

J. S. Carter

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LAKE NORMAN SUMMARY

VOLUME I

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LAKE NORMAN SUMMARY

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Duke Power Company

Technical Report DUKE PWR/82-02

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DEDICATION

This report was prepared and distributed with the belief that others might benefit from our work. In that belief, we dedicate its use to the memory of three of our fellow Duke Power Company environmentalists who lost their lives while sampling on Lake Norman in January 1980.

Robert Lynn Green

Elaine Faulk Jones

David Wayne Revill

PREFACE

Duke Power Company and other investigators have studied the aquatic environment of Lake Norman and vicinity since prior to its impoundment in the early 1960's. The purpose of the Duke Power studies was to develop a database of physical, chemical, and biological characteristics that would be useful in assessing the aquatic environmental impact of McGuire Nuclear Station, scheduled for operation in 1981, and of Marshall Steam Station, operating on the lake since 1965.

This document summarizes those environmental data collected by Duke Power from 1974 through 1980 at over fifty locations on Lake Norman and Mountain Island Lake. Volumes 1 and 2 contain these summaries, including statistical analyses, for representative portions of the database. The entire database is reproduced on microfiche in Volume 3.

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by increased concentrations of ammonia, iron, manganese, and alkalinity. Nutrient concentrations also exhibited typical seasonal cycles with nitrate plus nitrite being the dominant nitrogen species in winter and spring, and ammonia the dominant species during fall. Total phosphorus concentrations exhibited seasonal trends similar to turbidity. Trace element concentrations were within the North Carolina water quality standards for the protection of aquatic life, with occasional exceptions of zinc, mercury, and cadmium.

The phytoplankton community of Lake Norman was dominated by diatoms from late fall to mid-spring, cryptophytes in late spring, and green algae and dino-flagellates from summer to mid-fall. Blue-green algae were present in the summer at relatively low densities. The abundance of phytoplankton, especially diatoms, was fairly consistent among locations south of the Davidson Creek-Catawba River confluence, but was slightly greater at uplake locations. Spatial variation, however, was generally outweighed by temporal changes. Phytoplankton abundance was usually greatest in the spring and occasionally high again in the fall. Phytoplankton were patchily to uniformly distributed throughout the water column during the cool months. During the thermally stratified period, however, phytoplankton were heavily concentrated in the near-surface waters. Annual mean chlorophyll *a* concentrations have declined since 1974, perhaps due to a similar decline of total phosphorus concentrations.

The production rates of the phytoplankton community were apparently regulated primarily by light and temperature during the isothermal period, and by the availability of phosphorus during the stratified period. The latter observation was supported by the results of phytoplankton nutrient bioassays. Furthermore, when McGuire discharge conditions were simulated, bioassays showed that algal growth response in the laboratory was more strongly related to temperature increase than to increase in nutrient concentrations.

The periphyton community of Lake Norman was dominated by diatoms; green and blue-green algae were generally second and third, respectively, in abundance and biomass. Algal carbon and chlorophyll *a* were the best estimators of periphyton biomass. Biomass was generally highest in late spring and lowest in winter; periphyton growth appeared to be primarily a function of light and temperature, except during late summer when low nutrient availability and/or increased predation may have caused lower biomass. Spatial variation was small compared to seasonal changes.

Macrophytes were not abundant in Lake Norman. In the Ramsey Creek area they contributed less than one percent to the total annual production of plants and had a negligible contribution to lake metabolism, even with regard to oxygen depletion during their decomposition.

The zooplankton community of Lake Norman was dominated numerically by rotifers most of the year, although cladocerans and copepods were often abundant in the spring. Copepods usually dominated the community biomass. Zooplankton abundance and biomass were generally high in spring and fall; the spring pulse occurred for all major zooplankton groups, whereas only rotifers contributed substantially to the fall pulse.

Differences in zooplankton community structure among sampling locations were small, although cladocerans and rotifers were generally more abundant uplake

EXECUTIVE SUMMARY

This report summarizes aquatic ecosystem data collected by Duke Power Company from over fifty sampling locations on Mountain Island Lake and Lake Norman, especially the latter, from 1974 through 1980. During this period Marshall Steam Station on the upper end of Lake Norman was operating, and McGuire Nuclear Station on the lower end of the lake was under construction. When both electrical generating facilities are operating, Lake Norman will have the highest thermal loading from the discharge of once-through condenser cooling water of any comparable-sized lake in the United States.

Lake Norman is generally typical of other dendritic reservoirs in the Carolinas Piedmont physiographic province. However, the lake receives relatively low quantities of pollutants compared to some other lakes in the province; its trophic status is best characterized as oligo-mesotrophic (of excellent quality for body contact water sports but of low fishing potential).

Water temperature on Lake Norman followed seasonal patterns typical of Piedmont reservoirs. The lake began to thermally stratify during April. Maximum temperatures were measured during July and August and ranged from about 29 to 33°C in the surface waters and from about 9 to 14°C in the bottom waters. The lake began to cool during the fall and stratification decreased, resulting in relatively uniform temperatures from surface to bottom by the end of November. Minimum lake surface temperatures in the downlake areas were generally measured during February each year and ranged from about 2 to 8°C.

The thermal characteristics of the lake were determined primarily by local meteorology but were also influenced locally by the operation of Lookout Shoal and Cowans Ford Hydroelectric Stations at the upper and lower end of the lake, respectively, and by Marshall Steam Station. Because Marshall utilizes cool bottom waters for condenser cooling, discharge temperatures during the summer were approximately the same as surface temperatures measured at locations out of the influence of the Marshall discharge. Maximum differences between surface temperatures in the discharge cove and those in other areas of the lake were measured between October and March, with the thermal plume being observed over the largest area of the lake in January and February. During these latter months the plume was generally contained within the top 5 m of the water column and had dissipated most of the excess heat within 10 km of the Marshall discharge structure.

The physicochemical characteristics of Lake Norman waters reflected the geology of the basin. The lake was characterized by slightly acidic pH values, low hardness, stable mineral composition, and generally low nutrient and trace metal concentrations. Variables related to runoff, such as turbidity, iron, orthophosphate, and total phosphorus, were higher in the uplake areas with concentrations decreasing downlake. Surface turbidity values were high during winter and spring with low values being observed during the summer and fall.

Dissolved oxygen concentrations exhibited seasonal trends typical of Piedmont Carolina lakes with highest values occurring from December through April and lowest concentrations from July through October. Except for locations near the Marshall discharge, dissolved oxygen concentrations in the surface waters were above 5.0 mg·l⁻¹ throughout the year. Low dissolved oxygen concentrations existed in the bottom waters from August through October and were accompanied

sunfish and perch. Uplake abundance of larval shad and sunfish was higher than at downlake locations. However, uplake crappie abundance was considerably lower than downlake. Larval perch were also more abundant in downlake collections.

Newly hatched larval fish were usually more abundant in shoreline areas. Rapid dispersal from shoreline areas occurred as the larvae grew, and larger larvae were generally more abundant in the channel areas. No noticeable difference was observed in spawning times or duration of spawning throughout the lake, even though water temperatures near Marshall during early spring were slightly higher than ambient lake temperatures. Furthermore, no relationship was apparent between the number of larvae collected and the number of young-of-the-year fish present in August rotenone samples.

In summary, the results of these seven years of studies by Duke Power Company indicate the Lake Norman ecosystem prior to the operation of McGuire Nuclear Station is generally typical of other Carolina Piedmont reservoirs. Overall the principal trends identified were 1) low spatial variability, although slightly higher values of many variables were measured uplake compared to downlake, and 2) seasonal factors generally outweighed spatial ones, with many variables exhibiting a spring pulse of measured values, occasionally followed by a lesser pulse in the fall.

CHAPTER 1. INTRODUCTION

J. E. HOGAN

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BACKGROUND

Duke Power Company is constructing McGuire Nuclear Station on Lake Norman near Cowans Ford Dam, 27 km north-northwest of Charlotte, NC (Fig. 1-1 and 1-2). McGuire will have two generating units of 1180 MW net electrical design rating each. The station will utilize a cooling water intake drawing from the near-surface waters of Lake Norman. When water temperatures are warm, part of the once-through condenser cooling water will be supplied from a lower-level Lake Norman intake. The cooling water will be discharged back into Lake Norman.

Two other generating facilities also withdraw water from the lake (Fig. 1-2). The first, Cowans Ford Hydroelectric Station, utilizes a submerged skimmer weir allowing passage of surface water downstream to Mountain Island Lake. The second, Marshall Steam Station, is a 1900 MW net electrical capability coal-fired generating station, about 23 km uplake by water from McGuire. The once-through condenser cooling waters from Marshall are discharged to Lake Norman.

Although Lake Norman is the largest reservoir within North Carolina, it is the smallest body of standing water in the United States on which two large steam stations with once-through cooling are located (0.32 MW net electrical per surface hectare at full pool). Therefore, concerns have been raised as to whether the thermal component of the discharges will cause detrimental effects to the biota of the lake. Duke Power Company (1975) demonstrated that the thermal component of the cooling water discharge from Marshall Steam Station was such that the protection and propagation of a balanced indigenous aquatic community in Lake Norman was assured; however, insufficient data were presented in that demonstration to adequately evaluate the impact on Lake Norman of both Marshall and McGuire.

OBJECTIVES

The objectives of this study were to:

1. document the physical, chemical, and biological characteristics of Lake Norman and Mountain Island Lake as these characteristics relate to the construction and/or operation of electric generating stations on Lake Norman, and
2. develop a database sufficient to assess the environmental impact of the operation of McGuire Nuclear Station and Marshall Steam Station on Lake Norman and Mountain Island Lake.

REGIONAL CHARACTERISTICS

DEMOGRAPHY

Lake Norman lies in the central area of the Carolinas' heavily populated Piedmont (Fig. 1-1). This area is characterized by rapid population increase. The largest nearby population centers, based on the 1980 census results, are

Charlotte (314 447), Gastonia (47 333), Kannapolis (34 420), Hickory (20 757), Statesville (18 622), and Concord, NC (16 942). Numerous small towns and communities surround the lake, with populations ranging from a few hundred to several thousand people.

LAND USE

The area around Lake Norman is generally rural, non-farmland, and suburban. Principal farm crops are soybeans, wheat, and corn. Chickens, and milk and beef cows are the main farm animals raised for profit (North Carolina Department of Agriculture 1971 as cited in Clay et al. 1975). The industries of the area are varied, but there are numerous textile and apparel mills, and furniture and other wood product industries (Clay et al. 1975). However, none of these industries are located on the shores of Lake Norman. Numerous single-family residences are located on the lake's shoreline. Apartments, condominiums, and housing subdivisions have also been constructed on the shoreline within the past few years. Several recreation areas, such as golf courses and Duke Power State Park, are also located on the shoreline.

WATER USE

The towns of Mooresville, Davidson, and Huntersville, NC, obtain drinking water from Lake Norman; they withdraw a mean of 0.13, 0.028, and 0.007 $\text{m}^3 \cdot \text{s}^{-1}$, respectively. Charlotte, NC, obtains its drinking water from Mountain Island Lake, downstream from Lake Norman (Fig. 1-1), at a mean rate of 1.9 $\text{m}^3 \cdot \text{s}^{-1}$.

