A COMPARISON OF PREDICTED AND ACTUAL TROPHIC STATUS OF
LAKE RAY ROBERTS, TX BASED ON CHLOROPHYLL A

THESIS

Presented to the Graduate Council of the
University of North Texas in Partial
Fulfillment of the Requirements

For the Degree of

MASTERS OF SCIENCE

By

Lili Lisa Lytle, B.S. Biol.
Denton, Texas
May 1999

Two years before impoundment, the trophic status of Lake Ray Roberts was predicted by applying the total phosphorus input into the Organization for Economic Cooperation and Development (OECD) eutrophication model. Predicted mean summer epilimnetic (MSE) chlorophyll a of Elm Fork arm, Isle duBois arm and Main Body were in the eutrophic category of the OECD model. Observed MSE chlorophyll a two years after impoundment of Elm Fork arm, Isle duBois and Main Body had not reached their predicted means and were at the mesotrophic-eutrophic boundary of the OECD model. Six years after impoundment, observed MSE chlorophyll a for Main Body, was closer to its predicted mean and in the eutrophic category of the OECD model.

Six years after impoundment, Elm Fork arm was the most productive area of Lake Ray Roberts. Observed means of chlorophyll a, total phosphates, suspended solids and turbidity were often highest in the Elm Fork arm. Wastewater effluent from Gainesville and Valley View, TX, had an impact on productivity in Elm Fork arm.
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CHAPTER I

INTRODUCTION

There are 5,700 impoundments on the Texas river system; seventy-four of which supply 98% of the state’s surface water (Texas Water Board, 1991). Impoundments are typically dendritic with the majority of nutrients and water flowing in from a single tributary. As a result, gradients in water quality and trophic condition form from the inlet to the dam (Ryding and Rast, 1989).

A common threat to the life and water quality of impoundments is cultural eutrophication. Normally, eutrophication is a gradual process of increased productivity as a waterbody ages. Cultural eutrophication is accelerated productivity from increased nutrient loading by anthropogenic forces, resulting in a profusion of algal biomass and macrophytes (Wetzel, 1983). Accumulations of algal biomass can degrade water quality with offensive tastes and odors, high turbidity, low levels of dissolved oxygen, and diminished recreational appeal.

Bioavailable forms of phosphorus (orthophosphate) and nitrogen (nitrate) are the main nutrients required for algal growth. Most freshwater bodies are phosphorus limited. Lakes with hydraulic residence times longer than a few months can have 80-90% of their phosphorus load trapped in their sediments. Phosphorus in sediments can be released during turnover, but the internal cycling of phosphorus in a stratified lake has a limited influence on the accumulation of algal biomass (Lee et al., 1978).
Wastewater treatment plants' discharges are often the greatest external loading source of phosphorus. According to Bartsch (1970), 20-50% of nitrogen and phosphorus may be removed from conventionally treated wastewater, but it is often not enough to prevent potential enrichment.

The Vollenweider phosphorus-load relationship, based upon the ratio of mean depth over hydraulic residence time, quantifies the amount of phosphorus loading that may cause a waterbody to become eutrophic (Rast and Lee, 1978). In the Vollenweider phosphorus load diagram (Fig. 1), permissible total phosphorus loads that would maintain oligotrophic conditions are 10 mg/m$^3$ TP or less; excessive loads that result in eutrophic conditions are 20 mg/m$^3$ TP or greater, and concentrations from 10-20 mg/m$^3$ TP would categorize the waterbody in a mesotrophic or transitional state (Rast and Lee, 1978).

The Vollenweider phosphorus-loading relationship was the basis for the OECD (Organization for Economic Cooperation and Development) eutrophication model (Fig. 2). This model estimates Mean Summer Epilimnetic (MSE) chlorophyll a concentrations proportional to the total phosphorus load of a waterbody. Waterbodies with mean summer chlorophyll a concentrations above 10 ug/L chl a are classified as eutrophic, and concentrations below 5 ug/L chl a would be considered oligotrophic (Archibald and Lee, 1981). Between 5-10 ug/L chl a, the waterbody would be in a mesotrophic state.

Oligotrophic waterbodies have low nutrient flux, average depths greater than 15m, and high dissolved oxygen levels in their hypolimnion year round (Rast and Lee, 1978). Eutrophic waterbodies have high nutrient flux, higher productivity, algal blooms, shallower depth, dissolved oxygen depletion in the
hypolimnion during stratification, oxygen saturation in the surface water, and greater turbidity with secchi depths of 3m or less.

