Oklahoma Water Resources Board

Lake Thunderbird
Water Quality
2009

for the

Central Oklahoma Master Conservancy District

May 4th 2010

Draft Report

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

Executive Summary

Lake Thunderbird is listed in Chapter 45, Table 5 of the Oklahoma Water Quality Standards (OWQS) as a Sensitive Water Supply (SWS) (OAC 785:45). OWRB lake water quality monitoring in 2009 was altered to focus on the tributary inputs to the lake. The end of 2009 monitoring represents ten years of continuous monitoring.

Above average amounts of precipitation contributed to larger inflows than witnessed in 2008 and an annual hydraulic residence time of 2.45 years. Thermal stratification was first detected in the water column at the end of May; concurrent with an anoxic hypolimnion. Total mixing of the water column was first detected in mid-October. Over half of the water samples showed excessive chlorophyll-a values (>20 µg/L) larger than any other sample season. The number of taste and odor complaints during and after lake turnover tripled from the 2008 calendar year. Epilimnetic total nitrogen and phosphorus followed similar trends as in previous years, with a consistent build up of nutrients over the monitoring season, and mid-summer depletion of dissolved nutrients by algal uptake. Oxidation-reduction potentials in the hypolimnion remained low-to-negative during the summer growing season, providing conditions that allow for the solubilization of metals and sediment-bound phosphorus into the water column.

The 2009 monitoring data supports the 303 (d) integrated listing of Lake Thunderbird as impaired due to excessive turbidity, low dissolved oxygen and high chlorophyll-*a*. The Oklahoma Department of Environmental Quality Water Quality Division (ODEQ-WQD) currently has Lake Thunderbird prioritized for completion of a total maximum daily load (TMDL) allocation.

Active lake and watershed management is required for Lake Thunderbird to meet OWQS for turbidity, dissolved oxygen and chlorophyll-*a*. Lake management goals should focus on lake-wide reduction of algal biomass to mitigate low dissolved oxygen and decrease chlorophyll-*a*. Suspended solids control is also necessary in order meet OWQS for turbidity. Active hypolimnetic oxygenation project should provide relief to lakes D.O., algal problems, and reduce drinking water taste and odor complaints. Further recommendations to further lake management of Lake Thunderbird include:

- Expand the routine monitoring to include intense monitoring of hypolimnetic oxygenation.
- Ensure evaluative processes (TMDL) place watershed nutrient loads in context of in-lake loads using commonly accepted modeling procedures
- Review watershed evaluations to encourage nutrient reductions in the basin

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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 objective in 2009 was to finish the increased water quality monitoring for the Oklahoma Department of Environmental Quality (ODEQ) total maximum daily load modeling; and focus on monitoring Lake Thunderbird's tributaries in addition to routine water quality monitoring.

Lake Thunderbird is listed as Category 5 (303d list) in the State's 2008 Integrated Report as impaired due to turbidity, low dissolved oxygen, and color (http://www.deq.state.ok.us/wqdnew/305b_303d/2008_integrated_report_appendix_c_303d_list.pdf). Because of these impairments, Lake Thunderbird is currently undergoing a Total Maximum Daily Load (TMDL) analysis by the Oklahoma Department of Environmental Quality (ODEQ). As a Sensitive Water Supply (SWS), Lake Thunderbird is also required to meet a 10μg/L goal for chlorophyll-*a* concentrations. These parameters are evaluated according to the Oklahoma Water Quality Standards (OWQS) in this report.

Water Quality Evaluation

Sampling Regime

In 2009, Lake Thunderbird was sampled at the sites indicated in **Figure 1.** Sites 1, 2, and 4 represent the lacustrine zones of the lake. Site 6 embodies the riverine zone of the Little River arm, while the newly created Site 11 represents the riverine zone of Dave Blue Creek, Site 5 represents the transition zone between these two riverine sites and the main body of the lake. The Clear Creek and Hog Creek riverine zones are represented by Sites 7 and 8, respectively. Site 3 represents the transition zone of the Hog Creek arm.

Water quality sampling began with biweekly monitoring occurring from April 15th to October 19th. All sites were sampled at each visit, with the exception of sites 7 and 11. At the beginning of the new contracting period, July 1 2009, site 11 was added to the sampling regime, while Site 7 was removed. In addition to the routine biweekly monitoring; weekly visits were made from April 15th to June 4th, allowing the full development of thermal stratification to be captured.

Water quality profiles were measured at all sites and included oxidation-reduction potential, dissolved oxygen saturation and concentration, temperature, specific conductance, and pH. These parameters were measured in approximate one-meter intervals from the lake surface to sediment at each site. In addition, samples were collected for laboratory analysis of alkalinity, chloride, sulfate, total suspended solids, total organic carbon, and phosphorus and nitrogen series. Secchi disk depth, surface chlorophyll-*a*, and turbidity samples were collected at all seven sites.

From April 2009 to July 2009 water quality and nutrient samples were collected at the surface of sites 1, 2, and 4, with vertical samples collected at 4-meter depth intervals at site 1. Total organic carbon was collected at the surface of sites 1, 2, and 4. At the beginning of July 2009 the water quality and nutrient sample sites were changed from sites 1, 2 and 4 to sites 1, 6, and 8. Consequently sites 2, 4, 6 and 8 were only sampled for ½ of the summer monitoring period (**Table 1**).

Date	2/9	4/15	4/22	4/30	5/7	5/15	5/20	5/29	6/4	6/25	7/9	7/23	8/6	8/24	9/3	9/17	9/30	10/19
Hydrolab	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Chlorophyll-a	X	X			X		X		X	X	X	X	X	X	X	X	X	X
Water Quality	X	X			X		X		X	X	X	X	X	X	X	X	X	X
Secchi Depth	X	X			X		X		X	X	X	X	X	X	X	X	X	X
TOC	X	X			X		X		X	X	X	X	X	X	X	X	X	X
Turbidity	X	X			X		X		X	X	X	X	X	X	X	X	X	X
Nutrients	X	X			X		X		X	X	X	X	X	X	X	X	X	X

Table 1: 2009 water quality sampling dates and parameters measured.

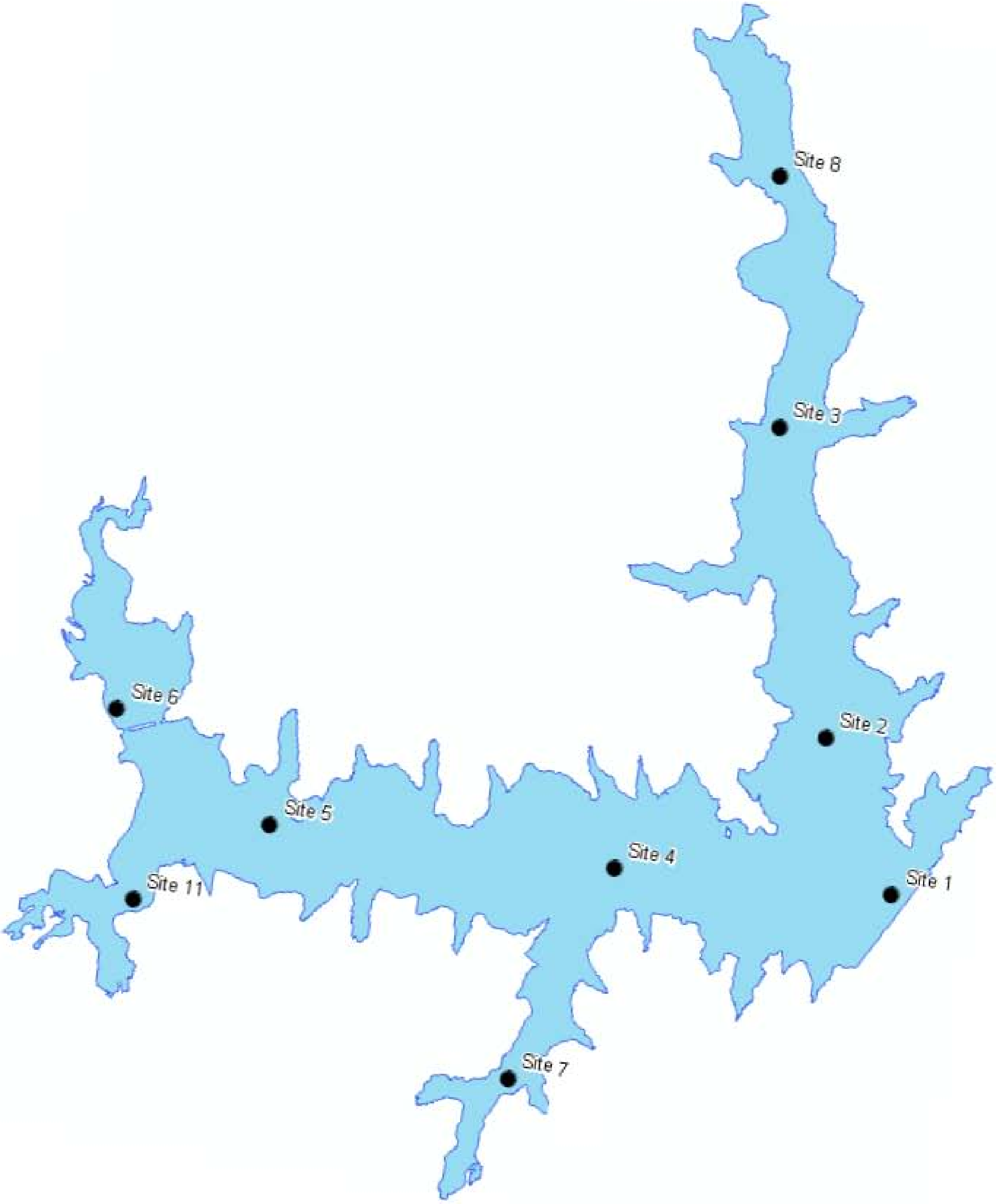


Figure 1: Lake Thunderbird 2009 sampling sites

Quality Assurance and Quality Control (QA/QC)

Water quality sampling included quality control samples to ensure that data collected was of high quality and the intrinsic error contained within the data could be determined. Laboratory quality control samples included field blanks, duplicates, and replicates. Field blanks were comprised of a sample bottle filled with reagent grade water prior to sampling. These samples then traveled through the field event before delivery to the laboratory for analysis. Duplicate samples were taken at the surface of site 1 and labeled “site 1” and “site 9” respectively and delivered to the laboratory for analysis. Site 1 chlorophyll-a samples were also subject to replicate sample preparation. These replicate samples were split during chlorophyll-a post processing at the OWRB lab and then delivered to the laboratory for analysis.

Duplicate and Replicate Samples

Duplicate samples yield an overall estimate of error either due to sampler, laboratory, or some combination of both . This paired data set yields a difference between the two “identical” samples. Site 9 is the duplicate sample label for site 1 surface samples. The percent absolute difference (PAD) was used to describe the precision of each laboratory analyzed parameter based on the paired comparison of duplicate samples.

(Eq.1) Abs. Dif. = $\left| x_{S1} - x_{S9} \right| / \; x * 100$

For each duplicate sample report parameter, equation 1 was applied. Results were tabulated and statistical summaries were generated using the box and whisker plot function (**Figure 2**). All parameters, with the exception of pheophytin-a, confirmed relatively good precision with median PAD well below 15%. Pheophytin-a gave a much higher estimate of error, with a median PAD of 27%. Because chlorophyll-a is subject to rapid decay into pheophytin-a with exposure to light, a greater PAD was expected for both pheophytin-a and chlorophyll-a, while only witnessed in the pheophytin-a data.

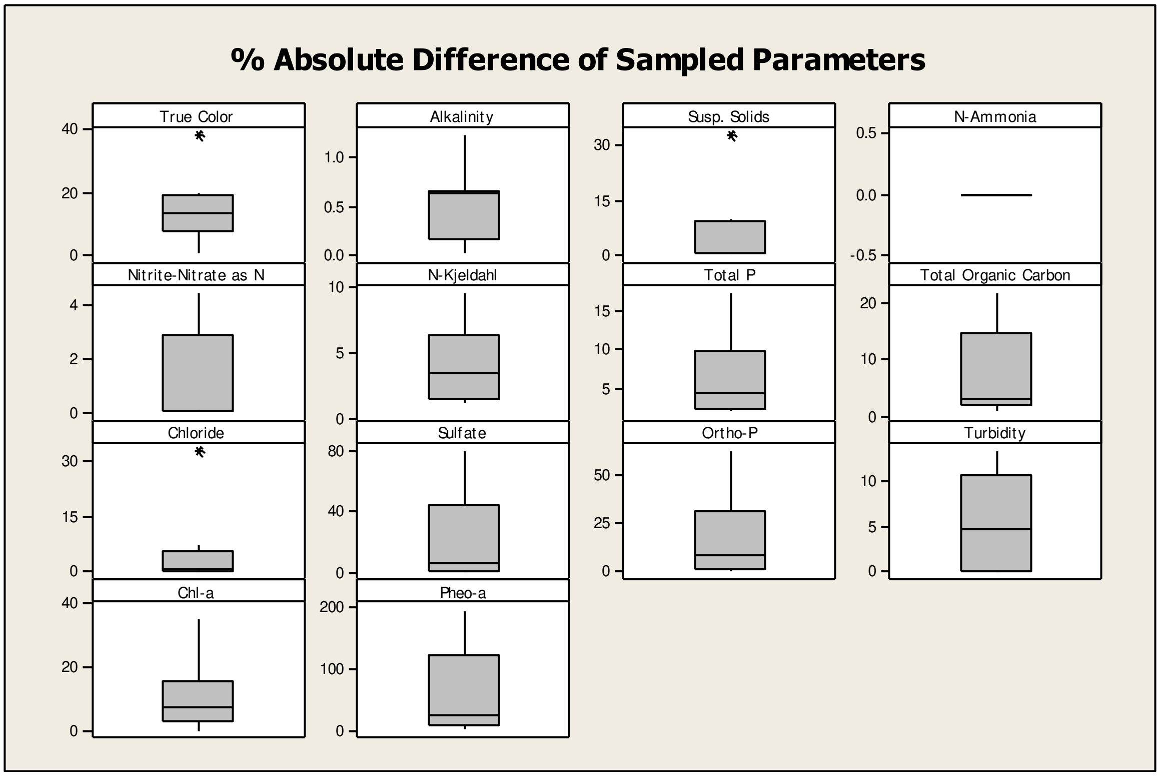


Figure 2: Statistical summary of Lake Thunderbird duplicate samples February 9th, 2009- October 19th, 2009. Box represents the middle 50%, the center bar the median reported value, top and bottom stems the upper and] lower 25% quartile and asterisks as outliers

Climate

Knowledge of potential climatologic influences is essential when assessing the water quality of a water body. The hydrology of a given lake, including dynamic inflows and elevations, can have significant impacts on internal chemical and biological characteristics and processes. Storm water inflows can increase nutrient and sediment loading into the lake, re-suspend sediments, and alter stratification patterns. In addition, changes in lake volume and nutrient concentrations can affect the extent of anoxia in the hypolimnion and alter oxidation-reduction potentials. This can lead to increased solubility of phosphorus and metals from the sediments.

Figure 3 provides a graphical representation of Lake Thunderbird's rainfall, elevation, inflow, and sampling dates for calendar year 2009. Lake elevations and inflows can vary considerably with rainfall patterns. Pool elevation varied from about 2.75 feet above conservation pool (1039 MSL) in mid-May to around 0.75 feet below conservation pool in August, September and October. In addition to hydrology, air temperature can also influence lake characteristics such as stratification patterns and primary productivity. 2009 average daily temperature values are illustrated in **Figure 4.** The average daily temperature for the 2009 calendar year was near the historical average with an average temperature of 59.2 °F, 0.8°F below average. Annual precipitation at Lake Thunderbird was above average in 2009 with a precipitation total of 43.41", 5.1" above average.

