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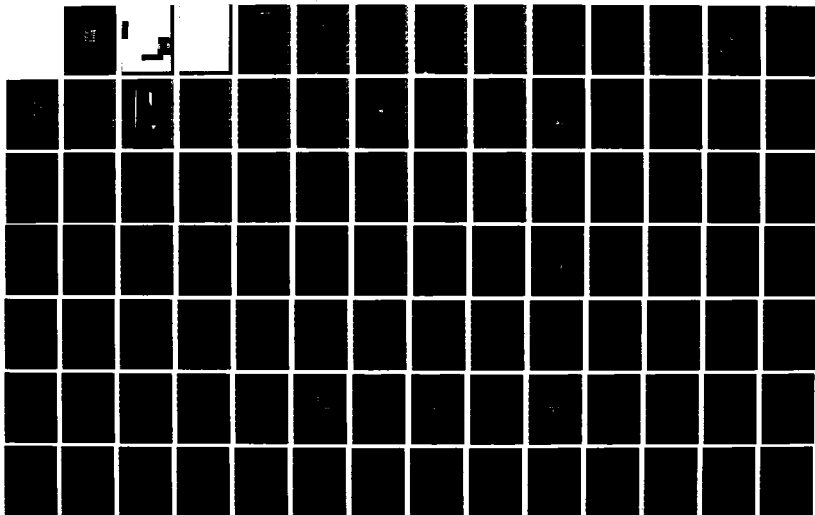| 4. TITLE (and Subtitle)	5. TYPE OF REPORT & PERIOD COVERED
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Loading	Water quality

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Eau Galle Lake, one of four Corps of Engineers reservoirs surveyed during the Environmental and Water Quality Operational Studies, is a small, dimictic, flood control reservoir located in west-central Wisconsin. Major land uses in this small glaciated watershed include dairy farming, residential habitation, and agriculture. Limnological conditions (i.e., oxygen depletion, algal blooms, reduced transparency, and macrophyte infestations), which are

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20. ABSTRACT (Continued).

characteristic of other eutrophic lakes in the area, are strongly influenced
by tributary material loadings and project operation.

This report documents investigative methodologies and results of gen-
eral studies designed to define general water quality conditions in Eau Galle
Lake and its tributaries. A subsequent report deals with the results of
other, more specific water quality studies.   *Originator - supplied*

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PREFACE

The work described in this report is part of the Environmental and Water Quality Operational Studies (EWQOS) Work Unit VIIA, Reservoir Field Studies, conducted by the US Army Engineer Waterways Experiment Station (WES) for the Office, Chief of Engineers (OCE), US Army. The OCE Technical Monitors were Dr. John Bushman, Mr. Earl Eiker, and Mr. James L. Gottesman.

The study was completed by the Aquatic Processes and Effects Group (APEG), Environmental Research and Simulation Division (ERSD), Environmental Laboratory (EL), WES. The report was prepared by Dr. Robert H. Kennedy, Mr. Joseph H. Carroll, Mr. Steven L. Ashby, Mr. David Johnson, Mr. Gerald Lauer, and Mr. William F. James, APEG. Dr. Robert H. Kennedy was editor. Dr. Gerald J. Filbin, Mr. Robert C. Gunkel, Ms. Freddie J. Thompson, and Dr. Robert F. Gaugush, APEG, contributed to the conduct of this study. The report was prepared under the supervision of Dr. Thomas Hart, Chief, APEG; Mr. Donald L. Robey, Chief, ERSD; and Dr. John Harrison, Chief, EL. Dr. Jerome L. Mahloch was Program Manager of EWQOS.

Commander and Director of WES during the study and preparation of this report was COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

This report should be cited as follows:

Kennedy, R. H., ed. 1985. "Limnological Studies at Eau Galle Lake, Wisconsin; Report 1: Introduction and Water Quality Monitoring Studies," Technical Report E-85-2, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

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CONTENTS

LIMNOLOGICAL STUDIES AT EAU GALLE LAKE, WISCONSIN

INTRODUCTION AND WATER QUALITY MONITORING STUDIES

PART I: INTRODUCTION*

Background

1. The influx of nutrients, organic material, and sediment to
lakes and reservoirs has led to a progressive deterioration of these
valuable water resources. Increased nutrient levels promote increased
algal production, resulting in reduced water transparency, taste and
odor problems, diminished aesthetic value, and reduced oxygen concentra-
tions in bottom waters. These problems are further aggravated by exces-
sive inputs of sediments and oxygen-demanding organic material. While
increased public awareness of these problems has prompted the establish-
ment of new research programs and the passage of water resource legisla-
tion, the need for improved management strategies for maintaining or en-
hancing the quality of these resources still exists.

2. The US Army Corps of Engineers (CE) presently maintains and
operates over 400 reservoir projects for the purposes of flood control,
hydropower, navigation, water supply, and recreation. In an effort to
better define reservoir water quality problems and to develop techno-
logical and managerial alternatives for ameliorating these problems in a
manner consistent with project purposes, the CE initiated the Environ-
mental and Water Quality Operational Studies (EWQOS) Program (Keeley
et al. 1978). A major portion of this program consisted of limnological
studies at four characteristic CE reservoirs. These included Lake Red-
rock, a flood control impoundment of the Des Moines River in central
Iowa; DeGray Lake, a large hydropower project located in a forested
watershed in south-central Arkansas; West Point Lake, a large hydropower
project created by impoundment of the Chattahoochee River approximately

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* Part I was written by Robert H. Kennedy and Joseph H. Carroll.

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100 km downstream from Atlanta, Georgia; and Eau Galle Lake, a small, eutrophic flood control reservoir in west-central Wisconsin.

3. Studies conducted at each of these sites since 1978 have been of two basic types: long-term monitoring studies and short-term, process-oriented studies. Long-term monitoring studies provided data needed for the calibration and evaluation of several ecological models as well as information concerning general water quality characteristics and trends. Short-term studies, often conducted during specific seasons of the year or under a predetermined set of hydrometeorologic conditions, were aimed at defining processes impacting reservoir water quality. These types of studies provided a means for improving existing water quality models and have greatly increased the understanding of reservoir ecosystem processes.

4. Since Eau Galle Lake was the smallest site investigated under the EWQOS Program and therefore posed the least logistical and sampling problems, many of the intensive, process-oriented studies were conducted here. In order to accomplish this, a field analytical laboratory was established at the site, as well as facilities and equipment for obtaining meteorologic and hydrologic data. The laboratory facility, which consisted of a completely equipped analytical laboratory and associated office and storage facilities, provided necessary capabilities for a wide variety of water quality analyses. Since laboratory and field personnel were located at the site, a wide range of field activities were possible.

Scope

5. Reported here and in a subsequent volume (Kennedy 1984) are the results of all major research efforts conducted at Eau Galle Lake during the period 1981-1982. Several objectives were addressed during this period, including establishment of a water quality database for model calibration and evaluation; evaluation of nutrient and metal dynamics; delineation of relations between material (dissolved and suspended) inputs, sedimentation, and losses by discharge; identification of factors

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affecting primary and secondary productivity; and an evaluation of
physical factors influencing lake dynamics. While having direct implica-
tions for future management activities at Eau Galle Lake, information
gained as a result of these studies also broadens the general under-
standing of water quality processes in reservoir ecosystems.

6. This report provides detailed documentation of research ap-
proaches, methodologies, and results. Since many sampling and analytical
methodologies were common to several of the studies, these are presented
together. Research approaches and methodologies unique to a particular
study are discussed separately.

References

Keeley, J. W., Mahloch, J. L., Barko, J. W., Gunnison D., and Westhoff,
J. D. 1978. "Identification and Assessment of Environmental Quality
Problems and Research Development," Technical Report E-78-1, US Army
Engineer Waterways Experiment Station, Vicksburg, Miss.

Kennedy, R. H., ed. 1984. "Limnological Studies at Eau Galle Lake,
Wisconsin; Report 2: Special Studies and Summary," Technical Report in
preparation, US Army Engineer Waterways Experiment Station, Vicksburg,
Miss.

Introduction

7. The Eau Galle Dam is located on the Eau Galle River immediately upstream from the town of Spring Valley in west central Wisconsin, approximately 80 km east of St. Paul, Minnesota (Figure 1). Although the dam is located in Pierce County, the reservoir and its watershed are located in St. Croix County. The primary purpose of the reservoir is to provide flood control protection for the village of Spring Valley and associated downstream areas. Other beneficial uses of the reservoir include recreation and fish and wildlife habitat. Recreational facilities include a campground, two picnic areas, two boat ramps, a swimming beach and numerous hiking trails.

History

8. Two major floods occurred on the Eau Galle River at Spring Valley in 1938 and 1942, prompting authorization of the reservoir under the Flood Control Act of 1958 (Public Law 85-500). Construction began 9 July 1965, and the dam was completed on 11 September 1968. On 23 September 1968 the reservoir was filled to 1.15 m above conservation pool by storm runoff. The pool was subsequently drained to permit final closure of the diversion structure and allow for completion of the embarkment and final cleanup. Final filling occurred in April 1969. The dam has been in operation since that time except for short periods of drawdown (to 285.3 m mean sea level (msl)) to allow minor repair work to be performed on the outlet structure.

9. Prior to construction, Lousy and Lohn Creeks were confluent with the Eau Galle River within or immediately downstream from the reservoir site. Several diversions of the Eau Galle River and Lousy and Lohn Creeks were required during the course of the construction of the dam

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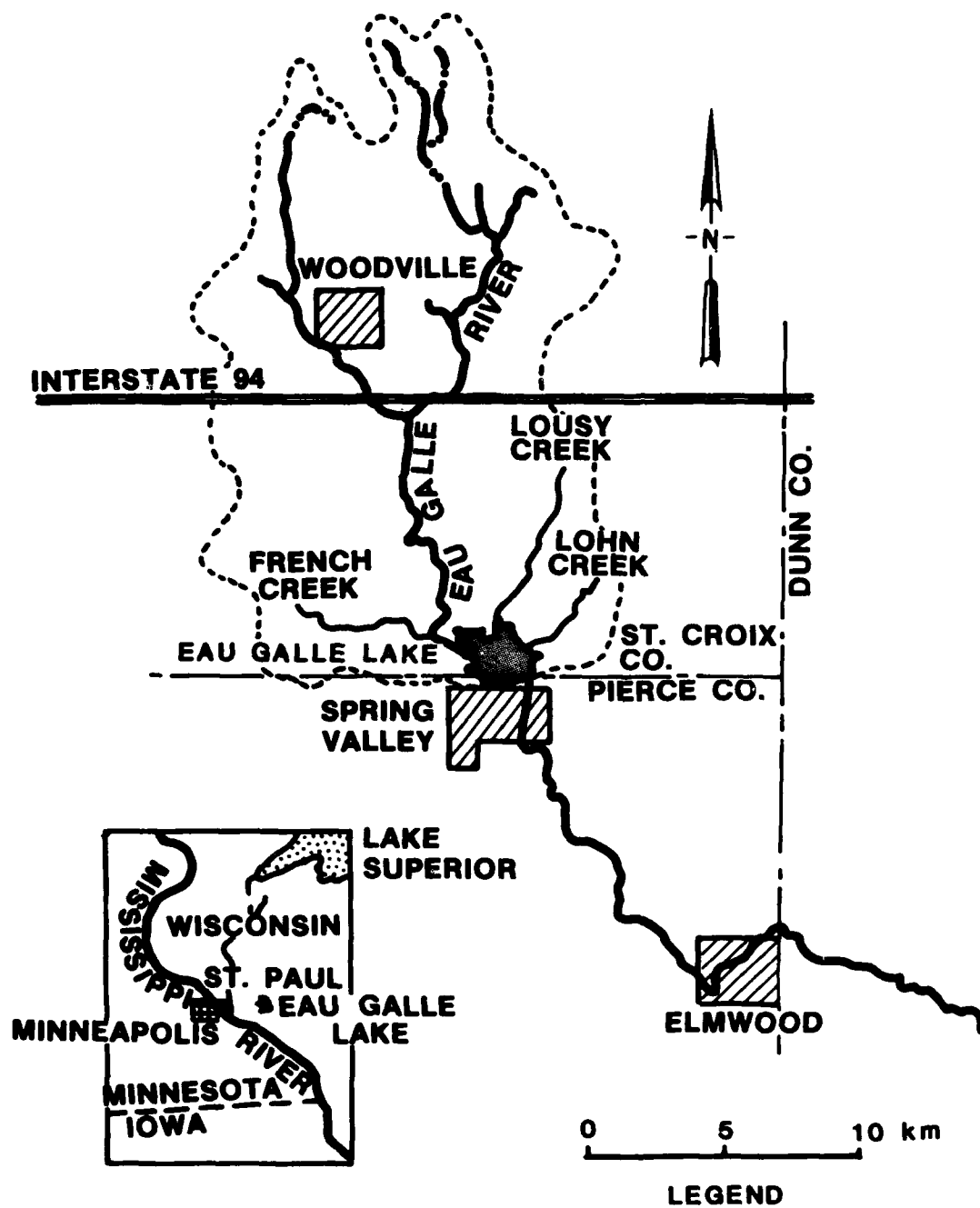* Part II was written by Steven L. Ashby.

VICINITY MAP

Figure 1. Major features of the Eau Galle Lake watershed

and outlet works (Figure 2). Initial diversions allowed for foundation excavation and construction of the outlet structure. These entailed diversion of the Eau Galle River to the west of the original channel and a rejoining downstream of the future outlet structure site and diversion of Lousy and Lohn Creeks southward to the Eau Galle River diversion. A second diversion of the Eau Galle River to the west allowed for clearing and excavation of borrow material within the proposed pool area. The final diversion consisted of rerouting the Eau Galle River eastward along the south edge of the borrow area to the approach channel and outlet structure. These excavations are reflected in the present bottom topography of the lake.

Description

10. The reservoir, which is roughly circular in shape with a surface area of approximately 0.6 km^2 at conservation pool elevation (286.5 m msl), has a mean and maximum depth of 3.2 and 9.0 m, respectively. The area/volume curve for the reservoir and other physical characteristics are presented in Figure 3 and Table 1, respectively.

11. The Eau Galle River enters the reservoir from the northwest and follows the western edge approximately halfway into the reservoir, where diversion activities resulted in a change of the river channel to the extent that it becomes undefined at this point. Other major inflows to the reservoir include Lousy Creek, which enters from the northeast, and Lohn Creek, which enters from the east. Other morphometric characteristics include coves to the north and southwest.

12. The dam is a rolled-earth and rock-filled structure 487.7 m long, 6.1 m wide at the top, with a maximum height above the streambed of 37.2 m. The elevation at the top of the dam is 316.5 m msl. Slopes of 1 on 2.5 are found for both the upstream and downstream sides of the dam. There is a 1.5-m freeboard above the spillway design-flood level.

13. The outlet structure (Figure 4) provides for both surface and near-bottom releases. At pool elevations above 286.5 m msl, surface releases occur via an uncontrolled morning glory inlet. Routine

water (i.e., American Public Health Association (APHA) 1980, US Environmental Protection Agency (EPA) 1974) whenever possible. All lab equipment, glassware, and sample handling gear also conformed to accepted guidelines. These laboratory procedures are described in general in the following paragraphs. Specific information concerning each analytical method is presented in Appendix A.

Equipment and equipment maintenance

34. Laboratory analyses employed the following analytical instruments: Hach Model 2100 A Turbidimeter (Hach Corporation, Ames, Iowa); Torbal-FAL analytical balance (Torsion Balance Company, Clifton, New Jersey); Precision Coliform Incubator Bath (GCA/Precision Scientific Group, Chicago, Illinois); Varion Techtron Model 635 Dual Beam U.V.-Visible Spectrophotometer (Varian Associates, Palo Alto, California); Oceanography International Model 524 Total Carbon Analyzer (Oceanography International Corporation, College Station, Texas); Technicon Autoanalyzer II (Technicon Instruments Corporation, Tarrytown, New York); and Perkin-Elmer Model 400 Atomic Absorption Spectrophotometer with flame and graphite furnaces (Perkin-Elmer Corporation, Norwalk, Connecticut). The equipment was maintained according to the manufacturers' instructions. The analytical balance was adjusted annually using a set of weights approved by the National Bureau of Standards. The Varian Spectrophotometer was checked quarterly with a set of standardized filters.

Lab water treatment

35. Well water, having an initial average hardness of 250 mg Ca/ℓ, was softened by sodium ion exchange to an average hardness of 5 mg Ca/ℓ. The water was then deionized, distilled or processed by reverse osmosis (RO) and, when necessary, further processed by a Nanopure ultrapurification system (Barstead Nanopure, Boston, Massachusetts). Feed-water for the still was deionized by a mixed-bed deionizer cartridge (Barnstead High Capacity) with a minimum resistance of 0.025 MΩ. Water was distilled in an all-glass, 3-ℓ/hr still (Corning "ACS," Glass Still, Corning Glass Company, Corning, New York) and stored in a 12-gal glass bottle. All connections between the still and the collection bottle were glass.

36. The RO unit was a 40-ℓ/hr Barnstead R.O. Pure (Barnstead,

Chemical and Physical Parameters Determined Routinely for All In-Reservoir Stations the Abbreviations Used in This Study

Parameter	Abbreviation	Parameter	Abbreviation
Column depth	--	Total iron	TFe
Secchi depth	--	Dissolved iron	DFe
Water temperature	Temp	Total manganese	TMn
Dissolved oxygen	DO	Dissolved manganese	DMn
Alkalinity	TAlk	Total potassium	TK
pH	pH	Dissolved potassium	DK
Conductivity	SpCond	Total calcium	TCa
Turbidity	Turb	Dissolved calcium	DCa
Total phosphorus	TP	Total magnesium	TMg
Total soluble phosphorus	TSP	Dissolved magnesium	DMg
Soluble reactive phosphorus	SRP	Dissolved silica	DSi
Total nitrogen	TN	Total solids	TS
Nitrate/nitrite nitrogen	NO_3/NO_2-N	Total filterable solids	TSS
Ammonium nitrogen	NH_4-N		
Total sulfides	TSul	Total organic carbon	TOC
Sulfate	SO_4	Total filterable organic carbon	DOC
Chlorophyll A	ChlA	Total carbon	TC
Chlorophyll B	ChlB	Fecal coliform	FColi
Chlorophyll C	ChlC	Total sodium	TNa
Phaeophytin A	Phaeo	Dissolved sodium	DNa

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PART IV: GENERAL METHODS*

Introduction

30. This section describes routine limnological field sampling methods, analytical methods, and equipment used in the conduct of studies at Eau Galle Lake. Also included is a discussion of the accuracy and precision of analytical methods. Accepted standardized procedures were followed whenever possible. Analytical procedures, with the exception of metal analyses, were completed at a laboratory facility located within 1 km of the reservoir. Samples for metal analyses were prepared as necessary onsite by filtration and acid preservation, then shipped to another laboratory for analysis.

31. Due to the small size of the study area and the location of the laboratory facilities, it was possible to complete sampling of all stations for all physicochemical parameters (Table 2) in one day. Primary productivity and light penetration measurements and sampling for phytoplankton, zooplankton, and integrated chlorophyll were conducted on the day preceding the collection of physicochemical samples.

32. Routine sampling was conducted at 2-week intervals throughout the study period. In situ measurements, including dissolved oxygen (DO), temperature, specific conductance, pH, and Secchi depth, were made weekly. Routine sampling was normally initiated at 0900 hr and completed by 1400 hr. A rigid time schedule for visiting each sampling station was followed on each sampling day in order to maintain continuity and ensure timely sample transportation to the lab. When possible, samples were preserved in the field and stored prior to analysis. All other samples arrived at the lab for processing within 2 hr of collection.

Laboratory Analytical Procedures

General lab protocol

33. This laboratory used accepted methods for the analysis of

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* Part IV was written by David Johnson and Gerald Lauer.

short fall and spring seasons. The movement of weather systems from west to east and southward from Canada can result in pronounced temperature changes and prolonged periods of wind activity. Thunderstorms occur on an average of 40 days a year, and the average annual precipitation is 75 cm. As much as 85 percent of this occurs as rain from May through September, with heaviest amounts in June. The remainder occurs as snow in the winter months. The average annual temperature is 6.7° C, with average temperatures of 22° C and -10° C occurring in July and January, respectively.

References

Borman, R. G. 1976. "Ground-water Resources and Geology of St. Croix County, Wisconsin," Information Circular No. 32, US Geological Survey.

Langton, J. 1978. "Soil Survey of St. Croix County, Wisconsin," Soil Conservation Service, US Department of Agriculture.

are found near the reservoir where the topography is steep and have high ground-water recharge rates. The depth of the ground-water table is greater than 3 m except around the reservoir and near the rivers, where numerous springs occur.

28. Ground water moves in the direction of decreasing head, approximately at right angles to elevation contours (Borman 1976). Ground-water movement within the watershed is generally in a westward direction as determined from the water table contours (Figure 6).
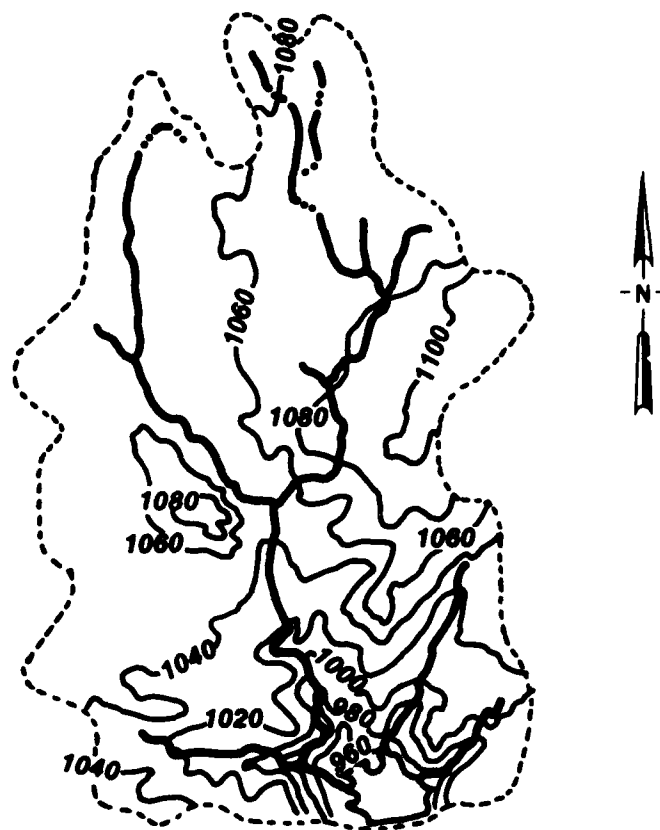

Figure 6. Average water table elevations
(ft msl) in the Eau Galle watershed
(based on Borman 1976)

Climatology

29. The Eau Galle River watershed has a continental climate with long, cold, and snowy winters, warm and occasionally humid summers, and

St. Peter Sandstone dominate the bedrock of the watershed. The Prairie du Chien Group is one of the major water-yielding rock formations in this sandstone aquifer. The bottom of the Prairie du Chien ranges from 340 m msl along the eastern county line to less than 180 m msl in the southwest corner of the county.

25. Water quality characteristics in these aquifers have been described by Borman (1976). The water is hard to very hard with a median hardness between 180 and 190 mg/ℓ. Calcium and magnesium compounds, which contribute to hardness in direct proportion to their concentrations, are present in the limestone and dolomite formations that are abundant in the aquifer. These are dissolved readily by ground water. Dissolved solids have a median concentration of 270 mg/ℓ with bicarbonate (HCO_3) as the major constituent (median concentration of 216 mg/ℓ). Other constituents include calcium (49 mg/ℓ), magnesium (19 mg/ℓ), silica (18 mg/ℓ), and sulfate (12 mg/ℓ). Sodium and potassium levels are 3.4 and 0.9 mg/ℓ, respectively.

26. Nitrate, the final oxidation product of nitrogen-containing matter such as fertilizers, animal wastes, and septic-tank effluents, has a median concentration of 12 mg/ℓ in the St. Peter and Prairie du Chien sandstone aquifer and 1.8 mg/ℓ in the Cambrian sandstone aquifer. Iron and manganese concentrations are relatively high (0.3 and 0.07 mg/ℓ, respectively) for all of the sandstone aquifers.

27. Interactions between precipitation, evapotranspiration, topography, and soil characteristics govern ground-water movement in the watershed. The soils in the watershed are fine- to medium-grained, moderate to low in permeability, and overlay sandstone containing bands of kaolinite clay and limestone and dolomite bedrock. Areas with thin layers of unconsolidated material are found near the reservoir where the topography is steep and numerous outcrops of bedrock occur. These conditions allow for rapid runoff of precipitation and slow recharge of the ground water. Between 30 and 300 mm of precipitation per year infiltrates and recharges the ground-water reservoir (Borman 1976). Numerous solution channels and cracks throughout the dolomite bedrock provide pathways for rapid movement of the available ground water. These areas

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21. Skyberg soils occur in drainageways and on slopes of till plains. Most areas having these soils are cultivated or used for pasture. Unless drained, the subsoil is saturated with water throughout most of the year. Water is ponded in many places during wet seasons. High water capacity, moderately slow permeability, moderate organic matter content, and high natural fertility are other characteristics of Skyberg soils. These soils have severe limitations for homesites, septic tank absorption fields, roads, and trench-type sanitary landfills.

22. The reach of the Eau Galle River east of Woodville flows through the Saltre-Pillot-Antigo association. Here the river valley is poorly defined and resembles a bowl-shaped depression. In contrast to other soil associations, these soils exhibit a moderate to very rapid permeability. These soils are found on stream terraces and outwash plains and have moderate water capacity and medium to high natural fertility. Moderate organic matter content of the surface layer is characteristic of soils in this association. Dairying and beef operations are major land uses on these soils. Main management concerns include controlling erosion and maintaining soil tilth and fertility. These soils have several limitations for trench-type sanitary landfills and sewage lagoons.

23. The soils around the reservoir are part of the Santiago-Otterholt-Arland association. These soils occur on sandstone and limestone uplands that are covered in most places by a thin mantle of glacial drift or a thick mantle of windblown silt loam. Water capacity is moderate to high, and natural fertility ranges from low to high. Permeability is moderate to slow.

Ground-Water Hydrology

24. Ground water, which provides all of the potable water used in the Eau Galle River watershed, is contained in sandstone aquifers that underlie the entire county. These include sandstones of Cambrian age, and the Prairie du Chien Group, the St. Peter Sandstone, and the Galena-Platteville units of Ordovician age. The Prairie du Chien Group and
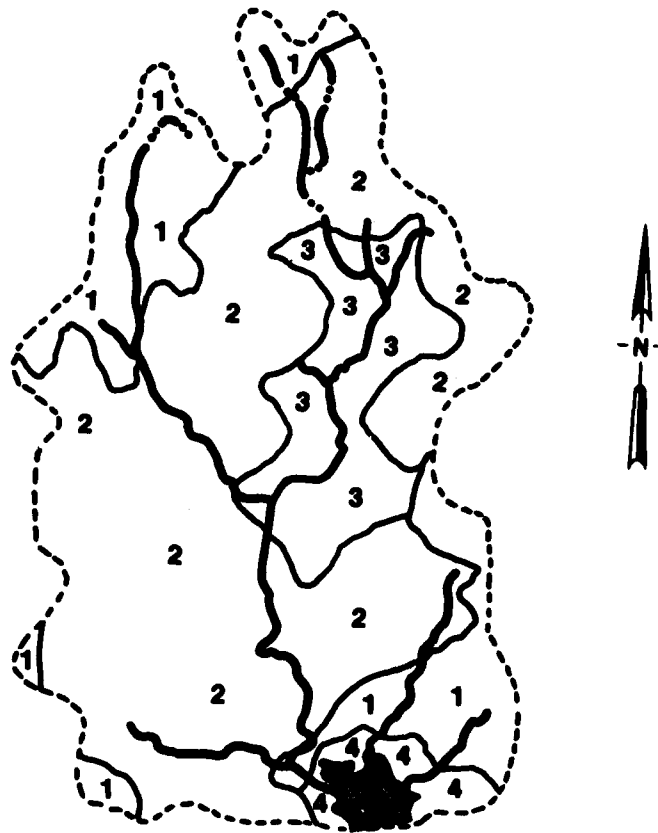
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Figure 5. Major soil associations in the Eau Galle
River watershed. Numbers indicate the various soil
associations; (1) Santiago-Jewett-Magnor;
(2) Vlasaty-Skyberg; (3) Saltre-Pillot-Antigo; and
(4) Santiago-Otterholt-Arland.

of the watershed. Most of these areas are cultivated. The available
water capacity is high and permeability is moderate. Surface layers of
these soils have a moderate organic matter content and a medium natural
fertility.

    20. Excluding the area immediately around the reservoir and an
area around the Eau Galle River near Woodville, the Vlasaty-Skyberg as-
sociation dominates the remainder of the watershed. Vlasaty soils are
found on low ridges of till plains. Most of these areas are cultivated;
however, tillage is often delayed for relatively long periods in spring
and after heavy rains due to low soil permeability. The surface layer
has a moderate organic matter content and high natural fertility.

mixed hardwoods and pines. Dominant hardwoods include oak, elm, and birch. Low areas along the river, particularly on the north side of the reservoir, are old fields where the vegetation is reverting to native grasses and shrubs.

Geomorphic Development and Topography

17. The main valley in which the Eau Galle River is located and the other deeply cut tributary valleys in the watershed are character- istic of the topography found in this naturally dissected plateau region. Glacial deposits give the upland areas a gentle rolling topography, while the lower reaches of the basin are less modified by glaciation. Sandstones and shales of Upper Cambrian Age are exposed or overlain by soils in lowland areas, but overlain in the uplands by the St. Peter sandstones and Prairie du Chien dolomites of Ordovician age. Upland sur- face relief also reflects the deposition of glacial till. The rather impervious nature of the glacial till and loess blanket, which reaches thicknesses of approximately 50 m, allows for rapid runoff of surface waters.

18. The reservoir is located within a deeply trenched glacial till plain of the Superior Upland Province. The river valley near the dam is approximately 549 m wide. During the glacial epoch, the valley was cut 12 to 15 m deeper than its present level. The dam was con- structed on Upper Cambrian and Lower Ordovician siltstones, sandstones, and dolomites, and the outlet conduit is founded on sandstone.

Soil Associations

19. Four major soil associations dominate the watershed of the Eau Galle River (Figure 5) (Langton 1978). The headwater region of the Eau Galle River contains soils of the Santiago-Jewett-Magnor association. These soils are also found along the eastern edge of the watershed, in- cluding the Lousy Creek watershed. The Santiago soils dominate this as- sociation in the eastern part of the county, including the above areas

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PART III: WATERSHED DESCRIPTION*

Introduction

14. Tributaries of the Eau Galle Reservoir drain a 166-km^2,
roughly rectangular watershed (17.7 km long and 9.7 km wide) in south-
eastern St. Croix County, Wisconsin. Tributaries include the Eau Galle
River and Lousy and Lohn Creeks (see Figure 1). The Eau Galle River,
which is the major inflow to the reservoir, drains approximately 131 km^2
(77 percent of the total drainage area). The river valley in the head-
water region is a poorly defined, bowl-shaped depression surrounded by
gently rolling hills. The river valley becomes more defined south of
Interstate 94 due to the higher hills surrounding the valley. Stream
slopes vary from 3.22 m/km near the source to 0.76 m/km immediately up-
stream from the reservoir.

15. French Creek, which enters the Eau Galle River from the west
just upstream from the reservoir, has an approximate drainage area of
11.4 km^2 (7.5 percent of the total drainage area). Incorporating the
drainage area of French Creek with that of the Eau Galle River, the
actual drainage area of the Eau Galle River is approximately 142.4 km^2
(84.5 percent of the total drainage area). Lousy Creek enters the reser-
voir from the northeast and drains an area of 16.6 km^2 (10.9 percent of
the total drainage area). Lohn Creek enters on the southeastern side of
the reservoir near the morning glory outlet structure and drains an area
of 7.0 km^2 (4.6 percent of the total drainage area).

Land Use

16. Major land uses include dairy operations and associated agri-
culture (corn, hay, and oats), pastureland, and woodlots; urban and res-
idential development is minimal. Agricultural uses are nearly equally
distributed between pastureland and feed crops. Woodlots consist of

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* Part III was written by Steven L. Ashby.

near-bottom releases occur by way of a 1.2-m-wide vertical slide gate with a bottom elevation of 279.3 m msl. Controlled operation of this gate accounts for releases during a majority of the year. During high-flow periods, however, releases from the morning glory inlet may exceed 75 percent of the total daily discharge.
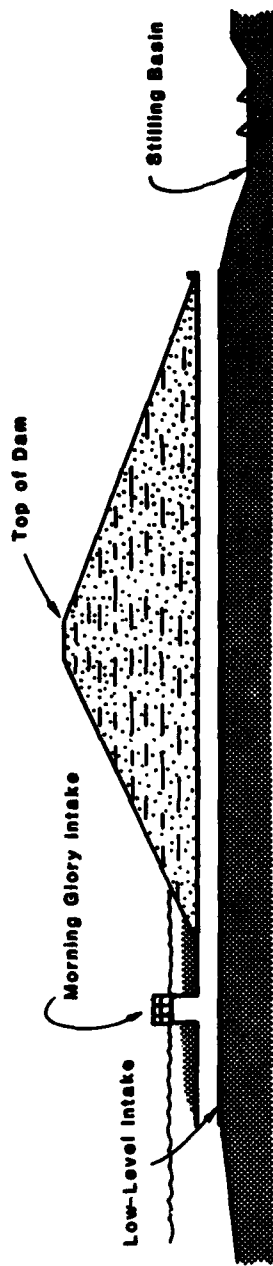
EAU GALLE DAM AND OUTLET WORKS
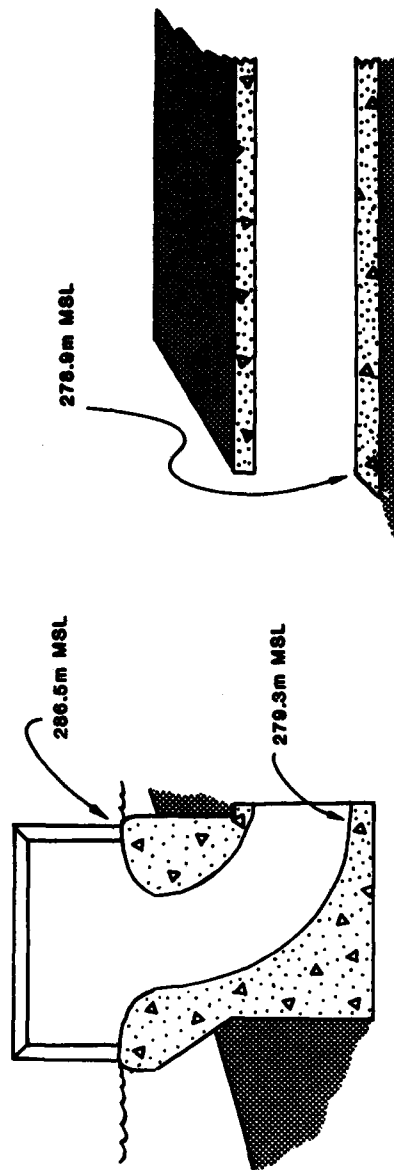
MORNING GLORY INTAKE STRUCTURE

LOW-LEVEL INTAKE STRUCTURE

Figure 4. Eau Galle Dam, showing (a) general features, (b) surface (morning glory) structure, and (c) low-level intake structure

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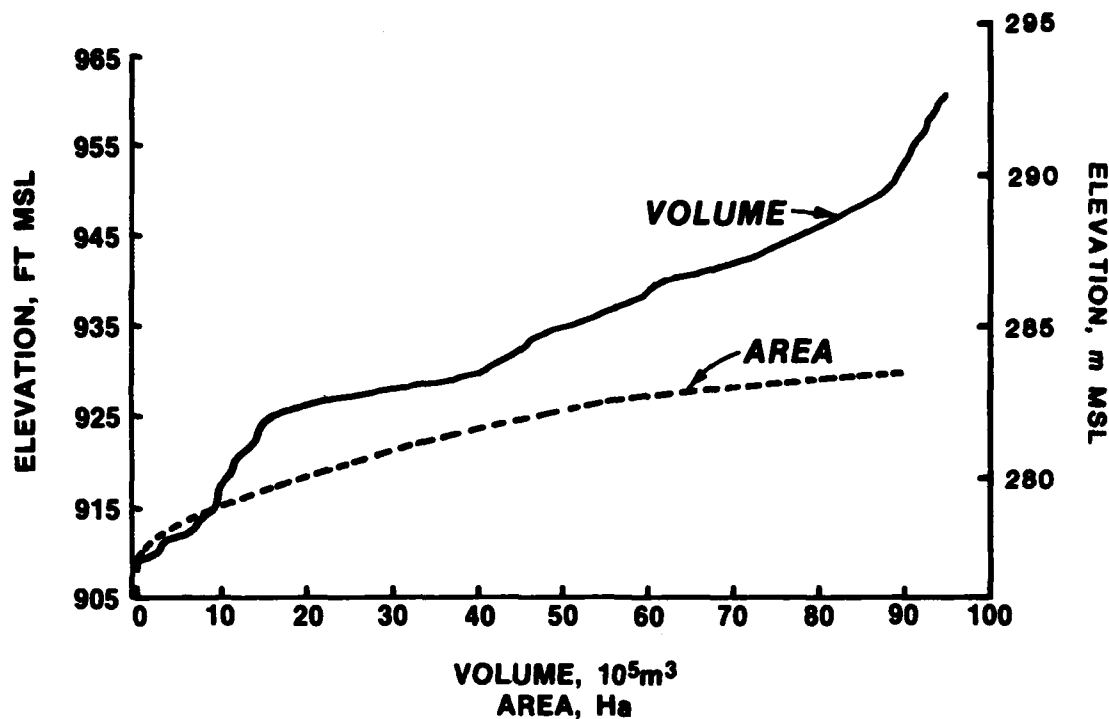
Figure 3. Area and volume relationships for Eau Galle Lake

Table 1

Physical Characteristics* of Eau Galle Reservoir

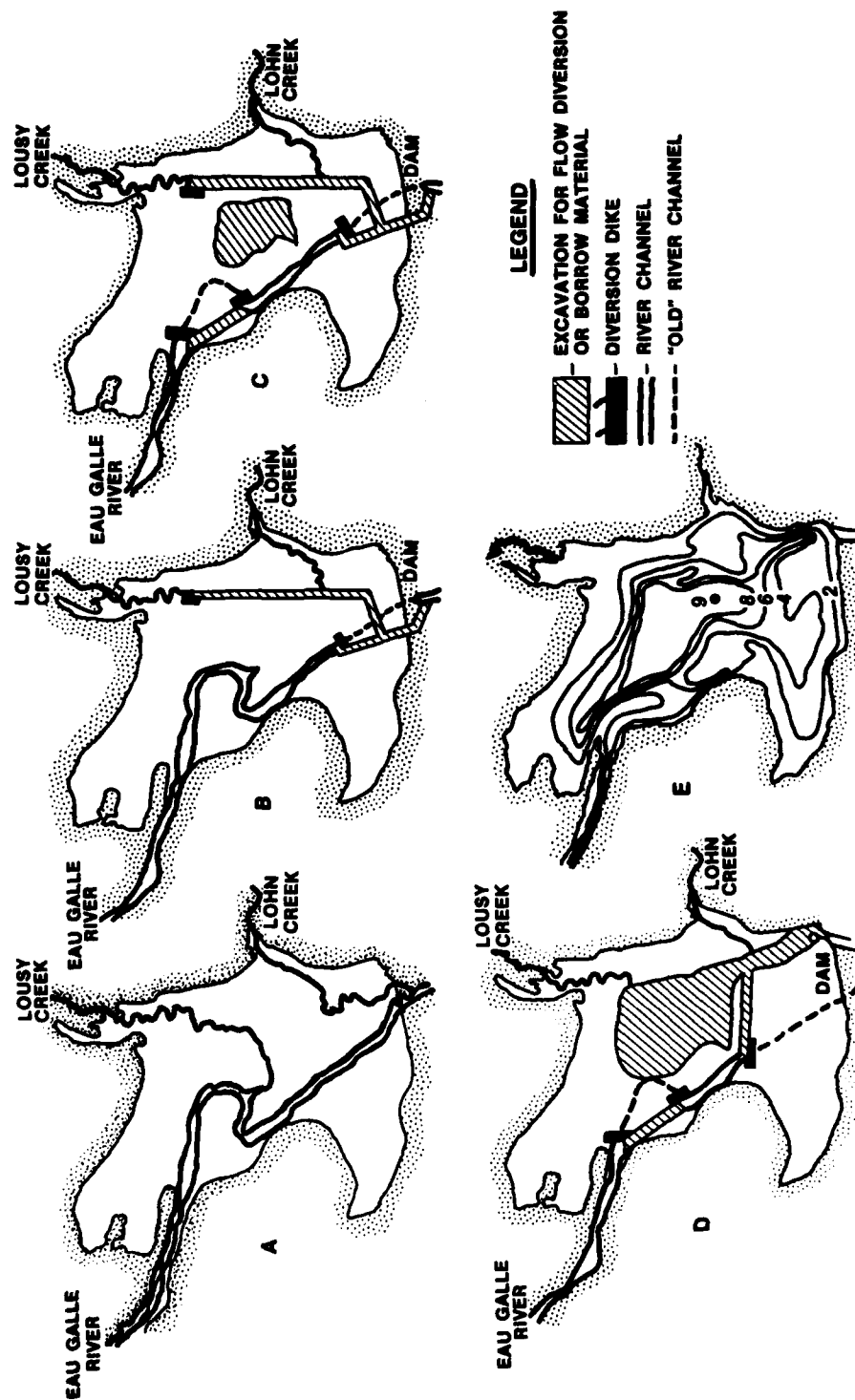| Parameter	Value
Surface area, km^2	0.6
Volume, $10^6 m^3$	1.9
Maximum depth, m	9.0
Mean depth, m	3.2
Reservoir length, km	1.0
Shoreline length, km	4.0
Shoreline development ratio	1.5
Drainage area, km^2	166.0
Residence time, yr	0.07

* Based on conservation pool elevation of 286.5 m, msl.

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Figure 2. Location of major tributaries to Eau Galle Lake (a) prior to construction, (b-d) following major excavations and diversions, and (e) with present morphometry. Lake depth contours (e) are in metres. Based on photographs supplied by US Army Engineer District, St. Paul, and Donald Blegen, Spring Valley, Wisconsin.

