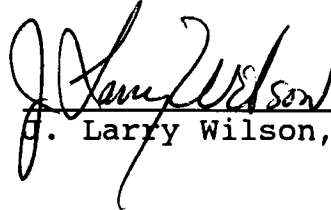


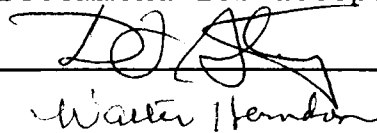
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PHYTOPLANKTON DYNAMICS IN THE MAIN CHANNEL AND EMBAYMENTS  
OF A MAINSTREAM RESERVOIR.

A Thesis  
Submitted for the  
Degree of  
Master of Science  
The University of Tennessee, Knoxville

Tyler F. Baker

December 1993

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## ABSTRACT

Phytoplankton dynamics and related environmental factors at 10 main channel sites and 17 different embayments of a mainstream Tennessee River reservoir were studied for 6 months. Dynamics of 6 main divisions (Chlorophyta, Chrysophyta, Cryptophyta, Cyanophyta, Euglenophyta, and Pyrrophyta) were studied. Main channel phytoplankton productivity and community relationships developed on a continuum from riverine (hydraulic mixing) through transition (available light and nutrients) to lacustrine (nutrient competition) ecosystems. Embayment productivity and composition were highly influenced by nutrient availability (nitrogen and phosphorus). Strong associations among embayment divisions and environmental factors were: 1) cyanophytes, chlorophytes, pyrrophytes and total densities; low  $\text{NO}_2$  and  $\text{PO}_4$ ; watersheds with greater cropland composition; and fish with better health, 2) cryptophytes and euglenophytes; high nutrients; watersheds with greater pastureland composition; lower macrophyte coverage; and lower fish densities; 3) chrysophytes and high total phosphorus; and 4) forestland; lower nutrients; lower phytoplankton productions; increased macrophytes; and higher fish densities. Urban land-use showed no strong association with any other variables.

## TABLE OF CONTENTS

| CHAPTER                                                        | PAGE |
|----------------------------------------------------------------|------|
| I. INTRODUCTION . . . . .                                      | 1    |
| II. DESCRIPTION OF STUDY AREA . . . . .                        | 7    |
| III. METHODS . . . . .                                         | 10   |
| Data Collection . . . . .                                      | 10   |
| Phycological Sampling and Analysis . . . . .                   | 10   |
| Flow Estimations . . . . .                                     | 11   |
| Water Quality Sampling and Analysis . . . . .                  | 12   |
| Bathymetrics . . . . .                                         | 13   |
| Fish Communities Assessments . . . . .                         | 14   |
| Fish Health Assessments . . . . .                              | 14   |
| Aquatic Macrophytes . . . . .                                  | 15   |
| Land Use Classification . . . . .                              | 16   |
| Statistical Analyses . . . . .                                 | 16   |
| Normality . . . . .                                            | 19   |
| Factor Analysis . . . . .                                      | 19   |
| Prediction Models . . . . .                                    | 20   |
| Correlation Analysis . . . . .                                 | 21   |
| IV. RESULTS . . . . .                                          | 22   |
| Factor Analysis With Water Quality Variables . . . . .         | 22   |
| Differences of Water Quality Data Among<br>Locations . . . . . | 22   |
| Water Temperature . . . . .                                    | 22   |
| pH . . . . .                                                   | 24   |
| Turbidity . . . . .                                            | 24   |
| Secchi Disk Transparency . . . . .                             | 27   |
| True Color . . . . .                                           | 27   |
| Nutrients . . . . .                                            | 27   |
| Alkalinity . . . . .                                           | 38   |
| Conductivity . . . . .                                         | 41   |
| Total Organic Carbon . . . . .                                 | 41   |
| Total Hardness . . . . .                                       | 44   |

|                                                                                             |     |
|---------------------------------------------------------------------------------------------|-----|
| Phytoplankton Dynamics . . . . .                                                            | 44  |
| Total Phytoplankton Densities . . . . .                                                     | 44  |
| Chlorophyll <u>a</u> . . . . .                                                              | 47  |
| Correlations Among Divisions . . . . .                                                      | 47  |
| Factor Analysis . . . . .                                                                   | 50  |
| Chlorophyll <u>a</u> Relationships With<br>Phytoplankton and Environmental Factors. . . . . | 58  |
| Relationships Among Fish Parameters,<br>Phytoplankton, and Macrophytes . . . . .            | 59  |
| Relationships Between Macrophytes and<br>Water Quality . . . . .                            | 60  |
| Relationships Between Phytoplankton and<br>Land-Use . . . . .                               | 61  |
| Relationships Between Land-Use and<br>Environmental Factors . . . . .                       | 62  |
| V. DISCUSSION . . . . .                                                                     | 64  |
| VI. SUMMARY . . . . .                                                                       | 82  |
| Literature Cited . . . . .                                                                  | 86  |
| APPENDIXES . . . . .                                                                        | 93  |
| A. Mean Phytoplankton Division Densities . . . . .                                          | 94  |
| B. Estimated Creek Flows For Embayments . . . . .                                           | 96  |
| C. Main Channel Cross-Sectional Areas . . . . .                                             | 98  |
| D. Data Obtained From Chickamauga Reservoir<br>Embayment Study-1990 (TVA 1992) . . . . .    | 100 |
| VITA . . . . .                                                                              | 106 |

## LIST OF FIGURES

| FIGURE                                                                                                                                       | Page |
|----------------------------------------------------------------------------------------------------------------------------------------------|------|
| 1. Chickamauga Reservoir, Tennessee, and<br>Sampling Locations . . . . .                                                                     | 8    |
| 2. Mean water temperature (C) at the 1-m depth<br>in Chickamauga Reservoir, April through<br>September 1990 . . . . .                        | 23   |
| 3. Mean Ph levels at the 1-m depth in Chickamauga<br>Reservoir, April through September 1990 . . . .                                         | 25   |
| 4. Mean turbidity (NTU) at the 1-m depth in<br>Chickamauga Reservoir, April through<br>September 1990 . . . . .                              | 26   |
| 5. Mean Secchi disk transparency at the 1-m depth<br>in Chickamauga Reservoir, April through<br>September 1990 . . . . .                     | 28   |
| 6. Mean true color (PCU) at the 1-m depth in<br>Chickamauga Reservoir, April through<br>September 1990 . . . . .                             | 29   |
| 7. Mean nitrite+nitrate nitrogen concentrations<br>(mg/l) at the 1-m depth in Chickamauga<br>Reservoir, April through September 1990 . . . . | 30   |
| 8. Mean ammonia nitrogen concentrations (mg/l) at<br>the 1-m depth in Chickamauga Reservoir, April<br>through September 1990 . . . . .       | 31   |
| 9. Mean organic nitrogen concentrations (mg/l)<br>at the 1-m depth in Chickamauga Reservoir,<br>April through September 1990 . . . . .       | 33   |
| 10. Mean total nitrogen concentrations (mg/l) at<br>the 1-m depth in Chickamauga Reservoir,<br>April through September 1990 . . . . .        | 34   |
| 11. Mean orthophosphate concentrations (mg/l) at<br>the 1-m depth in Chickamauga Reservoir,<br>April through September 1990 . . . . .        | 36   |
| 12. Mean total phosphorus concentrations (mg/l)<br>at the 1-m depth in Chickamauga Reservoir,<br>April through September 1990 . . . . .      | 37   |

|     |                                                                                                                                                                                      |    |
|-----|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| 13. | Mean total nitrogen / total phosphorus ratios<br>at the 1-m depth in Chickamauga Reservoir,<br>April through September 1990 . . . . .                                                | 39 |
| 14. | Mean alkalinity (mg/l) at the 1-m depth in<br>Chickamauga Reservoir, April through<br>September 1990 . . . . .                                                                       | 40 |
| 15. | Mean conductivity ( $\mu$ mhos/cm) at the 1-m<br>depth in Chickamauga Reservoir, April<br>through September 1990 . . . . .                                                           | 42 |
| 16. | Mean total organic carbon (mg/l) at the 1-m<br>depth in Chickamauga Reservoir, April<br>through September 1990 . . . . .                                                             | 43 |
| 17. | Mean total hardness concentrations<br>(mg/l as $\text{CaCO}_3$ ) at the 1-m depth in<br>Chickamauga Reservoir, April through<br>September 1990 . . . . .                             | 45 |
| 18. | Mean total phytoplankton densities (cells/l)<br>at the 1-m depth in Chickamauga Reservoir,<br>April through September 1990 . . . . .                                                 | 46 |
| 19. | Mean chlorophyll <u>a</u> concentrations ( $\text{mg/m}^3$ ) at<br>the 1-m depth in Chickamauga Reservoir,<br>April through September 1990 . . . . .                                 | 48 |
| 20. | Factor patterns for factor 1 and factor 2 of<br>mean phytoplankton division densities at<br>the 1-m depth in Chickamauga Reservoir<br>embayments, April through September 1990 . .   | 52 |
| 21. | Factor patterns for factor 1 and factor 3 of<br>mean phytoplankton division densities at<br>the 1-m depth in Chickamauga Reservoir<br>embayments, April through September 1990 . .   | 54 |
| 22. | Factor patterns for factor 1 and factor 2 of<br>mean phytoplankton division densities at<br>the 1-m depth in Chickamauga Reservoir's<br>main channel, April through September 1990 . | 57 |
| 23. | Factor patterns of mean phytoplankton division<br>densities in Chickamauga Reservoir's main<br>channel with riverine, transition, and<br>lacustrine classification . . . . .         | 67 |

## CHAPTER I

### INTRODUCTION

Our water resources have suffered degradation from mans cultural expansion and is subject to increasing demand for industrial and municipal supply, recreation and other human related activities. Fostered by the concern for water quality, it has become imperative that management strategies for many resources incorporate objectives conducive to good water quality. Such objectives must address several disciplines which in themselves directly or indirectly address the complex problems associated with chemical and biological limnology.

Two facets germane to chemical and biological limnology are phytoplankton and cultural eutrophication. Phytoplankton, as primary producers, provide energy upon which much of the aquatic ecosystem depends and directly influence water quality parameters (dissolved oxygen, pH, relative proportions of nutrient forms, water clarity). Cultural eutrophication refers to excessive anthropogenic nutrient loadings which are commonly manifested in large increased phytoplankton standing crops.

Developing a better understanding of the processes involved in a changing environment, from oligotrophic to eutrophic to possibly hypo-eutrophic, is desired for making better water management decisions. A better

understanding of environmental factors governing phytoplankton productivity and composition is important to understanding the process of eutrophication.

Several factors have been identified as having influenced phytoplankton dynamics. Some of these include factors or a combination of factors such as temperature and temperature/nutrient interactions (Taylor et al. 1980, Erga 1989), pH/carbon (King 1970, Talling 1976), mixing depth (Grobbelaar 1990) mixing and available phosphate and nitrate (Haertel 1976, Moss and Balls 1989), nitrogen/nitrogen limitation (Canfield et al. 1985, Sterner 1989), utilization of different nitrogen compounds (Syrett 1962), total nitrogen and total phosphorus (Soballe and Kimmel 1987), light and nutrients (Rhee and Gotham 1981), water residence time and/or flow (Soballe and Kimmel 1987, Sabater and Munoz 1990), depth (Duarte and Kalff 1989), turbidity (Schwartzkopf and Hergenrader 1978) and many others. Although these factors are important to the phytoplankton dynamics in rivers, reservoir and lakes, their degree of importance in each system type is not the same. Phytoplankton dynamics within rivers are more controlled by the physical factors, while lakes are more controlled by nutrient factors. However, given reservoirs constitute a majority of the large bodies of water in the Southeast, the hydrodynamics of these systems must be considered before interpreting

the relationships of biological and chemical factors. Reservoirs have been described as "river-lake hybrids" because they possess characteristics of both rivers and lakes in morphologic and hydrologic characteristics, and internal and external nutrient cycles (Kimmel et al. 1990). These characteristics are often manifested along an interacting continuum from riverine ecosystems through transition to lacustrine ecosystems where cause/effect relationships have the potential to become more complex than those of natural systems.

Several studies within Tennessee Valley reservoirs have acknowledged the importance of flow in phytoplankton dynamics. Wade (1984) studied phytoplankton dynamics in the main channel forebay of Wilson Reservoir on the Tennessee River and found that seasonal increases in phytoplankton production and changes in community composition were related to the interaction of lower flows and increased retention time with increased solar radiation, temperature, and changes in nutrient levels. Peterson and Stevenson (1989) compared seasonal changes in phytoplankton assemblages among four Ohio River sites and six Ohio River tributaries. Discharge was one of the important parameters in determining among river and seasonal patterns in algal abundance. Studies conducted on Guntersville Reservoir on the Tennessee River (TVA 1985) acknowledged the effects of flow on phytoplankton

abundance and community composition. Main channel stations were more similar in community structure than overbank stations, but main channel stations had lower phytoplankton abundance. The low degree of similarity among overbank stations was the result of flow isolation which allowed development of distinct and separate communities, whereas, channel stations were contiguous with regard to flow. Greater phytoplankton abundance for the overbank habitat was also attributed to the lower flows. Trophic state evaluations of several TVA tributary and mainstem reservoirs led to the development of two different indices due to the predominant effects of hydraulics on phytoplankton productivity within the mainstem reservoirs, while productivity was more nutrient regulated in tributary reservoirs (Cox 1991).

Reservoir embayments add another dimension to the complexity of reservoir dynamics. Embayments tend to be hydrologically isolated from the main channel. Water exchange is more a function of water level fluctuations due to power production or mosquito control (for TVA reservoirs). Embayments are generally more shallow with longer detention times and less hydraulic mixing when compared to the main channel. Consequently, embayments have the potential to exhibit more extreme responses to pollutant loadings and changes in land use than the main channel region (Butkus 1989). Embayments can also become

dominated by extensive macrophyte and associated epiphyte communities. The relative contribution of these primary producers to the overall productivity in reservoirs is undetermined.

Reservoir phytoplankton dynamics from headwaters to forebay and within embayments provides a complex system of interrelating factors which need to be addressed in order to understand the biological productivity of these systems. The Tennessee Valley Authority (TVA) initiated a project in 1990 to assess physical, chemical, and biological conditions within the embayments and main channel of Chickamauga Reservoir (TVA 1992). Several disciplines (fish abundance and health, aquatic macrophyte abundance and diversity, physical/chemical characteristics of water and sediments, land-use characteristics and nutrient load estimates, and phytoplankton communities) were addressed.

The present study assesses the relationships of the phytoplankton community to some of the physical, chemical and biological parameters collected in conjuncture with the Chickamauga Reservoir Embayment Study-1990 (TVA 1992). The author performed the phycological sampling and subsequent lab analysis. The primary objective of this study was to determine: 1) environmental factors most prevalent in determining phytoplankton structure and productivity; 2) land-use relationships to phytoplankton

structure and productivity; and 3) fish community relationships to phytoplankton structure and productivity.

## CHAPTER II

### DESCRIPTION OF THE STUDY AREA

Chickamauga Reservoir was formed by the 1940 closure of Chickamauga Dam at Tennessee River Mile (TRM) 471. The reservoir extends 94.8 km from Chattanooga, Tennessee, north to Watts Bar Dam (Figure 1). The reservoir has a major arm formed by the confluence with the Hiwassee River at TRM 499.4. Pool elevation normally varies from 205.9 m mean sea level (msl) in winter to 208.2 m msl in the summer. The reservoir volume is normally  $462.8 \times 10^6 \text{ m}^3$  during winter and increases to  $907 \times 10^6 \text{ m}^3$  at full pool with a mean depth of 6.1 m and a maximum depth of 24.1 m at the dam. At full pool, the reservoir surface area is  $143.3 \times 10^6 \text{ m}^2$  and has 1303.3 km of shoreline. In accordance with the TVA Act of 1933, the project is managed for the primary purposes of navigation, flood control, and power production.

Chickamauga Reservoir was sampled at 30 different locations consisting of 10 main channel sites and 20 embayment sites (Figure 1). Seven main channel sites were located on the Tennessee River arm of the reservoir (TRM 472.3, 478.2, 490.5, 496.5, 506.5, 518.0, and 529.9) and 3 were located on the Hiwassee River arm of the reservoir (HRM 7.4, 13.4, and 20.0). Embayment sites consisted of 14 embayments located on the Tennessee River arm (Waconda Bay 2.9, Wolftever Creek 4.1, Wolftever Creek 5.5,

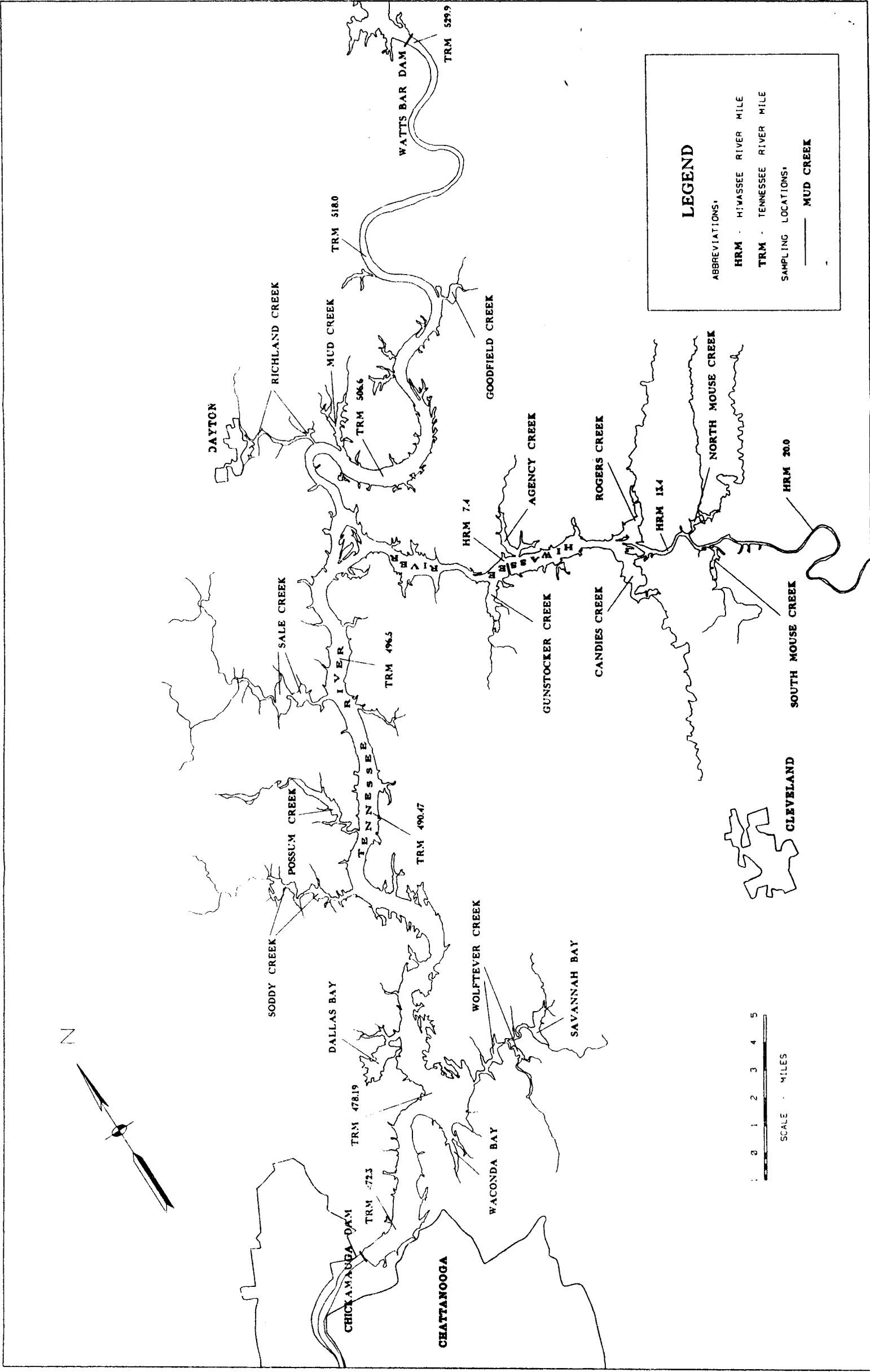


Figure 1. Chickamauga Reservoir, Tennessee, and Sampling Locations.

Savannah Bay 2.9, Dallas Bay 1.5, Soddy Creek 1.7, Soddy Creek 4.0, Possum Creek 2.0, Sale Creek 1.3, Sale Creek 2.0, Richland Creek 0.5, Richland Creek 2.9, Mud Creek 1.0, and Goodfield Creek 1.0) and 6 embayments located on the Hiwassee River arm (Gunstocker Creek 1.0, Agency Creek 1.5, Rogers Creek 1.5, Candies Creek 1.5, North Mouse Creek 0.5, and South Mouse Creek 1.1).

## CHAPTER III

### METHODS

#### DATA COLLECTION

##### Phycological Sampling and Analysis

Sampling was conducted biweekly by the author from 5 April 1990 to 11 September 1990 at locations shown in Figure 1. Samples were collected over the original river or creek channel by use of a low volume 12-V peristaltic pump with attached hose. A single 1.0-L sample was collected from the 1.0-m depth at each station for phytoplankton enumeration and phytopigment concentrations. All samples remained in the dark on ice until laboratory processing.

One-liter samples were processed after returning to the laboratory. Approximately 100 ml of sample were placed in a 125 ml brown Nalgene container and preserved with 2 ml of M<sup>3</sup> solution (iodine, glacial acetic acid, and formalin). The remaining sample received 1 ml of magnesium carbonate suspension. A 500 ml sample was then filtered through a Whatman 0.45-micron glass-fiber filter with pressure not exceeding 15 psi. Each filter was placed in a light-excluding test tube with 5.0 ml of 90% buffered acetone and frozen until laboratory analysis.

Phytoplankton enumeration samples were agitated and a 5 or 10 ml aliquot was poured into a Uttermohl counting chamber and allowed to settle for 12 hours. Algal cells

were enumerated at the generic level by counting every cell within a 40X field for one pass across the chamber. Conversion factors of 10,191 or 5,096 were used to obtain cells/L for 5 and 10 ml aliquots, respectively.

Phytopigment (chlorophyll a) samples were allowed to reach room temperature, ground with a glass rod, and subjected to ultrasonic vibrations to rupture algae cell walls. Samples were then clarified by centrifugation and analyzed spectrophotometrically. Optical densities at 750, 664, 647, and 630 nm were read. Each sample was then acidified with two drops of 0.1 n HCL, allowed to steep for one minute, then reread at 750 and 664 nm. Chlorophyll a, b, and c and phaeophytin a concentrations were calculated using Jeffery-Humphery (1975) equations for the chlorophylls and the Lorenzen (1967) equations for phaeophytin a.

#### Flow Estimations

##### Embayments

The embayment flows were estimated based on a  $\text{m}^3/\text{sec}/\text{km}^2$  calculation (Appendix B). The following streamgages were used for this determination: Sewee Creek, located near Decatur Tennessee and flowing into Chickamauga Reservoir, and South Chickamauga Creek, located just south of Chickamauga Dam and flowing into Nickajack Reservoir. Average annual flow for each creek

was divided by total drainage area ( $\text{km}^2$ ) to yield flows based on a  $\text{m}^3/\text{sec}/\text{km}^2$  calculation. The calculated water yields for South Chickamauga and Sewee Creek were averaged. The average water yield was then multiplied by the drainage areas ( $\text{km}^2$ ) for each of the 17 study embayments to obtain estimates of average annual flow.

#### Main Channel

Flow in terms of  $\text{m}^3/\text{sec}$  was not used in this study, the reason being that  $\text{m}^3/\text{sec}$  represents volume of flow irrespective of channel morphology. Therefore, potential hydraulics (turbulence) are not considered in this form of measure. TVA's Engineering Division provided the cross-sectional areas of each sample site within the main channel (Appendix C).

Data for water quality, bathymetrics, fish communities assessments, fish health assessments, aquatic macrophytes, and land use classifications (Appendix D) were obtained from TVA's Chickamauga Reservoir Embayment Study-1990 (C.R.E.S.) (TVA 1992). A brief description of these collection methodologies follows.

#### Water Quality Sampling and Analysis

Water quality surveys were conducted by TVA (1992) monthly (April through September 1990) at locations shown in Figure 1. All samples and measurements were taken over the original river or creek channel. Single in situ

measurements of temperature, pH, dissolved oxygen (DO), and conductivity were made at the 1-m depth with a Hydrolab Surveyor II (Hydrolab Corporation. Austin, Texas) and Secchi disk transparency recorded for each site. Single samples for orthophosphate, total phosphorus, nitrate plus nitrite nitrogen, ammonia nitrogen, organic nitrogen, total and soluble organic carbon, suspended solids, total hardness, true and apparent color, turbidity and alkalinity were collected from the 1-m depth with a 8-L Van Dorn sampler. Grab samples were collected from the surface for fecal coliform analysis. All samples remained in the dark on ice for transport to the laboratory.

Water quality measurements, sample collections, and sample handling followed standard practices accepted by the Environmental Protection Agency (EPA 1979, and 40 CFR 136), US Geological Surveys (USGS 1977), and American Public Health Association (AWWA, WPCF, APHA 1989) as specified in TVA quality assurance/quality control (QA/QC) procedures (TVA 1987,1990). Laboratory analysis conformed to established QA/QC procedures (TVA 1989).

