

Technical Review of Chatfield Reservoir Control Regulation: Standards

Control regulations are promulgated to promote attainment of a standard. Standards are promulgated to protect specific uses. In the case of Chatfield Reservoir, the phosphorus standard was adopted for the purpose of preserving or restoring water quality conditions representing an acceptable level of algal abundance. In concept, the standard could have been based on chlorophyll, nutrients, or trophic status. In practice, the numeric standard was based on phosphorus with the assumption that an increase in phosphorus concentration would cause a corresponding increase in chlorophyll concentration.

A value judgment was made concerning the acceptable level of algal abundance (expressed as chlorophyll concentration), and that target level for chlorophyll was “translated” into a numeric standard for phosphorus. The connection between the control regulation, which contains the chlorophyll target, and the basin regulation, which contains the adopted numeric standard, is therefore central to the technical review.

The Chatfield Reservoir Control Regulation is based on a phosphorus standard of 27 ug/L assessed as a “growing season” (Jul-Sep) average¹. The purpose for adopting a phosphorus standard is given clearly in the control regulation (albeit with units of mg/L instead of ug/L): “The 0.027 mg/l total phosphorus standard was adopted by the Commission with the intent of maintaining the chlorophyll a level in the reservoir at no more than 0.017 mg/l during the growing season.”

The magnitude of the chlorophyll target was proposed during the Clean Lakes study, which was completed in 1984. The first of three general water quality goals dealt specifically with chlorophyll: “Allow no water quality degradation; maintain chlorophyll a as close to the present concentration of 14.6 ug/L as possible.” Modeling results in the report forecast higher chlorophyll in the future, with an expectation of 17 ug/L based on wastewater flows projected for 2010. The Commission’s decision to accept a chlorophyll target of 17 ug/L was based in part on consideration of treatment costs to remove phosphorus and in recognition of the relative importance of nonpoint sources of phosphorus.

Magnitude of the Standard

For the purpose of discussion, the Division assumes that a chlorophyll standard (rather than the current phosphorus standard) is likely to be proposed in the future. Stakeholders have expressed interest in adopting a chlorophyll standard, and chlorophyll is likely to be the central feature of the Division’s eventual proposal of nutrient criteria for lakes. The Division assumes further that the long-standing target for chlorophyll (17 ug/L as a growing season average) remains valid today. The Division is unaware of any concerns with the current chlorophyll target for Chatfield.

¹ The terms *average* and *mean* are used interchangeably, and both refer to the arithmetic mean.

Duration of the Standard

Assessment of chlorophyll and phosphorus concentrations in control regulation lakes has been based on average conditions over a span of three or four months, an extended duration in comparison to those typically applied for acute and chronic standards. Justification for a long averaging period comes in part from the general aim of documenting trophic status rather than a toxicity threshold.

The current phosphorus standard for Chatfield Reservoir, as well as the chlorophyll target in the Control Regulation, is defined in terms of the average concentration measured during the “growing season,” which was defined as the months of July through September. There seems to be no clear origin for that definition of the growing season, although it is clearly within the summer months when growth rates of algae are likely to be high. The Division has undertaken a review of averaging periods as they relate to development of nutrient criteria for lakes (Appendix A: “Chlorophyll Averaging Period”). A brief synopsis of the review is included here, with details pertinent to Chatfield Reservoir.

There is no clearly articulated definition for growing season as it relates to lakes. In Colorado, it has been defined as July-September or July-October, but the origin is murky. Given the uncertain origin of the definition as it applies to lakes, the Division believes it would be better to start over and begin the discussion with “chlorophyll averaging period” rather than “growing season.” One way to approach the subject is to consider what periods of time would logically be associated with protection of uses.

Average chlorophyll during the period of stratification has a logical connection to protection of aquatic life use in that it reflects the potential for depletion of oxygen in the hypolimnion. As long as a lake is stratified, algal cells that settle out of the mixed layer will consume oxygen as they decompose in the hypolimnion. In general, the *stratification season* extends from April through September in lower elevation lakes, like Chatfield.

For protection of recreational use, the averaging period might extend from Memorial Day to Labor Day (Jun-Aug), consistent with the focal period for swim beach monitoring of coliforms. The focus for the *recreation season* might be on the potential for production of cyanotoxins or on less quantifiable aesthetic considerations. Instantaneous measurements are most relevant to concerns about toxins, although a close connection between mean and variance (detailed in Appendix B: “Characterizing Chlorophyll Distributions in Colorado Lakes”) confers management value on the mean.

