Oklahoma Water Resources Board

Lake Thunderbird
Algae and Water Quality
2002

for the

Central Oklahoma Master Conservancy District

July 2003

Final Report

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

Executive Summary

Chlorophyll-a content, the commonly accepted measure of algae content, was the lowest in three years of monitoring by the OWRB and well below the goal set in 2000 by the COMCD and municipalities. Although impressive, Lake Thunderbird continues to be considered "eutrophic" or having high levels of algal growth. The monitoring years of 2000, 2001 and 2002 show a dramatic reduction of algal growth (**Figure 0. 1**). The stark reductions noted imply that in-lake management techniques can be an effective means of controlling algal growth in Lake Thunderbird.

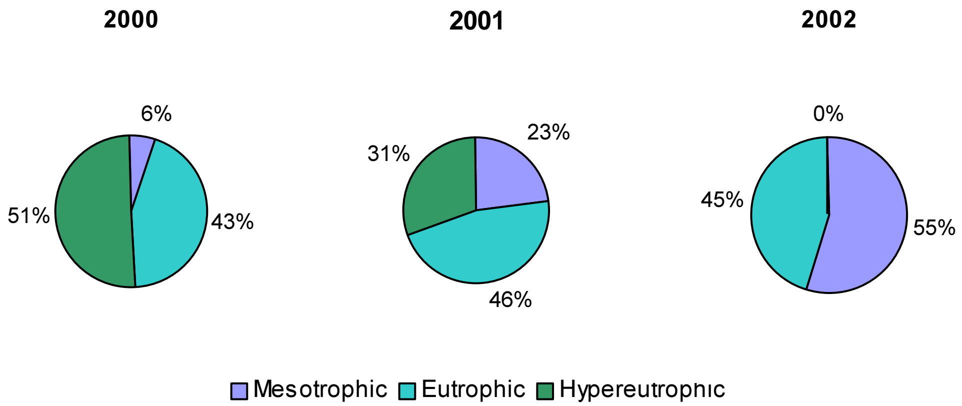

Figure 0. 1: Percent distribution of trophic state using chlorophyll-a concentration May - September.

Because abnormal climatic conditions during the spring of 2002 reduced nutrient cycling within the lake, COMCD should not expect similar chlorophyll-a levels in subsequent years.

Data was also assessed for algae's ability to affect water supply, as the organic portions in algae contribute to the production of disinfection by-products, taste and odor (T&O) chemicals and toxin production. No clear pattern of algae content and water supply complaints by City of Norman was seen. The clearest link between lake conditions and water supply was the concurrence of lake destratification and peak of Norman drinking water complaints in September. Additional information on the lake and water supply side is needed to provide a proper evaluation.

Two species of algae identified have the potential to produce toxic chemicals. One species was only noted in 2001 while the other was present both years. Cell density of *Cylindrospermopsis raciborskii* presented a low to moderate risk from direct exposure or accidental ingestion in 2001 and low risk in 2002. This risk was for recreational exposure. No evidence of risk was noted for water supply.

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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. 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 COMCD. The Oklahoma Water Resources Board (OWRB) has provided water quality-based environmental services for the Master Conservancy District (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 being placed on 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 and its municipal customers. 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 20µg/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 20µg/L (**OWRB, 2002**). Cessation of aeration was the primary contributor to the reduction. Although significant, chlorophyll-a samples still exceeded the 20µg/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. OWRB objectives in 2002 were narrowed to assisting municipalities in completing a pilot plant study and continuing seasonal water quality monitoring. Pilot plant testing was delayed until 2003 to allow for a full season of lake monitoring. Results of routine water quality monitoring have been compiled and presented in this report. Recommendations for 2003 follow the discussion.

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 April 22, 2002, through September 24, 2002, at all sites. Sampling for nutrients (nitrogen and phosphorus series) occurred three times: April 22, July 15 and September 24. Samples were taken at the surface and 0.5 meter from the bottom at each site. The diagnostic parameters

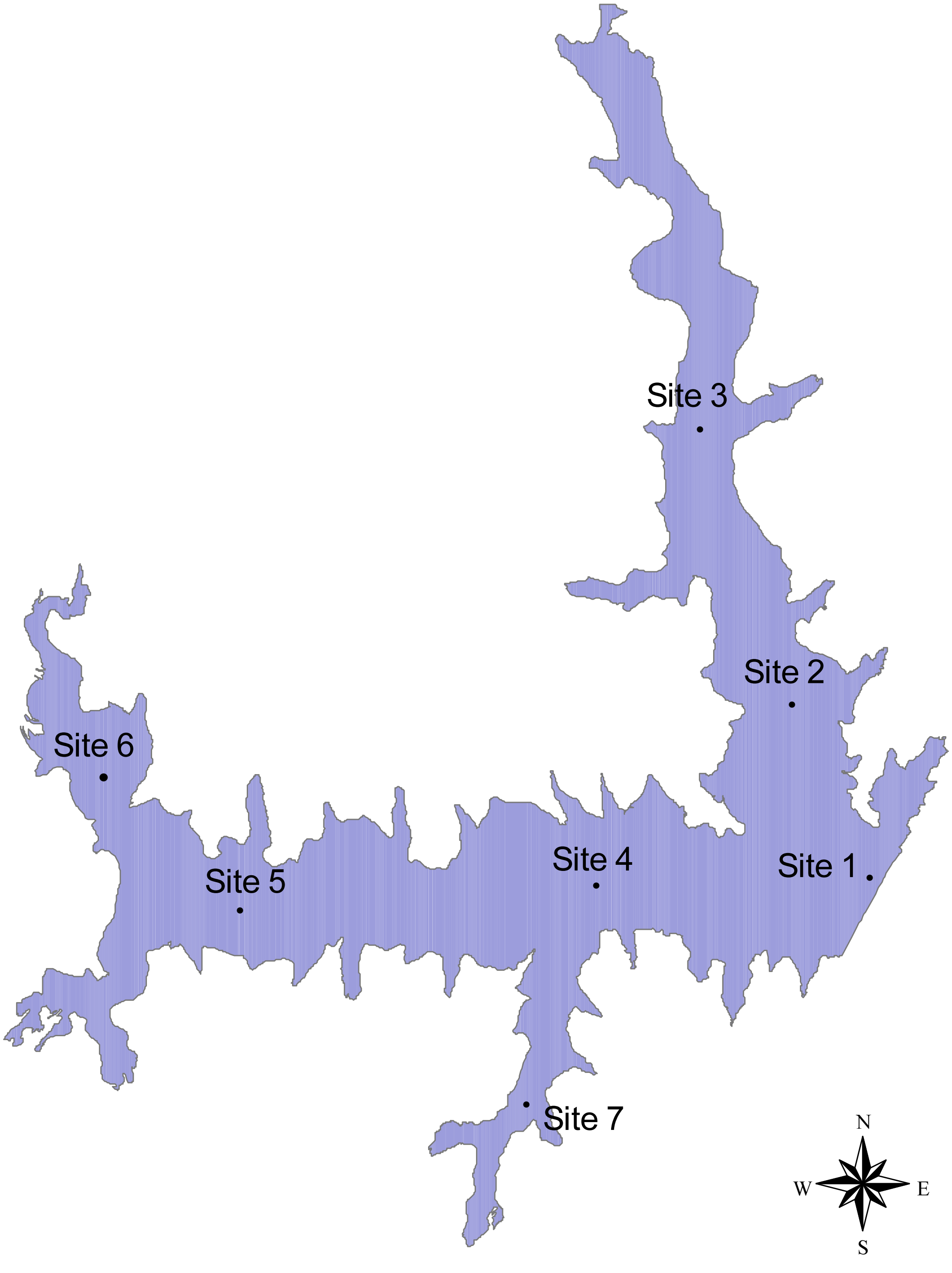

Figure 1: Lake Thunderbird sample sites.

for this report are temperature, dissolved oxygen, and dissolved nitrogen, phosphorus constituents, chlorophyll-a and algae counts. 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 while the algae counts serve as direct measures.

Additional parameters were collected during the monitoring period. Surface grab samples were taken at sites 1,2 and 4 during the 2001 and 2002 monitoring periods and were sent to a contractor for algae identification (cell density and biovolume) to the species level as discussed earlier. These parameters have been added to the long-term database to serve as a diagnostic tool. A brief discussion of lake stratification and its effects on lake water quality are given before 2002 monitoring data are presented.

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 more dense 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 water temperature in the metalimnion decreases rapidly with depth. The figure also shows the depletion of dissolved oxygen in the lower layer of the lake as a result of the stratification. Decaying organic matter depletes the oxygen in the hypolimnion. Prior to the onset of stratification, the lake has isothermal conditions throughout the entire depth. As stratification sets in and strengthens, the epilimnion stays homogenous while the

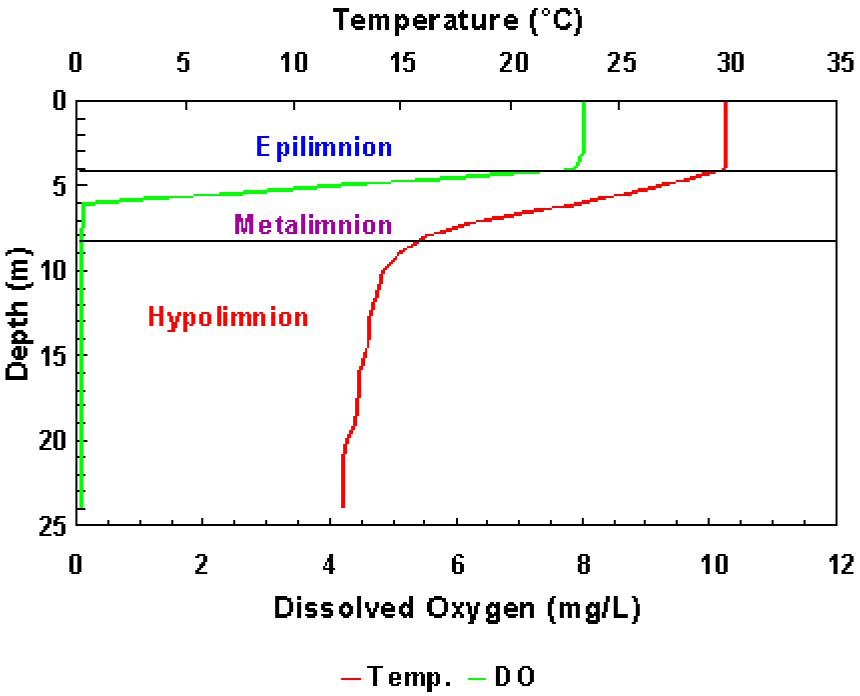

Figure 2: Temperature and dissolved oxygen profile for a typical eutrophic lake showing the three distinct layers (epilimnion, metalimnion and hypolimnion).

metalimnion (often called the “thermocline”) changes radically with depth until the hypolimnion is reached. This physical structure maintains until surface temperatures start to decline and epilimnetic temperature 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.