### Bathymetrics

Bathymetric data were collected by use of hydroacoustic survey equipment. The method involves suspending an acoustic transmitter-receiver just below the water surface from a boat equipped with appropriate

data logging equipment (BioSonics 1988). In each embayment, diagonal (zig-zag) transects are made at a constant speed. The result is a well-defined acoustic echo representing the bottom of the body of water. Calibration tests revealed the depth sounding precision of the signal to be approximately 0.05 +/- feet (Stone and Tschantz 1991). Golden Software's SURFER (1990) was used to compute surface areas and volumes at one foot increments from the bottom of each embayment to the normal summer pool level of 683.0 msl.

#### Fish Communities Assessments

The fish community assessment was done in conjuncture with the bathymetrics survey in August 1990. Mobile hydroacoustics techniques were used to estimate fish densities (fish/m<sup>3</sup> of water) and to approximate the average fish size (length in cm) in each of the study embayments.

#### Fish Health Assessments

Fish health was assessed using a TVA modified Fish Health Assessment Index (FHAI). Largemouth bass (Micropterus salmoides) were selected as a representative species of warmwater fish because of their ease of capture and position in the food chain as top predator. The FHAI consisted of an autopsy observation of 15 external and

internal conditions (liver, spleen, kidney, parasites, hematocrit, etc.) on each of the 15 individual fish (greater than 250 mm total length) in each embayment. Results were tabulated and a relative numerical FFAI value was calculated for each embayment. This index value is inversely related to the health of the fish. Therefore, a fish with a relatively high index is in poorer health. Fish were collected with standard reservoir electrofishing equipment and transported to a mobile laboratory for immediate examination.

#### Aquatic Macrophytes

Aquatic macrophyte coverage was determined using color aerial photographs taken in late summer or early autumn. Aerial photography was acquired from a Beechcraft Aerocommander. The processed negative film was inspected and appropriate prints made to allow coverage of each Chickamauga Reservoir embayment. A transparent mylar overlay was attached to each print. Matchpoints were determined on sequential photographs to avoid overlap on the acreage determinations. The aquatic plant colonies were delineated on the mylar overlay and species determinations were checked for consistency and accuracy with ground truth information.

## Land Use Classification

SPOT (1989) imagery, acquired 6 September 1986, was used to classify land use within each of the Chickamauga Reservoir embayment watersheds. Computer-aided land use classification techniques (ERDAS 1990) were employed, with the following qualifications. Three watersheds (Rogers Creek, North Mouse, and South Mouse) were not covered in the September 1986 SPOT imaging and were consequently classified manually using National High Altitude Photography (NHAP 1983) flown between 1981 and 1985. In addition, SPOT imagery did not provide adequate resolution to allow classification of agricultural lands into cropland (cultivated) and pasture (non-cultivated). Consequently, in each watershed, the proportion of crop and pasture land for those parcels classified as agriculture was provided by the Soil Conservation Service, based on the 1987 National Resources Inventory (NRI 1987).

## STATISTICAL ANALYSIS

The present study examines whole system phytoplankton dynamics of a single reservoir and was done in conjuncture with the Chickamauga Reservoir Embayment Study-1990 (TVA 1992). Chickamauga Reservoir was sampled at 30 different locations consisting of 20 embayment and 10 main channel sites (Figure 1). Phycological variables were collected on a biweekly basis (11 sample dates) while 21 water

quality measurements were made once each month for six months. Land-use, morphometrics, macrophyte, fish community and fish health data were collected only once during the course of the study. The author acknowledges the importance of the complex interactions which operate at both the spatial and temporal scale to influence phytoplankton dynamics, but further acknowledges the present sampling regime as inadequate to properly interpret complex temporal interactions given the limited number of samples during the 6 month period. This limitation could obscure true interactions and yield statistical relationships untrue of real cause and effect relationships. Therefore, broad scale spatial comparisons were made by averaging all variables by site, revealing predominant whole system interactions less affected by the present sampling regime.

Soddy, Sale, and Richland Creek embayments were sampled at two sites. The two sites were combined into a single average for those embayments. The Wolftever sites remained separate because Wolftever 4.1 is below the confluence of the Savannah Bay drainage.

Data analyses including normality, factor analysis, prediction models, and correlation analysis were conducted with PCSAS (SAS Institute 1987) and are detailed in the following sections. Significant levels for all analysis were set at  $\alpha=0.05$ . Tables and graphics were accomplished

with Amipro word processing and Lotus Freelance Plus software (Lotus Development Corporation 1989). The following defines symbols given to the multiple variables used in the analyses, graphs, and tables.

### Phytoplankton

|                             |        |              |         |
|-----------------------------|--------|--------------|---------|
| Chlorophyta                 | CHLORO | Cyanophyta   | CYANO   |
| Chrysophyta                 | CHRYSO | Euglenophyta | EUGLENO |
| Cryptophyta                 | CRYPTO | Pyrrophyta   | PYRRO   |
| Total Phytoplankton Density | TOTAL  |              |         |

### Water Quality Variables

|                          |          |                          |          |
|--------------------------|----------|--------------------------|----------|
| Temperature              | TEMP     | Total Phosphorus         | TOT_P    |
| pH                       | pH       | Orthophosphate           | ORTHO    |
| Dissolved Oxygen         | DO       | Total Nitrogen           | TOT_N    |
| Conductivity             | COND     | Organic Nitrogen         | ORGANIC  |
| Secchi Disk Transparency | SECCHI   | Ammonia Nitrogen         | NH3      |
| Total Hardness           | TOT_HARD | Nitrite+Nitrate Nitrogen | NH2      |
| Alkalinity               | ALK      | Total Nitrogen/          |          |
| Turbidity                | TURB     | Total Phosphorus Ratio   | TN/TP    |
| Suspended Solids         | SS       | Soluble Organic Carbon   | SOC      |
| Aparent Color            | AP_CLR   | Total Organic Carbon     | TOC      |
| True Color               | TRU_CLR  | Fecal Coliform           | FEC_COLI |

### Fish Community

|                                     |         |
|-------------------------------------|---------|
| Fish Density                        | DENSITY |
| Fish Size (length)                  | SIZE    |
| Fish Health Assessment Index (FHA1) | HEALTH  |

### Land-Use Classifications

|                     |         |
|---------------------|---------|
| Percent Urban       | URBAN   |
| Percent Cropland    | CROP    |
| Percent Pastureland | PASTURE |
| Percent Forestland  | FOREST  |

### Other Variables

|                                     |        |
|-------------------------------------|--------|
| Percent Aquatic Macrophyte Coverage | %MACRO |
| Creek Flow into Embayment           | FLOW   |
| Average Depth                       | DEPTH  |
| Detention Time                      | DENT   |
| Cross-Sectional Area                | X-AREA |

## Normality

Data normality was examined using the SAS univariate procedure. All variables pertaining to this study were checked for normality. The SAS univariate procedure was applied to each variable over the total study period. Algal abundance data were converted from the initial cells/L to cells/ml and a logarithmic transformation was used to reduce the range in cell counts and establish an approximately normal distribution. All water quality variables, land-use, macrophyte, fish community and fish health variables, with the exception of temperature, pH, and DO, were log-transformed to help establish an approximately normal distribution.

## Factor Analyses

Multivariate statistical techniques were used to elucidate complex associations among algal populations and their physical and chemical environment. Chronological grouping of algae by division and factor analysis with orthogonal rotation (Varimax option) were used to generate factor scores for each site. Factor analysis was done with two different site groupings; 1) embayments and 2) main channel. Embayment and main channel sites were separated to allow inherent differences in the affects of hydraulic mixing (flow vs. cross-sectional area) to be removed thereby allowing for better separation among sites

and providing models more representative of true cause and effect relations. Factor scores were plotted for visual reference of similarities and differences among sample sites.

The 21 water quality variables were subjected to factor analysis and common factors rotated by an orthogonal transformation. This was done separately for embayments and main channel sites. Variables were then eliminated based on the weights across factors and/or strong correlations among like measurements.

#### Prediction Models

Relationships between dependent variables and the remaining water quality variables were examined using the Stepwise Procedure with the MAXR option. This procedure selects a subset of the water quality (independent) variables to produce discrimination models which maximize the coefficient of determination. Variables are selected and/or removed based on their contribution to the discriminatory power of the model at each step of adding another variable.

Models were constructed for embayments and main channel separately. Models for phytoplankton factors and macrophytes were constructed.

## Correlation Analyses

Correlation analyses using Pearson Correlation Coefficients were done to reveal pertinent information aiding in the interpretation of the data. Data were separated by classification of embayment or main channel sites. Correlation analyses included the means for 21 water quality variables, 5 physical variables, mean density of phytoplankton divisions, mean total density, and factors for phytoplankton divisions.

## CHAPTER IV

### RESULTS

#### FACTOR ANALYSIS WITH WATER QUALITY VARIABLES

Factor analysis for water quality variables revealed strong correlation between AP\_CLR and TRU\_CLR, SOC and TOC, and SS and TURB across all factors. The variables TRU\_CLR, TOC, and TURB received stronger weighing and were maintained. AP\_CLR, SOC, and SS were removed. DO was removed because it was not considered as a growth controlling variable. Water quality variables TEMP, pH, ALK, COND, TOT\_HARD, TURB, TRU\_CLR, TOC, TOT\_P, ORTHO, ORGAN, NH3, NO2, TOT\_N, and FEC\_COLI were chosen for further statistical analysis.

#### DIFFERENCES OF WATER QUALITY DATA AMONG LOCATIONS

##### Water Temperature

Water temperatures ranged from 11.9 to 30.2 C during the study period. The highest temperatures occurred in July with Dallas Bay reaching 30.2 C and HRM 20 reaching a high of only 20.7 C. These locations also represented a range in mean water temperatures from 18.6 to 24.7 C (Figure 2). Embayments had higher mean temperatures than the main channel. Main channel sites of the Tennessee arm of the reservoir had higher mean temperatures than the Hiwassee arm; similarly, the Tennessee embayments had higher mean temperatures than Hiwassee embayments. Main

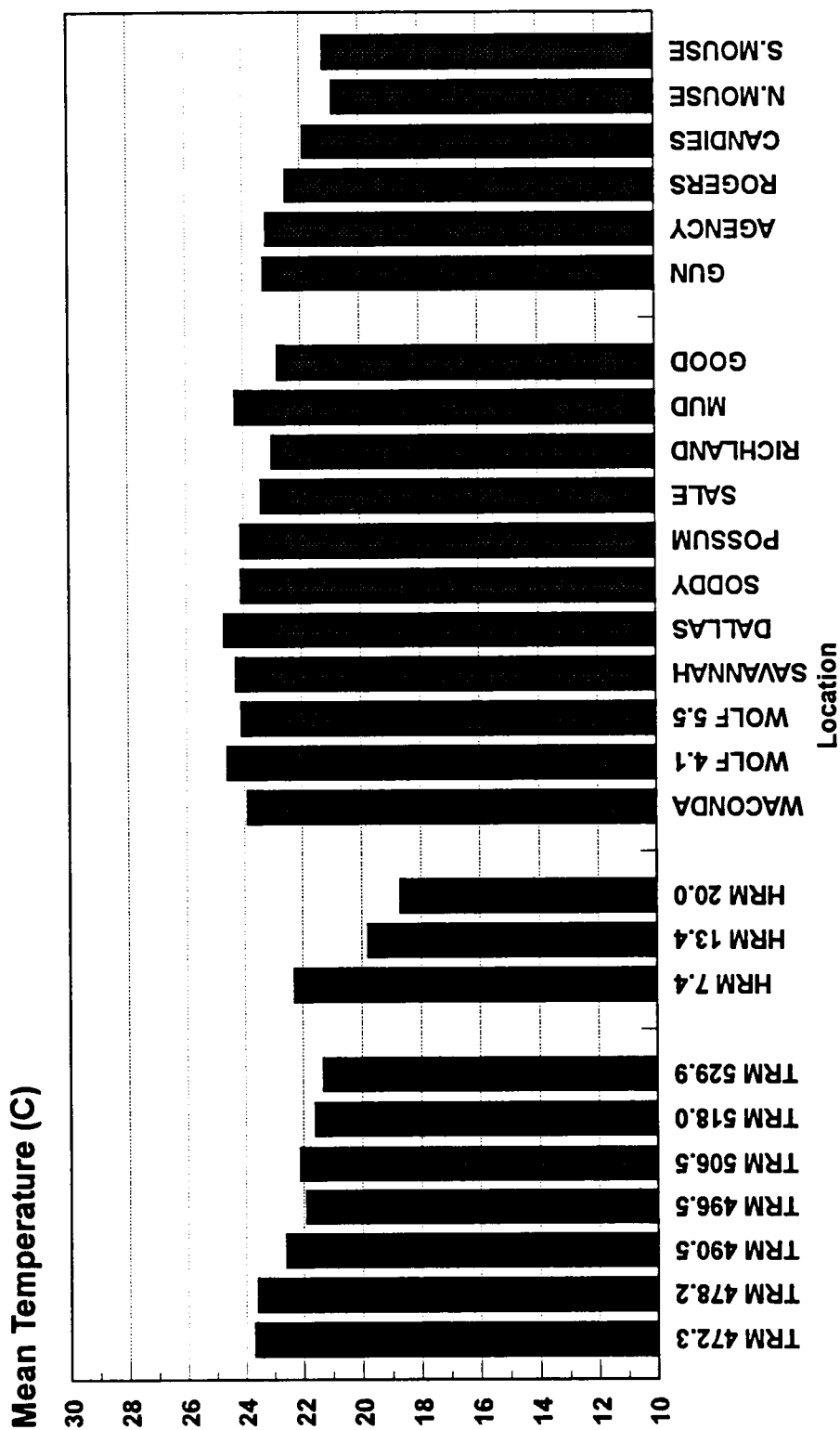


Figure 2. Mean water temperatures (C) at the 1-m depth in Chickamauga Reservoir, April through September 1990.

channel sites for both the Tennessee and Hiwassee Rivers exhibited a progressive increase in temperature from upstream to downstream. Mean water temperature at TRM 496.5 may have been reduced due to the confluence of the Hiwassee river at TRM 499. The same upstream to downstream temperature increase was evident among Hiwassee embayments, but not among Tennessee embayments.

#### pH

Values for pH ranged from 6.8 to 8.8 for the six-month study. Mean pH values ranged from 7.33 to 8.33 and were lower in the Main channel than in embayments, while Hiwassee embayments had lower mean values than the Tennessee embayments (Figure 3).

#### Turbidity

Turbidity ranged from 1.0 to 88.0 NTU for the study period. The lowest turbidities occurred in Soddy, Sale, and Possum embayments while the highest turbidity occurred in South Mouse Creek. Likewise, Soddy, Sale, and Possum had the lowest mean turbidities with 2.6, 2.9, and 2.2 NTU, respectively, and South Mouse had the highest mean turbidity with 37.7 NTU (Figure 4). HRM sites had higher mean turbidities than TRM sites; turbidities were generally high in the Hiwassee embayments and variable among the Tennessee embayments.

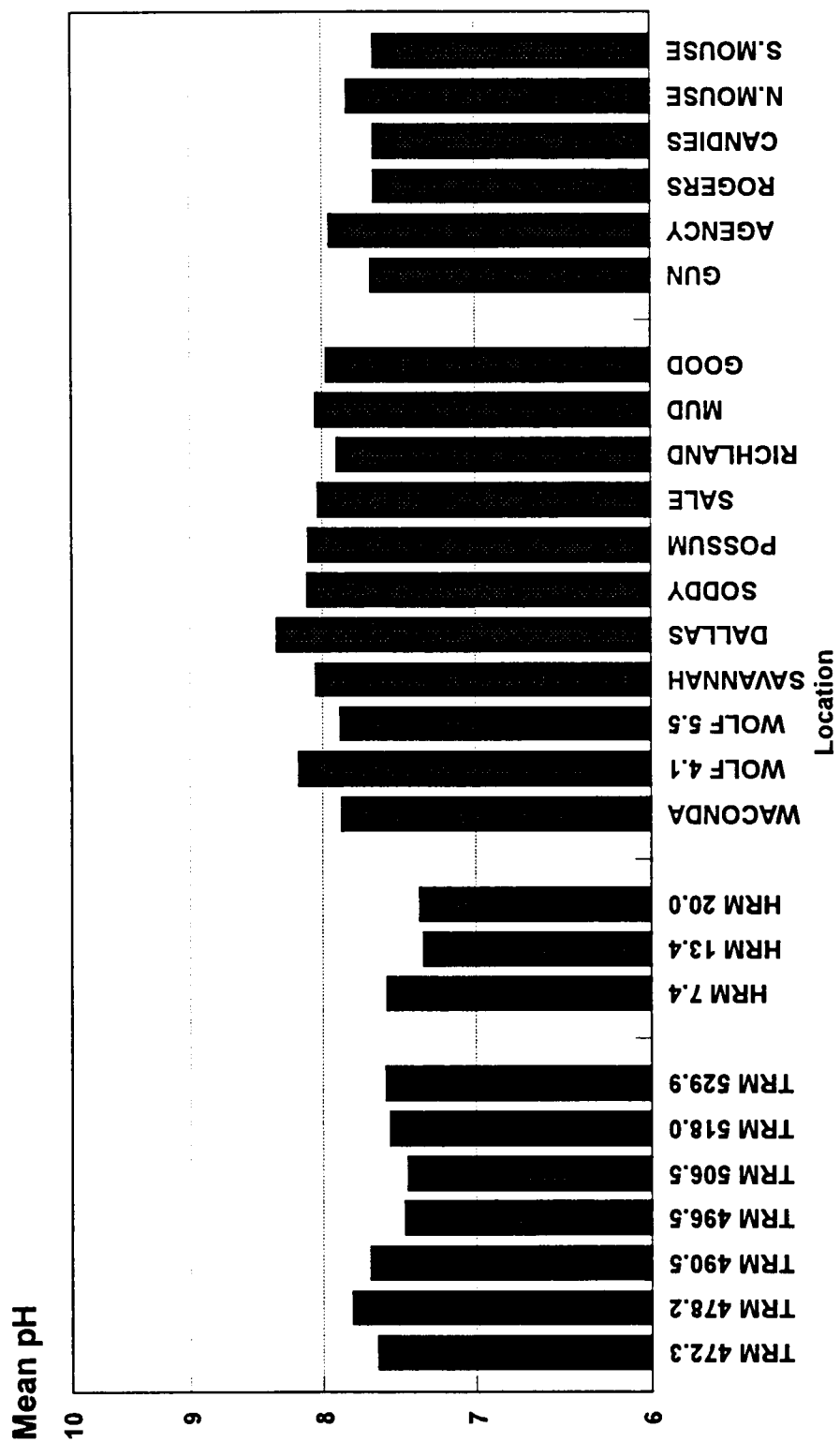


Figure 3. Mean pH levels at the 1-m depth in Chickamauga Reservoir, April through September 1990.

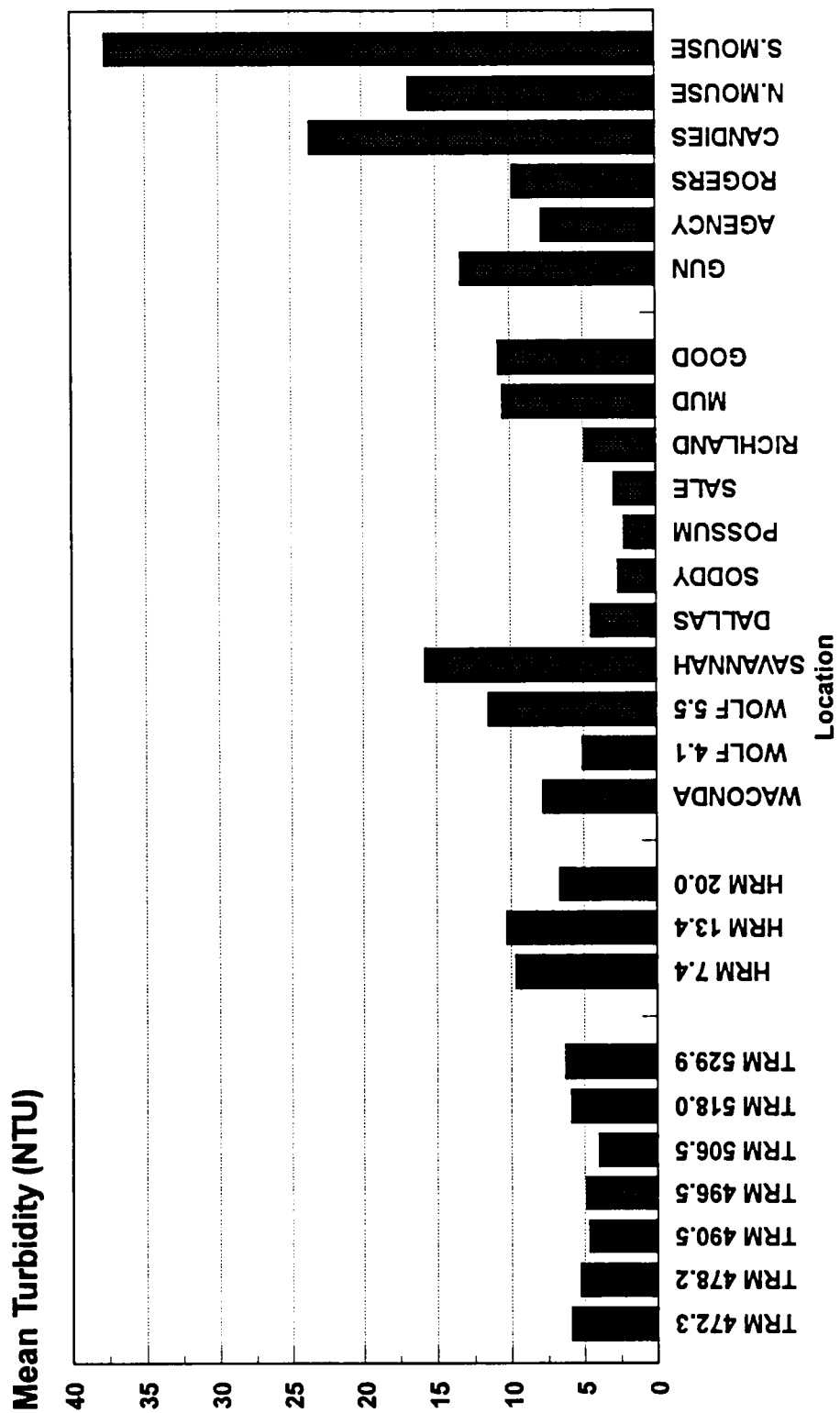


Figure 4. Mean turbidity (NTU) at the 1-m depth in Chickamauga Reservoir, April through September 1990.

## Secchi Disk Transparency

Mean Secchi disk transparency (Secchi depth) ranged from 0.36 to 1.8 m at South Mouse and Possum Creeks, respectively (Figure 5). Secchi depth showed an increasing trend from upstream to downstream for Hiwassee embayments. HRM sites showed a decrease with substantial decreases occurring from HRM 20 to HRM 13.4. Possum and Sale Creeks had the highest values among embayments while TRM 506 was highest within the main channel.

## True Color

Mean true color ranged from 10.2 at TRM 518 to 59.2 at South Mouse Creek (Figure 6). Hiwassee sites had greater mean true color than Tennessee sites and showed a upstream/downstream decrease in color. Main channel sites had a upstream/downstream trend of increasing color.

## Nutrients (Nitrogen and Phosphorus)

Mean nitrite plus nitrate nitrogen ( $\text{NO}_2 + \text{NO}_3$ ) concentrations ranged from 0.02 to 0.34 mg/l (Figure 7). As a group, the main channel sites had greater mean concentrations than embayments with a general decreasing trend from upstream to downstream.