Boston, Massachusetts) equipped with a 100-ℓ plastic reservoir. The Nanopure system was connected directly to the RO reservoir and employed a carbon removal cartridge (activated carbon), two deionizer cartridges (Barnstead Ultrapure), and a spiral 0.45-μ filter cartridge. Barnstead reports that the Nanopure System produces 18-MΩ (Class I) water, but in our experience the water was closer to 3 to 5 MΩ. The deionized cartridges were changed when the resistance was less than 1 MΩ or when the silica concentration was greater than 1 mg/ℓ. Processed water normally had a carbon concentration less than 1 ppm and a resistance of approximately 3 MΩ. All lab water was checked weekly for resistance and silica. Dissolved organic carbon (DOC) was determined on a monthly basis.

Glassware preparations

37. Glassware and sample bottles were treated by one of two different methods. Most glassware was washed in soap and water with a brush, rinsed with hot tap water, rinsed three times with RO water, and allowed to air dry. All glassware and sample bottles for nutrient and metal analyses were acid washed in 10-percent concentrated hydrocloric acid, rinsed five times with nanopure water, inverted, and allowed to air dry. Bottles for total organic carbon (TOC) and DOC were soap and water washed, rinsed three times in warm tap water, rinsed two times with RO, and finally rinsed five times with distilled water.

Sample handling and processing

38. All samples were handled according to Standard Methods for the Examination of Water and Wastewater (APHA 1980). In general, required filtering was done within 4 hr of sample collection, and samples requiring refrigeration were kept in coolers and refrigerated upon arrival at the lab (within 2 hr of collection). Samples requiring digestion were digested on the day of collection or within 24 hr of collection. Metal samples were filtered and acidified within 4 hr and shipped within 48 hr of collection to another laboratory for analysis.

Quality control

39. Analytical quality control was maintained by three techniques: standard calibration curves, replicate and split sampling, and the

analysis of EPA standards. Standards or standard curves were used for instrument calibration. Split and replicate samples were used to check sampling and analytical precision. Analysis of EPA standards provided a check of laboratory analytical accuracy.

40. <u>Standard calibration curves.</u> Primary standards which give direct measurements of their respective parameters (e.g., conductivity, turbidity, pH) were used to calibrate field and laboratory equipment. When the value of a parameter was determined by chemical reaction and/or color development (e.g., nutrients), standard curves covering the expected sample concentration range were established for each batch of samples. Standard curves were evaluated using appropriate statistical procedures, and the percent recovery of each standard was calculated.

41. While the EPA recommends a new standard curve be run for each new set of reagents, this lab ran curves before each batch of samples. In the case of nutrients and carbon, additional standards were analyzed at the end of each batch. The slope, intercept, and correlation coefficient, as well as percent recovery of each standard, were subjectively compared to values of previous curves. If the curve was significantly different from previous curves, the run was rejected and the analyses were repeated.

42. <u>Replicates.</u> Replicate samples were obtained from three randomly selected sampling locations during each sampling trip. These samples provided a means for estimating errors due to sampling and/or intrinsic variability. Coefficients of variation (CV) have been calculated for each variable for each replicate, and then a mean of the coefficients has been calculated. These values (Table 3) represent the relative sampling precision and provide a means for comparing different analytical procedures.

43. <u>Splits--reliability and precision.</u> The analytical precision of each assay was evaluated by splitting samples in the lab and analyzing each subsample separately. As with replicates, three samples were randomly selected for each sampling period. These samples provided a test of analytical reliability and a measure of the normal variability due to analysis. The CV was calculated for each split, and means were

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Table 3

Mean Coefficients of Variation for Replicate and Split Samples

Variable	Replicates Mean CV*	Replicates Adjusted Mean CV**	Splits Mean CV*	Splits Adjusted Mean CV**
TMn	18.11	9.46	21.68	11.55
DMn	36.23	8.96	24.27	2.43
TFe	24.65	19.79	24.81	17.48
DFe	45.32	17.85	35.99	8.25
TCa	2.94	2.94	3.42	3.41
DCa	5.48	5.48	2.06	2.06
TMg	1.55	1.55	2.13	2.13
DMg	1.69	1.69	1.63	1.63
TNa	6.61	6.61	5.60	5.60
DNa	3.33	3.33	1.80	1.80
TK	6.42	6.42	5.16	5.16
DK	1.74	1.74	1.89	1.89
TSul	21.82	21.82	62.85	23.57
SO_4	5.07	2.73	3.85	2.17
DSi	3.18	3.18	1.27	1.27
TAlk	0.73	0.73	2.98	2.98
ChlA	7.84	4.54	5.15	4.35
ChlB	27.43	20.47	29.93	20.36
ChlC	23.36	13.23	29.32	17.72
Phaeo	61.45	20.88	46.99	20.28
TP	6.35	6.35	4.22	4.22
TSP	12.49	8.56	8.71	4.97
SRP	17.58	6.92	9.24	3.00
TS	3.09	3.09	2.79	2.79
TSS	13.77	12.61	16.95	10.31
Turb	5.17	5.17	--	--
FColi	83.76	19.08	49.31	15.53
TOC	5.65	5.65	3.85	3.54
DOC	7.98	7.98	4.31	4.26
NH_4-N	26.18	8.02	12.13	3.36
TN	4.08	4.08	2.97	2.97
NO_3/NO_2-N	9.09	5.22	1.56	1.50
DN	4.03	4.03	--	3.94

* Coefficient of variation ((standard deviation/mean) × 100); all values considered.

** Coefficient of variation; only values greater than analytical detection limit considered.

calculated for each variable (Table 3). The high CVs for several variables are due to the low levels of those constituents in the samples; most were at or below detection limits. At low levels, small differences can become as large as the value itself and hence give a large CV. This tendency of exaggerated error due to low sample values is noted by the EPA, and they suggest control limits be established for different ranges of values. For all procedures by which the values were generally above detection limits, the CV (percent relative error) was less than 10. Table 3 also lists the average CV when all values below the detection limit for each analysis have been removed.

44. _Accuracy._ Accuracy describes how closely the analyzed values agree with the actual values. The accuracy of the lab's analytical procedures was evaluated by analysis of EPA Quality Control Standards (Quality Assurance Branch, Environmental Monitoring and Support Laboratory, EPA, Cincinnati, Ohio). Standards were obtained from the EPA on four separate occasions. Laboratory values were compared to EPA values and recorded as percent recovery ((lab value/EPA value) × 100). The results are tabulated in Table 4. Most analytical procedures yielded values that were within the 95-percent confidence interval on all four occasions. When the results did not fall within the confidence interval, immediate action was taken to correct the error, and the EPA standards were then reanalyzed.

45. Inaccuracies in nutrient and carbon analyses were usually corrected by preparing fresh laboratory standards. The inaccuracy of the pigment samples for the first set of EPA standards was corrected by recalibration of the spectrophotometer. The instrument was thereafter checked more frequently with standard filters. The metals were analyzed by an independent lab that monitored their own accuracy and precision. In addition, one set of EPA standards was analyzed at our request.

Field Measurements

Field logistics

46. In general, sampling on the reservoir was conducted either from a 4.3-m aluminum boat or on foot, and by snowmobile during periods

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Table 4

EPA Quality Control Unknowns*

Parameter	Percent Recovery			
	EPA No. 1	EPA No. 2	EPA No. 3	EPA No. 4
Turbidity	95.1	95.1	91.3	ND
	112.5	100.0	117.1	ND
pH	101.2	98.8	99.4	100
	101.3	98.7	103.4	100
Alkalinity	99.1	97.7	100.5	102.3
	99.1	101.4	99.4	101.3
Conductivity	93.5	92.4	104.4	95.1
	106.2	89.4	96.0	101.9
Sulfate	103.6	97.6	101.1	101.8
	104.2	100.0	106.0	100
Calcium	ND	ND	95.5	ND
			100.0	
Magnesium	ND	ND	100.0	ND
			97.2	
Sodium	ND	ND	85.7**	ND
			80.0**	
Potassium	ND	ND	94.1	ND
			95.8	
Iron	ND	ND	ND	ND
Manganese	ND	ND	ND	ND
Total solids	86.6**	98.1	100.6	80.0**
	97.8	99.6	102.6	96.1
	93.2	93.6	99.9	98.0
Dissolved solids	101.2	96.2	110.0	79.3**
		96.2	98.1	104.7
		94.5	91.6	114.7
Total organic carbon	98.4	79.8	80.0**	92.7
	95.9	82.0	94.3	97.6

(Continued)

Note: ND = standard not analyzed.

    * Date standard obtained: No. 1, December 1980; No. 2, March 1981; No. 3, January 1982; No. 4, March 1983.

   ** Values outside 95-percent confidence interval.

Table 4 (Concluded)

Parameter	Percent Recovery			
	EPA No. 1	EPA No. 2	EPA No. 3	EPA No. 4
Chlorophyll A	98.0	92.3	ND	ND
B	112.0**	109.0	ND	ND
C	140.2	95.3	ND	ND
Active chlorophyll	81.6	86.5	ND	ND
Phaeophytin	142.2**	108.4	ND	ND
Nitrate	101.9	100.0	103.2	91.7
	111.3	98.0	97.5	98.8
Ammonia	126.3**	97.6	100.0	130.0**
	111.5	92.7	102.3	
Orthophosphorus	98.4	96.8	96.8	101.3
	107.1	101.9	99.4	97.0
Total nitrogen	104.2	100.6	90.4	140.0
	99.3	92.1	100.0	108.0
Total phosphorus	90.0	98.6	70.7**	100.0
	99.5	102.9	93.1	97.2

** Values outside 95-percent confidence interval.

of ice cover. In addition to the boat, a 3- by 3.6-m raft was occa-
sionally used for work with heavier equipment. All inflow and outflow
stations were reached by truck.

In situ measurements

47. A Hydrolab Surveyor (Hydrolab Corporation, Austin, Texas),
consisting of a sonde unit, cable, and deck unit, was used to measure
four in situ parameters: dissolved oxygen, temperature, specific con-
ductance, and pH. The instrument was calibrated prior to each use with
known conductivity and pH standards, Winkler DO titration, and an NBS-
checked thermometer. Periodic checks of conductivity and pH were also
performed using EPA standards.

48. The instrument cable was marked at 1-m intervals using a
color-coded tape system. In situ measurements were taken at 0.1 m below
the water surface and then at 1-m intervals to the bottom. The last
measurement was taken 0.5 m from the bottom. Column depth was deter-
mined by gently lowering the Hydrolab sonde until bottom was felt and
recording total column depth.

49. Replicate in situ samples were taken by repeated measurement
at predetermined in-pool stations and depths. Inflow and outflow repli-
cate in situ measurements were taken by removing the sonde from the
water after first sampling, pausing briefly, then lowering the sonde
back into the water to obtain a second measurement.

50. The sonde unit was stored in a large water bath when not in
use. Cleaning of sonde probes and renewal of the water bath were per-
formed as needed. The DO probe membrane was inspected before each use
and replaced when needed, as specified in the instrument manual.

51. Secchi disc depths were determined at all in-pool stations
using a standard black/white, 20-cm Secchi disc suspended on a 0.2-m in-
terval calibrated line. The Secchi disc was lowered into the water until
out of sight and then raised slowly until again visible. The reported
depth was determined (to the nearest 0.1 m) as the average of these two
depths.

52. A Li-Cor 185A Quantum/Radiometer/Photometer (Li-Cor, Inc./
Li-Cor, Ltd; Lincoln, Nebraska) was used to measure light penetration.

Measurements were taken at a depth of 0.1 m and at 0.5-m intervals from 0.5 m to the depth at which light was reduced to 1 percent of surface irradiance. During ice-free periods, the submarine cell was affixed to one end of a 3-m pole, which was suspended horizontally in such a manner as to prevent shading effects from the boat. During ice-cover conditions, the submarine cell was fixed to the end of an L-shaped conduit pipe, which could be submerged through a hole in the ice. Deck and submarine cell measurements for each depth were taken within seconds of each other so as to limit the effect of short-term changes in cloud cover.

Ice thickness and snow depth

53. During ice-covered periods, ice thickness was determined at each in-pool station by drilling a 23-cm-diam hole through the ice, lowering the Secchi disc attached to a calibrated line through the hole and hooking the disc on the underside of the ice pack. With the calibrated line held taut, ice thickness could be determined to the nearest 0.05 m through the hole. Snow cover depth was determined by poking a metre stick into the snow as far as possible and recording the depth. On several occasions snow compacted to form an ice/snow layer above the solid ice pack; this was measured and reported as "glaciated snow."

Water Sample Collection

Discrete samples

54. Water samples were collected using a small-volume, plastic chambered, 12-V diaphragm pump and a rubber garden hose marked at metre intervals. Samples were pumped from 0.1 m below the water surface and at metre intervals from 1.0 m to near bottom; the last sample was always 0.5 m from bottom. The hose was flushed for a minimum of 30 sec at each depth before sample water was collected. As with in situ measurements, replicate water samples were collected at predetermined stations and depths. During anoxic periods, special techniques were used to collect metal, nutrient, and sulfide samples at depths where DO concentrations were less than 1.0 mg/ℓ. By attaching a two-way "Y" valve to the pump

outlet and adjusting the valves such that a bubbleless laminar flow
stream was produced out of one side, sample bottles and/or syringes were
filled from the other outlet with minimal exposure to air. Data for
water samples collected in this fashion were compared to data for sam-
ples collected using a Van Dorn bottle and found to provide more reli-
able, less variable information.

Integrated samples

55. An integrated sampler was used to sample epilimnetic water
for phytoplankton, chlorophyll, and metals. The sampler consisted of a
3-m-long, 5-cm-diam polyvinylchloride pipe and a one-way check valve af-
fixed to one end of the pipe. The check valve allowed the capture of a
continuous column of water as the device was slowly lowered into the
water column. Upon retrieval, the valve would close, thereby capturing
water. The sample was then poured into a clean container from which
sample bottles were filled.

References

American Public Health Association. 1980. Standard Methods for the
Examination of Water and Wastewater, 15th ed., American Public Health
Association, New York.

Environmental Protection Agency. 1974. "Methods for Chemical Analysis
of Water and Wastes," US Environmental Protection Agency,
EPA-625/6-74-003.

PART V: LIMNOLOGY OF EAU GALLE TRIBUTARIES*

Introduction

56. The transport of materials and nutrients during periods of
elevated flow strongly affects the water quality of reservoirs and lakes
(Baxter 1977; Carmack et al. 1979; Gloss, Mayer, and Kidd 1980; Kennedy,
Thornton, and Gunkel 1982). Fluctuations in river nutrient concentra-
tions and loading are generally associated with storm events and runoff.
One of the major high-flow periods in the upper Midwest occurs each
spring due to the melting and subsequent runoff of the winter snowpack.
During the winter, the decomposition of organic matter from fall defolia-
tion and the application of manure to agricultural areas result in the
accumulation of easily transportable nutrients and pollutants. In addi-
tion, winter precipitation and associated atmospheric fallout concen-
trate materials in the snowpack (Colbeck 1981). Once weather conditions
are sufficient to initiate runoff of the melting snowpack, these nutri-
ents and other materials are rapidly released to receiving streams
(Johannessen and Henriksen 1978). Depending on watershed characteris-
tics and flushing rate, nutrient loads and reservoir nutrient concentra-
tions would thus be expected to exhibit marked fluctuations in response
to snowmelt and runoff.

57. Presented here are the results of routine studies to define
and compare seasonal trends in tributary water quality and a short-term
intensive study of water quality changes in the Eau Galle River conducted
during a snowmelt runoff period in spring 1982. Since the latter event
resulted in significant changes in lake elevation, this is discussed in
relation to lake water quality. Discussions of tributary water quality
will deal primarily with data for the Eau Galle River; however, data for
all tributaries are presented graphically in Appendix B.

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* Part V was written by Steven L. Ashby and William F. James.

Methods

58. The locations of tributary sampling stations are indicated in Figure 7. Water collection methodologies are described by Johnson and Lauer (see Part IV). Collections of water samples for chemical analyses were performed at biweekly intervals. In situ determinations of temperature (°C), dissolved oxygen (mg/ℓ), pH, and specific conductance (μmhos/cm) were made on a weekly basis. Data from continuous monitoring of stream levels and flow from each tributary were obtained from US Geologic Survey gaging houses.
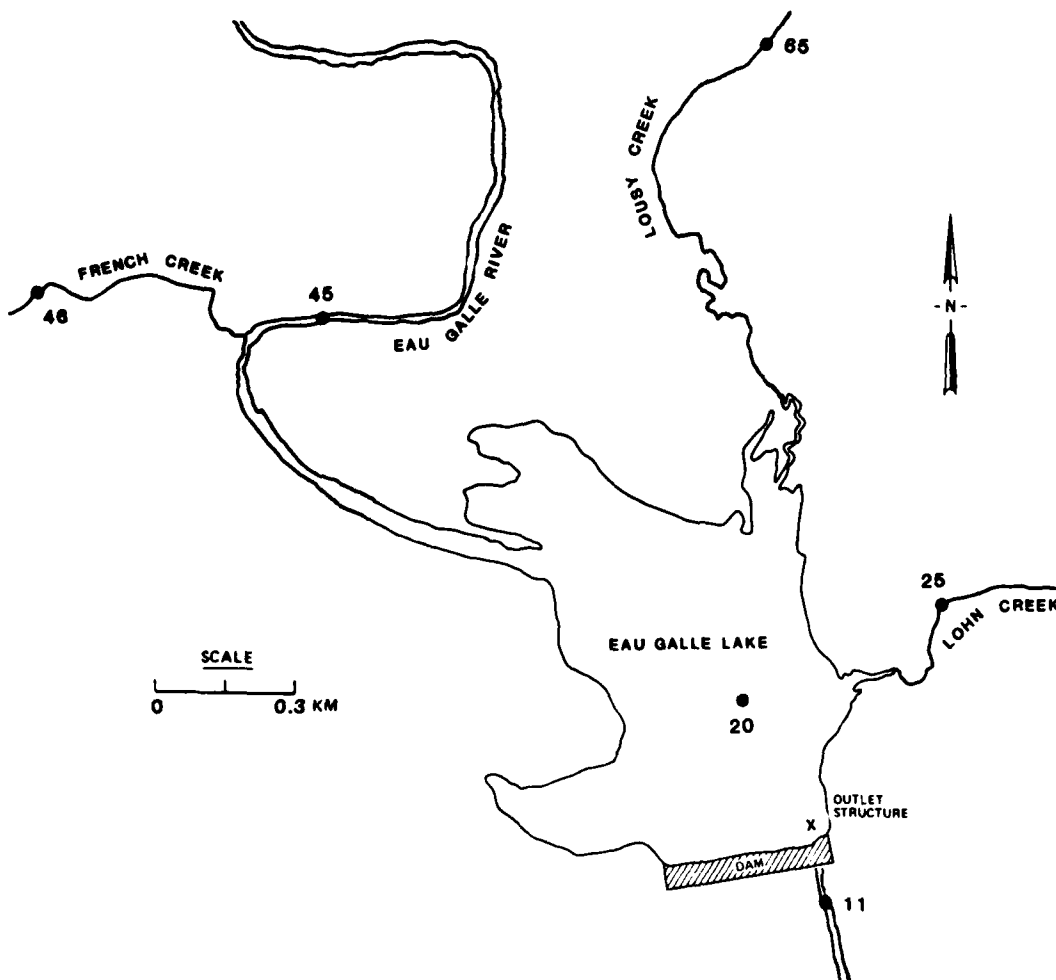
Figure 7. Location of tributary sampling stations at Eau Galle Lake. The outflow station (station 11) and major lake sampling station (station 20) are also indicated.

59. Sa..pling times and frequencies during the 1982 snowmelt were linked to changes in streamflow. In general, samples for chemical analysis and in situ determinations were collected immediately before, during, and following the period of elevated flow. Sample collection was most frequent during and immediately prior to peaks in flow. Additionally, in situ profile (2-m intervals) measurements and water samples were collected at station 20 every 2 days during this period. Samples and in situ determinations were also collected in the tailwater area below Eau Galle Lake (station 11). Lake and tailwater levels were gaged continuously.

60. Physicochemical analyses of all variables discussed by Johnson and Lauer (Part IV) and listed in Appendix A were performed on samples collected biweekly. Selected variables were examined during the 1982 snowmelt. Filtration and digestion procedures were performed within hours of sample collection for both routine and snowmelt events.

Results

Routine studies

61. Differences in discharge between tributaries reflected differences in the relative size of each tributary and its watershed. The Eau Galle River contributed approximately 85 percent of the annual water income while Lousy and Lohn Creeks combined contributed only 12 percent. The remaining 3 percent was apparently derived from precipitation and ground-water inputs. Physical characteristics and average discharges for each tributary are presented in Table 5. In general, Eau Galle River

Table 5

Physical Characteristics of Eau Galle Lake Tributaries

Characteristic	Eau Galle River	Lousy Creek	French Creek	Lohn Creek
Length (km)	24.0	6.5	6.5	4.0
Watershed area (km^2)	131.0	16.6	11.4	7.0
Contribution to total flow (%)	79.5	9.7	5.1	2.1
Discharge (m^3/sec)				
Mean	0.88	0.08	0.04	0.02
Mode	0.21	0.06	0.01	0.01

discharges were 10 times higher than those for French, Lousy, and Lohn Creeks.

62. Marked seasonal differences in discharge were apparent for all tributaries (Figure 8). Maximum discharges were observed in spring and fall, while minimum discharges occurred during winter and summer. The runoff of the 1982 winter snowmelt produced a peak discharge in the Eau Galle River of 80 cm/sec (maximum observed during the 2-year study period). Other major peaks in the Eau Galle River occurred following snowmelt in February 1981 (8 cm/sec), following rain events in April and May 1981 (6 and 10 cm/sec, respectively), and in April 1982 (8 cm/sec). Minor peaks (less than 2 cm/sec) were observed in June, August, and October 1981 in the Eau Galle River but were absent in the other tributaries (with the exception of the August peak). The absence of these peaks may be attributed to localization of thunderstorms within the reservoir watershed.

63. Mean constituent concentrations varied among the four tributaries. The Eau Galle River exhibited highest mean annual concentrations of turbidity, suspended solids, total and dissolved organic carbon, and total and total soluble phosphorus. In contrast, highest mean annual concentrations of dissolved silica and nitrate/nitrite nitrogen were observed in Lousy and Lohn Creeks. Highest mean annual concentrations of dissolved solids, calcium, and magnesium occurred in French and Lohn Creeks. These differences were probably related to tributary and watershed size and to such watershed differences as soil associations, bedrock geology, and land use.

64. Seasonal variations in constituent concentrations, measured at biweekly intervals, were related to fluctuations in discharge and biological activity. These variations occurred as increases or decreases in concentrations depending upon the nature of the variable and are best described with data from the Eau Galle River. For instance, pronounced peaks in suspended solids and turbidity coincided with periods of elevated flow (Figure 9). Similar responses were observed in total organic carbon, nitrogen, and phosphorus concentrations (Figure 10). However, specific conductance, total alkalinity, and total solids exhibited
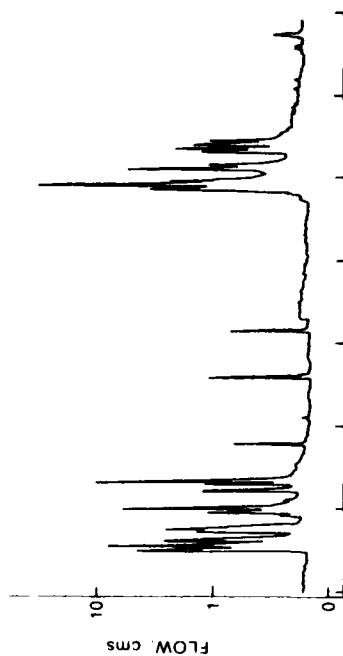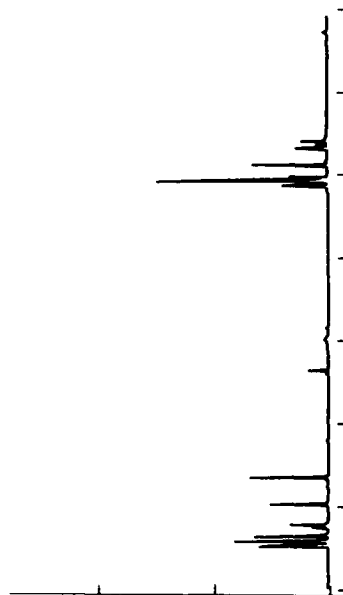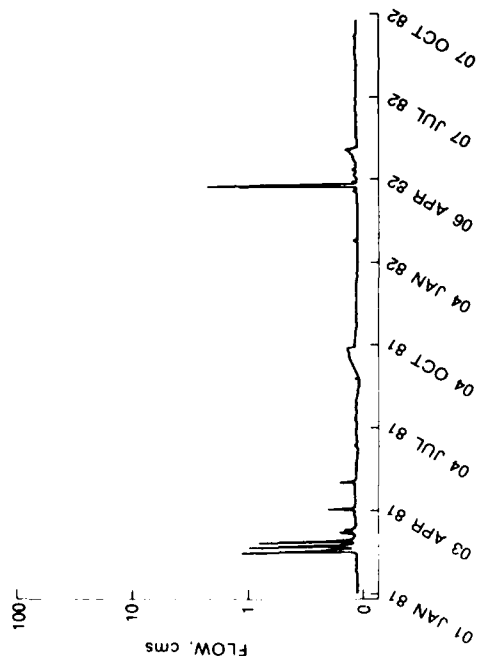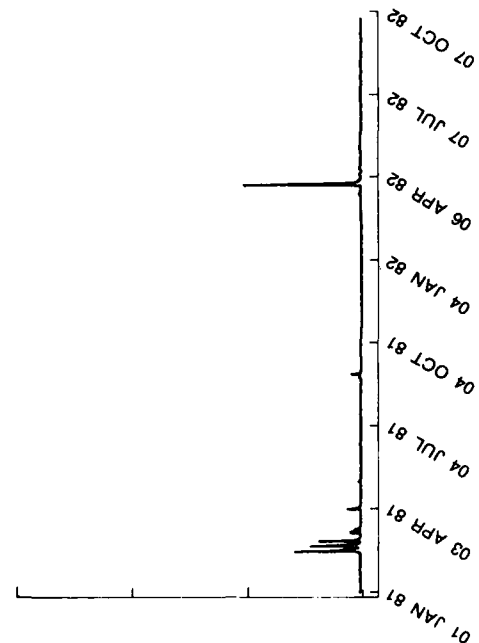
Figure 8. Daily fluctuations in discharge (m^3/sec) in tributary streams during 1981-1982
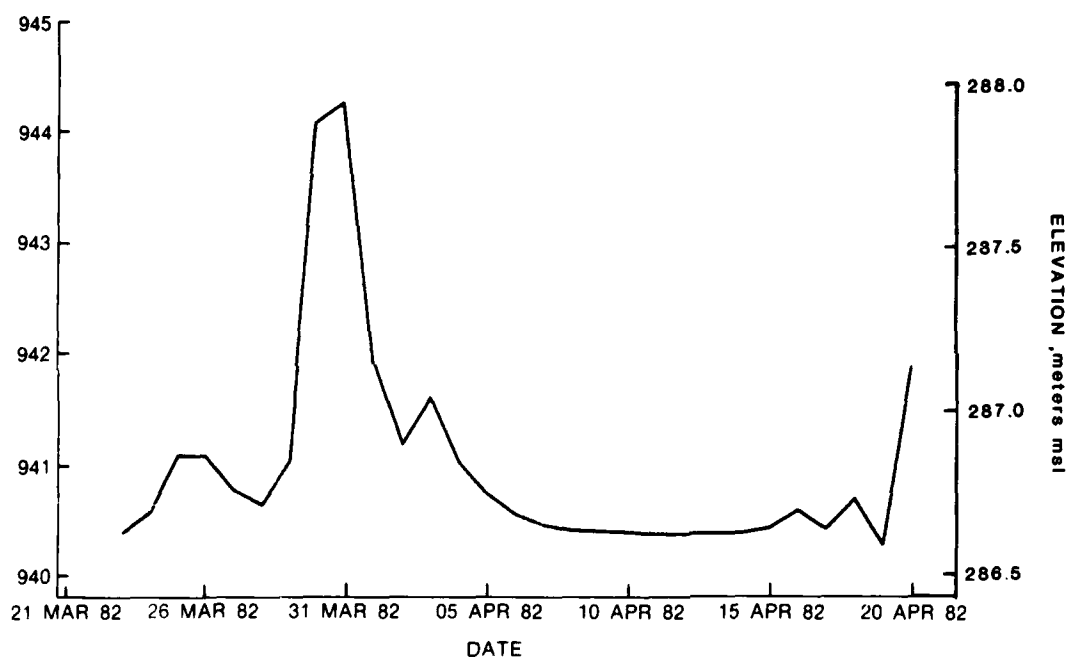
Figure 21. Daily fluctuations in Eau Galle Reservoir pool elevation
during the 1982 snowmelt
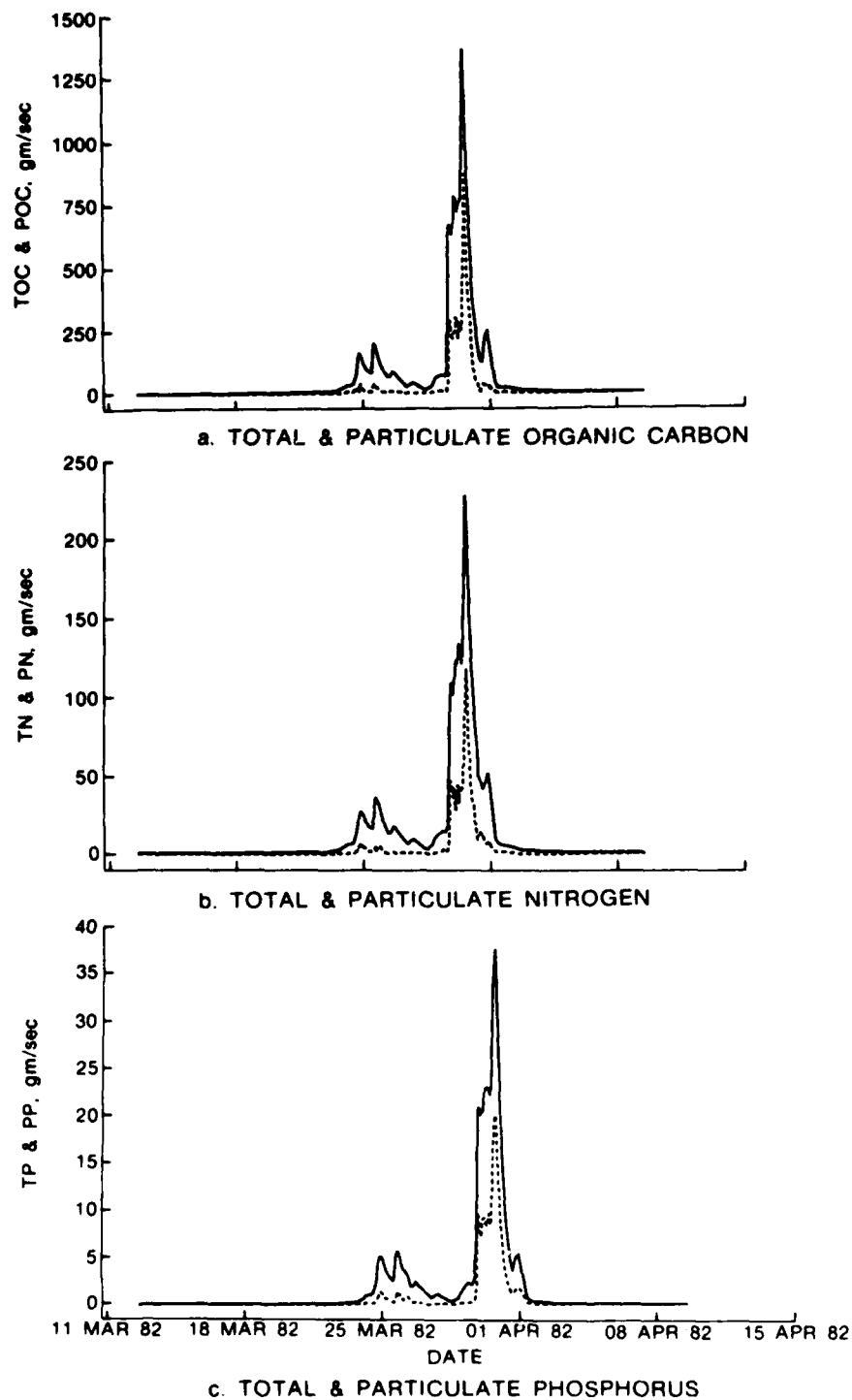
Figure 20. Daily fluctuations in flux of total (–) and particulate (---) organic carbon, nitrogen, and phosphorus in the Eau Galle River during the 1982 snowmelt
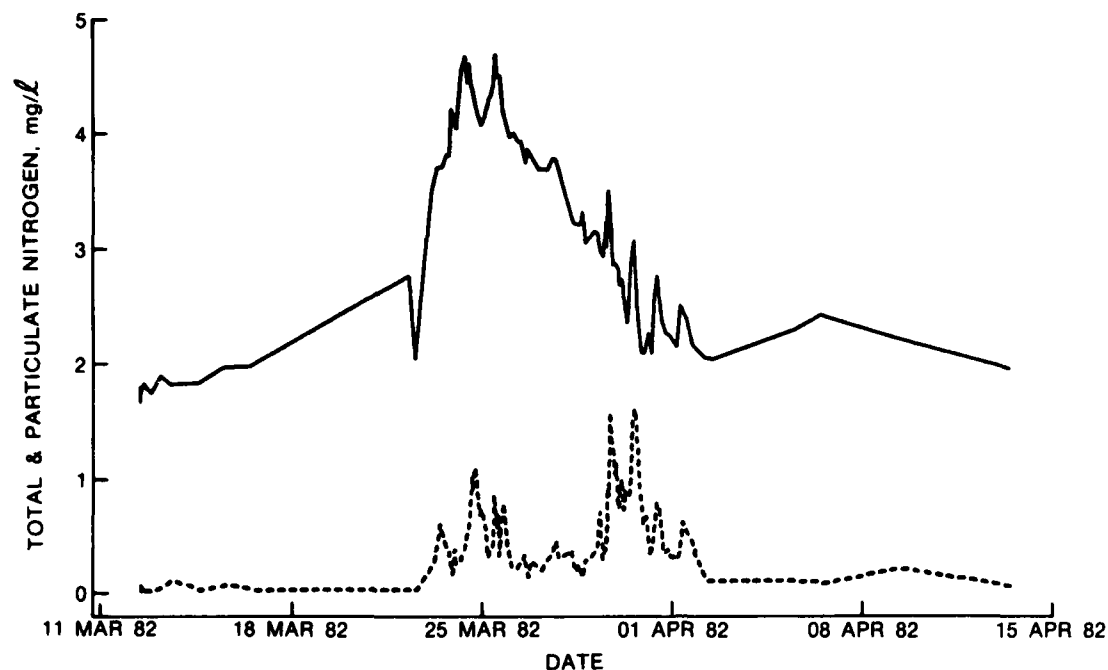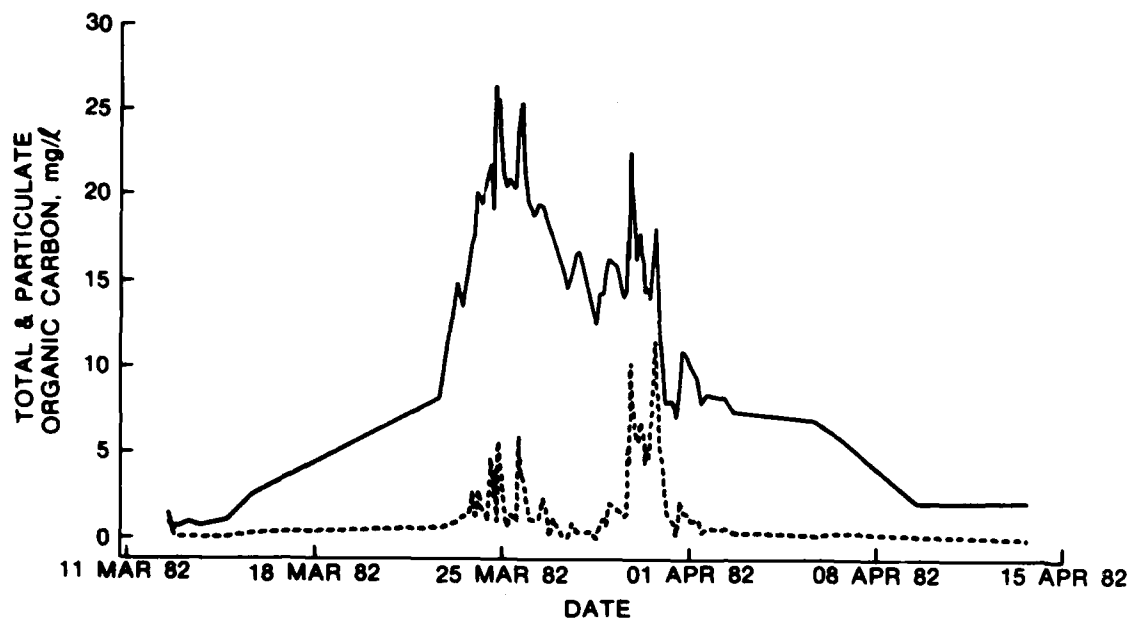
Figure 19. Daily fluctuations in total (—) and particulate (---)
nitrogen in the Eau Galle River during the 1982 snowmelt

Patterns of change in particulate nitrogen concentrations, however,
coincided with those of particulate organic carbon and phosphorus
concentrations.

72. Estimates of loading (grams/second), which differed markedly
from patterns of concentration changes, revealed a similar pattern for
all variables measured. In general, major loading was associated with
the rising limb of the major peak of the hydrograph. For instance,
total organic carbon, total nitrogen, and total phosphorus exhibited
peaks of approximately 840, 122, and 38 gm/sec, respectively (Figure 20).
In addition, the dissolved species of all measured variables comprised
the majority of the load from runoff.

73. This period of elevated flows caused pronounced fluctuations
in lake levels and nutrient concentrations, resulting in a net change in
lake conditions. The major peak of the Eau Galle River hydrograph pro-
duced a 1.0-m rise in lake level and a peak discharge in the outflow on
March 30, indicating a rapid flushing rate (Figure 21).

74. An inverse temperature gradient existed at station 20 prior

a. Organic carbon
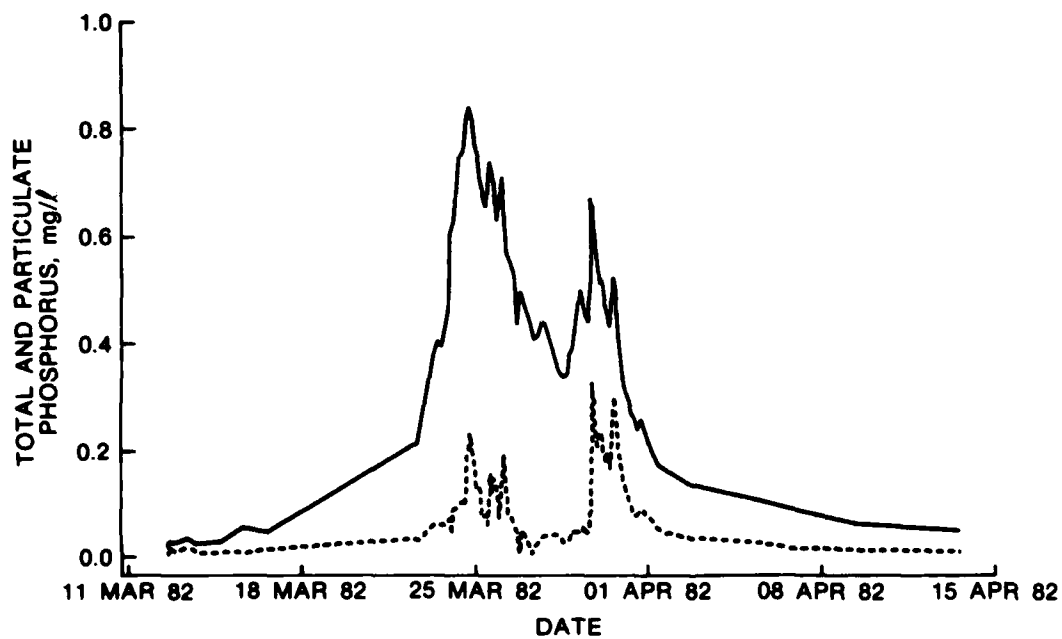
b. Phosphorus

Figure 18. Daily fluctuations in total (—) and particulate (---) carbon and phosphorus in the Eau Galle River during the 1982 snowmelt

47
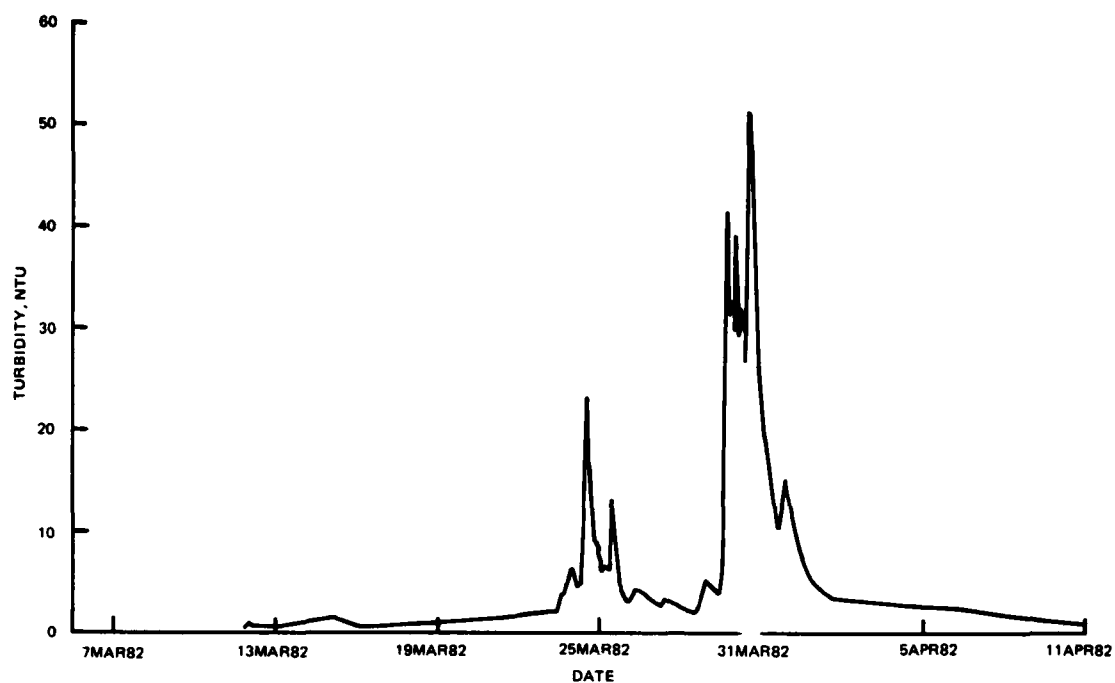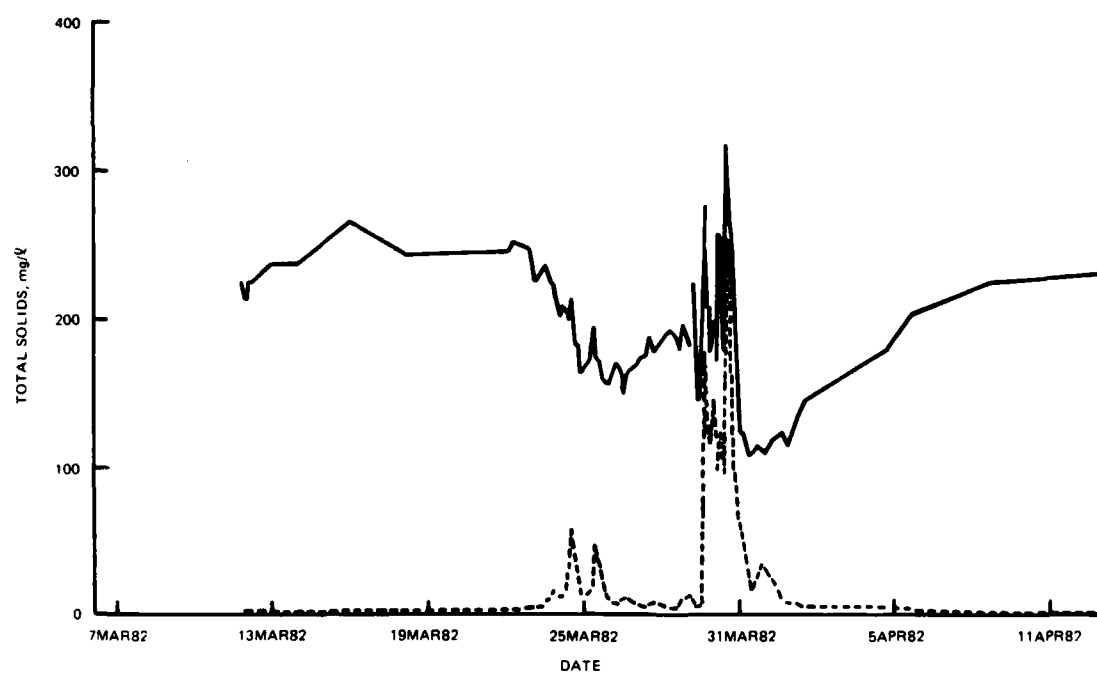
a. Turbidity

b. Total solids

Figure 17. Daily fluctuations in (a) turbidity and (b) total (—) and suspended solids (---) concentrations in the Eau Galle River during the 1982 snowmelt

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During the two melt-related peaks in the hydrograph, specific conductance decreased from 370 μmhos/cm to 200 and 80 μmhos/cm, respectively. Alkalinity concentrations decreased from 170 mg $CaCo_3/\ell$ to 50 and 30 mg $CaCO_3/\ell$, respectively. Both variables returned to normal levels by 9 April.

