Group Cy #1A
GB 11-30-81

PART I ENVIRONMENTAL STUDIES OF COFFEEN LAKE, A THERMALLY-ALTERED RESERVOIR

PART II ECOLOGICAL INVESTIGATIONS OF SHOAL CREEK

Final Report

to

Central Illinois Public Service Company

by

Illinois Natural History Survey
Urbana, Illinois

Submitted
July 1981

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Volume I - Text

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ACKNOWLEDGMENTS

We wish to acknowledge those graduate and undergraduate students who helped with field sampling and data analysis: included were Debbie Bevis, Joan Brower, Chris Gorka, Marla Hall, Faye Hemann, and Jeff Koopleman from Eastern Illinois University and Jim Pfeiffer, Ray Roller, and John Schultz from Sangamon State University. The contributions of technicians Dwight Garrels, Bill Kraus, and Jeff Van Orman at the field laboratory were also appreciated. Carl Alde, John Barlow, and Christina Clark were contributing members of the algal team who helped with equipment design, sampling, and data processing. Christina Clark and Scott O'Grady assisted in zooplankton equipment design and data collection and analysis. We also acknowledge Diane Lynn, Mark Schauer, and Steve Sobasky for benthic processing and analysis, and Mark Wetzel for identification of oligochaetes. Patricia M. Duda and William L. Anderson were contributing authors in the chemical constituents study (first and second annual reports). Aaron Griffith and Roger Davis assisted in trace metal analysis and data processing and James W. Seets assisted in trace metal sample collections. James H. Buckler served as project coordinator during the first year of the study and Tom Joy was instrumental in initiating the fisheries investigations during the first year. Thanks are also extended to Mike Zwilling for data processing and statistical analyses. Special thanks are offered to Sue Peratt and Jana Waite for typing the manuscript and to Janet Kennedy, project manager for Central Illinois Public Service Company, for her suggestions and assistance during this investigation.

PART I ENVIRONMENTAL STUDIES OF COFFEEN LAKE, A THERMALLY-ALTERED RESERVOIR

SECTION

INTRODUCTION

by

John A. Tranquilli and Lance G. Perry

In July 1978, at the request of Central Illinois Public Service Company (CIPS), the Illinois Natural History Survey began a 3-year investigation of the environmental effects of CIPS Coffeen Power Station on Coffeen Lake and its receiving stream, Shoal Creek. The overall objective of this study was to provide diagnostic data for use in determining whether Coffeen Lake and Shoal Creek were environmentally acceptable in terms of supporting shellfish, fish, wildlife, and recreational uses consistent with good management practices. In particular, the study was designed to evaluate the effects of new wastewater treatment facilities on lake water quality; these included (1) isolation of ash pond effluents, (2) creation of a coal-pile run-off settling pond, and (3) mixing of brine and regeneration wastes prior to release. The environmental program included integrated investigations conducted by an interdisciplinary team of biologists and chemists in the areas of water quality, chemical constituents, phytoplankton, periphyton, zooplankton, benthos, and fish.

Results of the first year investigations on Coffeen Lake and Shoal Creek were presented in a report entitled "Environmental Studies of Coffeen Lake" which was submitted by the Illinois Natural History Survey in October 1979. A second annual report encompassed data collected from Coffeen Lake through July 1980 and was submitted in October 1980. This final report includes a three-year biological analysis of Coffeen Lake and results of a one-year investigation of Shoal Creek, its receiving stream. During the second year of study, a 1-year impingement and entrainment project and a larval fish distribution study were added to the sampling program to assess the impact of the cooling water intake system on the Coffeen Lake fishery. Reports on these investigations are included herein. Data appendices were included with the two previous annual reports. Only data which were not previously submitted is included in the Appendix associated with this final report.

DESCRIPTION OF STUDY AREA

Coffeen Lake lies on the Effingham Plain Section of the Central Lowland Province in southeastern Montgomery County (T7N, R3W, Section 14) ([illegible], Schwegman 1973). It was built in 1961 by impounding McDavid Branch, a tributary of the East Fork of Shoal Creek, creating a watershed drainage area of 4.45 × 10^3 ha. A substantial amount of water (55 percent of the final lake volume) was pumped from the East Fork to hasten lake filling (CIPS 1977). The normal operating level (590 MSL) was reached by late 1966 providing 446 ha of lake surface area and a storage capacity of 2.72 x 10^7 m^3. Table 1.1 lists additional morphological information for Coffeen Lake. Coffeen Lake is located on light-colored soils developed from loess. The Hosmer-Stoy-Weir soil association found there formed under forest vegetation and occurs on nearly level to strongly sloping uplands (Fehrenbacher et al. 1967).

Coffeen Lake is a relatively deep impoundment in comparison to other Illinois reservoirs. The EPA (1978a, 1978b) listed selected parameters for 353 Illinois lakes and reported that Coffeen had a greater mean depth (5.7 m) and maximum depth (17.7 m) than 95 percent of the lakes tabulated. The lake also has a relatively high volume development ratio (0.97) and an extensive shoreline (77.1 km).

The coal-fired Coffeen Power Station complex is located adjacent to and obtains most of its fuel (No. 6 Herrin) from Consolidated Hillsboro Coal Companys' underground coal mine. The first of two units at the Coffeen Power Station began operation in 1965. Unit 1 has a generating capacity of 350 MeW with an associated circulating water pump discharge of 146,500 gpm. Unit 2, which began electric generation in 1972, provides 595 MeW and has a circulating water pump discharge of 253,000 gpm. These two units, based on a 70 percent load factor, have a maximum heat rejection of 4.36 BTU hr^{-1} and establish an average 12° C rise in water temperature across the condensors. The thermal effluent leaves the generating facility via a 0.9-km-long discharge canal and enters Coffeen Lake by flowing over a hot dam. The discharge then follows a clockwise pattern along a 6.6-km cooling loop. This provides 324 ha of cooling area (73 percent of the lake surface) and produces a total lake loading rate of 0.86 MeW $acre^{-1}$.

Table 1.1. Physical Characteristics of Coffeen Lake

Surface area:	446 ha
Mean depth:	5.7 m
Maximum depth:	17.7 m
Shoreline length:	77.1 km
Storage capacity:	2.72×10^{7} m^{3}
Watershed drainage:	4.45×10^{3} ha
Bottom slope index	.3206
Shoreline development index	10.6
Drainage area/lake capacity ratio	.6
Annual loss in capacity:	.05 percent
Volume development index	.97

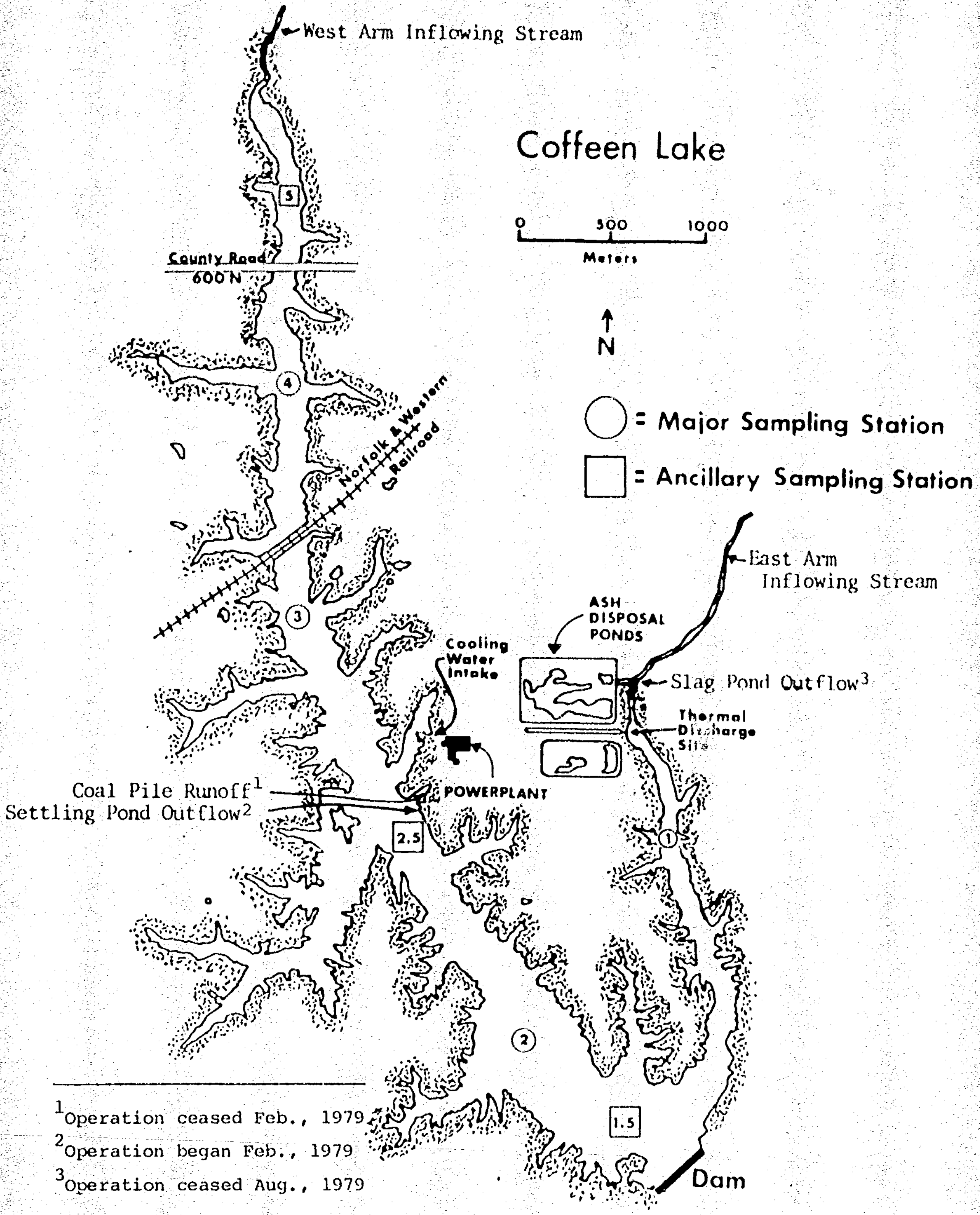
4,357 X 10^{6} BTU hr^{-1}

Gross electrical output of the Coffeen Generating Station was quite variable (Fig. 1.1) as is typical of most coal-fired units. During the months of April, May, November and December of 1979 and 1980, output was reduced because of scheduled maintenance and repair work at the power plant. Since the onset of this study, maximum summer and winter discharge temperatures, measured at the end of the mixing zone, were 43° and 26° C, respectively.

Several modifications of [illegible] wastewater treatment facilities at the power station were completed after this environmental study began. Included were isolation of ash disposal ponds from the lake basin (completed in August 1979), construction of a settling basin for coal pile run-off (completed in February 1979), and construction of an equalization tank for mixing of brine and demineralizer waste products (Fig. 1.2). These facilities served to 1) prevent ash pond effluents from entering the lake, 2) prevent coal pile particulates from entering the lake, and 3) buffer brine and demineralizer wastes (a solution of brine, sulfuric acid, and sodium hydroxide) from pH extremes prior to release into the lake.

Four major sampling stations were established to represent areas exposed to various thermal regimes and were sampled by all investigators. Station 1 was located in the thermal discharge arm, Station 2 was established near the midpoint of the cooling loop, Station 3 was situated north of the intake bay as a thermal transition area, and Station 4 (which was partially isolated from the rest of the lake by a railroad causeway) was regarded as the ambient area. Approximate distances from the thermal outfall to Stations 1 through 4, respectively, were 0.8, 4.0, 6.9, and 8.4 Km. In addition, ancillary stations for certain aspects of the study were located near the intake and discharge structures, at two other intermediate points within the cooling loop, and at the north end of the lake where McDavid Branch enters the lake basin (Figure 1.2).

Figure 1.1 Weekly electrical output of Coffeen Generating Station from August 1978 through December 1980.



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[1] Operation ceased Feb., 1979

[2] Operation began Feb., 1979

[3] Operation ceased Aug., 1979

Figure 1.2 Sampling stations on Coffeen Lake.

LITERATURE CITED

Central Illinois Public Service Company, 1977. Thermal Demonstration for Coffeen Power Station Units 1 and 2. Submitted to the Illinois Pollution Control Board, May 1977.

Fehrenbacher, J. B., G. O. Walker, and H. L. Wascher. 1967. Soils of Illinois. University of Illinois Agricultural Experiment Station. Bulletin 725, 47 pp.

Illinois Environmental Protection Agency, 1978a. Assessment and Classification of Illinois Lakes, Volume I. 208 Water Quality Management Planning Program Staff Report. State of Illinois, Environmental Protection Agency, Springfield, Illinois.

Illinois Environmental Protection Agency, 1978b. Assessment and Classification of Illinois Lakes, Volume II. 208 Water Quality Management Planning Program Staff Report. State of Illinois, Environmental Protection Agency, Springfield, Illinois.

Illinois Natural History Survey. 1979. Environmental Studies of Coffeen Lake. First Annual Report to Central Illinois Public Service Company, Vol. I, Text; Vol. II, Appendices.

Lopinot, A. C. 1970. Montgomery County surface water resources. Illinois Department of Conservation, Springfield, Illinois. 119 pp.

Schwegman, J. E. 1973. Comprehensive plan for the Illinois Nature Preserves system, Part 2. The Natural Divisions of Illinois. Illinois Nature Preserves Commission. 32 pp.

SECTION 2

THERMAL MAPPING OF COFFEEN LAKE

by

Sarah Liehr-Storck

ABSTRACT

Thermal mapping was conducted quarterly at Coffeen Lake during the period from September 1978 through September 1979, and semi-annually during the two following years. Little variation was found in surface temperatures measured across transects located at known distances from the discharge. The only major exception occurred in March 1980 and February 1981 when the thermal plume stayed close to the east bank north of the dam for a distance of 1.0 to 1.5 kilometers. The discharge arm of the lake usually had different vertical temperature distributions than the rest of the lake, with a distinct change occurring in the vicinity of the dam. The discharge arm of the lake tended to stay thermally stratified at a depth of about two meters, with much warmer water in the top layer. In the vicinity of the dam, greater mixing and larger water volume caused a distinct decrease in surface water temperatures. Water temperatures in the cooling loop did not vary greatly between the dam and the intake canal cove. A distinct decrease in temperature occurred at the railroad causeway, indicating that water temperatures north of the railroad causeway were not affected by the thermal discharge to the same extent as water temperatures south of the causeway. Vertical temperature distributions did not correspond to normal stratification patterns. Thermal discharges prevented winter stratification and ice formation except for the area north of the railroad causeway. Both winter temperatures and summer hypolimnetic temperatures were higher than normal in the lower region of the lake, possibly allowing greater bacterial activity and thus greater rates of cycling of nutrients and other minerals. In the summer near the dam, rather than the normal situation of two isothermal layers of water separated by a thermocline, there were three isothermal layers separated by two thermoclines. The top layer resulted from warm water from the discharge arm staying on the surface rather than mixing.

INTRODUCTION

Water temperature is an important parameter affecting lakes because it influences not only their physical characteristics, but also their chemical and biological characteristics. Because different plant and animal species have different temperature tolerance limits and temperature optima, temperature can affect the biota directly by limiting the distribution of species or by determining the species composition of communities. Temperature also affects the rate of biological activities, and thus affects factors such as growth, decomposition, oxygen consumption and evolution, and nutrient and other mineral cycling that determine the biological characteristics of a lake. Also, because of the relationship between water temperature and density, temperature distribution determines circulation patterns, and thus oxygen levels, in parts of the lake which may restrict animal life and alter bacterial activity. Therefore, a thorough understanding of temperature distribution is essential to assessing the impact of thermal effluents on the chemical and biological characteristics of a lake.

Coffeen Lake would be expected to have different temperature patterns than most lakes in this geographical area because it is a cooling lake which circulates large quantities of water and receives a heated effluent. Temperature distributions were also affected by climatological events and by power plant generation (Fig. 1.1). The purpose of this study is to provide background information on annual temperature patterns in Coffeen Lake so that the chemical and biological data can be interpreted in the context of their thermal environment.

MATERIALS AND METHODS

The thermal plume was measured at quarterly intervals during the first year of sampling, and at semi-annual intervals during the second and third years. Vertical profiles were measured at 1-meter depth intervals along transects at known distances from the thermal discharge. Two to five vertical profiles were measured along each transect, depending on the length of that transect. Three boats were used when possible to complete measurements over the entire lake in as little time as possible. Temperatures were measured with YSI Model 57 dissolved oxygen and YSI Model 33 S-C-T meters.

Profiles of temperature and dissolved oxygen were measured twice per month at 1-meter depth intervals from mid-lake locations at Stations 1, 1.5, 2, 2.5, 3 and 4 (Fig. 1.2). These measurements were taken with a YSI Model 57 dissolved oxygen meter.

RESULTS AND DISCUSSION

Thermal mapping data collected during all three years of this study can be found in Appendices to annual reports (Liehr 1979; Liehr-Storck 1980; Liehr-Storck 1981). Temperature and dissolved oxygen profile data are also listed in Appendices to these reports.

TEMPERATURE DIFFERENCES ACROSS TRANSECTS

In general, very little variation in temperature occurred across transects linking one side of the lake with the other. There were two locations in the lake, however, where some differences were observed.

In the main arm of the lake, temperatures were substantially higher along the east bank on the dates of 4 March 1980 and 16 February 1981. The difference in surface temperatures between the east and west banks just north of the dam was 6.7°C on 4 March 1980 and 5.4°C on 16 February 1981. Temperatures remained different for a distance of 1.0 to 1.5 kilometers. Winds were fairly strong on both of these sampling days at about 10 mph from the south and southwest. However, strong winds from the south and southwest were also present on other days that thermal mapping measurements were taken, and these large temperature differences were not observed.

A much less pronounced difference in temperature across a lakewide transect occurred just north of the railroad causeway. Temperatures were slightly higher in the middle of the transect on 20 November 1978 and 16 February 1981. Slightly higher temperatures were observed on the east side of the transect on 8 August 1979 and 22 August 1980. Openings (culverts) are located in the middle and on the east side of the railroad causeway, and these temperature variations may be the result of water movement through these culverts. Again, wind data were inconclusive as a causative agent, since this phenomenon was not always observed under similar wind conditions. If water exchange was occurring through the culverts, however, it was either at a very slow rate, or mixing was rapidly occurring, as temperature differences were difficult to detect.

TEMPERATURE DIFFERENCES WITH DISTANCE FROM DISCHARGE

Since temperatures were fairly uniform across transects, mean temperatures at 0, 2, 5, 10 and 15 meter depth intervals were calculated to observe seasonal patterns of distribution of waste heat with depth and distance from the discharge. Temperature distribution in the summer season was notably different from thermal distribution in the winter season.

Thermal mappings completed on 12 September 1978, 8 August 1979, and 22 August 1980 indicated that temperature distributions were similar during the hottest times of the year (Fig. 2.1). Thermal stratification (a barrier to mixing as defined on page 2.8) occurred at a depth of about two meters in the area of the lake between the discharge and the dam. Stratification at nine to ten meters occurred at locations in the lake that were at least ten meters deep. The temperature in the top two meters of the water column decreased gradually throughout the length of the discharge arm. A more dramatic decrease in

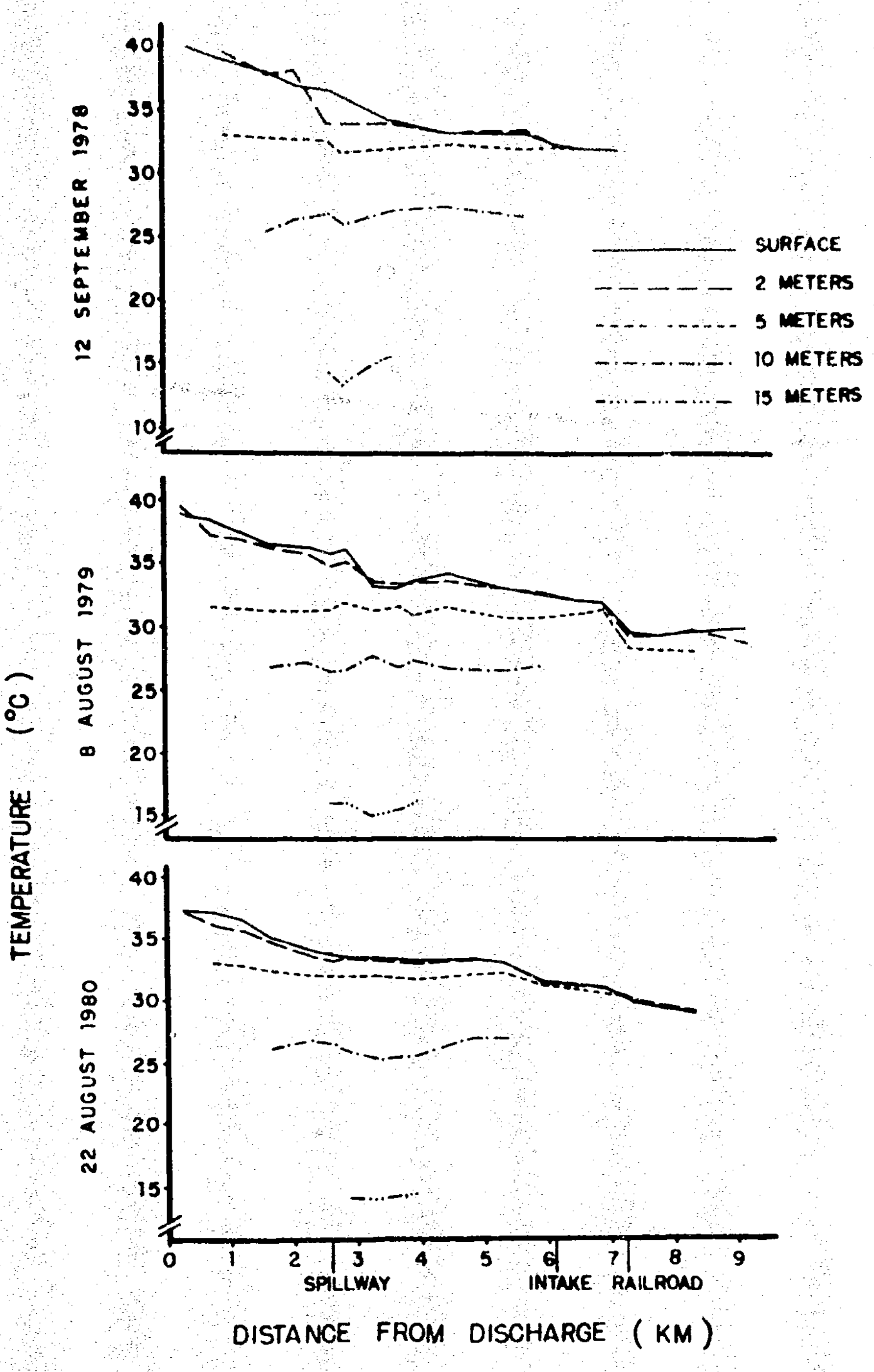


Figure 2.1. Temperature distribution in Coffeen Lake in relation to depth and distance from discharge on 12 September 1978, 8 August 1979, and 22 August 1980.

temperature occurred at the dam (except on 22 August 1980 when plant generation was reduced) followed by only slight decreases in water temperature along the remaining length of the cooling loop. Temperatures decreased more rapidly in the area of the lake beyond the intake cove, and then a rapid decline occurred at the railroad causeway. Water temperatures at five and ten meter depths did not change much along the cooling loop or beyond to the railroad causeway.

The winter thermal mappings also showed similar temperature distributions (Fig. 2.2). Data from 8 March 1979 were not included because the power plant was not operating on that date. Thermal stratification occurred at a depth of one to two meters in the area of the lake between the discharge and the spillway, with temperatures in the top two meters again decreasing gradually with increasing distance from the discharge point. At the spillway, however, a very rapid temperature drop occurred. During winter, the rest of the lake was not stratified, and surface temperatures decreased only slightly within the remainder of the cooling loop. Other temperature differences occurred at the intake cove and at the railroad causeway. Water temperatures at five and ten meter depths increased in the region of the lake between the spillway and the intake cove as a result of more even winter vertical distribution of heat throughout the water column in areas beyond the discharge arm.

Water temperatures that were 2 to 3°C cooler were found at the railroad causeway at all times that measurements were taken beyond that structure except 22 August 1980 when the decrease was only about 1°C. These data indicated that the mixing of water from the north and south sides of the causeway was considerably slowed, and that the portion of the lake on the north side of the causeway was noticeably less impacted by thermal effluents from the power plant than was the portion of the lake on the south side.

THERMAL STRATIFICATION

A physical property of water is that its density increases with decreasing temperatures (to a temperature of 4°C). Because of this property, lakes become stratified when some layers change temperature more rapidly than other layers. In temperate regions, this phenomenon is a common occurrence in most lakes

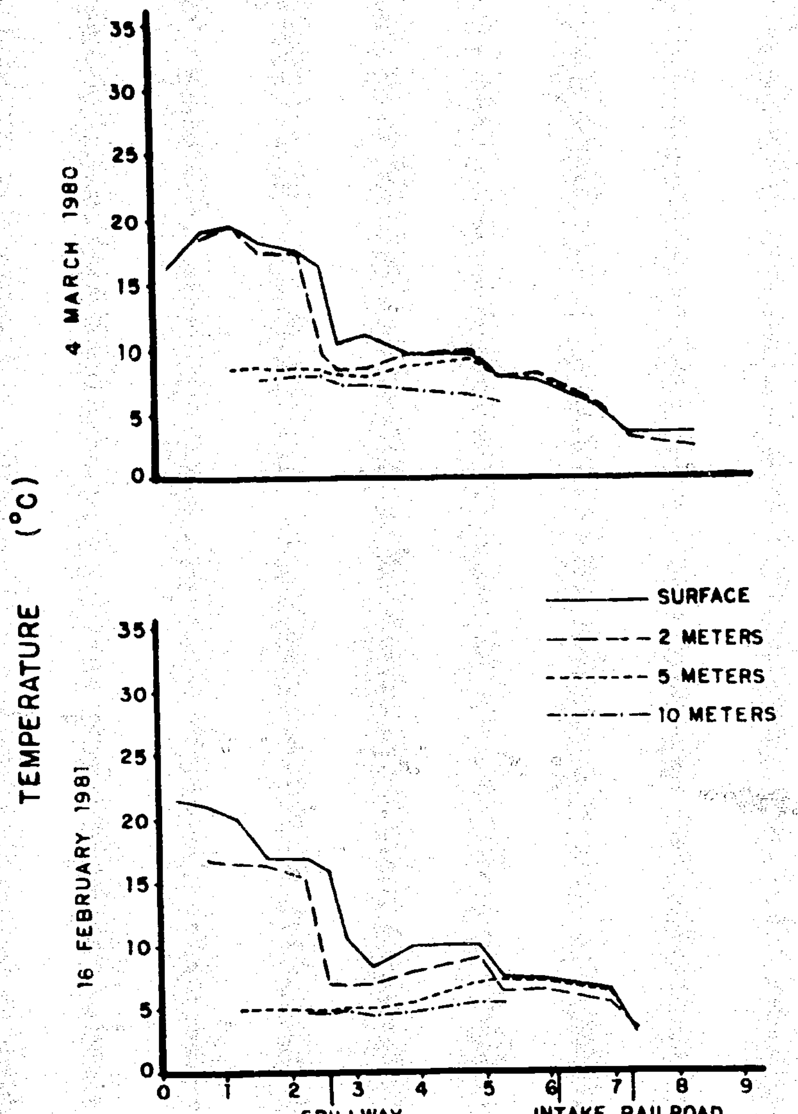


Figure 2.2. Temperature distribution in Coffeen Lake in relation to depth and distance from discharge on 4 March 1980 and 16 February 1981.

during the summer and winter. A temperature drop of 1°C per meter depth is generally considered to cause a density gradient sufficient to act as a barrier to mixing, and will herein be used as the definition of thermocline. Since Coffeen Lake is subjected to temperature influences other than climatological ones, i.e., it receives a heated effluent, this lake would not be expected to stratify in the same patterns as other lakes in the same geographical area that are subjected to only climatological influences. Stratification patterns were studied by means of temperature profiles measured twice per month. Dissolved oxygen concentrations were also studied to help determine the stability of the thermal stratifications observed.

Stratification in the winter normally occurs when the water cools to below 4°C. Water at 4°C has the greatest density and therefore stays at the bottom while water above it continues to cool until it freezes at 0°C. Under the ice, biological processes continue, although at a reduced rate, and oxygen can become depleted since there is no exchange with the atmosphere. In Coffeen Lake, this type of stratification was observed only at Station 4, and no oxygen depletion was observed during periods of ice cover. Consistent stratification was also observed in winter at Station 1 at a depth of one to three meters, where thermal effluents from the power plant caused water at the surface to be considerably warmer than water at the bottom. In spite of this winter stratification pattern in the discharge arm, however, dissolved oxygen levels were fairly uniform throughout the water column. The water column at the other stations was generally completely mixed with temperatures mostly in the range of 6 to 14°C and oxygen levels in the range of 8 to 12 mg/1.

The normal process of summer stratification begins in the spring as the ice melts and the water warms. When the temperature reaches 4°C, the water column completely mixes (spring turnover). Warming continues and the cooler, more dense water stays at the bottom while surface temperatures continue to rise. A thermocline develops, with water above (epilimnion) able to mix freely causing it to be fairly uniform in temperature. The water below (hypolimnion) is not able to mix with the upper layer, and thus receives no new supplies of oxygen. Decomposition of organic material at the bottom of the lake consumes oxygen, and in most eutrophic lakes, oxygen becomes depleted.

Variations of this typical summer thermal stratification pattern were observed in Coffeen Lake. The water column at Station 1 was stratified throughout the summer at a depth of one to three meters. Temperatures in the upper layer of water were often extremely high (once reaching 43°C in 1980), because this station was located close to the power plant discharge. While a thermocline does not normally appear that close to the surface, it was likely caused by the warm water discharged from the plant tending to stay at the surface. Hypolimnetic dissolved oxygen concentrations were low (frequently below 3 mg/l) but oxygen did not become depleted. Oxygen in the lower layer could have been present as a result of unstable stratification or, more likely, replacement of the water caused by the current from the discharge.

Station 2 was stratified from May through September in 1979. No stable stratification developed in that region during 1980. At Station 2.5 there was no continuous stratification for extended periods, although thermoclines did appear on occasions in the summer. Stratification did not occur at a consistent depth, but occurred anywhere from three to eleven meters. Oxygen depletion occurred at Stations 2 and 2.5 from June to September in 1979 and from May to August in 1980, indicating that stratification, though unstable, was sufficient to prevent consistent mixing of the entire water column.

Station 1.5, located near the dam, was adjacent to the discharge arm and was also the deepest part of the lake. Continuous stratification was observed in this region from May through October of both 1979 and 1980. At the beginning of the summer, for example in 1980 on June 3, the typical seasonal vertical temperature distribution developed (Fig. 2.3), although hypolimnetic temperatures were higher than normal because spring circulation had occurred at a temperature much higher than 4°C. At the depth where the temperature began to decrease rapidly, dissolved oxygen levels also began to decline rapidly. As the summer progressed, however, two thermoclines developed. One thermocline at a depth of one to three meters, resulted from heated water from the discharge arm staying on the surface rather than mixing. The other occurred at a depth of seven to eleven meters (Fig. 2.3). Oxygen was fairly uniform or increased slightly with depth in the upper layer and became depleted in the lowest layer.

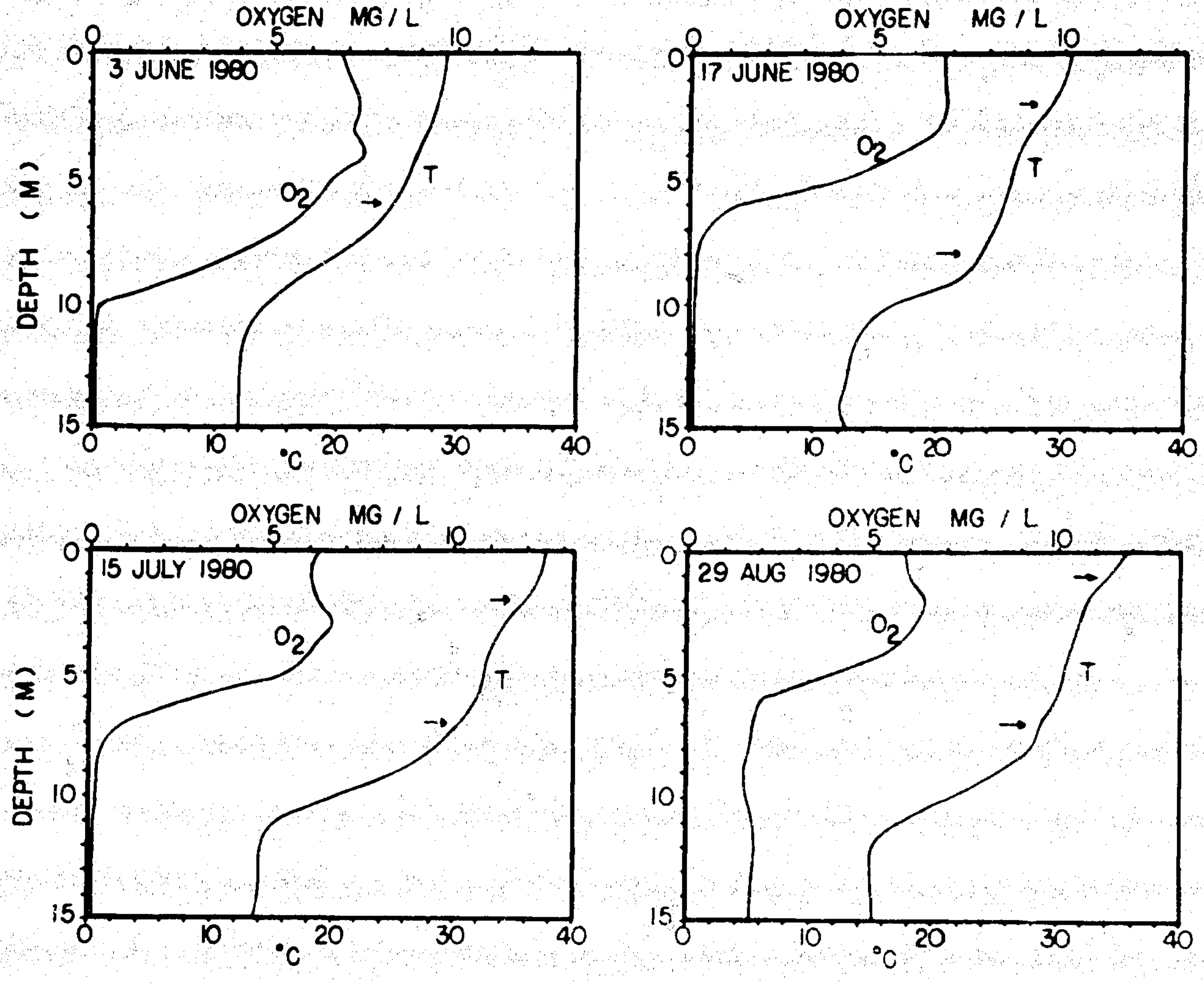


Figure 2.3. Temperature (T) and oxygen (O_2) profiles during the summer of 1980 in Coffeen Lake near the dam. Arrows indicate depths at which the thermoclines begin.

Between the two thermoclines, oxygen rapidly decreased in concentration with increasing depth but did not become depleted, whereas temperatures in this zone were fairly uniform (Fig. 2.3). These three layers of the lake, which were partitioned by the thermoclines, possibly did not mix with each other during the entire summer. Since the middle layer was at least partially in the euphotic zone, oxygen was generated by algal photosynthesis thus compensating for oxygen consumed by organic decomposition and preventing oxygen depletion. Oxygen in that layer might also have been present as a result of occasional mixing with the upper layer if instability occurred from interruptions in power plant generation.

LITERATURE CITED

Liehr, S. 1979. Thermal mapping. In: J. A. Tranquilli and R. W. Larimore (eds.). Environmental studies of Coffeen Lake: First Annual Report to Central Illinois Public Service Company, Illinois Natural History Survey.

Liehr-Storck, S. 1980. Thermal mapping. In: J. A. Tranquilli and R. W. Larimore (eds.). Environmental studies of Coffeen Lake: Second Annual Report to Central Illinois Public Service Company, Illinois Natural History Survey.

SECTION 3

WATER QUALITY OF COFFEEN LAKE

by

Sarah Liehr-Storck

ABSTRACT

Water quality was studied in Coffeen Lake from August 1978 through December 1980. Total dissolved solids and sulfate concentrations decreased during the spring flood of 1979, and then gradually increased to the end of 1980. The total amount of dissolved solids and sulfate in the lake also increased from June 1979 to December 1980. Periodic flushing of water from the lake was apparently necessary to maintain constant sulfate levels. Alkalinity increased from 1979 to 1980, providing additional beneficial buffering capacity against pH changes. Turbidity was highest at the north end of the lake after periods of heavy precipitation. The railroad causeway with two small culverts through it served as a barrier, preventing much of the turbidity entering from the watershed at the upper end of the lake from reaching the lower part of the lake. Total phosphorus levels were generally highest in the upper end of the lake. Inorganic nitrogen concentrations increased dramatically at all stations in late 1979 and 1980. The greatest increases of inorganic nitrogen occurred at stations nearest the power plant discharge, and normal seasonal nitrogen cycles were disrupted. Chlorophyll a concentrations were consistently highest at the north end of the lake above the railroad causeway and lowest in the discharge arm. The conclusion that the north end of the lake supported greater standing crops of algae was consistent with observations of higher pH value and greater saturation of dissolved oxygen there. Direct impact of power plant effluents on lake water pH was apparently minimal. Low concentrations of dissolved oxygen were observed for extended periods in deeper areas of the lake during summer months. Oxygen was depleted for most of the summer throughout extensive areas of the lake indicating eutrophic conditions. In winter, complete mixing of most of the lake beyond the discharge arm prevented oxygen depletion from occurring.

INTRODUCTION

The water quality investigation was undertaken with the purpose of evaluating water quality in Coffeen Lake after the installation of new wastewater treatment facilities at the power plant and with more normal precipitation patterns. The investigation included (1) monitoring water quality parameters in the lake and determining the cause of changes, and (2) determining how temperature distribution resulting from the discharge of a thermal effluent affected water quality. The investigation included studies of circulation patterns in the lake, climatological events, and chemical inputs to the lake. These data were used to assess the relative impacts of climatological events and plant operation on the lake, and to determine how the temperature distribution affected mineral cycling and eutrophication. Water quality parameters that affected the biota are discussed with particular reference to affects on algal populations.

MATERIALS AND METHODS

SAMPLING SCHEDULE

Water samples were collected monthly at Stations 1, 2, 3, and 4 at the top, middle, and bottom of the water column and at Station 5, the slag pond outflow, the coal pile runoff, the coal pile runoff settling pond outflow, the east arm inflowing stream, and the west arm inflowing stream (see Fig. 1.2). Sampling at the slag pond was discontinued after it was abandoned in August 1979. The station at the coal pile runoff was changed to the settling pond outflow in the middle of the first year when settling pond operation began. After operation began, direct runoff from the coal pile no longer ran into the lake. Streams flowing into the east and west arms of the lake were both intermittent, and they could only be sampled in the spring.

The following parameters were measured at monthly intervals from August 1978 through December 1979: turbidity, total alkalinity, free carbon dioxide, EDTA hardness, total phosphorus, soluble orthophosphate, ammonia, nitrate, nitrite, total iron, soluble iron, ferrous iron, sulfate, sulfite, total sulfide, dissolved hydrogen sulfide, un-ionized hydrogen sulfide, chloride, and fluoride. At quarterly intervals water samples were also analyzed for organic nitrogen, total organic carbon, particulate organic carbon, dissolved organic carbon, and chemical oxygen demand. After December 1979, fluoride, sulfite, iron forms, chemical oxygen demand, and particulate and soluble organic carbon were eliminated from the parameter list. Sulfide forms were measured only when oxygen was depleted in the hypolimnion. Chlorophyll a, pheophytin a, and total and particulate organic carbon were measured monthly from duplicate integrated samples of the euphotic zone at the four major lake stations and at the intake of the power plant.

Profiles of temperature, dissolved oxygen, and total dissolved solids were measured twice monthly at 1-m depth intervals at the four major stations and at Stations 1.5 and 2.5 (Fig. 1.2). At the same time, pH was measured at the surface, middle, and bottom of the water column at those stations.

The three depths sampled at the major lake stations, the surface, middle, and bottom of the water column, were selected so that physico-chemical measurements at the bottom could be compared with measurements at the surface and at one other depth within the water column. Station 1.5 was added to include a station at the dam, and Station 2.5 was added to include a sampling site located within the cooling loop and prior to the intake. The other additional stations were included to monitor other discharges to the lake.

FIELD AND ANALYTICAL METHODS

Water samples were collected with a plastic Kemmerer bottle. Samples analyzed for soluble iron were filtered immediately and fixed with hydrochloric acid. Ferrous iron samples were fixed immediately with hydrochloric acid. Samples analyzed for sulfide forms were fixed immediately with 0.2N zinc acetate, and analyzed within 24 hours. Sulfite and pH were measured in the field or in the laboratory immediately after collection. Temperature and dissolved oxygen were measured in the field with a YSI Model 57 dissolved oxygen meter. Conductivity was measured in the field with a YSI Model 33 S-C-T meter, and the results were corrected for temperature and used to calculate total dissolved solids. Methods used to analyze water quality parameters in the laboratory are listed in Table 3.1.