Mean ammonia nitrogen ( $\text{NH}_4^+$ ) concentrations ranged from 0.01 to 0.08 mg/l (Figure 8) and were lower for embayment sites than for main channel sites. A

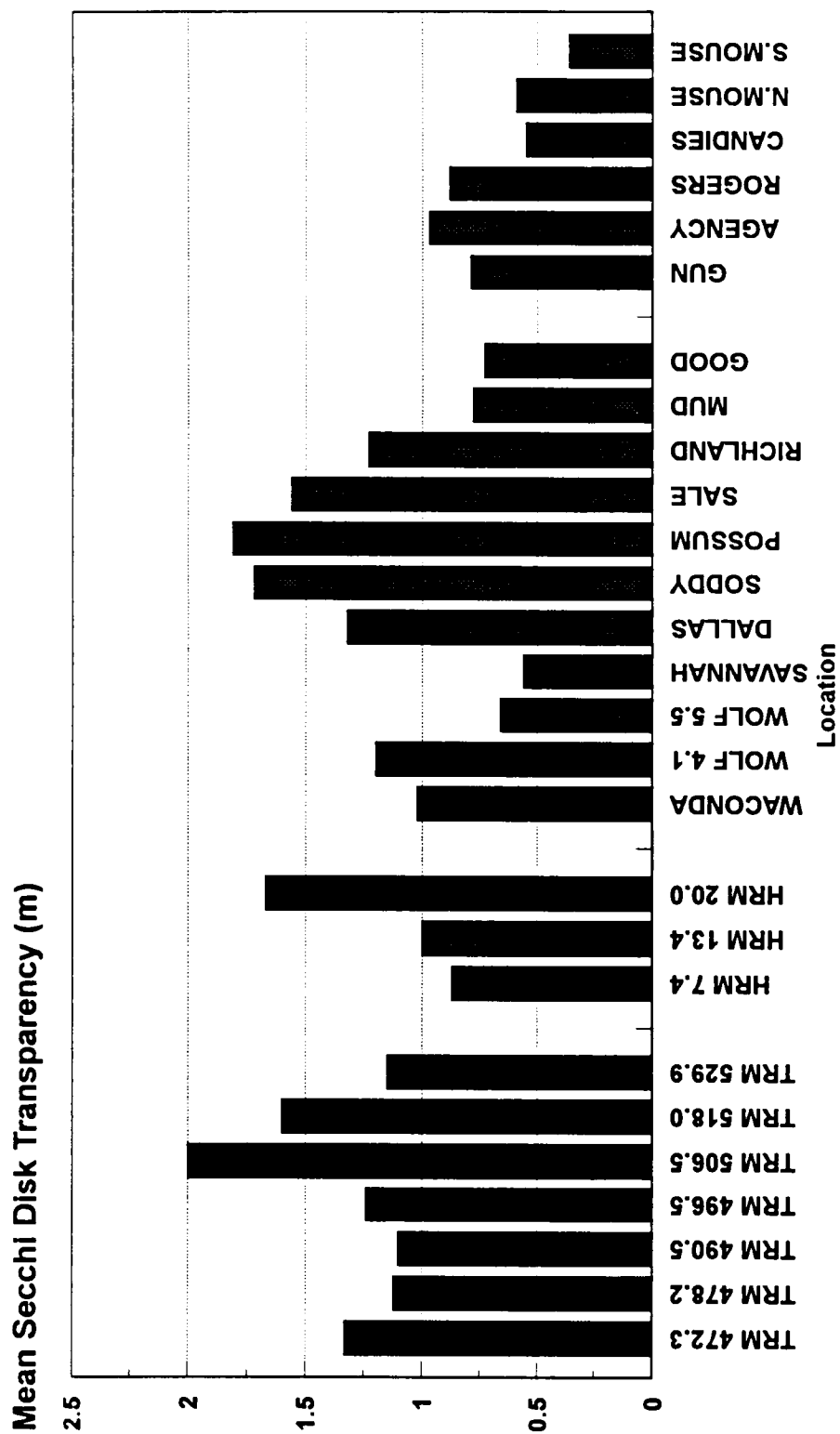


Figure 5. Mean Secchi disk transparency (m) in Chickamauga Reservoir, April through September 1990

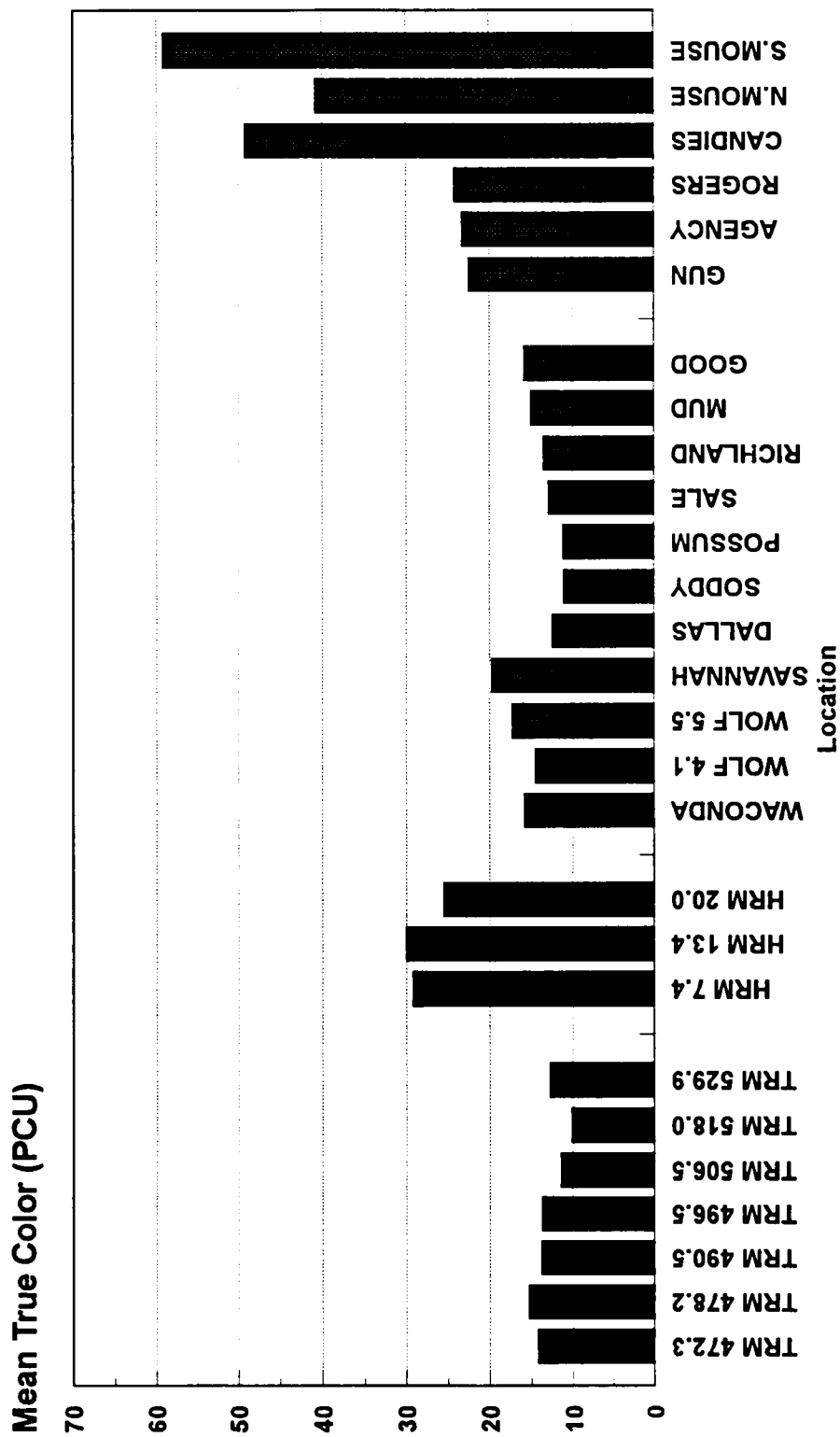


Figure 6. Mean true color (PCU) at the 1-m depth in Chickamauga Reservoir, April through September 1990.

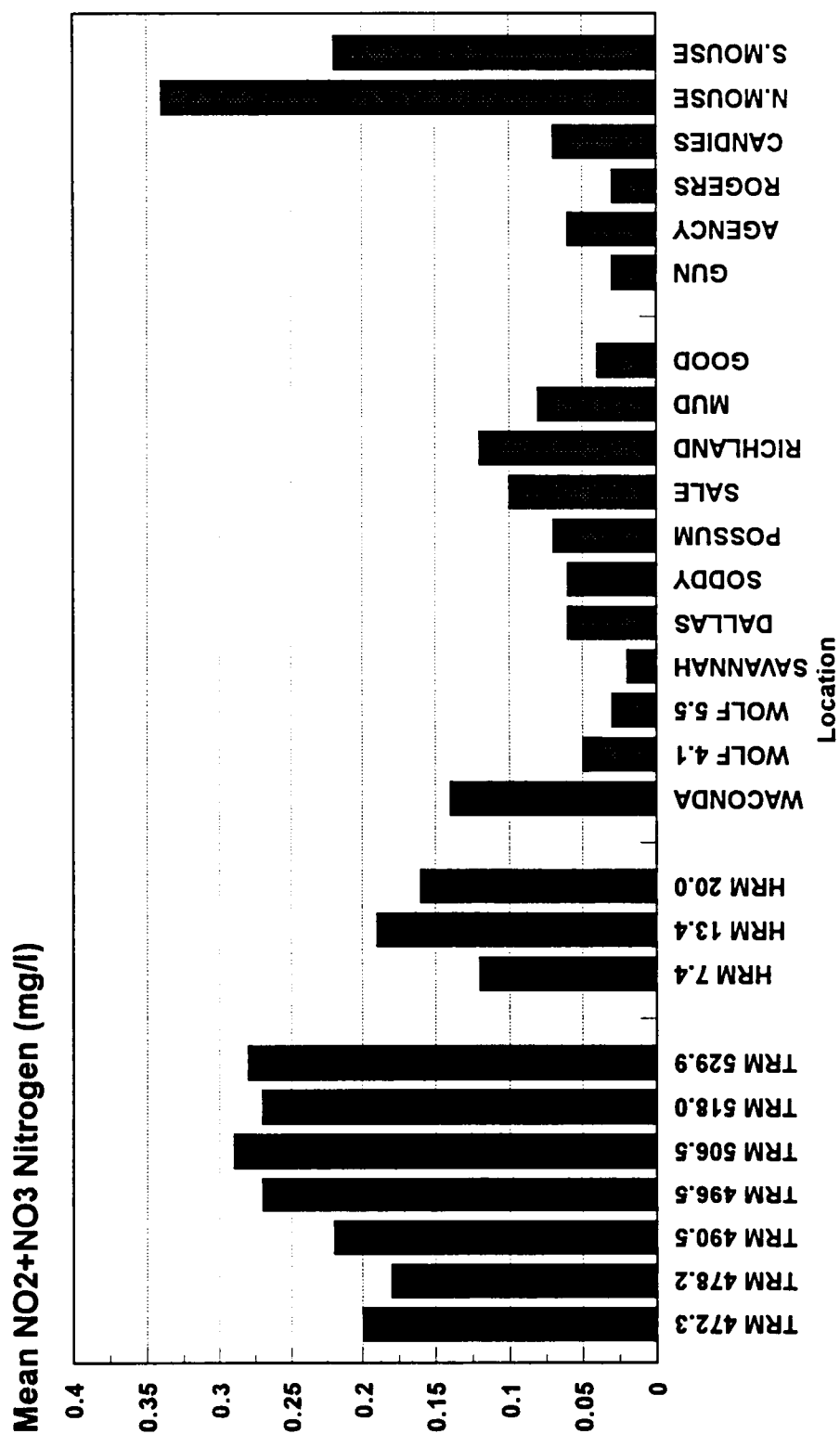


Figure 7. Mean nitrite+nitrate nitrogen concentrations (mg/l) at the 1-m depth in Chickamauga Reservoir, April through September 1990.

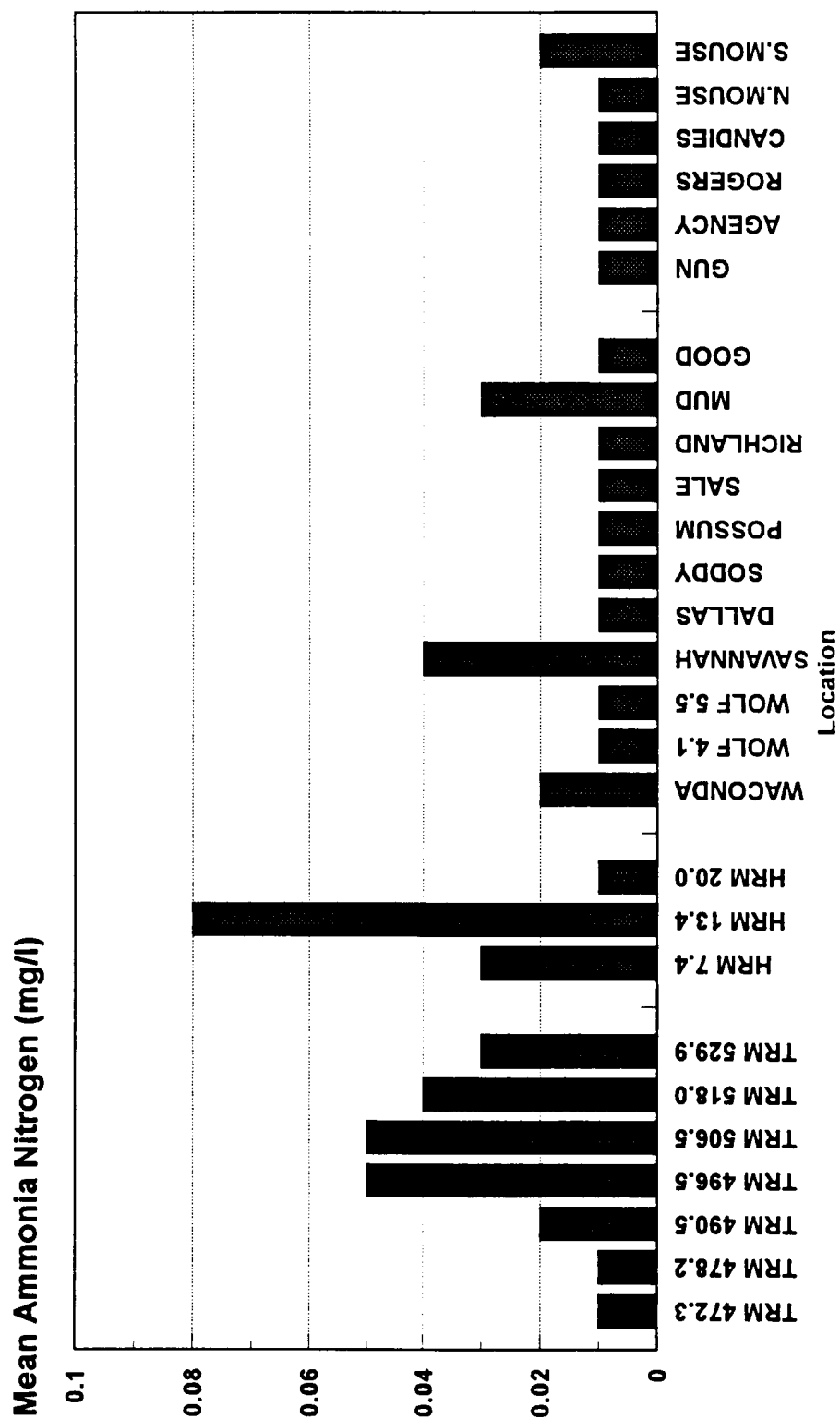


Figure 8. Mean Ammonia Nitrogen concentrations (mg/l) at the 1-m depth in Chickamauga Reservoir, April through September 1990.

substantial increase was found from HRM 20 to HRM 13.4, with concentrations decreasing again downstream. TRM sites indicated that mean ammonia concentrations tended to increase from upstream (TRM 529.9) to downstream (TRM 506.5). They decreased at TRM 496.5 and continued to decline until TRM 490.5 where concentrations remained the same into the forebay at Chickamauga Dam (TRM 472.3).

Mean organic nitrogen concentrations ranged from 0.12 to 0.83 mg/l (Figure 9) and were generally higher at embayment sites than main channel sites, with Hiwassee river embayments being greater than Tennessee river embayments. Soddy, Possum, and Sale Creeks had the lowest concentrations among the embayments. Savannah Bay had the highest concentration among Tennessee River sites. HRM sites exhibited a progressive increase from upstream to downstream. TRM sites showed a progressive decrease in the upper reach of the reservoir, TRM 529.9 to TRM 496.5; then the mean concentrations increased at TRM 490.5 and TRM 478.2, followed by a decrease at TRM 472.3 (forebay).

Mean total nitrogen concentrations ranged from 0.19 to 1.06 mg/l (Figure 10). The highest concentrations occurred at South Mouse followed by North Mouse; Possum Creek had the lowest mean concentration. Savannah Bay had the highest mean among Tennessee River embayments, with TRM sites exhibiting a decreasing trend from upstream to

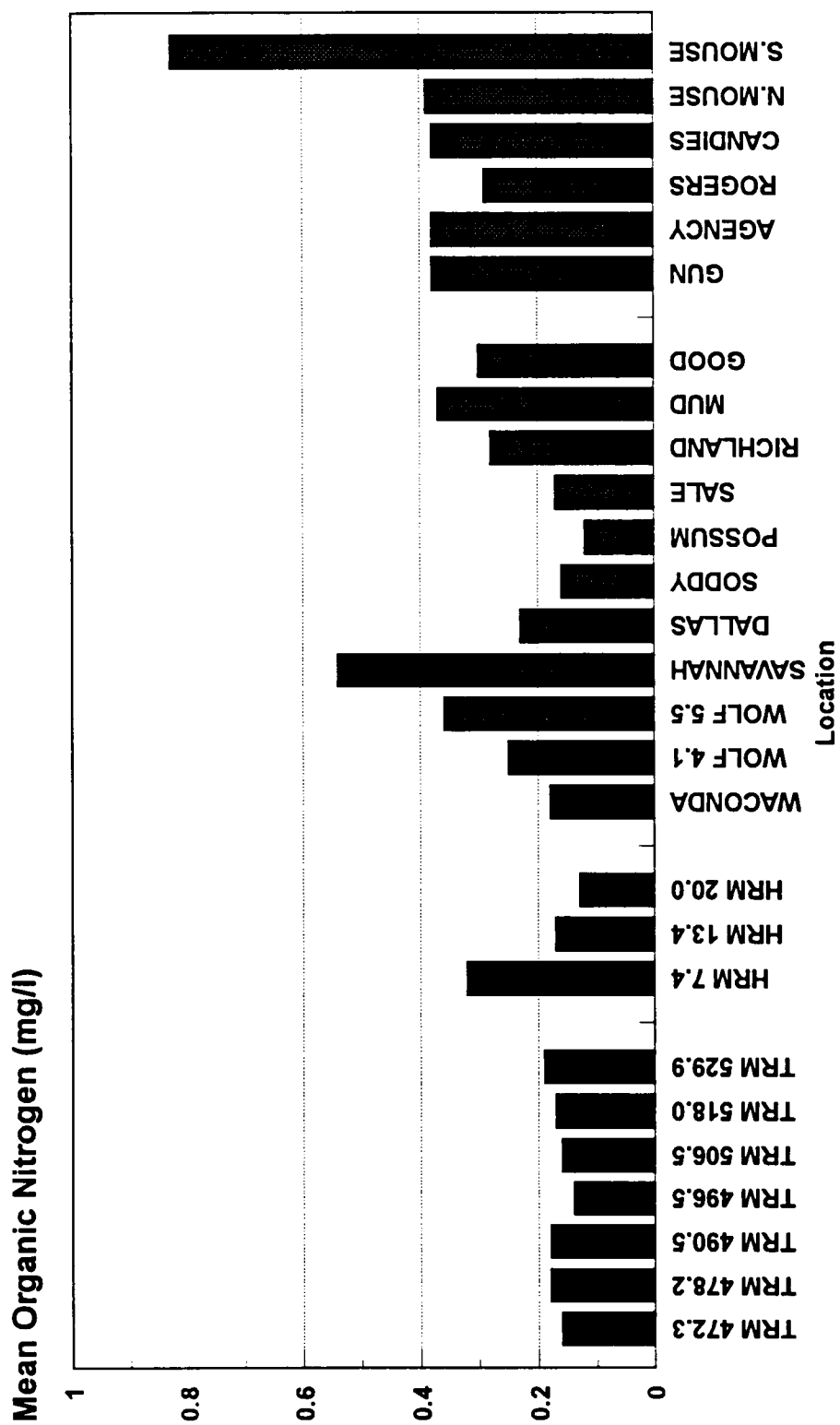


Figure 9. Mean organic nitrogen concentrations (mg/l) at the 1-m depth in Chickamauga Reservoir, April through September 1990.

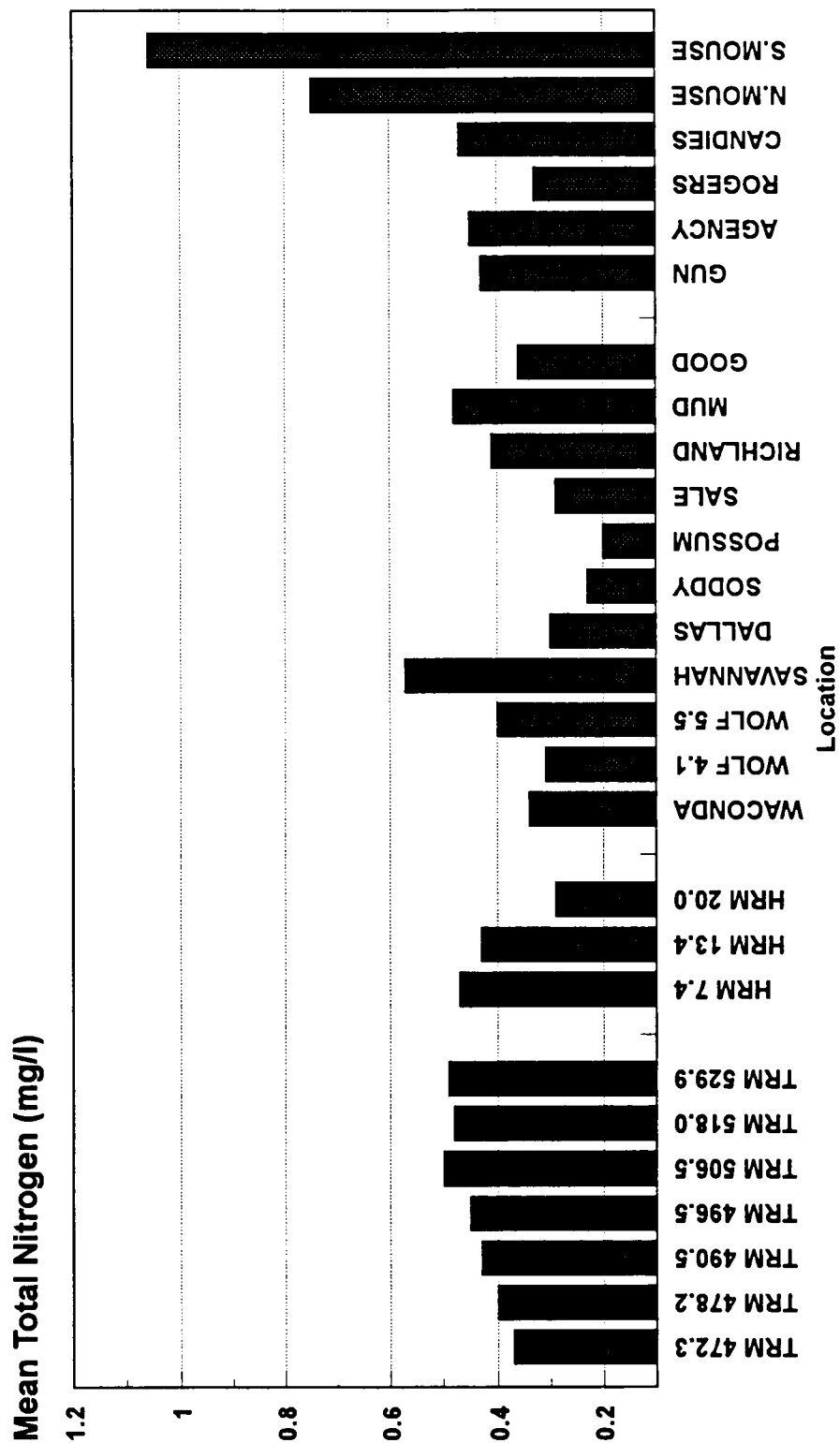


Figure 10. Mean total nitrogen concentrations (mg/l) at the 1-m depth in Chickamauga Reservoir, April through September 1990.

downstream. Mean concentrations increased from upstream to downstream at HRM sites.

Mean orthophosphate concentrations ranged from 0.003 to 0.022 mg/l (Figure 11). Generally, main channel sites showed greater mean concentrations than embayment sites with the noticeable exception of the upper Hiwassee embayments (South Mouse, North Mouse, and Candies). Generally, Hiwassee river embayments had higher mean concentrations than Tennessee river embayments. As with ammonia nitrogen, mean total phosphorus concentrations showed a noticeable increase from HRM 20.0 to HRM 13.4. Mean orthophosphate exhibited a upstream/downstream trend of increasing concentrations until TRM 496.5, after which concentrations decreased into the forebay (TRM 472.3).