69. Total solids exhibited a similar pattern of decreased concentrations with elevated flow; however, suspended solids and turbidity exhibited peaks in concentration during these periods (Figure 17). Total solids decreased from 250 to 160 mg/ℓ during the first peak of the hydrograph. Prior to the second peak of the hydrograph, total solids increased to 280 mg/ℓ, then decreased substantially (to 120 mg/ℓ) in association with the second peak. Suspended solids concentrations increased to 50 and 250 mg/ℓ, respectively, in association with these two peaks in the hydrograph. Baseline concentrations were less than 10 mg/ℓ. The response of turbidity was similar to that of suspended solids, exhibiting values of 20 and 50 NTU, respectively, coincident with the two peaks in the hydrograph (Figure 17).

70. Nutrient concentrations displayed a different response during the elevated flow period. In contrast to patterns observed for suspended solids and turbidity, highest nutrient concentrations were observed during the first peak. Total phosphorus concentrations increased from 0.025 to 0.800 mg/ℓ and total organic carbon concentrations increased from 1.0 to 25.0 mg/ℓ during the first peak of the hydrograph (Figure 18). Although lower concentrations were observed with the major peak, particulate phosphorus and particulate organic carbon concentrations were highest during the major (i.e., second) peak of the hydrograph, coincident with high suspended solids concentrations. Highest concentrations of dissolved fractions of these nutrients, however, were observed during the first peak.

71. The response of total nitrogen concentrations to this runoff event was markedly different than that of total phosphorus and carbon (Figure 19). While the first peak of the hydrograph resulted in a change in concentration of total nitrogen from 1.8 to 4.7 mg/ℓ, no increase in total concentration was observed during the major peak of the hydrograph.
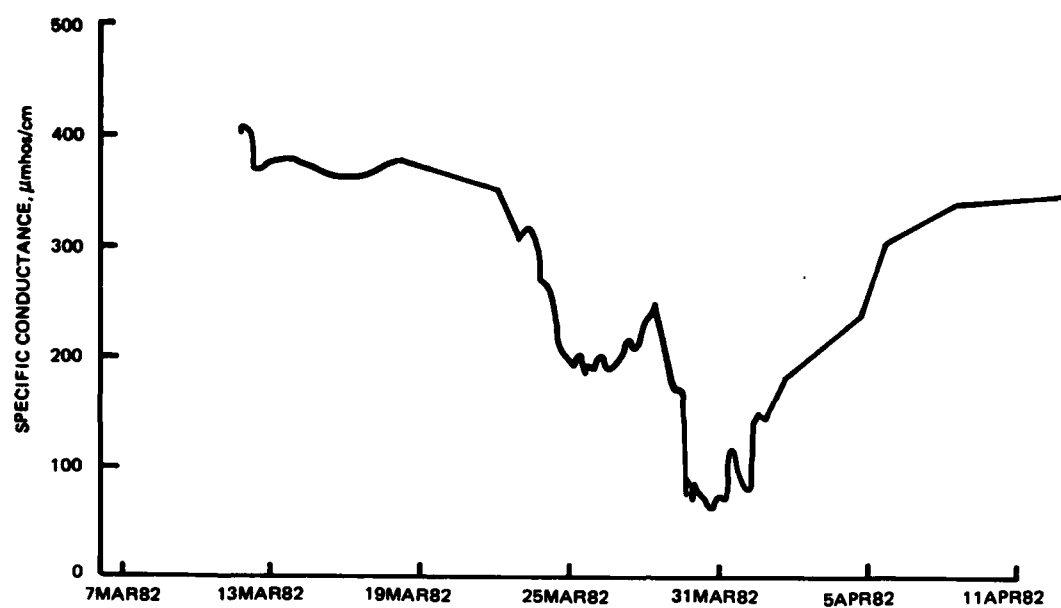
a. Specific conductance
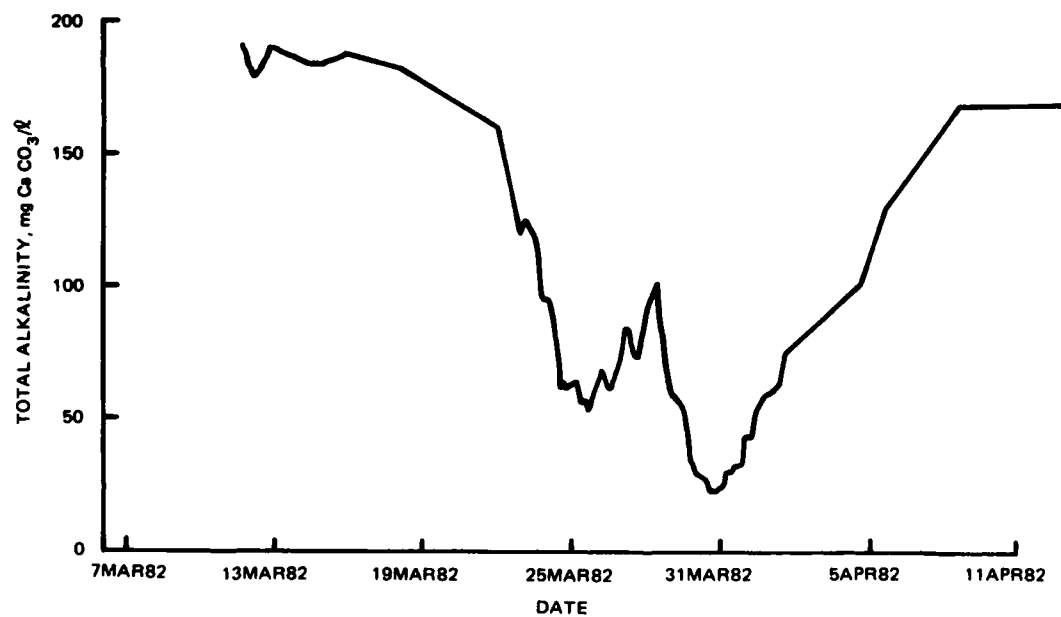
b. Total alkalinity

Figure 16. Daily fluctuations in specific conductance and total alkalinity in the Eau Galle River during the 1982 snowmelt
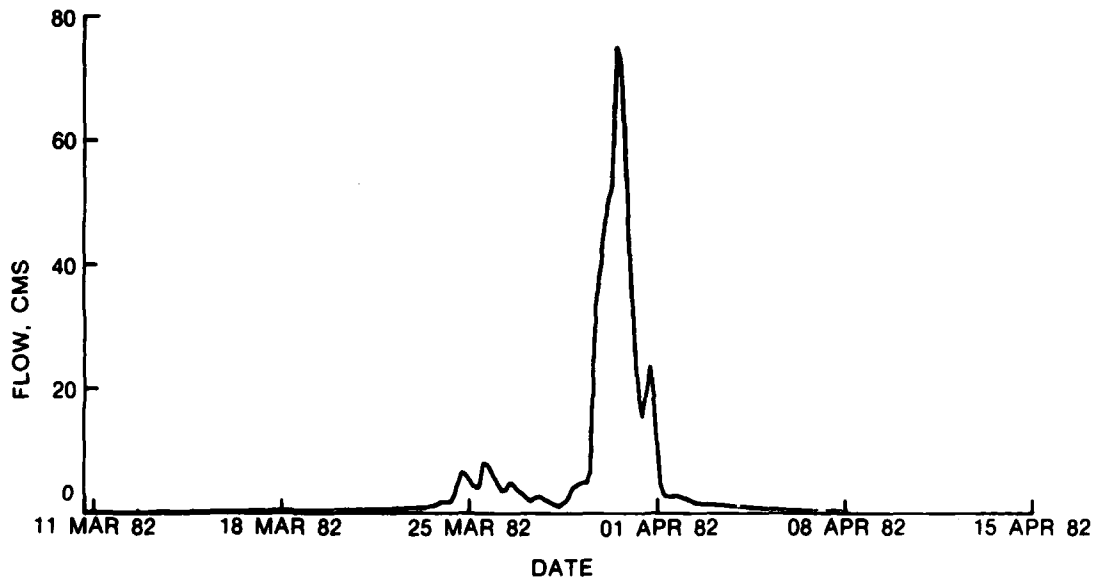
Figure 14.   Daily fluctuations in discharge in the Eau Galle River
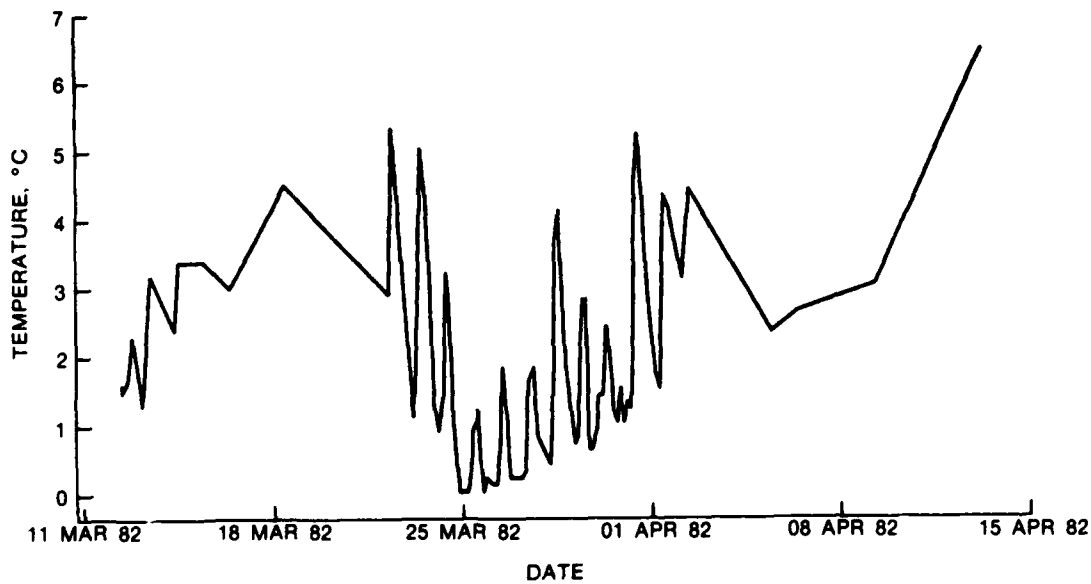during the 1982 snowmelt

Figure 15.   Daily fluctuations in water temperature in the
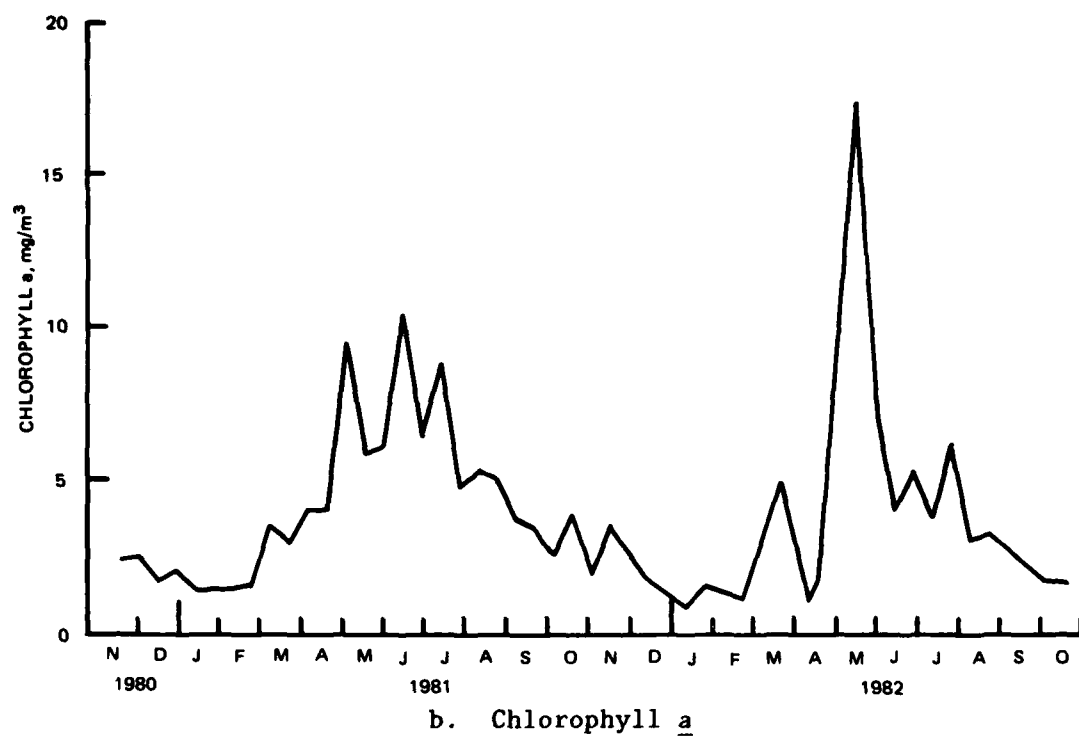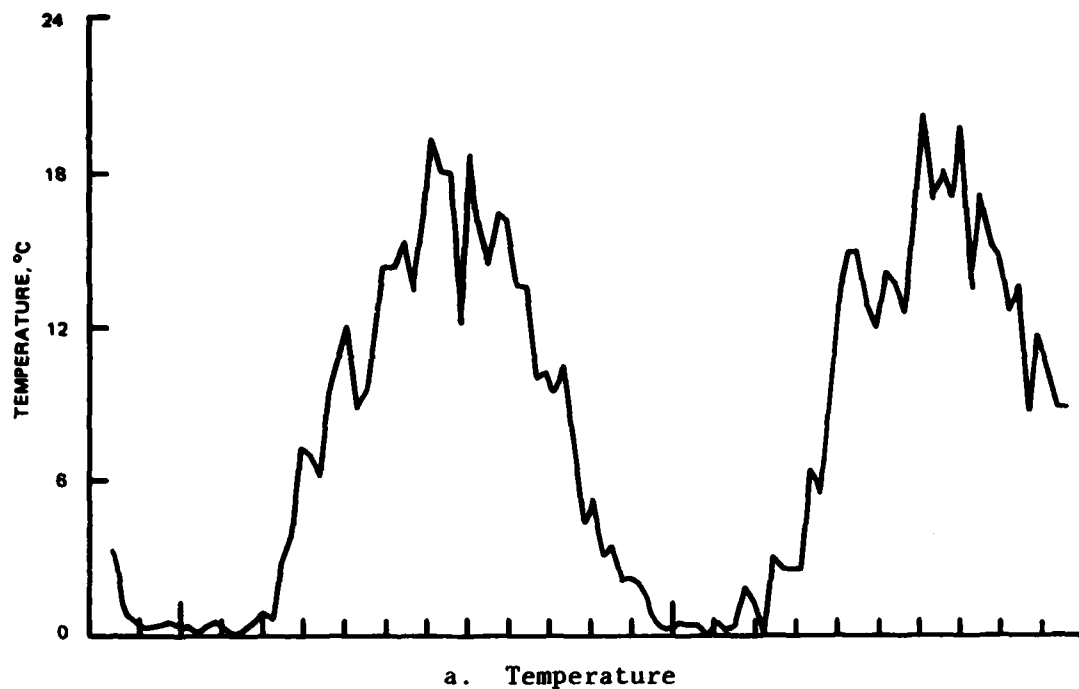Ea Galle River during the 1982 snowmelt

43

a.   Temperature

b.   Chlorophyll a

Figure 13.   Seasonal fluctuations in temperature and chlorophyll a
concentration in the Eau Galle River

42

b. Total magnesium

c. Dissolved silica

a. Total calcium
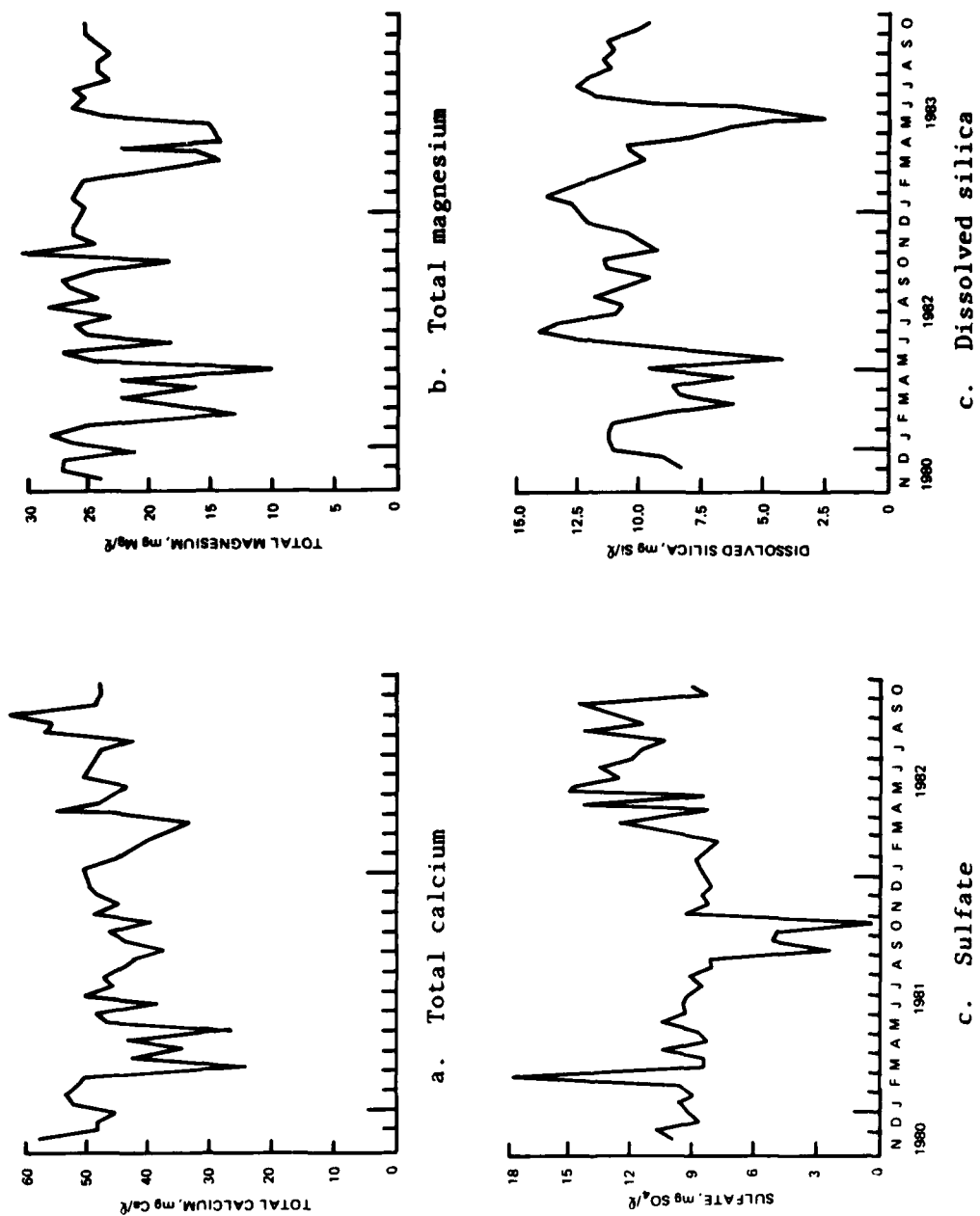
c. Sulfate

Figure 12. Seasonal fluctuations in total calcium, total magnesium, sulfate, and dissolved silica in the Eau Galle River

41

decreased levels during these periods (Figure 11). Total calcium and magnesium, sulfate, and dissolved silica, which compose a substantial portion of the total solids concentration, also generally decreased in concentration with periods of elevated flow (Figure 12). During periods of low discharge, inflow concentrations generally returned to baseline levels, indicating that periods of snowmelt and storm events had a substantial impact on concentration fluctuations.

65. Biological activities increase with warmer temperatures and this was reflected in changes in chlorophyll concentrations (Figure 13). Water temperature changes coincided with changes in air temperatures, with lower temperatures (2.5° C mean) occurring during the winter months and higher temperatures (13.4° C mean) during summer. Highest chlorophyll concentrations were observed during summer months, suggesting increased productivity with warmer water temperatures.

1982 snowmelt runoff study

66. A snow accumulation of approximately 2.3 m during the winter of 1981-1982 provided approximately 25 cm of water available for runoff when melt of the snowpack occurred. The Eau Galle River hydrograph produced by this runoff exhibited two peaks in association with two warm periods (Figure 14). The first peak (8 cms) occurred after a 3-day period (March 21-24) when air temperatures exceeded 5° C. Air temperatures then decreased to less than 5° C (March 24-27), resulting in reduced runoff. A second warming period (March 27-30) melted most of the remaining snow, causing a major runoff between March 30 and April 2. This second warming period, when mean air temperature was 15° C, produced the major peak in the hydrograph (80 cms) on March 30.

67. Eau Galle River temperatures exhibited daily changes that were related to changes in the temperature of runoff waters (Figure 15). Temperatures in the stream prior to the melt event ranged from 2° to 4° C but decreased to near 0° C during the first peak of the hydrograph. During the second peak of the hydrograph, water temperatures gradually returned to pre-high flow temperatures.
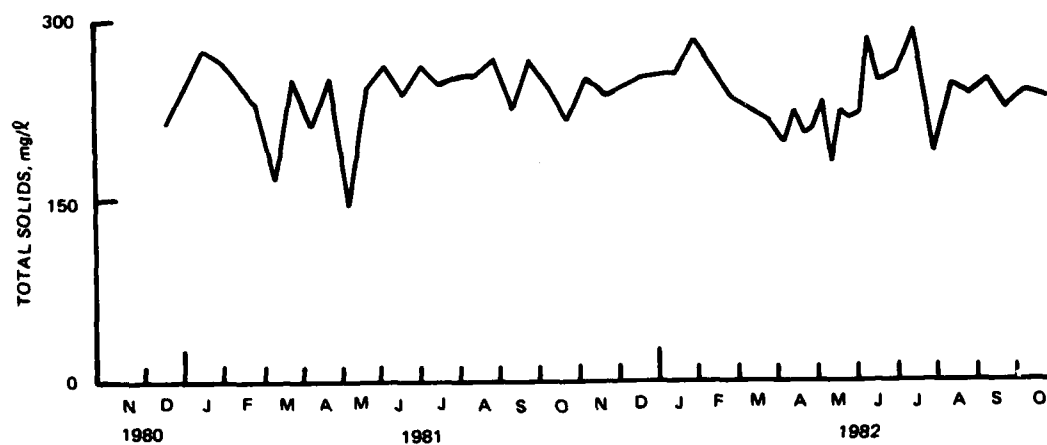
68. Specific conductance and alkalinity exhibited a dilution response in association with the input of runoff water (Figure 16).
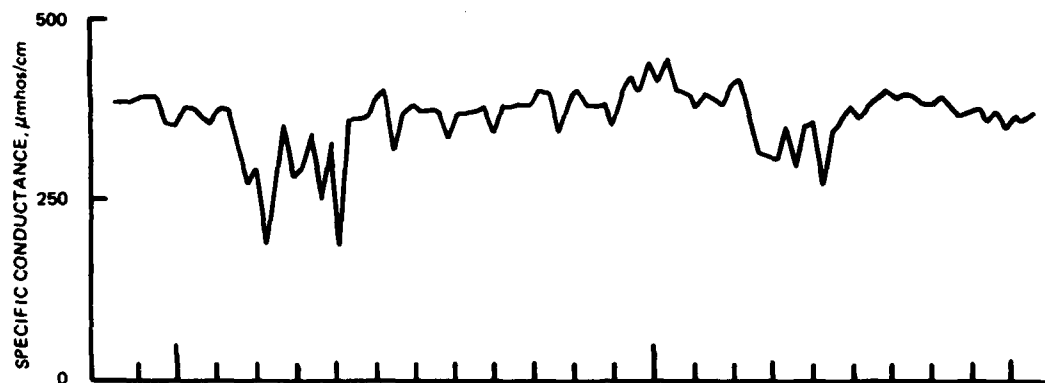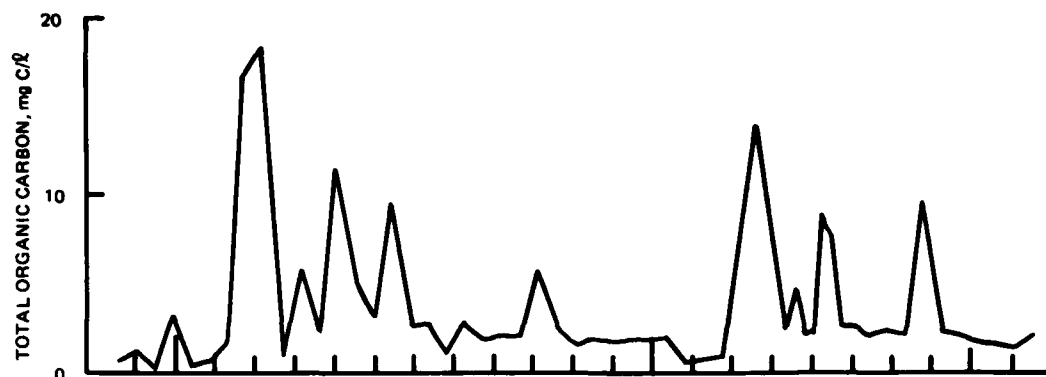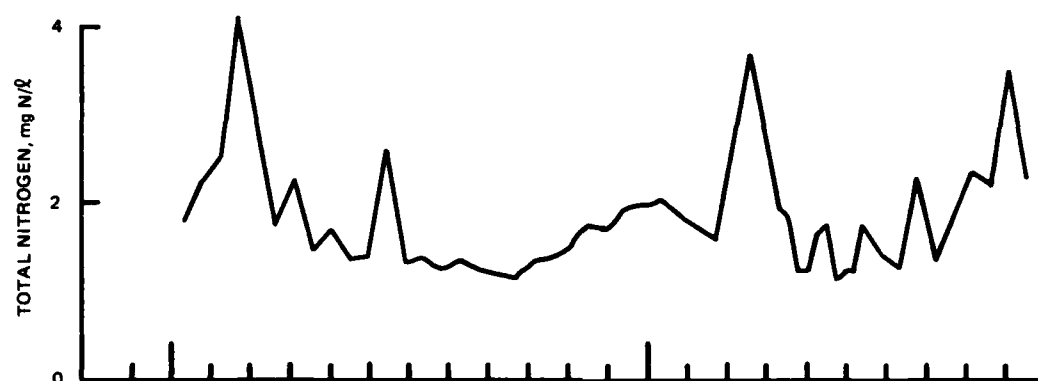
a. Specific conductance
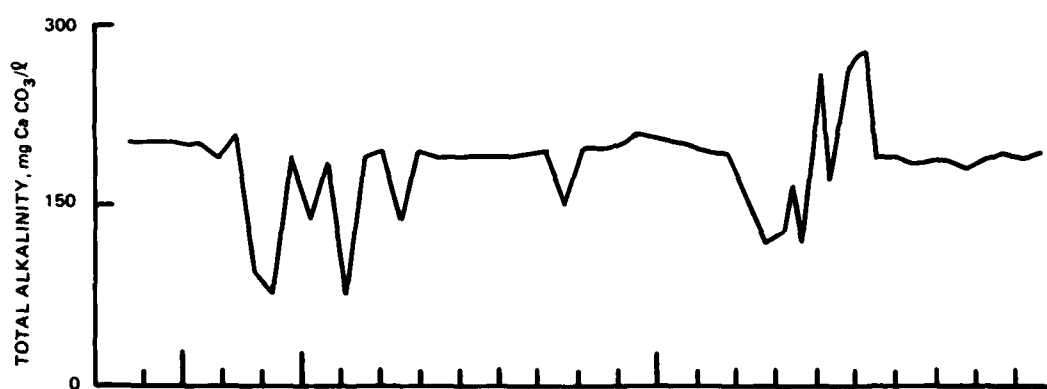
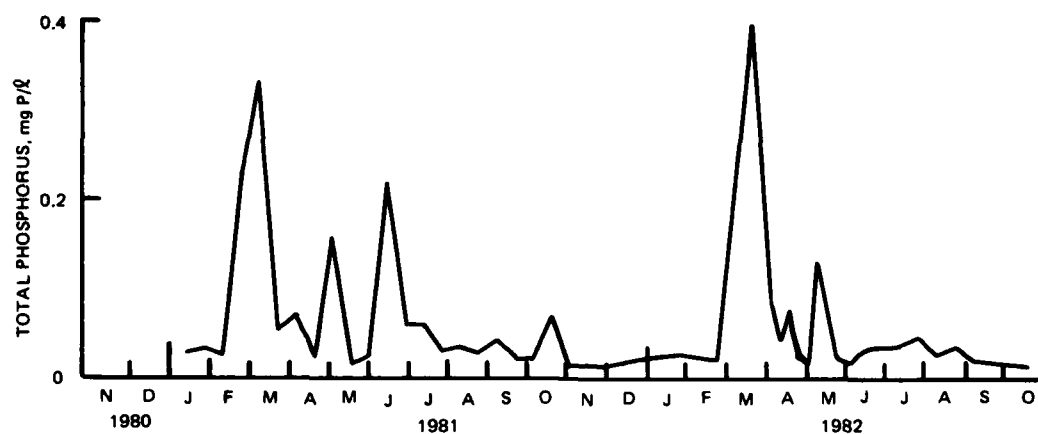b. Total alkalinity

c. Total solids

Figure 11. Seasonal fluctuations in specific conductance,
total alkalinity, and total solids
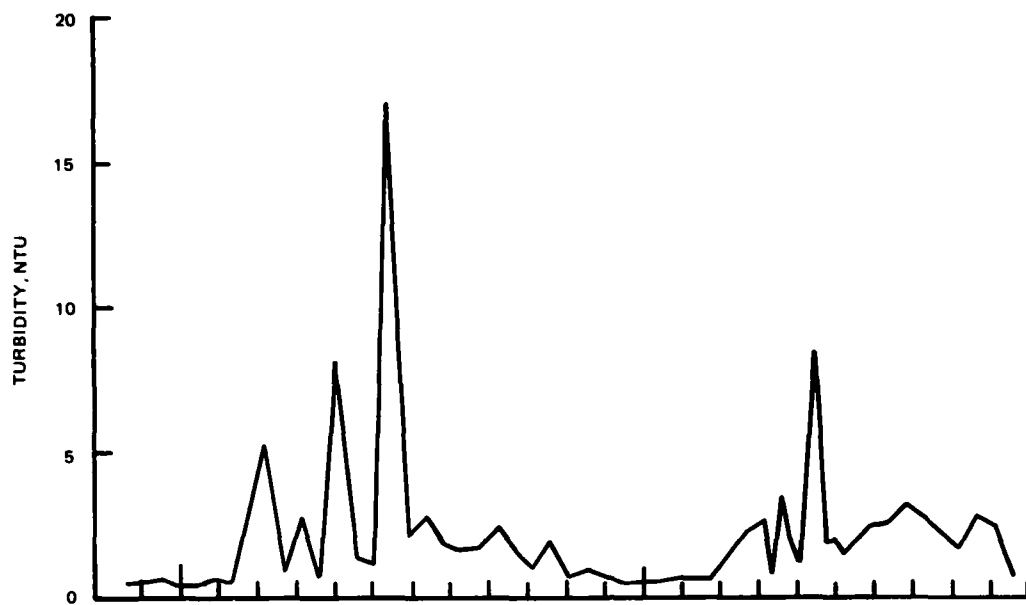
39

a. Total organic carbon
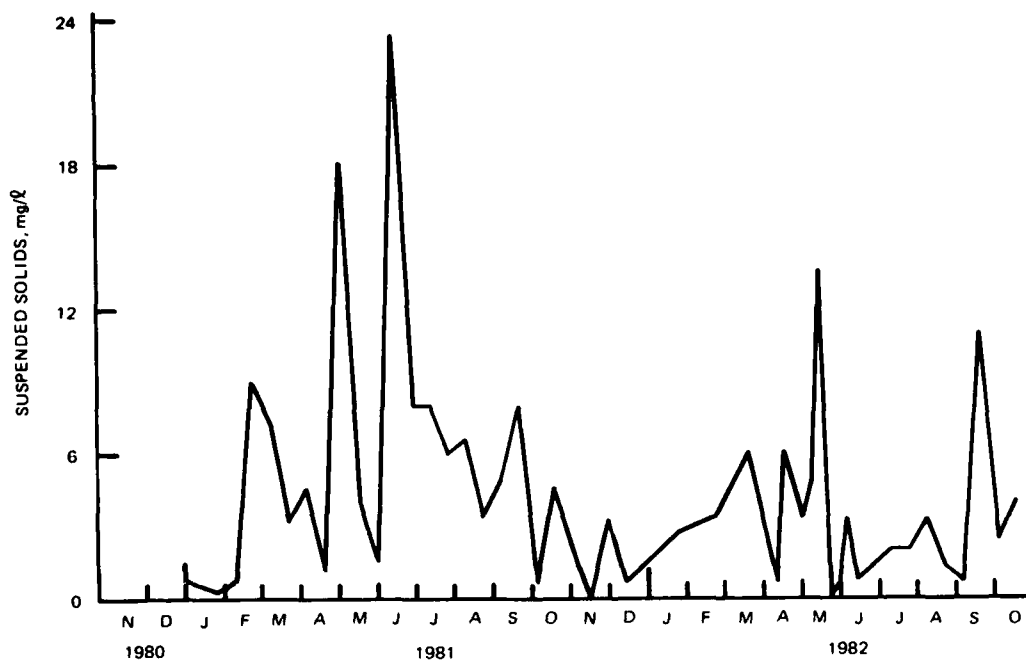
b. Total nitrogen

c. Total phosphorus

Figure 10. Seasonal fluctuations in total organic carbon, total nitrogen, and total phosphorus in the Eau Galle River

38

a. Turbidity

b. Suspended solids

Figure 9.   Seasonal fluctuations in turbidity and suspended
solids in the Eau Galle River

to the runoff (Figure 22). The intrusion of the first peak of the hydrograph (25 March) occurred as an overflow under the ice, resulting in decreased temperatures in the upper 2 m of the lake. With the arrival of the second peak of the hydrograph, temperatures at station 20 were lowered and nearly uniform to a depth of 8.0 m, suggesting the occurrence of mixing. Water column temperatures remained vertically uniform and gradually increased as a result of mixing. A similar response was observed in specific conductance and total alkalinity.

75. Changes in turbidity at station 20 reflect inflow patterns following the arrival of the runoff hydrograph (Figure 23). For instance, a slight increase in turbidity was observed in the upper 2 m on 25 March, in association with the first peak of the hydrograph. Pronounced increases in turbidity occurred on 30 March, coincident with the arrival of the major peak of the hydrograph. Levels were highest at depths of 2 to 6 m on this date. Turbidity values were distributed nearly uniformly by 20 April, suggesting the occurrence of mixing.

76. Phosphorus concentrations at station 20 also changed in response to inputs from the Eau Galle River (Figure 24). Furthermore, the data suggest a high degree of flushing, resulting in a net change in lake concentrations. Following the first peak of the hydrograph, lake total phosphorus concentrations increased dramatically. A maximum observed concentration of 0.600 mg P/ℓ at the surface was comparable to the concentration of total phosphorus observed in the inflow during this period (see Figure 18). Due to the magnitude of the major peak and resultant mixing, increased and nearly uniform phosphorus concentrations were observed throughout the water column on 30 March. Total phosphorus concentrations then declined to approximately 0.130 mg P/ℓ by 20 April due presumably to losses by sedimentation. However, these concentrations were still five times greater than lake concentrations observed before the snowmelt runoff. Total organic carbon exhibited a similar net increase in concentration as a result of the snowmelt runoff.