Because drinking water treatment may be affected by algal abundance at any time of year, an annual average may be most appropriate for protection of the water supply use. Algae may be as abundant in winter as they are in summer.

Finally, the July-September *summer season* is included because of historical precedent – three of the four existing control regulations use this averaging period. In the past, monitoring programs have been designed to provide adequate data in the relevant

averaging period, and coverage may not have been as complete for other averaging intervals (annual or stratification season, for example).

When the four alternative averaging periods are compared in several lakes, some important conclusions emerge: 1) algal abundance in the winter may equal or exceed that in the summer, 2) the annual mean and the summer mean typically are comparable, 3) the stratification season mean and the recreation season mean typically are comparable, and 4) annual mean (or the summer mean) tends to be higher than the stratification season mean (or the recreation season mean). The Division recommends continued application of the summer averaging period because it is efficient in terms of minimizing sampling effort, it is an appropriate surrogate for the annual average, it is conservative (high) with respect to alternative averaging periods, and a strong precedent exists. The Division's general preference for the summer averaging period does not preclude definition of a different averaging period on a site-specific basis, where suitable justification exists.

Chlorophyll concentrations in Chatfield Reservoir show clear seasonal variation with a minimum during spring and early summer and higher values at fall overturn and in early spring (Figure 1). The means derived for the four averaging periods (Figure 2) conform in rank to the pattern described above for Colorado lakes in general, but the means are not significantly different from one another in Chatfield Reservoir. The summer season remains the Division's preference for Chatfield because it is consistent with the control regulation and because there appears to be no compelling reason to change.

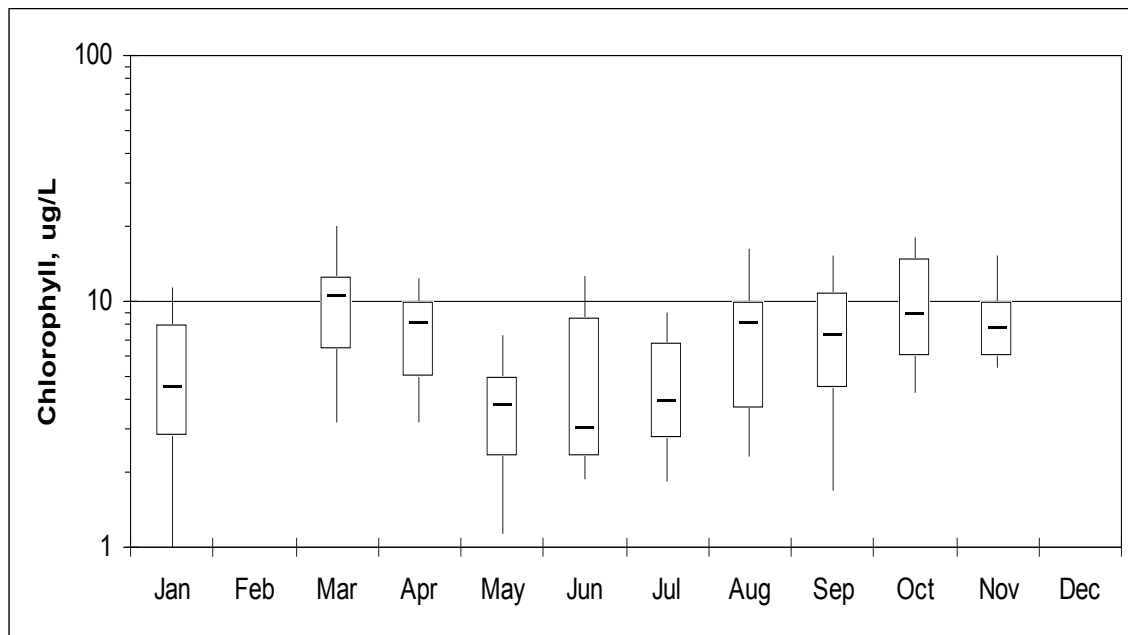


Figure 1. Box-and-whisker plots of chlorophyll concentrations measured in Chatfield Reservoir from 1996-2005. The “box” in each plot defines the range between the 25th and 75th percentile values of chlorophyll, the tips of the “whiskers” represent the 5th and 95th percentiles, and the dash indicates the magnitude of the median (50th percentile). Because few measurements were available for January and February, the data were combined.