Lake Norman is also used extensively for recreational purposes. The most frequent uses are boating, fishing, and swimming. Estimates indicate that over 3.6×10^5 people used Lake Norman access areas in 1979 (Duke Power Company 1981).

Few point sources discharge wastes to Lake Norman either directly or through tributaries. Duke Power Company's Marshall Steam Station discharges up to $64.4 \text{ m}^3 \cdot \text{s}^{-1}$ of industrial wastes resulting from ash pond overflow and once-through cooling. Duke Power also discharges up to $0.0009 \text{ m}^3 \cdot \text{s}^{-1}$ from its Training and Technology Center. The town of Catawba, NC, discharges municipal wastes into Lyle Creek at a rate up to $0.011 \text{ m}^3 \cdot \text{s}^{-1}$, of which about 40% is industrial waste derived from hosiery dying operations (North Carolina Department of Natural Resources and Community Development 1976a).

Non-point sources of wastes entering Lake Norman are largely derived from runoff, particularly from agricultural and forest lands, but also from construction activities. Residential developments on the lake shoreline generally have septic tanks and drain fields; a small amount of domestic waste may enter the lake as a result of inefficient operation of this form of waste treatment in clay soils. The lake also receives runoff from lawns and golf courses on the shoreline.

TERRESTRIAL ECOLOGY

The major forests of the Lake Norman area are representative of the Oak-Hickory-Scrub Oak, or the Shortleaf Pine climax. Thirty to fifty percent of this area

is forested. Subclimax successional communities dominate in the region as a result of discontinued logging, agricultural, or residential uses. Bottomland and streamside communities are usually dominated by willows, sycamore, sweetgum, and red maple (Clay et al. 1975).

Wildlife found in the Lake Norman area is typical of both the successional plant community and man-disturbed areas such as roads, buildings, farmland, and parks. Of species probably found in the area, about 35 are mammals, over 100 are birds, 35 are reptiles, and 23 are amphibians. Although not on a principal waterfowl flyway, Lake Norman is used by several species of migratory aquatic birds (Duke Power Company 1976).

No substantiated observations of rare, endangered, or threatened plant or animal species in the Lake Norman area have been recorded. The southern bald eagle is the only such species which may occur near the McGuire site (Duke Power Company 1976).

GEOLOGY

Lake Norman is in the rolling hills of the North Carolina Piedmont physiographic province (Fig. 1-1). The underlying rock of Lake Norman is within the Piedmont geologic province, predominately in the Inner Piedmont belt but partially in the Charlotte belt in the area around Cowans Ford Dam. Rocks of the Charlotte belt are of plutonic and metamorphic origin; they consist of granites, diorites, and gabbros, with intrusions of felsic and mafic gneisses, and schists. Rocks of the Inner Piedmont belt are of metamorphic origin consisting almost entirely of mica gneisses and schists; these rocks contain lesser amounts of hornblende gneiss and granite (Clay et al. 1975).

Soils in the Lake Norman area are characterized by acidic, highly leached and weathered clay subsoils (Clay et al. 1975). These soils generally have a loamy surface horizon, but they have slow percolation rates due to the clayey subsoil (Buol 1973 as cited in Clay et al. 1975).

METEOROLOGY

Lake Norman is located about 100 km from the Appalachian Mountains and about 300 km from the Atlantic Ocean. The mountains and ocean moderate winter temperatures, but have little effect on summer temperatures. The mean air temperature in January is 5.4°C (range from -1.1 in 1977 to 12.0°C in 1950), with instantaneous temperatures seldom below -12°C. The mean July temperature is 25.9°C (range from 24.6 in 1947, 1971, and 1975 to 28.0°C in 1977), with instantaneous temperatures seldom above 35°C. [Mean temperatures are based on the 1879 through 1975 record at Charlotte, NC (National Oceanic and Atmospheric Administration 1980). Instantaneous temperatures are from Clay et al. (1975)].

Mean annual precipitation is 1.14 m (range from 0.85 in 1950 to 1.58 m in 1975). [Mean precipitation is based on the 1878 through 1979 record at Charlotte, NC (National Oceanic and Atmospheric Administration 1980.)]. The driest weather is typically during the fall. Summer rainfall comes principally from thundershowers interspersed between occasional dry periods. Daily

precipitation at the McGuire site is shown in App. Fig. 1.1-1. Approximately 60 to 70% of total precipitation is lost from ground and surface water resources due to evapotranspiration. Mean annual evaporation of water from lakes of the region ranges from 0.96 to 1.02 m (Clay et al. 1975).

Wind is generally from the southwest at a mean speed of $12.1 \text{ km} \cdot \text{h}^{-1}$. During February, September, and October the prevailing direction is northeasterly. [Based on the 1950 through 1979 record of speed and 1963 through 1979 record of prevailing direction at Charlotte, NC (National Oceanic and Atmospheric Administration 1980)].

Sky conditions from sunrise to sunset are clear a mean of 111 days per year, partly cloudy 103 days, and cloudy 151 days. The clearest months are October and November; the cloudiest are December through March. [Based on the 1949 through 1979 record at Charlotte, NC (National Oceanic and Atmospheric Administration 1980)]. Daily solar irradiance at the McGuire site is shown in App. Fig. 1.1-2.

HYDROLOGY

Lake Norman is in the Catawba River Drainage Basin (Fig. 1-3). The river begins at an elevation of about 640 m mean sea level (m.s.l.), 8 km southwest of Old Fort, NC. It flows easterly about 110 km through three impoundments to near Millersville, NC, where it turns and flows southerly another 10 km through a fourth impoundment into Lake Norman. The river continues southward 175 km through six more impoundments to Wateree Dam, where it becomes the Wateree River. The Wateree flows via the Congaree and Santee/Cooper Rivers to the Atlantic Ocean.

Lake Norman was formed by Cowans Ford Dam, which was completed in 1963. The lake extends from Cowans Ford Dam about 54 km uplake to the tailwater of Lookout Shoals Dam, which has a normal tailwater elevation of 232.01 m m.s.l. Mountain Island Lake extends to the tailwater of Cowans Ford Dam, about 24 km upstream from Mountain Island Dam. At full pool elevation of 231.65 m m.s.l., Lake Norman has a surface area of 13 156 ha, a volume of $1.3489 \times 10^9 \text{ m}^3$ (Fig. 1-4), a shoreline of about 837 km, a mean depth of 10.25 m, and a maximum depth of 36.5 m. The lake drains a watershed of approximately 4640 km^2 . The average annual flow from Cowans Ford Dam and Hydroelectric Station is $75.6 \text{ m}^3 \cdot \text{s}^{-1}$. The mean retention time within the lake is 207 d (Duke Power Company 1976, 1981).

The principal stream feeding Lake Norman is the Catawba River, which normally enters the lake through the Lookout Shoals Hydroelectric Station turbines located 11 to 17 m below full pool of Lookout Shoals Reservoir which has a maximum depth of about 24 m. During flood conditions, the waters of Lookout Shoals Reservoir may spill over the dam crest at full pool elevation of 255.45 m m.s.l. Other streams feeding Lake Norman are now completely or partially inundated at full pool (App. Table 1.1-1). Those streams which had high average discharge before the area was flooded are Lyle Creek ($2.8 \text{ m}^3 \cdot \text{s}^{-1}$), Mountain Creek ($1.5 \text{ m}^3 \cdot \text{s}^{-1}$), and Davidson Creek ($1.3 \text{ m}^3 \cdot \text{s}^{-1}$) (Wilder and Slack 1971).

Prior to the construction of Cowans Ford Dam, the nearest recorded flows were from a gaging station 43.3 km uplake from the dam near Catawba, NC, with a drainage area of 3976 km^2 . The average flow past the gage for the 30-year

period prior to 1962, when the gage was inundated, was $66 \text{ m}^3 \cdot \text{s}^{-1}$. The maximum and minimum flow rates were $712 \text{ m}^3 \cdot \text{s}^{-1}$ on 14 August 1940, and $2 \text{ m}^3 \cdot \text{s}^{-1}$ on 15 September 1957, respectively. On 16 July 1916, the river reached maximum flood stage of 13.4 m at the Cowawha gage, and on 17 July 1916 the estimated flow at Cowans Ford Dam site was $5650 \text{ m}^3 \cdot \text{s}^{-1}$ (Duke Power Company 1976). The largest flood since Cowans Ford Dam was built occurred on 15 March 1975 with Lake Norman surface level at 231.83 m m.s.l. and an approximate flow of $1100 \text{ m}^3 \cdot \text{s}^{-1}$ through the Dam and Hydroelectric Station (Duke Power Company 1981). Flows recorded at Cowans Ford and Lookout Shoals Dams from June 1973 through December 1980 are given in Table 1-1.

Lake Norman attained full pool in April 1964. During a typical summer surface elevation is about 231 m m.s.l. (12 600 ha surface area), and during a typical winter lake elevation is about 229.5 m m.s.l. (11 600 ha surface area). The lowest lake level to date (227.8 m m.s.l.) was recorded in late summer 1970. Duke Power Company is committed to no more than a 15 ft (4.572 m) lake drawdown (Duke Power Company 1976). Lake levels from June 1973 through December 1980 are shown in Fig. 1-5.

LAKE NORMAN GENERATING FACILITIES

COWANS FORD HYDROELECTRIC STATION

Cowans Ford Hydroelectric Station has four generating units, each rated at 90-MW net electrical capability at median operating conditions. The station typically operates in a peaking capacity about four hours per day. A submerged weir in the forebay allows passage of surface water from Lake Norman while retaining the water below elevation 221 m m.s.l. (Fig. 1-6). The average annual flow through Cowans Ford Hydroelectric Station is $75.6 \text{ m}^3 \cdot \text{s}^{-1}$. The Federal Energy Regulatory Commission (1958) requires a minimum average daily flow of $8.6 \text{ m}^3 \cdot \text{s}^{-1}$. Monthly mean flows from Cowans Ford Hydroelectric Station are given in Table 1-1.

Cowans Ford Dam, beside the hydroelectric station, has a spillway flow capacity of $5964 \text{ m}^3 \cdot \text{s}^{-1}$ through 11 gates, each 10.7 m wide by 8.5 m high. Water seldom overtops the spillway or is released through the gates.

MARSHALL STEAM STATION

Marshall Steam Station was recognized by the electric utility industry as the most efficient steam station in the United States from 1966 through 1974. Its four generating units have a combined net electrical capability of 1900 MW: two units are rated at 320 MW and the other two units are 630 MW each. The two smaller units became operational in 1965 and 1966; the larger units began operating in 1969 and 1970.

Marshall obtains cooling water from under a skimmer wall which retains lake water above 213.6 m m.s.l. (Fig. 1-7). The maximum rate of cooling water flow is $12 \text{ m}^3 \cdot \text{s}^{-1}$ for each of the smaller units and $20 \text{ m}^3 \cdot \text{s}^{-1}$ for the larger units.

