aspects of the data. The TCEQ metric, because it is based on the *mean*, which dampens the influence of individual points, is more akin to a detector of chronic problems. The TPWD metric, which accentuates the importance of the individual points, is more akin to a detector of acute problems. While these are their basic tendencies, neither criterion strictly fits these definitions.

Confidence, Tolerance and Prediction Intervals

Considering the basic tendencies discussed above, it appears that the TCEQ proposal and simulation are somewhat at odds with one another. On the one hand, the TCEQ criteria are developed from the *mean* using a *confidence interval* to state the region of acceptance. Yet in the simulation portion (TCEQ 2006a), TCEQ looks at how many of the individual values exceeded the criterion. If the individual points are of interest, then the criterion should be set using a *tolerance interval*, not a *confidence interval*. Typically, if the *mean* is of interest, then the criterion should be set using a *prediction interval*, not a *confidence interval*. Interestingly, if the time series aspect of the problem is ignored, the TCEQ approach to calculation of the criterion appears to be exactly the same as one would use to estimate a *prediction interval*. The following definitions should help in clarifying the situation:

Confidence Interval

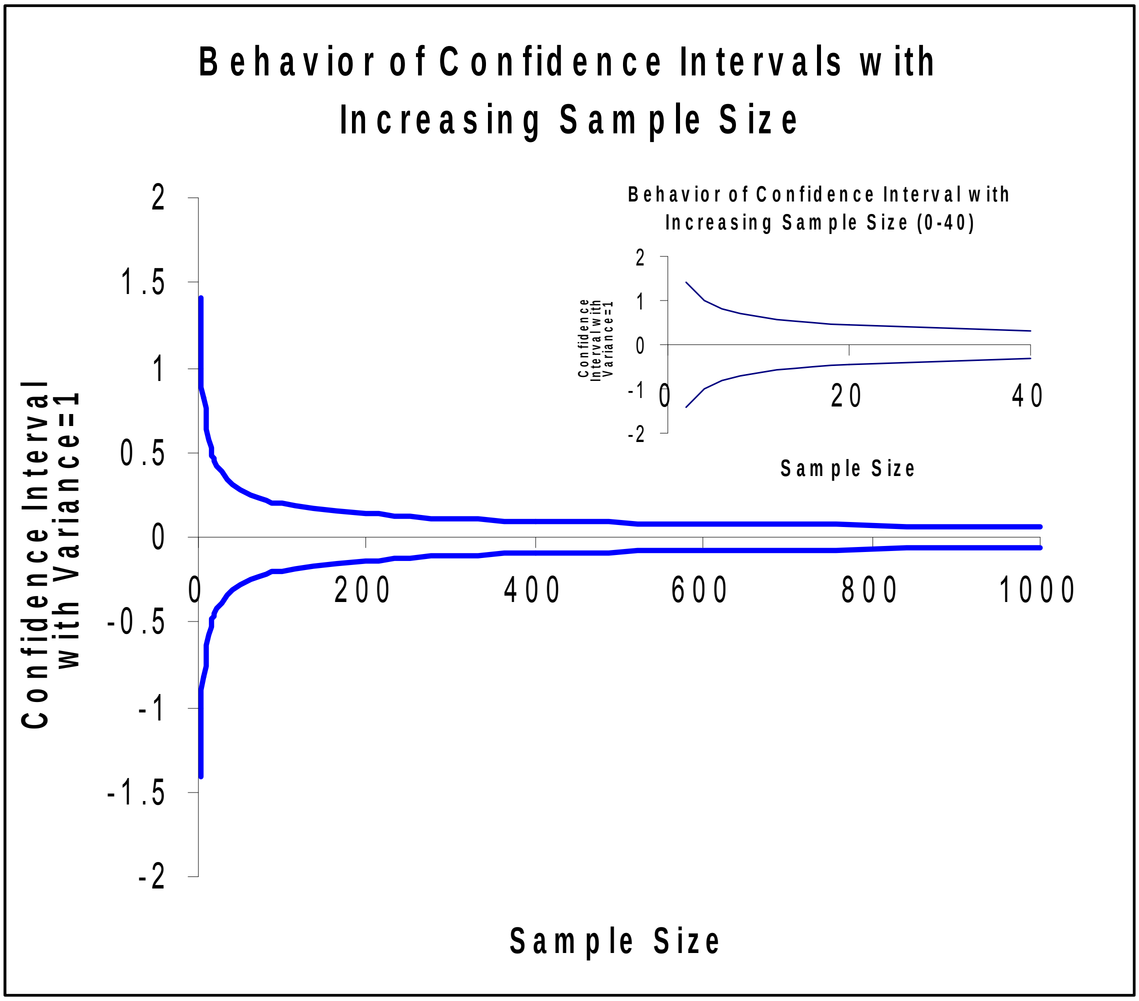

Figure 2. Behavior of confidence intervals with increasing sample size.

Confidence intervals are most often used in general statistical analyses. *Confidence intervals* give us the range within which we expect the *mean* of the population to occur given we sample the same population repeatedly. It would be rarely used in detection monitoring or comparing to health or environmental standards because the *confidence interval* does not address individual measures (e.g., the highest concentration – the value we are often most concerned with), but instead addresses only the average concentration of a population. One issue is *confidence* *interval* widths shrink towards zero as the sample size increases, for the more you repeatedly sample the same population, the less likely it becomes that you will observe a *mean* that differs from the true population *mean*. The larger frame in Figure 2 shows the behavior of the *confidence interval* as the sample size goes to 1000 observations; the inset shows the behavior as the sample size goes to 40 observations.

Tolerance Interval

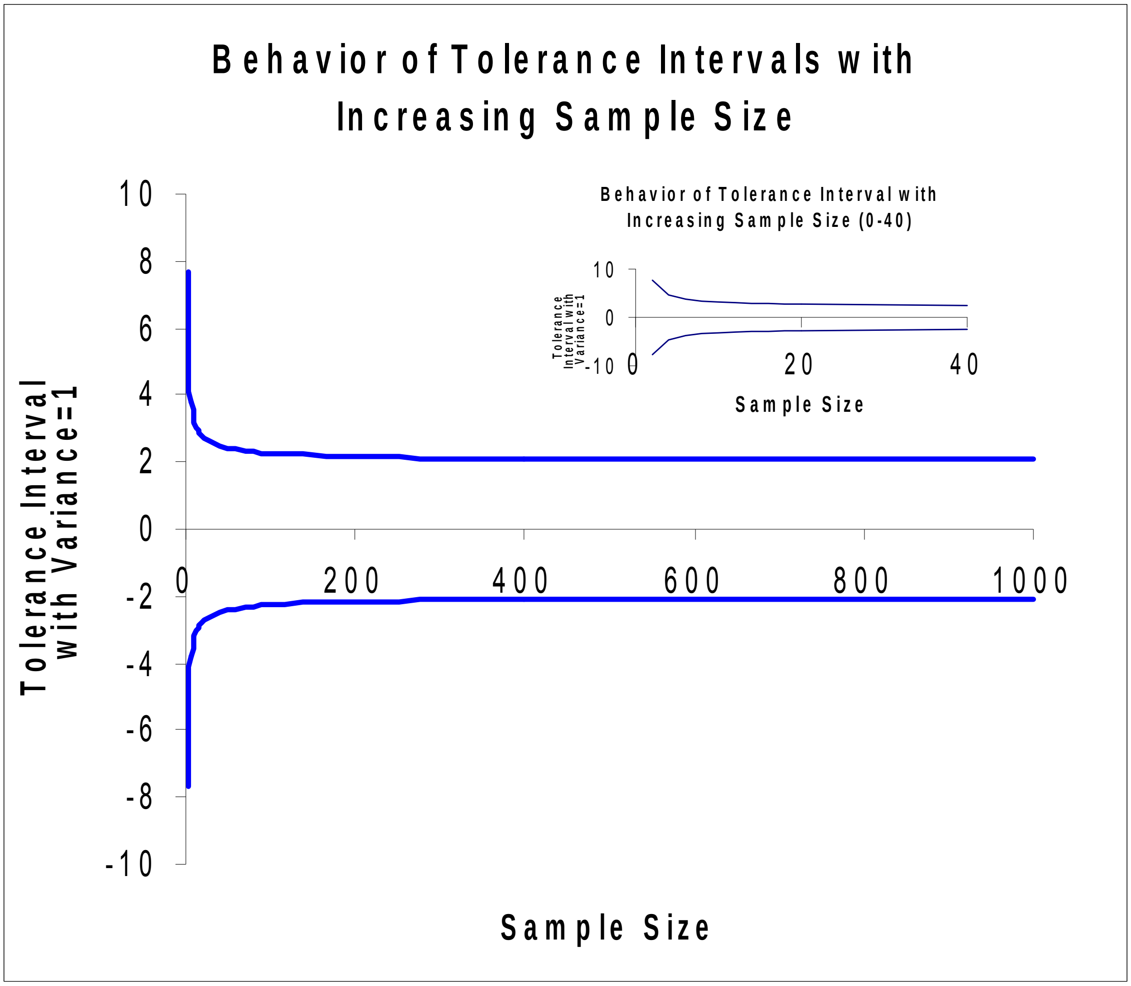

Figure 3. Behavior of tolerance intervals with increasing sample size.

The *tolerance interval* gives us an idea of what range each <u>individual measurement</u> should fall within. *Tolerance intervals* are fundamental to *control charts*. Thus, it is especially useful in compliance monitoring when one is concerned with Maximum Contaminant Levels (MCLs). The *tolerance interval* already takes into account the fact that some values will be high. So if a few values exceed the MCL standard, a site may still not be in violation (because the calculated *tolerance interval* may still be lower than the MCL). But if too many values are above the MCL, the calculated *tolerance interval* will extend beyond the acceptable standard. *Tolerance interval* widths tend towards a fixed value as the sample size increases (unlike *Confidence Intervals*, which, as mentioned above, tend to zero width with increasing sample size). Note also, that while the *confidence interval* width varies between -2 to 2, the *tolerance interval*, because it is based on individual points and not *mean* tendencies in the data, varies between -8 to 8. The larger frame in Figure 3 shows the behavior of the *tolerance interval* as the sample size goes to 1000 observations; the inset shows the behavior as the sample size goes to 40 observations.

Prediction Interval

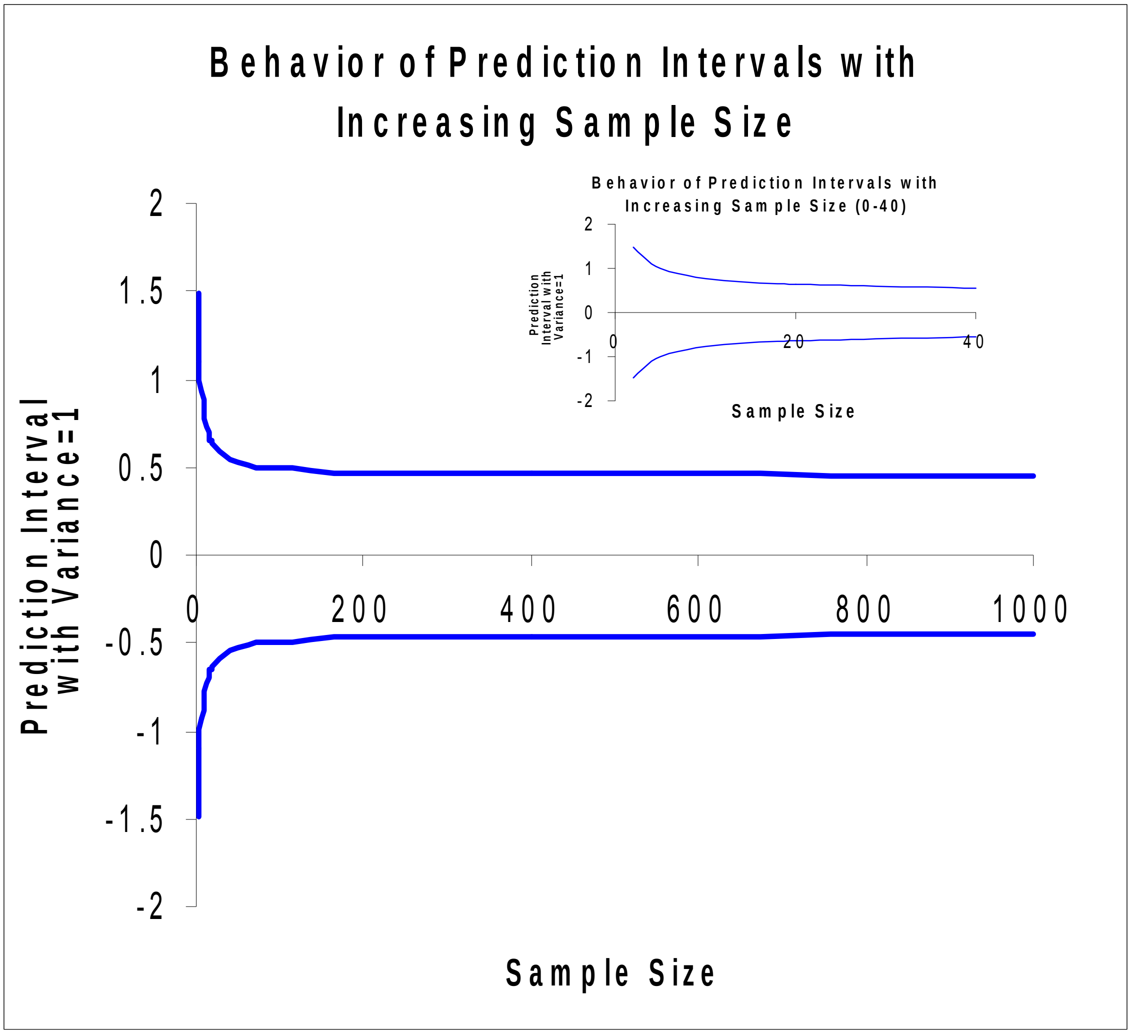

Figure 4. Behavior of prediction intervals with increasing sample size.

Prediction intervals give us the range within which we expect the future observations of the *mean* of the population to occur, given we sample the future population. Because we are no longer sampling from the same population, but are extrapolating to a new population, the interval is wider. *Prediction intervals* tend to be applied in detection monitoring in two main ways. They can be used either to compare a sample to a reference sample, or they can be used to compare a new sample to an older sample from the same site. In either case, if the *mean* of the sampled data is greater than upper prediction limit, this is indicative of contamination. Like *tolerance* *intervals, prediction interval* widths tend towards a fixed value as the sample size increases. The larger frame in Figure 4 shows the behavior of the *prediction interval* as the sample size goes to 1000 observations; the inset shows the behavior as the sample size goes to 40 observations.

Sample Size and Representativeness

Small sample sizes are problematic for both the TCEQ and TPWD metrics. Small sample sizes tend to make the TCEQ metric less robust to single, large values. On the other hand, small samples with single large values typically do not affect the TPWD metric, but the TPWD metric is less robust to a few large values. More sampling during the assessment period would improve the reliability of both metrics.

A problematic aspect of the current criterion-setting process is that some years and seasons are not equally represented. As chlorophyll-a (and other metrics) often vary seasonally, non-representative sampling can affect the criteria. There are no excellent ways to fix this issue, although there are satisfactory ways this issue could be addressed.

Outliers

Frequent "*outliers*" demonstrate why a parametric approach will have difficulties. Unless some form of *Winsorization* or *Trimming* is used, *outliers* will most often affect the *mean* value more than the *nonparametric* criteria suggested by TPWD. If *Winsorization* is used, except when there are insufficient data, the *nonparametric* criteria will be unaffected by manipulations of the extreme values. In fact, the current TCEQ methodology suggests TCEQ will be excluding "*outliers*" from the data before they create their parametric criteria.

This will improve the robustness of their criterion. Unfortunately, they do not include details about how they define the "*outliers*" they choose to exclude. Further, it is not clear from the TCEQ explanation whether the "*outliers*" were excluded from their calculations of the *means* only, or if "*outliers*" were also excluded from their calculations of the variance.

It should be noted that the current TCEQ protocol suggests excluding *outliers* from the criterion-setting, but keeping *outliers* in for the assessment. *Outliers* in the assessment period will increase the *mean* that is estimated, but under the current setup, will not affect the variance estimate, for only the data collected during the baseline period is being used to compute the variance.

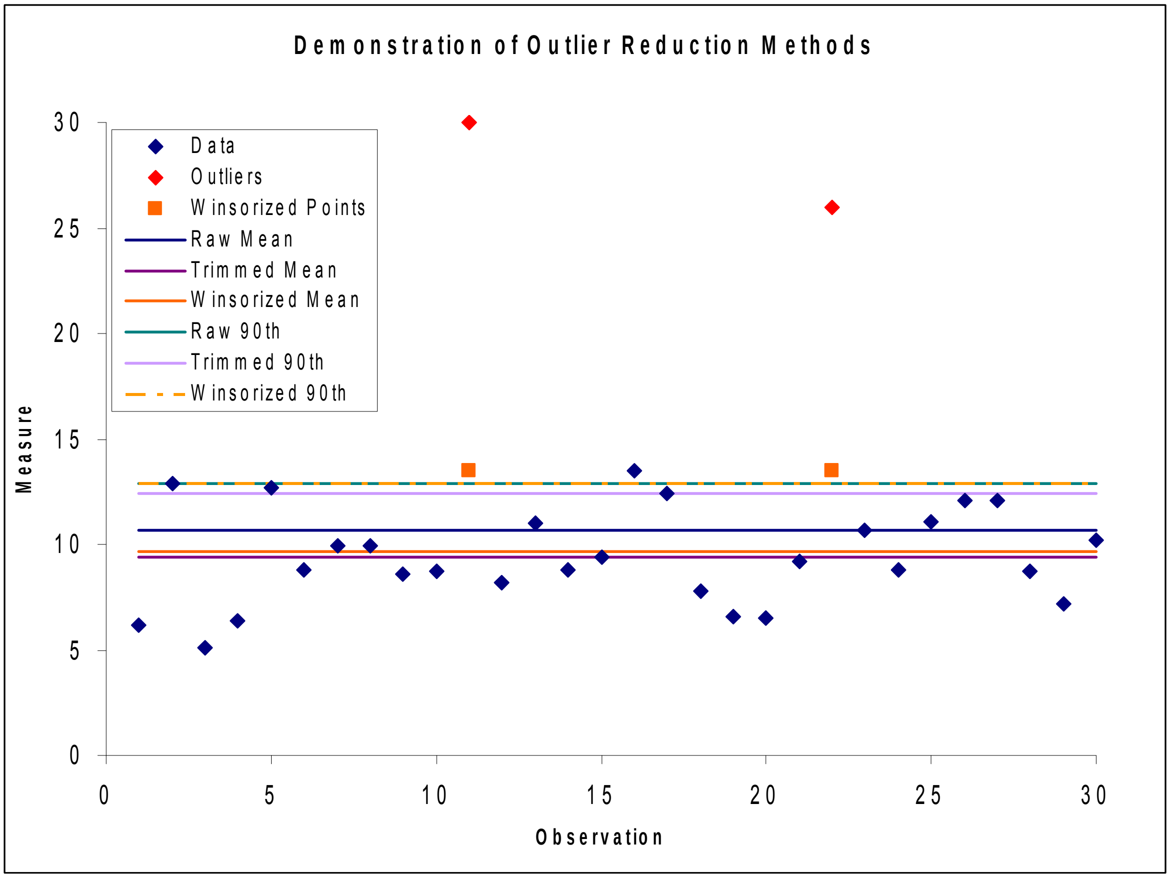

Figure 5. Demonstration of outlier reduction methods.

Retrospective Analysis

Under the current methods for the *retrospective* analysis, adjacent time series within a reservoir contain many of the same points; and some are complete subsets of one another. Hence, there is considerable lack of independence across tests during the *retrospective* analysis (note dates of sequential 5-year assessments found in TCEQ 2006a). A more satisfactory way of looking retrospectively would be to make all time series independent of one another. There are a variety of ways this could be accomplished. Again, one of the better ways to test the *sensitivity* and *specificity* of a criterion is to use simulated data with known deviations.

In many cases, it requires more than 5 years worth of data to attain sufficient sample sizes (i.e., 10 data points) during the assessment period of the retrospective analysis.

TCEQ Calculations

TPWD believes that the formula for the variance used in the calculation of the TCEQ criterion is incorrect. The "pooled" variance is the weighted average variance from two samples. Because, in this case, there is only one sample, and TCEQ is "pretending" there are two, the pooled variance, which is the weighted average of the same sample twice, should equal the calculated variance. It does not, and instead equals almost twice the estimated variance. This is because the numerator is correct, but the denominator is about half as large as it should be. Moore and McCabe's *Introduction to the Practice of Statistics* (1999) provides a formula (p. 550) which was used to correct the TCEQ calculations.

In the Nutrient Criteria Development in Texas handout (TCEQ 2006a) presented at the RTAG meeting in January 2006, TCEQ sets the size of the assessment sample (n2 in their formula) as 10. This does not strictly follow the concept of estimating the standard error under the current protocol. The quantity "n2" is supposed to reflect the number of data points in the second sample. The quantity "n2" decreases the standard error of the *mean* because the more data you have the better you know what the *mean* value is. Since there should be at least 10 data points in the assessment, it should be noted that using "n2"=10 creates the largest possible criterion; if "n2" were to reflect the actual number of data points, the criterion could be smaller. The problem with allowing "n2" to change is that it allows the criterion to change, so one can see why setting it at 10 is attractive from a regulatory perspective. A defensible alternative, since none of the data from the assessment period is being used to estimate the variance, would be to use the variance and the sample size from the baseline period only.

Whereas the TCEQ formula on page 5 of the Nutrient Criteria Development in Texas handout (TCEQ 2006a) for the criteria states the 95th *percentile confidence interval* of the *mean* will be used for their criteria, the criteria TCEQ presented are actually calculated using the 99th *percentile confidence interval* of the *mean* (see Table 1).

Even after we adjusted our calculations to account for the issues discussed above, while trying to recreate the TCEQ-calculated criteria, we found several small disagreements between our calculations and the TCEQ criteria. These small deviations could have been caused by rounding issues or because it was unclear which points were being deleted as *outliers* during the TCEQ retrospective analysis.

While minor, the current TCEQ excel spreadsheet does not calculate the TPWD criteria correctly (Table 2). In the TPWD proposal (TPWD 2004) we stated that the last 10 years would be used to set the criteria; TCEQ uses all the historic data. Another minor point is that TCEQ uses the Excel function that computes the 90th *percentile* of the data. This function is not strictly *nonparametric,* and in fact, interpolates to estimate the 90th *percentile*. The TPWD proposal was based on the observed 90th *percentile* of the data, not an interpolated measure.

TPWD Calculations

Data from TCEQ (TCEQ 2006b) were used to calculate the TPWD and TCEQ criteria for chlorophyll-a for each waterbody. TPWD criteria were established using the guidelines presented in the TPWD proposal (TPWD 2004). The TPWD proposal suggested calculating the *empirical* 90th *percentile* values based on the last ten years of data for non-degraded reservoirs. We assumed all reservoirs in this sample were non-degraded, for had they been degraded, it would have been inappropriate to use the current data to set the criteria (as outlined in the TPWD methodology). In the case of degraded reservoirs, the TPWD proposal suggests a suite of other methods available for setting the criteria. In the assessment phase, assessments are conducted every two years using the last five years of data and at least 10 samples are required for assessment. If ≤ 10% of samples exceed the criterion, the reservoir will be considered as fully compliant with numeric nutrient standards.

TCEQ criteria (Table 1) were established using the guidelines given in the Nutrient Criteria Development in Texas handout (TCEQ 2006a) presented at the RTAG meeting in January 2006, with the following changes: a) the formula for the pooled variance,

$$s_p^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}$$

from Moore and McCabe (1999, p. 550) was used to estimate the standard error of the *mean*, and b) the critical value of the *t* distribution was derived where alpha=0.01 (one-tailed), and the degrees of freedom were equal to n_1 (the number of samples in the baseline sample) plus n_2=10.

For the assessments in the *retrospective* analysis, if there were less than 10 data points in the 5 years, full years were added to the assessment data until there were at least 10 data points. This is similar to the TCEQ approach, except TCEQ added data until they had 5 year's worth of data; the TCEQ retrospective analysis had no minimal sample size for the assessment. Hence, for some of the assessments within the TCEQ retrospective analysis, assessments were conducted with as few as 5 data points.

The initial year data were collected was designated as Year 0. Subsets began at Year 0 and were created every two years for five or more years until 10 data points existed. Hence, subset 1 is the subset beginning with year 0, and subsets 2-14 are subsequent samples starting every even-numbered year – because assessments were to be conducted every two years. When data did not exist for even-numbered years, the subsequent odd-numbered year was used as the starting year.

