Oklahoma Water Resources Board

Lake Thunderbird
Capacity and Water Quality
2001

for the

Central Oklahoma Master Conservancy District

June, 2002

Final Report

Oklahoma Water Resources Board
3800 North Classen Boulevard
Oklahoma City, OK 73118

Executive Summary

Lake Capacity

Lake capacity at conservation pool (1039 Mean Sea Level) was estimated by integrating Global Positioning System (GPS) with a fathometer, interpolating depth surface area with a Geographic Information System (GIS) and finally, using morphometric models. The 2001 bathymetric survey determined Lake Thunderbird to have a maximum depth of 58 feet, mean depth of 15.4 feet, surface area of 5,439 acres and volume of 105,838 acre-feet. All of these values represent a reduction since impoundment in 1966.

The overall sedimentation rate was estimated as 393 acre-feet per year with a total loss of 13,762 acre-feet. This sedimentation rate compares to the 100-year estimate of 350 acre-feet per year (a 35,000 acre-feet loss). Since impoundment most of the sediment accumulation has occurred in the conservation pool. The decrease of surface area is mostly due to inflow of large-grained solids from tributaries. The rate of sediment accumulation in Lake Thunderbird is about 12% higher than originally planned, which is not a great amount. The distribution of sediment accumulation also shows that most of the sediment has accumulated in the upper portion of the conservation pool.

Water Quality Evaluation

Cessation of aeration allowed for more stable summer stratification and thus a greater partition between the lake epilimnion (surface waters) and the nutrient-rich hypolimnion (bottom waters). This was evident by higher nutrient concentrations at the bottom of site 1 in 2001. However, when stratification weakened anoxic and nutrient-rich waters mixed with the surface water.

Chlorophyll-a gave the best picture of the net effect on water quality. Chlorophyll-a concentrations decreased 20% in 2001 without the aeration system in operation. The increased partitioning between surface and bottom waters can account for most of the observed decrease. Even with the observed algae decrease, however, City of Norman taste and odor complaints increased in 2001. The increase in complaints indicates that byproducts of anaerobic decomposition (mixed hypolimnetic water), rather than taste and odor causing algae, may be the culprit.

Water Quality Goals

Our main goal is to maintain or improve water quality in Lake Thunderbird. High chlorophyll-a concentrations have been documented in the lake, indicating excessive algal productivity. A long-term goal is to reduce chlorophyll-a concentrations from hypereutrophic to eutrophic conditions (between 20 and 7.2 µg/L). The COMCD has made enormous strides in attaining this goal. In 2001, the number of hypereutrophic samples fell 20%. While the number of eutrophic samples remained relatively unchanged, the difference was seen in the mesotrophic zone, with a 17% rise from the previous year. (Figure 0.1).

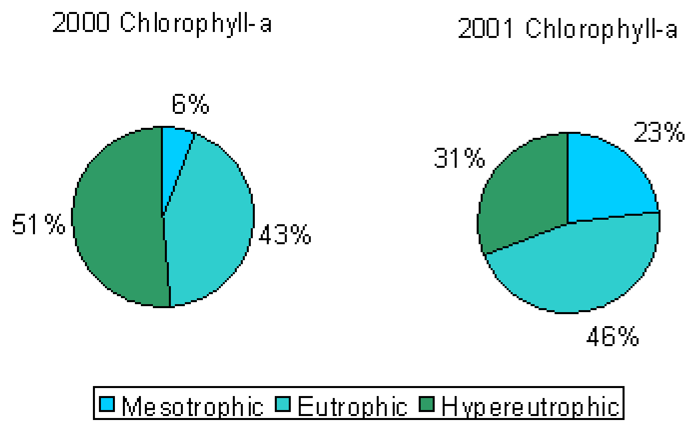

Figure 0.1: Percent distribution of Trophic State using chlorophyll-a concentration for 2001 and 2000 monitoring seasons (May - September).

Although chlorophyll-a levels showed an appreciable decrease from last year, chlorophyll-a still indicates hypereutrophic conditions. Oxygenation of the deeper, bottom lake waters would be another step toward reducing excessive algae growth. This effort should also decrease taste and odor complaints August through November.

OWRB staff recommends that a new, adequately sized aeration system be installed to oxygenate the hypolimnion. A new aeration system will significantly reduce taste and odor problems associated with anoxic hypolimnetic waters and decrease nutrient levels and high algal productivity in the epilimnion. Water quality monitoring should be continued to extend the long-term data set and to record progress toward water quality goals. Reductions based on watershed processes should be addressed if chlorophyll-a concentrations fail to consistently meet the goal of less than 20 mg/L. COMCD and OWRB will work together to determine if this review will be necessary in the future.

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Introduction

The Oklahoma Water Resources Board (OWRB) monitors water quality in Lake Thunderbird for the Central Oklahoma Master Conservancy District (COMCD). 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.

COMCD and OWRB recently set both long-term and short-term goals for water quality in Thunderbird. These goals are outlined in the OWRB 2000 report to the COMCD. The reduction in chlorophyll-a concentrations to between 7.2 and 20 µg/L (eutrophic) in the main body of the lake was identified as a long-term goal. Short-term goal setting evaluated current management practices to achieve the long-term goal. The evaluation indicated that the current aeration system was under-powered. A potential consequence of an under-powered system is stimulated algae growth through entrainment of nutrient-rich sediment from the lake depths to the lake surface. Chlorophyll-a measurements for 2000 showed that approximately 50% of the time algae growth exceeded the lake goal (was greater than 20 µg/L or in the hypereutrophic state). Recommendations based on these results were threefold:

1. Determine current lake capacity,
2. Change the current aeration scheme, and
3. Continue to monitor water quality as feedback to management and to expand the long-term data set.

With concurrence by the Cities of Norman, Del City and Midwest City, the COMCD decided to discontinue use of the under-powered aeration device and monitor water quality for improvements in 2001. The COMCD directed the OWRB to monitor water quality and determine current lake capacity during 2001. Cost savings from the discontinued aeration operation were allocated to identify and enumerate algae species at sites 1, 2 and 4. Additionally, lake capacity determination was identified as necessary to determine proper sizing for an aeration device. Results of lake capacity determination and routine water quality monitoring have been compiled and presented in this report. Recommendations for 2002 follow the discussion section.

Lake Bathymetry

The following is a brief description of the methods used to define morphometric features and presentation of the results. Data collection occurred in 2001 on June 6-8, 11-14, and 25-26. Digitally rectified aerial photographs dated February 21, 1995 were used to establish a digitized lake boundary approximating conservation pool elevation of 1039. Corps of Engineers records indicate the pool elevation of Lake Thunderbird to be 1039.02 on February 21,1995. A differential global satellite positioning system, acoustic depth sounder, and oceanographic mapping software were used to collect the initial morphometric data. Transects were run across the lake at 300 foot intervals slightly modified to follow the shoreline when possible. After completion of field surveying, the software package was used to post-process and construct ASCII files in an XYZ format. GIS technology was used for boundary determination and data interpolation. Methods outlined by Håkanson (1981) were used to provide the most accurate capacity possible following GIS applications. Following these procedures the relative percent error for capacity determination was 0.18%. The percent error in area determination for Thunderbird was 3.1%. Documentation of data collection and interpretation is compiled in Appendix A.

Results and Discussion

Requested morphometric parameters such as maximum depth, mean depth, surface area and total capacity are listed along with additional parameters salient to the physical structure of Lake Thunderbird (Table 1). Although not immediately applicable, these limnological features may be of use for future lake management applications. For example length, width and fetch measurements combined with wind direction and velocity data are diagnostic tools for the design of shoreline erosion control structures.

Table 1: Summary of Lake Thunderbird morphometric features at 1039-ft pool elevation.

Parameter	units	
	Metric	English
Maximum depth	17.69 meter	58.0 feet
Mean depth	4.7 meter	15.4 feet
Median depth	3.56 meter	11.7 feet
Relative depth	0.33 %	
Surface area	22.01 km^2	5439 acres
Capacity	130,550,115 m^3	105,838 acre-feet
Shoreline length	95.72 km	154.0 miles
Shoreline development	5.76	
Direction of major axis	E - W	
Main body Width (E-W)	7.7 km	12.4 miles
Main body Length (N-S)	1.7 km	2.7 miles
Hog Cr. Arm length	7 km	11.3 miles
Blue Cr. Arm length	2.4 km	3.9 miles
Little R. arm length	1.2 km	1.9 miles
Clear Cr. Arm length	3 km	4.8 miles
Maximum effective width	8.3 km	13.4 miles
Maximum effective length	8.2 km	13.2 miles
Effective fetch	8.2 km	13.2 miles
Maximum length	18.3 km	29.5 miles
Mean width	1.2 km	1.9 miles

All of the lengths in Table 1 are approximate straight-line distances except for maximum length. The maximum length is the distance between the two farthest points on the lake and follows the shortest path between the points, which is a curved line in irregular lakes like Thunderbird. In this case the maximum length is between the Little River arm of the lake and the Hog Creek arm of the lake. Figure 1 shows examples of some lake measurements.

Fetch, or the distance a wind-driven wave travels across a body of water, affects the mixing properties of a lake and can have a significant impact on sediment movement, potentially changing the lake shape over time. The maximum effective length and width are at right angles to each other and describe the longest unobstructed distance across the lake, which is the distance wind/waves would travel in a straight line. In this case, the effective length is also the effective fetch. Effective fetch is the longest distance across the lake in the direction that wind predominantly travels in this area, which is shown in Figure 1. A wind rose was used to determine predominant wind direction (Figure 2). Relative depth is the ratio between the maximum depth of the reservoir and the mean diameter of the lake and can be used to describe the stability of stratification of lakes. The shoreline development value describes the irregularity of the shoreline. For example, a lake perfectly round in shape would have a shoreline development value of 1.00. Man-made reservoirs have a higher shoreline development value than most natural lakes. The 5.76 value in Table 1 defines Lake Thunderbird as dendritic, meaning it has many cuts and coves along the shoreline.

