Oklahoma Water Resources Board

Lake Thunderbird Water Quality 2003

for the

Central Oklahoma Master Conservancy District

May 2004

Final Report

Oklahoma Water Resources Board
3800 N. Classen Boulevard
Oklahoma City, OK 73118

Executive Summary

Lake Thunderbird was stratified and anoxic conditions encompassed the hypolimnion at all main body sites in 2003. These can be considered typical conditions for Lake Thunderbird. Chlorophyll-a showed a eutrophic lake with periods of excessive algae growth. Chlorophyll-a content, the commonly accepted measure of algal content, exceeded the 20 µg/L goal in August, September, and October.

The Oklahoma Water Resources Board (OWRB) has provided environmental services to the COMCD since the year 2000. Following the first year the COMCD modified lake management to enhance water quality. Monitoring over the last three years has allowed a wider view of lake water quality. Without additional management, a reasonable expectation for Lake Thunderbird should be eutrophic (high) summer time algae growth with occasional periods of excessive algae growth (**Figure 0.1**). Statistical analysis of lake water quality data showed significant relationships between nutrients and chlorophyll-a. Total phosphorus was shown to be the single most important nutrient toward predicting chlorophyll-a concentrations. Options to reduce the tendency toward excessive algae growth in Lake Thunderbird include in-lake and watershed measures, either by reducing movement of nutrients from lake sediments into the water column or by reducing nutrient loading to the lake. Additional management will be needed to meet the 20 µg/L upper limit for algae growth. Methods to assess lake nutrient sources and show the effect of nutrient concentrations on algae growth are given.

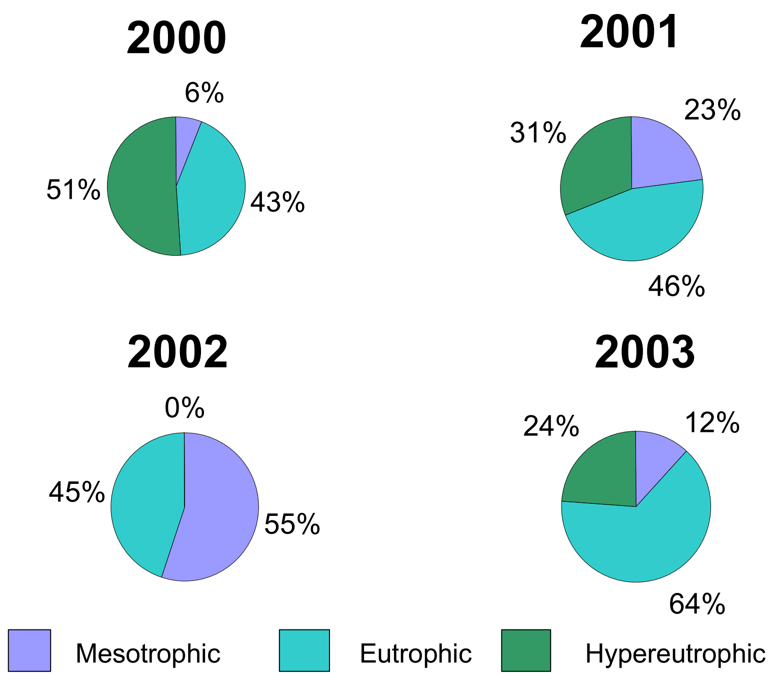

Figure 0.1: Percent distribution of trophic state using chlorophyll-a concentration May - September.

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Introduction

Lake Thunderbird was constructed by the Bureau of Reclamation and began operation in 1966. Designated uses of the dam and the impounded water are flood control, municipal water supply, recreation, and fish and wildlife propagation. As a municipal water supply, Lake Thunderbird furnishes raw water for Del City, Midwest City, and the City of Norman under the authority of the Central Oklahoma Master Conservancy District (COMCD). The Oklahoma Water Resources Board (OWRB) has provided water quality-based environmental services for the COMCD since 2000. The focus of OWRB services is the management of Lake Thunderbird.

When the OWRB first came aboard in 2000, algae content (as measured by chlorophyll-a content) was at excessive levels, putting Lake Thunderbird at risk of becoming a category 5 waterbody in Oklahoma's 303(d) list. This listing would have required extensive state and local action. In 2000 the OWRB evaluated lake management practices and facilitated water quality-based goal setting with the COMCD. Short-term goals established were to oxygenate the lake and determine the current capacity of the reservoir. A long-term goal of reducing summer chlorophyll-a below 20 µg/L (the breaking point for excessive algae growth) was also established (**OWRB, 2001**). Water quality monitoring in 2000 confirmed the state's assessment of excessive algae: over one-half of the samples were >20 µg/L. Evaluation of lake management practices concluded that the underpowered aeration system was not oxygenating the lake as intended and was likely stimulating algae growth. The OWRB recommended refurbishing or ceasing operation of the aerator for the next year.

For 2001, the COMCD ceased aeration and requested that the OWRB monitor reservoir water quality and determine lake capacity. 2001 chlorophyll-a data showed a significant reduction from the previous year with only 31% of the samples greater than 20 µg/L (**OWRB, 2002**). Cessation of aeration was the primary contributor to the reduction. Although significant, chlorophyll-a samples still exceeded the 20 µg/L level and the lake bottom lacked oxygen during summer stratification. Conceptual design of a whole lake-mixing system (to refurbish the current system) was completed; however the cost was significantly greater than previously estimated. No action was recommended without a cost-effective design to oxygenate the lake. The OWRB objective in 2002 was to continue seasonal water quality monitoring (**OWRB, 2003**). In 2002 reduced nutrient cycling within the lake facilitated low chlorophyll-a; the long-term goal of chlorophyll-a under 20 µg/l was achieved at all main body sites. OWRB objectives in 2003 were to assist municipalities in completing a pilot plant study, continue seasonal water quality monitoring, and compile a database of water quality data. Results of routine water quality monitoring are presented in this report. Results of the algae study and pilot plant study are presented in separate reports. Recommendations for 2004 water quality management are made following the report summary.

Water Quality Evaluation

Lake Thunderbird was sampled at the sites indicated in **Figure 1**. Sites 1, 2, and 4 represent the main body of the lake while site 3 represents the Hog Creek arm. Sites 5 and 6 represent the Little River arm of the lake and site 7 represents the Clear Creek arm. Turbidity, chlorophyll-a, Secchi disk depth, dissolved oxygen, temperature, and oxidation-reduction potential were monitored twice a month from May 1, 2003, through October 22, 2003, at all sites. Sampling for nutrients (nitrogen and phosphorus series) occurred three times: May 1, July 24, and September 16. Samples were taken at the surface and 0.5 meters from the lake bottom at each site. The diagnostic parameters for this report are temperature, dissolved oxygen, dissolved nitrogen and phosphorus constituents, and chlorophyll-a. Temperature and dissolved oxygen show water quality changes and the extent of stratification. Nitrogen and phosphorus are the primary chemical nutrients for algae growth. Chlorophyll-a serves as an indicator of algae content. The OWRB worked cooperatively with the OU Environmental Science Department and shared monitoring resources with a Master's candidate, Jackie Simmons, whose research topic is the water quality of Lake Thunderbird. Cooperation consisted of coordinating sample events to reduce duplication and loaning out a hydrolab unit for the vertical profiles. The OWRB was pleased to assist and facilitate the Environmental Science program at OU.