77. In the outflow, concentrations of turbidity, total organic carbon, and total phosphorus began to increase on 23 March (Figure 25). Peaks in concentration on 30 March coincided with the major peak in the
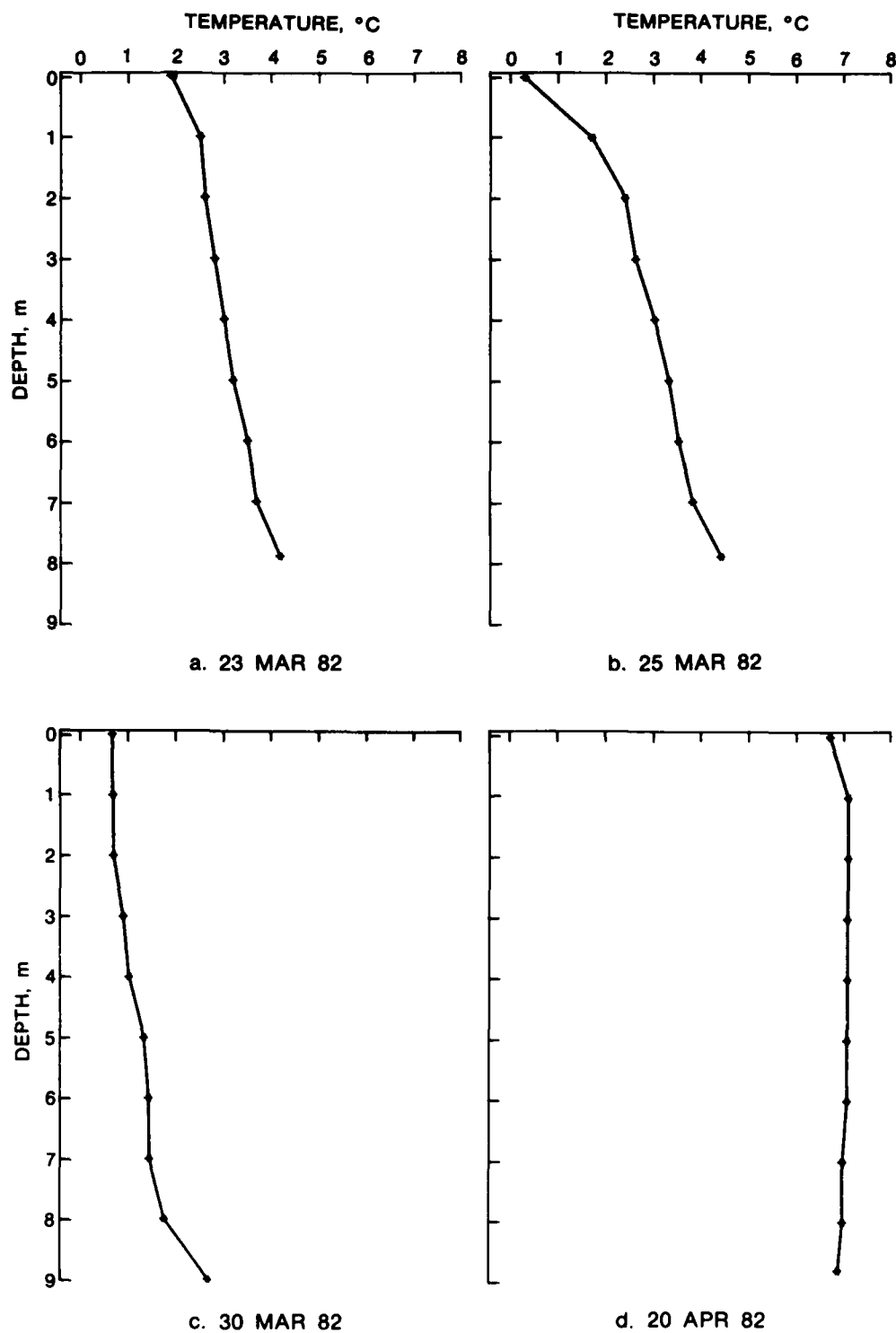
Figure 22. Changes in temperature (°C) profiles at station 20 before (a), during (b and c), and after (d) the 1982 snowmelt event
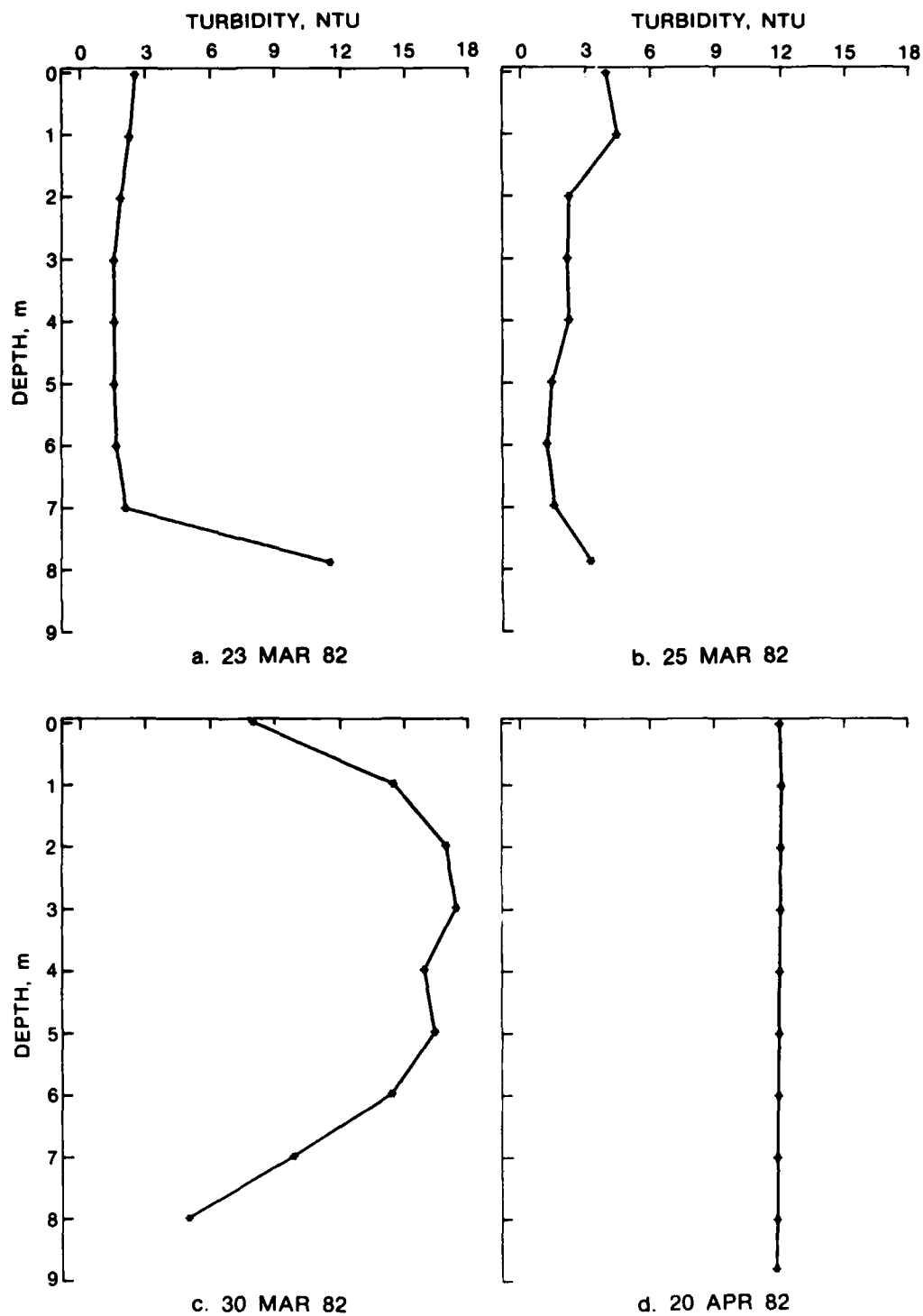
Figure 23. Changes in turbidity (NTU) profiles at station 20 before (a), during (b and c), and after (d) the 1982 snowmelt event
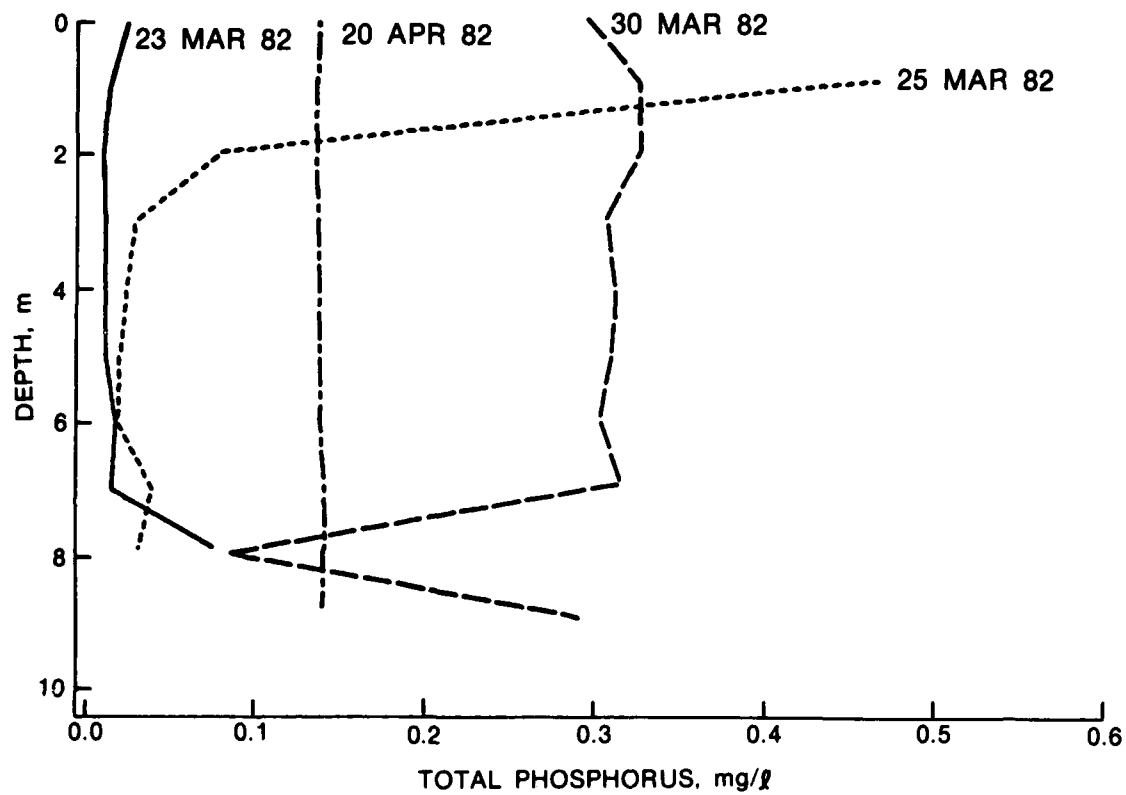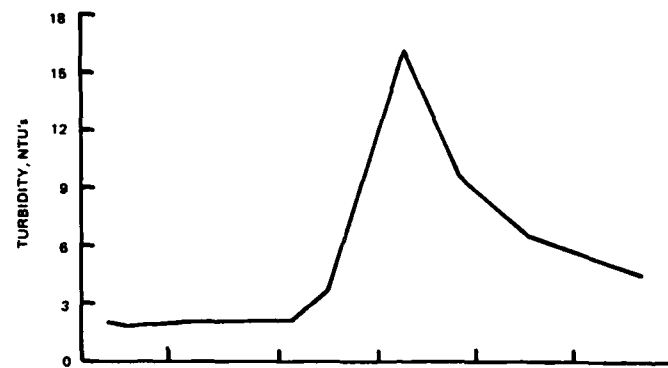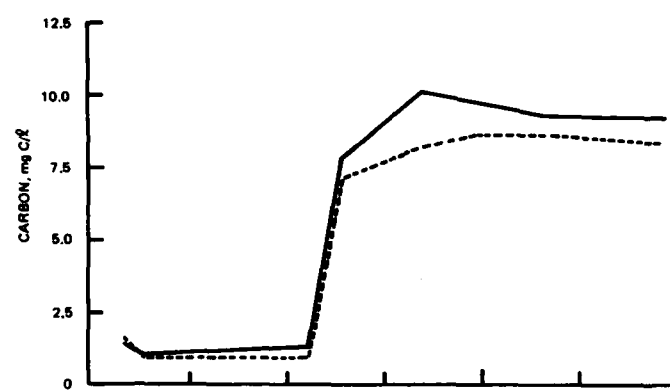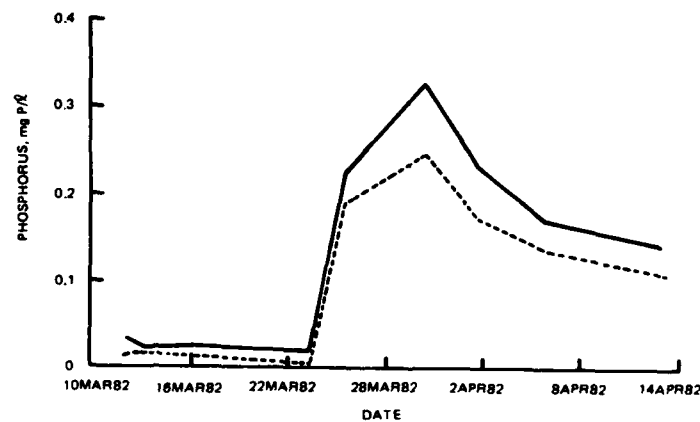
Figure 24. Changes in total phosphorus profiles at station 20 before, during, and after the 1982 snowmelt

a. Turbidity

b. Total and dissolved carbon

c. Total and dissolved phosphorus

Figure 25. Daily fluctuations in turbidity and total (–) and dissolved (---) carbon and phosphorus in the Eau Galle Lake discharge

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hydrograph, suggesting that some of the material load was not retained in the lake.

Discussion

78. An understanding of seasonal patterns in nutrient concentrations and responses to material loads following major inflows provides insight to mechanisms affecting nutrient dynamics in Eau Galle Lake and other reservoirs. Eau Galle Lake, like most reservoirs, receives a majority of its external water and material load from a single tributary. This characteristic, and the fact that loads are seasonally variable, suggests a strong linkage between watershed characteristics, hydrology, and lake water quality.

79. Major variations in biweekly concentrations in the Eau Galle River were associated with fluctuations in discharge resulting from snow-melt runoff and storm events. Data indicate that runoff from hydrologic events resulted in increased levels of turbidity, suspended solids, carbon, nitrogen, and phosphorus. However, concentrations of relatively conservative variables such as specific conductance, total alkalinity, dissolved solids, dissolved silica, sulfate, calcium, and magnesium exhibited marked decreases during these periods.

80. Potential factors contributing to increased concentrations during these periods include watershed land uses and processes occurring within the stream. Land use activities within the watershed which could cause increased nutrient concentrations include extensive dairy operations and associated agriculture. These activities involve the application of fertilizers and manure, which contribute nonpoint sources of nitrogen and phosphorus. In addition, the impervious nature of the soil, which is high in organic matter (see Part III), results in a potentially rapid runoff containing high concentrations of carbon and other nutrients and particulate matter. Increased turbulent flow during periods of runoff would also cause increases in turbidity, suspended solids, and nutrient concentrations due to sediment resuspension and scour of the riverbed.

81. Variables that decreased during high-flow events (Ca^{++}, Mg^{++}, SiO_2, $SO_4^=$, dissolved solids, alkalinity, and specific conductance) were perhaps influenced by availability during runoff. Calcium and magnesium carbonates, along with silicates and sulfates, are abundant within the bedrock and overlying soils and are subject to chemical weathering. However, the impervious nature of the soil contributes to increased surface runoff, thus reducing solubilization and resulting in a dilution of existing concentrations of these minerals and ions. Dissolved forms of these constituents comprise the majority of the total solids and are directly proportional to specific conductance and total alkalinity. Thus, a decrease in Ca^{++}, Mg^{++}, SiO_2, and $SO_4^=$ results in a decrease in total solids, specific conductance, and total alkalinity.

82. Variations in concentration and discharge were most pronounced during the 1982 snowmelt runoff. In northern temperature regions, nutrients may become immobilized or accumulate in the watershed during snowfall and freezing of the ground surface. This in turn can increase the pollutant stores available for release during spring thaw (Colbeck 1981, Johannessen and Henriksen 1978). The presence of leaf litter and agricultural and animal waste on the soil surface under the snowpack can become a potentially greater source of nutrients during runoff because of leaching and solubilization. This appears to be the case for the Eau Galle watershed.

83. Patterns of change in discharge during the 1982 snowmelt runoff were temperature related. The initial peak of the hydrograph occurred after a slight warming trend, which caused meltwater to percolate through the snowpack and into stream channels. The larger, second peak of the hydrograph was produced by complete melting of the snowpack. Due to the large amount of snow, a large quantity of water was released as runoff over a short period of time.

84. Patterns of concentration change suggest distinct temporal differences in the quality of runoff water. For instance, a rapid pulse of primarily dissolved nutrients occurred during the first peak, suggesting the initial runoff of meltwater was highly concentrated with leachate from decaying organic matter and fall defoliage. Field and

laboratory experiments have shown that 50 to 80 percent of the pollutant load can be released with the first 30 percent of the meltwater (Johannessen and Henriksen 1978). This pattern is similar to the initial flushing pattern observed during other high-flow events in which concentrations reach a peak prior to maximum discharge (Verhoff and Melfi 1978).

85. During the second peak of the hydrograph, concentrations decreased as a result of dilution. However, marked increases in the particulate fraction coincident with the major peak in discharge suggest removal of particulate matter from the watershed and resuspension of material from the streambed. In general, highest total concentrations, composed primarily of dissolved fractions, were observed during the first peak, while notable increases in the particulate fraction occurred during the major peak of the hydrograph.

86. Although higher nutrient concentrations were observed during the first peak, major material fluxes occurred during the rising limb of the major peak of the hydrograph. Exemplary of this pattern were changes in the flux of phosphorus. During the rising limb of the hydrograph, 30 percent of the total runoff volume accounted for 42.6 percent (1950 kg) of the total phosphorus flux (4580 kg) for this high-flow event. This percentage was slightly lower than the estimates of Johannessen and Henriksen (1978), but still lends support to the contention that significant loading generally occurs prior to peak flow. This point should be considered when making loading estimates.

87. The tremendous volume of runoff combined with the lake's shallow basin and regulated outflow resulted in mixing and rapid flushing of the spring nutrient load. This was reflected by similar total phosphorus concentrations in the reservoir and in the outflow on 30 March. These concentrations were, however, lower than total phosphorus concentrations observed in the inflow, indicating the effects of dilution, mixing, and sedimentation. The rapid rise in total phosphorus concentrations in the outflow reflects the short hydraulic residence time (less than 1 day) during this period.

Conclusions

88. Reservoirs with large, single tributary inputs are often strongly influenced by episodic loading events. These influences often have a marked impact on nutrient dynamics, deposition, and primary productivity. Monthly or biweekly monitoring of inflow concentrations cannot adequately quantify material loads to a reservoir. Emphasis should be placed on intensive sampling of high-flow events, which contribute the majority of the annual load. Snowmelt runoff can be the greatest single loading event for northern reservoirs. The dramatic changes in nutrient concentrations observed in Eau Galle Reservoir following snowmelt could have profound implications for summer water quality conditions.

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PART VI: PHYSICOCHEMICAL LIMNOLOGY OF EAU GALLE LAKE*

Overview and Design of Study

89.   Limnological studies at Eau Galle Lake were initiated in
November 1980 and continued into October 1982.   This part of the report
presents and discusses physicochemical and phytoplankton pigment data
collected from the reservoir pool on a routine basis throughout this
period.

90.   Sampling station locations were selected based on (a) his-
torical data, (b) intensive short-term pilot studies directed at design-
ing a reservoir sampling program, (c) lake morphometry, and (d) stream
hydrology.   Locations of the six major pool stations and the outflow
station are shown in Figure 26.   Due to the lake's circular shape and
low shoreline development ratio (1.7), a major portion of the reservoir
can be represented by station 20, located at the deepest portion of the
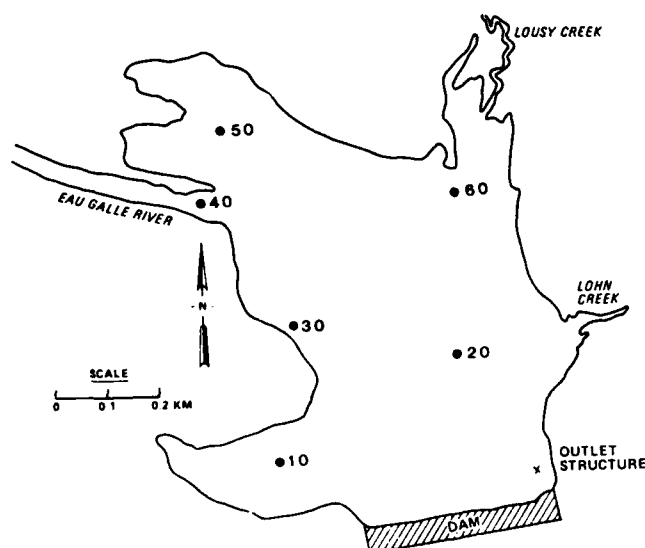reservoir.   Station 20 was located northwest (upstream) of the outlet

Figure 26.   Eau Galle Lake sampling
station locations

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*   Part VI was written by David Johnson and Joseph H. Carroll.

tructure and was 9 m deep at normal pool level. Station 10, located
n 4 m of water, was situated in a cove west of the outlet structure.
tation 30, which was approximately 4 m deep, was located over the old
au Galle River thalweg west of station 20 and 25 m from the west shore.
his area was found to be directly affected by Eau Galle River flows,
articularly during high-flow conditions. Station 40 was located in
he Eau Galle River channel. Depending upon flow conditions, the water
olumn at station 40 varied from primarily river water (high-flow pe-
iods) to primarily lake water (low-flow period). The water column
epth at this station varied from 2.5 to 3 m during the study. A rela-
ively shallow but expansive cove located in the northwest corner of
he reservoir was represented by station 50. This cove is primarily a
ittoral area dominated by macrophytes and ranges from 0.5 to 2 m deep;
he station was 0.9 m deep. Station 60 (1.5 to 2 m deep) was located
djacent to the major northeast cove in the pool. This cove is domi-
ated by inflow from Lousy Creek, the second largest inflow to the
eservoir.

91. The study period spanned two complete annual cycles. Partial
ampling for selected variables began on 4 November 1980 following fall
ixing, and all variables were included by January 1981. The last sam-
ling occurred 19 October 1982, again following fall mixing. Sampling
nd analysis of all variables at all stations were conducted at 2-week
ntervals for the entire study period. In addition, weekly in situ mea-
urements were obtained for dissolved oxygen, temperature, specific con-
luctance, and pH. The 2-week interval was, because of logistics, the
hortest interval possible for the study team and laboratory.

92. All stations, including inflow and outflow, were sampled for
hose chemical and physical variables listed in Table 2 (Part IV) as
ell as for phytoplankton pigments. Samples were collected 0.1 m below
he surface, at 1-m intervals to the bottom, and 0.5 m from the bottom.
luring the second year, metal profiles were modified to include fewer
ample depths. In addition, measurements of water column depth, light
enetration, and Secchi disc transparency were included.

93. A one-way analysis of variance of station differences was performed for data partitioned by time and depth. The data were first grouped by limnological season (fall-mixed, winter-stratified, spring-mixed, and summer-stratified), then split into the mixed layer and the water below the mixed layer or by actual depth intervals (e.g., 0-2 m, 2-4 m, etc.). Delineation of season was based on an interpretation of data for station 20. The mixed layer depth was determined by the DO profiles at station 20. When the variance between stations was significant (i.e., $P \leq 0.05$), rank was determined by Duncan's Multiple Range Test. On this basis, station 40 was found to be significantly different from the other stations for many variables during all seasons of the year (Table 6).

94. Because the analysis of variance indicated a lack of significant differences for all but station 40, station 20 is discussed in greatest detail in the following paragraphs. Station 40 is discussed in light of the differences that were found. Patterns observed at station 20, located in the deepest part of the pool, are therefore representative of the patterns that occurred in the reservoir as a whole. Station 40 was at times similar to the other lake stations, but generally showed the influence of the river. Where other differences were apparent, other stations are discussed.

Temperature

95. Annual variations in water temperature were typical of a dimictic, north-temperate lake (Figure 27). The annual mean temperature was 10.6° C, and temperatures ranged from 0.0° to 29.5° C (Table 7). As expected, lake temperatures were lowest in winter and warmest during summer stratification. Turnover generally occurred in October, with continued mixing until ice formation in December. During this period, mean lake temperatures dropped from an average of 13.2° C in October to 1.2° C by the first week of December (Figure 27). The lake was stratified throughout the period of ice cover during the first year, but isothermal prior to ice-out in 1982 due to high flows resulting from

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Analysis of Variance for Station Differences by Season and Depth

Variable	Depth Interval m	Season			
		Fall	Winter	Spring	Summer
DO	0-2	NS	*	NS	NS
	2-4	NS	NS	NS	*10 GT (6.6)
Temp	0-2	NS	*	NS	NS
	2-4	NS	*40 GT (3.49)	NS	*40 LT (16.2)
SpCond	0-2	*40 GT (363.2)	NS	NS	*
	2-4	*40 GT (368.2)	NS	*40 GT (326.6)	*40 GT (326.1)
TAlk	0-2	*40 (190.0)	NS	*40 GT (131.8)	NS
	2-4	*40 (186.4)	NS	*40 GT (134.3)	*40 GT (178.5)
TP	0-2	NS	NS	*40 LT (0.076)	NS
	2-4	NS	NS	*40 LT (0.075)	NS
SRP	0-2	*40 GT (0.010)	NS	NS	NS
	2-4	*40 GT (0.014)	NS	NS	*40 GT (0.022)
TN	0-2	*40 (1.34) 50 (1.01)	NS	NS	NS
	2-4	*40 GT (1.31)	NS	NS	NS

(Continued)

NS = No significant differences (i.e., $P > 0.05$).
* = Significant differences (i.e., $P \leq 0.05$). If followed by a station number, that station was different than others in the group. Letters indicate if difference was less than LT or greater than GT overall mean. The mean for that station is indicated in parentheses. If no station is indicated after the asterisk, then no station stood out as a result of Duncan's Multiple Range test.

| Variable	Depth Interval m	Season			
		Fall	Winter	Spring	Summer
NO₃	0-2	*40 GT (0.99)	NS	NS	*
	2-4	*40 GT (0.92)	*	*40 GT (1.54)	*40 GT (0.68)
NH₄	0-2	NS	NS	NS	*50 GT (0.057)
	2-4	NS	NS	NS	*
DSi	0-2	*40 GT (8.31)	*	*40 GT (9.2)	NS
	2-4	*40 GT (9.13)	*40 GT (9.13)	*40 GT (9.3)	*40 GT (8.9)
TOC	0-2	NS	NS	*40 LT (5.8)	NS
	2-4	NS	NS	*40 LT (4.9)	*40 LT (4.94)
DOC	0-2	NS	NS	*40 LT (4.5)	NS
	2-4	NS	NS	*30 LT (6.8) 40 (4.7)	*40 LT (3.68)
TFe	0-2	NS	NS	NS	NS
	2-4	NS	NS	NS	NS
ChlA	0-2	*40 LT (12.9)	*50 GT (38.9)	NS	NS
	2-4	*40 LT (10.5) 30 LT (26.6)	NS	NS	*40 LT (16.7)

NS = No significant differences (i.e., $P > 0.05$).
* = Significant differences (i.e., $P \leq 0.05$). If followed by a station number, that station was different than others in the group. Letters indicate if difference was less than LT or greater than GT overall mean. The mean for that station is in parentheses. If no station is indicated after the asterisk, then no station stood out as a result of Duncan's Multiple Range test.

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SUSPENDED SOLIDS, mg/ℓ

a. November 1980-October 1981

b. November 1981-October 1982
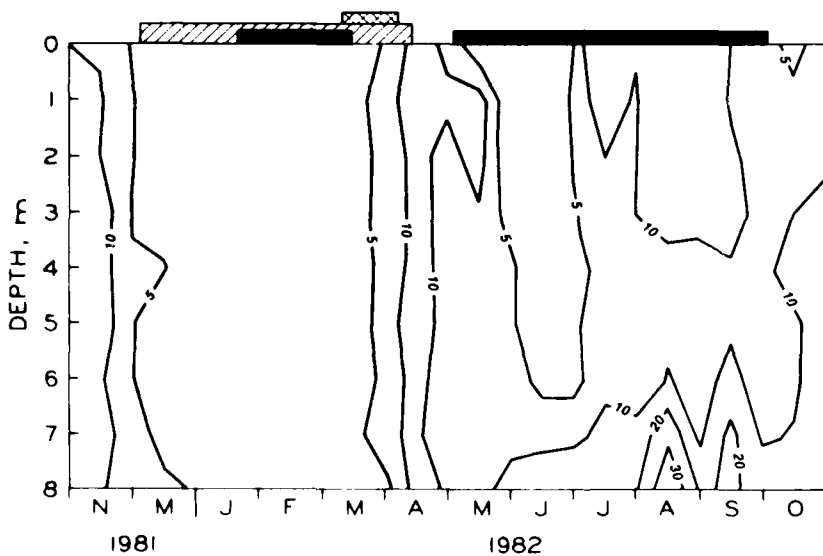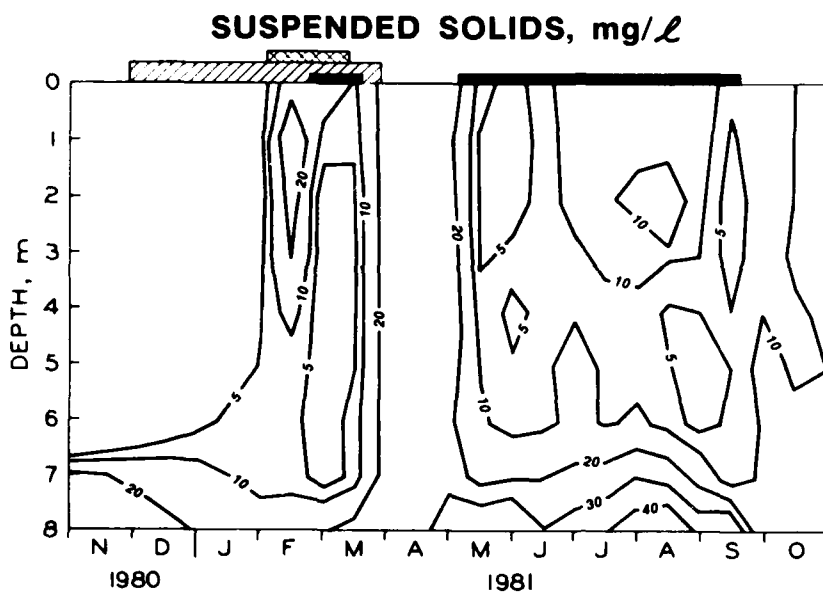
Figure 33. Vertical changes in suspended solids con-
centration for the two study periods. Periods of
anoxia (solid bar), ice cover (hatched bar), and
spring runoff (cross-hatched bar) are indicated.

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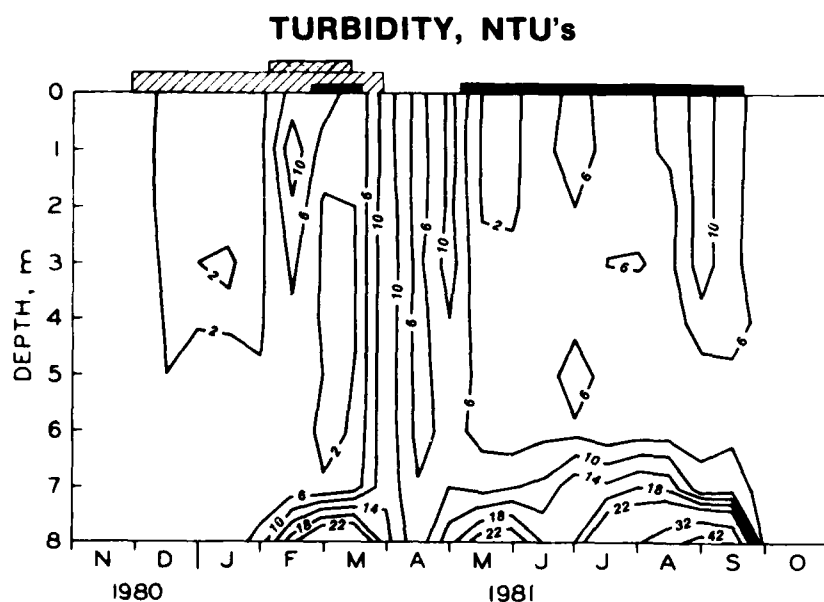
TURBIDITY, NTU's

a.   November 1980-October 1981
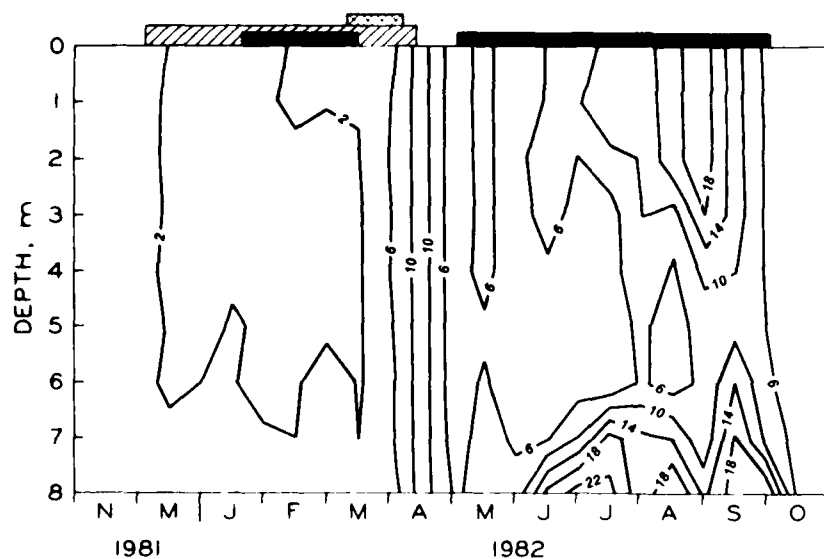
b.   November 1981-October 1982

Figure 32.   Vertical changes in turbidity for the
two study periods.   Periods of anoxia (solid bar),
ice cover (hatched bar), and spring runoff (cross-
hatched bar) are indicated.

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lese cases, maxima coincided with periods of high photosynthetic activ-
:y (Barko et al. 1984). The lowest pH measured (6.5) occurred during
lmmer stratification in bottom waters at station 20. Low pH values
lring this period presumably were the result of the release of CO_2 dur-
lg microbial metabolism.

106. The pH in the reservoir was stable during the fall mixed
>riod and during winter stratification in 1981. In 1982, pH steadily
>clined during these same periods. In the spring of 1981, when ice-out
:curred in early April, there was a major diatom bloom that raised the
{ of the lake to above 9.0. In the spring of 1982, however, ice-out
:curred 3 weeks later with a mixed period of only 10 days duration.
le spring diatom bloom in this year was later and somewhat smaller
3arko et al. 1984); however, similar pH increases were observed.

irbidity

107. Turbidity reflects the amount of suspended particles in
ater and is an index to water clarity. Turbidity was uniformly low
lring the winter stratification period with values as low as 0.3 NTU
it increased to an average of 12.5 NTU during spring as a result of
lowmelt and other high-flow events (Figure 32). During summer stratifi-
ation, values at station 20 ranged from 5 to 60 NTU, with the lowest
alues found in the metalimnion. Means for the epilimnion and the
ypolimnion during this study were 20 and 64 NTU, respectively. The
igh values at the surface at station 20 were influenced by the presence
f phytoplankton and zooplankton while the high values for bottom waters
ere possibly due to the accumulation of suspended particulates. Tur-
idity was relatively low during fall mixing and throughout the winter
neans of 3.9 and 2.8 NTU, respectively).

olids

108. Suspended solids are directly related to turbidity and,
hether their presence is the result of autochthonous or allochthonous
aterial loading, they indicate general water quality. Dissolved solids,
n the other hand, are more closely related to the specific conductance.

109. Suspended solids ranged from 0.0 to 128 mg/ℓ and varied
easonally in a pattern similar to that of turbidity (Figure 33).
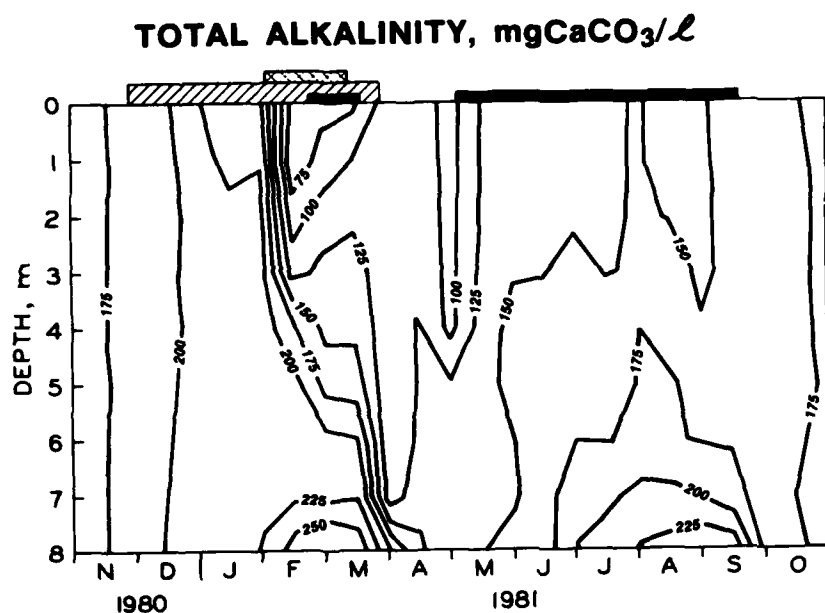
pH
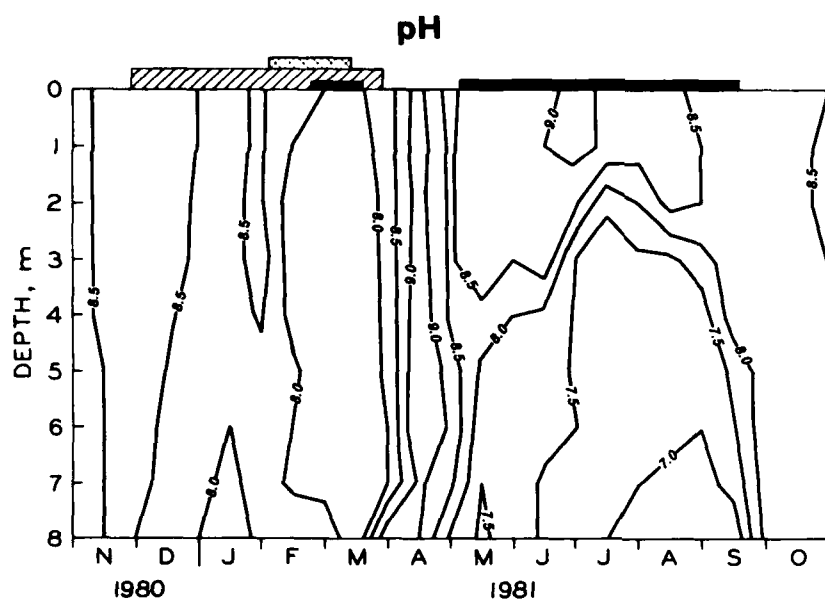
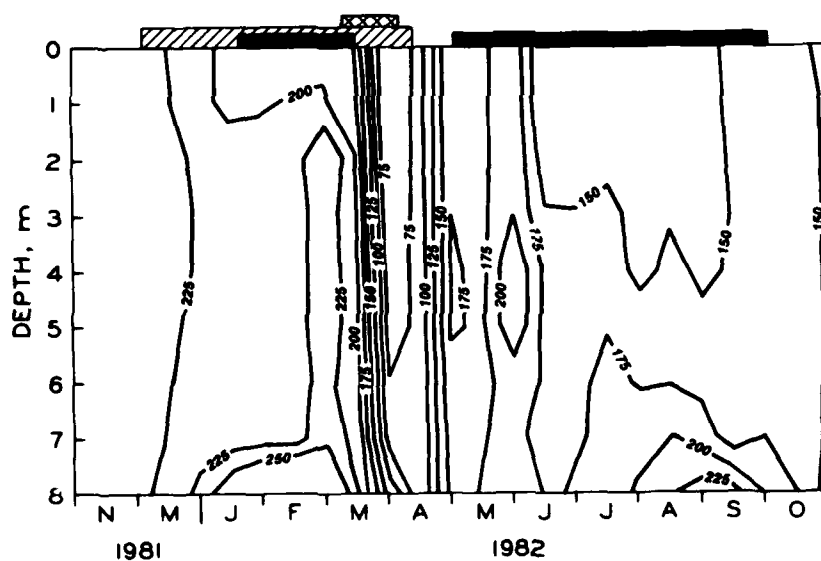a. November 1980-October 1981
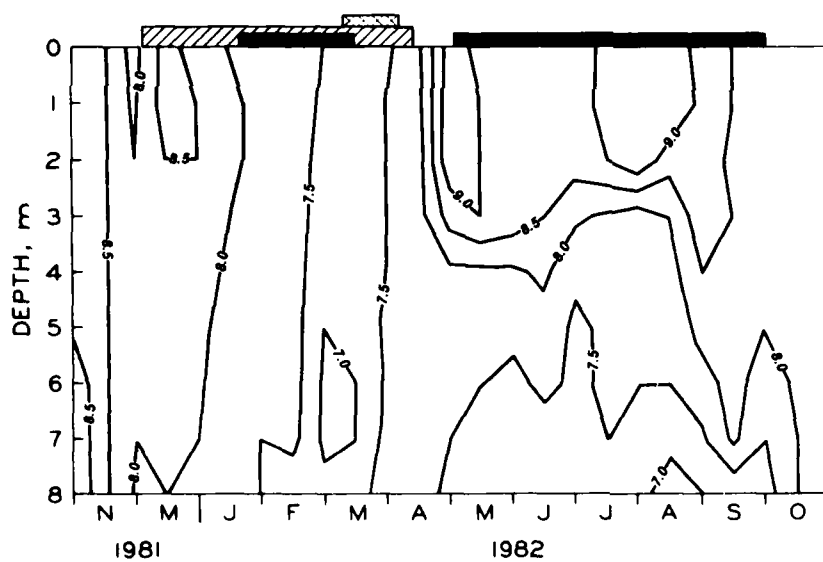
b. November 1981-October 1982

Figure 31. Vertical changes in pH for the two study
periods. Periods of anoxia (solid bar), ice cover
(hatched bar), and spring runoff (cross-hatched bar)
are indicated.

75

TOTAL ALKALINITY, mgCaCO₃/ℓ

a. November 1980-October 1981

b. November 1981-October 1982

Figure 30. Vertical changes in total alkalinity for
the two study periods. Periods of anoxia (solid
bar), ice cover (hatched bar), and spring runoff
(cross-hatched bar) are indicated.

waters had a very high specific conductance as a result of underflowing
river water and the release of nutrients and minerals from sediments and
settling seston. Fall turnover redistributed bottom waters high in spe-
cific conductance and increased the mean conductance for the lake. Con-
ductance continued to rise after fall turnover and through the winter
stratification period due to increased levels in the inflows. During
the winter stratification period, upper lake strata were influenced by
high-conductance river water entering the lake as an overflow. During
this same period, conductivity rose in the hypolimnion due to the re-
lease of NH_3 and soluble reactive phosphorus (SRP) from anoxic
sediments.

Alkalinity

103. Total alkalinity, which is the sum of all titratable bases
and a measure of the buffering capacity of water, was changed by dilu-
tion following spring snowmelt, and in response to anoxia and photosyn-
thetic activity (Figure 30). Alkalinities at station 20 ranged from a
low of 26 mg $CaCO_3/\ell$ during the 1982 snowmelt to 268 mg $CaCO_3/\ell$ in the
hypolimnion during summer stagnation.

104. Seasonal variations in alkalinity were similar to those of
specific conductance, with the lowest seasonal values occurring in the
spring and increasing to a maximum just prior to the next spring snow-
melt. During summer stratification the waters of the mixed layer de-
creased in alkalinity, dropping from more than 180 mg $CaCO_3/\ell$ to at
times less than 125 mg $CaCO_3/\ell$. In the phototrophic zone, high photo-
synthetic activity utilized CO_2, thus reducing the alkalinity; at the
same time, the release of bicarbonate, ammonia, and phosphates in the
tropholytic zone increased the alkalinity in those depths.

pH

105. Changes in lake water pH, which is the measure of the hydro-
gen ion concentration, are the result of photosynthesis, respiration,
and the dissolution of atmospheric CO_2. The pH ranged from 6.5 to 10.8,
with a mean of 8.3 during the course of this study. There were pH
maxima (e.g., pH values above 9) during summer stratification each year
and during the turnover in the spring of 1981 (Figure 31). In each of

73

SPECIFIC CONDUCTANCE, μmhos/cm

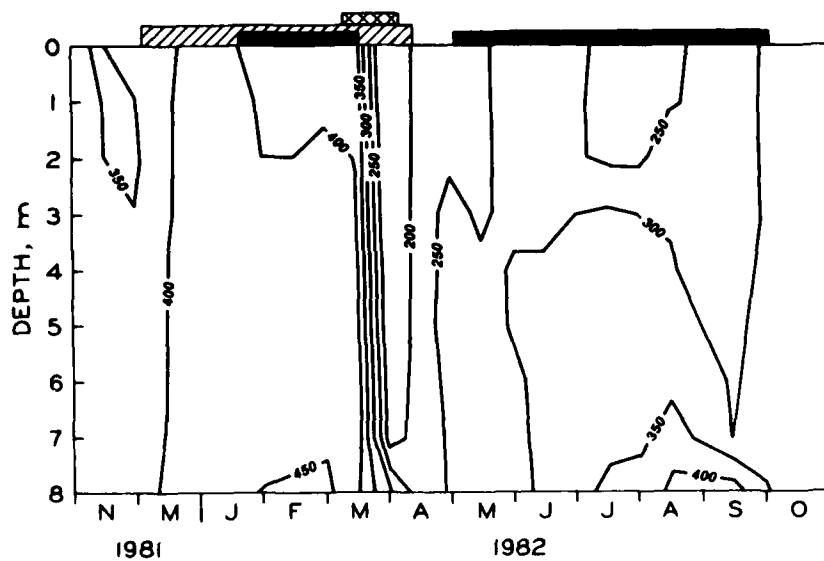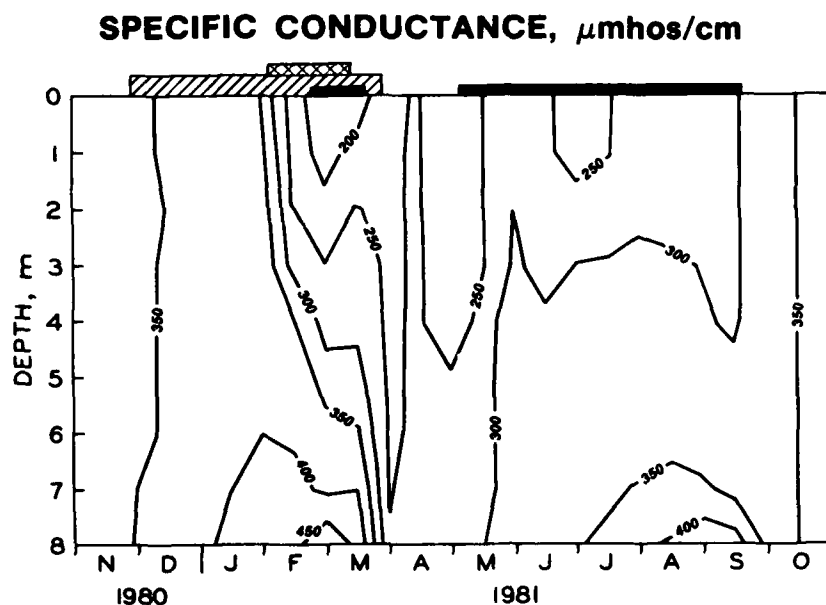a.   November 1980-October 1981

b.   November 1981-October 1982

Figure 29.   Vertical changes in specific conductance
for the two study periods.   Periods of anoxia (solid
bar), ice cover (hatched bar), and spring runoff
(cross-hatched) are indicated.