STATISTICAL METHODS

The statistical analysis used for water quality parameters was a three-way analysis of variance with two-way interactions. Main effects were stations, months, and years. Single degree of freedom contrasts were made for the station effects. Station 1 was compared to Station 2 to test for differences between the two stations most affected by power plant discharges. Station 3 (south of the railroad causeway) was compared to Station 4 (north of the railroad causeway) to test for differences between the upper end of the lake and the area separated from it by the railroad causeway. Stations 1 and 2 were collectively compared to Stations 3 and 4 to determine if water quality parameters were different in the lower (heated) portion of the lake than in the upper portion. The analysis of variance was performed using SAS (Statistical Analysis System) GLM (General Linear Model) procedure (Barr et al. 1976) on an IBM 360/75 computer at the University of Illinois, Urbana-Champaign.

Table 3.1 Methods used to analyze chemical parameters.

Parameter	Method
Turbidity	Monitek Model 21 nephelometer
Total alkalinity	Standard Methods 14th ed., titrated to pH 4.60
Free carbon dioxide	Calculated by method of Harvey (1960) and Park (1969)
Total phosphorus	Stannous chloride method
Soluble orthophosphate	Stannous chloride method (Autoanalyzer)
EDTA hardness	EDTA colorimetric method
Ammonia nitrogen	Modified phenate method (Autoanalyzer)
Nitrate nitrogen	Cadmium reduction method (Autoanalyzer)
Nitrite nitrogen	Diazotization method (Autoanalyzer)
Sulfate	Turbidimetric method
Chloride	Argentometric method
Fluoride	Electrode method on Orion Model 601 meter
Iron (total, soluble, and ferrous)	Phenanthroline method
Sulfide (total and dissolved and un-ionized hydrogen sulfide)	Methylene blue visual color matching method
Organic nitrogen	Total Kjeldahl method (Autoanalyzer)
Organic carbon (total, particulate, and dissolved)	Direct injection method on Oceanography International Carbon System
Chemical oxygen demand	Hach Reactor Digestion COD method (Jirka and Carter 1975)
Chlorophyll _a_, pheophytin _a_	Standard Methods

RESULTS AND DISCUSSION

Data from the final collection period of July 1980 through December 1980 are contained in Appendices 3.1-3.4. Previously collected data are listed in Appendices 3.1-3.4 of the first annual report (Liehr 1979) and Appendices 3.1-3.3 of the second annual report (Liehr-Storck 1980).

DISSOLVED SOLIDS

Coffeen Lake had a much greater concentration of total dissolved solids (TDS) than did five other lakes in this geographical area. The mean concentration of TDS in Coffeen Lake on 17 June 1980 was 853 mg/l as NaCl, while five other lakes in the area sampled on 18 June 1980 (Liehr-Storck 1980) had concentrations in the range from 138 to 321 mg/l as NaCl (Table 3.2). Lake Sangchris, another cooling lake in central Illinois, had a mean TDS concentration of 319 mg/l as NaCl (Table 3.2) (Brigham 1981).

Little variation in TDS occurred among stations at most times of the year during this study. In the spring, however, concentrations at Station 4, in the upper end of the lake, dropped considerably relative to the other stations, corresponding to increased rainfall and runoff creating higher lake elevation (Fig. 3.1). The largest drop in TDS at Station 4 occurred in the spring of 1979 when the most dramatic increase in lake elevation occurred. The concentration at Station 4 also decreased relative to the other stations in August 1979 during a period of heavy rains.

The overall concentration of TDS varied considerably during this study, with a large decrease occurring in the spring of 1979 followed by a progressive increase. Since the volume of the lake also varied, however, the total amount of dissolved solids in the lake may be a more meaningful parameter for determining whether dissolved solids actually increased or decreased. Using a lake elevation-volume relationship (Fig. 3.2; Sargent and Lundy) the amount of dissolved solids was calculated and plotted against time (Fig. 3.3). A large decrease was observed in the spring of 1979 when water stored in the reservoir was flushed over the spillway as large amounts of rain and runoff water entered

Table 3.2. Mean water quality data for samples collected from Coffeen Lake on 17 June 1980, from Lake Sangchris from September 1973 through April 1976, and from all other lakes on 18 June 1980.

	Coffeen Lake	Old Hillsboro	Glenn Shoals	Lou Yaeger	Gov. Bond	Lake Vandalia	Lake Sangchris
Sulfate mg/l	431	49.2	40.1	39.4	42.4	20.7	49.9
Alkalinity mg/l $CaCO_3$	78.6	109.4	91.8	85.1	101.8	59.3	88.9
Hardness mg/l $CaCO_3$	282	343	306	303	317	304	184.3
Chloride mg/l	20.2	9.8	6.9	16.9	7.8	4.0	24.3
Turbidity NTU	2.7	5.8	4.6	10.3	6.0	13.4	24.9*
Total phosphorous mg P/l	.04	.07	.05	.07	.07	.05	.19
Ortho-phosphate mg P/l	.02	.01	.03	.04	.02	.03	.04
Ammonia-N mg N/l	.29	.12	.14	.22	.23	.16	.10
Nitrate-N mg N/l	.86	1.09	1.22	.97	1.31	1.29	1.89
Nitrite-N mg N/l	.34	.08	.12	.11	.15	.13	.23
Total inorganic-N mg N/l	1.49	1.29	1.48	1.30	1.69	1.58	2.22
Total dissolved solids mg/l NaCl	853	321	259	232	239	138	319

*Nephelometer Turbidity Units
**JTU (Jackson Turbidity Units)

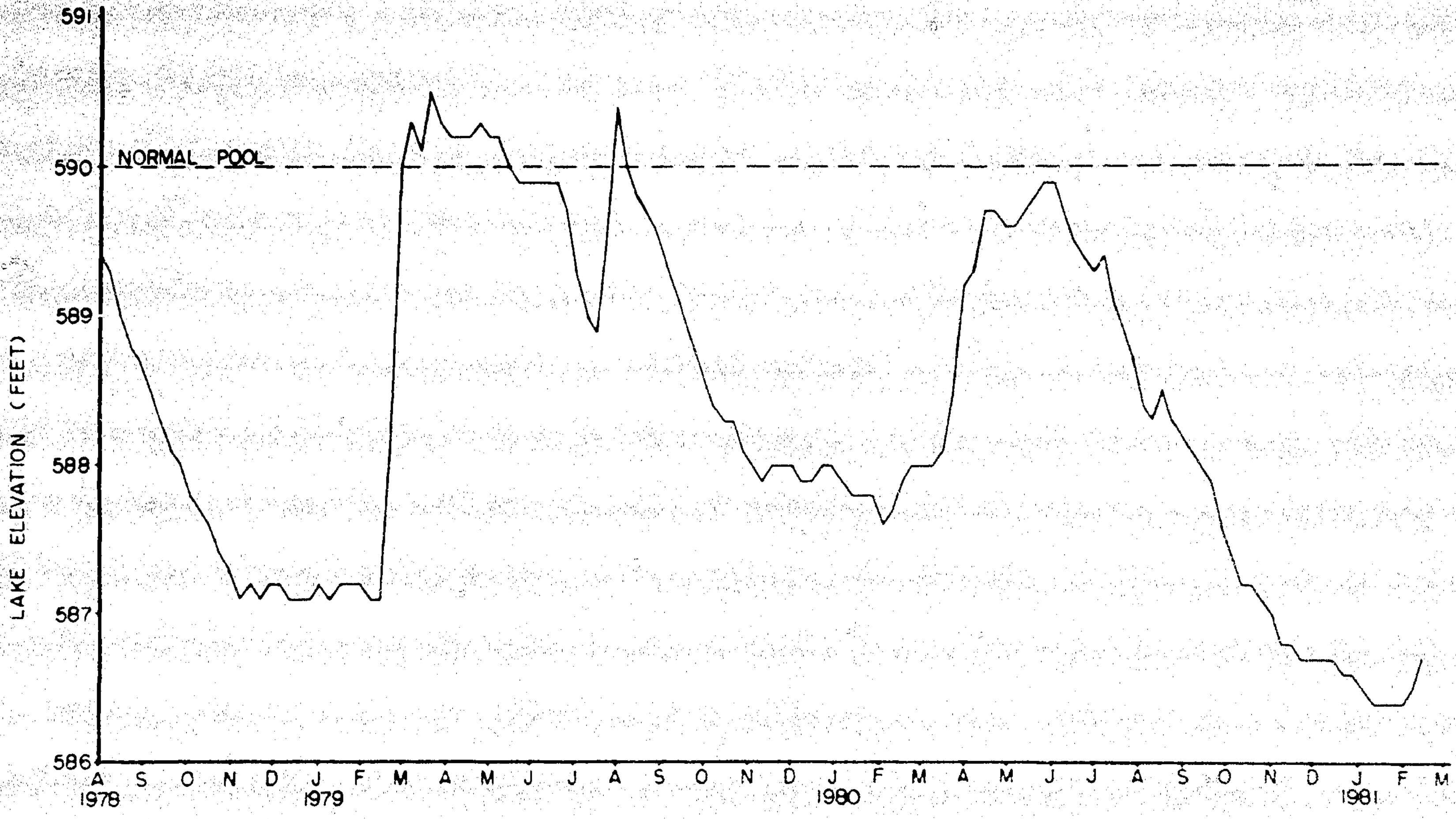


Figure 3.1. Weekly lake elevation means at Coffeen Lake from August 1978 through February 1981.

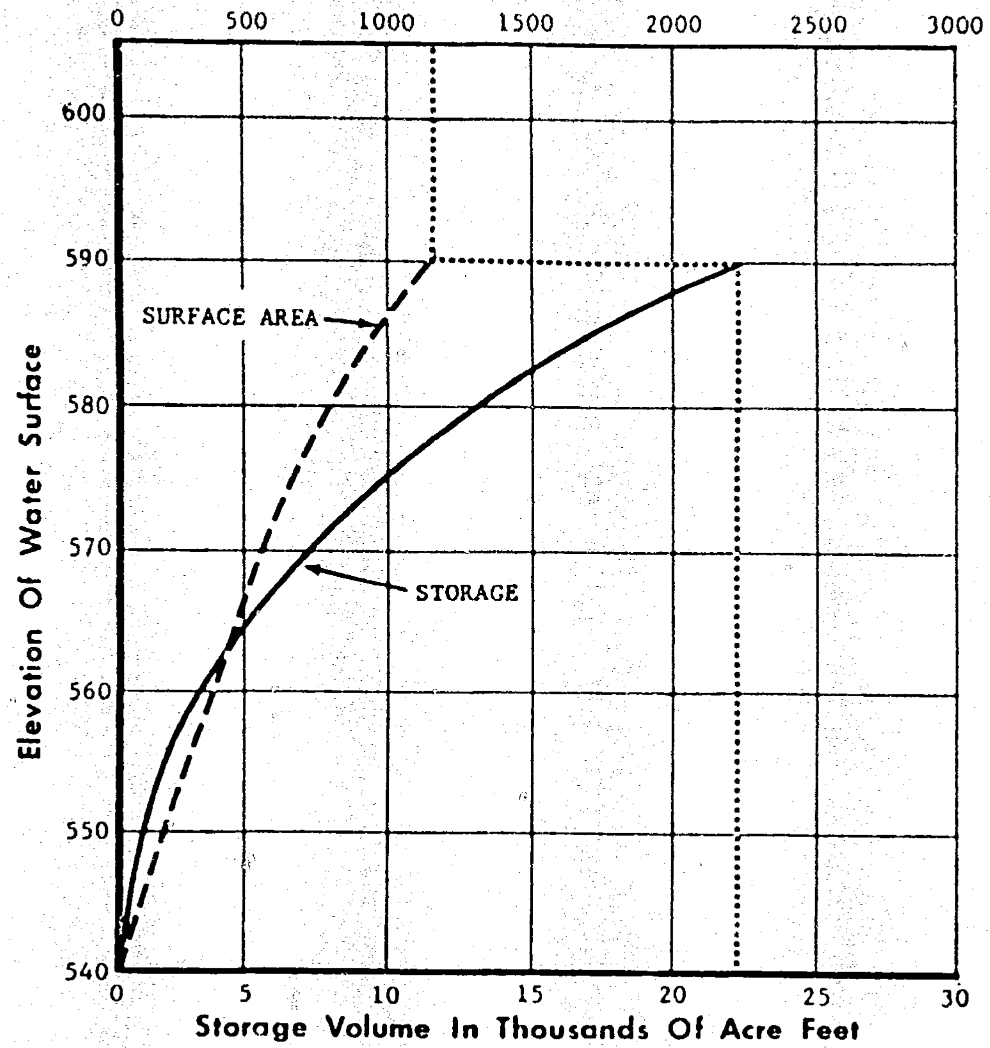


Figure 3.2. Relationship of lake elevation with storage volume and surface area in Coffeen Lake. (Source: Sargent and Lundy Report SL 1990)

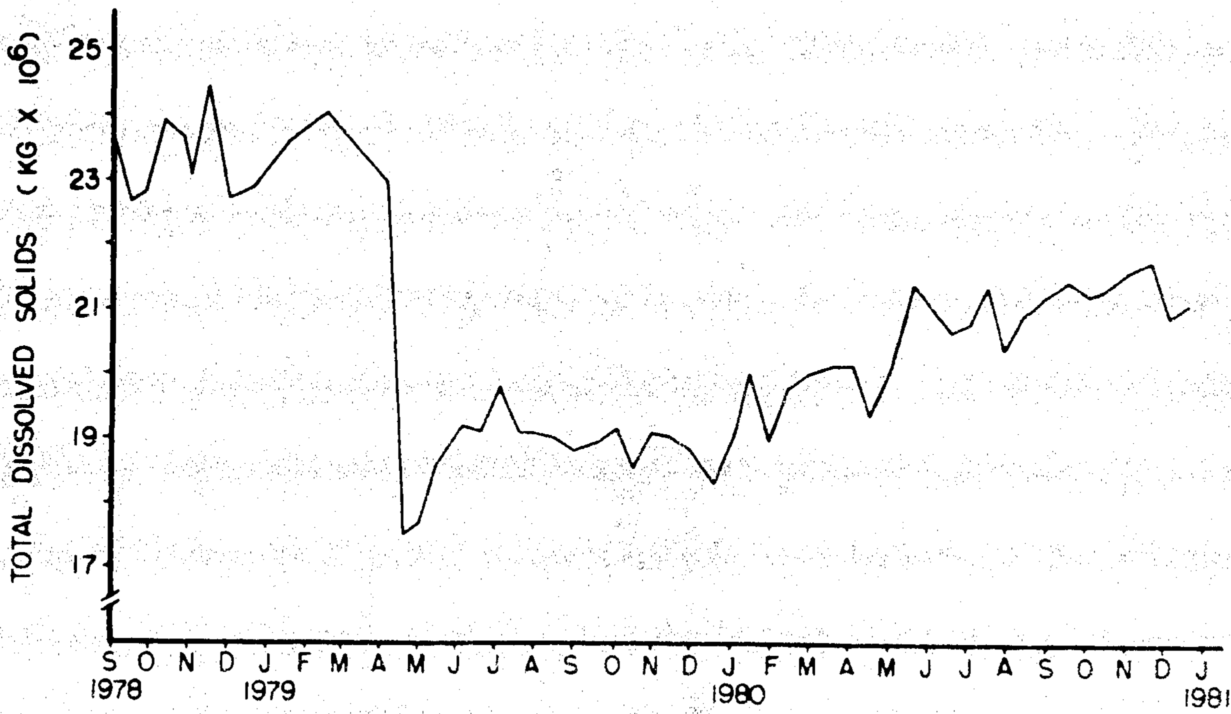


Figure 3.3. Mean total dissolved solids in Coffeen Lake from September 1978 to December 1980.

the lake. From late summer of 1979 until the end of the study, little additional water was flushed from the lake, and a fairly constant increase in total dissolved solids was observed. This increase can be attributed to inputs from precipitation and runoff as well as from demineralizer wastes and coal pile runoff pond effluents.

Even though total dissolved solids concentrations changed during the study period, the relative composition of the anion components changed only slightly during that time (Fig. 3.4), except at Station 4 during the spring flood of 1979, and, to a lesser extent, during the spring flood of 1980. Instead of the carbonate-bicarbonate anions expected to be dominant in bodies of water in temperate regions (Hutchinson 1957), sulfate was the dominant anion. Sulfate concentrations were much higher in Coffeen Lake than in five lakes of the surrounding area or in Lake Sangchris (Table 3.2). Both the high concentration of sulfate and the extreme dominance of the sulfate anion suggest that Coffeen Lake contained sulfate concentrations that are considerably greater than normal. The increase in sulfate concentration over time is illustrated by data collected and provided by the power plant since 1966 (Fig. 3.5). The most rapid increase occurred during the period from 1975-1976, with a decrease following in 1977. Sulfate levels in the lake generally corresponded to sulfate levels in the asn ponds (Fig. 3.5). These ponds were taken out of use in 1978, and apparently sulfate levels in the lake have dropped substantially as a result.

Sulfate concentrations were found to be significantly different among stations (Station 3 vs. 4 and Stations 1 + 2 vs. 3 + 4), months, and stations by months interaction (Table 3.3). These differences were mostly caused by the large decrease in sulfate concentrations at Station 4 during the springs of 1979 and 1980 (Tables 3.4 and 3.5). At other times of the year there was little difference among stations (Fig. 3.6). Significantly lower sulfate levels occurred in 1979 than in 1980 (Table 3.6) as a result of from the spring flood of 1979. A substantial drop in the lakewide sulfate means occurred in the spring of 1979, from 596 mg/l in January 1979 to 310 mg/l in May 1979. After that time, however, sulfate concentrations increased steadily (Fig. 3.6) until they reached 512 mg/l in December 1980. This increase was accompanied by an overall decrease in lake elevation (Fig. 3.1). Therefore, to determine if the

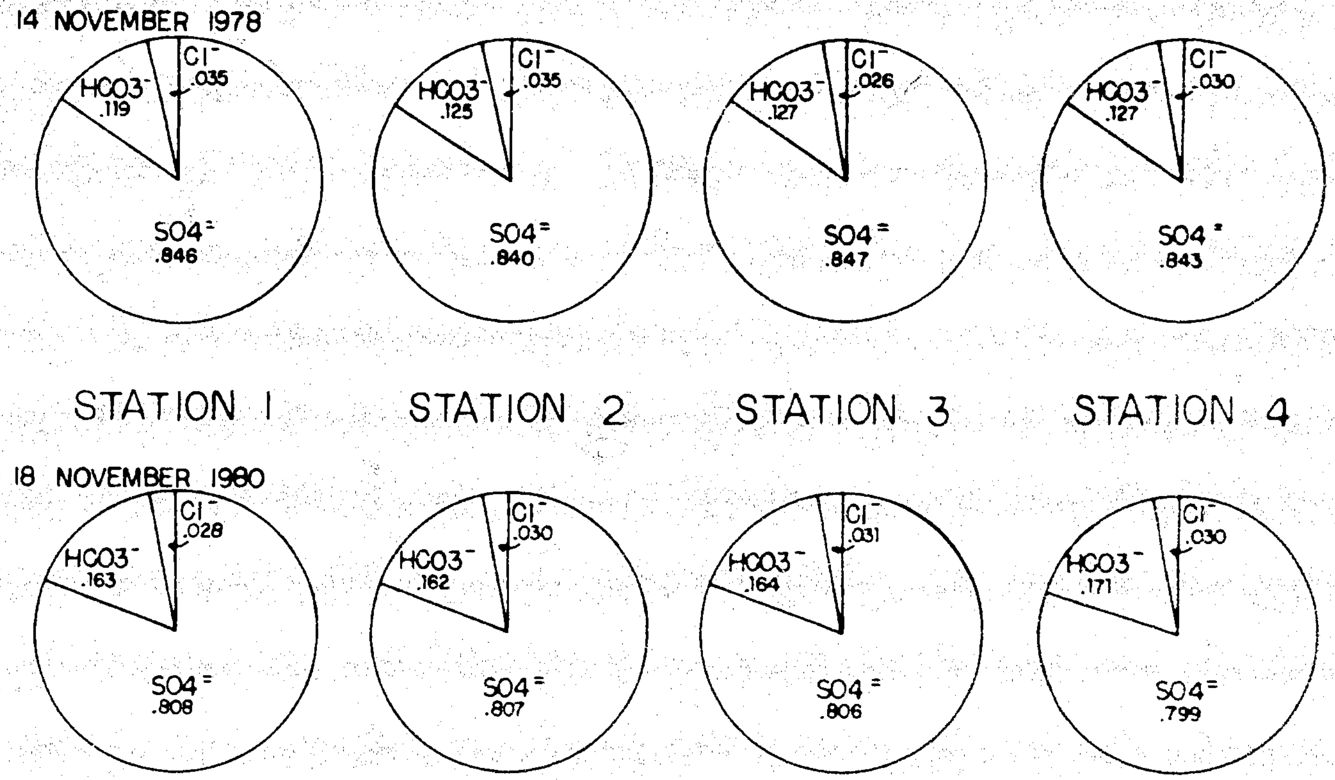


Figure 3.4. Percent composition of major anion components of total dissolved solids at Coffeen Lake on 14 November 1978 and 18 November 1980.

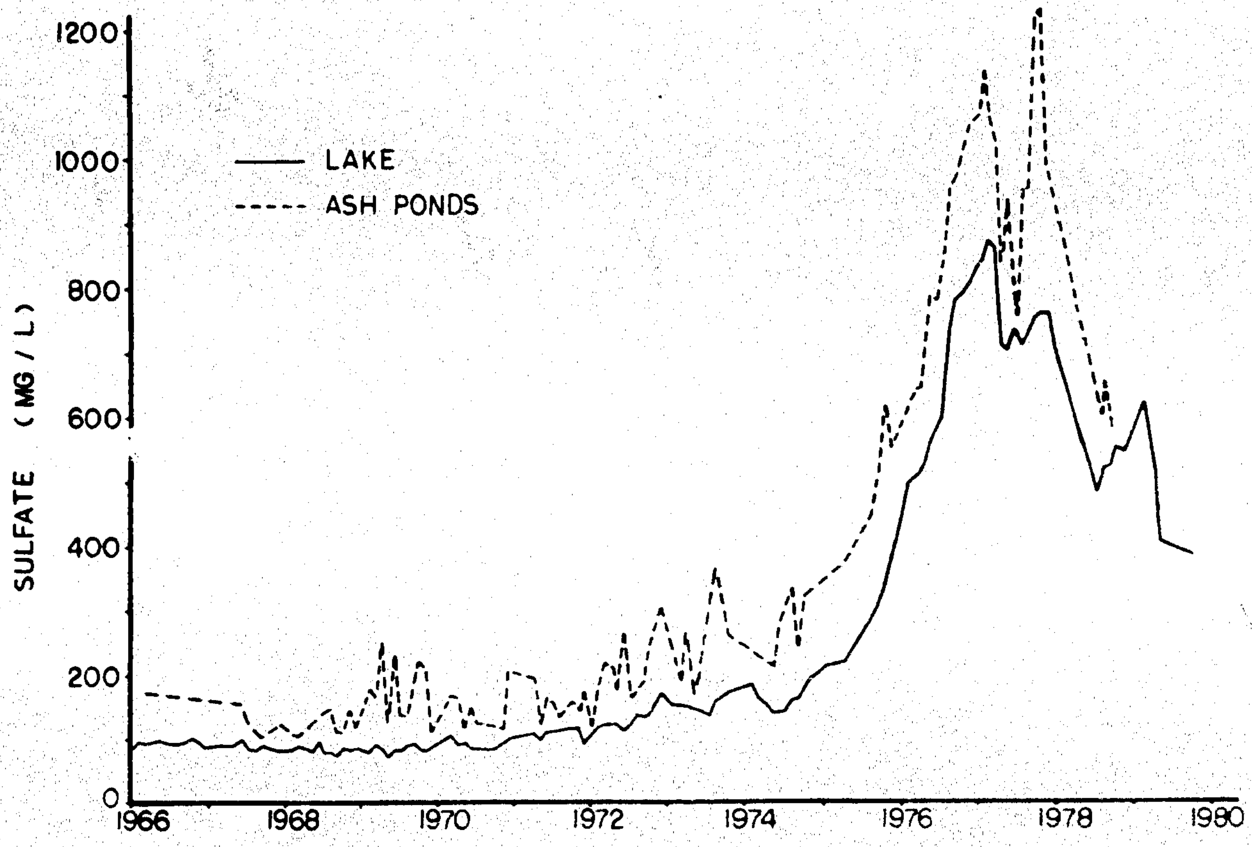


Figure 3.5. Sulfate concentration in Coffeen Lake near the dam and in ash ponds operated by CIPS from 1966 to 1979. Data were collected and provided by CIPS personnel.

Table 3.3 Analysis of variance table of parameters measured at monthly intervals at Coffeen Lake from January 1979 to December 1980.

Source of	Sulfate		Alkalinity		Chloride		Hardness		Turbidity	
Variation	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.
Stations	3	39153**	3	69.75**	3	39.69**	3	11102**	3	7075**
1 vs 2 (C1)	1	339	1	0.34	1	0.74	1	278	1	184
3 vs 4 (C2)	1	63590**	1	75.90**	1	69.12**	1	19499**	1	14122**
1+2vs3+4 (C3)	1	53528**	1	133.01**	1	49.22**	1	13530**	1	6921**
Months	11	52652**	11	9443.60**	11	64.50**	11	23510**	11	5341**
Stations by Months	33	9129**	33	43.02**	33	9.94**	33	2612**	33	3347**
C1 by months	11	87	11	7.93	11	0.47	11	45	11	21
C2 by months	11	15205**	11	70.34**	11	17.50**	11	4701**	11	6798**
C3 by months	11	12095**	11	50.79**	11	11.84**	11	3089**	11	3221**
Years	1	210722**	1	19976.60**	1	345.20**	1	25	1	7214**
Stations by years	3	7821**	3	9.77	3	19.37**	3	4555**	3	4363**
C1 by years	1	646	1	18.06	1	0.31	1	125	1	2.4
C2 by years	1	15016**	1	10.30	1	35.23**	1	8005**	1	9344**
C3 by years	1	7801**	1	0.94	1	22.58**	1	5536**	1	3742**
Months by years	11	55652**	11	397.81**	11	47.53**	11	14649**	11	4458**
Residual	222	527	222	5.77	222	0.977	222	223	222	454
Coefficient of determination (R^2)	.942		.966		.909		.920		.721	

*indicates significance $P<0.05$

**indicates significance at $P \le 0.01$

Table 3.3 Analysis of variance table of parameters measured at monthly intervals at Coffeen Lake from January 1979 to December 1980. (continued)

Source of Variation	Total Phosphorus		Ammonia Nitrogen		Nitrate Nitrogen		Nitrite Nitrogen		Total Inorganic Nitrogen	
	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.	d.f.	M.S.
Stations	3	.02232 **	3	1.405**	3	0.736**	3	0.0061 **	3	4.147**
1 vs 2 (C1)	1	.000937	1	1.039**	1	0.0013	1	0.0018 *	1	1.205**
3 vs 4 (C2)	1	.03586 **	1	0.629**	1	1.073**	1	0.0103 **	1	3.727**
1+2vs3+4 (C3)	1	.03017 **	1	2.548**	1	1.135**	1	0.0063 **	1	7.510**
Months	11	.007501**	11	0.470**	11	0.799**	11	0.0537 **	11	1.378**
Stations by Months	33	.004466**	33	0.206**	33	0.024**	33	0.00094**	33	0.199**
C1 by months	11	.000496	11	0.347**	11	0.0019	11	0.00026	11	0.353**
C2 by months	11	.007429**	11	0.024	11	0.035**	11	0.00077**	11	0.044
C3 by months	11	.005472**	11	0.246**	11	0.036**	11	0.0018 **	11	0.201**
Years	1	.0000639	1	5.830**	1	17.564**	1	0.1876 **	1	49.543**
Stations by years	3	.000318	3	0.948**	3	0.050**	3	0.00028	3	1.351**
C1 by years	1	.0000121	1	1.090**	1	0.0005	1	0.00006	1	1.154**
C2 by years	1	.000319	1	0.166*	1	0.076**	1	0.00001	1	0.469**
C3 by years	1	.000622	1	1.588**	1	0.073**	1	0.00077	1	2.430**
Months by years	10	.003235**	11	0.576**	11	0.396**	11	0.0209 **	11	0.547**
Residual	272	.0005333	222	0.0361	222	0.00712	222	0.000275	222	0.0449
Coefficient of determination (R^2)	.759		.795		.956		.946		.905	

*indicates significance at $P<0.05$
**indicates significance at $P\leq0.01$

Table 3.4. Station means of water quality parameters for samples collected at Coffeen Lake from January 1979 through December 1980.

	Station 1			Station 2			Station 3			Station 4		
	mean	std. dev.	n	mean	std. dev.	n	mean	std. dev.	n	mean	std. dev.	n
Sulfate mg/l	456	70	72	453	67	72	449	68	72	399	114	69
Alkalinity mg/l $CaCO_3$	74.9	11.3	72	74.8	10.0	72	74.2	10.4	72	72.6	14.2	69
Hardness mg/l $CaCO_3$	296	37	72	299	36	72	295	37	72	267	65	69
Chloride mg/l	19.9	2.1	72	20.0	2.1	72	19.8	2.2	72	18.3	4.3	69
Turbidity NTU	7.7	8.7	72	5.5	7.0	72	6.4	8.6	72	26.5	69.3	69
Total phosphorus mg P/l	.045	.033	69	.040	.022	69	.047	.028	69	.082	.059	66
Ortho phosphate mg P/l	.011	.004	69	.012	.004	69	.013	.007	69	.029	.026	69
Ammonia-N mg N/l	.501	.577	72	.331	.304	72	.293	.235	72	.173	.120	69
Nitrate-N mg N/l	.859	.361	72	.853	.351	72	.817	.343	72	.637	.333	69
Nitrite-N mg N/l	.082	.062	72	.075	.063	72	.078	.066	72	.063	.060	69
Total inorganic-N mg N/l	1.442	.814	72	1.259	.528	72	1.189	.480	72	.873	.373	69

Table 3.5. Monthly means of water quality for samples parameters collected at four locations at Coffeen Lake from January 1979 through December 1980.

	January			February			March			April			May			June		
	mean	std. dev.	n	mean	std. dev.	n	mean	std. dev.	n	mean	std. dev.	n	mean	std. dev.	n	mean	std. dev.	n
Sulfate mg/l	513	85	24	512	70	21	439	97	24	372	114	24	369	84	24	396	36	24
Alkalinity mg/l $CaCO_3$	77.4	2.7	24	76.6	3.0	21	69.9	10.0	24	64.0	15.4	24	69.3	11.3	24	71.0	8.2	24
Hardness mg/l $CaCO_3$	361	57	24	347	51	21	261	52	24	257	73	24	269	32	24	283	4	24
Chloride mg/l	21.1	2.1	24	21.6	1.7	21	18.6	3.2	24	16.6	4.1	24	17.[illegible]	5.0	23	18.0	2.[illegible]	24
Turbidity NTU	4.8	4.7	24	2.5	1.9	21	16.0	22.3	24	57.9	110.6	24	9.5	12.3	24	9.6	21.1	24
Total phosphorus mg P/l	.032	.018	24	.030	.014	21	.057	.039	24	.083	.089	24	.065	.044	24	.039	.025	24
Ortho phosphate mg P/l	.013	.009	24	.010	.000	12	.028	.035	24	.029	.023	24	.017	.015	24	.023	.01[illegible]	24
Ammonia-N mg N/l	.259	.158	24	.456	.385	21	.523	.401	24	.441	.316	24	.461	.395	24	.17[illegible]	.086	24
Nitrate-N mg N/l	.833	.075	24	.917	.163	21	1.083	.286	24	.558	.153	24	.566	.3[illegible]	24	.56[illegible]	.24[illegible]	24
Nitrite-N mg N/l	.033	.017	24	.032	.013	21	.074	.218	24	.038	.016	24	.052	.025	24	.202	.106	24
Total inorganic-N mg N/l	1.124	.257	24	1.405	.537	21	1.579	.661	24	1.137	.453	24	1.174	.175	24	.933	.384	24

Tab e 3.5. Monthly means of water quality parameters for samples collected at four locations at Coffeen Lake from January 1979 through December 1980. (continued)

	July			August			September			October			November			December		
	mean	std. dev.	n	mean	std. dev.	n	mean	std. dev.	n	mean	std. dev.	n	mean	std. dev.	n	mean	std. dev.	n
Sulfate mg/l	426	46	24	438	44	24	426	55	24	445	77	24	482	75	24	469	45	24
Alkalinity mg/l $CaCO_3$	73.4	6.3	24	70.0	11.1	24	72.3	10.8	24	79.0	8.6	24	83.5	10.8	24	83.7	14.4	24
Hardness mg/l $CaCO_3$	285	7	24	268	17	24	279	16	24	285	13	24	290	8	24	293	13	24
Chloride mg/l	19.2	1.3	24	19.9	2.7	24	20.6	2.6	24	20.6	2.2	24	19.9	0.9	24	21.4	1.7	24
Turbidity NTU	6.5	5.3	24	7.0	5.3	24	6.2	3.9	24	6.3	4.0	24	5.9	5.4	24	3.0	0.9	24
Total phosphorus mg P/l	.048	.028	24	.101	.032	12	.062	.022	24	.056	.026	24	.058	.017	24	.026	.008	24
Ortho phosphate mg P/l	.015	.007	24	.015	.008	24	.012	.005	24	.010	.000	24	.011	.003	24	.010	.000	24
Ammonia-N mg N/l	.242	.143	24	.289	.213	24	.202	.122	24	.217	.169	24	.137	.092	24	.537	.473	24
Nitrate-N mg N/l	.950	.516	24	.748	.426	24	.553	.456	24	.517	.288	24	.996	.272	24	.458	.204	24
Nitrite-N mg N/l	.089	.043	24	.083	.059	24	.102	.054	24	.095	.034	24	.050	.030	24	.040	.009	24
Total inorganic-N mg N/l	1.281	.634	24	1.120	.425	24	.857	.556	24	.928	.372	24	1.183	.349	24	1.035	.999	24

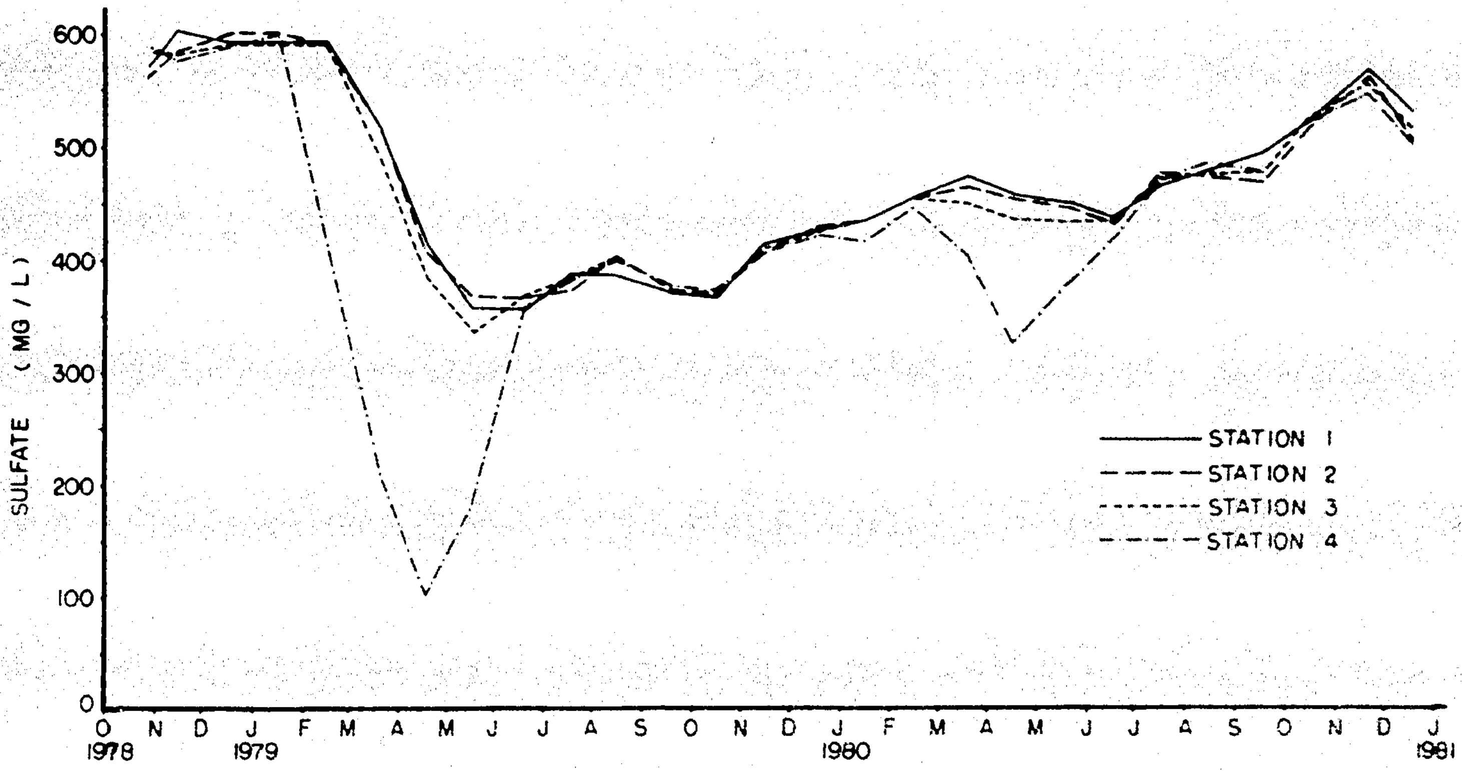


Figure 3.6. Mean sulfate concentrations at all sampling depths of each station at Coffeen Lake from October 1978 to December 1980.

Table 3.6. Annual means of water quality parameters for samples collected at Coffeen Lake from August 1978 through December 1980.

	1978*			1979			1980		
	mean	std. dev.	n	mean	std. dev.	n	mean	std. dev.	n
Sulfate mg/l	538	63	59	411	103	141	468	46	144
Alkalinity mg/l $CaCO_3$	70.9	6.7	60	65.5	8.4	141	82.6	6.9	144
Hardness mg/l $CaCO_3$	274	91	59	289	65	141	290	14	144
Chloride mg/l	26.1	6.9	59	18.4	3.4	141	20.7	1.7	144
Turbidity NTU	5.4	3.5	59	16.3	49.7	141	6.5	7.5	144
Total phosphorus mg P/l	--	--	--	.100	.180	132	.054	.036	144
Ortho phosphate mg P/l	.011	.004	59	.019	.020	132	.014	.009	144
Ammonia-N mg N/l	.075	.127	59	.185	.123	141	.465	.468	144
Nitrate-N mg N/l	.223	.236	59	.538	.241	141	1.043	.264	144
Nitrite-N mg N/l	.028	.021	59	.049	.032	141	.100	.075	144
Total inorganic-N mg N/l	.326	.256	59	.772	.255	141	1.608	.565	144

*1978 data included the months of August through December. These data were not used in the statistical analysis.

Table 3.6. Annual means of water quality parameters for samples collected at Coffeen Lake from August 1978 through December 1980.

	1978*			1979			1980		
	mean	std. dev.	n	mean	std. dev.	n	mean	std. dev.	n
Sulfate mg/l	538	63	59	411	103	141	468	46	144
Alkalinity mg/l $CaCO_3$	70.9	6.7	60	65.5	8.4	141	82.6	6.9	144
Hardness mg/l $CaCO_3$	274	91	59	289	65	141	290	14	144
Chloride mg/l	26.1	6.9	59	18.4	3.4	141	20.7	1.7	144
Turbidity NTU	5.4	3.5	59	16.3	49.7	141	6.5	7.5	144
Total phosphorus mg P/l	--	--	--	.100	.180	132	.054	.036	144
Ortho phosphate mg P/l	.011	.004	59	.019	.020	132	.014	.009	144
Ammonia-N mg N/l	.075	.127	59	.185	.123	141	.465	.468	144
Nitrate-N mg N/l	.223	.236	59	.538	.241	141	1.043	.264	144
Nitrite-N mg N/l	.028	.021	59	.049	.032	141	.100	.075	144
Total inorganic-N mg N/l	.326	.256	59	.772	.255	141	1.608	.565	144

*1978 data included the months of August through December. These data were not used in the statistical analysis.

quantity of sulfate in the lake had increased or decreased, the elevation-volume relationship (Fig. 3.2) was again used. There was a substantial decline in the sulfate content of the lake in the spring of 1979 when a considerable amount of water stored in the reservoir was flushed over the spillway. From that time until the end of the study, the amount of sulfate in Coffeen Lake increased fairly steadily. When the study ended in December 1980, the sulfate content of the lake had not increased to the amount present at the beginning of the study, so the amount lost by flushing in the spring of 1979 had not yet been replaced (Fig. 3.7). This pattern of decreasing sulfate with a subsequent increase was very similar to the pattern observed for total dissolved solids. The percent of sulfate in the composition of anions did not change dramatically throughout the study, except at Station 4 in the spring as already discussed. Prior to the spring of 1979, sulfate comprised about 84% of the anion content by weight. From June 1979 through the remainder of the study, sulfate was about 80% by weight, with little variation.