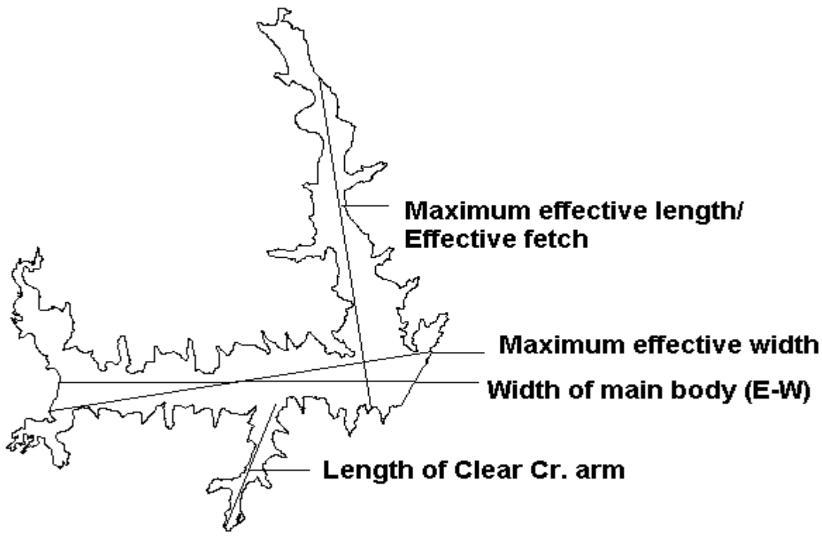


Figure 1 Examples of Lake Thunderbird morphometric measurements

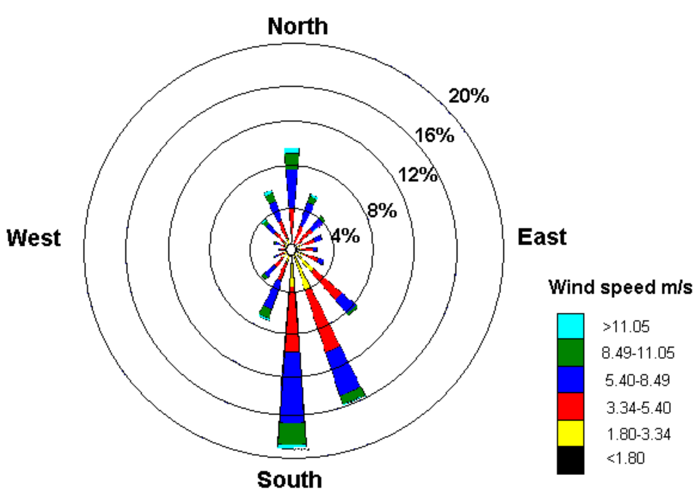


Figure 2: Central Oklahoma Wind Rose, POR Jan. 1984 – Dec. 1992, Will Rogers airport

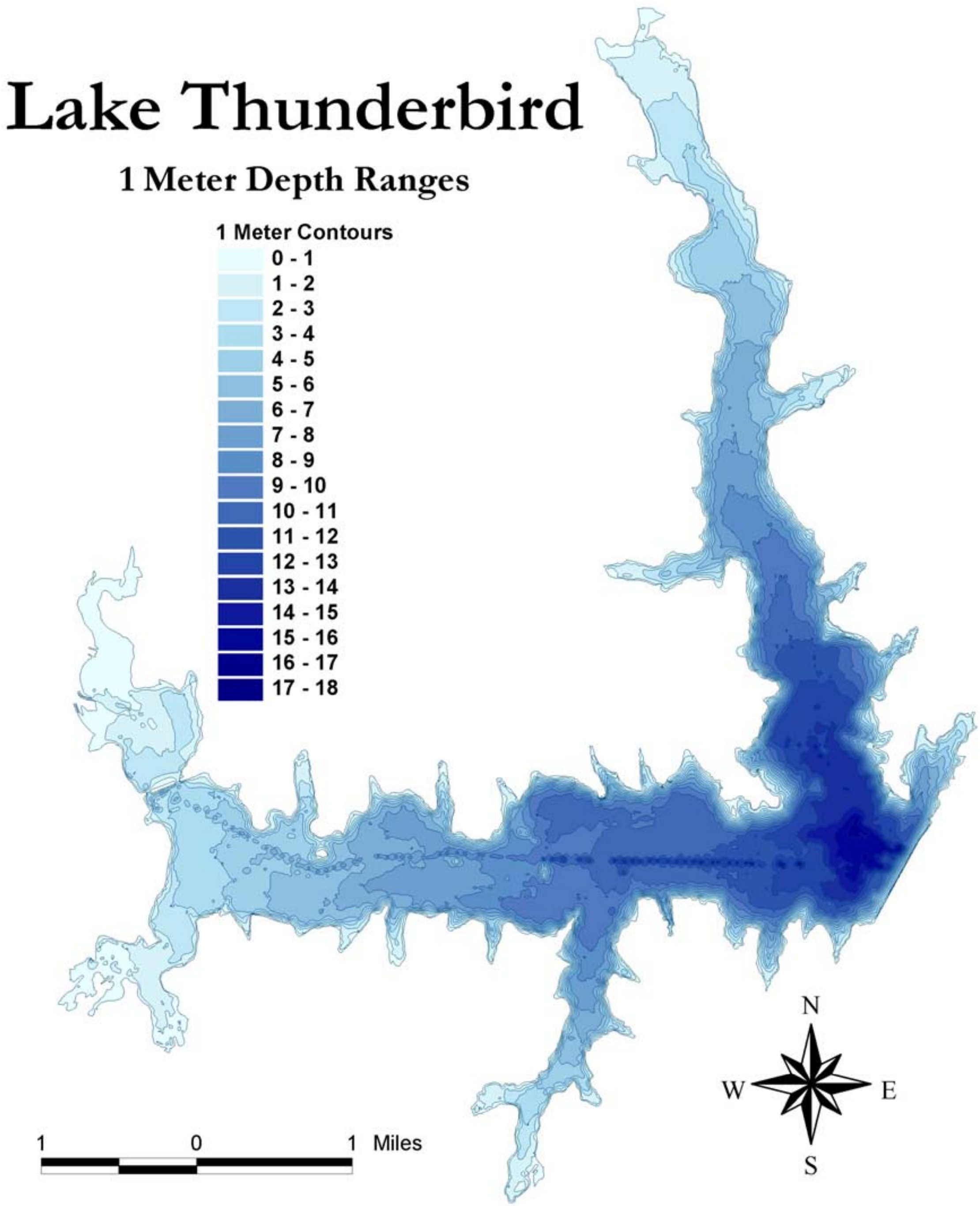


Figure 3: Bathymetric map of Lake Thunderbird June 2001.

Current capacity was then determined by integrating area measurements with depth (Figure 3) and allowed for capacity to be broken into intervals (Table 2). These values were then compared to original design capacity to yield an estimate of sediment accumulation and the distribution within the conservation pool. Since impoundment most of the sediment accumulation has occurred in upper portion of the conservation pool. The relatively little accumulation in the inactive and dead pool suggest that sediment accumulation is mostly attributable to larger, settleable solids than fine grained, suspended solids. The information in Table 3 was graphed to give an idea of how the lake's shape has changed below elevation 1039 since impoundment (Figure 4). The approximately 600-acre loss of area at 1039 elevation was not expected or consistent with a reservoir experiencing shoreline erosion.

Table 2: Tabular summary of area and capacity versus depth for Lake Thunderbird, June 2001

	1966		2001	
Depth(meters)	Cumulative Area (acres)	Cumulative Volume (acre-feet)	Cumulative Area (acres)	Cumulative Volume (acre-feet)
0	6070	119567	5439	105838
1	5400	100734	4848	88958
2	4800	83981	4189	74135
3	4300	69042	3712	61174
4	3750	55772	3288	49690
5	3240	44307	2864	39599
6	2800	34416	2501	30797
7	2390	25883	2144	23179
8	2000	18679	1780	16746
9	1570	12779	1502	11365
10	1230	8105	1140	7042
11	880	4610	717	4020
12	525	2320	480	2067
13	230	1051	243	902
14	90	570	100	356
15	55	320	56	104
16	40	176	8	11
17	25	72	0	0
18	8	15	0	0

Table 3 Comparison of segregated pool capacity with estimated loss.

Lake Pool	Year		Loss	
(elevation range)	1966	2001	acre-feet	%
Conservation (1010-1039)	105,900	93,613	12,287	11.6
Inactive (997 - 1010)	12,500	11,095	1,405	11.2
Dead (970 - 997)	1,200	1,130	70	5.8
Totals	**119,600**	**105,838**	**13,762**	**11.5**

Comparison of the current shoreline to an aerial photograph from 1981 revealed considerable encroachment of tributary creeks into the original lake surface area. Most noticeable were the upper end of Dave Blue Creek, Clear Cove Creek, Little River and Hog Creek arms of the lake. In Thunderbird most of the sedimentation, or loss in area, has occurred in the shallower to medium-depth parts of the lake. Between 8 m deep and the surface (0 m), at each 1-m depth, the loss in area between 1966 and 2001 has been around 10%. Sedimentation rates were also compared against original capacity. Table 4 contains a summary of major morphometric features as well as the estimated sedimentation rate. Examination of the OWRB's Project Files turned up correspondence from the Bureau of Reclamation to the OWRB detailing anticipated sediment accumulation over a 100 year period (BoR, 1965). Capacity loss over 100 years was anticipated at 35,000 acre-feet for a rate of 350 acre-feet/yr. Capacity loss was distributed within the conservation pool from the streambed to elevation 1039. Although the specific distribution of sediment accumulation does not effect the allocation of water for beneficial use the distribution does give clues as to the sources of sediment. Larger grained sediment washed in from the watershed seems to account for the bulk of the accumulated sediment. The current estimated sedimentation rate of 393 acre-feet/yr. compares fairly closely to the BOR estimate of 350 acre-feet/year over a 100-year period.

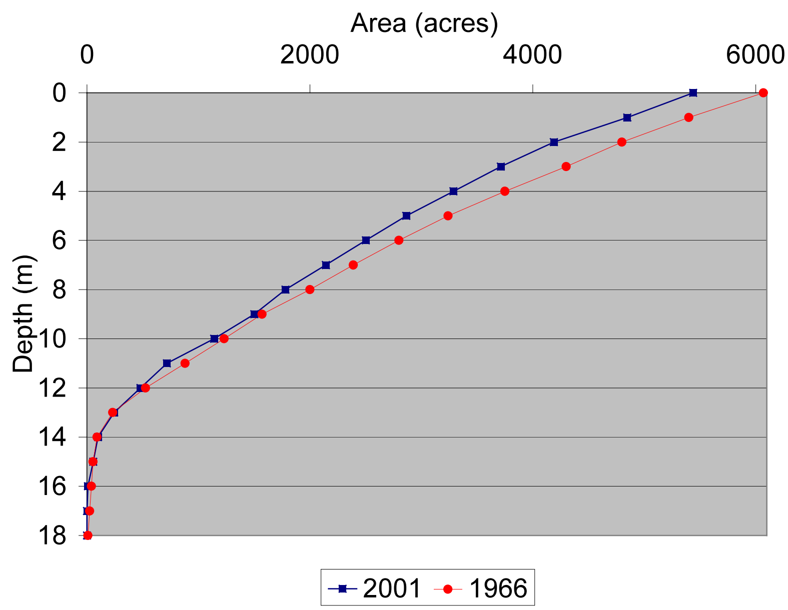


Figure 4: Change in area distribution in Lake Thunderbird

Table 4. Comparison of morphologic features over time with estimated sedimentation rates.