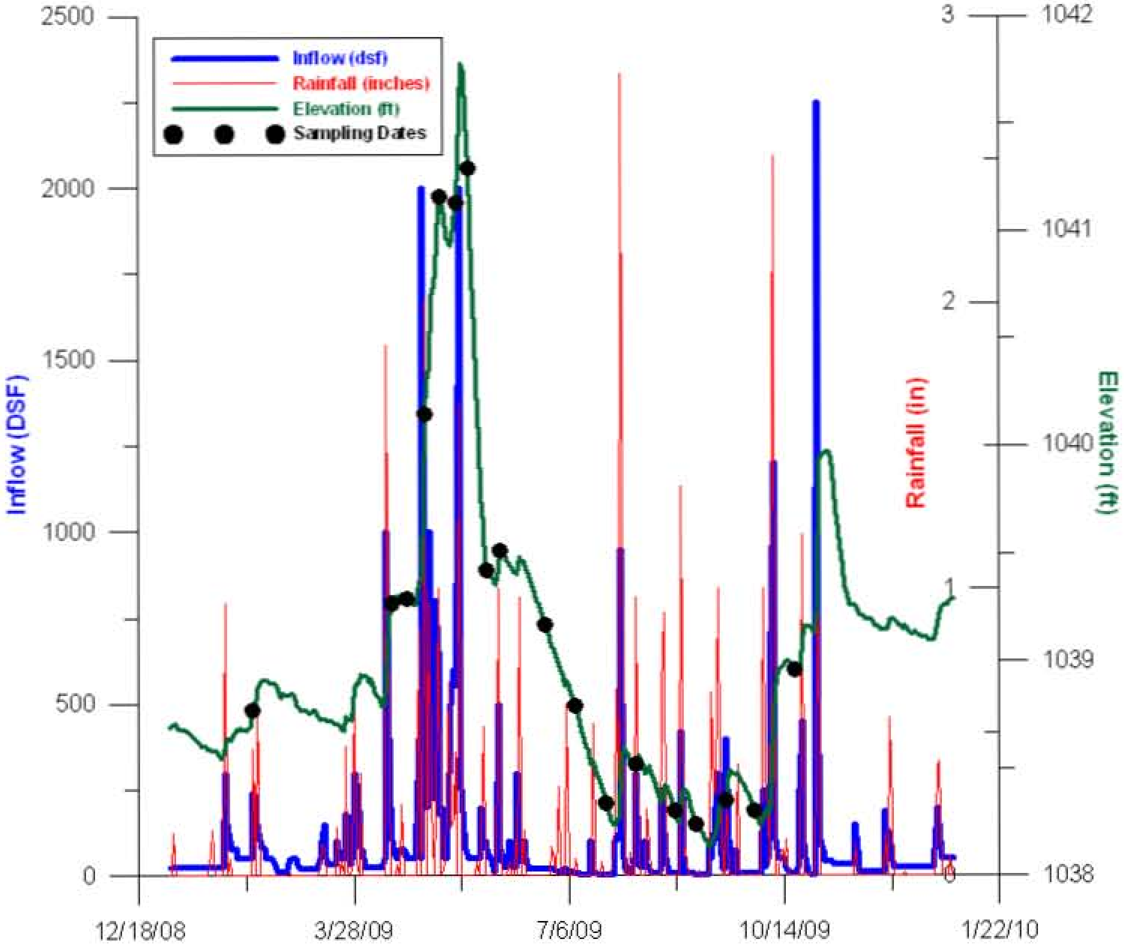


Figure 3: 2009 Inflow, precipitation, and elevation data for Lake Thunderbird, with sample dates indicated.

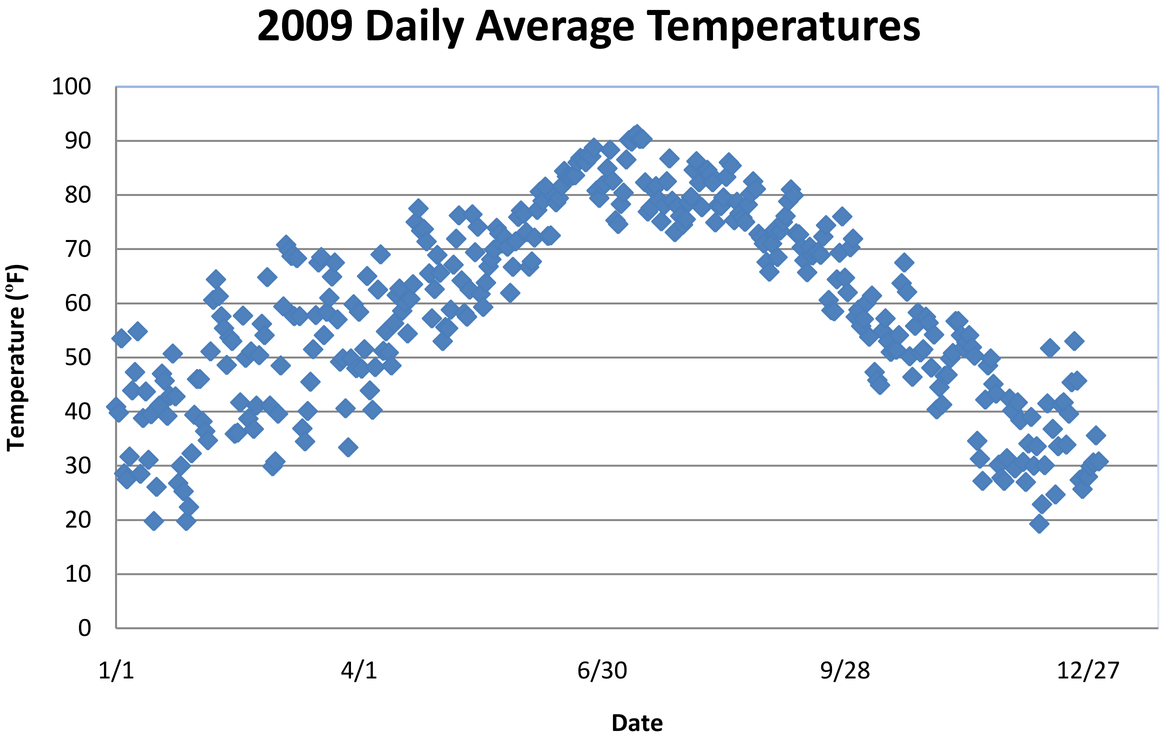


Figure 4: 2009 average daily temperature values at the Norman mesonet station.

Hydrologic Budget

A hydrologic or water balance is of considerable importance in water quality analyses and management. A general and simple hydrologic budget equation for a given water body such as a lake is given by:

$$\mathbf{dV/dt = Q_{in} - Q + PA_s - E_vA_s - W_S}$$

where V = lake volume [L^3],

A_s = lake surface area [L^2],

Q_{in} and Q [L^3/T] represent net flows into and out of the lake due to tributary inflows and gated releases,

P [L/T] is the precipitation directly on the lake,

E_v [L/T] is the lake evaporation,

W_S is the water exported for water supply use.

In other words, the rate of change in storage of the volume of water in or on the given area per unit time is equal to the rate of inflow from all sources minus the rate of outflows. The input or inflows to a lake may include surface inflow, subsurface inflow, and water imported into the lake. The outputs may include surface and subsurface outputs and water exported (e.g. water supply) from the lake. For Lake Thunderbird we will assume that subsurface flow is insignificant, based on the relatively impermeable lake substrate.

The inputs to Lake Thunderbird include precipitation and inflow from the tributaries, which includes all surface runoff in the basin. The outputs are evaporation, dam releases (spilled), and water supply intake. Precipitation was estimated from the direct rainfall measurements/data provided by the United States Army Corps of Engineers (USACE). The precipitation contribution to the total inflows was obtained by multiplying the daily rainfall amounts by the surface area of the lake on each date, as shown by:

$$\mathbf{Q_P = P*A_s}$$

where P [L/T] is rainfall amount and A_s [L^2] is the surface area of the lake.

Daily evaporation rates were calculated and reported by the USACE. Here, empirical equations were used to relate solar radiation, wind speed, relative humidity, and average daily air temperature to the rate of evaporation from the lake. These rates are multiplied by the daily average surface area of the lake to give the amount of water evaporated per unit time.

$$\mathbf{Q_E = E_v * A_s}$$

where E_v [L/T] is the evaporation rate and A_s [L^2] is the surface area of the lake.

Water released from Lake Thunderbird includes gated dam releases and water supply withdraws. Both are reported by the USACE. Change in volume or storage was recorded by the USACE at the end of every day. The lake volumes corresponding to the elevations were computed and the difference between them is the change in volume for that month. The volumes used were estimated from elevation-capacity curves generated from the OWRB's 2001 bathymetric survey of the lake.

Results

Water budget calculations were summarized on a monthly basis for Lake Thunderbird as described previously **(Table 2).** Total input is the sum of all the flows into the lake. Total output is the sum of all the outflows from the lake. From equation 1, the difference between the inputs and the outputs must be the same as the change in volume of the lake for an error free water budget. The difference between the inflow and outflow is in the I-O column. Total monthly error is calculated as the difference between the change in lake volume and I-O. Examination of the estimated budget for Lake Thunderbird shows that estimated inputs and outputs are close to the actual volume changes with relatively little error.

	INPUTS			**OUTPUTS**				**RESULTS**		
Month	Inflow	Rainfall	**Total Inputs**	Evaporation	Water Supply	Releases	**Total Outputs**	I-O	ΔV	Error
Jan	2678	626	3304	1894	1245	0	3139	165	-103	268
Feb	3511	487	3998	2108	1099	0	3206	791	669	122
Mar	4463	906	5368	3063	1285	0	4348	1021	669	352
Apr	12159	2542	14701	3511	1217	0	4729	9972	6894	3078
May	19488	3185	22672	3254	1314	21031	25599	-2926	-4682	1756
Jun	3431	1214	4645	4769	1920	0	6689	-2044	-1852	-192
Jul	3124	2593	5717	4568	2116	0	6684	-967	-2058	1091
Aug	3201	2014	5215	3904	1836	0	5740	-525	-1389	864
Sep	3160	1464	4624	2094	1624	0	3719	905	-103	1008
Oct	12569	3884	16453	1403	1334	0	2737	13717	8541	5176
Nov	2102	119	2221	1425	1251	4715	7390	-5169	-4168	-1002
Dec	2886	748	3634	871	1239	0	2110	1524	823	701
Total	72772	19781	92553	32864	17481	25745	76090	16463	3241	13221

Table 2: Lake Thunderbird 2009 water budget calculations

Once a hydrologic budget has been constructed, retention times can be estimated. The hydrologic retention time is the ratio of lake capacity at normal pool elevation to the exiting flow (usually on an annual basis). This represents the theoretical time it would take a given molecule of water to flow through the reservoir. The combination of lake releases and water supply withdrawals give Lake Thunderbird water a hydrologic residence time of 2.45 years for 2009 and a an average hydrologic residence time of 4.18 years since 2001 (including 2009 data). The relatively short 2009 residence time reflects the increased inflows due to high rainfall amounts in April, May and October (**Figure 5**).

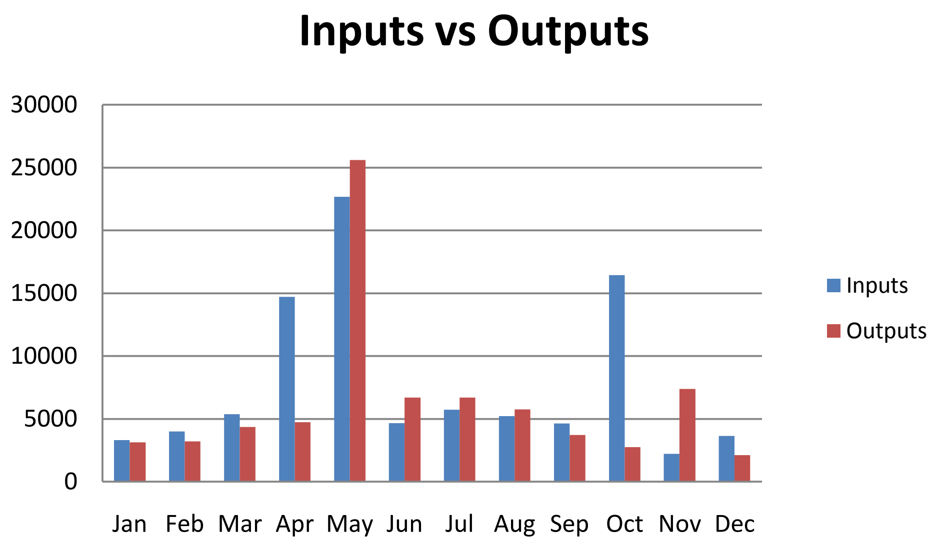


Figure 5: 2009 Lake Thunderbird inflows and outflows by month

For the period of calendar year 2009, 79% of the inputs into Lake Thunderbird were from inflows, while the majority of outputs were from lake body evaporation (**Figure 6**).

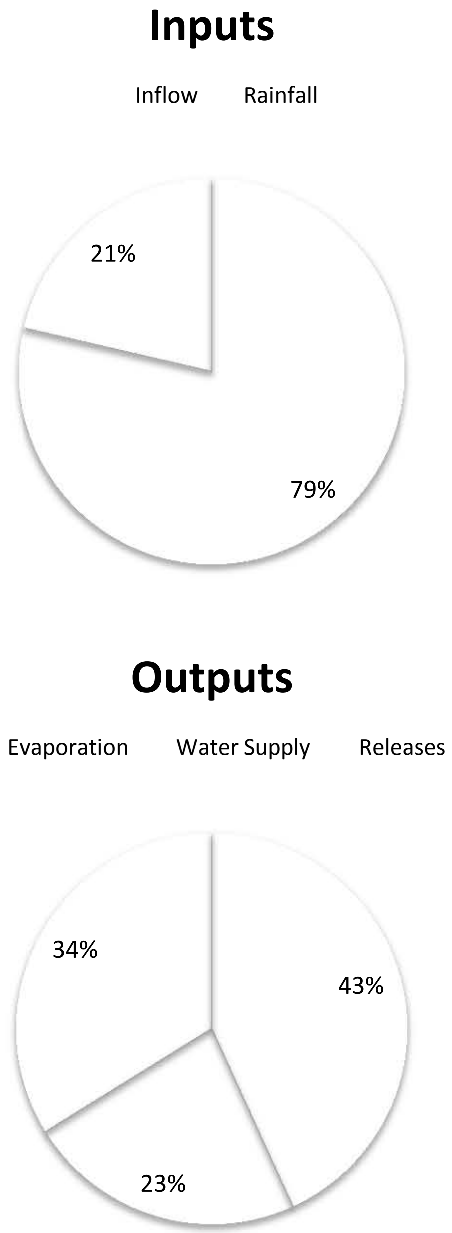


Figure 6: 2009 Lake Thunderbird input and output sources expressed as the percent of totals.

Sources of error

Although robust, the hydrologic budget does contain error. In the 2009 calendar year the hydrologic budget contains a cumulative ***annual*** error of 13,221 acre-feet, with an average ***monthly*** error of 1,101 acre-feet in 2009. Additionally the two measures of monthly change in capacity (I-O, and ΔV) match in sign (either negative or positive) for every month but January and September. This fact suggests the error is small. The greatest error noted was with the month of highest lake inputs: April, May, and October. Based on the simplifying assumptions made in calculating some of the parameters, the following potential sources of error have been identified.

- Evaporation rates used for water losses due to evaporation were calculated rather than measured.

- Inflow from the tributaries was estimated by the USACE based on changes in lake volume using the original lake bathymetry. The 2001 survey showed significant sedimentation of the lake, which could greatly influence the calculation of inflows.

- Transpiration through plants and seepage through the dam were assumed to be negligible.

- Groundwater loss and gain to the lake were assumed to be negligible. This could be verified with field measurements or through a review of the geology in the area.

Of these potential sources of error the greatest source of uncertainty in the budget is inflow. Implementing two of three actions would reduce uncertainty of inflow estimates: install a gauge and record instantaneous flow on the main tributary to the lake, develop modeled estimates of inflow to the lake, and back calculate inflow volume based on recent bathymetry. It is important to note that while the hydrologic budget contains sources of error, it is still robust enough to support lake nutrient budget development.

Temperature and dissolved oxygen

As warming of the lake surface progresses through spring, so does the onset of stratification. Thermal stratification occurs when an upper, less dense layer of water (epilimnion) forms over a cooler, denser layer (hypolimnion). The metalimnion, or thermocline, is the region of greatest temperature and density differences of water at depth intervals between the epilimnion and hypolimnion (**Figure 7**). Because of these differences, thermal resistance to mixing prevents the epilimnion and hypolimnion from coming in contact during stratification. Therefore, when dissolved oxygen is consumed and depleted by the decomposition processes occurring in the hypolimnion, it is not replenished.

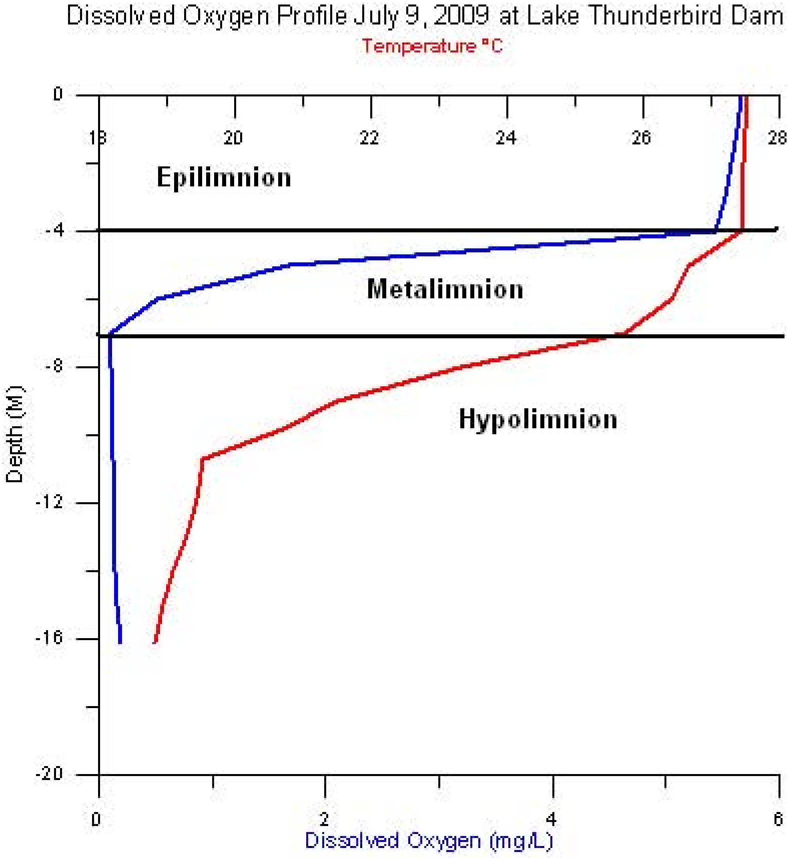


Figure 7: Temperature and dissolved oxygen vertical profile for Lake Thunderbird at its period of greatest thermal stratification.