Sulfate concentrations were significantly lower ($P \leq 0.02$) in the hypolimnion when dissolved oxygen concentrations were low. Sulfate is reduced to sulfide under low oxygen conditions, but hydrogen sulfide was not detected. All sulfide produced was apparently precipitated as iron sulfide. Lack of stratification in winter probably prevented sulfide from being formed at that time.

Alkalinity levels were lower in Coffeen Lake than in most of the five lakes in the same geographical area and lower than in Lake Sangchris (Table 3.2). Statistical differences were similar to differences for sulfate concentrations (Table 3.3). All stations had about the same alkalinity levels, with the exception of Station 4 during the spring of 1979 and 1980. Alkalinity was probably more diluted at Station 4 than the other stations as a result of spring rains and runoff, although alkalinity levels decreased at all stations at that time. Overall, however, alkalinity increased in Coffeen Lake during this study. The mean alkalinity in 1979 was 65.5 mg/l as $CaCO_3$, and the mean in 1980 was 82.6 mg/l as $CaCO_3$ (Table 3.6). These levels were an improvement since 1975-76 when data collected at the power plant indicated that alkalinity levels plunged dramatically to abnormally low levels (Fig. 3.8). The higher alkalinity is a desirable characteristic because it provides greater buffering capacity

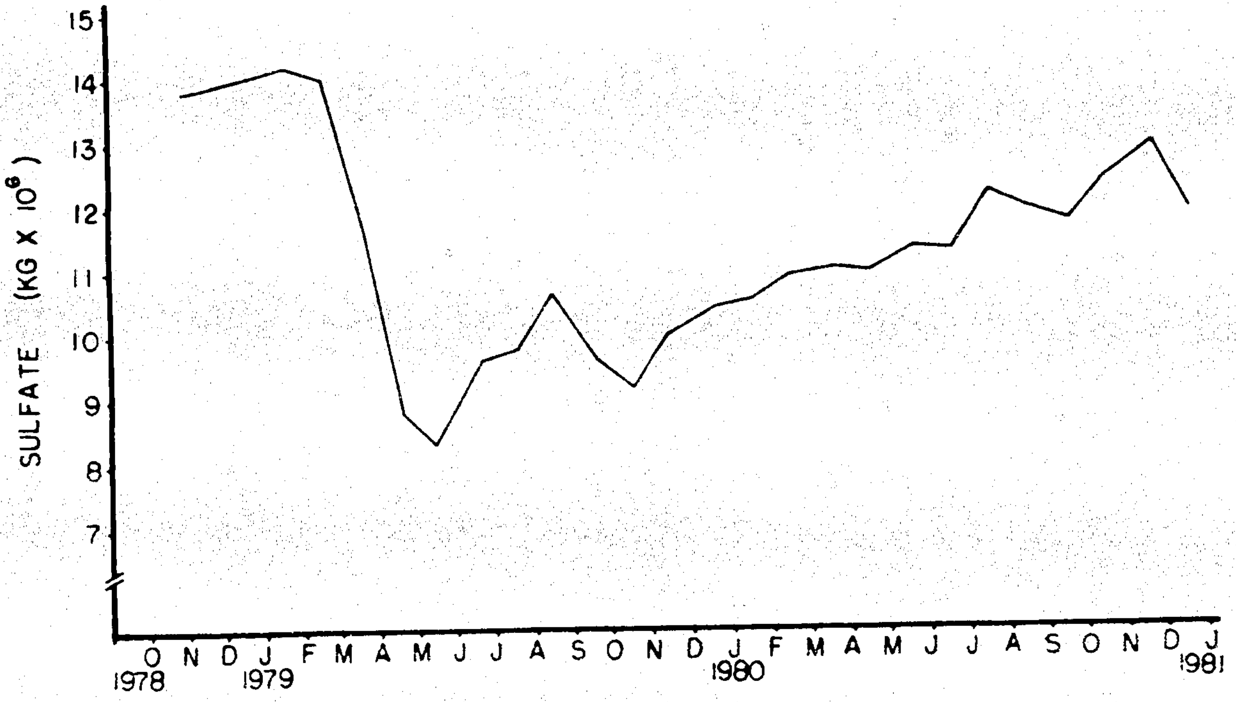


Figure 3.7. Mean sulfate content of Coffeen Lake from October 1978 to December 1980.

Figure 3.8. Alkalinity in Coffeen Lake near the dam from 1966 to 1979. Data were collected and provided by CIPS personnel.

against pH changes and is often accompanied by more desirable species of algae (King 1970).

The two other major components of total dissolved solids in Coffeen Lake were hardness (calcium and magnesium) and chloride. Hardness levels were lower than in the five lakes in the same area but higher than levels in Lake Sangchris, while chloride levels were lower than levels at Lake Sangchris but higher than in the other five lakes (Table 3.2). The data for these parameters were observed in patterns similar to the patterns of sulfate and alkalinity (Table 3.3). Hardness was not significantly different between years, but chloride was significantly higher in 1980 than in 1979 (Table 3.6), although chloride did not reach levels as high as those observed at the beginning of this study. Decreased concentrations of both parameters were observed at Station 4 during the springs with the biggest decline occurring in the spring of 1979. As with the other two TDS parameters, there was little variation among stations at other times of the year.

TURBIDITY

Statistical differences in turbidity (Table 3.3) were caused to a large extent by extremely high levels (mean 143.6 NTU) at Station 4 in the spring of 1979. This occurrence resulted in higher levels at Station 4 (Table 3.4) in the spring months (Table 3.5), and also resulted in significantly higher turbidity levels in 1979 than in 1980 (Table 3.6). The high turbidity corresponded to heavy precipitation and high lake levels at that time. Increased turbidity levels were also observed at Station 4 in August 1979 (mean 14.0 NTU) and during the spring of 1980 (mean 20.0 NTU), which were also associated with heavy precipitation and rapid increases in lake elevation (Fig. 3.1). Turbidity at the other down-lake stations did not increase to the same extent as at Station 4 located at the upper end of the reservoir. During the spring of 1979 the mean turbidity at the three down-lake stations was only 15.6 NTU. Apparently movement of water through the railroad causeway that separates Station 4 from the other stations was slowed enough to allow much of the particulate matter to settle before the water mixed with other parts of the lake. High turbidity levels were generally associated with high levels of total phosphorus and total iron.

PHOSPHORUS

The form of phosphorus used by plants as a nutrient is soluble orthophosphate. Because this form is rapidly cycled and converted to other forms, it is not a good indicator of available phosphorus in the system. Total phosphorus is considered to be a more reliable estimate of available phosphorus (Pomeroy 1960).

A large increase in total phosphorus at all stations in August 1979 could not be explained. Therefore, to exclude possibly erroneous data, the data from that month were not used in the statistical analysis (Table 3.3). Phosphorus was not significantly different in 1979 and 1980, with annual means of 0.051 mg P/l and 0.054 mg P/l, respectively (Table 3.6). Station differences (Station 3 vs. 4 and Stations 1 + 2 vs. 3 + 4) were mostly accounted for by higher levels at Station 4 (Table 3.4). Increase in phosphorus at Station 4 generally accompanied turbidity increases, and the highest levels were found in the spring (Table 3.5), with maximum concentrations of .277 mg P/l in April 1979 and 0.173 mg P/l in April 1980. From the spring of 1979 until the following spring, phosphorus levels at all stations were similar, with Stations 3 and 4 generally having slightly higher levels than Stations 1 and 2. In 1980, however, phosphorus levels remained higher at Station 4 throughout the summer. Phosphorus levels were similar at the three stations in the lower end of the lake, and gradually rose throughout the summer. Phosphorus levels then decreased at all four stations in the fall.

NITROGEN

The nitrogen content of water is composed of organic and inorganic forms. The inorganic forms found in natural water are ammonia, nitrate, and nitrite, although nitrite is usually found in only small amounts.

The typical seasonal pattern for unstratified lakes is a summer maximum of ammonia (Hutchinson 1957). Stations 1, 3, and 4 were not typically stratified, and Station 2, although it was thermally stratified in the summer, did not have significantly different ammonia concentrations at the surface and bottom during the months that stratification occurred. The ammonia cycle observed during 1979 was basically the typical pattern with ammonia concentrations increasing through the summer and the maximum occurring at all stations in August. The only apparent deviation from this pattern was the increase at Station 4 in the spring, which can probably be explained by the rapid inflow of runoff water at that time. During 1980, however, the typical ammonia pattern was not observed. Ammonia levels began to rise at all stations in late 1979 with the smallest increase occurring at Station 4. Levels continued to rise until March, with Stations 1 and 2 having the highest concentrations (1.017 and 1.107 mg N/l, respectively), and Station 4 the lowest (0.417 mg N/l). The maximum ammonia concentration of 1.150 mg N/l was observed in May 1980 at Station 1, located in the discharge arm. In June, ammonia levels dropped at all stations, with concentrations subsequently increasing at Station 1 but continuing to decrease at the other stations (Fig. 3.9). The extremely high concentrations (2.780 mg N/l) observed at Station 1 in December 1980 were apparently affected by operations at the power plant. Significant differences of ammonia concentration among stations for all station contrasts (Table 3.3) are explained by the gradient around the lake, with highest levels found at Station 1 and lowest levels at Station 4 (Table 3.4). Monthly means were highest in the spring months and in December (Table 3.5), contrary to the normal cycle in which maximum levels occur in late summer. Ammonia concentrations were significantly lower at all stations during 1979 than during 1980 (Table 3.6). Deviation from the typical annual pattern of ammonia cycling plus the rapid increase in ammonia concentrations in 1980, which were significantly higher at the sampling stations nearest the power plant discharge indicated that ammonia levels were affected by the power plant.

The typical seasonal pattern for nitrate is a maximum in winter and spring when the rate of nitrification, i.e., the oxidation of reduced nitrogen compounds, is most rapid, and minimum in July and August when the rate of nitrate reduction is the greatest (Hutchinson 1957). Again, the pattern observed in Coffeen Lake in 1979 approximated the expected pattern (Fig. 3.10). Nitrate concentrations increased at all stations beginning in the fall of 1978, and reached a maximum in March of 0.808 mg N/l. Concentrations started to decrease in April, and the

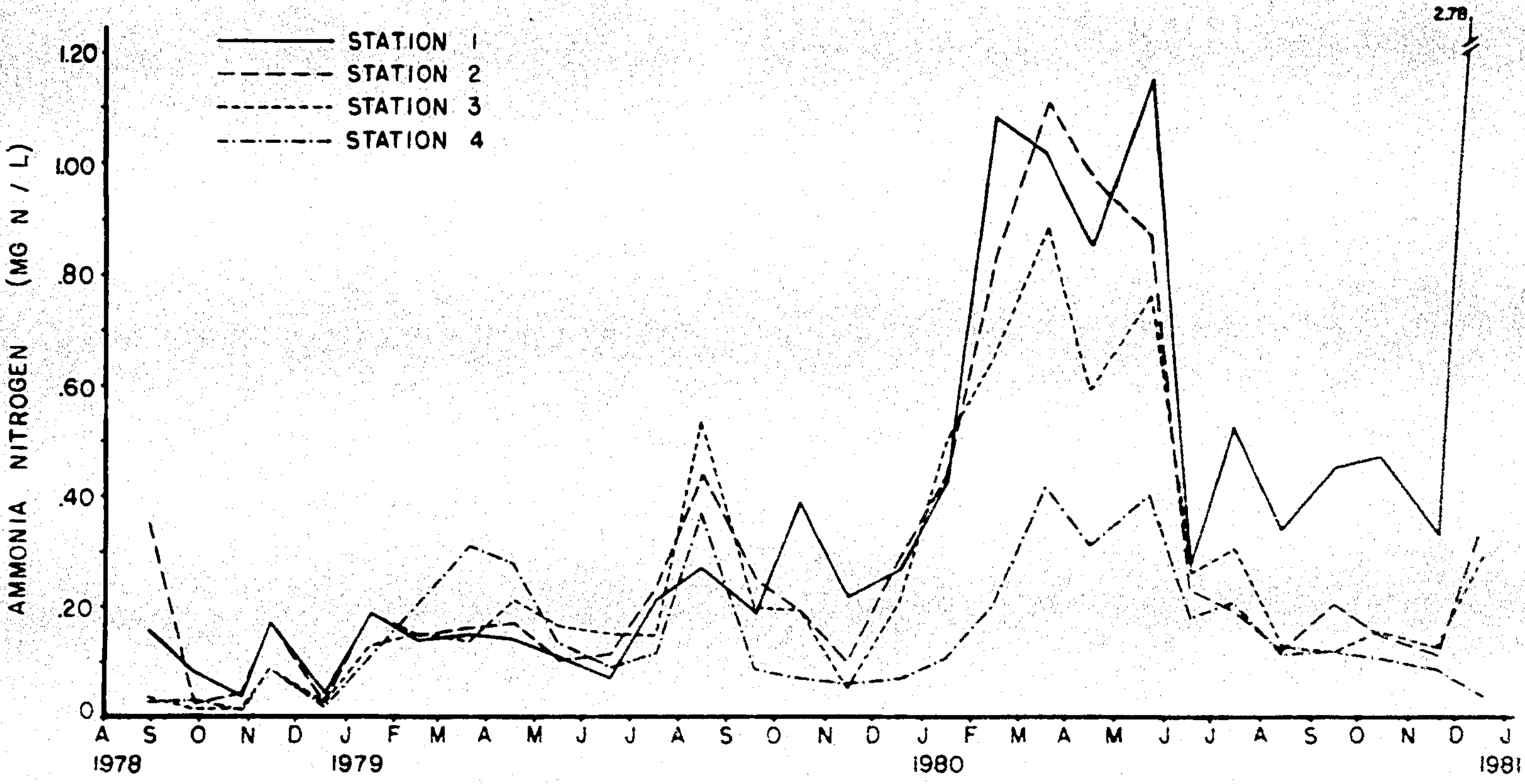


Figure 3.9. Mean ammonia nitrogen concentrations at all sampling depths of each station at Coffeen Lake from August 1978 to December 1980.

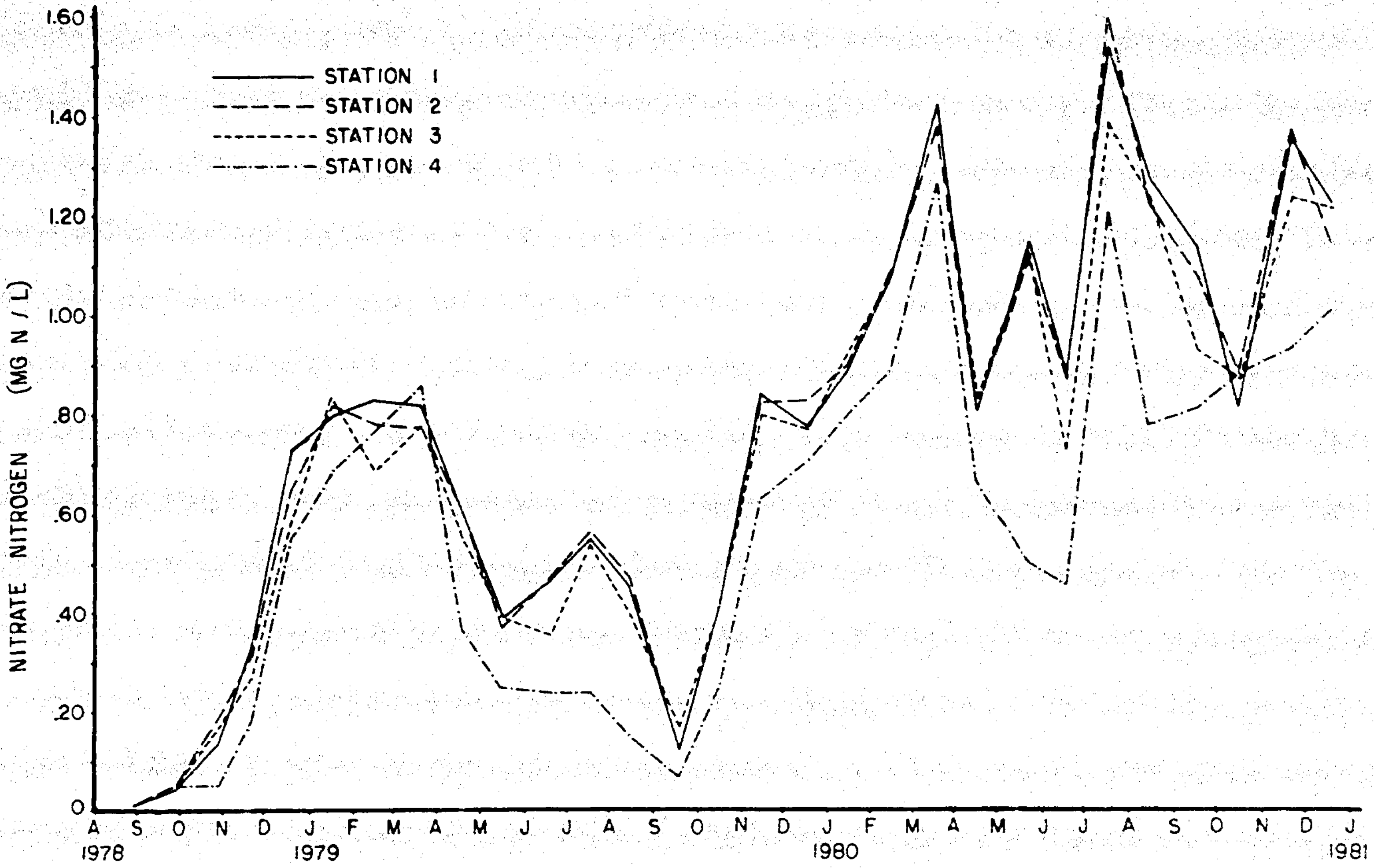


Figure 3.10. Mean nitrate nitrogen concentrations at all sampling depths of each station at Coffeen Lake from August 1978 to December 1980.

minimum was observed in late summer. This pattern was observed at all stations; however, concentrations throughout the summer at Station 4 were lower than at the other stations. Nitrate levels then began to increase, and continued to increase through the winter as expected, however, the increase was much greater than it had been the previous year, and reached 1.359 mg N/l in March. Concentrations fluctuated for the remainder of 1980, but no consistent decline was observed during the summer and nitrate levels reached a maximum in July. Significant differences in nitrate concentrations among stations (Table 3.3) can mostly be explained by consistently lower levels at Station 4 (Fig. 3.10). The other three stations, which were located closer to the power plant, did not have nitrate levels substantially different from each other (Table 3.4). A significant difference between years was again explained by substantially higher concentrations during 1980 than during 1979 (Table 3.6).

Nitrite levels were also higher in 1980 than in 1979, with mean concentrations increasing from .049 mg N/l in 1979 to .100 mg N/l in 1980 (Table 3.6). The highest mean nitrite concentration was observed at Station 1 and the lowest at Station 4 during both years. The warmer months, June through October, were months with the highest nitrite concentrations (Table 3.5).

The total inorganic nitrogen concentration was significantly higher in 1980 (Table 3.3), with a mean of 1.608 mg N/l, than in 1979, with a mean of .772 mg N/l (Table 3.6). The greatest increase took place during the period from September 1979 to March 1980, with the maximum occurring in March 1980. During that period, the mean concentration of inorganic nitrogen increased from .363 mg N/l to 2.273 mg N/l. During the last half of 1979 and during all of 1980, levels of inorganic nitrogen were considerably lower at Station 4 than at the other stations (Fig. 3.11). Station 1, located in the discharge arm, had the highest levels for most of 1980, with significantly higher levels than Station 2 (Table 3.3). The mean inorganic nitrogen concentration in 1980 at Station 4 was 1.126 mg N/l and at Station 1 was 2.046 mg N/l, i.e, there was almost twice the concentration of inorganic nitrogen at Station 1 as at Station 4 during 1980. Both the increased levels in 1980 and the disturbed seasonal cycle of nitrogen in the lake indicate that a significant loading of nitrogen occurred, probably starting in late 1979. While the rate of cycling of nitrogen from organic forms

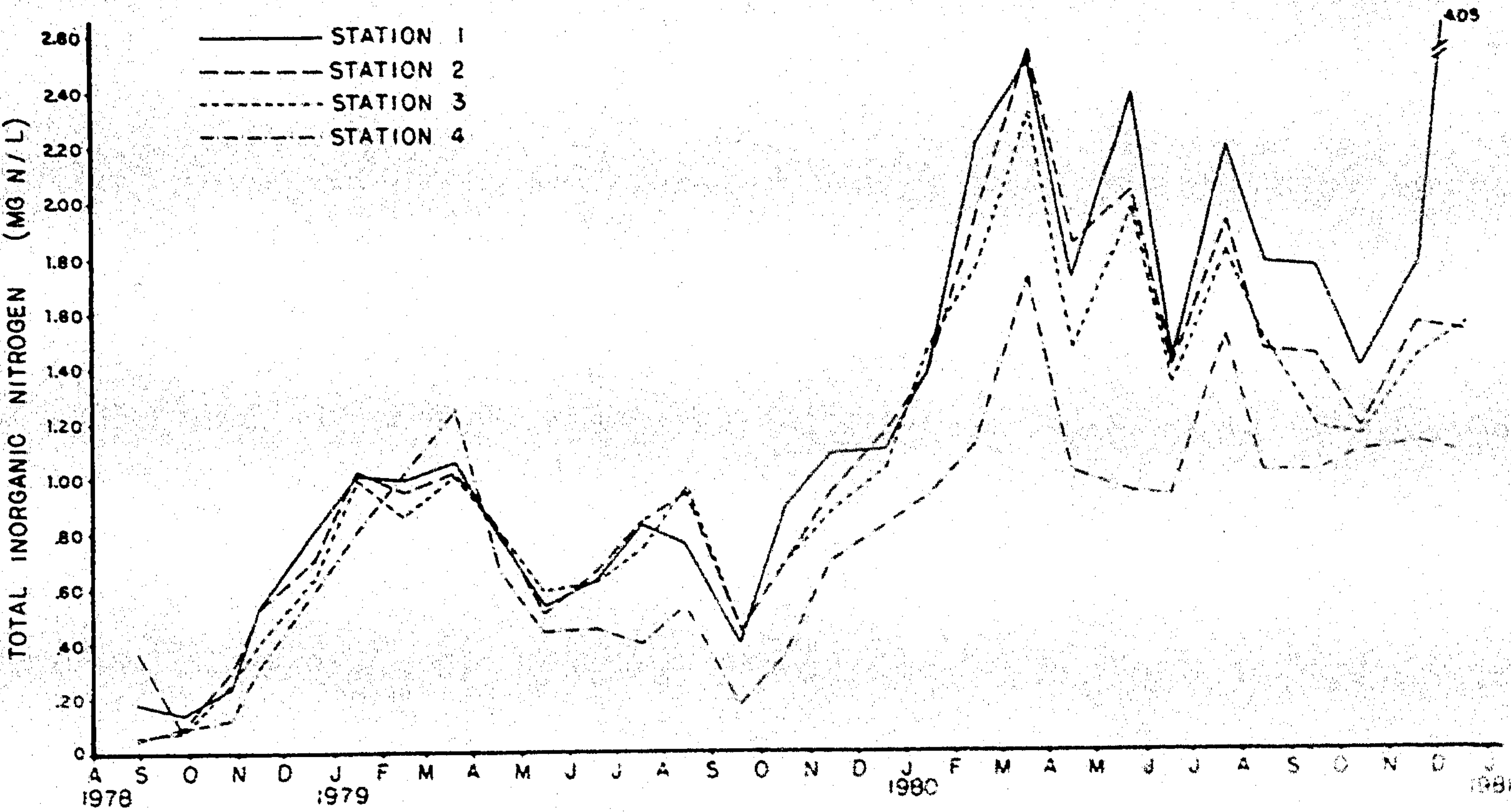


Figure 3.11. Mean total inorganic nitrogen concentrations at all sampling depths at each station at Coffeen Lake from August 1978 to December 1980.

to inorganic forms, and from one inorganic form to another may have been accelerated because of thermal effluents, the higher temperatures alone cannot explain the difference in nitrogen levels between the two years. The distribution of nitrogen levels in the lake indicated the power plant was probably having a major impact on these parameters, although the source of the nitrogen input is unknown.

Organic nitrogen levels were fairly consistent among stations and months sampled. The concentration was highest in May 1980 (mean .55 mg N/l) and the lowest in August 1979 (mean 0.14 mg N/l). In other months, concentrations were in the range between 0.26-0.40 mg N/l. Overall, the mean was greater in 1980 (0.40 mg N/l) than in 1979 (0.27 mg N/l). Little difference was observed among organic nitrogen levels at different stations.

N:P RATIOS

Ratios of total nitrogen to phosphorus were generally greater than 12, indicating phosphorus to be the limiting nutrient for algal growth rather than nitrogen (Dillon and Rigler 1974). Station 4 consistently had the lowest N:P ratios, which can be accounted for by both relatively low nitrogen and high phosphorus levels. However, total nitrogen may not be as good an indicator of available nitrogen as total inorganic nitrogen. At Station 4 in 1979, when inorganic nitrogen was considered rather than total nitrogen, N:P ratios were less than 12 for most of the year (March through November). In 1980, N:P ratios were less than 12 at Station 4 only during the months of April, August, and September, which were the months when maximum phosphorus levels occurred at Station 4. Ratios of less than 12 were never observed at the other three stations during 1980, but occurred occasionally (May, September, and November) at these stations in 1979. The increased nitrogen levels in Coffeen Lake appear to have caused the north end of the lake to change from being nitrogen limited to being phosphorus-limited. However, the lower part of the lake appeared to have been phosphorus-limited most of the time even before nitrogen levels increased.

CHLOROPHYLL A , pH, DISSOLVED OXYGEN

Chlorophyll a concentrations were greatest at Station 4 and least at Station 1 during all months sampled (December 1979 through November 1980) except January 1980. Stations 2 and 3 generally had concentrations that were intermediate. The greatest concentrations at Station 4 were observed in the spring and summer, while the greatest concentrations at Station 1 were observed in the fall (Fig. 3.12). The failure of particulate and total organic carbon to follow the same pattern suggested that organic carbon was not a good measure of algal biomass.

Algal activity was reflected in the pH, dissolved oxygen, and percent saturation of dissolved oxygen. All stations had higher pH in the summer months than in the winter. At Station 4, there were several times during the summers that the pH was above 9.0, indicating vigorous photosynthestic activity (Hutchinson 1957). Low pH was found only in the deep water at thermally stratified stations. Stations 1.5 and 2 were stratified during much of the summers, and low pH (less than 7.5) occurred at the bottom of these stations. These low pH values corresponded to high concentrations of carbon dioxide that were produced by decomposition of organic matter and accumulated in the hypolimnion during stratification. During the summer of 1979, pH values were higher in the surface water and lower in the deep water than in 1980. This occurence could be the result of higher alkalinity, and thus, greater buffering capacity, in 1980. Fluctuations in pH did not appear unnatural, and direct impact of power plant effluents on lake water pH was apparently minimal.

Dissolved oxygen (D.O.) was depleted in the hypolimnion of the deep stratified stations during most of both summers (1979 and 1980), thus restricting a large part of the deep section of the lake to most animal life for a considerable period of time. Surface D.O. levels were lower in the summers than in the winters, due to warmer temperatures causing lower oxygen solubility in the summers. At all times of the year D.O. concentrations were the highest at Station 4, reflecting cooler temperatures and greater algal activity. Dissolved oxygen became fairly low (less than 4 mg/l) in the summers at Station 1 when water temperatures were very high. However, D.O. levels were always above or near saturation at Station 1 at the surface. High saturation levels were likely

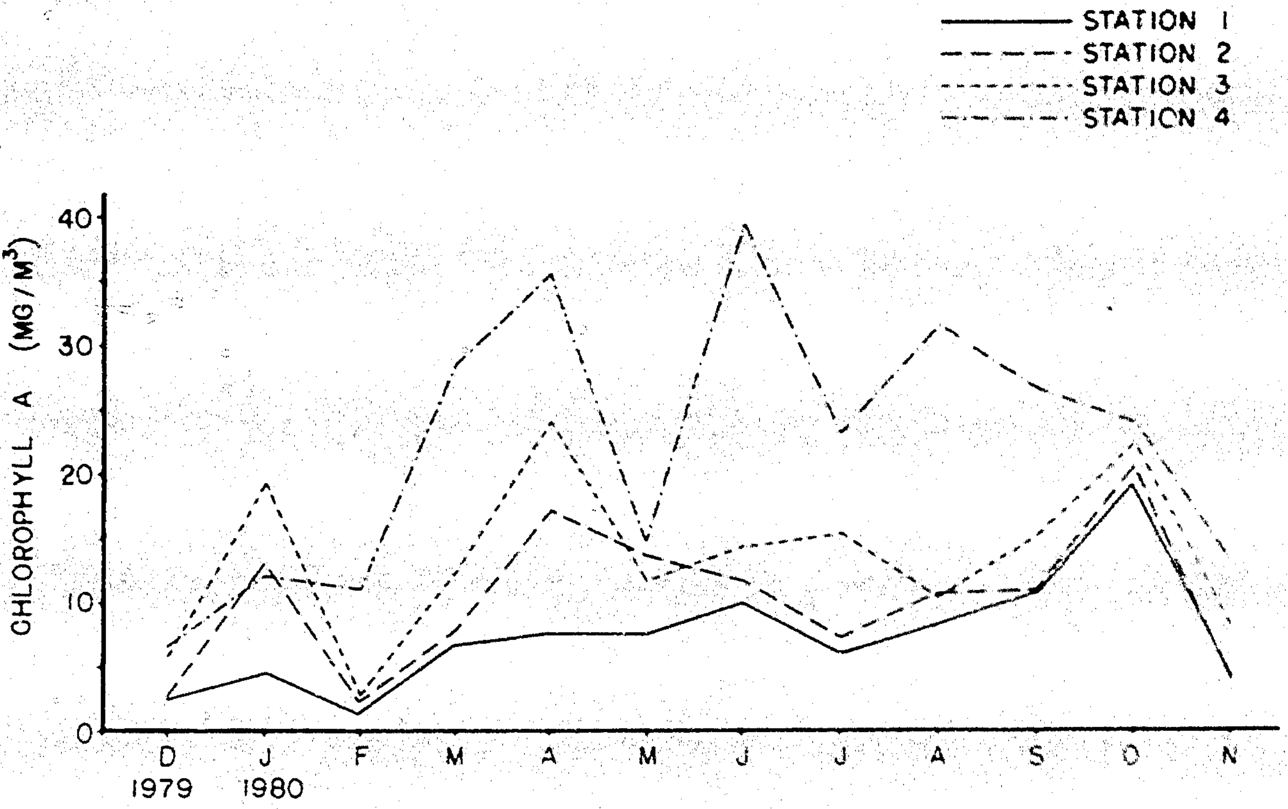


Figure 3.12. Concentrations of chlorophyll a in the euphotic zone in Coffeen Lake from December 1979 through November 1980.

caused by the turbulence of the water going over the discharge spillway. Supersaturation occurred occasionally at the surface of Stations 1.5 and 2 during the summers, as a result of photosynthetic activity. Stations 2.5, 3, and 4 were supersaturated with D.O. at the surface most of the time during the summers. High levels (up to 157 percent) occurred several times at Station 4, reflecting greater algal activity corresponding to higher concentrations of chlorophyll a and higher pH. About the same amount of supersaturation occurred during both summers at most of the stations. Station 3 was the only area of the lake to have a lower mean percent saturation at the surface during the summer of 1980 than during the summer of 1979. This observation supports the hypothesis that higher pH during the summer of 1979 at Station 4 was probably due to less buffering capacity rather than greater algal activity.

Although Station 4, located north of the railroad causeway, supported the greatest standing crop of algae, greater rates of primary productivity often occurred at Station 1, located in the discharge arm (Coutant 1980). This phenomenon may indicate greater rate of nutrient regeneration at Station 1, due to warmer temperatures and power plant operations. The amount of nutrients present effects the amount of biomass; however, the rate of regeneration of nutrients can affect the rate of primary productivity (Rigler 1974).

The physical and chemical factors responsible for limiting algal growth are difficult to assess. Although higher water temperatures and power plant operation appeared to have affected algal activity, the impact of these factors is difficult to assess because the station in this cooling lake that was least affected by the power plant, Station 4, was very different from the other stations in other ways, making comparisons difficult. Light intensity was greatly reduced at Station 4 since the turbidity at the upper end of the lake was by far the greatest. Nutrients were also different at Station 4 since phosphorus, nitrogen and carbon (alkalinity) concentrations at Station 4 all varied from the other three stations. In addition, some of these parameters varied from 1979 to 1980, which may account for differences in algal activity between the two years. Alkalinity was increased in 1980 over 1979, thus providing a greater carbon source as well as more adequately buffered water. Also at Station 4, turbidity was much less in 1980 than in 1979, and the nutrient limiting factor shifted from nitrogen to phosphorus. All of these factors could have been important in determining the amount of algal activity and in determining the composition of the algal species present. However, the clear gradient of chlorophyll *a* present from the discharge arm to the north end of the lake (Fig. 3.12) strongly suggests a direct impact of power plant operations on algal activity.

LITERATURE CITED

Barr, A.J., J.H. Goodnight, J.P. Sall, and J.T. Helwig. 1976. A user's guide to SAS 76, SAS Institute, Inc., Raleigh, NC. 329 pp.

Brigham, A.R. 1981. Water quality in a cooling water reservoir. In R.W. Larimore and J.A. Tranquilli, eds., The Lake Sangchris study: case history of an Illinois cooling lake. Illinois Natural History Survey Bulletin 32(4):290-319.

Coutant, L.W. 1980. Algal investigations of Coffeen Lake. In J.A. Tranquilli and R.W. Larimore, eds., Environmental Studies of Coffeen Lake, Section 5. Second Annual Report to Central Illinois Public Service Company. Illinois Natural History Survey.

Dillon, P.J., and F.H. Rigler. 1974. The phosphorus - chlorophyll relationship in lakes. Limnol. Oceanogr. 19(5):767-773.

Harvey, H.W. 1960. The chemistry and fertility of sea waters. Cambridge Univ. Press., London. 240 pp.

Hutchinson, G.E. 1957. A Treatise on Limnology. Vol. I, Part 2. John Wiley and Sons, Inc., New York. 1015 pp.

Jirka, A.M., and M.J. Carter. 1975. Anal. Chem. 47(8):1397.

King, D.L. 1970. The role of carbon in eutrophication. Journal Water Pollution Control Federation 42:2035-2051.

Liehr, S. 1979. Coffeen Lake water quality. In J.A. Tranquilli and R.W. Larimore, eds., Environmental Studies of Coffeen Lake: First Annual Report to Central Illinois Public Service Company. Illinois Natural History Survey.

Liehr-Storck, S. 1980. Coffeen Lake water quality. In J.A. Tranquilli and R.W. Larimore, eds., Environmental Studies of Coffeen Lake: Second Annual Report to Central Illinois Public Service Company. Illinois Natural History Survey.

Park, P.K. 1969. Ocean CO_2 system: An evaluation of ten methods of investigation. Limnol. Oceanogr. 14:179.

Pomeroy, L.R. 1960. Residence time of dissolved phosphate in natural waters. Science 131:1731-1732.

Rigler, F.H. 1974. Phosphorus cycling in lakes. In F. Ruther, Fundamentals of Limnology 263-273.

Sargent and Lundy, Report SL 1990. 1977. In Ecology Consultants, Inc. Thermal demonstration pursuant to Illinois Pollution Control Board rules and regulations, Central Illinois Public Service Company, Coffeen Power Station, units 1 and 2, May 31, 1977.

Standard Methods for the Examination of Water and Wastewater, 14th ed. 1976. American Public Health Association, American Water Works Association, Washington, DC. 874 pp.

Wetzel, R.G. 1975. Limnology. W.B. Saunders Company, Philadelphia. 743 pp.

SECTION 4

CHEMICAL CONSTITUENTS

by

Susanne G. Wood and Teresa A. Schuller

ABSTRACT

A three-year study of the chemical constituents present in Coffeen Lake was undertaken as part of a multi-disciplinary 3-year investigation to evaluate the environmental effects of CIPS Coffeen Power Station on Coffeen Lake. Major changes in the disposal of coal combustion wastes and the discharge of wastewater at the power plant were implemented between March 1978 and November 1979 for the purpose of reducing the amount of pollutants entering the lake. The major objective of this study was to determine how effective these changes were. Water, sediments, sediment cores, two species of macrophyes, and six species of fishes were analyzed for their contents of chemical constituents.

The concentrations of chemical constituents that sometimes accumulate to undesirable levels in aquatic ecosystems (Cd, Cr, Hg, Pb, and Se) were considered to be of paramount importance. Pb concentrations were below the detection limit of the analytical instrument for most of the samples. Of the four ecosystem components showing measurable Pb concentrations during the first year (pondweed and three species of fish), only one fish species contained measurable amounts during the second year. None of the ecosystem components contained measurable levels of Pb during the final year, a gratifying finding when improvement in environmental quality is the aim.

In the present study, the steady decrease in Cd concentrations in all ecosystem components during the 3-year period is indicative of improvement in environmantal quality. The same conclusion can be drawn for Cr and Hg. These decreasing trends are reflections of similar decreases in the surrounding milieu.

There has been concern about the reported reproductive failure in fishes inhabiting lakes that are subject to exposure to industrial wastes. In the present study, the annual mean concentrations of Se in six species of fish taken from

Coffeen Lake between 1978 and 1981 ranged from less than the detection limit of the analytical instrument (0.29 ppm) to 1.89 ppm. All of these levels are well within the range of concentrations (0.5-7.0 ppm) reported for fishes from another lake where fish reproduction was normal. Thus, the reproductive success of fishes in Coffeen Lake should not be affected by Se at the present.

The overall conclusion for this 3-year study of the chemical constituents in Coffeen Lake might best be stated as: improvements in the disposal of the coal combustion wastes and the discharge of the wastewater generated by the power plant have led to a significant improvement in the environmental quality of the lake's ecosystem.

INTRODUCTION

The need for large quantities of water to cool steam in electric-generating stations has resulted in construction of many lakes in recent years. When the generating stations associated with these lakes are fueled with coal, combustion wastes are a source of trace metal contamination to both the lakes and the surrounding lands. Coffeen Lake, which was built in 1963 to provide water for Central Illinois Public Service Company's Coffeen Power Plant, is one such lake. Because little outflow normally occurs, this lake retains almost all of the chemical constituents entering by means of both the thermal effluent from the power plant and the inflowing water from the lake's watershed. Loss of water from the lake via evaporation concentrates the chemical constituents. Dressen et al. (1977) and Griffin et al. (1978) demonstrated that many metals in slag and fly ash - waste products of burned coal - have substantial solubilities when leached by water. Since these leachates entered Coffeen Lake from 1965 to 1978, enhancement of the lake's chemical constituent content and concomitant deterioration of its water quality were distinct possibilities.

Major changes in the disposal of coal combustion wastes and the discharge of wastewater at the Coffeen Power Plant, which were made between March 1978 and November 1979, greatly reduced the amount of pollutants entering Coffeen Lake. Because of these changes, the overall quality of the lake's water, sediments, and biota may have begun to improve. In particular, concentrations of chemical constituents in sediments and biota may have begun to decline. Thus, the objectives of this study were twofold: (1) to determine concentrations of chemical constituents in selected components of the lake's ecosystem during the time disposal of combustion wastes and wastewater was improved, and (2) to assess the recovery of the lake by monitoring changes in concentrations of chemical constituents during the following two years. The first objective was addressed between September and June 1979, the results of which were reported by Smith and Duda (1979). The second report analyzed and interpreted data collected from July 1979 to June 1980, i.e., the first year of recovery of the lake following modifications of the combustion waste disposal and the wastewater discharge into the lake (Anderson et al. 1980). The present report analyzes and interprets the data collected from July 1980 to December 1980, i.e., the second year of recovery of the lake. This report also interprets the results of the 3-year investigation of the lake's ecosystem.

Samples of water, sediment, macrophytes, and fishes were analyzed for silver (Ag), arsenic (As), boron (B), barium (Ba), calcium (Ca), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), potassium (K), magnesium (Mg), manganese (Mn), sodium (Na), nickel (Ni), lead (Pb), selenium (Se), and zinc (Zn). Coal, slag, and fly ash samples were analyzed for the above constituents plus aluminum (Al), cobalt (Co), phosphorus (P), silicon (Si), and titanium (Ti). Water was also analyzed for cyanide (CN^-).

STUDY AREA

The Coffeen Power Plant is a 945-MW generating station located in southeastern Montgomery County of central Illinois. The first unit (350-MW) began generating electricity for commercial consumption in 1965, and the second unit (595-MW) went on line in 1972. Fuel burned at this facility is primarily Number 6 coal that is obtained from a shaft mine (Consol Hillsboro Mine) located adjacent to the plant. Number 6 (Herrin) coal is the most extensively mined coal in Illinois (Ruch et al. 1971). The plant consumed 2.08 million tons of high sulfur (3.4 percent) Number 6 coal and 2.21 million tons of total coal in 1978 (Lin and Dotter 1979). Coal burned in the Coffeen Plant is reduced to approximately 23 percent of its original mass; about 70 percent of the residue is slag (bottom ash) and the remainder is fly ash (Janet Kennedy, pers. comm.). The fly ash is removed from the smoke by electrostatic precipitators. From 1965 to 1978, the slag and fly ash were sluiced to an area located to the east of the power plant and in close proximity to the east (heated) arm of the lake. Leachates in the returned sluice water entered the lake unabated near the thermal discharge. Because of changes beginning in March 1978 and completed in November 1979, the slag is now dewatered in bins and then transported by truck to a slag storage area (formerly the slag pond), and fly ash is accumulated in a silo and then trucked several miles to an approved landfill site.