Pillard (1988) developed a nutrient mass balance for Lake Ray Roberts, TX. He found the Elm Fork of the Trinity River to be the greatest source of mean annual total areal phosphorus ($98.67 \times 10^6$ g/m²/yr) compared to Isle duBois Creek ($60.89 \times 10^6$ g/m²/yr) and runoff into the Main Body ($55.19 \times 10^6$ g/m²/yr) (Table 1) (Pillard, 1988). Pillard (1988) predicted the mean depth of Lake Ray Roberts to be 27 feet (8.2 m) and hydraulic residence time of 4.5 years. According to the Vollenweider relationship, mean annual total phosphorus in both arms and Main Body were excessive (Fig. 1).

Mean areal P loads for Elm Fork arm (3480 mg/m²), Isle duBois arm (920 mg/m²), and Main Body (1875 mg/m²) (Table 1) were plotted into the OECD eutrophication model. Pillard (1988) calculated mean summer epilimnetic (MSE) chlorophyll a concentrations for Elm Fork arm (38 ug/L), Isle duBois arm (29 ug/L), and the whole lake (47 ug/L). Predicted MSE chlorophyll a indicated both arms and main body would be eutrophic.

Observed MSE chlorophyll a two years following impoundment (1989) for the Elm Fork arm (12 ug/L), Isle duBois arm (11 ug/L) and the Main Body (10 ug/L) fell below their predicted concentrations (Cairns, 1993) (Fig. 5). Observed MSE chlorophyll a for the three areas of Lake Ray Roberts were at the boundary of mesotrophic and eutrophic categories.

The Elm Fork arm of Lake Ray Roberts receives the majority of its nutrients from the waste water treatment plant upstream, in Gainesville, TX, via the Elm Fork of the Trinity River. During times of low flow, sewage effluents can
comprise up to 100% of the Elm Fork's discharge, and as other creeks dry up from July to September, the Elm Fork of the Trinity River can constitute up to 80 to 90% of the flow into Lake Ray Roberts (Pillard, 1988). Higher nutrient loads to the Elm Fork arm of Lake Ray Roberts result in higher chlorophyll a concentrations than the Isle du Bois arm and main body (Pillard, 1988). Additional sewage effluent enters Lake Ray Roberts through Spring Creek, from the wastewater treatment lagoons in Valley View, TX, further enhancing productivity in the Elm Fork arm.

Nutrient loading to Isle duBois Creek is from non-point sources during storm events (Pillard, 1988). Landuse of the Elm Fork of the Trinity river is comprised of agricultural and pasture/grassland areas. The watershed of Isle duBois Creek has a larger percentage of pasture/grasslands in addition to upland/transitional woods and bottomland hardwoods.

Lake Ray Roberts, TX has been the subject of a long term study by the U.S. Army Corps of Engineers in cooperation with the Institute of Applied Sciences at the University of North Texas in Denton, TX. The first environmental assessment was in 1986, before impoundment. Subsequent studies were two and six years after impoundment in 1989 and 1993, respectively.

The purpose of this investigation was to determine if predictions of Lake Ray Roberts trophic status made by Pillard (1988) using the Vollenweider and OECD eutrophication models were achieved six years after impoundment (1993)
of Lake Ray Roberts. Specific objectives were:

Objective 1: Determine if observed Mean summer epilimnetic (MSE) chlorophyll a six years after impoundment (1993) supported a eutrophic state as predicted by Pillard (1988) for Main Body of Lake Ray Roberts.

Objective 2: Compare observed MSE chlorophyll a for the Main Body two and six years after impoundment to determine whether or not there was a change.

Objective 3: Determine if there were any significant differences in means of chlorophyll a, total phosphates, ortho-phosphates, nitrates, suspended solids, turbidity, and secchi depth between Elm Fork arm, Isle duBois arm and Main Body from May-October, 1993.
Figure 1. Vollenweider P loading-mean depth/hydraulic residence time relationship.
Excess Loading

Permissible Loading

Phosphorus Loading (g/m²/yr)

Mean Depth/Hydraulic Residence Time

1000

100

10

1

0.1

0.1

0.01

0.01
Table 1. Predicted annual phosphorus loading to Lake Ray Roberts and predicted mean summer epilimnetic chlorophyll a (Pillard, 1988).
<table>
<thead>
<tr>
<th>Source</th>
<th>Main Body</th>
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<th>Isle du Bois Arm</th>
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<td></td>
<td>Mean</td>
<td>Min.</td>
<td>Max.</td>
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<td>10.81</td>
<td>361.09</td>
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<td>Isle duBois Creek</td>
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<td>Runoff to Main Body</td>
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<td>8.32</td>
<td>188.47</td>
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<td>Atmosphere</td>
<td>7.96</td>
<td>7.96</td>
<td>7.96</td>
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<tr>
<td><strong>Total:</strong></td>
<td>222.71</td>
<td>46.19</td>
<td>700.80</td>
</tr>
<tr>
<td>Areal P mg/m²</td>
<td>1875</td>
<td>389</td>
<td>5900</td>
</tr>
<tr>
<td>Predicted MSE Chla ug/L</td>
<td>47</td>
<td>14</td>
<td>112</td>
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\[a\] Values x 10^6 grams

\[b\] Source not applicable
Figure 2. Total phosphorus load-chlorophyll a line of best fit for U.S. OECD waterbodies with 95 % confidence limits.
Total Phosphorus Load (mg P/m$^3$)
CHAPTER II