Winter and summer condenser cooling water design flows are 48 and $64 \text{ m}^3 \cdot \text{s}^{-1}$ respectively. Temperature rise across the condenser (ΔT) during winter and summer was designed at 16.1 and 9.4°C , respectively. Monthly average winter

(January through March) and summer (July through September) discharge temperatures have not exceeded 20.5 and 31.5°C (Table 1). The North Carolina National Pollutant Discharge Elimination System (NPDES) permit for Marshall (North Carolina Department of Natural Resources and Community Development 1976b) stipulates that monthly average discharge temperatures are not to exceed 94°F (34.4°C) from July 1 to October 15, and 92°F (33.3°C) for the remainder of the year. These permit limitations have not been exceeded.

McGUIRE NUCLEAR STATION

McGuire Nuclear Station will have two pressurized water generating units with a net design rating of 1,800 MW electrical each. Units 1 and 2 are scheduled for commercial operation in September 1981 and June 1983, respectively.

Condenser cooling water for McGuire will be drawn from Lake Norman through two intake structures. Water will be drawn through an upper-level intake (Fig. 1-8) located between 217.9 and 227.1 m m.s.l., at a maximum flow of 64.1 m³·s⁻¹ per generating unit. Water will also be drawn from a lower-level intake (Fig. 1-9) located between 199.3 and 204.2 m m.s.l., at a maximum flow of 28.3 m³·s⁻¹ per unit. Flow from the lower-level intake will displace an equal flow from the upper-level intake, resulting in the same maximum flow per unit as the upper-level intake alone could provide. Four pumps per unit will be able to supply cooling water to the steam condenser. Two pumps per unit will produce a flow of 40.4 m³·s⁻¹; three pumps will produce 54.7 m³·s⁻¹; and four pumps will produce 64.1 m³·s⁻¹.

The quantity and source of cooling water will be determined by the temperature of the intake water. During the months when the intake water temperatures are cool (approximately December through April), only two pumps per unit will be operated. When temperatures become warmer (approximately June through October) four pumps per unit will be operated. Three pumps per unit will be used for the short transitional periods. The upper-level intake will supply the entire cooling water needs except when the discharge water temperature approaches 35°C. Water will then be drawn from the lower-level intake to moderate temperatures such that average monthly discharges are maintained at or below 35°C. Total condenser cooling water flow per unit will remain 64.1 m³·s⁻¹ when the lower-level intake is in operation. Thus, the lower-level intake will provide up to 44% of the condenser cooling water flow when McGuire is operating at full capacity during months with the warmest intake water temperatures.

Condenser cooling water from McGuire will be discharged into a canal from pipes located between 219.6 and 222.9 m m.s.l. The 1-km canal has a depth of about 12 m when Lake Norman is at full pool. The discharge flows over an earthen weir submerged at about 225 m m.s.l.

Heated effluent from the canal will initially mix with the surface waters of the lake and then stabilize vertically and spread over the lake surface, ultimately transferring most of its heat to the atmosphere (Colon and Leavitt 1973; Duke Power Company 1976). The condenser cooling water ΔT is projected to reach a maximum of 14.1°C during the winter months when intake temperatures are the coolest. The ΔT is expected to be a maximum of 8.9°C during the warmest months. Monthly average discharge temperatures are not permitted to exceed 95°F (35.0°C) w³.

the assigned thermal mixing zone (North Carolina Department of Natural Resources and Community Development 1978). Furthermore, the temperatures outside the mixing zone (Fig. 1-2) are not permitted to exceed 5°F (2.7°C) above the natural water temperature or a maximum of 90°F (32.2) measured as a 24-h average 0.3 m below the water surface.

Although McGuire was not operational during the time period this report covers, several activities which could affect the waters of Lakes Norman and Mountain Island were in progress during the preoperational period. Construction at the McGuire site began in April 1971 and major earth moving activities were completed prior to 1974. Major exceptions were dredging and draglining at the intake and discharge areas. These activities are summarized in Table 1-2.

Wastewater from McGuire is treated in one of two systems and discharged to Mountain Island Lake, immediately downstream from Cowans Ford Dam. A wastewater collection basin receives only treated domestic wastes, overflow from the standby nuclear service water pond, and runoff from the station yard; this treatment system began continuously discharging in September 1974. The second, a Conventional Wastewater Treatment System treats all other non-radioactive waste and began discharging on a batch basis in May 1978.

Tests of various systems at McGuire have resulted in water being discharged through the discharge canal to Lake Norman. The Emergency Core Cooling System obtained water from the standby nuclear service water pond during 1978 and discharged it to the lake. The Condenser Cooling Water System has continuously obtained water from the upper- and/or lower-level intake structures in Lake Norman through one or more pumps since the mid-1970's.

PREVIOUS ENVIRONMENTAL STUDIES

Numerous aquatic environmental studies have been conducted on Lake Norman and on the adjacent waters of Lookout Shoals and Mountain Island Lakes. The most extensive studies were by Duke Power Company (1976), Jensen (1974), and Weiss et al. (1975). These studies will be only briefly described here, although more extensive summaries can be found in other chapters, as appropriate.

DUKE POWER COMPANY (1976)

The purpose of the Environmental Report for the operating license stage of McGuire Nuclear Station was to establish pre-operational baseline data, on which an assessment of the effects of McGuire Nuclear Station could be made. The aquatic environmental portion of the report covers chemical and biological data collected during 1973 and 1974. The report characterizes the water chemistry of Lakes Norman and Mountain Island with regard to nutrients, minerals, and metals, as well as general water quality variables such as temperature, dissolved oxygen, pH, and alkalinity. The report also characterizes the aquatic ecology of the lake through an examination of density and composition of phytoplankton, periphyton, zooplankton, benthos, and fishes. Productivity and biomass of selected taxonomic groups were also examined.

The potential effects on the aquatic ecosystem due to the operation of McGuire were assessed, based on the monitoring program results. Species of importance

to the ecosystem were identified, and species-environment relationships were investigated to aid in the assessment. No potential effects of the station's operation were assessed as being of significant detriment to the functioning of the pre-operational ecosystem or to any of its components.

JENSEN (1974)

Studies of thermal effects of the cooling water discharge of Marshall Steam Station were initiated in July 1965. Work during the first three years involved the collection of physical and meteorological data for use in evaluating the thermal behavior of the lake. In 1968 the research was expanded to include biological studies of thermal effects. Data pertaining to water temperatures, various meteorological and water quality variables, and populations of fish, plankton, and benthic invertebrates were collected from 18 locations on Lake Norman in the vicinity of Marshall. The biological data involved population and diversity studies in the main body of the lake, and in the Marshall intake and discharge coves. Studies on the effects of entrainment of planktonic organisms, and their passage through the condenser system of the station were also conducted.

WEISS et al. (1975)

This study was conducted on the downlake end of Lake Norman from February 1973 through January 1974 as part of an overall program examining physical, chemical, and biological variables in five Catawba River impoundments. Variables that were measured include temperature, dissolved oxygen, nutrients, chlorophyll, and densities and taxonomic composition of phytoplankton and zooplankton. Data were treated statistically and the significance of interaction of environmental factors on the aquatic biota was postulated.

THE PRESENT ENVIRONMENTAL STUDY

Chemical and biological constituents of Lake Norman and downstream Mountain Island Lake were studied extensively by Duke Power Company from 1974 through 1980. Data resulting from this study are the subject of the remaining chapters of this document. These data are in the form of microfiche in Volumes 3 and 4. Only certain of these data were analyzed in detail and are discussed in Volumes 1 and 2. This restriction was due to changes in study design, limitations of statistical techniques, and an attempt to keep the document concise yet representative of data collected throughout the study period.

The study design reflected changes in McGuire's schedule, and actual and anticipated regulatory requirements, as well as knowledge gained by continuing evaluations of the data collected throughout the study. Because these changes were specific to individual constituents of the study, they are described fully in later chapters. All locations on Lake Norman and Mountain Island Lake which were monitored during this study are shown in Fig. 1-10 and 1-11, respectively, and described in Table 1-3.

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Table 1-1. Average monthly flow in Lake Norman and average monthly coolant variables of Marshall Steam Station, June 1973 through December 1980.

Month	LAKE NORMAN FLOW		MARSHALL COOLANT VARIABLES		
	Lookout Shoals ($\text{m}^3 \cdot \text{s}^{-1}$)	Cowans Ford ($\text{m}^3 \cdot \text{s}^{-1}$)	Flow ($\text{m}^3 \cdot \text{s}^{-1}$)	ΔT ($^{\circ}\text{C}$)	Discharge Temperature ($^{\circ}\text{C}$)
Jun. 1973	93	111			
Jul.	63	89			
Aug.	85	99			
Sep.	61	81			
Oct.	54	45			
Nov.	45	56			
Dec. 1973	90	74			
Jan. 1974	118	96			
Feb.	95	111			
Mar.	78	103			
Apr.	114	161			
May	85	114			
Jun.	80	58			
Jul.	67	80			
Aug.	108	94			
Sep.	86	70			
Oct.	60	92	36	9.2	28.4
Nov.	48	66	38	9.3	25.0
Dec. 1974	65	52	45	10.2	19.4
Jan. 1975	80	76	45	10.2	18.6
Feb.	87	86	48	8.4	16.6
Mar.	120	220	38	8.4	17.7
Apr.	99	128	47	8.7	21.6
May	101	117	47	8.7	23.5
Jun.	119	176	49	8.5	25.1
Jul.	69	71	46	8.0	25.8
Aug.	54	86	50	9.2	28.9
Sep.	76	72	45	9.0	30.3
Oct.	87	93	35	7.7	28.2
Nov.	95	109	30	8.2	24.4
Dec. 1975	60	96	31	8.3	18.9
Jan. 1976	93	90	41	8.9	15.5
Feb.	76	92	39	9.2	17.3
Mar.	67	41	38	8.9	20.5
Apr.	49	26	43	8.3	22.8
May	57*	26*	43	8.2	23.7
Jun.	123*	147*	41	7.5	24.9
Jul.	54	71	38	7.5	26.1
Aug.	29	33	37	7.9	27.9
Sep.	40	35	38	8.2	29.4
Oct.	99	145	37	8.3	27.4
Nov.	54	112	42	10.0	22.4
Dec. 1976	83	91	41	9.1	17.2
Jan. 1977	63	125	39	8.3	12.6
Feb.	34	39	37	8.4	14.0