Mean total phosphorus concentrations ranged from 0.006 to 0.120 mg/l (Figure 12). With few exceptions, Hiwassee River embayments had higher mean total phosphorous concentrations than other sites. South Mouse Creek had over twice the total phosphorous concentration than any other site. Soddy, Possum and Sale Creeks had the lowest concentrations (0.008, 0.006, and 0.010 mg/l, respectively) followed closely by Dallas Bay (0.011). Savannah Bay had the highest concentrations among the Tennessee River embayments. Substantially increased concentrations occurred from HRM 20.0 to HRM 13.4. Mean total phosphorus values for 20 of the 27 sites sampled

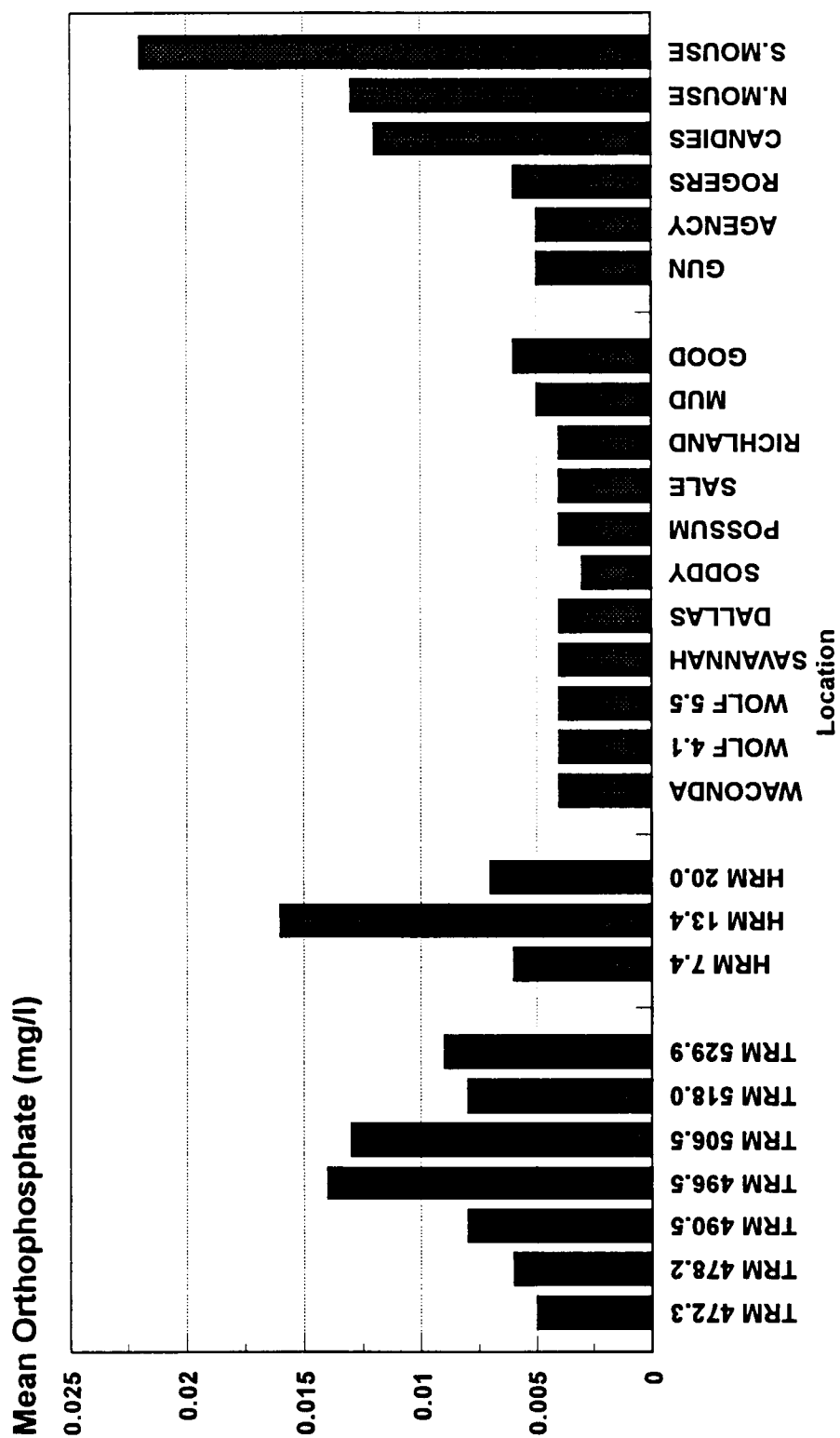


Figure 11. Mean orthophosphate concentrations (mg/l) at the 1-m depth in Chickamauga Reservoir, April through September 1990.

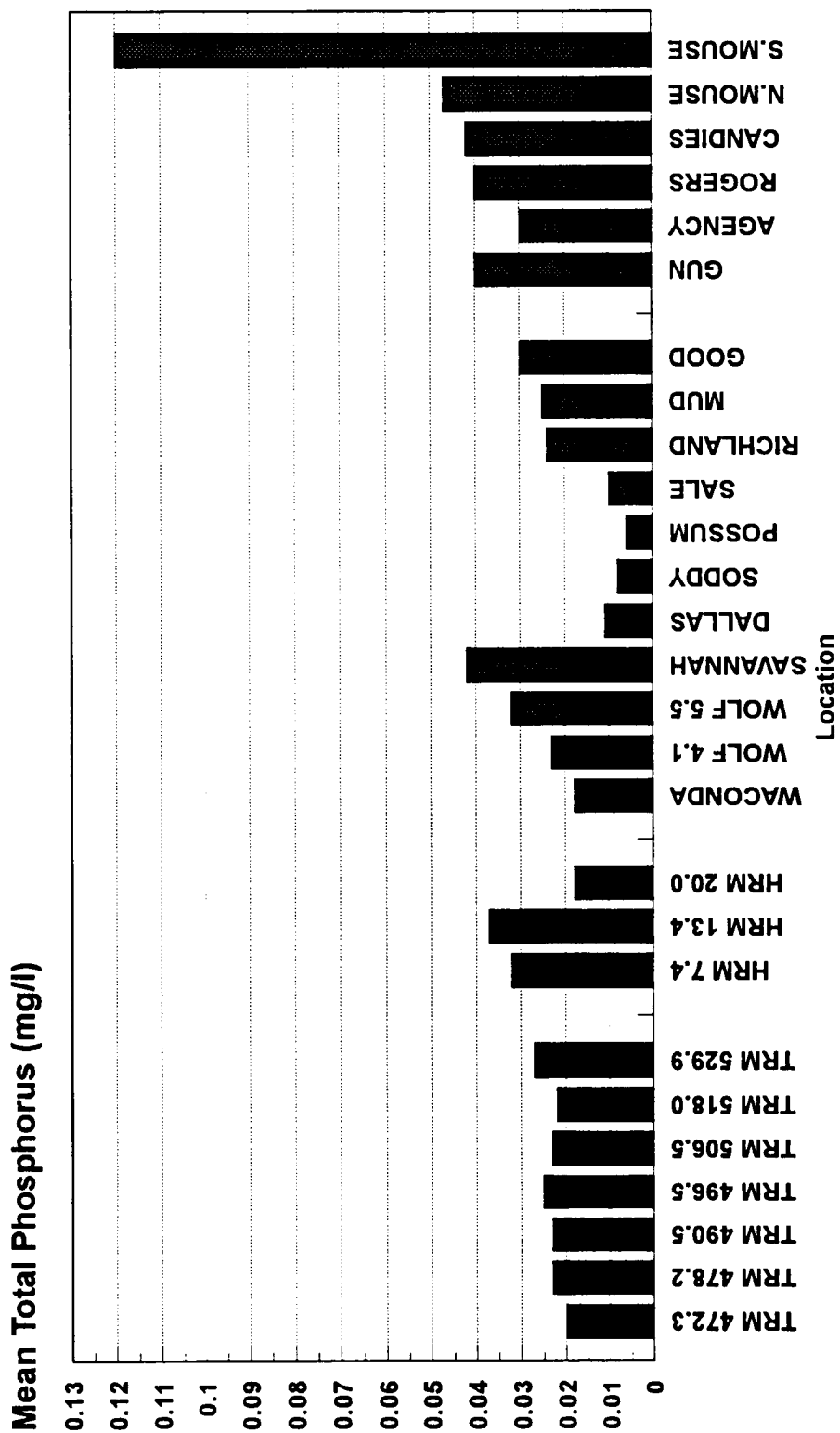


Figure 12. Mean total phosphorus concentrations (mg/l) at the 1-m depth in Chickamauga Reservoir, April through September 1990.

exceeded 0.02 mg/l, a value considered the lower limit for eutrophic conditions.

Mean total nitrogen and total phosphorus ratios (TN/TP) ranged from 8.7 to 39.1 (Figure 13). TRM 472 had the highest mean TN/TP ratio and Roger Creek had the lowest. Hiwassee embayments as a group had lower mean TN/TP ratios than the Tennessee embayments. Soddy, Possum, and Sale Creeks had the highest ratios among embayments. TN/TP dropped substantially from HRM 20 to HRM 13.

#### Alkalinity

Alkalinity, a measure of bicarbonate ion ( $\text{HCO}_3^-$ ) concentration, ranged from 12 to 150 mg/l. The lowest alkalinities were recorded at HRM 20 (12 mg/l), while the highest occurred at North Mouse Creek (150 mg/l). These sites also had the lowest and highest means of 17 and 120 mg/l, respectively (Figure 14). TRM sites have mean alkalinity values almost twice as high as HRM sites. HRM sites showed a progressive increase in mean alkalinity going downstream while TRM sites showed a progressive decrease. A noticeable increase occurred from HRM 20.0 and HRM 13.4. Mean alkalinity was greater in Savannah Bay than at other Tennessee embayments.

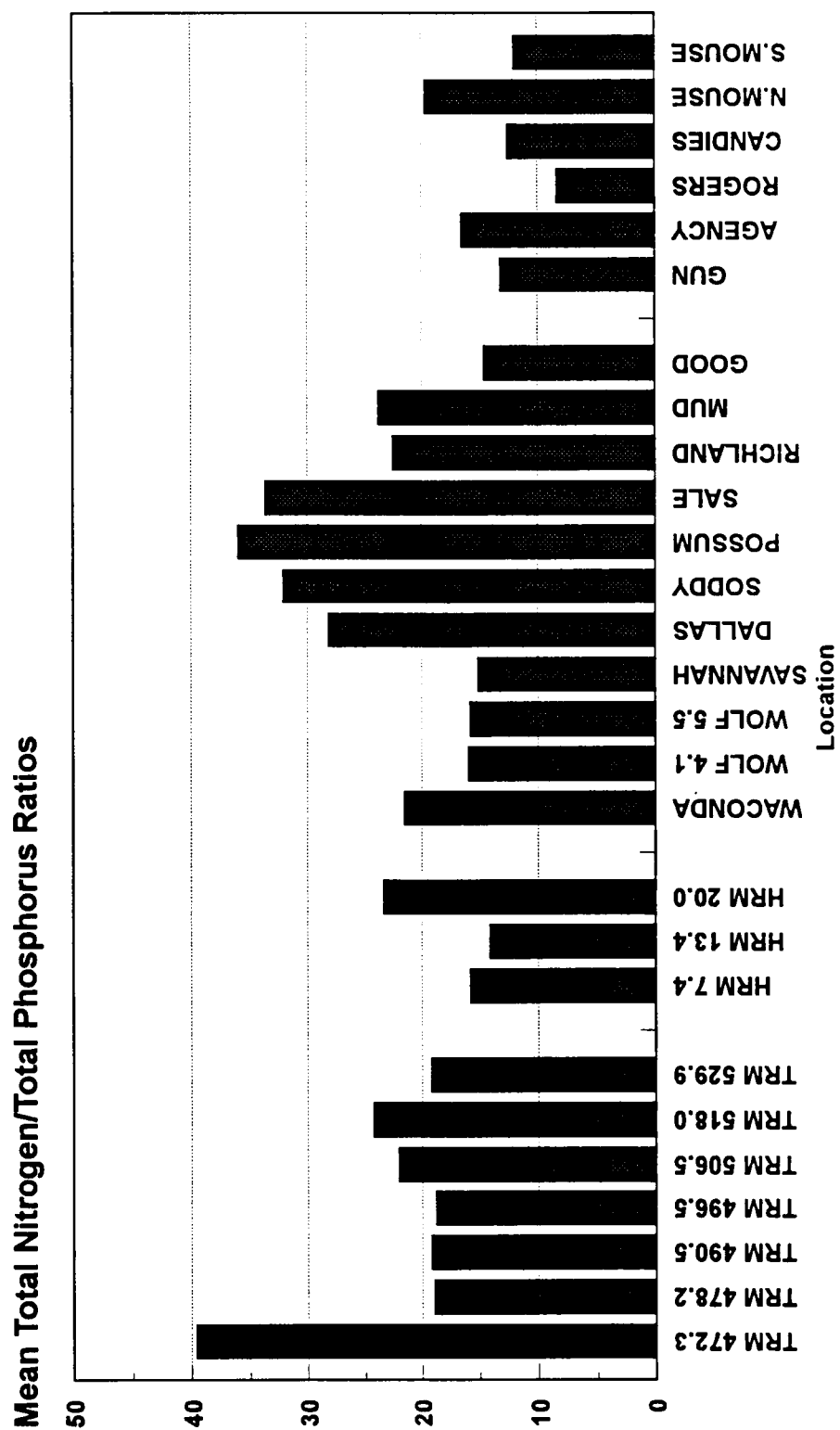


Figure 12. Mean total nitrogen/total phosphorus ratios at the 1-m depth in Chickamauga Reservoir, April through September 1990.

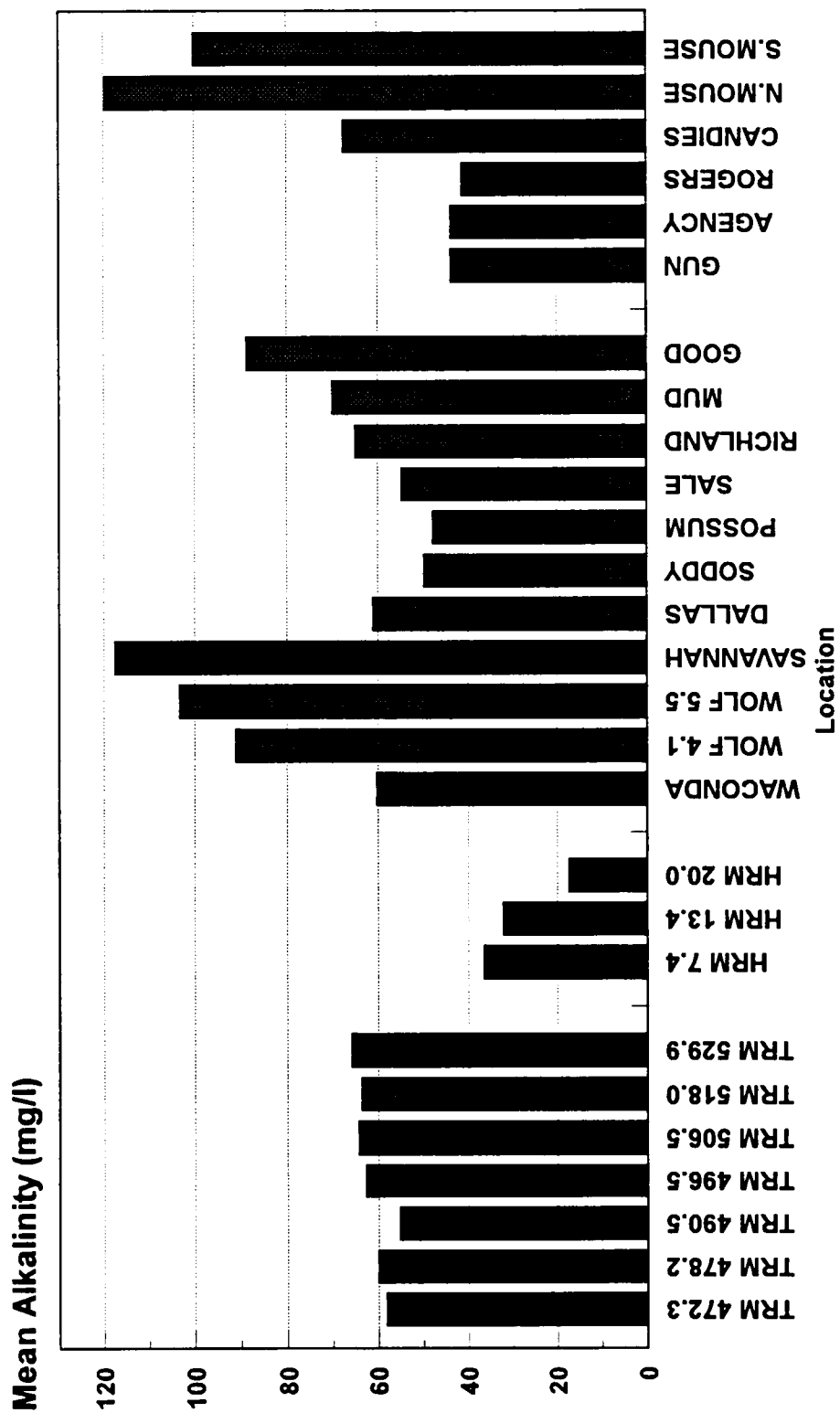


Figure 14. Mean alkalinity (mg/l) at the 1-m depth in Chickamauga Reservoir, April through September 1990.

## Conductivity

Conductivity ranged from 53 to 292  $\mu\text{mhos/cm}$  during the course of the study. Mean conductivity values ranged from 70  $\mu\text{mhos/cm}$  at HRM 20 to 243  $\mu\text{mhos/cm}$  at Savannah Bay (Figure 15). Mean conductivity decreased from the headwaters to the forebay at the TRM sites. HRM sites showed an increase from upstream to downstream, but remained below TRM levels. Conductivity increased greatly from HRM 20.0 to HRM 13.4.

## Total Organic Carbon

Mean total organic carbon (TOC) ranged from 1.4 to 3.8 mg/l at HRM 20.0 and South Mouse Creek, respectively (Figure 16). Mean TOC was generally greater in the embayments than in the main channel and greater at Hiwassee sites than Tennessee sites. HRM 20.0 had the lowest mean concentrations followed by Possum Creek. South Mouse had the highest mean TOC concentrations followed by Savannah Bay. The Tennessee River main channel sites varied little from headwater to forebay, but did show a general increasing trend from upstream to downstream. The Hiwassee River main channel sites showed increases from upstream to downstream with a prominent increase occurring between HRM 20.0 and HRM 13.4. Soddy, Possum, and Sale Creeks had the lowest mean TOC concentrations among the embayments.

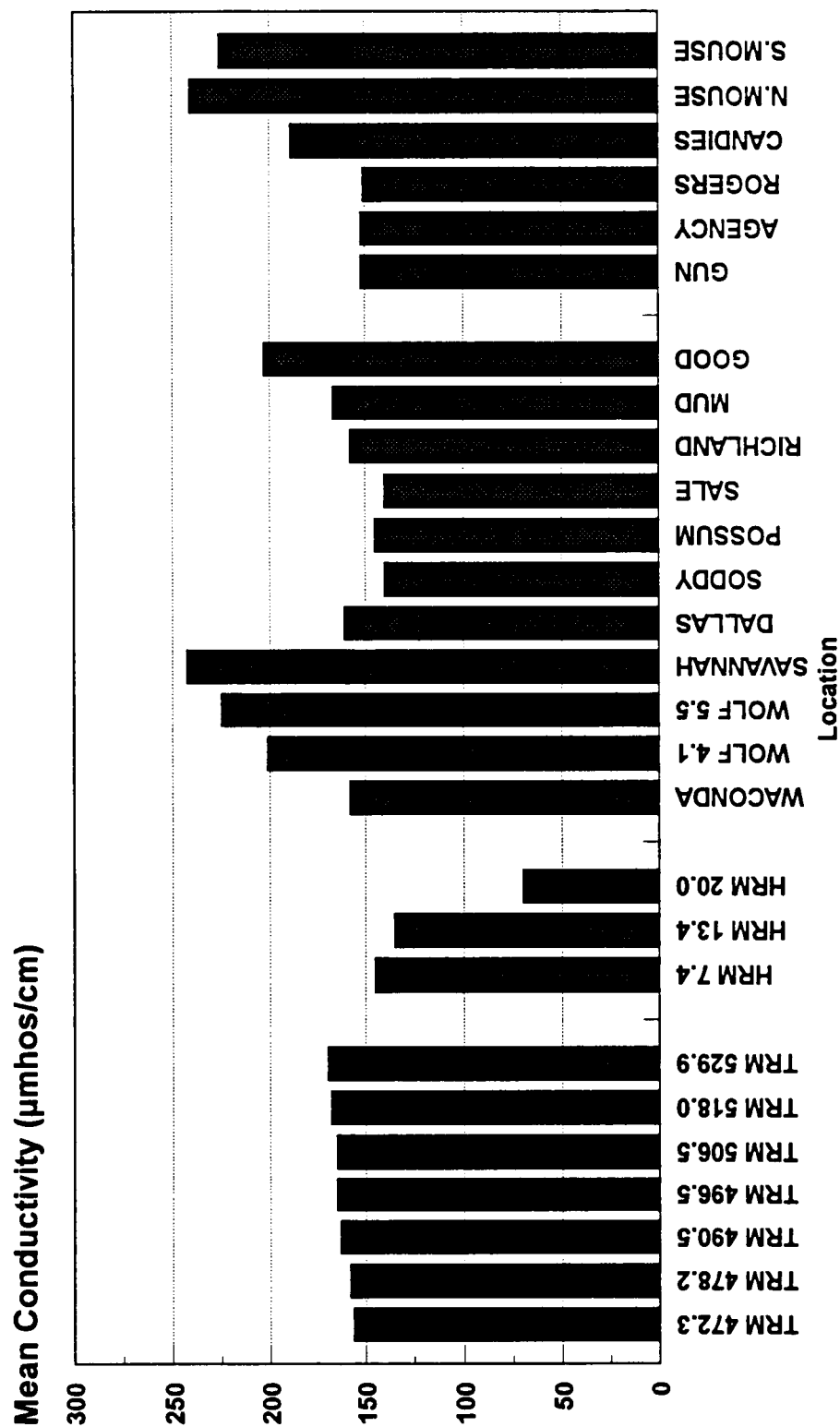


Figure 15. Mean conductivity (µmhos/cm) at the 1-m depth in Chickamauga Reservoir, April through September 1990.

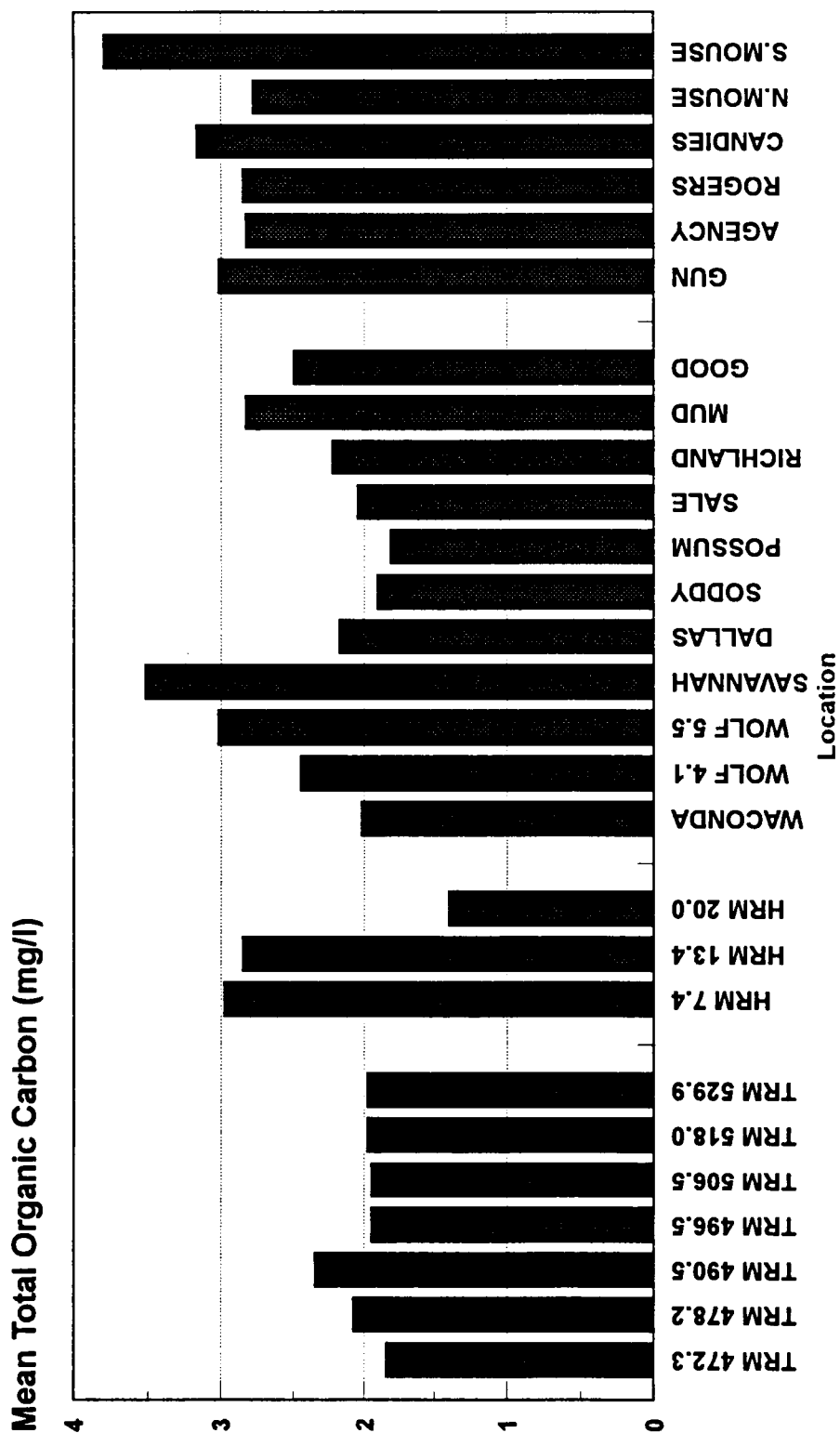


Figure 16. Mean total carbon organic concentrations (mg/l) at the 1-m depth in Chickamauga Reservoir, April through September 1990.

## Total Hardness

Mean total hardness values ranged from 71.3 mg/l (as  $\text{CaCO}_3$ ) at HRM 7.4 to 123 mg/l at North Mouse (Figure 17). Variation was greatest among Hiwassee embayments with much higher concentrations at North and South Mouse Creeks. Concentrations decreased from upstream to downstream at HRM sites. The highest concentrations at the Tennessee sites were found at Savannah Bay (99.8 mg/l) among embayments and at TRM 478.2 (92.3 mg/l) among channel stations.

## PHYTOPLANKTON DYNAMICS

### Total Phytoplankton Densities

Hiwassee River sites, HRM 20 and HRM 13, maintained the lowest phytoplankton densities for the study period with mean densities of  $2.0 \times 10^6$  and  $2.2 \times 10^6$  cells/l, respectively (Figure 18). North Mouse Creek had the lowest mean phytoplankton density among embayments with  $6.3 \times 10^6$  cells/l; followed by Possum Creek with  $9.8 \times 10^6$  cells/l. Densities were greatest in Mud Creek, Richland Creek, and Savannah Bay with approximately equal populations of  $41 \times 10^6$  cells/l. Wolftever 5.5 followed closely with a mean density of  $38 \times 10^6$ . TRM 529, TRM 518, and TRM 506 had mean densities of 9.4, 7.1, and  $3.9 \times 10^6$  cells/l, respectively, while TRM 496 had a mean density of  $8.9 \times 10^6$ .