MATERIALS AND METHODS

Study Area

Lake Ray Roberts dam was completed by the U.S. Army Corps of Engineers in June, 1987. The reservoir was constructed to provide for flood control, water supply, and recreation. Lake Ray Roberts (Fig. 3) is located 10 miles north of Denton, at river mile 60.0 (96.6 km) of the Elm Fork of the Trinity River, 30 miles (48.3 km) upstream from Lake Lewisville. Ray Roberts dam is in Denton county, but the reservoir spans into Cooke and Grayson counties. Lake Ray Roberts impounds runoff from the Elm Fork of the Trinity River and Isle duBois creek, with the total watershed above the dam encompassing 692 square miles in the north central basin of the Trinity River. Lake Ray Roberts conservation pool is 29,350 ac (11,878 ha), and it's flood pool is 36,900 ac (19,566 ha) (I.A.S., 1995).

In May 1993, the U.S. Army Corps of Engineers began to drawdown the level of Lake Ray Roberts in order to repair the dam. The water level decreased a total of 12 ft msl. The lowest depth was in September 1993 at 622 ft msl (Fig. 4). The drawdown continued until January 1994.

Sample Sites

Water samples were collected in triplicate from open water of Lake Ray Roberts on a monthly basis during the growing season from May-October, 1993.
A description of the eight sampling sites (Fig. 5) are as follows:

SPC- Spring Creek
EF0- uppermost reach of the Elm Fork arm. Not sampled from August to October, 1993, due to low depth.
EF1- timbered part of the Elm Fork arm approximately 100 meters north of Farm Market Road 3002 bridge.
EF2- open water in the Elm Fork arm 1.0 km north of the boat ramp located where old highway 455 enters the reservoir.
MB- 0.5 km north of the dam.
ID0- uppermost reach of the Isle du Bois arm. Not sampled from August to October, 1993, due to low depth.
ID1- timbered part of the Isle du Bois arm directly east of Wolf island.
ID2- open water of the Isle du Bois arm where old highway 455 enters the reservoir.

Main Body was the only site that achieved thermal stratification beginning in June and ending in September 1993. Sites SPC and EF0 were added to the sampling regime during the 1993 study. There were no data available for May 1989.

Water Quality Analyses

Secchi (20 cm diameter disc) depth measurements were recorded to the nearest centimeter. Water samples were collected at 0.5m, in 2 liter, acid washed Nalgene bottles and analyzed following Standard Methods for the Examination of Water and Wastewater for total and ortho phosphates, nitrates, chorophyll a, suspended solids, and turbidity (American Public Health
Association, 1985). Mean summer epilimnetic chlorophyll a was calculated for the Main Body by averaging chlorophyll a concentrations from May to October 1993. Main Body was the only site that was stratified from June through September.

**Statistical Analyses**

Means and standard deviations of each trophic parameter (phosphates, nitrates, chlorophyll a, suspended solids, turbidity, and secchi depth) were calculated at each sample site for each month during the growing season, May-October 1993. Significant differences were determined using Tukey’s MRT (a=0.05) or Kruskal-Wallis (a=0.05), dependent upon whether data sets were normal (Shapiro Wilkes, a=0.01) and if variances were homogenous (Hartley’s, a=0.01).

Correlation analyses were conducted for all trophic parameters each month to detect trophic relationships. Only significant correlations (p<0.05) with an $R=0.90$ or greater are discussed.
Figure 3. Study area of Lake Ray Roberts.
Figure 4. Drawdown of Lake Ray Roberts (Courtesy Dr. Doyle).
Lake Ray Roberts Water Levels 1993
Figure 5. Sample sites for Lake Ray Roberts, 1993 (IAS, 1995).
CHAPTER III

RESULTS

The ranges of predicted mean summer epilimnetic (MSE) chlorophyll a concentrations of Elm Fork arm, Isle duBois arm and Main Body of Lake Ray Roberts included both eutrophic and mesotrophic categories of the OECD eutrophication model (Fig. 6). Main Body had the highest predicted MSE chlorophyll a (47 ug/L) with the greatest range (14-112 ug/L). Elm Fork arm had a lower predicted MSE chlorophyll a (38 ug/L) within a lower range of concentrations (8-102 ug/L). Isle duBois arm had the lowest predicted MSE chlorophyll a (29 ug/L) and the narrowest range (13-54 ug/L).