Results and Discussion

TCEQ criteria were calculated using several variations on TCEQ's methodology. Results are presented in Table 1. Criteria presented by TCEQ in the Nutrient Criteria Development in Texas handout (TCEQ 2006a) are given in column 1. TPWD's calculations using TCEQ's formulation of the pooled variance at the 99th *percentile confidence interval* of the *mean* using all historic data are given in column 2. Column 3 repeats the calculation at the 99th *percentile confidence* *interval* of the *mean* using the pooled variance as formulated by Moore and McCabe (1999). Column 4 repeats the calculation of column 3 using only the last 10 years of data. Columns 5 and 6 repeat the calculations of columns 2 and 3 (i.e., column 5 uses TCEQ's formulation of the pooled variance; column 6 uses the pooled variance as formulated by Moore and McCabe) at the 95th *percentile confidence interval* of the *mean*. Column 7 repeats the calculation of column 4 using the 90th *percentile confidence interval* of the *mean*. Finally, Column 8 holds TPWD criteria as calculated by TPWD (column 2 of Table 2).

Table 2 presents TPWD criteria. Criteria calculated according to the TPWD proposal (TPWD 2004) are compared to the TPWD criteria presented by TCEQ in the Nutrient Criteria Development in Texas handout (TCEQ 2006a). There are small differences, as discussed above.

It is important to consider the procedure to assess compliance as part of the process of establishing criteria. Table 3, Table 4 and Table 5 present comparisons of which reservoirs would be identified as noncompliant using TCEQ and TPWD criteria. The TPWD calculation of the TPWD criteria (column 2 of Table 2) is used throughout. Table 3 compares the TPWD criteria with the TPWD calculation of the TCEQ criteria at the 99th *percentile confidence interval* of the *mean* using all historic data and using the Moore and McCabe pooled variance formulation (column 3 of Table 1). Table 4 compares the TPWD criteria with a TPWD calculation of the TCEQ criteria at the 99th *percentile confidence interval* of the *mean* using the last 10 years of data and using the Moore and McCabe pooled variance formulation. Table 5 compares the TPWD criteria with a TPWD calculation of the TCEQ criteria at the 90th *percentile confidence interval* of the *mean* using the last 10 years of data and using the Moore and McCabe pooled variance formulation.

As indicated in Table 6, both approaches agreed on most reservoirs (although the timing of the noncompliance was often somewhat different). On those reservoirs where differences existed, more details are provided below. Details on all noncompliant reservoirs can be found in the Appendix.

Considering Table 3, the *retrospective* analysis showed that the TPWD method flagged many more subsetted time periods (102) as potentially problematic than did the TCEQ method (28). There was 33% correlation between the two analyses. Virtually all subsets that were flagged as being of concern under the TCEQ method were also flagged by the TPWD method, but the converse was not true. The few occasions when the TCEQ method indicated a problem, but the TPWD method did not, occurred because one or two high values inflated the *mean*, but did not trigger noncompliance under the TPWD method. There are three reasons the TPWD method flagged more points:

1. The TPWD method uses only the last 10 years to set the criterion. Hence, if a reservoir previously had higher chlorophyll-a values than it does presently, the TPWD method is likely to detect those higher levels during the *retrospective* analysis. However, the TCEQ method, because it incorporates the entire time series to define its criterion, allows those higher levels to inflate both its *mean* and its variance. Because the variance is used to estimate the confidence interval, which is what TCEQ uses to set its criteria, using the entire time series inflates the criterion, making it less likely that a higher chlorophyll-a

value will be flagged as noncompliant. This is especially true in those reservoirs which have experienced lower chlorophyll-a values in the past 10 years. If instead, the TCEQ criteria were based on only the last 10 years (Table 4), more subsets would be flagged (75 instead of 28) and the correlation between the TPWD and the TCEQ methods increases to 50%.

2. The TPWD method uses the 90th *percentile* to set the bounds, whereas the TCEQ method uses the 99th *percentile confidence interval* bounds. While the *distribution* of the *empirical* data and the *confidence interval* of the *mean* are not directly comparable, the larger the percentage, the wider the bounds around the criterion (e.g., a 95% *confidence interval* is about 4 standard deviations wide whereas a 99% *confidence interval* is about 6 standard deviations wide). Thus, we would expect to observe fewer subsets with values outside the bounds of the historic when using the TCEQ criteria. If you based the TCEQ criteria on only the last 10 years, and restricted the confidence bounds to 90%, more subsets would be flagged (87 instead of 28) and the correlation between the TPWD and the TCEQ methods increases to 55% (Table 5). What was of note is that decreasing the width of the confidence bounds primarily increased the agreement between the TPWD and the TCEQ criteria on which subsets were non-compliant within a reservoir. Concurrent with the decrease in *confidence interval* width, only two more reservoirs (i.e., Houston County Lake and Marble Falls) were added to the TCEQ noncompliant list. Table 6 details which reservoirs both TPWD and TCEQ either flagged or did not flag, as well as which reservoirs were flagged by only one of the two methods.

3. The TPWD method looks at individual data points and not *mean* values. For the TPWD method, the historic data determines the upper bounds of the observations. For the TCEQ method, the historic data determines the *mean*, but the criterion is set based on a parametric ideal of the assumed *normal distribution*. If the ideal and reality do not conform, then there can be *overcoverage* or *undercoverage* in the extremes of the *distribution* (i.e., the values the method is using to determine compliance).

Reservoir Non-compliance: Comparing TPWD and TCEQ using Defined Criteria

The following details the 13 reservoirs where the TPWD and TCEQ criteria did not agree on whether the reservoir was ever noncompliant. Comparisons are between TPWD calculations of TPWD criteria using the last 10 years of the data to set the criteria and the TPWD calculation of TCEQ criteria using the 99th *percentile confidence interval* of the *mean*, all of the historic data to set the criteria, and the Moore and McCabe formulation of pooled variance, corresponding to column 3 of Table 1. The data discussed below are depicted in Table 3.

In the figures below the blue points represent the sampled data, the pink line is the TPWD criterion, and the black line is a linear fit to the data. A downward-sloping black line is suggestive of decreasing chlorophyll-a levels in recent times, an upward-sloping black line is suggestive of increasing chlorophyll-a levels in recent times, and a flat line is suggestive of no change in the chlorophyll-a levels throughout the time series.

Amistad Reservoir

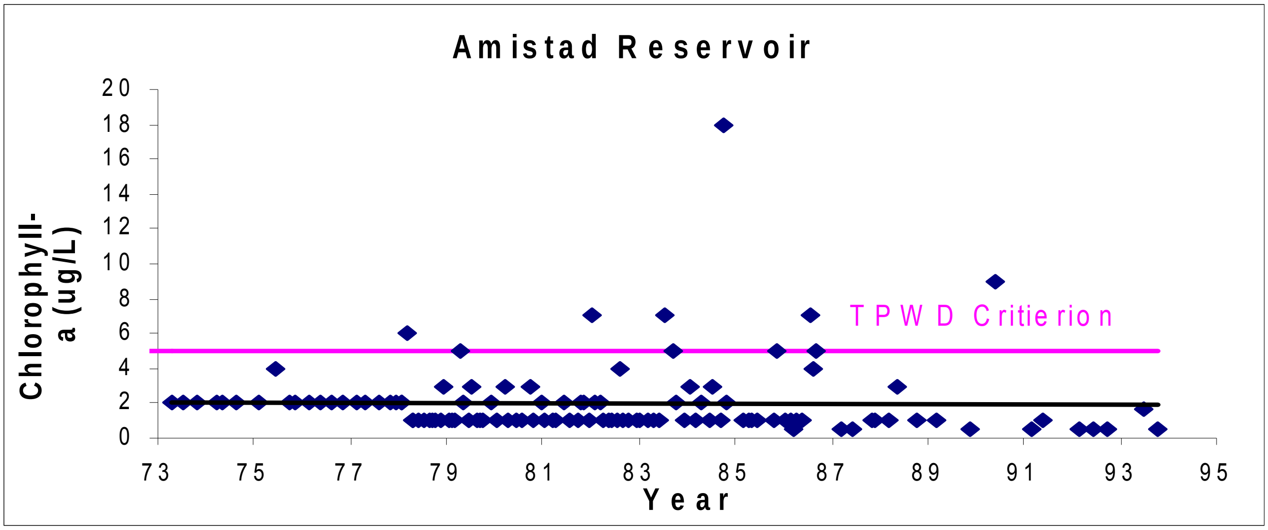

Figure 6. Amistad Reservoir.

The TPWD criterion for Amistad is 5µg/L. In subset 8, the criterion was exceeded because two values (7 and 9 µg/L) out of 15 exceeded the 90th *percentile* (i.e., noncompliance rate of 13%). The TCEQ criterion was not surpassed because even with these higher values, the overall *mean* value was 2.40 µg/L and the criterion was 3.02 µg/L.

Lake Bridgeport

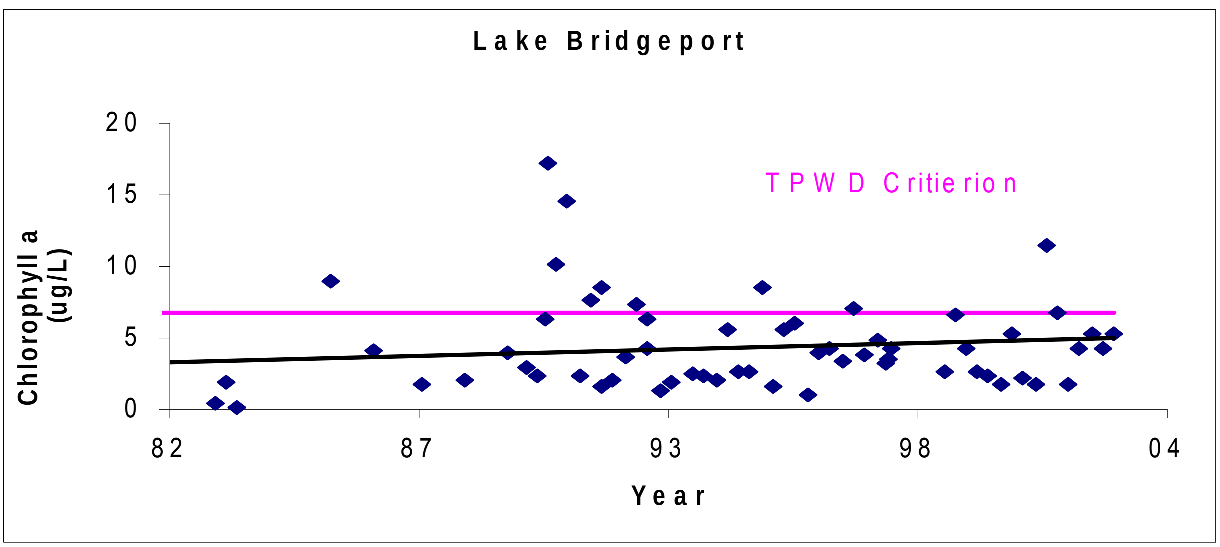

Figure 7. Lake Bridgeport.

The TPWD criterion for Bridgeport is 6.7µg/L. In subsets 6-10, the criterion was exceeded because between three and six of the following 7 values (9, 17.2, 10.2, 14.6, 7.7, 8.5, and 7.3

μg/L) out of 10 to 22 exceeded the 90th *percentile* (i.e., noncompliance rates of 23% to 36%). In subsets 2 and 12, two values out of 18 and 19 respectively exceeded the 90th *percentile* (i.e., noncompliance rate of 11%) The TCEQ criterion was not surpassed because even with these higher values, the highest *mean* value was 6.1 μg/L and the criterion was 6.3 μg/L.

Houston County Lake

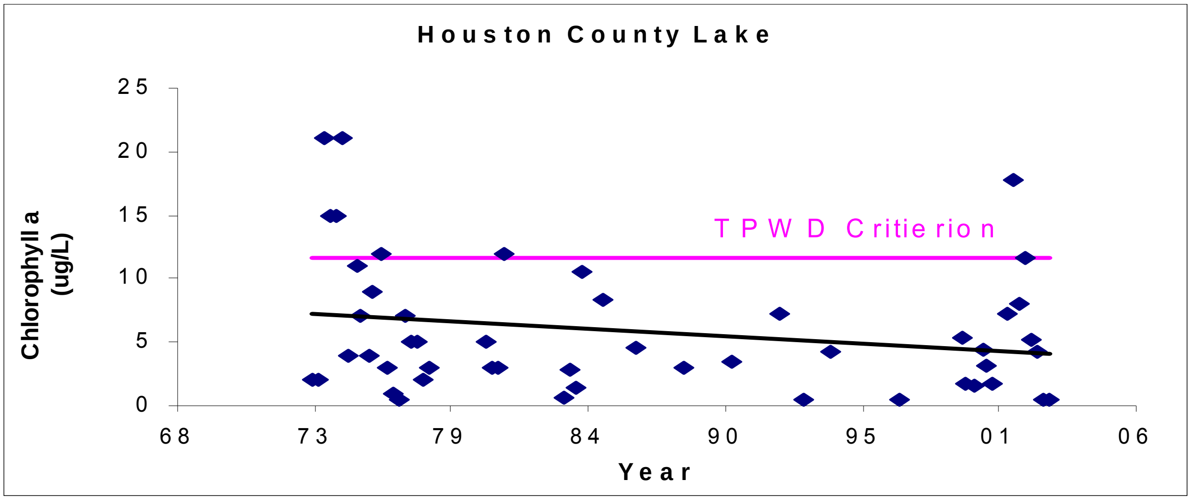

Figure 8. Houston County Lake.

The TPWD criterion for Houston County is 11.6 μg/L. In subset 1, the criterion was exceeded because five values (21, 15, 15, 21 and 12 μg/L) out of 19, exceeded the 90th *percentile* (i.e., noncompliance rate of 26%). The TCEQ criterion was not surpassed because even with these higher values, the overall *mean* value was 7.71 μg/L and the criterion was 10.2 μg/L, primarily because of the high chlorophyll-a values in the 1970s.

Canyon Lake

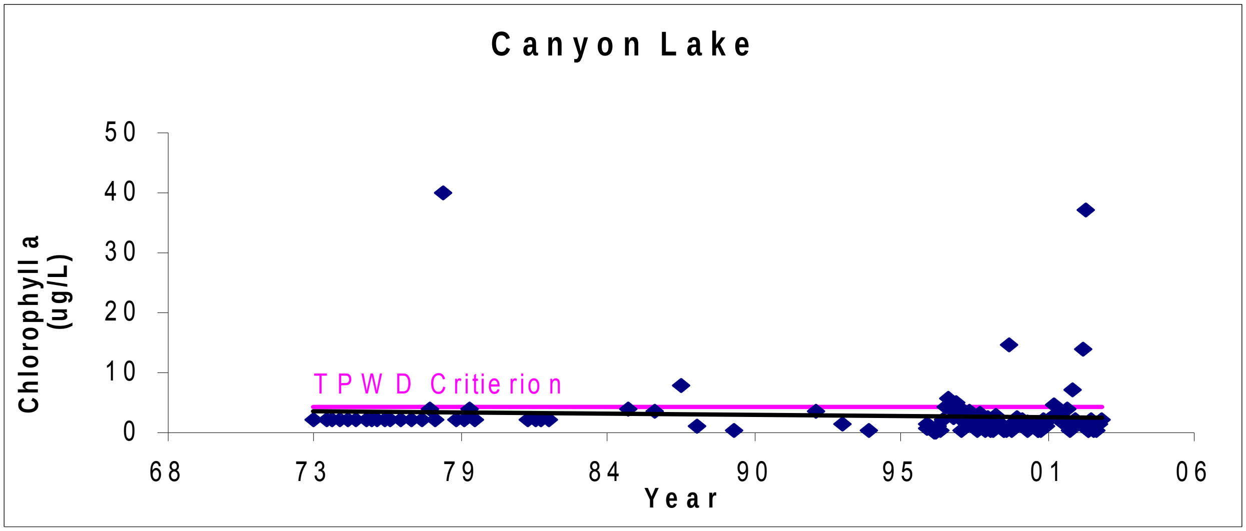

Figure 9. Canyon Lake.

The TCEQ criterion for Canyon is 3.05 µg/L. In subsets 2 and 3, the criterion was exceeded because a single value of 40 µg/L pulled the *mean* value above 3.05 µg/L. This single value did not cause the TPWD criterion to be exceeded.

Choke Canyon

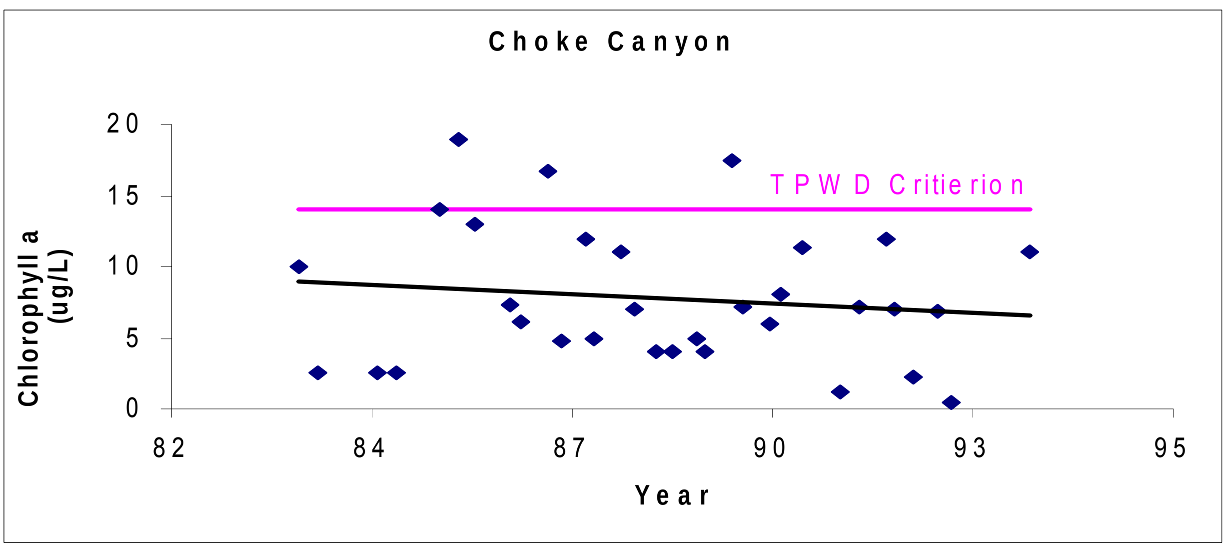

Figure 10. Choke Canyon.

The TPWD criterion for Choke Canyon is 14.1µg/L. In subsets 1 and 2, the criterion was exceeded because two values (19 and 16.7 µg/L) out of 14 and three values (19, 16.7 and 17.4 µg/L) out of 18, respectively, exceeded the 90th *percentile* (i.e., noncompliance rates of 14% and 17%). The TCEQ criterion was not surpassed because even with these higher values, the overall *mean* values for these subsets were 9.0 and 9.1µg/L, respectively, and the criterion was 12.00 µg/L.

Diversion Lake

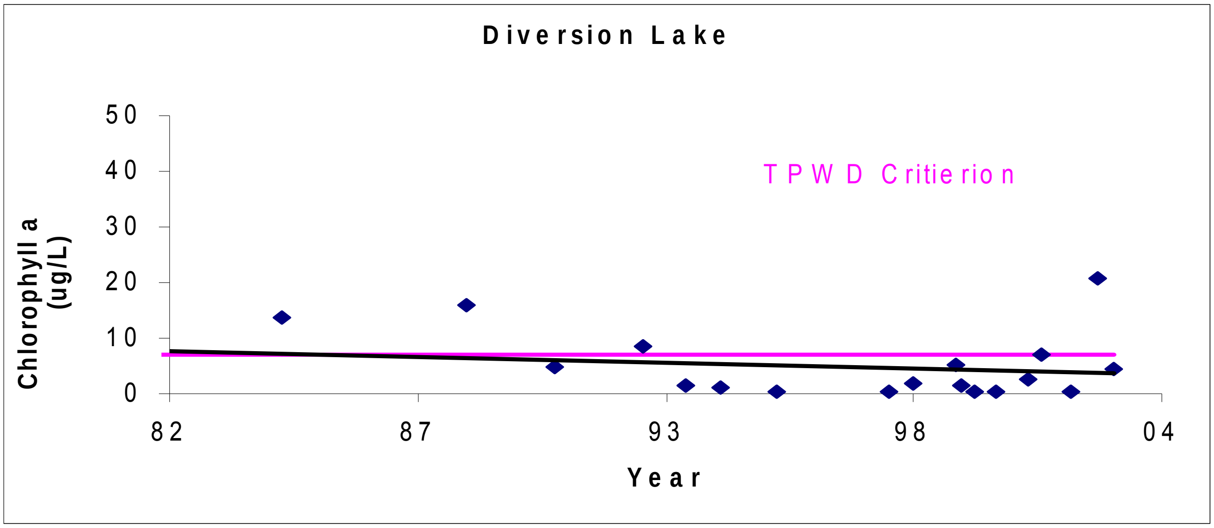

Figure 11. Diversion Lake.

The TPWD criterion for Diversion Lake is 7.1µg/L. In subsets 1 and 2, the criterion was exceeded because at least three values of the following six values (40, 9, 9, 9, 17.6 and 10.3 µg/L) out of 11 or 12 exceeded the 90th *percentile* (i.e., noncompliance rates of 42% and 36%). In subsets 3-5, the criterion was exceeded because four or five of the following five values (17.6, 10.3, 13.8, 16, and 8.6µg/L) out of 10 exceeded the 90th percentile (i.e., noncompliance rates of 40% to 50%). In subsets 6 and 7, at least two of these same values exceeded the criterion (i.e., noncompliance rates of 25% to 18%). The TCEQ criterion was not surpassed because even with these higher values, the highest overall *mean* value for this dataset was 8.7 µg/L and the criterion was 10.32 µg/L. This higher criterion for the TCEQ method is primarily a result of using the entire time series, when the last 10 years have lower chlorophyll-a values than did previous years.

Lake Cypress Springs

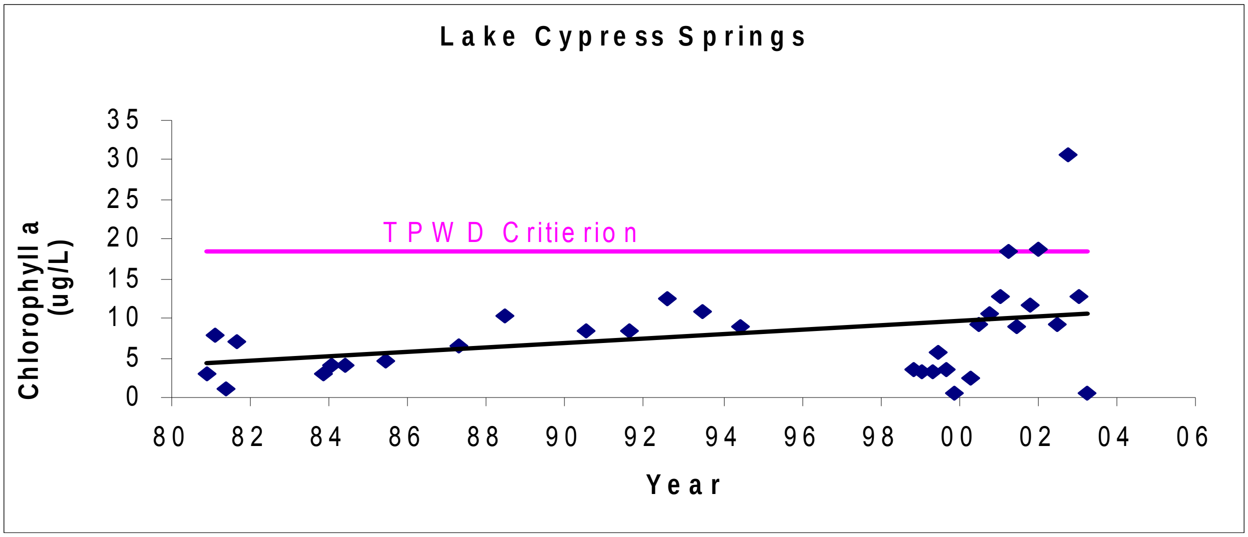

Figure 12. Lake Cypress Springs.

The TPWD criterion for Lake Cypress Springs is 18.44 µg/L. In subset 9, the criterion was exceeded because two values (18.7 and 30.6 µg/L) out of 18 exceeded the 90th *percentile* (i.e., noncompliance rate of 11%). These two values are the highest in the history of this reservoir and both occurred in 2002. Despite this, the TCEQ criterion was not surpassed because even with these higher values, the overall *mean* value for this subset was 6.8 µg/L and the criterion was 11.52 µg/L.