Month	LAKE NORMAN FLOW		MARSHALL COOLANT VARIABLES		
	Lookout Shoals ($\text{m}^3 \cdot \text{s}^{-1}$)	Cowans Ford ($\text{m}^3 \cdot \text{s}^{-1}$)	Flow ($\text{m}^3 \cdot \text{s}^{-1}$)	ΔT ($^{\circ}\text{C}$)	Discharge Temperature ($^{\circ}\text{C}$)
Mar.	94	40	34	8.2	17.8
Apr.	97	89	28	7.9	20.9
May	55	60	41	9.5	23.2
Jun.	49	69	45	9.5	24.7
Jul.	40	75	37	7.8	24.3
Aug.	35	54	51	9.6	28.3
Sep.	62	33	48	8.5	30.2
Oct.	42	41	48	8.2	27.7
Nov.	109	230	46	8.2	23.7
Dec. 1977	76	107	44	8.5	18.2
Jan. 1978	94	64	44	9.1	14.5
Feb.	66	140	40	7.7	11.6
Mar.	79	76	32	7.4	14.3
Apr.	61	62	29	9.3	19.9
May	87	90	31	9.1	21.8
Jun.	55	74	31	9.2	23.3
Jul.	38	47	38	8.8	23.9
Aug.	69	93	51	8.8	25.5
Sep.	44	57	48	8.6	28.2
Oct.	30	36	47	8.2	28.1
Nov.	33	41	47	8.1	24.6
Dec. 1978	54	90	47	9.2	21.0
Jan. 1979	98	93	45	8.5	15.8
Feb.	67	65	43	9.0	14.4
Mar.	104	168	41	7.1	16.3
Apr.	86	148	30	7.8	20.6
May	98	132	49	8.9	23.7
Jun.	77	91	52	8.4	24.7
Jul.	83	96	52	8.8	27.3
Aug.	51	70	53	9.0	29.3
Sep.	108	116	51	7.9	30.3
Oct.	103	159	51	7.9	27.4
Nov.	107	115	43	8.0	23.3
Dec. 1979	81	118	44	8.8	19.4
Jan. 1980	100	123	46	9.5	17.5
Feb.	62	62	46	10.0	16.6
Mar.	90	34	44	9.2	17.8
Apr.	130	193	42	9.5	22.2
May	91	111	38	9.3	23.8
Jun.	70	70	52	9.3	25.3
Jul.	65	94	52	9.0	27.7
Aug.	36	48	51	9.4	30.1
Sep.	31	27	51	9.2	31.5
Oct.	36	41	44	8.5	28.8
Nov.	36	36	34	9.2	23.8
Dec. 1980	31	43	55	10.6	20.8

*Data from 30 May through 20 June 1976 were not included in the average due to a computer malfunction on those days.

*No data are available prior to October 1974 for the Marshall coolant variables.

Table 1-2. Dredging and draglining activities in the intake and discharge areas of McGuire Nuclear Station.

<u>Date</u>	<u>Intake Area</u>	<u>Discharge Area</u>
Aug. 75		Siphoned intake water to discharge canal
Sep. 75		No activity
Oct. 75	Started dredging	No activity
Nov. 75	Dredged	No activity
Dec. 75	Dredged. Cofferdam breached Draglined	Backhoe used to breach cofferdam to equalize canal and lake water levels
Jan. 76	Dredged and draglined	No activity
Feb. 76	Dredged and draglined	No activity
Mar. 76	Dredged and draglined	No activity
Apr. 76	No activity	No activity
May 76	No activity	No activity
Jun. 76	No activity	No activity
Jul. 76	Started dredging 12 July and started draglining 20 July	Started pumping water from Nuclear Service Water Pond to discharge on 26 July
Aug. 76	Dredged and draglined. Finished draglining on 11 August	Stopped pumping water from Nuclear Service Water Pond to discharge on 4 August Started draglining on 13 August
Sep. 76	Dredged	Draglined
Oct. 76	Dredged	Finished draglining on 15 October
Nov. 76	Dredge was not used until 10 November. Draglined on 11-12 November	
Dec. 76	Dredged	
Jan. 77	Dredged	
Feb. 77	Dredged	
Mar. 77	Finished dredging on 17 March	

Table 1-3. Description of sampling locations on Lakes Norman and Mountain Island. Locations are shown in Figures 1-10 and 1-11, respectively. The depth listed is not necessarily the sample depth and is intended only as a guide for aid in determining relative depths among sampling locations.

Mountain Island Lake Locations

Location 16.0

On Catawba River arm, 10 m south-southeast from the mouth of Jackson's Pond (Jackson's Pond is accessible by Lucia Access Area); depth of 4 m.

Location 16.2

On Catawba River arm, at the mouth of McGuire Nuclear Station non-radioactive wastewater effluent channel; depth of 0.2 m.

Location 16.5

Within Jackson's Pond (Jackson's Pond is accessible by Lucia Access Area); depth of 1 m.

Location 277.5

On Catawba River arm, 100 m northeast from the mouth of Riverbend Steam Station ash basin discharge; depth of 5 m.

Lake Norman Locations

Location 1.0

Forebay of Cowans Ford Hydroelectric Station at center gate of spillway, 30 m from the dam; in the McGuire mixing zone; depth of 36 m.

Location 1.2

In the McGuire Nuclear Station upper-level intake area, 50 m from the center of the lakeside of the intake structure; in the McGuire mixing zone; depth of 15 m.

Location 1.7

Forebay of Cowans Ford Hydroelectric Station at mid-channel, 65 m from the dam; in the McGuire mixing zone; depth of 33 m.

Location 2.0

On Catawba River arm, midway between Catawba River Channel Marker 1 and the northernmost point of the peninsula to the east-southeast; in the McGuire mixing zone; depth of 34 m.

Location 3.0

On Ramsey Creek arm, midway between Ramsey Creek Channel Marker R-1 and the northernmost cove on peninsula to the southwest; in the McGuire mixing zone; depth of 22 m.

Location 3.8

In the McGuire Nuclear Station discharge canal, on the west side of the bridge; in the McGuire mixing zone; depth of 2 m.

Location 3.9

In the McGuire Nuclear Station discharge canal, on the northeast side of the bridge; in the McGuire mixing zone; depth of 12 m.

Location 4.0

On Ramsey Creek arm, 50 m northeast from the mouth of the McGuire Nuclear Station discharge canal; in the McGuire mixing zone; depth of 8 m.

Location 4.3

On Ramsey Creek arm, 665 m north-northeast from the mouth of the McGuire Nuclear Station discharge canal; in the McGuire mixing zone; depth of 22 m.

Location 4.5

On Ramsey Creek arm, 150 m southwest of the midpoint of the line joining the two large islands, 1.3 km northeast from the mouth of McGuire Nuclear Station discharge canal; in the McGuire mixing zone; depth of 17 m.

Location 5.0

On Ramsey Creek arm, midway between Ramsey Creek Channel Markers R-3 and R-4; in the McGuire mixing zone; depth of 24 m.

Location 6.0

On Ramsey Creek arm, in the cove northwest of Ramsey Creek Access Area, 10 m northwest of the midpoint of a line connecting the points of the mouth of the cove; in the McGuire mixing zone; depth of 8 m.

Location 6.5

On Ramsey Creek arm, in the cove northwest of Ramsey Creek Access Area, in the eastern terminal branch of the cove; in the McGuire mixing zone; depth of 5 m.

Location 7.0

On Lucky Creek cove, at the intersection of 1) a line connecting Catawba River Channel Marker 2 and the top of a 525 kv transmission line tower and 2) a line connecting the point of the second peninsula west on the north side of the mouth of Lucky Creek cove and the point of the peninsula to the south-southeast; in the McGuire mixing zone; depth of 8 m.

Location 7.3

On Black's cove, at the intersection of 1) a line drawn west-northwest of Catawba River Channel Marker 2 and 2) a line drawn south from the center of the first cove from the mouth on the northern shoreline of Black's cove; in the McGuire mixing zone; depth of 8 m.

Location 7.5

On Catawba River arm, 100 m west of Catawba River Channel Marker 2; in the McGuire mixing zone; depth of 30 m.

Location 7.6

On Catawba River arm, 750 m northwest of Catawba River Channel Marker 2; on the northern boundary of the McGuire mixing zone; depth of 25 m.

Location 8.0

On Catawba River arm, 250 m southeast of Catawba River Channel Marker 3; depth of 30 m.

Location 8.5

Southwest of the Catawba River arm, in a narrow, unnamed cove, 1.1 km south of Catawba River Channel Marker 5; depth of 10 m.

Location 9.0

On Davidson Creek arm at the intersection of 1) a line drawn southeast from Davidson Creek Channel Marker D-4 and 2) a line drawn perpendicular to the midpoint of the line connecting the midpoints of the two large islands directly east and east-southeast, respectively, of Davidson Creek Channel Marker D-4; depth of 21 m.

Location 9.5

On Davidson Creek arm, 375 m southwest of Torrence Fork Channel Marker T-2 near the town of Davidson municipal water intake; depth of 25 m.

Location 10.0

On Davidson Creek arm, third cove north-northeast of Davidson Creek Channel Marker D-7, 60 m north of the midpoint of the line connecting the points of the mouth of that cove; depth of 10 m.

Location 10.5

On Davidson Creek arm, mid-channel, 1.7 km north-northeast of Davidson Creek Channel Marker D-7; depth of 18 m.

Location 11.0

On Catawba River arm, midway between Catawba River Channel Markers 9 and 10; depth of 30 m.

Location 12.0

On Beaver Dam Creek arm, northwest of Catawba River Channel Marker 13, one-third of the way into the southernmost large cove on the west side; depth of 6 m.

Location 13.0

On Catawba River arm, midway between Catawba River Channel Markers 14 and 15; depth of 28 m.

Location 14.0

In Marshall Steam Station discharge cove, directly north of Catawba River Channel Marker 15, 0.5 km northwest from the mouth of the cove; depth of 9 m.

Location 14.5

In the Marshall Steam Station discharge canal, southeast from the discharge structure under the line warning of "no trespassing"; depth of 5 m.

Location 14.7

In Marshall Steam Station discharge cove, first cove along northern shoreline from the mouth of the discharge cove; depth of 4 m.

Location 15.0

On Catawba River arm, under North Carolina Highway 150 bridge, midway between bridge abutments; depth of 30 m.

Location 15.2

On Catawba River arm, 0.6 km north from the middle of North Carolina Highway 150 bridge and 0.3 km east from Marshall Steam Station skimmer wall; depth of 30 m.

Location 15.5

On Catawba River arm, the first cove uplake from Marshall Steam Station intake cove, 0.8 km west from Catawba River Channel Marker 17A along the southern shoreline; depth of 4 m.

Location 15.9

On Catawba River arm, mid-channel, 500 m southwest from Catawba River Channel Marker 18A; depth of 25 m.

Location 17.0

On Catawba River arm, 300 m north of Catawba River Channel Marker 19; depth of 14 m.

Location 17.5

On Hicks Creek arm, within Duke Power State Park, under the bridge crossing Hicks Creek; depth of 0.3 m.

Location 18.0

In Marshall Steam Station intake cove, 15 m from the ash basin discharge structure; depth of 2 m.

Location 19.0

East from the southeast end of Goat Island, which is near Catawba River Channel Marker 12, in an elongated, unnamed cove, the long axis of which lies on an east-west line; depth of 4 m.

Location 25.0

On Catawba River arm, at the mouth of Lyle Creek; depth of 4 m.

Location 25.2

On Lyle Creek arm, mid-channel, 1.0 km west from the mouth of Lyle Creek; depth of 1 m.

Location 25.5

On Lyle Creek arm, in the mouth of the first southern branch of Lyle Creek 0.2 km northeast from N. C. Highway 10 bridge crossing Lyle Creek; depth of 1 m.