Main Body was the only site stratified throughout the 1993 growing season. Observed MSE chlorophyll a for Main body (17 ug/L) was in the eutrophic category within it's predicted range (Fig. 6). Observed MSE chlorophyll a for Elm Fork arm (12 ug/L Chla) two years after impoundment (1989) was at the low end of it's predicted range and Isle duBois arm (11 ug/L Chla) and Main Body (10 ug/L Chla) were below their predicted ranges (Cairns, 1993).

May 1993

In May, 1993, the upper Elm Fork arm was turbid with significantly high chlorophyll a (Fig. 7). Mean chlorophyll a at SPC (87 ug/L Chla) and EF0 (60
Figure 6. Comparison of predicted and observed mean summer epilimnetic chlorophyll a.
Figure 7. Water quality parameters May 1993.
Water Quality Parameters

May 1993

- SPC
- EF0
- EF1
- EF2
- MB
- ID2
- ID1
- ID0

Legend:
- Chla
- Total P
- Ortho P
- NO3
- Turb.
- Secc.
ug/L Chla) were significantly different (Tukey's, \(a=0.05\)) from each other and all other sites (9-24 ug/L Chl a). Site EF0 (0.15 mg/L P) had more than twice the mean total phosphorus of any other site (0.03-0.06 mg/L P), with the exception of the main body (0.11 mg/L P) (Fig. 7). Mean orthophosphates were only detected at sites in the Elm Fork arm and Spring Creek (0.01-0.03 mg/L P). May mean nitrates were the highest of the growing season (4.0-6.1 mg/L).

Mean turbidity at SPC (17 NTUs) and EF0 (45 NTUs) were significantly different (Tukey, \(a=0.05\)) from each other and more turbid than all the other sites (4-8 NTUs) during May 1993 (Fig. 7). Mean secchi depths were significantly different (Tukey's, \(a=0.05\)) among all the sites, either individually or in a group: ID1 (157 cm); ID2 (140 cm) and the main body (144 cm); ID0 (124 cm); EF1 (94 cm) and EF2 (95 cm); EF0 (21 cm); and SPC (34 cm).

In May 1993, significantly greater chlorophyll a at SPC and EF0 indicated an accumulation of algal biomass coincident with detectable concentrations of mean orthophosphates in the Elm Fork arm (Fig. 7). There were no significant correlations among the above water quality parameters.

June 1993

High concentrations of mean chlorophyll a, total phosphates, and nitrates were coincident with high turbidity at the upper reaches of the the Elm Fork arm in June, 1993 (Fig. 8). The range of mean chlorophyll a concentrations (6-32 ug/L Chla) had increased since June, 1989 (IAS, 1992) (7-10 ug/L Chl a). Mean total phosphates at SPC (0.08 mg/L P) and EF0 (0.09 mg/L P) were significantly greater (Tukey's, \(a=0.05\)) than the rest of the sites (0.01-0.04 mg/L P) (Fig. 8).
Figure 8. Water quality parameters June 1993.
Mean orthophosphates were below detectable concentrations with the exception of SPC (0.05 mg/L P). In June, 1989, all sites had mean orthophosphate concentrations (0.03-0.06 mg/L P), with the exception of site ID1. Mean nitrates ranged from 0.39-1.24 mg/L, with highest concentrations in the Elm Fork arm.

Turbidities for Lake Ray Roberts in June, 1993 (2-12 NTUs) and 1989 (4-16 NTUs) were similar, with the exception of site EF0 (30 NTUs) in 1993. Mean secchi depths in 1993 (103-155 cm) were greater than in 1989 (58-109 cm), with the exceptions of EF0 (32 cm) and SPC (45 cm). All sites within the Isle duBois arm (148-155 cm), and the main body (137 cm), were significantly different (Tukey's, a=0.05) from all other sites (Fig. 8). Sites EF1 (103 cm) and EF2 (106 cm) were significantly different (Tukey's, a=0.05) from EF0 (32 cm) and SPC (45 cm).

In June 1993, mean orthophosphates were below detectable levels for all sites within Lake Ray Roberts, with the exception of Spring Creek, possibly due to its proximity to the inlet of the Trinity river. High turbidity at EF0 may have suppressed algal productivity and the uptake of orthophosphates. Mean turbidity and mean secchi depth were significantly correlated with an $R = 0.92$ (Spearman, $p = 0.0001$) (Fig. 9).