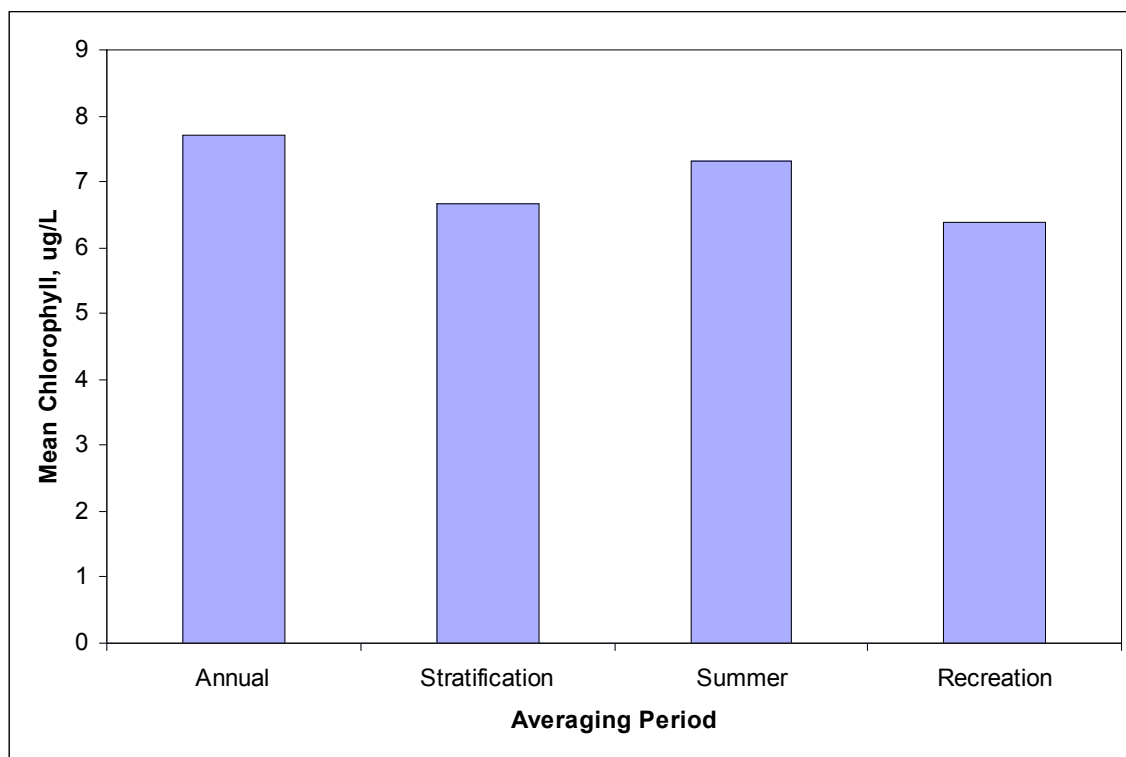


Figure 2. Seasonal mean of chlorophyll concentrations in Chatfield Reservoir for each of four averaging periods. The period of record was restricted to the last 10 years.

Allowable Exceedance Frequency of the Standard

Exceedance frequencies were not defined when standards and control regulations first were adopted. Moreover, there is little guidance concerning what would make sense for attainment of standards that are not based directly on toxicity. Recent adoption of a chlorophyll standard for Cherry Creek Reservoir included language (in Regulation 38) specifying that the standard should be met 9 out of 10 years. Comparable expectations have not been stated for the other control regulation lakes, making assessment problematic. The Division believes all parties will benefit from a discussion of attainment issues, including the attainment expectation that have been adopted for Cherry Creek Reservoir. To that end, a draft is attached of a document describing the statistical basis for assessing attainment of chlorophyll standards in Colorado (Appendix B: “Characterizing Chlorophyll Distributions in Colorado Lakes”).

Overview of Chatfield Reservoir Chlorophyll Data

Chlorophyll has been measured in Chatfield Reservoir as part of the routine monitoring program since the Clean Lakes Study; the last 20 years are shown as a time series (Figure 3). There may be multi-year patterns in concentration, but there is no clear trend of net increase or decrease over the period of record. The chlorophyll concentrations fit a log-normal distribution (Figure 4), which is important for establishing assessment procedures.