Location 34.0

On Catawba River arm, 335 m northeast of Catawba River Channel Marker 13; depth of 21 m.

Location 45.5

On Catawba River arm, the first cove downlake from Marshall Steam Station discharge cove, 0.5 km northwest from Catawba River Channel Marker 15; depth of 12 m.

Location 50.0

On Catawba River arm, midway between Catawba River Channel Markers 16 and 17; depth of 17 m.

Location 60.0

In Marshall Steam Station intake cove, lakeside of Marshall intake structure, 6 m from the intake; depth of 9 m.

Location 65.0

On Catawba River arm, mid-channel, 6.4 km downlake from Lookout Shoals Dam and 0.6 km downlake from the Southern Railway Bridge; depth of 4 m.

Location 68.0

East from the southern end of Long Island, which is 1.4 km southeast from County Road 1004 bridge across the Catawba River arm in Catawba and Iredell counties, in an elongated, unnamed cove, the long axis of which lies on a northeast-southeast line; depth of 4 m.

Location 69.0

On Catawba River arm, beneath the Buffalo Shoals Bridge (State Road 1004 in Catawba/Iredell Counties); depth of 8 m.

Location 72.0

On Catawba River arm, mid-channel, 0.2 km uplake from the U. S. Highways 64 & 70 bridge crossing Lake Norman; depth of 4 m.

Location 80.0

On Catawba River arm, mid-channel, 0.2 km uplake from Interstate Highway 40 bridge crossing Lake Norman; depth of 2 m.

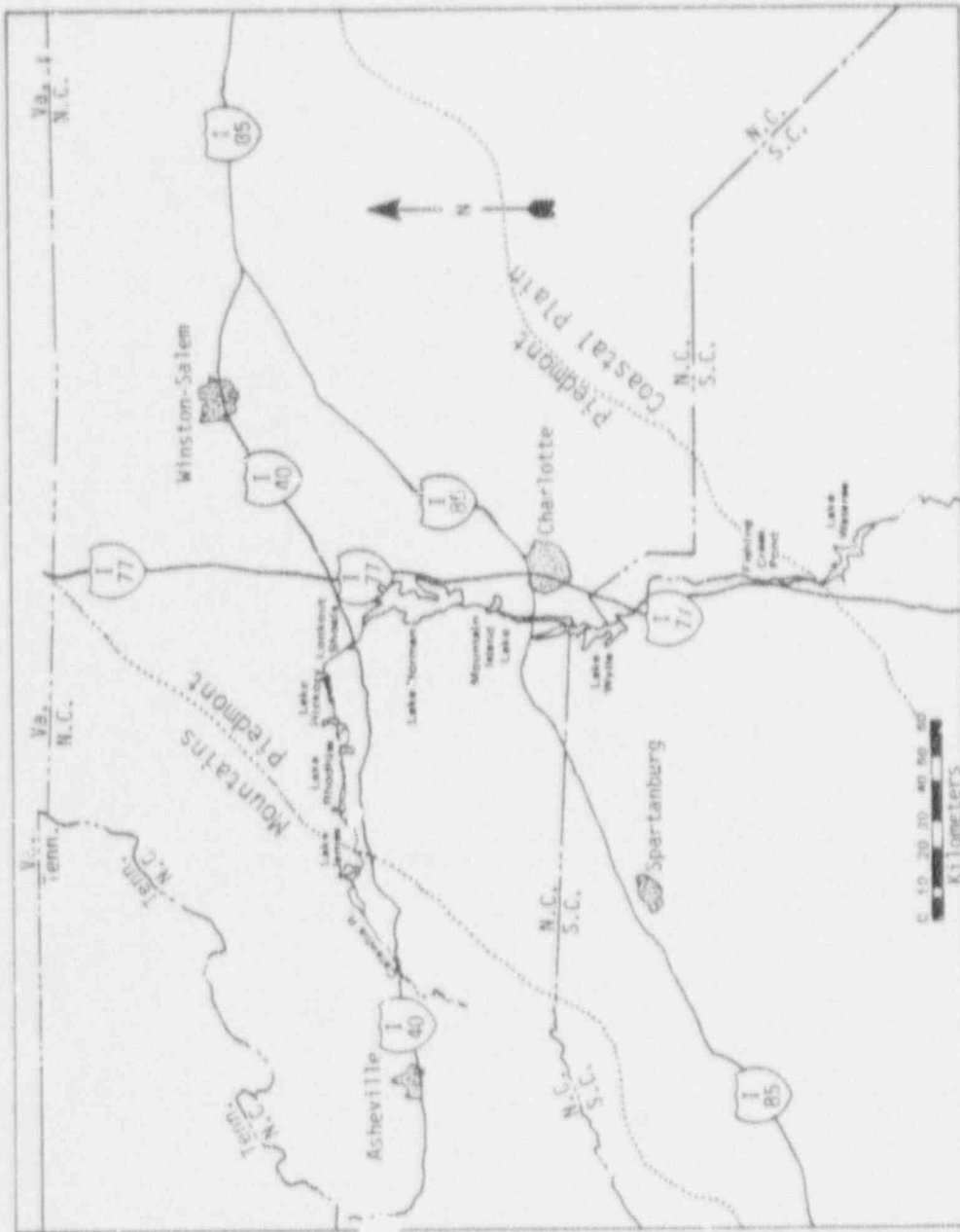


Figure 1-1. Regional setting of Lake Norman, NC, showing physiographic provinces.

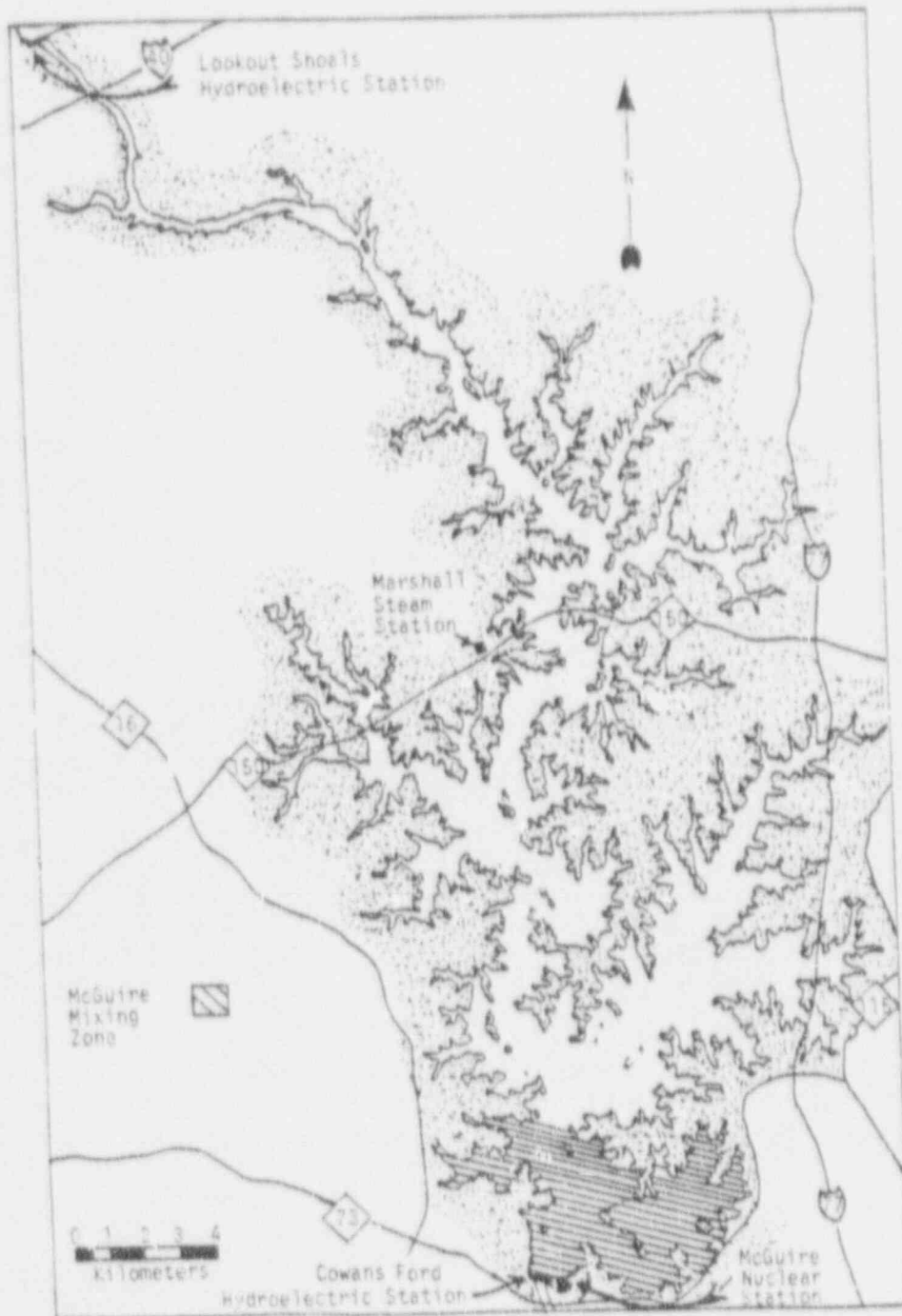


Figure 1-2. Lake Norman, North Carolina, showing the thermal mixing zone for McGuire Nuclear Station. (North Carolina Department of Natural Resources and Community Development 1978).