**July 1993**

In July, 1993, site EF0 was turbid, with high concentrations of mean chlorophyll a, total phosphates, nitrates, and suspended solids (Fig. 10).
Figure 9. Correlation of mean turbidity and mean secchi depth June 1993.
Mean Turbidity vs. Mean Secchi Depth

June 1993
Figure 10. Water quality parameters July 1993.
Water Quality Parameters

July 1993
The mean chlorophyll a concentration at site EF0 was five times greater (124 ug/L Chla) and significantly different (Tukey's, a=0.05) from all the other sites (13-24 ug/L Chla). Mean chlorophyll a concentrations were lower in July, 1989 (7-14 ug/L Chla). Site EF0 (0.13 mg/L P) was significantly greater in mean total phosphates (Tukey's, a=0.05) than the rest of the sites (0.03-0.08 mg/L P) (Fig. 10). The range of mean total phosphates in July, 1989 (0.02-0.13 mg/L P) was similar to that in 1993, but without localization in any particular area of the lake. Mean orthophosphates in July, 1993 (0.00-0.07 mg/L P) did not deviate from the range of concentrations in 1989 (0.00-0.06 mg/L P). July mean orthophosphates were the highest recorded for the growing season, 1993. Site EF0 had more than double the mean nitrate concentration (0.90 mg/L) of the majority of the other sites (0.18-0.48 mg/L) (Fig. 10). The range of mean nitrate concentrations in July, 1989 was narrower (0.33-0.45 mg/L) than in 1993.

In July 1993, mean suspended solids of the Elm Fork arm (14-39 mg/L) were greater than concentrations in the Main Body and the Isle duBois arm (0-2 mg/L), but the difference was not significant (Fig. 10). Mean suspended solids in July, 1989 (4-18 mg/L) were similar to 1993 concentrations with the exception of sites EF0 (39 mg/L) and SPC (24 mg/L). Mean turbidity at sites EF0 (20 NTUs) and SPC (14.3 NTUs) were at least two times greater than all other sites in July 1993 (2-7 NTUs) (Fig. 10) and the range of turbidities in July 1989 (3-5 NTUs). Site ID2 (150 cm) had a significantly greater mean secchi depth than the rest of the sites sampled (Tukey's, a=0.05). Mean secchi depths of the main body (142 cm), ID1 (144 cm) and ID0 (146 cm) were significantly different (Tukey's,
a=0.05) from all other sites. Mean secchi depths of EF1 (61 cm) and EF2 (93 cm), were each statistically distinct (Tukey’s, a=0.05). EFO (34 cm) and SPC (31 cm) had the significantly lowest (Tukey’s, a=0.05) mean secchi depths of Lake Ray Roberts. In July, 1989, mean secchi depths (132-160) for the entire lake were greater than those of the Elm Fork arm in 1993.

There were significant associations among mean phosphates, mean suspended solids, mean turbidity and mean secchi depth in July 1993. Mean suspended solids correlated with mean turbidity (Spearman, p=0.0001, R=0.93) and mean total phosphates (Spearman, p=0.0001, R=0.91) (Fig. 11, 12). Mean turbidity correlated with mean secchi depth (Spearman, p=0.0001, R=-0.90) (Fig. 13).

Chlorophyll a and turbidity were high at EFO in July 1993. Algal biomass, in addition to suspended solids, may have contributed to the turbidity at EFO which may have caused shading effects. High orthophosphates and a decrease in nitrates may indicate a switch to nitrogen limitation.

August 1993

In August, 1993, SPC was the most turbid site with significantly greater suspended solids than all other sites (Fig. 14). EF1 had more than twice the mean chlorophyll a concentration (50 ug/L Chla) than most of the other sites (6-27 ug/L Chla). Mean chlorophyll a was lower in August, 1989 (8-16 ug/L Chla) than in 1993. Mean total phosphates (0.002-0.06 mg/L P) and mean orthophosphates (0.00-0.02 mg/L P) in August 1993, had increased to detectable levels at most sites in Lake Ray Roberts from undetectable
Figure 11. Correlation of mean turbidity and mean suspended solids July 1993.
Mean Turbidity vs. Mean Suspended Solids

July 1993

Turbidity (NTUs)

Suspended Solids (mg/L)

- turbidity
- solids
Figure 12. Correlation of mean total phosphates and mean suspended solids
July 1993.
Mean Total Phosphates vs. Mean Suspended Solids

July 1993

![Graph showing the relationship between Total P (mg/L) and Suspended Solids (mg/L) for July 1993. The graph includes data points indicating the correlation between the two variables. The x-axis represents Suspended Solids in a logarithmic scale from 0.01 to 100 mg/L, and the y-axis represents Total P in a linear scale from 0.00 to 0.35 mg/L. The data points are differentiated by symbols: • for total P and ▲ for solids. The graph visually demonstrates the increasing trend of Total P with Suspended Solids.]
Figure 13. Correlation of mean turbidity and mean secchi depth July 1993.
Figure 14. Water quality parameters August 1993.
Water Quality Parameters

August 1993
concentrations in 1989. Mean nitrates in July 1993 had escalated (1.27-1.69 mg/L) since 1989 (0.18-0.25 mg/L).