Lake Marble Falls

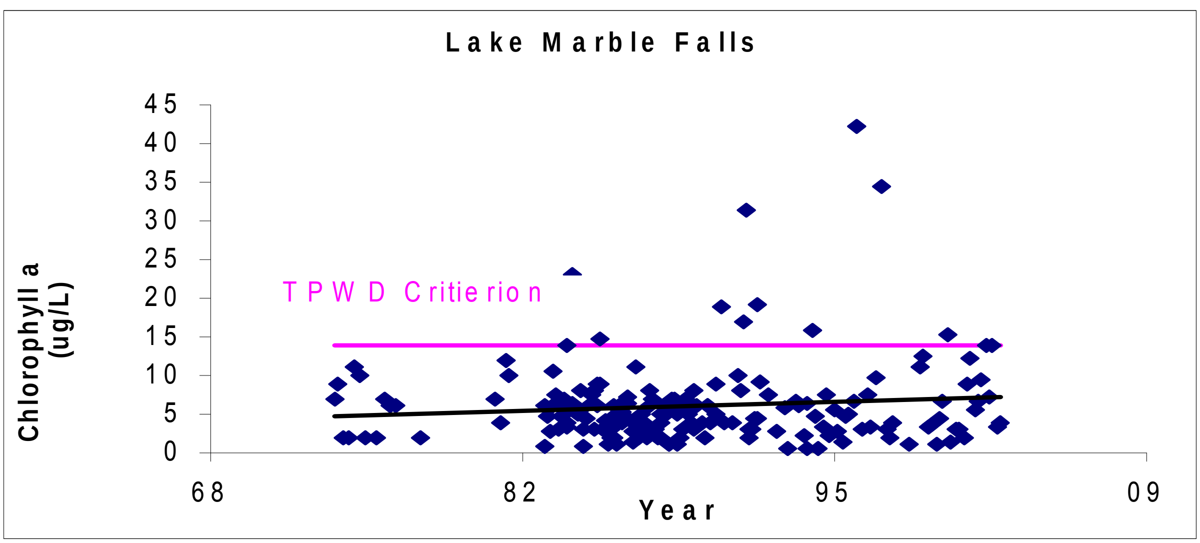

Figure 13. Lake Marble Falls.

The TPWD criterion for Marble Falls is 13.8 µg/L. In subsets 8 and 9, the criterion was exceeded because four of the following five values (19, 17, 31.3, 19.2, and 15.8 µg/L) out of 32 and 30, respectively, exceeded the 90th *percentile* (i.e., noncompliance rates of 13%). In subset 10, the criterion was exceeded because three values (15.8, 42.3, and 34.5 µg/L) out of 27 exceeded the 90th *percentile* (i.e., noncompliance rate of 11%). In all instances, the TCEQ criterion was not surpassed because even with these higher values, the overall *mean* values for these subsets were 7.2, 6.6, and 7.2 µg/L, respectively, and the criterion was 8.56 µg/L.

Lake Amon Carter

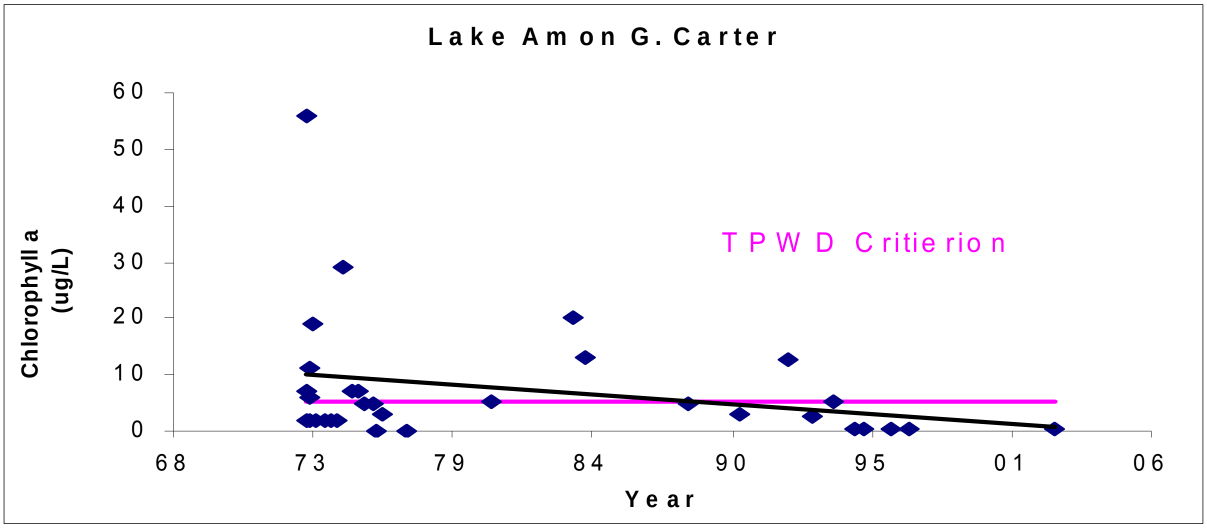

Figure 14. Lake Amon Carter.

The TPWD criterion for Amon Carter is 5.1µg/L. In subset 1, the criterion was exceeded because eight values (56, 7, 6, 11, 19, 29, 7 and 7 µg/L) out of 19 exceeded the 90th *percentile* (i.e., noncompliance rate of 42%). In subsets 2-5, the criterion was exceeded because between three to five of the following values (7, 7, 5.4, 20, 13, 12.5) out of 10 exceeded the 90th percentile (i.e., noncompliance rates of 30% to 50%). The TCEQ criterion was not surpassed because even with these higher values, the overall *mean* value for this subset was 8.8 µg/L and the criterion was 9.71 µg/L. This higher criterion for the TCEQ method is primarily a result of using the entire time series, when the last 10 years have lower chlorophyll-a values than did previous years.

Lake Jacksonville

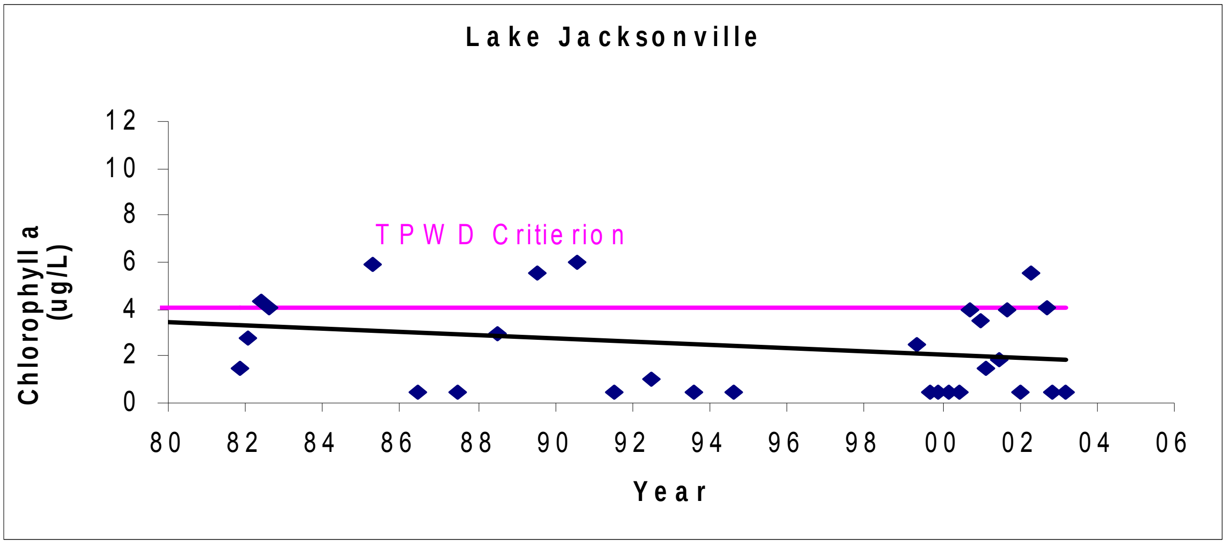

Figure 15. Lake Jacksonville

The TPWD criterion for Jacksonville is 4.09 µg/L. In subsets 1 to 8, the criterion was exceeded, with noncompliance rates varying from 17% to 50%. The primary reason for this is because the last 10 years at Jacksonville have lower chlorophyll-a values than did previous years. The exception to lower chlorophyll-a is in 2002, when a single value of 5.51 µg/L was observed. The TCEQ criterion was not surpassed because even with these higher values, the overall *mean* value for this subset was never higher than 4.1 µg/L and the criterion was 4.58 µg/L. This higher criterion for the TCEQ method is primarily a result of using the entire time series, when the last 10 years have lower chlorophyll-a values than did previous years.

Lake Travis

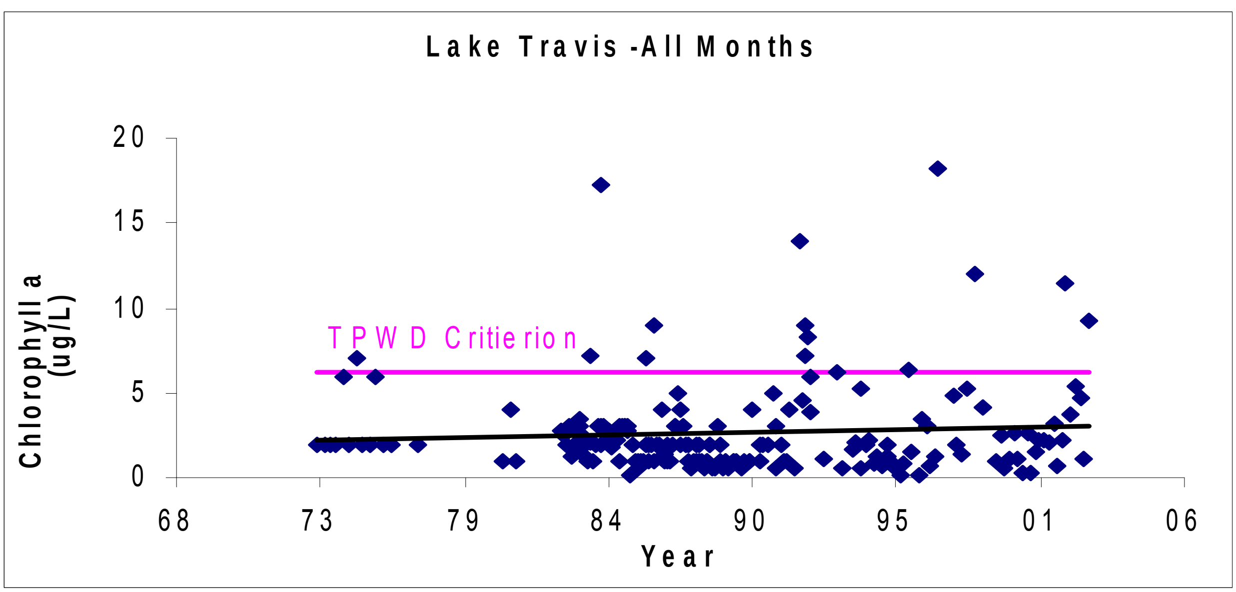

Figure 16. Lake Travis.

The TPWD criterion for Travis is 6.14 µg/L. In subsets 8 and 9, the criterion was exceeded because four values (14, 8.9, 7.2, and 8.3 µg/L) out of 35 and 31, respectively, exceeded the 90th *percentile* (i.e., noncompliance rates of 11% and13%). In subsets 11 and 12, the criterion was exceeded because three of the following four values (6.3, 18.2, 12, and 11.4 µg/L) out of 25 and 24, respectively, exceeded the 90th *percentile* (i.e., noncompliance rates of 12% and 13%). The TCEQ criterion was not surpassed because even with these higher values, the overall *mean* value for these subsets never exceeded 3.5 µg/L and the criterion was 4.15µg/L.

Lake Tyler

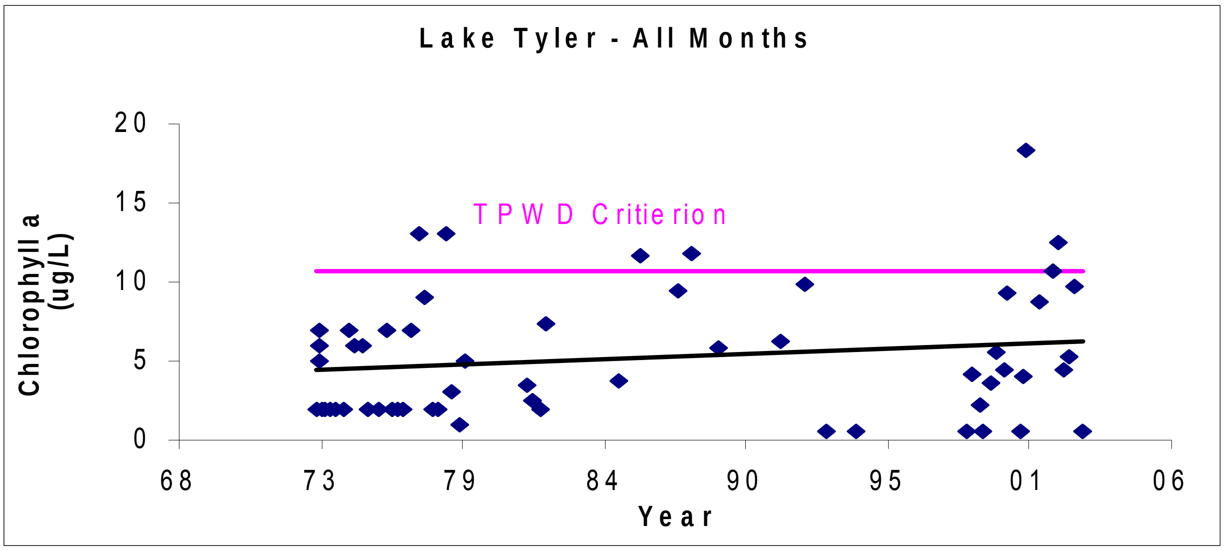

Figure 17. Lake Tyler.

The TPWD criterion for Tyler is 10.7 µg/L. In subsets 2 and 3, the criterion was exceeded because two values (13 and 13 µg/L) out of 16 and 11, respectively, exceeded the 90th *percentile* (i.e., noncompliance rates of 13% and 18%). In subsets 4, 5 and 6, the criterion was exceeded because two values (11.7 and 11.8 µg/L) out of 10, 10, and 11, respectively, exceeded the 90th *percentile* (i.e., noncompliance rates of 20%, 20%, and 18%). The TCEQ criterion was not surpassed because even with these higher values, the overall *mean* value for these subsets never exceeded 6.4 µg/L and the criterion was 7.93 µg/L.

Red Bluff Reservoir

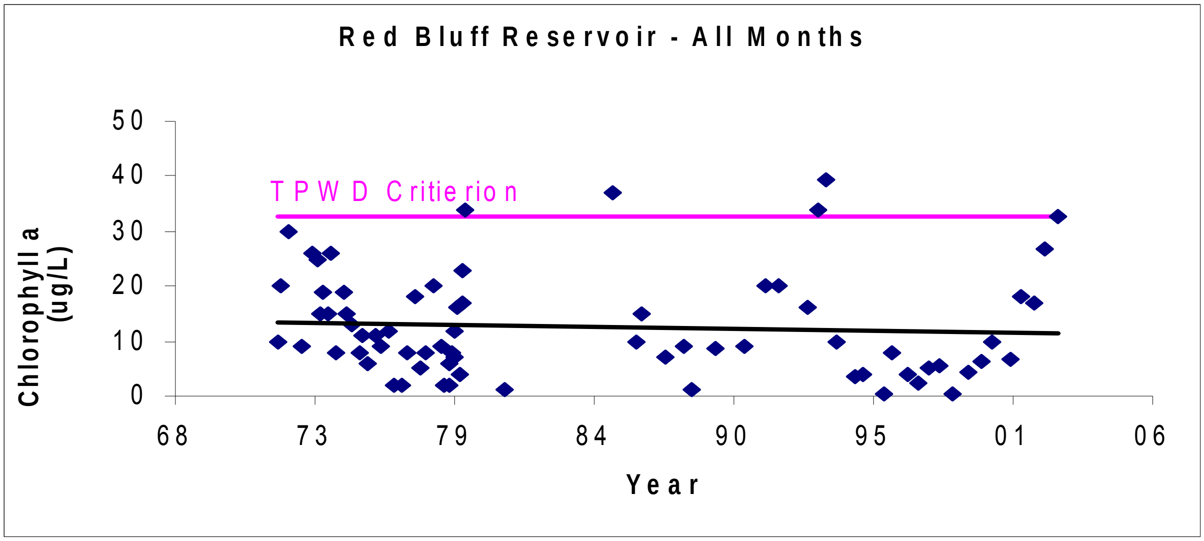

Figure 18. Red Bluff Reservoir.

The TPWD criterion for Red Bluff is 32.6 µg/L. In subset 4, the criterion was exceeded because two values (34 and 37 µg/L) out of 17 exceeded the 90th *percentile* (i.e., noncompliance rate of 12%). In subsets 8, 9 and 10, the criterion was exceeded because two values (33.8 and 39.3 µg/L) out of 10, 11, and 11, respectively, exceeded the 90th *percentile* (i.e., noncompliance rates of 20%, 18%, and 18%). The TCEQ criterion was not surpassed because even with these higher values, the overall *mean* value for these subsets never exceeded 16.7 µg/L and the criterion was 20.31 µg/L.

Reservoir Non-compliance: Comparing TPWD and TCEQ When Both Use the Last 10 Years to Set the Criteria

There were 11 reservoirs that did not agree on whether a reservoir was ever noncompliant when assessment was based on TPWD and TCEQ criteria which were calculated using a 10-year window for their baseline. Using the last 10 years to set the criteria for both TPWD and TCEQ caused there to be a high degree of agreement in Lake Amon Carter, Lake Bridgeport, Lake Jacksonville, and Diversion Lake. All of these reservoirs had data that suggested the chlorophyll-a levels have not been constant throughout the historic data collection. Under the parametric approach used by TCEQ, such non-constancy can inflate the estimate of variance, and hence inflate the TCEQ criterion. For Amistad, Houston County, Canyon Lake, Choke Canyon, Marble Falls, Travis, Tyler and Red Bluff, using the last 10 years to set the TCEQ criterion reduced the TCEQ criteria (compare columns 3 and 4 of Table 1 or compare Table 3 to Table 4); for Cypress Springs the TCEQ criterion went upwards slightly. Regardless, in all 9 of these cases, just as before, the TPWD and TCEQ criteria would not agree on whether the reservoir was ever noncompliant. For Murval and Palo Pinto, changing the TCEQ criterion caused a disagreement on whether the reservoir was ever noncompliant.

Comparisons are between TPWD calculations of TPWD criteria and the TPWD calculation of TCEQ criteria using the 99th *percentile confidence interval* of the *mean*, 10 years of data, and the Moore and McCabe formulation of pooled variance, corresponding to column 4 of Table 1. The data discussed below are depicted in Table 4.

In the figures below the blue points represent the sampled data, the pink line is the TPWD criterion, and the black line is a linear fit to the data. A downward-sloping black line is suggestive of decreasing chlorophyll-a levels in recent times, an upward-sloping black line is suggestive of increasing chlorophyll-a levels in recent times, and a flat line is suggestive of no change in the chlorophyll-a levels throughout the time series.

Lake Murvaul

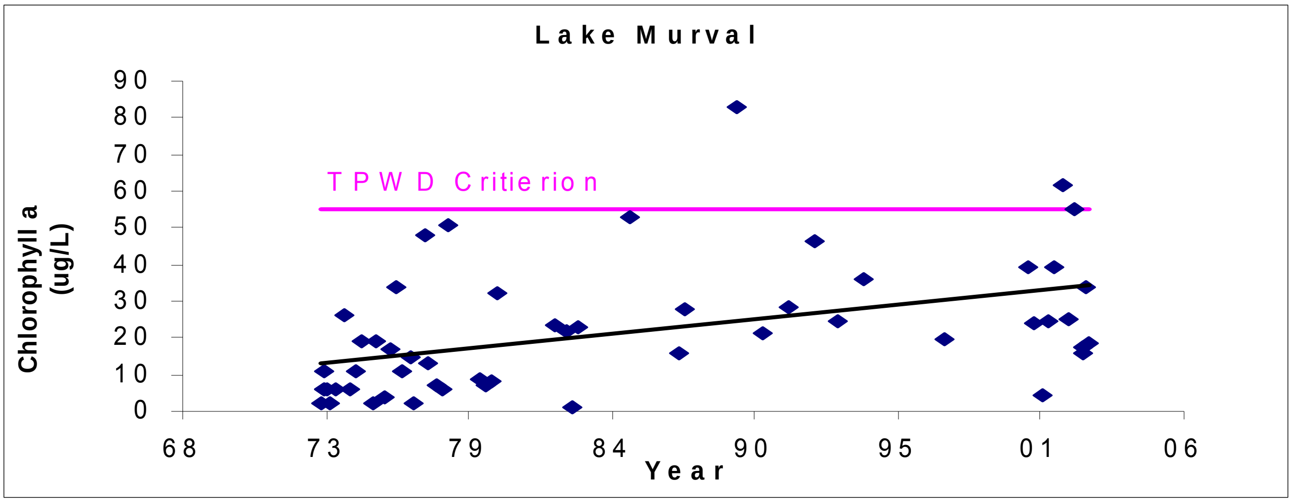

Figure 19. Lake Murvaul.

The TPWD criterion for Murvaul is 55.2 µg/L. In subset 9, the criterion was exceeded because two values (82.9 and 61.4 µg/L) out of 13 exceeded the 90th *percentile* (i.e., noncompliance rate of 15%). The TCEQ criterion was not surpassed because even with these higher values, the overall *mean* value for this subset was 34.8 µg/L and the criterion was 39.8 µg/L. For Lake Murval, limiting the baseline period to the last 10 years raised the TCEQ criterion from 33.3 to 39.8 µg/L.

Lake Palo Pinto

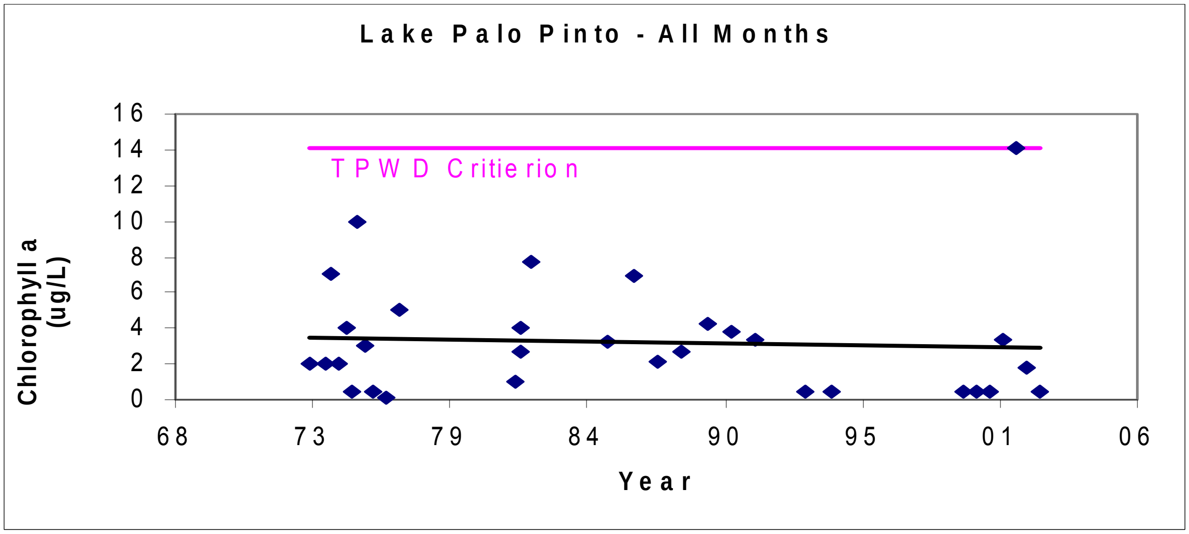

Figure 20. Lake Palo Pinto

The TCEQ criterion for Palo Pinto is 1.87 µg/L. In all subsets except 6, the criterion was exceeded. The primary reason for this is because the last 10 years at Palo Pinto have much lower chlorophyll-a values than did previous years. The exception to lower chlorophyll-a is 2001, when a single value of 14.1 µg/L was observed. When the TPWD criterion was set using the last 10 years of data, only 9 values were present. Under the rules for setting the TPWD criteria, this maximum value became the TPWD criterion. Hence, none of the subsets had values that exceeded the TPWD criterion. For Lake Palo Pinto, limiting the baseline period to the last 10 years lowered the TCEQ criterion from 5.06 to 1.87 µg/L.

Conclusions

This exercise shows that both the TCEQ and the TPWD criteria are able to detect deviations from the baseline. The TPWD criteria, because there is a one-to-one correspondence to the individual data points, because it is based on the last 10 years of data, and because it uses the 90th percentile as the cut-off, was more sensitive to deviations than was the TCEQ criteria. For instance, in several instances in the retrospective analysis, 50% of the data in a subset exceeded the observed 90th percentile from the last 10 years, yet the TCEQ criteria did not detect a problem (See Lake Amon Carter, Lake Jacksonville and Diversion Lake). The only times that the TCEQ criteria suggested a problem existed, and the TPWD criteria did not was when a single large value inflated the mean (See Canyon Lake and Inks Lake). In all of these cases, it would seem that the TPWD-based criteria were providing a better picture of compliance than were the TCEQ-based criteria.

These data suggest that chlorophyll-a levels in some reservoirs have changed over the historic record. Using a criterion based on all the data would seem to be unwise, as the criterion may not reflect the current conditions. Estimating a mean and a variance from data exhibiting a trend will produce an inaccurate estimate of the current mean and an imprecise measure of the current variance.