Coffeen Lake is a man-made impoundment with 420 ha of surface area and a water capacity of 27.2 x 10^7 m^3. For a more detailed description of the morphological characteristics of the lake, the reader is referred to Section 1 of this document. In accordance with the interdisciplinary approach to conducting investigations at the lake, four major sampling stations were estalished by mutual agreement with other researchers. Station 1 was located in the thermal discharge arm, Station 2 was established near the midpoint of the cooling loop, Station 3 was situated north of the intake bay and is considered a transition zone, and Station 4 was located north of the railroad causeway and is regarded as the ambient area (Fig. 1.2). In addition, ancillary stations were established between Stations 1 and 2 and Stations 2 and 3 for some aspects of this study; these were designated Station 1.5 and Station 2.5, respectively.

MATERIALS AND METHODS

Materials and methods for this study were modified following the first year of investigation. The four major stations remained the same throughout the study's duration, but two ancillary stations, 1.5 and 2.5 (see Fig. 1.2), were added during the second and third years of study. Other minor changes included: (1) reducing the collection of water samples to once a month, (2) eliminating the filtering of the water samples, (3) discontinuing the cyanide analysis following the June 1980 water collection, (4) adding three species of fish during the third year of study, (5) obtaining a more thorough collection of macrophytes during the second and third years of investigation, (6) collecting and analyzing sediment core samples in the third year, (7) collecting and analyzing coal, slag, and fly ash samples from October 1980 through February 1981, (8) conducting Na and K analyses by emission spectrophotometry, and (9) modifying the sample preparation procedure in the third year.

SAMPLE COLLECTION

Table 4.1 lists the total number of samples collected for the chemical constituents portion of this study from September 1978 through May 1981. Water samples were collected daily during one week each in September and October 1978. Duplicate unfiltered and filtered (0.45-micron) water samples were collected monthly from November 1978 through June 1979. Quadruplicate unfiltered water samples were collected monthly from July 1979 through December 1980. All water

Table 4.1. Total number of samples collected and analyzed for chemical constituents from September 1978 through July 1981.

	1978-79	1979-80	1980-81	Total by Type
Water	330	182	96	608
CN⁻	120	96	32	248
Macrophytes				
American Pondweed	1	9	15	25
Creeping Waterprimrose	3	11	21	35
Sediment	8	30	30	68
Fish				
Largemouth Bass	50	40	40	130
Gizzard Shad	33	40	40	113
Black Bullhead	16	20	12	48
Carp			20	20
Bluegill			20	20
Channel Catfish			20	20
Cores			30	30
Coal			20	20
Slag			32	32
Fly Ash			30	30
Yearly Totals	561	428	458	
Grand Total				1,447

samples collected for chemical constituent analysis were 250-ml surface samples and were preserved with nitric acid (0.8% final concentration). Water samples for cyanide (CN^-) analysis were 2-liter surface samples collected in duplicate from September 1978 through June 1979 and preserved with sodium hydroxide (0.2% final concentration). All samples for measurements of chemical constituents were refrigerated until analyzed; samples for cyanide determination were analyzed within 24 hours after collection.

Bottom sediment samples were collected in the fall of 1978 at the four major stations (Fig. 1.2). During spring and fall of 1980, bottom sediment samples were collected at the four major and the two ancillary stations (Fig. 1.2). A 15.2-cm x 15.2-cm x 15.2-cm Ekman dredge with a chamber volume of 3540 cm^3 was used to collect sediment from the lake bottom; the top 2 cm of material were retained for analysis. Shore line samples containing primarily sand were disallowed during the final two years of the study. All samples were frozen until prepared for analysis.

The species and numbers of macrophyte samples collected per year are given in Table 4.1. Creeping waterprimrose (*Jussiaea repens*) was collected at Stations 1, 2, and 4 in September 1978, at all four major stations in September 1979, and at all four major and the two ancillary stations in September 1980. No waterprimrose was found at Station 3 during the 1978 collection period. American pondweed (*Potamogeton nodosus*) was collected at only Station 3 in September 1978, at Stations 2, 3, and 4 in September 1979, and at Stations 2, 3, and 4 and the two ancillary stations in September 1980. This macrophyte was not found at Station 1 during any of the collecting periods. The samples were stored in polyethylene bags under refrigeration until prepared for analysis.

Species of fish collected for this study included: gizzard shad (*Dorosoma cepedianum*), a forage fish; black bullhead (*Ictalurus melas*), a low trophic level omnovore; and largemouth bass (*Micropterus salmoides*), a high trophic level carnivore. In addition to the above species, the following fishes were collected during the third year of the study: carp (*Cyprinus carpio*), a low trophic level omnivore; bluegill (*Lepomis macrochirus*), a carnivore; and channel catfish (Ictalurus punctatus), a low trophic level omnivore. The majority of the fishes were collected by electrofishing. Table 4.1 lists the fishes by species and number collected per year of the investigation. Data concerning the date and point of collection are presented in Table 4.2. All fishes were stored frozen until prepared for analysis.

Sediment cores were collected in June 1980 using a corer modelled after Wildco-Ballchek Single Tube Core Sampler Model 2311 with 3.5-cm-diameter by 61-cm-long plastic collection tubes and 5 kg of counterweights (Fig. 4.1). The samples were collected by means of a winch and pulley system mounted on a portable boat crane with a 6-foot boom. Five samples per station were collected along transects at Stations 1, 1.5, 2, 2.5, 3, and 4. The tubes were labeled, corked, and frozen until prepared for analysis.

Coal, slag, and fly ash samples were collected from October 17, 1980 through February 21, 1981. Coal samples were taken from conveyor belts entering the power plant, slag from the dewatering bins, and fly ash from the fly ash silo. Collections were made by CIPS personnel from zero to three times per week during the above-mentioned period. Samples were individually stored in sealed polyethylene bags until prepared for analysis.

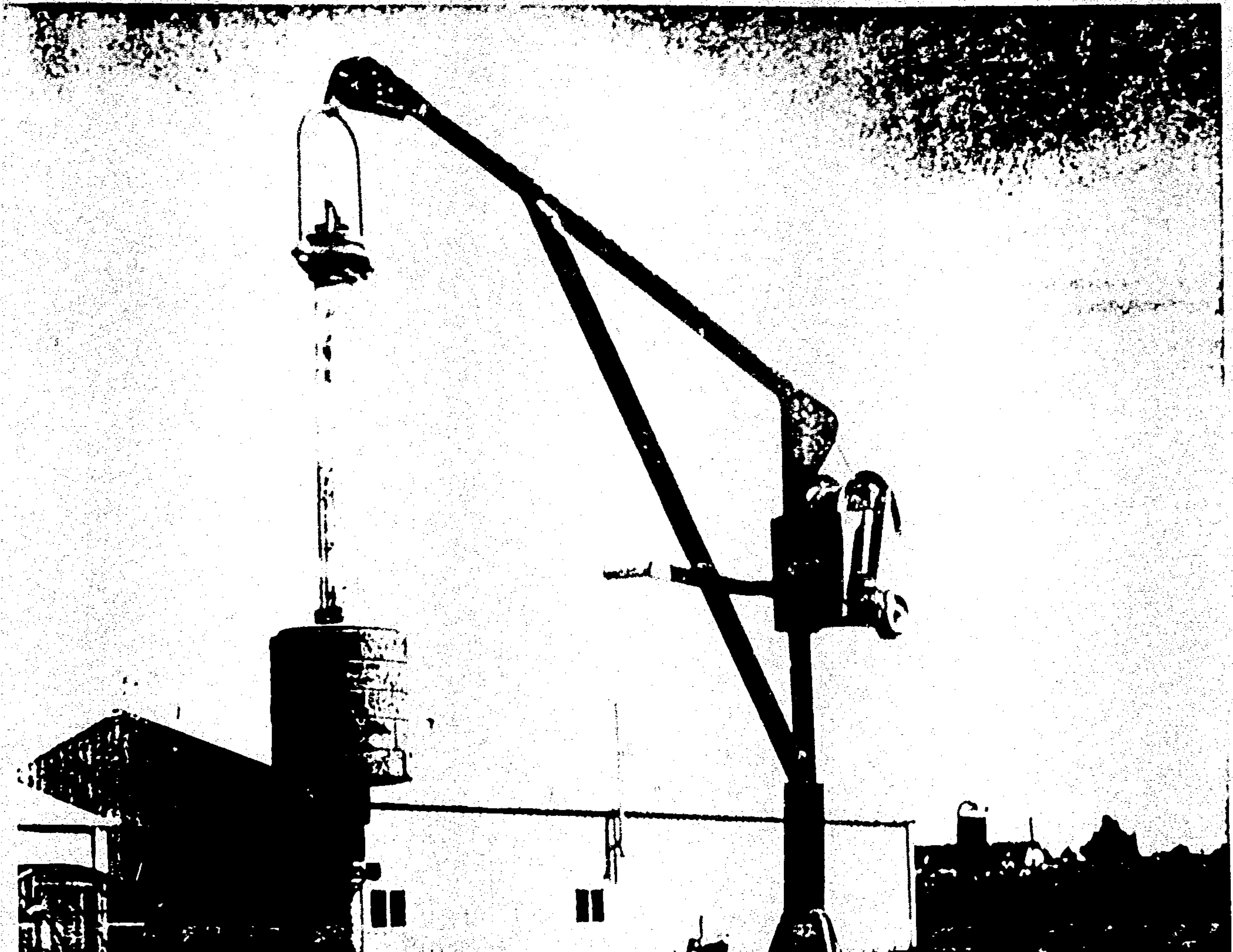
SAMPLE PREPARATION

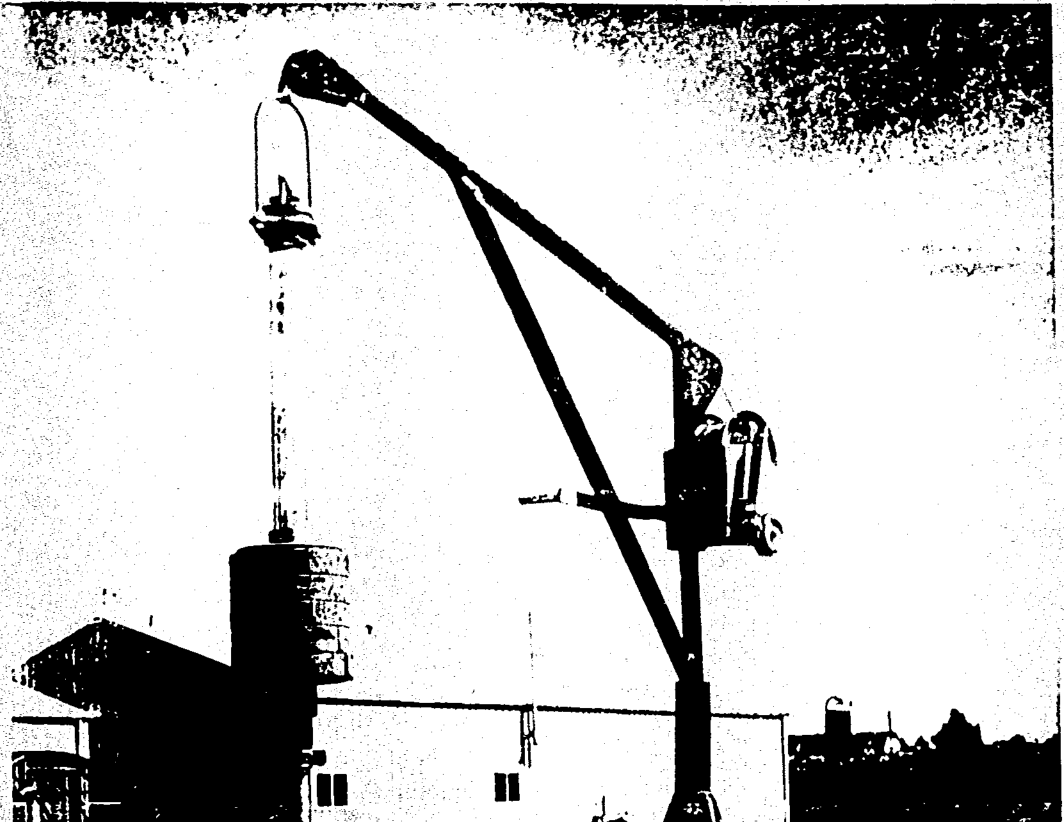
The water samples required no additional preparation prior to analysis. Sediment samples were freed of excess water by decantation; the samples were then placed in 150- or 300-ml Virtis bottles and freeze-dried. The freeze-dryer used in sample preparation was a Virtis Unitrap 10-100 with a Welch Duo-Seal Model #1402 vacuum pump. The sediment cores were split lengthwise and sectioned into six 3-to-8-cm segments, representing recent sediment, four intermediate sedimentation deposits, and an original sediment. The segments were then freeze-dried as above. A mortar and pestle was used to grind and homogenize the sediment and sediment core samples sufficiently to pass a 100-mesh nylon sieve. For macrophytes, a thorough washing with tap water removed mud and other extraneous material. The samples were rinsed several times with deionized water and thoroughly drained; the leaves and stems were separated, weighed,

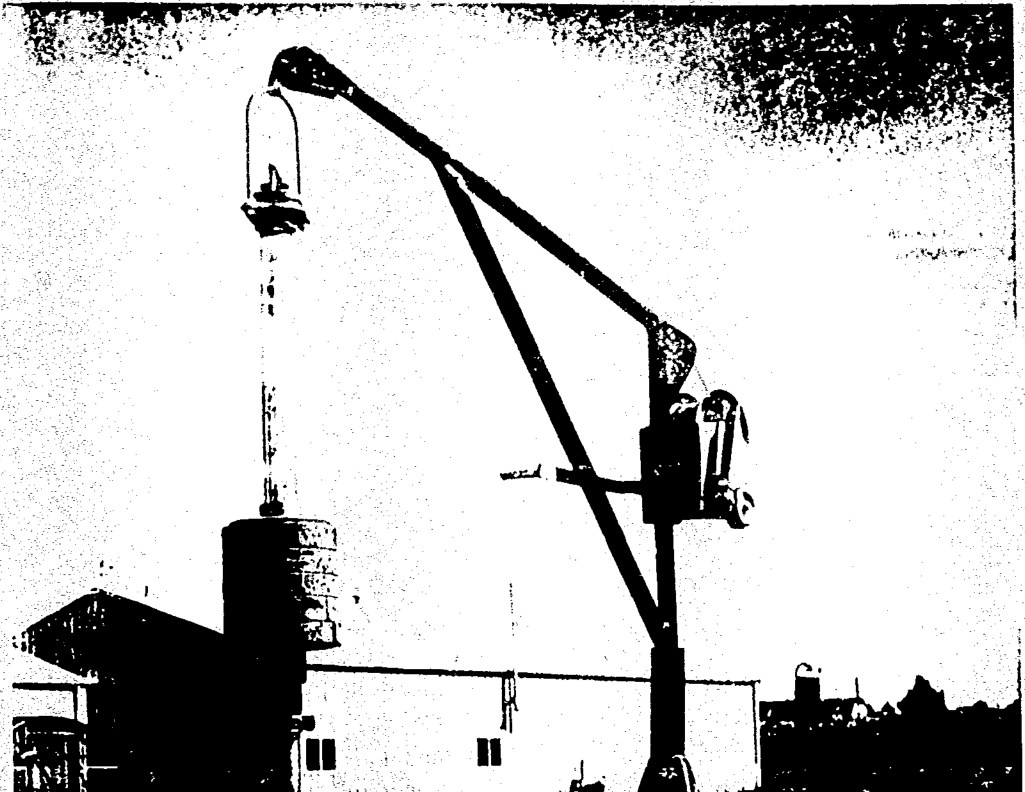
Table 4.2. Collection date, collection point, number, and species of fish obtained from Coffeen Lake.

	Collection Points			
Date Collected	Station 1	Station 2	Station 3	Station 4
1978-1979				
October 1978				26 LMB 8 SHAD 4 BLKBH
November 1978	4 LMB 5 SHAD	5 LMB 5 SHAD	5 LMB 5 SHAD	
March 1979	5 LMB	2 BLKBH	5 SHAD 5 BLKBH	5 LMB 5 SHAD 5 BLKBH
1979-1980				
November 1979	10 LMB 10 SHAD 1 BLKBH	10 LMB 10 SHAD 2 BLKBH	10 LMB 10 SHAD 4 BLKBH	10 LMB 10 SHAD 6 BLKBH
January 1980	3 BLKBH	3 BLKBH		
March 1980	1 BLKBH			
1980-1981				
May 1980				10 BLKBH
September 1980				10 SHAD 10 LMB
November 1980	10 LMB 10 SHAD 5 CARP 5 BGILL 5 CCAT	10 LMB 10 SHAD 1 BLKBH 5 CARP 5 BGILL 5 CCAT	10 LMB 10 SHAD 1 BLKBH 5 CARP 5 BGILL 5 CCAT	5 CARP 5 BGILL 5 CCAT

LMB = Largemouth Bass, SHAD = Gizzard Shad, BLKBH = Black Bullhead, CARP = Carp, BGILL = Bluegill, CCAT = Channel Catfish







and freeze-dried in aluminum foil boats. During the first two years of the investigation, leaf and stem samples were pulverized by placing samples individually into polyethylene bags and pounding with a rubber mallet and/or manipulating by hand. During the third year of the study, samples were placed in polystyrene bottles with several plastic beads and homogenized using a Spex 8000-11 mixer/mill. Fish were thawed, measured (length), and weighed. A fillet (muscle tissue) was removed from each fish specimen, cut into cubes, placed in plastic weighing boats, and then freeze-dried. The sample homogenization procedure duplicated that of the macrophytes. All freeze-dried samples were stored in polyethylene bottles at room temperature until aliquots were needed for digestion.

Coal, slag, and fly ash samples were air-dried, combined by type, and then sorted by means of a riffle to obtain representative subsamples for analysis. Four subsamples of each type were prepared to represent the four one-month periods (October 17, 1980-November 15, 1980; November 16, 1980-December 15, 1980; December 16, 1980-January 15, 1981; and January 16, 1981-February 21, 1981) of this subproject. These four subsamples of each type were ground to meet the specifications for analysis of the Illinois State Geological Survey.

SAMPLE DIGESTION

All samples were digested and analyzed in duplicate throughout the study. The water samples required digestion only for mercury (Hg) analysis. Potassium persulfate ($K_2S_2O_8$) solution was added to the samples to free any Hg that was adsorbed on particulate matter in the water (El-Awady et al. 1976). After one hour, the samples were analyzed for Hg as described below. The determination of total CN^- in water samples from September 1978 through June 1980 was performed according to the U.S. EPA standard method (Kopp and McKee 1979). The cyanide was released in the form of hydrogen cyanide (HCN) from the water by reflux-distillation in the presence of sulfuric acid and copper chloride (Fig. 4.2). The cyanide as the cyanide ion was then absorbed in a scrubber containing sodium hydroxide. Cyanide standards were treated in the same manner.

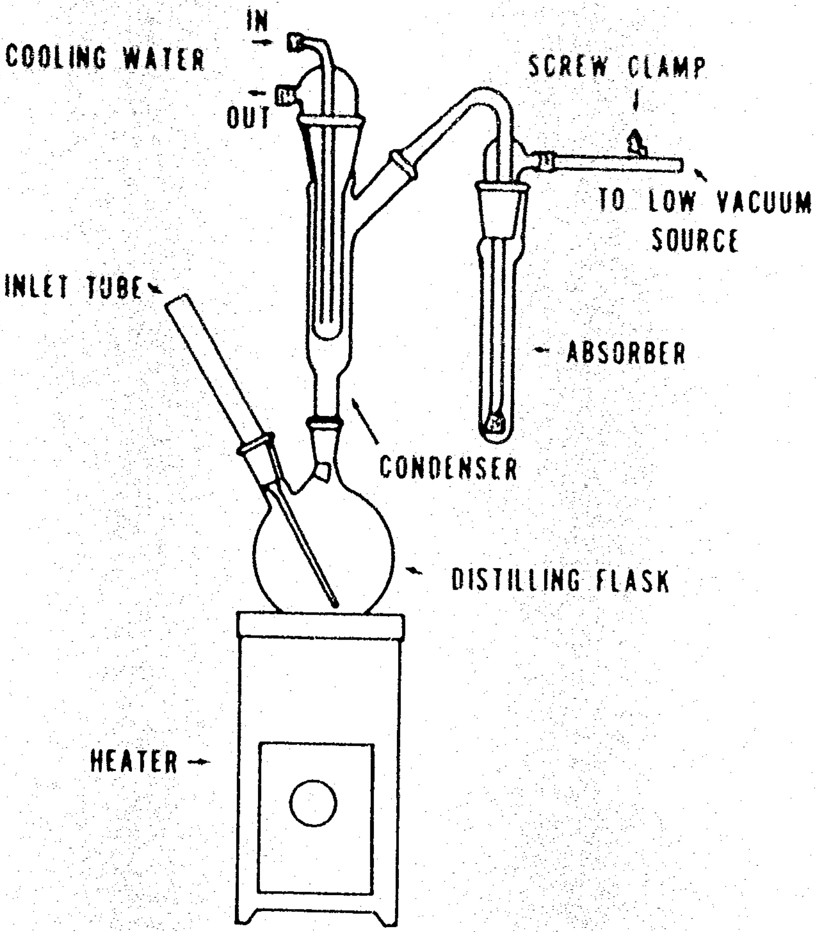


Figure 4.2. Diagram of distillation apparatus used for recovering cyanide from water samples.

The bottom sediments and sediment core samples were digested for chemical constituent analysis using a modification of the method described by Perkin-Elmer (1976). A dilute solution of hydrochloric (HCl) and sulfuric (H_2SO_4) acids was added to 5-g samples in 50-ml polypropylene centrifuge tubes to extract only the cations adsorbed on the sediment particles but not the metals of the sediment itself. The samples were shaken for one hour on a New Brunswick rotary shaker and then centrifuged using a Sorvall RC2B centrifuge. Ten-ml aliquots of the supernatants were diluted to a known volume (50 ml) and stored in polyethylene bottles until analysis.

Extraction of Hg from the sediments and sediment core samples was accomplished using a modification of the method described by Jacobs and Keeney (1979). Aqua regia ($HCl:HNO_3$, 1:1 by vol.) was added to 2-g samples in 250-ml wide-mouth Erlenmeyer flasks. The samples were boiled vigorously for one minute. After the samples had cooled, aliquots of 5% potassium permanganate ($KMnO_4$) and $K_2S_2O_8$ solutions were added to the flasks, which were then placed in a 95°C water bath for 30 minutes. During this digestion period small quantities of crystalline $KMnO_4$ were added to the samples to maintain an oxidizing environment. The samples were cooled, centrifuged, diluted to a known volume (100 ml), and analyzed within a few hours as described below.

To analyze macrophyte and fish samples for chemical constituents with the exception of Hg, a total digestion was required. A 5:1 mixture of nitric acid (HNO_3) and perchloric acid ($HClO_4$) was added to 1-g samples which had been preweighed into 150-ml round-bottom distillation flasks. The flasks were heated on a Kontes Rotary Kjeldahl Distillation Apparatus until the HNO_3 had decomposed (disappearance of reddish-brown fumes) and dense white $HClO_4$ fumes appeared. After cooling, the samples were diluted to an appropriate volume (25 or 50 ml). This final volume was 28%, 12%, and 5% with respect to $HClO_4$ concentration in the first, second, and third years, respectively, of the investigation. The macrophyte digests were centrifuged to remove insoluble silicates. Initially insoluble materials in the fish digests dissolved with time, making centrifugation unnecessary.

Digestions of macrophyte and fish samples for Hg analysis was accomplished using a modification of the method of Anderson and Smith (1977). Aliquots of H_2SO_4, HNO_3, and a 5% $KMnO_4$ solution were added to 0.5-g samples in 125-ml Erlenmeyer flasks in an ice bath. After thorough mixing of the flask contents, the flasks were removed from the ice bath. Following the completion of the reaction, usually 15 minutes at room temperature, aliquots of a 5% $K_2S_2O_8$ solution were added to the flasks which were then placed in a 95°C water bath for about an 8-hour digestion period. To maintain an oxidizing environment but prevent manganese dioxide formation, small amounts of crystalline $KMnO_4$ were added to the flask contents throughout the digestion period. This period was assumed to be complete when the purple color of $KMnO_4$ remained constant for 30 minutes. The samples were cooled, transferred completely to 100-ml volumetric flasks, and refrigerated until analyzed the following day.

Coal, slag, and fly ash samples were digested according to procedures outlined in Appendix C of a report by Ruch et al. (1979).

ANALYTICAL ANALYSES

The water samples, sediment and sediment core extracts, and macrophyte and fish digests were analyzed for Ag, As, B, Ba, Ca, Cd, Cr, Cu, Fe, Mg, Mn, Ni, Pb, Se, and Zn by direct-reading emission spectrophotometry with an inductively-coupled argon radio-frequency plasma torch source unit (ICAP). The instrument used was a Jarrell-Ash Model 975 Plasma AtomComp (Fig. 4.3). The macrophyte and fish digests were diluted 1:5, 1:2, and 0 during the first, second, and third years, respectively, in order to bring the $HClO_4$ concentration to an analyzable level of about 5%. Analysis accuracy was checked by means of matrix-matched standards which were run approximately every six samples.

Sodium and potassium in all samples during the first year of the study were determined by atomic emission spectrophotometry on an Instrumentation Laboratory Model 253 Atomic Absorption-Atomic Emission Spetrophotometer as described in the Atomic Absorption Procedure Manual (Instrumentation Laboratory, Inc. 1972).

How does an AtomComp work?

All the operator has to do is introduce a prepared liquid sample to the AtomComp. **Type** in a series of one-letter commands on the system's input/output device. **Read** the results printed out directly on the device.

The Plasma AtomComp does the rest. (See diagram at right.) A powerful, precisely regulated radio frequency (RF) generator provides energy to a plasma torch and creates an RF magnetic field. A stream of argon gas, passing through the field, is ionized to become the plasma.

An extremely efficient nebulizer atomizes the sample. Another stream of argon gas carries the atomized sample into the plasma where the elements in solution are thermally excited.

Excited elements emit photons of radiant energy (light). A precisely aligned optical system collimates and directs this emitted light through an entrance slit onto a concave grating surface. The grating diffracts wavelengths of light to a series of exit slits precisely positioned along the spectrometer's focal curve.

Photomultiplier tubes behind these exit slits convert emitted light to electrical energy proportional to the intensity of the spectral lines.

A computer converts the signals into desired concentrations units (e.g. in ppb or ppm) which can be read directly from the AtomComp.

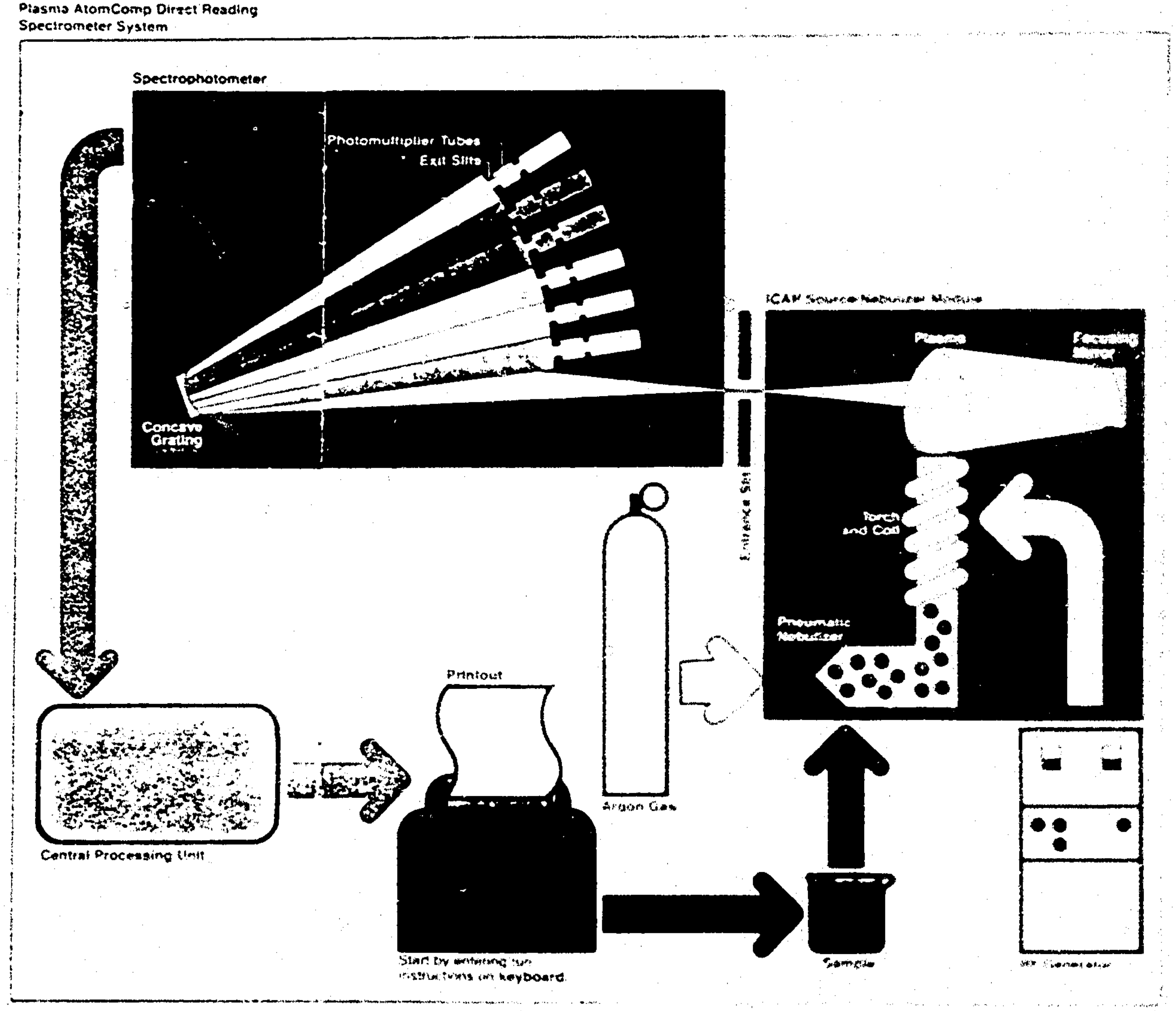


Figure 4.3. Simplified description and block diagram of ICAP used for analysis of chemical constituents in samples (Jarrell-Ash Division 1978).

Samples were diluted when necessary until they were within the analytical range of the instrument. For the second and third years of the investigation, Na and K were analyzed by ICAP as stated above.

Mercury concentrations were determined by cold-vapor atomic absorption spectrophotometry (Fig. 4.4). For macrophyte and fish digests, a 10-ml aliquot of the digested sample was transferred to the reaction vessel and a few drops of hydroxylamine hydrochloride ($NH_2OH \cdot HCl$) were added to remove any remaining $KMnO_4$. Stannous chloride was added to reduce the Hg to its vapor form (Hg^0), and the vapor was swept onto an activated silver wool plug where the Hg was trapped as an amalgam (Long et al. 1973). Following a 2-minute collection period, the silver wool plug was heated to de-amalgamate the Hg, and the vapor was swept through the absorption cell of a Fisher Mercury Analyzer. A Varian Model 485 Digital Integrator was used to measure peak areas which, when compared to the peak areas of Hg standards, corresponded to Hg concentrations. Water samples were treated similarly with the exception that the addition of $NH_2OH \cdot HCl$ was unnecessary.

Cyanide concentrations in the water samples were determined by analyzing the scrubber solutions (after the reflux-distillation) colorimetrically using a Spectronic 100 Spectrophotometer. An aliquot of chloramine-T solution at a pH>8 was added to convert the CN^- to cyanogen chloride (CNCl). The color (various shades of purple) was formed by adding pyridine-barbituric acid reagent; readings were taken at 578 nm within 15 minutes. The concentration of CN^- in the samples was calculated by comparing the sample readings with those of standard CN^- solutions treated in an identical manner. The potassium cyanide standard solution was standardized by titration with a primary silver nitrate solution.

Coal, slag, and fly ash samples were analyzed for the aforementioned elements plus aluminum (Al), cobalt (Co), molybdenum (Mo), phosphorus (P), and vanadium (V). Methods of analysis included neutron activation analysis, neutron activation analysis with radiochemical separation for Hg, optical emission spectrochemical analysis (both direct-reading and photographic), atomic

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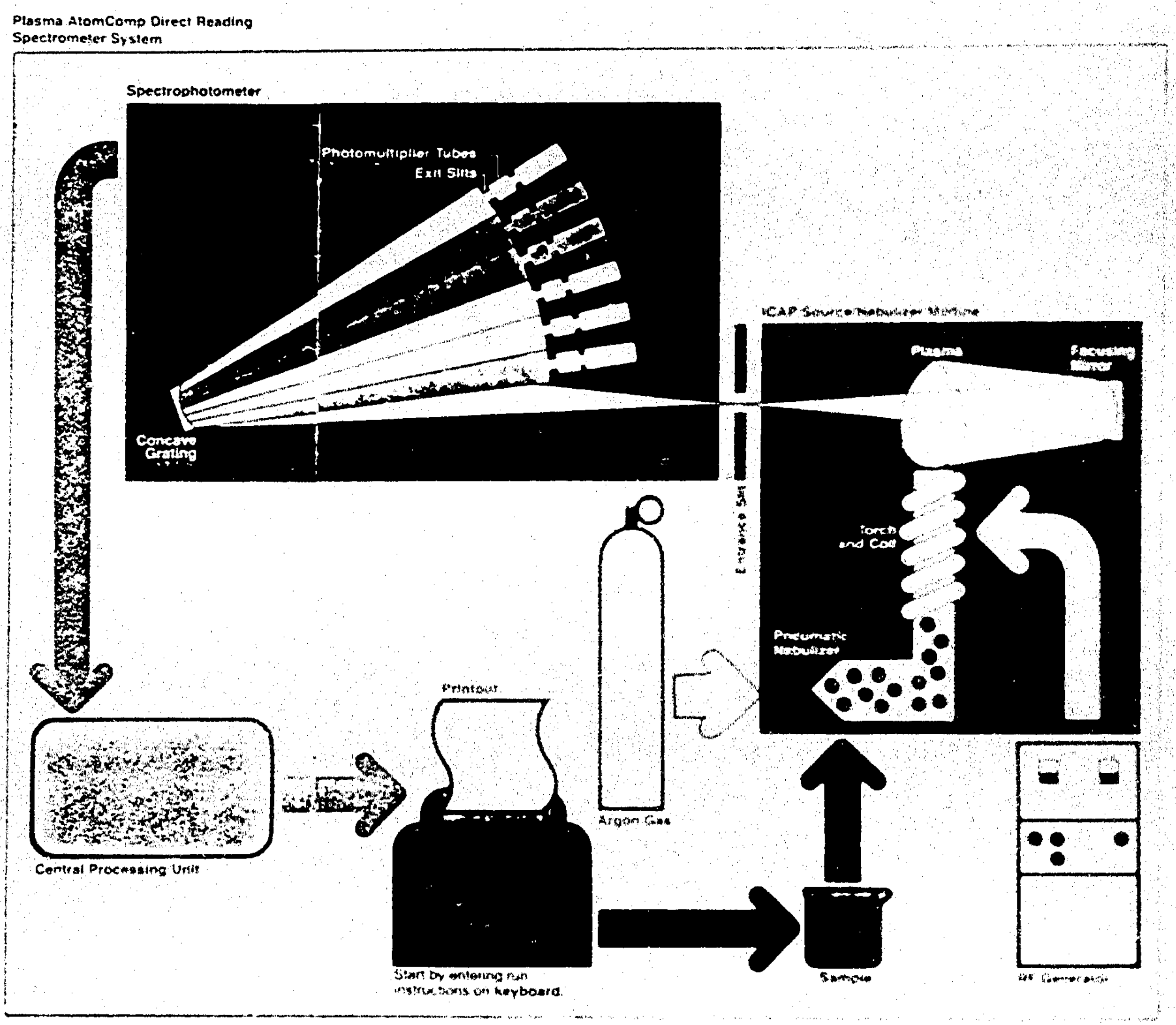


Figure 4.3. Simplified description and block diagram of ICAP used for analysis of chemical constituents in samples (Jarrell-Ash Division 1978).

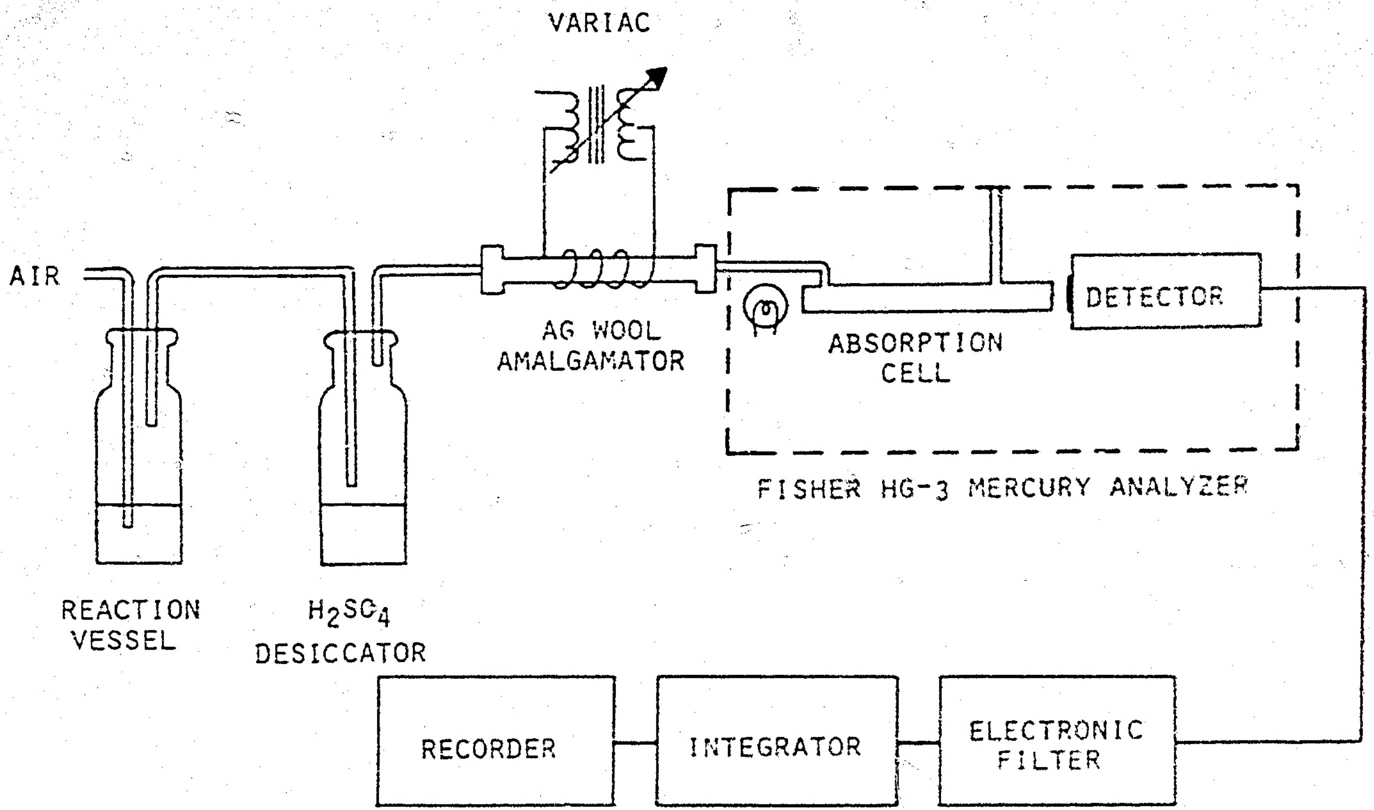


Figure 4.4. Block diagram of the instrumental apparatus used for cold vapor atomic absorption analysis of mercury in samples.

absorption analysis (both flame and graphite furnace and X-ray fluorescence). A description of each instrument, normal operating conditions, and test reference materials are contained in Appendix C of a report by Ruch et al. (1979).

DATA ANALYSIS

During statistical treatment of the chemical constituent data from the first year of the project, all concentration values less than the detection limit of the analytical instrument were disregarded (Smith and Duda 1979). This, in effect, biased the appropriate means in an upward direction, sometimes to unrealistic levels. During the second year of the investigation, values that were less than the detection limit were considered to be "0" (Anderson et al. 1980). Though more realistic than the former approach, this produced a bias in the downward direction. The present approach has been to set all values less than the detection limit equal to one-half of the detection limit. Where the majority of the values for a particular element (such as Pb or Se) in a particular set of samples (such as gizzard shad) are less than the detection limit of the instrument for that element, the sample mean would be reported as less than the detection limit. In such cases, the half-detection limit approach has no relevance. However, it becomes important for statistical considerations in those cases where below-detection-limit values are reported for a few of the total number of sample values for a particular element (such as Na in the case of macrophytes or Hg in the case of fish or macrophytes).