Year	1966*	2001**	% change
Area (acres)	6,070	5,439	-10.40%
Volume (acre-feet)	119,567	105,838	-11.48%
Shoreline (km)	86	96	+11.62%
Mean Depth (m)	6.0	4.7	-21.67%
Maximum Depth (m)	19	17.7	-6.84%
Cumulative Sedimentation Rate (acre-feet/year)	NA	393	NA
Annual area-adjusted depth loss (inch/year)	NA	0.87	NA

* - BoR capacity Allocations (**1965**)

** - OWRB Sedimentation Survey (**2001**)

Water Quality Evaluation

Lake Thunderbird was sampled at the sites indicated in Figure 5. Sites 1, 2 and 4 represent the main body of the lake while Site 3 represents the Hog Creek arm of the lake. Sites 5 and 6 represent the Little River arm of the lake, and site 7 represents the Clear Creek arm of the lake. The parameters of turbidity, chlorophyll-a, Secchi disk depth, dissolved oxygen, temperature and oxidation-reduction potential were monitored twice a week from April 12, 2001 through September 26, 2001 at all sites. Sampling for nutrients (nitrogen and phosphorus series) occurred four times: April 12, April 25, July 5 and September 17, 2001 with samples taken at the surface and 0.5 meter from the 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 the lake response to variable aeration. Nitrogen and phosphorus are the primary chemical nutrients for algae growth. Chlorophyll-a serves as an indicator of algae content.

Additional parameters were collected during the monitoring period. These parameters were collected because of the ease and low cost of adding parameters while on the lake. Surface grab samples were taken at sites 1,2 and 4 during the 2001 monitoring period and have been sent to a contractor for algae identification (cell density and biovolume) to the species level. These parameters will add to the long-term database and may serve diagnostic purposes in the future. A brief discussion of lake stratification and its effects on lake water quality are given before 2001 monitoring data are presented.

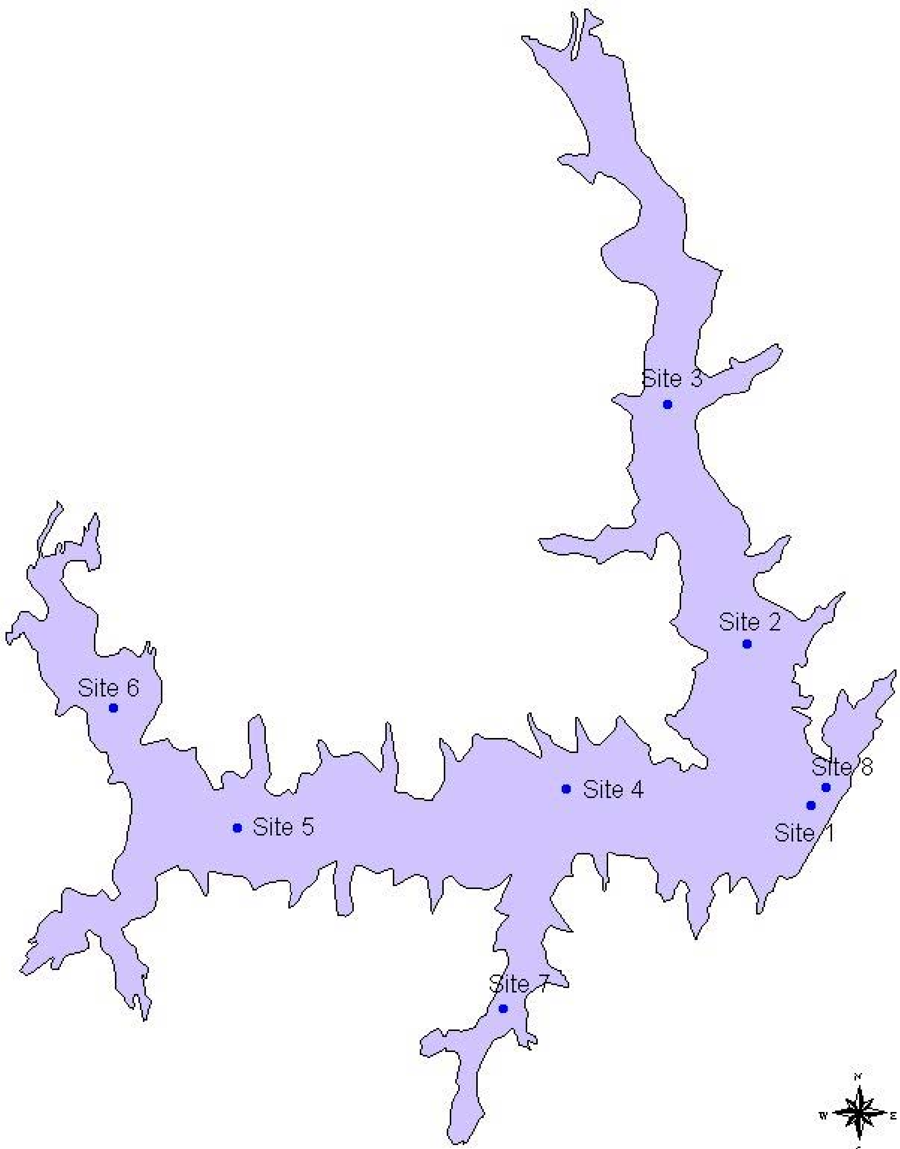


Figure 5. Lake Thunderbird sample sites.

In late spring and summer when temperatures rise, Oklahoma reservoirs generally stratify thermally with a warmer, lighter layer of water (epilimnion) overlying a colder, deeper, and denser layer of water (hypolimnion). Temperatures are generally constant with depth in the epilimnion or the uppermost layer and the hypolimnion. There is a transition layer between the epilimnion and the hypolimnion called the metalimnion. The metalimnion is defined by a sharp gradient (usually temperature) between the epilimnion and hypolimnion. These three layers of a stratified lake are based on density differences that determine the relative amount of mixing and, consequently, the water quality within each lake layer. The metalimnion generally serves to physically separate the epilimnion from the hypolimnion. Figure 6 is an example of thermal stratification showing associated lake layers. The effect of stratification on water quality (in this case dissolved oxygen) is also displayed. See Wetzel (1975) for a more detailed discussion of these processes.

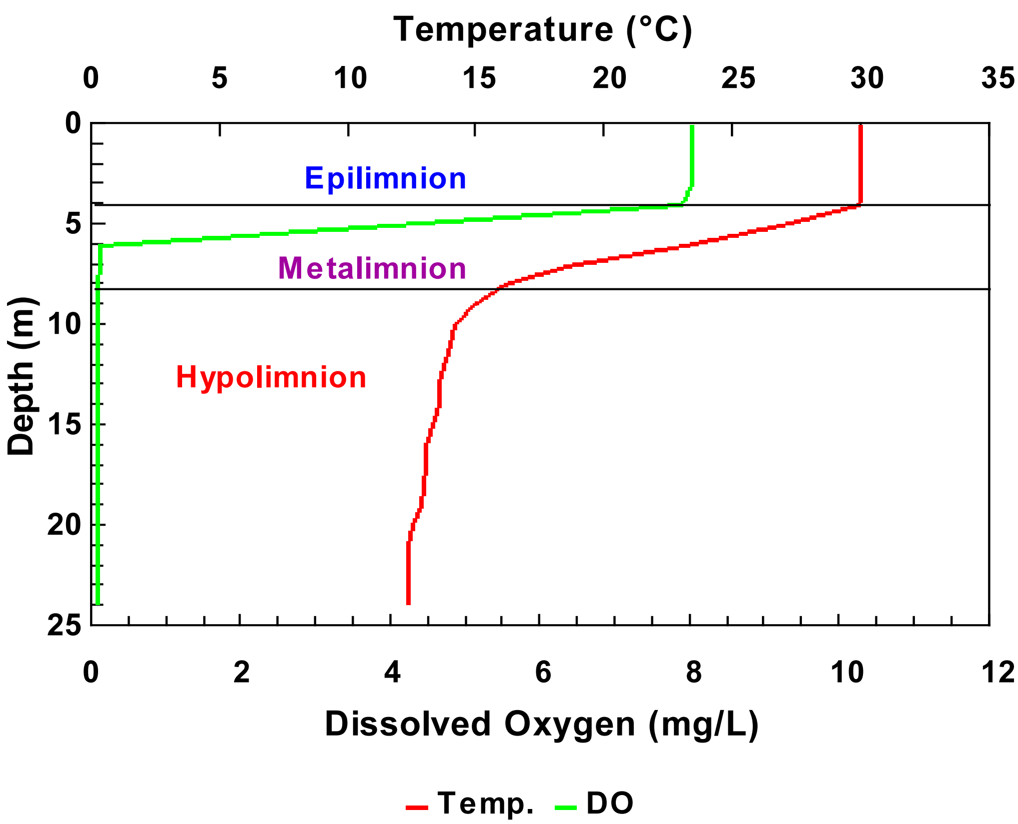


Figure 6. Typical temperature stratification of a eutrophic lake showing the three distinct layers (epilimnion, metalimnion and hypolimnion). From Eucha Lake, August 25, 1993.

Temperature and Dissolved Oxygen

Dissolved oxygen and temperature were used to compare water quality changes and the extent of lake stratification to when the aeration system was in operation. Isopleths were prepared to give a three-dimensional picture of changing 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 2000, Lake Thunderbird showed consistent stratification despite the operation of the aeration system. Figure 7 contains temperature isopleths for sites 1, 2 and 4, the main body of the lake. The beginning of June showed strong temperature stratification with a thermal difference of 4-5 degrees centigrade. The horizontal lines in June continue into September. Temperature isobars turn vertical showing the end of stratified conditions around mid-September. The horizontal lines from June into September for sites 1, 2 and 4 show that the lake was thermally stratified during most of the monitoring period.