SPC was significantly greater (Tukey's, a=0.05) in mean suspended solids (13 mg/L) than all other sites (2-5 mg/L) in August 1993 (Fig. 14). Consequently, SPC was also more turbid (11 NTUs) compared to the other sites (2-5 NTUs). Mean suspended solids and turbidity had not changed since 1989, with the exception of SPC. ID1 (160 cm) and ID2 (161 cm) were significantly (Tukey's, a=0.05) deeper than all other sites. Mean secchi depths of the main body (126 cm), EF2 (100 cm) and EF1 (86 cm) were each significantly different (Tukey's, a=0.05). Secchi depth at site SPC was not recorded for August, 1993. Mean secchi depths for August, 1989 (100-170 cm) were similar to those recorded in 1993. Mean secchi depth correlated with (Spearman, p=0.0001, R=-0.92) mean turbidity (Fig. 15).

In August 1993, mean orthophosphates began to decline with an increase in nitrates; an indication of nitrogen fixing bluegreen algae. Turbidity at SPC caused by high suspended solids content limited algal growth. High mean chlorophyll a at EF1 may have been due to a combination of incoming nutrients and higher water clarity.

September 1993

During September, 1993 (Fig. 16), mean chlorophyll a, mean suspended solids, and mean turbidity were greatest in the Elm Fork arm, but mean total phosphates were highest in the Isle duBois arm. Mean chlorophyll a at SPC (42 ug/L Chla), EF1 (30 ug/L Chla) and EF2 (27 ug/L Chla) were significantly greater
Figure 15. Correlation of mean turbidity and mean secchi depth August 1993.
Mean Turbidity vs. Mean Secchi Depth

August 1993

Secchi Depth (cm)

Turbidity (NTU)

- Turbidity • Secchi depth

(SlN) AHPqijnjL
Figure 16. Water quality parameters September 1993.
Water Quality Parameters

September 1993
(Tukey's, \(a=0.05\)) than all other sites (8-13 \(\mu g/L\) Chla). Mean chlorophyll \(a\) concentrations ranged from 6-20 \(\mu g/L\) Chla in 1989. Mean total phosphorus concentrations at sites ID1 (0.53 \(mg/L\) P), ID2 (0.63 \(mg/L\) P), and MB (0.54 \(mg/L\) P) were ten times the concentration and significantly greater (Tukey's, \(a=0.05\)) than all other sites (Fig. 16). Mean total phosphates in the Elm Fork arm (0.03-0.05 \(mg/L\) P) were in agreement with 1989 concentrations (0.01-0.06 \(mg/L\) P). No orthophosphates were detected during September, 1989 nor 1993. Mean nitrates had increased (0.66-1.69 \(mg/L\)) since two years after impoundment (1989) (0.35-0.55 \(mg/L\)).

Sites SPC (18 \(mg/L\)) and EF1 (10 \(mg/L\)) were significantly greatest (Tukey's, \(a=0.05\)) in mean suspended solids than all other sites (Fig. 16). The range of mean suspended solids of the other sites (0-4 \(mg/L\)) during September 1993 was lower than in 1989 (2-9 \(mg/L\)). Mean turbidities at SPC (13 NTUs), EF1 (8 NTUs), and EF2 (6 NTUs) were significantly different from each other and all other sites (Tukey's, \(a=0.05\)). Mean turbidity in the main body (4 NTUs) was significantly different (Tukey's, \(a=0.05\)) from ID1 (2 NTUs), but not ID2 (3 NTUs).

Mean turbidities in 1989 ranged from 1-2 NTUs. There were significantly different (Tukey, \(a=0.05\)) mean secchi depths among ID1 (174 cm), MB (149 cm) and ID2 (142 cm), EF2 (80 cm), EF1 (66 cm), and SPC (32 cm). Mean secchi depths in 1989 (150-185 cm) were similar to those of the Isle duBois arm in September 1993.

In September 1993, there were significant correlations among mean chlorophyll \(a\), mean suspended solids, mean turbidity and mean secchi depths.
Figure 17. Correlation of mean chlorophyll a and mean suspended solids September 1993.
Mean Chlorophyll a vs. Mean Suspended Solids

September 1993

Suspended Solids (mg/L)

Chlorophyll a (ug/L)
Figure 18. Correlation of mean turbidity and mean suspended solids September 1993.
Mean Turbidity vs. Mean Suspended Solids

September 1993

Turbidity (NTUs)

Suspended Solids (mg/L)

- turbidity ▲ solids
Mean chlorophyll a correlated with mean suspended solids (Spearman, \( p=0.0001, R=0.94 \)) (Fig. 17). Mean suspended solids correlated with mean turbidity (Spearman, \( p=0.0001, R=0.92 \)) (Fig. 18) and mean secchi depth (Spearman, \( p=0.0001, R=-0.92 \)) (Fig. 19). Mean turbidity significantly correlated with mean secchi depth, \( R=-0.90 \) (Spearman, \( p=0.0001 \)) (Fig. 20).