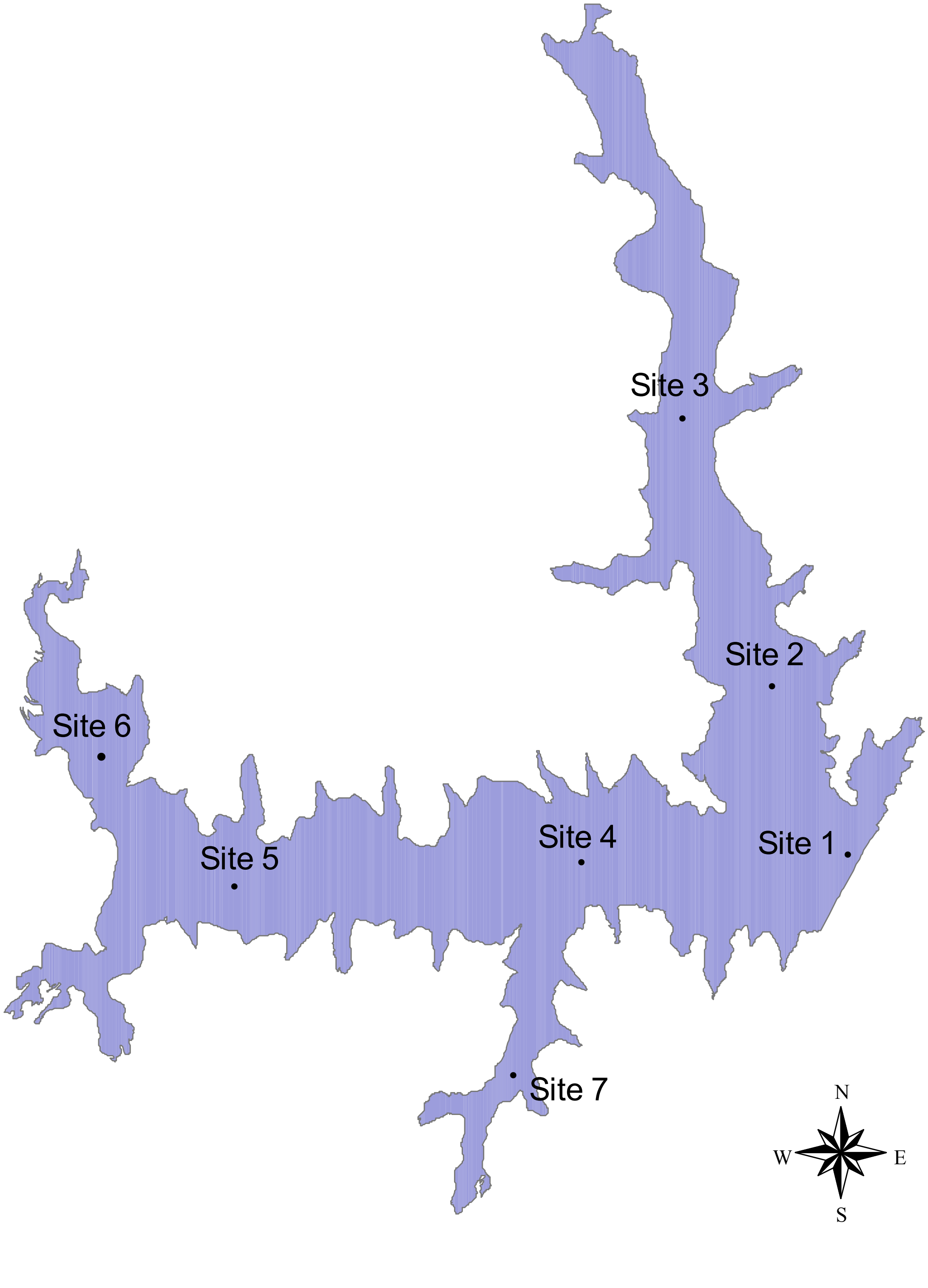

Figure 1: Lake Thunderbird sample sites.

Temperature and Dissolved Oxygen

In late spring and during summer when temperatures rise, lakes generally stratify thermally with a warmer, lighter layer of water (epilimnion) overlying a colder, deeper, and denser layer of water (hypolimnion). There is usually a transition layer between the epilimnion and the hypolimnion called the metalimnion or thermocline. The thermocline isolates the hypolimnion from the epilimnion and the atmosphere (**Figure 2**). The figure also shows the depletion of dissolved oxygen in the lower layer of the lake due to stratification and decaying organic matter in the hypolimnion. Decaying matter consume oxygen while oxygen recharge from the epilimnion is minimized by the metalimnetic barrier.

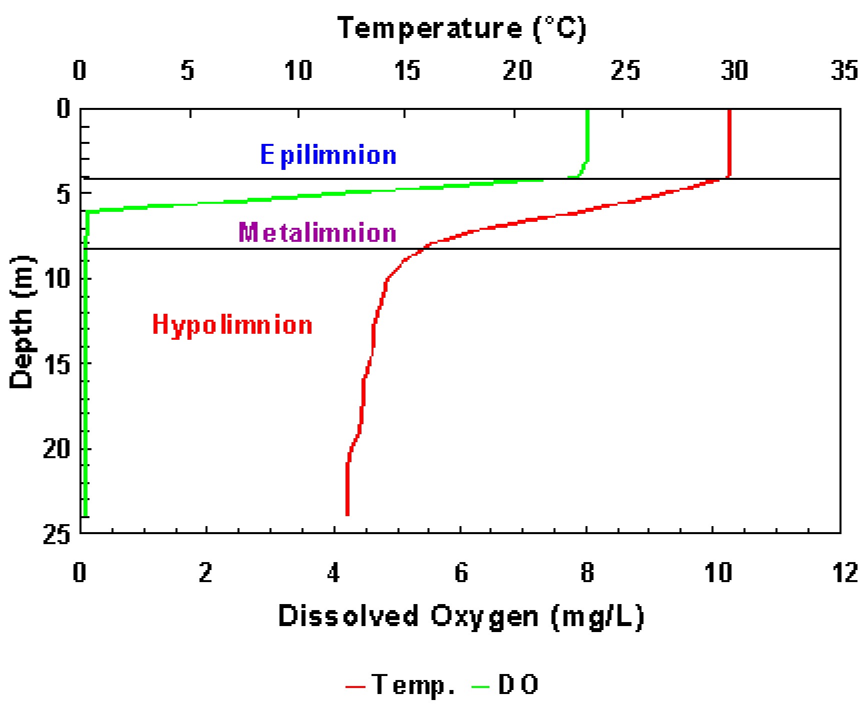

Figure 2: Temperature and dissolved oxygen profile for a typical eutrophic lake showing the three distinct layers (epilimnion, metalimnion and hypolimnion).

Prior to the onset of stratification, the lake has isothermal conditions throughout the water column. As stratification sets in and strengthens, the epilimnion stays homogenous while the metalimnion (thermocline) changes radically with depth until the hypolimnion is reached. This physical structure maintains until surface temperatures start to decline and epilimnetic temperatures match the top of the metalimnion. As cooling continues the thermocline disappears and fall mixing or "turnover" occurs. Lake stratification may have a significant effect on water quality by "trapping" nutrients or chemicals in areas of reduced exchange and water interaction (hypolimnion). This key feature can have implications for epilimnetic water quality.

Figure 3 depicts the 2003 pattern of stratification and destratification of Lake Thunderbird in monthly intervals. The green line in Figure 3 represents the boundary between the epilimnion and the metalimnion while the light blue line represents the boundary between the metalimnion and the hypolimnion. From May through July, the depth of the epilimnion remained consistent (6 meters). However, the extent of the metalimnion decreased from seven meters in May to two meters in July reflecting the continued heating of the epilimnion and increased density gradient in the metalimnion. The depletion of oxygen in the lower (hypolimnetic) layer of the lake was nearly completed in mid-May, however oxygen depletion increased until it encroached upon the metalimnion in July. This is indicative of a highly eutrophic system. Climatic events at the end of July and beginning of August caused surface water temperatures to cool and a deepening of the epilimnion. This partial mixing event heralded the onset of destratification. By the beginning of October, the lake showed isothermal conditions throughout the water column and complete mixing or destratification had completed.