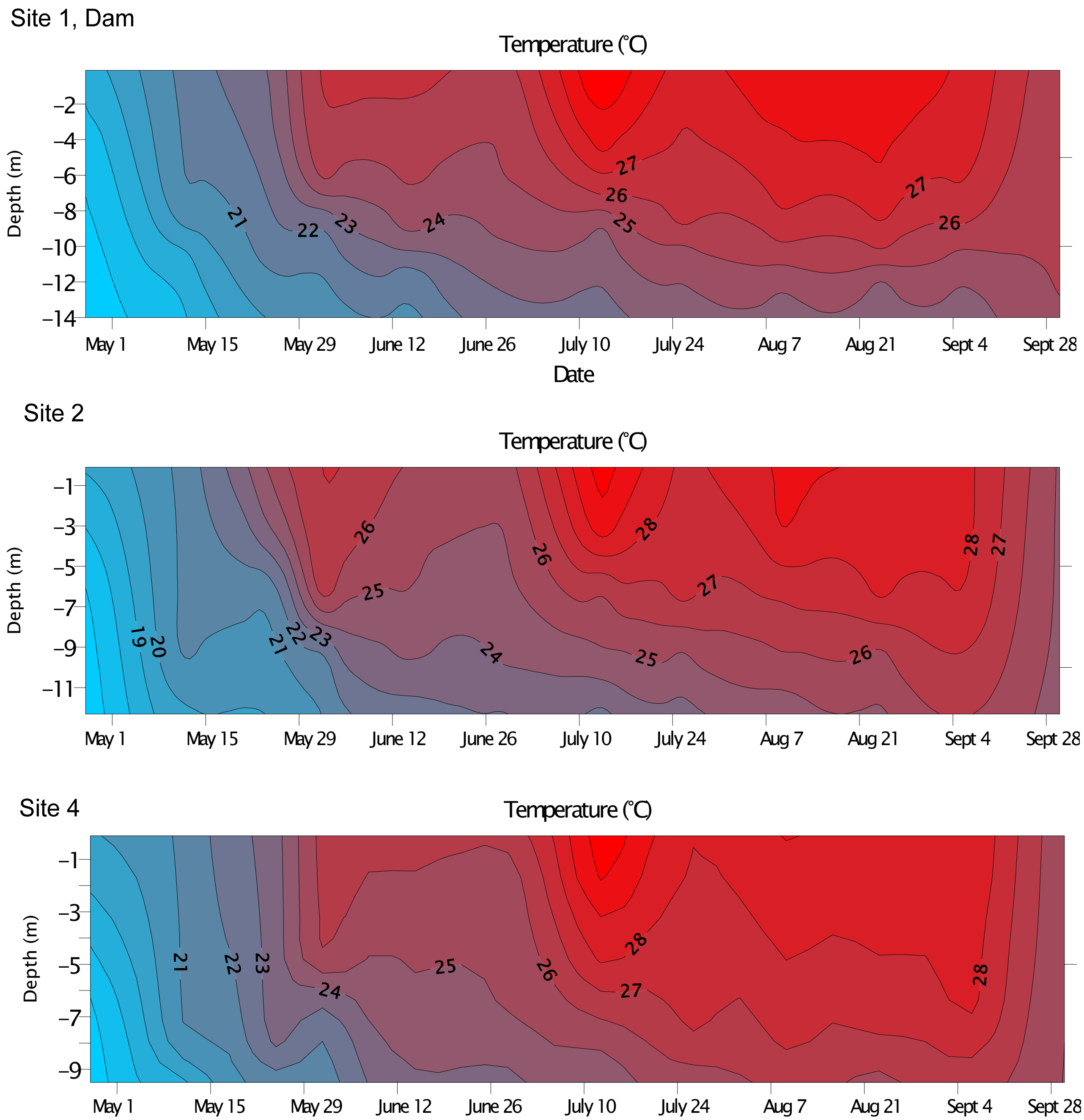


Figure 7. 2000 Temperature isopleths for the main body of Lake Thunderbird in degrees C

Figure 8 shows temperature isopleths for the same three main lake sites in 2001. In 2001, lake stratification was similar to that in 2000. Stratification began around mid-June and ended mid-to-late September. Hypolimnetic water temperatures were slightly cooler in 2001. This delayed breakup of stratification by a couple of weeks compared to 2000 indicating that stratification is much more stable and mixing between the upper and lower layers is less likely.

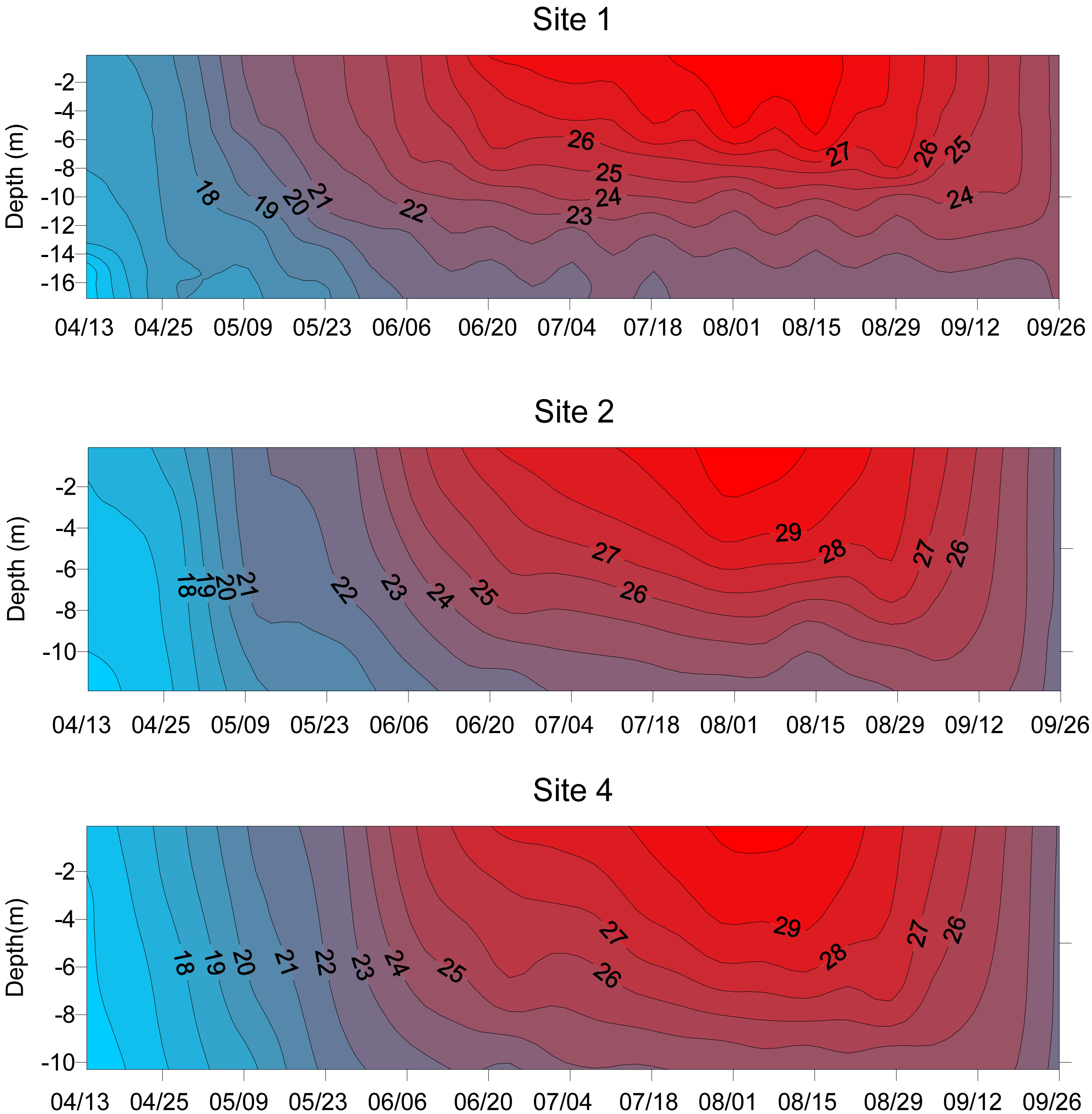
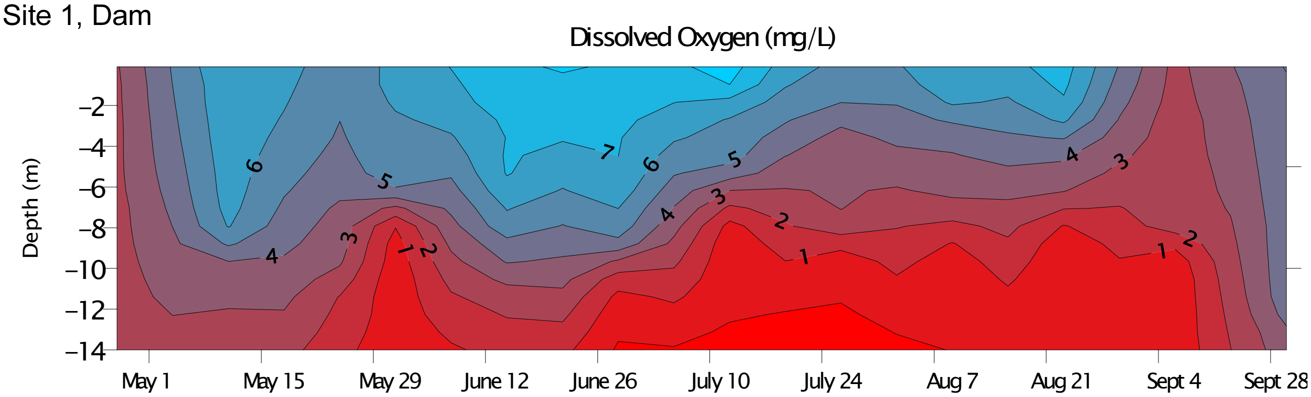


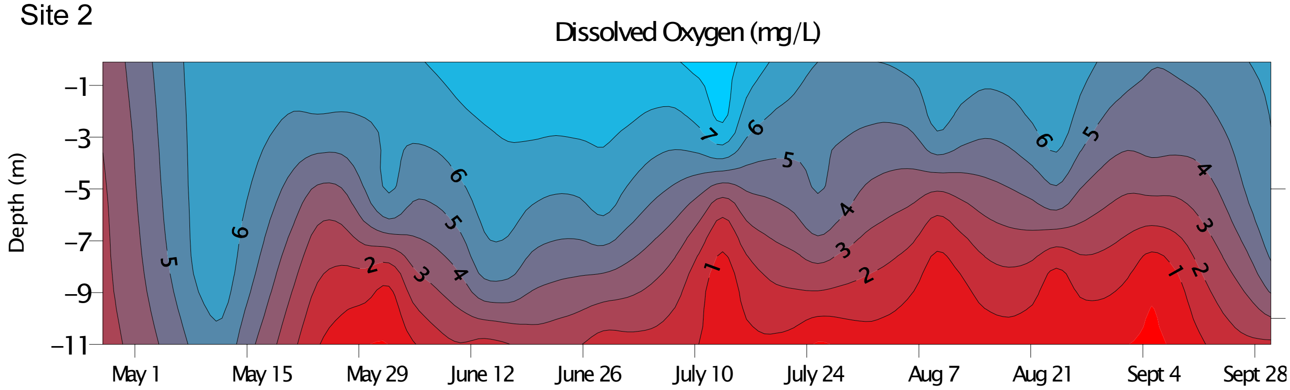
Figure 8: 2001 Temperature isopleths for the main body of Lake Thunderbird in degrees C

Dissolved oxygen, shown in Figures 9 and 10, was plotted to assess the oxygenation potential of the aeration system. The pattern of vertical (non-stratified) to horizontal (stratified) and back to horizontal lines should be very similar to the plots for temperature. This similarity exists because the thermal stratification separates the bottom layer from contact with the atmosphere and oxygen levels in the bottom layer decline. When dissolved oxygen is less than 2 mg/L the water can then be considered anaerobic.