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, the epilimnion cools, and the thermocline disappears as the epilimnion mixes with the lower layers. This process is referred to as fall mixing or "turnover". Lake stratification may have a significant effect on water quality by isolating nutrients or chemicals in areas of reduced exchange and water interaction (hypolimnion). These isolated nutrients are then entrained back into the epilimnetic waters in large volumes, causing significant fluxes in surface water chemistry. This key feature can have large implications for epilimnetic water quality as documented later in this report.

When sampling began, conditions were relatively isothermal at site 1, with fairly constant dissolved oxygen (DO) levels throughout the water column (**Figure 8**). By May 7, 2009 the water column temperature had increased approximately 5°C without thermal stratification. Within the two weeks that separated the May 20th and the June 4th sample dates, thermal stratification had set in and oxygen trapped in the hypolimnion had been consumed. Between

June 4 and 25, 2009 high temperatures had shrunk the fairly isothermal epilimnion from -6 to -4 meters.

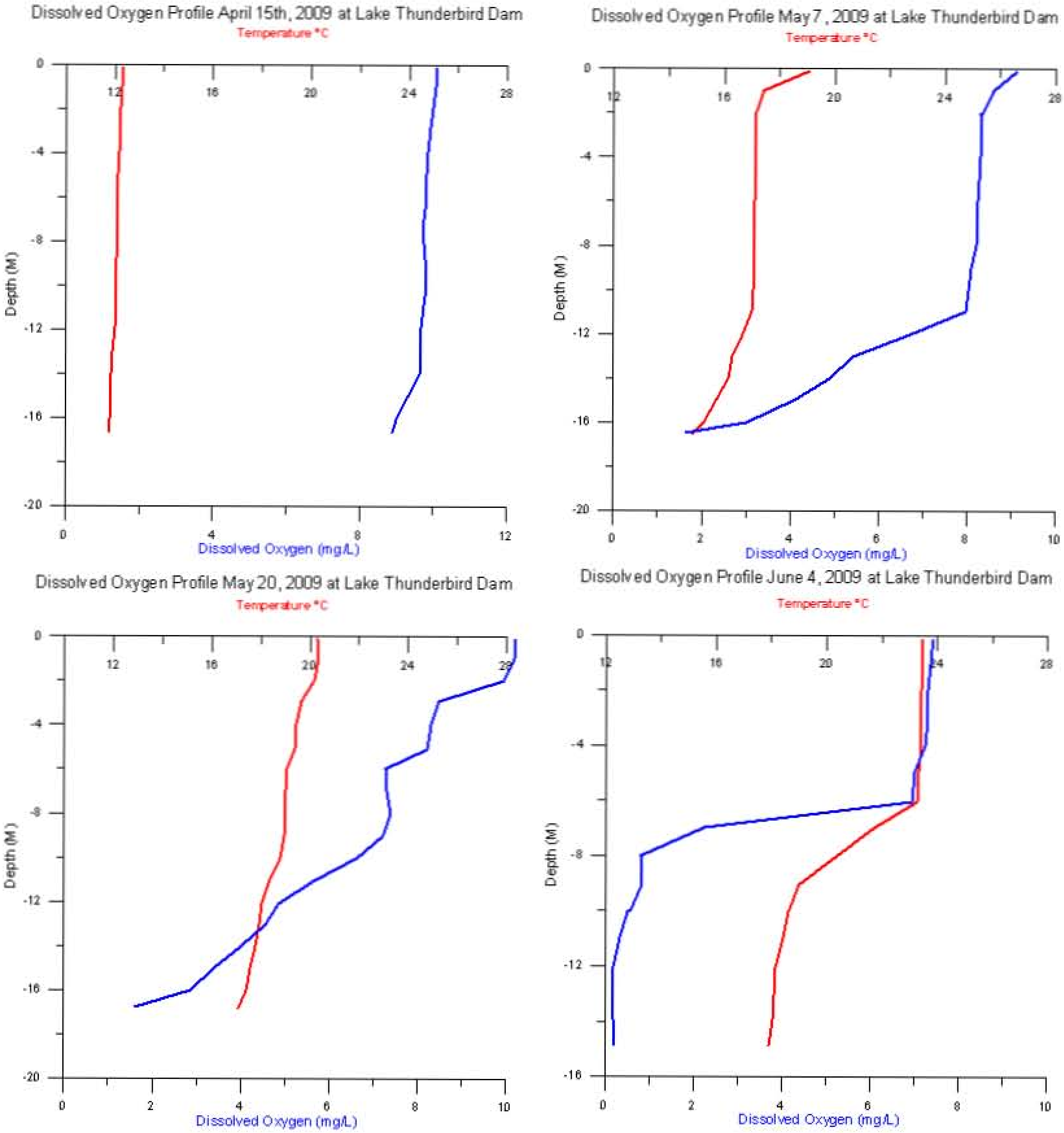


Figure 8: Temperature and dissolved oxygen vertical profile. Site 1: April 15, 2009 – June 4, 2009. Showing the strengthening of thermal stratification and onset of hypolimnetic anoxia.

As the summer progressed and the epilimnion warmed the largest volume of anaerobic water was observed on July 9, 2009 (**Figure 9**). On this date the epilimnion measured 4 meters in depth and at 5 meters depth dissolved oxygen fell below 2 mg/L. High rainfall, cooler average temperatures, along with windy conditions preceding the July 23rd sampling date combined to push the epilimnion from 4 meter depth to 9 meters.

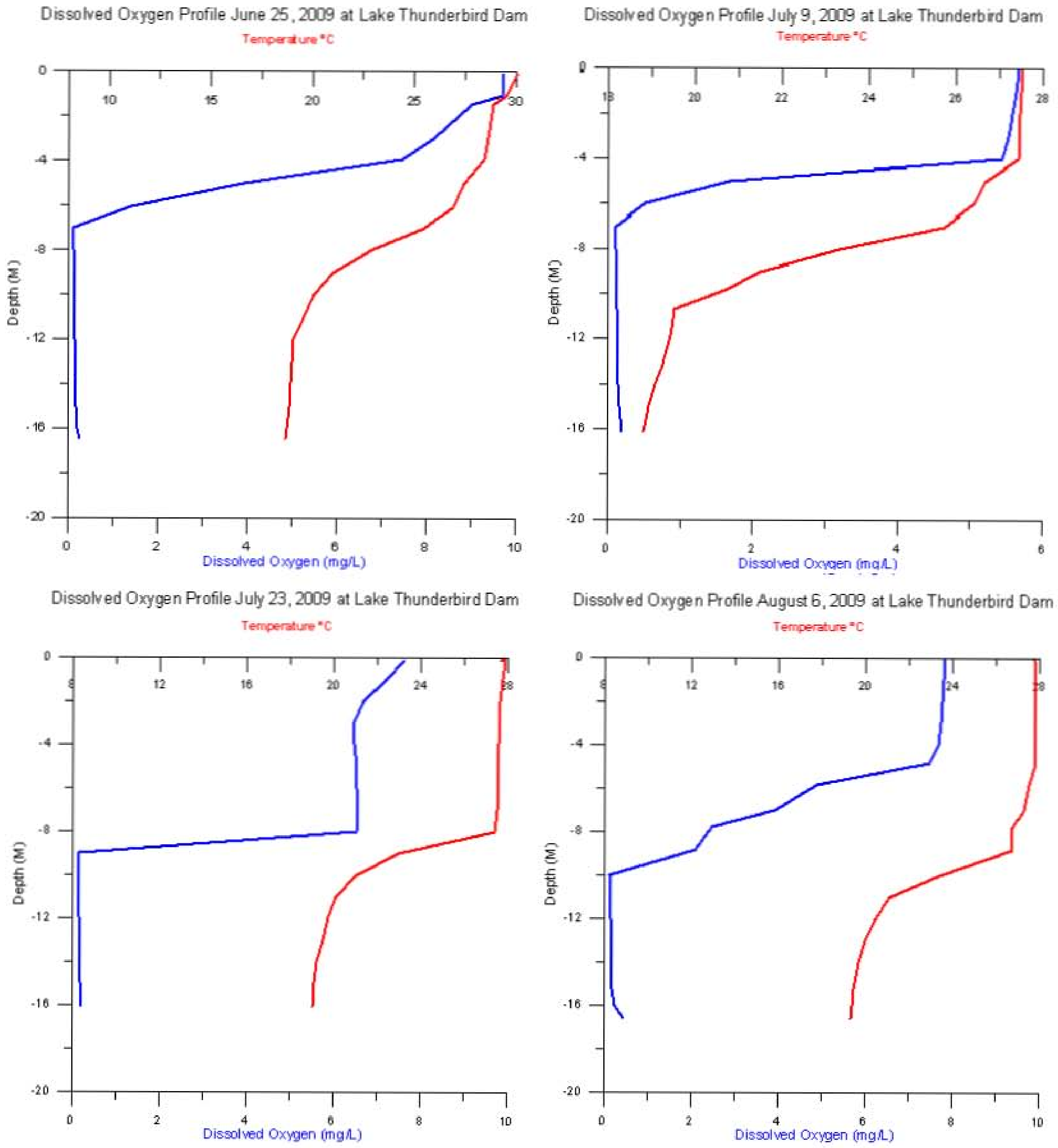


Figure 9: Temperature and dissolved oxygen vertical profile Site 1: June 25, 2009 – August 6, 2009. Showing the deepening of the epilimnion. The mixing of hypolimnetic waters into the epilimnion explains the lowered dissolved oxygen record on July 23 , 2009.

Between August 24 and September 17, 2009 the epilimnion began to cool as average daily temperatures dropped. As the epilimnion cooled, it also deepened, mixing with the anoxic hypolimnion which resulted in a slight drop in the dissolved oxygen values (**Figure 10**). By October 19, 2009 complete mixing had occurred while dissolved oxygen was still depressed (near 75% saturation). This indicates incomplete oxidation of the mixed anaerobic hypolimnetic waters.

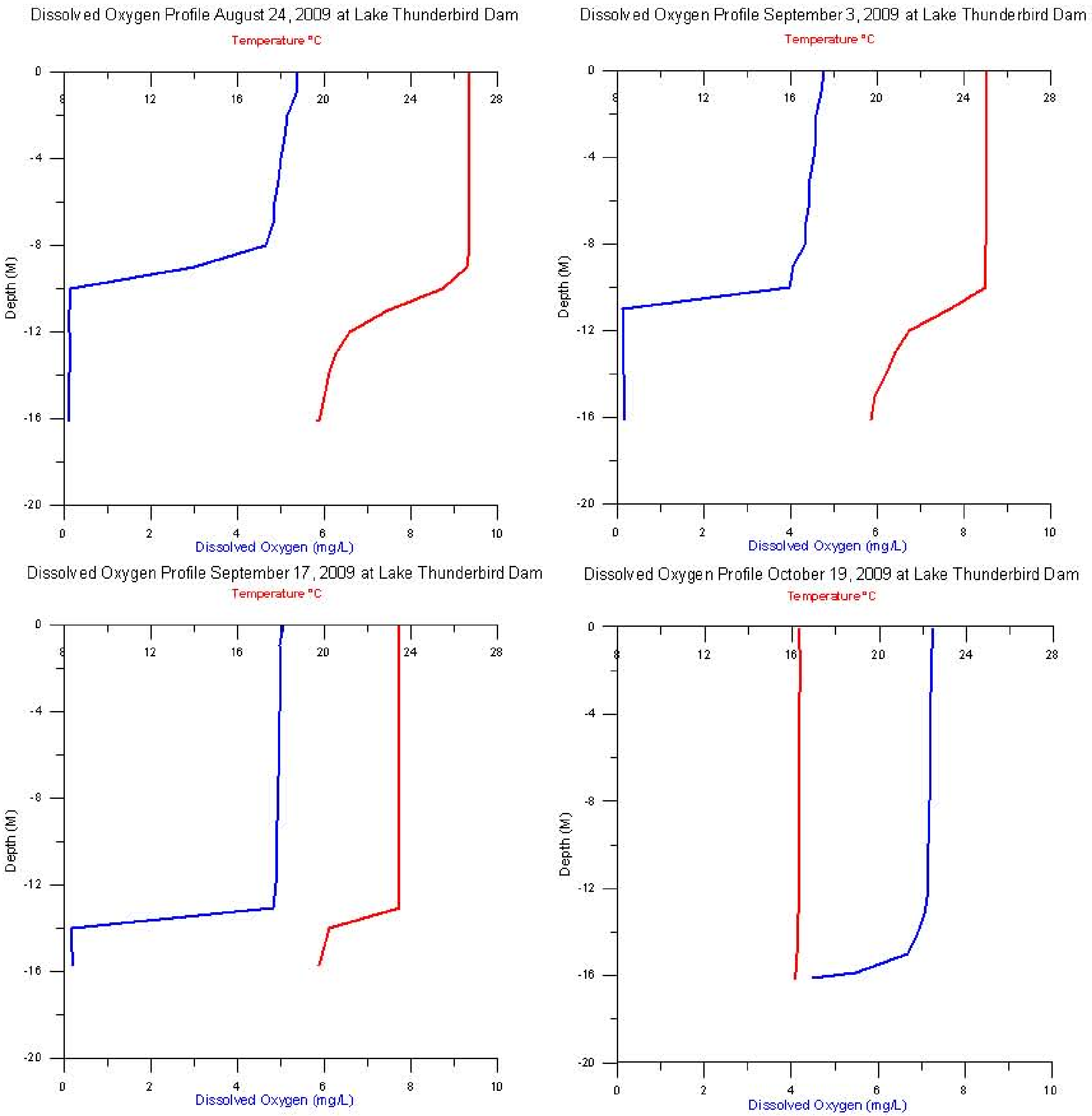


Figure 10: Temperature and dissolved oxygen vertical profile Site 1: August 24, 2009 – October 19, 2009. Showing complete turnover and recovery of dissolved oxygen (Oxidation of reduced compounds formed in the hypolimnion).

An alternate method for illustrating physical lake data is by using 3-dimensional isopleths, which show variation in physical parameters over depth and time. The following isopleths show the same temperature and dissolved oxygen data for site 1 in a summarized form (Figure 11). Site 1 is representative of seasonal dynamics and the lacustrine zone of Lake Thunderbird. Each line on the isopleths represents a specific temperature or DO value. Vertical lines indicate a completely mixed water column. When lines run horizontally, some degree of stratification is present. Also, warmer temperatures are colored red, graduating to blue as temperature decreases.

On the DO plots, low DO values are colored red, graduating to blue as dissolved oxygen increases.

Thermal stratification began to develop at the beginning of May, with strong stratification patterns observed by early June (**Figure 10**). Stratification peaked in early-July, with partial mixing events occurring in mid-July. Complete lake turnover was noted by mid-October. 2009 appears to have been an average year with respect to stratification patterns in that stratification set in and broke up in a typical pattern in respect to previous monitoring years.

Anoxia is defined as less than 2 mg/L of dissolved oxygen. Anoxia is witnessed in Lake Thunderbird exclusively in the isolated hypolimnion and hence follows the stratification pattern of the lake **(Figure 11**). In the hypolimnion, bacterial respiration and consumption of dead algae generally depletes oxygen trapped in the hypolimnion due to the lack of mixing with the upper water layer. When anaerobic conditions occur, elements other than oxygen are utilized as terminal electron acceptors in the decomposition process. This results in nutrients and other constituents being released from the sediment interface into the isolated waters of the hypolimnion. When mixing events occur, these released nutrients are fluxed to the surface waters where they can further stimulate algae growth. The partial mixing events are more evident when examining the oxygen isopleths as the blue area (higher oxygen content) pushes down into the red area (lower oxygen content). In Lake Thunderbird, dissolved oxygen depletion below the photic zone occurs so rapidly that any partitioning of water layers is followed by immediate depletion of dissolved oxygen. There is typically no lag time between onset of stratification and dissolved oxygen depletion in highly eutrophic systems.