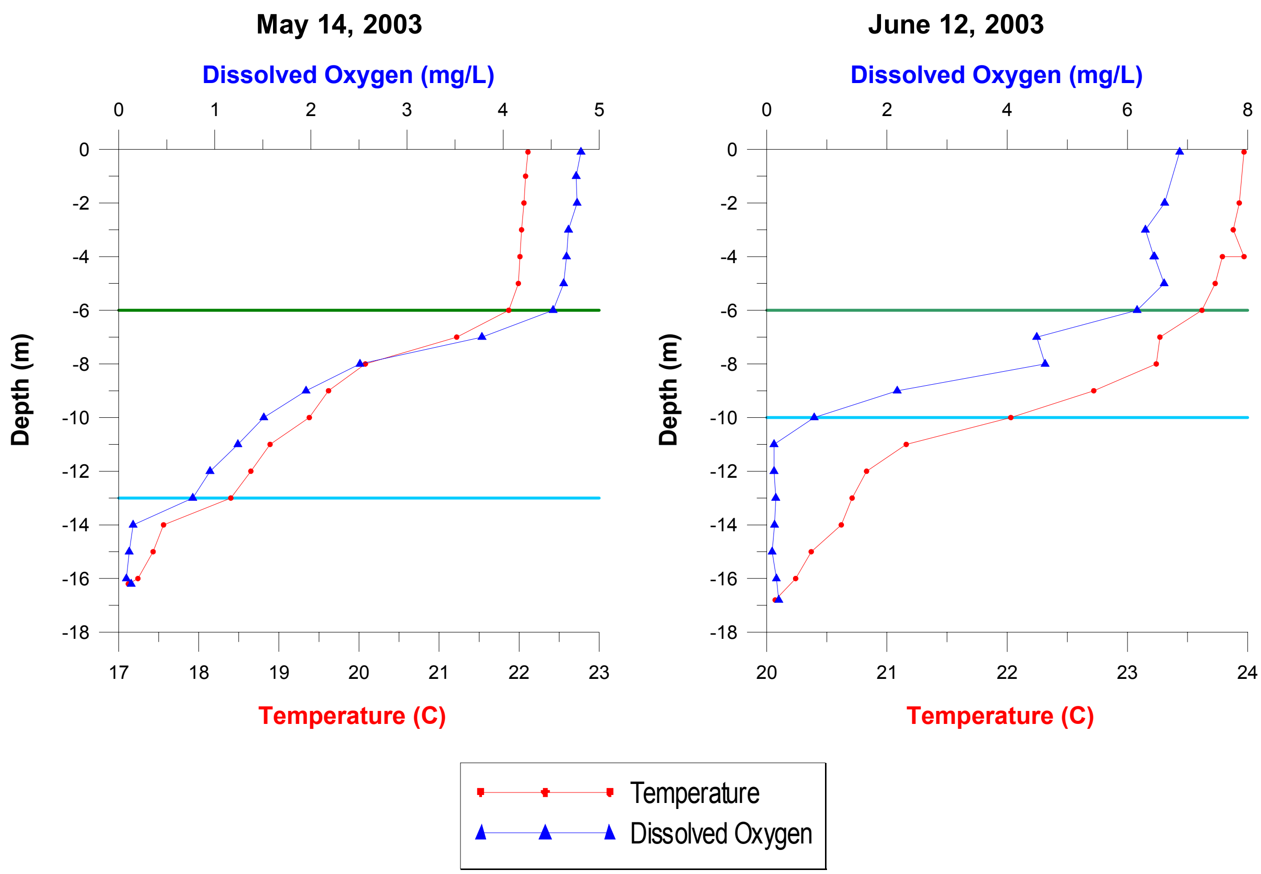

Figure 3: Temperature and dissolved oxygen profile for site 1 in Lake Thunderbird.

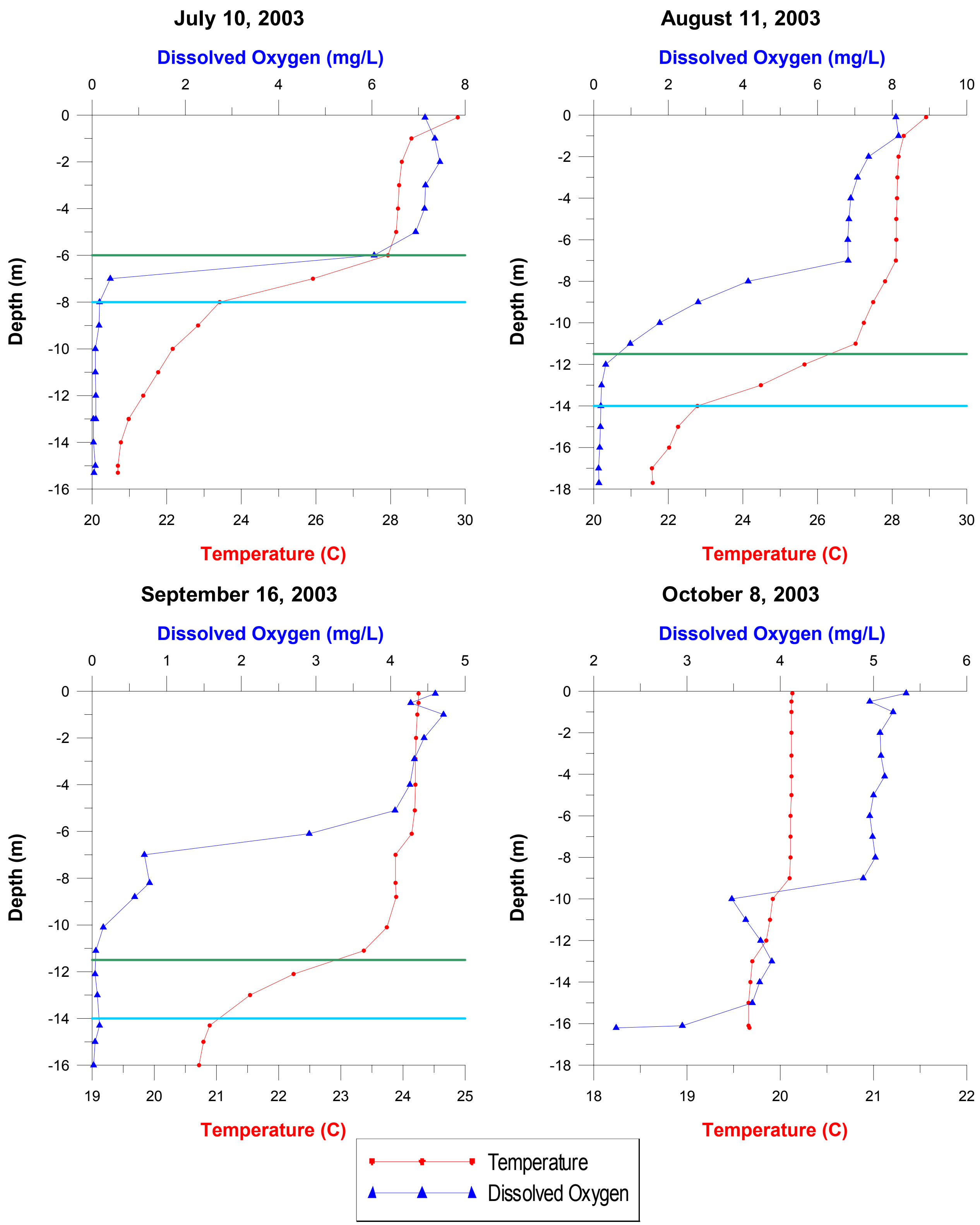

Figure 3 Continued: Temperature and dissolved oxygen profile for site 1 in Lake Thunderbird.

An alternative method for describing the physical conditions of Lake Thunderbird is the use of isopleths. These plots distill the biweekly monitoring with depth into a succinct (3-dimensional) summary of water quality over depth and time. Each line represents a specific temperature or dissolved oxygen value. When the lines are vertical, the dissolved oxygen and/or temperature are constant throughout the water column, and the temperature is termed “isothermal”. When the lines run horizontally, a strong gradient exists from top to bottom. For example, strong vertical temperature gradients indicate stratified water quality conditions. On the following graphs, Lake Thunderbird’s warmest temperatures are colored dark red. The red graduates into blue as temperature drops. High oxygen concentrations are colored blue. The blue graduates into red as the concentration drops to zero. The temperature isopleth of site 1 mirrors the information given in **Figure 3**.