Site 1, Dam



Site 2



Site 4

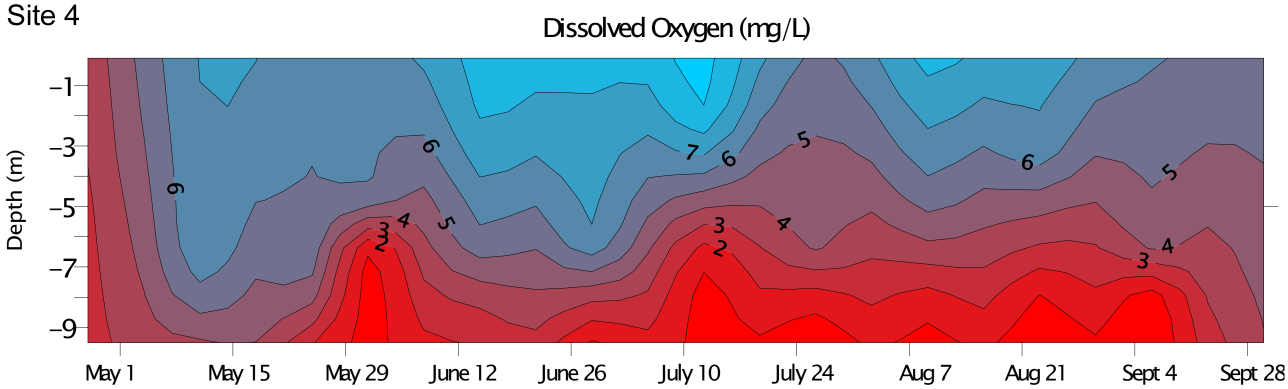


Figure 9. 2000 Dissolved Oxygen isopleths for the main body of Thunderbird in mg/L

By mid May 2000, dissolved oxygen concentrations at the bottom of the lake had fallen below 2 mg/L. Anaerobic conditions at all three main lake sites indicate the aeration system was not oxygenating the entire water column. Also, the fact that the horizontal lines on the isopleth are not flat gives further evidence of the internal mixing that is taking place in the water column.

In 2001, development of anaerobic conditions varied from site to site, generally because of depth differences. At site 1, near-anoxic water was seen below 13 meters at the beginning of May. At site 2, this drop in dissolved oxygen occurred in late May, site 4 in mid-June. Comparing conditions at the same depths for each site—10 m is the deepest that can be used in this case—anaerobic conditions developed around mid-June. To keep comparisons between the two years comparable, in 2000 at the 10-m mark anaerobic conditions still developed in mid-May.

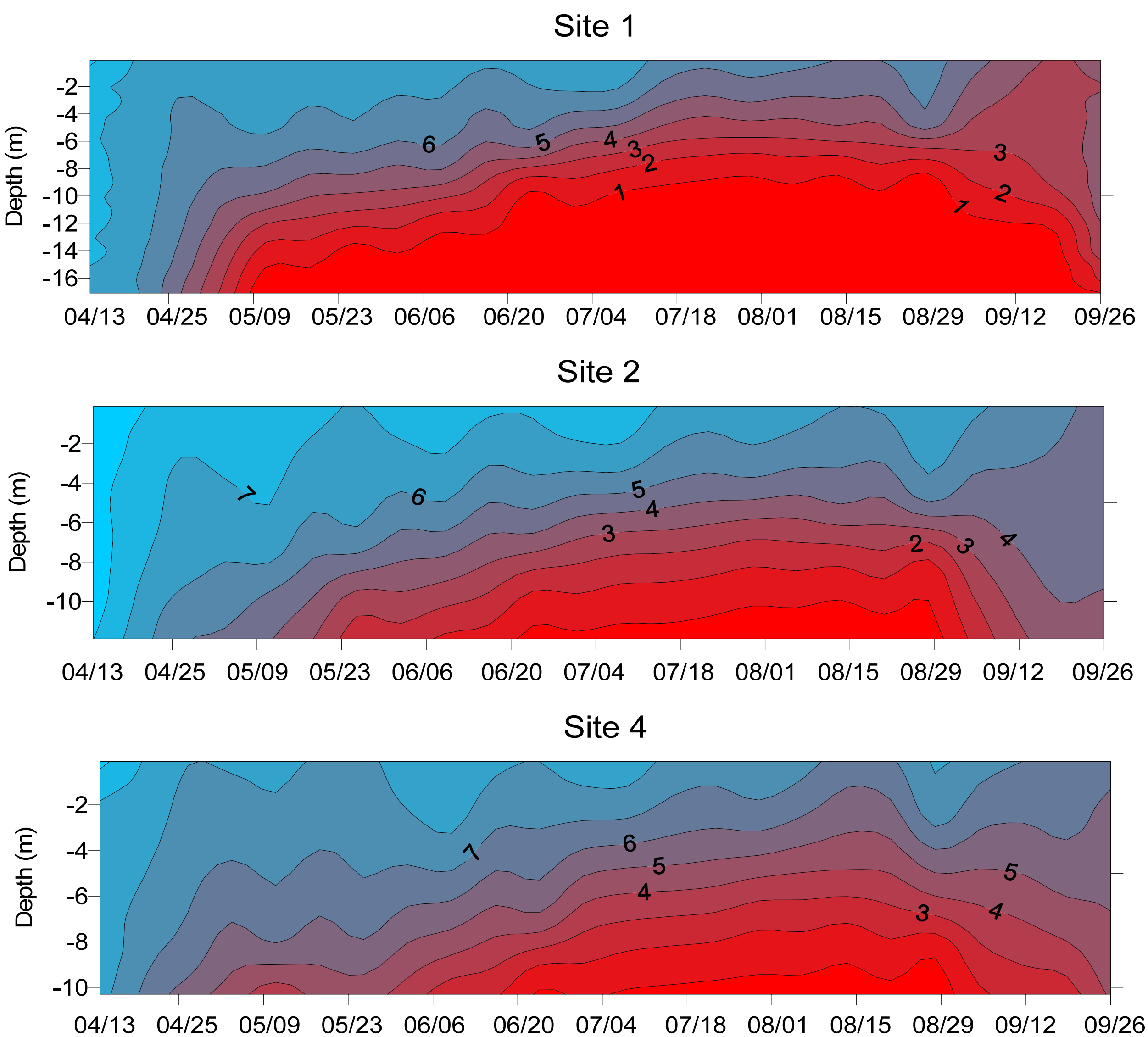


Figure 10: 2001 Dissolved oxygen isopleths for the main body of Lake Thunderbird in mg/L

Comparing Figures 9 and 10, again the horizontal lines are flatter in 2001, indicating greater stability of the water layers. Comparing the depths at which the water column becomes anaerobic, in both years the shallowest depth is 7 meters for all sites. In 2000, this region does not remain at 7 meters – the top of this near-anoxic region dips down to 11-12 meters. This means that the absolute volume of anaerobic water was greater in 2001 than in 2000. Of course, because anaerobic water is better partitioned from circulation to the surface, its effect should not matter until the lake turns over.

Low dissolved oxygen levels indicate that when the lake mixes nutrients in the form of ammonia and dissolved ortho-phosphorus may be released from the sediment, making them available for algae growth. Nutrient data will be examined as indicators of any potential nutrient flux from sediment to the overlying water column.

Nutrients

Analysis of surface and bottom samples for dissolved nutrients showed a mixed pattern comparing dissolved nitrogen species from 2000 to 2001. Figures 11-13 display these results for the main body of the lake. At all three main body sites, the surface nitrogen concentrations were not significantly different from 2000 to 2001. The greatest concentrations of nutrients were from the bottom samples at site 1 (the dam) in both years. In 2001, bottom dissolved nitrogen concentrations were lower for sites 2 and 4, but higher at site 1. The highest value in 2001, 3.4 mg/L at the bottom of site 1, was nearly 1 mg/L greater than the bottom of site 1 in 2000, 2.3 mg/L. This indicates greater release of nitrogen from the sediment. An alternative possibility is that the sediment release rate is the same each year but the difference in degree of stratification accounts for the higher 2001 concentration. Stronger stratification in 2001 would have partitioned the hypolimnion from the epilimnion better than in 2000, eliminating loss of nitrogen to the epilimnion. That site 1 values were higher than the other sites reflects the fact that site 1 is deeper than the other sites by around 6 meters and in both years had the highest potential for sediment releases due to the extended duration of anoxia.