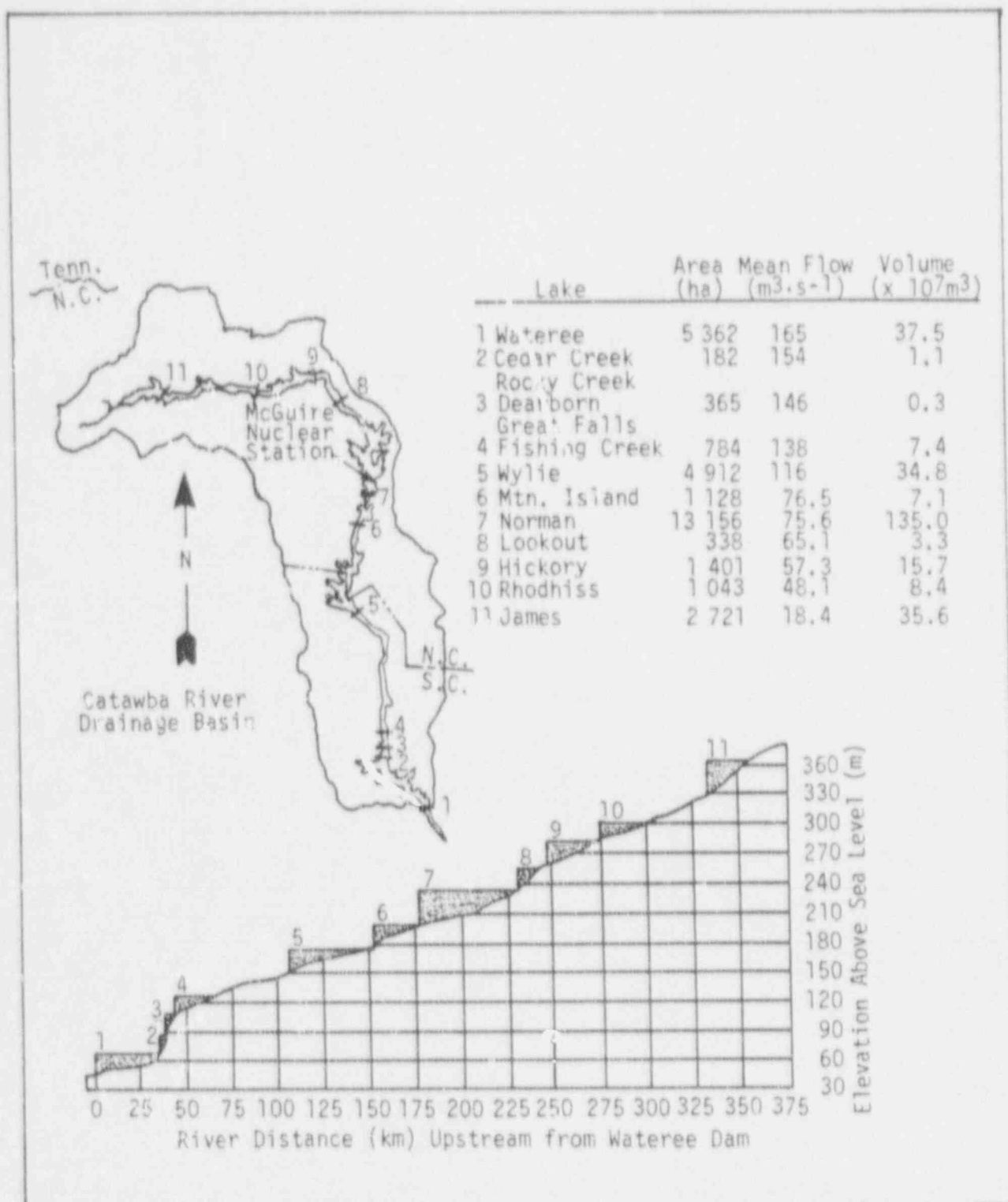


Figure 1-3. Schematic of the Catawba River system of dams and reservoirs. Area and volume are with respect to full pool and mean flow is with respect to outflow from that reservoir. (Duke Power Company 1976).

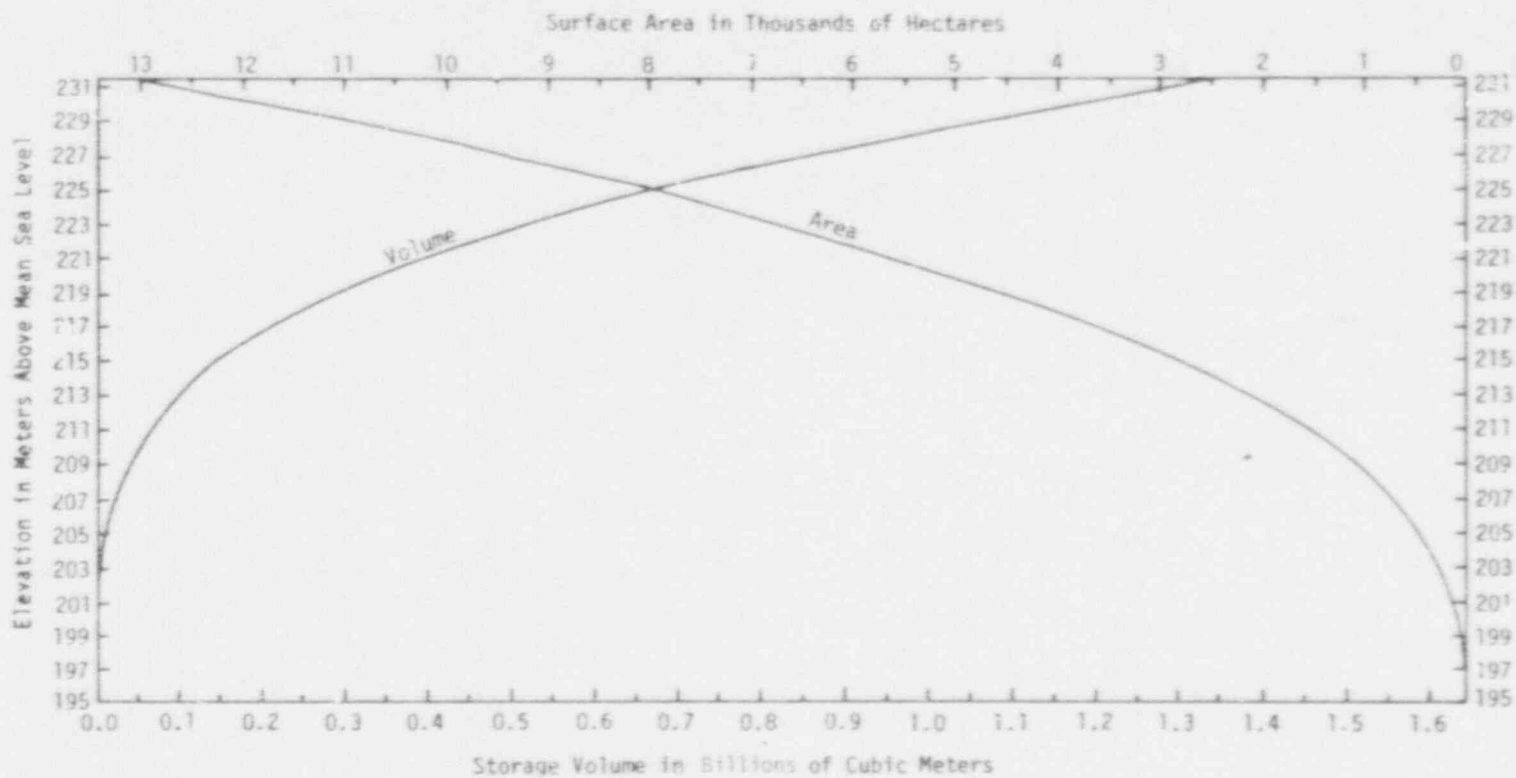
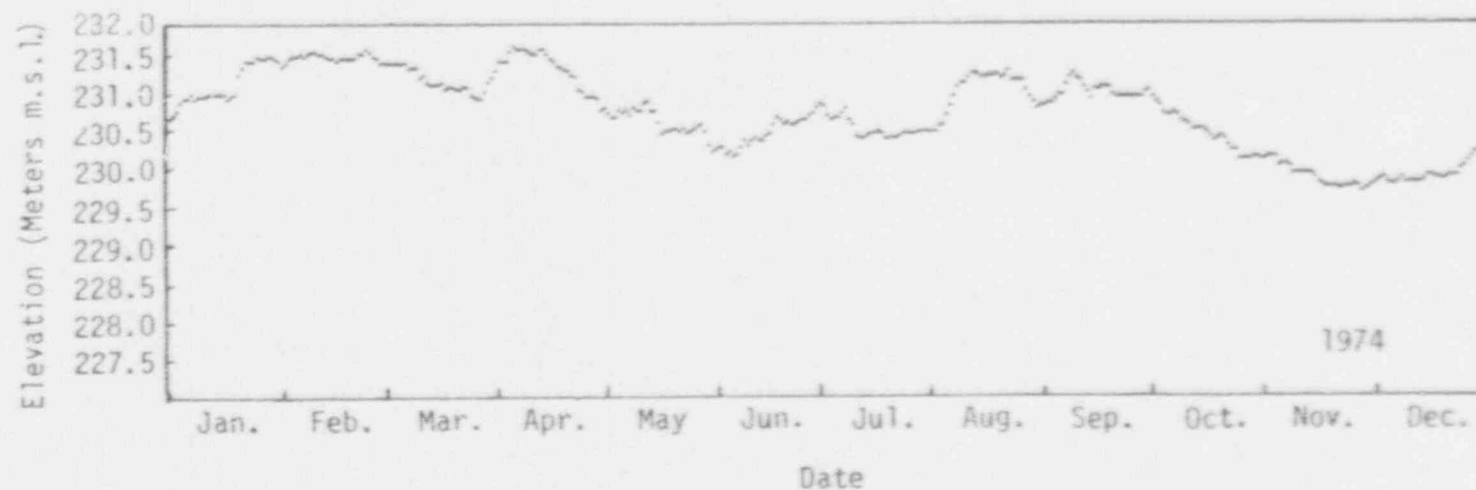
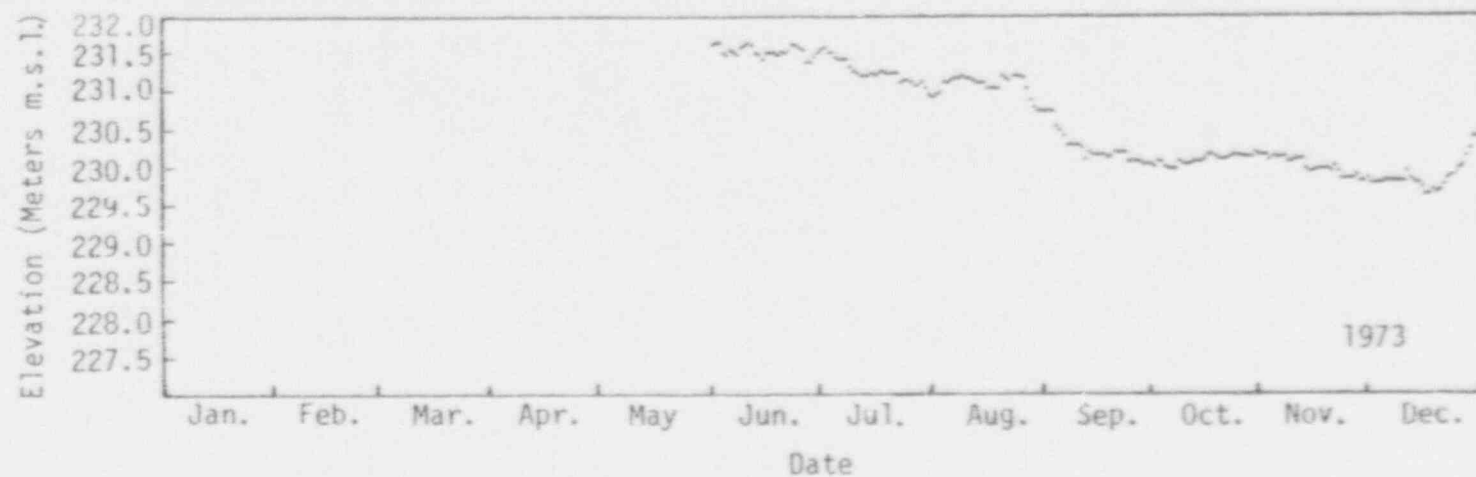


Figure 1-4. Lake Norman area-volume curve.



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Figure 1-5. Lake Norman surface elevations, June 1973 through December 1980. Each dot represents daily lake elevation. Full pool elevation is 231.65 m mean sea level (m.s.l.).