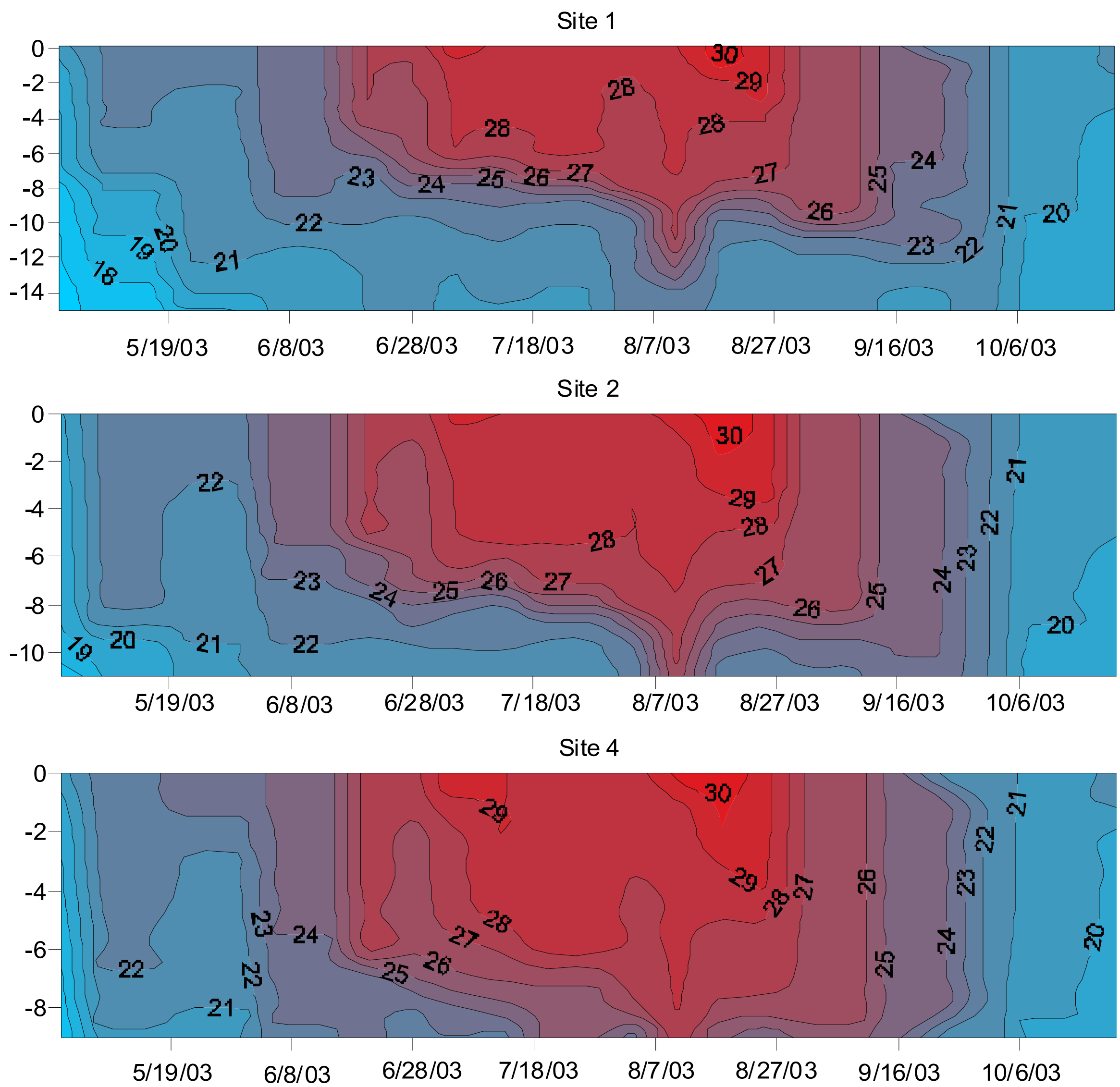

Figure 4: 2003 temperature isopleths for the main body of Thunderbird in degrees C.

2003 stratification began prior to the beginning of May and destratification was completed by the beginning of October (**Figure 4**). At the end of July and in mid August high winds, rain, and a cold front caused a small mixing event and the epilimnion increased in size. The small mixing event combined with an early cooling of atmospheric temperatures led to the early onset of turnover. The 2003 pattern approximates patterns seen in 2001. Unusual climatic features in 2002 may explain the difference between the three years.

The key feature for dissolved oxygen is anaerobic conditions, which is defined as dissolved oxygen less than 2 mg/L. Dissolved oxygen is lowered in the epilimnion by high plant and animal respiration rates. Bacterial respiration generally depletes oxygen trapped in the hypolimnion while dead algae feed the bacteria. When anaerobic conditions are reached at the lake bottom nutrients and other constituents are solubulized from the sediment into the water. When mixing events occur, the released nutrients can further stimulate algae growth. The release of nutrients from the sediment can be avoided by maintaining oxygen at the sediment/water interface. Delayed stratification, reduced algae growth and artificial oxygenation of the hypolimnion are means to stop or slow down the onset of anaerobic conditions in Lake Thunderbird.

Dissolved oxygen at the main lake sites showed similar plots for 2001, 2002 and 2003. Both the upper and lower lake layers are affected by algae growth: the upper will show elevated oxygen with high algae growth while the lower lake layer will show anaerobic (low to no oxygen) conditions due to the decomposition of dead algae. In 2003 anaerobic conditions began at the deeper sites and progressed to shallower sites (**Figure 5**). The pattern of anaerobic progression from deeper sites to shallow sites was also seen in 2001. This pattern of dissolved oxygen depletion does not follow the generalized pattern expected for reservoirs. According to **Thornton (1990)**, anaerobic conditions normally occur first in the shallow transition zone and progress to the deeper sites. The pattern of dissolved oxygen depletion progressing from shallow to deeper sites was observed in 2002. One explanation for the difference between the two patterns is the unusual climatic conditions seen in 2002 which caused a break in stratification in late May. That break in stratification may have oxygenated the deep bottom layer of the lake and shortened anaerobic conditions.

For all three years and at all sites, anaerobic conditions encompassed the hypolimnion. A comparison of days stratified versus days when an anaerobic hypolimnion was observed is a useful indicator of primary productivity or algae growth. When the number of days match for stratified and anaerobic conditions it can be concluded that high to excessive algae growth occurred. Such was the case in 2001. Lower growth was expressed in 2003 with a 13-day differential, and the lowest productivity was in 2002 with a 23-day differential (**Table 1**). This data suggests algae growth in 2003 was somewhere between that seen in 2001 and 2002. The presence of anaerobic conditions also predicts the release of nutrients from the sediment. These nutrients in turn will stimulate algae growth upon reaching the epilimnion. Higher algae growth then further increases the extent of anaerobic conditions.

Table 1: Comparison of stratified versus anaerobic hypolimnion as number of days for Lake Thunderbird Site 1, 2001-2003.

Days	2001	2002	2003
Stratified	139	126	138
Anaerobic	139	103	125
Difference	0	23	13
%Time Anaerobic	100%	82%	91%

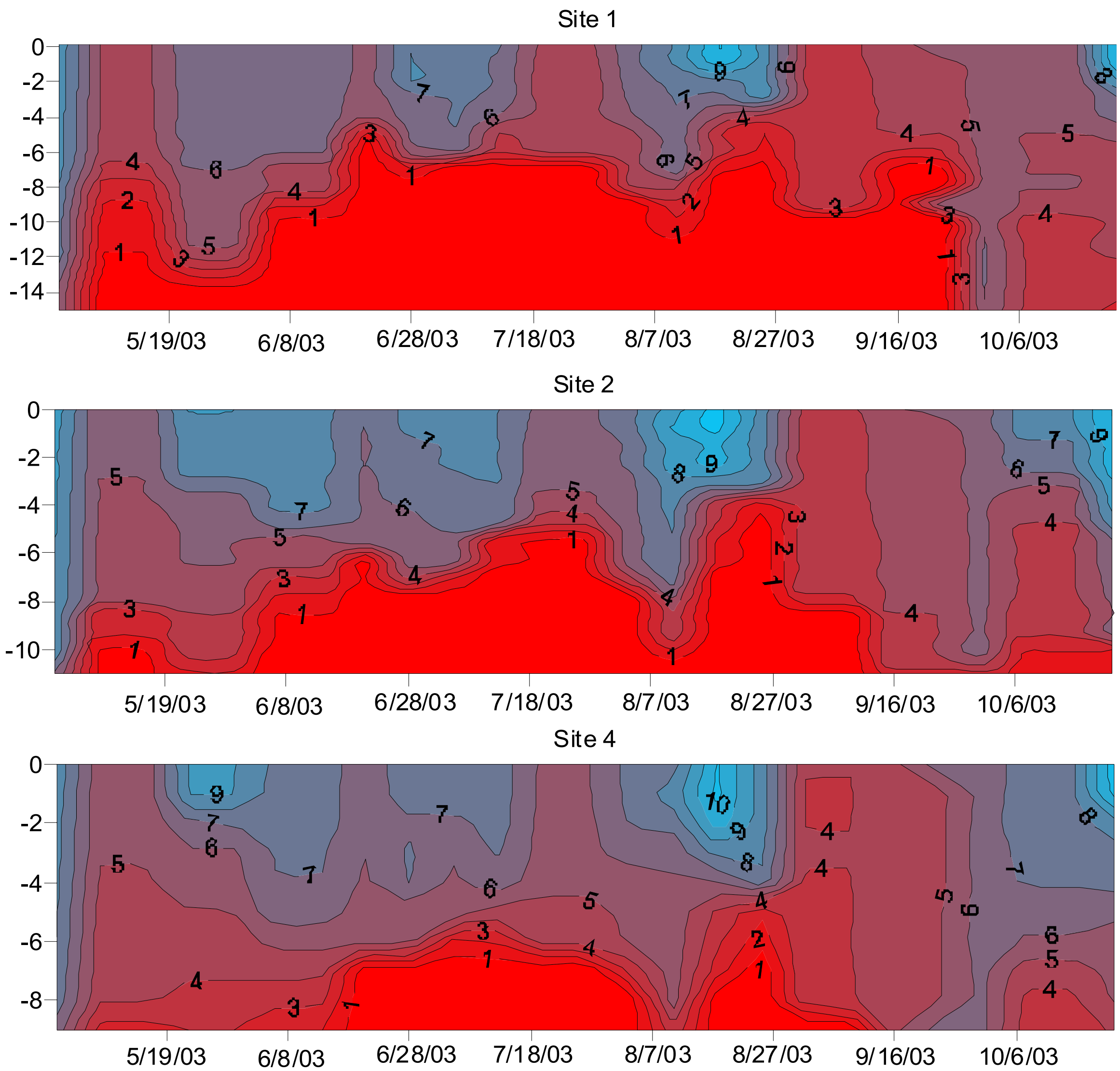

Figure 5: 2003 dissolved oxygen isopleths for the main body of Thunderbird in mg/L.