The third-year data have been calculated and statistically analyzed using the half-detection limit approach. In addition, the data for the first and second years have been recalculated and re-analyzed statistically using the half-detection limit approach. These results for the individual years are presented in tabular form in the Appendix of this report (Tables 4.A-4.V).

A check of the first-year sediment extraction method indicated that unduly harsh conditions prevailed which tended to destroy the integrity of the sediment itself rather than merely desorb the cations from the sediment particle surfaces. Fresh aliquots of first-year sediments were subjected to the s digestion regimen used for sediments from the following two years. The resulting data were calculated and statistically analyzed as part of the first-year data and are therefore included in the Appendix, as referred to above (Table 4.A).

All statistical analyses and comparisons of data for the three years have been carried out using standard analysis of variance packages available on the University of Illinois Cyber 175 computer.

RESULTS

SEDIMENTS

Major trends in the concentrations of several chemical constituents in Coffeen Lake sediment occurred over the course of the 3-year study. Both Ca and Mg exhibited significant increases in annual mean concentration during the 3-year period, and Hg showed a significant decrease (Table 4.3, Fig. 4.5). Similar trends for these three elements were evident at the station level (Table 4.4). Comparison of annual mean concentrations at individual stations indicated significant increases for Ca and Mg at most stations and non-significant increases at the remaining stations. In the case of Hg, three of the six stations showed significant decreases during the 3-year period; the other three also showed decreases, though not significant. The annual mean concentration of one additional element, Cd, decreased significantly at Stations 1 and 2 between the first and second years of the study (Table 4.4), but remained relatively constant at the other stations during the same period.

There were significant changes in the station distribution of some of the chemical constituents in the lake sediment from year to year, but none of the constituents showed progressive increases or decreases in concentration from Station 1 to Station 4 (Appendix Tables 4.A-4.C). During the first year of the study, the concentrations of both Cd and Cu were significantly greater at Stations 1 and 2 than at Stations 3 and 4. The differences in succeeding years were much less marked. For all three years of the study, the concentrations of

Table 4.3. Annual mean concentrations (mg/kg dry weight) of chemical constituents in bottom sediment collected at Coffeen Lake from September 1978 through December 1980. Sample quantities are in parentheses.

	1978-79 (8)	1979-80 (30)	1980-81 (30)	Mean	$\underline{F}$[a]
Ag	7.58	b	b		
As	<0.80	<0.76	<0.78		
B	5.82	8.83	7.04	7.68	2.8
Ba	1.32	1.63	1.00	1.32	$\underline{4.6}$
Ca	1686.	2398.	3224.	2678.	$\underline{22.1}$
Cd	1.98	1.21	1.35	1.36	1.2
Cr	0.56	<0.22	<0.16		
Cu	8.38	2.41	6.08	4.72	1.4
Fe	121.	297.	196.	232.	1.5
Hg[c]	134.	74.3	53.5	72.1	$\underline{23.6}$
K	160.	161.	121.	143.	$\underline{4.1}$
Mg	337.	488.	611.	525.	$\underline{10.2}$
Mn	106.	405.	315.	330.	$\underline{4.9}$
Na	175.	207.	242.	215.	1.5
Ni	1.73	2.05	1.94	1.96	0.2
Pb	<2.78	<0.90	<0.70		
Se	<0.67	<0.68	<0.60		
Zn	23.7	21.5	24.5	23.1	0.1

[a] Values that are underscored indicate significant differences ($\underline{P}<0.05$) between years.

[b] At the time of analysis the instrument was not functioning optimally for measurement of this element.

[c] Concentrations are in ug/kg dry weight.

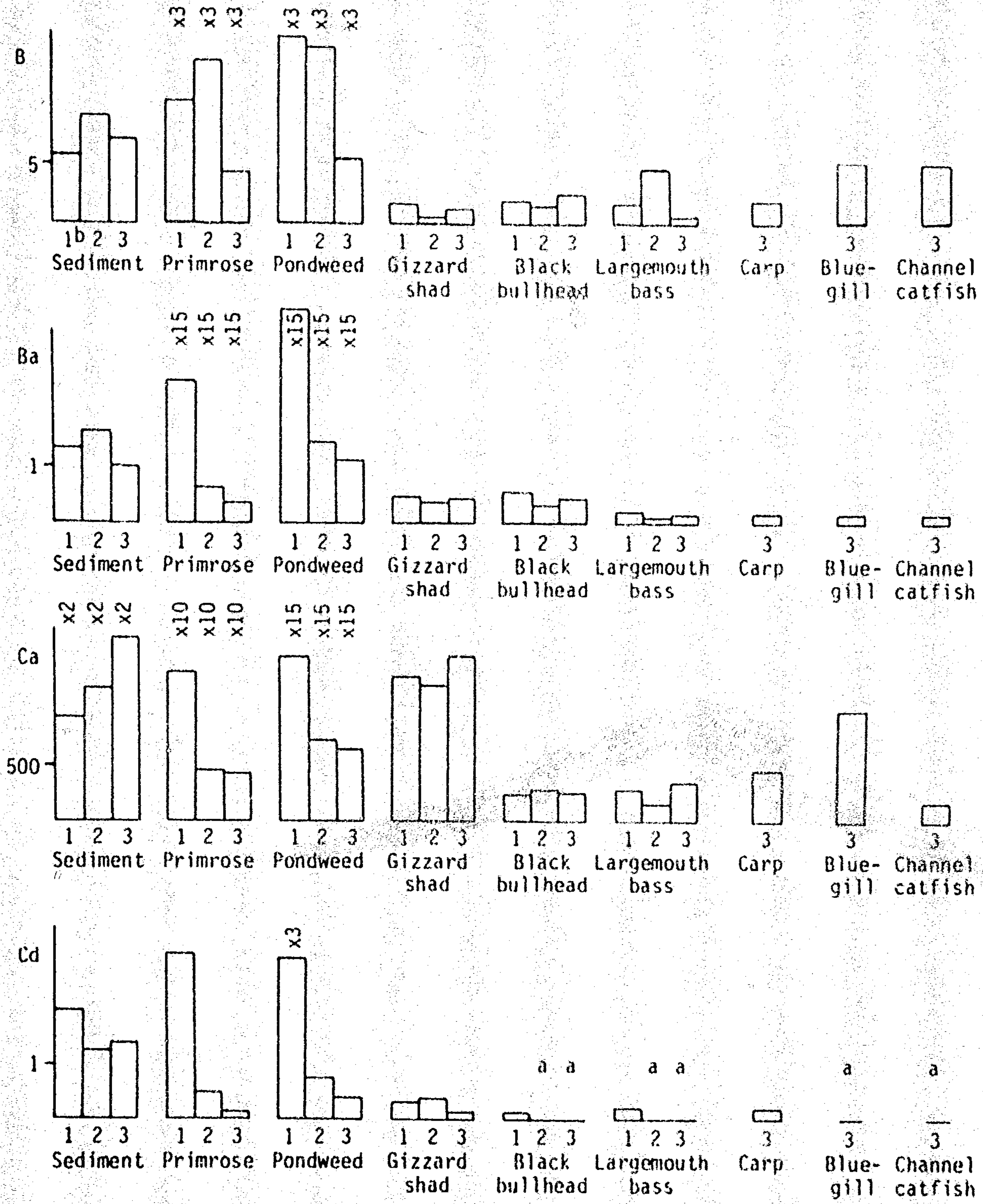


Figure 4.5. Annual mean concentrations (mg/kg fresh or dry weight) of chemical constituents in samples collected at Coffeen Lake from September 1978 through December 1980. (continued)

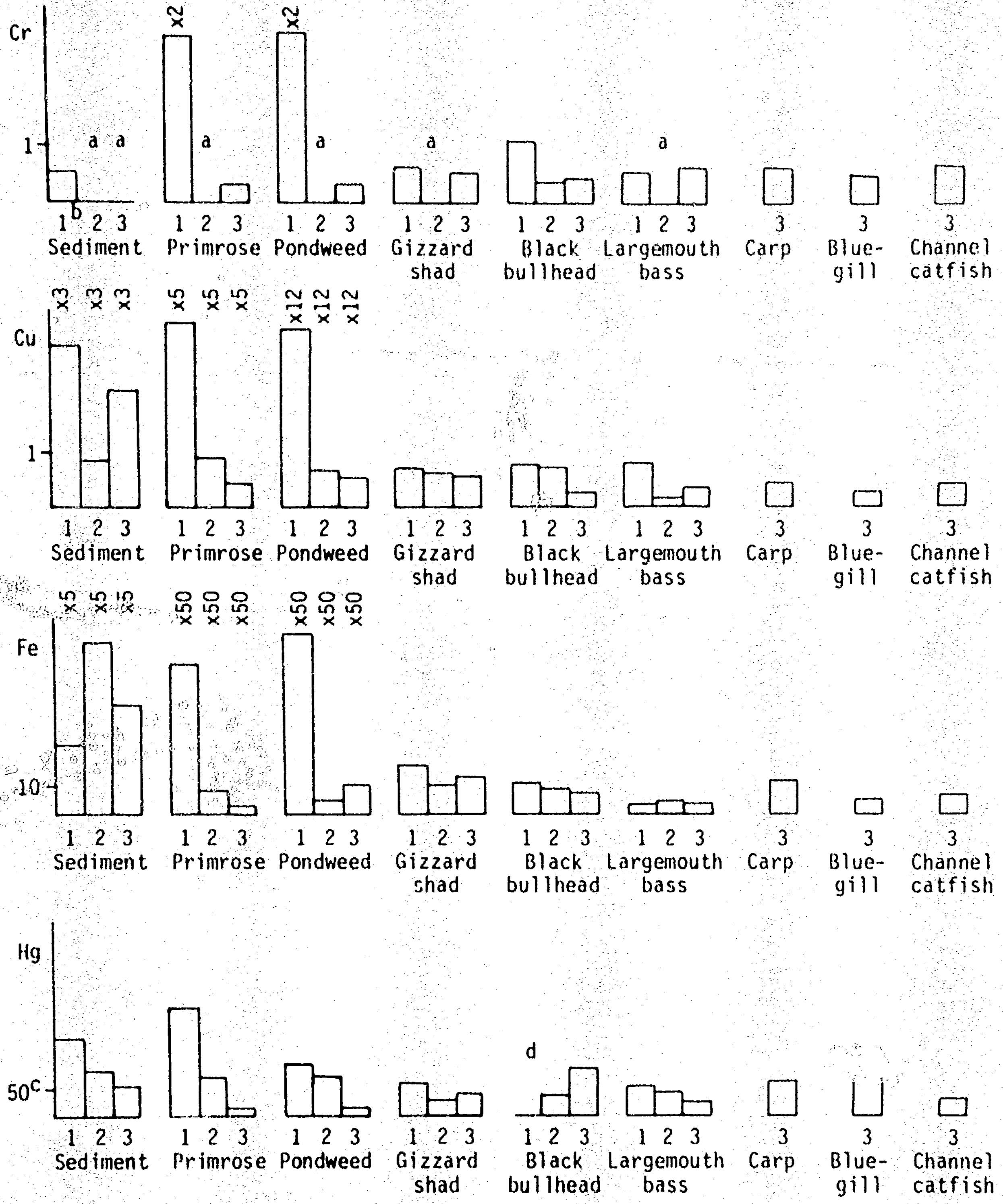


Figure 4.5. Annual mean concentrations (mg/kg fresh or dry weight)...(continued)

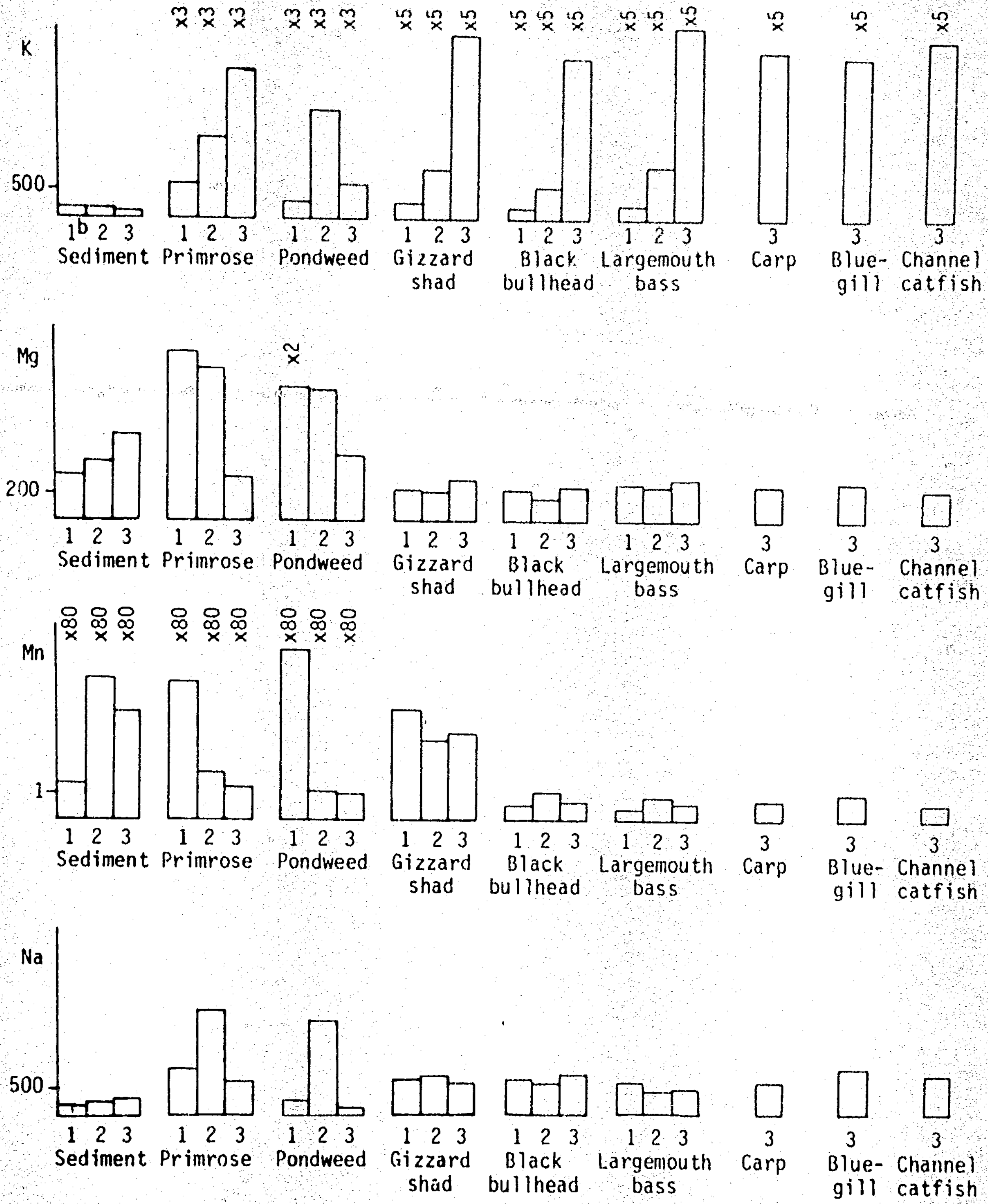
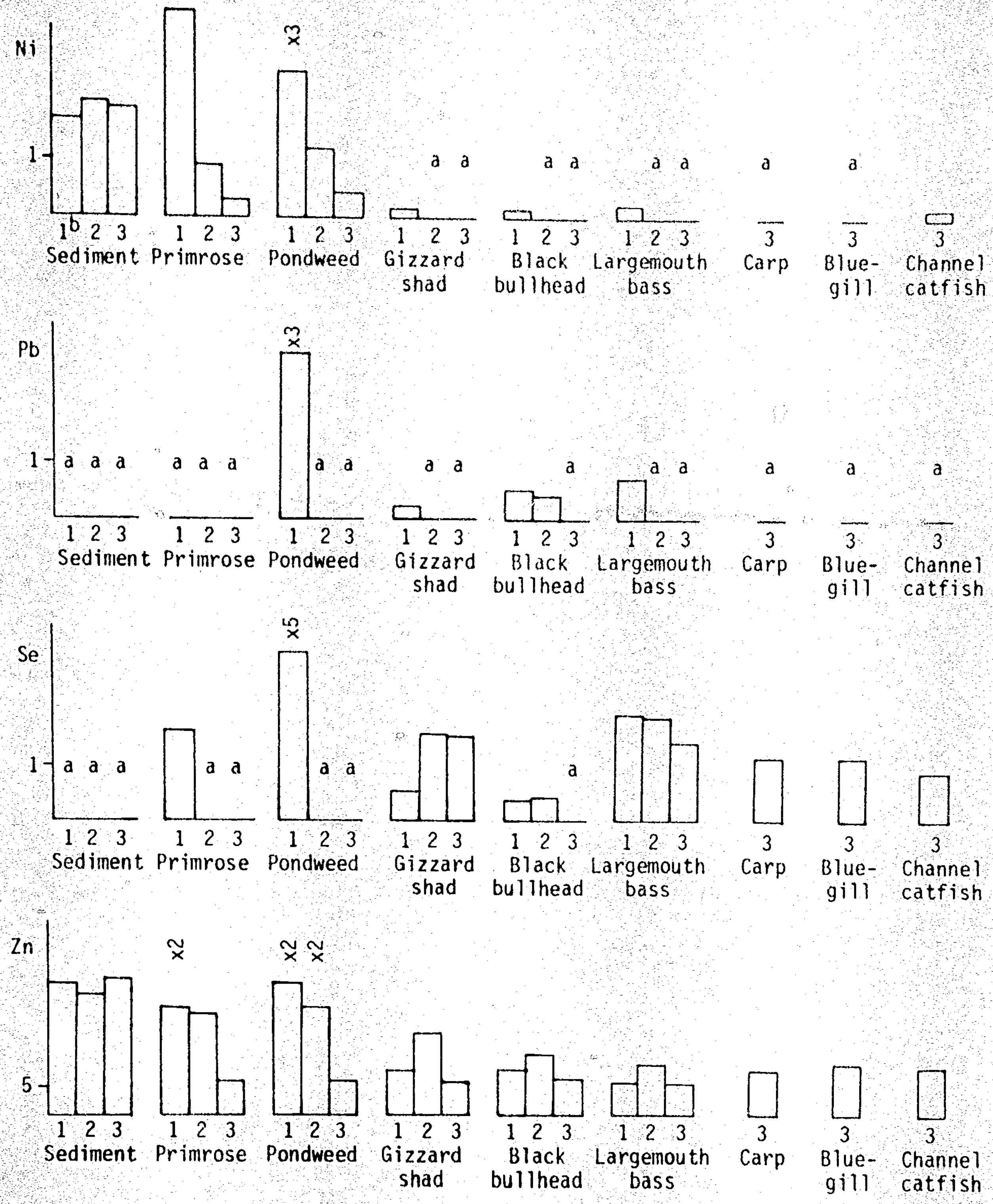


Figure 4.5. Annual mean concentrations (mg/kg fresh or dry weight)...(continued)



[a]Below the detection limit of the analytical instrument.
[b]1, 2, and 3 represent 1978-79, 1979-80, and 1980-81, respectively.
[c]Concentrations are in ug/kg fresh or dry weight.
[d]Insufficient quantities of samples for analysis.

Figure 4.5. Annual mean concentrations (mg/kg fresh or dry weight)...(continued)

Table 4.4. Annual mean concentrations (mg/kg dry weight) of chemical constituents in bottom sediment collected at four major and two ancillary stations at Coffeen Lake from September 1978 through December 1980.

	Station 1				
	1978-79	1979-80	1980-81	Mean	F[a]
Ag	8.82	b	b		
As	<0.80	<0.76	<0.78		
B	5.93	7.46	3.87	5.71	6.4
Ba	1.70	1.40	1.03	1.29	3.5
Ca	2,225.	2,936.	3,369.	2,997.	11.0
Cd	2.28	1.22	0.27	1.00	14.6
Cr	0.44	<0.22	<0.16		
Cu	0.58	<0.46	<0.12		
Fe	8.93	42.8	78.0	51.8	1.1
Hg[c]	172.	89.1	43.9	84.1	43.1
K	100.	79.0	49.1	70.0	1.3
Mg	218.	543.	540.	487.	2.4
Mn	188.	245.	208.	220.	1.5
Na	145.	117.	143.	126.	1.1
Ni	1.17	1.35	0.05	0.96	3.8
Pb	<2.78	<0.90	<0.70		
Se	<0.67	<0.68	<0.60		
Zn	12.0	14.7	5.23	10.3	3.6

(continued)

Table 4.4. Annual mean concentrations (mg/kg dry weight) of chemical constituents in bottom sediment collected at four major and two ancillary stations at Coffeen Lake from September 1978 through December 1980. (continued)

	Station 1.5			
	1979-80	1980-81	Mean	F[a]
Ag	b	b		
As	<0.76	<0.78		
B	12.6	9.46	11.0	1.3
Ba	1.48	0.72	1.10	7.3
Ca	1,994.	3,261	2,628.	24.8
Cd	1.01	2.16	1.58	2.3
Cr	<0.22	<0.16		
Cu	3.75	1.45	2.59	0.8
Fe	659.	72.8	366.	18.6
Hg[c]	61.1	57.7	59.4	0.1
K	179.	150.	164.	1.2
Mg	411.	693.	552.	143.
Mn	523.	556.	540.	0.04
Na	240.	321.	275.	0.9
Ni	2.72	2.54	2.63	0.05
Pb	<0.90	<0.70		
Se	<0.68	<0.60		
Zn	23.8	29.4	26.6	0.2

(continued)

Table 4.4. Annual mean concentrations (mg/kg dry weight) of chemical constituents in bottom sediment collected at four major and two ancillary stations at Coffeen Lake from September 1978 through December 1980. (continued)

	Station 2				
	1978-79	1979-80	1980-81	Mean	F[a]
Ag	11.1	b	b		
As	<0.80	<0.76	<0.78		
B	4.98	11.0	8.53	8.98	0.7
Ba	0.99	1.49	0.58	1.03	6.1
Ca	1,185.	1,927.	2,776.	2,153.	4.0
Cd	4.20	1.71	1.84	2.18	4.1
Cr	0.67	<0.22	<0.16		
Cu	32.5	4.74	24.6	17.7	2.7
Fe	397.	676.	531.	569.	0.4
Hg[c]	120.	56.9	59.2	69.4	14.1
K	170.	174.	169.	171.	0.03
Mg	208.	384.	606.	447.	6.8
Mn	112.	456.	516.	424.	1.8
Na	160.	209.	299.	234.	0.5
Ni	3.58	3.45	3.24	3.38	0.1
Pb	<2.78	<0.90	<0.70		
Se	<0.67	<0.68	<0.60		
Zn	66.8	36.0	39.1	42.4	1.3

(continued)

Table 4.4. Annual mean concentrations (mg/kg dry weight) of chemical constituents in bottom sediment collected at four major and two ancillary stations at Coffeen Lake from September 1978 through December 1980. (continued)

	Station 2.5			
	1979-80	1980-81	Mean	F^a
Ag	b	b		
As	<0.76	<0.78		
B	9.98	8.03	9.01	3.8
Ba	1.09	0.62	0.85	3.2
Ca	2,053.	2,923.	2,488.	11.1
Cd	1.79	2.93	2.36	1.7
Cr	<0.22	<0.16		
Cu	4.02	9.85	6.91	0.7
Fe	222.	366.	294.	0.9
Hg^c	68.0	50.0	58.0	1.2
K	162.	139.	151.	3.1
Mg	522.	725.	624.	29.7
Mn	762.	438.	600.	18.0
Na	236.	218.	224.	0.04
Ni	2.55	4.14	3.34	3.8
Pb	<0.90	<0.70		
Se	<0.68	<0.60		
Zn	33.7	60.8	47.3	3.3

(continued)

Table 4.4. Annual mean concentrations (mg/kg dry weight) of chemical constituents in bottom sediment collected at four major and two ancillary stations at Coffeen Lake from September 1978 through December 1980. (continued)

	Station 3				
	1978-79	1979-80	1980-81	Mean	F[a]
Ag	3.83	b	b		
As	0.95	<0.76	<0.78		
B	3.40	5.72	6.88	5.81	4.7
Ba	0.93	1.00	1.20	1.07	0.3
Ca	1,560.	2,073.	2,978.	2,365.	9.1
Cd	0.96	1.50	0.84	1.13	1.2
Cr	0.56	<0.22	<0.16		
Cu	<0.38	1.37	0.37	0.74	0.5
Fe	34.0	145.	108.	111.	0.5
Hg[c]	71.5	73.3	50.1	63.3	1.7
K	90.5	140.	124.	125.	2.3
Mg	562.	623.	710.	649.	0.5
Mn	79.8	319.	131.	201.	8.5
Na	105.	183.	257.	198.	3.6
Ni	1.20	1.93	1.06	1.44	2.1
Pb	<2.78	<0.90	<0.70		
Se	<0.67	<0.68	<0.60		
Zn	10.1	20.2	12.4	15.3	0.9

(continued)

Table 4.4. Annual mean concentrations (mg/kg dry weight) of chemical constituents in bottom sediment collected at four major and two ancillary stations at Coffeen Lake from September 1978 through December 1980. (continued)

	Station 4				
	1978-79	1979-80	1980-81	Mean	F[a]
Ag	6.64	b	b		
As	<0.80	<0.76	<0.78		
B	9.00	6.18	5.46	6.35	3.8
Ba	1.68	3.35	1.84	2.44	3.0
Ca	1,775.	3,404.	4,045.	3,400.	$\underline{13.7}$
Cd	<0.80	<0.08	<0.10		
Cr	0.57	<0.22	<0.16		
Cu	<0.38	<0.46	0.14		
Fe	46.4	39.5	20.8	32.9	0.6
Hg[c]	171.	92.8	60.0	92.2	$\underline{4.3}$
K	280.	233.	94.2	183.	$\underline{44.5}$
Mg	365.	444.	393.	409.	0.8
Mn	45.7	126.	42.3	77.6	$\underline{10.0}$
Na	289.	256.	215.	244.	2.2
Ni	0.97	0.33	<0.28	0.36	$\underline{78.0}$
Pb	<2.78	<0.90	<0.70		
Se	<0.67	<0.68	<0.60		
Zn	5.81	0.27	0.14	1.14	$\underline{574.}$

[a] Values that are underscored indicate significant differences ($\underline{P}<0.05$) between years.

[b] At the time of analysis the instrument was not functioning optimally for measurement of this element.

[c] Concentrations are in ug/kg dry weight.

both Fe and Zn were relatively low at Station 1 and high at Station 2, compared to the concentrations at most of the other stations.

CORES

Sediment cores were collected and analyzed for concentrations of chemical constituents only during the third year of the investigation. Cores were collected at five points along a transect across the lake at each of the four major and the two ancillary stations. Statistical analysis of the elemental concentration data indicates that the concentrations of certain elements differed significantly between stations (Table 4.5). The concentrations of B, Cd, and Hg in the cores decreased steadily and significantly from Station 1 to Station 4. In contrast, the concentrations of As, Cr, and Cu were higher in cores from Station 2 than from other stations.

A comparison of concentrations of chemical constitituents in the five cores obtained along a transect at a given station (one near each bank, one in the center of the lake, and two at intermediate points) indicates a fair degree of homogeneity in concentrations at points along each transect (Table 4.6). Although some of the differences in concentrations between points are statistically significant, there appear to be obvious trends for only three elements. The Fe concentrations in the cores decreased markedly and the Ba concentrations decreased moderately at the center of the lake (at each station); conversely, the Mg concentrations increased at the same location.

The cores were separated into six segments to represent recent sediment, four intermediate deposits, and original sediment. A comparison of the concentrations of chemical constituents in the six segments averaged across the five cores along each transect (at a given station) indicates a fair degree of homogeneity in concentrations of about half of the elements in the segments of cores collected at each station (Table 4.7). Exceptions are B, Cd, Cu, Hg, Ni, and Zn, whose concentrations tended to decrease as the depth of the segment in the core increased, and Fe, the concentration of which tended to increase with increasing depth into the core.

Table 4.5. Mean concentrations (mg/kg dry weight) of chemical constituents in cores collected at four major and two ancillary stations at Coffeen Lake in June 1980 (1980-81).

	Station								
	1	1.5	2	2.5	3	4	Mean	n	F[a]
Ag	<37.7	<37.7	<37.7	<37.7	<37.7	<37.3		168	
As	5.73	6.23	10.1	6.96	5.14	4.10	6.34	168	2.5
B	41.8	21.6	23.9	19.0	21.0	19.4	24.7	168	7.8
Ba	39.0	34.8	32.7	49.7	47.7	34.3	39.1	168	1.8
Ca	576.	514.	552.	520.	538.	465.	527.	168	1.5
Cd	7.60	5.94	7.48	3.73	4.11	1.71	5.13	168	2.7
Cr	9.54	15.2	14.2	17.9	15.9	11.2	13.7	168	3.4
Cu	6.36	30.6	48.5	18.5	26.7	2.27	22.2	168	2.4
Fe	1,186.	1,432.	2,133.	1,960.	1,639.	1,505.	1,627	168	1.9
Hg[b]	76.3	44.8	50.2	46.2	38.2	31.5	48.0	163	7.7
K	17.7	22.1	28.7	26.0	25.2	21.9	23.5	168	5.0
Mg	540.	572.	529.	434.	498.	586.	532.	168	1.4
Mn	1,616.	2,264.	1,757.	2,136.	1,488.	1,050.	1,684.	168	6.9
Na	9.98	13.9	12.9	11.0	10.5	18.3	12.9	168	2.3
Ni	10.6	13.4	16.6	13.6	14.5	9.72	13.0	168	2.7
Pb	<2.21	<2.21	<2.21	<2.21	<2.21	<2.21		168	
Se	<2.32	<2.32	<2.32	<2.32	<2.32	<2.32		168	
Zn	118.	122.	167.	97.4	104.	60.3	112.	168	1.7

[a] Values that are underscored indicate significant differences ($P<0.05$) between stations.

[b] Concentrations are in ug/kg dry weight.

Table 4.6. Mean concentrations (mg/kg dry weight) of chemical constituents in cores collected at five points along a transect at each of four major and two ancillary stations at Coffeen Lake in June 1980 (1980-81).

	Station 1								Station 1.5							
	A	B	C	D	E	Mean	n	F^a	A	B	C	D	E	Mean	n	F^a
Ag	<37.7	<37.7	<37.7	<37.7	<37.7		29		<37.7	<37.7	<37.7	<37.7	<37.7		28	
As	<2.26	2.40	<2.26	9.93	13.9	5.73	29	7.1	14.3	<2.26	<2.26	<2.26	11.2	6.23	28	8.1
B	29.9	50.0	67.5	30.4	29.6	41.8	29	2.8	18.4	22.5	22.4	30.6	17.0	21.6	28	0.8
Ba	57.6	29.0	21.9	58.7	31.3	39.0	29	7.7	42.4	29.1	20.8	65.7	26.3	34.8	28	2.4
Ca	614.	743.	727.	370.	391.	576.	29	9.0	401.	534.	544.	434.	631.	514.	28	3.2
Cd	5.34	13.0	11.0	5.33	2.87	7.60	29	1.0	3.83	4.53	7.31	3.58	9.66	5.94	28	0.6
Cr	8.10	7.85	5.89	15.3	11.5	9.54	29	2.6	13.3	16.4	19.5	12.0	13.7	15.2	28	0.6
Cu	4.36	8.20	9.53	7.03	2.80	6.36	29	0.3	46.2	3.13	8.94	1.87	83.2	30.6	28	1.5
Fe	900.	229.	169.	2125.	2666.	1186.	29	7.2	2247.	333.	216.	1292.	3025.	1432.	28	4.9
Hg^b	79.6	73.6	102.	86.7	41.7	76.3	29	1.2	32.8	48.2	43.9	42.2	54.1	44.8	28	1.0
K	23.3	13.7	15.2	18.3	18.1	17.7	29	2.4	27.1	20.8	16.3	25.3	22.2	22.1	28	1.2
Mg	585.	549.	709.	396.	437.	540.	29	4.9	314.	772.	807.	666.	332.	572.	28	25.2
Mn	1809.	1053.	1029.	1974.	2276.	1616.	29	5.5	1713.	2327.	2871.	1945.	2355.	2264.	28	0.6
Na	13.4	9.54	15.2	<7.48	<7.48	10.0	29	4.7	<7.48	21.6	17.0	22.4	7.85	14.0	28	3.4
Ni	10.8	7.68	8.81	12.0	14.0	10.6	29	1.3	18.5	9.60	13.8	6.29	16.5	13.4	28	1.3
Pb	<2.21	<2.21	<2.21	5.18	<2.21		29		<2.21	<2.21	<2.21	<2.21	<2.21		28	
Se	<2.32	<2.32	<2.32	<2.32	<2.32		29		<2.32	<2.32	<2.32	<2.32	<2.32		28	
Zn	88.4	201.	126.	83.9	83.4	118.	29	0.7	105.	98.1	159.	56.6	169.	122.	28	0.4

(continued)

Table 4.6. Mean concentrations (mg kg dry weight) of chemical constituents in cores collected at five points along a transect at each of four major and two ancillary stations at Coffeen Lake in June 1980 (1980-81). (continued)

	Station 2								Station 2.5							
	A	B	C	D	E	Mean	n	F^a	A	B	C	D	E	Mean	n	F^a
Ag	<37.7	<37.7	<37.7	<37.7	<37.7		30		<37.7	<37.7	<37.7	<37.7	<37.7		20	
As	6.33	<2.26	<2.26	16.3	23.8	10.1	30	62.3	<2.26	<2.26	3.28	2.25	17.8	6.96	20	37.1
B	12.7	35.7	19.9	35.6	15.7	23.9	30	2.5	54.5	16.1	19.4	12.5	13.8	19.0	20	2.4
Ba	45.6	25.1	23.5	50.2	21.2	32.7	30	2.9	16.7	30.4	29.1	65.3	69.0	49.7	20	1.3
Ca	588.	534.	496.	610.	533.	552.	30	0.4	545.	454.	401.	654.	535.	520.	20	1.7
Cd	5.52	7.23	3.59	9.02	12.0	7.48	30	0.5	14.3	1.80	4.09	3.38	2.93	3.73	20	1.4
Cr	3.96	22.4	14.7	19.1	10.6	14.2	30	6.3	17.3	17.4	14.3	29.5	11.4	17.9	20	5.8
Cu	69.0	5.99	0.53	83.8	83.0	48.5	30	1.1	4.59	<0.38	7.03	[illegible]	53.1	18.5	20	0.7
Fe	2837.	889.	315.	3227.	3395.	2133.	30	35.8	962.	728.	1640.	2851.	2263.	1959.	20	1.0
Hg^b	55.0	45.3	50.2	56.6	36.0	50.2	30	1.2	44.8	37.4	35.2	36.8	67.9	46.2	20	0.9
K	31.7	35.9	22.4	32.0	21.7	28.7	30	3.2	38.8	20.0	26.4	20.2	31.3	25.0	20	2.0
Mg	676.	664.	795.	309.	199.	529.	30	13.2	635.	714.	584.	348.	206.	434.	20	7.2
Mn	689.	2598.	1927.	1949.	1620.	1757.	30	4.0	2072.	2045.	1740.	3227.	1613.	2136.	20	3.4
Na	7.82	26.7	20.9	<7.48	<7.48	13.0	30	8.4	25.7	20.0	12.2	10.1	3.70	11.0	20	1.6
Ni	15.7	14.6	10.9	16.8	24.8	16.6	30	0.8	19.7	7.92	9.79	15.8	16.7	13.6	20	2.0
Pb	<2.21	<2.21	<2.21	<2.21	<2.21		30		<2.21	<2.21	<2.21	<2.21	<2.21		20	
Se	<2.32	<2.32	<2.32	<2.32	<2.32		30		<2.32	<2.32	<2.32	<2.32	<2.32		20	
Zn	105.	164.	84.2	209.	274.	167.	30	0.7	767.	46.4	82.6	58.9	139.	97.4	[illegible]	0.9

(continued)

Table 4.6. Mean concentrations (mg/kg dry weight) of chemical constituents in co s collected at five points along a transect at each of four major and two ancillary stations at Coffeen Lake in June 1980 (1980-81). (continued)

	Station 3								Station 4							
	A	B	C	D	E	Mean	n	$\underline{F}^a$	A	B	C	D	E	Mean	n	$\underline{F}^a$
Ag	<37.7	<37.7	<37.7	<37.7	<37.7		30		<37.7	<37.7	<37.7	<37.7	<37.7		31	
As	9.59	4.95	<2.26	<2.26	7.26	5.14	30	$\underline{7.0}$	<2.26	8.71	4.39	3.55	<2.26	4.10	31	1.1
B	21.5	21.8	21.2	22.9	18.0	21.1	30	0.4	23.7	18.8	23.2	16.4	15.3	19.4	31	0.7
Ba	50.2	51.2	26.5	38.6	72.1	47.7	30	1.3	36.6	36.5	35.6	38.6	23.5	34.3	31	1.1
Ca	589.	650.	505.	487.	460.	538.	30	0.8	521.	411.	509.	424.	463.	465.	31	1.9
Cd	5.17	6.09	2.87	2.82	3.59	4.11	30	0.4	1.76	1.68	2.00	0.97	2.28	1.71	31	0.5
Cr	26.0	23.5	6.49	8.25	15.3	15.9	30	$\underline{7.4}$	7.85	15.4	8.96	12.8	10.5	11.2	31	1.4
Cu	37.0	36.5	7.73	0.61	51.6	26.7	30	1.1	<0.37	2.18	6.82	1.24	1.07	2.27	31	0.8
Fe	2632.	2273.	369.	923.	1995.	1639.	30	$\underline{6.4}$	700.	2223.	1348.	1620.	1615.	1505.	31	2.6
Hg^b	53.9	39.7	28.5	37.2	31.9	38.3	30	1.5	33.3	41.9	27.9	25.3	29.8	31.5	31	0.7
K	24.9	25.7	22.3	26.9	26.1	25.2	30	0.2	21.4	21.0	25.2	23.3	19.2	21.9	31	0.3
Mg	252.	352.	726.	721.	439.	498.	30	$\underline{17.3}$	694.	503.	754.	477.	521.	586.	31	$\underline{6.2}$
Mn	1945.	1759.	977.	995.	1765.	1488.	30	$\underline{3.5}$	916.	1016.	862.	1049.	1408.	1050.	31	1.6
Na	3.70	7.70	13.7	23.6	<7.48	10.5	30	$\underline{7.5}$	23.5	13.8	20.8	16.7	17.2	18.4	31	0.4
Ni	19.8	16.4	9.52	12.2	14.7	14.5	30	$\underline{3.5}$	7.71	10.4	8.11	10.2	12.1	9.72	31	1.3
Pb	<2.21	<2.21	<2.21	<2.21	<2.21		30		<2.21	<2.21	<2.21	<2.21	<2.21		31	
Se	<2.32	<2.32	<2.32	<2.32	<2.32		30		<2.32	<2.32	<2.32	<2.32	<2.32		31	
Zn	141.	139.	67.4	62.4	110.	104.	30	0.8	64.3	63.5	74.0	46.9	54.9	60.5	31	0.5

[a] Values that are underscored indicate significant differences ($\underline{P}$<0.05) between points along the transect.

[b] Concentrations are in ug/kg dry weight.

Table 4.7. Mean concentrations (mg/kg dry weight) of chemical constituents in individual segments (6) of cores collected at four major and two ancillary stations at Coffeen Lake in June 1980 (1980-81).