Dissolved oxygen is also lowered in the epilimnion by high plant and animal respiration rates, but is offset by high photosynthetic rates and physical mixing of atmospheric oxygen into the water. The areas of intense blue in **Figure 11** represent oxygen production by excess algae growth with dissolved oxygen percent of saturation above 105% mid-June

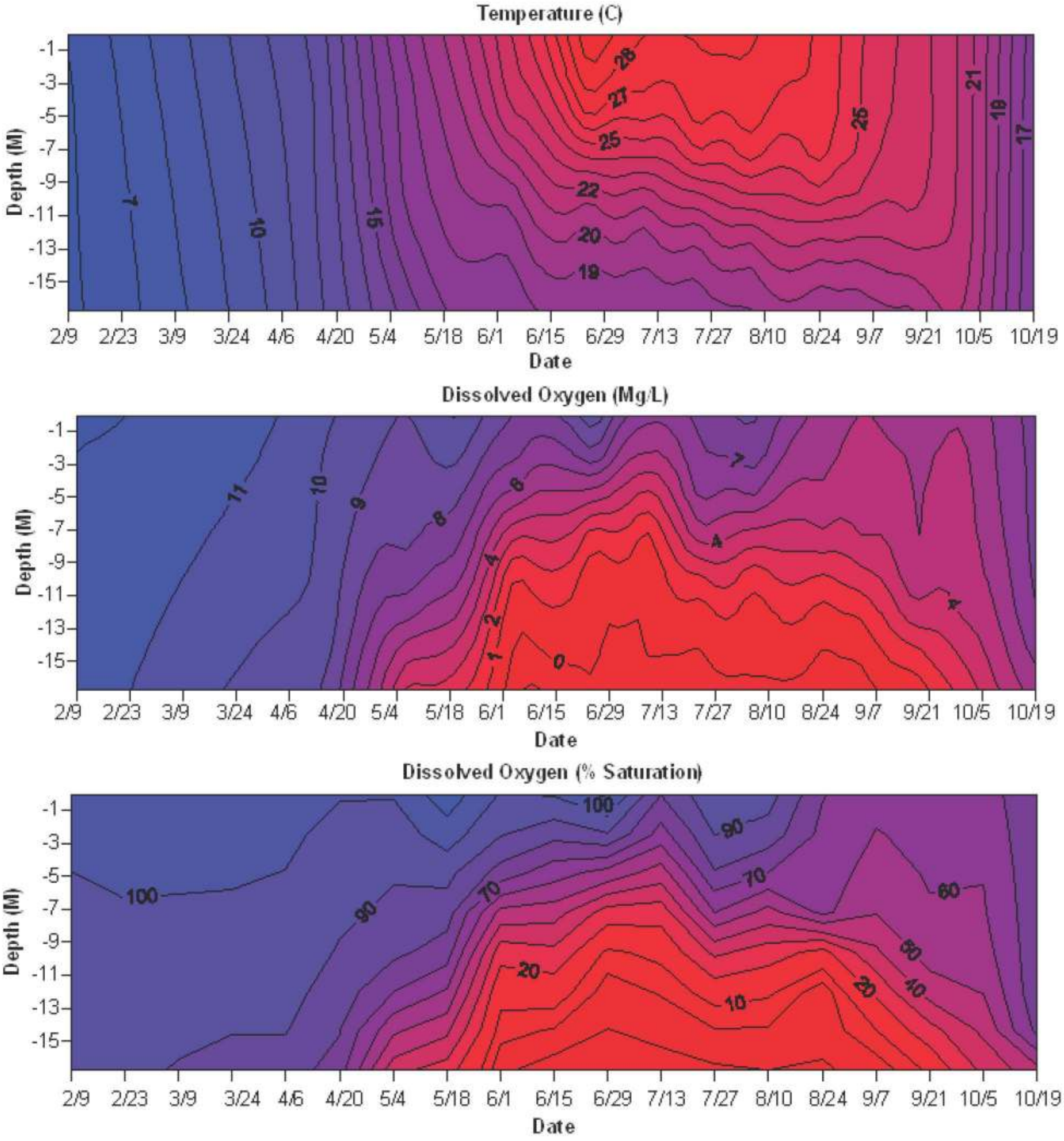


Figure 11: 2009 Lake Thunderbird dissolved oxygen concentration (mg/L), dissolved oxygen percent saturation (%DO), and temperature (°C) with depth at site 1, by date.

Water Quality Standards

All Oklahoma surface waters are subject to Oklahoma's water quality standards (OAC 785:46-15-5). Oklahoma water quality standards are a set of rules adopted by Oklahoma in accordance with the federal Clean Water Act, applicable federal regulations, and state pollution control and administrative procedure statutes. Water Quality Standards serve a dual role: they establish water quality benchmarks and provide a basis for the development of water-quality based pollution control programs, including discharge permits, which dictate specific treatment levels required of municipal and industrial wastewater dischargers.

Identification and protection of beneficial uses are vital to water quality standards implementation. Currently recognized beneficial uses for Lake Thunderbird include public water supply, fish and wildlife propagation, and primary body contact recreation. Physical, chemical, and biological data on Lake Thunderbird are used to ascertain the condition of lake waters, and determine if lake water quality support beneficial uses.

The Water Quality Standards Implementation rules contain Use Support Assessment Protocols (USAP) for Oklahoma waterbodies. Developed in coordination with all Oklahoma environmental agencies, the USAP establish a consistent and scientific decision methodology for determining whether a water body's beneficial uses are being supported, outlining minimum data requirements for that decision methodology. In the following sections, Lake Thunderbird's water quality parameters will be discussed with an emphasis on their accordance with Oklahoma water quality standards.

Dissolved Oxygen

Implementation protocols of Oklahoma's Water quality Standards (OAC 785:46-15-5) provide assessment methodologies for the beneficial use of Fish and Wildlife Propagation. This beneficial use is deemed not supported if more than 50% of the water column at any given sample site has D.O. concentrations less than 2 mg/L. A designation of not supporting requires an impaired listing in Oklahoma's Water Quality Assessment Integrated Report. Upon assessment, Lake Thunderbird was found to be not supporting its Fish and Wildlife Propagation beneficial use.

Anoxia (less than 2 mg/L of dissolved oxygen) was first witnessed on May 7th 2009 at the bottom sample of site 1, by May 29th strong thermal stratification had caused the lower 5.5 meters of site 1 to be anoxic. Water quality standards were first violated on June 4th, at site 1, when 51% of the water column had dissolved oxygen readings under 2 mg/L. Beneficial uses for fish and wildlife propagation continued to be violated for the next 2 sample dates, June 25th and July 9th, with anoxia peaking on July 9th with 69% of the water column having anoxic conditions. Site 2 also experienced anoxia greater than 50% of the water column on June 25th.

Water Clarity

Turbidity and Secchi disk depth are ways of measuring the water clarity and amount of suspended particles in a lake. While natural to pristine lakes often have Secchi disk depths of several meters, Oklahoma reservoirs typically have a majority of Secchi depth readings of less than one meter. In Lake Thunderbird, Secchi disk depths ranged from a 2009 average of 21 centimeters at site 6 to an average of 80 centimeters at site 1. The lacustrine sites (1, 2, and 4) had the greatest Secchi depths, while the riverine or transition zone sites had the lowest water clarity (**Figure 12**). As depicted in Figure 12, the west end of the lake (site 6 and 11) had the lowest water clarity of the whole system, while the lacustrine area by the dam had the highest water clarity.

The turbidity criterion for the protection of the beneficial use of Fish and Wildlife Propagation is 25 NTU (OAC 785:45-5-12 (f)(7)). If at least 10% of collected samples exceed this screening level, the lake is deemed to be not supporting its beneficial use, and is thus impaired for turbidity. In 2009, 41% of Lake Thunderbird samples exceeded the 25 NTU criteria. All sites except site 1, had at least one sample greater than 25 NTU. Sites 6, 8, and 11 had the highest turbidity values (**Figure 13**). Site 6 had the highest average turbidity, indicating that the Little River arm of Lake Thunderbird is contributing more turbidity to the lake body than either the Hog Creek (Site 8) or Dave Blue Creek (Site 11) arms.

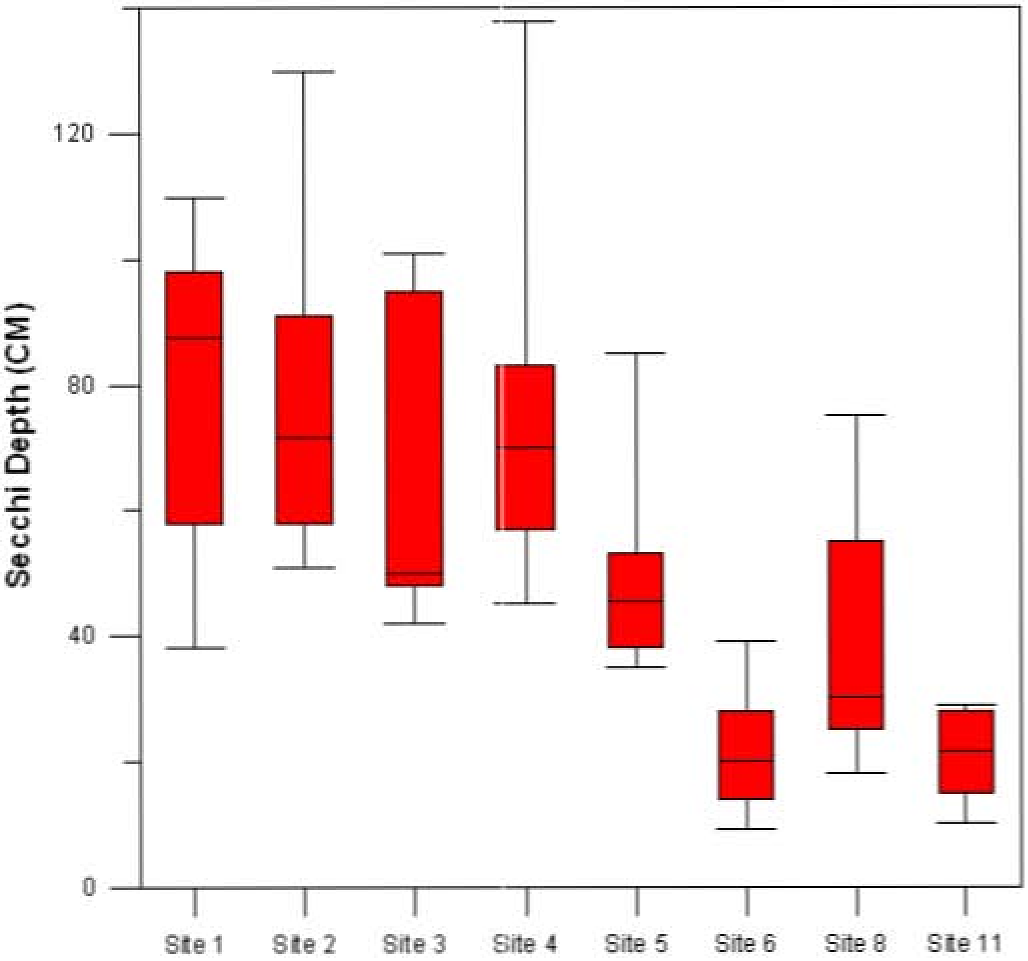


Figure 12: 2009 Lake Thunderbird Secchi disk depth, in centimeters, by Site, where boxes represent 25% of the data distribution above and below the median (horizontal black line), and lines (or whiskers) represent the other 50% of the data distribution.

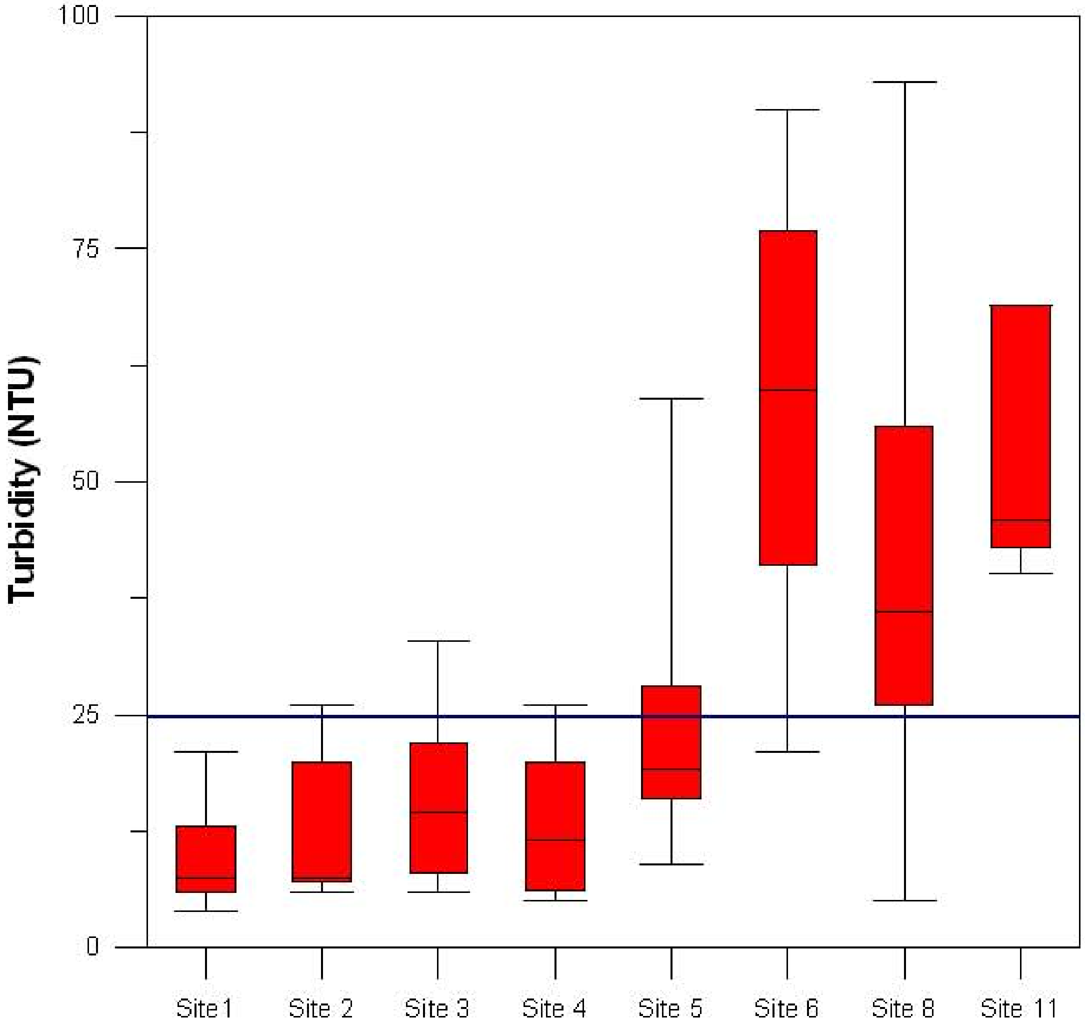


Figure 13: 2009 Lake Thunderbird turbidity, in NTU's, by site. The navy-blue line along the x-axis represents the 25 NTU turbidity criteria.

Nutrients

High nitrogen and phosphorus loading, or nutrient pollution, has consistently ranked as one of the top causes of degradation in U.S. waters for more than a decade. Excess nitrogen and phosphorus lead to significant water quality problems including reduced spawning grounds and nursery habitats, fish kills, hypoxic/anoxic conditions, harmful algal blooms, and public health concerns related to impaired drinking water sources.

Nutrient samples were collected fourteen times during the 2009 sampling season. Spring environmental conditions are represented by samples taken in April and May, while samples from June, July, August, and September represent summer conditions and samples from October represent fall conditions.

Several measures of nitrogen and phosphorus were made, including dissolved and total forms. Dissolved nutrient concentrations consist of nutrients that are available for algal growth, such as ortho-phosphorus, ammonia, nitrate and nitrite. High dissolved nutrient concentrations in the epilimnion generally indicate that nutrients are immediately available for and not limiting to algal growth, while hypolimnetic concentrations are nutrients that are available for future algal growth.

Nitrogen and phosphorus concentrations in the epilimnion can also indicate what may be limiting algal growth. Generally, when both nitrogen and phosphorus are readily available, neither is a limiting nutrient to algal growth, and excessive chlorophyll-*a* values are expected. When high phosphorus concentrations are readily available in comparison to very low nitrogen concentrations, algal growth may be nitrogen limited. High to excessive levels of algal growth, or primary production, can be expected under nitrogen-limited conditions, which can also give a competitive advantage to undesirable cyanobacteria (blue-green algae). In the absence of adequate dissolved nitrogen, certain blue-greens have the ability to convert atmospheric nitrogen into a usable form by way of specialized cells called heterocysts. Blue-green algae are the only type of algae that have heterocysts, and are generally implicated for producing harmful toxins and chemicals that can cause taste and odor problems in public water supplies.