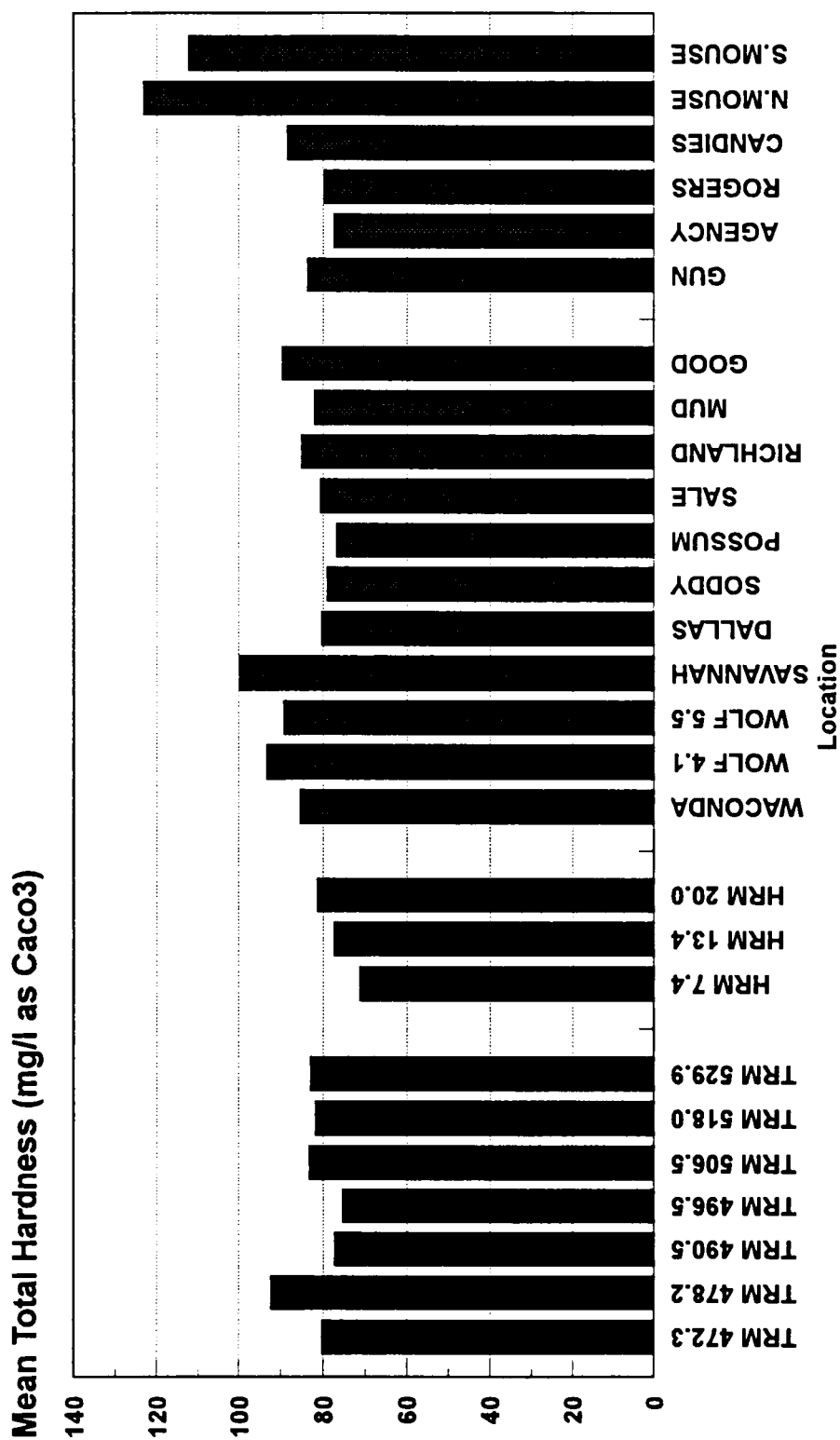


Figure 17. Mean total hardness concentrations (mg/l) at the 1-m in Chickamauga Reservoir, April through September 1990.

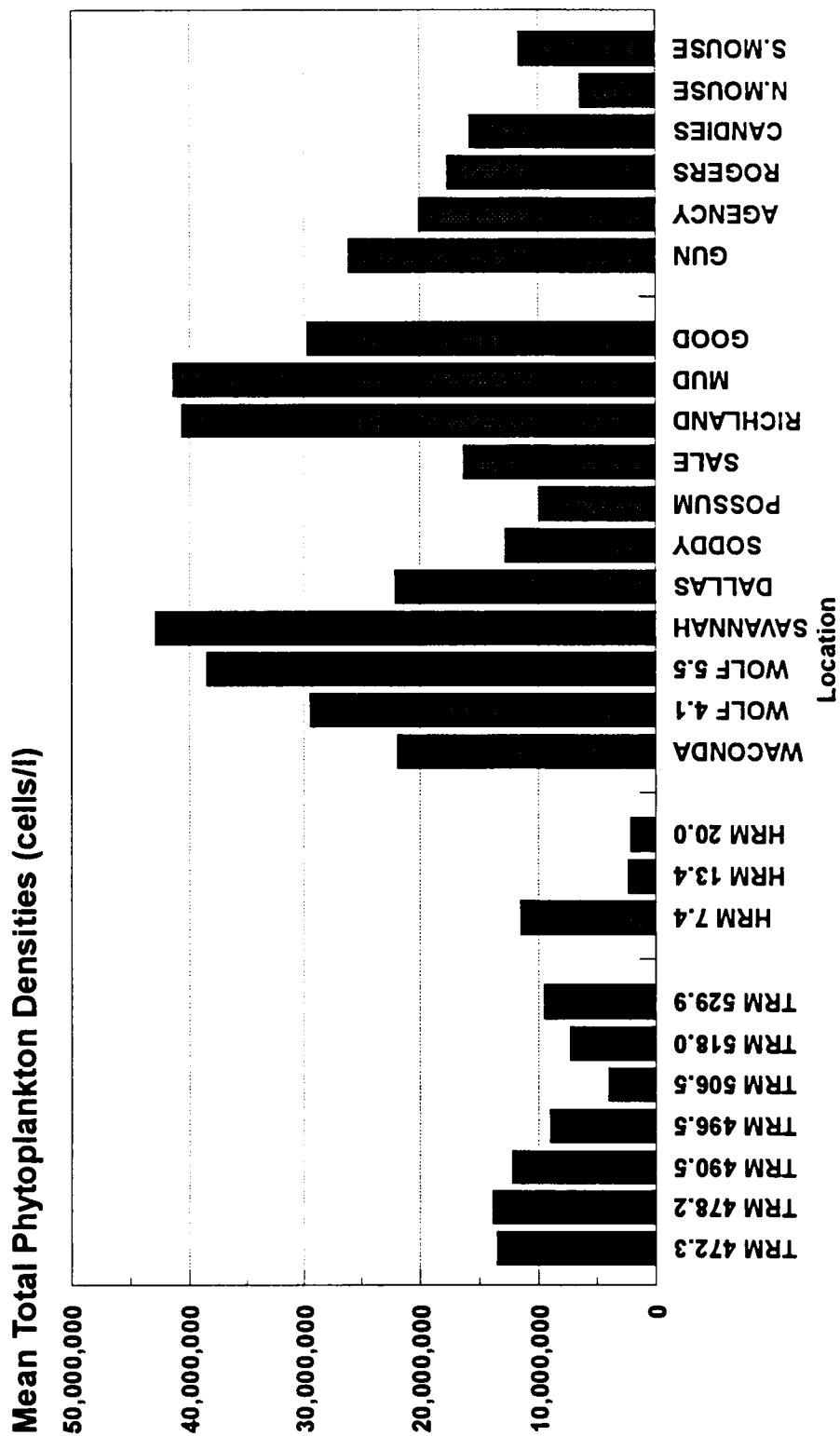


Figure 18. Mean total phytoplankton densities (cells/l) at the 1-m depth in Chickamauga Reservoir, April through September 1990.

## Chlorophyll a

Chlorophyll a concentrations ranged from 1.0 to 42.3 mg/m<sup>3</sup> during the study. Mean chlorophyll a concentrations ranged from 1.6 mg/m<sup>3</sup> at HRM 20.0 to 24.0 mg/m<sup>3</sup> at South Mouse. Figure 19 shows mean chlorophyll a concentrations to be greater in the Hiwassee River embayments than in the Tennessee River embayments, with the exception of North Mouse Creek. At HRM sites, mean concentrations increased from upstream to downstream. TRM sites indicated mean chlorophyll a levels decreased from TRM 529.9 (5.2 mg/m<sup>3</sup>) to TRM 506.5 (2.3 mg/m<sup>3</sup>) and increased from TRM 506.5 to a high of 10.3 mg/m<sup>3</sup> at TRM 490.9. Mean chlorophyll a decreased again at the downstream locations (TRM 478.2 and 472.3) to 8.7 mg/m<sup>3</sup>.

## Correlations Among Divisions

### Embayments

|         | CHLORO | CHRYSO         | CRYPTO         | CYANO          | EUGLENO        | PYRRO          | TOTAL          |
|---------|--------|----------------|----------------|----------------|----------------|----------------|----------------|
| CHLORO  |        | .5195<br>.0326 | .5028<br>.0397 | .8329<br>.0001 | .7536<br>.0005 | .7257<br>.0010 | .9094<br>.0001 |
| CHRYSO  |        |                | .2444<br>.3444 | .3123<br>.2223 | .3500<br>.1684 | .5137<br>.0349 | .4400<br>.0771 |
| CRYPTO  |        |                |                | .2106<br>.4171 | .8014<br>.0001 | .3910<br>.1207 | .6350<br>.0062 |
| CYANO   |        |                |                |                | .5477<br>.0228 | .7682<br>.0003 | .9795<br>.0001 |
| EUGLENO |        |                |                |                |                | .6477<br>.0049 | .6350<br>.0062 |
| PYRRO   |        |                |                |                |                |                | .7914<br>.0002 |

Correlations among all embayment division densities are positive. CHLORO had strong significant correlation

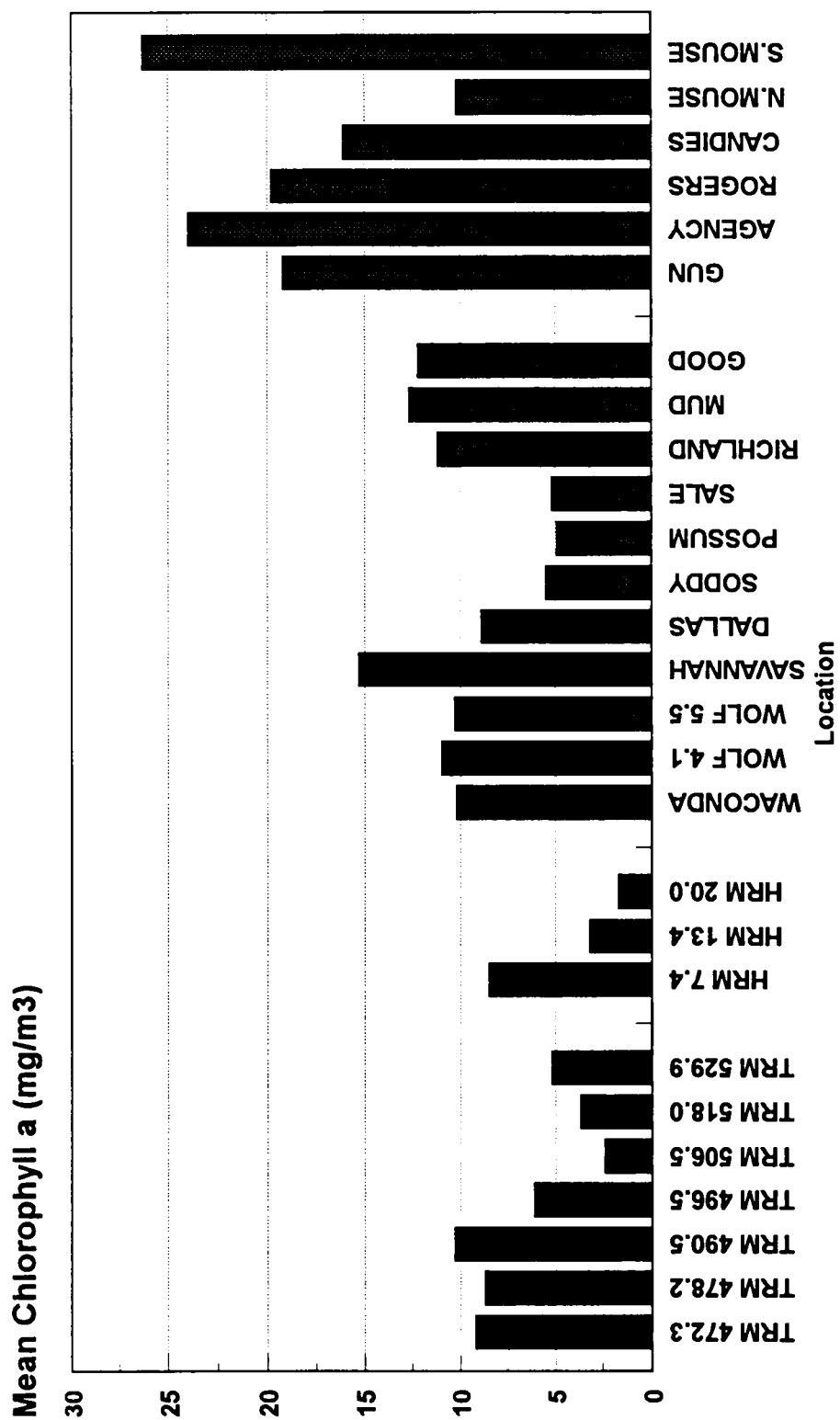


Figure 19. Mean chlorophyll a concentrations (mg/m3) at the 1-m depth in Chickamauga Reservoir, April through September 1990.

with all divisions. CHLORO correlated strongest with CYANO, EUGLENO, and PYRRO, while CHRYSO showed significant correlations with CHLORO and PYRRO. CRYPTO had the strongest correlation with EUGLENO (.80) followed by CHLORO (.50). CYANO correlated best with CHLORO (.83) and PYRRO (.77) followed by EUGLENO (.55). EUGLENO was significantly correlated with all divisions except CHRYSO. EUGLENO was most strongly correlated with CRYPTO (.80) and CHLORO (.75). PYRRO was significantly correlated with all divisions except CRYPTO. PYRRO was best correlated with CYANO (.77) followed closely by CHLORO (.73). Total algal density correlated most strongly with CYANO followed by CHLORO, PYRRO, CRYPTO and EUGLENO, while CHRYSO had the weakest correlation with TOTAL.

### Main Channel

|         | CHLORO | CHRYSO         | CRYPTO         | CYANO          | EUGLENO        | PYRRO          | TOTAL          |
|---------|--------|----------------|----------------|----------------|----------------|----------------|----------------|
| CHLORO  |        | .9672<br>.0001 | .9217<br>.0001 | .8770<br>.0009 | .9170<br>.0002 | .8231<br>.0034 | .9417<br>.0001 |
| CHRYSO  |        |                | .8568<br>.0015 | .9287<br>.0001 | .9032<br>.0003 | .8690<br>.0011 | .9734<br>.0001 |
| CRYPTO  |        |                |                | .6638<br>.0363 | .9266<br>.0001 | .6249<br>.0534 | .7745<br>.0085 |
| CYANO   |        |                |                |                | .7342<br>.0156 | .9336<br>.0001 | .9856<br>.0001 |
| EUGLENO |        |                |                |                |                | .6967<br>.0252 | .8306<br>.0029 |
| PYRRO   |        |                |                |                |                |                | .9166<br>.0002 |

Correlations among all divisions were significant and positive. CHLORO had the greater overall correlation with

all divisions followed by CHRYSO. CHRYSO was least correlated with CRYPTO, while CRYPTO and EUGLENO were highly correlated and least correlated with CYANO and PYRRO, respectively. CYANO was least correlated with CRYPTO and PYRRO was most highly correlated with CYANO and least correlated with CRYPTO and EUGLENO.

## Factor Analysis

### Embayments

Three factors were maintained and an orthogonal rotation applied. The three factors accounted for 92.3% of the variation among embayment sites.

Factor1 accounted for 41.7% with strong weighing on CYANO (.97), CHLORO (.79), and PYRRO (.79). Factor1 was composed of those divisions mostly highly correlated with total density and highly correlated with each other. The best regression model explained 60.5% of the variation within Factor1 using the independent variables ORTHO and ORGAN (p=.0015). Factor1 also had significant correlation with the water quality variables TEMP, ORTHO (-), NO2 (-), and TRU\_CLR (-).

$$\text{Factor1} = -0.02 - 529.97(\text{ORHTO}) + 12.04(\text{ORGAN})$$

|         | TEMP           | ORTHO           | NO2             | TRU_CLR         |
|---------|----------------|-----------------|-----------------|-----------------|
| Factor1 | .6499<br>.0047 | -.6559<br>.0042 | -.6354<br>.0061 | -.5336<br>.0274 |

Factor2 accounted for an additional 31.3% of the variation with CRYPTO (.97) and EUGLENO (.82). Factor2 was composed of those divisions intermediate in their correlation with total density but highly correlated with each other. The best regression model explained 69.7% of the variation within Factor2 using the independent variables TURB and ALK (p=.0002). Factor2 also had significant correlation those water quality variables listed below.

$$\text{Factor2} = 2.77 + 3.25(\text{TURB}) - 3.25(\text{ALK})$$

|         | TEMP            | pH              | TOT_P          | TOC            | TURB           | TRU_CLR        | ORGAN          | TOT_N          |
|---------|-----------------|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Factor2 | -.5356<br>.0267 | -.6737<br>.0030 | .6065<br>.0098 | .6836<br>.0024 | .7179<br>.0012 | .6263<br>.0069 | .6338<br>.0063 | .5472<br>.0230 |

Factor3 explained 19.3% of the variation with the only significant weight being CHRYSO (.96). Factor3 was composed of chrysophytes which were not significantly correlated with total density and weakly correlated with other divisions. The independent variables TEMP and TOT\_P accounted for 60.7% of the variation within Factor3 (p=.0016). Factor3 had no significant correlations with water quality variables.

$$\text{Factor3} = -20.12 + 0.81(\text{TEMP}) + 94.64(\text{TOT_P})$$

The plots of Factor1 with Factor2 (Figure 20) indicated good clustering with adherence to embayment location. South Mouse and North Mouse Creeks were located almost adjacent on the riverine portion of the Hiwassee

# FACTOR 1

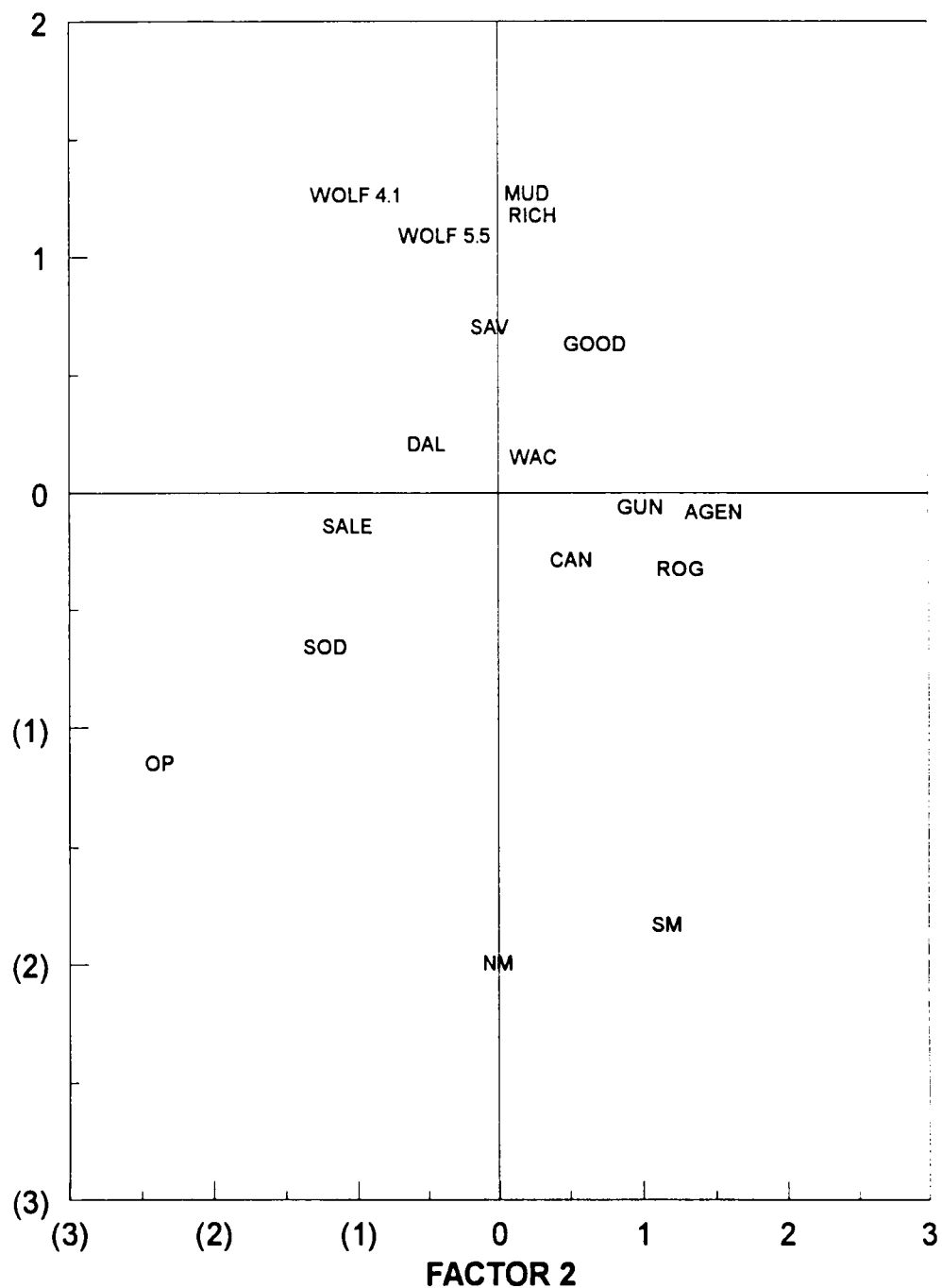


Figure 20. Factor patterns for factor 1 and factor 2 of mean phytoplankton division densities at the 1-m depth in Chickamauga Reservoir embayments, April through September 1990.

River and were low in overall mean phytoplankton density. North Mouse scored average for Factor2 but the plot showed the remaining Hiwassee embayments had greater mean CRYPTO and EUGLENO (Factor2) densities than Tennessee embayments. Hiwassee Embayments were also below average in CYANO and PYRRO densities with South Mouse and North Mouse scoring lowest among all embayments.

Soddy, Sale, and Possum embayments were low in overall mean phytoplankton density and lowest in CRYPTO and EUGLENO densities. Soddy, Sale and Possum differed in CYANO and PYRRO composition but their densities remained below average with respect to other Tennessee embayments. Mud and Richland embayments were located very close on the reservoir and were closely clustered for both Factor1 and Factor2. Savannah Bay, Wolftever 4.1, and Wolftever 5.5 scored high for Factor1 and below average for Factor2. Savannah Bay scored lower for Factor1 and higher on Factor2 than the Wolftever sites. Wolftever 4.1, located below the confluence of Savannah and Wolftever 5.5, showed reduced cryptophyte and euglenophyte densities, but due to much higher pyrrophyte densities, scored higher on Factor1. Goodfield Creek was the uppermost reservoir embayment and scored above average for both Factor1 and Factor2.