Temperature and Dissolved Oxygen

Dissolved oxygen and temperature were used to compare water quality changes and the extent of lake stratification. Isopleths were prepared to give a three-dimensional picture of water quality over depth and time. Each line represents a particular temperature or dissolved oxygen concentration. When the lines are vertical, the dissolved oxygen and/or temperature are constant throughout the water column, which is completely mixed at that point in time due to wind or other convective forces. When the lines run horizontally, a strong temperature (vertical) gradient exists from top to bottom. 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.

In 2001 stratification began the beginning of May and ended late September. This was in contrast to what was seen in 2002 when complete stratification started the end of May and final destratification the end of September. Unusual climatic features in 2002 can explain the difference between the two years. On April 22, 2002 the lake was stratified due to unusually warm weather. Then an unusually cool May caused little heating of the epilimnion while a strong cold front produced high winds to mix the lake at the end of May. In short, climatic conditions destratified Lake Thunderbird in late May (**Figure 3**). Following these early spring events weather in central Oklahoma was characterized as cooler than normal, preventing the entire lake (epilimnion and hypolimnion) of Lake Thunderbird from getting as warm as it was in 2001. Consequently weakening of stratification occurred later in 2002 than in 2001. The different climatic conditions in 2002 also resulted in a smaller epilimnion and larger hypolimnion in 2002. Although differences in duration were noted between 2001 and 2002 the magnitude of stratification was about equal. Strong stratification in 2002 had the largest effect on water quality by partitioning the hypolimnion from the epilimnion.

Dissolved oxygen at the main lake sites showed a similar pattern to the plots for temperature for both 2001 and 2002. The key feature for dissolved oxygen is anaerobic conditions: dissolved oxygen less than 2 mg/L. Low dissolved oxygen is caused by high organismal (animal and plant) respiration. 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 (such as iron and manganese) are solubulized from the sediment into the water.

In 2001 anaerobic conditions progressed from the deepest site (1) in the beginning of May towards the shallower sites (5/23/01 at site 2 and 6/1/01at site 4) and extended from May through September. This fits a pattern of high algae growth in the main lake body. The pattern of anaerobic conditions progressing from the deeper sites toward the shallower sites was not observed in 2002 (**Figure 4**). Instead, anaerobic conditions seemed to progress from shallow (started 5/20/02 at site 2 and 6/1/02 at site 4) to deep (6/8/02 at Site 1). The most likely explanation for the difference between the two years is the break in stratification noted in late May. This break served to oxygenate the deep bottom layer of the lake and shorten the duration of anaerobic conditions by one month. The physical difference between the two years is the most deterministic explanation.

As in 2001, anaerobic conditions eventually encompassed the entire hypolimnion and portions of the metalimnion in 2002. These low dissolved oxygen levels indicate that nutrients in the lake sediment dissolve into the hypolimnion. The decreased duration of anaerobic conditions in 2002 suggest lower dissolved nutrient levels in 2002 compared to 2001.

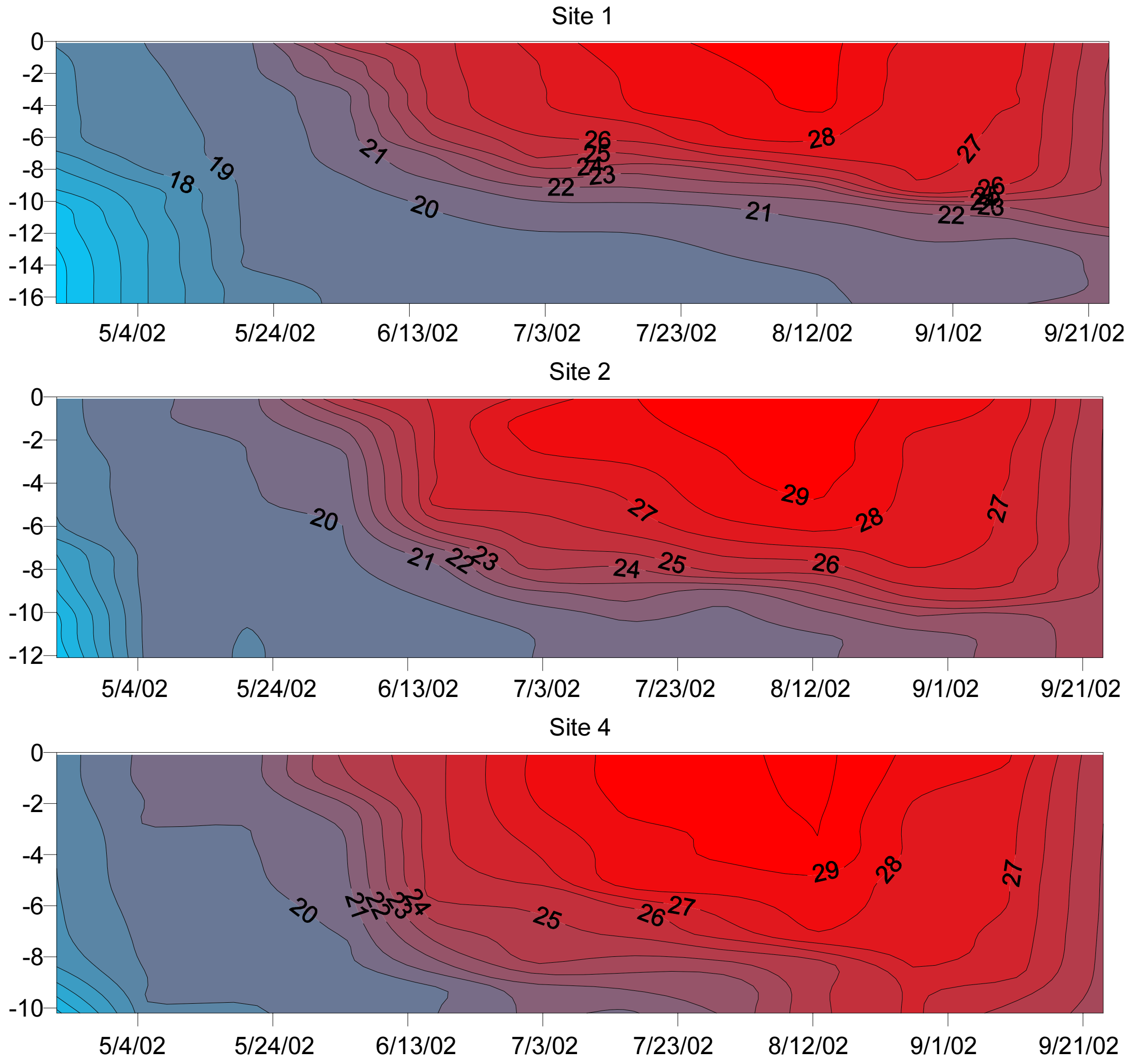

Figure 3: 2002 Temperature isopleths for the main body of Lake Thunderbird in degrees C.

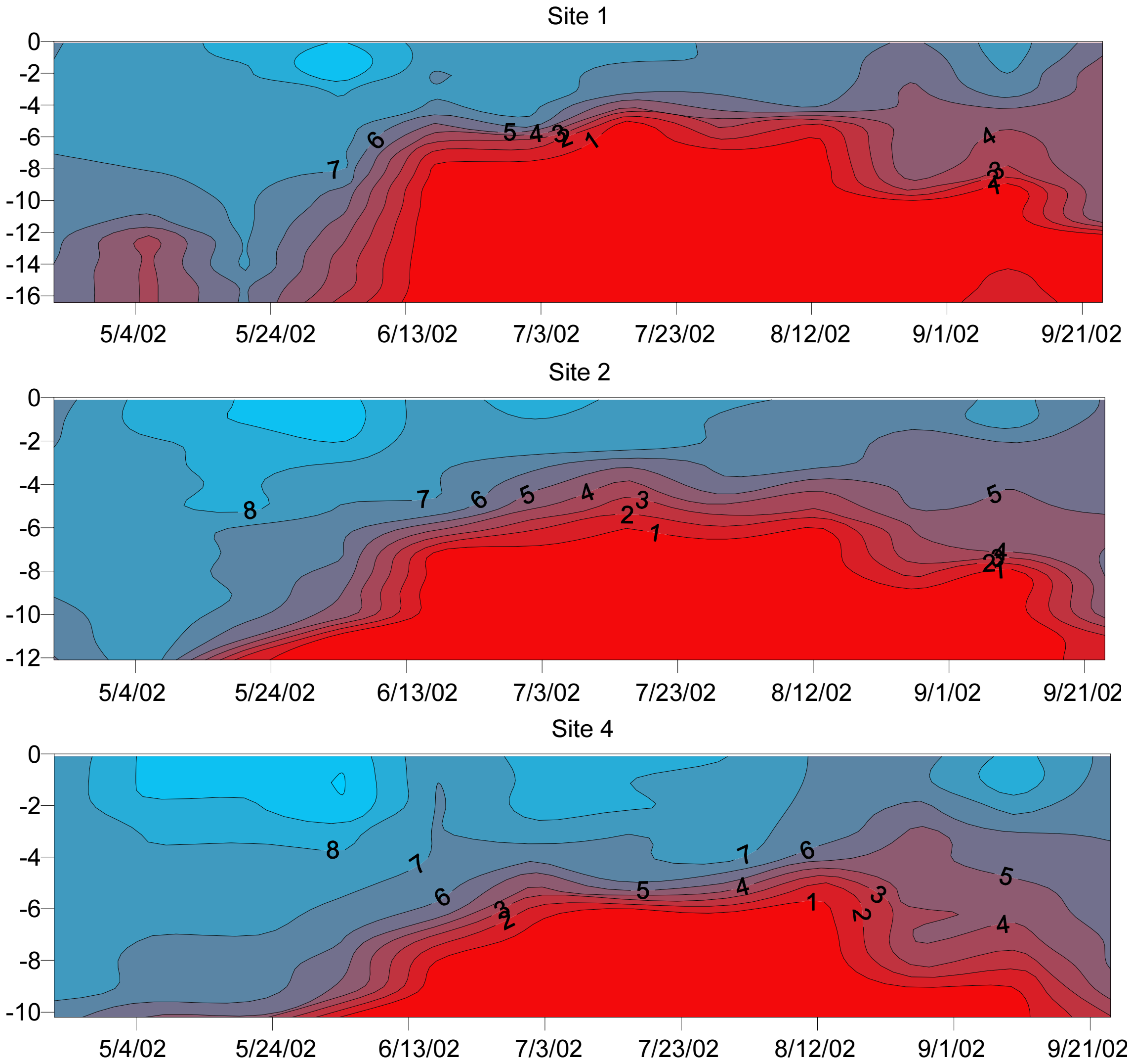

Figure 4: 2002 Dissolved oxygen isopleths for the main body of Lake Thunderbird in mg/L.