In regards to nutrient limitation, phosphorus as the limiting nutrient is desired for most freshwater systems. Under phosphorus limiting conditions, typically desirable green algae will be present, as opposed to the less desirable nitrogen-fixing blue-green algae. A recent study by Dzialowski *et al.* (2005) has broken the molecular ratio into three ranges, where a TN:TP of less than or equal to 18 indicates a nitrogen-limited waterbody, 20-46 is a co-limitation of nitrogen and phosphorous, and greater than 65 is defined as phosphorus-limited. The molecular ratios corresponds to TN:TP concentrations of less than 7 being nitrogen-limited, 8-18 co-limited, and greater than 26 phosphorus-limited, with gaps in classification between co-limitation and either nutrient. In most eutrophic reservoirs, a co-limitation condition is more of a “no-limitation”, where both nutrients are readily available in significant amounts.

Lake Thunderbird had molecular TN/TP ratios in the 20’s to 30’s over the years, indicating the lake was phosphorus and co-limited. Since the low in 2006, when all sample dates the lake fell within a co-limitation range of nitrogen and phosphorus, the ratio has trended upward with

TN/TP splitting between the co- and phosphorus–limitation (**Figure 14**). An average TN:TP concentration ratio of 28 at the surface of site 1 was observed in 2009. Each constituent of the TN/TP nutrient ratio needs examination to better understand the impact of nutrients on lake water quality.

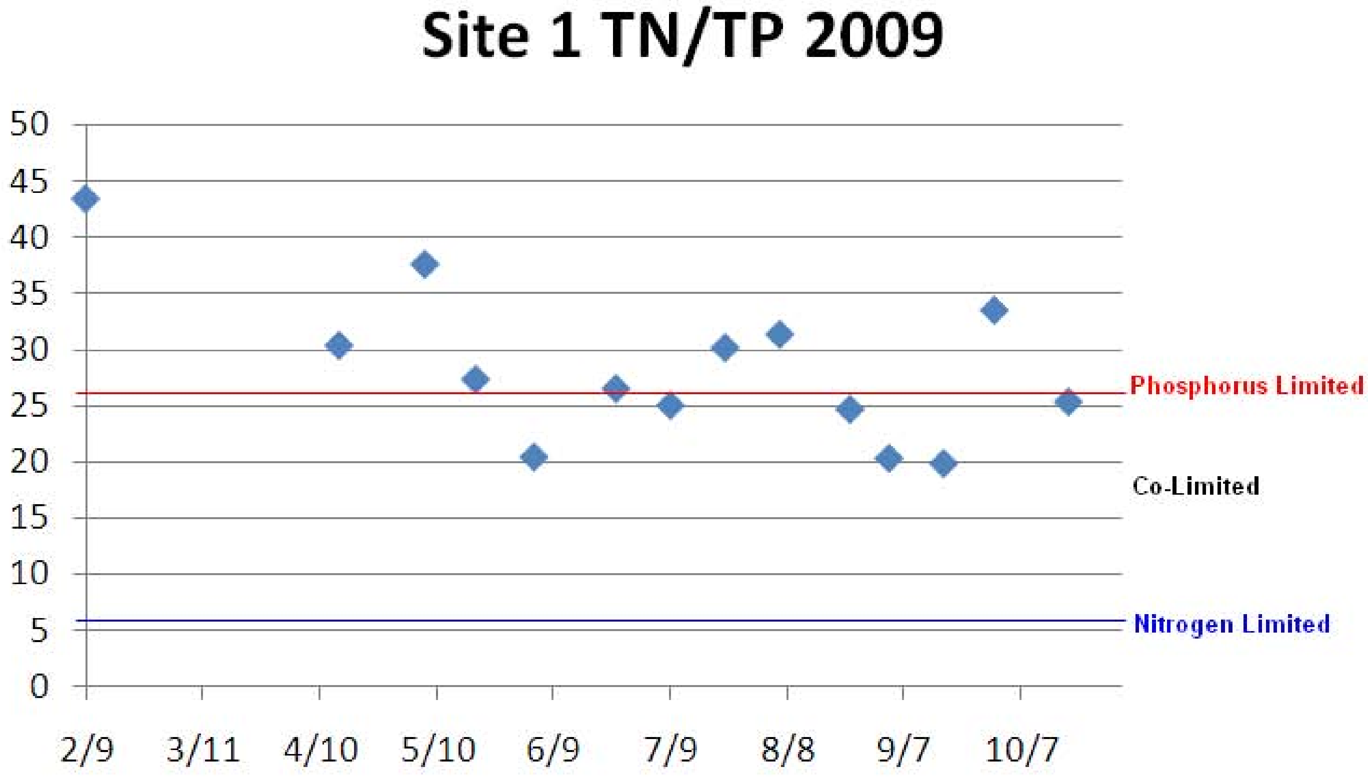


Figure 14: Total nitrogen to total phosphorus ratios at the surface of Lake Thunderbird Site 1 during 2009.

Phosphorus

Total and ortho-phosphorus concentrations produced patterns typical of seasonal ecological cycles in lakes (**Figure 15**). While ortho-phosphorus comprised the majority of total phosphorus values in early spring 2009, these values sharply dropped at the surface of site 1 at the end of May (**Figure 16**). Surface ortho-phosphorus values fell below detection limits at the end of May and throughout June, indicating depletion by algal uptake. These dates also coincide with below-detection limit dissolved nitrogen levels with-in the epilimnion, indicative of a co-limited environment (**Figure 18**). This idea is furthered by the witnessing of lower Chl-*a* values throughout this period.

An alternate history was seen when inspecting the hypolimnetic waters at site 1. When the lake initially stratified hypolimnetic waters had total and ortho-phosphorus concentration consistent with the epilimnetic waters. As the summer progressed, total and ortho-phosphorus concentrations grew in the hypolimnion as epilimnion concentrations fell. Mixing events beginning in mid-July began entraining nutrient rich hypolimnetic waters with the epilimnetic waters. This was witnessed by a rise in both total and ortho-phosphorous. Total and ortho-phosphorus peaked in late September, the last sampling date before the dissipation of thermal stratification. Once thermal stratification was broken total and ortho-phosphorus concentrations once again became equal throughout the water column.

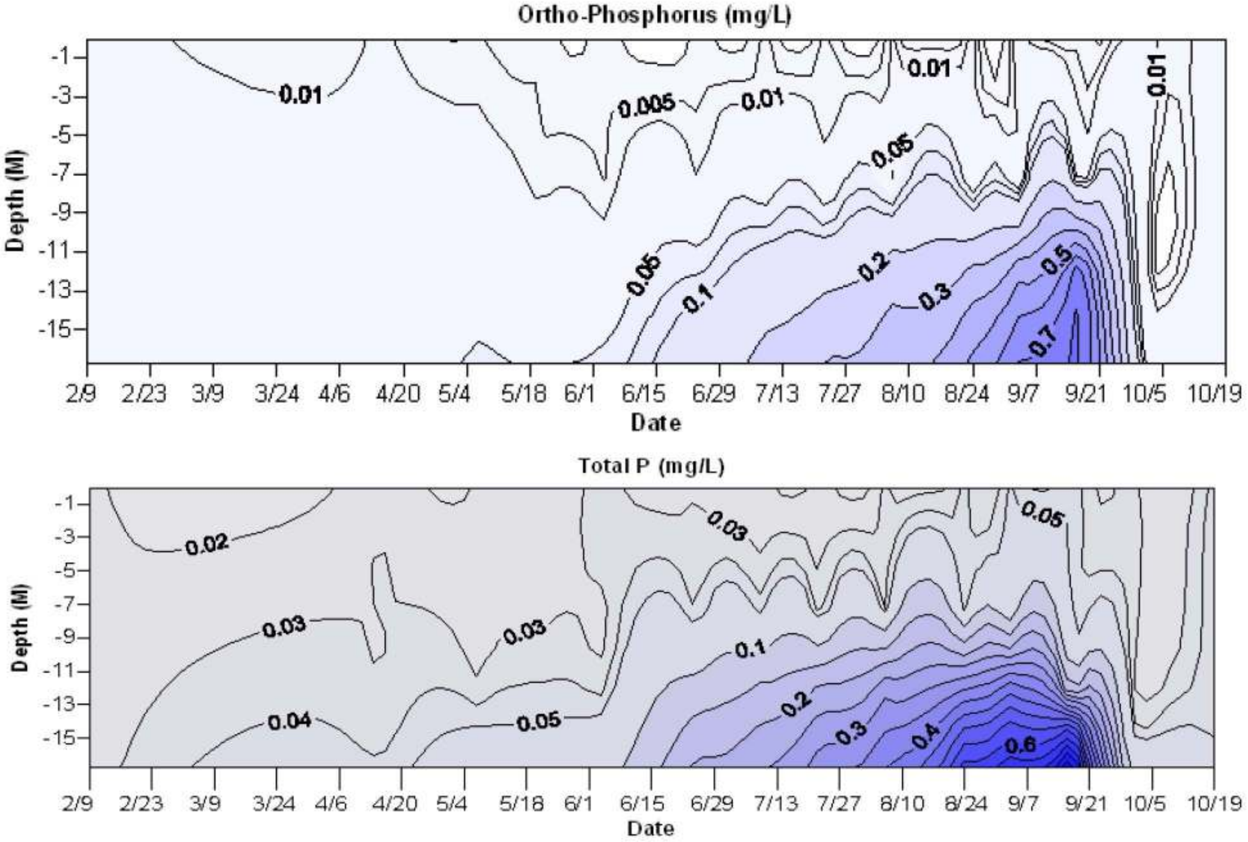
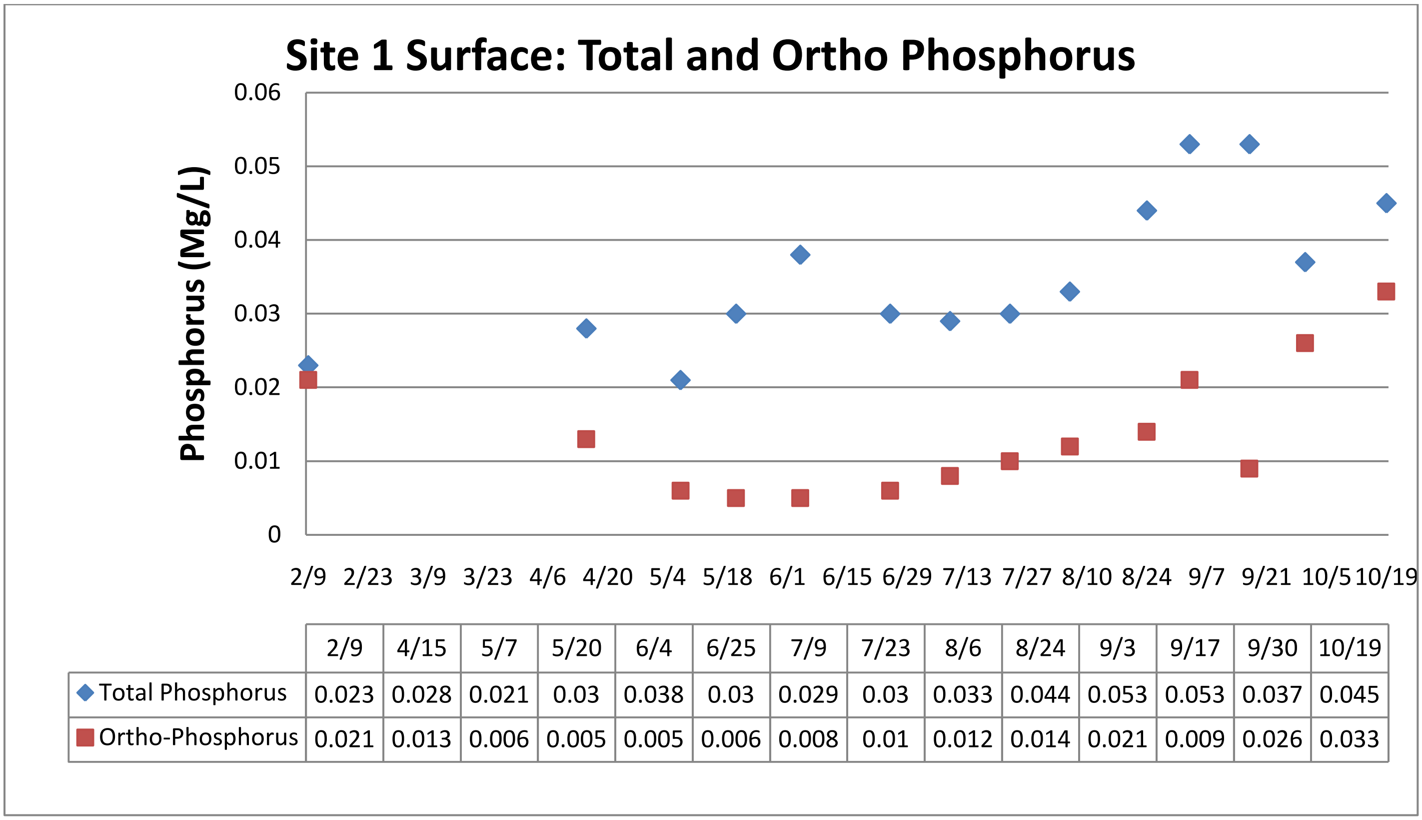


Figure 15: 2009 Lake Thunderbird ortho-phosphorus and total phosphorus contours with depth, by date, at Site 1.

Total phosphorus showed a seasonal increase representing an accumulation of epilimnetic phosphorus. In 2009, the most likely source for epilimnetic accumulation of phosphorus is from the hypolimnion and storm water inflow (**Figure 15**). Ortho-phosphorus from the hypolimnion reaches the epilimnion through two different processes: following the diffusion gradient across the metalimnion and direct mixing as the epilimnion cools and deepens by partial mixing events.



	2/9	4/15	5/7	5/20	6/4	6/25	7/9	7/23	8/6	8/24	9/3	9/17	9/30	10/19
◆ Total Phosphorus	0.023	0.028	0.021	0.03	0.038	0.03	0.029	0.03	0.033	0.044	0.053	0.053	0.037	0.045
■ Ortho-Phosphorus	0.021	0.013	0.006	0.005	0.005	0.006	0.008	0.01	0.012	0.014	0.021	0.009	0.026	0.033

Figure 16: 2009 Lake Thunderbird ortho-phosphorus and total phosphorus surface with depth, by date, at Site 1.

Since the sampling regiment changed throughout the 2009 sampling schedule, little information can be obtained from the data collected at sites 2, 4, 6, 8, and 11; each of which have half a season's data. The collection during 2010 will be informative as it will be the first full season in which each of the three major riverine tributaries will be sampled for nutrients.

Nitrogen

Total and dissolved nitrogen concentrations also produced patterns typical of seasonal ecological cycles in lakes (**Figure 17**). Surface total nitrogen showed a pattern of a general increase over the summer while dissolved forms of nitrogen fell below detection through the summer period. The annual or seasonal pattern observed warrants potential explanations.

The two most likely forces driving the surface dynamics seen in the last 3 years are due to algae growth (uptake) and sediment release of ammonia. Examination of dissolved nitrogen, ammonia and nitrate distribution with depth and over time illustrates.

Dissolved nitrogen decreased to below detection limits in the epilimnion from June into early September. The primary form of dissolved nitrogen in the epilimnion was nitrate. Nitrate is an algal macronutrient second only to ammonia for preferential uptake. Depletion by algal uptake, generally indicating nitrogen-limiting conditions, explains the below detection limits values observed in the epilimnion. It is worthwhile to note that there was no nitrate in the epilimnion past May 20, 2009 until it reappeared on September 17, 2009 (**Figure 17**). In the hypolimnion nitrate does not serve as a macronutrient but as an electron source for anaerobic (bacterial) metabolism. A plot of ammonia details the reason for the high levels of dissolved nitrogen noted in the hypolimnion (**Figure 20)**.