	Station 1									Station 1.5								
	1	2	3	4	5	6	Mean	n	F^a	1	2	3	4	5	6	Mean	n	F^a
Ag	<37.7	<37.7	<37.7	<37.7	<37.7	<37.7		29		<37.7	<37.7	<37.7	<37.7	<37.7	<37.7		28	
As	5.17	5.10	7.13	6.20	4.38	6.55	5.73	29	0.1	9.07	5.55	7.05	4.39	6.33	5.75	6.23	28	0.2
B	46.1	45.0	46.5	26.5	30.8	59.7	41.8	29	0.8	30.1	36.6	23.2	15.3	12.0	8.77	21.6	28	9.2
Ba	29.4	29.0	39.0	42.2	51.3	44.1	39.0	29	0.8	14.1	21.6	42.6	42.5	32.5	60.6	34.8	28	1.6
Ca	649.	717.	526.	456.	537.	569.	576.	29	1.0	598.	577.	434.	526.	457.	472.	514.	28	1.1
Cd	18.5	7.94	6.12	1.23	3.45	8.54	7.60	29	2.0	20.7	9.00	2.94	1.35	1.49	0.88	5.94	28	16.1
Cr	8.64	10.9	9.98	11.0	7.08	9.61	9.54	29	0.3	12.2	25.8	12.8	15.3	12.1	8.34	15.2	28	3.5
Cu	8.06	0.87	15.1	1.98	2.10	11.0	6.4	29	1.0	149.	5.56	34.0	4.50	8.48	6.67	30.6	28	4.1
Fe	639.	654.	1381.	1562.	1213.	1790.	1186.	29	0.5	1175.	1074.	1303.	1433.	2260.	1318.	1432.	28	0.3
Hg^b	124.	95.0	87.0	48.1	49.9	48.6	76.3	29	2.4	53.2	54.5	49.1	28.7	43.5	39.6	44.8	28	1.3
K	18.2	16.1	17.3	17.4	17.6	20.3	17.7	29	0.2	33.3	25.4	26.8	17.6	15.8	14.9	22.1	28	4.0
Mg	598.	537.	564.	537.	536.	451.	540.	29	0.3	633.	564.	544.	587.	529.	586.	572.	28	0.1
Mn	1515.	1277.	1433.	1817.	1815.	1883.	1616.	29	0.5	2772.	3417.	1838.	2056.	1772.	1324.	2264.	28	2.1
Na	10.0	12.1	7.66	9.32	11.0	9.78	10.0	29	0.3	15.9	26.8	14.3	11.0	<7.48	<7.48	14.0	28	2.8
Ni	14.4	8.52	10.3	8.77	9.33	12.7	10.6	29	0.9	30.9	15.2	12.1	8.23	9.26	6.09	13.4	28	7.2
Pb	<2.21	<2.21	5.18	<2.21	<2.21	<2.21		29		<2.21	<2.21	<2.21	<1.21	<2.21	<2.21		28	
Se	<2.32	<2.32	<2.32	<2.32	<2.32	<2.32		29		<2.32	<2.32	<2.32	<2.32	<2.32	<2.32		28	
Zn	274.	102.	112.	28.8	51.5	144.	118.	29	2.0	427.	187.	69.2	23.8	27.1	12.7	122.	28	34.7

(continued)

Table 4.7. Mean concentrations (mg/kg dry weight) of chemical constituents in individual segments (6) of cores collected at four major and two ancillary stations at Coffeen Lake in June 1980 (1980-81). (continued)

	Station 2									Station 2.5								
	1	2	3	4	5	6	Mean	n	F^a	1	2	3	4	5	6	Mean	n	F^a
Ag	<37.7	<37.7	<37.7	<37.7	<37.7	<37.7		30		<37.7	<37.7	<37.7	<37.7	<37.7	<37.7		20	
As	8.36	8.04	10.9	10.8	11.1	11.5	10.1	30	0.1	18.7	5.14	6.74	6.60	4.90	8.89	6.96	20	0.5
B	31.3	32.3	24.2	17.5	11.8	26.4	23.9	30	0.9	25.7	38.6	14.6	11.8	10.7	8.01	19.0	20	8.9
Ba	16.8	13.2	28.6	43.6	45.0	49.0	32.7	30	3.9	15.9	21.2	42.4	64.5	69.6	78.5	49.7	20	1.4
Ca	502.	439.	739.	620.	540.	472.	552.	30	3.2	477.	476.	453.	500.	658.	582.	520.	20	0.6
Cd	25.2	15.2	1.43	1.02	1.11	0.952	7.48	30	16.5	10.4	9.80	1.28	1.18	0.85	0.94	3.73	20	5.9
Cr	13.0	17.1	15.1	13.6	14.0	12.2	14.2	30	0.2	20.2	18.6	16.8	21.3	15.4	15.0	17.9	20	0.2
Cu	186.	81.9	4.86	4.89	7.72	5.59	48.5	30	4.4	265.	11.5	2.44	3.91	0.55	6.80	18.5	20	177.
Fe	1787.	2606.	2497.	1897.	2120.	1889.	2133.	30	0.3	2688.	1544.	1584.	2292.	1806.	2617.	1959.	20	0.4
Hg^b	63.0	67.6	55.3	42.4	38.1	40.3	50.2	30	1.2	167.	52.1	36.8	40.5	41.7	20.9	46.2	20	10.5
K	38.4	36.1	29.5	23.0	22.2	23.2	28.7	30	3.9	48.2	34.2	18.6	21.7	24.5	21.7	26.0	20	6.1
Mg	579.	527.	581.	520.	495.	470.	529.	30	0.1	455.	512.	517.	373.	408.	293.	434.	20	0.4
Mn	2860.	2301.	1319.	1238.	1478.	1345.	1757.	30	2.9	2128.	2094.	2075.	2378.	2324.	1778.	2136.	20	0.1
Na	14.3	21.1	16.9	11.1	7.90	<7.48	13.0	30	1.1	<7.48	26.4	<7.48	<7.48	9.03	<7.48	11.0	20	4.4
Ni	36.3	25.1	12.1	7.68	8.41	9.90	16.6	30	7.1	28.4	15.8	10.5	13.9	10.2	12.0	13.6	20	1.8
Pb	<2.21	<2.21	<2.21	<2.21	<2.21	<2.21		30		<2.21	<2.21	<2.21	<2.21	<2.21	<2.21		20	
Se	<2.32	<2.32	<2.32	<2.32	<2.32	<2.32		30		<2.32	<2.32	<2.32	<2.32	<2.32	<2.32		20	
Zn	516.	334.	52.3	34.2	35.3	31.9	167.	30	14.8	625.	190.	35.2	36.1	15.5	13.2	97.4	20	21.7

(continued)

Table 4.7. Mean concentrations (mg/kg dry weight) of chemical constituents in individual segments (6) of cores collected at four major and two ancillary stations at Coffeen Lake in June 1980 (1980-81). (continued)

	Station 3									Station 4								
	1	2	3	4	5	6	Mean	n	F[a]	1	2	3	4	5	6	Mean	n	F[a]
Ag	<37.7	<37.7	<37.7	<37.7	<37.7	<37.7		30		<37.7	<37.7	<37.7	<37.7	<37.7	<37.7		31	
As	4.98	7.76	5.57	4.60	4.35	3.58	5.14	30	0.6	4.84	<2.26	9.24	2.95	3.30	3.46	4.10	31	0.9
B	30.5	28.7	20.9	17.8	15.3	13.1	21.1	30	28.8	34.4	27.2	19.5	14.5	10.2	8.95	19.4	31	13.6
Ba	20.5	22.0	40.6	39.7	77.2	86.3	47.7	30	4.6	34.8	21.7	37.1	34.8	37.8	42.1	34.3	31	1.5
Ca	582.	506.	378.	422.	622.	721.	538.	30	2.2	602.	504.	435.	416.	411.	412.	464.	31	6.7
Cd	13.4	5.79	1.54	1.46	1.26	1.14	4.11	30	12.3	3.79	2.36	0.86	1.02	1.11	0.99	1.71	31	3.5
Cr	7.86	12.9	15.6	19.4	18.3	21.3	15.9	30	1.0	7.04	4.93	11.9	14.9	14.0	15.5	11.2	31	3.4
Cu	94.5	51.0	4.83	4.01	3.42	2.36	26.7	30	4.5	8.15	0.80	1.61	0.96	0.97	1.40	2.3	31	0.8
Fe	670.	1591.	1559.	1790.	1726.	2495.	1639.	30	1.2	1134.	1104.	1564.	1674.	1730.	1905.	1505.	31	0.6
Hg[b]	59.4	48.6	41.9	34.8	25.0	19.8	38.3	30	4.3	60.6	33.4	35.6	24.3	23.0	16.9	31.5	31	4.9
K	34.6	36.0	23.2	19.5	18.3	19.5	25.2	30	19.1	38.7	31.2	18.3	15.0	13.5	12.8	21.9	31	21.3
Mg	647.	564.	474.	442.	447.	413.	498.	30	0.7	687.	630.	624.	557.	517.	495.	586.	31	1.1
Mn	1079.	1030.	1204.	1739.	1877.	2002.	1488.	30	2.3	636.	767.	913.	1304.	1423.	1315.	1050.	31	4.9
Na	15.5	15.2	7.56	9.50	9.60	<7.48	10.5	30	0.7	36.4	30.3	13.2	12.7	7.56	<7.48	18.4	31	13.8
Ni	23.2	16.0	12.3	12.9	12.4	10.5	14.5	30	4.9	8.92	7.65	8.95	9.86	11.1	12.2	9.72	31	0.9
Pb	<2.21	<2.2.	<2.21	<2.21	<2.21	<2.21		30		<2.21	<2.21	<2.21	<2.21	<2.21	<2.21		31	
Se	<2.32	<2.32	<2.32	<2.32	<2.32	<2.32		30		<2.32	<2.32	<2.32	<2.32	<2.32	<2.32		31	
Zn	252.	181.	67.1	52.1	40.6	30.3	104.	30	9.1	90.7	83.3	44.8	48.3	48.2	41.6	60.3	31	2.2

[a] Values that are underscored indicate significant differences ($P<0.05$) between segments.

[b] Concentrations are in ug/kg dry weight.

MACROPHYTES

There was a significant downward trend in annual mean concentrations of the majority of the chemical constituents present in the leaves and stems of both creeping waterprimrose and American pondweed during the 3-year study period (Tables 4.8 and 4.9, Fig. 4.5). The exceptions were B, K, and Na. If, based on insufficient numbers of specimens collected, data from the first year of the project are disregarded, both B and Na show significant decreases in concentration in both species, and K a significant decrease in pondweed, during the remaining two years. The only anomalous trend appears to be for K in waterprimrose.

Smith and Duda (1979) and Anderson et al. (1980) observed for the first and second years of the investigation, respectively, that the plant stems usually contain higher concentrations of elements than the leaves (Tables 4.8 and 4.9), Appendix Tables 4.D and 4.E). In contrast, data for the third year of the investigation show a fairly equal distribution of concentrations of five elements between stems and leaves for both species; the majority of the remaining elements occurred in higher concentrations in the leaves of both species (Tables 4.8 and 4.9, Appendix Table 4.F). This disparity of distributions could reflect yearly technical differences in the procedure used for separation of leaves and stems. Regardless of these "discrepancies," the present authors have elected to consider average values (representing the total plant) for the preparation of Fig. 4.5.

Statistical comparison of concentrations of chemical constituents in plants collected at different stations during the second and third years of the study indicated that the location (station) of the plants had little bearing on most of the elemental concentrations (Appendix Tables 4.G-4.J). (There were too few specimens collected during the first year to warrant statistical comparison.) A few exceptions were noted for waterprimrose during the second year of the study (Appendix Table 4.G). Both stems and leaves of plants collected at Station 3 contained significantly higher K and Zn concentrations than those collected at other stations. Stems of plants collected at Stations 1 and 2 had higher Ca and Ba concentrations, respectively, than those collected at other stations. No

Table 4.8. Annual mean concentrations (mg/kg fresh weight) of chemical constituents in creeping waterprimrose collected at Coffeen Lake from September 1978 through September 1980. Sample quantities are in parentheses.

	1978-79		1979-80		1980-81		Mean		F[a]	
	Stems (3)	Leaves (3)	Stems (11)	Leaves (11)	Stems (21)	Leaves (21)	Stems	Leaves	Stems	Leaves
Ag	<0.5	<0.5	b	b	b	b				
As	<1.5	<1.5	b	b	1.26	<0.966				
B	32.1	38.3	49.4	36.0	9.86	14.2	25.5	24.0	4.0	1.9
Ba	50.7	23.8	11.7	8.08	3.27	4.57	10.6	7.58	43.8	17.6
Ca	19,037	7,460.	6,036.	3,346.	1,920.	2,730.	4,940.	3,385.	15.3	4.0
Cd	4.31	1.59	0.47	0.22	0.10	0.11	0.62	0.29	57.8	115.
Cr	7.13	4.43	<0.11	0.11	0.28	0.24	0.84	0.58	72.7	260.
Cu	20.2	11.7	4.14	4.21	1.67	2.49	4.26	3.95	55.8	8.2
Fe	3,843.	1,405.	214.	184.	135.	179.	510.	295.	33.1	43.9
Hg[c]	238.	137.	44.1	93.9	11.0	10.7	43.7	48.4	50.0	19.8
K	1,947.	1,117.	5,218.	3,368	9,202.	6,972.	7,153.	5,184.	5.0	6.2
Mg	1,365.	1,085.	1,113.	1,081.	305.	355.	682.	673.	10.1	6.3
Mn	486.	302.	134.	136.	88.1	105.	141.	134.	9.1	5.4
Na	1,123.	510.	2,416.	1,005.	753.	438.	1,359.	639.	9.5	8.3
Ni	5.37	2.07	0.90	0.88	0.23	0.32	0.94	0.68	77.0	11.9
Pb	<1.3	<1.3	<0.29	<0.29	<0.11	<0.11				
Se	2.82	<0.82	<0.25	<0.25	<0.17	<0.17				
Zn	44.2	31.9	14.8	20.8	5.17	7.53	12.2	14.4	31.7	6.9

[a] Values that are underscored indicate significant differences ($P<0.05$) between years.

[b] At the time of analysis the instrument was not functioning optimally for measurement of this element.

[c] Concentrations are in ug/kg fresh weight.

Table 4.9. Annual mean concentrations (mg/kg fresh weight) of chemical constituents in American pondweed collected at Coffeen Lake from September 1978 through September 1980. Sample quantities are in parentheses.

	1978-79		1979-80		1980-81		Mean[a]		F[ab]	
	Stems (1)	Leaves (1)	Stems (9)	Leaves (9)	Stems (15)	Leaves (15)	Stems	Leaves	Stems	Leaves
Ag	<0.5	<0.5	c	c	c	c				
As	<1.5	<1.5	c	c	1.08	<0.97				
B	46.5	54.2	76.7	18.0	9.75	11.6	35.9	14.1	3.6	0.4
Ba	59.6	53.2	20.7	22.6	15.3	18.4	17.4	20.0	1.4	0.5
Ca	21,100.	22,400.	12,954.	8,995.	9,464.	10,222.	10,829.	9,742.	1.4	0.4
Cd	8.22	8.86	0.88	0.51	0.30	0.38	0.52	0.43	10.6	1.3
Cr	5.97	6.04	<0.11	<0.11	0.27	0.24	0.20	0.19	8.8	3.7
Cu	33.2	41.0	7.37	7.56	5.10	7.45	5.99	7.49	1.7	0.002
Fe	3,320.	2,950.	307.	111.	432.	590.	383.	403.	1.4	43.0
Hg[d]	83.0	88.6	60.5	74.4	9.91	9.02	29.7	34.6	4.8	10.5
K	890	725	5,150.	4,401.	1,985.	1,355.	3,223.	2,547.	21.2	20.1
Mg	2,110.	1,780.	1,028.	894.	441.	459.	670.	629.	12.2	10.2
Mn	519.	452.	119.	48.5	67.9	88.4	87.9	72.7	5.7	3.9
Na	261.	210.	1,818.	1,246.	173.	75.0	817.	533.	55.1	73.0
Ni	7.52	8.12	1.35	1.07	0.78	1.06	1.00	1.06	5.5	0.004
Pb	8.46	9.28	<0.29	<0.29	<0.11	<0.11				
Se	15.8	14.6	<0.25	<0.25	<0.17	<0.17				
Zn	40.8	51.9	23.7	53.4	5.74	7.77	12.8	25.6	18.5	9.5

[a] Mean and F value were calculated for years 1979-80 and 1980-81 only; insufficient numbers of samples were collected during 1978-79 to warrant statistical comparison.

[b] Values that are underscored indicate significant differences ($P<0.05$) between years.

[c] At the time of analysis the instrument was not functioning optimally for measurement of this element.

[d] Concentrations in ug/kg fresh weight.

statistically significant differences in elemental concentrations were noted for waterprimrose collected at different stations during the third year of the study.

There were also a few exceptions for pondweed collected during both the second and the third years (Appendix Tables 4.I and 4.J). It should be stressed that no pondweed was found at Station 1 during any of the three years. Compared to specimens collected at other stations, specimens collected at Station 2 contained higher Cd concentrations in both stems and leaves during both years, higher Se concentrations in the leaves during the second year, higher Cu, Mn, Ni, and Zn concentrations in both stems and leaves during the third year, and higher Ca concentrations in the leaves during the third year. Leaves of pondweed collected at Station 3 during the second year contained higher Zn concentrations than those of pondweed collected at other stations.

FISH

Three species of fish were collected during the first two years of the investigation (Table 4.2). An additional three species were collected during the third year. No black bullheads were found at Station 1 during the first- or third-year collecting periods, and only one each at Stations 2 and 3 during the third year. Mean lengths and weights for the fishes collected during the individual years are presented in Appendix Tables 4.K-4.M. Statistical comparisons of fish sizes at the four stations indicated that variation in size at the different stations in any of the years was generally non-significant. However, a comparison of sizes during the entire 3-year period showed significant increases in both weight and length of gizzard shad and black bullheads between the first and second years of collection and lesser increases for largemouth bass during this period (Table 4.10).

Comparisons of annual mean concentrations of chemical constituents in gizzard shad, black bullheads, and largemouth bass in Coffeen Lake over the 3-year period are presented in Tables 4.11-4.13. Similar comparisons for individual stations in the lake are shown in Tables 4.14-4.16. A significant overall trend was noted for only one element, K. There was a significant increase in

Table 4.10. Annual mean (± standard deviation) length and weight of fishes collected at Coffeen Lake from September 1978 through December 1980.

	1978-79	1979-80	1980-81	Mean	n	F[a]
Gizzard shad						
Length	17.4 ± 2.1 cm	20.4 ± 1.9 cm	20.2 ± 2.2 cm	19.4 ± 2.4 cm	113	$\underline{23.6}$
Weight	47.1 ± 13.2 g	81.0 ± 21.3 g	85.8 ± 30.0 g	72.8 ± 28.3 g	113	$\underline{29.4}$
Black bullhead						
Length	16.1 ± 1.5 cm	18.9 ± 2.3 cm	19.8 ± 1.4 cm	18.2 ± 2.4 cm	48	$\underline{15.7}$
Weight	46.9 ± 12.1 g	83.2 ± 23.9 g	103. ± 21. g	76.2 ± 29.8 g	48	$\underline{29.4}$
Largemouth bass						
Length	29.5 ± 10.0 cm	34.8 ± 5.8 cm	33.7 ± 3.9 cm	32.7 ± 7.7 cm	130	$\underline{6.6}$
Weight	576. ± 549. g	731. ± 400. g	639. ± 240 g	643. ± 429. g	130	1.5

[a] Values that are underscored indicate significant differences ($P \leq 0.05$) between years.

Table 4.11. Annual mean concentrations (mg/kg fresh tissue) of chemical constituents in muscle tissue of gizzard shad collected at Coffeen Lake from September 1978 through December 1980. Sample quantities are in parentheses.

	1978-79 (33)	1979-80 (40)	1980-81 (40)	Mean	F[a]
Ag	<13.7	<1.60	<3.07		
As	<0.49	<0.56	<0.63		
B	1.50	0.56	0.93	0.97	27.2
Ba	0.42	0.31	0.39	0.37	3.0
Ca	1,298.	1,235.	1,436.	1,324.	2.3
Cd	0.29	0.33	0.09	0.23	12.8
Cr	0.56	<0.12	0.51	0.37	26.7
Cu	0.66	0.58	0.53	0.58	1.2
Fe	16.7	10.0	11.2	12.4	7.8
Hg[b]	54.1	28.8	37.5	34.7	3.6
K	1,174.	4,095.	16,923.	7,783.	485.
Mg	223.	215.	299.	247.	40.8
Mn	3.96	2.90	3.03	3.25	4.8
Na	615.	735.	553.	635.	8.5
Ni	0.13	<0.14	<0.12		
Pb	0.24	<0.17	<0.28		
Se	0.54	1.59	1.54	1.27	27.2
Zn	7.52	14.6	5.90	9.47	43.1

[a] Values that are underscored indicate significant differences ($P<0.05$) between years.

[b] Concentrations are in ug/kg fresh weight.

Table 4.12. Annual mean concentrations (mg/kg fresh tissue) of chemical constituents in muscle tissue of black bullhead collected at Coffeen Lake from September 1978 through December 1980. Sample quantities are in parentheses.

	1978-79 (16)	1979-80 (20)	1980-81 (12)	Mean	F[a]
Ag	<13.7	<1.60	<3.07		
As	<0.49	<0.56	<0.63		
B	1.80	1.20	2.21	1.65	$\underline{3.6}$
Ba	0.53	0.27	0.44	0.40	$\underline{3.5}$
Ca	218.	267.	228.	241.	0.4
Cd	0.07	<0.04	<0.09		
Cr	1.03	0.34	0.36	0.57	$\underline{19.4}$
Cu	0.73	0.70	0.29	0.60	1.6
Fe	10.2	8.45	6.04	8.43	1.1
Hg[b]		38.5	82.6	50.4	$\underline{4.2}$
K	994.	2,757.	14,354.	5,069.	$\underline{345}$.
Mg	207.	164.	235.	196.	$\underline{6.5}$
Mn	0.50	1.00	0.61	0.74	2.8
Na	613.	568.	700.	616.	$\underline{4.8}$
Ni	0.16	<0.14	<0.14		
Pb	0.54	0.40	<0.28	0.37	2.7
Se	0.36	0.38	<0.29	0.35	0.3
Zn	7.36	11.0	6.46	8.65	$\underline{6.5}$

[a] Values that are underscored indicate significant differences ($P<0.05$) between years.

[b] Concentrations are in ug/kg fresh weight; missing value = sample quantities insufficient for analysis.

Table 4.13. Annual mean concentrations (mg/kg fresh tissue) of chemical constituents in muscle tissue of largemouth bass collected at Coffeen Lake from September 1978 through December 1980. Sample quantities are in parentheses.

	1978-79 (50)	1979-80 (40)	1980-81 (40)	Mean	$\underline{F}$[a]
Ag	<13.7	<1.60	<3.07		
As	<0.49	<0.56	<0.63		
B	1.61	4.63	0.55	2.21	$\underline{7.0}$
Ba	0.13	0.01	0.05	0.07	2.0
Ca	260.	141.	324.	243.	$\underline{17.6}$
Cd	0.17	<0.04	<0.09	0.08	$\underline{5.4}$
Cr	0.49	<0.12	0.60	0.39	$\underline{17.2}$
Cu	0.75	0.13	0.32	0.42	$\underline{5.1}$
Fe	2.13	3.19	2.36	2.53	2.6
Hg[b]	51.0	31.9	23.1	36.5	$\underline{15.8}$
K	1,125.	4,368.	17,239.	7,081.	$\underline{1{,}659}$.
Mg	267.	240.	293.	267.	$\underline{28.3}$
Mn	0.30	0.75	0.57	0.52	2.2
Na	523.	417.	438.	464.	$\underline{20.8}$
Ni	0.23	<0.13	<0.12		
Pb	0.77	<0.17	<0.27	0.37	$\underline{11.5}$
Se	1.89	1.84	1.38	1.72	$\underline{3.8}$
Zn	6.18	8.50	5.47	6.68	19.0

[a] Values that are underscored indicate significant differences ($\underline{P}<0.05$) between years.

[b] Concentrations are in ug/kg fresh weight.

Table 4.14. Annual mean concentrations (mg/kg fresh tissue) of chemical constituents in gizzard shad collected at various stations at Coffeen Lake from September 1978 through October 1980.

	Station 1					Station 2				
	1978-79	1979-80	1980-81	Mean	F[a]	1978-79	1979-80	1980-81	Mean	F[a]
Ag	<13.7	<1.60	<3.07			<13.7	<1.60	<3.07		
As	<0.49	<0.56	<0.63			<0.49	<0.56	<0.63		
B	1.36	0.50	0.92	0.84	23.4	1.58	0.41	0.92	0.85	12.2
Ba	0.48	0.40	0.33	0.39	1.7	0.43	0.25	0.35	0.33	4.3
Ca	1,590.	1,514.	1,340.	1,460.	2.2	1,494.	1,168.	1,341.	1,302.	1.6
Cd	0.61	0.69	0.09	0.43	13.7	0.53	0.31	0.10	0.27	12.6
Cr	0.36	<0.12	0.41	0.26	35.7	0.27	<0.12	0.82	0.40	11.7
Cu	1.16	0.76	0.69	0.81	4.2	0.82	0.50	0.49	0.56	3.4
Fe	24.4	14.7	11.7	15.4	2.[illegible]	19.9	8.43	8.47	10.8	15.4
Hg[b]	45.8	25.3	33.4	30.5	1.0		27.0	30.2	28.3	0.2
K	1,230.	4,259.	16,745.	8,648.	465.	1,159.	4,070.	18,700.	9,340.	39.7
Mg	217.	238.	291.	255.	13.9	212.	205.	312.	249.	21.0
Mn	6.85	4.21	2.97	4.24	7.1	3.63	2.54	2.97	2.93	1.8
Na	626.	884.	534.	693.	28.2	625.	691.	515.	607.	1.9
Ni	0.33	0.16	<0.12	0.16	12.7	<0.10	<0.14	<0.12		
Pb	<0.35	<0.17	<0.27			<0.35	<0.17	<0.27		
Se	<0.31	2.02	1.65	1.50	48.3	<0.31	1.66	1.80	1.42	41.1
Zn	11.4	12.6	6.04	9.75	22.3	9.48	14.2	6.50	10.2	17.4

(continued)

Table 4.14. Annual mean concentrations (mg/kg fresh tissue) of chemical constituents in gizzard shad collected at various stations at Coffeen Lake from September 1978 through October 1980. (continued)

	Station 3					Station 4				
	1978-79	1979-80	1980-81	Mean	F[a]	1978-79	1979-80	1980-81	Mean	F[a]
Ag	<13.7	<1.60	<3.07			<13.7	<1.60	<3.07		
As	<0.49	<0.56	<0.63			<0.49	<0.56	<0.63		
B	1.67	0.35	0.69	0.90	$\underline{15.6}$	1.40	0.98	1.18	1.21	1.0
Ba	0.37	0.15	0.36	0.29	$\underline{5.9}$	0.42	0.44	0.50	0.45	0.3
Ca	1,154.	859.	1,324.	1,112.	3.2	1,220.	1,398.	1,737.	1,431.	3.3
Cd	0.19	0.14	0.11	0.15	1.9	0.16	0.16	<0.09	0.13	$\underline{5.6}$
Cr	0.77	<0.12	0.41	0.41	$\underline{10.1}$	0.59	<0.12	0.42	0.39	$\underline{6.7}$
Cu	0.44	0.46	0.52	0.47	0.4	0.58	0.59	0.44	0.53	0.5
Fe	17.4	7.78	11.1	12.1	$\underline{3.8}$	11.9	9.14	13.6	11.6	1.5
Hg[b]	56.3	32.1	42.7	38.3	2.8	55.7	29.9	41.2	38.5	0.7
K	1,180.	3,741.	14,466.	6,462.	$\underline{374.}$	1,160.	4,310.	17,781.	7,149.	$\underline{899.}$
Mg	229.	211.	283.	241.	$\underline{3.9}$	225.	209.	312.	246.	$\underline{14.9}$
Mn	3.11	2.00	2.94	2.68	2.3	3.62	2.83	3.26	3.27	1.2
Na	553.	467.	514.	511.	1.1	654.	896.	649.	726.	$\underline{4.5}$
Ni	0.11	<0.14	<0.12			<0.10	<0.14	<0.12		
Pb	<0.35	<0.17	<0.27			<0.35	0.17	<0.27		
Se	0.86	1.81	1.63	1.44	2.9	0.59	0.88	1.08	0.83	2.8
Zn	6.52	14.4	5.95	8.94	$\underline{11.0}$	6.05	17.4	5.09	9.18	$\underline{13.5}$

[a] Values that are underscored indicate significant differences ($\underline{P}<0.05$) between years.

[b] Concentrations are in ug/kg fresh weight; missing value = sample quantities insufficient for analysis.

Table 4.15. Annual mean concentrations (mg/kg fresh tissue) of chemical constituents in black bullheads collected at various stations at Coffeen Lake from September 1978 through October 1980.

	Station 1					Station 2				
	1978-79[a]	1979-80	1980-81[a]	Mean	F[bd]	1978-79	1979-80	1980-81	Mean	F[b]
Ag		<1.60				<13.7	<1.60	<3.07		
As		<0.56				<0.49	<0.56	<0.63		
B		1.85				1.31	1.41	0.83	1.32	0.4
Ba		0.30				0.21	0.32	1.38	0.40	22.3
Ca		287.				87.2	238.	647.	233.	3.2
Cd		0.05				<0.04	<0.04	<0.09		
Cr		0.30				0.55	0.42	0.24	0.44	1.8
Cu		0.73				<0.24	0.84	0.34	0.52	8.6
Fe		7.60				4.15	15.3	8.61	10.8	0.8
Hg[c]		20.8					55.9	236.	86.0	9.3
K		3,109.				1,011.	3,396.	14,769.	3,865.	24.0
Mg		155.				149.	151.	221.	158.	0.7
Mn		1.48				<0.03	1.37	1.91	0.99	2.8
Na		628.				548.	626.	877.	628.	2.9
Ni		<0.14				<0.10	<0.14	<0.12		
Pb		0.53				<0.35	0.39	<0.27		
Se		0.35				<0.31	0.54	<0.30	0.39	2.5
Zn		10.2				4.38	9.20	7.56	7.41	1.7

(continued)

Table 4.15. Annual mean concentrations (mg/kg fresh tissue) of chemical constituents in black bullheads collected at various stations at Coffeen Lake from September 1978 through October 1980. (continued)

	Station 3					Station 4				
	1978-79	1979-80	1980-81	Mean	F[b]	1978-79	1979-80	1980-81	Mean	F[b]
Ag	<13.7	<1.60	<3.07			<13.7	<1.60	<3.07		
As	<0.49	<0.56	<0.63			<0.49	<0.56	<0.63		
B	1.54	0.79	5.09	1.60	37.3	2.07	0.76	2.06	1.75	2.8
Ba	0.37	0.19	0.66	0.33	4.5	0.71	0.24	0.32	0.44	5.7
Ca	114.	310.	391.	232.	2.1	308.	245.	170.	238.	3.6
Cd	<0.04	<0.04	<0.09			0.12	<0.04	<0.09		
Cr	1.02	0.38	0.91	0.73	21.1	1.19	0.29	0.31	0.62	12.1
Cu	<0.24	0.71	0.32	0.38	103.	1.21	0.56	0.29	0.67	3.0
Fe	6.53	4.95	10.6	6.28	5.7	13.8	5.77	5.32	8.50	7.9
Hg[c]		39.0	131.	57.4	11.7		38.4	42.3	40.3	0.1
K	919.	687.	13,791.	2,246.	181.	1,021.	3,314.	14,368.	6,910.	232.
Mg	178.	149.	219.	170.	7.1	239.	192.	238.	227.	1.2
Mn	0.30	0.55	1.38	0.53	13.7	0.74	0.59	0.41	0.57	3.4
Na	584.	598.	1,015.	638.	20.8	547.	449.	650.	501.	11.1
Ni	<0.10	<0.14	<0.12			0.24	<0.14	<0.12		
Pb	<0.35	0.46	<0.27			0.82	0.25	<0.27	0.41	4.2
Se	<0.31	0.37	0.46			0.51	0.27	<0.30	0.36	1.1
Zn	5.58	11.0	10.7	8.54	2.0	9.14	13.2	5.92	8.82	6.4

[a] No samples were collected.

[b] Values that are underscored indicate significant differences ($P<0.05$) between years.

[c] Concentrations are in ug/kg fresh weight; missing values = sample quantities insufficient for analysis.

[d] Missing data precluded statistical analysis.

Table 4.16. Annual mean concentrations (mg/kg fresh tissue) of chemical constituents in largemouth bass collected at various stations at Coffeen Lake from September 1978 through October 1980.

	Station 1					Station 2				
	1978-79	1979-80	1980-81	Mean	F[a]	1978-79	1979-80	1980-81	Mean	F[a]
Ag	<13.7	<1.60	<3.07			<13.7	<1.60	<3.07		
As	<0.49	<0.56	<0.63			<0.49	<0.56	<0.63		
B	0.72	3.86	0.68	1.83	0.8	0.81	3.95	0.57	1.92	0.8
Ba	0.02	0.01	0.04	0.02	9.3	0.03	0.02	0.04	0.03	10.4
Ca	196.	159.	242.	199.	2.1	336.	170.	340.	273.	5.6
Cd	0.05	<0.04	<0.09			0.04	<0.40	<0.09		
Cr	0.29	<0.12	0.91	0.43	11.6	0.18	<0.12	0.66	0.33	12.1
Cu	0.14	0.11	0.31	0.19	15.3	0.44	0.30	0.35	0.35	0.3
Fe	2.32	2.97	1.97	2.43	1.9	2.83	2.36	2.58	2.55	0.5
Hg[b]	39.1	29.0	6.38	23.8	23.1	41.6	26.3	10.3	23.7	23.0
K	1,419.	4,724.	16,827.	8,102.	174.	1,275.	6,320.	17,222.	9,349.	252.
Mg	272.	258.	292.	274.	4.2	258.	273.	295.	277.	1.4
Mn	0.17	0.79	0.96	0.68	1.3	0.21	1.66	0.51	0.88	1.5
Na	516.	488.	423.	458.	4.5	510.	558.	438.	501.	3.4
Ni	0.18	<0.14	<0.12			<0.10	<0.14	<0.12		
Pb	0.44	<0.17	<0.27			0.88	<0.17	<0.27	0.30	7.7
Se	1.92	2.07	1.72	1.90	0.9	1.86	2.31	1.80	2.01	1.8
Zn	5.62	8.42	5.09	6.43	10.6	7.34	10.4	5.49	7.82	4.6

(continued)

Table 4.16. Annual mean concentrations (mg/kg fresh tissue) of chemical constituents in largemouth bass collected at various stations at Coffeen Lake from September 1978 through October 1980. (continued)

	Station 3					Station 4				
	1978-79	1979-80	1980-81	Mean	F[a]	1978-79	1979-80	1980-81	Mean	F[a]
Ag	<13.7	<1.60	<3.07			<13.7	<1.60	<3.07		
As	<0.49	<0.56	<0.63			<0.49	<0.56	<0.63		
B	0.75	8.60	0.58	3.96	5.3	2.14	2.12	0.39	1.76	1.5
Ba	0.02	<0.01	0.07	0.03	13.0	0.19	0.02	0.04	0.12	0.8
Ca	300.	134.	298.	230.	4.4	255.	101.	406.	257.	9.2
Cd	0.16	<0.04	<0.09			0.22	<0.04	<0.09	0.15	1.6
Cr	0.24	<0.12	0.37	0.21	58.7	0.65	<0.12	0.43	0.49	4.5
Cu	0.51	0.06	0.33	0.26	15.4	1.01	0.04	0.30	0.65	2.2
Fe	1.46	4.09	2.48	2.94	0.6	2.07	3.35	2.43	2.39	3.5
Hg[b]	15.5	22.5	21.5	20.7	1.5	61.6	49.7	51.1	57.1	1.0
K	1,420.	3,351.	17,301.	8,180.	1,045.	973.	3,077.	17,577.	4,890.	3,805.
Mg	256.	208.	294.	250.	54.9	270.	220.	294.	265.	22.9
Mn	0.18	0.27	0.38	0.29	2.4	0.36	0.27	0.43	0.36	0.3
Na	516.	319.	453.	410.	32.0	529.	334.	440.	475.	56.4
Ni	<0.10	<0.14	<0.12			0.30	<0.14	<0.12	0.20	2.4
Pb	0.50	<0.17	<0.27			0.88	<0.17	<0.27	0.56	2.9
Se	2.28	1.81	1.02	1.61	17.0	1.83	1.18	0.97	1.53	2.3
Zn	6.93	6.91	5.39	6.34	1.7	5.98	8.24	5.86	6.39	7.7

[a] Values that are underscored indicate significant differences ($P \leq 0.05$) between years.

[b] Concentrations are in ug/kg fresh weight.

K concentration in all three species during the 3-year period; this overall increase was a reflection of the increase at each of the individual stations.

Considering the species of fish individually, there are several elemental concentration trends. In gizzard shad (Tables 4.11 and 4.14), there were significant decreases in the overall concentrations of B, Fe, and Hg between the first and second years of the study. The decrease in B concentration was evident at each of the four stations; the level of Fe was decreased only at Stations 1 and 2, and that of Hg at Stations 1, 3, and 4. In addition, although not severe enough to affect their overall levels during this same period, the concentrations of Cd, Cr, and Cu in gizzard shad decreased at Station 2, Stations 3 and 4, and Stations 1 and 2, respectively. In contrast, during this same period (between the first and second years), the concentration of Se in gizzard shad increased at all four stations, significantly at Stations 1 and 2 and non-significantly at the other two. The single overall concentration trend (decrease) noted in gizzard shad between the second and third years occurred in the case of Cd; the location contributing most notably to the overall concentration decrease was Station 1. There were significant changes in the station distributions of some of the chemical constituents in gizzard shad from year to year (Appendix Tables 4.N-4.P). The elements showing progressive decreases in concentration from Station 1 to Station 4 were primarily those referred to above.

Concentration trends in the case of black bullheads (Tables 4.12 and 4.15) are somewhat difficult to assess, since these fish were not available at Station 1 (the heated station) during the first and third years. Only Cr showed a significant decrease in overall concentration between the first and second years, and this decrease was evident at each of the three stations (2, 3, and 4). Hg registered a significant overall concentration increase between the second and third years, and this increase was primarily a reflection of the increases at Stations 2 and 3. Though not sufficient to affect the overall concentrations of these elements, Ba, Ca, and Na increased in concentration at Stations 2 and 3 during the three years. The differences in elemental concentrations between stations for individual years are presented in Appendix Tables 4.Q-4.S.

In largemouth bass (Tables 4.13 and 4.16), the overall concentration of Hg decreased significantly during the three years, a reflection of the decreased levels at Stations 1 and 2 during these years. There were significant decreases in the overall levels of Cu, Na, and Pb between the first and second years; Stations 3 and 4 were the primary locations of the decreased concentrations of the three elements. The overall concentration of Se decreased significantly between the second and third years; this was probably a reflection of the decreased levels at Stations 3 and 4 between these years. Se was one of the few elements in largemouth bass that showed a progressive decrease in concentration from Station 1 to Station 4 (Appendix Tables 4.T-4.V).

The main comparisons to be made for carp, bluegills, and channel catfish, since they were collected only during the third year of the study, are between-station comparisons of elemental concentrations (Tables 4.17-4.19). There was no significant difference between stations for most of the elements. Of the few exceptions, K and Se generally decreased in concentration progressively from Station 1 to Station 4; this trend occurred for all three species. There was no apparent trend for Hg concentration in any of the species, although the differences between stations in the case of carp and bluegills were fairly large.

Table 4.17. Mean concentrations (mg/kg fresh tissue) of chemical constituents in carp collected at various stations at Coffeen Lake in 1980-81.

	Station 1	Station 2	Station 3	Station 4	Mean	n	F[a]
Ag	<3.07	<3.07	<3.04	<3.07		20	
As	<0.63	<0.63	<0.63	<0.63		20	
B	1.42	2.18	2.33	1.59	1.88	20	0.2
Ba	0.13	0.16	0.18	0.12	0.15	20	1.6
Ca	526.	513.	548.	264.	463.	20	1.8
Cd	0.14	0.15	0.13	<0.09	0.12	20	2.0
Cr	0.55	0.45	0.73	0.47	0.55	20	2.7
Cu	0.51	0.43	0.40	0.38	0.43	20	0.6
Fe	10.7	15.6	11.8	8.59	11.7	20	1.0
Hg[b]	41.8	27.8	47.5	120.	59.2	20	10.2
K	16,260.	14,912.	14,341.	13,403.	14,729.	20	4.0
Mg	259.	249.	242.	261.	253.	20	1.0
Mn	0.56	0.68	0.85	0.64	0.68	20	1.3
Na	534.	590.	591.	577.	573.	20	0.2
Ni	<0.12	<0.12	<0.12	<0.12		20	
Pb	<0.27	<0.27	<0.27	<0.27		20	
Se	1.89	1.46	0.72	0.63	1.17	20	4.5
Zn	6.83	7.95	7.39	7.77	7.48	20	0.2

[a] Values that are underscored indicate significant differences ($\underline{P}<0.05$) between stations.

[b] Concentrations are in ug/kg fresh weight.

Table 4.18. Mean concentrations (mg/kg fresh tissue) of chemical constituents in bluegill collected at various stations at Coffeen Lake in 1980-81.

	Station 1	Station 2	Station 3	Station 4	Mean	n	F[a]
Ag	<3.07	<3.07	<3.04	<3.07		20	
As	<0.63	<0.63	<0.63	<0.63		20	
B	5.72	5.37	5.12	5.24	5.36	20	0.5
Ba	0.10	0.12	0.06	0.16	0.11	20	1.3
Ca	922.	956.	880.	1,062.	955.	20	0.2
Cd	<0.09	<0.09	<0.09	0.10		20	
Cr	0.47	0.50	0.35	0.34	0.42	20	1.5
Cu	0.24	0.32	0.10	0.13	0.20	20	3.9
Fe	3.78	3.42	4.96	3.90	4.01	20	0.4
Hg[b]	35.0	74.3	102.	72.9	62.1	20	2.0
K	15,277.	15,884.	13,097.	12,427.	14,171.	20	4.4
Mg	279.	286.	241.	238.	261.	20	5.3
Mn	1.06	1.14	0.75	0.93	0.97	20	0.4
Na	737.	772.	782.	792.	771.	20	0.3
Ni	<0.12	<0.12	<0.12	0.19		20	
Pb	<0.27	<0.27	<0.27	<0.27		20	
Se	1.38	1.37	1.42	0.62	1.19	20	6.1
Zn	8.22	9.83	9.49	8.67	9.05	20	1.3

[a] Values that are underscored indicate significant differences ($P<0.05$) between stations.

[b] Concentrations are in ug/kg fresh weight.

Table 4.19. Mean concentrations (mg/kg fresh tissue) of chemical constituents in channel catfish collected at various stations at Coffeen Lake in 1980-81.