While the TPWD method is quite sensitive to fluctuations in the observed chlorophyll-a values, we are concerned that the TCEQ approach, through its focus on the confidence interval about the mean, may not be adequately or appropriately sensitive to reservoirs which have increasing nutrient concentrations. As was shown in Figure 1 using data for Amistad Reservoir, 44% of the individual data points exceeded the TCEQ criterion before a noncompliance was assessed. This approach has the potential of allowing significant nutrient enrichment to occur before a problem is detected. In order to limit the potential for hypereutrophication, TPWD recommends setting criteria not only for response variables, such as chlorophyll-a, but also for causal variables, such as orthophosphorus and nitrate-nitrogen (TPWD 2004).

The question of the relationship between causal and response factors will have to be addressed in order to implement numeric nutrient standards, for it will be necessary to derive allowable nitrogen and phosphorus loads for use in wastewater permits, Total Maximum Daily Loads, Implementation Plans and Watershed Protection Plans. Since nutrient cycling patterns are complex and are likely to be different in reservoirs having varying nekton, algal, and macrophyte communities, it will be important to have reservoir-specific information about the relationships among chlorophyll-a, phosphorus and nitrogen.

We are concerned by TCEQ's choice of a parametric analysis to set criteria. When data deviate from a normal distribution, such an approach is subject to inherent error which increases as the data deviate farther from a normal distribution.

Finally, we encourage TCEQ to re-examine the details of their calculations, particularly regarding the formula used to determine the pooled variance, the use of all historical data (as opposed to the last 10 years), the use of the 99th percentile confidence interval about the mean (as opposed to a lower percentile), and the treatment of outliers in both the criteria-setting and assessment procedures.

Table 1. Comparison of TCEQ criteria calculated using several variations on TCEQ's methodology. See text for discussion. TPWD criteria are included for ease of comparison. All values are chlorophyll-a in µg/L.

Reservoir Name	**TCEQ Published 99th Percentile (TCEQ 2006a)**	**TPWD Calculation 99th Percentile using all Historic Data and the TCEQ Pooled Variance Formula**	**TPWD Calculation 99th Percentile using all Historic Data and Moore and McCabe (1999) Pooled Variance Formula**	**TPWD Calculation 99th Percentile using 10 Years of Data and Moore and McCabe (1999) Pooled Variance Formula**	**TPWD Calculation 95th Percentile using all Historic Data and the TCEQ Pooled Variance Formula**	**TPWD Calculation 95th Percentile using all Historic Data and Moore and McCabe (1999) Pooled Variance Formula**	**TPWD Calculation 90th Percentile using 10 Years of Data and Moore and McCabe (1999) Pooled Variance Formula**	**TPWD Calculation of TPWD Criteria**
	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8
			See Table 3	See Table 4			See Table 5	
Amistad Reservoir	3.490	3.487	3.020	2.87	2.998	2.669	2.62	5
B. A. Steinhagen Reservoir	10.568	10.569	9.250	8.54	8.963	8.049	7.73	12
Caddo Lake	18.485	18.485	15.636	13.47	15.433	13.435	12.12	23
Canyon Lake	3.473	3.472	3.052	2.57	3.031	2.736	2.40	4.2
Choke Canyon	13.482	13.483	11.997	10.68	11.739	10.706	10.01	14.1
Diversion Lake	11.977	11.977	10.324	7.28	10.055	8.904	6.4	7.1
Farmers Creek Reservoir (Nocona Lake)	7.043	7.043	6.083	6.09	5.952	5.283	5.55	10.2
Houston County Lake	11.814	11.814	10.196	7.73	10.021	8.890	7.01	11.6
Hubbard Creek Reservoir	6.343	6.344	5.509	6.15	5.353	4.773	5.41	9.79
Inks Lake	13.421	13.386	11.675	13.14	11.625	10.420	12.22	19.4
Lake Amon G. Carter	11.322	11.323	9.706	3.01	9.405	8.281	2.65	5.1
Lake Bob Sandlin	8.959	8.959	7.970	7.28	7.680	6.996	6.63	9.8
Lake Bridgeport	7.247	7.248	6.298	5.28	6.240	5.573	4.99	6.7
Lake Buchanan	8.644	8.622	7.517	8.18	7.485	6.707	7.60	13.8

Reservoir Name	TCEQ Published 99th Percentile (TCEQ 2006a)		TPWD Calculation 99th Percentile using all Historic Data and the TCEQ Pooled Variance Formula	TPWD Calculation 99th Percentile using all Historic Data and Moore and McCabe (1999) Pooled Variance Formula	TPWD Calculation 99th Percentile using 10 Years of Data and Moore and McCabe (1999) Pooled Variance Formula		TPWD Calculation 95th Percentile using all Historic Data and the TCEQ Pooled Variance Formula	TPWD Calculation 95th Percentile using all Historic Data and Moore and McCabe (1999) Pooled Variance Formula		TPWD Calculation 90th Percentile using 10 Years of Data and Moore and McCabe (1999) Pooled Variance Formula		TPWD Calculation of TPWD Criteria
Lake Cisco	3.228		3.228	2.889	2.23		2.835	2.599		2.03		2.66
Lake Corpus Christi	16.794		16.796	14.609	7.98		14.459	12.925		7.29		13.8
Lake Cypress Springs	12.976		12.978	11.524	11.77		11.272	10.261		10.95		18.44
Lake Georgetown	5.008		5.008	4.358	2.46		4.236	3.784		2.23		4.82
Lake Jacksonville	5.205		5.205	4.576	3.02		4.517	4.077		2.75		4.09
Lake Limestone	20.748		20.747	18.521	15.45		18.014	16.472		14.12		17.8
Lake Marble Falls	9.758		9.735	8.555	7.88		8.519	7.688		7.36		13.8
Lake Murvaul	38.100		38.100	33.301	39.80		32.811	29.454		37.38		55.2
Lake Palo Pinto	5.819		5.820	5.060	1.87		4.919	4.391		1.67		14.1
Lake Travis	4.848		4.833	4.154	4.13		4.134	3.655		3.79		6.14
Lake Tyler	9.053		9.054	7.932	7.22		7.826	7.041		6.62		10.7
Medina Lake	4.568		4.568	3.968	1.06		3.918	3.497		0.99		1.77
O.C. Fisher Reservoir	31.796		31.799	27.155	33.59		26.630	23.386		30.28		52.5
Red Bluff Reservoir	23.233		23.235	20.306	19.71		20.085	18.032		17.98		32.6
Stillhouse Hollow Lake	2.141		2.141	1.925	1.15		1.895	1.745		1.05		1.03
Wright Patman Lake	24.697		24.696	21.437	17.83		21.002	18.729		16.07		34.6

Table 2. Comparison of TPWD criteria as calculated by TCEQ and as calculated using the methodology stated in the TPWD proposal.
All values are chlorophyll-a in µg/L.

Reservoir Name	**TCEQ-estimated TPWD criterion (TCEQ 2006a)**	**TPWD Calculation of TPWD Criterion**
	Column 1	Column 2
Amistad Reservoir	4	5
B. A. Steinhagen Reservoir	10.6	12
Caddo Lake	23.4	23
Canyon Lake	4	4.2
Choke Canyon	13.99	14.1
Diversion Lake	15.12	7.1
Farmers Creek Reservoir (Nocona Lake)	7.85	10.2
Houston County Lake	12.3	11.6
Hubbard Creek Reservoir	7.11	9.79
Inks Lake	15.59	19.4
Lake Amon G. Carter	18.40	5.1
Lake Bob Sandlin	8.72	9.8
Lake Bridgeport	7.46	6.7
Lake Buchanan	10.14	13.8
Lake Cisco	4.25	2.66
Lake Corpus Christi	20	13.8
Lake Cypress Springs	12.78	18.44
Lake Georgetown	7	4.82
Lake Jacksonville	6	4.09
Lake Limestone	23.45	17.8
Lake Marble Falls	11	13.8
Lake Murvaul	47.52	55.2
Lake Palo Pinto	7	14.1
Lake Travis	5.3	6.14
Lake Tyler	11	10.7
Medina Lake	5	1.77
O.C. Fisher Reservoir	33.86	52.5
Red Bluff Reservoir	26	32.6
Stillhouse Hollow Lake	2	1.03
Wright Patman Lake	34.88	34.6

Table 3. Comparison of reservoir compliance using TCEQ and TPWD criteria. Upper table analyzes TCEQ criteria as calculated by TPWD using the 99th percentile confidence interval of the mean, all historic data and the Moore and McCabe pooled variance formula (column 3 of Table 1).

Colors are used to show non-compliance: green cells are where both criteria flagged subsets as non-compliant; yellow and tan are where only the TCEQ or TPWD criteria flagged a subset as non-compliant, respectively. Values in the upper and lower table are mean chlorophyll-a (µg/L), and the proportion of points exceeding the TPWD criterion, respectively.

Lake_Name	Subs1	Subs2	Subs3	Subs4	Subs5	Subs6	Subs7	Subs8	Subs9	Subs10	Subs11	Subs12	Subs13	Subs14	TCEQ_Crit
Lake Corpus Christi	7.0	8.0	7.5	12.0	14.6	16.7	16.3	15.4	13.6	7.6					14.61
Medina Lake	3.7	2.8	2.7	10.6	11.8	3.3	4.0	1.8	1.0	0.8	0.8	0.6	0.8		3.97
Stillhouse Hollow Lake	2.1	1.9	2.0	2.0	1.8	1.6	1.6	0.9	0.8	0.8	0.8				1.93
Caddo Lake	10.6	12.1	13.9	15.3	14.1	15.9	19.4	13.4	12.9	13.0	5.4	6.3	8.8		15.64
Wright Patman Lake	10.7	15.0	20.0	27.6	30.0	30.3	30.3	28.9	15.2	13.8	9.2				21.44
Lake Amon G. Carter	8.8	6.6	6.7	6.7	6.3	3.1									9.71
Lake Cisco	2.4	3.0	3.0	3.4	3.3	1.9	1.9	1.9	1.1	1.2					2.89
Lake Jacksonville	3.9	4.1	3.9	3.3	3.4	2.4	1.8	1.8	1.3	1.4	2.0				4.58
Lake Bridgeport	2.8	2.7	1.9	1.5	2.3	4.8	6.0	6.1	6.1	5.3	3.8	4.0	4.0	4.1	6.30
Lake Limestone	15.0	15.5	18.6	16.3	12.8	12.4	8.9								18.52
Diversion Lake	8.7	6.1	8.0	7.9	6.2	4.7	3.8	2.6	2.2	1.6	2.1	4.1			10.32
Lake Georgetown	4.4	3.8	2.6	2.1	2.8	2.8	2.5								4.36
Houston County Lake	7.7	5.3	4.4	5.1	5.4	4.3	3.9	3.1	3.1	3.0	4.7	5.1			10.20
Amistad Reservoir	2.1	2.1	1.8	1.7	1.9	2.3	2.4	2.4	1.6						3.02
B. A. Steinhagen Reservoir	5.9	4.6	5.8	6.2	6.7	5.1	5.1								9.25
Canyon Lake	2.1	4.8	5.8	3.0	2.9	1.9	1.6	1.0	1.1	2.0	2.0	2.3			3.05
Choke Canyon	9.0	9.1	7.2	7.3											12.00
Farmers Creek Reservoir (Nocona Lake)	1.9	3.2	4.4	4.4	3.8	4.5	3.2	3.0	3.1	2.8	3.5	3.7			6.08
Hubbard Creek Reservoir	2.8	2.7	3.6	3.0	2.5	3.0	3.2								5.51
Inks Lake	6.0	5.4	5.5	7.3	6.6	5.6	6.2	6.9	5.8	6.1	10.4	12.8			11.68
Lake Bob Sandlin	6.1	5.0	5.0	4.7	4.5	3.6									7.97
Lake Buchanan	4.6	3.9	4.4	4.5	4.6	4.4	3.7	4.1	5.0	6.5	6.7	5.9	7.2		7.52
Lake Cypress Springs	5.2	7.3	7.4	6.3	6.3	5.9	5.4	6.8	9.2						11.52
Lake Marble Falls	5.5	5.4	6.9	6.0	5.4	4.7	5.7	7.2	6.6	7.2	7.7	7.0			8.56
Lake Murvaul	12.4	16.5	19.0	20.2	31.4	32.4	35.6	33.3	34.8	31.6	29.2	29.1			33.30
Lake Palo Pinto	3.3	3.5	4.0	3.8	2.8	1.9	3.1	2.6							5.06
Lake Travis	3.0	2.4	2.4	2.6	2.5	1.8	1.9	2.9	3.0	2.6	3.1	3.5			4.15
Lake Tyler	4.4	4.9	5.5	6.3	6.4	5.8	4.7	3.6	3.4	4.2	6.2	6.3			7.93
O.C. Fisher Reservoir	10.2	13.3	18.4	16.1	16.2	16.7	7.4	7.5	8.9	8.1	20.7				27.16
Red Bluff Reservoir	15.4	12.3	10.1	12.4	11.8	13.7	13.6	16.7	14.9	12.8	7.5	4.7	10.0		20.31

	Subs1	Subs2	Subs3	Subs4	Subs5	Subs6	Subs7	Subs8	Subs9	Subs10	Subs11	Subs12	Subs13	Subs14	TPWD_Crit
Lake Corpus Christi	0.06	0.06	0.11	0.26	0.41	0.47	0.47	0.45	0.33	0.20					13.8
Medina Lake	1.00	1.00	1.00	1.00	0.92	0.88	0.82	0.42	0.27	0.08	0.08	0.00	0.08		1.77
Stillhouse Hollow Lake	1.00	0.73	0.50	0.50	0.50	0.40	0.40	0.27	0.15	0.09	0.09				1.03
Caddo Lake	0.06	0.12	0.17	0.09	0.10	0.10	0.27	0.27	0.27	0.30	0.07	0.05	0.10		23
Wright Patman Lake	0.06	0.13	0.17	0.20	0.30	0.30	0.30	0.30	0.10	0.08	0.00				34.6
Lake Amon G. Carter	0.42	0.50	0.40	0.40	0.30	0.10									5.1
Lake Cisco	0.14	0.36	0.40	0.40	0.30	0.08	0.09	0.10	0.00	0.10					2.66
Lake Jacksonville	0.39	0.47	0.45	0.50	0.50	0.30	0.17	0.20	0.00	0.00	0.07				4.09
Lake Bridgeport	0.06	0.11	0.08	0.10	0.10	0.23	0.30	0.36	0.35	0.27	0.10	0.11	0.06	0.06	6.7
Lake Limestone	0.40	0.40	0.40	0.30	0.09	0.10	0.00								17.8
Diversion Lake	0.42	0.36	0.50	0.50	0.40	0.25	0.18	0.10	0.09	0.00	0.00	0.09			7.1
Lake Georgetown	0.50	0.40	0.18	0.00	0.08	0.10	0.08								4.82
Houston County Lake	0.26	0.08	0.09	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.08	0.10			11.6
Amistad Reservoir	0.00	0.05	0.03	0.03	0.06	0.06	0.08	0.13	0.10						5
B. A. Steinhagen Reservoir	0.00	0.00	0.08	0.08	0.09	0.07	0.08								12
Canyon Lake	0.00	0.07	0.09	0.09	0.10	0.07	0.08	0.00	0.00	0.10	0.05	0.08			4.2
Choke Canyon	0.14	0.17	0.05	0.07											14.1
Farmers Creek Reservoir (Nocona Lake)	0.00	0.00	0.10	0.10	0.10	0.09	0.00	0.00	0.00	0.00	0.10	0.09			10.2
Hubbard Creek Reservoir	0.00	0.00	0.00	0.00	0.00	0.00	0.00								9.79
Inks Lake	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.03	0.00	0.00	0.04	0.08			19.4
Lake Bob Sandlin	0.00	0.09	0.10	0.09	0.10	0.10									9.8
Lake Buchanan	0.00	0.00	0.00	0.00	0.04	0.03	0.02	0.02	0.03	0.06	0.07	0.08	0.08		13.8
Lake Cypress Springs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11						18.44
Lake Marble Falls	0.00	0.00	0.09	0.07	0.05	0.02	0.06	0.13	0.13	0.11	0.09	0.08			13.8
Lake Murvaul	0.00	0.00	0.00	0.00	0.09	0.10	0.10	0.09	0.15	0.09	0.07	0.08			55.2
Lake Palo Pinto	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00							14.1
Lake Travis	0.08	0.00	0.05	0.05	0.06	0.03	0.02	0.11	0.13	0.07	0.12	0.13			6.14
Lake Tyler	0.05	0.13	0.18	0.20	0.20	0.18	0.08	0.00	0.00	0.08	0.12	0.13			10.7
O.C. Fisher Reservoir	0.00	0.00	0.10	0.10	0.10	0.10	0.00	0.00	0.00	0.00	0.08				52.5
Red Bluff Reservoir	0.00	0.00	0.04	0.12	0.10	0.10	0.09	0.20	0.18	0.18	0.09	0.00	0.00		32.6

Table 4. Comparison of reservoir compliance using TCEQ and TPWD criteria. Upper table analyzes TCEQ criteria as calculated by TPWD using the 99th percentile confidence interval of the mean, 10 years of data and the Moore and McCabe pooled variance formula (column 4 of Table 1).

Colors are used to show non-compliance: green cells are where both criteria flagged subsets as non-compliant; yellow and tan are where only the TCEQ or TPWD criteria flagged a subset as non-compliant, respectively. Values in the upper and lower table are mean chlorophyll-a (µg/L), and the proportion of points exceeding the TPWD criterion, respectively.

Lake_Name	Subs1	Subs2	Subs3	Subs4	Subs5	Subs6	Subs7	Subs8	Subs9	Subs10	Subs11	Subs12	Subs13	Subs14	TCEQ_Crit
Lake Corpus Christi	7.0	8.0	7.5	12.0	14.6	16.7	16.3	15.4	13.6	7.6					7.98
Medina Lake	3.7	2.8	2.7	10.6	11.8	3.3	4.0	1.8	1.0	0.8	0.8	0.6	0.8		1.06
Stillhouse Hollow Lake	2.1	1.9	2.0	2.0	1.8	1.6	1.6	0.9	0.8	0.8	0.8				1.15
Caddo Lake	10.6	12.1	13.9	15.3	14.1	15.9	19.4	13.4	12.9	13.0	5.4	6.3	8.8		13.47
Wright Patman Lake	10.7	15.0	20.0	27.6	30.0	30.3	30.3	28.9	15.2	13.8	9.2				17.83
Lake Amon G. Carter	8.8	6.6	6.7	6.7	6.3	3.1									3.01
Lake Cisco	2.4	3.0	3.0	3.4	3.3	1.9	1.9	1.9	1.1	1.2					2.23
Lake Jacksonville	3.9	4.1	3.9	3.3	3.4	2.4	1.8	1.8	1.3	1.4	2.0				3.02
Lake Bridgeport	2.8	2.7	1.9	1.5	2.3	4.8	6.0	6.1	6.1	5.3	3.8	4.0	4.0	4.1	5.28
Lake Limestone	15.0	15.5	18.6	16.3	12.8	12.4	8.9								15.45
Diversion Lake	8.7	6.1	8.0	7.9	6.2	4.7	3.8	2.6	2.2	1.6	2.1	4.1			7.28
Lake Georgetown	4.4	3.8	2.6	2.1	2.8	2.8	2.5								2.46
Houston County Lake	7.7	5.3	4.4	5.1	5.4	4.3	3.9	3.1	3.1	3.0	4.7	5.1			7.73
Amistad Reservoir	2.1	2.1	1.8	1.7	1.9	2.3	2.4	2.4	1.6						2.87
B. A. Steinhagen Reservoir	5.9	4.6	5.8	6.2	6.7	5.1	5.1								8.54
Canyon Lake	2.1	4.8	5.8	3.0	2.9	1.9	1.6	1.0	1.1	2.0	2.0	2.3			2.57
Choke Canyon	9.0	9.1	7.2	7.3											10.68
Farmers Creek Reservoir (Nocona Lake)	1.9	3.2	4.4	4.4	3.8	4.5	3.2	3.0	3.1	2.8	3.5	3.7			6.09
Hubbard Creek Reservoir	2.8	2.7	3.6	3.0	2.5	3.0	3.2								6.15
Inks Lake	6.0	5.4	5.5	7.3	6.6	5.6	6.2	6.9	5.8	6.1	10.4	12.8			13.14
Lake Bob Sandlin	6.1	5.0	5.0	4.7	4.5	3.6									7.28
Lake Buchanan	4.6	3.9	4.4	4.5	4.6	4.4	3.7	4.1	5.0	6.5	6.7	5.9	7.2		8.18
Lake Cypress Springs	5.2	7.3	7.4	6.3	6.3	5.9	5.4	6.8	9.2						11.77
Lake Marble Falls	5.5	5.4	6.9	6.0	5.4	4.7	5.7	7.2	6.6	7.2	7.7	7.0			7.88
Lake Murvaul	12.4	16.5	19.0	20.2	31.4	32.4	35.6	33.3	34.8	31.6	29.2	29.1			39.80
Lake Palo Pinto	3.3	3.5	4.0	3.8	2.8	1.9	3.1	2.6							1.87
Lake Travis	3.0	2.4	2.4	2.6	2.5	1.8	1.9	2.9	3.0	2.6	3.1	3.5			4.13
Lake Tyler	4.4	4.9	5.5	6.3	6.4	5.8	4.7	3.6	3.4	4.2	6.2	6.3			7.22
O.C. Fisher Reservoir	10.2	13.3	18.4	16.1	16.2	16.7	7.4	7.5	8.9	8.1	20.7				33.59
Red Bluff Reservoir	15.4	12.3	10.1	12.4	11.8	13.7	13.6	16.7	14.9	12.8	7.5	4.7	10.0		19.71

	Subs1	Subs2	Subs3	Subs4	Subs5	Subs6	Subs7	Subs8	Subs9	Subs10	Subs11	Subs12	Subs13	Subs14	TPWD_Crit
Lake Corpus Christi	0.06	0.06	0.11	0.26	0.41	0.47	0.47	0.45	0.33	0.20					13.8
Medina Lake	1.00	1.00	1.00	1.00	0.92	0.88	0.82	0.42	0.27	0.08	0.08	0.00	0.08		1.77
Stillhouse Hollow Lake	1.00	0.73	0.50	0.50	0.50	0.40	0.40	0.27	0.15	0.09	0.09				1.03
Caddo Lake	0.06	0.12	0.17	0.09	0.10	0.10	0.27	0.27	0.27	0.30	0.07	0.05	0.10		23
Wright Patman Lake	0.06	0.13	0.17	0.20	0.30	0.30	0.30	0.30	0.10	0.08	0.00				34.6
Lake Amon G. Carter	0.42	0.50	0.40	0.40	0.30	0.10									5.1
Lake Cisco	0.14	0.36	0.40	0.40	0.30	0.08	0.09	0.10	0.00	0.10					2.66
Lake Jacksonville	0.39	0.47	0.45	0.50	0.50	0.30	0.17	0.20	0.00	0.00	0.07				4.09
Lake Bridgeport	0.06	0.11	0.08	0.10	0.10	0.23	0.30	0.36	0.35	0.27	0.10	0.11	0.06	0.06	6.7
Lake Limestone	0.40	0.40	0.40	0.30	0.09	0.10	0.00								17.8
Diversion Lake	0.42	0.36	0.50	0.50	0.40	0.25	0.18	0.10	0.09	0.00	0.00	0.09			7.1
Lake Georgetown	0.50	0.40	0.18	0.00	0.08	0.10	0.08								4.82
Houston County Lake	0.26	0.08	0.09	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.08	0.10			11.6
Amistad Reservoir	0.00	0.05	0.03	0.03	0.06	0.06	0.08	0.13	0.10						5
B. A. Steinhagen Reservoir	0.00	0.00	0.08	0.08	0.09	0.07	0.08								12
Canyon Lake	0.00	0.07	0.09	0.09	0.10	0.07	0.08	0.00	0.00	0.10	0.05	0.08			4.2
Choke Canyon	0.14	0.17	0.05	0.07											14.1
Farmers Creek Reservoir (Nocona Lake)	0.00	0.00	0.10	0.10	0.10	0.09	0.00	0.00	0.00	0.00	0.10	0.09			10.2
Hubbard Creek Reservoir	0.00	0.00	0.00	0.00	0.00	0.00	0.00								9.79
Inks Lake	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.03	0.00	0.00	0.04	0.08			19.4
Lake Bob Sandlin	0.00	0.09	0.10	0.09	0.10	0.10									9.8
Lake Buchanan	0.00	0.00	0.00	0.00	0.04	0.03	0.02	0.02	0.03	0.06	0.07	0.08	0.08		13.8
Lake Cypress Springs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11						18.44
Lake Marble Falls	0.00	0.00	0.09	0.07	0.05	0.02	0.06	0.13	0.13	0.11	0.09	0.08			13.8
Lake Murvaul	0.00	0.00	0.00	0.00	0.09	0.10	0.10	0.09	0.15	0.09	0.07	0.08			55.2
Lake Palo Pinto	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00							14.1
Lake Travis	0.08	0.00	0.05	0.05	0.06	0.03	0.02	0.11	0.13	0.07	0.12	0.13			6.14
Lake Tyler	0.05	0.13	0.18	0.20	0.20	0.18	0.08	0.00	0.00	0.08	0.12	0.13			10.7
O.C. Fisher Reservoir	0.00	0.00	0.10	0.10	0.10	0.10	0.00	0.00	0.00	0.00	0.08				52.5
Red Bluff Reservoir	0.00	0.00	0.04	0.12	0.10	0.10	0.09	0.20	0.18	0.18	0.09	0.00	0.00		32.6

Table 5. Comparison of reservoir compliance using TCEQ and TPWD criteria. Upper table analyzes TCEQ criteria as calculated by TPWD using the 90th percentile confidence interval of the mean, 10 years of data and the Moore and McCabe pooled variance formula (column 7 of Table 1).