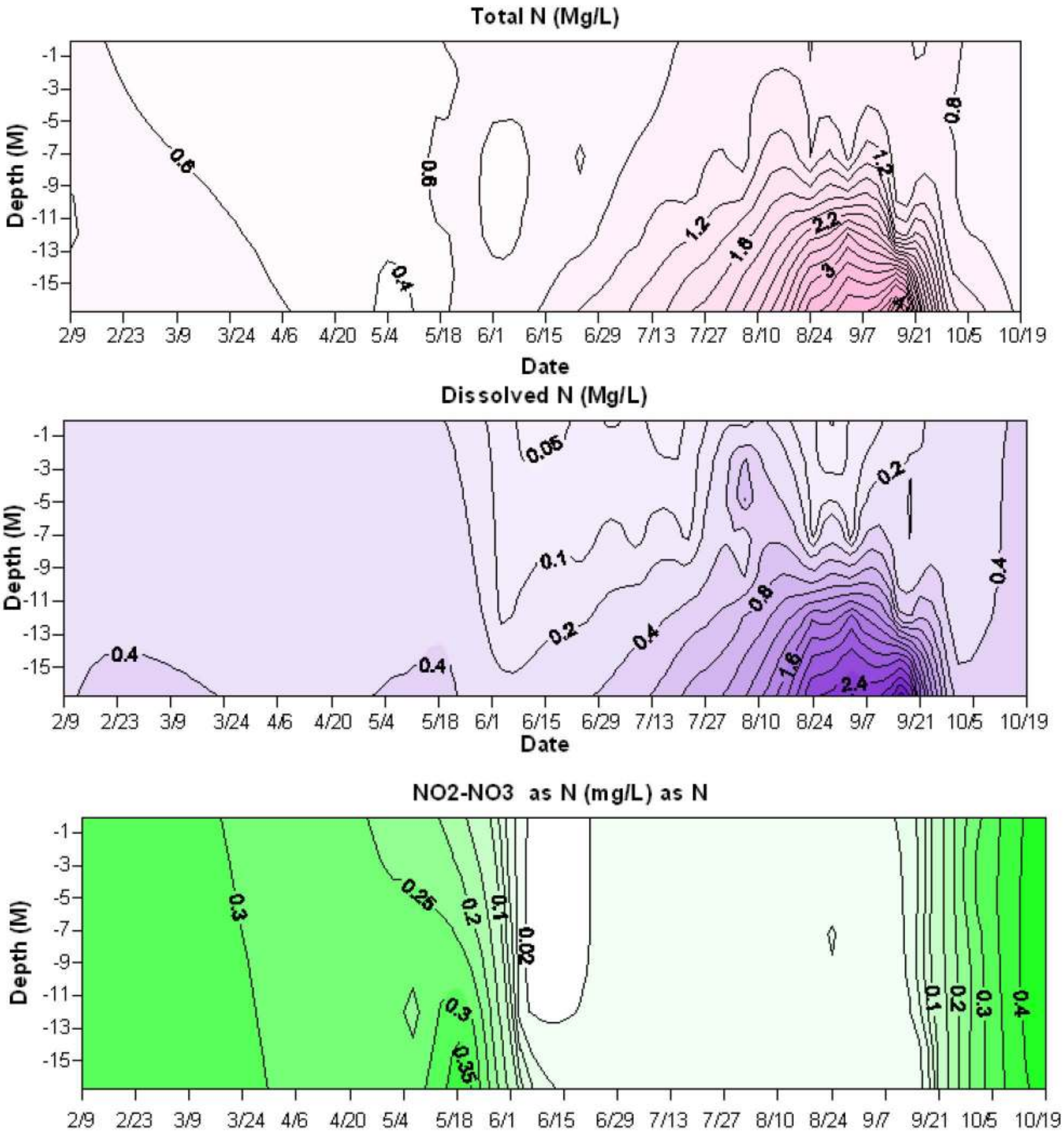


Figure 17: 2009 Lake Thunderbird total nitrogen, dissolved nitrogen, and NO_2-NO_3 as N contours with depth, by date, at Site 1.

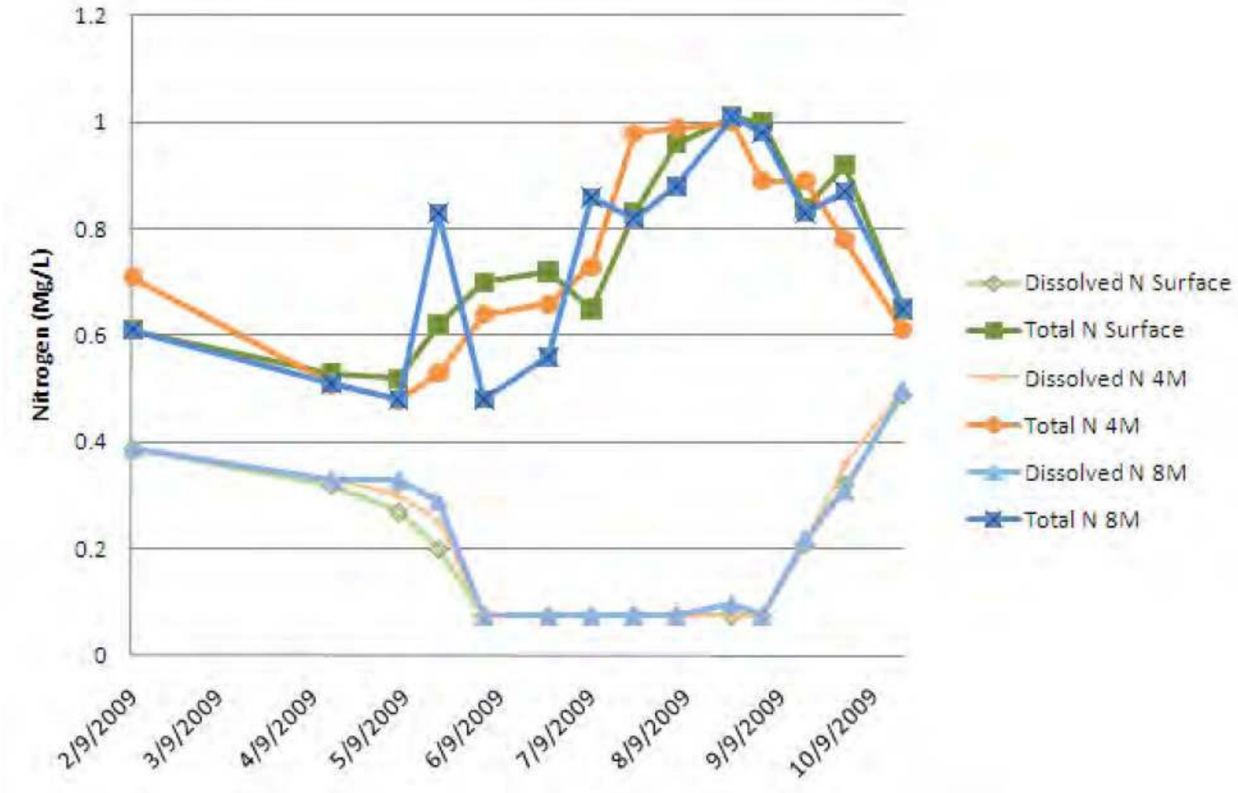


Figure 18: 2009 Lake Thunderbird total and dissolved nitrogen (N) at Site 1 surface, 4 and 8 meters below the surface.

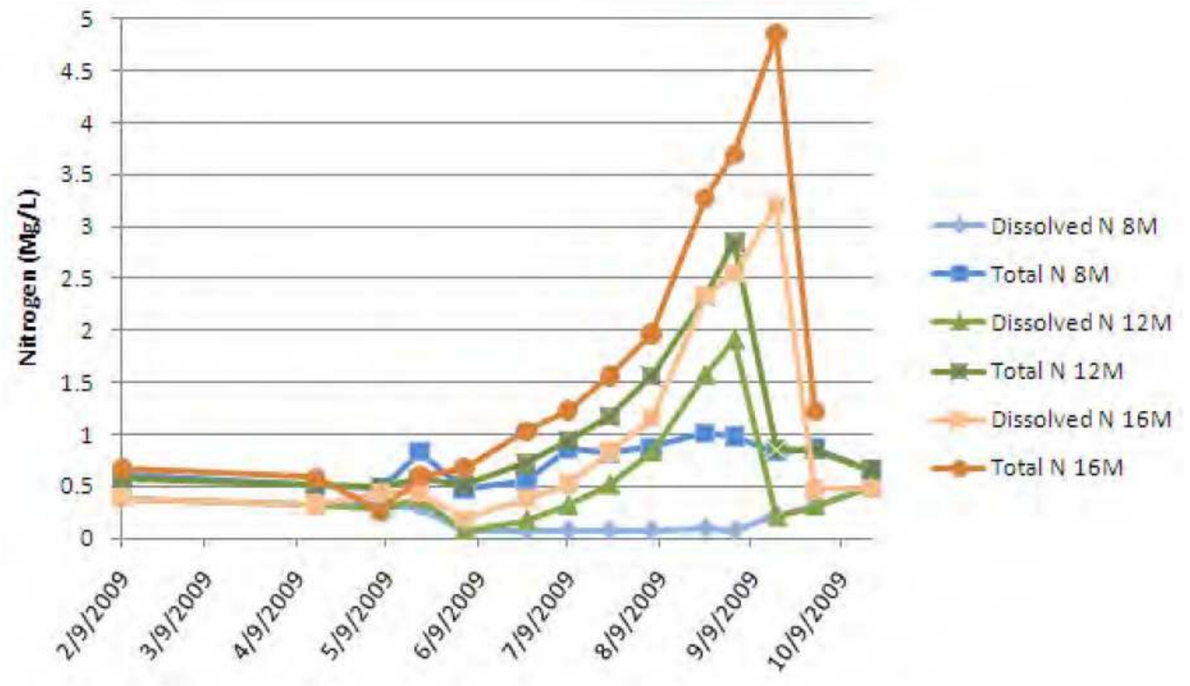


Figure 19: 2009 Lake Thunderbird total and dissolved nitrogen (N) at the bottom (1B) and 8 and 12 meters below the surface of Site 1 (1-8m and 1-12m).

It is not until the nitrate is consumed in the hypolimnion that ammonia accumulates. Simply put, ammonia is released from the sediment (the sediment absorptive capacity falls) as the oxidation-reduction potential falls in the hypolimnion. **Figure 20** and **Figure 21** illustrate how the onset of sediment mediated release of ammonia coincides with the July peak negative oxidation-reduction potential. This reservoir of dissolved nutrient (ammonia requires the least energy for uptake) is made available for algae growth as partial mixing events starting in early September.

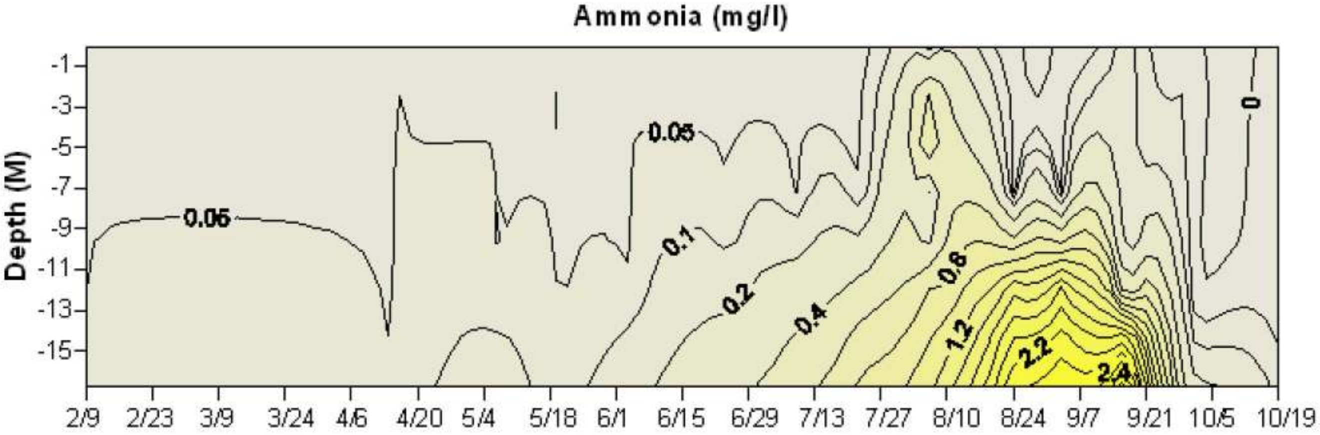


Figure 20: 2009 Lake Thunderbird ammonia contours with depth, by date, at Site 1.

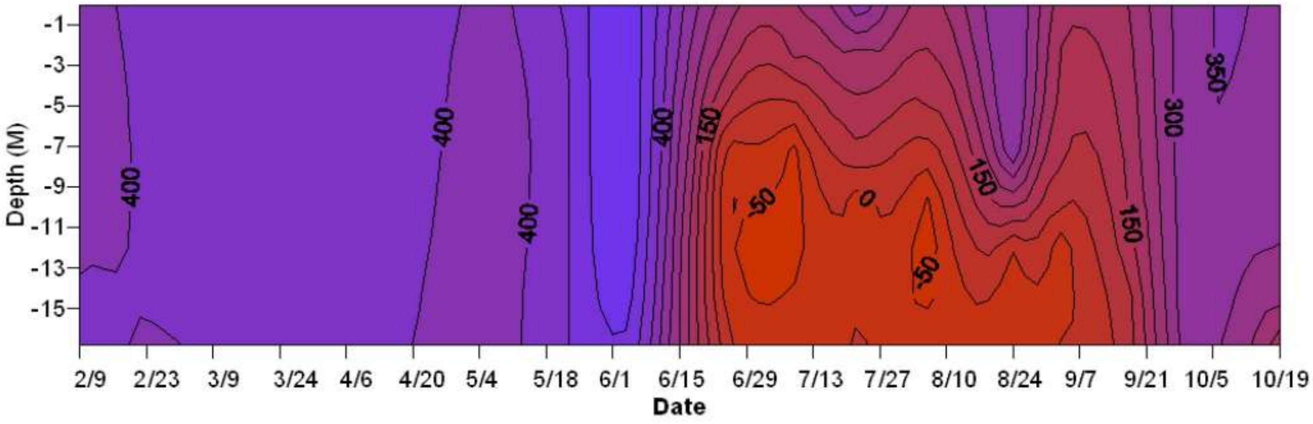


Figure 21: 2009 Lake Thunderbird oxidation-reduction potential versus depth over time Site 1.

Nutrient Budget

A phosphorus budget for Lake Thunderbird was prepared integrating the estimated outflows from the water budget with lake water quality data. Vertical profiles of physical parameters were used to partition total phosphorus reports between epilimnetic, metalimnetic and hypolimnetic layers. The cumulative summation of these layers allows the massing of phosphorus for each sample date (**Table 3**). Once the lake mass was established, the distribution within the lake and losses were estimated using United States Army Corp of Engineers (USACE) water quantity reports and OWRB water quality reports. Missing from this lake nutrient budget are estimates of phosphorus inflow, dry deposition and sediment flux. To complete the massing of Lake Thunderbird phosphorus, sample dates were averaged to yield monthly amounts (**Table 4**). The constructed budget demonstrates pre-stratification lake phosphorus mass in 2009 of approximately 3,700-4,000 kg. May and April marked the lowest observed phosphorus mass while September marked the highest (6,654 kg) mass of lake total phosphorus.

Monthly phosphorus masses demonstrate a general trend of baseline levels occurring in winter under mixed conditions, then steady increases progressing to a late-summer peak as the thermocline begins to break up. The phosphorus mass in October, following fall turnover, is about 2,800 kilograms greater than the pre-stratification mass. It is important to note that even though there were significant inflow events during monitoring, the hypolimnion still accumulated phosphorus. Accumulation of dying algae (settling) from the epilimnion, release of ortho-phosphorus from the sediment and stormwater inflow are the primary contributors.

This preliminary budget has set the foundation for understanding lake nutrient dynamics and placing external (runoff) and internal (sediment mediated release) factors in context of water quality based goals. Enhancements to increase the accuracy of the nutrient budget include assessing dry deposition and estimates of inflow load. It will not be until water quality data is available for the tributaries to the lake that sediment influence can be put in context of the phosphorus mass from runoff and total phosphorus inputs.

Depth (m)	15-Apr	7-May	20-May	4-Jun	25-Jun	9-Jul	23-Jul	6-Aug	24-Aug	3-Sep	17-Sep	30-Sep	19-Oct
0 - 1	595	430	624	783	771	592	625	592	917	1162	1041	796	1028
1 - 2	525	446	564	708	243	537	536	537	804	975	1021	695	846
2 - 3	408	373	437	633	828	433	449	433	705	889	783	614	758
3 - 4	517	349	418	525	496	398	401	398	640	701	779	484	671
4 - 5	367	316	376	478	445	355	388	355	529	647	580	447	573
5 - 6	368	269	268	465	369	380	351	380	512	626	494	432	500
6 - 7	287	250	259	352	336	361	267	361	401	490	537	338	445
7 - 8	241	204	226	210	290	340	225	340	337	412	402	285	395
8 - 9	164	185	195	173	252	311	186	311	279	341	377	236	311
9 - 10	193	160	194	149	343	424	389	424	216	264	251	182	248
10 - 11	110	125	167	112	289	382	474	382	148	181	152	125	176
11 - 12	71	94	119	77	218	290	287	290	408	512	117	79	108
12 - 13	42	62	86	52	168	231	280	231	400	504	72	44	73
13 - 14	23	50	55	31	102	119	152	119	231	296	28	27	23
14 - 15	10	27	29	15	49	58	73	58	139	134	15	12	14
15 - 16	4	12	12	6	17	23	28	23	39	47	26	4	5
16+	1	5	5	1	4	3	3	4	5	6	29	1	1
Total	**3925**	**3358**	**4035**	**4770**	**5220**	**5236**	**5115**	**5237**	**6710**	**8187**	**6703**	**4802**	**6176**
Hypo as % of total mass			8%	17%	47%	56%	33%	29%	20%	18%	1%	0%	0%

Table 3: 2009 Lake Thunderbird Site 1 phosphorus mass (kg) at depth intervals by sample date. Green cells represent hypolimnetic accumulation of phosphorus.