The plots of Factor1 with Factor3 (Figure 21) also exhibited good clustering with respect to embayment

# FACTOR 1

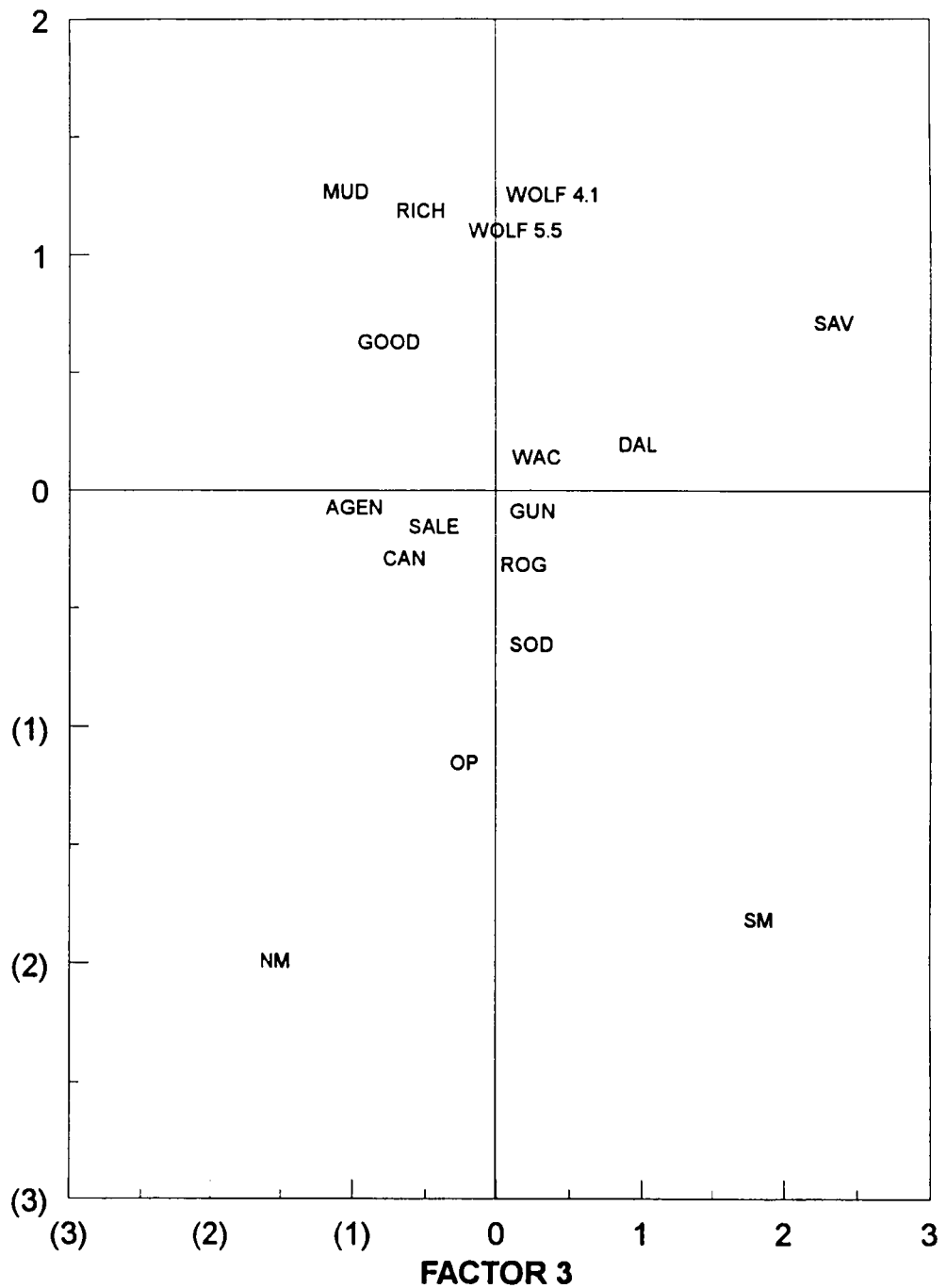


Figure 21. Factor patterns for factor 1 and factor 3 of mean phytoplankton division densities at the 1-m depth in Chickamauga Reservoir embayments, April through September 1990.

location. Most notably, Savannah Bay and South Mouse had much higher chrysophyte densities than other embayments, while North Mouse had the lowest. Soddy, Possum, and Sale, which were below average in all other division densities, were more nearly average in chrysophyte densities. Soddy, Possum, and Sale had greater mean chrysophyte compositions than all other embayments except South Mouse.

#### Main Channel

Two factors were maintained and an orthogonal rotation applied. The two factors accounted for 96.9% of the variation among main channel sites based on algal data.

Factor1 accounted for 50.0% of the variation among sites with CRYPTO (.93), EUGLENO (.88), CHLORO (.77) and CHRYSO (.69). Factor1 weighed strongest with CRYPTO and EUGLENO and weak for CYANO and PYRRO. CRYPTO and EUGLENO were highly correlated with each other and had their weakest correlation with CYANO and PYRRO. CRYPTO and EUGLENO were also the two divisions least correlated with TOTAL. Two variables, SECCHI and X\_AREA, accounted for 80.5% of the variation among sites ( $p=.0033$ ). No other significant relationships were found with water quality variables.

$$\text{Factor1} = 1.97 - 12.17(\text{SECCHI}) + 0.81 (\text{X\_AREA})$$

Factor2 weighed significantly in PYRRO (.92), CYANO (.90), CHRYSO (.71), and CHLORO (.62), accounting for an additional 46.9% of the variation among sites. Factor2 weighed strongest with PYRRO and CYANO, which were highly correlated with each other, followed by CHRYSO and CHLORO, which were highly correlated with them. The independent variables NH3, X\_AREA, and TOT\_N formed a model accounting for 96.0% of the variation in Factor2 (p=.0001). Other significant correlations are shown below.

$$\text{Factor2} = -7.23 - 99.66(\text{NH3}) + 0.67(\text{X\_AREA}) + 42.90(\text{TOT\_N})$$

|         | TEMP  | Ph    | COND  | TRU_CLR | ALK   | X_AREA |
|---------|-------|-------|-------|---------|-------|--------|
| Factor2 | .7061 | .6684 | .6203 | -.7160  | .7344 | .6274  |
|         | .0225 | .0346 | .0557 | .0199   | .0156 | .0522  |

The plot of Factor1 with Factor2 (Figure 22) revealed strong clustering among main channel sites with respect to reservoir location. TRM 529, 518 and 506 are located in the upper river reach of the reservoir and the plots revealed lower overall phytoplankton densities along with lower CRYPTO and EUGLENO densities. Mid-reservoir sites (TRM 490, TRM 496, and HRM 7.4) and lower reservoir sites (TRM 472 and TRM 478) clustered individually and represented a continuum from upstream to downstream in increased CRYPTO and EUGLENO densities. HRM 20 and HRM 13.4 had the lowest phytoplankton densities with HRM 13.4 showing greater scoring for Factor1, but both scored low

# FACTOR 1

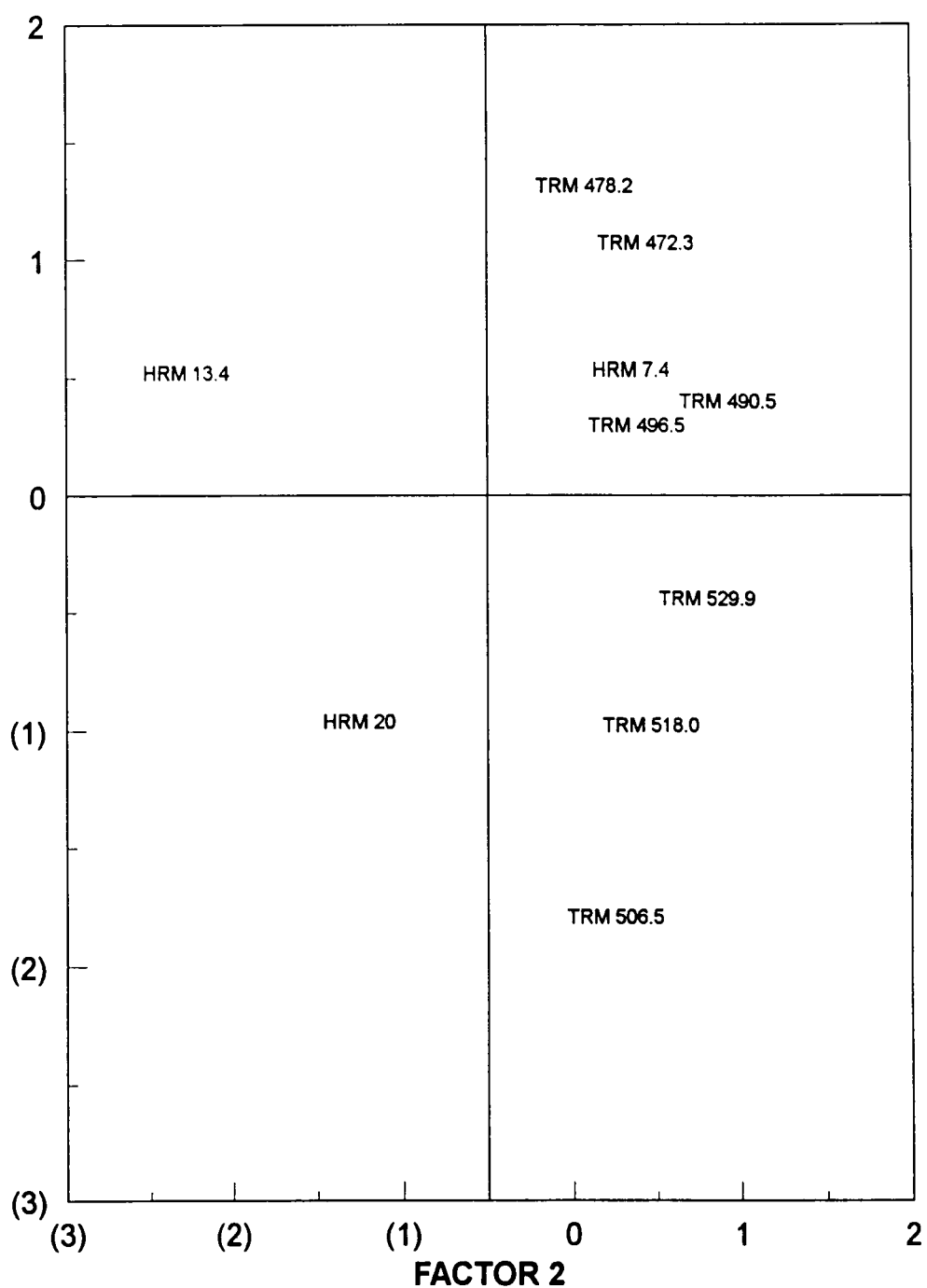


Figure 22. Factor patterns for factor 1 and factor 2 of mean phytoplankton division densities at the 1-m depth in Chickamauga Reservoir's main channel, April through September 1990.

on Factor2. Less variation occurred in cyanophyte composition among main channel stations with the exception of HRM 13.4 and HRM 20.0. Pyrrophyte densities remained low at all sites, but variation was greater. TRM 529 and TRM 490 had greater pyrrophyte densities while HRM 13.4 and HRM 20.0 had lower densities.

#### Chlorophyll a Relationships With Phytoplankton and Environmental Variables

|                   | CHLORO         | CHRYSO         | CRYPTO         | CYANO          | EUGLENO        | PYRRO          | TOTAL          |
|-------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| EMBAYMENT CHLA    | .4780<br>.0523 | .2961<br>.2486 | .8896<br>.0001 | .1236<br>.6365 | .8204<br>.0001 | .3206<br>.2096 | .2398<br>.3540 |
| MAIN CHANNEL CHLA | .9695<br>.0001 | .9368<br>.0001 | .9230<br>.0001 | .8036<br>.0051 | .9369<br>.0001 | .7688<br>.0094 | .8880<br>.0006 |

Chlorophyll a was significant and highly correlated with all divisions in the main channel and only highly correlated with EUGLENO and CRYPTO in the embayments. Furthermore, in the main channel, chlorophyll a was significant and highly correlated with TOTAL, while the embayment correlation was not significant. Notably, factors scoring highest with crptophytes and euglenophytes correlated strongest with chlorophyll a.

|                   | Factor1        | Factor2        | Factor3        |
|-------------------|----------------|----------------|----------------|
| EMBAYMENT CHLA    | .0365<br>.8895 | .9201<br>.0001 | .1764<br>.4982 |
| MAIN CHANNEL CHLA | .8140<br>.0042 | .5311<br>.1142 | NA             |

Chlorophyll a within the main channel had significant correlation with TEMP, pH, X-AREA, and SECCHI. Embayment

chlorophyll a was positively related to nutrient concentrations (TOT\_P, ORGAN, and TOT\_N), TOC, TURB and TRU\_CLR and inversely related to Ph, SECCHI, and DEPTH. Notably, chlorophyll a concentrations were most strongly correlated (inversely) with TN/TP which accounted for 74% ( $p=.0001$ ) of the variation among embayments in a single variable model (not shown).

|                 | Ph              | TOC            | SECCHI          | TURB           | TRU_CLR        | TOT-P          | ORGAN          | TOT-N          | DEPTH           | TN/TP           |
|-----------------|-----------------|----------------|-----------------|----------------|----------------|----------------|----------------|----------------|-----------------|-----------------|
| EMBAYMENTS CHLA | -.6161<br>.0084 | .8178<br>.0001 | -.7678<br>.0003 | .7787<br>.0002 | .6726<br>.0031 | .7020<br>.0017 | .7620<br>.0004 | .6214<br>.0078 | -.6504<br>.0047 | -.8600<br>.0001 |

|                   | TEMP           | Ph             | X-AREA         | SECCHI          |
|-------------------|----------------|----------------|----------------|-----------------|
| MAIN CHANNEL CHLA | .7827<br>.0075 | .8029<br>.0052 | .7098<br>.0215 | -.7127<br>.0207 |

#### Relationships Among Fish Parameters, Phytoplankton, and Macrophytes

The correlation structure among fish parameters revealed significant inverse correlations existed between HEALTH and SIZE and between DENSITY and SIZE.<sup>1</sup> %MACROS was positively correlated with DENSITY.

|         | HEALTH          | SIZE            | DENSITY         |
|---------|-----------------|-----------------|-----------------|
| %MACROS | -.3025<br>.2732 | -.1555<br>.5513 | .4910<br>.0453  |
| HEALTH  |                 | -.6169<br>.0143 | .3544<br>.1950  |
| SIZE    |                 |                 | -.7466<br>.0006 |

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<sup>1</sup>The fish health index is inversely related to the health of the fish.

The correlation structure suggested that embayments with greater fish densities tended to have fish of poorer health, smaller size, and were often associated with greater percent macrophyte coverage. Embayments with fewer fish tended to have larger fish with better overall health.

|         | CHLORO          | CHRYSO          | CRYPTO          | CYANO           | EUGLENO         | PYRRO           | TOTAL           | CHLA            |
|---------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| %MACROS | -.0282<br>.9144 | -.4272<br>.0872 | -.4272<br>.0872 | .3204<br>.2099  | -.3002<br>.2416 | .1765<br>.4980  | .2421<br>.3491  | -.4833<br>.0494 |
| HEALTH  | -.5805<br>.0233 | -.0570<br>.8402 | .0105<br>.9703  | -.5544<br>.0320 | .1907<br>.4960  | .0369<br>.8962  | -.6010<br>.0178 | -.0478<br>.8656 |
| SIZE    | .5506<br>.0220  | .3381<br>.1844  | .0864<br>.7417  | .3534<br>.1641  | .4086<br>.1035  | .2574<br>.3187  | .4388<br>.0780  | .2940<br>.2520  |
| DENSITY | -.6621<br>.0038 | -.3440<br>.1764 | -.3945<br>.1171 | -.3620<br>.1533 | -.5952<br>.0117 | -.3569<br>.1587 | -.4792<br>.0516 | -.5694<br>.0224 |

Total phytoplankton density was inversely related with HEALTH (-.60) as were CHLORO and CYANO. Size was positively correlated with CHLORO. DENSITY was inversely correlated with all division with significant negative correlations exiting with TOTAL, CHLORO, and EUGLENO. High phytoplankton densities, as related to this study, appeared to have little adverse effect upon fish health.

#### Relationships Between Macrophytes and Water Quality

Macrophytes have a strong significant correlation with SECCHI, and a strong inverse relation with TURB and TRU\_CLR. A model for percent macrophyte coverage

including TOC and TURB accounted for 89% ( $p=.0001$ ) of the difference among embayments.

$$\% \text{ Macrophyte Coverage} = -1.56 + 10.12(\text{TOC}) - 3.41(\text{TURB})$$

|         | TURB            | SECCHI         | TEMP           | Ph             | COND            | TOT_P           | ORTHO           | TRU_CLR         | TOT_N           | CHL_a           |
|---------|-----------------|----------------|----------------|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| % MACRO | -.7640<br>.0009 | .7271<br>.0009 | .6188<br>.0081 | .5804<br>.0146 | -.5761<br>.0155 | -.5920<br>.0123 | -.6577<br>.0041 | -.7109<br>.0014 | -.5688<br>.0172 | -.4833<br>.0494 |

### Relationships Between Phytoplankton And Land-Use

Few statistically significant relations occurred between algal divisions and percent land-use. Percent urban land-use had no significant correlations with phytoplankton divisions. Percent cropland had a positive correlation with all divisions and significant correlation with CHLORO, CYANO, and TOTAL. Percent land-use in pasture had a positive correlation with all divisions and a significant correlation with CRYPTO, EUGLENO, and CHLA. Percent forestland had a negative relationship with all divisions and significant negative correlation with EUGLENO and CHLA.

|         | CHLORO          | CHRYSO          | CRYPTO          | CYANO           | EUGLENO         | PYRRO           | TOTAL           | CHLA            |
|---------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| URBAN   | -.0361<br>.8905 | .1509<br>.5632  | -.2447<br>.3438 | -.1065<br>.6842 | -.0481<br>.8546 | .4403<br>.8667  | -.0295<br>.9106 | -.1468<br>.5740 |
| CROP    | .5868<br>.0133  | .1574<br>.5462  | .3293<br>.1968  | .6001<br>.0109  | .4532<br>.0677  | .2821<br>.2727  | .6278<br>.0070  | .3424<br>.1785  |
| PASTURE | .2940<br>.2520  | .0466<br>.8590  | .5161<br>.0339  | .2022<br>.4364  | .5322<br>.0279  | .1328<br>.6114  | .2367<br>.3603  | .5544<br>.0209  |
| FOREST  | -.2891<br>.2604 | -.2298<br>.3749 | -.3519<br>.1661 | -.2577<br>.3180 | -.5249<br>.0305 | -.2249<br>.3855 | -.3389<br>.1832 | -.4289<br>.0850 |

Urban land-use appeared to have little dominant effect on the algal community. As cropland increased, phytoplankton densities increased with greater increases occurring in CHLORO and CYANO. As pastureland increased, so did CHLA and phytoplankton densities with significant increases occurring in CRYPTO and EUGLENO. Forested land appeared to yield lower phytoplankton densities and lower CHLA levels than other land-uses, with significant negative affects to EUGLENO.

#### Relationships Between Land-Use And Environmental Factors

Percent urban land-use was not significantly correlated with any other variable. Percent cropland correlated significantly with NO2 and fish Health. Percent pastureland had significant positive correlation with COND, NH3, TOC, TURB, TRU\_CLR, ALK, ORGAN, and TOT\_N; and significant negative correlation with pH, SECCHI, FOREST, DEPTH, DENSITY and %MACROS. Percent forestland had significant correlation with SECCHI, TURB, TOC, NH3, ORGAN, TOT\_N, PASTURE, DEPTH, and fish SIZE and DENSITY.

|       |               |        |
|-------|---------------|--------|
|       | NO2           |        |
| %     | .4436         |        |
| URBAN | .0745         |        |
|       | NO2    HEALTH |        |
| %     | -.4390        | -.8243 |
| CROP  | .0779         | .0002  |

|         | PH     | COND   | SECCHI | TURB    | TUR-CLR | TOC   | NH3   | ORGAN | TOT_N |
|---------|--------|--------|--------|---------|---------|-------|-------|-------|-------|
| %       | -.4506 | .5844  | -.8066 | .7574   | .5702   | .7140 | .6255 | .5565 | .5670 |
| PASTURE | .0695  | .0138  | .0001  | .0004   | .0169   | .0013 | .0072 | .0203 | .0176 |
|         | FOREST | DEPTH  | MACROS | DENSITY |         |       |       |       |       |
| %       | -.6722 | -.6426 | -.5079 | -.5361  |         |       |       |       |       |
| FOREST  | .0013  | .0054  | .0374  | .0265   |         |       |       |       |       |

|        | SECCHI | TURB   | TOC    | NH3    | ORGAN  | TOT_N  | PASTURE | SIZE   | DENSITY |
|--------|--------|--------|--------|--------|--------|--------|---------|--------|---------|
| %      | .5991  | -.5725 | -.4992 | -.7324 | -.5296 | -.5584 | -.6722  | -.4435 | .5800   |
| FOREST | .0110  | .0163  | .0413  | .0005  | .0288  | .0198  | .0031   | .0745  | .0147   |

The correlations for land-use indicated that embayments with greater percent pastureland tended to be more shallow, more turbid, and more nutrient enriched; contained less macrophyte coverage; had greater chlorophyll a content; and contained greater cryptophyte and euglenophyte composition than other embayments. Land-use correlations also indicated that as embayments increased in percent forestland they tended to have greater water depth, less turbidity and be less nutrient enriched; contained more macrophyte coverage; had less chlorophyll a content; and contained lower phytoplankton densities with significantly less euglenophyte composition. Embayments with greater percent cropland tended to have less NO<sub>2</sub> concentrations; fish with better health; greater total phytoplankton densities which were composed largely of cyanophytes, chlorophytes, and euglenophyte with decreased chrysophyte composition. Watersheds of increased urban land-use tended to have higher NO<sub>2</sub> concentrations with no dominant effects on the algal community.

## CHAPTER V

### DISCUSSION

The phytoplankton correlation structure for both the main channel and embayments has shown all divisions to have a positive correlation with total phytoplankton density. This fact indicated that environments influencing growth in one division tend to similarly influence growth in all divisions, albeit of different intensities. This difference in intensity governs community structure.

Reviewing the correlation matrix among divisions and between divisions and chlorophyll a reveals strong significant correlations for all divisions within the main channel matrices and diverse correlations within the embayment matrices. Chlorophyll a had highly significant correlations with all divisions and total density in the main channel and only significant correlations with euglenophytes and cryptophytes in embayments. The primary differences are the predominant effect of turbulence (flow vs. cross-sectional area) on the phytoplankton community within the main channel, and that the main channel sites represent a community developing on a interacting continuum. Embayments contained individually developing communities and generally had greater productivity than the main channel (Figure 18,19). Diversity in the

embayment correlations indicated communities were governed by a variety of controlling factors. Main channel sites generally had higher concentrations of available nutrients ( $\text{NO}_2$ ,  $\text{NH}_3$ , and  $\text{PO}_4$ ), while the embayments had higher organic nutrients and higher organic carbon, indicating embayment communities were more regulated by nutrient competition. Hydraulic mixing as a controlling factor within embayments was not accounted for. Creek flow into embayments was not significantly correlated with any other variables. However, detention time had a significant inverse correlation with nutrient levels and positive correlation with water clarity indicating nutrient replenishment from the surrounding watershed and/or nutrient depletion through algal growth. Detention time had no significant correlations with phytoplankton divisions, but had higher correlations with cyanophyte and pyrrophytes ( $r=0.40$   $p=0.11$ ,  $r=0.47$   $p=0.06$ ; respectively).

Flow ( $\text{m}^3/\text{sec}$ ) could not account for the importance of hydraulic mixing as a light-limiting factor within the main channel of a single reservoir study. Therefore, cross-sectional area was substituted for flow. Simply, a given volume of water through a smaller section of a reservoir produces greater turbulence than the same volume through a larger section. The predominance of hydraulic mixing in limiting productivity was shown by the strong positive correlation found between cross-sectional area

and total phytoplankton densities, division densities, chlorophyll a, temperature and pH.

Phytoplankton and chlorophyll a correlations with cross-sectional area would probably be greater if not for the epilemnetic discharge received from the Watts Bar Reservoir forebay. Epilemnetic discharge caused phytoplankton densities (Figure 18) and chlorophyll a concentrations (Figure 19) to be high at TRM 529.9, but decreases occurred in the river reach from TRM 529.9 to 506.5 because hydraulic mixing remained sufficient to limit light exposure even though the cross-sectional area increased. Phytoplankton productivity in this reach was more controlled by physical factors rather than nutrient concentrations; therefore, this reach could be classified as riverine (Figure 23).

Productivity remained low until mixing was reduced to the point algal cells remained in the photic zone long enough to sustain growth and reproduction. This transition appeared to have happened by TRM 496.5 where densities and chlorophyll values began to increase. Greater mean chlorophyll a concentrations at TRM 490.5 most likely indicated elevated productivity due to the increased availability of light and nutrients. Other known potential contributors to the increased production

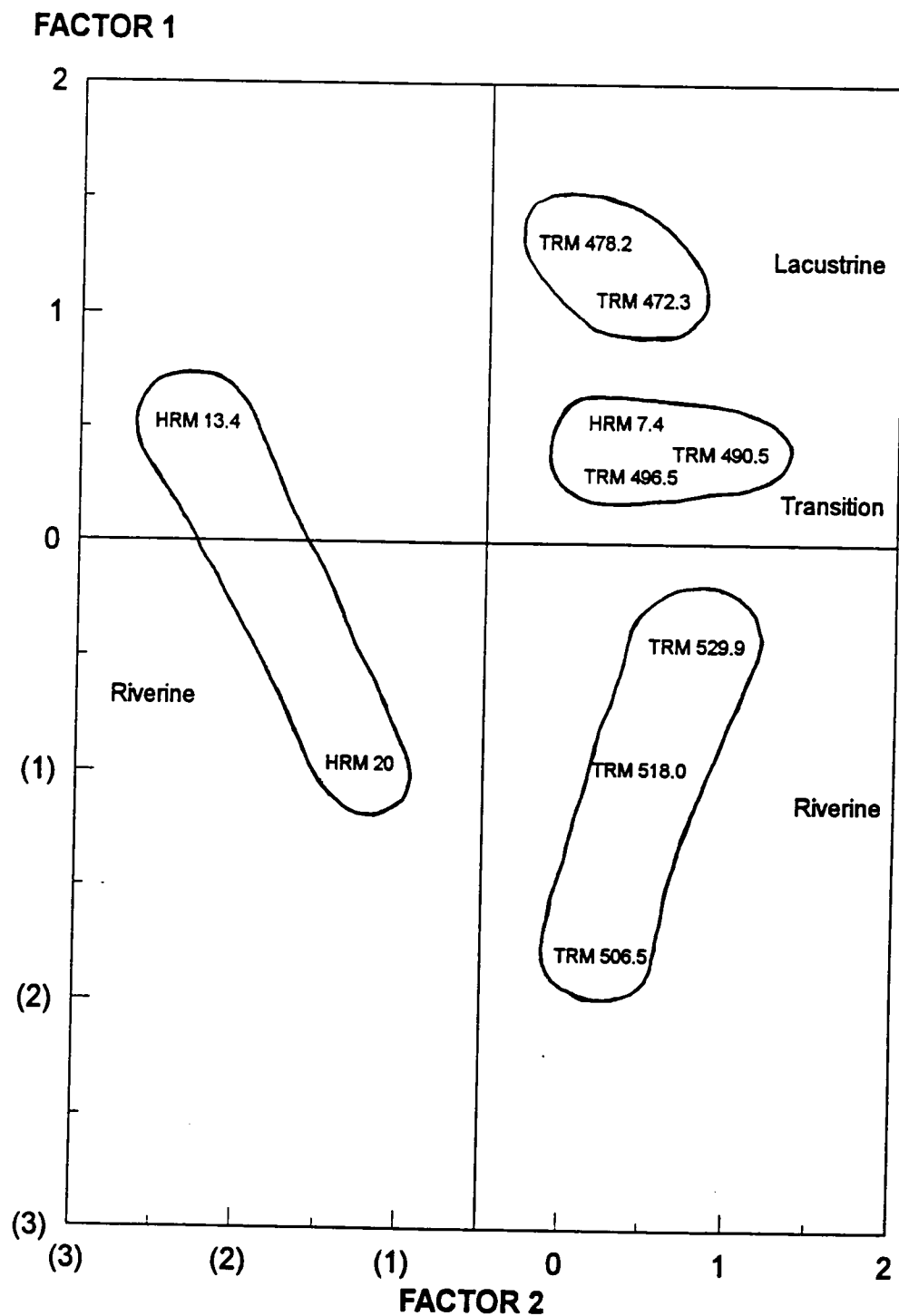


Figure 23. Factor patterns of mean phytoplankton division densities in Chickamauga Reservoir's main channel with riverine, transition, and lacustrine classifications.

at TRM 496.5 were: 1) Dayton's municipal sewage (tertiary) treatment discharge at TRM 503, and 2) the confluence of Hiwassee River at TRM 499.4.