Nutrients

While several measures of nitrogen and phosphorus were made of the water quality samples taken the dissolved nutrient totals are presented here to yield an estimate of available nutrients. This indicates the raw materials available for algal growth. High values in the epilimnion indicate nutrient immediately available for algal growth while high values in the hypolimnion indicate nutrients available for future algae growth. The relatively higher dissolved nitrogen values in bottom samples show hypolimnion accumulation of ammonia. This is to be expected with an anaerobic hypolimnion. The effect of delayed stratification in 2002 can be shown by the relatively lower maximum value, 2.6 mg/L, compared to 3.4 mg/L in 2001 (**Figure 5**).

A close comparison between years for each site and depth showed a key pattern. In general 2002 dissolved nitrogen levels were comparable to 2001 levels during the first sample event but then the two years started to diverge. With the exception of the fall site 1 bottom sample most other samples showed higher levels of dissolved nitrogen in 2002 (**Figure 5, Figure 6, Figure 7**). Higher epilimnetic dissolved nitrogen suggests that algae needed less nitrogen for growth: an indicator of phosphorus limitation.

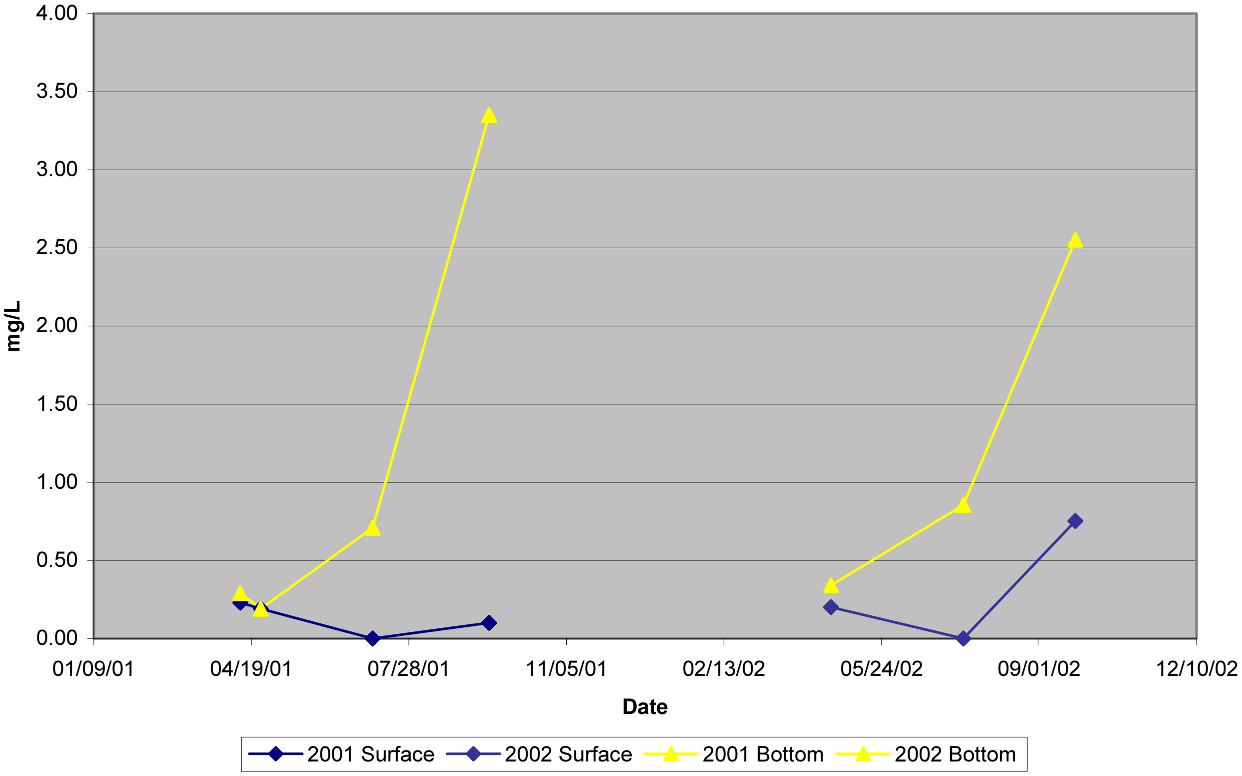

Figure 5: Total dissolved nitrogen species concentrations for Site 1.

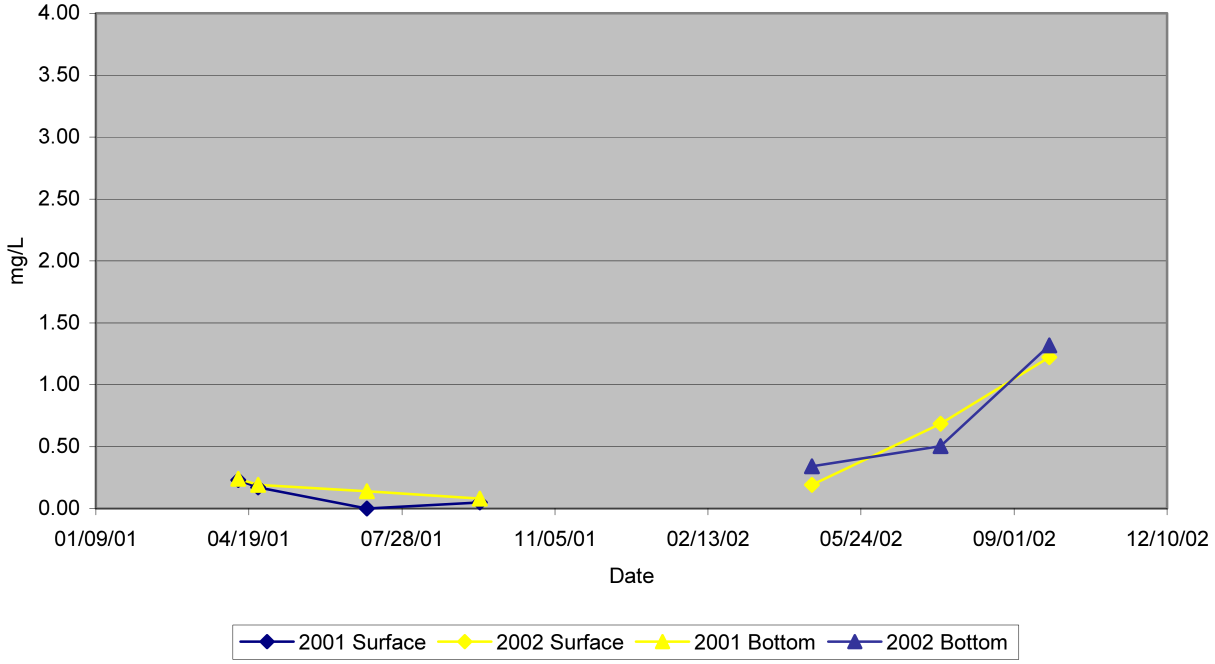

Figure 6: Total dissolved nitrogen species concentrations for Site 2.

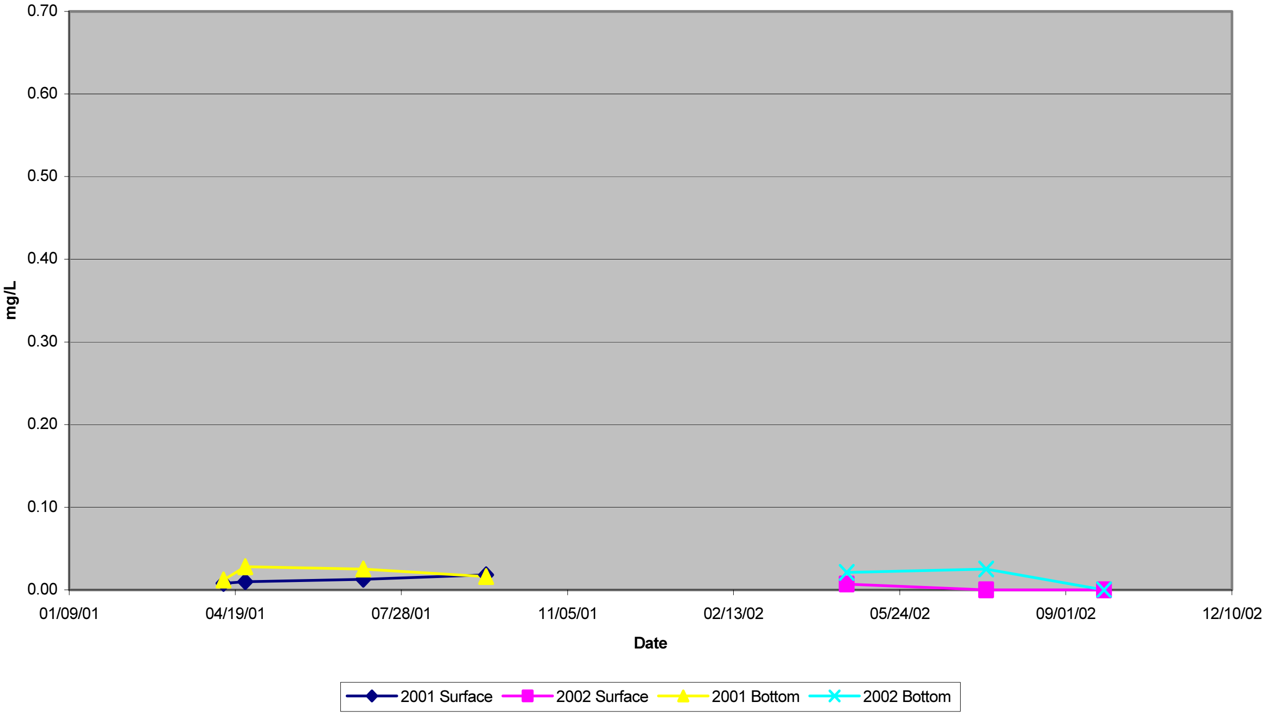

Figure 7: Total dissolved nitrogen species concentrations for Site 4.