Nutrients

Nutrient samples were collected three times during the season. Samples taken in April and May represent spring conditions, samples from July represent summer conditions, and samples from September represent fall conditions. While several measures of nitrogen and phosphorus were made, only dissolved nutrient totals are presented. Dissolved nutrient totals indicate the raw materials available for algal growth. Total phosphorus can also sometimes indicate the total amount of algae present. High values in the epilimnion generally indicate nutrients immediately available for algal growth while high values in the hypolimnion indicate nutrients available for future algae growth. The higher dissolved nitrogen values in bottom samples show hypolimnion accumulation of ammonia. This is to be expected with an anaerobic hypolimnion.

Dissolved nutrients (nitrogen and phosphorus) in the epilimnion can also indicate what may be limiting algae growth. Generally when they are both available, nutrients are not limiting algae growth and excessive chlorophyll-a values are expected. When dissolved phosphorus is readily available but very low dissolved nitrogen, algae growth may be limited by nitrogen. High to excessive levels of algae growth can be expected under nitrogen-limited conditions. Nitrogen-limited conditions also cause a shift in the algae species present towards the blue-green algae. Blue-green algae have a competitive edge under nitrogen-limited conditions due to their ability to “fix” atmospheric nitrogen into a form usable for algal uptake using specialized cells called heterocysts. Blue-green algae with the ability to create their own nitrogen fertilizer also have the ability to create chemicals that cause objectionable taste and odors as well as toxic chemicals. In short, nitrogen limitation is not desirable for Lake Thunderbird.

Phosphorus limitation is the normal state for most freshwater systems. The 2002 monitoring season was indicative of phosphorus-limited conditions. Here none of the chlorophyll-a samples showed excessive growth and less than half showed high growth. Very low to non-detectable ortho-phosphorus and increasing dissolved nitrogen can be a hallmark of phosphorus-limited algae growth. Because phosphorus limitation has slowed algae growth, dissolved nitrogen, unused for algae growth, can increase in the epilimnion. Under phosphorus limiting conditions more desirable green algae will be present replacing the less desirable nitrogen-fixing blue-green algae.

Maximum nitrogen and phosphorus levels were noted in the bottom (hypolimnetic) lake layer. A comparison for each site and depth showed a general decrease in 2003 nitrogen levels when compared to 2002. At site 1, the 2003 maximum nitrogen levels were the lowest seen in the three years of sampling. Those maximum nitrogen levels were 1.05 mg/L in 2003, compared to 2.6 mg/L in 2002, and 3.4 mg/L in 2001 (**Figure 6**). The presence of dissolved nitrogen species in the hypolimnion is consistent with anaerobic conditions and reflects an accumulation of nutrients for future algae growth. The depression of dissolved surface nitrogen at the summer sample each year indicates algae growth not limited by nitrogen. The elevation or accumulation of dissolved nitrogen for surface samples in the fall of 2002 is notable and will be discussed in relation to phosphorus in the next section.

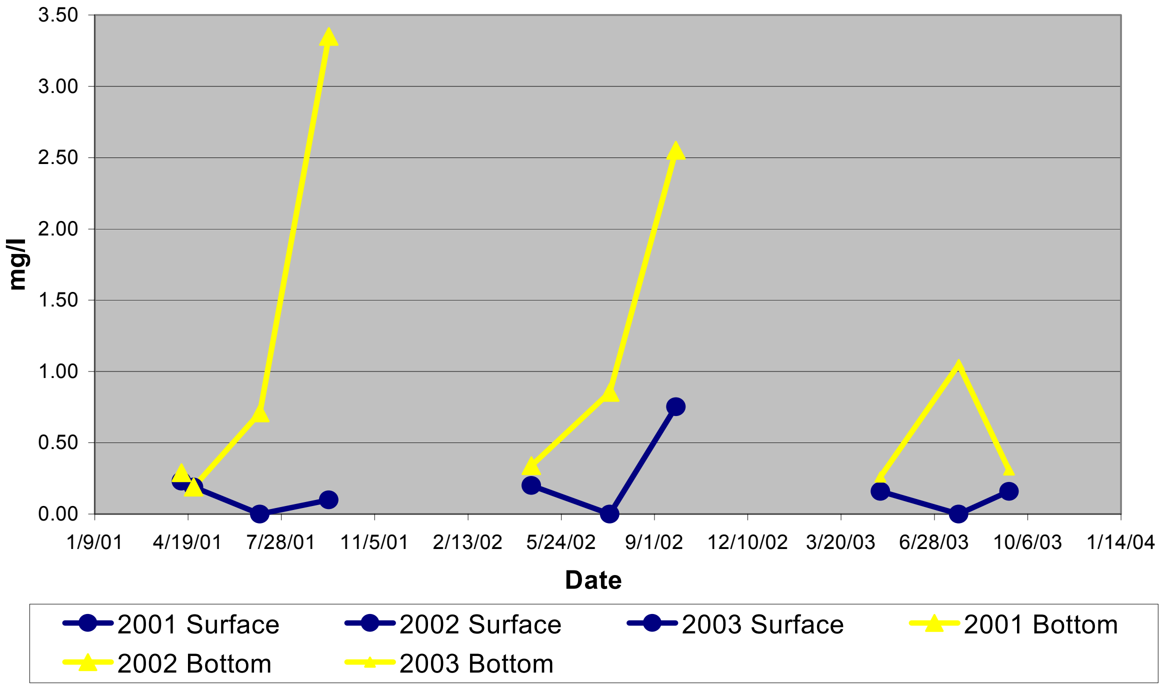

Figure 6: Total dissolved nitrogen species concentrations for site 1.

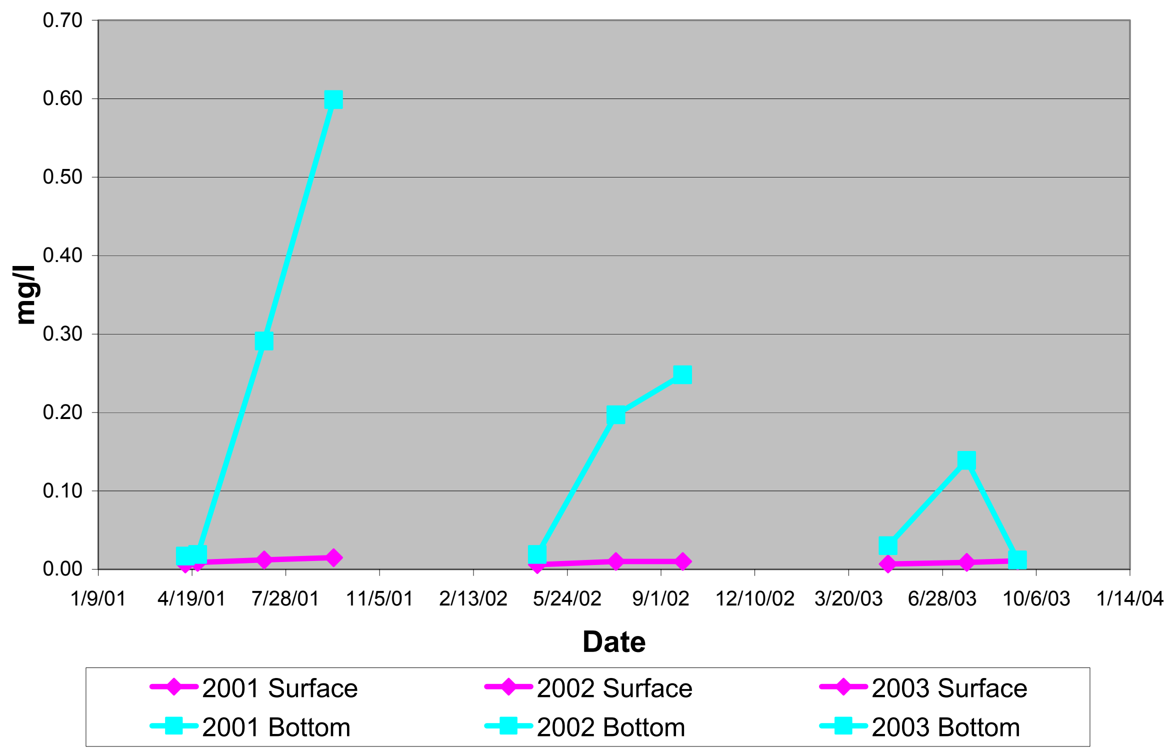

Figure 7: Dissolved ortho-phosphorus concentrations for site 1.