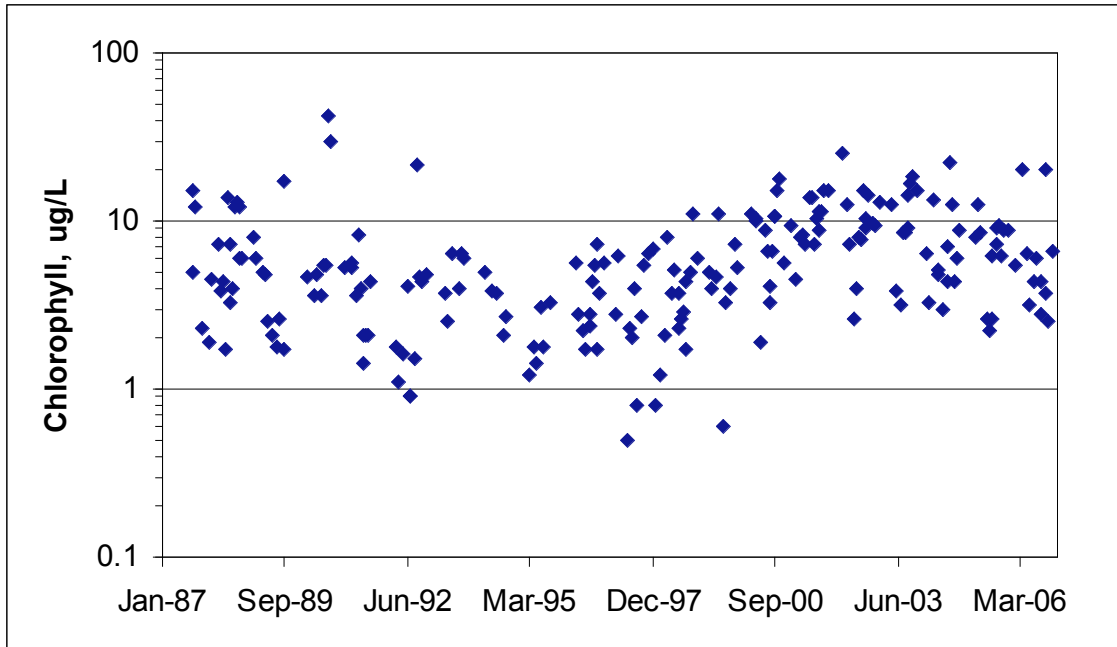


Figure 3. Time series of chlorophyll concentrations (log scale) in Chatfield Reservoir, 1987-2006.