Colors are used to show non-compliance: green cells are where both criteria flagged subsets as non-compliant; yellow and tan are where only the TCEQ or TPWD criteria flagged a subset as non-compliant, respectively. Values in the upper and lower table are mean chlorophyll-a (µg/L), and the proportion of points exceeding the TPWD criterion, respectively.

Lake_Name	Subs1	Subs2	Subs3	Subs4	Subs5	Subs6	Subs7	Subs8	Subs9	Subs10	Subs11	Subs12	Subs13	Subs14	True_Crit
Lake Corpus Christi	7.0	8.0	7.5	12.0	14.6	16.7	16.3	15.4	13.6	7.6					7.29
Medina Lake	3.7	2.8	2.7	10.6	11.8	3.3	4.0	1.8	1.0	0.8	0.8	0.6	0.8		0.99
Stillhouse Hollow Lake	2.1	1.9	2.0	2.0	1.8	1.6	1.6	0.9	0.8	0.8	0.8				1.05
Caddo Lake	10.6	12.1	13.9	15.3	14.1	15.9	19.4	13.4	12.9	13.0	5.4	6.3	8.8		12.12
Wright Patman Lake	10.7	15.0	20.0	27.6	30.0	30.3	30.3	28.9	15.2	13.8	9.2				16.07
Lake Amon G. Carter	8.8	6.6	6.7	6.7	6.3	3.1									2.65
Lake Cisco	2.4	3.0	3.0	3.4	3.3	1.9	1.9	1.9	1.1	1.2					2.03
Lake Jacksonville	3.9	4.1	3.9	3.3	3.4	2.4	1.8	1.8	1.3	1.4	2.0				2.75
Lake Bridgeport	2.8	2.7	1.9	1.5	2.3	4.8	6.0	6.1	6.1	5.3	3.8	4.0	4.0	4.1	4.99
Lake Limestone	15.0	15.5	18.6	16.3	12.8	12.4	8.9								14.12
Diversion Lake	8.7	6.1	8.0	7.9	6.2	4.7	3.8	2.6	2.2	1.6	2.1	4.1			6.40
Lake Georgetown	4.4	3.8	2.6	2.1	2.8	2.8	2.5								2.23
Houston County Lake	7.7	5.3	4.4	5.1	5.4	4.3	3.9	3.1	3.1	3.0	4.7	5.1			7.01
Amistad Reservoir	2.1	2.1	1.8	1.7	1.9	2.3	2.4	2.4	1.6						2.62
B. A. Steinhagen Reservoir	5.9	4.6	5.8	6.2	6.7	5.1	5.1								7.73
Canyon Lake	2.1	4.8	5.8	3.0	2.9	1.9	1.6	1.0	1.1	2.0	2.0	2.3			2.40
Choke Canyon	9.0	9.1	7.2	7.3											10.01
Farmers Creek Reservoir (Nocona Lake)	1.9	3.2	4.4	4.4	3.8	4.5	3.2	3.0	3.1	2.8	3.5	3.7			5.55
Hubbard Creek Reservoir	2.8	2.7	3.6	3.0	2.5	3.0	3.2								5.41
Inks Lake	6.0	5.4	5.5	7.3	6.6	5.6	6.2	6.9	5.8	6.1	10.4	12.8			12.22
Lake Bob Sandlin	6.1	5.0	5.0	4.7	4.5	3.6									6.63
Lake Buchanan	4.6	3.9	4.4	4.5	4.6	4.4	3.7	4.1	5.0	6.5	6.7	5.9	7.2		7.60
Lake Cypress Springs	5.2	7.3	7.4	6.3	6.3	5.9	5.4	6.8	9.2						10.95
Lake Marble Falls	5.5	5.4	6.9	6.0	5.4	4.7	5.7	7.2	6.6	7.2	7.7	7.0			7.36
Lake Murvaul	12.4	16.5	19.0	20.2	31.4	32.4	35.6	33.3	34.8	31.6	29.2	29.1			37.38
Lake Palo Pinto	3.3	3.5	4.0	3.8	2.8	1.9	3.1	2.6							1.67
Lake Travis	3.0	2.4	2.4	2.6	2.5	1.8	1.9	2.9	3.0	2.6	3.1	3.5			3.79
Lake Tyler	4.4	4.9	5.5	6.3	6.4	5.8	4.7	3.6	3.4	4.2	6.2	6.3			6.62
O.C. Fisher Reservoir	10.2	13.3	18.4	16.1	16.2	16.7	7.4	7.5	8.9	8.1	20.7				30.28
Red Bluff Reservoir	15.4	12.3	10.1	12.4	11.8	13.7	13.6	16.7	14.9	12.8	7.5	4.7	10.0		17.98

	Subs1	Subs2	Subs3	Subs4	Subs5	Subs6	Subs7	Subs8	Subs9	Subs10	Subs11	Subs12	Subs13	Subs14	TPWD_Cri
Lake Corpus Christi	0.06	0.06	0.11	0.26	0.41	0.47	0.47	0.45	0.33	0.20					13.8
Medina Lake	1.00	1.00	1.00	1.00	0.92	0.88	0.82	0.42	0.27	0.08	0.08	0.00	0.08		1.77
Stillhouse Hollow Lake	1.00	0.73	0.50	0.50	0.50	0.40	0.40	0.27	0.15	0.09	0.09				1.03
Caddo Lake	0.06	0.12	0.17	0.09	0.10	0.10	0.27	0.27	0.27	0.30	0.07	0.05	0.10		23
Wright Patman Lake	0.06	0.13	0.17	0.20	0.30	0.30	0.30	0.30	0.10	0.08	0.00				34.6
Lake Amon G. Carter	0.42	0.50	0.40	0.40	0.30	0.10									5.1
Lake Cisco	0.14	0.36	0.40	0.40	0.30	0.08	0.09	0.10	0.00	0.10					2.66
Lake Jacksonville	0.39	0.47	0.45	0.50	0.50	0.30	0.17	0.20	0.00	0.00	0.07				4.09
Lake Bridgeport	0.06	0.11	0.08	0.10	0.10	0.23	0.30	0.36	0.35	0.27	0.10	0.11	0.06	0.06	6.7
Lake Limestone	0.40	0.40	0.40	0.30	0.09	0.10	0.00								17.8
Diversion Lake	0.42	0.36	0.50	0.50	0.40	0.25	0.18	0.10	0.09	0.00	0.00	0.09			7.1
Lake Georgetown	0.50	0.40	0.18	0.00	0.08	0.10	0.08								4.82
Houston County Lake	0.26	0.08	0.09	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.08	0.10			11.6
Amistad Reservoir	0.00	0.05	0.03	0.03	0.06	0.06	0.08	0.13	0.10						5
B. A. Steinhagen Reservoir	0.00	0.00	0.08	0.08	0.09	0.07	0.08								12
Canyon Lake	0.00	0.07	0.09	0.09	0.10	0.07	0.08	0.00	0.00	0.10	0.05	0.08			4.2
Choke Canyon	0.14	0.17	0.05	0.07											14.1
Farmers Creek Reservoir (Nocona Lake)	0.00	0.00	0.10	0.10	0.10	0.09	0.00	0.00	0.00	0.00	0.10	0.09			10.2
Hubbard Creek Reservoir	0.00	0.00	0.00	0.00	0.00	0.00	0.00								9.79
Inks Lake	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.03	0.00	0.00	0.04	0.08			19.4
Lake Bob Sandlin	0.00	0.09	0.10	0.09	0.10	0.10									9.8
Lake Buchanan	0.00	0.00	0.00	0.00	0.04	0.03	0.02	0.02	0.03	0.06	0.07	0.08	0.08		13.8
Lake Cypress Springs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11						18.44
Lake Marble Falls	0.00	0.00	0.09	0.07	0.05	0.02	0.06	0.13	0.13	0.11	0.09	0.08			13.8
Lake Murvaul	0.00	0.00	0.00	0.00	0.09	0.10	0.10	0.09	0.15	0.09	0.07	0.08			55.2
Lake Palo Pinto	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00							14.1
Lake Travis	0.08	0.00	0.05	0.05	0.06	0.03	0.02	0.11	0.13	0.07	0.12	0.13			6.14
Lake Tyler	0.05	0.13	0.18	0.20	0.20	0.18	0.08	0.00	0.00	0.08	0.12	0.13			10.7
O.C. Fisher Reservoir	0.00	0.00	0.10	0.10	0.10	0.10	0.00	0.00	0.00	0.00	0.08				52.5
Red Bluff Reservoir	0.00	0.00	0.04	0.12	0.10	0.10	0.09	0.20	0.18	0.18	0.09	0.00	0.00		32.6

Table 6. Comparison of TPWD and TCEQ criteria for assessing reservoirs compliance (Table 4). Reservoirs could be flagged by the TPWD criterion only, by the TCEQ criterion only, by both criteria or by neither criterion. It was assumed that both TPWD and TCEQ criteria used only the last 10 years of data for determining the criteria.

Reservoir Name	Flagged by both or flagged by neither	Flagged by only TCEQ	Flagged by only TPWD
Lake Corpus Christi	X		
Medina Lake	X		
Stillhouse Hollow Lake	X		
Caddo Lake	X		
Wright Patman Lake	X		
Lake Amon G. Carter	X		
Lake Cisco	X		
Lake Jacksonville	X		
Lake Bridgeport	X		
Lake Limestone	X		
Diversion Lake	X		
Lake Georgetown	X		
B. A. Steinhagen Reservoir	X		
Farmers Creek Reservoir (Nocona Lake)	X		
Hubbard Creek Reservoir	X		
Inks Lake	X		
Lake Bob Sandlin	X		
Lake Buchanan	X		
O.C. Fisher Reservoir	X		
Canyon Lake		X	
Lake Palo Pinto		X	
Lake Cypress Springs			X
Lake Marble Falls			X
Lake Murvaul			X
Lake Travis			X
Lake Tyler			X
Red Bluff Reservoir			X
Houston County Lake			X
Amistad Reservoir			X
Choke Canyon			X

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Texas Commission on Environmental Quality, 2006a. "Nutrient Criteria Development in Texas: Handouts," presented at EPA Region 6 Regional Technical Advisory Group meeting at Region 6 headquarters in Dallas, January 18, 2006.

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Glossary

Control Chart – A statistical technique in which a graphical display of data that has been measured through time is used to assure quality control. The chart typically contains lines that represent the value of the quality characteristic corresponding to the in-control state. As long as the points plot within the control limits, the process is assumed to be in control, and no action is necessary. However, points that plot outside of the control limits are interpreted as evidence that the process is out of control, and investigation and corrective action is required to find and eliminate the assignable causes responsible for this behavior.

Confidence Interval – In frequentist statistics, it is the interval between two numbers, such that under repeated measures of the same population, the true population parameter will exist within that interval within a certain specified level of probability.

Coverage – In a confidence-bounds setting, coverage is the measure of how well the theoretical confidence bounds match the true distribution.

Distribution – The frequency of occurrence for values of a variable. Distributions can be constructed to show the observed (i.e., empirical) or the theoretical frequency of occurrence.

Empirical – Based on the actual observed values rather than from a theoretical construct of how the data should look or behave.

Mean – A measure of central tendency, estimated by summing all the observations and dividing the sum by the number of observations present.

Nonparametric – Statistical procedures that make no assumptions about the shape of the frequency distributions of the variables being assessed.

Normal Distribution – A family of distributions commonly used in data analysis. This distribution has a probability density that resembles a bell, and thus is often called the bell curve.

Observation Error – An error arising from imperfections in the method of observing a quantity, whether due to instrumental or to human factors. Most data have some observation error, as our devices for measurement rarely capture the actual value of the metric.

Outlier – An atypical and extreme observation. There are generally two types of outliers. One type of outlier is one for which the observed value is not an accurate representation of the true value. An example of this type of outlier would occur if the chlorophyll-a level was really 4, but the recorded value was 40. This type of outlier occurs because of observational error. The second type of outlier is one for which the observed value is an accurate representation of the true value, but the process which generated that value is different from the process which generated the remainder of the data. An example of this type of outlier would occur if the chlorophyll-a level was really 40, but the reason was because we sampled in the middle of rare bloom phenomenon. This type of outlier occurs because of process error.

Overcoverage – In a confidence-bounds setting, overcoverage occurs when the estimated confidence bounds are wider than they truly are. Overcoverage can occur if observational-error outliers are used during construction of a confidence interval.

Percentile – A given value of the data, above and below which a certain proportion of the data should exist. For example, 90% of the data should fall below the 90^{th} percentile.

Prediction Interval – A prediction interval bears the same relationship to a future observation that a confidence interval bears to an unobservable population parameter.

Process Error – Process error arises from the fact that any model is by definition a simplification of the real system. An example of such a simplification is the assumption that repeated measures over time give replicate measures of a simple and stable system, when in fact, things change.

Retrospective – A study that looks backwards in time. In this case, a study that uses the actual historical data to estimate how well the criteria would have worked, given the real time-series of data that exist.

Sensitivity – One half of a pair of measures, which must be used together, used to gauge how good a test is (the other is specificity). Sensitivity is the proportion of time a method detects a problem when a problem truly exists. In disease testing, a test with good sensitivity detects an individual with a disease when that individual is truly diseased. Declaring everyone "diseased" results in high sensitivity, which is why sensitivity must be used in conjunction with specificity.

Skewness – For a distribution, a measure of symmetry about the average. The theoretical normal distribution has perfect symmetry, with its plane of reflection passing through the average.

Specificity - One half of a pair of measures, which must be used together, used to gauge how good a test is (the other is sensitivity). Specificity is the proportion of time a method detects no problem when no problem truly exists. In disease testing, a test with good specificity suggests an individual is disease-free when that individual truly is disease-free. Declaring everyone "disease-free" results in high specificity, which is why specificity must be used in conjunction with sensitivity.

Tolerance Interval – Tolerance intervals quantify the variation manifest within a process. They bound a region that contains a certain proportion of the total population with a specified probability. Because tolerance intervals are based upon only a sample of the entire population, we cannot be 100% confident that that interval will contain the specified proportion. Thus there are two different proportions associated with the tolerance interval: a degree of confidence, and a percent coverage. For instance, we may be 95% confident that 90% of the population will fall within the range specified by the tolerance interval.

Trimming – One method for dealing with outliers. Data beyond a certain distance from the center of the distribution are deleted.

Undercoverage – In a confidence-bounds setting, undercoverage occurs when the estimated confidence bounds are narrower than they truly are. Undercoverage can occur when one half of the confidence bounds extends into non-observable portions of the data. For example, in many chemical metrics, the lower bound is zero. If a symmetric confidence bound is imposed on that metric, and the lower half extends below zero, then the upper bound will be too short to provide proper coverage of the upper tail.

Winsorize – One method for dealing with outliers. Data beyond a certain distance from the center of the distribution are set at a value equaling a predefined value.

Appendix 1 – Noncompliance Analysis

This appendix details when and why certain subsets of the data would have been deemed noncompliant under the *retrospective* analysis. This analysis considers TCEQ criteria developed using all historic data, the 99^{th} *percentile confidence interval* of the *mean* and the Moore and McCabe formulation of the pooled variance corresponding to column 3 of Table 1. The comparison data are depicted in Table 3. For criteria developed using the TCEQ methodology, a reservoir was deemed noncompliant when the *mean* during the assessment period exceeded the TCEQ criterion. For the criteria developed using the TPWD methodology, a reservoir was deemed noncompliant when more than 10% of the observations during the assessment period exceeded the TPWD criterion. The TPWD criterion was based on the 90^{th} *percentile* of the data in the most recent 10 years of the historic data (Column 8 of Table 3).

Noncompliance Based on TCEQ Criteria

Using calculated TCEQ criteria, the *retrospective* analysis rarely indicated a problem of compliance in the reservoirs. When more than one instance of noncompliance occurred within a reservoir, frequently the multiple occurrences reflected the non-independence of the adjacent data sets.

What follows are detailed examinations of why reservoirs failed the TCEQ criteria:

Caddo Lake (Subsets 6 and 7)

The criterion based on the upper bound of the 99^{th} *confidence interval* of the *mean* for Caddo Lake is 15.64 µg/L. In subset 6, the criterion was exceeded because two values (16.7 and 84.9 µg/L) pulled the *mean* value to 15.9 µg/L. In subset 7, the criterion was exceeded because four values (84.9, 20.4, 33.7 and 26.6 µg/L) pulled the *mean* value to 19.4 µg/L.

Canyon Lake (Subsets 2 and 3)

The criterion based on the upper bound of the 99^{th} *confidence interval* of the *mean* for Canyon Lake is 3.05 µg/L. In both subsets, the criterion was exceeded because a single value of 40 µg/L pulled the *mean* value above 3.05 µg/L.

Inks Lake (Subset 12)

The criterion based on the upper bound of the 99^{th} *confidence interval* of the *mean* for Inks Lake is 11.68 µg/L. In subset 12, the criterion was exceeded because one high value (27 µg/L) and several higher values (15.2, 15.5, 15.6 and 17.0 µg/L) pulled the *mean* value to 12.8 µg/L.

Lake Cisco (Subsets 2 to 5)

The criterion based on the upper bound of the 99^{th} *confidence interval* of the *mean* for Lake Cisco is 2.89 µg/L. In subsets 2 to 5, the criterion was exceeded because values 8.6 and 7.8 µg/L elevated the *mean* values to 3.0 – 3.4 µg/L.

Lake Corpus Christi (Subsets 5 to 8)

The criterion based on the upper bound of the 99^{th} *confidence interval* of the *mean* for Lake Corpus Christi is 14.61 µg/L. In subsets 5 and 6, the criterion was exceeded because values 30, 30 and 60 µg/L elevated the *mean* values to 14.62 and 16.7 µg/L, respectively. In subsets 7 and 8 µg/L, the criterion was exceeded because values 23, 29 and 73 µg/L elevated the *mean* values to 16.3 and 15.4 µg/L, respectively.

Lake Georgetown (Subset 1)

The criterion based on the upper bound of the 99^{th} *confidence interval* of the *mean* for Lake Georgetown is 4.36 µg/L. In subset 1, the criterion was exceeded because three values of 7 µg/L elevated the *mean* value to 4.4 µg/L.

Lake Limestone (Subset 3)

The criterion based on the upper bound of the 99^{th} *confidence interval* of the *mean* for Lake Limestone is 18.52 µg/L. In subset 3, the criterion was exceeded because values of 30.4 and 52.1 µg/L elevated the *mean* value to 18.6 µg/L.

Lake Murvaul (Subsets 7 and 9)

The criterion based on the upper bound of the 99^{th} *confidence interval* of the *mean* for Lake Murvaul is 33.30 µg/L. In subset 7, the criterion was exceeded because three values of 52.8, 82.9, and 46.4 µg/L elevated the *mean* value to 35.6 µg/L. In subset 9, the criterion was exceeded because three values of 82.9, 46.4 and 61.4 µg/L elevated the *mean* value to 34.8 µg/L.

Medina Lake (Subsets 4, 5, and 7)

The criterion based on the upper bound of the 99^{th} *confidence interval* of the *mean* for Medina Lake is 3.97 µg/L. In subsets 4 and 5, the criterion was exceeded because of a single value of 107 µg/L elevated the *mean* value to 10.6 and 11.8 µg/L, respectively. In subset 7, the criterion was exceeded because a single value of 19 µg/L elevated the *mean* value to 4.0 µg/L.

Stillhouse Hollow Lake (Subsets 1, 3, and 4)

The criterion based on the upper bound of the 99th *confidence interval* of the *mean* for Stillhouse Hollow Lake is 1.93 µg/L. In subset 1, the criterion was exceeded because every value exceeded the *criterion*, which elevated the *mean* value to 2.1 µg/L. In subsets 3 and 4, the criterion was exceeded primarily because a single value of 6.2 µg/L elevated the *mean* value to 2.0 µg/L.

Wright Patman Lake (Subsets 4 to 8)

The criterion based on the upper bound of the 99th *confidence interval* of the *mean* for Wright Patman Lake is 21.44 µg/L. In all subsets, the criterion was exceeded because two values of 50.9 and 96.4 µg/L elevated the *mean* values above 21.44 µg/L. In subsets 6 to 8, the addition of measures at 52.2 and 34.6 µg/L increased the problem.

Noncompliance Based on TPWD Criteria

Using calculated TPWD criteria, the *retrospective* analysis frequently indicated a problem of compliance in the reservoirs. When more than one instance of noncompliance occurred within a reservoir, frequently the multiple occurrences reflected the non-independence of the adjacent data sets.

What follows are detailed examinations of why reservoirs failed the TPWD criteria:

Amistad Reservoir (Subset 8)

The 90th *percentile* for Amistad Reservoir is 5 µg/L. In subset 8, the criterion was exceeded because two values (7 and 9 µg/L) out of 15 exceeded the 90th *percentile* (i.e., noncompliance rate of 13%).

Caddo Lake (Subsets 2, 3, 7-10)

The 90th *percentile* for Caddo Lake is 23 µg/L. In subsets 2 and 3, the criterion was exceeded because two values (75 and 30 µg/L) out of 17 and 12, respectively, exceeded the 90th *percentile* (i.e., noncompliance rates of 12% and 17%). In subset 7, the criterion was exceeded because three values (84.9, 33.7 and 26.6 µg/L) out of 11 exceeded the 90th *percentile* (i.e., noncompliance rate of 27%). In subsets 8, 9, and 10, the criterion was exceeded because three values (33.7, 26.6, and 35.5 µg/L) out of 11, 11, and 10, respectively, exceeded the 90th *percentile* (i.e., noncompliance rates of 27%, 27%, and 30%, respectively).

Choke Canyon (Subsets 1 and 2)

The 90th *percentile* for Choke Canyon is 14.1 µg/L. In subsets 1 and 2, the criterion was exceeded because two values (19 and 16.7 µg/L) out of 14 and three values (19, 16.7, and 17.4

µg/L) out of 18, respectively, exceeded the 90th *percentile* (i.e., noncompliance rates of 14% and 17%).

Diversion Lake (Subsets 1 to 7)

The 90th *percentile* for Diversion Lake is 7.1 µg/L. In subset 1, the criterion was exceeded because five values (40, 9, 9, 9, and 10 µg/L) out of 12, exceeded the 90th *percentile* (i.e., noncompliance rate of 42%). In subset 2, the criterion was exceeded because four values (9, 10, 17.6, and 10.3 µg/L) out of 11, exceeded the 90th *percentile* (i.e., noncompliance rate of 36%). In subsets 3 and 4, the criterion was exceeded because five values (17.6, 10.3, 13.8, 16.0, and 8.6 µg/L) out of 10, exceeded the 90th *percentile* (i.e., noncompliance rates of 50%). In subsets 5, 6, and 7, the criterion was exceeded because subsets of these five values (17.6, 10.3, 13.8, 16.0, and 8.6 µg/L) recurred, and sample sizes were from 10 to 12 (i.e., noncompliance rates of 40%, 25%, and 18%, respectively).

Houston County Lake (Subset 1)

The 90th *percentile* for Houston County Lake is 11.6 µg/L. In subset 1, the criterion was exceeded because five values (21, 15, 15, 21 and 12 µg/L) out of 19, exceeded the 90th *percentile* (i.e., noncompliance rate of 26%).

Lake Amon G. Carter (Subsets 1 to 5)

The 90th *percentile* for Lake Amon G. Carter is 5.1 µg/L. In subset 1, the criterion was exceeded because eight values (56, 7, 6, 11, 19, 29, 7, and 7 µg/L) out of 19, exceeded the 90th *percentile* (i.e., noncompliance rate of 42%). In subset 2, the criterion was exceeded because five values (7, 7, 5.4, 20, and 13 µg/L) out of 10, exceeded the 90th *percentile* (i.e., noncompliance rate of 50%). In subsets 3, 4, and 5, the criterion was exceeded because at least three of the following four values (5.4, 20, 13, and 12.5 µg/L) out of 10, exceeded the 90th *percentile* (i.e., noncompliance rates of 40%, 40%, and 30%, respectively).

Lake Bridgeport (Subsets 2, 6 to 10, and 12)

The 90th *percentile* for Lake Bridgeport is 6.7 µg/L. In subset 2, the criterion was exceeded because two values (7 and 9 µg/L) out of 18, exceeded the 90th *percentile* (i.e., noncompliance rate of 11%). In subsets 6, 7, 8, and 9, the criterion was exceeded because at least three of the following seven values (9.0, 17.2, 10.2, 14.6, 7.7, 8.5, and 7.3 µg/L) out of 13, 10, 14, and 17 values respectively, exceeded the 90th *percentile* (i.e., noncompliance rates of 23%, 30%, 36%, and 35%, respectively). In subset 10, the criterion was exceeded because six values (17.2, 10.2, 14.6, 7.7, 8.5, and 7.3 µg/L) out of 22, exceeded the 90th *percentile* (i.e., noncompliance rate of 27%). In subset 12, the criterion was exceeded because two values (8.5 and 7.1 µg/L) out of 19, exceeded the 90th *percentile* (i.e., noncompliance rate of 11%).