Dissolved orthophosphorus is the form of phosphorus most easily used by algae for growth. As with dissolved nitrogen the relatively higher levels in bottom samples show the accumulation in the hypolimnion. Anaerobic conditions in the water mediated release of phosphorus from the sediment. Although both years showed sediment release of phosphorus, the delay of stratification in 2002 could be shown by the relatively lower maximum value 0.25 mg/L compared to 0.60 mg/L in 2001(**Figure 8**).

Aside from this distinct difference of the deep-water samples little year-to-year variation is noted for the other sites and samples (**Figure 9, Figure 10**). These indicate utilization of phosphorus for algal growth. A brief comparison of surface total phosphorus between years shows lower amounts. All surface samples were above 0.02 mg/L in 2001 while no sample in 2002 was above 0.02 mg/L.

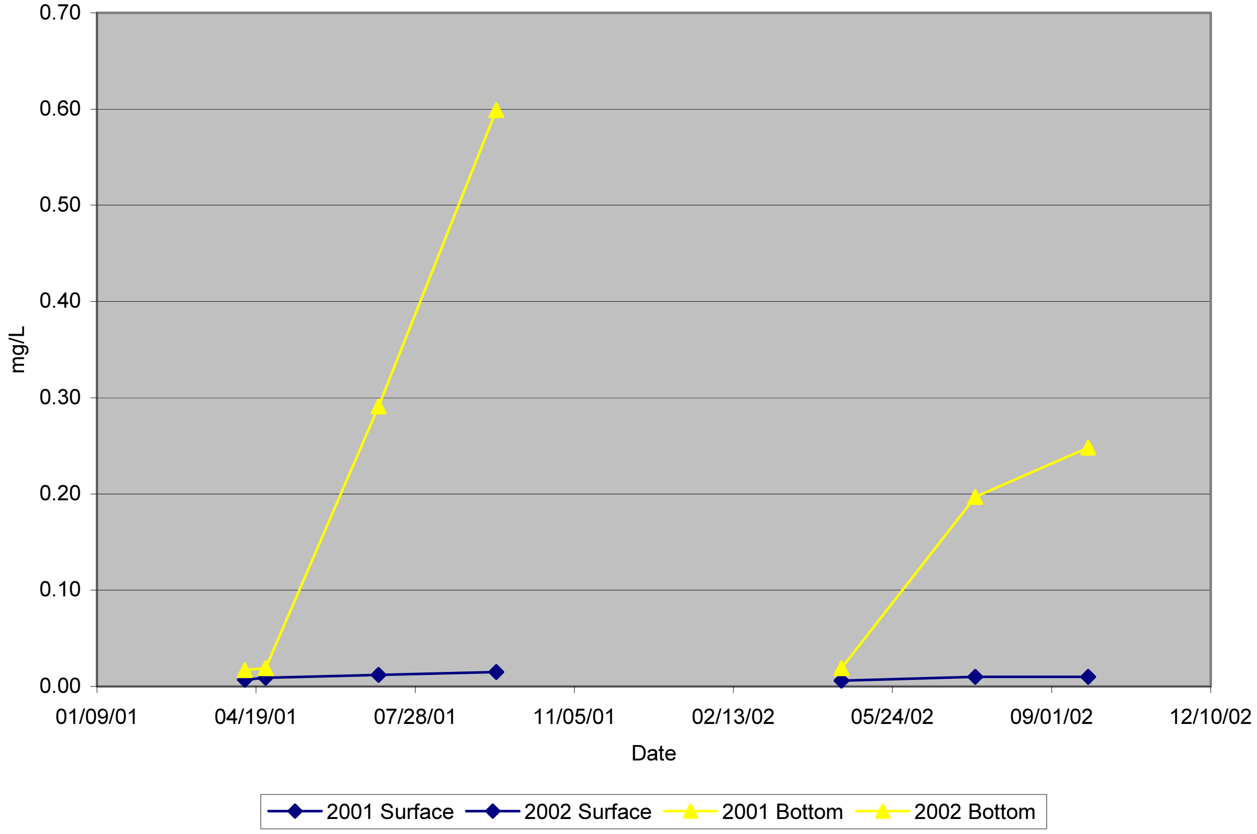

Figure 8: Dissolved ortho-phosphorus concentrations for Site 1.

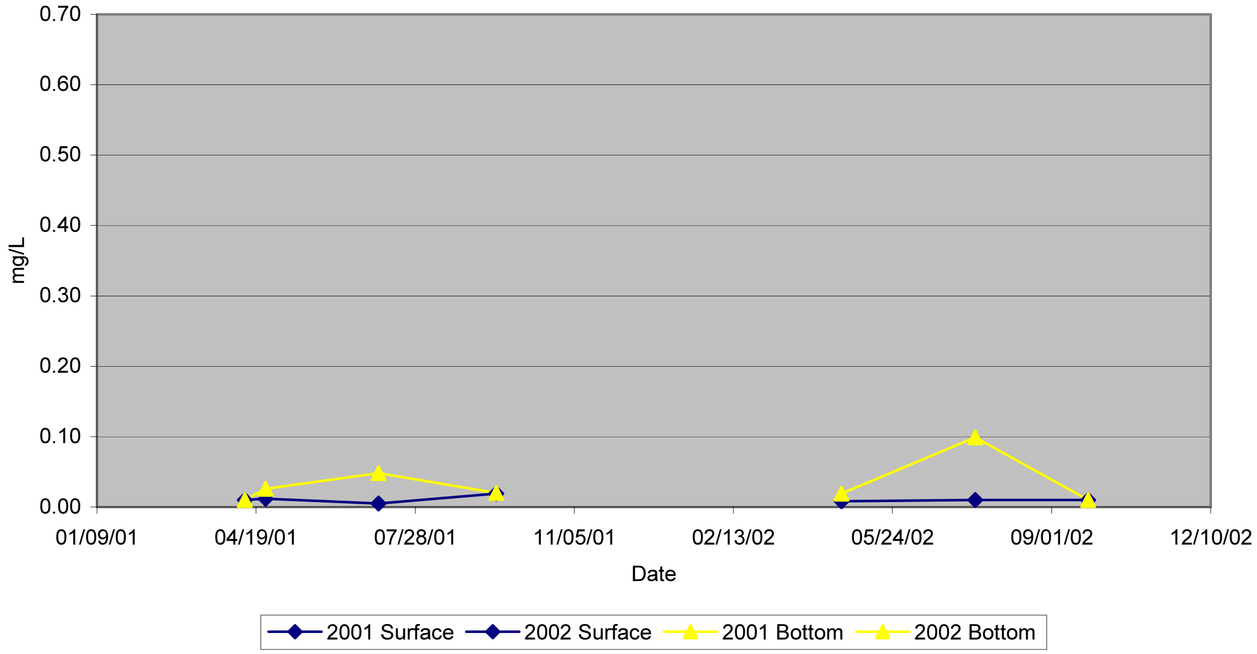

Figure 9: Dissolved ortho-phosphorus concentrations for Site 2.

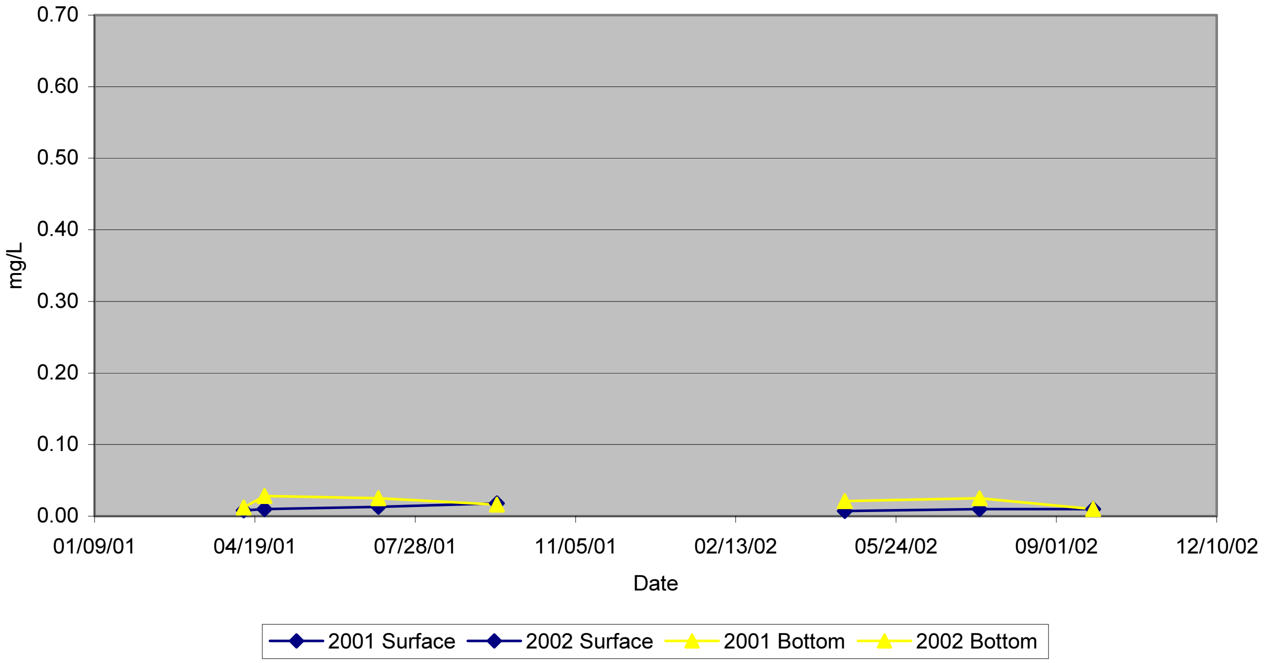

Figure 10: Dissolved ortho-phosphorus concentrations for Site 4.

Generally, as long as the lake is stratified, surface nutrients are the primary determinant of algae growth. Stratification conditions were radically different between 2001 and 2002. The delay of stratification in 2002 delayed the duration of anaerobic conditions in the hypolimnion. Consequently, less phosphorus was released from the sediment into the water. 2002 nutrient data indicate that phosphorus is the chemical nutrient limiting algae growth. Dissolved phosphorus serves as an indicator of nutrients available for growth. When dissolved phosphorus is low total phosphorus can indicate the amount of algae in the water. These along with the earlier indication of lower dissolved nitrogen use in 2002 suggest algae levels should be lower in 2002 than in 2001. Chlorophyll-a serves as a suitable surrogate for direct algae enumeration.