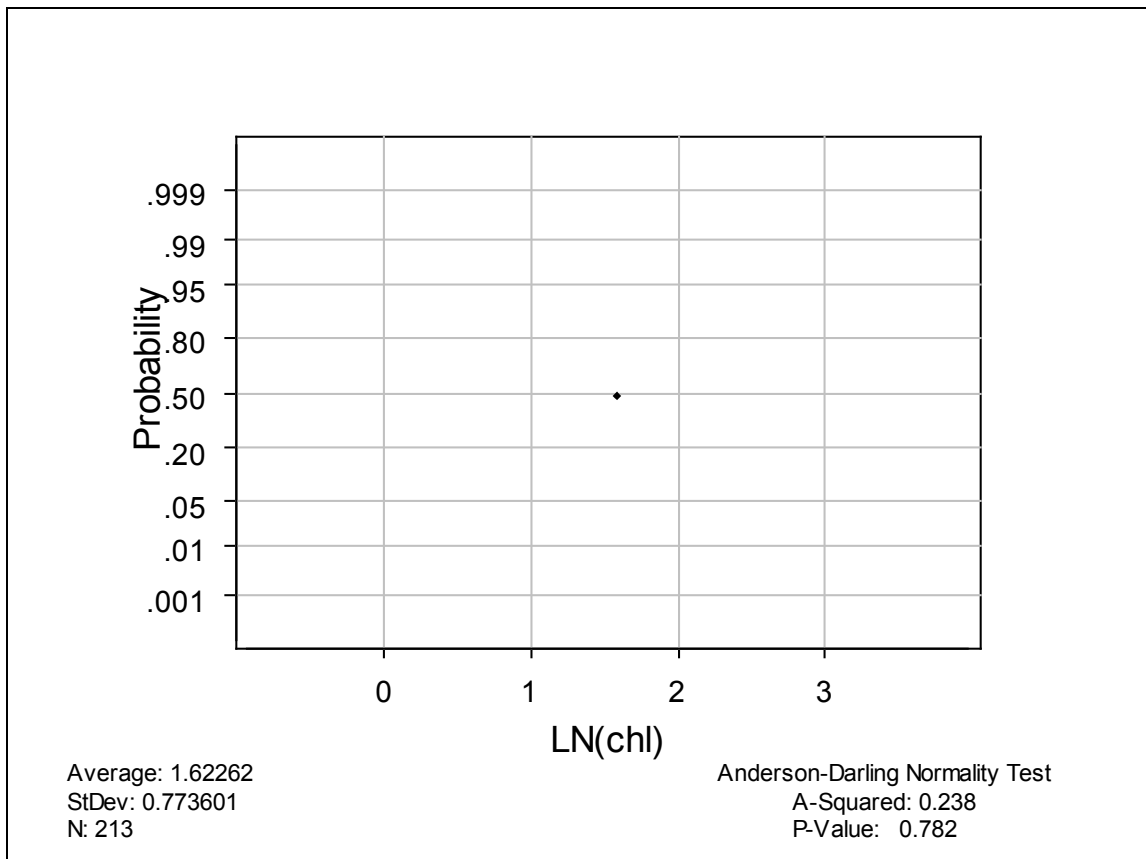


Figure 4. Test for normality of log-transformed chlorophyll data (performed with Minitab software). The high P-value (=0.782) indicates that the lognormal distribution is appropriate.

Basis for Assessment

The development of a chlorophyll standard for Chatfield Reservoir should include consideration of what constitutes attainment. How often and by how much must the measured values exceed the standard before it is clear that the reservoir is not in attainment of the chlorophyll standard? As mentioned previously, because the chlorophyll standard does not represent a toxicity threshold, the Division has some flexibility in defining what constitutes an exceedance.

The Division holds the view that a chlorophyll standard represents a long-term average, which is taken to be the “population mean” in a statistical sense. In contrast, the set of measurements taken in one season are used to calculate the “sample mean,” which is the basis for judging attainment.

Associated with any mean is a variance, which is a measure of the spread (dispersion) of individual measurements about the mean. A review of chlorophyll data from Colorado lakes (see Appendix B for a more complete presentation) shows a wide range of values for the mean and a very strong dependence of the standard deviation (=the square root of the variance) on the mean ($r^2=0.95$; Figure 5). This kind of dependence is expected with lognormal distributions. When the standard deviation is predicted using the regression equation in Figure 5, it is assumed to represent the “population standard deviation.” The ability to predict the standard deviation from the mean is very useful because it becomes possible to define the probability distribution for a standard of any magnitude.