Lake Cisco (Subsets 1 to 5)

The 90th *percentile* for Lake Cisco is 2.66 µg/L. In subset 1, the criterion was exceeded because two values (5 and 4 µg/L) out of 14, exceeded the 90th *percentile* (i.e., noncompliance rate of 14%). In subsets 2 and 3, the criterion was exceeded because three values (4, 3.4, and 8.6 µg/L) out of 11, and 10 values respectively, exceeded the 90th *percentile* (i.e., noncompliance rates of 36% and 40%). In subsets 4 and 5, the criterion was exceeded because at least three of the following four values (3.0, 3.4, 8.6, and 7.8 µg/L) out of 10, exceeded the 90th *percentile* (i.e., Noncompliance rates of 40% and 30%).

Lake Corpus Christi (Subsets 3 to 10)

The 90th *percentile* for Lake Corpus Christi is 13.8 µg/L. In subset 3, the criterion was exceeded because two values (20 and 20 µg/L) out of 19, exceeded the 90th *percentile* (i.e., noncompliance rate of 11%). In subsets 4, 5, and 6, the criterion was exceeded because at least five of the following nine values (20, 60, 30, 30, 14, 20, 20, 20, and 15 µg/L) out of 19, 17, and 17, respectively, exceeded the 90th *percentile* (i.e., noncompliance rates of 26%, 41% and 47%, respectively). In subsets 7, 8, and 9, the criterion was exceeded because at least five of the following ten values (20, 15, 18, 29, 18, 73, 15.7, 23, 17.3, and 20.9 µg/L) out of 17, 20, and 15, respectively, exceeded the 90th *percentile* (i.e., noncompliance rates of 47%, 45%, and 33%, respectively). In subset 10, the criterion was exceeded because two values (17.3 and 20.9 µg/L) out of 10, exceeded the 90th *percentile* (i.e., noncompliance rate of 20%).

Lake Cypress Springs (Subset 9)

The 90th *percentile* for Lake Cypress Springs is 18.44 µg/L. In subset 9, the criterion was exceeded because two values (18.7 and 30.6 µg/L) out of 18, exceeded the 90th *percentile* (i.e., noncompliance rate of 11%). (It should be noted that these two values are the highest in the history of this reservoir, and both occurred in 2002. The average value excluding these values is near 7 µg/L.)

Lake Georgetown (Subsets 1 to 3)

The 90th *percentile* for Lake Georgetown is 4.82 µg/L. In subsets 1 and 2, the criterion was exceeded because at least four of the following five values (7, 5, 5, 7, 7 µg/L) out of 10, exceeded the 90th *percentile* (i.e., noncompliance rates of 50% and 40%). In subset 3, the criterion was exceeded because two values (7 and 7 µg/L) out of 11 exceeded the 90th *percentile* (i.e., noncompliance rate of 18%).

Lake Jacksonville (Subsets 1 to 8)

The 90th *percentile* for Lake Jacksonville is 4.09 µg/L. In subset 1, the criterion was exceeded because nine values (6, 11, 6, 7, 6, 7, 6, 6, and 6 µg/L) out of 23, exceeded the 90th *percentile* (i.e., noncompliance rate of 39%). In subsets 2 and 3, the criterion was exceeded because at least five of the following eight values (7, 6, 7, 6, 6, 6, 5 and 5 µg/L) out of 17 and 11, respectively, exceeded the 90th *percentile* (i.e., noncompliance rates of 47% and 45%). In subset 4, the criterion was exceeded because five values (5, 4.3, 4.1, 5.9, and 5.5 µg/L) out of 10 exceeded the 90th *percentile* (i.e., noncompliance rate of 50%). In subsets 5 and 6, the criterion was exceeded because at least three values of the following five values (4.3, 4.1, 5.9, 5.5, and 6 µg/L) out of 10, exceeded the 90th *percentile* (i.e., noncompliance rates of 50% and 30%). In subsets 7 and 8, the criterion was exceeded because two values (5.5, and 6 µg/L) out of 12 and10, respectively, exceeded the 90th *percentile* (i.e., noncompliance rates of 17% and 20%).

Lake Limestone (Subsets 1 to 4)

The 90th *percentile* for Lake Limestone is 17.8 µg/L. In subsets 1 and 2, the criterion was exceeded because four values (23.3, 30.4, 19.9 and 23.6 µg/L) out of 10 exceeded the 90th *percentile* (i.e., noncompliance rates of 40%). In subsets 3 and 4, the criterion was exceeded because at least three of the following four values (30.4, 19.9, 23.6, and 52.1 µg/L) out of 10 exceeded the 90th *percentile* (i.e., noncompliance rates of 30-40%).

Lake Marble Falls (Subsets 8 to 10)

The 90th *percentile* for Lake Marble Falls is 13.8 µg/L. In subsets 8 and 9, the criterion was exceeded because four of the following five values (19, 17, 31.3, 19.2, and 15.8 µg/L) out of 32 and 30, respectively, exceeded the 90th *percentile* (i.e., noncompliance rates of 13%). In subset 10, the criterion was exceeded because three values (15.8, 42.3, and 34.5 µg/L) out of 27 exceeded the 90th *percentile* (i.e., noncompliance rate of 11%).

Lake Murvaul (Subset 9)

The 90th *percentile* for Lake Murvaul is 55.2 µg/L. In subset 9, the criterion was exceeded because two values (82.9 and 61.4 µg/L) out of 13 exceeded the 90th *percentile* (i.e., noncompliance rate of 15%).

Lake Travis (Subsets 8-9 and 11-12)

The 90th *percentile* for Lake Travis is 6.14 µg/L. In subsets 8 and 9, the criterion was exceeded because four values (14, 8.9, 7.2, and 8.3 µg/L) out of 35 and 31, respectively, exceeded the 90th *percentile* (i.e., noncompliance rates of 11% and 13%). In subsets 11 and 12, the criterion was exceeded because three of the following four values (6.3, 18.2, 12, and 11.4 µg/L) out of 25 and 24, respectively, exceeded the 90th *percentile* (i.e., noncompliance rates of 12% and 13%).

Lake Tyler (Subsets 2-6 and 11-12)

The 90th *percentile* for Lake Tyler is 10.7 µg/L. In subsets 2 and 3, the criterion was exceeded because two values (13 and 13 µg/L) out of 16 and 11, respectively, exceeded the 90th *percentile* (i.e., noncompliance rates of 13% and18%). In subsets 4, 5, and 6, the criterion was exceeded because two values (11.7 and 11.8 µg/L) out of 10, 10, and 11, respectively, exceeded the 90th *percentile* (i.e., noncompliance rates of 20%, 20%, and 18%).

Medina Lake (Subsets 1 to 9)

The 90th *percentile* for Medina Lake is 1.77 µg/L. In subsets 1 to 4, the criterion was exceeded because all values (range was 2 to 107 µg/L) exceeded the 90th *percentile* (i.e., noncompliance rates of 100%). In subsets 5, 6, and 7, the criterion was exceeded because only one or two values (1.5 and 0.5 µg/L) out of 13, 16, and 11, respectively, did **not** exceed the 90th *percentile* (i.e., noncompliance rates of 92%, 88%, and 82%). In subsets 8 and 9, the criterion was exceeded because at least three of the following five values (2, 9, 2, 2, and 2.8 µg/L) out of 12 and 11, respectively, exceeded the 90th *percentile* (i.e., noncompliance rates of 42% and 27%).

Red Bluff Reservoir (Subsets 4 and 8-10)

The 90th *percentile* for Red Bluff Reservoir is 32.6 µg/L. In subset 4, the criterion was exceeded because two values (34 and 37 µg/L) out of 17 exceeded the 90th *percentile* (i.e., noncompliance rate of 12%). In subsets 8, 9, and 10, the criterion was exceeded because two values (33.8 and 39.3 µg/L) out of 10, 11, and 11, respectively, exceeded the 90th *percentile* (i.e., noncompliance rates of 20%, 18%, and 18%).

Stillhouse Hollow Lake (Subsets 1 to 9)

The 90th *percentile* for Stillhouse Hollow Lake is 1.03 µg/L. In subset 1, the criterion was exceeded because **all** 16 values exceeded the 90th *percentile* (i.e., noncompliance rate of 100%). In subset 2, the criterion was exceeded because only 3 of 11 values did **not** exceed the 90th *percentile* (i.e., noncompliance rate of 73%). In subsets 3 to 5, the criterion was exceeded because five of the following seven values (2, 2, 4.3, 1.4, 6.2, 1.8, and 1.7 µg/L) out of 10 exceeded the 90th *percentile* (i.e., noncompliance rates of 50%). In subsets 6 and 7, the criterion was exceeded because four values (6.2, 1.8, 1.7, and 2.36 µg/L) out of 10 exceeded the 90th *percentile* (i.e., noncompliance rates of 40%). In subsets 8 and 9, the criterion was exceeded because at least two of the following 3 values (1.8, 1.7, and 2.36 µg/L) out of 11 and 13, respectively, exceeded the 90th *percentile* (i.e., noncompliance rates of 27% and 15%).

Wright Patman Lake (Subsets 2 to 8)

The 90th *percentile* for Wright Patman Lake is 34.6 µg/L. In subset 2 and 3, the criterion was exceeded because two values (36 and 35 µg/L) out of 16 and 12, respectively, exceeded the 90th *percentile* (i.e., noncompliance rates of 13% and 17%). In subsets 4 to 8, the criterion was exceeded because at least two of the following three values (50.9, 96.4, and 52.2 µg/L) out of 10 exceeded the 90th *percentile* (i.e., noncompliance rates of 20% and 30%).

Appendix 2 – TPWD Nutrient Criteria Proposal – June 2004

A Proposed Approach for Establishing Reservoir Nutrient Criteria for Texas

June 30, 2004

Texas Parks and Wildlife Department

4200 Smith School Road

Austin, TX 78744

Background

The Environmental Protection Agency (EPA) has tasked the states with developing numeric criteria for nutrients in surface water by December 2004. The Texas Commission on Environmental Quality (TCEQ) is the agency in Texas charged with carrying out the requirements of the Clean Water Act, such as setting water quality standards, assessing state waters, and issuing permits. Currently, the state has only a narrative standard for nutrients, at 30 TAC 307.4(e), which states that *"Nutrients from permitted discharges or other controllable sources shall not cause excessive growth of aquatic vegetation which impairs an existing, attainable, or designated use."* Based on EPA's direction, TCEQ will ultimately need to establish numeric criteria for nutrients for all state waters – rivers, streams, reservoirs, and estuaries. For now, TCEQ is approaching this task in stages, beginning with reservoirs.

Development of nutrient criteria is an area of critical importance to the Texas Parks and Wildlife Department (TPWD) because the department is responsible for conserving aquatic systems. TPWD's Resource Protection Division has historically worked closely with TCEQ biologists in developing and evaluating the scientific research used in establishing water quality standards. TPWD's Inland Fisheries Division is responsible for managing the state's diverse freshwater fisheries resources, which includes approximately 800 public impoundments covering 1.7 million acres and 80,000 miles of rivers and streams. TPWD's State Parks Division oversees more than 600,000 acres of land owned or leased by the department, including 123 state parks, historic sites and natural areas, many of which provide a venue for swimming, boating and other outdoor recreational opportunities, as well as operating public water supply systems and/or wastewater treatment systems.

Because the development of numeric criteria for nutrients can impact the mission of TPWD, the department has actively participated in TCEQ's Nutrient Criteria Development Advisory Work Group. Over the course of the past year, TCEQ and other entities have made various proposals and suggestions regarding the development of nutrient criteria. TPWD followed these discussions with an initial response, provided to TCEQ in a letter dated February 9, 2004. Within that letter, it was recommended that the anti-degradation intent of the Clean Water Act be specifically considered. TPWD noted that it could manage Texas reservoirs for multiple uses under a diversity of nutrient levels; however, it could not work effectively with a hypereutrophic situation. Thus, it is desirable to avoid a process that leads to a decline in water quality. The material that follows is TPWD's further contribution to the state's efforts to develop numeric nutrient criteria for reservoirs. Specifically, it demonstrates how an anti-degradation approach could be implemented.

To address the anti-degradation intent of the Clean Water Act, TPWD proposes a no-degradation policy. This policy refers to the prevention of degradation in water quality from additional nutrients. Thus, under this policy, water quality could not be degraded from current levels, although short-term variations in water quality could be allowed.

Current nutrient levels are not limiting TPWD's ability to manage most Texas reservoirs from a fisheries perspective. In a recent survey of TPWD Inland Fisheries biologists, very few of the 251 reservoirs larger than 100 acres were considered to suffer from excessive nutrient levels (i.e., decreasing nutrient levels would improve the fishery or the ability to manage it). However, at this time, TPWD biologists believe that there are numerous reservoirs that are borderline hypereutrophic. Thus, TPWD believes it is an appropriate time to implement a no-degradation policy. Such an approach would not only prevent further nutrient enrichment of Texas reservoirs, but would also allow numeric criteria to be developed that fully reflect localized conditions and would protect current uses, thus meeting EPA's recommendations for establishing numeric standards. This approach could also be practical and cost efficient, as it works within current regulatory guidance established by TCEQ.

Relevant Guidance and Constraints

Because TCEQ is only developing numeric nutrient criteria for the most downstream portions of reservoirs, coves and embayments were not considered in this approach. At some later date, TCEQ will develop criteria for rivers and streams, estuaries, wetlands and, presumably, coves and embayments in reservoirs. Constraints relevant to implementation of the approach follow.

Monitoring

- Data must be collected under an approved Quality Assurance Project Plan or be of demonstrable, comparable quality.
- Sampling must be representative, covering at least two seasons and spanning at least two years.
- Sampling frequency varies. Monthly or quarterly monitoring is typical, but available resources (staff and funds for laboratory analyses) may limit monitoring frequency.

Assessment

- Assessments are conducted every two years using the last five years of data.
- Surface measurements, typically collected at a depth of approximately 1 foot below the water surface, are generally used to assess nutrients and chlorophyll-a.
- A monitoring site may not represent more than 5,120 acres of a water body.
- Data are assessed using binomial statistics (i.e., pass/fail) and at least 10 samples are required for assessment. If < 10 samples are available, then a water body may be placed on a concerns list, but will not be placed on the state's list of impaired waters. A water body fully supports its use if ≤ 10% of samples exceed the criteria. A water body partially supports its use if > 10 and ≤ 25% of samples exceed criteria, and is nonsupporting if > 25% of samples exceed criteria.

In a situation without these constraints, or with a different set of constraints, it is likely that TPWD would develop different recommendations.

Proposed Approach

A no-degradation policy would require the establishment of baseline, reservoir-specific criteria for nutrient parameters. All future assessments would involve comparisons using these values. Because these criteria will be the basis for future decisions, selected nutrient parameters must reflect nutrient levels within the reservoir and incorporate temporal variability. Monitored variables should include both nitrogen and phosphorus because nutrient-related problems could arise from either. In addition, measurement of chlorophyll-a is recommended. The use of both causal and response variables reflects EPA's stance that "Nitrogen and phosphorus are the primary causes of overenrichment and are obvious nutrient criteria variables, but biological response variables are also important in addressing the consequences of overenrichment" (EPA 2000). Specifically, it is recommended that orthophosphorus, nitrate-nitrite and chlorophyll-a be measured. The use of orthophosphorus is proposed, rather than total phosphorus, because orthophosphorus more accurately accounts for phosphorus directly used by algae (Lee and Jones-Lee 2002). Using the TCEQ 2002 Draft Water Quality Inventory Summary of Water Bodies with Water Quality Concerns, it was noted that the majority (79%) of the reservoirs with nitrogen-related issues were impaired because of nitrate-nitrite, hence the nitrate-nitrite recommendation.

The central premise of a no-degradation approach is that current nutrient levels are not limiting TPWD's ability to manage fisheries in most Texas reservoirs. The goal of the approach is to have the mean values of future measurements of ortho-phosphorus, nitrate-nitrite and chlorophyll-a be the same as or better than the mean values of past data, for each non-degraded reservoir. To accomplish this, one could set the criteria as the means of the appropriate data. However, given that TCEQ has allowed up to 10% of values to exceed criteria in the assessment process, it is more appropriate to use 90th percentile values as the criteria. Setting the criteria at the 90th percentile and using the assessment process described below will ensure that the current mean values are protected. It is appropriate to use an empirical, rather than a theoretical, 90th percentile value, because use of the empirical 90th percentile value does not require one to assume a distributional form for the data. Reservoir-specific criteria for each of these three parameters should be established by calculating empirical 90th percentile values based on the last ten years of data (1994-2003) for non-degraded reservoirs (Appendix 1).

To determine if increased nutrient inputs have degraded water quality, reservoir assessments should occur every two years. At the time of the assessment, values for orthophosphorus, nitrate-nitrite, and chlorophyll-a would be evaluated using the last five years of data compared to the criteria described above. For data sets having TCEQ's required number of sampling events, orthophosphorus, nitrate-nitrite, and chlorophyll-a would be assessed individually, as independent criteria. If $\leq$ 10% of samples exceed the criterion for each variable, the reservoir will be considered as fully compliant with numeric nutrient standards. However, if > 10 and $\leq$ 25% of samples exceed the criterion for any variable, the reservoir will be considered in partial compliance with numeric nutrient standards, and placed on the list of water bodies with concerns for use attainment. If > 25% of samples exceed the criterion for any of the three variables, the reservoir will be considered as noncompliant with numeric nutrient standards, and will be included on the 303(d) list. Once a reservoir is considered partially compliant or noncompliant, removal from either the concerns or 303(d) list would require ≤ 10% of the samples to exceed the criterion for each variable during an assessment.

TPWD has listed a limited number of degraded reservoirs (Appendix 2) identified by TCEQ in the 2002 and 2004 Draft Water Quality Inventory Summaries of Water Bodies with Water Quality Concerns that had elevated orthophosphorus, nitrate-nitrite, or chlorophyll-a concentrations throughout the entire reservoir or at the sampling site nearest the dam. For these reservoirs, determination of criteria for orthophosphorus, nitrate-nitrite, and chlorophyll-a should be guided by, in order of preference, a) calculating historic values based on the lowest nutrient values for five consecutive years of data since 1978, b) calculating values from similar (in terms of geography, size, function, etc.), non-degraded reservoirs, or c) using the 2002 TCEQ 85th percentile screening levels, which are 50 μg/L for orthophosphorus, 320 μg/L for nitrate-nitrite, and 21.4 μg/L for chlorophyll-a. Region-specific criteria may be calculated in lieu of these statewide values. For examples of establishing criteria for degraded reservoirs, see Appendix 1. After criteria are established, the reservoir would be considered degraded until ≤ 10% of the samples exceed the criterion for each variable.

Discussion

The no-degradation policy described represents a logical approach for several reasons, including:

- it maintains current water quality and prevents further degradation of reservoirs from nutrients.
- it protects current reservoir uses from being negatively impacted by nutrient enrichment.
- numeric criteria reflect localized conditions.
- it is relatively simple to implement.
- it can be accomplished within current regulatory guidance established by TCEQ.

Utilization of orthophosphorus, nitrate-nitrite, and chlorophyll-a measurements at a sampling site near the dam serves several goals, including:

- Selection of these three variables addresses many of the major causes for degraded water quality. Certainly other parameters could also be examined, but these cover the most significant without creating additional demands on time and budgets.
- TCEQ, river authorities, United States Geological Survey, and other monitoring agencies already measure these parameters. No new types of tests would be required. Parameters with little or no major importance to nutrients are not included.

- Measurement of these three variables at the dam can be indicative of the quality of the water being discharged downstream for reservoirs with spillways or other "top-release" mechanisms.

Unfortunately, the proposed approach has some limitations, including the following:

- Dealing with a single, standardized location (i.e., at the dam) in a reservoir for monitoring and assessment purposes is best from a simplicity and standardization standpoint. However, a single sampling location at the dam limits the ability to assess changes in nutrient input from upstream that may negatively impact the reservoir. Thus, nutrients may cause problems within specific embayments, yet not reduce water quality at the dam site. In addition, nitrogen and phosphorus can be reduced by passage through a reservoir (caused by a variety of mechanisms) and there may be a time lag in detection of increased nutrient inputs because of dilution. Although these problems may somewhat limit the ability of the proposed approach to identify nutrient problems in the short-term, we suggest that future development of nutrient criteria by the TCEQ for rivers and streams, estuaries, wetlands, and coves and embayments in reservoirs should incorporate temporal and spatial variability and allow sources of nutrient inputs to be better identified.
- Surface sampling ignores any effects of reservoir stratification.
- Identification of degraded reservoirs may be affected because of limited data. Using the 2002 and 2004 TCEQ Inventory Summaries of Water Bodies with Water Quality Concerns lists to establish the initial list of degraded reservoirs limits the list to those reservoirs for which there are sufficient data to perform an assessment.
- Limiting monitoring to nitrogen, phosphorus and chlorophyll-a may miss impairment from:

    a. excessive benthic algae - in some cases, benthic algae (periphyton) may cover the substrate and other structures so extensively that major ecological problems occur, yet nutrient and chlorophyll-a levels in the water column above show no excess (reflecting excessive nutrients tied up in the benthic algae).
    b. excessive macrophytes - dense beds of rooted or floating macrophytes can tie up nutrients within a reservoir resulting in clear waters with reduced nitrogen, phosphorus, and chlorophyll-a levels in the water column, again masking the presence of excessive nutrients. Aquatic vegetation provides important fish habitat and may result in improved water clarity; however, non-native, invasive or excessive aquatic vegetation may cause fisheries management and recreation problems.
    c. blue-green algae - using chlorophyll-a as the only measure of phytoplankton biomass may not address situations where blue-green and other non-green planktonic algae dominate the plankton community. Chlorophyll-a levels may be very low, but plankton densities supported by excessive nutrients may be high enough to degrade water quality and threaten ecosystem stability.

High densities of algae or macrophytes supported by excessive nutrients often result in exaggerated diurnal dissolved oxygen (D.O.) variability. Under such conditions, D.O. levels often drop below those lethal to fishes, resulting in fish kills.

The limitations discussed above may be demonstrated by considering some reservoirs that TPWD Inland Fisheries biologists have identified as degraded that are not captured in the 2002 and 2004 TCEQ Inventory Summaries of Water Bodies with Water Quality Concerns lists:

- Lake LBJ (Segment 1406) has been identified by TPWD biologists as having excessive filamentous algae. While Lake LBJ is screened routinely for nutrient parameters, this approach fails to identify nutrient impacts due to benthic algae.
- TPWD biologists have identified several reservoirs as degraded by nutrients, where insufficient or no data exist to perform an assessment. These include:
    - Lake Wichita (Segment 0219) has heavy algal blooms. The most recent TCEQ assessment shows no data for this water body.
    - Rita Blanca Lake (Segment 0105) is known to have extremely high nutrient levels. However, the most recent TCEQ assessment shows that there are insufficient data to assess the water body.
    - Mitchell Lake (in the drainage of Segment 1903) has been identified by the San Antonio River Authority and TPWD as a water body that has been impacted by nutrients. It may have been part of a sewage treatment plant at one time. The most recent TCEQ assessment shows no data for this water body.

- Bowie City Lake (in the drainage of Segment 0204) is impacted by macrophytes and algae. Relying solely on criteria for nitrate-nitrite nitrogen, orthophosphorus and chlorophyll-a may lead to missing impacts resulting from macrophytes. In addition, the most recent TCEQ assessment shows no data for this water body.

Summary

The proposed approach for establishment of reservoir nutrient criteria in Texas supports a no-degradation policy. If adopted, it would provide for reservoir-specific protection from nutrient overloading of public waters, thus assuring continued quality water-based habitat and recreation for future generations.

References

Lee, G. F., and A. Jones-Lee. 2002. Developing nutrient criteria/TMDLs to manage excessive fertilization of waterbodies. Proceedings of the Water Environmental Federation, TMDL 2002 Conference, Phoenix, AZ.

EPA (U. S. Environmental Protection Agency). 2000. Nutrient criteria technical guidance manual: lakes and reservoirs. 1st edition, EPA-822-B00-001.

Appendix 1. Examples Showing Establishment of Reservoir Nutrient Criteria

Note: Although it is recognized that most nutrient data are collected monthly or quarterly, data presented in Figures 1-4 have been condensed, for illustrative purposes, into fewer points per annum and, again for illustrative purposes, only chlorophyll-a is shown. Data are hypothetical, though based on actual reservoir values.

Non-degraded reservoirs (maintain current conditions)

When historic data are available and these suggest a non-degraded state, it is recommended that data from the reservoir be used to establish its criteria. Use the empirical 90^{th} percentile of the data from 1994 through 2003 to calculate criteria to maintain the current condition. (Reservoir A1, Figure 1).