Algae

Several direct and indirect measures are used to indicate algae growth. The most commonly accepted indirect measure is chlorophyll-a concentration. A more direct measure of algae growth is the identification and enumeration of species in the algae community. Perhaps the best measure of algae growth is the determination of primary production rate. The choice of measure is dependent on the application. In the case of Lake Thunderbird and the COMCD, the first two measures have the most applicability to lake management and raw water supply. The use of chlorophyll-a as an indicator of trophic state in a trophic state index (TSI) allows for quick assessment of water quality within a lake and across the state. Within the range of TSI for Oklahoma reservoirs break points have been determined to quantify varying levels of algae production. Identification of algae density to the species level allows for refinement of the assessment to estimate impact to raw water supply. For example by identifying species known to produce objectionable chemicals and estimating organic content the potential to affect raw water supply can be estimated.

Chlorophyll-a

Chlorophyll-a, the molecule or pigment common to all algae for growth, makes analysis of its concentration a commonly accepted measure of algae content. In 2001 chlorophyll-a was relatively steady until July when concentration increased into September (**Figure 11**). Starting in August chlorophyll-a exceeded the 20 µg/ml goal. 2002 chlorophyll-a showed a pattern of relatively constant concentration while no sample-exceeded 20µg/ml (**Figure 12**). By all indications algae growth was significantly lower in 2002 than any other monitored year. In 2002 the long-term goal of chlorophyll-a under 20µg/L was achieved.

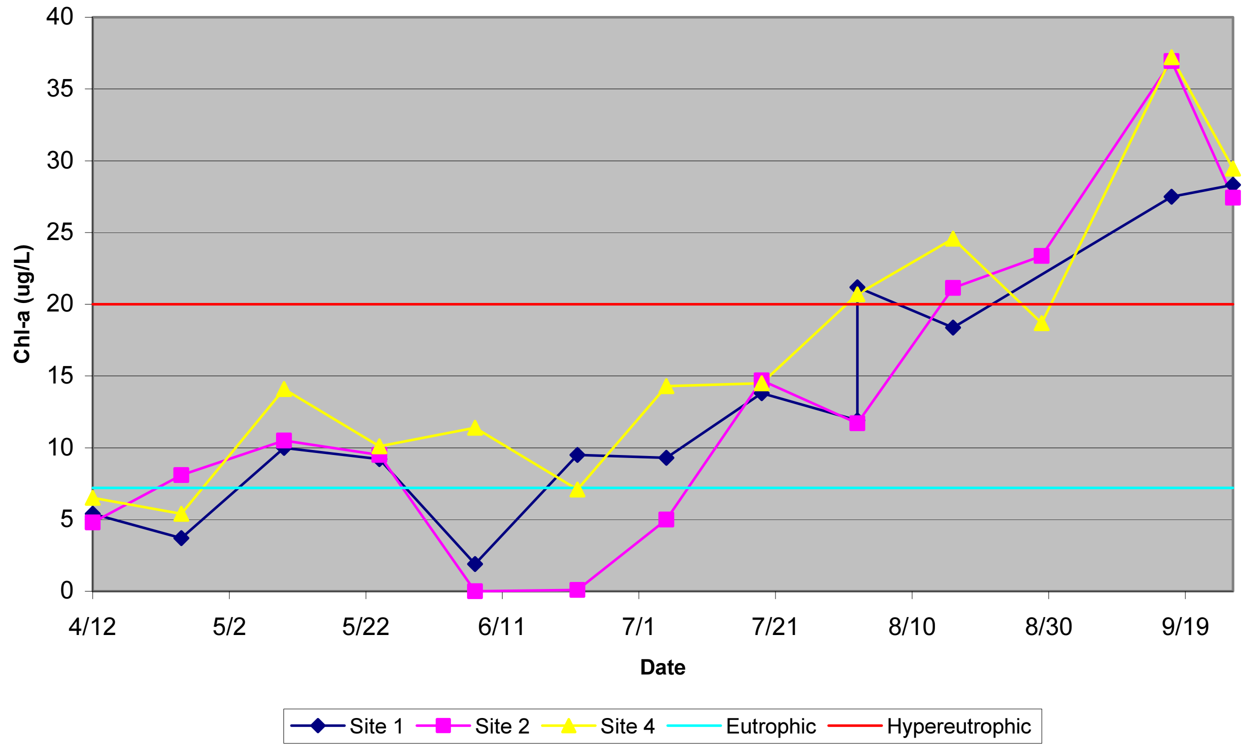

Figure 11: 2001 Chlorophyll-a concentrations for main lake body sites.

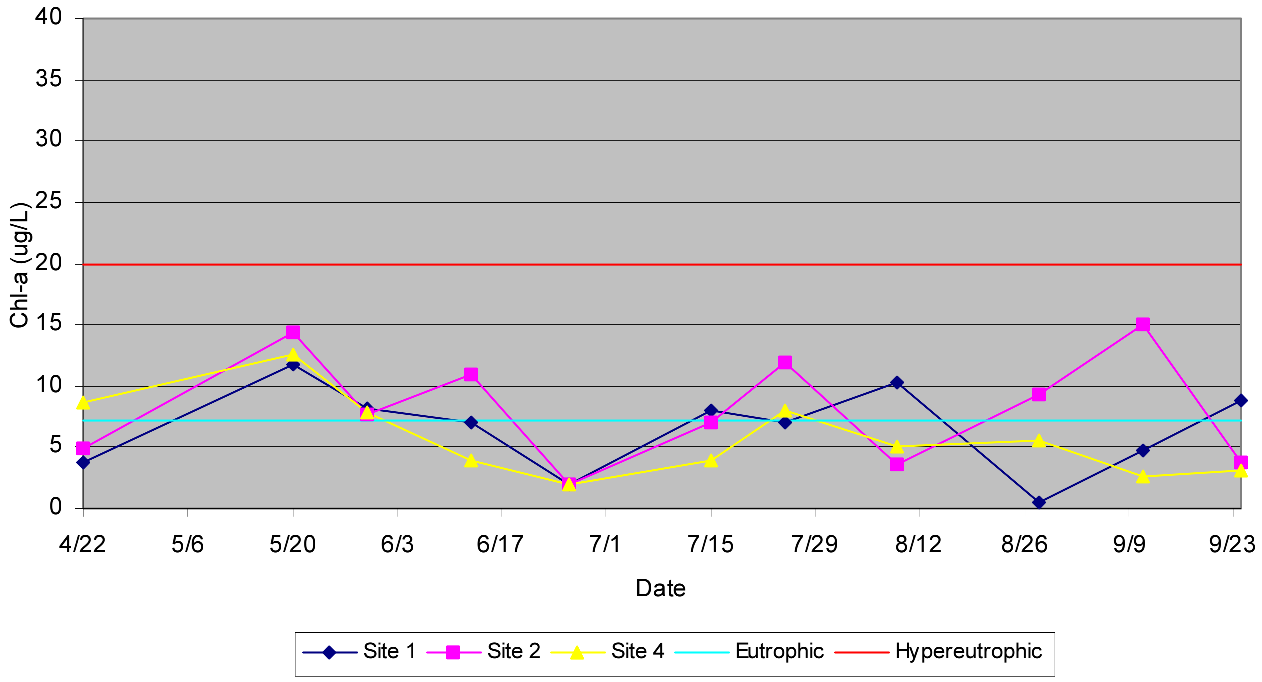

Figure 12: 2002 Chlorophyll-a concentrations for main lake body sites.

The annual progression of lowered algae growth over the years is most easily expressed by transforming chlorophyll-a into the three trophic states represented by the red and blue lines in **Figure 13**. The red line in Figure 11 and Figure 12 represents the boundary (at 20 µg/L) between high (eutrophic) and excessive (hypereutrophic) algae growth while the blue line represents the boundary (7.2 µg/L) between high and lower (mesotrophic) algal growth. Eutrophic or high algae growth conditions have remained relatively constant over the three years while hypereutrophic conditions have consistently declined and mesotrophic conditions consistently increased (**Figure 13**). In short the quality of Lake Thunderbird has consistently increased over the last three years. While chlorophyll-a is a commonly accepted surrogate for algae content surface samples were taken in 2001 and 2002 as direct measures of algae content. These data are used to support or refute conclusions based in previous indicators.

Figure 13: Trophic State using chlorophyll-a concentration for 2000 through 2002 monitoring seasons (May - September).

Algae data are a direct measure of the trophic status and a result of nutrient levels in Lake Thunderbird. Algae and raw water supply also have a very important relationship because of the effect compounds created by algae can have on the finished water: Algae cell contents released into the raw water supply have been documented to affect the finished drinking water quality whether by increase the level of disinfectant byproducts (**Jack, et. al., 2002**), presence of taste and odor compounds **(Perrson, 1983)** or presence of toxins (**Sze, 1986**). Lake Thunderbird algae data is presented in two basic forms: cell density and cellular volume (biovolume). Cell density, the easier value to determine, is the traditional measure of abundance while biovolume, requiring a higher level of analysis, is a better measure of cell content. Because of the potential to estimate impact of algae content to water supply particular attention is given to site 4, located next to the COMCD raw water intake structure. Algae samples for identification were taken at the main body sites for both 2001 and 2002. For both 2001 and 2002 algae samples were collected bi-weekly allowing for direct comparison.

Cell Density

In general, cell density was relatively constant over the sample period for both 2001 and 2002 (**Figure 14** and **Figure 15**). This does not match the trends noted for chlorophyll-a with an increasing trend in 2001 (**Figure 11**) and relatively flat level in 2002 (**Figure 12**). However, the general conclusion comparing chlorophyll-a between years is corroborated: lower algae content in 2002. Cell density in 2001 varied around the 1,000,000 cells/ml while 2001 density varied around 100,000 cells/ml. Cell counts for both years were well over 15,000 cells/ml, an indicator of eutrophic or nutrient rich systems. Hutchinson (**1967**) describes "eutrophic associations" by the appearance of the following three species: *Aphanizomenon, Anabaena,* and *Oscillatoria*. All three of these genera occurred in Lake Thunderbird.