Mean nitrogen levels (all forms, Figures 7,8,9,10) dropped from TRM 506.5 to 496.5, but orthophosphate and total phosphorus increased (Figures 11 and 12, respectively). Phosphorus concentrations began increasing prior to the municipal sewage discharge and the Hiwassee River confluence. Due to spatial differences between channel sites, chemical and biological changes certainly occurred and precluded any definitive statement concerning the contribution of the municipal discharge and the Hiwassee confluence to productivity. TRM 490.5 had the highest mean chlorophyll a levels among channel sites, indicating the highest productivity and possibly reflecting the most optimal light and nutrient conditions among channel sites. Lower chlorophyll a downstream of 490 and decreasing algal populations at TRM 472.3 may be the result of increased competition for nutrients. Mean total nitrogen and total phosphorus began to decrease at TRM 496.5 and continued decreasing into the forbay indicating a potential for nutrient limitation. The high TN/TP ratio (Figure 13) of 40 at TRM 472.3 supports strong phosphorus limitations.

Phytoplankton productivity at TRM 472.3 and 478.2 appeared more regulated by increased competition for

available resources. The Hiwassee river stations showed the same increased productivity from upstream to downstream, but competition for nutrients was not as evident. Reductions in available nutrient forms occurred due to increased productivity. Some of the large measured differences in water quality from HRM 20 to HRM 13.4 were due to discharges from: 1) paper mill settling ponds at HRM 16.5, 2) a chemical company located at HRM 16, and 3) the Cleveland Municipal Waste Treatment discharge at HRM 15. HRM 13.4 was still highly influenced by hydraulic mixing and the overall effect of these perturbations were not apparent within the phytoplankton community until HRM 7.4, where productivity certainly benefitted from the increase nutrients.

The dominance of hydraulic mixing was also revealed in the models for main channel factors 1 and 2, which included cross-sectional area. No significant correlation was found between channel factors and nutrient variables. However, the model for Factor2 did include an inverse relationship with  $\text{NH}_3$  and positive relationship with  $\text{TOT}_\text{N}$ . The direct relationship with  $\text{TOT}_\text{N}$  probably reflected increased algal biomass, while  $\text{NH}_3$  was being incorporated, given Factor2's significant relation to total density. Figure 8 and 9 showed increasing  $\text{NH}_3$  and decreasing organic nitrogen concentrations from 529.0 to 506.5 as phytoplankton densities decreased, and the

subsequent decrease in  $\text{NH}_3$  and increase in organic nitrogen as populations increased into the forebay.  $\text{NO}_2$  concentrations (Figure 7) mimicked the same patterns as  $\text{NH}_3$ .

The longitudinal difference in hydraulic mixing within the main channel was the predominant factor controlling light and nutrient availability, and thereby, established the spatial heterogeneity found in channel productivity. As concluded by Kimmel and Groeger (1991), these longitudinal differences must be given consideration before interpreting the relationships of biological and chemical factors and to appropriately use empirical models and indices.

Factor analysis applied to phytoplankton divisions for main channel sites and embayments sites separately revealed differences in phytoplankton communities among locations. As previously stated, correlations were greater among divisions within the main channel than they were for embayments. However, stronger relationships between cryptophytes and euglenophytes, and between cyanophytes, pyrrophytes, and total density, were evident for both the main channel and embayment sites. Chlorophytes were relatively abundant in all environments. Chrysophyta, within embayments, was the only division which did not have a significant positive correlation with total density.

Embayment Factor1 revealed strong relationships between cyanophytes, chlorophytes, and pyrrophytes, and were highly correlated to total phytoplankton density. These communities relationships were more prominent in low orthophosphate and low nitrite+nitrate environments with higher organic nitrogen concentrations. This suggested that the phosphate and nitrate were being depleted as populations increased. All embayments, except North Mouse and South Mouse, fell well below the critical limit levels for  $\text{NO}_2$  (Figure 7) of 0.3 to 0.2 mg/l proposed by Hannan et al. (1973).

Negative correlations between cyanophyte densities and/or total densities with orthophosphate concentrations have been found in previous studies (Jackson 1964, Haertel 1976, Wade 1984). Both the negative correlations with ORTHO and  $\text{NO}_2$  may be attributed to the fact phytoplankton can procure phosphorus (Jackson 1964, Haertel 1976, Rhee and Gotham 1980) and nitrogen (Rhee and Gotham 1980, Lean et al. 1982) in excess of immediate needs and utilizing it later when supplies are limiting. Furthermore, this may reflect the ability of phytoplankton to maintain nearly maximum growth rates at very low levels of ambient nutrients due to the recycling of nutrients (Erga 1989). Mean concentrations of  $\text{NH}_3$  (Figure 8) were often below the detection limit and preclude any statements of its value as an alternative source.

A shift to cyanophyte dominance in the summer months is common in most all Tennessee Valley reservoirs. The predominance of cyanophytes during low nutrient concentrations has been established, though cause and effect relationships are not fully understood. Some of the factors Wade (1984) attributed with the onset of cyanophyte dominance were increased detention time, low orthophosphate concentrations preceded by high concentrations, and declining  $\text{NO}_2$  concentrations. Cyanophyte composition often decreases when nutrients are more available because they lose their competitive advantage. Although a limited number of species have been studied, cyanophytes have been found as superior nitrogen competitors, while chlorophytes are dominant over cyanophytes in phosphorus competition (Sommer 1989). Pyrrophytes have also been found to predominate when nutrients are low; in nutrient studies they have been found to better exploit low nutrient concentrations than other phytoplankton groups (Erga 1989). Studies conducted on the cause of red tides have pointed out that pyrrophyte blooms are often associated with high temperatures and increased light intensity and are preceded by an increase in available nutrients followed by their reduction before pyrrophyte blooms occurred (Cullen et al. 1982, Lee 1989). However, their contribution to the overall productivity within the Tennessee Valley reservoirs remains extremely

low and usually comprises less than 3% of the community composition.

Other factors or a combination of factors must be limiting pyrrhophyte production. Interestingly, Horstmann (1980) noted diurnal migration patterns of pyrrhophytes in relation to solar radiation and their ability to attach to solid objects. Peridinium quinquecorne detached and moved into the water column during direct sunlight, but remained settled when it was cloudy. Notably, the organisms migrated to a distinct near-surface layer. Potentially, pyrrhophytes composition may be reduced due to sampling methods, although it is probable that the percent composition would still be low.

Cryptophyta and Euglenophyta were favored in more shallow environments with greater turbidity, higher nitrogen and phosphorus concentration, higher organic carbon and lower pH and alkalinity. These conditions were also associated with pastured land and reduced under forested conditions. Cropland was associated with higher phytoplankton densities, and was more conducive to cyanophytes and chlorophytes. Cropland only correlated significantly with (-)NO<sub>2</sub>. Runoff from cropland may have had greater effects during early spring cultivation and late summer early fall during harvest with reduced effects during crop growth. Rainfall events could produce the peak nutrient loads that would be conducive to

phytoplankton growth, but a reduction in available nutrients between rains would occur as algal production increase; therefore, this could be more conducive to cyanophytes, chlorophytes, and pyrrophytes.

Pastureland would undergo fewer changes, but runoff from feed lots and/or heavily grazed pastures along with cattle having direct access to water sources (embayments directly or tributaries) could increase potential year round effects. Cyanophyte and pyrrophyte may not be as favored in the higher nutrient conditions associated with pastureland because they lose their competitive advantage. Euglenophytes are often more prominent in environments rich in organic matter (Kolkwitz and Marrson 1970, Lee 1989). This is support by euglenophytes significant positive and negative association with pastureland and forestland, respectively. Embayments with greater percent pastureland also tended to have shallower mean depths in which the recirculation of nutrients from sediments could have contributed to their overall production. Mean depth and pastureland are interrelated and both correlated significantly with nutrients, embayment factor1, and chlorophyll a concentrations. Urban land-use had no significant correlations. The effects of urban land-use may be overshadowed by the effects of agricultural runoff. Embayments of increased forestland had reduced nutrient

concentrations and yielded lower phytoplankton production, with significant reductions in euglenophytes.

Although the percent land-use characteristics in this study were simplistic, in general, the relationships found are supported by other studies. Beaulac and Reckhow (1982) compared data from many land use-nutrient export studies and found increasing nutrient exports (median value) from forest to pasture, urban, row crop, and highest exports from feedlot/manure storage. Forested watersheds were found to yield lower total nitrogen and total phosphorus than all other land uses, significantly lower than all others uses except pasture. However, a distinction was made between pasture and feedlot/manure storage which was not made in this study. Nutrient exports from feedlot/manure storage were several orders of magnitude higher than all other land uses. Combining the two categories would yield results more similar to this study, with 'pasture' having higher exports. Urban land-use had low median values, but exhibited a relatively wide range of values. Beulac and Reckhow (1982) noted that a majority of the export values came from suburban-residential watersheds, which tend to have a low impact, as compared to commercial-industrial activities. A majority of the urban land-use in the present study would be classified suburban-residential, and may further help

explain the the lack of significant relationships between urban land-use and other variables.

Chrysophytes were favored by high temperatures and high total phosphorus concentrations. The greatest mean densities occurred in Savannah Bay and South Mouse Creek with mean total phosphorus concentrations of .042 and .120 mg/L, respectively. Wade (1984) also found association between chrysophytes and total phosphorus concentrations such that the greatest densities occurred at concentrations above .05 mg/L.

Chlorophyll a concentrations are often strongly correlated with algal biomass (Canfield 1985). Thus, chlorophyll a is commonly used is as an index of algal biomass or primary production. The relationships between chlorophyll a and environmental variables within the main channel and within the embayments were extremely different. Main channel chlorophyll a only had significant correlation with temperature, pH, cross-sectional area, and Secchi and has been discussed. Embayment chlorophyll a correlated strongly with nutrient factors (total phosphorus +; total nitrogen +; organic nitrogen +), total organic carbon (+) , water clarity (turbidity +; true color +; Secchi (-), and pH (-) and depth (-). The greater nutrient concentrations allowed greater photosynthesis and increased algal biomass, which consequently would increase organic carbon and organic

nitrogen concentrations, and decrease water clarity. Chlorophyll's negative correlation with pH was not expected. The association of chlorophyll a with high nutrients and turbidity, which have significant positive correlations with total hardness, indicated increased dissolved solids which could reduce pH shifts that occur during photosynthesis. Negative correlation with depth may be explained from the interaction of increased nutrient loads from pastureland and greater potential for the recycling of nutrients from sediments in shallower embayments.

Correlation between embayment chlorophyll a and total phytoplankton densities was lacking. Cellular chlorophyll of different taxa of algae can vary potentially influencing the chlorophyll-biomass ratios. Chlorophyll content was also affected by nutrient-light relationships. Cyanophyta densities had the lowest correlation with chlorophyll a and highest correlation with total density. Canfield et al. (1985) found cyanophytes to have the lowest average chlorophyll content per unit biomass, but not statistically significant from the other groups (Bacillariophyta, Chlorophyta, Pyrrophyta) studied. Studies have shown that over a wide range of natural phytoplankton assemblages, the chlorophyll content per unit of phytoplankton biomass has not been strongly

influenced by the taxonomic composition of the phytoplankton sampled (Canfield et al. 1985).

Since biomass was not determined in this study, a direct relationship cannot be established. However, cyanophytes contributed most to maximum phytoplankton densities based on cell numbers and contribution to overall biomass would not be proportionally as great due their relatively small cell size. Wade (1984) found a lack of correlation between maximum phytoplankton abundances, composed mainly of cyanophytes, and chlorophyll a. He also attributed the poor correlation to the smaller individual size of the blue-green cell and to potential nutrient stress due to nutrient depletion. Nutrient limitation could also be a factor in this study given the strong positive relationship between chlorophyll a and nutrients, the lack of correlation between chlorophyll a and total density, and the inverse relation between total density and nutrients.

Studies have shown that fish biomass generally increases with increased primary production (Larkin and Northcote 1967, Oglesby 1977). However, a shift in fish composition can also accompany increase primary production, especially in highly eutrophic waters, from desired game fish to populations dominated by rough fish (O'Brien 1990, Lee and Jones 1992).

Although the limitations of this study are acknowledged due to the lack of information on fish composition and the time scale of the study, relationships found within embayments of forested, cropped, and pastured watersheds potential reflect changing conditions from oligotrophic to more eutrophic systems, respectively.

Fish health was better and fish densities lower in embayments with greater total phytoplankton densities. A positive relationship existed between fish densities and percent macrophyte coverage, and between fish densities and percent forestland; and all were inversely related to chlorophyll a and turbidity. Although forestland was not significant related to macrophytes, a positive relationship did exist. Soddy, Possum and Sale Creeks, which had greater than 70% forestland, also had the highest macrophyte coverage, ranging from 16 to 34%, and the highest fish densities. Fish densities and forestland were inversely related to phytoplankton densities, while macrophytes had a positive association with cyanophyte and pyrrophyte.

Positive relationships between macrophyte densities and fish abundance have been reported. Macrophytes can provide protection for smaller fish, and spawning and foraging areas (Furse et al. in press). However, the effects of macrophytes on both fisheries and phytoplankton are complex and can depend on macrophyte species and

densities, as well as overall nutrient availability (Lodge et al. 1988, Kilgore et al. 1989).

Fish density was inversely related to percent pastureland, which was more shallow with greater turbidity and less macrophyte coverage. Fish densities could have been lowered due habitat loss (macrophytes) or from negative effects of increased turbidity. Increased turbidity, associated with increased algal growth or abiotic turbidity can reduce the grazing ability, by reducing vision, of piscivorous and insectivorous fish (O'Brien 1990, Lee and Jones 1992). Turbidity could favor planktivorous (i.e., clupeids) fish which can filter feed without visual location. However, increases in planktivorous fish would be expected with decreased predation and a increase in productivity.

Fish densities may have been lower due to the limitations of the hydroacoustic system, which may affect fish density estimates more in shallower water. The system was unable to detect fish within the first 1.0 m from the transducer, plus the transducer must be submersed. This 'dead-area' would account for more of the water column in shallower embayments. Fish in shallower embayments may also be more disturbed by the boat.

Increases in cropland indicated increased phytoplankton densities and fish in much better health. Weak associations also occurred between cropland and fish

densities ( $r = -0.23$   $p = 0.38$ ), fish size ( $r = 0.41$   $p = 0.10$ ) and higher macrophyte coverage ( $r = 0.37$   $p = 0.14$ ). These relationship suggested that runoff from cropland increased an embayment's primary production, but not to levels detrimental to the health of fish.

## CHAPTER VI

### SUMMARY

1. Main channel phytoplankton productivity and community composition were influenced predominately by the degree of hydraulic mixing (cross-sectional area) which occurred. Main channel chlorophyll a was highly correlated to all phytoplankton divisions. No significant correlations existed among nutrient factors and phytoplankton divisions or chlorophyll a.

2. Main channel sites conformed to the river-lake hybrid scenario, developing an interacting continuum from riverine ecosystem through transition to lacustrine ecosystem from the headwaters to the forebay, which developed along a continuum of increasing cross-sectional area.

3. Phytoplankton within the riverine section were light limited due to hydraulic mixing. The riverine zone had higher available nutrient ( $\text{NO}_2$ ,  $\text{NH}_3$ , and  $\text{PO}_4$ ) concentrations with lower primary production.

4. The transition zone had the highest chlorophyll a concentrations among channel sites, indicating the highest productivity and possibly reflecting the most optimal combination of light and nutrients among channel sites.

5. Lacustrine zone's lower nutrient levels, lower chlorophyll a, and decreasing phytoplankton densities indicated nutrient competition as the controlling factor.

6. Embayment phytoplankton communities were highly influenced by nutrient availability. Embayments generally had: 1) higher phytoplankton densities, 2) higher chlorophyll a concentrations, 3) higher organic nutrient levels, 4) higher organic carbon, and 5) lower  $\text{NO}_2$ ,  $\text{NH}_3$ , and  $\text{PO}_4$  concentrations than the main channel.

7. Main channel phytoplankton community relationships were significant ( $p < 0.05$ ) among all phytoplankton divisions, but stronger associations existed between cryptophytes and euglenophytes and between cyanophytes and pyrrophytes, while chlorophytes and chrysophytes correlated equally with both groups.

8. Embayment community relationships were stronger among: 1) cyanophytes, pyrrophytes, chlorophytes, and total density, and were associated with low orthophosphate and low nitrite-nitrate environments; 2) cryptophytes and euglenophytes, which were associated with low water clarity and higher nutrients; and 3) chrysophytes which were associated with high temperatures and high total phosphorus concentrations.

9. Embayment chlorophyll a was highly correlated to cryptophyte and euglenophyte densities, high nutrients, low water clarity, and high organic carbon. Chlorophyll

was inversely related to total density, potentially because of: 1) the lower biomass of contributed by smaller celled cyanophytes, which were associated with higher densities, and 2) the lower available nutrient concentrations, which were associated with higher densities.

10. Macrophyte growth was best in embayments with lower turbidity, obtaining greater than 15% coverage in embayments with turbidities less than 3 (NTU). Macrophyte coverage of less than 3% occurred with mean turbidities ranging from 8 to 39 (NTU). No significant relationship existed between percent macrophyte coverage and phytoplankton divisions. Chlorophyll a levels showed a significant inverse relationship.

11. Percent urban land-use had no significant relationships with other variables. Two factors are attributed: 1) a majority of the urban classification was composed of suburban-residential development as compared to commercial-industrial, and therefore would have a lower impact; and 2) agricultural practices are believed to overshadow effects from urban runoff in mixed watersheds.

12. Percent crop land-use was associated with higher phytoplankton densities, and more conducive to cyanophytes and chlorophytes over other divisions due to increased competition for available nutrients. Percent cropland was also highly correlated with good fish health, which may

reflect good primary production, but without significant deleterious effects to water quality.

13. Embayments of watersheds with greater pastureland tended to be more shallow and turbid with greater nutrients and chlorophyll a concentrations, and were more conducive to cryptophytes and euglenophytes. The turbidity limited macrophyte coverage and may have contributed to lower fish densities.

14. Forested land yielded lower phytoplankton production due to lower nutrient concentrations, and had significant reductions in euglenophyte densities. Fish densities increased in possible association with the greater macrophyte coverage which occurred in more heavily forested watersheds.

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## APPENDIXES

APPENDIX A  
MEAN PHYTOPLANKTON DIVISION DENSITIES

Mean phytoplankton division densities (cells/L) at the 1-m depth in Chickamauga Reservoir, April through September 1990.

| STATION          | CHLOROPHYTA | CHRYSOPHYTA | CRYPTOPHYTA | CYANOPHYTA | EUGLENOPHYTA | PYRROPHYTA | TOTAL      |
|------------------|-------------|-------------|-------------|------------|--------------|------------|------------|
| TRM 472.3        | 2371445.7   | 1678457.7   | 743943.0    | 8542096.2  | 75413.4      | 23439.3    | 13434795.3 |
| TRM 478.2        | 2779085.7   | 1972977.6   | 706236.3    | 8218022.4  | 68279.7      | 12229.2    | 13756830.9 |
| TRM 490.5        | 2451954.6   | 1560242.1   | 505473.6    | 7528091.7  | 50955.0      | 31592.1    | 12128309.1 |
| TRM 496.5        | 1658353.6   | 1341506.2   | 375214.1    | 5441994.0  | 52807.9      | 17602.6    | 8887478.4  |
| TRM 506.5        | 703179.0    | 602288.1    | 96814.5     | 2448897.3  | 8152.8       | 6114.6     | 3865446.3  |
| TRM 518.0        | 1077706.5   | 781152.9    | 177841.1    | 5085338.2  | 16306.3      | 8153.0     | 7146498.0  |
| TRM 529.9        | 1424478.3   | 1136305.2   | 207785.1    | 6580565.9  | 44727.2      | 16985.1    | 9410846.9  |
| SALE CREEK       | 2317062.8   | 1767212.1   | 241341.4    | 11781259.2 | 65778.3      | 18529.1    | 16191182.9 |
| POSSUM CREEK     | 1790558.7   | 1712088.0   | 149807.7    | 6146192.1  | 21401.1      | 5095.5     | 9825143.1  |
| SODDY CREEK      | 2277436.0   | 2082280.2   | 258088.4    | 8007580.7  | 39745.2      | 17579.6    | 12682710.0 |
| DALLAS BAY       | 2897301.3   | 2986982.1   | 388277.1    | 15611592.9 | 72356.1      | 60126.9    | 22016636.4 |
| WOLFFTEVER 4.1   | 3781880.1   | 2468260.2   | 250698.6    | 22646440.2 | 133502.1     | 70317.9    | 29351099.1 |
| WOLFFTEVER 5.5   | 4285315.5   | 2412209.7   | 360761.4    | 31265988.0 | 125349.3     | 35668.5    | 38418622.6 |
| SAVANNAH BAY     | 4738815.0   | 5792564.4   | 452480.4    | 31567641.6 | 148788.6     | 49935.9    | 42750225.9 |
| WACONDA BAY      | 2989031.8   | 2467771.8   | 406633.2    | 15729883.5 | 145733.0     | 39745.2    | 21778798.5 |
| RICHLAND CREEK   | 4749006.0   | 2036091.0   | 457066.4    | 33180202.0 | 117196.5     | 36687.6    | 40576249.4 |
| MUD CREEK        | 3586305.6   | 1735249.4   | 373361.2    | 35341461.6 | 191776.1     | 40764.0    | 41268917.7 |
| GOODFIELD CREEK  | 4523784.9   | 1858838.4   | 467766.9    | 22573065.0 | 172227.9     | 20382.0    | 29616065.1 |
| HRM 7.4          | 2307343.6   | 1352635.9   | 415522.2    | 7285187.7  | 49103.6      | 12970.8    | 11422763.8 |
| HRM 13.4         | 755986.9    | 487315.1    | 225128.5    | 739310.7   | 24087.8      | 926.5      | 2232755.5  |
| HRM 20.0         | 639488.7    | 340890.0    | 135035.2    | 908533.7   | 8662.6       | 2547.8     | 2035158.0  |
| GUNSTOCKER CREEK | 3338942.6   | 2635763.2   | 585519.3    | 19273033.9 | 184364.5     | 24087.8    | 26041711.2 |
| AGENCY CREEK     | 3037844.5   | 1623148.4   | 652224.0    | 14453617.4 | 197334.8     | 31777.4    | 19995946.4 |
| ROGERS CREEK     | 3184224.3   | 2234608.4   | 661488.6    | 11266613.7 | 154717.9     | 40764.0    | 17542416.8 |
| CANDIES CREEK    | 2725181.9   | 1707470.4   | 441001.6    | 10652871.1 | 129242.6     | 25941.3    | 15681708.8 |
| N. MOUSE CREEK   | 1805659.9   | 1033923.3   | 341861.7    | 3051741.3  | 45396.3      | 4632.3     | 6283214.7  |
| S. MOUSE CREEK   | 3001712.7   | 3893878.6   | 521595.4    | 3900373.6  | 164908.9     | 14823.3    | 11497292.6 |

APPENDIX B  
ESTIMATED CREEK FLOWS FOR EMBAYMENTS

Estimated average creek flows into Chickamauga Reservoir  
embayments, 1990 water year.