Dissolved ortho-phosphorus is the form of phosphorus most easily used by algae for growth. As with dissolved nitrogen, the relatively higher levels in bottom samples show phosphorus accumulation in the hypolimnion. Phosphorus in the hypolimnion is released from the sediment under anaerobic conditions. This phosphorus release is considered internal loading, though it originally entered the lake through external loading from the lake's watershed. There has been a steady decline for site 1 maximum ortho-phosphorus levels in the past three years, 0.14 mg/L in 2003, compared to 0.25 mg/L in 2002, and 0.60 mg/L in 2001 (**Figure 7**). Aside from this difference at site 1, little year-to-year variation is noted for the other sites and samples. In short, phosphorus is released from the lake bottom during stratification. These hypolimnetic nutrients when brought to the surface can further stimulate algae growth.

Generally, as long as the lake is stratified, surface or epilimnetic nutrients are the primary determinant of algae growth. Average epilimnetic total phosphorus was tabulated from the open water sites (sites 1, 2 and 4) for each season to indicate relationships between nutrients and algae (**Table 2**). Late April and early May samples represented spring, mid-July samples represented summer, and mid and late September samples represented fall. Distinct patterns were noted between sample seasons (spring, summer and fall) as well as between years. In general total phosphorus was at about the same level (around 20 μg/L) each spring. 2002 was distinct in that the total phosphorus did not significantly increase over the growing season (ranged from 20 to 19 μ/L). It is also notable that dissolved nitrogen increased in the epilimnion in 2002. The two facts, low total phosphorus and relatively high dissolved nitrogen, are a clear indication of algae growth limited by phosphorus. 2001 and 2003 were similar in that total phosphorus increased over the growing season. In 2001 the increase started earlier (in the summer) while the increase was not noted until later in the season (fall) in 2003.

Table 2: Mean total phosphorus concentrations for surface samples in μg/L for Lake Thunderbird sites 1, 2, and 4.

Year	Spring	Summer	Fall
2001	24	40	50
2002	20	20	19
2003	20	24	43

These patterns of total phosphorus changes within seasons and years will be compared to the changes of chlorophyll-a as a first step toward establishing a relationship between epilimnetic nutrients and algae content. The hypothesis suggested by these patterns is that chlorophyll-a will follow total phosphorus concentration in a linear fashion.

Chlorophyll-a

Chlorophyll-a, the molecule or pigment common to all algae for growth, is a commonly accepted measure of algae content. Goal setting in 2000 by the COMCD, the three municipalities, and OWRB resulted in an upper limit of 20 µg/L of chlorophyll-a for open water sites during the growing season. This upper limit represents a commonly accepted boundary between high (eutrophic) and excessive (hypereutrophic) algae growth. The boundary between eutrophic and lower (mesotrophic) algae growth is 7.2 µg/L. These two boundaries are presented on all Lake Thunderbird chlorophyll-a plots. Data analysis earlier in this report suggests high algae growth in 2003 based on a high percentage of stratified dates that show anaerobic conditions. The relative increase of dissolved nutrients in the surface waters throughout 2003 indicates a high potential for algae growth.

2003 chlorophyll-a was relatively steady until July when concentrations increased until the end of August. From this late summer peak, chlorophyll-a concentrations decreased from the end of August until a post-stratification peak in October (**Figure 8**). These specific observations followed the general nutrient predictor of low algae levels until after the mid-July summer sample. Examination of 2002 chlorophyll-a concentrations showed consistently low algae content (**Figure 9**). The relatively flat chlorophyll-a and low epilimnetic phosphorus values in 2002 suggest phosphorus was the limiting nutrient in 2002. In 2001 chlorophyll-a was relatively steady until July when concentrations steadily increased through September (**Figure 10**). This pattern also seemed to match the relatively large increase of epilimnetic total phosphorus noted in the summer and fall samples. The seemingly close track of chlorophyll-a and epilimnetic total phosphorus noted over the last three years suggests the potential to predict chlorophyll-a (or algae growth) by knowing the total epilimnetic phosphorus concentration.

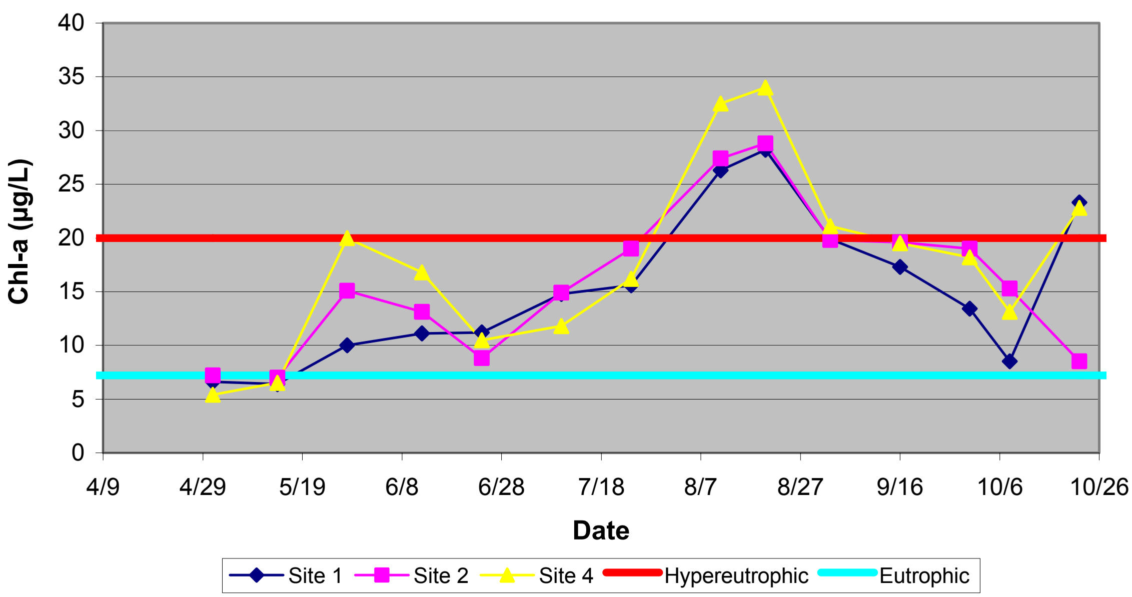

Figure 8: 2003 chlorophyll-a concentrations for main body sites.

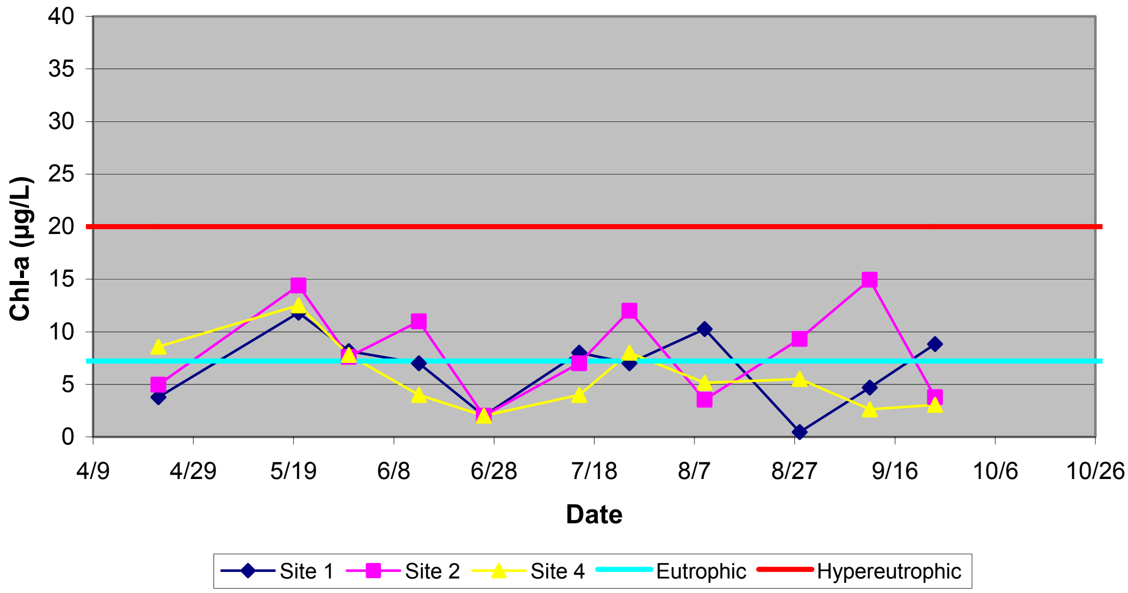

Figure 9: 2002 chlorophyll-a concentrations for main lake body sites.