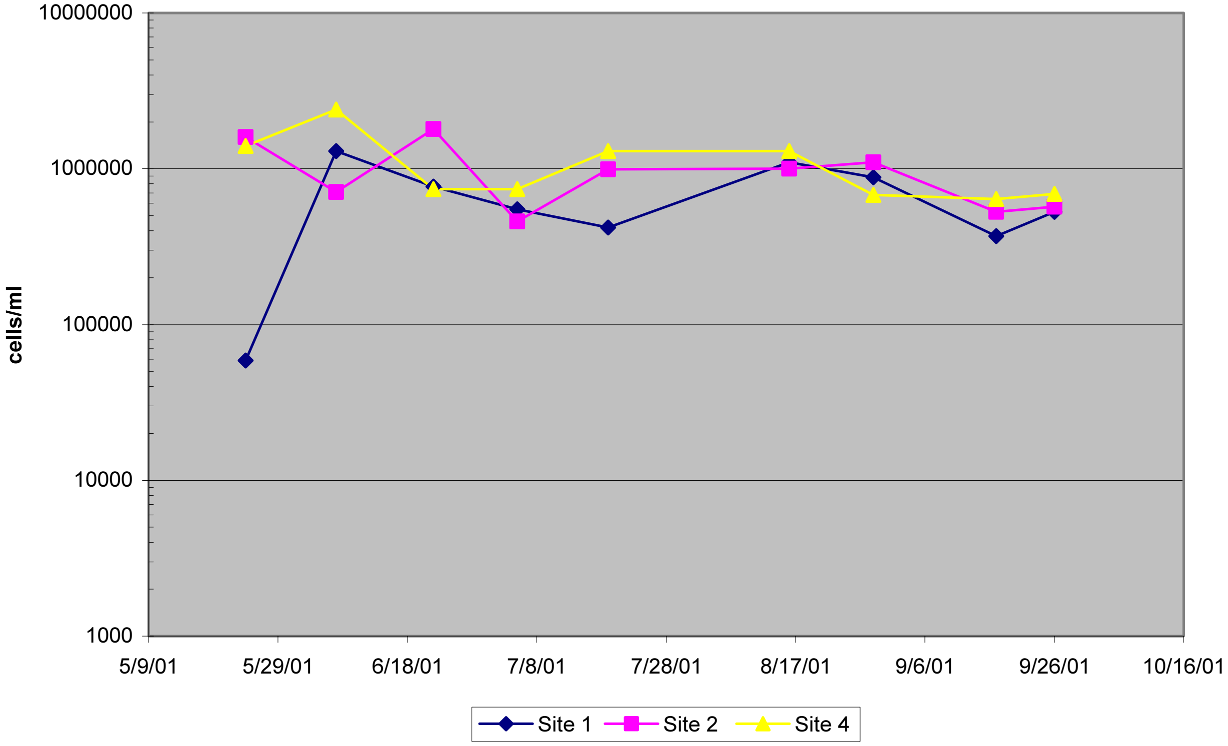

Figure 14: 2001 Algae Cell Density

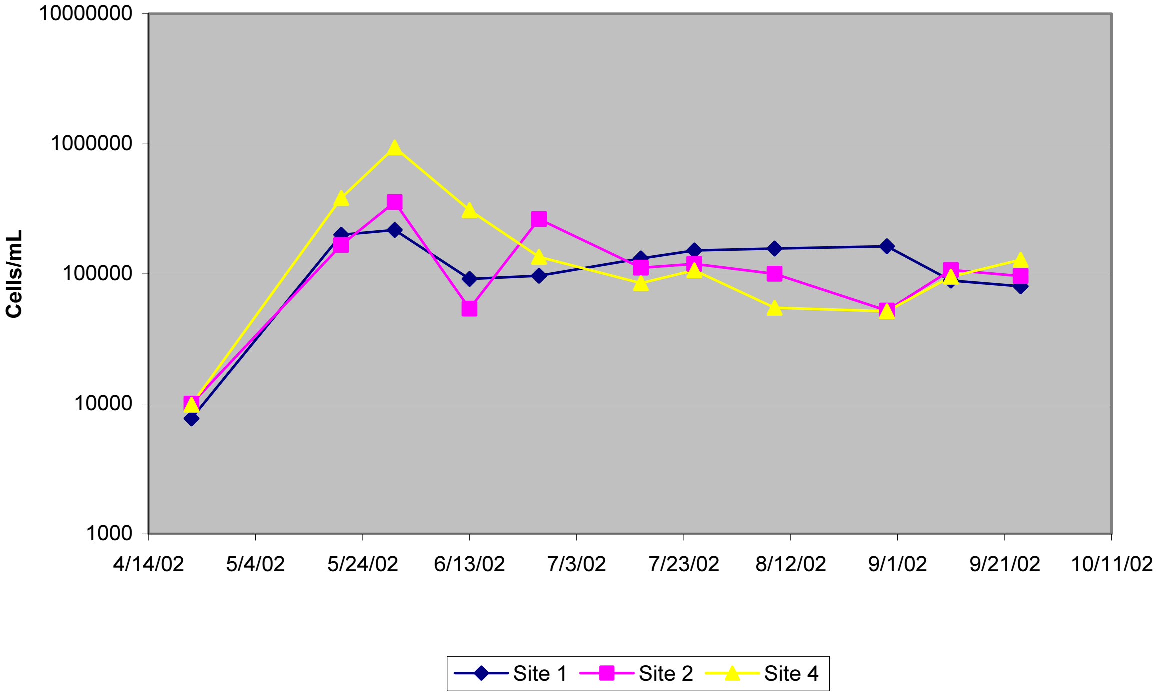

Figure 15: 2002 Algae Cell Density

As pointed out by Hutchinson, the types of algae can be as important as the amount. Examination of the algae types showed an abnormal pattern for Oklahoma reservoirs: blue-green algae throughout the sample season. The generally accepted pattern of seasonal succession is diatom dominance in the spring followed by dominance of green algae and finally dominance of blue green algae (**Wetzel, 1983**). Blue-green algae dominance throughout the summer season has only been noted in highly eutrophic Oklahoma reservoirs by the OWRB. In 2001 the primary blue-green species responsible for overall dominance was *Aphanocapsa delicatissima* during the beginning of the sample season with C*ylindrospermopsis raciborskii* dominating the second half of the sample season.

In 2002, cell density was again dominated by small unicellular blue-greens with other divisions represented in varying abundances. Some exceptions were noted. The first exception occurred at the beginning of the sample season -- all three sites showed the cryptophytes, miscellaneous microflagellates, chlorophytes, and euglenophytes had noticeably larger peaks in comparison to the cell density from the rest of the year. The second noticeable difference was an even larger peak of green algae towards the beginning of August. *Nephroselmis olivacea* was the dominant green algae species in all of these peaks. In 2001, *N. olivacea* did not even contribute over one percent of the cell density at any of the three sample sites. This indicates the potential of algae type to change positively (away from blue-greens) with reduced algal content. While these results are positive algal biovolume as well as cell density should be examined before conclusions are drawn.

Biovolume

Disinfection Byproducts

Comparing biovolume between the two years showed 2002 to have much higher biovolume in the spring then in 2001(**Figure 16**). Interestingly, biovolume for both years seem to converge in the summer and fall periods. Although cell density counts from 2001 and 2002 showed greatly reduced amounts of algae in 2002 the volume occupied by algae in the two years seem to have remained the same. This is because algae cells in 2002 were (on the average) much larger then those in 2001. One conclusion based on these results is contribution of disinfection byproducts in raw drinking water from algae should have been about the same in 2002 as in 2001. Examination of biovolume by species is necessary to compare potential for taste and odor chemical production between 2001 and 2002.

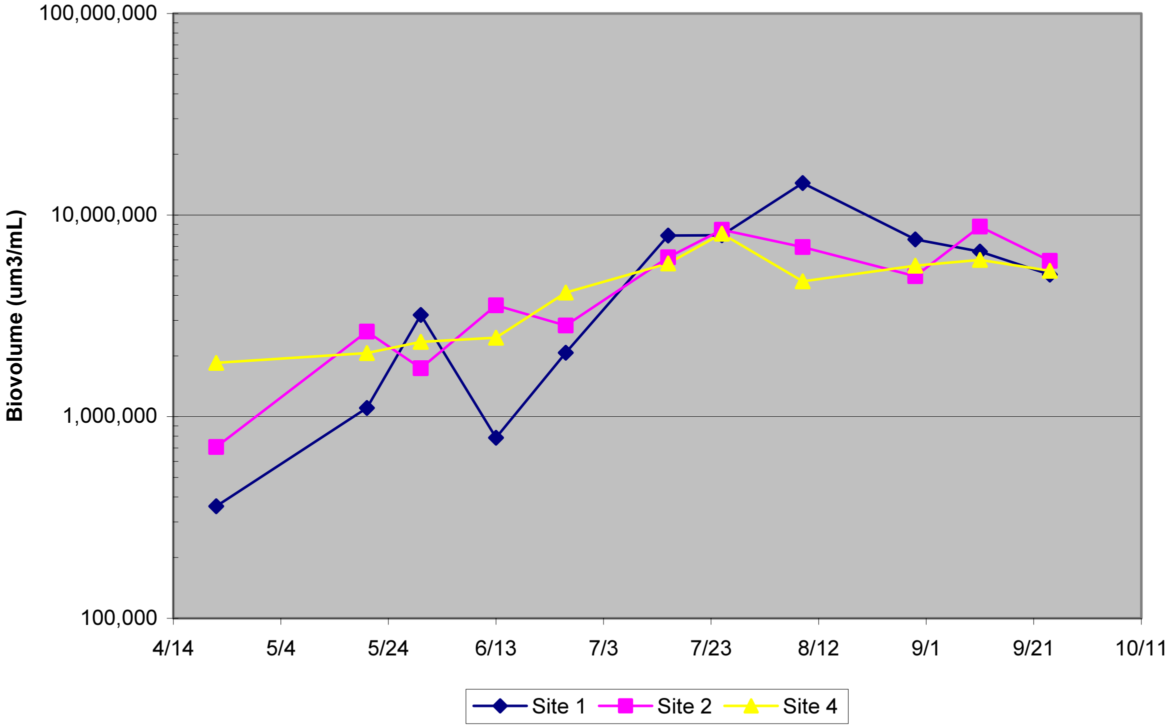

Figure 16: 2002 Biovolume by site.

Taste and Odor

The most notable difference between cell density and biovolume plots are that blue-greens were not dominant until the diatoms and dinoflagellates decreased in the summer. This general pattern occurred in 2001 and 2002 and is closer to the norm for seasonal succession of algae. The dominant blue-greens were larger, mostly filamentous forms in comparison to the small, unicellular forms that dominate the numerical abundance. Blue-green algae have often been recognized as a nuisance in the drinking waster industry because of the ability of several taxa to produce earthy and musty smelling compounds. Earthy and musty smells produced by algae are commonly called taste and odor (T&O) compounds. Geosmin and 2-methyl isoborneol (MIB) are common T&O compounds that produce musty smells. A*phanizomenon*, *Microcystis*, *Oscillatoria* and *Anabaena* are known geosmin producers (**Perrson, 1983**) and were found in Lake Thunderbird. *Lyngbya limnetica* another cyanophyte in the lake, has also been known to cause a musty smell in large quantities. *Ceratium hirundinella* a dinoflagellate found both years in Lake Thunderbird is known to produce a fishy smell and bitter taste. The biovolume of the potential taste and odor chemical producers can serve as indicators of algae contribution to customer complaints regarding finished drinking water.