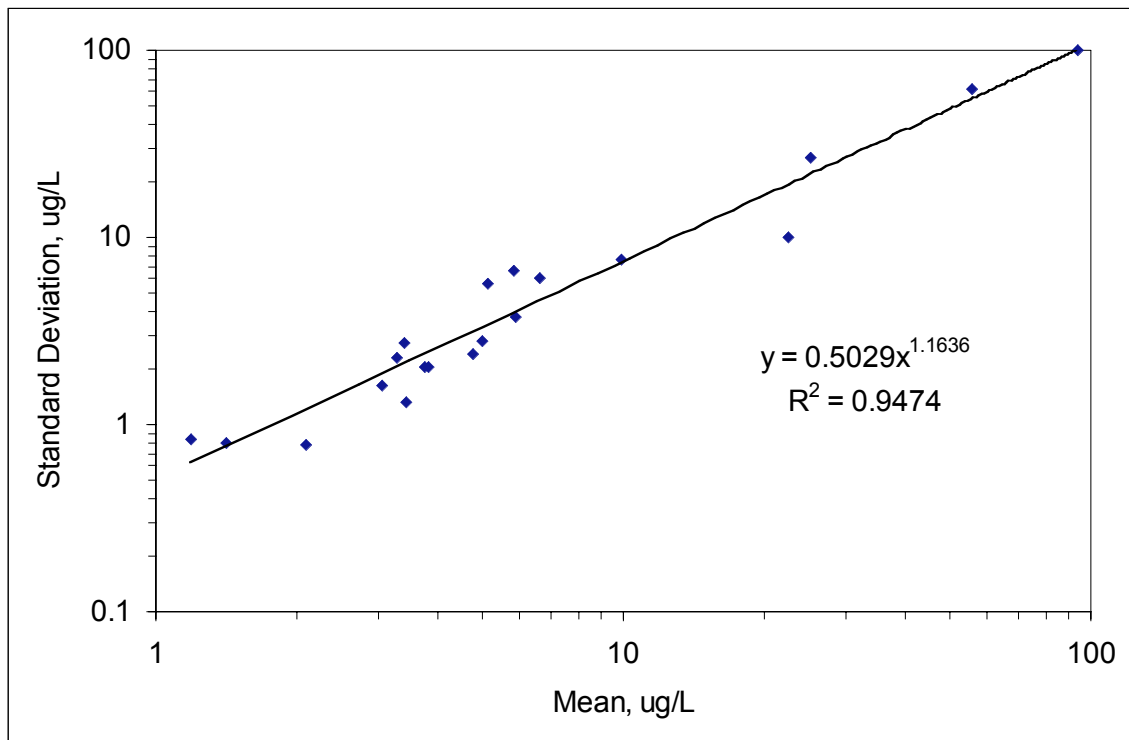


Figure 5. Relationship between mean and standard deviation of Jul-Sep chlorophyll data (untransformed) from 20 Colorado lakes. Both axes are plotted on log scales.

Each year, new measurements are made of chlorophyll concentration in the mixed layer of Chatfield Reservoir. Currently, these measurements are used to calculate the seasonal mean concentration, which is compared to the existing chlorophyll target of 17 ug/L. In the future, if a chlorophyll standard were adopted for Chatfield Reservoir, exceedance could be assessed on the basis of individual measurements, as well as the seasonal mean, using the following techniques.

Each new observation can be compared with values expected from the distribution of the standard using the statistical concept of the prediction interval. The question becomes: Is the new observation likely to have come from the same distribution underlying the standard, or is it from a different distribution (i.e., one with a larger mean)? A new observation that exceeds the 90th (or 95th) percentile for the distribution of the standard is likely to foreshadow a year in which the standard will not be attained. Prediction limits are shown in Table 1.

Some perspective is helpful for understanding why attention should be paid to individual observations that are large. Because chlorophyll concentrations in Chatfield are lognormally distributed, a probability can be attached to a measured value. Using the distribution defined previously for a chlorophyll standard of 17 ug/L and defining the prediction interval for the 90% percentile of the distribution, the threshold value for a new observation is 33 ug/L. This means that a single new observation greater than 33 ug/L is likely to signal a year in which the seasonal average will not be in attainment of the standard. The logic is made convincing by considering that if only three samples are taken, and one is at least 33 ug/L, the average is very likely to be in excess of 17 ug/L unless the other two observations are both very small (i.e., <10 ug/L). A single new observation outside of the prediction interval is thus a strong signal about algal abundance.

	Prediction Limit	Confidence Limit
90 th percentile	33.0	
95 th percentile	42.9	

Table 1. Prediction limits and confidence limits relevant to assessment of summer season chlorophyll measurements from Chatfield Reservoir. Calculations assume adoption of a seasonal standard of 17 ug/L.

Chlorophyll concentrations also can be assessed in terms of the summer mean. In this case, the observed mean is compared to the 90th or 95th percentile confidence interval for the distribution of the standard. Determination of the confidence limits, which is relatively simple for a normal distribution, becomes more challenging for lognormal distributions. The H-statistic procedure is often used for locating the percentile as an untransformed value, but concerns have been raised about this statistic (see Appendix B). The Division is still reviewing options for estimating confidence limits.

In situations where only a few samples are taken during the averaging period, the confidence interval is likely to be broad, making it difficult to say with much certainty that the standard has been exceeded. A weight-of-evidence approach, based on a

sequence of years where the mean is larger than the standard, might also be useful. One disadvantage of such an approach is that it can only be applied after data have been gathered for several years. Nevertheless, it is worth discussing a range of options as facets of an assessment strategy.

Future Considerations

Currently, chlorophyll concentrations in Chatfield Reservoir are substantially less than the existing target of 17 ug/L. At the same time, total phosphorus concentrations have exceeded the adopted standard of 27 ug/L. The apparent misalignment of the two constituents was a major motivation behind the technical review now underway to evaluate the “concentration translator.” Whether or not a chlorophyll standard is adopted in place of the phosphorus standard, the potential exists for the technical review to conclude that a higher phosphorus concentration would be consistent with the chlorophyll target. If that happens, it is likely to trigger consideration of anti-degradation provisions when permits are re-issued; not all of the increased assimilative capacity would automatically be available. While there is no reason to speculate now on where this would lead, it is important to make sure all parties are aware of the possibility.

This document is intended to promote discussion about chlorophyll standards and not to limit options. The Division has described a rationale for a chlorophyll standard and for assessing attainment, but has reached no formal conclusion about what might eventually be included in a proposal. There is no particular urgency for reaching conclusions at this time.