In September 1993, Lake Ray Roberts returned to phosphorus limitation. Elm Fork arm was more turbid than the main body and the Isle duBois arm, and had higher chlorophyll a concentrations and suspended solids. Significantly greater mean total phosphates were found in the Isle duBois arm possibly due to runoff from a grass farm on Buck Creek. Lack of a coincident increase of orthophosphates may be explained by the predominance of particulate and unavailable forms of phosphorus in the Isle du Bois arm.

October 1993

In October, 1993, the Elm Fork arm of Lake Ray Roberts was turbid with high chlorophyll a (Fig. 21). Mean chlorophyll a at SPC (82 ug/L Chla) and EF1 (41ug/L Chla) were each significantly different (Tukey's, \( a=0.05 \)) than all other sites (15-28 ug/L Chla). Mean chlorophyll a within Lake Ray Roberts during October 1993 had increased since 1989 (8-12 ug/L Chla). The resurgence of mean total phosphates (0.14-0.40 mg/L) at all sites in October 1993 was ten times greater than concentrations recorded in 1989 (0.02-0.04 mg/L P). Mean orthophosphate concentrations had increased to detectable amounts in October 1993 (0.01-0.02 mg/L P) since 1989. Mean nitrate at MB (0.94 mg/L) was significantly different (Tukey's, \( a=0.05 \)) from ID2 (0.79 mg/L).
Figure 19. Correlation of mean suspended solids and mean secchi depth

September 1993.
Mean Suspended Solids vs. Mean Secchi Depth

September 1993
Figure 20. Correlation of mean turbidity and mean secchi depth September 1993.
Mean Turbidity vs. Mean Secchi Depth

September 1993

- • turbidity
- ▲ secchi depth
Figure 21. Water quality parameters October 1993.
Water Quality Parameters

October 1993
EF2 (0.74 mg/L), and ID1 (0.72 mg/L), which were significantly different from EF1 (0.57 mg/L) and SPC (0.53 mg/L) (Appendix). Mean nitrate concentrations for Lake Ray Roberts October, 1989 (1.25-1.43 mg/L) were higher than observed in 1993.

The range of mean suspended solids during October, 1989 (6-35 mg/L) was greater than in 1993 (2-9 mg/L). Mean turbidity at SPC (14 NTUs) and EF1 (9 NTUs) were each significantly different from EF2 (6 NTUs), which was significantly different from ID1 (3 NTUs) and ID2 (4 NTUs), but not from MB (4 NTUs) (Fig. 21). EF1 was the only site that increased in turbidity since October, 1989 (4-6 NTUs). Mean secchi depth at ID1 (147 cm) was significantly deeper than all other sites. ID2 (130 cm) and MB (130 cm) had significantly different (Tukey's, a=0.05) secchi depths than all other sites. All the Elm Fork arm sites (55-81 cm) and SPC (36 cm) were each significantly different from each other and all other sites (Tukey's, a=0.05). October secchi depths in the Elm Fork had decreased since 1989 (120-175 cm).

Mean chlorophyll a correlated with mean secchi depth, $R=-0.93$ (Spearman, p=0.0001) (Fig. 22). There was also a significant correlation between mean secchi depth and mean turbidity (Spearman, p=0.0001, $R=-0.92$) (Fig. 23).

Fall turnover in October 1993, dispersed nutrients throughout Lake Ray Roberts, which resulted in increased mean total phosphates and chlorophyll a at all the sites.
Figure 22. Correlation of mean chlorophyll a and mean secchi depth October 1993.
Mean Chlorophyll a vs. Mean Secchi Depth

October 1993

Chlorophyll a (µg/L) vs. Secchi Depth (cm)

- Chlorophyll a
- Secchi depth
Figure 20. Correlation of mean turbidity and mean secchi depth October 1993.
Mean Turbidity vs. Mean Secchi Depth

October 1993
CHAPTER IV

CONCLUSIONS

Pillard had predicted that Lake Ray Roberts would be eutrophic from the relationship of total phosphorus loading to mean summer epilimnetic (MSE) chlorophyll a exhibited by the OECD eutrophication model. An objective of this study was to determine if observed mean summer epilimnetic (MSE) chlorophyll a for Lake Ray Roberts six years after impoundment (1993) supported a eutrophic state as predicted by Pillard (1988). In addition, observed MSE chlorophyll a for Main Body two (1989) and six years after impoundment (1993) were compared to determine whether or not there was a change.