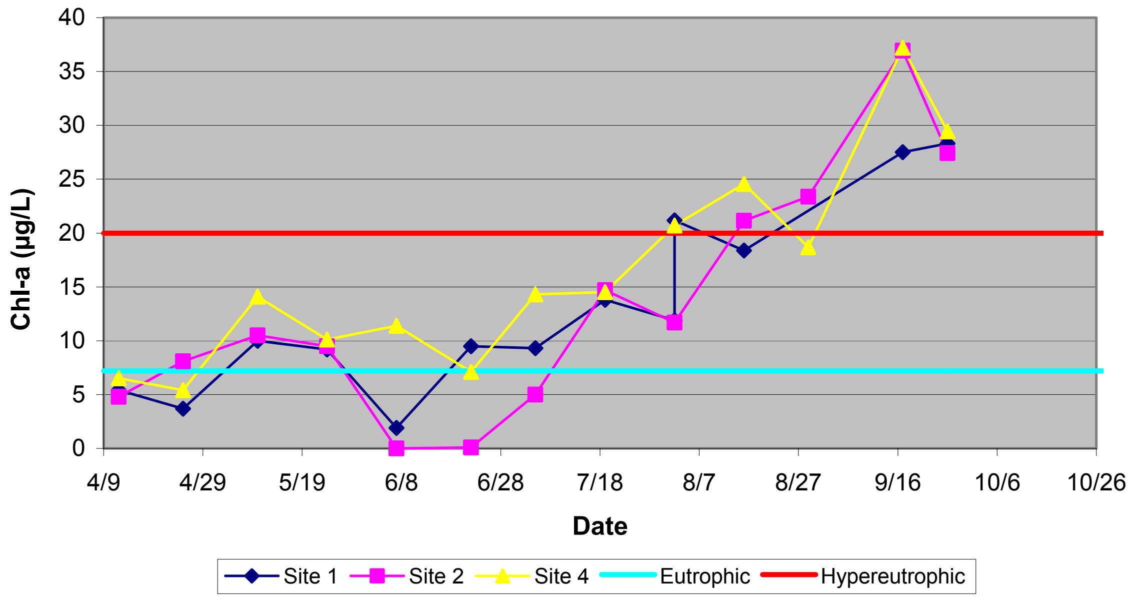

Figure 10: 2001 chlorophyll-a concentrations for main lake body sites.

Statistical Analysis

Sufficient nutrient and algae data has been gathered while under consistent lake management (2001 – 2003) to seek the relationship between lake nutrients and algae growth in the main body sites. Such a relationship could allow for predicting a main lake body nutrient concentration to maintain chlorophyll-a at or below 20 µg/L. Water quality parameters of nutrients: Kjeldahl nitrogen, total nitrogen, dissolved nitrogen (ammonia-N + nitrate-N + nitrite-N), ortho-phosphorus, and total phosphorus, as well as measures of transparency: Secchi disk depth and turbidity, were compiled with corresponding chlorophyll-a values on a sample-by-sample basis.

With this data set, statistical tests using Minitab© software were performed. First, regressions of chlorophyll-a versus separate water quality parameters were performed seeking the most influential parameters on chlorophyll-a. The regression is considered significant when a p-value is less than 0.05. Only statistically significant regressions are given. Initial evaluation showed the 2002 data to reduce the significance of regression analysis. The numerous below detection limit reports for ortho-phosphorus in 2002 interfered with meaningful regression analysis. For this reason the 2001 and 2003 data sets were used to develop a relationship between nutrients and chlorophyll-a. Three equations were developed with increasing degrees of complexity predicting chlorophyll-a from nutrients. The utility of developing these equations is to enable predictions of algae response to variable lake nutrient levels.

The simplest regression predicts chlorophyll-a best by using surface total phosphorus concentration with a R^2 of 36.1% (Equation 1). Equation 1 says for every 0.01 mg/L change of phosphorus, chlorophyll-a will change by 6.32 µg/L. This equation also predicts chlorophyll-a of 20 µg/L when total phosphorus reaches 0.040 mg/L. The second equation, incorporating the nitrogen/phosphorus ratio and substituting ortho-phosphorus for total phosphorus, has an R^2 of 69.3% (Equation 2). In general, for every 0.01 mg/L change in ortho-phosphorus, chlorophyll-a should change by approximately 23 µg/L. This equation predicts chlorophyll-a will reach to 20 µg/L level when ortho-phosphorus is above 0.013 mg/L independent of the N:P ratio. N:P ratios in Lake Thunderbird have fluctuated between 7 and 180, suggesting the influence of the N:P ratio is much less than ortho-phosphorus. The third equation adds kjeldahl nitrogen to the parameters in equation 2, for an R^2 of 79.9% (Equation 3). In general, for every 0.01 mg/L change of ortho-phosphorus, chlorophyll-a should change by approximately 18 µg/L.

Equation 1: Chlorophyll-a = -5.49 + 632 * Total P

Equation 2: Chlorophyll-a = -7.56 - 0.146 * N:P + 2312 * Ortho P

Equation 3: Chlorophyll-a = -7.91 - 0.316 * N:P + 14.9 * KjN + 1856 * Ortho P

Chlorophyll-a (µg/L)
Total P = total phosphorus as P (mg/L)
N:P = ratio of total nitrogen to total phosphorus
Ortho-P = ortho-phosphorus as P (mg/L)
KjN = Kjeldahl nitrogen as N (mg/L)

Limitations exist for each equation developed. For example, as phosphorus levels decrease and N:P ratios increase, equations 2 and 3 break down and predict negative chlorophyll-a. This shows that these regressions are most applicable during nutrient rich periods. Equation 1 worked the best under lower phosphorus conditions but was not very accurate. The lack of data during phosphorus limited periods has limited predictive ability. Overall, regression analysis showed that the addition of nutrients, whether nitrogen or phosphorus, will increase chlorophyll-a in Lake Thunderbird. The sensitivity of chlorophyll-a to nutrients appears to be highest for ortho-phosphorus, and lower for total phosphorus, kjeldahl nitrogen and N:P ratio. Ortho-phosphorus seems to affect chlorophyll-a by approximately 20 µg/L for every 0.01 mg/L. Total phosphorus seems to effect chlorophyll-a by approximately 6 µg/L for every 0.01 mg/L. Kjeldahl nitrogen seems to effect chlorophyll-a by approximately 0.15 µg/L for every 0.10 mg/L. N:P ratio has the potential to vary chlorophyll-a by 3 µg/L for every 10 unit change.

Trophic Status

While chlorophyll-a is a commonly accepted surrogate for algae content, surface algae samples were taken in 2001, 2002, and 2003 as a direct measure of algae content. That data is presented in a separate report (**OWRB, 2004**).

A simple and effective management tool for tracking algae growth in lakes worldwide is to express chlorophyll-a as trophic status. Here the concentration of chlorophyll-a is correlated to the biomass of algae in the sampled water. **Carlson's (1977)** trophic state index is one of the most commonly used measurements to compare lake trophic status, which is based on algal biomass. Carlson's TSI uses chlorophyll-a concentrations to define level of eutrophication on a scale of 1 to 100. The trophic scale is set up so that a ten-unit increase in trophic state represents a doubling of algae biomass.

The OWRB's statewide lakes sampling program assigns one of three trophic states to Oklahoma reservoirs on an annual basis. A lake is considered oligotrophic below 40, mesotrophic from 41-50, eutrophic 51-60, and hypereutrophic when greater than 60 (**OWRB, 2002**). The biological condition of the waterbody indicates the lake's level of nutrient enrichment or eutrophication. The relatively high chlorophyll-a values led the OWRB to lump mesotrophic and oligotrophic values together for ease of presentation and evaluation.

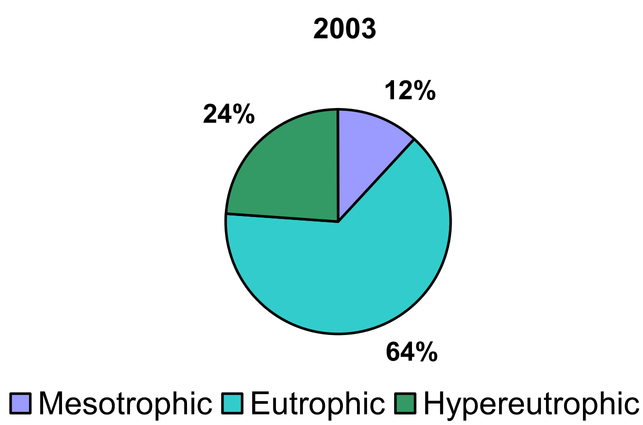

Figure 11: Trophic state summary of 2003 chlorophyll-a data.