72

generally occurred in early June and late July of each year and were associated with periods of thermal instability (Gaugush 1984). These episodes were probably prompted by high winds and the passage of cold fronts. Between these periods of instability, the depth experiencing anoxia decreased each year (3 m at station 20 in July 1981 and 4 m in July 1982). Winter anoxia involved only the bottom 1-2 m at station 20 and was probably limited to these depths by temperature and the low-level discharge.

99. The bottom 2 m at stations 10 and 30 also experienced brief periods of oxygen depletion during the summer (16 June to 15 September in 1981 and 20 July to 24 August in 1982). During summer stratification, the bottom waters at stations 30 and 40 frequently had higher oxygen concentrations than at the other stations as a result of the Eau Galle River inflows.

Specific conductance

100. Specific conductance varied seasonally, with maxima occurring during stratification in winter and summer and minima during the spring snowmelt. The mean specific conductance for the reservoir was 319 μmhos/cm and ranged from 95 to 500 μmhos/cm (Figure 29). Bottom waters at station 40 were significantly different than other stations due to the presence of undiluted river water of higher conductance in three of the four seasons. The means for station 40 were 363, 326, and 326 μmhos/cm for fall, spring, and summer, respectively, compared to 344, 266, and 284 μmhos/cm at station 20 for the same seasons.

101. The influx of low-conductance river water diluted lake waters during periods of high flow. Since most of these occurred during spring when the lake was mixed, these events also contributed to the low mean conductance observed each spring. An exception was a major high-flow event that occurred in October 1982 during the fall mixed period.

102. During summer, when flows were greatly reduced and river water entered as an underflow, the epilimnion was effectively isolated from riverine influences and conductivity remained low. High algal productivity during the summer acted to maintain the low conductance of the surface waters by utilizing dissolved minerals and nutrients. Bottom

DISSOLVED OXYGEN, mg/ℓ
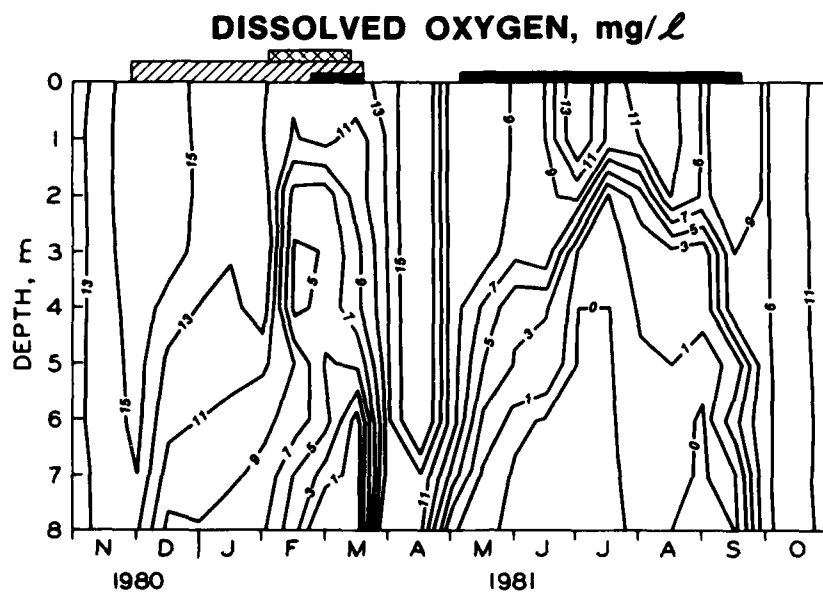
a. November 1980-October 1981
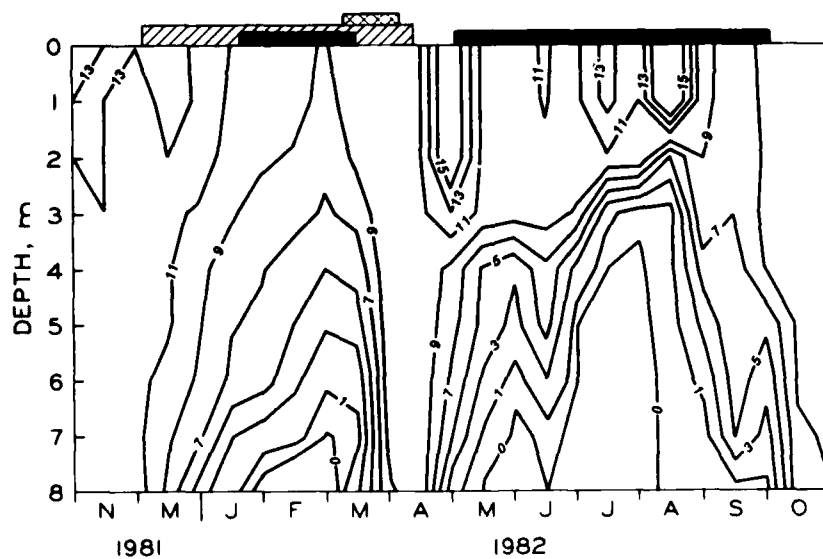
b. November 1981-October 1982

Figure 28. Vertical changes in DO for the two study
periods. Periods of anoxia (solid bar), ice cover
(hatched bar), and spring runoff (cross-hatched bar)
are indicated.

70

snowmelt. Temperatures during winter ranged from near 0.0° C just below the ice to 3.5° C near the bottom at station 20.

96. The spring mixed periods, which began after ice-out in 1981 (7 April) and during snowmelt in 1982 (30 March), lasted until the first week of May each year. The mean temperature was 7.7° C (range from 5.8° to 9.3° C) in the spring of 1981 but averaged 4.6° C in 1982 (range from 1.7° to 7.2° C). The mixed period after ice-out lasted 3 weeks the first year and only 10 days the second year. Summer stratification lasted 23 and 24 weeks for the 2 years of study, respectively.

97. Two factors affected the temperature profiles of Eau Galle Reservoir during the summer stratified period. The first was that the river entered the lake as an underflow at station 40. Underflows continued at station 30 then spread across the lake as an interflow at a depth of between 3 and 4 m.* This, coupled with the low-level discharge, created a situation where the average temperature in the hypolimnion increased throughout the period of stratification (e.g., 8.1° C in May 1982 to 13.7° C in September 1982). This situation produced a lake of low thermal stability which was then subject to deep mixing during wind events (Gaugush 1984).

Dissolved oxygen

98. Dissolved oxygen concentrations ranged from zero in bottom waters during summer stratified periods to a surface maximum of 20.6 mg/ℓ during a period of high algal productivity. The annual mean was 9.8 mg/ℓ. The reservoir annually experienced two periods of anoxia coincident with periods of stratification. Major periods of anoxia coincided with summer stratification at station 20 (5 May to 29 September in 1981 and 4 May to 5 October in 1982) (Figure 28). There was also a period of anoxia at station 20 during winter stratification which lasted from 24 Feb to 31 March in 1981 and for a longer period (26 January to 23 March) during the winter of 1982. There were two or three periods each summer when the depth of anoxia moved downward. These periods

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* Personal Communication, 1984, M. Johnson, Civil Engineer, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Table 7 (Concluded)

Variable		Yearly	Fall	Winter	Spring	Summer
DNa	Mean	2.53	2.02	2.45	2.93	2.63
(mg/ℓ)	Max	6.90	3.30	4.80	3.40	6.90
	Min	0.90	1.50	1.00	0.90	1.80
TK	Mean	3.19	3.09	3.16	4.39	3.11
(mg/ℓ)	Max	20.00	6.30	20.00	5.10	11.00
	Min	0.70	1.00	0.70	2.00	1.40
DK	Mean	2.73	2.1	3.23	4.08	2.47
(mg/ℓ)	Max	16.00	3.2	16.00	4.60	4.60
	Min	0.60	1.2	0.60	1.70	1.10
TFe	Mean	0.67	0.312	0.375	0.76	0.956
(mg/ℓ)	Max	16.00	6.300	5.800	2.00	16.000
	Min	0.00	0.000	0.000	0.20	0.000
DFe	Mean	0.19	0.004	0.021	0.080	0.362
(mg/ℓ)	Max	11.50	0.200	2.70	0.300	11.500
	Min	0.00	0.000	0.000	0.000	0.000
TMn	Mean	0.38	0.171	0.257	0.130	0.558
(mg/ℓ)	Max	8.40	3.100	5.000	0.800	8.400
	Min	0.00	0.000	0.000	0.000	0.000
DMn	Mean	0.27	0.039	0.190	0.065	0.413
(mg/ℓ)	Max	5.20	0.300	5.200	0.200	5.200
	Min	0.00	0.000	0.000	0.000	0.000
ChlA	Mean	29.45	28.21	12.20	27.69	40.02
(mg/m^3)	Max	281.95	52.48	281.95	81.64	197.25
	Min	0.05	2.48	0.05	0.77	1.15
ChlB	Mean	1.42	1.36	0.71	2.21	1.80
(mg/m^3)	Max	7.44	4.87	7.41	7.05	7.44
	Min	0.00	0.00	0.00	0.09	0.00
ChlC	Mean	6.35	7.93	3.95	6.36	7.45
(mg/m^3)	Max	65.95	27.04	36.85	28.01	65.95
	Min	0.00	0.75	0.00	0.00	0.00
Phaeo	Mean	1.90	1.52	0.96	0.838	2.68
(mg/m^3)	Max	44.83	6.41	32.63	2.720	44.83
	Min	0.00	0.00	0.00	0.000	0.00

(Sheet 3 of 3)

Table 7 (Continued)

Variable		Yearly	Fall	Winter	Spring	Summer
NO_3	Mean	0.553	0.667	1.260	1.046	0.215
(mg N/ℓ)	Max	1.989	1.499	1.990	1.683	1.320
	Min	0.000	0.299	0.005	0.424	0.000
NH_4	Mean	0.326	0.094	0.227	0.110	0.435
(mg N/ℓ)	Max	10.810	0.326	2.960	0.202	10.810
	Min	0.000	0.000	0.000	0.000	0.000
DSi	Mean	6.88	6.14	8.30	7.10	6.250
(mg Si/ℓ)	Max	15.20	10.25	14.50	9.66	15.200
	Min	0.32	2.83	1.74	2.20	0.320
TOC	Mean	6.66	4.53	4.80	8.26	8.00
(mg C/ℓ)	Max	35.10	8.20	35.10	10.90	17.20
	Min	0.20	0.00	0.20	3.30	1.90
DOC	Mean	4.90	2.45	4.50	7.40	5.44
(mg C/ℓ)	Max	33.20	7.80	33.20	9.80	13.30
	Min	0.00	0.50	0.30	2.70	0.00
SO_4	Mean	8.30	5.84	9.23	9.70	8.39
(mg/ℓ)	Max	19.40	10.30	19.40	12.90	19.40
	Min	0.00	0.00	0.10	2.60	0.00
TSul	Mean	0.04	0.00	0.029	0.00	0.05
(mg/ℓ)	Max	2.70	0.00	2.700	0.00	1.40
	Min	0.00	0.00	0.000	0.00	0.00
TCa	Mean	39.61	43.78	46.69	28.46	34.85
(mg/ℓ)	Max	440.00	68.00	107.00	42.00	440.00
	Min	7.50	32.00	12.00	7.50	18.00
DCa	Mean	34.13	36.35	41.76	24.29	29.5
(mg/ℓ)	Max	54.00	46.00	54.00	33.00	49.0
	Min	2.60	29.00	2.60	7.40	16.0
TMg	Mean	20.88	22.1	23.0	11.38	20.06
(mg/ℓ)	Max	40.00	36.0	33.0	16.00	40.00
	Min	2.30	16.0	7.0	2.30	7.40
DMg	Mean	19.82	21.2	22.0	10.99	18.84
(mg/ℓ)	Max	32.00	27.0	32.0	15.00	25.00
	Min	2.10	18.0	7.0	2.10	8.40
TNa	Mean	3.07	2.73	2.84	3.70	3.20
(mg/ℓ)	Max	6.80	4.00	6.80	4.60	6.60
	Min	1.40	2.10	1.40	1.90	2.20

(Continued)

(Sheet 2 of 3)

Table 7

Means, Maxima, and Minima for All Years, by Season, All Stations and Depths Pooled

Variable		Yearly	Fall	Winter	Spring	Summer
Temp	Mean	10.57	6.63	2.52	6.02	17.70
(°C)	Max	29.50	14.10	7.70	9.30	29.50
	Min	0.00	1.50	0.00	1.70	7.60
DO	Mean	9.75	11.68	11.06	11.99	8.11
(mg/ℓ)	Max	20.60	16.00	20.00	16.90	20.60
	Min	0.00	5.10	0.00	8.70	0.00
SpCond	Mean	319.0	343.90	369.50	226.60	248.60
(μmhos/	Max	500.00	459.00	462.00	361.00	500.00
cm)	Min	95.00	305.00	95.00	109.00	191.00
TAlk	Mean	163.75	177.40	184.50	94.96	155.7
(mg Ca	Max	268.00	205.00	268.00	140.00	266.0
CO_3/ℓ)	Min	26.00	156.00	56.00	26.00	77.0
pH	Mean	8.3	8.3	8.1	8.1	8.4
(std.	Max	10.8	8.7	10.8	9.4	9.8
Units)	Min	6.5	7.3	6.8	7.4	6.5
Turb	Mean	6.21	3.89	2.82	9.08	8.42
(NTU)	Max	64.00	8.20	31.00	13.00	64.00
	Min	0.30	0.60	0.30	1.70	1.20
TS	Mean	214.69	227.80	239.10	165.30	205.83
(mg/ℓ)	Max	534.00	266.00	306.00	246.00	534.00
	Min	44.00	204.00	120.00	44.00	92.00
TSS	Mean	10.70	9.53	5.85	12.97	12.40
(mg/ℓ)	Max	128.95	22.00	32.00	25.70	128.95
	Min	0.00	0.00	0.00	2.00	0.00
TP	Mean	0.123	0.039	0.108	0.139	0.147
(mg P/ℓ)	Max	2.301	0.074	0.840	0.187	2.301
	Min	0.015	0.018	0.015	0.071	0.022
SRP	Mean	0.039	0.004	0.046	0.062	0.042
(mg P/ℓ)	Max	1.537	0.024	0.387	0.135	1.537
	Min	0.000	0.000	0.000	0.004	0.00
TN	Mean	1.802	1.197	2.211	1.990	1.738
(mg N/ℓ)	Max	17.960	1.542	5.790	2.274	17.960
	Min	0.540	0.716	0.860	1.012	0.540

(Continued)

(Sheet 1 of 3)

66

TEMPERATURE, °C

a. November 1980-October 1981

b. November 1981-October 1982
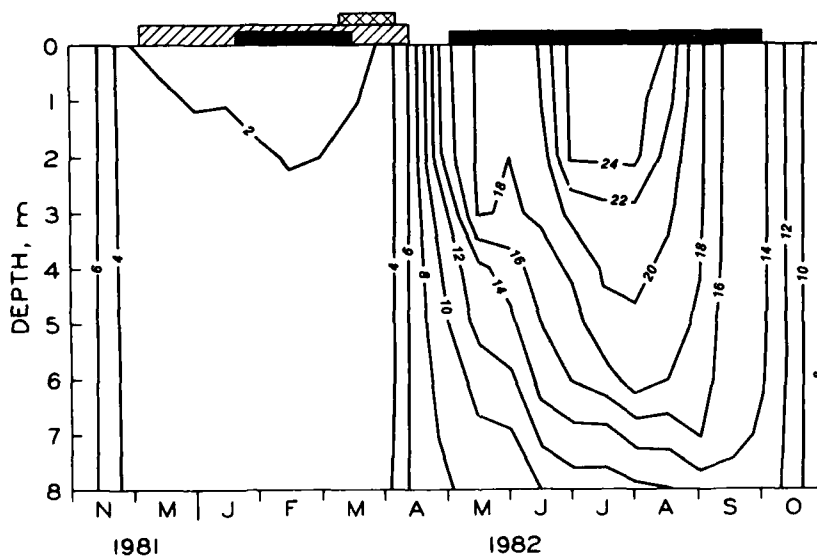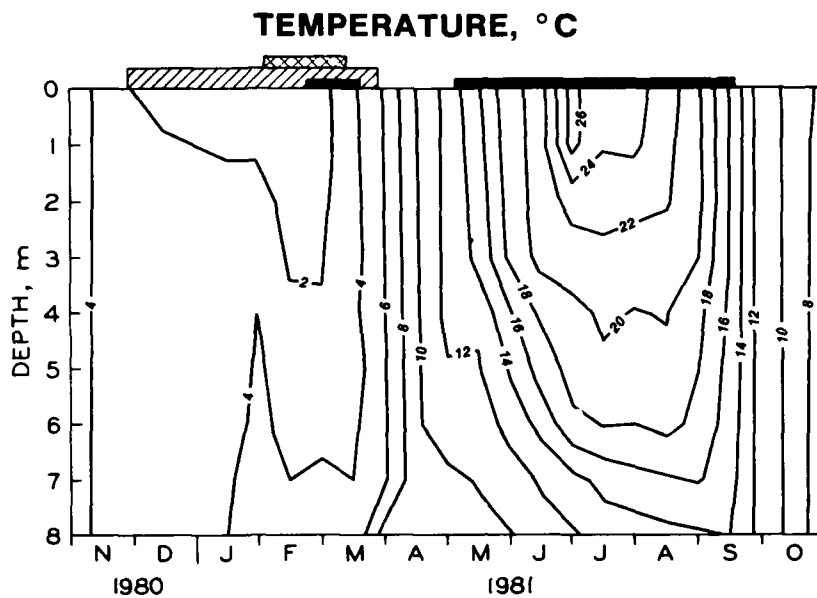
Figure 27. Vertical changes in temperature for the
two study periods. Periods of anoxia (solid bar),
ice cover (hatched bar), and spring runoff (cross-
hatched bar) are indicated.

65

Concentrations were lowest during winter stratification (less than 10 mg/ℓ in 1981 and less than 5 mg/ℓ in 1982) due to low productivity in the lake and low tributary loadings. Suspended solid concentrations increased markedly, however, during snowmelt, reflecting high material loadings associated with this high-flow event. During summer stratification, suspended solids levels in the epilimnion decreased; a summer metalimnetic minimum in suspended solids, similar to the pattern in turbidity, was also apparent. Suspended solids below a depth of 7 m were high during both summers (40 mg/ℓ in 1981 and over 30 mg/ℓ in 1982). Like turbidity, suspended solids levels were elevated in the phototrophic zone due to phytoplankton blooms. This was especially noticeable during the diatom bloom which occurred during April and May 1981. Suspended solids were low during fall turnover with a mean of 9.5 mg/ℓ and concentrations decreased throughout the period of fall mixing.

110. Changes in total solids were similar to those of specific conductance and alkalinity, with values ranging from 44 to 534 mg/ℓ and having a mean of 214.7 mg/ℓ (Figure 34). Levels were above 225 mg/ℓ during the fall mixed period and rose somewhat (to 250 mg/ℓ) in winter with some depth-related differences accompanying winter stratification (values ranging from 225 mg/ℓ at the surface to 275 mg/ℓ at the bottom). Levels dropped during spring snowmelt (220 mg/ℓ in 1981 and 130 mg/ℓ in 1982) and remained less than 200 mg/ℓ through the spring mixed period. In the period of summer stratification, total solids remained less than 200 mg/ℓ in the mixed layer with some peaks (>250 mg/ℓ) near the surface, but rose sharply in the hypolimnion to levels above 300 mg/ℓ.

Soluble reactive phosphorus

111. Soluble reactive phosphorus is the most readily utilizable form of phosphorus for phytoplankton, and its annual dynamics are often closely tied to those of iron and manganese. SRP concentrations varied seasonally in both the mixed layer and the hypolimnion (Figure 35). In general, concentrations were low (0.012 mg P/ℓ) during winter stratification, increased due to the high loading from snowmelt runoff (0.200 mg P/ℓ), and then decreased to less than 0.050 mg P/ℓ during spring mixing. Concentrations decreased in summer in the mixed layer reaching only

79
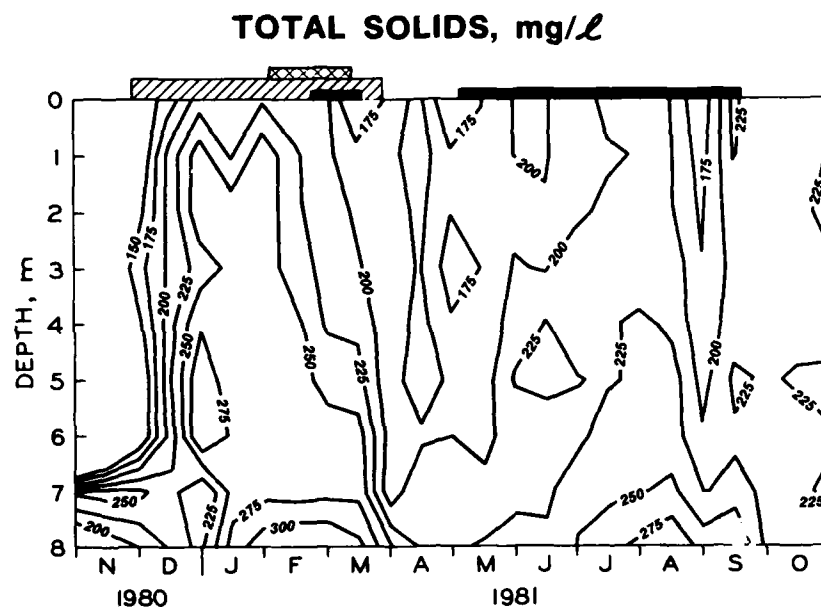
TOTAL SOLIDS, mg/ℓ

a. November 1980-October 1981
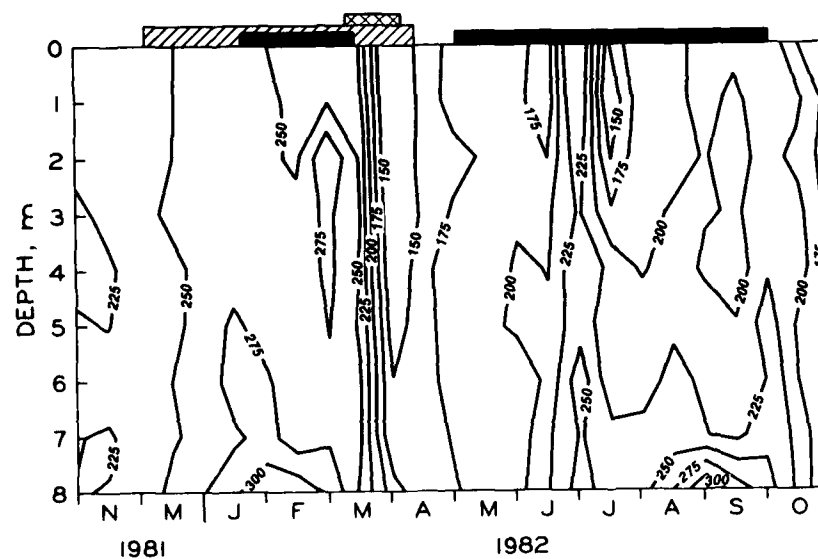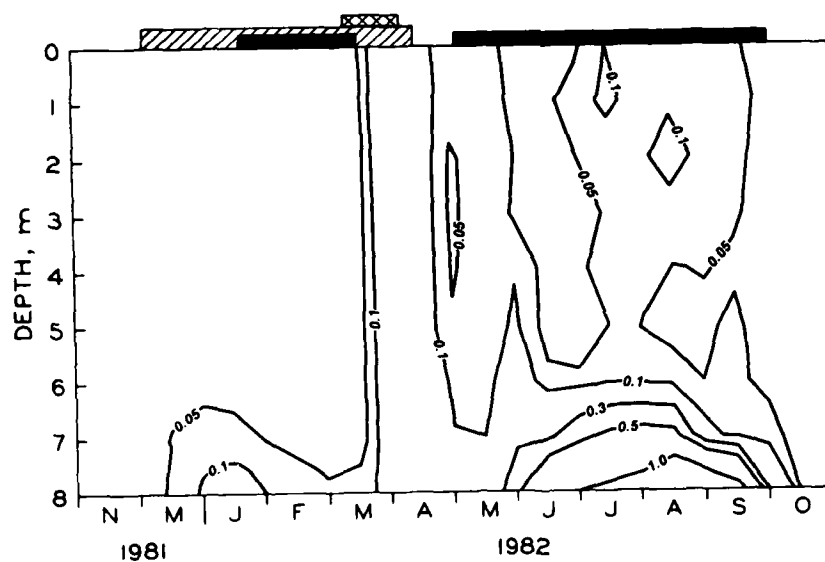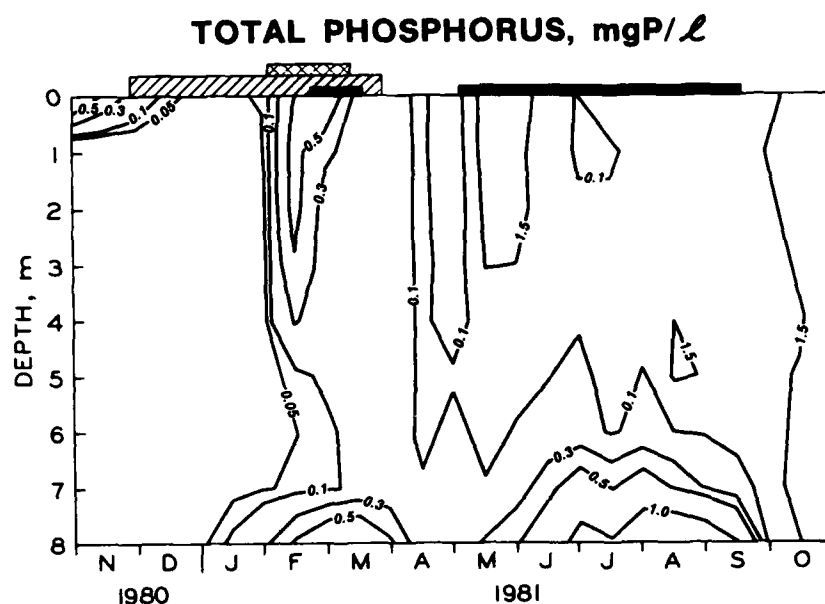
b. November 1981-October 1982

Figure 34. Vertical changes in total solids concentration for the two study periods. Periods of anoxia (solid bar), ice cover (hatched bar), and spring runoff (cross-hatched bar) are indicated.

80

SOLUBLE REACTIVE PHOSPHORUS, mg P/ℓ

a.   November 1980-October 1981

b.   November 1981-October 1982
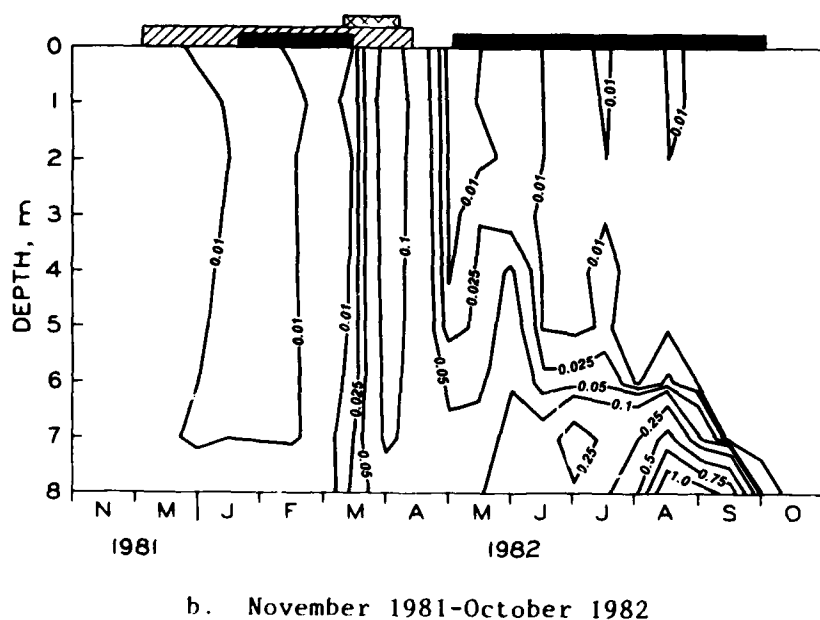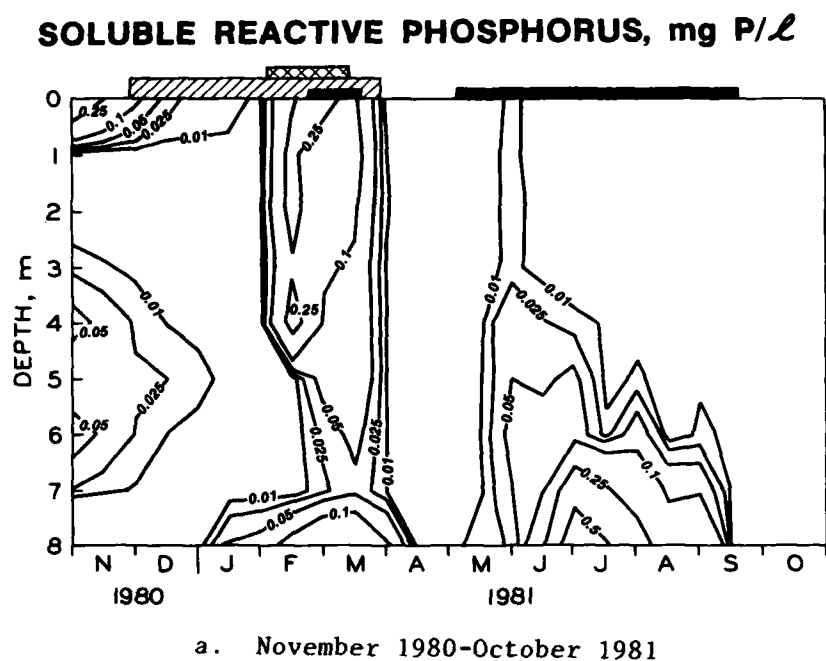
Figure 35.   Vertical changes in soluble reactive phos-
phorus for the two study periods.   Periods of axoxia
(solid bar), ice cover (hatched bar), and spring run-
off (cross-hatched bar) are indicated.

trace levels (>0.005 mg P/ℓ) as a result of utilization by phytoplankton. In contrast, concentrations in the anoxic bottom waters rose to over 0.700 mg P/ℓ. These high levels were due, in part, to the release of phosphorus from settling seston but mostly to release from the sediments. Fall mixing resulted in sharp declines in SRP. This was due presumably to co-precipitation with iron and manganese. This annual event acts to enrich sediments with iron, phosphorus, and manganese, while controlling the levels of phosphorus in the lake.

112. SRP concentrations at station 40 were significantly different from those of other stations during the fall and summer seasons. During fall they were significantly higher for the entire column depth with a mean of 0.012 mg P/ℓ compared to the lake mean of 0.004 mg P/ℓ. SRP was also significantly higher at station 40 during summer below a depth of 2 m due to the fact that the river entered the lake as an underflow. Average summer SRP values below a depth of 2 m at station 40 were 0.022 mg P/ℓ compared to 0.011 mg P/ℓ for the rest of the lake.

Total and total soluble phosphorus

113. Total phosphorus (TP) (Figure 36) and total soluble phosphorus (TSP) exhibited seasonal patterns similar to those for SRP with measured values ranging from 0.015 to 2.3 mg P/ℓ for total phosphorus and from <0.005 to 1.53 mg P/ℓ for total soluble phosphorus. The highest mean seasonal values for both TP and TSP in the mixed layer occurred during snowmelt runoff. In contrast, highest hypolimnetic concentrations were observed during summer stratification. The lowest mean seasonal values in both layers were measured during the winter of 1982. Because snowmelt and the accompanying high phosphorus loading occurred in late February and early March 1981, the mean seasonal values for that winter were much higher than those of 1982.

114. Prior to the arrival of snowmelt runoff, TSP concentrations were relatively high. However, with the arrival of melt water the proportion of the TP concentration represented by particulate phosphorus increased. TP concentrations, which averaged 0.50 mg P/ℓ during the early stages of runoff, dropped to 0.40 mg P/ℓ during the highest flow period. Similarly, TSP was measured at 0.40 mg P/ℓ in the early stages

82

TOTAL PHOSPHORUS, mgP/ℓ

a. November 1980-October 1981

b. November 1981-October 1982

Figure 36. Vertical changes in total phosphorus for the two study periods. Periods of anoxia (solid bar), ice cover (hatched bar), and spring runoff (cross-hatched bar) are indicated.

of runoff and dropped to 0.20 mg P/ℓ during highest flow.

115. Pronounced vertical gradients in TP and TSP occurred during summer stratification. In the mixed layer, TSP decreased to levels at or below detection limit (0.01 mg P/ℓ), while TP increased slightly due to suspended particulate phosphorus. Waters below the mixed layer exhibited high concentrations of both TSP (0.15 mg P/ℓ) and TP (2.30 mg P/ℓ). These values were the highest measured in the reservoir and were due to the release of phosphorus from the sediments and seston.

116. Fall mixing and the reaeration of the phosphorus-rich hypolimnion resulted in marked declines in phosphorus concentrations. Coincident declines in iron and manganese suggest the importance of the coprecipitation of phosphorus with metal complexes. These events deposited phosphorus in sediments and lowered reservoir TP concentrations to less than 0.050 mg P/ℓ. Phosphorus concentrations were generally low during winter stratification despite the occurrence of short periods of anoxia and the concomitant release of iron and phosphorus. These releases, however, were not as extensive as during the summer.

117. Significant differences in TP concentrations between stations were noted only during spring, when TP was lowest at station 40. Concentrations at station 40 averaged 0.076 mg P/ℓ, while the lake mean was 0.139 mg P/ℓ.

Total nitrogen

118. Nitrogen is found in several forms in natural waters, including nitrate, nitrite, ammonia, and organic nitrogen. Total nitrogen (TN), which is comprised of these forms, ranged from 0.54 mg N/ℓ to 17.96 mg N/ℓ in the lake with a mean of 1.80 mg N/ℓ (Figure 37). Patterns of change in concentration were similar to those for TP, with maxima of 5.0 mg N/ℓ in the mixed layer as a result of snowmelt runoff and 17.0 mg N/ℓ during summer in the hypolimnion as a result of seston settling and ammonia release from sediments. Seasonal lows (<1.0 mg N/ℓ) occurred during summer stratification in the mixed layer, while the hypolimnetic waters experienced lows during fall turnover (to 1.2 N mg/ℓ). Fall mixing redistributed nitrogen, which previously was stored in anoxic waters, throughout the water column with some losses to the sediments.

TOTAL NITROGEN, mgN/ℓ

a. November 1980-October 1981

b. November 1981-October 1982
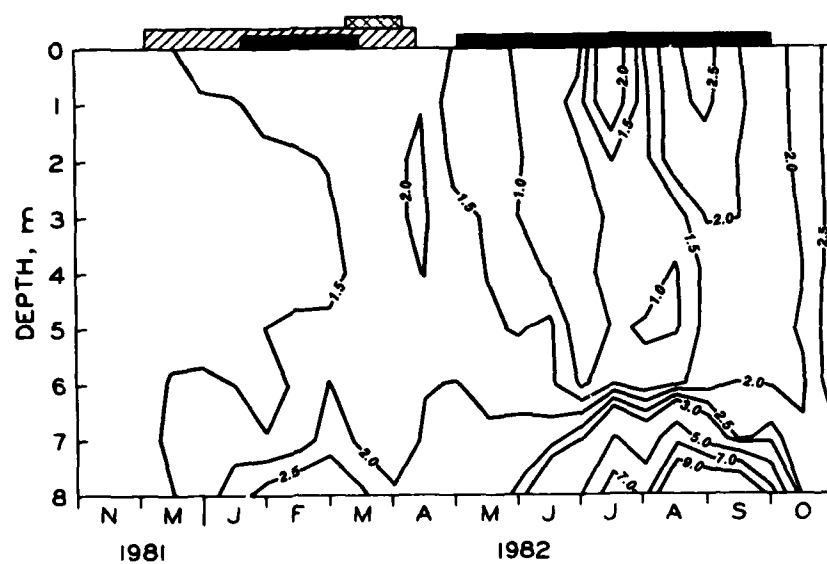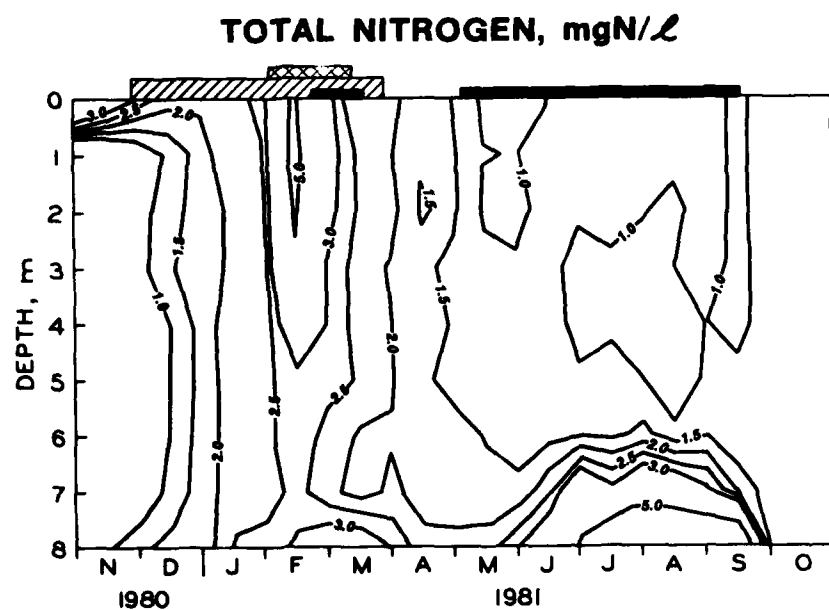
Figure 37. Vertical changes in total nitrogen for the
two study periods. Periods of anoxic (solid bar), ice
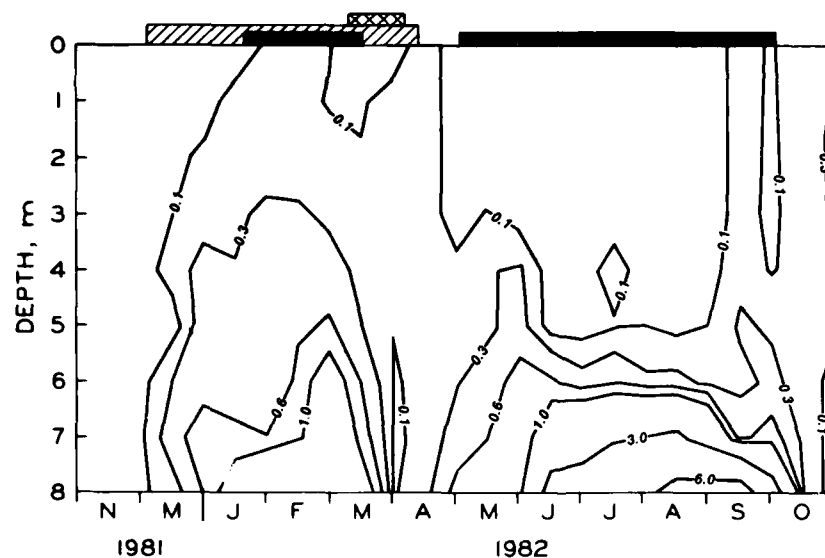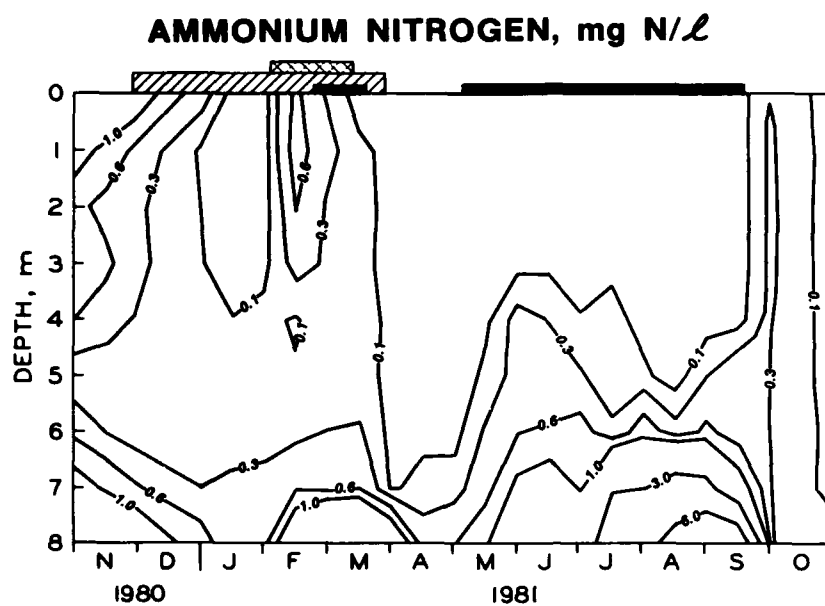cover (hatched bar), and spring runoff (cross-hatched
bar) are indicated.