	Station 1	Station 2	Station 3	Station 4	Mean	n	F[a]
Ag	<3.07	<3.07	<3.04	<3.07		20	
As	<0.63	<0.63	<0.63	<0.63		20	
B	6.43	4.71	4.76	4.67	5.14	20	9.5
Ba	0.21	0.05	0.16	0.10	0.13	20	1.8
Ca	160.	136.	282.	163.	185.	20	1.3
Cd	0.12	<0.09	0.10	<0.09		20	
Cr	0.69	0.44	0.59	0.57	0.58	20	2.2
Cu	0.50	0.34	0.47	0.37	0.42	20	0.6
Fe	5.08	6.63	10.1	4.91	6.67	20	0.8
Hg[b]	14.7	30.2	35.4	25.4	26.9	20	0.5
K	18,770.	16,145.	15,850.	16,891.	16,194.	20	2.8
Mg	276.	232.	221.	211.	235.	20	7.0
Mn	0.49	0.52	0.51	0.34	0.47	20	0.9
Na	658.	631.	610.	802.	675.	20	4.1
Ni	0.14	<0.12	0.14	<0.12	0.12	20	0.4
Pb	<0.27	<0.27	<0.27	<0.27		20	
Se	0.92	0.98	0.70	0.59	0.80	20	2.5
Zn	10.2	7.31	7.40	7.39	8.08	20	3.7

[a] Values that are underscored indicate significant differences ($\underline{P}<0.05$) between stations.

[b] Concentrations are in ug/kg fresh weight.

DISCUSSION

Two of the questions addressed in the second-year report (Anderson et al. 1980) are applicable to the final report. First, did the concentrations of any of the chemical constituents in the lake's ecosystem increase or decrease during the 3-year period? Second, are any of the constituents present in sufficiently high concentration to be environmentally damaging, to contaminate fish, or to pose a human health problem?

With regard to the first question, the changes in concentration of chemical constituents over the 3-year period are depicted in Fig. 4.5. The levels of the constituents in the various types of samples analyzed (sediments, two species of plants, and six species of fish) were quite variable. Five elements (Cd, Cr, Cu, Hg, and Ni) showed moderate to strong decreasing concentration trends in most components of the lake's ecosystem during the 3-year period. Three of these elements, Cd, Cr, and Hg, are recognized environmental contaminants (they appear on the U.S. Environmental Protection Agency's list of priority pollutants; Callahan et al. 1979); therefore, any reduction in their concentrations points toward effective clean-up procedures. On the other hand, the concentration of one element, K, increased in all samples except sediment during the same period. Pb concentrations were below the detection limit of the analytical instrument for most of the samples; the detection limit varies with the type of sample being analyzed.

Equally important in answering the first question is the trend in concentrations of chemical constituents from Station 1 to Station 4. Since the discharge from the slag and fly ash ponds was allowed to drain into the lake near Station 1 during the period which ended with the completion of the first year of this study, it seemed likely that components of the lake's ecosystem at this station would contain higher concentrations of some, if not all, chemical constituents than ecosystem components elsewhere in the lake. Only a few constituents showed concentration trends, and these trends were quite variable in magnitude. During the first year, Cd and Cu concentrations in sediment and gizzard shad decreased from the cooling loop to the ambient area. The fact that the same trend occurred in shad as in sediment is not surprising, since this fish is a forage fish.

Some additional decreasing trends from Station 1 to Station 4 were noted during the third year: B, Cd, and Hg in sediment cores; Se in largemouth bass, bluegills, and channel catfish; and K in carp, bluegills, and channel catfish. Why some of these trends showed up as late as the third year is puzzling, since the conditions to enhance lake ecosystem quality were implemented almost two years earlier. However, in the case of sediment cores, the layers (referred to as segments in the present report) of sediment were laid down during the whole period of evolution of the lake. Nevertheless, the greatest increases in concentration of the three constituents in question occurred in the upper one or two segments, representing recent deposits. When one considers that the lake is a relatively deep impoundment and therefore sediments may not be subject to wind and wave action to the extent found in a shallower lake, it is possible that these upper segments represent more than just the most recent year or two.

Several other factors contributed to the lack of sufficient trend evidence between the first and second years and between Stations 1 and 4. Too few macrophyte samples were collected during the first year, a critical year in the "before-after" evaluation of the waste disposal improvements, for valid statistical comparison with samples collected during subsequent years. No American pondweed was found at Station 1 during any of the years, and no black bullheads during the first and third years, making it impossible to determine what effect this station might have had on the chemical constituent concentrations of these two ecosystem components. Based on the findings of Mayes et al. (1977) and Mudroch and Capobianco (1979), we might expect to have found that the concentration trends between stations evident in the sediments during the first year were reflected in the macrophytes.

Considering the general decreasing concentration trends in the various components of the lake's ecosystem over the 3-year period, an adjunct to the first question is: Where did these elements go? The outflow from the lake is normally not very large and probably would not account for the apparent decrease in elemental concentrations. However, the flood conditions that were prevalent in the spring of 1979 (see Section 3) resulted in dilution of the elements dissolved in the lake water. Subsequent discharge of the excess volume of water over the spillway in effect depleted the lake of a significant quantity of its chemical constituents. In turn, the uptake of these chemical constituents by other components of the lake's ecosystem was reduced.

There are at least two other factors that may have contributed to the decreasing trends. Thus far, no yearly measurements have been conducted on the standing crop of macrophytes in the lake. While the elemental concentrations in these plants have decreased from year to year, it is possible that the total biomass of the plants may have increased during the same period. Distribution of a constant quantity of elements within the increased biomass would result in an apparent decrease in concentration of the elements.

Another alternative might involve the number of fishes taken by fishermen. Although the lake is closed to public fishing, a large number of "trespassing" fishermen avail themselves of the opportunity in any given season. If large quantities of fish are taken from the lake, and if there is a reduction in the quantities of chemical constituents being added to the lake's ecosystem (by virtue of the recent modifications of discharge disposal at the power plant), there would be a gradual reduction in elemental concentrations in the fishes, especially as new crops of fishes appear.

The answer to the second question can be approached by considering the concentrations of chemical constituents that sometimes accumulate to undesirable levels in aquatic ecosystems; these include Cd, Cr, Hg, Pb, and Se. As mentioned above, Pb concentrations were below the detection limit of the analytical instrument for most of the samples. Of the four ecosystem components showing measurable Pb concentrations during the first year (pondweed, gizzard shad, black bullheads, and largemouth bass), only the bullheads contained measurable concentrations during the second year (Fig. 4.5). None of the ecosystem components contained measurable levels of Pb during the final year of the investigation, a gratifying finding when improvement in environmental quality is the aim.

Atchison et al. (1977) and Murphy et al. (1978) have pointed out that fishes in ecosystems contaminated with high levels of Cd and Zn take up substantially higher quantities of these elements than do fishes in uncontaminated ecosystems. They conclude that the relative levels of these elements in fishes correlate strongly with the relative levels of the same elements in both the water and the sediment phases of the ecosystem. In the present study, the steady decrease in Cd concentrations in all ecosystem components during the 3-year period (Fig. 4.5), to the extent of being below the detection limit in several fish species, is indicative of improvement in environmental quality. The same conclusion can be drawn for Cr, although the decreases did not approach the level of non-detectability. These decreasing trends are reflections of similar decreases that have occurred in the surrounding milieu.

The remaining two elements of environmental concern are Hg and Se. As evident in Fig. 4.5, Hg concentrations decreased in all ecosystem components except black bullheads during the 3-year period. These trends, along with those for Se, are presented numerically in Table 4.20. Several investigators (Rudd et al. 1980, Speyer 1980) had indicated that Se may suppress the bioaccumulation of Hg or may be protective against toxic effects of Hg in fishes. The data in Table 4.20 suggests that in Coffeen Lake Se may suppress the bioaccumulation of Hg in gizzard shad, but not in largemouth bass.

There has been concern about the reproductive failure of fishes inhabiting lakes contaminated with Se. In lakes not subject to exposure to industrial and/or commercial wastes, the concentration of Se in fish muscle rarely exceeds 1 ppm (Pakkala et al. 1972, May and McKinney 1981). Fish reproduction in such lakes is usually normal. Cumbie and Van Horn (1978) reported that fishes from the main portion of a cooling lake for a coal-fired power plant in North Carolina contained Se atlevels ranging from 10 to 50 ppm. Reproduction in these fishes was markedly reduced. Conversely, these investigators found that the Se concentrations in fishes from a remote (uncontaminated) portion of the lake ranged from 0.5 to 7.0 ppm. These fish reproduced normally.

Since both Coffeen Lake (the subject of the present study) and Lake Sangchris (located approximately 45 miles north of Coffeen Lake) are cooling lakes for coal-fired power plants, there is concern that the fishes in both of these lakes may contain high levels of Se and may thus pose a human health problem. As evident in Table 4.20, the annual mean concentrations of Se in six species of fish taken from Coffeen Lake between 1978 and 1981 ranged from less than the detection limit

Table 4.20. Annual mean concentrations and concentration ranges of mercury (Hg) and selenium (Se) in muscle tissue of fish collected at Coffeen Lake from September 1978 through December 1980

Species[a]	Year	Hg (ug/kg fresh weight)		F[b]	Se (mg/kg fresh weight)		F[b]
		Mean	Range		Mean	Range	
SHAD	1978-79	54.1	45.8 - 56.3		0.54	<0.31 - 0.86	
	1979-80	28.8	25.3 - 32.1	3.6	1.59	0.85 - 2.07	27.2
	1980-81	37.5	30.2 - 42.7		1.54	1.08 - 1.80	
BLKBH	1978-79	c	c		0.36	<0.31 - 0.51	
	1979-80	38.5	20.8 - 55.9	4.2	0.38	0.27 - 0.54	0.3
	1980-81	82.6	42.3 - 236.		<0.29	<0.30 - 0.46	
LMB	1978-79	51.0	15.5 - 61.6		1.89	1.83 - 2.78	
	1979-80	31.9	22.5 - 49.7	15.8	1.64	1.10 - 2.01	5.8
	1980-81	23.1	6.38 - 51.1		1.38	0.97 - 1.80	
CARP	1980-81	59.2	27.8 - 120.		1.17	0.63 - 1.69	
BGILL	1980-81	62.1	35.0 - 102.		1.19	0.62 - 1.42	
CCAT	1980-81	26.9	14.7 - 35.4		0.80	0.59 - 0.98	

[a] SHAD = gizzard shad, BLKBH = black bullhead, LMB = largemouth bass, CARP = carp, BGILL = bluegill, CCAT = channel catfish.

[b] Values that are underscored indicate significant differences ($P<0.05$) between years.

[c] Sample quantities were insufficient for analysis.

of the analytical instrument (0.39 ppm) to 1.9 ppm). [illegible] collected in 1979 at Lake Sangchris contained Se at a level of 1.11 ppm (Dr. R. J. Larimore, pers. comm.). All of these levels are well within the range of concentrations (0.3-2.0 ppm), indeed at the low end, reported for fishes from the uncontaminated portion of another lake where fish reproductive abnormalities [illegible] (Cumbie and Van Horn 1978). Thus, the reproductive success of fishes in Coffeen Lake should not be affected by Se at the present.

Regarding the possibility that the Se content of fishes from Coffeen Lake might pose a human health problem, Dr. Roy W. Upham, Division of Food and Drugs, Illinois Department of Public Health, addressed the matter in a letter to Mr. D. Grant (CIPS), dated August 19, 1982. The following excerpt is particularly applicable:

> "An opinion from the Bureau of Foods, Federal Food and Drug Administration received today confirmed my opinion, based upon a study of literature research, that there is a low probability of chronic selenium toxicity through the normal ingestion of largemouth bass from Lake Coffeen.
>
> "True, the daily consumption of 300 to 500 grams of largemouth bass containing between 3 to 4 ppm selenium could result in selenium intakes ranging from 0.9 to 2.0 mg levels which exceed the NRC/NAS estimated safe and adequate daily intake of 0.05 to 0.2 mg selenium per day. Chronic selenium toxicity has resulted when 2.4 to 3.0 mg were ingested daily, over a continuous period of several months and this amount of course is approached by the highest projected daily intake of 2 mg per day. There is a safety factor, however, of perhaps 10-20 built in between the projected daily intake and the intake at which toxic effects might occur. It appears unlikely that the public would daily consume one-half to one pound of largemouth bass from Lake Coffeen on a continuing basis and thus a risk of chronic selenium poisoning inasmuch as the lake is on posted, privately owned property and fishing is not allowed."

Thus, it would appear that there is a low probability of chronic Se toxicity the normal ingestion of fishes from Coffeen Lake.

The overall conclusion for this 3-year study of the chemical constituents in Coffeen Lake might best be stated as: improvements in the disposal of the coal combustion wastes generated by the power plant have led to a significant improvement in the environmental quality of the lake's ecosystem. If the improvement continues, on the basis of current trends, the primary concern should be maintenance in order to preclude any deterioration which may arise from neglect.

LITERATURE CITED

Anderson, W. L., and K. E. Smith. 1977. Dynamics of mercury at coal-fired power plant and adjacent cooling lake. Environ. Sci. Technol. 11:75-80.

Anderson, W. L., T. A. Overton, and K. E. Smith. 1980. Chemical constituents. pp. 4.1-4.37 in J. A. Tranquilli and R. W. Larimore, Environmental Studies of Coffeen Lake. Second Annual Report to Central Illinois Public Service Company by Illinois Natural History Survey, Urbana.

Atchison, G. J., B. R. Murphy, W. E. Bishop, A. W. McIntosh, and R. A. Mayes. 1977. Trace metal contamination in bluegill (Lepomis macrochirus) from two Indiana lakes. Trans. Am. Fish. Soc. 106:637-640.

Callahan, M. A., M. W. Slimak, N. W. Gabel, I. P. May, C. F. Fowler, J. R. Freed, P. Jennings, R. L. Durfee, F. C. Whitmore, B. Maestri, W. R. Mabey, B. R. Holt, and C. Gould. 1979. Water-related environmental fate of 129 priority pollutants. U.S. Environ. Prot. Ag. Rep. No. EPA-440/4-79-029a.

Cumbie, P. M., and S. L. Van Horn. 1978. Selenium accumulation associated with fish mortality and reproductive failure. Proc. Ann. Conf. S.E. Assoc. Fish & Wildl. Agencies 32:612-624.

Dresson, D. R., E. S. Gladney, J. W. Owens, B. L. Perkins, C. L. Wienke, and L. E. Wangen. 1977. Comparison of levels of trace elements extracted from fly ash and levels found in effluent waters from a coal-fired power plant. Environ. Sci. Technol. 10:1017-1019.

El-Awady, A. A., R. B. Miller, and M. J. Carter. 1976. Automated method for the determination of total and inorganic mercury in water and wastewater samples. Anal. Chem. 48:110-116.

Griffin, R. A., R. M. Schuller, J. J. Suloway, S. J. Russell, W. F. Childers, and N. F. Shimp. 1978. Solubility and toxicity of potential pollutants in solid coal wastes. Environmental Aspects of Fuel Conversion Technology III. Environ. Prot. Technol. Series EPA-600/7-78-063.

Instrumentation Laboratory, Inc. 1972. Procedure manual for atomic absorption spectrophotometry. Lexington, MA.

Jacobs, L. W., and D. R. Keeney. 1974. Aqua regia for quantitative recovery of mercuric sulfide from sediments. Environ. Sci. Technol. 8:267-268.

Jarrell-Ash Division, Fisher Scientific Co. 1978. Jarrell-Ash plasma AtomComp direct-reading spectrometer system for multi-element trace determinations. Waltham, MA.

Kopp, J. F., and G. D. McKee. 1979. Manual - Methods for chemical analysis of water and wastes, 1978. U.S. Environ. Prot. Ag. Rep. No. EPA-600/4-79-020. 460 pp.

Lin, K., and J. Dotter. 1979. Steam electric plant factors. National Coal Assoc., Washington, DC. 137 pp.

Long, S. J., D. R. Scott, and R. J. Thompson. 1973. Atomic absorption determination of elemental mercury from ambient air on silver wool. Anal. Chem. 45:2227-2233.

May, T. W., and G. L. McKinney. 1981. Cadmium, lead, mercury, arsenic, and selenium concentrations in freshwater fish, 1976-77 - National Pesticide Monitoring Program. Pest. Monit. J. 15:14-38.

Mayes, R. A., A. W. McIntosh, and V. L. Anderson. 1977. Uptake of cadmium and lead by a rooted aquatic macrophyte (*Elodea canadensis*). Ecology 58:1176-1180.

Mudroch, A., and J. A. Capobianco. 1979. Effects of mine effluent on uptake of Co, Ni, Cu, As, Zn, Cd, Cr and Pb by aquatic macrophytes. Hydrobiologia 64:223-231.

Murphy, B. R., G. J. Atchison, and A. W. McIntosh. 1978. Cadmium and zinc in muscle of bluegill (*Lepomis macrochirus*) and largemouth bass (*Micropterus salmoides*) from an industrially contaminated lake. Environ. Pollution 17:253-257.

Pakkala, I. S., W. H. Gutenmann, D. J. Lisk, G. E. Burdick, and E. J. Harris. 1972. A survey of the selenium content of fish from 49 New York State waters. Pest. Monit. J. 6:107-114.

Perkin-Elmer. 1976. Analytical methods for atomic absorption spectrophotometry. Norwalk, CT.

Ruch, R. R., H. J. Gluskoter, and E. J. Kennedy. 1971. Mercury content of Illinois coals. Environ. Geol. Notes No. 43, Illinois State Geol. Survey, Urbana. 15 pp.

Ruch, R. R., S. J. Russell, R. Malhotra, J. D. Steele, S. B. Bhagwat, G. B. Dreher, R. A. Cahill, J. K. Frost, R. D. Harvey, and J. F. Ashby. 1979. Determination of valuable metals in liquefaction process residues. Final report (FE-8004-42) prepared for Dept. of Energy, Oak Ridge, TN. 187 pp.

Rudd, J. W., M. A. Turner, B. E. Townsend, A. Swick, and A. Furutani. 1980. Dynamics of selenium in mercury-contaminated experimental freshwater ecosystems. Can. J. Fish. Aquat. Sci. 37:848-857.

Smith, K. E., and P. M. Duda. 1979. Trace metals. pp. 4.1-4.31 In J. A. Tranquilli and R. W. Larimore, Environmental studies of Coffeen Lake. First Annual Report to Central Illinois Public Service Company by Illinois Natural History Survey, Urbana.

Speyer, M. R. 1980. Mercury and selenium concentrations in fish, sediments, and water of two northwestern Quebec lakes. Bull. Environ. Contam. Toxicol. 24:427-432.

SECTION 5

ALGAL INVESTIGATIONS OF COFFEEN LAKE

by

Larry W. Coutant

ABSTRACT

Samples were taken from July 1978 through January 1981 in Coffeen Lake, a cooling lake for a coal-fired electrical power generating station, to characterize the phytoplankton and periphyton in the lake and determine the impacts of the power plant on those ecosystem components. Power plant operations were a major influence in the following differences in phytoplankton composition and abundance at stations sampled: flagellates occurred less frequently in the discharge area and frequency of occurrences increased gradually at locations further away from the discharge to maximum frequencies of occurrence at the ambient station (Station 4); pennate diatoms, typical of periphyton, occurred more frequently in the discharge area (Station 1) and less frequently at the ambient area (Station 4); all major algal divisions had significantly lower densities in the discharge area (Station 1) than in the ambient area (Station 4); phytoplankton were significantly more diverse in the discharge area than in the ambient area (Station 4); chlorophyll *a* concentrations were significantly lower in the discharge area than at all other stations sampled. Most of these power plant effects were related to the intake of water from a depth of approximately 11m where populations of all groups of algae were more sparse, thus the abundance of all phytoplankters in the discharge area were also reduced. The overall abundance of phytoplankton and chlorophyll *a* concentrations were within the ranges of abundance in Lake Shelbyville and Lake Sangchris, two other central Illinois lakes. Phytoplankton primary production rates in the heated area were not significantly different from those values at other locations in the lake. The periphyton in the discharge area of Coffeen Lake was stressed such that reduced growth rates and diversity of the periphyton were observed in relation to those at the intake area. Recovery of the periphyton was gradual at stations located within the cooling loop from the point of discharge to the intake area where mean abundance on glass slides was more than six times as great as in the discharge area.

Waste heat and current were not the sole sources of periphyton stress in the discharge area; apparently some other growth limiting or inhibiting factor was present in that area of the lake.

INTRODUCTION

Investigations of aquatic environments have been undertaken in many cases to determine the effects of a particular stress on the biota within such waters. Many trophic levels are present in most aquatic ecosystems and there is considerable complexity and interaction between groups of organisms in such systems. The effects of stress situations on the biota are often so subtle that studying only one group of organisms may give a biased viewpoint of the condition of that body of water. For that reason, it is quite important to study groups of organisms from different trophic levels to make an assessment of an aquatic ecosystem. One important group is the algae; as primary producers, they produce much of the organic material consumed by the "higher" trophic levels. Algae, including phytoplankton ("suspended" algae) and periphyton (attached algae), are not only useful as water quality indicators and as primary producers of oxygen in aquatic environments, but they also aid in determining the trophic state of a body of water. Based on those concepts, investigations of the phytoplankton and periphyton communities of Coffeen Lake were undertaken to satisfy the following objectives: (1) to determine differences between phytoplankton species composition and abundance in different areas of Coffeen Lake, (2) to evaluate periphyton colonization of glass slides in the intake and discharge areas of the lake, (3) to estimate primary production rates in heated and ambient areas of Coffeen Lake, (4) to use data on phytoplankton, periphyton, and primary production to characterize Coffeen Lake in relation to other Illinois lakes, and (5) to determine the effects of power plant operation on the phytoplankton, periphyton, and primary production in Coffeen Lake.

MATERIALS AND METHODS

PHYTOPLANKTON

Triplicate phytoplankton samples were collected monthly from 28 July 1978 through 15 September 1980 at four lake stations (i.e., Stations 1, 2, 3, and 4, respectively) (Figure 1.2). A phytoplankton sample consisted of a one-liter sample of depth-integrated water taken from the surface to the bottom of the euphotic zone. One-liter samples were also taken near the lake bottom with a Kemmerer water sampler at the four major lake stations during the same time period and at a depth of 6m at the power plant intake from September 1979 through September 1980. The samples were preserved at the time of collection with 10 ml of acidified Lugol's solution. The samples were returned to the laboratory where they were allowed to settle for approximately 7 days. The water was removed from each sample using a suction hose and a "j" shaped tube so that the final volume of water and organisms was 50 ml. Three subsamples from each of two replicate samples from each station were placed in three Palmer-Maloney nannoplankton cells and four visible fields from each cell were examined at 400x. All non-diatom algae were identifed to the lowest possible taxon and diatoms were recorded as centric, pennate, or Melosira spp., with the exception of Rhizosolenia spp. and Skeletonema potamos which were identified to species when possible. Permanent diatom slides were prepared for specific identifications by cleaning a subsample of a given sample slurry according to modified methods of Van der Werff (1953) and mounting the diatoms in Hyrax. Diatom valves were counted and identified at 1,000x or 1,250x in random transects and the densities of diatoms in the original samples were computed by combining relative abundance estimates from diatom slides with centric, pennate, and Melosira spp. counts from the Palmer-Maloney chambers. Non-diatom densities in the original samples were computed using the appropriate multiplication factors. Phytoplankton were reported in algal units per liter; an algal unit was defined as follows:

ALGAL FORM	CELLS PER UNIT
Unicellular	-each cell or diatom frustule
Colonial	-4 cells except bluegreen algae with cells less than two microns in diameter in 50 cell units
Filamentous	-100 micron lengths

Taxonomic keys used for algal identifications included Hustedt (1930), Smith (1950), Prescott (1962), Patrick and Reimer (1966), Tiffany and Britton (1971), and Patrick and Reimer (1975).

PRIMARY PRODUCTION

Primary production measurements were made at Stations 1, 2, and from the intake area (Figure 1.2) bimonthly from September 1978 through January 1981 and at Station 4 bimonthly from March 1979 through January 1981 using oxygen methodology. Integrated water samples collected from the euphotic zone were placed in light (clear) and dark (opaque) bottles and the dissolved oxygen concentrations were determined using a YSI oxygen meter (September 1978) and Winkler methods (November 1978 through January 1981) according to Standard Methods (APHA et al. 1976). The light and dark bottles were suspended in the water at the surface, 1-meter, and 2-meter depths. After 3 to 5 hours of incubation, the oxygen concentrations were determined again. The rates of net production were determined using methods described by APHA et al. (1976). The euphotic zone depth and an pyranometer chart of solar radiation during each day used for primary productivity were used to calculate the net euphotic zone primary productivity in $O_2/m^2/day$ and in $O_2/g \cdot Kcal$ of solar radiation.

PERIPHYTON

Periphyton was collected quarterly on glass slides suspended for 28 days in floating periphyton samplers at a depth of approximately 0.025 m. Quarterly collections were made from August 1978 through February 1981. Triplicate slides were collected at each of two sampling stations located near the Discharge and Intake areas of Coffeen Lake on all eleven sampling dates and at Station 1 and the dam area on the last six sampling dates. At the time of collection, each slide was preserved intact in bottles containing 2 ml of acidified Lugol's solution and 63 ml of water. Scrapings from duplicate slides were stirred in a Waring blender and diluted to a known volume (e.g., 50 ml). The algae in the samples were then identified and counted by the same procedures outlined for phytoplankton samples except that the appropriate multiplication factors were used to give densities in algal units per 10 cm^2.

ANCILLARY MEASUREMENTS

Ancillary measurements including temperature, pH, salinity, dissolved oxygen, light penetration, light intensity, and conductivity were taken at the surface at the time of sampling for phytoplankton collections and primary productivity measurements and twice during exposure of periphyton slides.

STATISTICAL PROCEDURES

Data for phytoplankton total and major group densities, phytoplankton primary productivity, periphyton major group and total densities, water temperature, and nutrients were statistically analyzed using a two-way analysis of variance (by station and month) followed by a Duncan's multiple range test according to the General Linear Model procedure of Barr et al. (1976) available on the Statistical Analysis System at the University of Illinois, Urbana-Champaign. Data for chlorophyll a statistical analyses were the same as those data presented in Section 3, Part I, herein and data for total inorganic nitrogen, soluble orthophosphate, and total phosphorus were obtained from Section 3, Part I, herein. Data from the top and middle sampling locations were averaged for the various nutrients since it was felt that those two levels would better represent the nutrients available to the phytoplankton that were actively photosynthesizing than, for example, only surface nutrients. Also, only nutrient data from months in which phytoplankton were sampled (i.e., during the period from July 1978 through September 1980) were analyzed statistically. All tests for significance discussed in the results and discussion section were made at the 0.05 level.

RESULTS AND DISCUSSION

POWER PLANT RELATED PARAMETERS

Temperature

Since the addition of waste heat on a cooling lake is one of the major effects of power plant operation, temperatures at different stations in the lake were of particular importance to this study. For the phytoplankton and periphyton, water temperatures in the euphotic zone (zone of active photosynthesis) were of greatest interest. Temperature data taken at the surface and mid-depth in conjunction with the water chemistry data (Section 3, herein) at Stations 1, 2, 3, and 4 were averaged for each month from July 1978 through September 1980 and analyzed using a general linear models procedure followed by a Duncan's multiple range test to detect differences between stations and between months.

Water temperatures in Coffeen Lake were significantly greater at Station 1 (heated) than all other stations, significantly lower at Station 4 (ambient) than all other stations and not significantly different between Stations 2 and 3 (Table 5.1).

Table 5.1

Mean water temperatures (°C) of surface and mid-depth locations for four stations sampled monthly in Coffeen Lake from August 1978 through September 1980. Means underscored by the same line are not significantly different.

	Stations			
	1	2	3	4
$\bar{X}$	25.4	19.8	19.1	17.1

PHYTOPLANKTON

Data for phytoplankton densities, species, and diversities for collections from July 1978 through June 1980 are contained in Coutant (1980a). Data for densities, number of occurrences of taxa, diversities, and redundancies for phytoplankton collected from July through September 1980 are contained in Tables A5.1, A5.2, A5.3, and A5.4, respectively, in the appendix of this report.

Dominant taxa

Two hundred and twenty six taxa were identified from phytoplankton collections made in the euphotic zone at four stations and from the intake area at a depth of six meters (Table A5.1). Of those taxa, more than 60 occurred 10 or more times at one or more stations (Table 5.2). The flagellated organisms tended to be less common in the Discharge area (i.e., Station 1) and increased in frequency at stations around the lake to Station 4 (ambient). Apparently, effects related to operation of the power plant were responsible for lower frequencies of occurrence of most flagellates. This lower frequency could have been a result of entrainment and destruction of the cells or a result of intake of water with lower concentrations or less diversity of flagellates. The fact that many pennate diatoms seemed to occur more frequently at Station 1 and generally decreased in frequency of occurrence at stations around the lake to Station 4 may be a result of additions of diatoms from the periphyton growing along the concrete-lined discharge canal. No trends for the frequency of occurrence of bluegreen algae were apparent; although slightly greater frequency of occurrence was expected in the area of heated effluent, due to additions from coves which had continually high temperatures during late summer, bluegreen algal taxa were similarly abundant in all parts of the lake (Table 5.2). No trends were apparent for non-flagellated members of the Chlorophyta.

Abundance

During the study period from July 1978 through September 1980, the mean densities of phytoplankton were significantly greater at Station 4 than at all other stations and significantly greater at Station 3 than at the intake area

Table 5.2. Algal taxa that occurred 10 or more times at any one station in Coffeen Lake during monthly collections from July 1978 through September 1980. Flagellates are designated F. Total number of possible occurrences was 54 at Stations 1, 2, 3, and 4 and 26 at the intake.

	TAXA	Stations				
		1	2	3	4	Intake
	Chlorophyta					
	Green coccoids	49	50	49	45	21
	Green colonies	14	12	12	14	4
F	Chlamydomonads	48	48	51	50	22
F	Carteriads	21	24	37	32	15
F	*Chlorogonium* spp. Ehr.	4	12	12	22	3
	Golenkinia radiata Chodat	24	24	26	25	11
	Schroederia setigera (Schroder) Lemm.	10	11	11	14	5
	Coelastrum microporum Nageli	13	11	12	10	2
	Treubaria setigerum (Archer) G. M.Smith	14	20	16	7	5
	Tetraedron minimum (A. Braun) Hansgirg	7	3	7	15	2
	Monoraphidium arcuatum (Korshikov) Hindak	8	10	8	7	4
	M. contortum (Thuret In Breb) Kom.-Legn.	54	54	52	52	24
	Monoraphidium minutum (Nageli) Kom.-Legn.	10	10	8	9	5
	Scenedesmus bijuga (Turpin) Lagerh.	18	20	17	11	9
	Scenedesmus dimorphus (Turpin) Kutz.	15	20	20	23	5
	Scenedesmus quadricauda (Turpin) De Brebisson	49	44	43	35	23
	Scenedesmus trainorii v. *trainorii* Shubert	10	10	11	7	3
	Cosmarium spp. Corda	9	12	10	6	10
	Euglenophyta					
F	*Trachelomonas* spp.	16	18	18	24	8
F	*Euglena* spp. Ehr.	8	6	14	22	4
	Chrysophyta					
F	cf. *Chrysochromulina* spp. Lackey	24	30	33	41	19
	Bacillariophyta					
	Centric diatoms					
	Melosira varians Agardh	11	9	5	4	5
	Cyclotella atomus Hust.	14	12	15	26	5
	Cyclotella glomerata Bachmann	20	24	23	27	10
	Cyclotella meneghiniana Kutz.	38	35	35	29	11
	Cyclotella pseudostelligera Hust.	16	12	10	16	4
	Cyclotella stelligera Grun.	28	22	19	23	9
	Stephanodiscus sp. 1	24	20	22	25	8
	Stephanodiscus hantzschii Grun.	34	32	31	30	10
	Skeletonema potamos (Weber) Hasle	15	11	12	27	5

Table 5.2. Algal taxa that occurred 10 or more times at any one station in Coffeen Lake during monthly collections from July 1978 through September 1980. Flagellates are designated F. Total number of possible occurrences was 54 at Stations 1, 2, 3, and 4 and 26 at the intake. (continued)

	TAXA	Stations				
		1	2	3	4	Intake
	Pennate diatoms					
	Synedra rumpens Kutz.	21	21	17	10	6
	Achnanthes delicatula (Kutz.) Grun.	8	9	10	2	5
	Achnanthes exigua Grun.	10	9	9	3	1
	Achnanthes minutissima (Kutz.) Cleve.	36	32	28	24	9
	Navicula spp. Bory	30	29	25	18	9
	Navicula capitata Ehr.	11	3	5	4	0
	Navicula capitata v. *hungarica* (Grun.) Ross	14	13	13	8	4
	Navicula protracta Grun.	16	7	10	5	6
	Navicula symmetrica Pat.	14	12	9	2	2
	Diploneis sp. 1	31	30	22	9	9
	Gomphonema cf. *angustatum* (Kutz.) Rabh.	7	6	10	2	1
	Nitzschia spp.	37	33	35	29	11
	Nitzschia sp. 4	40	38	37	31	11
	Nitzschia sp. 7	12	16	9	8	0
	Nitzschia acicularis W. Smith	9	11	9	8	1
	Nitzschia filiformis (W. Smith) Hust.	10	8	10	3	4
	Nitzschia ignorata Krasske	11	8	3	0	2
	Nitzschia palea (Kutz.) W. Smith	38	38	38	32	11
	Nitzschia rostellata Hust.	34	35	33	24	9
	Surirella angustata Kutz.	12	6	5	3	2
	Cyanophyta					
	Bluegreen coccoid colonies	12	10	12	9	1
	Bluegreen coccoids	9	9	10	8	4
	Unidentified bluegreen filaments	16	16	18	23	4
	Aphanocapsa delicatissma West & West	46	50	47	43	20
	Gloeothace spp. Nageli	21	23	24	29	8
	Merismopedia glauca (Ehr.) Nageli	10	8	7	13	2
	Merismopedia tenuissima Lemm.	47	44	42	37	21
	Spirulina spp. Turpin	2	4	4	14	2
	Oscillatoria geminata Menegh.	10	11	10	10	1
	Oscillatoria limnetica Lemm.	48	47	43	45	19
	cf. *Raphidopsis curvata* Fritsch & Rich	6	5	6	21	0
	Cryptophyta					
F	Cryptomonads	35	44	52	53	23
F	cf. *Rhodomonas* spp. Karsten	45	50	50	53	27

(6m depth) and Stations 1 and 2. Mean densities at Stations 1 and 2 and the intake area were not significantly different from each other (Table 5.3).

Table 5.3

Groupings of mean phytoplankton densities (algal units $\cdot ml^{-1}$) at five sampling stations in Coffeen Lake based on collections from July 1978 through September 1980; means underscored by the same line are not significantly different. Sample sizes (n) and means ($\overline{x}$) are given.

	Stations				
	4	3	Intake	2	1
n	54	54	26	54	54
$\overline{x}$	19,370	12,980	8,940	10,310	8,020

Another difference between phytoplankton densities, especially between Station 1 (heated) and Station 4 (ambient), was the dramatic fluctuations in densities at the ambient location in comparison to the uniform densities of phytoplankton found in the discharge area (Station 1) (Figure 5.1). In Lake Sangchris, another central Illinois power plant cooling lake, greater fluctuations in algal abundance also occurred at the control station than at the station located in the discharge area according to Coutant (1979a). This trend of more uniform concentrations of algae in the discharge area than in the control area is probably related to the subsurface intake which would minimize the effect of surface water "blooms". Essentially, the water passing through the power plant would be from deeper waters where active algal production would be reduced and populations would be generally lower than at the surface.

Chlorophyll a, another measure of phytoplankton standing crop, was also greatest at Station 4 (22.3 $mg \cdot m^{-3}$) where concentrations were significantly greater than all other stations. As noted for phytoplankton densities, Station 3 also had signficantly greater concentrations of chlorophyll a than Stations 1 and 2 and the intake area. Concentrations of chlorophyll a at Station 1 were significantly lower than concentrations at all other sampling locations (Table 5.4). Samples at the intake were taken at a depth of 6m but the actual depth at which water is taken into the power plant was found to be 11m. The fact that

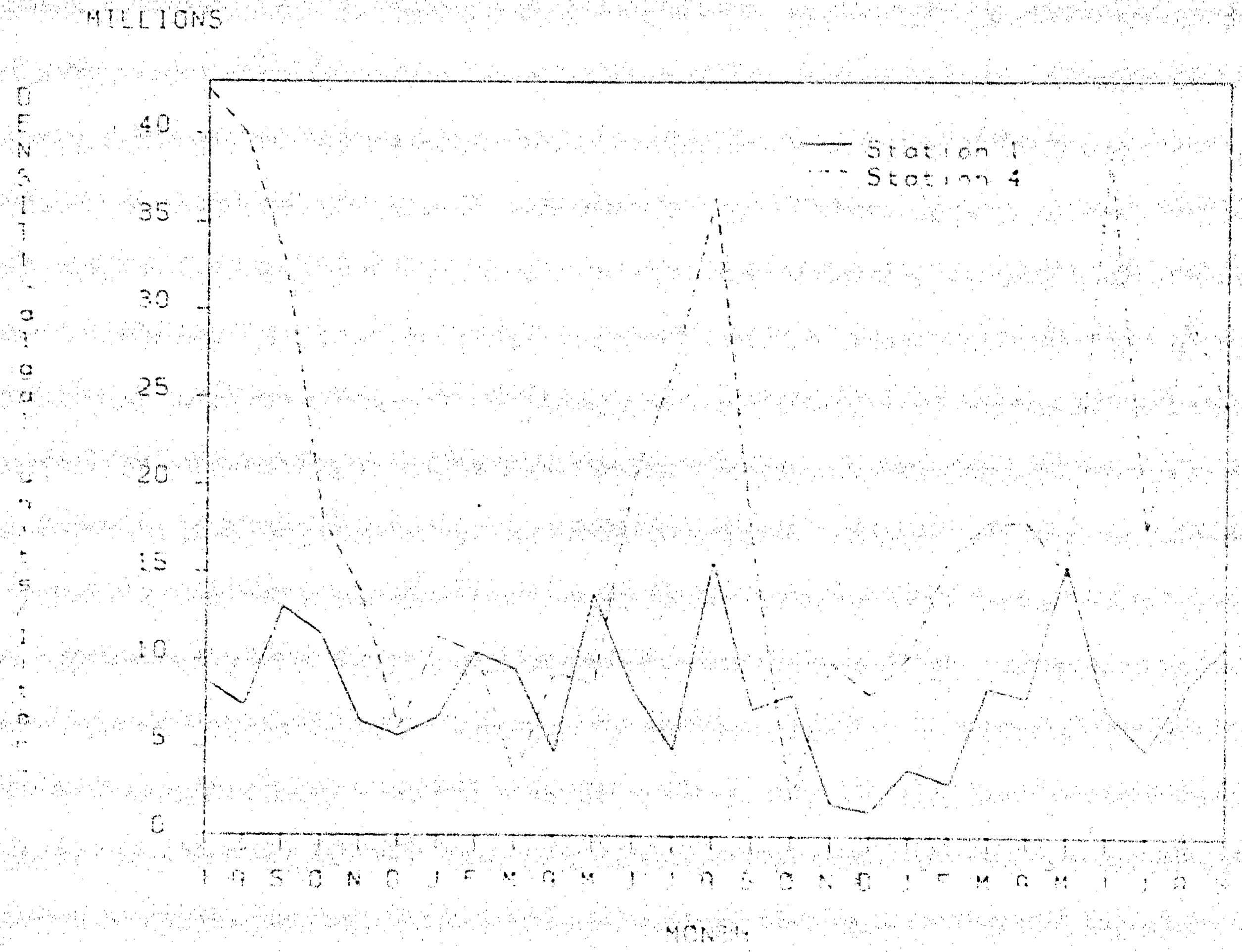


Figure 5.1. Euphotic zone phytoplankton densities (algal units · liter^{-1}) at the area receiving heated effluent (Station 1) and the ambient area (Station 4) of Coffeen Lake during monthly collections from July 1978 through September 1980.

Table 5.4

Groupings of mean chlorophyll a concentrations (mg/m³) at at five sampling stations in Coffeen Lake based on collections from December 1979 through November 1980; stations underscored by the same line are not significantly different. Sample sizes (n) and means ($\bar{x}$) are given.

	Stations				
	4	3	Intake	2	1
n	24	24	24	24	24
$\bar{x}$	22.3	13.5	10.9	10.2	7.4

population levels at the 6m depth were considerably lower than those at Stations 3 and 4 (Tables 5.3 and 5.4) supports the theory that the phytoplankton abundance was probably even less at the 11m depth. Thus, significantly lower densities of phytoplankton and lower concentrations of chlorophyll a at Station 1 could be explained by the intake and discharge of water with sparse phytoplankton populations.

Based on algal abundance, Station 4 was two to three times as productive as all other stations in Coffeen Lake except Station 3 (Tables 5.3 and 5.4). The greater standing crop of phytoplankton at Station 4 was most likely related to the greater concentrations of phosphorus available there (Table 5.5).