Degraded reservoirs

A limited number of reservoirs that are currently considered degraded by nutrients have been identified. Because a reservoir is degraded, use of data from 1994 through 2003 would establish inappropriate criteria. For these degraded reservoirs, calculation of criteria should be guided by the following three options, in order of preference:

a. Use Five Consecutive Years of Historical Records with the Lowest Nutrient Values

Some reservoirs that are currently degraded will have extensive historical data sets depicting adequate water quality in the past (Reservoir A2, Figure 2). To establish criteria, it is recommended that data from those five consecutive years with the lowest nutrient values since 1978 be used, in this example, data from 1981 through 1986. The criterion is calculated as the empirical 90^{th} percentile of the data from 1981 through 1986.
In some instances, the historic record will be too short or all the data will have been collected during the time the reservoir has been degraded. Two potential approaches to setting the criteria under these data-limiting situations follow.

b. Use Similar Reservoirs

Although data may be limited for the degraded reservoir, it may be possible to locate sufficient data for non-degraded reservoirs within close geographic proximity. Selection of reservoirs for comparison should be based on expert opinion, and include consideration of such factors as ecoregion, drainage area, and hydrology. The water quality data from these reservoirs could be used to provide criteria for the degraded reservoir. In this example, data from a degraded reservoir (Reservoir A3) for ten years is presented (Figure 3). However, the data suggest the use of the ten years with the lowest nutrient levels would set criteria that are influenced by a period when the reservoir was becoming degraded. Data collected from four non-degraded reservoirs in close geographic proximity suggest that the regional average chlorophyll-a level between 1993 and 2003 was about 4.5 µg/L. The recommended criterion for Reservoir A3 is 7.2 ug/l, the empirical 90th percentile of the monthly/quarterly 1993-2003 data from the non-degraded reservoirs.

c. Use TCEQ 2002 Screening Levels

In this example, data from a degraded reservoir (Reservoir A4) is presented for twenty-six years (Figure 4). However, the data suggest that the reservoir was hypereutrophic during the entire period since 1978. As such it is inappropriate to calculate a criteria using any period of data. Further, insufficient data exist from surrounding reservoirs to allow a geographic comparison. Under such a scenario, it is recommended that the TCEQ 2002 85th percentile screening levels be used to establish criteria. These values are 50 µg/L for orthophosphorus, 320 µg/L for nitrate-nitrite, and 21.4 µg/L for chlorophyll-a.

Figure 1. To establish the criterion to maintain the current status of Reservoir A 1, the empirical 90th percentile of the monthly/quarterly data from 1994 through 2003 was used.

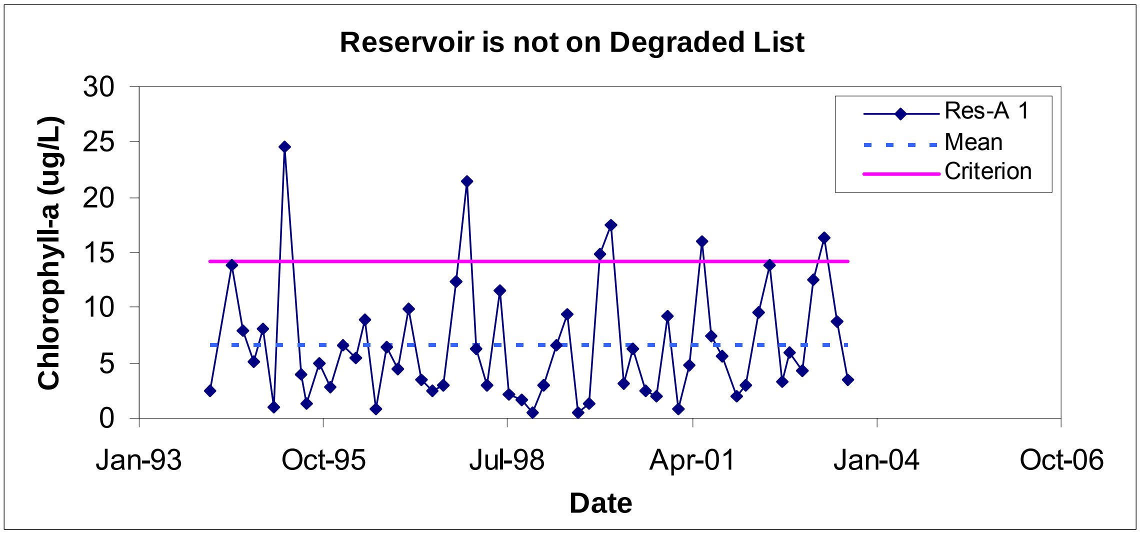


Figure 2. To establish the criterion for a degraded reservoir with historic data (Res-A 2), the empirical 90th percentile of the five consecutive years of monthly/quarterly historical data with the lowest nutrient levels (1981-1986) was used.

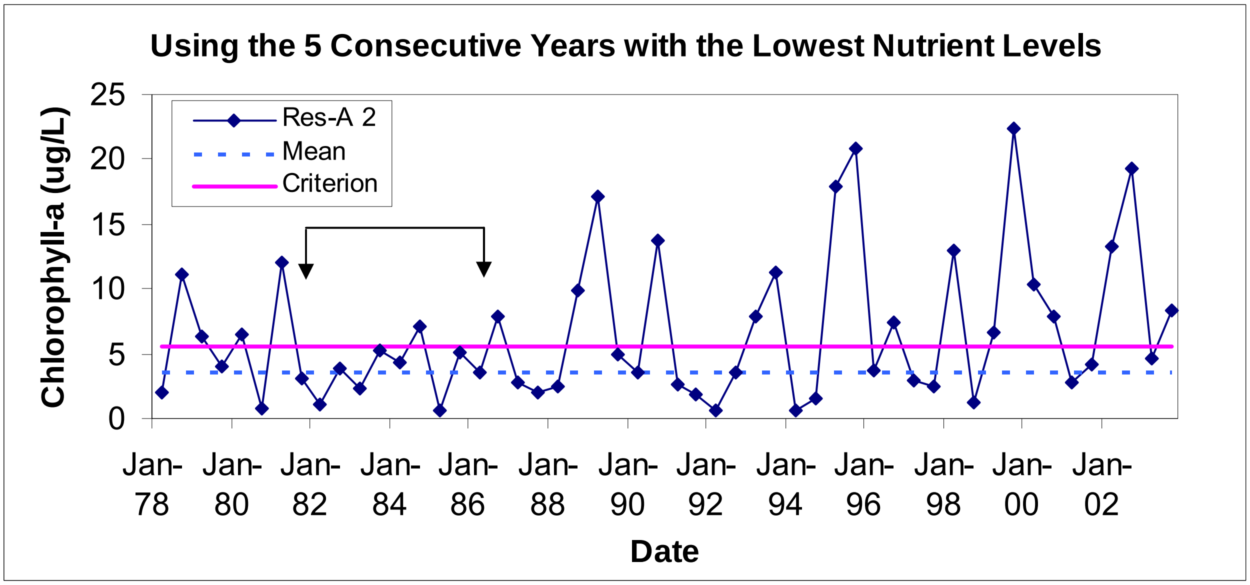


Figure 3. To establish the criterion for the degraded reservoir (Res-A 3), data from four reservoirs in close geographic proximity (Res B through Res E) were used. Using the monthly/quarterly 1993-2003 data, the criterion was established as the empirical 90th percentile for all four non-degraded reservoirs.

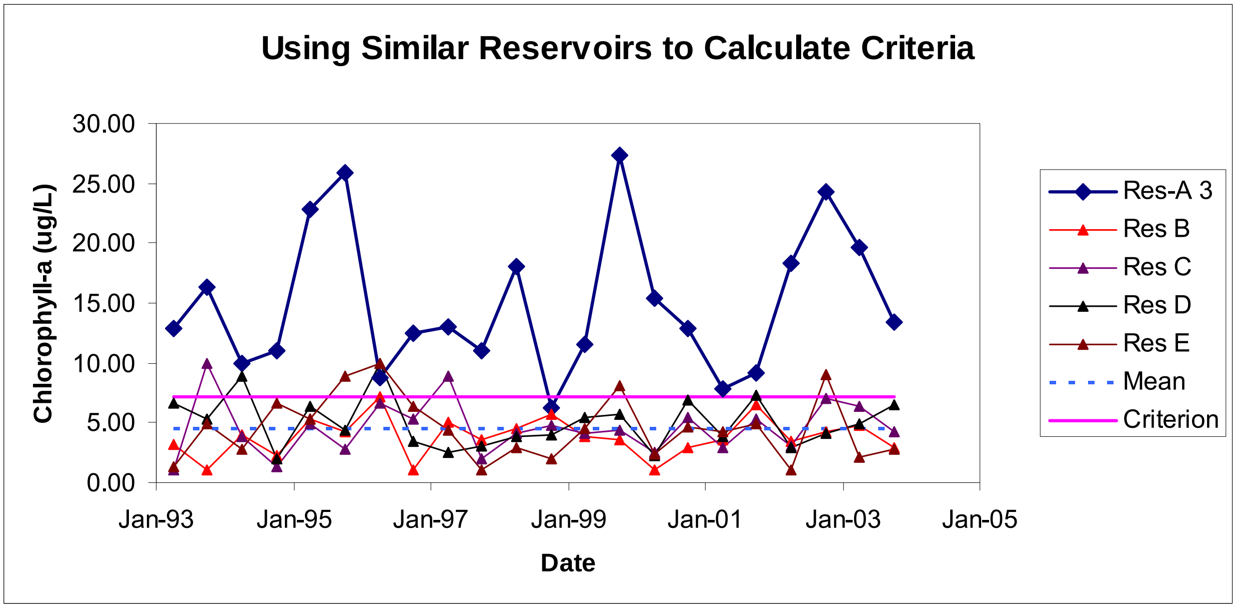
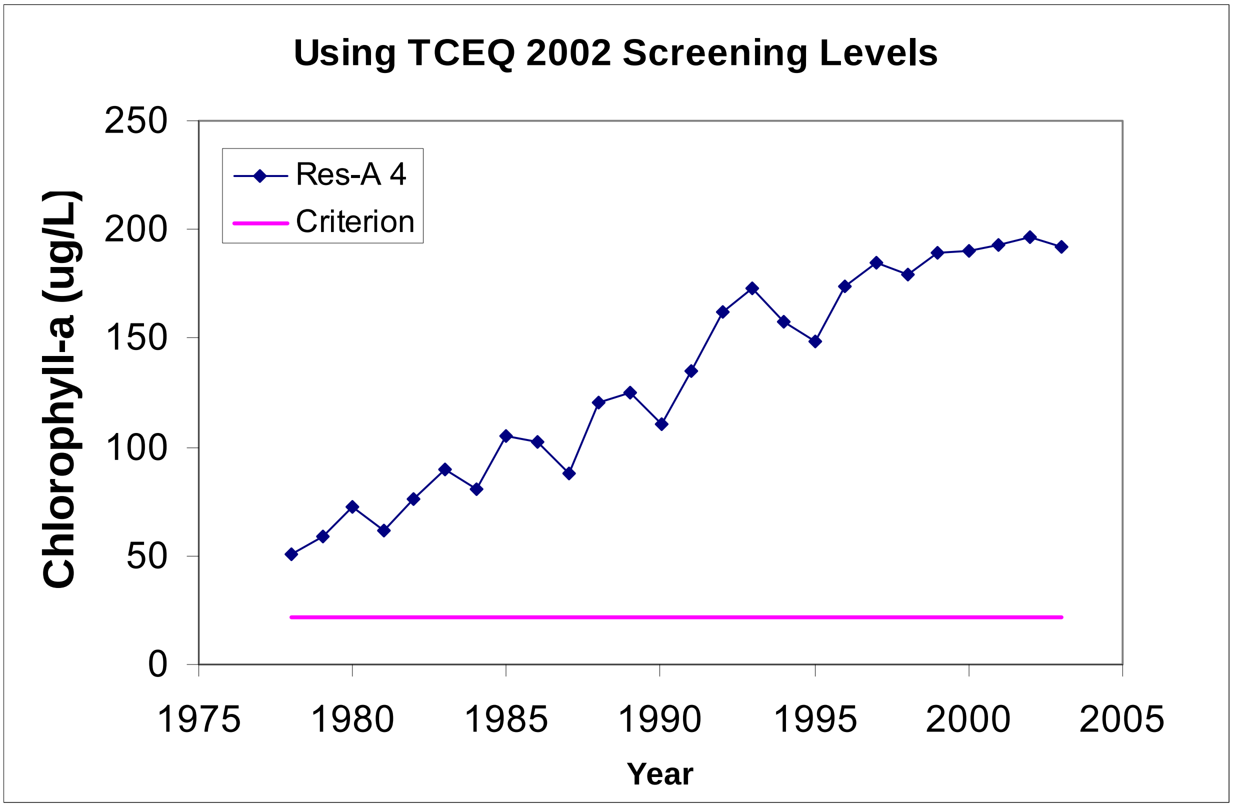


Figure 4. To establish the criterion for the degraded reservoir (Res-A 4), the TCEQ 2002 85th percentile screening criteria of 21.4 µg/L was used for Res-A 4.



Appendix 2. List of Currently Degraded Reservoirs

The list is a subset of the TCEQ's 2002 and 2004 Draft Water Quality Inventory Summaries of Water Bodies with Water Quality Concerns. Only reservoirs that had a nutrient concern for orthophosphorus, nitrate-nitrite, or chlorophyll-a throughout the entire reservoir or at the sampling site nearest the dam are included.

		TCEQ Concern		
Water Body	Segment	OP	nitrate-nitrite	algal (chl a)
Palo Duro Reservoir	199A		x	
Lake Tanglewood	0229A	x	x	x
Lake Tawakoni	507			x
Lake Livingston	803	x		x
Eagle Mountain Reservoir	809			x
Bardwell Reservoir	815		x	
Cedar Creek Reservoir	818			x
Lake Lavon	821		x	
Benbrook Lake	830			x
Richland-Chambers Reservoir	836		x	
Lake Houston	1002	x	x	
Waco Lake	1225		x	x
Lake Limestone	1252		x	
Aquilla Reservoir	1254		x	
Fayette Reservoir	1402G			x
Town Lake	1429		x	
Lake Texana	1604		x	x

Appendix 3 – Retrospective Analysis done by the TCEQ for EPA Region 6 RTAG – January 18, 2006

Nutrient Criteria Development in Texas

Handouts

Chlorophyll *a* Criteria for Least Impacted Texas Reservoirs

1. Criteria Based on Historical Conditions in Individual Reservoirs

Criteria based on historical ambient data on individual reservoirs can be appropriate for those reservoirs that are in good trophic condition. The purpose for nutrient criteria for such reservoirs (termed "least impacted") is to maintain and protect existing conditions. This approach reduces some of the high variability that's inherent in calculations based on aggregated reservoirs. Initial factors used to select "least impacted" reservoirs include the following: 1) availability of historical data, 2) limited urban and agricultural land use in the watershed, 3) absence of major discharges in the nearby watershed 4) no trend of increasing eutrophication, and 5) judgment of experts with firsthand knowledge of a reservoir's watershed and water quality characteristics.

2. How Reservoirs were selected How we selected this group of reservoirs to draft criteria for.

   a. Land use. Reservoirs with a total of less than 10% of the land use in the surrounding watershed as a combination of urban land use (such as, high intensity residential, low intensity residential, urban / recreational grasses, and commercial, industrial, transportation land uses) or agricultural land use (such as orchards / vineyards, row crops, small grains, and fallow land). The applicable watershed is truncated to exclude the watershed of upstream reservoirs. The TCEQ Source Water Assessment and Protection (SWAP) data base is used to determine land use for those listed in the data base. For reservoirs not included in the SWAP data base, USGS acquired land use data from the Nation Land Cover Data set.

   b. Major Domestic Point source discharges. There are no major domestic point source discharges directly into the reservoir or within a two-hour water travel time of the reservoir. A major discharge is defined as one which is permitted to discharge more than 1 million gallons per day.

3. Criteria calculation. Under this approach, preliminary criteria are calculated as the upper confidence interval of the mean, with the assumption that a sample size of 10 is used to assess a statistically significant departure from the mean. Confidence levels evaluated included 80^{th}, 90^{th}, 95^{th}, and 99^{th} percent (one-tailed).

   a. Data used to calculate criteria
      i. Dates included: 1/1/70 to 4/31/03
      ii. Origin of data: TCEQ's TRACS & USGS's NWIS data bases
      iii. The main pool stations for each reservoir were selected to perform the calculations and only surface values of a constituent were used. Data from main pool areas was selected because the availability of data from coves, small arms, and transition zones is highly variable; and because peripheral sampling sites are often representative of relatively small areas of a

reservoir. Data was restricted to surface samples because of a lack of uniformly available data from deeper samples.

iv. If more than one sample was taken on a day, all were averaged.

v. A reservoir was excluded if there were less than 15 data points over the period of record

vi. Outliers were deleted based on visual observation after they were sorted and plotted.

vii. The 99th percent confidence interval was selected for use as the criteria.

Criteria values for reservoirs with 0-10% land use of urban plus agriculture.
Mean, median, and criteria values are for chlorophyll *a* in ug/L.
Criteria are calculated as the upper confidence interval of the mean of historical data.
Criteria are shown for each of the three indicated levels of statistical confidence.

Lake_Name	Seg_ID	Count	Avg	Median	Criteria		
					99th	95th	90th
Amistad Reservoir	2305	117	1.839	1	3.490	3.000	2.741
B. A. Steinhagen Reservoir	0603	26	5.330	4.45	10.568	8.962	8.140
Caddo Lake	0401	75	8.263	6	18.485	15.433	13.833
Canyon Lake	1805	108	2.015	2	3.473	3.032	2.799
Choke Canyon Reservoir	2116	32	7.756	7	13.482	11.739	10.840
Diversion Lake	0215	34	5.653	4.7	11.977	10.054	9.061
Farmers Creek Reservoir	0210	40	3.438	2.2	7.043	5.952	5.386
Houston County Lake	0813	50	5.856	4.26	11.814	10.021	9.087
Hubbard Creek Reservoir	1233	30	3.097	2	6.343	5.353	4.843
Inks Lake	1407	210	7.622	6	13.421	11.640	10.700
Lake Amon G. Carter	0834	30	5.037	3.05	11.322	9.405	8.417
Lake Bob Sandlin	0408	20	4.822	4.95	8.959	7.679	7.028
Lake Bridgeport	0811	87	3.863	3	7.247	6.240	5.709
Lake Buchanan	1408	207	4.825	3.4	8.644	7.495	6.888
Lake Cisco	1234	35	1.934	2	3.228	2.835	2.632
Lake Corpus Christi	2103	78	8.966	7.5	16.794	14.458	13.232
Lake Cypress Springs	0405	32	7.376	7.5	12.976	11.272	10.391
Lake Georgetown	1249	30	2.478	2	5.008	4.237	3.839
Lake Jacksonville	0614	57	2.913	2	5.205	4.517	4.157
Lake Limestone	1252	25	11.843	10.7	20.748	18.016	16.613
Lake Marble Falls	1405	203	5.742	5	9.758	8.529	7.880
Lake Murvaul	0509	53	20.504	18.7	38.100	32.808	30.051
Lake Palo Pinto	1230	30	2.867	2.4	5.819	4.919	4.455
Lake Travis	1404	199	2.472	2	4.848	4.140	3.767
Lake Tyler	0613	57	4.963	4.12	9.053	7.826	7.184
Medina Lake	1904	65	2.396	2	4.568	3.918	3.578
O.C. Fisher Reservoir	1425	48	14.643	9	31.796	26.633	23.937
Red Bluff Reservoir	2312	72	12.599	9.485	23.233	20.086	18.434
Stillhouse Hollow Lake	1216	39	1.330	1.4	2.141	1.895	1.768
Wright Patman Lake	0302	41	12.483	9.5	24.697	21.001	19.084

Texas Commission on Environmental Quality

Development of Chloride, Sulfate and Total Dissolved Solids Criteria in the Texas Surface Water Quality Standards

Currently these criteria are developed from ambient data for each individual segment within a river basin. From time to time the criteria may be recalculated to reflect the expanding data base. If recalculations are performed care must be taken to ensure that a pollution source is not responsible for increased concentrations of these parameters. The actual criteria are derived by a formula which utilizes the arithmetic mean, standard deviation and Student's t value for the number of data values used for each calculation. Water quality standards attainment is evaluated as an assessment period mean of at least ten samples taken on different dates not to exceed the derived criterion. The assessment period must be at least one year.

The calculation is based on the minimum value for the assessment period mean TDS, chloride or sulfate would have to attain such that a Student's t test would reject the null hypothesis that the assessment period mean and the mean of the baseline data were drawn from the same population with a probability of 0.05 (one-tailed). Assumes assessment period mean is based on at least ten samples and the variances of the baseline data set and data used for calculating the assessment period mean are the same.

Calculated as follows:

Criterion = $\bar{x}_1 + t_{(1)(0.05)}(s_{\bar{x}1 - \bar{x}2})$

Where: criterion = the value the assessment period mean should not exceed

$\bar{x}_1$ = mean of the baseline data set

$t_{(1)(0.05)}$ = critical value of the t distribution where $\propto = 0.05$ one tailed at $n + 10$ degrees of freedom

$s_{\bar{x}1 - \bar{x}2}$ = standard error for the difference of two means

$= \sqrt{(s_p^2/n_1 + s_p^2/n_2)}$

Where: n_1 = number of samples in baseline data set

$n_2 = 10$ = number of samples used to calculate assessment period mean

$s_p^2 = 2(s^2(n_1 - 1))/(n_1 + 2)$

s = standard deviation of the baseline data

Reference: Moore, D. S. and G. P. McCabe. 1993. The pooled two-sample t procedures. pp 542-549. In *Introduction to the practice of statistics*. W. H. Freeman and Company, New York.

C. Bayer
TNRCC-WQS

Underlines indicate an addition to the existing standards.
Strikeouts indicate a deletion from the existing standards.

§307.3 Definitions and Abbreviations.

(a) Definitions. ...

...

(37) Nutrient criteria - Criteria that are established to protect surface waters from excessive growth of aquatic plants such as phytoplankton, floating algae and floating higher plants, attached algae, and rooted plants. Nutrient criteria can be expressed in terms of chlorophyll *a* concentration per unit volume or area, concentration of total or soluble reactive phosphorus in water, concentration of total or inorganic nitrogen in water, or similar measures.

§307.4 General Criteria

...

(e) Nutrients. Nutrients from permitted discharges or other controllable sources shall not cause excessive growth of aquatic vegetation which impairs an existing, attainable, or designated use. Site-specific nutrient criteria, nutrient permit limitations, and/or separate rules to control nutrients in individual watersheds will be established where appropriate after notice and opportunity for public participation and proper hearing. Site-specific criteria related to nutrients and aquatic plants are listed in Appendix F of this title.

§307.7 Site-specific Uses and Criteria.

...

(b) Appropriate uses and criteria ...

...

(4) Additional criteria.

...

(E) Nutrient criteria. Criteria to preclude excessive growth of aquatic plants are intended to protect multiple uses, such as contact and noncontact recreation, aquatic life, and public water supplies. Nutrient criteria for specific reservoirs, expressed as concentrations of chlorophyll *a* in water, are listed in Appendix F of this title.

§307.8 Application of Standards.

...

(b) Mixing zones ...

(1) The following portions of the standards do not apply within mixing zones:

...

(I) Nutrient criteria (e.g., chlorophyll *a*)

§307.9 Determination of Standards Attainment.

...

(c) Collection and preservation of water samples.

...

(2) ... Standards for chloride, sulfate, total dissolved solids, ~~and~~ pH, and nutrient criteria are applicable to the mixed surface layer, but a single sample taken near the surface normally provides an adequate representation of these parameters.

...

(e) Sampling periodicity and evaluation.

...

(7) Nutrient criteria. Standards attainment will be based on the average of at least 10 measurements taken over a period of at least one year. In reservoirs, nutrient criteria apply to the main pool; and compliance is assessed using the mean of long term data from one or more stations that represent conditions in deep, open-water areas of the main pool adjacent to the dam.

§307.10 Appendices A - ~~E~~ F.

...

Appendix F - Site-specific Nutrient Criteria

In the following table, nutrient criteria for selected reservoirs are specified in terms of concentrations of chlorophyll *a* in water as a measure of the density of phytoplankton (suspended microscopic algae). Nutrient criteria are expressed as averages over at least an annual period, and the criteria are applicable to the main pool of each reservoir (see §307.9 (c)(2) and §307.9(e)(7)). For reservoirs where the calculated are criteria are less than 5.00 micrograms per liter, the criteria will be considered to be 5.00 micrograms per liter.

[Criteria formulations were based on the following steps and assumptions:
(1) Available data from 1970 through 2003.
(2) Selected sampling stations represent the deep pool of each reservoir near the dam.
(3) Criteria represent average conditions with an allowance for statistical variability.
(4) Criteria are calculated as the upper confidence interval of the mean (0.01 confidence level), with the assumption that a sample size of 10 is used to assess a statistically significant departure from the mean.]