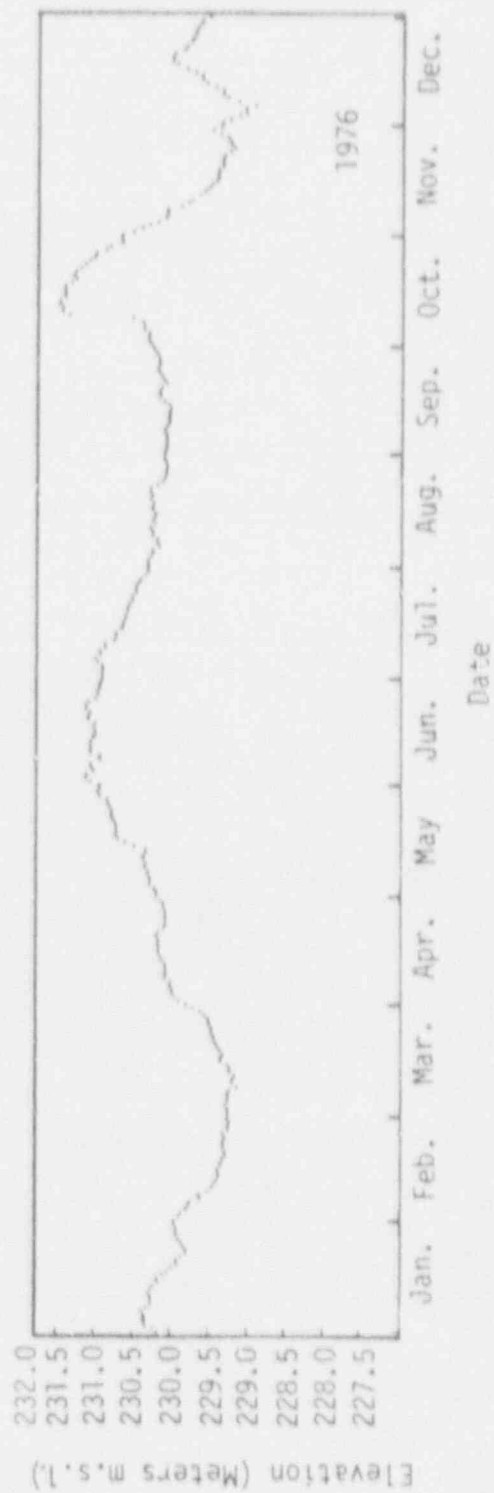
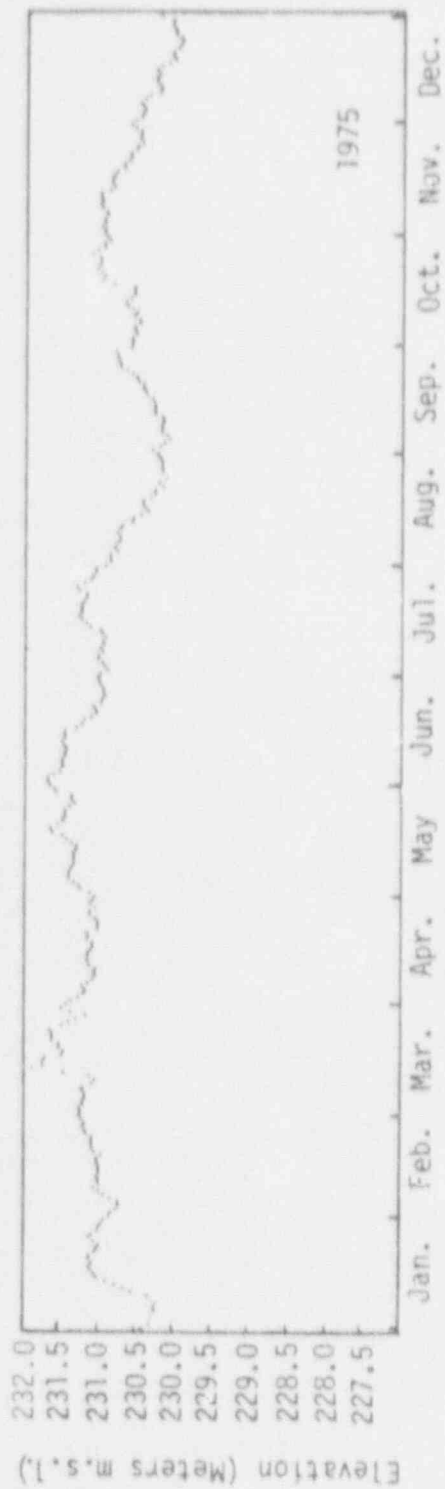


Figure 1-5. (continued).

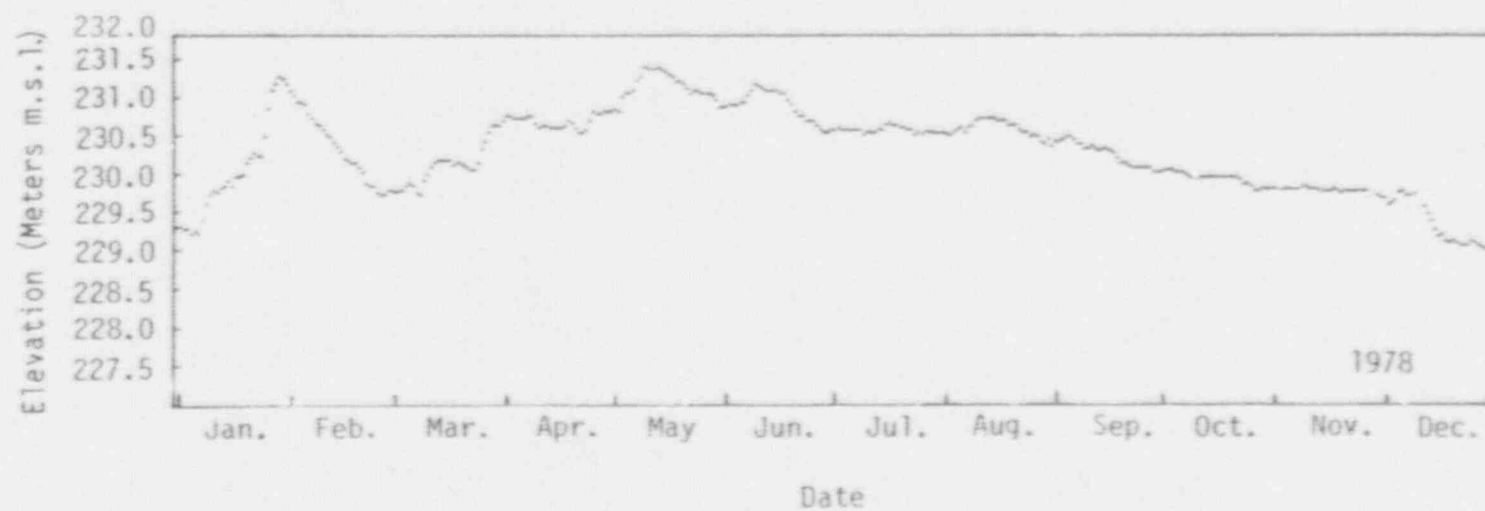
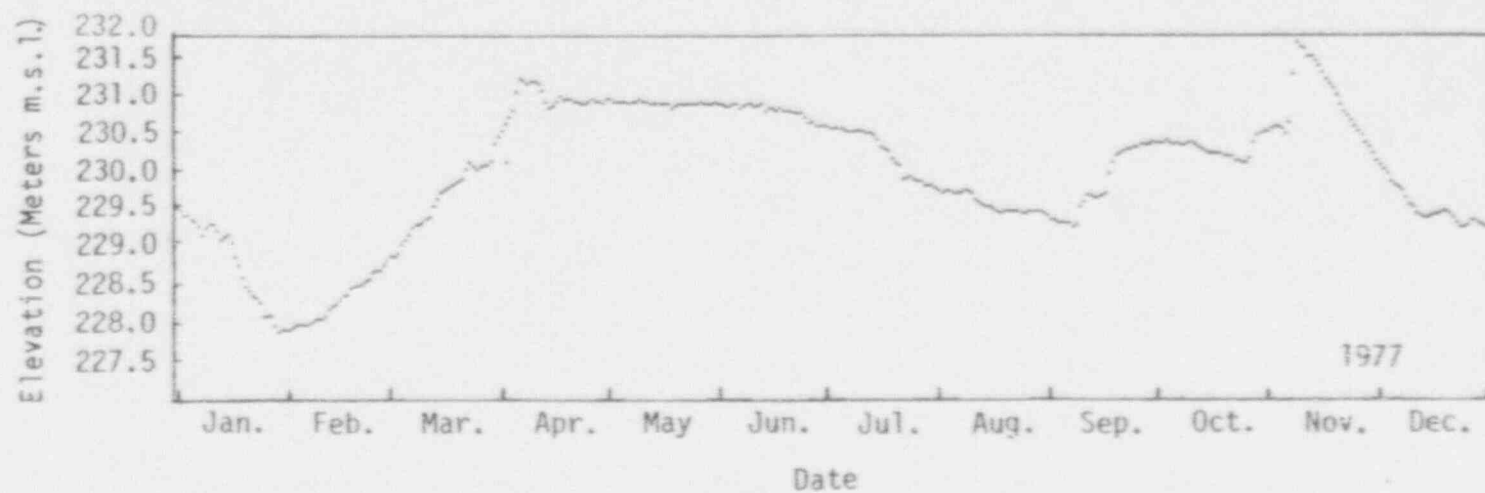


Figure 1-5. (continued).