Month	Lake P	Runoff	Sediment	Rainfall	Releases
January	NA	NA	NA	0.8	0
February	NA	NA	NA	0.6	0
March	NA	NA	NA	1.1	0
April	3925	NA	NA	3.1	0
May	3696	NA	NA	3.9	588
June	4995	NA	NA	1.5	0
July	5176	NA	NA	3.2	0
August	6079	NA	NA	2.5	0
September	6564	NA	NA	1.8	0
October	6176	NA	NA	4.8	0
November	NA	NA	NA	0.1	0
December	NA	NA	NA	0	0

Table 4: Partitioning of Lake Thunderbird phosphorus mass for nutrient budget as kilograms of total phosphorus in the lake (runoff, sediment release and direct rainfall) and out of the lake due to gated releases and water supply withdraw during 2009.

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Chlorophyll-a

Chlorophyll-*a* is a pigment common to all photosynthetic plants, and is used as a proxy for algal biomass in aquatic ecosystems. Chlorophyll-*a* samples were collected at the surface of all eight sites sampled at each sampling event during 2009. Chlorophyll-*a* concentrations reached their peak in late August (**Figure 22**). In 2009, 91% of samples were considered eutrophic based on a 7.2 μg/L division between mesotrophy (Wetzel 2001). This is slightly higher than the 87% seen in 2008 and 80% in 2007. Perhaps the most notable item of the 2009 seasonal chlorophyll-*a* was the large jump in values that started in July and peaked in late August. Also notable was that the chlorophyll-*a* reports following the mid-august jump were among the highest reported during the OWRB's monitoring of Lake Thunderbird. In open water lacustrine zones, chlorophyll-*a* appears to have continued to increase over the years since a low in 2005 (**Figure 23**).

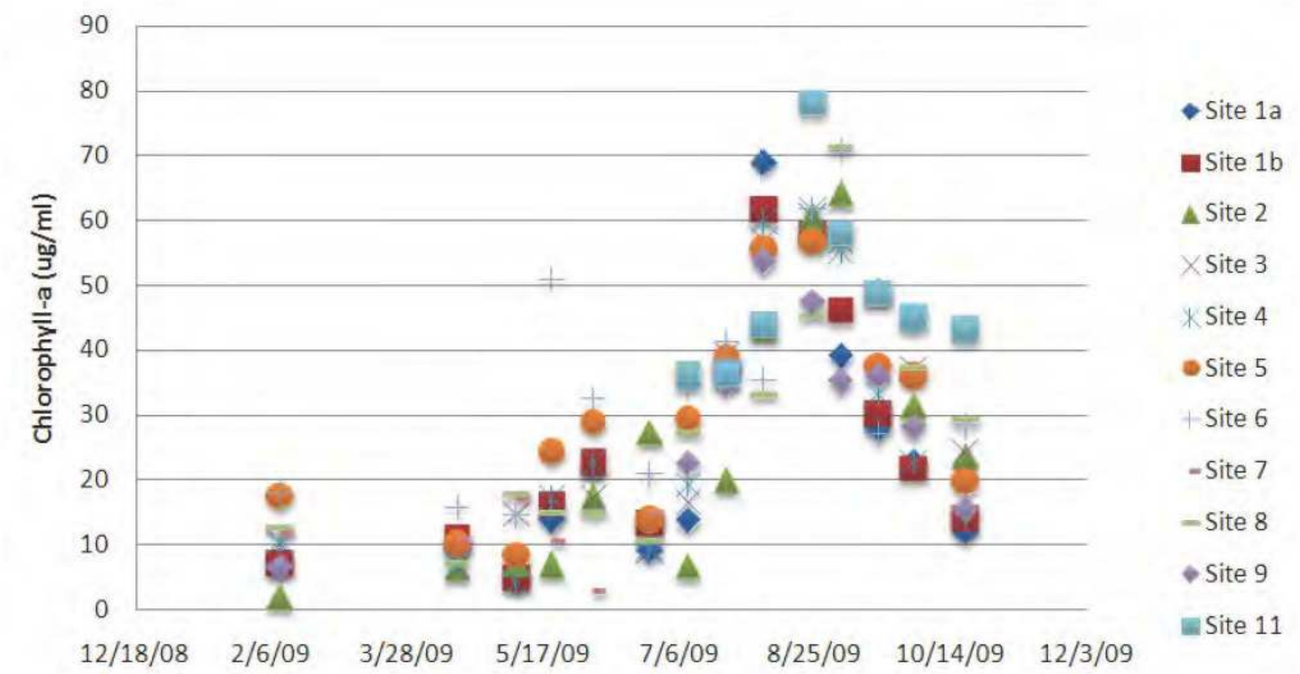

Figure 22: Lake Thunderbird surface chlorophyll-*a* (μg/L) by Site February 9th, 2009 through October 19th, 2009

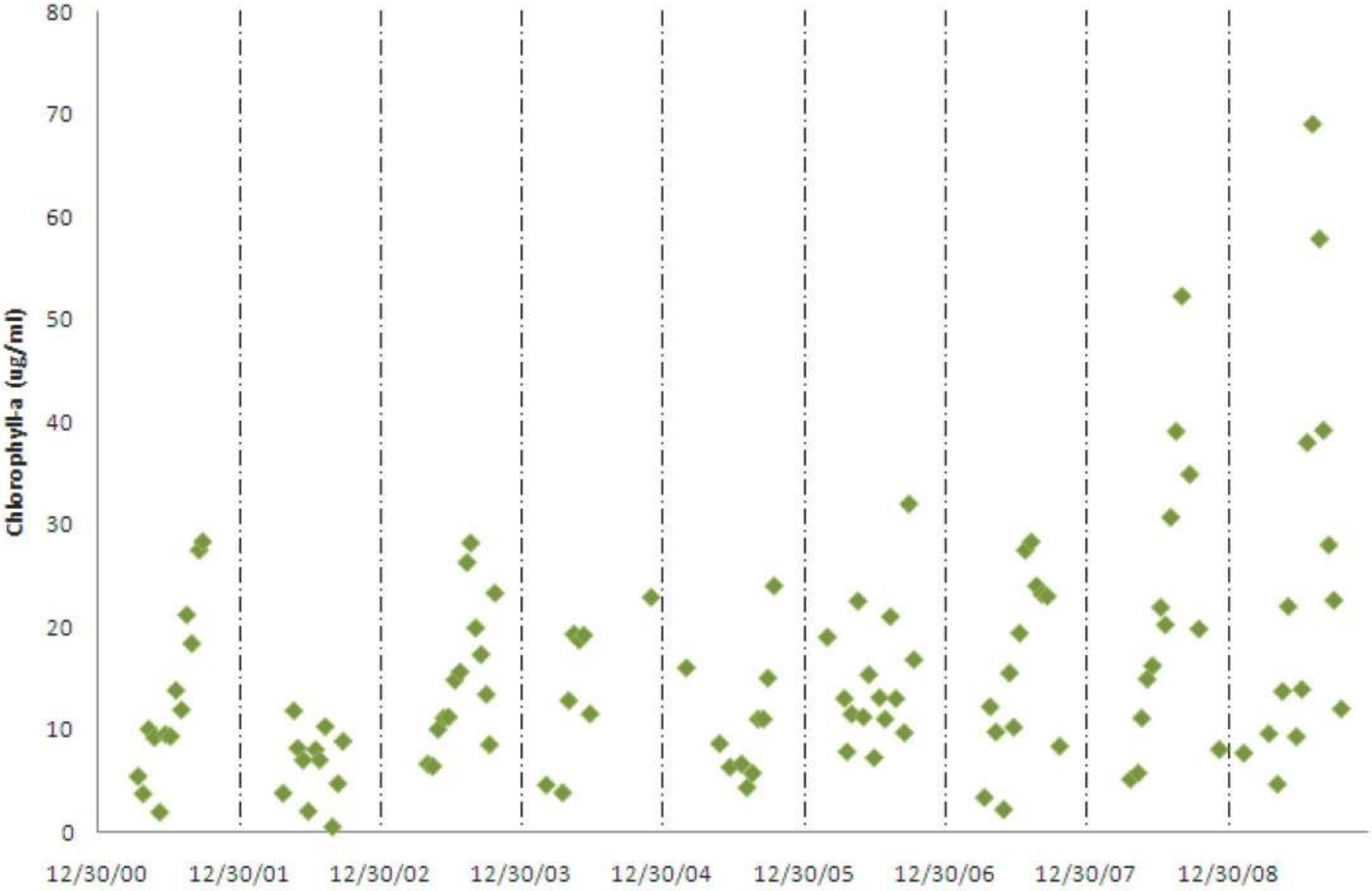

Figure 23: 2001-2009 Lake Thunderbird surface chlorophyll-*a* (μg/L) at Site 1

Goal setting by the COMCD in previous years set a maximum chlorophyll-*a* of 20 μg/L. During the 2009 sampling season, 58% of chlorophyll-*a* samples exceeded this upper limit (**Figure 23**). This number is higher than the 53% in 2008 and the 38% seen in 2007. The large number of eutrophic samples could be due to the excessive nutrient inputs that results from large run-off events in this year and partial mixing of nutrients from the hypolimnion starting in late July. The Norman community which lies within the Lake Thunderbird watershed has also experienced growth since the low chlorophyll-a values seen in 2001, which could also be responsible for continually larger nutrient loads for the lake.

Because Lake Thunderbird is a designated Sensitive Water Supply, it is required to meet a chlorophyll-*a* standard of 10 μg/L (OAC 785:45-5-10 (7)). 86% of the 2009 samples were above this concentration (**Figure 26**), larger than the 47% in 2008 and the 69% in 2007. Although this standard is obtainable for Lake Thunderbird, abatement of nutrient inputs into the watershed is necessary to significantly reduce chlorophyll-*a* concentrations on a long-term basis. The Oklahoma Department of Environmental Quality will draft a watershed management plan to address specific recommendations in regards to thwarting nutrient pollution.

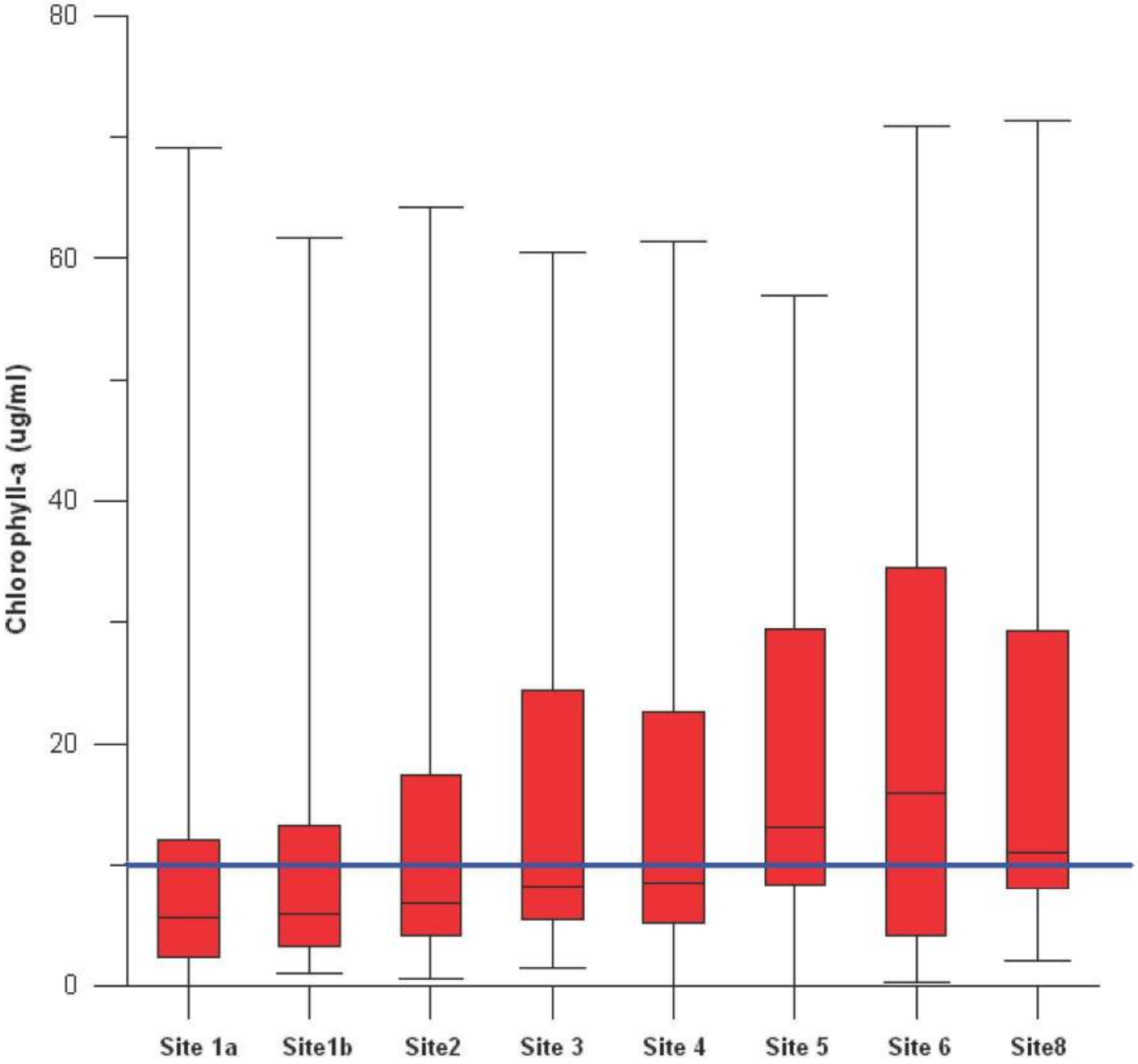

Figure 24: 2009 Lake Thunderbird chlorophyll-*a* (µg/L) averages by Site. The blue line at 10 µg/L indicates the water quality standard for sensitive water supplies (SWS)

Taste and Odor Complaints

The City of Norman provided data on the number of taste and odor complaints from their customers in 2009 and previous years. Because Lake Thunderbird is the major source of raw water for the city, water quality parameters in the lake can be correlated with complaints in the final finished water. Taste and odor causing compounds can be detected at the tap in extremely low concentrations (~5-10 ng/L) (Graham et al 2008). The majority of these compounds are by-products of high algal productivity. The most commonly known taste and odor compounds, geosmin and 2-methylisoborneol (MIB), are produced primarily by cyanobacteria.

Eutrophication results in cyanobacteria dominance of algal communities in lakes, and therefore corresponds to excessive nutrient concentrations.

In 2009, the City of Norman received the majority of taste and odor complaints in August (31) (**Figure 25**). This pattern is somewhat similar to previous years, where a hypolimnetic mixing event in late summer or early fall, causes a spike in the number of complaints (**Figure 26**). In 2009 the spike in complaints coincided temporally with the highest chlorophyll-*a* average seen in 2009.