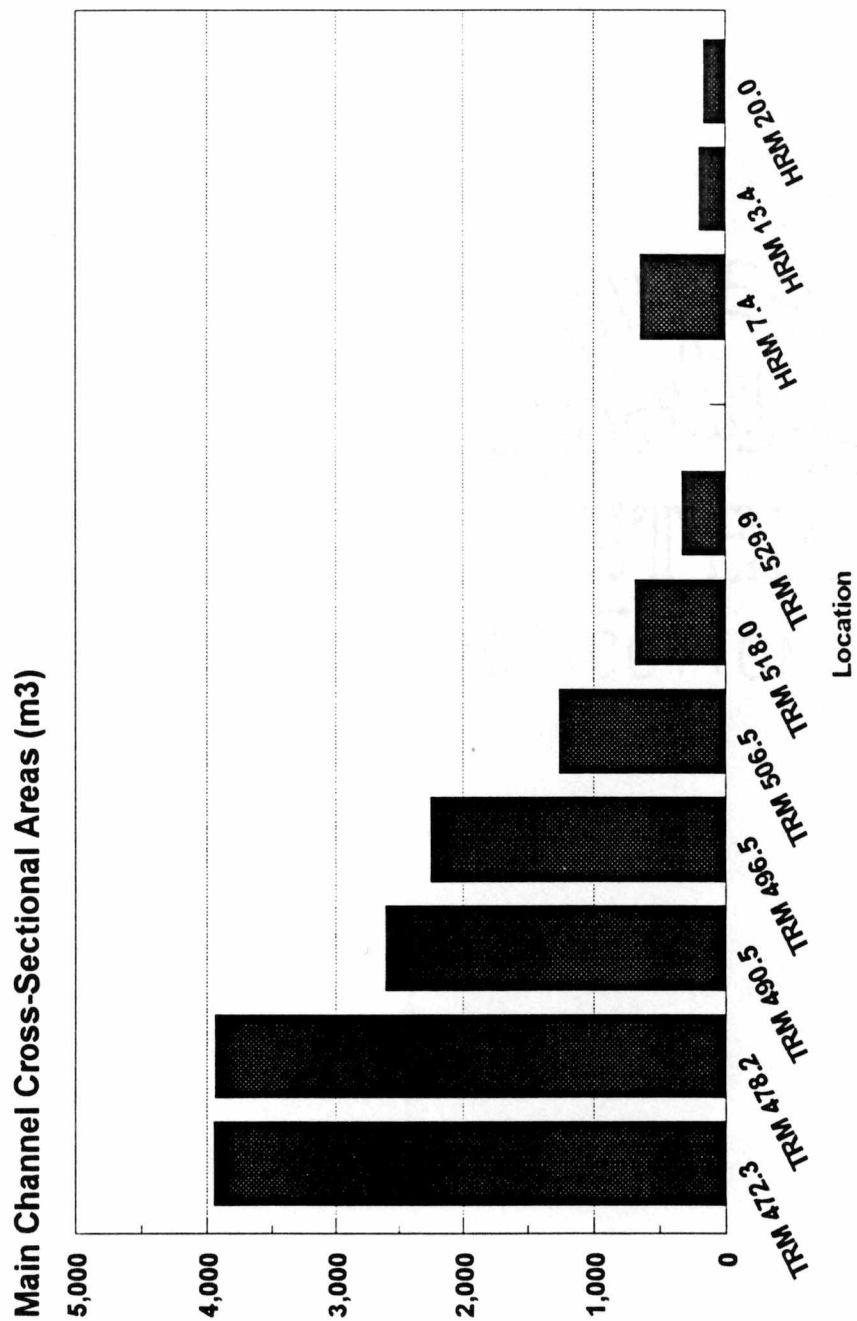
| Embayment           | Drainage Area<br>(sq.mi.) | Average Annual<br>Flow**<br>(cfsm) |
|---------------------|---------------------------|------------------------------------|
| Waconda Bay         | 2.58                      | 1.90                               |
| Wolftever Creek 4.1 | 96.60                     | 70.70                              |
| Wolftever Creek 5.5 | 59.00                     | 43.20                              |
| Savannah Bay        | 37.60                     | 27.50                              |
| Dallas Bay          | 9.94                      | 7.30                               |
| Soddy Creek         | 65.70                     | 48.10                              |
| Possum Creek        | 33.70                     | 24.70                              |
| Sale Creek          | 116.00                    | 84.90                              |
| Richland Creek      | 81.20                     | 59.40                              |
| Mud Creek           | 7.61                      | 5.60                               |
| Goodfield Creek     | 24.90                     | 18.20                              |
| Gunstocker Creek    | 19.70                     | 14.40                              |
| Agency Creek        | 19.00                     | 13.90                              |
| Rogers Creek        | 55.80                     | 40.80                              |
| Candies Creek       | 112.00                    | 81.90                              |
| North Mouse Creek   | 93.70                     | 68.50                              |
| South Mouse Creek   | 39.90                     | 29.20                              |

\*\*The embayment flows were estimated based on a cubic feet per second per square mile (cfsm) calculation. The Following streamgages and data were evaluated for this determination.

| Gage Location                     | Drainage Area<br>(sq.mi.) |
|-----------------------------------|---------------------------|
| South Chickamauga Creek mile 12.2 | 428.00                    |
| Sewee Creek mile 5.70             | 117.00                    |

Average of South Chickamauga and Sewee Creeks  $X = .7315165$

APPENDIX C  
MAIN CHANNEL CROSS-SECTIONAL AREAS



Chickamauga Reservoir main channel cross-sectional areas (m3) .

APPENDIX D  
DATA OBTAINED FROM CHICKAMAUGA RESERVOIR  
EMBAYMENT STUDY-1990 (TVA 1992)

Averages for water quality data at the 1-meter depth in Chickamauga Reservoir, April through September 1990

| Location                   | Dissolved           |                  |      | Conductivity<br>(µmhos/cm) | Secchi<br>(m) | Hardness<br>(mg/L) | Alkalinity<br>(mg/L) | Turbidity<br>(NTU) | Suspended        |                            | True<br>Color<br>(PCU) |
|----------------------------|---------------------|------------------|------|----------------------------|---------------|--------------------|----------------------|--------------------|------------------|----------------------------|------------------------|
|                            | Temperature<br>(°C) | Oxygen<br>(mg/L) | pH   |                            |               |                    |                      |                    | Solids<br>(mg/L) | Apparent<br>Color<br>(PCU) |                        |
| TRM 472.3                  | 23.72               | 7.72             | 7.63 | 156                        | 1.33          | 80.2               | 58.2                 | 5.9                | 4.2              | 20.2                       | 14.2                   |
| TRM 478.2                  | 23.63               | 7.97             | 7.80 | 158                        | 1.12          | 92.3               | 60.0                 | 5.3                | 4.0              | 21.0                       | 15.3                   |
| TRM 490.5                  | 22.60               | 8.02             | 7.68 | 163                        | 1.10          | 77.2               | 55.2                 | 4.7                | 3.5              | 18.2                       | 13.8                   |
| TRM 496.5                  | 21.92               | 6.55             | 7.45 | 165                        | 1.24          | 75.3               | 62.7                 | 4.9                | 3.2              | 18.2                       | 13.7                   |
| TRM 506.5                  | 22.12               | 5.72             | 7.43 | 165                        | 2.00          | 83.2               | 64.3                 | 4.0                | 2.5              | 15.3                       | 11.5                   |
| TRM 518.0                  | 21.57               | 6.18             | 7.55 | 168                        | 1.60          | 81.7               | 63.7                 | 5.9                | 5.5              | 14.0                       | 10.2                   |
| TRM 529.9                  | 21.30               | 6.40             | 7.58 | 170                        | 1.15          | 82.8               | 65.8                 | 6.3                | 5.3              | 16.2                       | 12.8                   |
| HRM 7.4                    | 22.28               | 8.25             | 7.57 | 145                        | 0.87          | 71.3               | 36.5                 | 9.7                | 6.5              | 33.3                       | 29.2                   |
| HRM 13.4                   | 19.83               | 8.13             | 7.33 | 135                        | 1.00          | 77.3               | 32.2                 | 10.3               | 6.8              | 34.7                       | 30.0                   |
| HRM 20.0                   | 18.63               | 9.25             | 7.35 | 70                         | 1.67          | 81.2               | 17.3                 | 6.7                | 5.8              | 28.0                       | 25.5                   |
| Waconda Bay                | 23.90               | 7.80             | 7.87 | 158                        | 1.02          | 85.3               | 60.3                 | 7.8                | 6.2              | 20.5                       | 15.8                   |
| Wolftever Creek 4.1        | 24.62               | 8.52             | 8.17 | 201                        | 1.20          | 93.2               | 91.2                 | 5.1                | 3.8              | 18.8                       | 14.5                   |
| Wolftever Creek 5.5        | 24.10               | 7.40             | 7.88 | 225                        | 0.66          | 89.2               | 103.3                | 11.5               | 10.8             | 23.0                       | 17.3                   |
| Savannah Bay 2.9           | 24.30               | 7.50             | 8.05 | 243                        | 0.56          | 99.8               | 117.5                | 15.8               | 16.5             | 24.7                       | 19.7                   |
| Dallas Bay 1.5             | 24.73               | 9.25             | 8.33 | 161                        | 1.32          | 80.2               | 61.0                 | 4.5                | 4.0              | 15.3                       | 12.5                   |
| Soddy Creek (1.7 & 4.0)    | 24.10               | 9.00             | 8.11 | 140                        | 1.72          | 79.0               | 49.8                 | 2.6                | 1.7              | 14.2                       | 11.1                   |
| Possum Creek 2.0           | 24.05               | 9.15             | 8.10 | 145                        | 1.81          | 76.8               | 47.8                 | 2.2                | 0.9              | 13.5                       | 11.2                   |
| Sale Creek (1.3 & 2.0)     | 23.36               | 8.63             | 8.03 | 140                        | 1.56          | 80.5               | 54.7                 | 2.9                | 2.7              | 15.6                       | 12.9                   |
| Richland Creek (0.5 & 2.9) | 23.00               | 8.29             | 7.90 | 158                        | 1.23          | 85.1               | 64.8                 | 4.9                | 4.3              | 17.6                       | 13.5                   |
| Mud Creek 1.0              | 24.25               | 7.55             | 8.05 | 167                        | 0.78          | 82.0               | 70.0                 | 10.5               | 9.8              | 20.8                       | 15.0                   |
| Goodfield Creek 1.0        | 22.75               | 8.20             | 7.97 | 203                        | 0.73          | 89.5               | 88.8                 | 10.8               | 10.8             | 21.8                       | 15.8                   |
| Gunstocker Creek 1.0       | 22.82               | 7.12             | 7.67 | 152                        | 0.79          | 83.5               | 43.7                 | 13.3               | 13.8             | 28.7                       | 22.5                   |
| Agency Creek 1.5           | 23.22               | 8.82             | 7.95 | 152                        | 0.97          | 77.3               | 43.8                 | 7.8                | 6.7              | 29.5                       | 23.3                   |
| Rogers Creek 1.5           | 22.47               | 8.07             | 7.65 | 151                        | 0.88          | 79.7               | 41.3                 | 9.8                | 8.2              | 31.8                       | 24.2                   |
| Candies Creek              | 21.87               | 6.80             | 7.65 | 189                        | 0.55          | 88.4               | 67.5                 | 23.7               | 20.2             | 59.2                       | 49.2                   |
| North Mouse 0.5            | 20.90               | 6.70             | 7.83 | 241                        | 0.59          | 123.3              | 119.7                | 16.8               | 15.3             | 56.2                       | 40.8                   |
| South Mouse 1.1            | 21.20               | 6.32             | 7.65 | 226                        | 0.36          | 112.3              | 100.2                | 37.7               | 38.8             | 68.3                       | 59.2                   |

| Location                 | Total Phosphorus (mg/L) | Ortho Phosphorus (mg/L) | Total Nitrogen (mg/L) | Organic Nitrogen (mg/L) | Ammonia Nitrogen (mg/L) | Nitrate Nitrogen (mg/L) | Total-N Total-P Ratio | Total Organic Carbon (mg/L) | Soluble Organic Carbon (mg/L) | Fecal Coliform (#/100ml) |
|--------------------------|-------------------------|-------------------------|-----------------------|-------------------------|-------------------------|-------------------------|-----------------------|-----------------------------|-------------------------------|--------------------------|
|                          |                         |                         |                       |                         |                         |                         |                       |                             |                               |                          |
| TRM 472.3                | 0.020                   | 0.005                   | 0.37                  | 0.16                    | 0.01                    | 0.20                    | 39.1                  | 1.85                        | 1.82                          | 5.0                      |
| TRM 478.2                | 0.023                   | 0.006                   | 0.37                  | 0.18                    | 0.01                    | 0.18                    | 17.8                  | 2.08                        | 1.87                          | 8.3                      |
| TRM 490.5                | 0.023                   | 0.008                   | 0.43                  | 0.18                    | 0.02                    | 0.22                    | 19.1                  | 2.35                        | 1.87                          | 8.3                      |
| TRM 496.5                | 0.025                   | 0.014                   | 0.45                  | 0.14                    | 0.05                    | 0.27                    | 18.7                  | 1.95                        | 1.82                          | 6.7                      |
| TRM 506.5                | 0.023                   | 0.013                   | 0.50                  | 0.16                    | 0.05                    | 0.29                    | 22.1                  | 1.95                        | 1.80                          | 5.0                      |
| TRM 518.0                | 0.022                   | 0.008                   | 0.48                  | 0.17                    | 0.04                    | 0.27                    | 24.4                  | 1.98                        | 1.75                          | 5.0                      |
| TRM 529.9                | 0.027                   | 0.009                   | 0.49                  | 0.19                    | 0.03                    | 0.28                    | 19.2                  | 1.98                        | 1.73                          | 5.0                      |
| HRM 7.4                  | 0.032                   | 0.007                   | 0.47                  | 0.32                    | 0.03                    | 0.12                    | 15.6                  | 2.98                        | 2.58                          | 18.3                     |
| HRM 13.4                 | 0.037                   | 0.016                   | 0.44                  | 0.17                    | 0.08                    | 0.19                    | 14.1                  | 2.85                        | 2.50                          | 42.0                     |
| HRM 20.0                 | 0.018                   | 0.007                   | 0.29                  | 0.13                    | 0.01                    | 0.16                    | 23.1                  | 1.40                        | 1.20                          | 391.7                    |
| Waconda Bay              | 0.018                   | 0.004                   | 0.34                  | 0.18                    | 0.02                    | 0.14                    | 21.4                  | 2.02                        | 1.87                          | 13.3                     |
| Wolftever Creek 4.1      | 0.023                   | 0.004                   | 0.31                  | 0.25                    | 0.01                    | 0.05                    | 15.5                  | 2.45                        | 2.17                          | 5.8                      |
| Wolftever Creek 5.5      | 0.032                   | 0.004                   | 0.40                  | 0.36                    | 0.01                    | 0.03                    | 15.2                  | 3.02                        | 2.55                          | 5.8                      |
| Savannah Bay 2.9         | 0.042                   | 0.004                   | 0.59                  | 0.54                    | 0.04                    | 0.02                    | 16.0                  | 3.52                        | 2.97                          | 84.2                     |
| Dallas Bay 1.5           | 0.011                   | 0.004                   | 0.30                  | 0.23                    | 0.01                    | 0.06                    | 27.6                  | 2.18                        | 1.98                          | 5.0                      |
| Soddy Creek (1.7 & 4.0)  | 0.008                   | 0.003                   | 0.22                  | 0.16                    | 0.01                    | 0.06                    | 31.3                  | 1.91                        | 1.73                          | 8.8                      |
| Possum Creek 2.0         | 0.006                   | 0.004                   | 0.19                  | 0.12                    | 0.01                    | 0.07                    | 34.8                  | 1.82                        | 1.62                          | 5.8                      |
| Sale Creek (1.3 & 2.0)   | 0.010                   | 0.004                   | 0.28                  | 0.17                    | 0.01                    | 0.10                    | 33.2                  | 2.05                        | 1.78                          | 5.0                      |
| Richland Cr. (0.5 & 2.9) | 0.024                   | 0.004                   | 0.40                  | 0.28                    | 0.01                    | 0.12                    | 22.3                  | 2.23                        | 1.88                          | 22.5                     |
| Mud Creek 1.0            | 0.025                   | 0.005                   | 0.48                  | 0.37                    | 0.03                    | 0.08                    | 23.7                  | 2.83                        | 2.47                          | 10.8                     |
| Goodfield Creek 1.0      | 0.030                   | 0.006                   | 0.35                  | 0.30                    | 0.01                    | 0.04                    | 14.3                  | 2.50                        | 1.98                          | 15.0                     |
| Gunstocker Creek 1.0     | 0.040                   | 0.005                   | 0.42                  | 0.38                    | 0.01                    | 0.03                    | 12.9                  | 3.02                        | 2.50                          | 15.0                     |
| Agency Creek 1.5         | 0.030                   | 0.005                   | 0.44                  | 0.38                    | 0.01                    | 0.06                    | 16.3                  | 2.83                        | 2.50                          | 9.2                      |
| Rogers Creek 1.5         | 0.040                   | 0.006                   | 0.33                  | 0.29                    | 0.01                    | 0.03                    | 8.7                   | 2.85                        | 2.47                          | 111.0                    |
| Candies Creek            | 0.042                   | 0.012                   | 0.47                  | 0.38                    | 0.01                    | 0.07                    | 12.4                  | 3.17                        | 2.85                          | 701.0                    |
| North Mouse 0.5          | 0.047                   | 0.013                   | 0.74                  | 0.39                    | 0.01                    | 0.34                    | 19.6                  | 2.78                        | 2.35                          | 14.2                     |
| South Mouse 1.1          | 0.120                   | 0.022                   | 1.06                  | 0.83                    | 0.02                    | 0.22                    | 12.0                  | 3.80                        | 3.37                          | 509.2                    |

Land Use Classifications For Chickamauga Reservoir Embayments (TVA 1992).

| EMBAYMENT LOCATION         | WATERSHED |       | URBAN |       | CROPLAND     |       | PASTURE          |       | FOREST |      |
|----------------------------|-----------|-------|-------|-------|--------------|-------|------------------|-------|--------|------|
|                            | (ha)      | (%)   | (ha)  | (%)   | (Cultivated) | (ha)  | (Non-cultivated) | (ha)  | (%)    | (ha) |
| Waconda Bay                | 784       | 33.21 | 260   | 0.00  | 0            | 24.38 | 191              | 36.81 | 289    |      |
| Wolftever Creek 4.1        | 25014     | 9.23  | 2306  | 8.13  | 2033         | 28.82 | 7209             | 52.88 | 13228  |      |
| Wolftever Creek 5.5        | 14399     | 13.81 | 1989  | 4.77  | 687          | 16.90 | 2434             | 63.44 | 9135   |      |
| Savannah Bay 2.9           | 10615     | 3.01  | 320   | 12.69 | 1347         | 44.98 | 4775             | 38.56 | 4093   |      |
| Dallas Bay 2.9             | 2687      | 18.71 | 503   | 4.82  | 130          | 17.09 | 459              | 49.74 | 1337   |      |
| Soddy Creek (1.7 & 4.0)    | 16989     | 5.36  | 911   | 2.56  | 435          | 9.07  | 1541             | 81.38 | 13826  |      |
| Possum Creek 2.0           | 8814      | 7.08  | 624   | 2.82  | 249          | 10.01 | 882              | 78.00 | 6875   |      |
| Sale Creek (1.3 & 2.0)     | 29911     | 5.43  | 1624  | 4.94  | 1476         | 17.49 | 5233             | 70.94 | 21219  |      |
| Richland Creek (0.5 & 2.9) | 21309     | 8.29  | 1766  | 12.05 | 2567         | 18.11 | 3859             | 60.88 | 12973  |      |
| Mud Creek 1.0              | 2115      | 11.12 | 235   | 24.13 | 510          | 36.20 | 766              | 21.57 | 456    |      |
| Goodfield Creek 1.0        | 6496      | 4.80  | 312   | 13.08 | 849          | 22.25 | 1446             | 57.97 | 3766   |      |
| Gunstocker Creek 1.0       | 5263      | 1.70  | 89    | 20.18 | 1062         | 34.37 | 1809             | 41.20 | 2168   |      |
| Agency Creek 1.5           | 5193      | 5.68  | 295   | 13.28 | 689          | 22.61 | 1174             | 56.38 | 2928   |      |
| Rogers Creek 1.5           | 14388     | 0.50  | 72    | 4.08  | 586          | 21.40 | 3080             | 72.45 | 10424  |      |
| Candies Creek              | 28799     | 2.04  | 587   | 1.75  | 503          | 41.96 | 12084            | 53.34 | 15361  |      |
| North Mouse Creek 0.5      | 24356     | 7.44  | 1811  | 1.85  | 452          | 44.49 | 10837            | 45.52 | 11087  |      |
| South Mouse Creek 1.1      | 10142     | 36.46 | 3697  | 3.85  | 391          | 20.23 | 2052             | 38.75 | 3930   |      |

Land classification for percentage crop (cultivated) or pasture (non-cultivated) land were provided by the Soil Conservation Service based on 1987 National Resources Inventory (NRI, 1987).

Fish community data collected in Chickamauga Reservoir embayments, 1990 (TVA 1992).

| LOCATION                   | ABUNDANCE           |                     | FISH SIZE                  |                            | FISH HEALTH                         |                       |                       |
|----------------------------|---------------------|---------------------|----------------------------|----------------------------|-------------------------------------|-----------------------|-----------------------|
|                            | Fish/Cubic<br>Meter | + or -<br>95% C.L.* | Target<br>Strength<br>(db) | Target<br>Strenght<br>(cm) | Health<br>Assessment<br>Index (HAI) | Standard<br>Deviation | Coeffic.<br>Variation |
| Waonda Bay                 | 0.2260              | 0.1795              | -53.03                     | 3.7                        | 98                                  | 41.80                 | 42.51                 |
| Wolftever Creek 4.1        | 0.0790              | 0.0651              | -51.37                     | 4.5                        | 47                                  | 32.55                 | 68.77                 |
| Wolftever Creek 5.5        | 0.0445              | 0.0235              | -42.29                     | 13.5                       |                                     |                       |                       |
| Savannah Bay 2.9           | 0.0216              | 0.0152              | -41.37                     | 15.1                       | 47                                  | 32.55                 | 68.77                 |
| Dallas Bay 1.5             | 0.5346              | 0.1328              | -53.95                     | 3.3                        | 78                                  | 37.38                 | 47.72                 |
| Soddy Creek (1.7 & 4.0)    | 1.5477              | 0.3025              | -55.32                     | 2.8                        | 75                                  | 26.66                 | 35.55                 |
| Possum Creek 2.0           | 1.0009              | 0.4044              | -54.27                     | 3.2                        | 60                                  | 40.33                 | 67.22                 |
| Sale Creek (1.3 & 2.0)     | 1.5888              | 0.5744              | -55.36                     | 2.8                        | 55                                  | 38.62                 | 70.65                 |
| Richland Creek (0.5 & 2.9) | 0.2102              | 0.1046              | -51.99                     | 4.2                        | 47                                  | 33.40                 | 71.57                 |
| Mud Creek 1.0              | 0.0361              | 0.0126              | -44.50                     | 10.3                       | 47                                  | 35.15                 | 75.32                 |
| Goodfield Creek 1.0        | 0.0366              | 0.0274              | -43.45                     | 11.7                       | 44                                  | 22.45                 | 51.02                 |
| Gunstocker Creek 1.0       | 0.5273              | 0.2424              | -52.38                     | 4.0                        | 55                                  | 28.02                 | 50.63                 |
| Agency Creek 1.5           | 0.8824              | 0.2795              | -53.14                     | 3.6                        | 65                                  | 35.75                 | 54.72                 |
| Rogers Creek 1.5           | 0.2929              | 0.1509              | -52.74                     | 3.8                        | 71                                  | 35.38                 | 49.59                 |
| Candies Creek              | 0.5387              | 0.5331              | -54.86                     | 3.0                        | 81                                  | 39.31                 | 48.33                 |
| North Mouse 0.5            | 0.2547              | 0.1884              | -48.75                     | 6.2                        | **                                  |                       |                       |
| South Mouse 1.1            | 0.0434              | 0.0359              | -48.07                     | 6.7                        | 64                                  | 39.75                 | 62.53                 |

\* Ninety-five percent confidence limits

\*\* No largemouth bass were captured.

Aquatic macrophyte data for Chickamauga Reservoir embayments.

| Embayment         | Total<br>Hectares | Percent<br>Coverage |
|-------------------|-------------------|---------------------|
| Waconda           | 0.0               | 0.0                 |
| Wolftever Creek   | 14.5              | 9.2                 |
| Savannah Bay      | 6.5               | 5.4                 |
| Dallas Bay        | 16.4              | 6.3                 |
| Soddy Creek       | 38.1              | 15.6                |
| Possum Creek      | 30.2              | 16.6                |
| Sale Creek        | 92.6              | 34.1                |
| Richland Creek    | 13.2              | 13.5                |
| Mud Creek         | 19.3              | 15.4                |
| Goodfield Creek** | >0.2              | >0.3                |
| Gunstocker Creek  | 3.4               | 2.5                 |
| Agency Creek      | 8.8               | 9.6                 |
| Rogers Creek      | 9.1               | 5.4                 |
| Candies Creek     | 0.2               | 0.1                 |
| North Mouse Creek | 0.0               | 0.0                 |
| South Mouse Creek | 0.0               | 0.0                 |

\*\* Photographs covered only about 60 percent of embayment;  
however, a dramatic decline in aquatic vegetation from previous  
years.

#### VITA

Tyler Franklin Baker was born on April 17, 1965, in Cleveland, Tennessee. He graduate from Cleveland High School in 1983. He attended Cleveland State Community College for two years prior to attending The University of Tennessee where he received a Bachelor of Science degree in Wildlife and Fisheries Science in 1988 and a Master of Science degree in Ecology in December 1993.

Since 1988 Tyler has been working for Fish and Wildlife Associates, Inc., under contract to Tennessee Valley Authority as an aquatic biologist in Water Management.