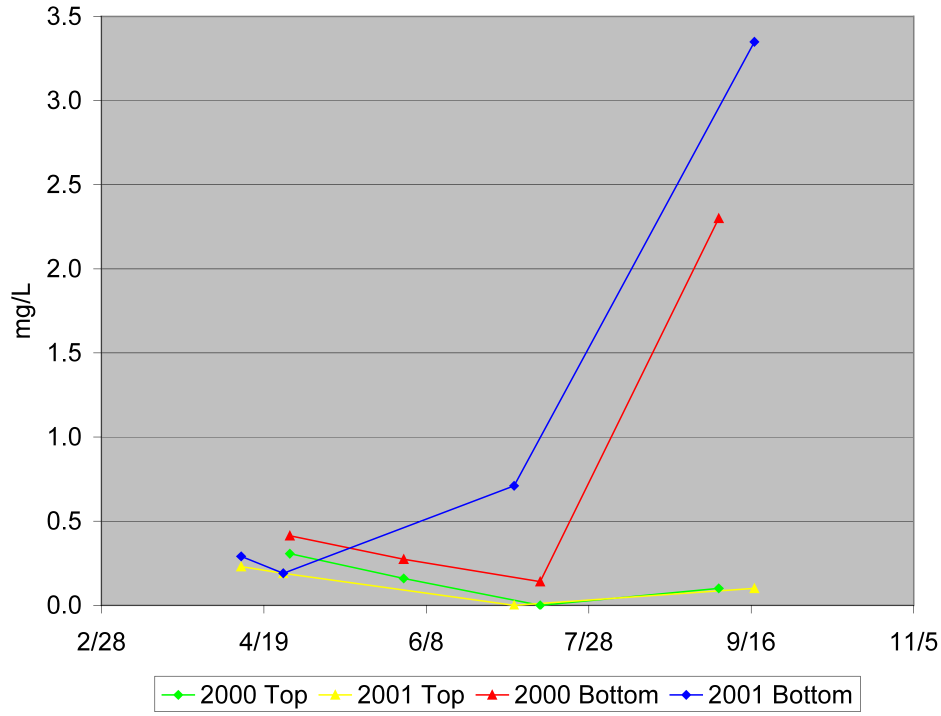


Figure 11: Total dissolved nitrogen species concentrations for Site 1

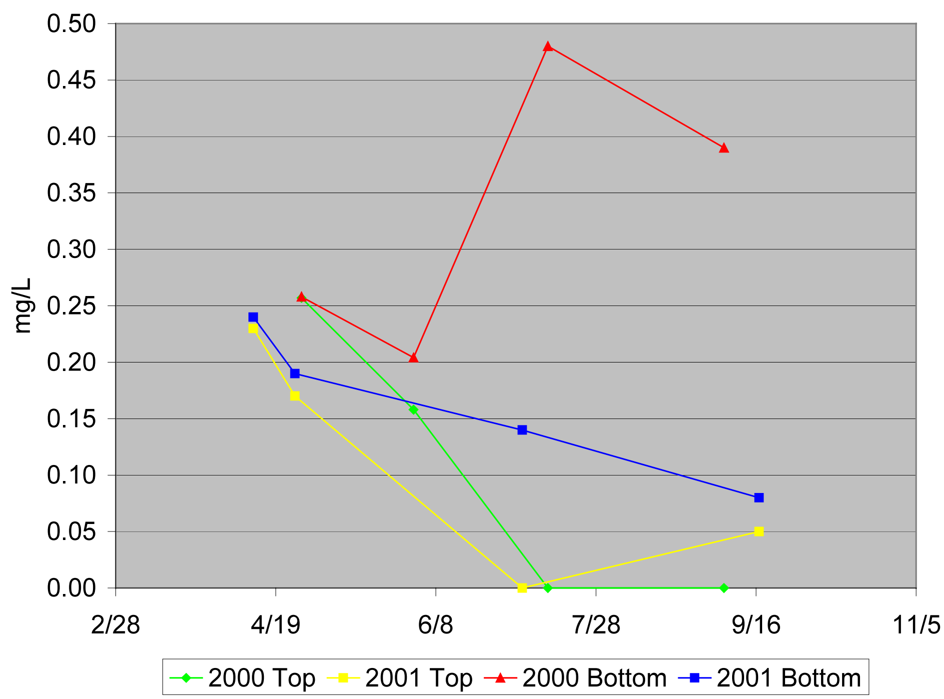


Figure 12: Total dissolved nitrogen species concentrations for Site 2

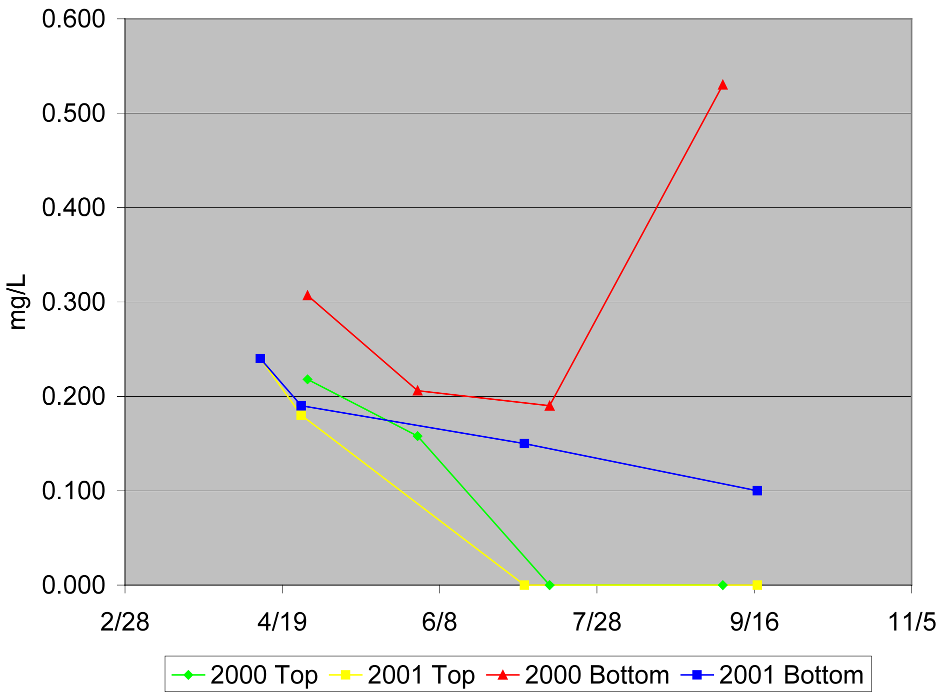


Figure 13: Total dissolved nitrogen species concentrations for Site 4

When comparing bottom nutrient concentrations it is also important to compare physical lake characteristics, namely, whether the lake is stratified or mixed at that time. When stratification is noted, figures must be analyzed a different way. Figure 11 is straightforward because in both years the lake was stratified to the depth of site 1 until after nutrient sampling ended. At sites 2 and 4, the lake remained stratified in 2000, but in 2001 de-stratification began around the beginning of September. Because of this, nitrogen levels most likely increased after the July sampling event to an unknown maximum and then sharply decreased to the level of the last sampling event when mixing had occurred and the nutrients became available for plant uptake.

Dissolved ortho-phosphorus, the bioavailable form of phosphorus, is graphed in Figures 14-16. Dissolved orthophosphorus can also serve as an indicator of sediment-released phosphorus. At site 1 surface and bottom phosphorus levels were comparable both years.

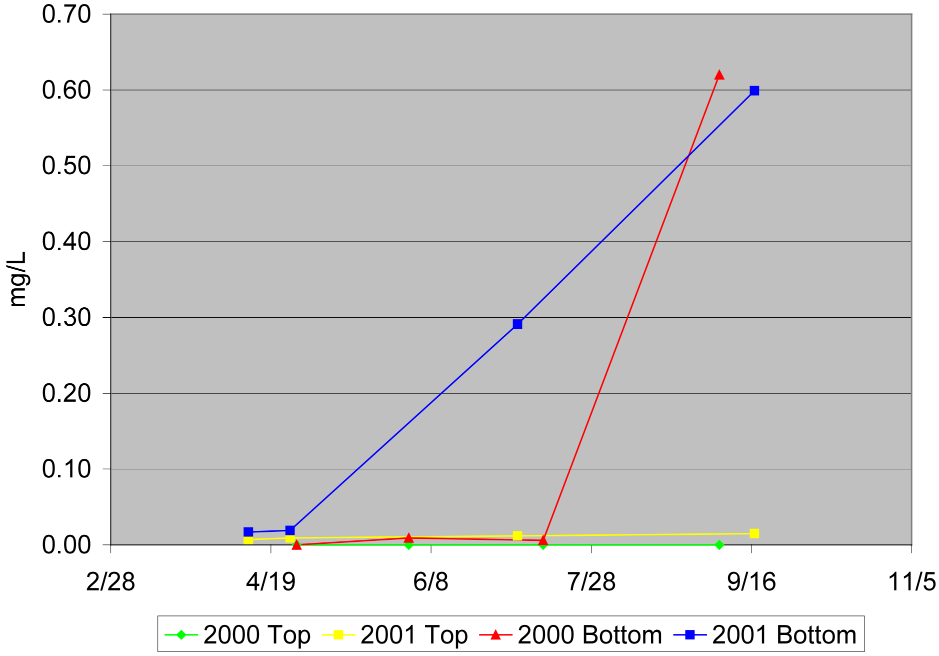


Figure 14: Dissolved ortho-phosphorus concentrations for Site 1

At site 2 the maximum surface phosphorus measurement occurred in 2000. At that time, a greater concentration was measured at the surface than on the bottom of the lake. This measurement occurred just after several major inflows from precipitation runoff – possibly with high phosphorus loads. Although the aeration system was turned on at this time, the measured phosphorus probably came from inflow rather than mixing from the lake bottom due to the low phosphorus concentrations measured at the bottom.

At site 2, bottom phosphorus concentrations were higher in 2001. When comparing phosphorus concentrations of the completely mixed lake, which occurred both years at the first sampling event, 2001 also had a higher concentration.