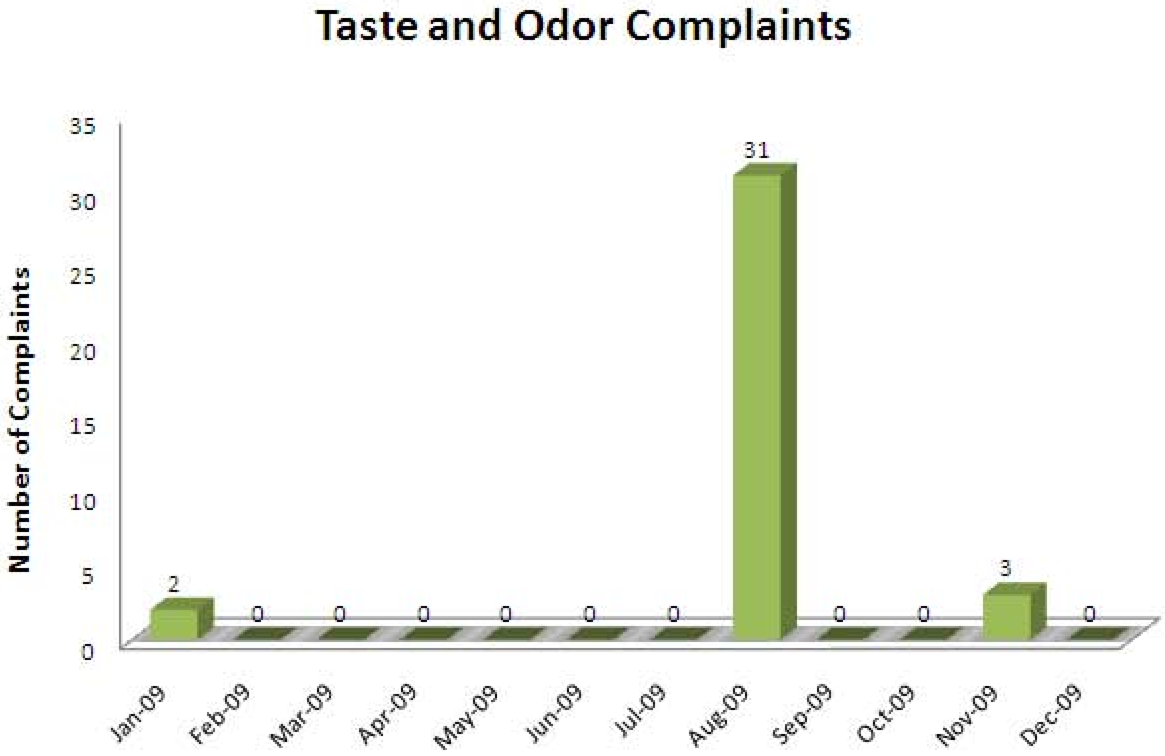

Figure 25: Taste and odor complaints to the City of Norman during 2009

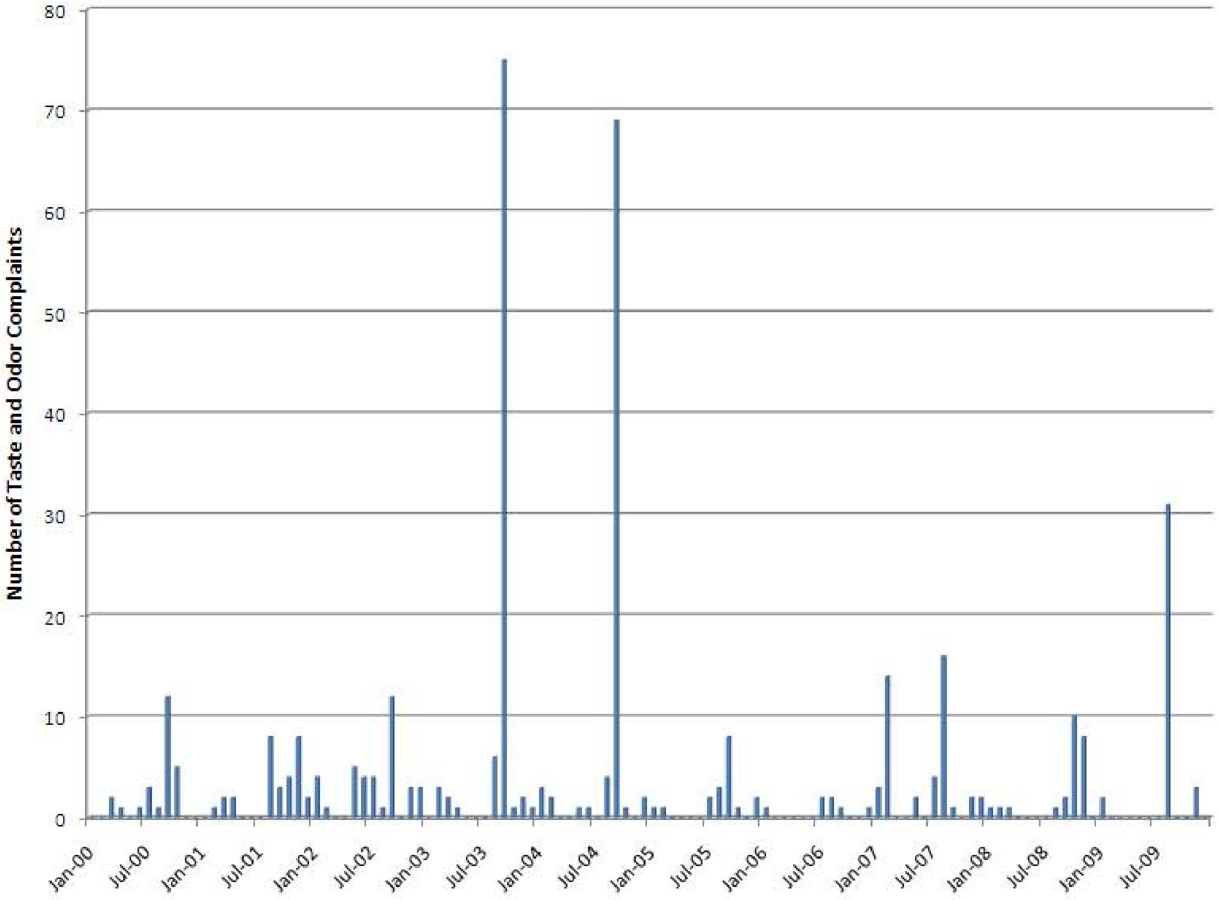

Figure 26: Taste and odor complaints to the City of Norman from 2000 through 2009

General Water Quality

Total organic carbon (TOC) is an additional measure of organic content and productivity. TOC samples were collected at the surface of the three lacustrine sites and three riverine sites within the 2009 calendar year. Site 1 was sampled at every scheduled sample date. The other two lacustrine sites (2 and 4) were sampled to the end of July 2009. The other three riverine sites (6, 8, and 11) were added at the start of the August 2009.

In general, TOC concentrations increased during spring and early summer, with peak concentrations occurring in late August (**Figure 27**). Concentrations consistently declined after this peak date. This trend is consistent with other proxies of primary production, such as chlorophyll-*a* (**Figure 23**) and pH (**Figure 28**). Statistical regression suggested that 66% of the variability in reported chlorophyll-a could be explained by TOC. It is evident that TOC and chlorophyll-a are intimately related parameters. The TOC sampling schedule was changed during the middle of the sampling season from lacustrine sites to riverine sites. This change thwarted possible conclusions that could be made concerning the lacustrine sites but will be greatly informative in the future years by providing data on the inputs to the lake.

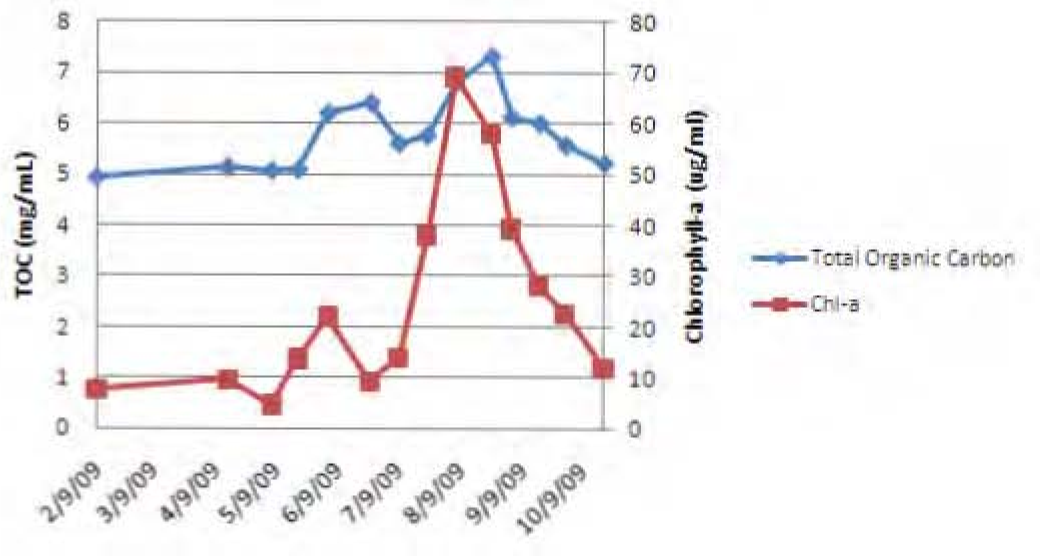

Figure 27: Total organic carbon concentrations and Chlorophyll-*a* at Site 1 surface on Lake Thunderbird during the 2009 sampling season

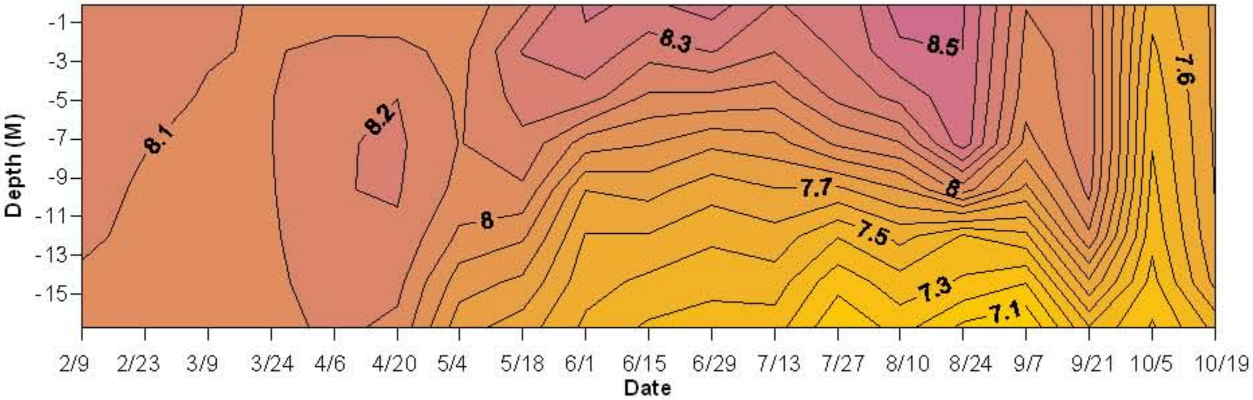

Figure 28: 2009 Lake Thunderbird pH (S.U.) versus depth over time Site 1

High algae growth affects other basic water quality parameters. Increases in surface pH during the summer months indicate high rates of photosynthesis while lower hypolimnetic pH is due to the buildup of bacterial respiration byproducts. It is the sinking organic matter in the summer months (due to high algal production) that stimulates decomposition processes in the hypolimnion.

Hypolimnetic oxidation reduction (redox) potential in Lake Thunderbird approached 0 mV during the last week of June (**Figure 21**). Negative redox potential occurred from this time throughout the growing season, until fall turnover began in mid-September. Sediment bound phosphorus and common metals such as iron will desorb as redox potential falls below 100 mV. Low redox potential is associated with anaerobic conditions and is also associated with the production of sulfide and methane.

Initially, oxygen is used as a terminal electron acceptor. As oxygen is depleted, other compounds are reduced this is reflected by a decreasing hypolimnetic redox potential. For example, ferric iron is reduced to ferrous iron when the redox potential (Eh) approaches 100mV. This results in the release of ortho-phosphorus that was chemically bound to ferric iron in the sediment. When this phosphorus reaches the epilimnion it can contribute to additional algae production. Other metals are reduced to soluble forms when the redox falls below 100mV. Dissolved metals such as iron and manganese should be expected in the water column with low redox potential.

Summary and Discussion

Water Quality

Nutrients such as nitrogen and phosphorus are essential components of aquatic food webs, as they are utilized by primary producers (i.e. algae) for growth. Algae then serve as food sources for zooplankton, which are consumed by planktivorous and juvenile fish. In a healthy ecosystem, these trophic levels interact and together form a balanced food web. Excessive nutrients inputs into lakes such as Thunderbird can cause algal growth to increase past the ability of primary consumers to utilize and will cause imbalances that are easily identifiable. The most notable of these imbalances are reflected as overabundant algal populations, algal blooms and surface scums. Consequences of these occurrences include high chlorophyll-*a*, high total organic carbon, elevated pH, super-saturation of surface level dissolved oxygen, lowered Secchi depth, and increased color and turbidity all occurring at the water's surface. In addition, lower dissolved oxygen concentrations will occur at hypolimnetic depths and oxidation-reduction potentials will decrease; releasing sediment bound phosphorus and metals such as iron and manganese. This process of elevated algal growth and ensuing consequences is known as cultural eutrophication, anthropogenic point and non-point sources are almost always the cause of excess nutrients in aquatic environments, where in-lake dynamics will exacerbate associated problems.

Consequences of cultural eutrophication were observed in Lake Thunderbird in 2009. These included high chlorophyll-*a*, elevated total organic carbon, elevated pH, super-saturation of dissolved oxygen, lowered Secchi depth, and increased turbidity, all occurring at the water's surface during the summer growing season. Anoxia occurred during the summer months as well, coinciding with low to negative oxidation-reduction potentials. During this time phosphorus and metals were released back into the water column and entrained during fall turnover.

Harmful algal blooms, or HABs, are another consequence of cultural eutrophication that can lead to many environmental problems. Cyanobacteria, or blue-green algae, are the most common group of harmful algae in freshwaters. Several species of cyanobacteria occur in and dominate phytoplankton communities in Oklahoma waters, including Lake Thunderbird. Taste and odor causing compounds such as geosmin and MIB (2-methylisoborneol) are released from blue-green algal cells following lyses, or senescence, and decomposition. This causes problems in public drinking water supply lakes because of the difficulty in removing these chemicals beyond detection limits in the treatment process. The City of Norman annually receives taste and odor complaints attributable to the presence of these compounds in finished drinking water. In addition, blue-green algae have the capability to produce multiple toxins that can cause skin irritations, harm or lethality to humans, livestock, and pets that drink from contaminated water sources. As cultural eutrophication remains unabated, risks of harmful algal blooms and their associated consequences continue to increase. The higher chlorophyll-*a* in 2009 represents a greater recreational risk than previous years.

State Water Quality Standards

In 2006, Lake Thunderbird was listed on Oklahoma's 303(d) list as impaired due to color, low dissolved oxygen and turbidity, with the causes of these impairments unknown. Data collected in 2009 were analyzed for beneficial use impairments in accordance with the Use Support Assessment Protocols (OAC 785:46-15) of the Oklahoma Water Quality Standards (OWQS). In 2009 Lake Thunderbird was found to be not supporting its Fish and Wildlife Propagation beneficial use in regards to dissolved oxygen and turbidity, and therefore should remain listed as impaired for these uses. 2009 data was insufficient to make an aesthetic use support determination for true color. In addition, Lake Thunderbird was not meeting the 10 μg/L chlorophyll-*a* requirement for sensitive water supplies. Lastly, water quality standards state that water bodies used for fish and wildlife propagation should maintain a pH of 6.5-9.0; while Lake Thunderbird remained within these parameters, a peak pH of 8.72 was witnessed on August 24th. If increased peak algae growth continues as witnessed through increasing peak chlorophyll-a values (**Figure 23**), Lake Thunderbird may surpass this 9.0 impairment threshold.

Future Work

The 2010 calendar year will be a markedly unique and exciting year at Lake Thunderbird. The COMCD partnered with the OWRB to install and operate a supersaturated dissolved oxygen pump that will disperse oxygenated water throughout the lakes typically anoxic hypolimnion without disrupting the natural thermal stratification that develops there each summer. The primary effect of the pump will be oxygenating the lower seven meters of the hypolimnion to 2mg/ml for the duration of thermal stratification. Ideally the entire hypolimnion would remain oxygenated for the duration of the stratification period, however due to practical constraints on liquid oxygen supply and funding, only the lower 7 meters is targeted. With an oxygenated hypolimnion several secondary effects should also be witnessed. When oxygen is present, it is used as the terminal electron acceptor in respiration, allowing the redox potential in the hypolimnion to be spared from the drop that is witnessed when other compounds are reduced through anaerobic respiration. The drop of redox potentials increases the solubility of a wide range of nutrients and metals, causing a large sediment flux during the late summer months. Providing an oxygen rich hypolimnion should prevent this increased nutrient load by minimizing the recycling of nutrients from the sediment, and lead to a drop in peak chlorophyll-*a* values. Reduced sediment release of phosphorous will depend on how well the SDOX satisfies the sediment oxygen demand. However, the introduction of oxygen in the hypolimnion should reduce dissolved metals such as iron and manganese in the water column. While some effects may be seen the first year of SDOX operation, it is logical to believe that the full impact of the installed system will not be witnessed during the first year of operation due to the large amount of settled organic matter that currently exists at the lake. It is also reasonable to expect reduced dissolved metals in 2010 should a portion of the hypolimnion be oxidized.

The OWRB is also studying the connection between water quality and treatment costs at Lake Thunderbird. Cyanobacteria favored in highly eutrophic waters, produce a number of taste and odor causing compound. It is our belief that a reduction of eutrophic algae growth may result in reduction in water treatment costs. During the 2010 calendar year, it will be our objective to gather historical data concerning treatment cost, total organic carbon, and chlorophyll-*a* data to evaluate the possible link between the three.

Closing Remarks

The goal of compiling a comprehensive long term data set has been realized. While monitoring the lake could never be finished; the OWRB has collected and reported data for the COMCD since 2000, and long-term trends can be visualized. While the specific parameters and duration of monitoring has changed over the years there is enough data to look for deterministic parameters of water quality and the effect of varying water quality over time. Statistical trend detection of long term water quality data is most useful when combined with a clear understanding of watershed land use changes and lake management changes over time. The OWRB is currently performing statistical analysis, in-lake and watershed modeling with the purpose of determining the cost-benefit ratio of implementing BMPs, and in-lake treatments. The ultimate goal of the OWRB is to improve Lake Thunderbird water quality to the point where raw water will provide high quality drinking water and improved habitat for fish and wildlife.

COMCD should also look forward to the results of the non-point source pollution program (319) watershed evaluation and seek ways to encourage adoption of best land management practices (BMPs) throughout the watershed. Targeting practices that reduce nutrient and sediment in runoff to the lake would be an investment in the quality and longevity of the raw water supply.

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