85

In winter, concentrations of TN were nearly equivalent to those of the inflows, and some release of ammonia occurred in the bottom 2 m when anoxic conditions existed.

119. Significant differences in total nitrogen between stations occurred only during the fall season. During these periods, station 40 had higher values (1.31 mg N/ℓ) and station 50 had lower values (1.01 mg N/ℓ) than all other stations.

Nitrate-nitrite nitrogen

120. Dissolved nitrate, which is a major source of nitrogen for all but nitrogen-fixing algae and rooted aquatic plants, and nitrite, which is rapidly oxidized in oxygen-rich waters, were determined simultaneously. Values for nitrate-nitrite ranged from 0.0 to 1.98 mg N/ℓ, with a mean of 0.55 mg N/ℓ (Table 6 and Figure 38). There were yearly maxima in the mixed layer (1.8 mg N/ℓ) and the layer below the mixed layer (1.3 mg N/ℓ) during winter. Considerably lower concentrations occurred in both layers during summer, when in the mixed layer nitrate was utilized by phytoplankton and anoxia in the hypolimnion led to the reduction of nitrate to ammonia. Fall mixing resulted in increases (fall mean of 0.68 mg N/ℓ) due to the oxidation of ammonia to nitrate. Concentrations continued to rise during winter stagnation (1.26 mg N/ℓ) primarily because of the higher levels found in the inflows.

121. Significant differences among stations were observed during all seasons. During fall, nitrate-nitrite concentrations at station 40 averaged 0.96 N mg/ℓ and were significantly higher than other stations in both the 0- to 2-m and 2- to 4-m depth intervals. However, in spring and summer, differences were apparent only in the 2- to 4-m depth interval.

Ammonia nitrogen

122. Ammonia, the sources of which include runoff from feedlots and biological degradation of organic compounds, was present throughout the year in trace amounts in surface waters at all stations. High concentrations were observed in the hypolimnion during winter and summer stratification (Figure 39). Values ranged from below detection limit levels in the epilimnion during most seasons to 10.8 mg N/ℓ in the

86

NlTRATE PLUS NITRATE NITROGEN, mg N/ℓ
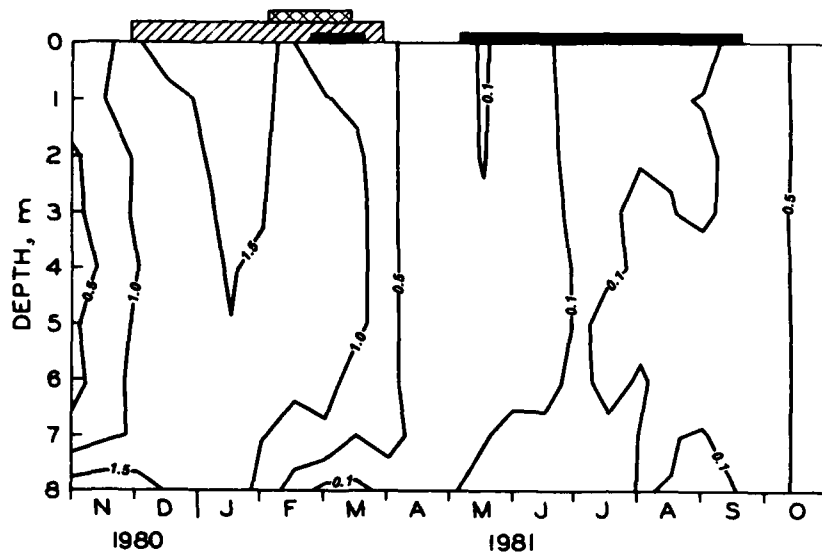
a. November 1980-October 1981
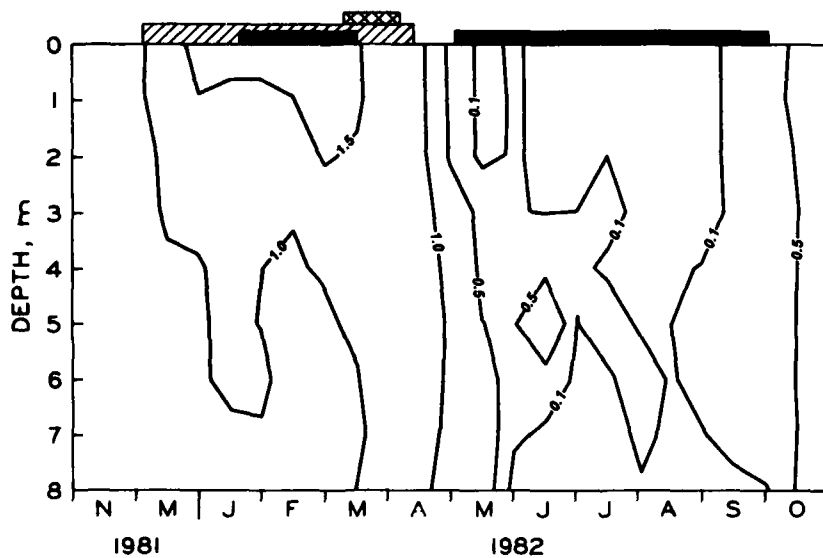
b. November 1981-October 1982

Figure 38. Vertical changes in nitrate-nitrite nitrogen
for the two study periods. Periods of anoxia (solid
bar), ice cover (hatched bar), and spring runoff (cross-
hatched bar) are indicated.

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AMMONIUM NITROGEN, mg N/ℓ

a. November 1980-October 1981

b. November 1981-October 1982

Figure 39. Vertical changes in ammonia nitrogen for
the two study periods. Periods of anoxia (solid
bar), ice cover (hatched bar), and spring runoff
(cross-hatched bar) are indicated.

mnion during summer stratification following the degradation of
c nitrogen and release from the sediments. The mixed layer had
mly low levels (generally less than 0.1 mg N/ℓ), with increases
ing only during snowmelt runoff and after fall turnover when high
mnetic levels (greater than 10.0 mg N/ℓ) were redistributed
hout the water column. After the influx of ammonia, concentra-
gradually decreased until they were again less than 0.10 mg N/ℓ
the oxidation of ammonia to nitrate.

123. The only significant difference in ammonia between stations
ed in summer, when station 50 was significantly higher (0.06 mg
han other stations in the upper 2 m of the reservoir. The in-
likely was due to release from the sediments in that shallow
than 1.0-m), macrophyte-infested cove.

c nitrogen

124. Organic nitrogen was determined as the difference between
nitrogen and the sum of ammonia and nitrate-nitrite nitrogen. Con-
tions of up to 4.0 mg N/ℓ occurred during snowmelt when consider-
articulate nitrogen entered the reservoir. Concentrations were
t in the hypolimnion at station 20 during summer stratification.
organic nitrogen was redistributed in the lake during fall turn-
the settling of the particulate matter resulted in low concentra-
of organic nitrogen during winter.

ved silica

125. Dissolved silica, although necessary for all phytoplankton,
rincipal nutrient for diatoms. Values in Eau Galle Lake ranged
.32 to 15.0 mg Si/ℓ during the study period. Major diatom blooms
ed in the reservoir in early spring soon after ice-out and during
urnover, when silica was most abundant and the waters were cool
ll mixed (Barko et al. 1984). In the first year of the study, when
it occurred in early April, the reservoir remained mixed and cool
long period. These conditions allowed a massive diatom bloom that
ed nearly all the available silica and other nutrients. Dissolved
concentrations during this period decreased from more than 8 mg
o less than 2 mg Si/ℓ (Figure 40). The highest concentrations of

89

DISSOLVED SILICA, mgSi/ℓ

a. November 1980-October 1981

b. November 1981-October 1982
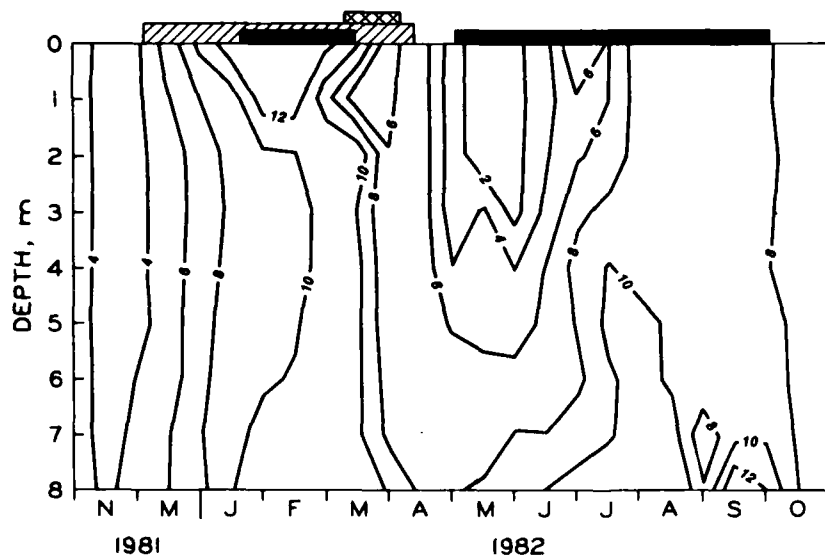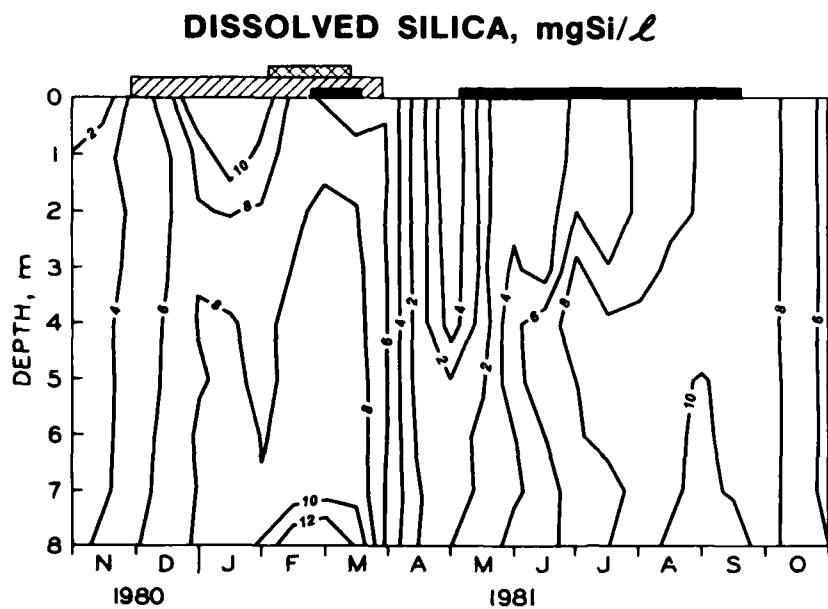
Figure 40. Vertical changes in dissolved silica for
the two study periods. Periods of anoxia (solid
bar), ice cover (hatched bar), and spring runoff
(cross-hatched bar) are indicated.

90

1 silica, which were found in the waters just beneath the ice
inter and just off the bottom during summer, were due to riverine
s or underflows, respectively, during those periods. Unlike
trients, silica did not exhibit strong vertical gradients, but
bit temporal gradients. The lack of vertical gradients is re-
 the fact that silica contained in settling material is not
resolubilized and returned to the lake. Silica levels were
e more closely associated with those of the inflows. Therefore,
 vertical gradients present in the lake appeared as a result of
w into a stratified lake.

6. Station 40 was significantly different from other stations
easons of the year. Concentrations at this near-river station
 1-2 mg Si/ℓ higher than concentrations in surface waters at
-lake stations.

d dissolved organic carbon

7. Organic carbon concentrations, more than any other water
constituent, were dependent upon snowmelt runoff. Normal levels
 organic carbon (TOC) in the river were less than 4.0 mg C/ℓ but
over 30 mg C/ℓ during snowmelt. Levels in the lake rose from
/ℓ to 12 mg C/ℓ after snowmelt and generally declined during the
r of the year. Small increases, following other storm events,
o detected during July and August 1981.

8. Vertical patterns in the distribution of TOC were apparent
ummer stratification (Figure 41). During these periods, TOC con-
ons frequently were highest at the surface and in the hypolim-
or example, on 24 August 1982, TOC values dropped from 10.4 mg
he surface to 3.5 mg C/ℓ at 5 m, then rose to 12.1 mg C/ℓ at the
 Profiles for dissolved organic carbon (DOC) were similar.
fferences reflect the presence of algae in surface waters (Barko
984) and the accumulation of sedimenting particulate matter in
aters (James 1984). The importance of particulate matter during
riods is indicated by the fact that DOC accounted for only
nt of the TOC in summer as opposed to 90 percent or more in

TOTAL ORGANIC CARBON, mgC/ℓ

a. November 1980-October 1981
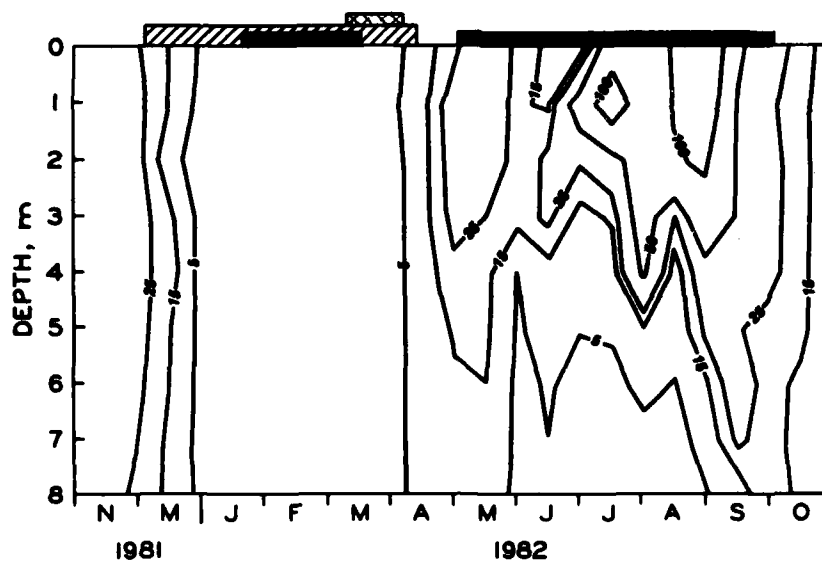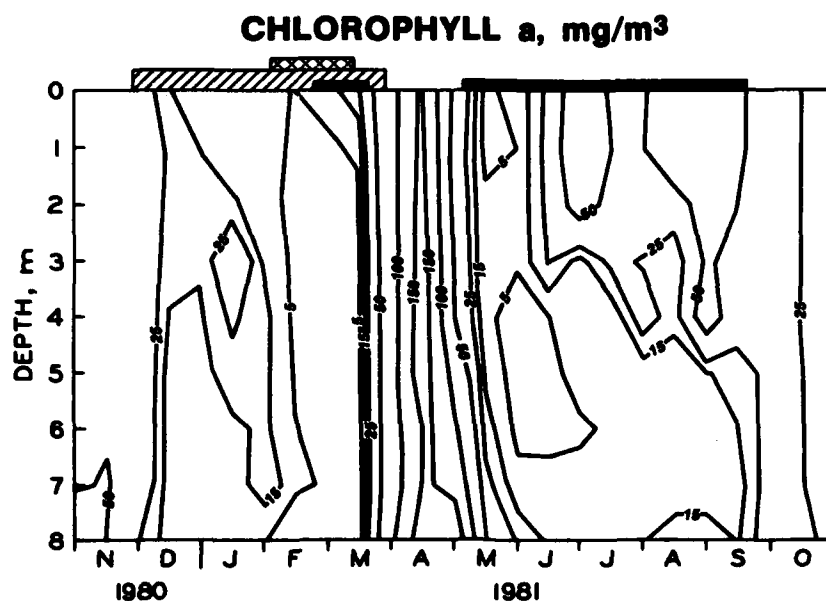

b. November 1981-October 1982
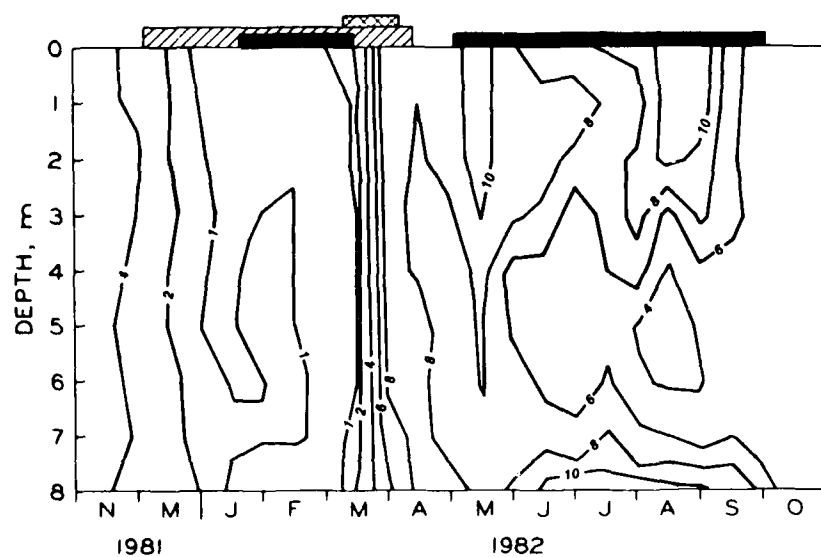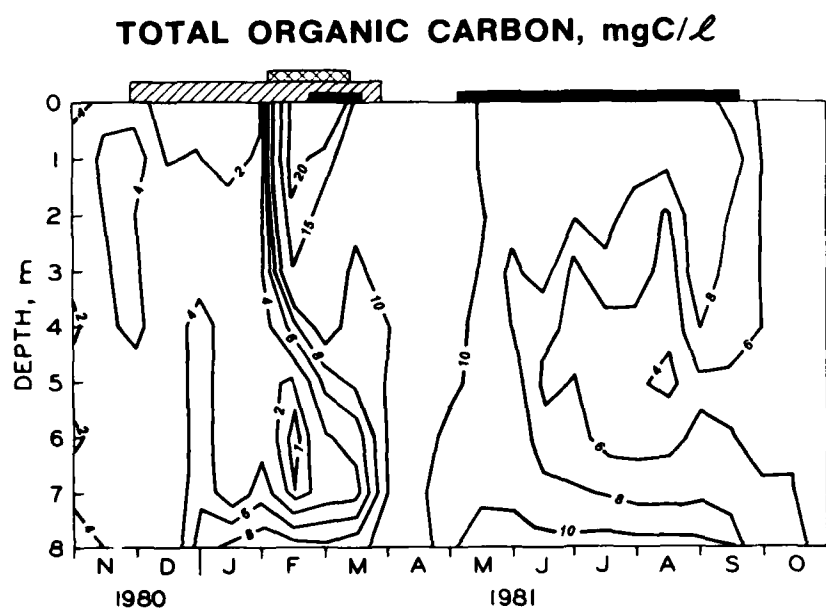
Figure 41. Vertical changes in total organic carbon for the two study periods. Periods of anoxia (solid bar), ice cover (hatched bar), and spring runoff (cross-hatched bar) are indicated.

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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

129. Values for DOC at station 30 in the spring and for TOC and DOC at station 40 in the spring and summer were significantly lower than those of the lake in general. The spring mean DOC concentration for station 30 was 6.8 mg C/ℓ compared to 4.6 mg C/ℓ for station 40 and 7.4 mg C/ℓ for the lake as a whole. TOC levels were 5.4 mg C/ℓ in spring and 4.9 mg C/ℓ in the summer for station 40 compared to 8.0 and 8.3 mg C/ℓ in the rest of the lake for these seasons, respectively.

Photosynthetic pigments

130. Photosynthetic pigments, which were measured in appreciable quantities during spring, summer, and fall, reflect phytoplankton abundance. While typically highest in surface waters, a notable exception in the distribution of chlorophyll a (ChlA) occurred during spring turnover of 1981 (Figure 42). A large diatom bloom during this period produced high concentrations of ChlA (197 μg/ℓ), which were evenly distributed throughout the water column. Other peaks in ChlA concentration coincided with phytoplankton blooms during summer stratification. Annual minima in ChlA (0.05 μg/ℓ) concentrations were in winter during ice cover. Seasonal patterns in pigment concentration are discussed in greater detail by Barko et al. (1984).

131. Spatial differences were apparent in fall and summer when concentrations at station 40 were lower than other in-lake stations and in winter when station 50 exhibited highest concentrations. During this latter period, mean values at station 50 were nearly three times higher than at other stations.

Sulfate and sulfide

132. Sulfur, which occurs in natural waters as both sulfate and sulfide, was supplied to the reservoir by riverine loadings. During this study, sulfate, which occurs under oxic conditions, ranged from 0.0 mg/ℓ to 19.4 mg/ℓ and displayed no distinct seasonal patterns (Figure 43). However, changes in sulfate concentration in the lake coincided with concentration changes in the Eau Galle River. Sulfide was present at levels above 1.0 mg/ℓ only during the winter of 1981 in the anoxic bottom 2 m of the lake. Since, in the presence of reduced iron, sulfide is precipitated as iron sulfide, its levels were likely controlled by

CHLOROPHYLL a, mg/m³

a.   November 1980-October 1981

b.   November 1981-October 1982

Figure 42.   Vertical changes in chlorophyll a for
the two study periods.   Periods of anoxia (solid
bar), ice cover (hatched bar), and spring runoff
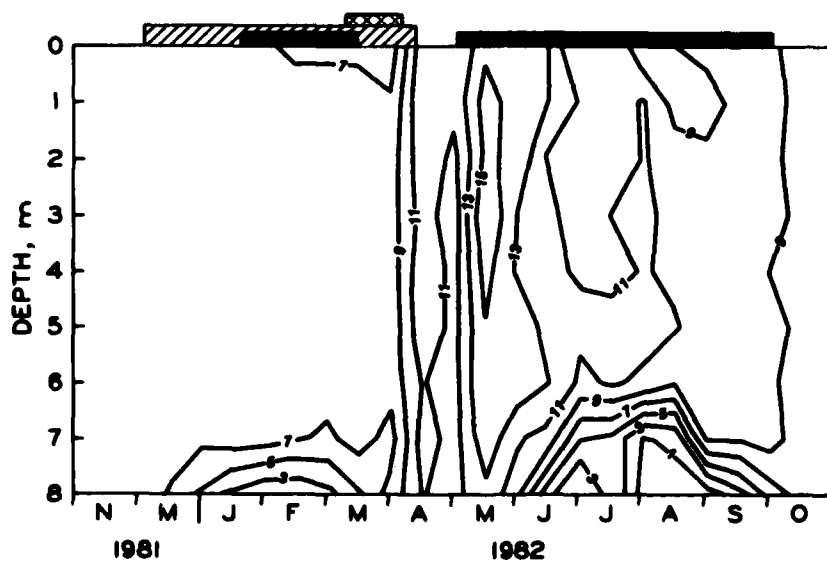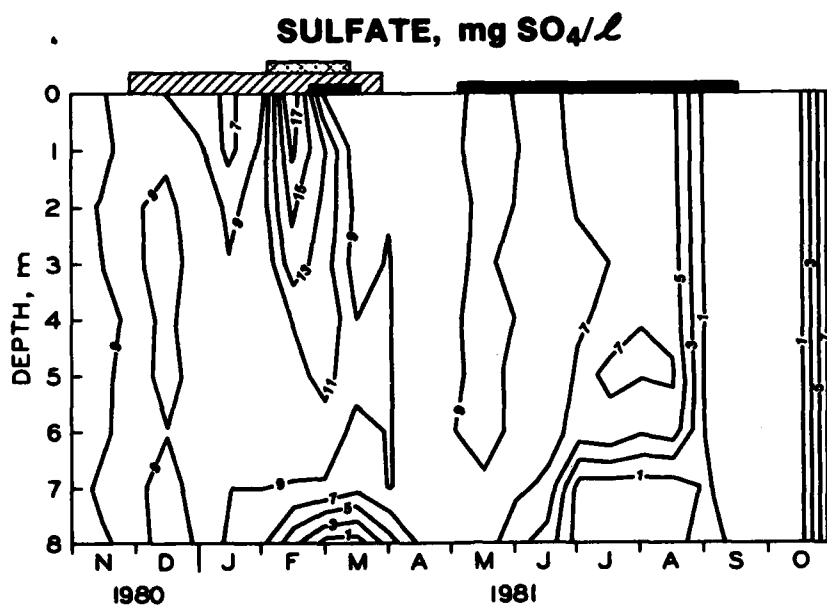(cross-hatched bar) are indicated.

SULFATE, mg SO$_4$/ℓ

a.   November 1980-October 1981

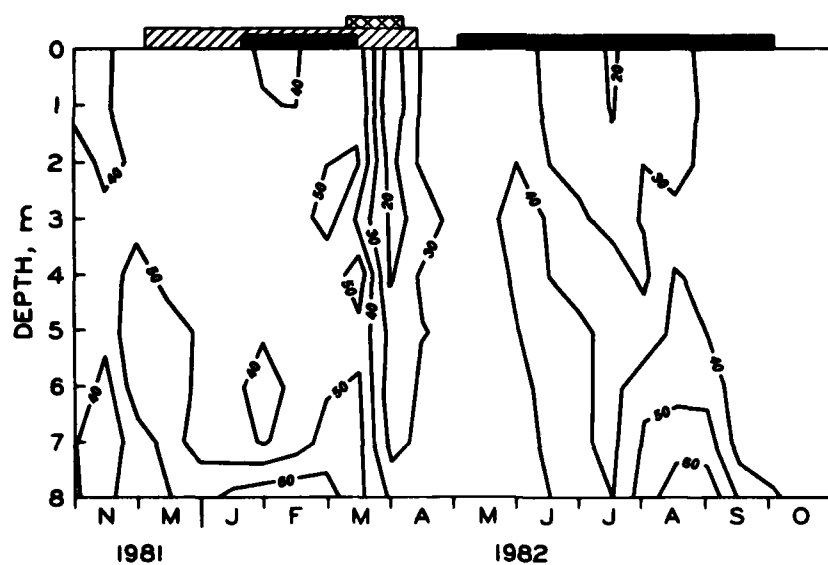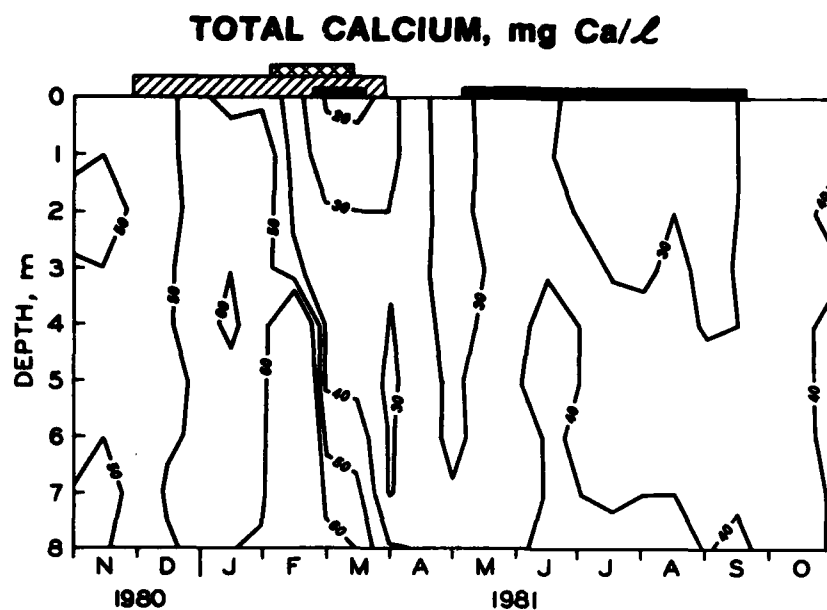b.   November 1981-October 1982

Figure 43.   Vertical changes in sulfate concentration
for the two study periods. Periods of anoxia (solid
bar), ice cover (hatched bar), and spring runoff
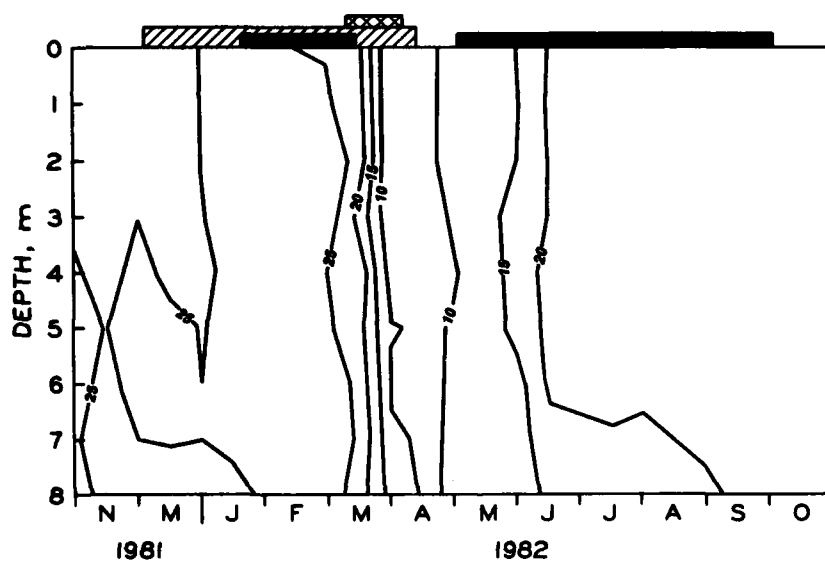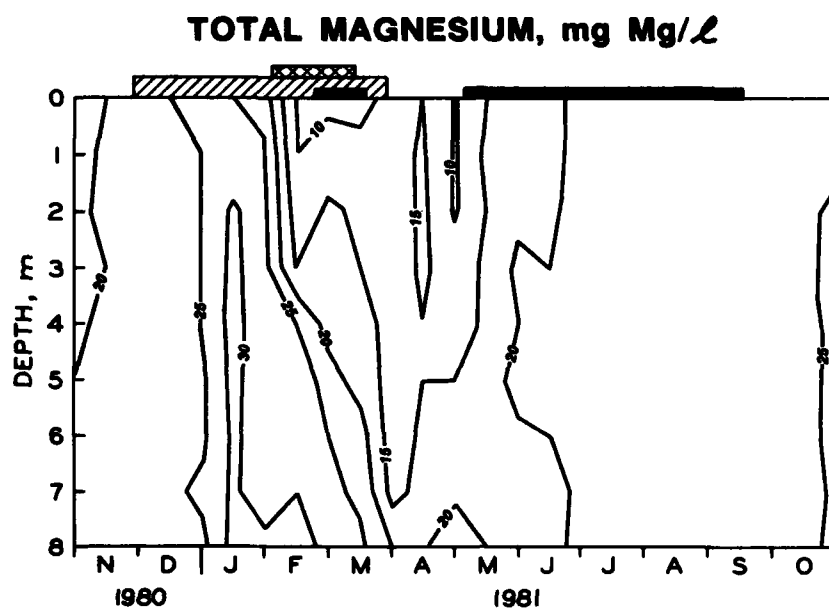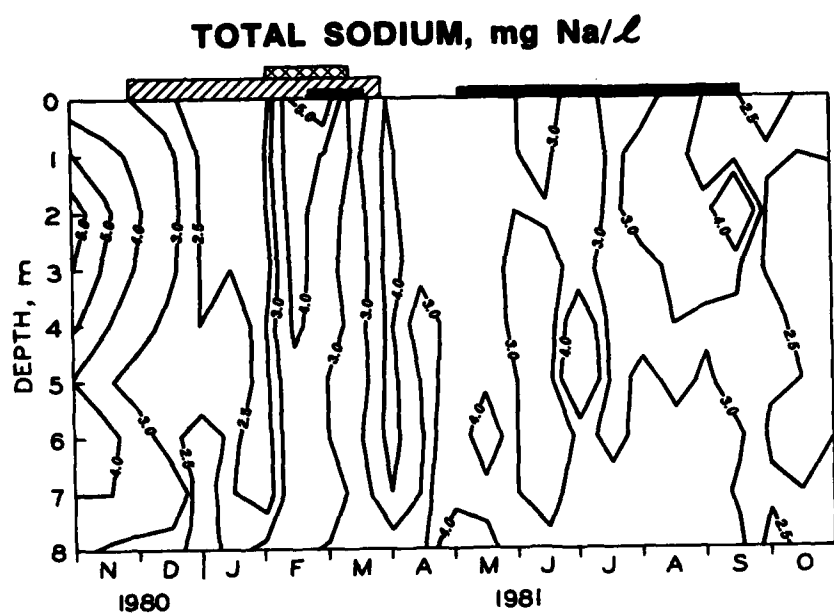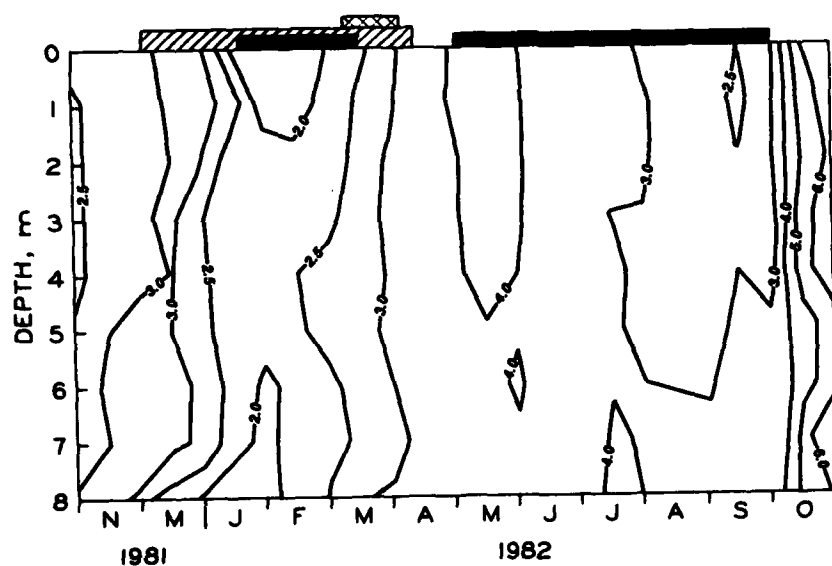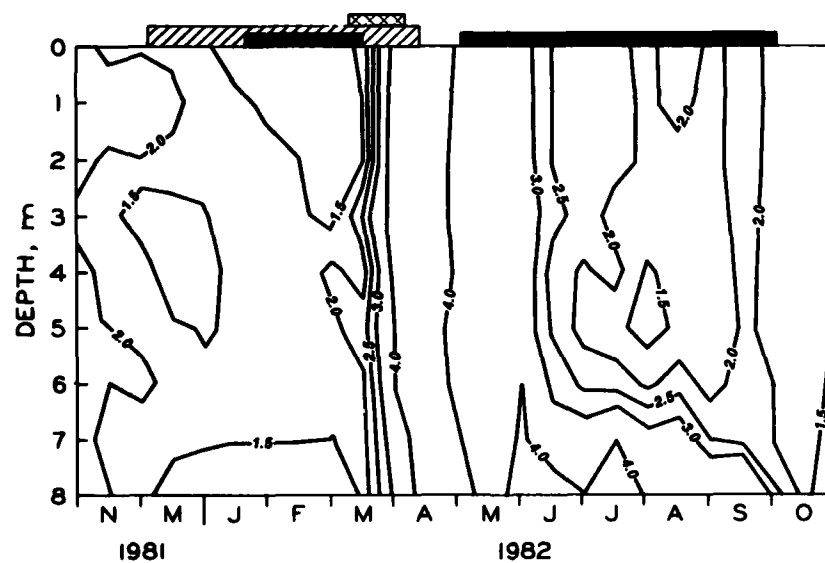(cross-hatched bar) are indicated.

95

ferric iron. This possibility is strengthened by the fact that iron concentrations increased dramatically during periods of anoxia.

133. Patterns of change in sulfate concentration differed considerably during each of the 2 years of the study. During the first year, the highest seasonal mean was in winter with a minimum in summer. In contrast, concentrations during the second year dropped to their lowest levels during fall of 1981 and increased continually to a peak during the following summer. These changes reflect differences observed in the inflows, since tributary concentrations in the second year were generally higher than those of the first year.

Calcium and magnesium

134. Concentrations of calcium and magnesium, two major cations in Eau Galle Lake and its inflows, varied markedly in response to tributary flow (Figures 44 and 45). In general, calcium and magnesium concentrations in the lake were diluted (by as much as 50-75 percent) following high-flow events.

135. During stratified periods, vertical concentration gradients were observed for total calcium. Hypolimnetic concentrations were commonly above 40 mg Ca/ℓ during both summers. Vertical gradients in magnesium concentration did not occur, however.

Total and dissolved
sodium and potassium

136. Similar patterns of seasonal variation were observed for sodium and potassium concentrations (Figure 46 and 47). Sodium concentrations ranged from 1.4 to 6.8 mg Na/ℓ for total and 0.9 to 9.4 mg Na/ℓ for dissolved, with mean values of 3.0 and 2.5 mg Na/ℓ, respectively. Potassium concentrations ranged from 0.7 to 20.0 mg K/ℓ for total and 0.6 to 16.0 mg K/ℓ for dissolved. Means concentrations were 3.2 and 2.7 mg K/ℓ respectively. The yearly minima for each metal were observed during winter stratification.

137. Sharp increases in lake concentrations were noted during snowmelt each year. Prior to snowmelt, sodium and potassium concentrations were approximately uniform through the water column; however, after snowmelt events, concentrations reached relatively high levels.

TOTAL CALCIUM, mg Ca/ℓ

a. November 1980-October 1981

b. November 1981-October 1982

Figure 44. Vertical changes in total concen-
tration for the two study periods. Periods of
anoxia (solid bar), ice cover (hatched bar),
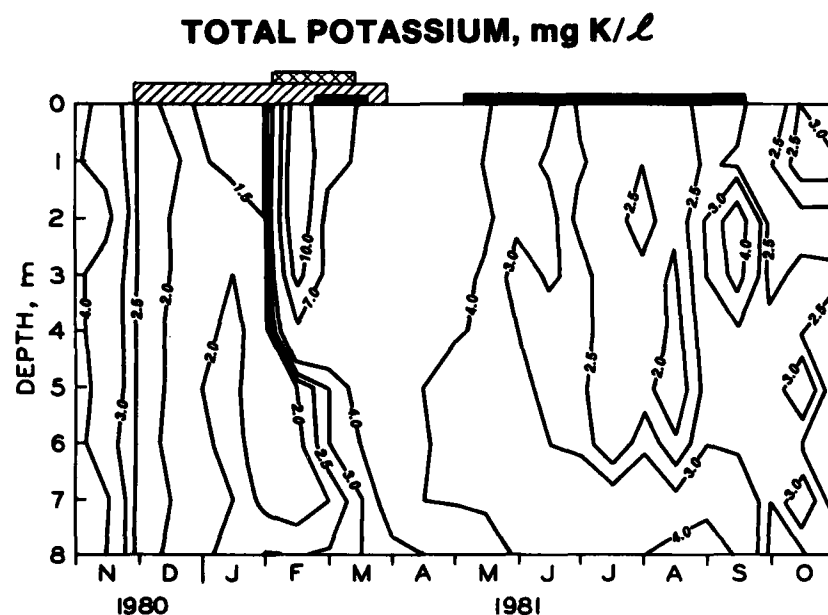and spring runoff (cross-hatched bar) are
indicated.

97

TOTAL MAGNESIUM, mg Mg/ℓ

a.   November 1980-October 1981

b.   November 1981-October 1982

Figure 45.   Vertical changes in total magnesium con-
centration for the two study periods.   Periods of
anoxia (solid bar), ice cover (hatched bar), and
spring runoff (cross-hatched bar) are indicated.

98

TOTAL SODIUM, mg Na/ℓ

a. November 1980-October 1981

b. November 1981-October 1982

Figure 46. Vertical changes in total sodium concen-
tration for the two study periods. Periods of
anoxia (solid bar), ice cover (hatched bar), and
 spring runoff (cross-hatched bar) are indicated.

99

TOTAL POTASSIUM, mg K/ℓ

a. November 1980-October 1981

b. November 1981-October 1982

Figure 47. Vertical changes in total potassium con-
centrations for the two study periods. Periods of
anoxia (solid bar), ice cover (hatched bar), and
spring runoff (cross-hatched bar) are indicated.

100

Concentrations increased to 11.0 and 8.7 mg K/ℓ for total and dissolved potassium, respectively, following the 1981 snowmelt and to 7.5 and 6.2 mg K/ℓ following the 1982 snowmelt. While sodium also increased during both spring snowmelts, increases were not as great. Concentrations of Na and K gradually decreased during summer.

Total and dissolved iron and manganese

138. Iron and manganese are important trace metals affected by low DO concentrations in lake waters. Both are found in the soluble state when they are reduced (Mn^{++}, Fe^{++}) but are insoluble in their oxidized states (Mn^{+4}, Fe^{+3}). Their cycles are also closely tied to that of SRP. When reduced forms of these metals are oxidized during periods of mixing, they form precipitates ($Fe(OH)_3(s)$ and $MnO_2(s)$) that adsorb soluble phosphorus, thus reducing phosphorus concentrations in the water column.

139. In the 2 years of study, ranges in iron and manganese concentration were extreme (Figures 48 and 49) and reflected changes in DO concentration and tributary loading. During winter stratification, minor increases occurred in bottom waters, coincident with a short period of anoxia. Major increases, however, occurred during summer stratification when anoxic conditions were most pronounced. These high levels were the result of the resolubilization of $Fe(OH)_3$ and MnO_2. During lake stratification, iron may have been returned to sediments as FeS.

140. Fall turnover, with the accompanying reoxygenation of the anoxic hypolimnetic waters, induced the oxidation of reduced forms of iron and manganese, resulting in their precipitation. Since these metal precipitates tend to adsorb soluble phosphorus, this cycle of events resulted in the trapping of iron, manganese, and phosphorus in the sediments.