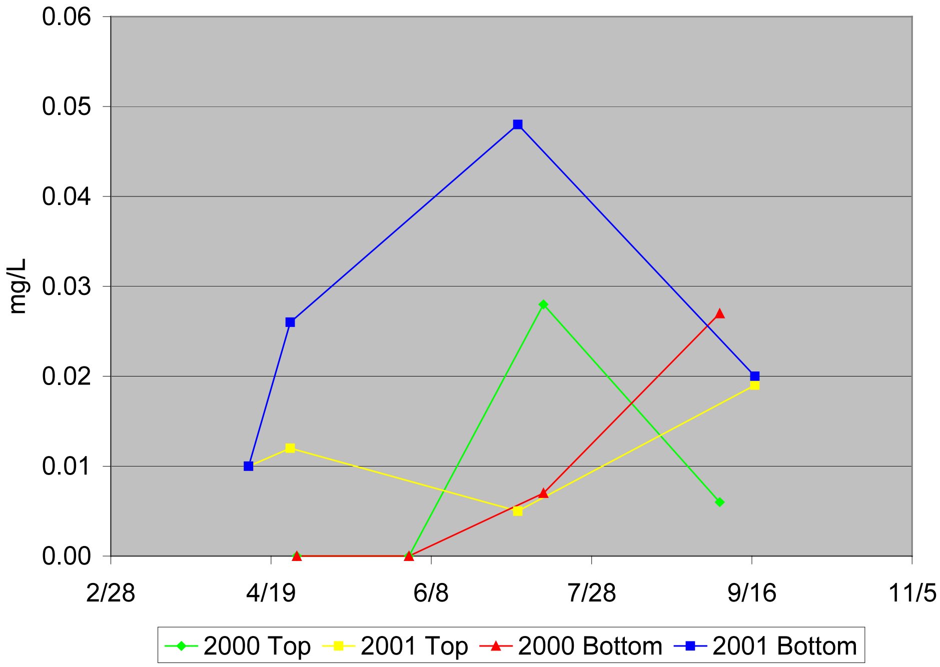


Figure 15: Dissolved ortho-phosphorus concentrations for Site 2

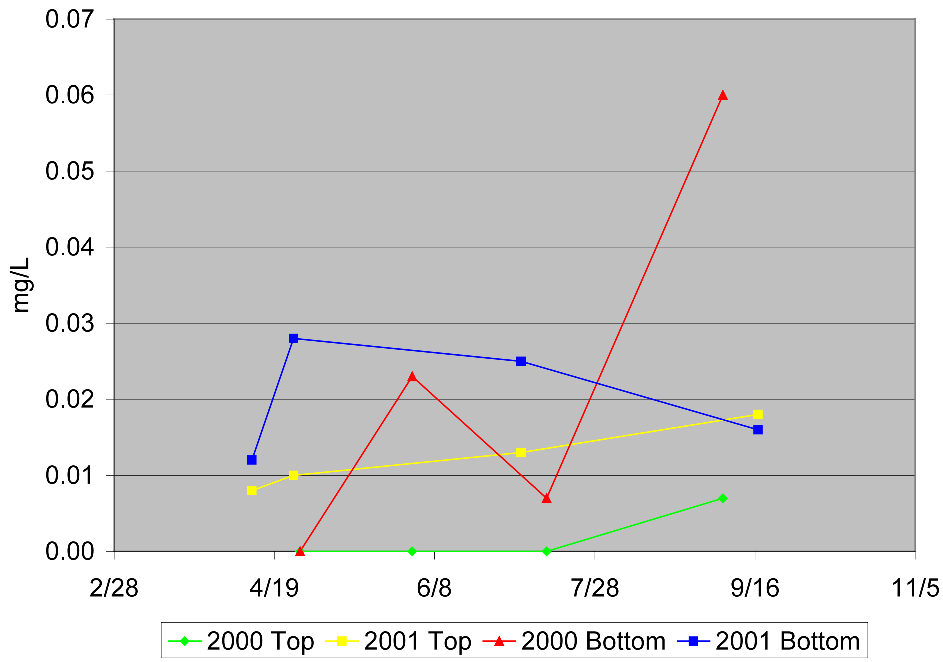


Figure 16: Dissolved ortho-phosphorus concentrations for Site 4

Site 4 had consistently higher surface phosphorus levels in 2001. Bottom phosphorus was variable. The absolute maximum of measured samples was in 2000. When we compare the completely mixed state of the lake from one year to the next—or look at the first sampling event—2001 had a greater concentration of phosphorus.

Generally, as long as the lake is stratified, surface nutrients are the primary determinant of algae growth. In this case, 2001 surface nutrient concentrations are very similar to 2000 levels and remain fairly low. Comparison of the nutrient data at site 1 suggests that the cessation of aeration increased the thermal (and thus physical) barrier between the epilimnion until stratification weakened. A prediction based on this data was lower chlorophyll-a concentrations for the first part of 2001 than seen in 2000. As the data will show, this prediction turned out to be an accurate one.

Chlorophyll-a

Chlorophyll-a is the primary chemical all plants use to covert solar energy into chemical energy. In both years, all three sites showed a similar trend of increasing chlorophyll-a concentrations toward the end of the year (Figures 17 and 18). After the aeration system was turned off, chlorophyll-a concentrations dropped for most of 2001.

Two lines were added to the chlorophyll-a plot in Figures 17 and 18 to show the boundaries for hypereutrophic or excessive algae growth (greater than 20 µg/L) and eutrophic or high algae growth (between 7.2 and 20 µg/L). The upper line represents the goal for maximum concentration as determined by the COMCD.

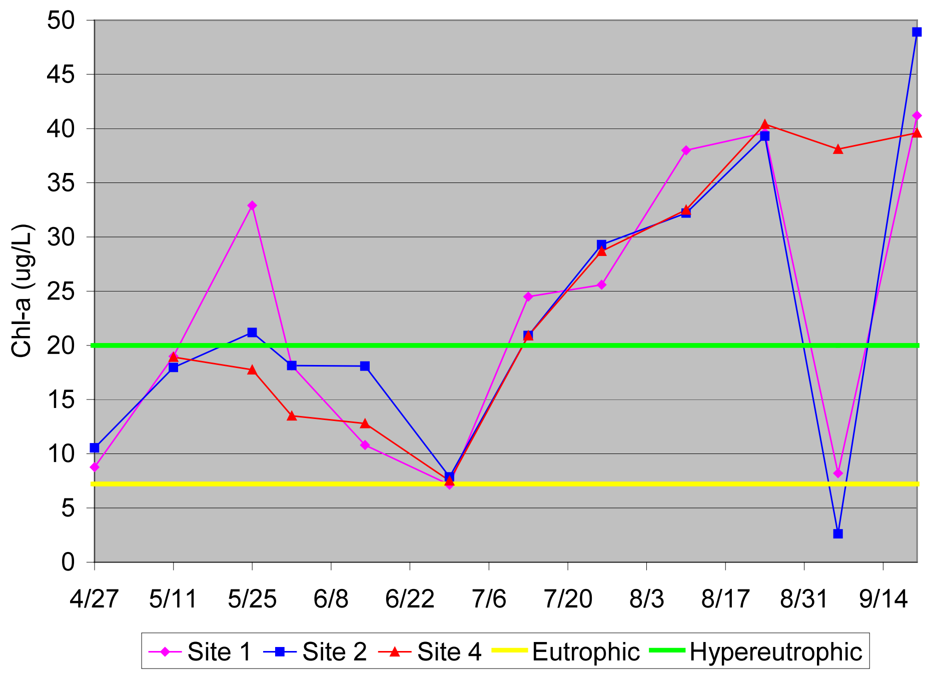


Figure 17: 2000 Chlorophyll-a concentrations for sites in the main body of the lake

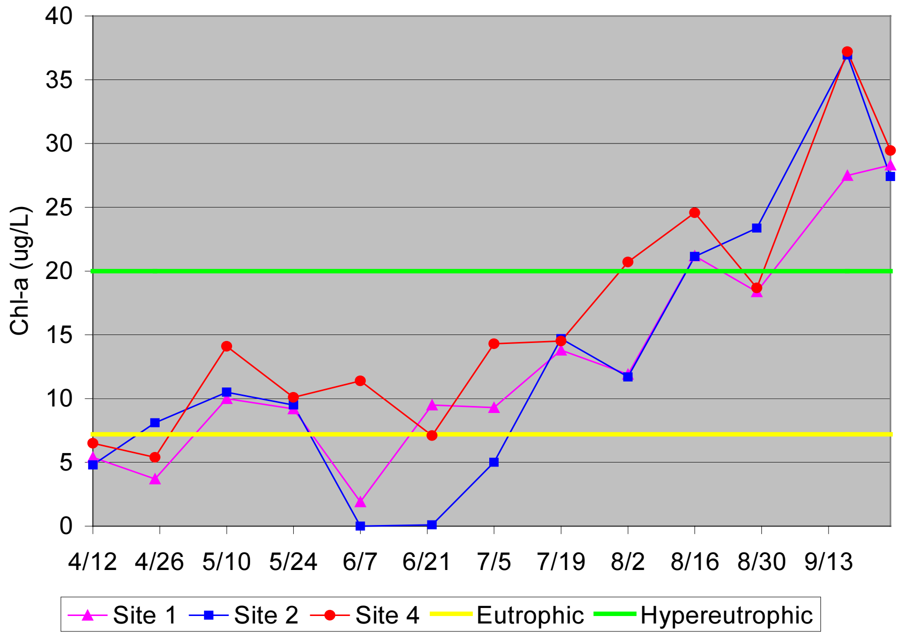


Figure 18: 2001 Chlorophyll-a concentrations for sites in the main body of the lake

Comparing Figures 17 and 18, we did see a decrease in chlorophyll-a concentrations during the summer months. In 2000, concentrations were above the hypereutrophic level briefly in May and then again from early July to the end of the year. In 2001, concentrations were not above hypereutrophic until the beginning of August. In addition, the overall average concentration decreased from 23 µg/L in 2000 to 15 µg/L in 2001. If we compare chlorophyll-a concentrations only during stratification, the average decreased from 21 µg/L to 9.5 µg/L.

Comparing the data sets from the two years studied to the eutrophic/hypereutrophic boundaries, chlorophyll-a has decreased in the last year. The relative percentages are shown below in Figure 19.

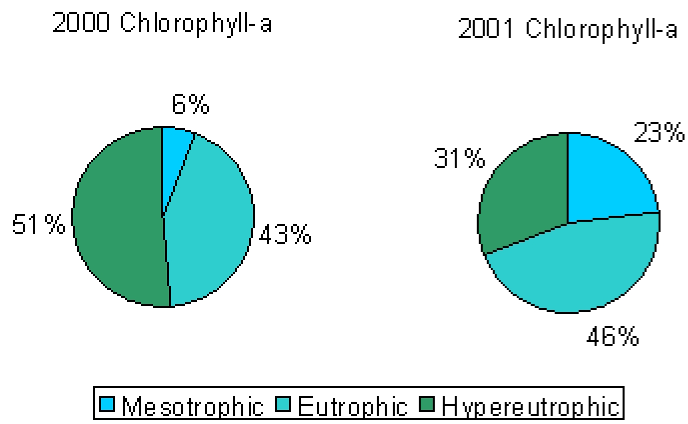


Figure 19: Percent distribution of Trophic State using chlorophyll-a concentration for 2001 and 2000 monitoring seasons (May - September).