Nutrients

Mean nutrient concentrations using the surface and mid-depth locations were compared between stations and months using a two-way analysis of variance (general linear models procedure). The mean concentration of inorganic nitrogen was significantly greater at Station 1 than at Station 4, total phosphorus was not significantly different between stations, and soluble orthophosphate was significantly greater at Station 4 than at Stations 1, 2, and 3 (Table 5.5). As was pointed out in Section 3 (herein), apparently the power plant septic tanks and the sewage treatment plant inflow were potential sources of inorganic nitrogen. Since a significantly greater standing crop of phytoplankton

Table 5.5

Mean concentrations (mg·liter^{-1}) of total inorganic nitrogen, soluble orthophosphate, and total phosphorus based on mean concentrations at the surface and mid-depth samplings at monthly intervals from August 1978 through September 1979 in Coffeen Lake. Means underscored with the same line are not significantly different.

	Stations			
Nutrient	1	2	3	4
inorganic nitrogen	1.11	1.07	1.01	0.77
soluble ortho-phosphate	0.011	0.012	0.013	0.078
total phosphate	0.087	0.054	0.062	0.093

developed at Station 4 according to densities and chlorophyll a concentrations, phosphorus was indicated as the limiting nutrient for most stations during most of the study period. Phosphorus seemed limiting because although nitrogen concentrations were greater at Station 1, the greatest algal biomass developed at Station 4 where orthophosphate concentrations were significantly greater than those found at all other stations. During a 1973 survey, the U.S. Environmental Protection Agency (1975a) found that Coffeen Lake was phosphorus limited in May and August but nitrogen limited in October.

Comparison to other Illinois lakes

The mean concentration of phytoplankton in Coffeen Lake (12,700 algal units ·ml^{-1}) was slightly lower than the mean concentration in Lake Shelbyville (15,600 algal units ·ml^{-1}), an unheated central Illinois reservoir, and in Lake Sangchris (20,100 algal units ·ml^{-1}), another Illinois cooling lake, based on data presented for those two lakes by Coutant (1979a). Slightly different analysis and sampling methods plus the lower nutrient loading of Coffeen Lake (see Environmental Protection Agency; 1975a, 1975b, and 1975c) would seem to explain the generally lower concentrations of phytoplankton observed in Coffeen Lake.

The mean concentration of chlorophyll a in Coffeen Lake ([illegible] mg m-3) in the euphotic zone was lower than that in Lake Shelbyville ([illegible] mg m-3), based on data from three locations from October 1975 through September 1976, but slightly greater than concentrations in Lake Sangchris (12.5 mg m-3). (Data from three locations from September 1973 through September 1976 for Lake Shelbyville were summarized using Dufford et al. [1977], Dufford et al. [1978], and Clement et al. [1979], and data from Lake Sangchris were summarized using Brigham [1977], and Moran [personal communication]).

Major groups

The major divisions of algae in the phytoplankton of Coffeen Lake included the Chlorophyta, Bacillariophyta, Cyanophyta, and Cryptophyta. The densities generally followed a similar pattern for each algal division; densities were greatest at Station 4 and decreased in order of stations around the cooling loop from Station 3 to the intake to Station 2 to Station 1 (Table 5.6).

Table 5.6

Groupings of mean phytoplankton densities at five sampling stations in Coffeen Lake by Division based on collections from July 1978 through September 1980; means underscored by the same line are not significantly different.

	Stations				
Divisions	4	3	Intake	2	1
Chlorophyta	4,490	3,810	3,070	3,110	3,000
Bacillariophyta	2,490	1,300	900	1,200	1,100
Cryptophyta	4,140	3,220	2,090	1,950	740
	4	3	2	1	Intake
Cyanophyta	4,590	3,140	2,290	2,240	1,630

The exception to the general trend among algal division densities was for the Cyanophyta which had the lowest concentrations of organisms at the intake area; these densities were not significantly lower than those at either Station [illegible] or Station 1, however. Lower densities might be expected at the intake area due to sampling at a 6m depth. Lower numbers of the Cyanophyta were probably found because they generally are more buoyant than other algae and would not be expected to be as abundant in deeper waters.

The only algal division that had significantly lower densities at Station 1 than in the intake was the Cryptophyta. As noted earlier, the intake samples were actually taken at 6m instead of the actual intake depth of 11m, thus the concentrations of the Cryptophyta actually taken into the power plant at a depth of 11m and discharged through Station 1 may have been lower than the concentrations at the depth sampled.

The mean relative abundance of the major algal divisions found in the phytoplankton of Coffeen Lake were as follows: Chlorophyta (30%), Bacillariophyta (12%), Cryptophyta (19%), and Cyanophyta (24%). By comparison, those same divisions had relative abundances of 21%, 37%, 13%, and 15%, respectively, in Lake Shelbyville and 19%, 29%, 14%, and 32%, respectively, in Lake Sangchris, two other central Illinois lakes, based on data presented by Coutant (1979a). The Chlorophyta and Cryptophyta had greater importance in the phytoplankton in Coffeen Lake and the diatoms had lesser importance in that lake while the Cyanophyta had similar abundance in Coffeen Lake in comparison to Lake Shelbyville and Lake Sangchris. These four algal divisions accounted for approximately 85%, 86%, and 94% of the total phytoplankton in Coffeen Lake, Lake Shelbyville, and Lake Sangchris, respectively.

Vertical differences

Student's t tests were used to determine differences between euphotic zone and near bottom phytoplankton densities (Table 5.7). As was expected, most stations

TABLE 5.7

Number of significant differences using Student's t-tests between euphotic zone and near bottom phytoplankton densities and number of tests for four stations sampled monthly from July, 1978 through September 1980 in Coffeen Lake.

	Station 1	Station 2	Station 3	Station 4
# of tests	26	26	26	26
# of significant differences	6	11	[illegible]	[illegible]

were sufficiently well mixed on most sampling dates that there were no significant differences between sampling points in the water column. Station 2, however, due to its greater overall depth (approximately 15m), had greater vertical differences than other stations sampled. The greater overall depth at Station 2 allowed more time for algae settling out of the water column to be ingested by zooplankton or degraded by bacteria following mortality than at the other stations where total depths were approximately 2 to 6 meters. Also, the power plant discharge would have contributed to mixing at Station 1. Due to the relatively shallow depth at Station 4 (approximately 2 to 3m), the euphotic zone samples were actually taken almost to the bottom on many sampling dates. Thus, there were often some overlap in the zones sampled for vertical comparisons at that station.

Diversity

The diversity of phytoplankton at Stations 1, 2, and 3 and at Stations 2, 3, and 4 were not significantly different from one another based on a two-way analysis of variance by station and month and a Duncan's multiple range test (Table 5.8). Station 4 had a significantly lower mean diversity (3.17) than Station 1 (3.34) according to the Duncan's test. The fact that Station 1 had greater diversity than Station 4 was expected due to the fact that the water sampled from Station 1 came primarily from water taken in at the intake area a short time before.

Table 5.8

Mean diversity indices for phytoplankton collected at four stations in Coffeen Lake monthly from July 1978 through September 1980. Means underscored by the same line are not significantly different.

	Stations			
	1	2	3	4
$\overline{x}$	3.34	3.25	3.25	3.17

The depth of water intake (11m) would influence the composition of the phytoplankton and it is likely that any predominant algae found in the surface waters would not be as abundant at the intake depth and thus the diversity of algae at that location would be greater than in the surface waters. Also, a diversity value of 3.17 (Station 4) does not indicate a stress situation and in fact, naturally occurring lower diversities may result from normal pulses or "blooms" of one or a few taxa.

The mean diversity values computed for Lake Shelbyville (3.29) and Lake Sangchris (3.59) were similar to the overall mean for Coffeen Lake (3.24) based on data of Coutant (1979a) from four stations in Lake Shelbyville and three stations in Lake Sangchris from June 1976 through August 1977. The ranges of diversities for Lake Shelbyville and Lake Sangchris were from 1.95 to 4.42 and from 2.69 to 4.27, respectively. In Coffeen Lake, the range of mean diversities for the lake was from 1.89 to 4.20.

In summary, there were several differences in phytoplankton composition and abundance between stations in Coffeen Lake that were apparently related to power plant operation. Flagellated phytoplankters occurred least frequently in the area of heated discharge (Station 1) and increased in frequency of occurrence at successive stations around the lake to the ambient area (Station 4). The euphotic zone phytoplankton densities and chlorophyll a concentrations were significantly greater at Station 4 (ambient) and gradually decreased in successive order around the cooling loop toward Station 1 (heated). Diversity of phytoplankton at Station 1 was significantly greater than at Station 4. These trends were apparently caused by the subsurface intake of water by the power plant which resulted in entrainment of lower numbers of algae and discharge of the sparser populations through Station 1. Pennate diatoms were generally more common in the discharge area (Station 1) and gradually occurred less frequently at successive stations around the lake to Station 4 (ambient). This trend may have been due to the addition of diatoms to the effluent from periphyton growing along the concrete discharge canal.

There were other trends which were not related to power plant operation. There was considerable vertical mixing of phytoplankton at most locations except Station 2 which was the deepest station sampled. Mean phytoplankton densities and chlorophyll _a_ concentrations in Coffeen Lake were similar to those from Lake Shelbyville and Lake Sangchris; the slightly lower algal densities in Coffeen Lake could be explained by different methods of analysis and by the lower nutrient loading of that lake. The diatoms had lower relative abundance in Coffeen Lake than in Lake Shelbyville and Lake Sangchris; green algae and the Cryptophyta had greater relative abundance in Coffeen Lake than in the other two lakes.

Primary productivity

Data for net primary productivity (mg $O_2 \cdot m^{-2} \cdot day^{-1}$) collected from September 1978 through May 1980 are contained in Coutant (1980a). Data for net primary productivity collected from July 1980 through January 1981 are contained in Table A5.5 in the appendix of this report.

Net primary productivity (mg $O_2 \cdot gKcal^{-1}$ of solar radiation) was greatest at Station 4 (0.91 $mgO_2 \cdot gKcal^{-1}$) and lower at the intake area (0.73 $mgO_2 \cdot gKcal^{-1}$), Station 2 (0.68 $mgO_2 \cdot gKcal^{-1}$) and Station 1 (0.59 $mgO_2 \cdot gKcal^{-1}$) (Table 5.9).

Table 5.9

Mean net primary productivity (mg O_2·gcal^{-1} of solar radiation) during the photoperiod at four sampling stations in Coffeen Lake based on data collected from September 1979 through January 1981. Means underscored by the same line are not significantly different.

	Stations			
	4	Intake	2	1
$\bar{x}$	0.91	0.73	0.68	0.59

Mean net primary production rates were not significantly different between stations according to the analysis of variance and Duncan's grouping tests (Table 5.9).

Generally speaking, at intake temperatures of 15°C or less, stimulation of primary production has been observed, but at intake temperature of 20°C or more there has been inhibition of primary productivity in certain receiving waters according to Warriner and Brehmer (1966) and Morgan and Stross (1969). Other researchers have indicated that any combination of intake temperature and t that did not exceed 25°C were stimulatory to primary productivity (Miller et al. 1976). They also indicated that inhibition of primary productivity was observed at discharge temperatures greater than 34°C regardless of ambient temperatures. Other researchers have found that primary productivity has been inhibited regardless of intake temperatures with t's of 10 to 30°F (Gurtz and Weiss 1974).

Moran (in press) found that primary production by photoplankton was inhibited in the discharge area of Lake Sangchris, a cooling lake, during periods when water temperatures in the discharge area were in excess of 30°C and that the primary productivity was significantly greater in the discharge area than in the intake area during periods when water temperatures were below 30°C in the discharge area. Though other researchers have found heat-related differences in productivity, no significant differences were found in this study, probably due to infrequent sampling and few replicates or due to the real similarity between stations.

PERIPHYTON

Data for periphyton densities, species, and diversities for collections from July 1978 through June 1980 are contained in Coutant (1980a). Data for densities, species, diversities, and redundancies for collections from August 1980 through January 1981 are contained in Tables A5.6, A5.7, A5.8, and A5.9, respectively, in the appendix of this report.

Composition

One hundred and eighty three taxa were identified from periphyton collected from glass slides after quarterly 28-day exposure periods at four stations in Coffeen Lake (Table A5.2). Stations included the Intake, Discharge, and Dam areas and Station 1 (Fig. 1.2).

Abundance

Periphyton accumulations on glass slides at four stations were significantly different between locations (Table 5.10). Mean densities (algal units·10 cm^{-2}) were significantly greater at the Intake area than all other stations, significantly greater at the Dam area than at Station 1 and the Discharge area, and not significantly different between Station 1 and the Discharge area. As can be seen in Fig. 5.2, inhibition of growth did not occur at the Discharge area only in the warmer months when temperatures were near 40°C. The inhibition

Table 5.10

Mean periphyton densities (algal units · 10 cm^{-2}) on glass slides exposed for 28 days quarterly from September 1978 through February 1981 at four locations in Coffeen Lake. Means underscored with the same line are not significantly different.

	Stations			
	Discharge	1	Dam	Intake
$\bar{x}$	945,000	1,785,000	3,783,000	6,432,000

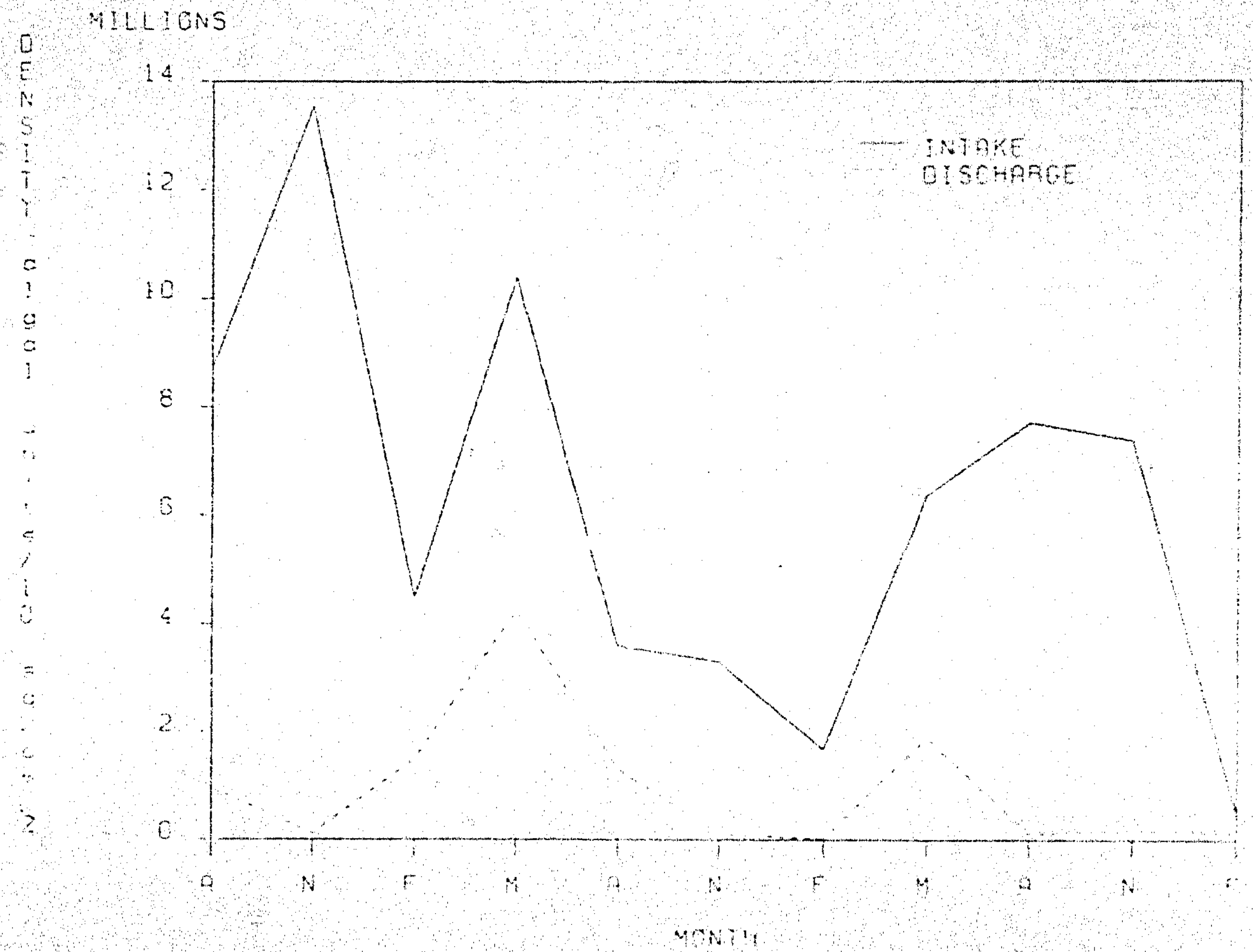


Figure 5.2. Periphyton densities (algal units · 10 cm^{-2}) on glass slides after 28 days of exposure in the Intake and Discharge areas of Coffeen Lake during quarterly samplings from September 1978 through February 1981.

of periphytic algal growth in the Discharge area was apparent during all sampling periods throughout the study; since temperature-induced inhibition of periphytic growth generally occurs only at temperatures over 30°C, other factors must have been responsible for the reduced growth rates of periphyton in the Discharge area. Apparently, factors related to the power plant effluent were responsible for the reduced growth of periphyton in the Discharge area. It should also be noted that the inhibitory effect on the periphyton was still apparent at Station 1 and that growth of periphyton at the Dam area was still significantly less than at the Intake area. There was a gradual recovery of periphytic growth at successive stations from the discharge around the cooling loop to the intake. Current was a physical factor which was different at the intake and discharge areas and might have affected the colonization rates of periphyton. Current was constantly greater at the discharge area than at the intake area and decreased as it progressed around the cooling loop to the intake. It is not likely that current alone was responsible for the observed trends because periphytic growth rates are usually positively correlated with current velocity; thus one would expect greater accumulations in the discharge area.

The mean density of periphyton in the Kankakee River was 6,400,000 algal units $\cdot 10\ cm^{-2}$ using the same sampling apparatus and exposure periods based on data collected in May, August, and November of 1977, 1978, and 1979 by Coutant (1978, 1979b, and 1980b). A mean periphyton density for Coffeen Lake based on all data collected from May, August, and November samplings in 1978, 1979, and 1980 was 4,400,000 algal units $\cdot$ 10 cm^{-2}. The lower densities in Coffeen Lake would be expected due to the generally nutrient rich environment of most rivers (Williams 1964), such as the Kankakee River, plus the positive influence of greater current in the river which would enhance nutrient mixing. Even so, the intake area, which had the greatest periphyton growth in Coffeen Lake, had mean periphyton densities of 6,400,000 algal units $\cdot$ 10 cm^{-2}, approximately the same as that found on the Kankakee River substrates. The overall lower production of periphyton in Coffeen Lake can be attributed to the reduced growth in the discharge area which was apparently a result of some growth limiting or inhibiting factor in that area of the lake.

Major groups

Three divisions of algae were responsible for the majority of periphytic algal growth on glass slides in this study. Those groups were the Chlorophyta, Bacillariophyta, and Cyanophyta (Table 5.11). As was pointed out for total densities of periphyton, the mean densities of these major groups of algae were always lower at the Discharge area and increased as one proceeded around the cooling loop toward Station 1, the Dam area, and the Intake area. The periphyton densities were always significantly greater at the Intake area than at the Discharge area (Table 5.11). Among each major division periphyton densities at Station 1 were not significantly different from those densities at the Discharge area.

Table 5.11

Mean densities (algal units · $10\ cm^{-2}$) ($\bar{x}$) of the Chlorophyta, Bacillariophyta, and Cyanophyta in periphyton collected after quarterly 28-day exposure periods at four stations in Coffeen Lake from September 1978 through February 1981. Means underscored by the same line are not significantly different.

Divisions	Stations			
	Discharge	1	Dam	Intake
Chlorophyta				
$\bar{x}$	572,000	517,000	869,000	1,427,000
Bacillariophyta				
$\bar{x}$	180,000	659,000	2,220,000	4,268,000
Cyanophyta				
$\bar{x}$	175,000	258,000	682,000	667,000

Diversities

Periphyton diversities computed according to the equations of Shannon (1948) were significantly different between sampling locations; the diversity of the periphytic algae on glass slides at the Intake area was significantly greater than the diversities at the Dam and at the Discharge area (Table 5.12).

Table 5.12

Mean diversities ($\bar{x}$) for periphyton collected from glass slides after quarterly 28-day exposure periods at four stations in Coffeen Lake from August 1978 through February 1981. Means underscored with the same line are not significantly different.

	Stations			
	Intake	1	Dam	Discharge
$\bar{x}$	3.20	3.01	2.61	2.42

The gradual density increases noted for major divisions of algae as one progressed around the cooling loop toward the intake were not apparent for diversity values. The mean diversities increased from the discharge area (2.42) to the dam area (2.61) to Station 1 (3.01) to the Intake area (3.20). It is likely that the factors responsible for the reduced growth at the Discharge area also were responsible for the reduced diversity of algae at that location.

In summary, there were several differences in periphyton composition and abundance between stations in Coffeen Lake that may have been related to power plant operation. Periphyton accumulations on glass slides were significantly lower in the discharge area than in the intake area. Since waste heat and current were ruled out as the sole causes of the lower periphyton growth rates, growth inhibiting or limiting factors present in the discharge area seem likely as a cause for the observed lower growth. Diversity of periphyton was also significantly lower in the discharge area than in the intake area presumably due to the same factors which caused the lower periphytic algal growth in the discharge area.

LITERATURE CITED

American Public Health Association, American Water Works Association, and Water Pollution Control Federation. 1976. Standard methods for the examination of water and wastewater, 14th ed. American Public Health Association, Washington, D.C. 1193 pp.

Barr, A. J., J. H. Goodnight, J. P. Sall, and J. T. Helwig. 1976. A user's guide to SAS 76, SAS Institute, Inc., Raleigh, NC. 329 pp.

Brigham, A. 1977. Water quality investigations at Lake Sangchris, Section I. In R. W. Larimore and J. A. Tranquilli (eds.) Annual report for fiscal year 1976, Lake Sangchris project. Illinois Natural History Survey (unpublished).

Clement, K., J. Kasprowicz, and S. O. Swadener. 1979. Annual summary of water quality and biological investigations in Lake Shelbyville basin. Annual report to U.S. Army Corps of Engineers, St. Louis, MO. Illinois Natural History Survey (unpublished).

Coutant, L. W. 1978. Periphyton of the Kankakee River. In R. W. Larimore and M. J. Sule (eds.) Construction and preoperational aquatic monitoring program for the Kankakee River. First annual report by Illinois Natural History Survey to Commonwealth Edison Company, Chicago, IL.

_____. 1979a. Algal dynamics of Lake Sangchris and Lake Shelbyville. In Evaluation of a cooling lake fishery, Vol. IV. Ill. Nat. Hist. Survey final report to Electric Power Research Institute, Palo Alto, CA.

_____. 1979b. Periphyton of the Kankakee River. In R. W. Larimore and M. J. Sule (eds.) Construction and preoperational aquatic monitoring program for the Kankakee River. Second annual report by Illinois Natural History Survey to Commonwealth Edison Company, Chicago, IL.

_____. 1980a. Algal investigations of Coffeen Lake. In J.A. Tranquilli and R.W. Larimore (eds.) Environmental Studies of Coffeen Lake, Section 5. Second annual report from Illinois Natural History Survey to Central Illinois Public Service Company (unpublished)

_____. 1980b. Periphyton on artificial substrates in the Kankakee River and Horse Creek. In R. W. Larimore and M. J. Sule (eds.) Construction and preoperational aquatic monitoring program for the Kankakee River. Third annual report by Illinois Natural History Survey to Commonwealth Edison Company, Chicago, IL (unpublished).

Dufford, D. W., L. W. Coutant, S. O. Swadener, and S. W. Waite. 1977. Water quality and biological investigations in the Lake Shelbyville basin. Annual report to U.S. Army Corps of Engineers, St. Louis, MO. Illinois Natural History Survey (unpublished).

_____, S. W. Waite, S. O. Swadener, and L. W. Coutant. 1978. Water quality and biological investigations in the Lake Shelbyville basin. Annual report to U.S. Army Corps of Engineers, St. Louis, MO. Illinois Natural History Survey (unpublished).

Gurtz, M. E., and C. M. Weiss. 1974. Effect of thermal stress on phytoplankton productivity in condenser cooling water. In J. W. Gibbons and R. R. Sharitz, eds. Thermal Ecology. ERDA Symposium Series (CONF-730505), Augusta, GA.

Hustedt, F. 1930. Bacillariophyta (Diatomaceae). In Pascher (ed.). Die Susswasser Flora Mitteleuropas, Heft 10. Gustav Fischer, Jena. 466 pp.

Miller, M. C., G. H. Hater, T. W. Federic, and J. P. Reed. 1976. Effects of power plant operation of the biota of a thermal discharge canal. In G. W. Esch and R. W. McFarlane, eds. Thermal Ecology II. ERDA Symposium Series (CONF-750425), Augusta, GA.

Moran, R. (in press). Phytoplankton dynamics in a cooling-water reservoir. In R. W. Larimore and J. A. Tranquilli eds. Lake Sangchris Study: Case history of an Illinois cooling lake. Ill. Nat. Hist. Surv. Bull. 32(4). pp. 320-341.

Morgan, R. P., II, and R. G. Stross. 1969. Destruction of phytoplankton in the cooling water supply of a steam-electric station. Chesapeake Sci. 10(3,4): 165-171.

Patrick, R., and C. Reimer. 1966. The diatoms of the United States, vol. I. Acad. Nat. Sci., Philadelphia. 213 pp.

_____, and _____. 1975. The diatoms of the United States, vol. II, part I. Acad. Nat. Sci., Philadelphia. 213 pp.

Prescott, G. 1962. Algae of the western Great Lakes area, 2nd ed. W. C. Brown, Dubuque. 977 pp.

Shannon, C.E. 1948. A mathematical theory of communication. Bell System Tech. Jour. 27:379-423, 623-656. 5.83

Smith, G.M. 1950. The fresh-water algae of the United States, 2nd ed. W.C. Brown, Dubuque. 977 pp.

Tiffany, L. and M. Britton. 1971. The algae of Illinois, 2nd ed. McGraw-Hill Book Co., New York. 719 pp.

U.S. Environmental Protection Agency. 1975a. Report on Coffeen Lake Montgomery County Illinois EPA Region V. U.S. Environmental Protection Agency Working Paper No. 300. Corvallis Environ. Res. Lab., Corvallis. 13 pp.

U.S. Environmental Protection Agency. 1975b. Report on Sangchris Lake Christian County Illinois EPA Region V. U.S. Environmental Protection Agency Working Paper No. 314. Corvallis Environ. Res. Lab., U.S. Environmental Protection Agency. 1975c. Report on Shelbyville Reservoir Moultrie and Shelby Counties Illinois EPA Region V. U.S. Environmental Protection Agency Working Paper No. 315. Corvallis Environ. Res. Lab., Corvallis. 17 pp.

Van der Werff, A. 1953. A new method of concentrating and cleaning diatoms and other organisms. Verh. Int. Ver. Limnol. 12:276.

Warriner, J. E., and M. L. Brehmer. 1966. The effects of thermal effluents on marine organisms. Int. J. Air Water Pollut. 10:277-289.

Wetzel, R.G. 1975. Limnology. W.B. Saunders Co., Philadelphia. 743 pp.

Williams, L. G. 1964. Possible relationships between plankton-diatom species numbers and water quality estimates. Ecology 45(4):809-823.

SECTION 6

ZOOPLANKTON OF COFFEEN LAKE

by

Stephen W. Waite

ABSTRACT

An investigation of zooplankton dynamics at Coffeen Lake was conducted from July 1978 to November 1980 as part of an interdisciplinary effort to document changes in water quality in the cooling lake and receiving stream. General information was obtained regarding dynamics of zooplankton communities and individual species and of trends in standing crop biomass. The overall structure of zooplankton communities in Coffeen Lake closely resembled those reported for both Lake Sangchris, a cooling lake, and Lake Shelbyville. That the number or richness of species was lower within the cooling loop compared to cooler waters at Stations 3 and 4 may be the consequence of power plant perturbations, including heat, entrainment and increased water velocities. However, morphological characteristics of the lake basin at Station 4 (e.g, the railroad causeway) probably promoted littoral communities that contained taxa not found elsewhere in the lake. There was little evidence that the thermal gradient restricts or enhances the distribution of taxa to any certain region of the lake. Lake morphology and year variations probably were the principal factors governing spatial distribution of species. Stations with high water temperatures during the warmest months sustained unexpectedly high diversities of species, but probably a majority of those forms resided below the thermal plume. Rotifers were less tolerant of high temperatures near the discharge than were cladocerans and copepods. The organic fraction of plankton mass increased with distance from the discharge and reflected the settling characterstics of fly ash-slag particulates. The zooplankton of Coffeen Lake were found to be productive and viable despite atypical temperature regimes, entrainment mortality, and unusual water chemistry. Short-term projects investigated possible reasons for the paucity and infrequent occurrence of *Leptodora kindtii* and *Bosmina* in Coffeen Lake and assessed the usefulness of two methods for determining zooplankton entrainment.

INTRODUCTION

Animal constituents of the limnoplankton that inhabit electrical power plant cooling lakes are subject to a wide variety of unnatural conditions. Frequent concerns of environmental studies of these systems have centered on: (1) problems resulting from additions of chlorine and other biocides to prevent fouling; (2) effects of internal mechanical forces within the plant, such as turbulence, pressure and vacuum; and, (3) excess heat contained in discharge cooling waters. These and other concerns, including ash-pond effluents, coal-pile runoff, and brine wastes, have led to a recent environmental study at Coffeen Lake. This study was charged with documenting a change in water quality concommitant with improvements in water treatment procedures. The overall purpose of the Coffeen Lake study was to determine whether Coffeen Lake supports aquatic life consistent with contemporary lake management practices and to assess the degree of recovery resulting from the commencement of new waste-water treatment facilities.

The scope of the first-year zooplankton work was oriented toward assessing the status of zooplankton communities in light of the improvement in the lake's water quality. Specifically, information was obtained regarding numbers, composition and distribution of species; species diversity; absolute and relative abundance of major groups; and standing crop biomass. Although these categories were continued through Year 2 for comparative purposes, additional efforts were directed toward several more specific ecological and methodological questions which were developed as subprojects for this report.

METHODS AND MATERIALS

From July 1978 through June 1980, Coffeen Lake zooplankton communities were sampled monthly from six permanent locations (Fig. 1.2), four of which were intermutual with other project subgroups, i.e., fish, benthos, algae. Two sampling stations were established within close proximity of the plant; one was located adjacent to the intake screens and the other immediately downstream of the discharge canal. Occasionally, samples were procured from a 6-m stratum at the intake station (Station X).

All monthly zooplankton collections in Coffeen Lake consisted of triplicate samples of the water column from lake bottom to surface at each station. Samples were collected with a submersible filter-pump apparatus (Waite and O'Grady 1980) that filtered 88 liters of lake water per minute. It was lowered and raised such that all water strata were sampled equally. The total volume filtered per sample was a function of time allotted for pumping; in Coffeen Lake, a pumping duration of 2 minutes was adequate and thus the total volume filtered at each sampling location was approximately 0.5 m^3. An ethanol-formalin solution was used in the field to kill and preserve the organisms immediately after collection.

Analytical procedures began by diluting the concentrated field samples to 100-200 ml, depending on organism density and amounts of debris and slag particles. Following sample homogenation, three 1-ml subsamples were withdrawn and placed in gridded Sedgewick-Rafter cells for identification and counts. Identification keys and other published literature used in these analyses included: Ahlstrom (1940, 1943), Brooks (1957, 1959), Chengalath (1977), Edmondson (1959), Goulden (1968), Grothe and Grothe (1977), Pennak (1978), Smirnov (1974), Wilson (1959), Wilson and Yeatman (1959), and Yeatman (1959).

Filtering, drying, and ashing procedures described by APHA et al. (1976) were used to compute standing stocks of zooplankton biomass. The residues were reported in milligrams (mg) dry and ash-free weight per cubic meter (m^3) of lake water.

Methods particular to the ancillary studies will be briefly described within those subsections of this report.

RESULTS AND DISCUSSION

COMPOSITION, DISTRIBUTION AND DIVERSITY OF SPECIES

Species Composition

The monthly structure of zooplankton communities in Coffeen Lake during this 2-year study closely resembled those of both Lake Sangchris, a cooling lake, and

Lake Shelbyville, a flood control reservoir (both lakes are within 80 km of Coffeen Lake), in 1976 (Waite 1979a) (Table 6.1). The predominant taxa in Coffeen Lake included 32 rotifers, 25 cladocerans, and 11 copepods. Although the totals varied slightly from Year 1 to Year 2, they were well within the expected range of year-to-year variability. In comparison to Year 1, Year 2 had fewer total species at each station for all but five monthly collections (Table 6.2). Except for September of Year 2, the overall lake means for each month were greater in Year 1. Furthermore, there was a significant difference in the overall lake means of the two consecutive 1-year periods (Student's t-test, 0.01 level).

Lakewide comparisons of the number of zooplankton taxa in Coffeen Lake showed that in virtually all collecting periods in Year 1, the numbers present at all stations in the cooling loop (discharge, Stations 1 and 2, and intake) were remarkably similar (Table 6.2). While there were few trends showing gradual increases or declines in species numbers in the direction of cooling water flow, the mean numbers of species at the cooling loop stations, collectively, were virtually always less than the mean number of species at Stations 3 and 4 for any particular month. During Year 2 the fewest number of taxa for all stations occurred in November and, with few exceptions, the greatest number of taxa each month was at Station 4, which was similar to the pattern reported for Year 1. Contrary to observations in Year 1, however, the species' numbers were highly variable throughout the cooling loop in Year 2. The lower overall number of species in the cooling loop (discharge, Stations 1 and 2, and intake) compared to those at Stations 3 and 4 may be the consequence of of heat, entrainment-related mortality, and water velocity, all of which are synergistic conditions associated primarily with the former. On the other hand, the relatively shallow waters north of the railroad causeway (Station 4 and vicinity) appeared to promote the development of littoral taxa, many of which were not observed in the cooling loop. These observations were not unexpected due to the unusual morphology of the lake basin.

Of the rotiferan taxa reported for Years 1 and 2, more than 50% belonged to the loricate family Brachionidae. Dominant constituents from other families included the genera Synchaeta, Polyarthra, and Asplanchna. An unusually large

Table 6.1. Summary of numbers of zooplankton taxa collected in Coffeen Lake in 1978-1979 and 1979-1980, Lake Sangchris in 1976, and Lake Shelbyville in 1976. Data from the latter two lakes was derived from Waite (1979a).

Taxa	Number/lake Coffeen Lake Year 1	 Year 2	 Lake Sangchris	 Lake Shelbyville
Rotifera	27	28	27	30
Cladocera	22	20	29	20
Copepoda	11	9	9	12
Total	60	57	65	62

Table 6.2. Monthly record of the total numbers of zooplankton taxa identified from Coffeen Lake, July 1978 through June 1980.

Station	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual Mean
YEAR 1 - 1978-1979													
Mean - Cooling Loop[1]	19	17	11	12	12	10	12	11	14	17	19	16	15
Mean - Stations 3 and 4	19	22	14	14	12	12	16	15	19	23	18	19	17
Overall Lake Mean for Year 1	19	18	12	13	12	11	13	12	15	19	19	17	15
YEAR 2 - 1979-1980													
Mean - Cooling Loop[1]	15	13	12	7	5	7	7	7	11	13	16	13	11
Mean - Stations 3 and 4	16	11	14	11	7	8	11	11	12	20	19	14	13
Overall Lake Mean	16	12	13	9	5	8	8	8	11	16	17	13	11

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[1] Includes intake, discharge, and Stations 1 and 2

fraction of the Year 2 rotifer fauna consisted of unknown types, primarily unidentifiable males and immature life history stages.

The cladoceran fauna of Lake Coffeen in Year 2 was represented by 20 species and six families. However, most of these taxa, particularly the chydorids, occurred infrequently. *Daphnia parvula*, *Diaphanosoma leuchtenbergianum*, *Ceriodaphnia quadrangula*, and *Chydorus sphaericus* were the dominant forms in both study years. The paucity of *Leptodora* during Years 1 and 2 of this study, also noted in the Lake Sangchris study, suggested that certain conditions (biological and/or physicochemical) associated with cooling lakes may have prevented the occurrence of this otherwise common taxon.

The dominant copepods of Coffeen Lake in both Years 1 and 2 included the calanoid, *Diaptomus siciloides*, and to a lesser extent two cyclopoids, *Mesocyclops edax* and *Cyclops vernalis*. *C. bicuspidatus thomasi*, a coldwater species, is a typical winter form in several Illinois reservoirs (including Lake Sangchris) but was rarely collected in Coffeen Lake. Parasitic cyclopoids on fish, such as *Ergasilus*, have not been collected in their free-living planktonic form. The third order of copepods, Harpacticoida, typically inhabit the substrate, and consequently only several individuals were collected in the plankton.

Previous analyses of zooplankton populations in Lake Sangchris (1975-1978) revealed an annual "damping" of the number of species present in the cooling loop (Waite 1979a). In general, the numbers of species in temperate lakes exhibit cyclic pulses, unless natural succession and periodicity are modified by synergistic effects of various biological and physicochemical parameters. The annual fluctuations of species numbers in the cooling loop at Coffeen Lake more nearly resembled the typical situation which was exhibited by populations in unheated Lake Shelbyville: a pulse in spring and/or summer followed by a gradual decrease to a late-winter low. In light of the Lake Sangchris data, this was an unlikely result because the thermal load (in megawatts per acre) at Coffeen Lake was much greater than that of Lake Sangchris. If the damping effect on zooplankton species is indeed a function of waste heat loads as implied for Sangchris data, then a similar damping should have been observed for zooplankton populations in Coffeen Lake. Unless the latter is a very unusual system, it is postulated that other conditions, in addition to or combined with heat loads, are important in regulating zooplankton biology in cooling lakes.

Temporal Distribution of Species

Rotifera. One rotifer, *Polyarthra vulgaris*, occurred in nearly all collections during both study years. This species and *Synchaeta stylata* were the dominant annual forms in Year 2. Although the brachionids were well represented, the occurrence of individual species was clearly season-related. In both years, *Brachionus angularis* inhabited all lake areas from May through October while *B. caudatus* and *B. patulus* occurred for a shortened duration in late summer. Having a preference for cooler water, *B. urceolaris* was common from February through April in both years while *Epiphanes* sp. was collected at all stations primarily in January of Year 2. July, September, February, and May samples contained the soft-bodied *Asplanchna* in Year 2, but in Year 1 this species occurred continually from March to October.

Cladocera. A typical constituent of the summer fauna of most lakes in this region, *Diaphanosoma leuchtenbergianum* occurred from May through December at most sampling stations in Coffeen Lake during both study years. That taxon, in addition to *Daphnia parvula*, *Ceriodaphnia quadrangula*, and *Chydorus sphaericus* were the four most persistent cladocerans in the lake during the study. *Bosminia longirostris* was limited in both years to the mid- to late-spring period (see ancillary study on *Bosmina*). Three taxa, *Diaphanosoma brachyurum*, *Leydigia quadrangularis*, and *Camptocercus rectirostris*, were observed only in winter.

Copepoda. Other than nauplii and copepodids, the calanoid copepod *Diaptomus siciloides* was not only the most common copepod but was also the most persistent zooplankter; it occurred in every sample. Of the cyclopoid fauna, *Cyclops vernalis* occurred in at least one station throughout the study period. *Mesocyclops edax* was also a dominant cyclopoid species. All remaining taxa were sporadic in occurrence and the harpacticoids were prevalent only from mid-summer to late fall.

Spatial Distribution of Species

Spatial distribution was studied to determine if any taxa were consistently limited to or excluded from any particular region(s) of the lake. Relatively few taxa were restricted to one station or even one general region. *Sida crystallina*, a littoral cladoceran, was found only in the December collection at the discharge station in Year 1; it was probably swept through the plant from the intake where it was present in extraordinarily high densities on artificial substrate samplers in November of Year 1 (Buckler 1979). In Year 2 it was collected in December at Station 4 and in some cooling loop stations in May and June 1980. The brachionid rotifers, *Colurella* sp. and *Brachionus variabilis* were collected only at Stations 1 and 3, respectively, in Year 1; neither were collected in Year 2. In Year 1 no species were found exclusively at Station 2 or the intake canal. In Year 2 two cladocerans, *Moina micrura* and *Leydigia quadrangularis*, were collected only at Station 2, and two rotifers, *Euclanis* and *Trichotria* were collected in the intake regions exclusively. Station 4, which was not a direct part of the cooling loop, favored the exclusive development of several littoral species, including three copepod species, *Leydigia acanthocercoides*, *Brachionus rubens*, and *Daphnia schodleri*. Species occurring only at Stations 3 and 4 combined were *Alona costata*, *Notholca* sp. and *Camptocercus rectirostris*. *Daphnia longiremis* was the only taxon limited to the first half of the cooling loop (discharge, stations 1 and 2) during Year 1; it did not occur in Year 2. Taxa collected only from cooling loop stations included *Brachionus bidentata* (stations 1 and 2), *Mytilina* sp. (discharge, Station 2), *Monostyla bulla* (intake, discharge, Station 2), *Alona costata* and *A. guttata* (stations 1 and 2). The occurrence of the cyclopoid *Cyclops vernalis* was restricted to the intake and stations 3 and 4.

There appears to be little conclusive evidence that the thermal gradient consistently restricts or enhances the production of specific taxa within any certain region of the lake. Rather, it is more likely that lake morphological features (deep, pelagic versus shallow, littoral regions) and natural year-to-year variations in population occurrence are the principal factors governing spatial distribution of species.