Discussion and Conclusions

141. The Eau Galle Reservoir is a dimictic, eutrophic lake exhibiting high algal productivity, decreased water transparency, and reduced oxygen concentrations in the bottom waters. These conditions
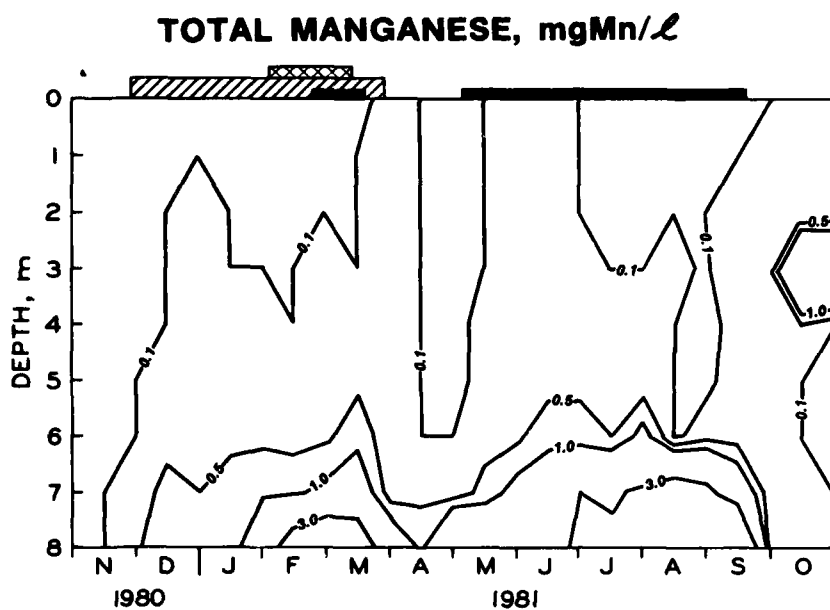
TOTAL IRON, mgFe/ℓ
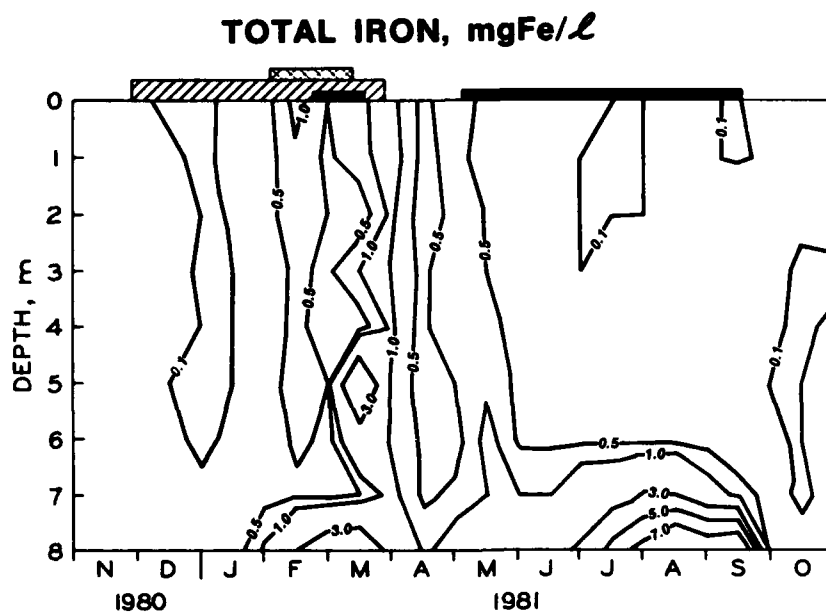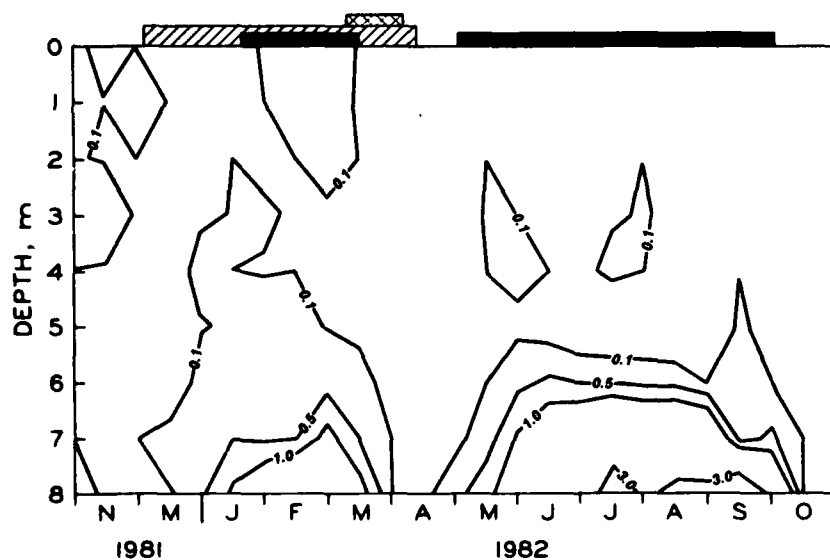

a. November 1980-October 1981
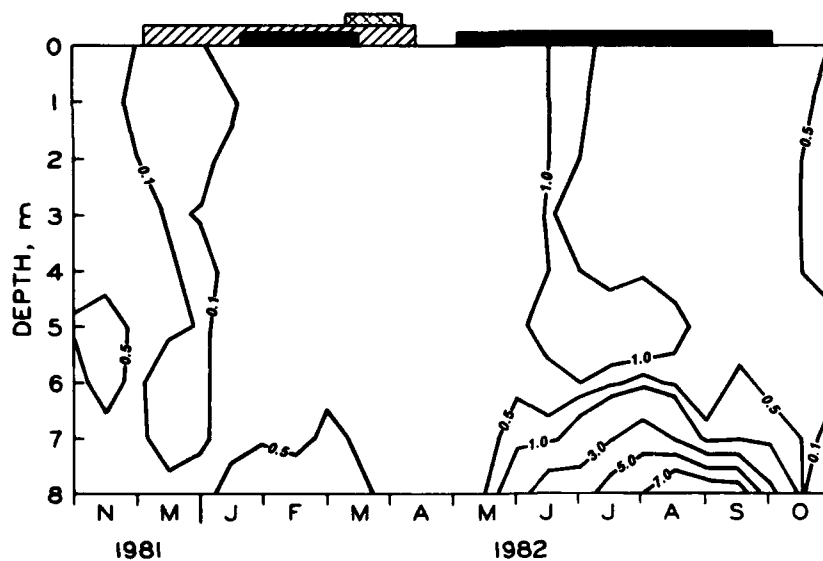
b. November 1981-October 1982

Figure 48. Vertical changes in total iron concentra-
tion for the two study periods. Periods of anoxia
(solid bar), ice cover (hatched bar), and spring run-
off (cross-hatched bar) are indicated.

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TOTAL MANGANESE, mgMn/ℓ

a. November 1980-October 1981

b. November 1981-October 1982

Figure 49. Vertical changes in total manganese concentration for the two study periods. Periods of anoxia (solid bar), ice cover (hatched bar), and spring runoff (cross-hatched bar) are indicated.

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are due largely to the high nutrient and material loadings associated
with spring snowmelt/runoff. Although water quality studies involve the
evaluation of individual water quality constituents, as presented here,
water quality is also an expression of the complex interaction between
individual constituents. The cycles of many constituents are linked, so
that their individual concentrations are interdependent. For example,
water transparency is related to turbidity, suspended solids, nutrients,
and algal productivity. While particulates are elevated in the tropho-
genic zone of the Eau Galle Reservoir during summer stratification, dis-
solved variables are correspondingly low, often near their respective
detection limits. At the same time, in the tropholytic zone, where dis-
solved oxygen is low, many variables are at their highest levels. These
examples suggest that water quality constituents and their interactions
can be logically grouped for ease of discussion.

142. Three groups of water quality constituents are apparent when
similarities in seasonal patterns of change in concentration are con-
sidered (Table 7). It should be noted that these groups correspond well
with those determined for material loadings (Montgomery 1984). The vari-
ables of the first group have their seasonal maxima during winter and,
with the exception of TN, are diluted during snowmelt/runoff (Montgomery
1984). TN had a positive correlation to flow during early snowmelt, but
was diluted during the later stages of the runoff. The Group II vari-
ables have their seasonal maxima in spring and display increased concen-
trations as a result of snowmelt/runoff. The exception among this group
is chlorophyll b (ChlB). ChlB is found in high concentrations in dia-
toms, which have major blooms during the spring mixed period. The third
group is affected directly or indirectly by biogenic processes, and
their summer maxima are related to the trophic state of the reservoir.
Of the variables in Group III, pH, ChlA, and phaeophytin (Phaeo) all
have maxima resulting from high algal productivity. The other variables
in the group experience seasonal highs as a result of anoxic conditions
in the hypolimnion. These variables (NH_4-N, TSul, TFe, DFe, TMn, and
DMn) exist primarily during periods of anoxia and are released from the
sediments or settling seston. An exception in the third group is TP.

(4) Fecal Coliform Bacteria

Method: Membrane filter procedure.

Reference: APHA 1980.

C. Continuous Monitoring of Meteorological Conditions, Stream Discharge, and Water Temperature

(1) Meteorological Conditions

Method: A portable meteorological station was maintained near the lake to monitor the following:

(a) Wind speed

(b) Wind direction

(c) Rainfall

(d) Solar radiation

(e) Barometric pressure

(f) Relative pressure

(g) Pan evaporation

(h) Air temperature

(i) Lake water temperature

The data were recorded continuously on a digital recorder and transmitted to the WES via satellite for computer storage and processing. The station was located on the west bank of the lake within 10 m of the water at normal pool level. Meteorological data were also obtained at the site of the laboratory by lab personnel and the reservoir manager. Other data were obtained from the National Weather Service.

(2) Stream Discharge

Method: All inflows (Eau Galle River, French Creek, Lousy Creek, and Lohn Creek) and the outflow were monitored for water discharge rates using appropriate gaging and rating techniques.

References

American Public Health Association. 1980. Standard Methods for the Examination of Water and Wastewater, 15th ed., American Public Health Association, New York, N. Y.

Environmental Protection Agency. 1974. Methods for Chemical Analysis of Water and Wastes, US Environmental Protection Agency, EPA-625/6-74-003.

(3) Primary Productivity

Method: The primary productivity studies consisted of light/
dark bottle oxygen analyses conducted at three in-pool
sampling stations. Each of the 300-ml glass light/
dark bottles were triplicated in the euphotic zone
with only the dark bottle triplicated in the aphotic
zone. This resulted in six bottles at each euphotic
zone depth and three bottles at each aphotic zone
depth. The dark bottles were coated with black
opaque plastic. The depths for euphotic zone sam-
pling were 10 cm below the surface and every metre
down to and including the Secchi disc depth. If the
Secchi disc depth was less than 1 m, the triplicate
light/dark bottles were placed at 10 cm and the Secchi
depth. Three dark bottle samples were located 0.5 m
off the bottom, if they were in the aphotic zone.
Three additional dark bottles were suspended 1 m be-
low the compensation point if this depth was greater
than 1 m from the bottom. The compensation point was
defined to be twice the Secchi disc depth. This per-
mitted an evaluation of respiration at two points in
the aphotic zone.

Water to fill the light/dark bottles was taken from
the same depth at which the samples were incubated
with a nonmetallic Van Dorn sampler. The Van Dorn
sampler was opaque and had sufficient volume to fill
all sample bottles for that depth. Care was exer-
cised when filling the bottles to avoid aeration or
exposure to direct sunlight, in order to prevent light
shock. The initial temperature was recorded and the
initial dissolved oxygen concentration of the sample
was measured on a blank bottle prepared identically
to the light/dark bottles using the Winkler method.

The sample bottles were incubated in a manner to mini-
mize shading. The incubation period lasted 2-4 hr
depending on photosynthetic activity and bracketed
solar noon. The exact length of the incubation pe-
riod was determined through initial experimentation.
The incubation period was short enough to prevent the
dissolved oxygen concentration in the dark and light
bottles from dropping below 2 mg/ℓ or rising above
140 to 180 percent saturation, respectively. The sam-
ples were fixed for Winkler analysis immediately upon
removal at the end of the incubation period and
titrated for dissolved oxygen within 4 hr. Results
were expressed as the initial and final dissolved
oxygen concentrations and the incremental change for
each sample bottle.

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analysis was not to be performed within
2 hr of sampling).

Sample Storage: Minimized storage time.

(38) Total Filterable Organic Carbon

Method: Wet persulfate wet chemical oxidation and infrared
carbon analysis.

Reference: EPA 1974.

Sample Preservation: Filtered through 0.45-μ membrane prior
to preservation. Preserved as with total
organic carbon.

Sample Storage: Minimize storage time.

(39) Total Carbon

Calculated as the sum of total organic carbon and total
inorganic carbon.

(40) Total Particulate Organic Carbon

Calculated by difference as total organic carbon minus total
filterable organic carbon.

B. Biological Parameters

(1) Pigments

Method: Spectrophotometric determination.

Reference: APHA 1980.

Comments:

(a) Chlorophylls a, b, and c were determined by the
tichromatic method using equations of Strick-
land and Parsons (1968).

(b) Pheopigment was determined by the method of
Lorenzen (1967).

(2) Phytoplankton Species Enumeration

Method: Utermohl's method.

Reference: Vollenweider 1969.

Sample Preservation: Preserved with Lugol's solution or M-3
preservative.

Comments:

(a) Enumerated to species when possible.

(b) Counts per species or group were expressed as
cell number.

A8

Sample Preservation: Filtered immediately through 0.45-µ membrane filter and preserved as for total magnesium.

(32) Dissolved Silica

Method: Automated molybdosilicate method.

Reference: APHA 1980.

Sample Preservation: Cooled (4° C).

Sample Storage: Stored in polyethelylene containers and determined as soon as possible.

(33) Total Solids

Method: Total residue at 105° C.

Reference: APHA 1980.

Sample Preservation: Cooled (4° C).

Sample Storage: Determined as soon as possible; did not exceed 7 days.

Comments: Sample volume was 100 ml or greater.

(34) Total Filterable Solids

Method: Filterable (standard glass fiber filter) residue at 105° C.

Reference: APHA 1980.

Sample Preservation: Cooled (4° C).

Sample Storage: Determined as soon as possible; did not exceed 7 days.

Comments: Sample volume was 100 ml or greater.

(35) Suspended Solids

Calculated by difference as total solids residue minus total filterable residue.

(36) Total Inorganic Carbon and Free CO_2

Method: Chemical equilibrium.

References: Kelley, Church, and Hornberger 1974; APHA 1980.

(37) Total Organic Carbon

Method: Persulfate wet chemical oxidation and infrared carbon analysis.

Reference: EPA 1974.

Sample Preservation: Stored in brown glass container and cooled to 4° C (acidity was adjusted to pH $\leq$ 2 with concentrated HCl or H_2SO_4 if

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(26) Total Potassium

Method: Atomic absorption spectrophotometry.

Reference: APHA 1980.

Sample Preservation: Acidified to pH < 2 with concentrated
                      nitric acid.

Sample Storage: 6 months.

(27) Dissolved Potassium

Method: Atomic absorption spectrophotometry.

Reference: APHA 1980.

Sample Preservation: Filtered immediately through 0.45-μ mem-
                      brane filter and preserved as for total
                      potassium.

Sample Storage: 6 months.

(28) Total Calcium

Method: Atomic absorption spectrophotometry.

Reference: APHA 1980.

Sample Preservation: Acidified to pH < 2 with concentrated
                      nitric acid.

Sample Storage: 6 months.

(29) Dissolved Calcium

Method: Atomic absorption spectrophotometry.

Reference: APHA 1980.

Sample Preservation: Filtered immediately through 0.45-μ mem-
                      brane filter and preserved as for total
                      calcium.

Sample Storage: 6 months.

(30) Total Magnesium

Method: Atomic absorption spectrophotometry.

Reference: APHA 1980.

Sample Preservation: Acidified to pH < 2 with concentrated
                      nitric acid.

Sample Storage: 6 months.

(31) Dissolved Magnesium

Method: Atomic absorption spectrophotometry.

Reference: APHA 1980.

(20) Total Sulfides

Method: Titrimetric (iodine) method.

Reference: APHA 1980.

Sample Preservation: Filled sample bottle completely and pre-
served with zinc acetate.

(21) Sulfate

Method: Turbidimetric (nephelometric) method.

Reference: APHA 1980.

Sample Preservation: Cooled to 4° C.

Sample Storage: Did not exceed 7 days.

(22) Total Iron

Method: Atomic absorption spectrophotometry.

Reference: APHA 1980.

Sample Preservation: Acidified to pH < 2 with concentrated
nitrite acid.

Sample Storage: 6 months.

(23) Dissolved Iron

Method: Atomic absorption spectrophotometry.

Reference: APHA 1980.

Sample Preservation: Filtered immediately through 0.1-μ mem-
brane filter and preserved as for total
iron.

Sample Storage: 6 months.

(24) Total Manganese

Method: Atomic absorption spectrophotometry.

Reference: APHA 1980.

Sample Preservation: Acidified to pH < 2 with concentrated
nitric acid.

Sample Storage: 6 months.

(25) Dissolved Manganese

Method: Atomic absorption spectrophotometry.

Reference: APHA 1980.

Sample Preservation: Filtered immediately through 0.1-μ mem-
brane filter and preserved as for total
manganese.

Sample Storage: 6 months.

(13) **Soluble Unreactive Phosphorus**

Calculated by differences as total soluble phosphorus minus soluble reactive phosphorus.

(14) **Particle Phosphorus**

Calculated by difference as total phosphorus minus total soluble phosphorus.

(15) **Total Nitrogen**

Method: Automated NH_3 analysis of the persulfate oxidized sample reduced to NH_3 with Devarda's alloy.

References: Raveh and Avnimelech 1979, APHA 1980.

Comments: Although this method is not approved by APHA or the EPA, it provided two advantages:

  (a) The same sample could be analyzed for total phosphorus and total nitrogen.

  (b) Allowed for the use of automated procedures. Our own studies and results from the analysis of EPA standards indicated that the method's precision and accuracy are good.

(16) **Total Soluble Nitrogen**

Method: Automated NH_3 analysis of 0.45-μ filtered, persulfate oxidized sample which was reduced to NH_3 by Devarda's alloy.

References: Raveh and Avnimelech 1979, APHA 1980.

(17) **Nitrate/Nitrite Nitrogen**

Method: Automated cadmium reduction.

Reference: APHA 1980.

Sample Preservation: Filtered through 0.45-μ membrane filter; cooled to 4° C.

Sample Storage: Did not exceed 24 hr.

(18) **Total Kjeldahl Nitrogen**

Calculated by difference as total nitrogen minus nitrate/nitrite nitrogen.

(19) **Ammonium Nitrogen**

Method: Automated alkaline phenate.

Reference: APHA 1980.

Sample Preservation: Added 2 ml concentrated H_2SO_4/ℓ and cooled to 4° C.

Sample Storage: Did not exceed 24 hr.

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(7) pH

Method: Electrometric.

Reference: APHA 1980.

Sample Preservation: Field determination.

Comments: Standardized as per APHA method for routine analysis (using commercially available buffers). Read to nearest 0.5 pH units.

(8) Alkalinity (Total)

Method: Potentiometric titration.

Reference: APHA 1980.

Comments: Reported as mg $CaCO_3/\ell$.

(9) Turbidity

Method: Nephelometric.

Reference: APHA 1980.

Sample Preservation: Stored in dark.

Sample Storage: Did not exceed 24 hr.

(10) Total Phosphorus

Method: Automated acid/persulfate digestion method and as corbic acid colorimetric method.

Reference: APHA 1980.

Sample Preservation: H_2SO_4 to pH < 2; cool to 4° C in polyethylene container.

Sample Storage: Did not exceed 48 hr after digestion.

(11) Total Soluble Phosphorus

Method: Automated acid/persulfate digestion method and ascorbic acid colorimetric method.

Reference: APHA 1980.

Sample Preservation: Filtered through 0.45-μ membrane filter immediately following collection.

Sample Storage: Did not exceed 48 hr.

(12) Soluble Reactive Phosphorus

Method: Automated ascorbic acid colorimetric method.

Reference: APHA 1980.

Sample Preservation: Filtered through 0.45-μ membrane filter immediately following collection. Stored at 4° C.

Sample Storage: Did not exceed 24 hr.

Outline of General Procedures and Methods

A. **Chemical and Physical Parameters**

    (1) **Depth of Water Column**

        Method: Depth sounding.

    (2) **Dissolved Oxygen**

        Method: Membrane electrode.

        Reference:* APHA 1980.

        Sample Preservation: Field determination.

        Comments: Calibrated versus Winkler prior to each sampling trip. The residual current at zero dissolved oxygen was determined for the probe to be used. This was done using water deoxygenated by either (a) purging with N_2 or (b) adding sufficient sulfite to produce a saturated solution.

    (3) **Light Penetration**

        Equipment: Submarine photometer.

        Comments: Measured at 0.1-m and 1-m intervals from 1.0 m to depth at which 1 percent surface irradiance occurred.

    (4) **Secchi Disc Transparency**

        Equipment: Standard black/white, 20-cm Secchi disc.

        Comments: Line calibrated in 0.2-m intervals with 0.1-m interval measurements made using metre stick.

    (5) **Water Temperature**

        Equipment: Thermistor.

        Comments: Calibrated with a National Bureau of Standards certified thermometer prior to each sampling trip. Readings to nearest 0.1° C.

    (6) **Conductivity**

        Method: Electrometric.

        Reference: APHA 1980.

        Sample Preservation: Field determination.

        Comments: Read to 1.0 μmho/cm and converted to μmho/cm at 25° C.

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* Bibliographic information for the references given in Appendix A is presented on page A10.

APPENDIX A: ANALYTICAL METHODS

inflow entered the lake as an overflowing density current or mixed completely with lake waters. In addition to increases in lake level and discharges, these events markedly increased lake nutrient, metal, and solids concentrations. Increases were also apparent in the discharge. Based on comparisons with other loading events, these events supply a significant portion of the total annual load and thus greatly influence lake nutrient levels prior to the summer growing season.

d. Few differences were observed between lake sampling stations, suggesting that conditions observed at station 20 were indicative of conditions in the lake as a whole. Differences observed for stations 40 and 50 reflect influences of the inflowing river and the growth of macrophytes in the shallow northern cove, respectively. Marked vertical differences were observed seasonally. Thermal stratification, although relatively weak, fostered the establishment of an anoxic hypolimnion and subsequent releases from sediments of nutrients and metals.

148. Information contained in this report provides a basis of verification of the one-dimensional water quality model CE-QUAL-R1 and the assessment of specific processes influencing water quality conditions. The greater understanding of these processes will further expand the knowledge of reservoir limnology and facilitate the formulation of sound management practices.

PART VII: SUMMARY

145. Eau Galle Lake, a small, dimictic, flood-control reservoir in west-central Wisconsin, exhibits water quality characteristics similar to those of other eutrophic lakes in this glaciated region. These include macrophyte infestations, algal blooms, reduced transparency, and hypolimnetic oxygen depletion.

146. Routine studies conducted at Eau Galle Lake during the period November 1980 to October 1982 were designed to provide detailed water quality data for use in the calibration and verification of the one-dimensional ecological model CE-QUAL-R1. These data, as well as data collected during short-term, more extensive, studies also allow characterization of trends and key processes influencing water quality dynamics. This information provides a sound basis for the formulation of management alternatives and a historical perspective from which to gage future conditions.

147. Several general conclusions can be drawn from information contained in this the first of two reports summarizing studies at Eau Galle Lake:

   a. Morphometric characteristics of the lake basin reflect excavations and channel diversions during construction. These characteristics include a deep central basin, a deep narrow approach channel, and modifications to the river channel near the river inflow. Preliminary findings indicate that these characteristics and the operation of the outlet structure strongly influence in-lake flow patterns.

   b. Seasonal variability in flow and material concentrations reflects geologic and land use patterns in each tributary basin and the impacts of spring snowmelt events. In general, material loadings were highest during late winter and early spring, coincident with snowmelt and spring rains. Within these high-flow events, changes in concentrations are predictable; dissolved constituent concentrations are highest prior to peaks in the hydrograph, while particulate concentrations are highest coincident with peaks in flow.

   c. Seasonal variations in flow and material loads had pronounced impacts on lake conditions; most notable were impacts of snowmelt and runoff. During these periods,

Phosphorus can exist in oxygenated waters, but due to its rapid utilization in the epilimnion by algae, is normally found in high concentrations only in the hypolimnion. Like ammonia, iron, and manganese, the high levels of phosphorus are the result of its release from the sediments during anoxia.

143. Associations based upon seasonal means of the lake ignore any depth-related differences of the variables. If depth-related differences are considered, four variables would be moved in Group II: TN, TP, TFe, and DFe. These four all exhibit epilimnetic maxima in the spring but have their highest concentrations in the anoxic bottom waters during summer stratification. These, along with Turb, TSS, TOC, TSP, and SRP, which were already in Group II but also show increases in the bottom waters during anoxia, would form Group IIb.

144. If the groups created by the association of seasonal maxima are compared to those of flow correlations (Table 7), a high degree of similarity is apparent. The greatest similarity is between Groups I and II by all methods. These similarities underscore the importance of loading events to water quality in Eau Galle Reservoir.

References

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Table 7

Variable Groupings by Seasonal Maxima or Flow Correlation

Group	Seasonal Maximums	Correlation to Flow*	Seasonal Maximum and Depth
I	TS	TS	TS
	NO_3/NO_2-N	NO_3/NO_2-N	NO_3/NO_2-N
	DSi	DSi	DSi
	TCa	TCa	TCa
	DCa	DCa	DCa
	TMg	TMg	TMg
	DMg	DMg	DMg
	TN	SO_4	TAlk
	TAlk		SpCond
	SpCond		
II	DOC	DOC	a DOC
	TK	TK	TK
	DK	DK	DK
	TSS	SS	DO
	TOC	TOC	TNa
	DO	TN	DNa
	Turb	NH_4-N	b Turb
	TNa	TP	SS
	DNa	TSP	TOC
	TSP	SRP	TN
	SRP	TFe	NH_4-N
	SO_4	TMn	TP
	ChlB		TSP
			SRP
			TFe
			DFe
			SO_4
III	DMn	DMn	DMn
	TMn	TNa	TMn
	Temp**	DNa	Temp**
	Phaeo**	DFe	Phaeo**
	pH**		pH**
	TSul**		TSul**
	ChlA		ChlA
	TFe		
	DFe		
	TP		
	NH_4-N		

* Obtained from Montgomery (1984).
** Not considered by Montgomery (1984).

Kelley, M. G., Church, M. R., and Hornberger, G. M. 1974. "A Solution of the Inorganic Carbon Mass Balance Equation and Its Relation to Algal Growth Rates," Water Research, Vol 10, pp 493-497.

Lorenzen, C. J. 1967. "Determination of Chlorophyll and Pheo-pigments: Spectrophotometric Equations," Limnology and Oceanography, Vol 12, pp 343-346.

Raveh, A. and Avnimelech, Y. 1979. "Total Nitrogen Analysis in Water, Soil and Plant Material with Persulfate Oxidation," Water Research, Vol 13, pp 911-912.

Strickland, J. D. H., and Parsons, T. R. 1968. A Manual of Seawater Analysis, Bulletin of the Fisheries Research Board of Canada, Vol 125, pp 1-185.

Vollenweider, R. A. 1969. A Manual of Methods for Measuring Primary Production in Aquatic Environments, Blackwell Science Publications, Oxford.

APPENDIX B: TRIBUTARY DATA DISPLAYS

NOTE: Sampling stations referenced in the following
        figures were located as follows: station 45
        (Eau Galle River), station 46 (French Creek),
        station 65 (Lousy Creek), and station 25 (Lohn
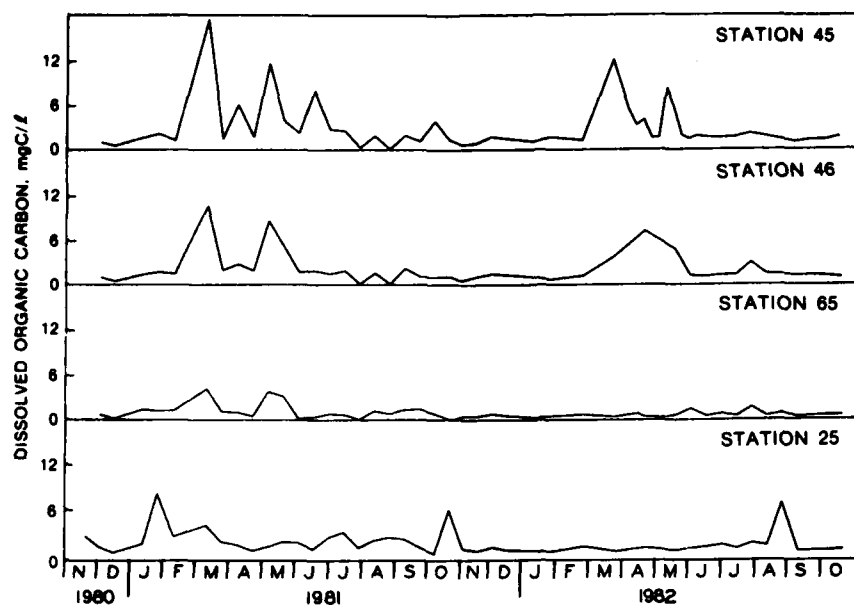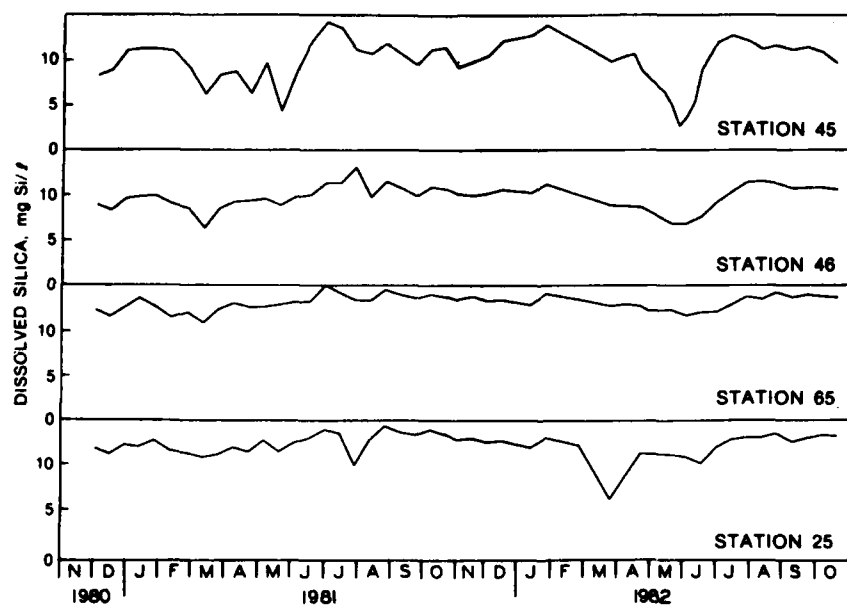   Creek).   (See Figure 7 in main text.)
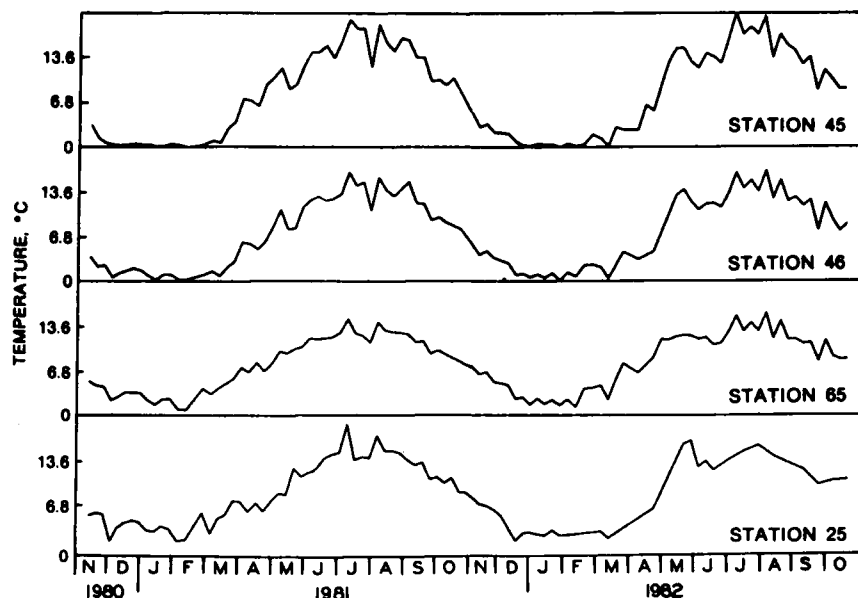
Figure B1.   Changes in temperature in the tributary
sampling stations, November 1980-October 1982
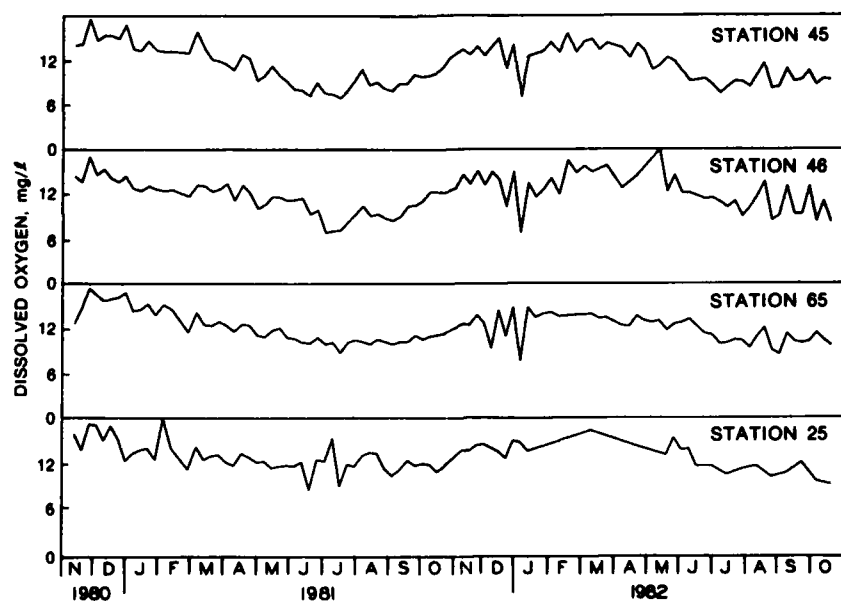
Figure B2.   Changes in dissolved oxygen in the tribu-
tary sampling stations, November 1980-October 1982
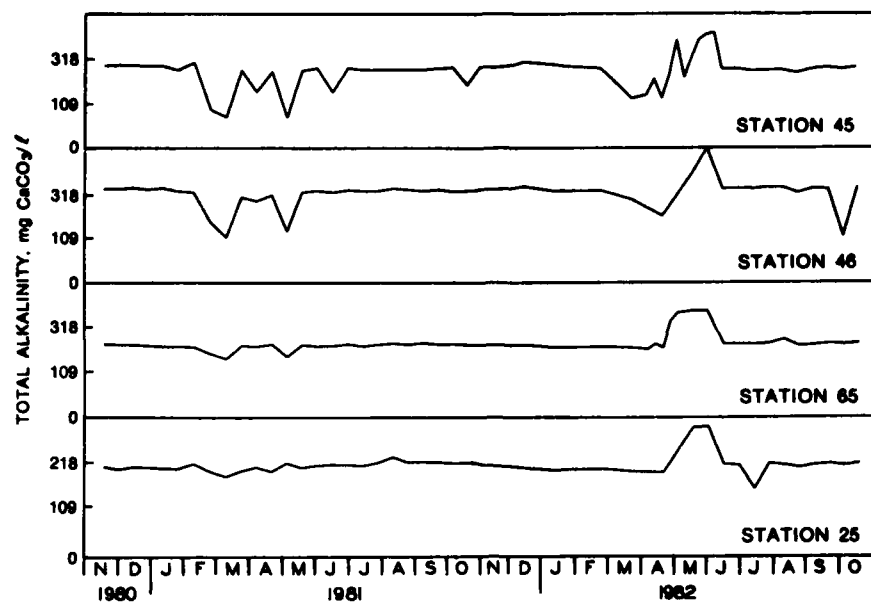
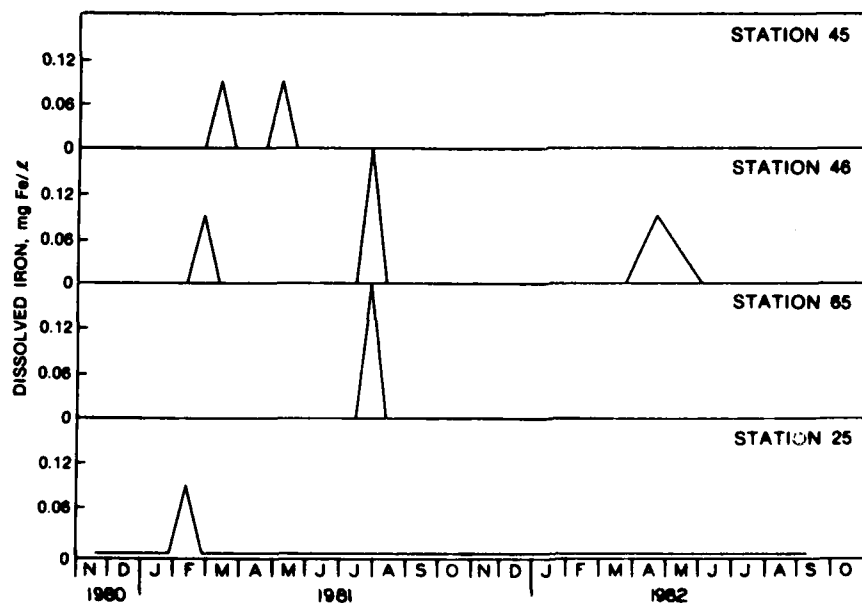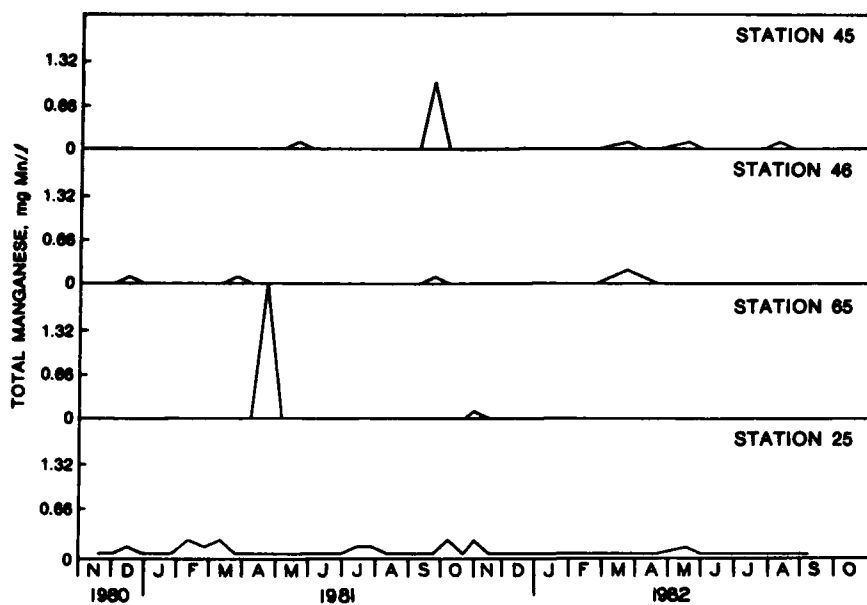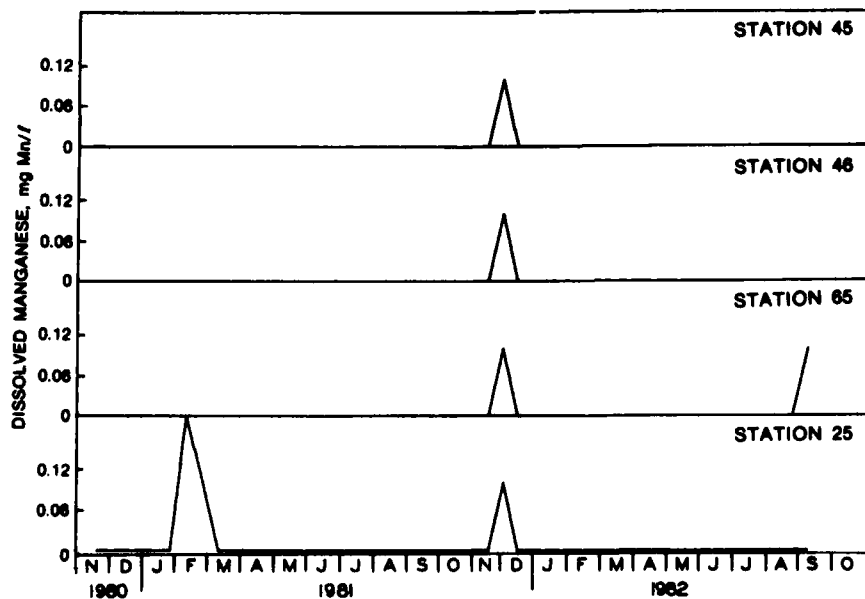Figure B3. Changes in total alkalinity in the tributary sampling stations, November 1980-October 1982
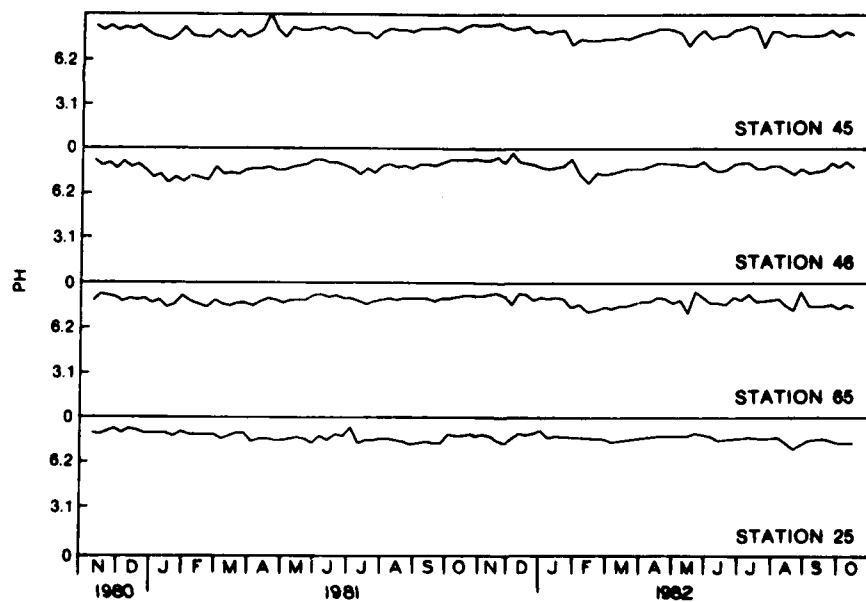
Figure B4. Changes in pH in the tributary sampling stations, November 1980-October 1982
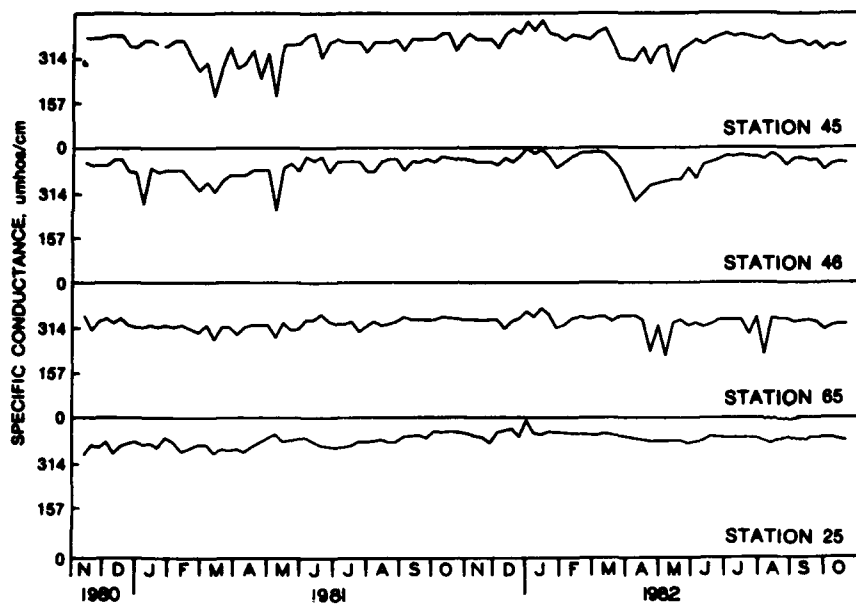
Figure B5.   Changes in specific conductance in the trib-
utary sampling stations, November 1980-October 1982
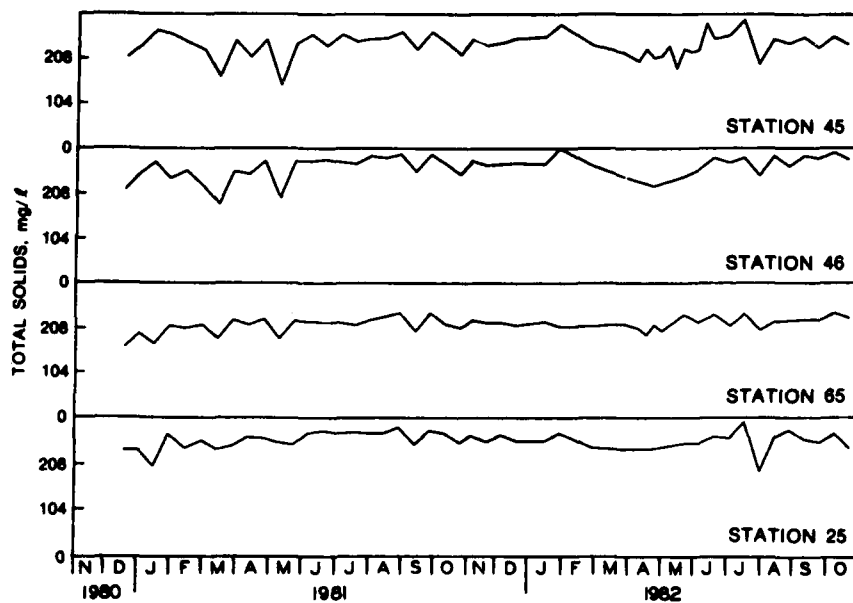
Figure B6.   Changes in total solids in the tributary
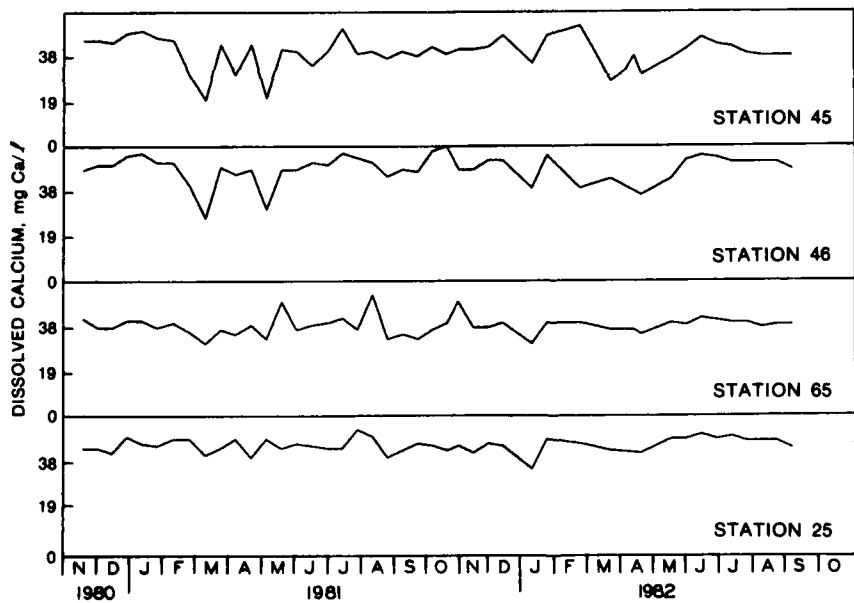sampling stations, December 1980-October 1982