Appendix F – Nutrient Criteria

Segment number	Segment Name	Criteria - Chlorophyll *a* (µg/L)
0210	Farmers Creek Reservoir	7.0
0215	Diversion Lake	12.0
0302	Wright Patman Lake	24.7
0401	Caddo Lake	18.5
0405	Lake Cypress Springs	13.0
0408	Lake Bob Sandlin	9.0
0509	Lake Murvaul	38.1
0603	B. A. Steinhagen Reservoir	10.6
0613	Lake Tyler	9.1
0614	Lake Jacksonville	5.2
0811	Lake Bridgeport	7.2
0813	Houston County Lake	11.8
0834	Lake Amon G. Carter	11.3
1216	Stillhouse Hollow Lake	2.1
1230	Lake Palo Pinto	5.8
1233	Hubbard Creek Reservoir	6.3
1234	Lake Cisco	3.2
1249	Lake Georgetown	5.0
1252	Lake Limestone	20.7
1404	Lake Travis	4.8
1405	Lake Marble Falls	9.8

1407	Inks Lake	13.4
1408	Lake Buchanan	8.6
1425	O.C. Fisher Reservoir	31.8
1805	Canyon Lake	3.5
1904	Medina Lake	4.6
2103	Lake Corpus Christi	16.8
2116	Choke Canyon Reservoir	13.5
2305	Amistad Reservoir	3.5
2312	Red Bluff Reservoir	23.2

Simulated Assessment Using Draft Criteria

Draft criteria were calculated using the following formula.

Criterion = $\bar{x}_1 + t_{(1)(0.05)}(s_{\bar{x}1 - \bar{x}2})$

Where: criterion = the value the assessment period mean should not exceed

$\bar{x}_1$ = mean of the baseline data set

$t_{(1)(0.05)}$ = critical value of the t distribution where $\propto = 0.05$ one tailed at $n + 10$ degrees of freedom

$s_{\bar{x}1 - \bar{x}2}$ = standard error for the difference of two means

$= \sqrt{(s_p^2/n_1 + s_p^2/n_2)}$

Where: n_1 = number of samples in baseline data set

$n_2 = 10$ = number of samples used to calculate assessment period mean

$s_p^2 = 2(s^2(n_1 - 1))/(n_1 + 2)$

s = standard deviation of the baseline data

Reference: Moore, D. S. and G. P. McCabe. 1993. The pooled two-sample t procedures. pp 542-549. In *Introduction to the practice of statistics*. W. H. Freeman and Company, New York.

The mean and median for five years of data was calculated and plotted against the criteria. Outliers were removed from the criteria calculation, but were included in the assessment.

Chart explanation

The dark bar is the **mean** calculated value. The lighter or crosshatched bar is the **median**.

Why do x axis years cover more than 5 years?

The historical data was divided into 5 year increments. If a reservoir data set did not contain sufficient data for a 5 year assessment, additional years were added to get 5 years worth of data. For example: the first 5 year increment covered 2003 to 1999. If there was no data from 2000, data from 1998 was added so that there were 5 years worth of data.

Light blue bars, what are they?

The light blue bars indicate that there was an outlier in at least one of the 5 years covering the assessment.

Numbers above the bars, what are they?

The numbers above the bars indicates the number of data values that exceeded the criteria.

Red bars, what are they?
The red bar is the calculated draft criteria using the above methodology.

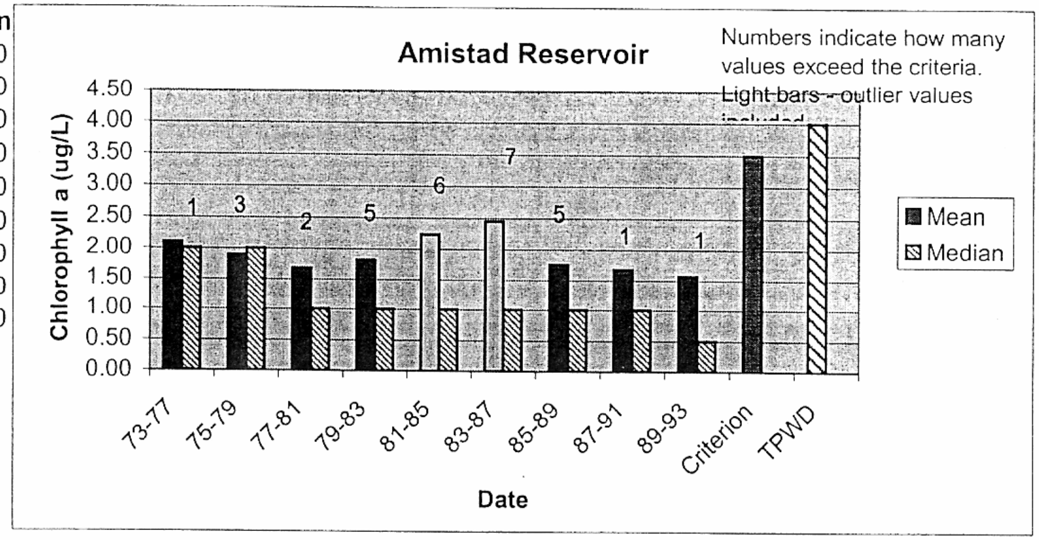
Last striped bar labeled TPWD, what are they?
This bar shows the 90^{th} percentile value that TPWD suggested as a methodology for calculating criteria.

Reservoir	Years without data	Other changes to get 5 years of data	Number of data points that exceed the criteria	Count	Number of outliers
Amistad Reservoir			13	118	1
B.A. Steinhagen Reservoir	81, 83-85, 87	Data begins in 79. 79-89 to get 5 years	2	26	0
Caddo Lake		Data begins in 73. 73-77 to get 5 years	10	77	2
Canyon Lake	80, 90, 91, 95		11	111	4
Choke Canyon Reservoir			1	32	0
Diversion Lake	79, 82, 83, 85, 86, 87, 89, 91, 96, 97	Data begins in 73. 73-77 to get 5 years	4	35	1
Farmers Creek Reservoir	79, 82, 83, 85, 86, 87, 89, 91	Data begins in 73. 73-77 to get 5 years	4	40	0
Houston County Lake	79, 82, 89, 91, 95, 96, 98	Data begins in 73. 73-77 to get 5 years	7	50	0
Hubbard Creek Reservoir	79-80, 83-84, 92, 96, 98-00	Data begins in 73. 73-77 to get 5 years	6	30	
Inks Lake	78-79, 82		25	182	2
Lake Amon G. Carter	78		6	32	2
Lake Bob Sandlin	78-79, 81-82, 85-87, 89, 91		2	20	0
Lake Bridgeport	83, 84, 86, 95-97		10	87	
Lake Buchanan	78, 79, 82	Data begins in 73. 73-	32	182	2

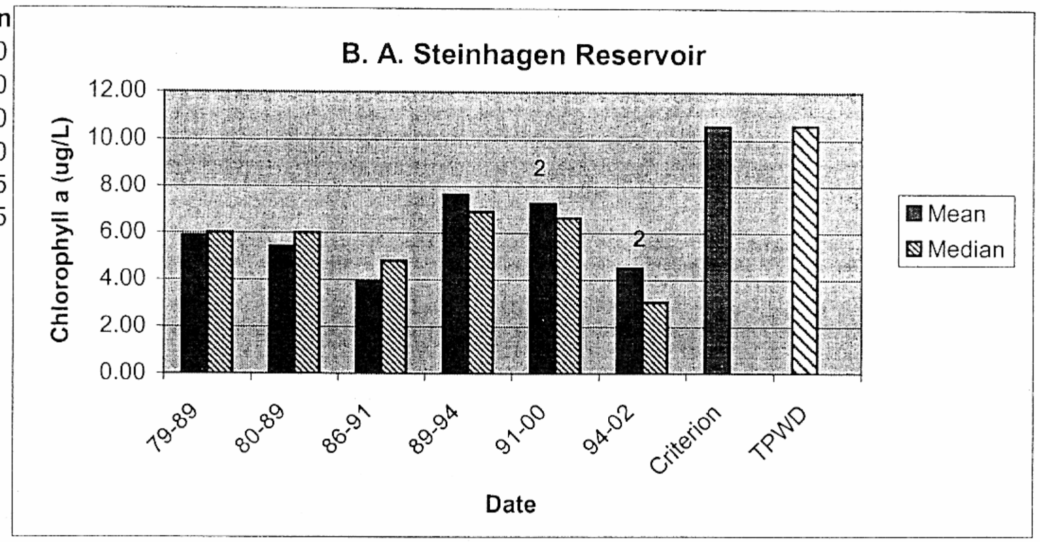
		77 to get 5 years			
Lake Cisco	78, 80, 83-84, 86, 88-90, 95-97, 02		5	37	2
Lake Corpus Christi	94-98		15	80	2
Lake Cypress Springs	82, 86, 89, 95-97		3	33	1
Lake Georgetown	84, 92,		4	31	1
Lake Jacksonville	80, 83-84, 95-98		13	58	1
Lake Limestone	81, 84-85,97-01		4	26	1
Lake Marble Falls	78, 79, 82		21	177	3
Lake Murvaul	81, 84, 86, 88, 95-96, 98-99	Data begins in 73. 73-77 to get 5 years	9	54	1
Lake Palo Pinto	78-80, 83-84, 92, 95-98		4	31	1
Lake Travis	78-79, 82		23	186	2
Lake Tyler	80, 83-84, 90, 95-97		10	58	1
Medina Lake	80, 91, 95-96	Data begins in 73. 73-77 to get 5 years	6	67	2
O.C. Fisher Reservoir	79-82, 84, 95-97	Data begins in 73. 73-77 to get 5 years	5	48	0
Red Bluff Reservoir	80, 82-84, 95, 96	Data begins in 73. 73-77 to get 5 years	10	71	0
Stillhouse Hollow Lake	78, 81, 84, 85, 97-99		4	42	3
Wright Patman Lake	81, 84, 86, 95, 96	Data begins in 73. 73-77 to get 5 years	8	44	3

5 Year Assessments

Lake name	Date	N	Mean	Median
Amistad Reservoir	73-77	10	2.10	2.00
Amistad Reservoir	75-79	36	1.89	2.00
Amistad Reservoir	77-81	45	1.67	1.00
Amistad Reservoir	79-83	47	1.81	1.00
Amistad Reservoir	81-85	42	2.24	1.00
Amistad Reservoir	83-87	34	2.46	1.00
Amistad Reservoir	85-89	23	1.74	1.00
Amistad Reservoir	87-91	12	1.67	1.00
Amistad Reservoir	89-93	10	1.57	0.50
	Criterion		**3.49**	
	TPWD		**4.00**	



Lake name	Date	N	Mean	Median
B. A. Steinhagen Reservoir	79-89	9	5.87	6.00
B. A. Steinhagen Reservoir	80-89	7	5.40	6.00
B. A. Steinhagen Reservoir	86-91	5	3.92	4.80
B. A. Steinhagen Reservoir	89-94	5	7.64	6.90
B. A. Steinhagen Reservoir	91-00	8	7.25	6.65
B. A. Steinhagen Reservoir	94-02	14	4.50	3.05
	Criterion		**10.57**	
	TPWD		**10.60**	



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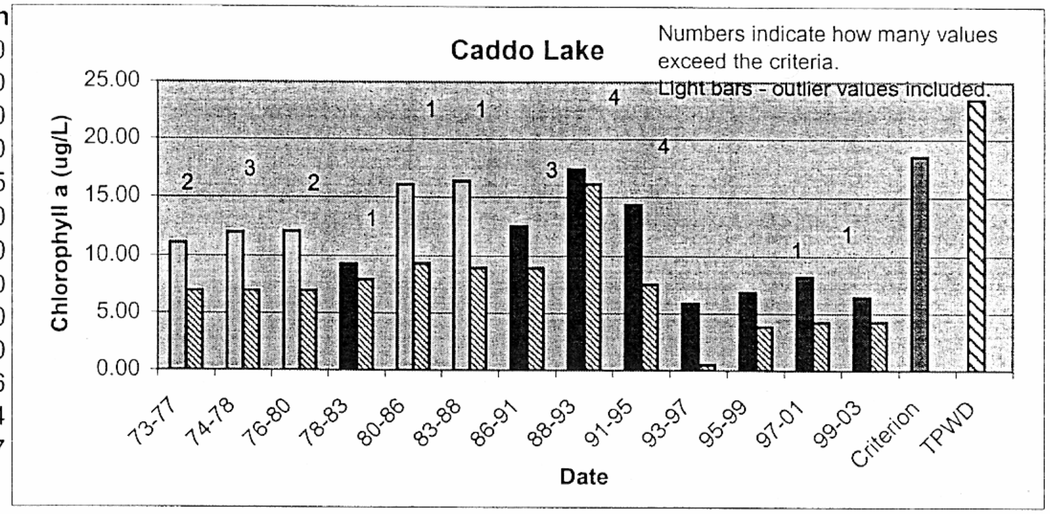
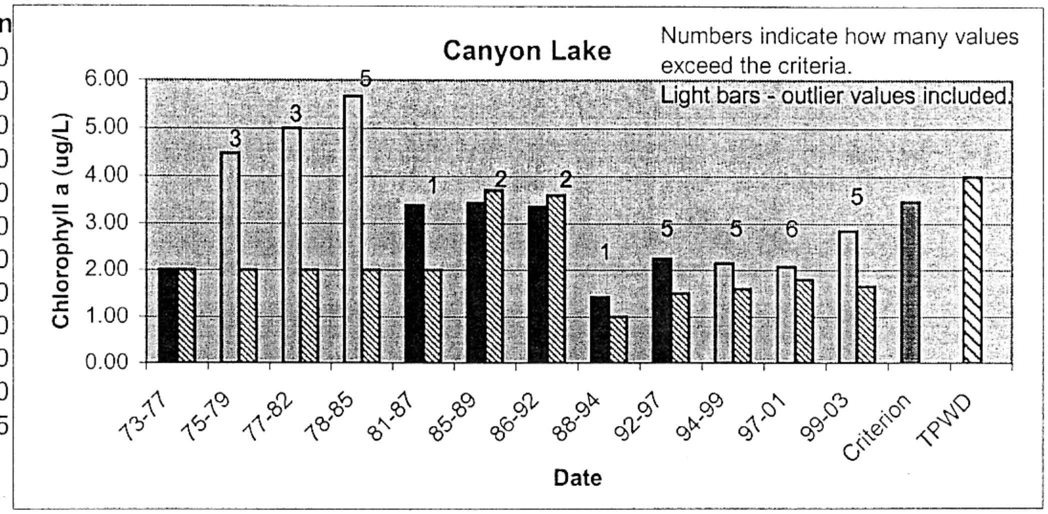
5 Year Assessments

Lake name	Date	N	Mean	Median
Caddo Lake	73-77	17	11.09	7.00
Caddo Lake	74-78	19	11.97	7.00
Caddo Lake	76-80	15	12.07	7.00
Caddo Lake	78-83	11	9.29	8.00
Caddo Lake	80-86	10	16.04	9.35
Caddo Lake	83-88	9	16.36	9.00
Caddo Lake	86-91	9	12.50	9.00
Caddo Lake	88-93	8	17.35	16.10
Caddo Lake	91-95	9	14.34	7.60
Caddo Lake	93-97	13	5.85	0.50
Caddo Lake	95-99	18	6.87	3.86
Caddo Lake	97-01	20	8.28	4.24
Caddo Lake	99-03	19	6.43	4.27
	Criterion		**18.49**	
	TPWD		**23.40**	



Lake name	Date	N	Mean	Median
Canyon Lake	73-77	14	2.00	2.00
Canyon Lake	75-79	17	4.47	2.00
Canyon Lake	77-82	14	5.00	2.00
Canyon Lake	78-85	12	5.67	2.00
Canyon Lake	81-87	7	3.39	2.00
Canyon Lake	85-89	5	3.44	3.70
Canyon Lake	86-92	5	3.36	3.60
Canyon Lake	88-94	5	1.42	1.00
Canyon Lake	92-97	17	2.24	1.50
Canyon Lake	94-99	39	2.16	1.60
Canyon Lake	97-01	59	2.08	1.80
Canyon Lake	99-03	52	2.84	1.65
	Criterion		**3.47**	
	TPWD		**4.00**	



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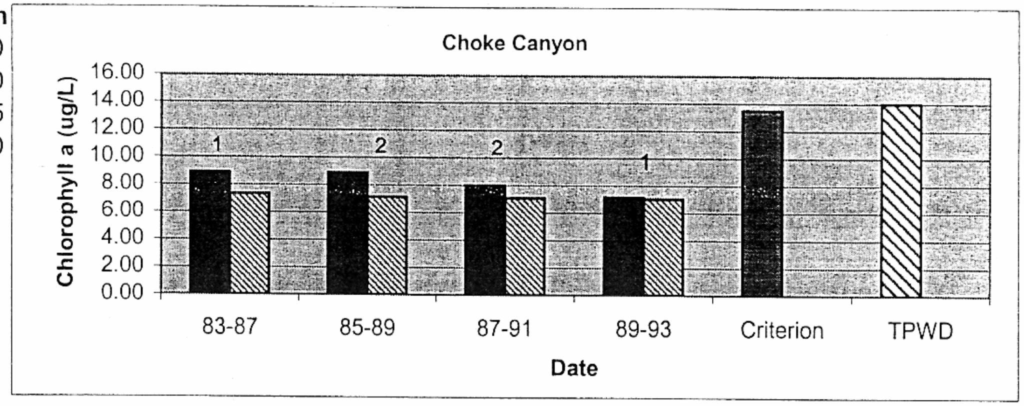
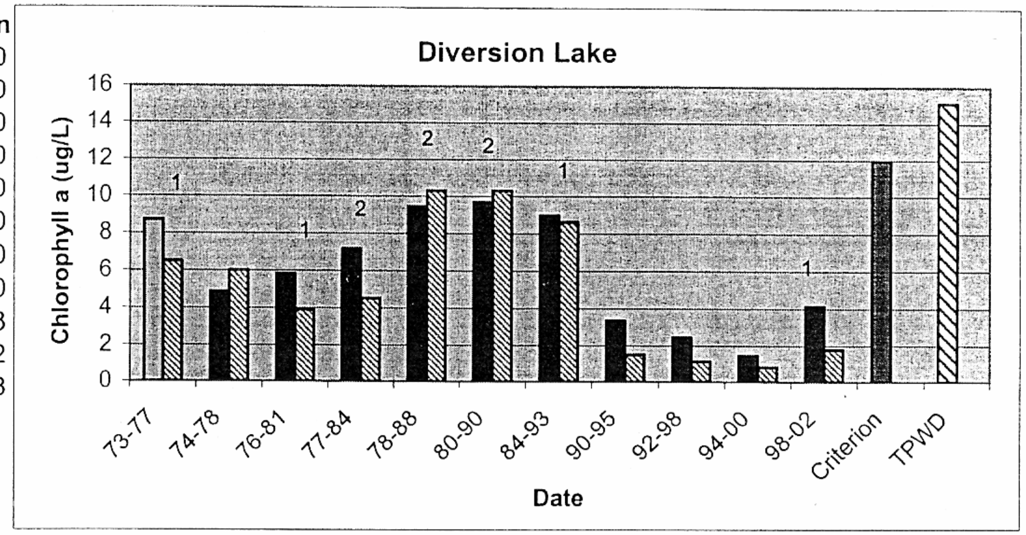
5 Year Assessments

Lake name	Date	N	Mean	Median
Choke Canyon	83-87	13	8.88	7.30
Choke Canyon	85-89	18	8.89	7.10
Choke Canyon	87-91	18	7.97	7.05
Choke Canyon	89-93	15	7.11	7.00
	Criterion		**13.48**	
	TPWD		**13.99**	



Lake name	Date	N	Mean	Median
Diversion Lake	73-77	12	8.68	6.50
Diversion Lake	74-78	9	4.83	6.00
Diversion Lake	76-81	8	5.81	3.90
Diversion Lake	77-84	7	7.16	4.50
Diversion Lake	78-88	7	9.44	10.30
Diversion Lake	80-90	7	9.67	10.30
Diversion Lake	84-93	5	8.96	8.60
Diversion Lake	90-95	5	3.33	1.50
Diversion Lake	92-98	5	2.45	1.13
Diversion Lake	94-00	8	1.46	0.82
Diversion Lake	98-02	11	4.12	1.78
	Criterion		**11.95**	
	TPWD		**15.12**	



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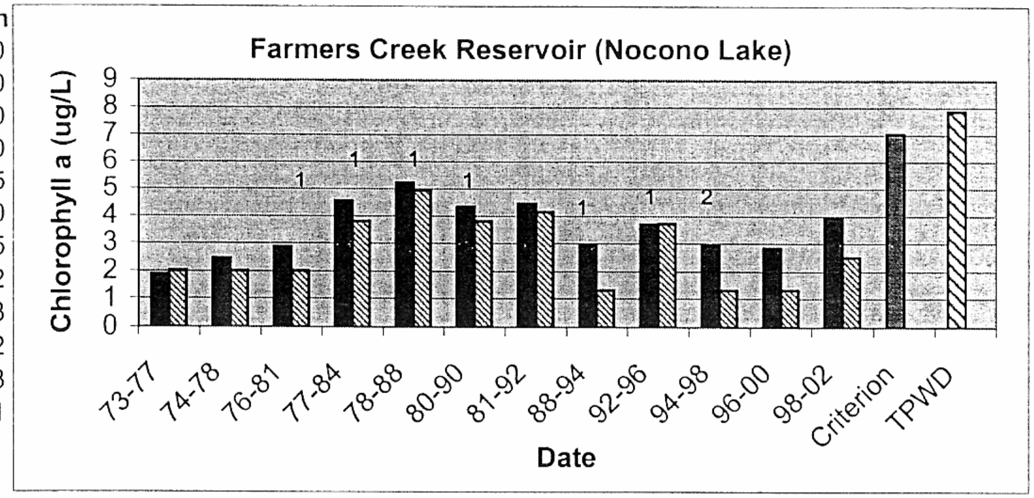
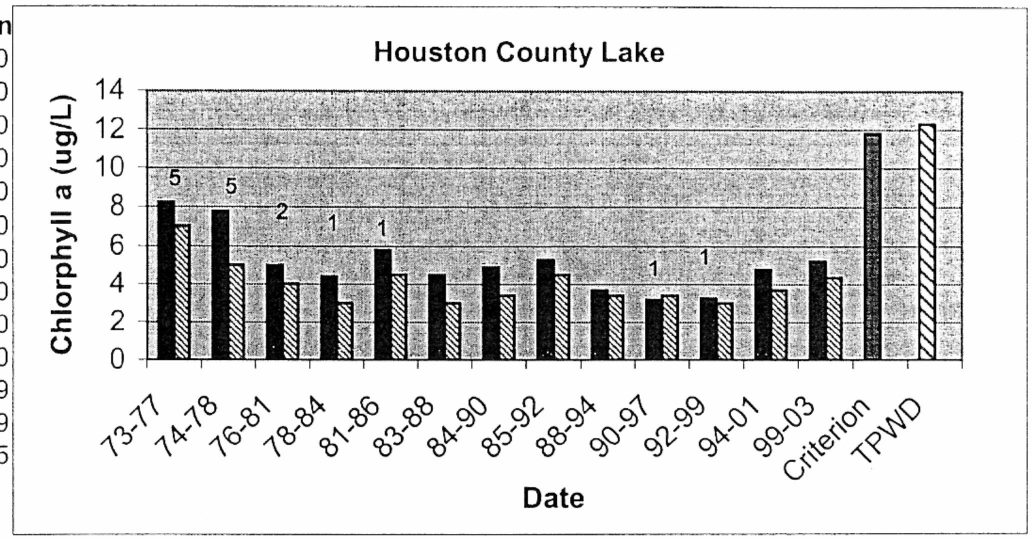
5 Year Assessments

Lake name	Date	N	Mean	Median
Farmers Creek Reservoir (N	73-77	13	1.87	2.00
Farmers Creek Reservoir (N	74-78	13	2.45	2.00
Farmers Creek Reservoir (N	76-81	9	2.86	2.00
Farmers Creek Reservoir (N	77-84	8	4.55	3.80
Farmers Creek Reservoir (N	78-88	8	5.21	4.95
Farmers Creek Reservoir (N	80-90	8	4.33	3.80
Farmers Creek Reservoir (N	81-92	8	4.44	4.15
Farmers Creek Reservoir (N	88-94	7	2.92	1.32
Farmers Creek Reservoir (N	92-96	6	3.70	3.73
Farmers Creek Reservoir (N	94-98	7	2.92	1.32
Farmers Creek Reservoir (N	96-00	8	2.83	1.33
Farmers Creek Reservoir (N	98-02	10	3.95	2.51
	Criterion		**7.04**	
	TPWD		**7.85**	



Lake name	Date	N	Mean	Median
Houston County Lake	73-77	17	8.21	7.00
Houston County Lake	74-78	19	7.76	5.00
Houston County Lake	76-81	15	4.97	4.00
Houston County Lake	78-84	11	4.41	3.00
Houston County Lake	81-86	7	5.77	4.50
Houston County Lake	83-88	7	4.49	3.00
Houston County Lake	84-90	7	4.89	3.40
Houston County Lake	85-92	5	5.30	4.50
Houston County Lake	88-94	5	3.67	3.40
Houston County Lake	90-97	5	3.17	3.40
Houston County Lake	92-99	6	3.25	2.99
Houston County Lake	94-01	10	4.77	3.69
Houston County Lake	99-03	14	5.22	4.35
	Criterion		**11.81**	
	TPWD		**12.30**	



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