Comparing the 2001 reports at site 4 (near the water supply point of diversion) against total biovolume of algae genera known to produce taste and odor chemicals indicate potential for T&O reports from June through September; almost the entire sample season (**Figure 17**). Ten species of algae were counted distributed in six genera of potential T&O producers. Fishy smell and bitter taste could be expected from *Ceratium hirundella* in June while more traditional T&O complaints such as musty smell are predicted to predominate July through September due to the presence of *Microcystis aeruginosa*, *Oscillatoria limnetica* and various species of *Anabaena*. 2002 reports of T&O algae at Site 4 showed a different distribution of species and amount over time but indicate the potential for T&O reports from may through September. Compared to 2001 there were one less genus and three less species of potential T&O algae. No new species of algae were noted in 2002 than were identified in 2001. Of the identified species the largest difference was for the genus *Anabaena* and species *Ceratium hirundella*. In 2002 *Anabaena sp*. were noted earlier in the season and at higher levels than in 2001. Also in 2002 *Ceratium hirundella* was consistently present from May through July but at lower levels than the two occasions it was identified in 2001. The relatively warmer spring season of 2002 may have encouraged earlier growth of *Anabaena* while the relatively cooler summer may have extended the growth period of *Ceratium hirundella*.

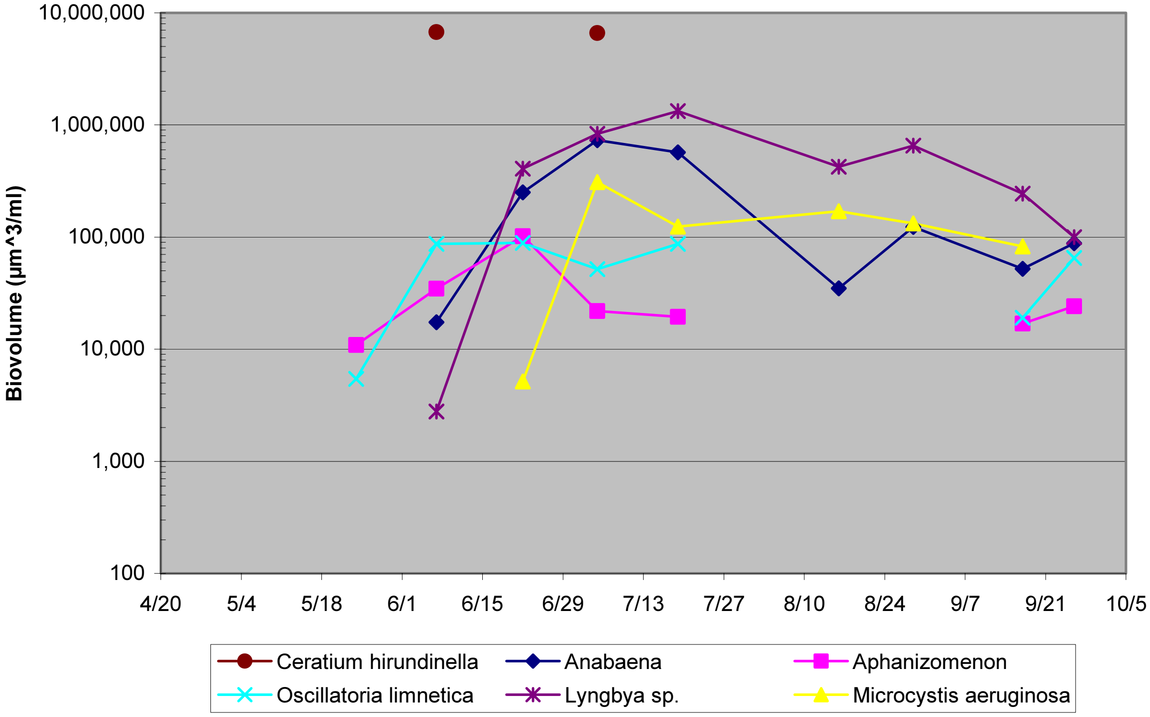

Figure 17: Biovolume of taste and odor algae producing at Site 4, 2001.

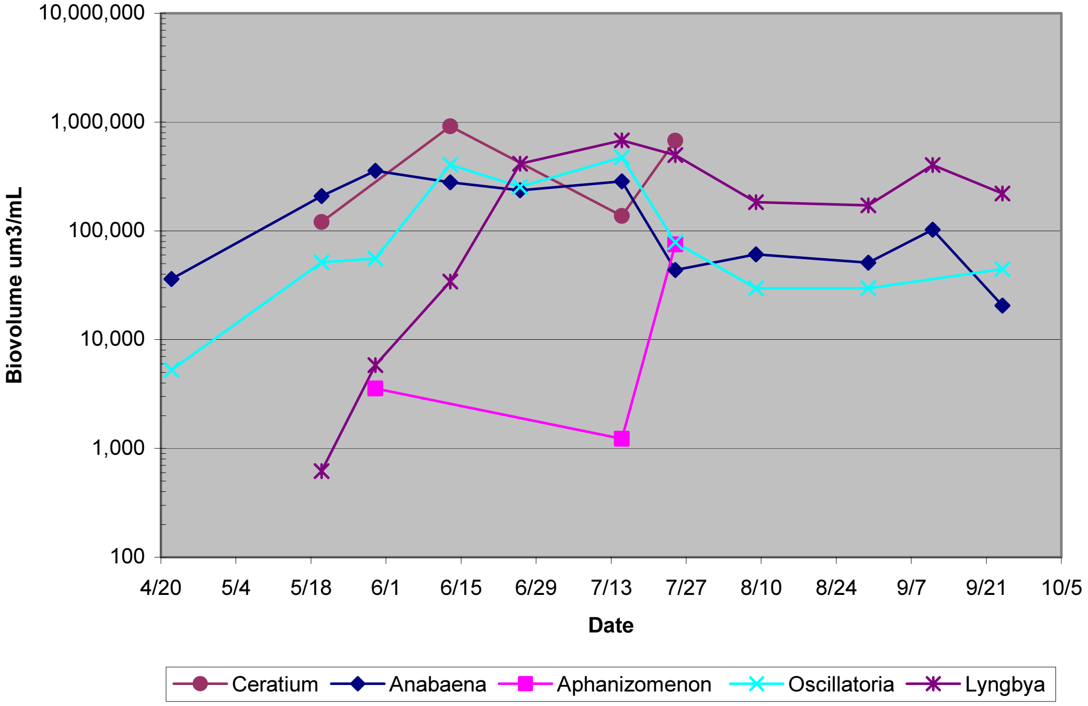

Figure 18: Biovolume of taste and odor producing algae at Site 4, 2002.

The purpose of enumerating potential T&O causing species is to relate algae content to the finished water supply. Understanding algae distribution is a step towards defining the potential input of T&O chemicals. A measure of T&O quality of the finished product is also needed to establish a reliable relationship to algae. To date the best measure of finished water quality is the complaint record maintained by the City of Norman. Communication with Vernon Campbell of the City of Norman has established that complaints are due to the quality of water leaving the plant and not due to the distribution system.

A summary of taste and odor complaints reported to the City of Norman has been plotted to cross reference to biovolume plots of taste and odor producing algae. During the 2001 and 2002 sample season Norman received complaints in April of 2001 with a large peak in August with eight complaints and finally three complaints received in September (**Figure 18**). 2002 showed a distinctly different pattern with five complaints in May, four in June and July, one in August and a large peak of twelve on September. The water treatment plant superintendent also noted that taste and odor complaints regularly peak in September almost every year. Although the complaint record overlapped with the potential for T&O chemical production no clear pattern or relationship was noted. Recent research in Cheney Reservoir, a water supply for the City of Wichita, suggested a combined *Anabaena* and A*phanizomenon* biovolume of 300,000 µg/ml as a threshold for an increase of consumer complaints (**Smith, et. al., 2002**). Application of this potential threshold to Lake Thunderbird showed no overlap in 2001 and little in 2002. Our initial evaluation does not suggest a determinant factor between algae content and the quality of water from the treatment plant. Several analytical and physical factors may obscure any relationship that may exist. Two physical factors identified were the blending of well water with treated water prior to distribution and the effect of lake mixing on raw water T&O content. Flow data showed the amount of lake water reaching customers varied from 95% to 71% in 2001 and 2002. Varying the percent of treated water would alter concentrations of T&O chemicals in the distribution system. Mixing of hypolimnetic water into the epilimnion, usually completed in late September, could account for the consistent peak of complaints noted in September. While the lake was stratified dying algae cells settled into the hypolimnion. T&O chemicals released by these dead and dying algae would be stored until the hypolimnion is eroded in the fall. Two analytical factors identified are the lack of examination for species level effect and the reliance on customer complaint as the measure of treatment plant finished water quality. Since general comparisons were not conclusive the OWRB did not perform species level comparisons. It is possible that this detailed evaluation would suggest a specific species. Choosing of a more direct measure of T&O such as taste and odor number, geosmin concentration, MIB concentration and/or total organic carbon content of water leaving the treatment plant would enable a more conclusive evaluation.

Toxins

Unfortunately many T&O algae can also produce toxic chemicals. Blue-green algae are the taxa with the most species documented to produce toxic compounds (**Carmicheal, 1985**). *Microcystis aeruginosa* and *Cylindrospermopsis raciborskii* were the two algae species identified in collected samples. *Microcystis aeruginosa* has been documented to produce a variety of hepatotoxins and was noted in the 2001 but not in 2002. *Cylindrospermopsis raciborskii* has been documented to produce a neurotoxin and cytotoxin (**WHO, 1998**). Most toxic effects are noted when the particular species is present as a scum, indicative of hypereutrophic conditions. No scum formation was noted in any year the OWRB monitored Lake Thunderbird water quality. The most common method for toxic effects to be manifested is through direct exposure and NOT following conventional water plant treatment. The draft guidelines developed by the World Health Organization (**Table 1**) assessing relative risk of these toxic chemicals have been compared against actual levels measured in Lake Thunderbird. Cell densities showed *Microcystis aeruginosa* below the low risk level at all times while *Cylindrospermopsis raciborskii* was in the low risk level in June and moderate level in August and September of 2001 (**Figure 19**). In 2002 only the species Cylindrospermopsis *raciborskii* was noted. Cell density fluctuated around the low risk level from July through September (**Figure 20**). These risk levels were assessed for recreational exposure only.

Risk Level	**Cell density**	**Magnitude of Potential Health Effects**
Low	20,000	Short-Term
Moderate	100,000	Short-term and long term
High	Up to millions (Scum formation)	Poisoning to short term

Table 1: Assessment of human risk to blue-green algae produced toxins. Adapted from World Health Organization (1998).