B4
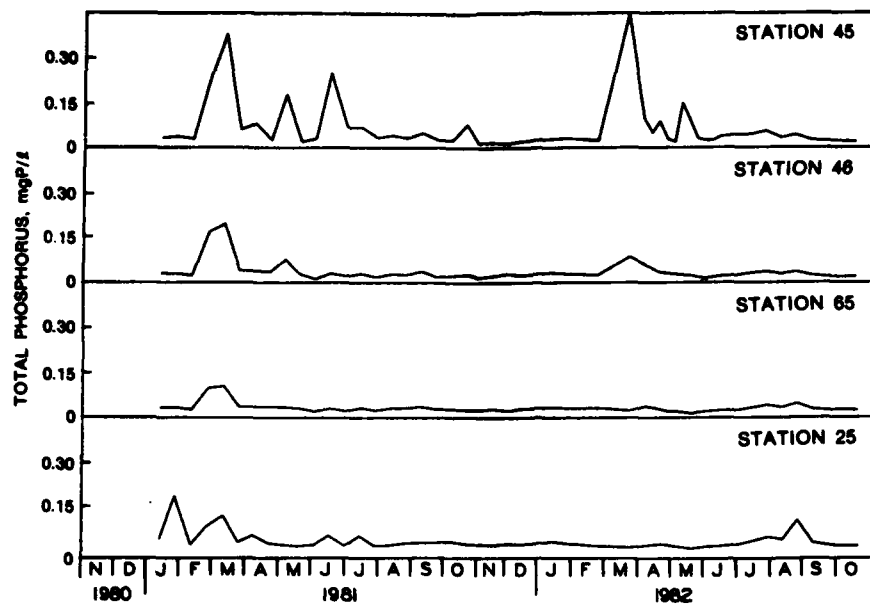
Figure B7. Changes in total phosphorus in the trib-
utary sampling stations, January 1981-October 1982
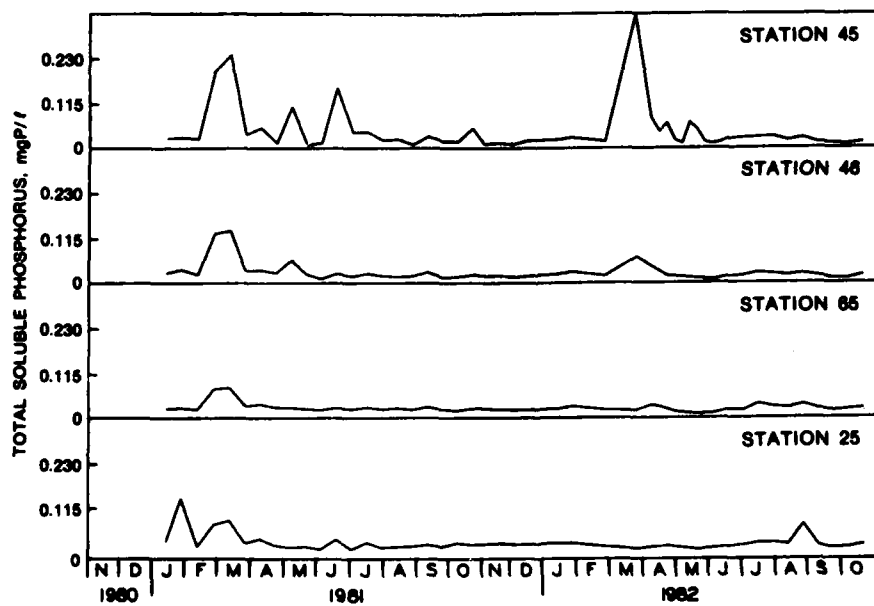
Figure B8. Changes in total soluble phosphorus in the
tributary sampling stations, January 1981-October 1982

B5
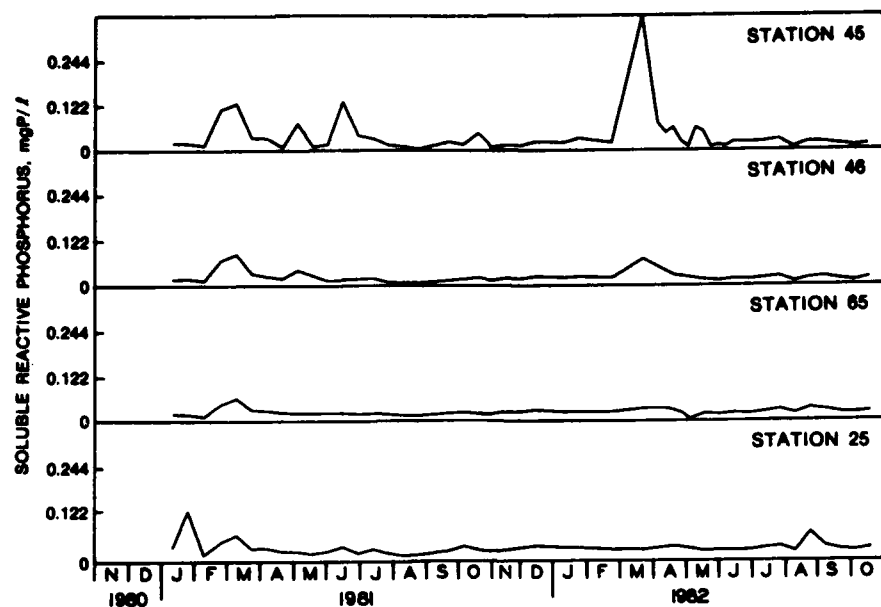
Figure B9. Changes in soluble reactive phosphorus in the tributary sampling stations, January 1981-October 1982
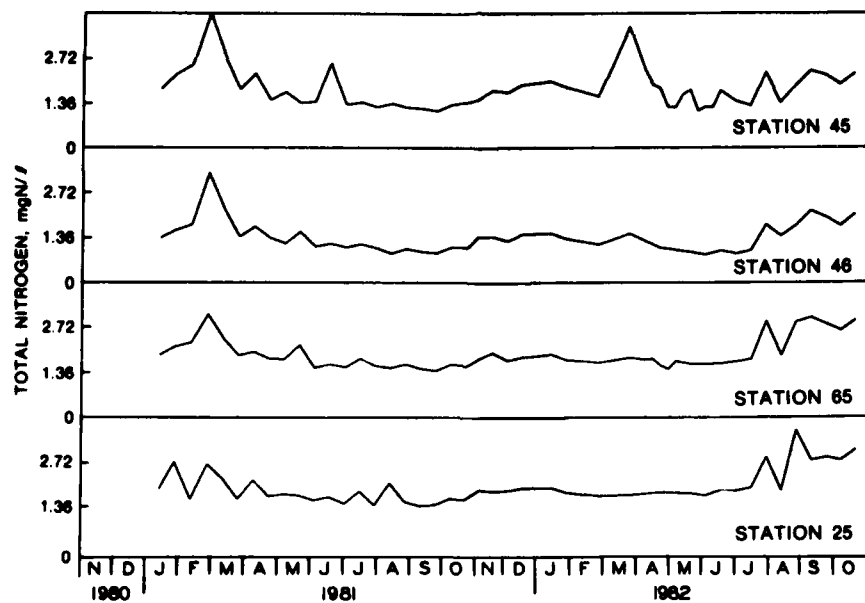
Figure B10. Changes in total nitrogen in the tributary sampling stations, January 1981-October 1982
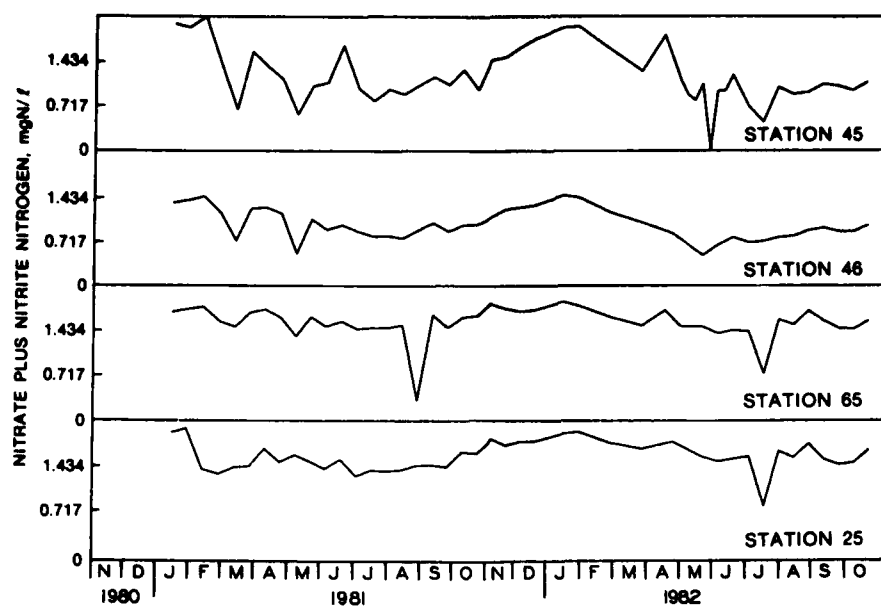
Figure B11.   Changes in nitrate/nitrite in the tribu-
tary sampling stations, January 1981-October 1982
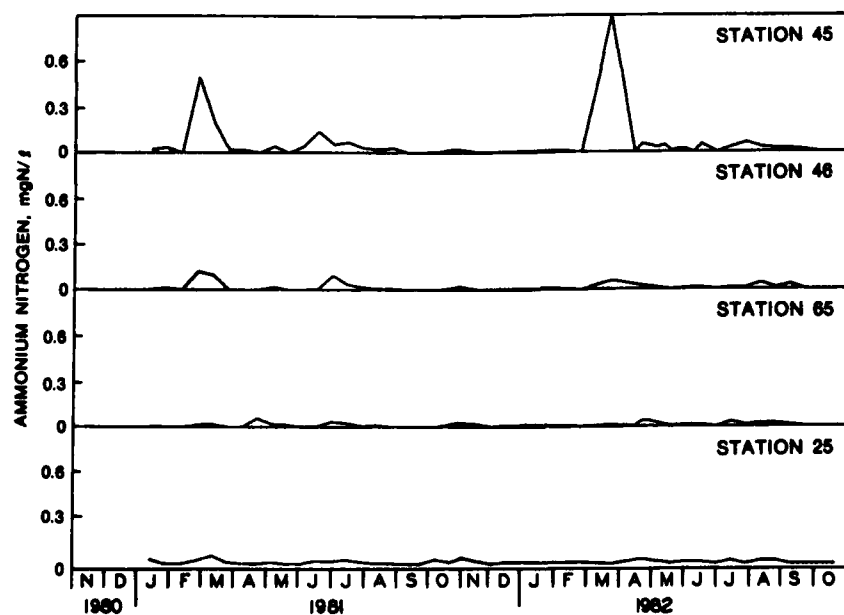
Figure B12.   Changes in ammonium in the tributary
sampling stations, January 1981-October 1982

B7
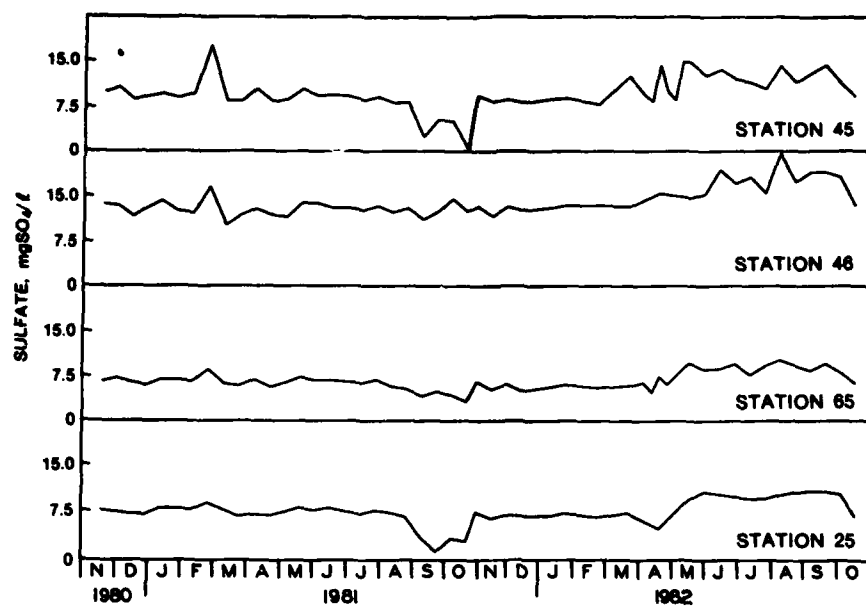
Figure B13. Changes in sulfate in the tributary sampling stations, November 1980-October 1982
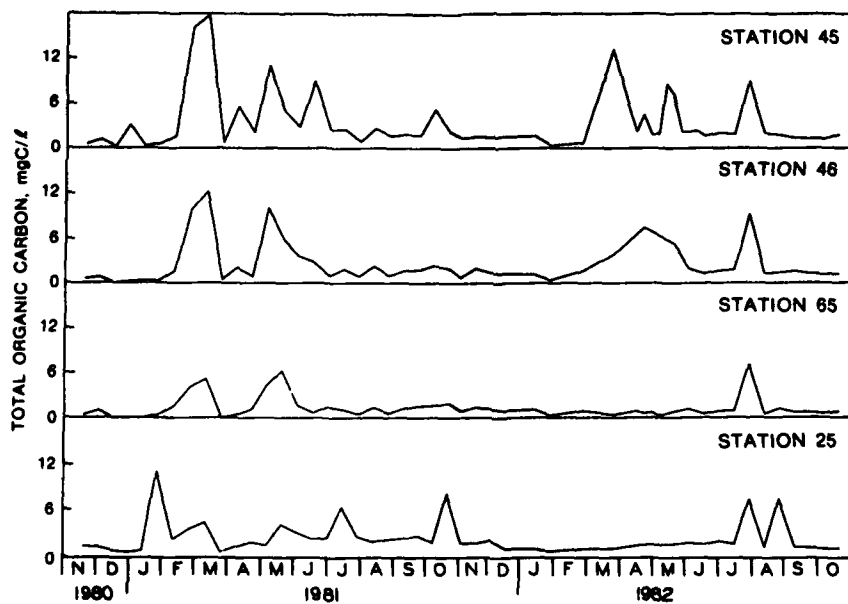
Figure B14. Changes in total organic carbon in the tributary sampling stations, November 1980-October 1982
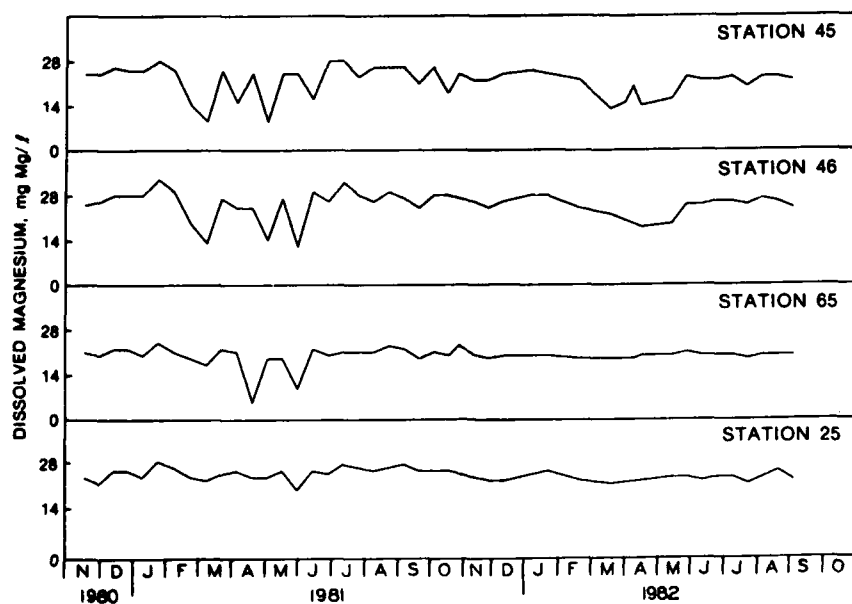
B8

Figure B15. Changes in dissolved organic carbon in the tributary sampling stations, November 1980-October 1982

Figure B16. Changes in dissolved silica in the tributary sampling stations, November 1980-October 1982
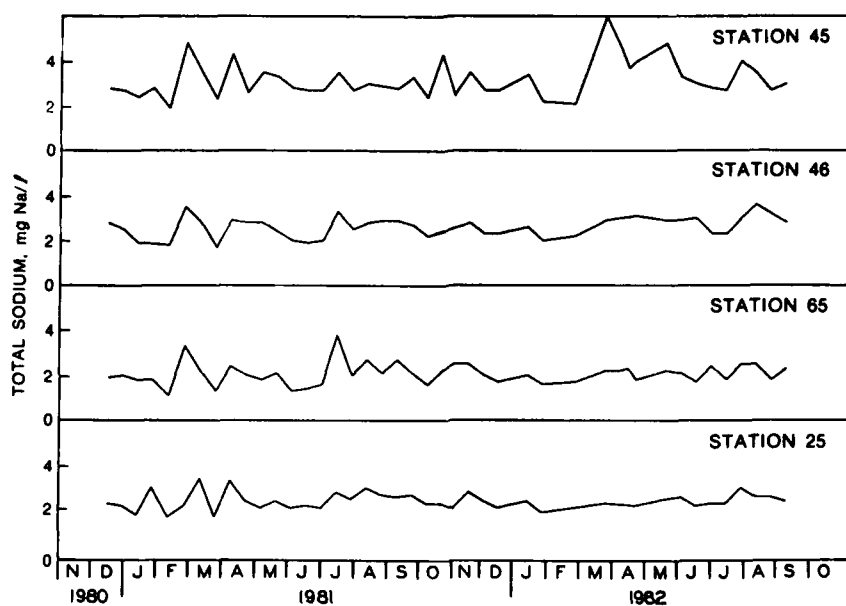
B9
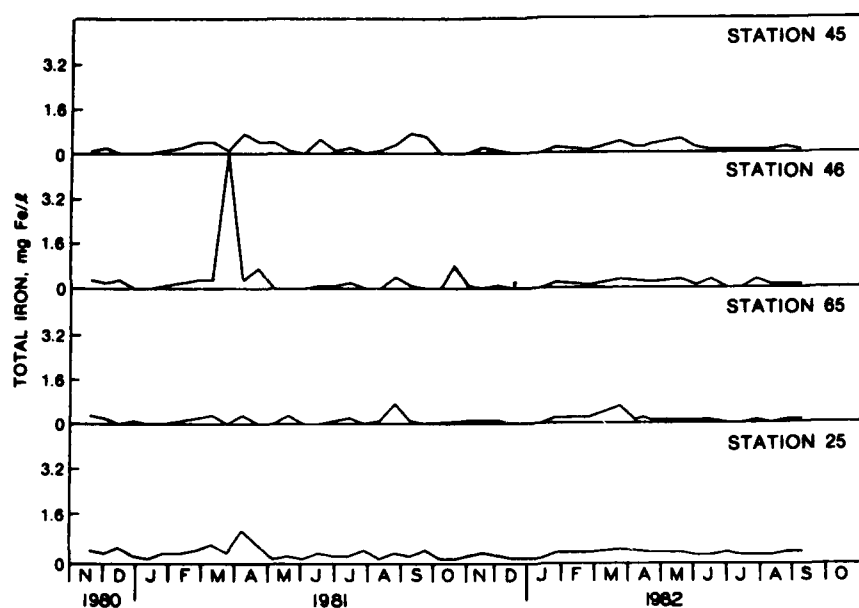
Figure B17.   Changes in total iron in the tributary
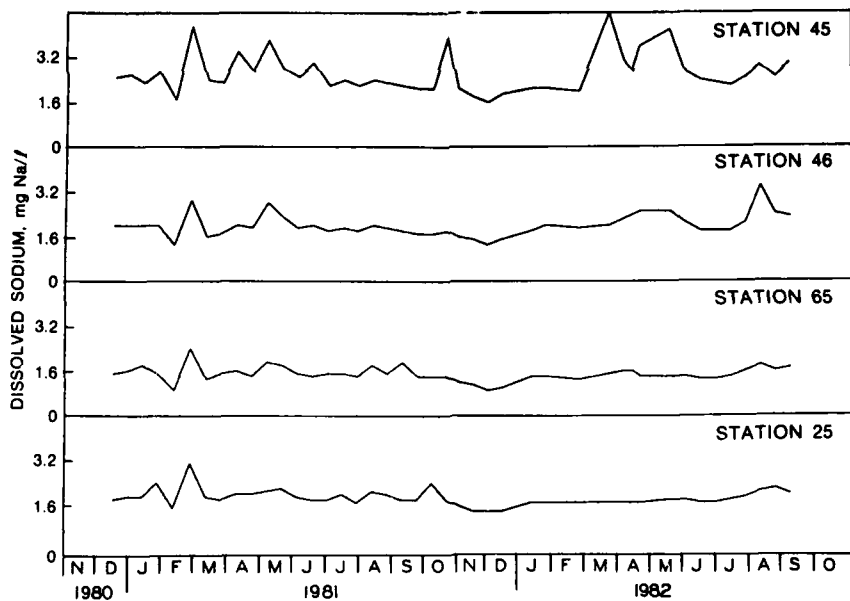   sampling stations, November 1980-September 1982

Figure B18.   Changes in dissolved iron in the tribu-
             tary sampling stations, November 1980-September 1982

Figure B19. Changes in total manganese in the tributary sampling stations, November 1980-September 1982

Figure B20. Changes in dissolved manganese in the tributary sampling stations, November 1980-September 1982
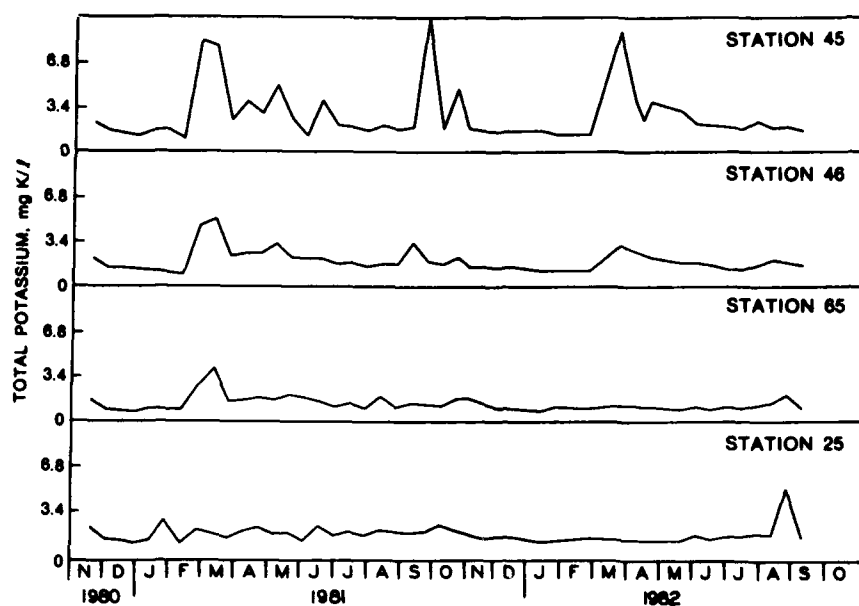
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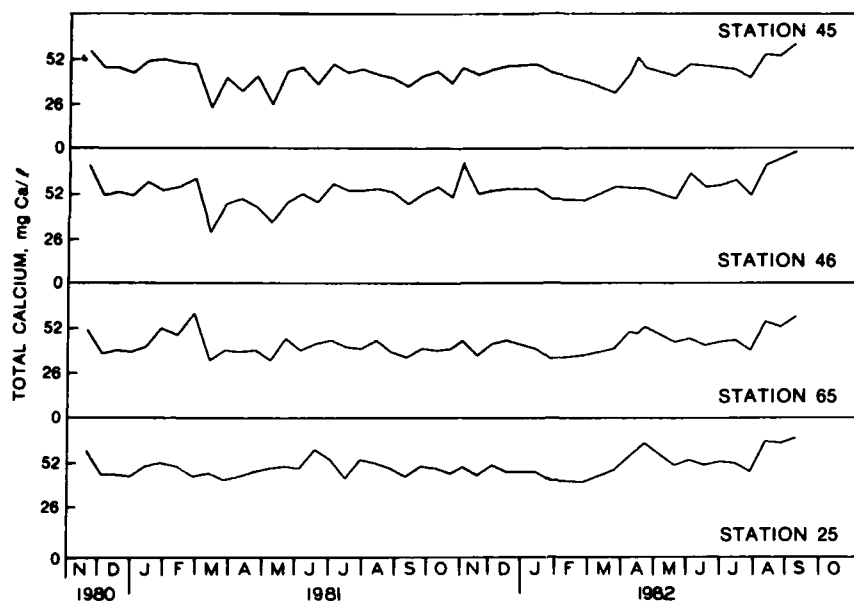
Figure B21.   Changes in total calcium in the tributary
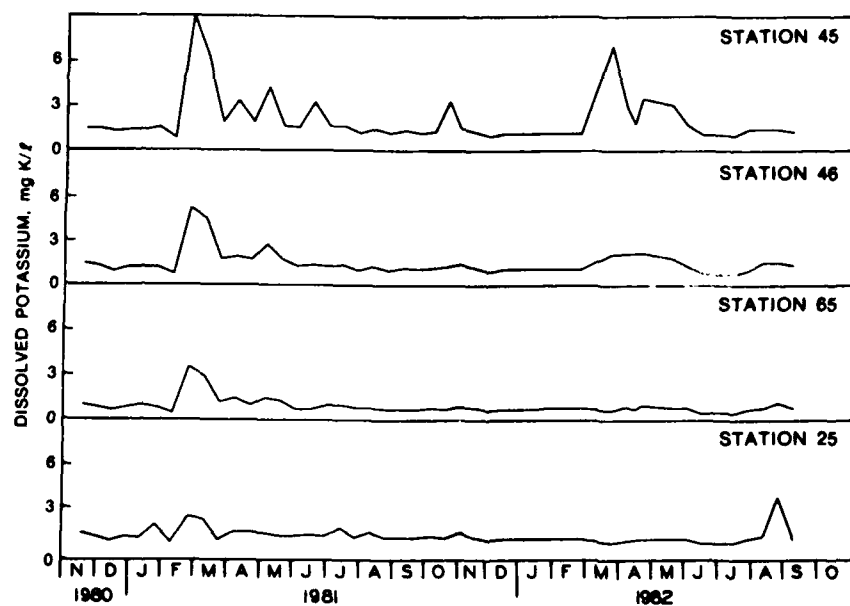sampling stations, November 1980-September 1982

Figure B22.   Changes in dissolved calcium in the trib-
utary sampling stations, November 1980-September 1982

B12
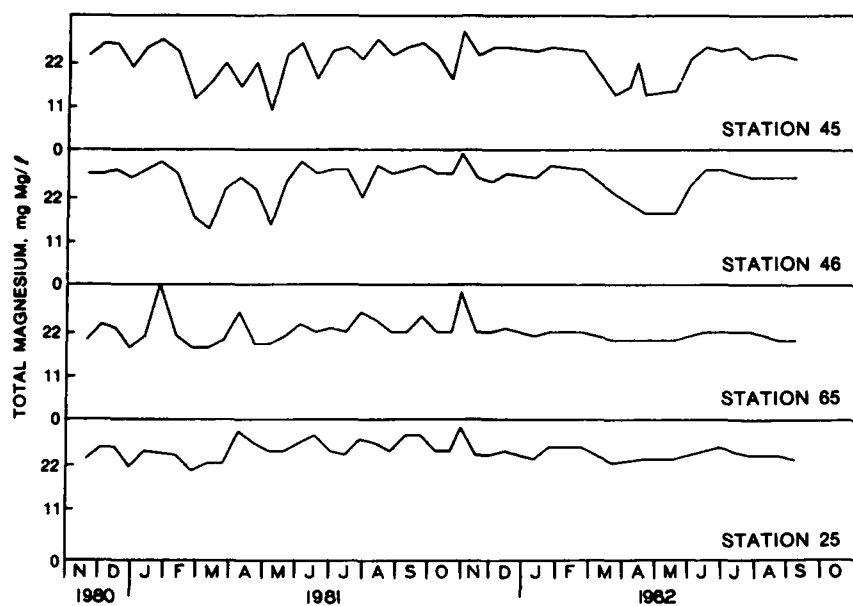
Figure B23. Changes in total magnesium in the tributary sampling stations, November 1980-September 1982

Figure B24. Changes in dissolved magnesium in the tributary sampling stations, November 1980-September 1982
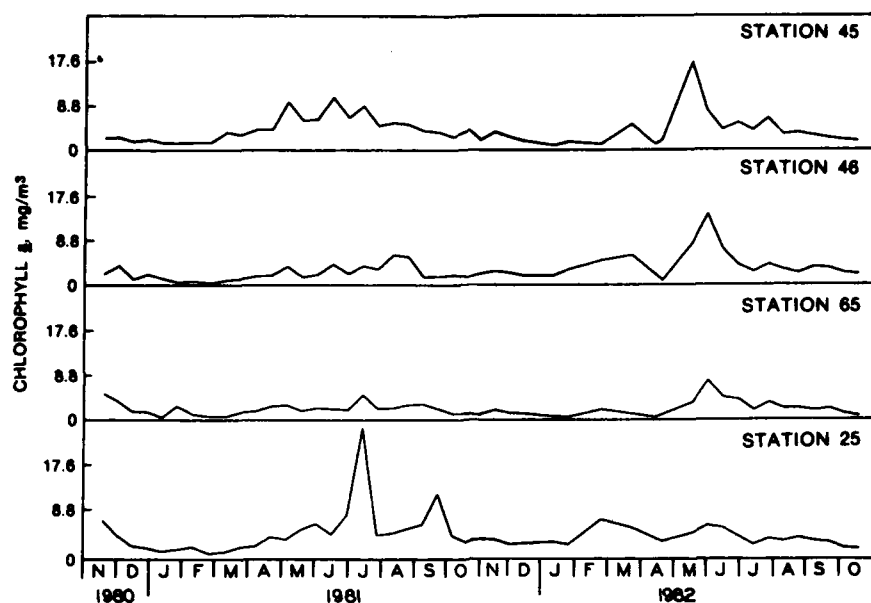
B13

Figure B25.   Changes in total sodium in the tributary
sampling stations, December 1980-September 1982

Figure B26.   Changes in dissolved sodium in the tribu-
tary sampling stations, December 1980-September 1982

B14

Figure B27.   Changes in total potassium in the tribu-
tary sampling stations, November 1980-September 1982

Figure B28.   Changes in dissolved potassium in the trib-
utary sampling stations, November 1980-September 1982

B15

Figure B29.   Changes in chlorophyll a in the tributary
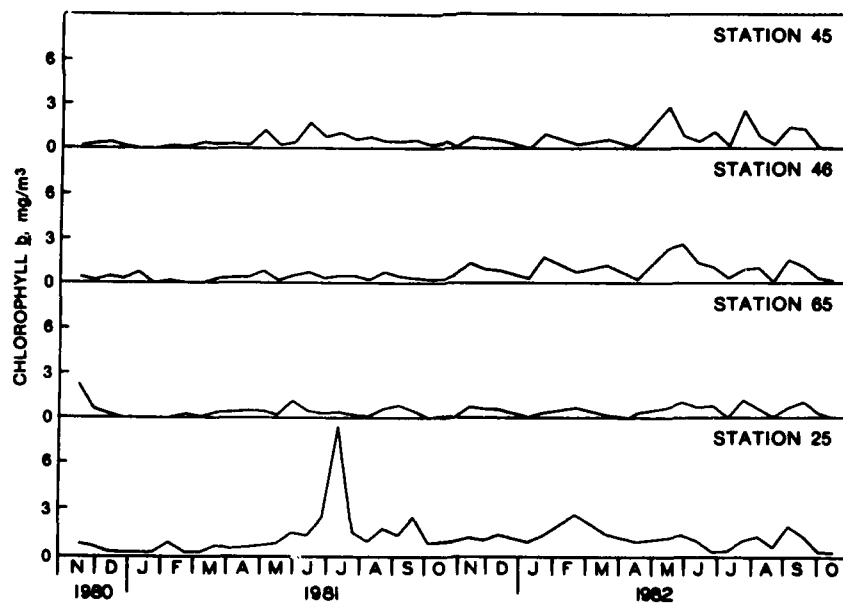   sampling stations, November 1980-October 1982

Figure B30.   Changes in chlorophyll b in the tributary
             sampling stations, November 1980-October 1982
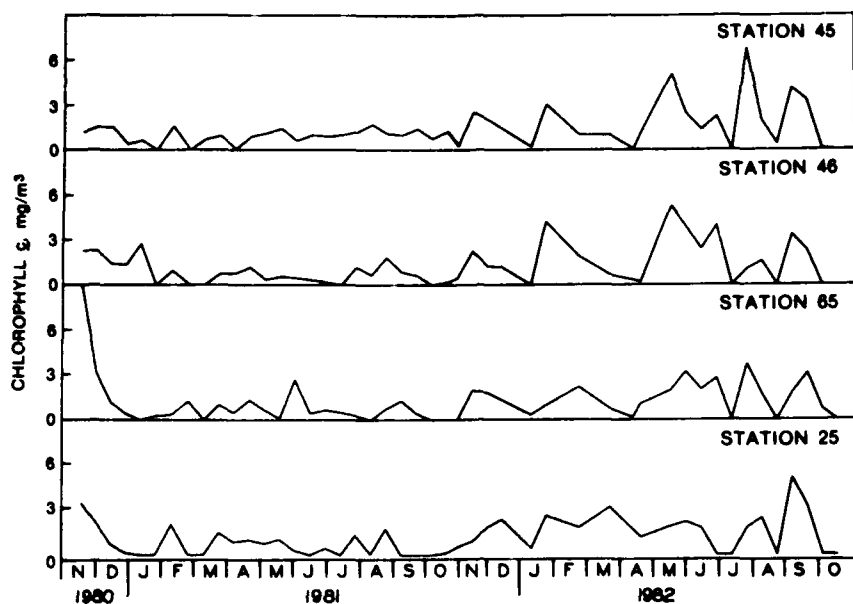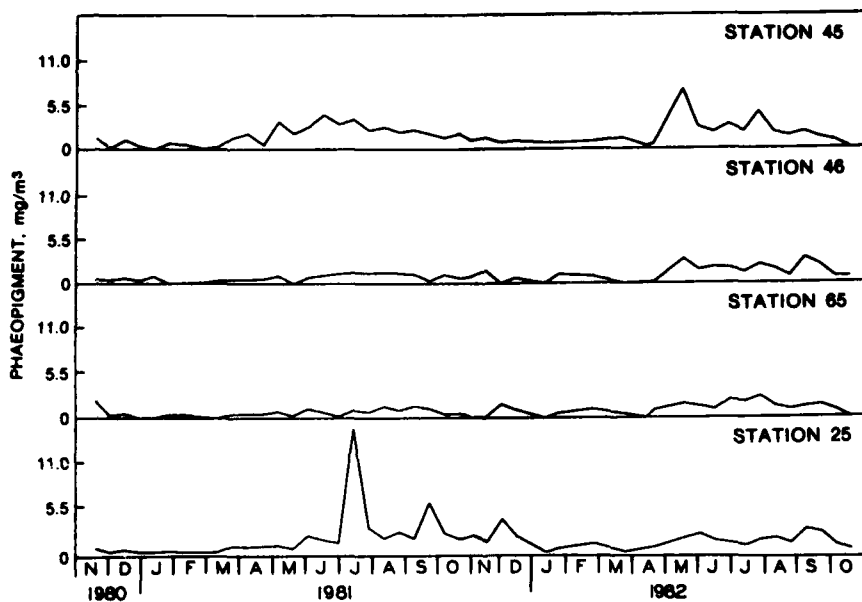
B16

Figure B31. Changes in chlorophyll c in the tributary
sampling stations, November 1980-October 1982

Figure B32. Changes in pheopigment in the tributary
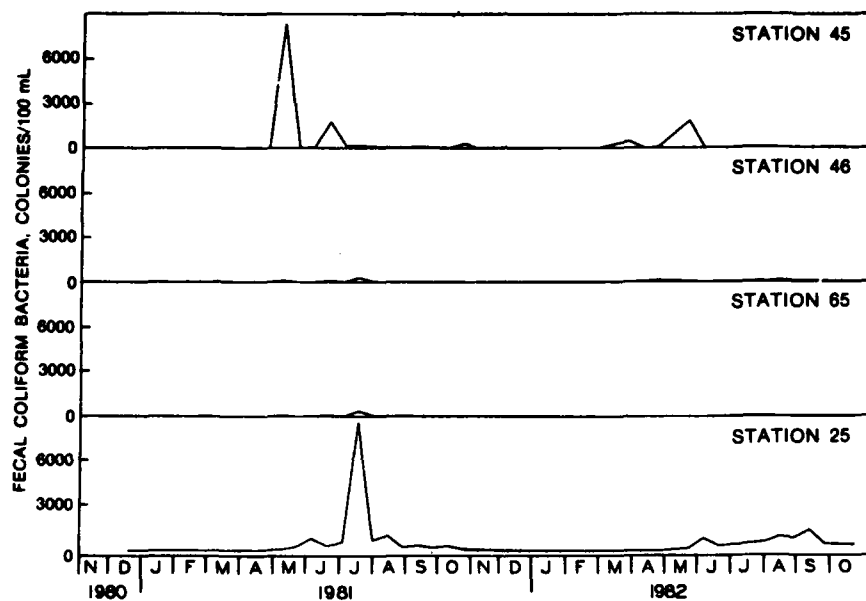sampling stations, November 1980-October 1982

B17

Figure B33.   Changes in fecal coliform bacteria in
the tributary sampling stations, December 1980-
October 1982

B18

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