Only the Main Body stratified from June through September 1993. Other sites remained mixed, possibly as a consequence of the drawdown of Lake Ray Roberts. Observed MSE chlorophyll a for Main Body six years after impoundment (1993) (17 ug/L) was higher than observed two years after impoundment (1989) (10 ug/L), but did not reach it's predicted concentration of 47 ug/L. Observed MSE chlorophyll a concentrations for Elm Fork arm (12 ug/L), Isle duBois arm (11 ug/L) and Main Body (10 ug/L) two years after impoundment (1989) occurred at the low end of their ranges at the mesotrophic-eutrophic boundary of the OECD model. MSE chlorophyll a for Main Body of Lake Ray Roberts had increased in 1993. A switch to nitrogen limitation in July and October 1993 may have obscured any phosphorus/chlorophyll a
relationships. High nonalgal turbidity may have also depressed the assimilation of phosphorus to algal biomass, particularly in the Elm Fork arm. Lind, et al. (1992) suggested that algal productivity in an inorganically turbid, tropical lake was limited more by light than nutrients. Resuspension of sediments at shallow depths were suspect in perpetuating high turbidity. Sites in the shallower upper Elm Fork arm received high concentrations of phosphorus and nitrogen, but accumulations of algal biomass were limited by turbidity.

Another objective of this study was to examine significant differences in means of chlorophyll a, total phosphates, ortho-phosphates, nitrates, suspended solids, turbidity, and secchi depth. Above trophic parameters were investigated to determine if the Elm Fork arm and Isle duBois arm were significantly different due to differences in the nutrient loads of the Elm Fork of the Trinity River and Isle duBois Creek, respectively. Pillard (1988) had predicted a difference in the two arms of Lake Ray Roberts from the results of the nutrient budgets of the aforementioned tributaries.

Elm Fork arm of Lake Ray Roberts receives sewage effluent from wastewater treatment plants in Gainesville and Valley View, TX, transported by the Elm Fork of the Trinity River and Spring Creek, respectively. Nutrients, principally phosphorus, present in the effluent continuously fueled algal productivity in Elm Fork arm. Elm Fork arm often had higher, often significant, concentrations of mean chlorophyll a, total phosphorus, suspended solids and turbidity than Main Body and Isle duBois arm. Differences between Main Body and Isle duBois arm were small compared to their differences with Elm Fork arm.
Vollenweider and OECD models were not meant for exact predictions, but to monitor change in algal productivity. Comparison of observed MSE chlorophyll a of Main Body of studies two and six years following impoundment indicated an increase in algal productivity, but not to the level of its predicted concentration. Effluent from wastewater treatment plants in Gainesville and Valley View, TX, influenced productivity in the Elm Fork arm with high concentrations of nutrients, particularly phosphorus and nitrogen. As phosphorus became abundant from loading, resuspension from the sediments, and light limitation (low assimilation), algal productivity became nitrogen limited. High turbidity, algal and nonalgal, may have also limited algal productivity. Higher chlorophyll a concentrations were often localized in the upper Elm Fork arm, indicating some shading effects. High turbidity and solids content were typical in the upper Elm Fork arm. Due to the high loading from the Elm Fork of the Trinity River, in the absence turbid conditions, observed MSE chlorophyll a at a stratified Elm Fork arm may have achieved its predicted concentration. High suspended solids in the Elm Fork arm may have trapped greater concentrations of nutrients than anticipated, diminishing the nutrient load to the rest of Lake Ray Roberts.

Pillard (1988) had predicted that Lake Ray Roberts would be eutrophic. In their chemical and trophic classification of Texas reservoirs, Ground and Groeger (1994) separated the state’s reservoirs into geographical regions of East, West and Central Texas. Lake Ray Roberts was not included in the study but is located in the Central region. Central and West groups of lakes had the highest percentage of oligotrophic lakes. Calcium carbonate (CaCO₃)
precipitate in these regions bind up and coprecipitate phosphorus, depressing algal productivity. Lakes in the central group were also found to have comparably low nitrate concentrations, which resulted in nitrogen limitation.

Elm Fork arm has the greatest potential of becoming problematic and displayed symptoms of cultural eutrophication, with high chlorophyll $a$ and turbidity. A more stringent treatment regime should be applied to wastewater effluent that removes greater concentrations of phosphorus and nitrogen. Costs of implementation would be outweighed by extended life and improved water quality for drinking and recreation, thereby increasing the value of Lake Ray Roberts.
APPENDIX
WATER QUALITY PARAMETER MEANS AND STANDARD DEVIATIONS
MAY-OCTOBER 1993.
Water quality parameters (means and standard deviations) 1993.

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