The summary for 2003 summer shows Lake Thunderbird to be eutrophic (high algae growth) 64% of the time while almost one quarter of the time (24%) samples were hypereutrophic and 12% of the samples were mesotrophic (less than eutrophic) (**Figure 11**). Overall, this pie chart represents a eutrophic lake with periods of excessive algae growth. Prior to the 2003 sample season the relative percentage of eutrophic samples for each sample season varied near 45% with the percentages of hypereutrophic and mesotrophic oscillating (**Figure 12**). Unfortunately, 2003 showed a large increase in eutrophic conditions in comparison to previous years. With three years of consistent management it may reasonable to start characterizing the trophic condition of Lake Thunderbird during the summer period: excessive algae growth will occur with regularity without additional management. Options to reduce the tendency toward excessive algae growth in Lake Thunderbird include in-lake and watershed measures, either by reducing the movement of nutrients from the sediment into the water column or reducing nutrient loading to the lake.

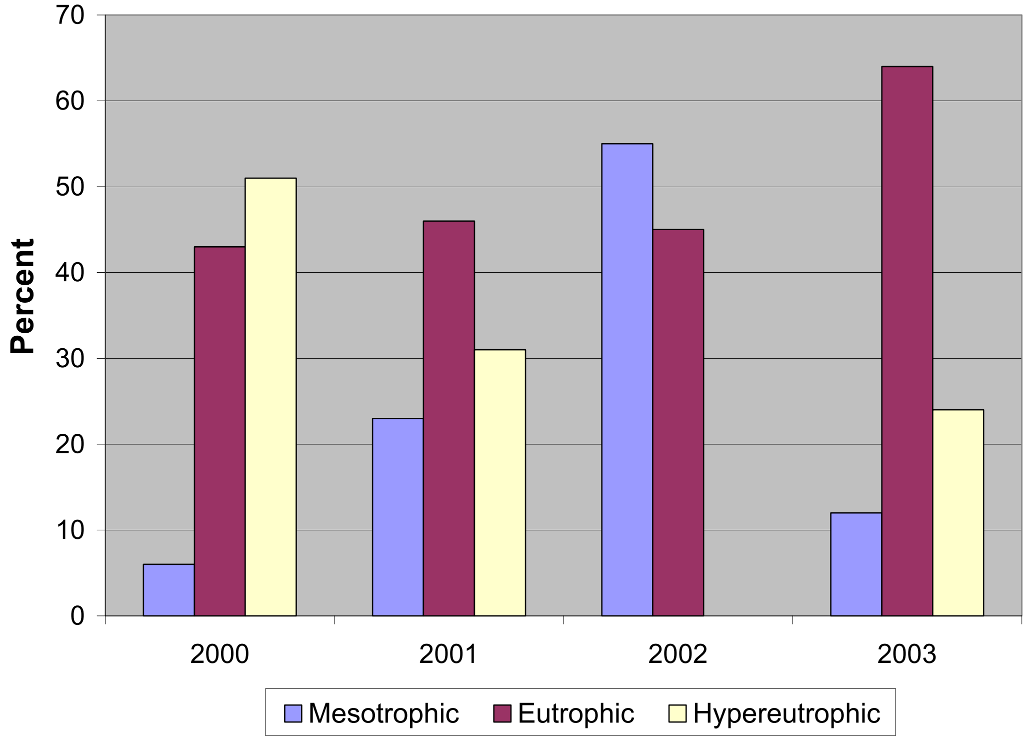

Figure 12: Trophic state using chlorophyll-a concentration for 2000 through 2003 monitoring seasons.

Summary

Monitoring in 2003 showed a set of physical conditions typical for Lake Thunderbird and similar to those seen in 2001. In 2003, stratification began in the spring and continued through September. Hypolimnetic oxygen dynamics indicate a rapid consumption of the oxygen trapped in the hypolimnion. Dead and dying algae settling from the hypolimnion are contributors to the hypolimnetic oxygen consumption. Depletion of hypolimnetic oxygen subsequently triggers solubulization of nutrients from the lakebed into the hypolimnion. Partial mixing (and deepening) of the epilimnion in early August stimulated excessive algae growth into the fall period. Lake mixing in late September served to temporarily depress algae growth but also to mix in new nutrients for the excessive growth noted in October.

An overview of all the collected data suggested a strong relationship between epilimnetic nutrients and chlorophyll-a. Significant relationships were identified. Statistical analysis indicated that chlorophyll-a values could be predicted utilizing ortho-phosphorus, total phosphorus, kjeldahl nitrogen and total nitrogen values. Statistical analysis also revealed that total phosphorus is the single most important variable in predicting chlorophyll-a.

Chlorophyll-a content, the commonly accepted measure of algal content, exceeded the 20 µg/L goal in August, September and October (**Figure 8**). Although higher than in 2002, the proportion of excessive algae or hypereutrophic samples was lower than in 2000 and 2001 (**Figure 13**). Unfortunately 88% of the samples in 2003 were eutrophic (high) or hypereutrophic (excessive) algae growth, second only to 2000 when 94% of the samples were eutrophic or greater. The trophic status of Lake Thunderbird in 2002 was eutrophic, punctuated by hypereutrophic growth.

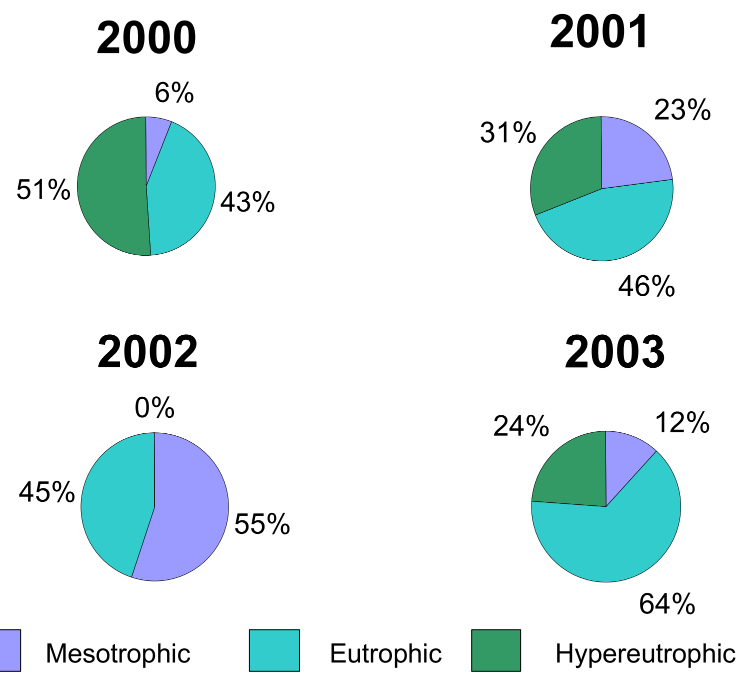

Figure 13: Percent distribution of trophic state using chlorophyll-a concentration May-September.

These data indicate that for chlorophyll-a to remain under 20 µg/L, epilimnetic nutrients need to decrease. Primary sources of nutrients are tributary inflow and the lake bottom itself. To estimate the impact of nutrient sources on chlorophyll-a modifications and additions to the current monitoring schedule are needed.

Recommendations

Determine the feasibility of oxygenating the hypolimnion of Lake Thunderbird. Maintaining an oxidized hypolimnion reduces the movement of nutrients from the lake bottom into the epilimnion, where nutrients can be used for algae growth. It is possible that this action could eliminate hypereutrophic (excessive) algae growth during the summer period. Previously, the OWRB provided the concept design to mix the entire water column in order to achieve an oxygenated water column. Implementation of a whole lake mixing system proved to be too costly to implement. Less energy intensive methods exist to accomplish oxygenation such as layered or hypolimnetic aeration. These and other options should be evaluated for Lake Thunderbird.

Increase nutrient sampling to monthly schedule. Routine nutrient data segregated by depth would allow for in-depth analysis of sediment-derived nutrients.

Extend water quality monitoring to include April, continue to monitor in October and include tributary water quality data collection. Lake data collected prior and subsequent to stratification will aid in determining nutrient sources, as will sampling the main tributaries (Hog Creek and the Little River). Efforts to include storm flow events should be a priority. The OWRB has sampled Lake Thunderbird as part of its statewide assessment program. These samples can be leveraged to aid nutrient source assessments.

Evaluative processes. The OWRB recommends that increased monitoring of the lake and tributary are placed in the context of nutrient sources. Additional work will be needed to develop estimates of nutrient sources, loads, and a predictive model. The predictive model can be used to estimate the impact of various management options. The University of Oklahoma, City of Norman, and the Bureau of Reclamation are potential partners to lend technical and fiscal support.

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