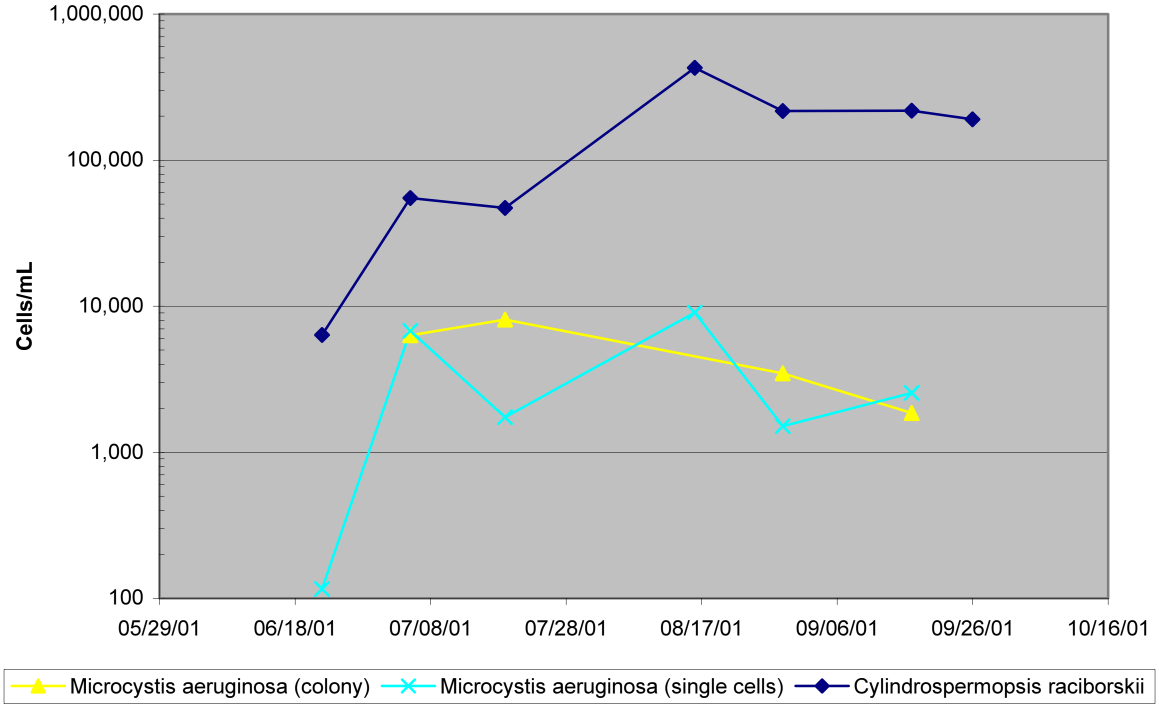

Figure 19: Cell density of potential toxin producing algae Site 4, 2001.

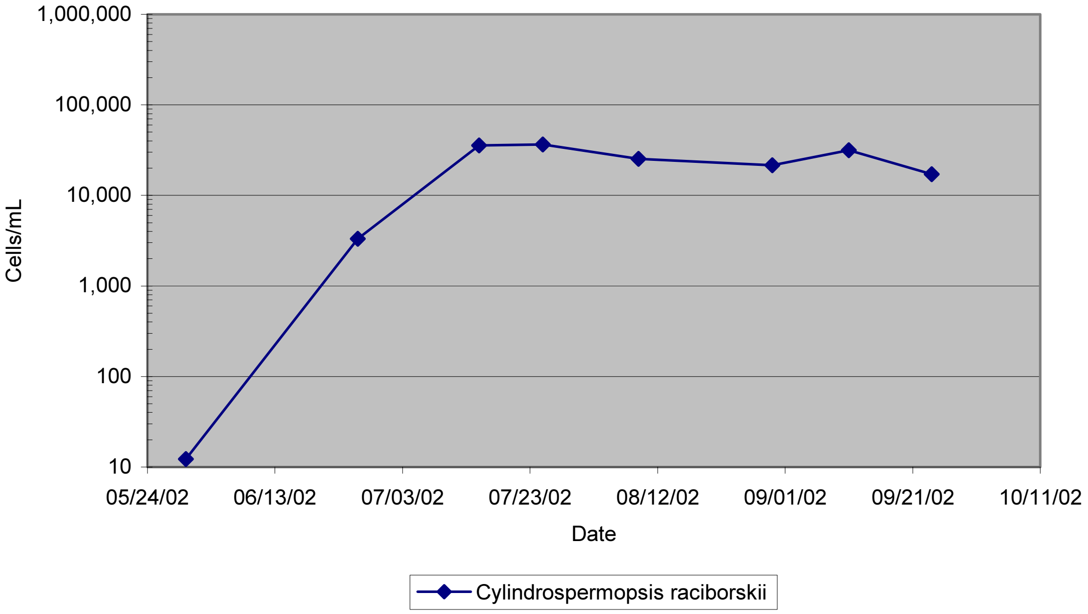

Figure 20: Cell density of potential toxin producing algae Site 4, 2002.

Over the two-year period that algae identification was performed the presence of toxic algae seems to have declined. *Microcystis aeruginosa*, present in 2001 was not identified in any 2002 samples. C*ylindrospermopsis raciborskii* was present in both years but at a significantly lower cell density in 2002. Clearly, the presence of C*ylindrospermopsis raciborskii* is disturbing and should bear future investigation. This species appears to be a newcomer to Oklahoma only reported on one other occasion in 1998 (**OWRB, 2002b**). In 1998 both Eucha and Spavinaw lakes had this species in the summer with no subsequent identifications in the following three years: 1999 – 2001. It is possible that C*ylindrospermopsis raciborskii* shows an initial peak following introduction and then declines to more desirable levels.

Summary and Discussion

Monitoring in 2002 showed a set of physical conditions unique to Lake Thunderbird: abnormal climatic events combined to disrupt stratification and introduce additional oxygen into the bottom lake layer (hypolimnion). Subsequently the duration of anaerobic conditions were 1.5 months shorter than in 2001. This shorter period of anaerobic hypolimnion resulted in less nutrients released from the lake bottom. Nutrient data suggested lower algae content because of higher amounts of dissolved nitrogen in 2002. Chlorophyll-a content, the commonly accepted measure of algal content, was the lowest in OWRB's three years of monitoring and well below the goal set in 2000 by the COMCD and municipalities. Although impressive, Lake Thunderbird continues to be considered "eutrophic" or having high levels of algae growth. The monitoring years of 2000, 2001 and 2002 show a dramatic reduction of algae growth (**Figure 21**). The stark reductions noted do imply that in-lake management techniques can be an effect means to control algal growth in Lake Thunderbird.

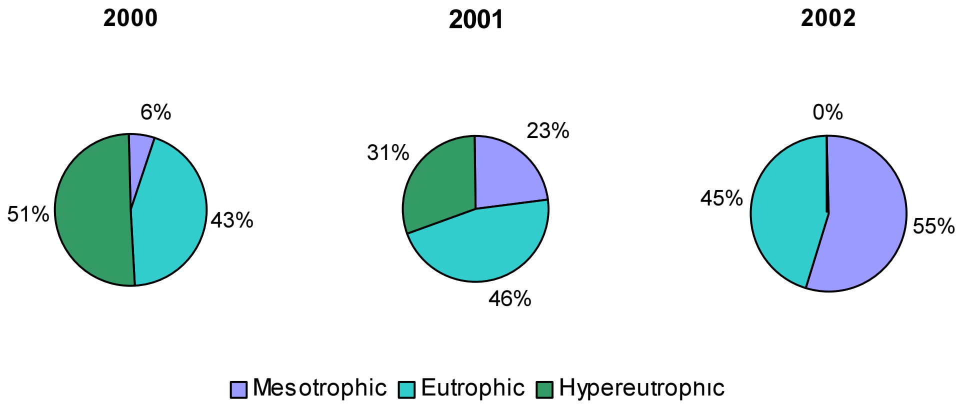

Figure 21: Percent distribution of trophic state using chlorophyll-a concentration May-September.

Because abnormal climatic conditions reduced nutrient cycling within the lake, the COMCD should not expect similar chlorophyll-a levels subsequent years. However, 2002 monitoring does present a strong argument to evaluate the feasibility of providing chemical oxidants into the bottom layer of the lake to lower algae growth.

Total algae cell density comparisons confirmed what was suggested by the chlorophyll-a data: algal cell density was almost ten times less in 2002 than 2001. Algae data was also evaluated for its ability to affect water supply by examining the biovolume results at the COMCD point of diversion. Algal biovolume provides an estimate of cellular contents. Portions of the organic contents contribute to the production of disinfection byproducts, taste and odor chemicals and toxin production. Comparison of biovolume suggests about equal contribution towards disinfection byproducts from 2001 and 2002. Comparison of specific identifications against the complaint record from the City of Norman did not yield clear pattern. It is possible that short-term storage of dead and dying algae cells in the hypolimnion released during destratification could account for the traditional peak of complaints around September. It was also evident that many complaints were in October or November, after the OWRB's monitoring period. Two species of algae identified have the potential to produce toxic chemicals. One species was only noted in 2001 while the other was present both years. Comparison of cell density of these species indicated *Cylindrospermopsis raciborskii* presented a low to moderate risk in 2001 and low risk in 2002 from direct exposure or accidental ingestion. Risk was assessed for recreational exposure only. Formation of algae scum in the fall would indicate a high-risk situation.

Recommendations

Determine the feasibility of oxygenating the hypolimnion of Lake Thunderbird. Concept design of a whole lake mixing device requires a new compressor and would increase compressor operation and maintenance by a factor of four. Other options to oxygenate the lake exist such as layered or hypolimnetic aeration. These and other options should be evaluated for Lake Thunderbird.

Proceed with the pilot plant project. The receipt of algae data has brought the effect of algae in water supply into tighter focus. More specific data from the municipalities is needed for an effective evaluation. Addition of test parameters such as total organic carbon content, Trihalomethane precursor formation potential, haloacetic acid formation, T&O number, geosmin and 2-methyl isoborneol at Site 4 and the finished product would provide the necessary data for evaluation. The municipalities have proposed pilot plant studies to assess economical means to reduce potential impact of detrimental algae in Lake Thunderbird. This proposal has the potential to provide the needed data.

Extend water quality monitoring into October and possibly November. This would allow for monitoring data to overlap municipal complaints better. Chlorophyll-a, algae identification and basic field parameters are sufficient for extended monitoring.

Engage the Bureau of Reclamation to assess procedures and protocols necessary to modify the current aeration system. Feasibility results may indicate a means to meet water quality-based goals with a compressor similar to the current system. By understanding requirements before action is requested the COMCD may shorten the time to implementation.

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