In 2001, 20% fewer samples were hypereutrophic and 17% more of the samples were below eutrophic, indicating a significant decrease in algae productivity since the aeration device was discontinued. Chlorophyll-a concentrations above the 20 µg/L threshold were still noted. It is likely that a refurbished aeration system would further reduce summer season chlorophyll-a values to below 2001 levels.

Taste and Odor Events

The City of Norman noted an unusually high number of complaints during the fall of 2001, continuing through December. There were 23 complaints recorded with 5-7 per month from August to November. Midwest City and Del City did not experience an increase in complaints but did note an increase in organic content beginning around September to October. The fact that only Norman had an increase in customer complaints might be attributed to differences in treatment methods among the municipalities. Both the complaints and the noted increase in organic content correspond to the weakening and elimination of stratification. Mixing of hypolimnetic water is the most likely contributor to the expressed treatment problems.

Conclusions

After the aeration system was turned off, OWRB staff expected to see a greater partitioning of nutrients into two layers. This projected outcome would result in an increase in bottom nutrients and a decrease in summer chlorophyll-a concentrations until stratification ended. Site 1, which is the deepest and was stratified throughout nutrient sampling, did show an increase in bottom nutrients. Sites 2 and 4 showed increases in bottom phosphorus but decreases in nitrogen during stratification. The results are difficult to quantify because the last sampling event for each year cannot be directly compared – in 2000 the lake was still stratified and in 2001 the lake had already mixed.

Chlorophyll-a gives a better overall picture of the net effect on water quality.

Chlorophyll-a concentrations decreased by 20% in 2001 without the aeration system in operation. This clearly indicates that the previous aeration system was contributing to algae growth beyond what would naturally be seen.

A basic assumption of chlorophyll-a concentrations is that they may be used as an indicator of algae growth, and that excessive algae growth can be correlated to taste and odor problems. In reality, the particular species of algae rather than overall amount might be more useful for explaining taste and odor problems. Taste and odor complaints increased in 2001 while the chlorophyll-a concentrations decreased. The increase in complaints indicates that byproducts of anaerobic decomposition (mixed hypolimnetic water), rather than taste and odor causing algae, may be the culprit.

Water Quality Goals

Goals have been partitioned into short-term and long-term time scales. Short-term is considered to be within the next 5 years, while long-term is in the 40-50 year time frame.

Short-term Goals

The major short-term goal is to achieve a fully oxygenated reservoir to improve water quality. The data demonstrate that the previous aeration system was inadequate and likely increased algae production through nutrient loading from lake sediment. Turning off the aeration system resulted in a 20% reduction in chlorophyll-a. The next step in reduction of algae growth is to design and install an adequately sized aeration system using the newly measured lake dimensions.

Long-term Goals

Long-term goals were established during last year's goal-setting meetings. The major goal is to maintain or improve water quality in Lake Thunderbird. In particular, high chlorophyll-a concentrations have been documented in the lake, indicating excessive algal productivity. A long-term goal is to reduce chlorophyll-a concentrations from hypereutrophic to within the eutrophic zone (between 20 and 7.2 µg/L).

Another concern is taste and odor-producing algae. When circulation of the reservoir ended, in 2001 taste and odor complaints increased. This is likely a result of no aeration. Oxygenation of the anoxic hypolimnetic waters should reduce these complaints. Another goal is to document algal community structure and determine its effect on taste and odor complaints.

Recommendations

The OWRB recommends that a new, adequately sized aeration system be put into operation. A new aeration system will significantly reduce taste and odor problems associated with hypolimnetic waters and decrease the problem with nutrients and high algal productivity. Water quality monitoring should be continued to extend the data set and record progress towards lake water quality goals. Should the water quality based goal of no chlorophyll-a concentrations above 20µg/L not be achieved then watershed measures should be reviewed to meet this goal.

References

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Lake Thunderbird

Capacity and Water Quality

2001

Appendix A

GIS Procedures for Lake Thunderbird Bathymetric Mapping

1) Create an Accurate Lake Boundary File

In order to create an accurate boundary file for Lake Thunderbird, it was determined that the best source data was the USGS Digital Orthophoto Quarter Quads (DOQQ). The DOQQs have a spatial resolution of 1 meter. Four DOQQs cover the entire lake. They are the SE quarter of the Franklin quad, the SW quarter of the Stella quad, the NW corner of the Little Axe quad, and the NE quarter of the Denver quad. The photo date for each of the images was August 5, 1998. On this date, the lake elevation was 1039.02 feet. The normal pool elevation for the lake is 1039 feet.

The DOQQs were in the UTM coordinate system with NAD83 as the horizontal datum. These DOQQs were reprojected into the Oklahoma North State Plane coordinate system with the NAD83 horizontal datum using ARCINFO 8.01 GIS software from ESRI.

Using ArcView 3.2 GIS Software from ESRI, the reprojected DOQQs were used as a reference to digitize the boundary of the lake on-screen. The boundary was digitized at a screen scale of 1:3000. The total surface area of the created lake boundary excluding the island areas was 5,438 acres.

2) Import the Collected Bathymetric Data into a GIS Format

The bathymetric data was delivered in a Microsoft Excel spreadsheet format. This data was converted to a comma delimitated ASCII text file containing the X, Y, and Z point information. This file was imported into ArcView and converted into a shapefile.

3) Create a Point Coverage of all Data Points.

The lake polygon boundary coverage was densified to create more vertex points. This coverage was then converted to a point coverage and each point was given a depth value of zero. This coverage was then merged with the collected data points to create a point coverage with all of the data points.

4) Create the GRID Model

ArcInfo's Arc ToolBox, TOPOGRID Tool, was used to create the GRID surface model. This model created an elevation surface based on the point data coverage and the lake boundary.

5) Contour Depth Coverage

ArcInfo's Arc ToolBox, Contour Wizard was used to create a 1-meter interval contour depth coverage from the Grid surface model.

6) Lake Volume Calculations

The surface area of each 1-meter contour interval was calculated and used in the lake volume calculation model.

Lake Thunderbird Results

Surface area calculated from Digitized Lake Boundary = 5,438 acres

GRID Calculations (20 ft cells)

Volume:	105,644.36 acre-ft
Area:	5,438 acres
Maximum Depth:	-57.648 ft
Average Depth:	-19.114 ft

Depth Range Statistics from Edited GRID Calculations

Depth Range (m)	Count	Area (acres)
0 - 1	1	590.96
1 - 2	24	659.85
2 - 3	9	477.06
3 - 4	9	423.97
4 - 5	17	423.07
5 - 6	15	363.29
6 - 7	12	357.34
7 - 8	13	364.01
8 - 9	10	277.93
9 - 10	10	362.04
10 - 11	13	422.59
11 - 12	7	237.28
12 - 13	16	236.78
13 - 14	21	143.39
14 - 15	13	44.30
15 - 16	4	47.21
16 - 17	7	8.17
17 - 18	1	0.16
Sum	**202**	**5439.374**

Bathymetric Mapping is the process utilized to determine the storage capacity of reservoirs. The process utilizes a differential global satellite positioning system (DGPS)[1], an acoustic depth sounder (Echosounder)[2], and Coastal Oceanographic software[3]. The implementation of this technology in bathymetric mapping has allowed the surveying process to become more efficient and accurate. This mapping process was utilized to survey Lake Thunderbird in June 2001.

The process of conducting a bathymetric survey consists of three successive procedures. These procedures include setup, field surveying, and post-processing of collected data. In the first procedure setup, Hypack software from Coastal Oceanographic is used to create virtual track lines that are laid across a digital rendering of the reservoir that has GPS coordinates. These virtual track lines are spaced between 300 or 400 feet apart. The determination of the spacing is related to the accuracy that is required for the surveying project. The closer the virtual lines are together the more data that will be collected in the surveying process. The data directories for which the collected data will be stored are also created in the setup procedure. The next step in the surveying process is the field surveying.

Field Surveying consists of the actual data collection. Once the destination reservoir has been reached the equipment is setup on the boat (Carolina Skiff) and networked together. The equipment is then tested to ensure that the individual components are working properly together. The echosounder is calibrated to the salinity concentration of the reservoir to provide accurate depth readings. Once on the lake, each virtual line is followed across the reservoir until the entire navigable surface area of the reservoir has been covered. A DGPS (XY) point and a depth reading (Z) are collected every one to three seconds (depending on desired accuracy) while navigating on each virtual line that cuts across the reservoir. The raw data is collected in State Plane 1983 Geodetic Parameters. In this mode the XYZ coordinates are collected in feet. The Coastal Oceanographic Hypack software is used to display the map of the reservoir, the virtual lines, and store all data points that are logged while on the reservoir. After the field surveying has been completed the mapping process continues back in the office where post-processing takes place.

The last procedure in the bathymetic mapping process is the post-processing. The raw data collected in the field is brought back to the office. Utilizing the Hypack Software the raw data is reviewed. The reason for reviewing the data is that when surveying in the

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[1] Trimble, AgGPS122
Sub meter accuracy
DGPS antennae

[2] Raytheon Depth Sounder Precision Surveying Fathometer
Model: DE719D MK2
Range 500' or 150m
Resolution 0.1 units
Accuracy +/- 0.5% of indicated depth (ft or m)

[3] Coastal Oceanographics, Inc. Hypack for Windows
(Bathymetric surveying, dredging maintenance, construction, and general navigation software.)

field there is always the possibility that the equipment has processed a false reading, whether it is a DGPS reading or echosounder reading. The raw data is viewed using the Hypack Single Beam Editing program. The Editing program can allow one to see a virtual line and the data collected on that line. Each virtual line is reviewed individually. In the process of reviewing a line, each XYZ point collected on that line is examined to ensure that it is an accurate value. XYZ Coordinate points on the line that are not accurate are corrected to closely match other accurate surrounding points. The day to day fluctuations in lake levels are also adjusted in the raw data during this process. This is done by recording the lake levels on the days that the surveying takes place and then this data is used to adjust the raw Z coordinate values. Once the raw data has been corrected the data is sorted. The Sort program can eliminate conflicting data points based on either a Radius or DX-DY distances. With a Radius, which is preferred, the program eliminates any other data record that is within the radial distance of the accepted point. The smaller the accepted point the less edited data is rejected and a larger accepted value results in more edited data that is rejected. The Sort program then saves the edited data to an ASCII XYZ data file with the .XYZ extension. Once the edited data has been sorted it can be rendered in a map, such as a contour map, or some other form of graphical representation to satisfy the needs of the project.