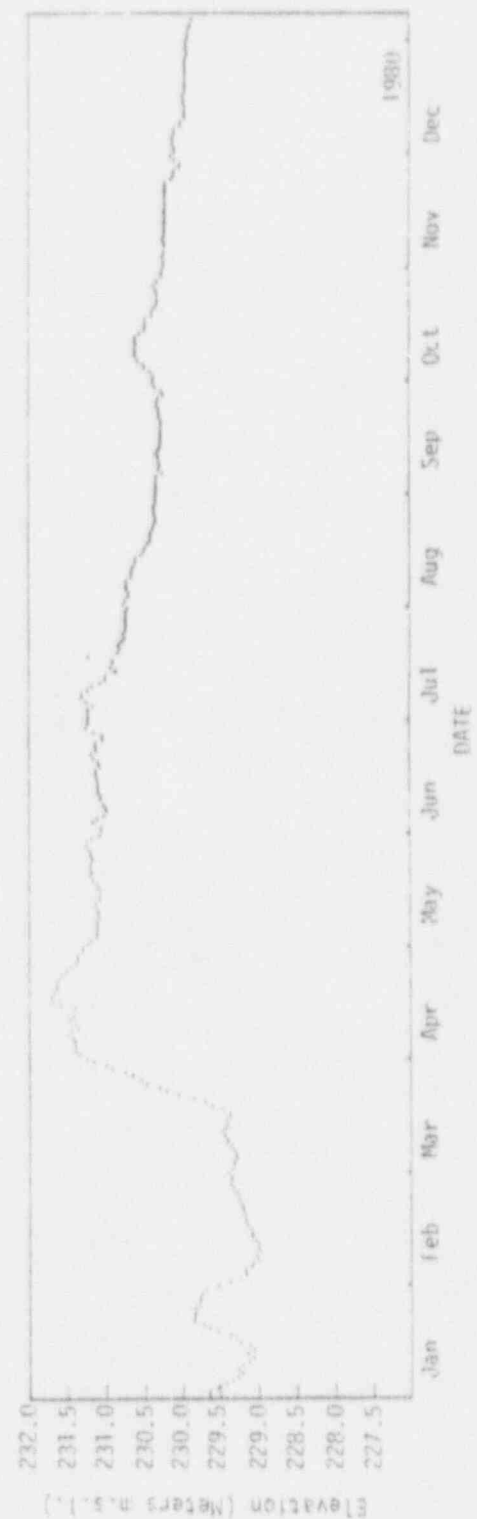
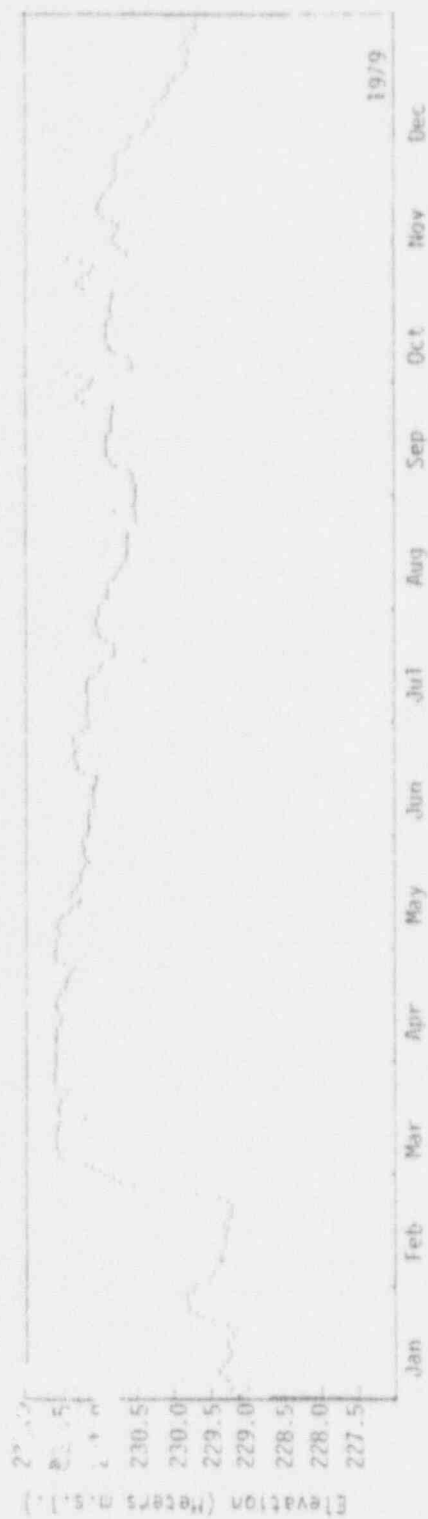


Figure 1-5 (continued)

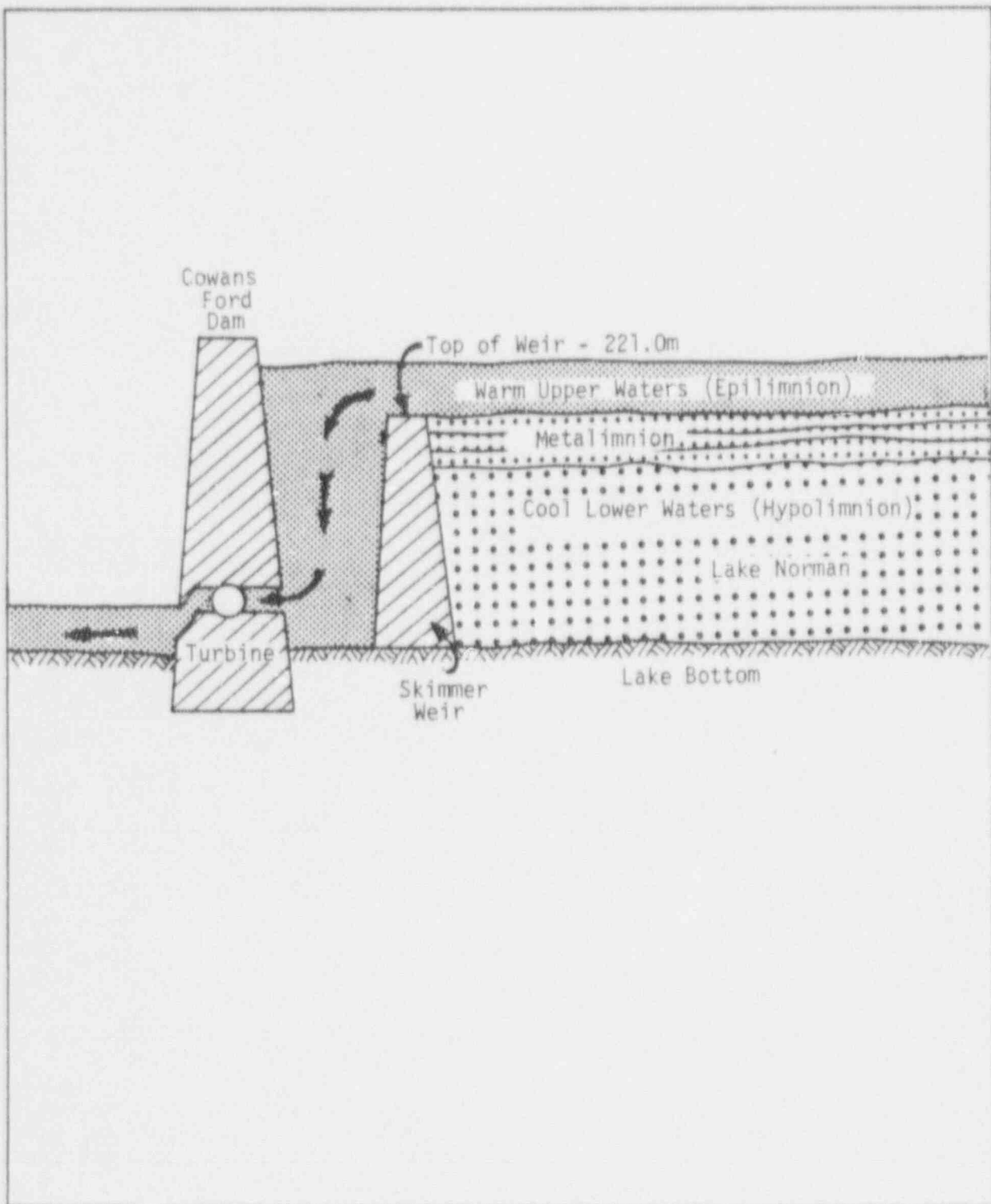


Figure 1-6. Schematic of Cowans Ford Hydroelectric Station during a typical summer. Elevations given are referenced to mean sea level. (Not drawn to scale)

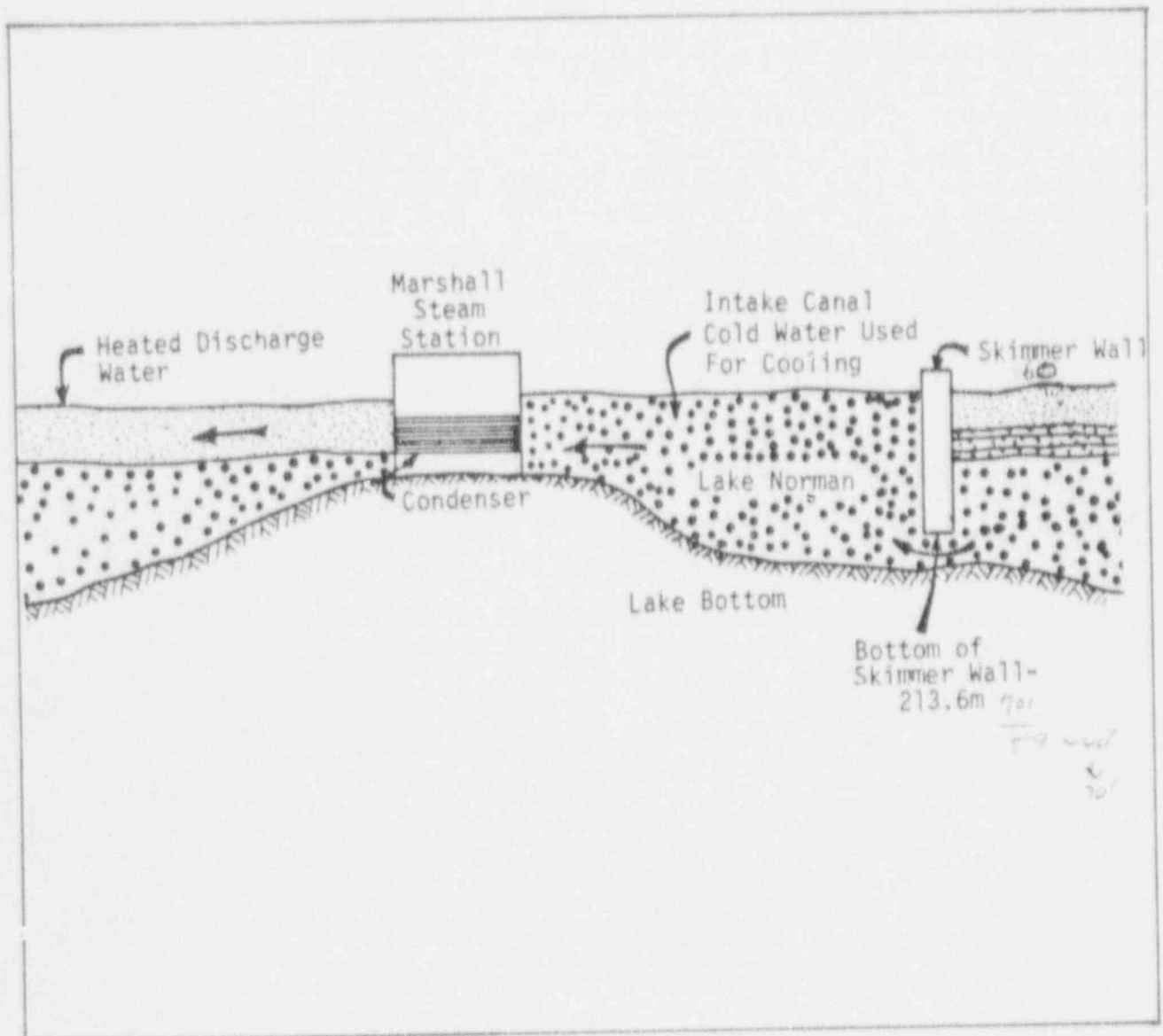


Figure 1-7. Schematic of Marshall Steam Station intake and discharge configuration during a typical late spring or early fall. The elevation given is referenced to mean sea level. (Not drawn to scale)

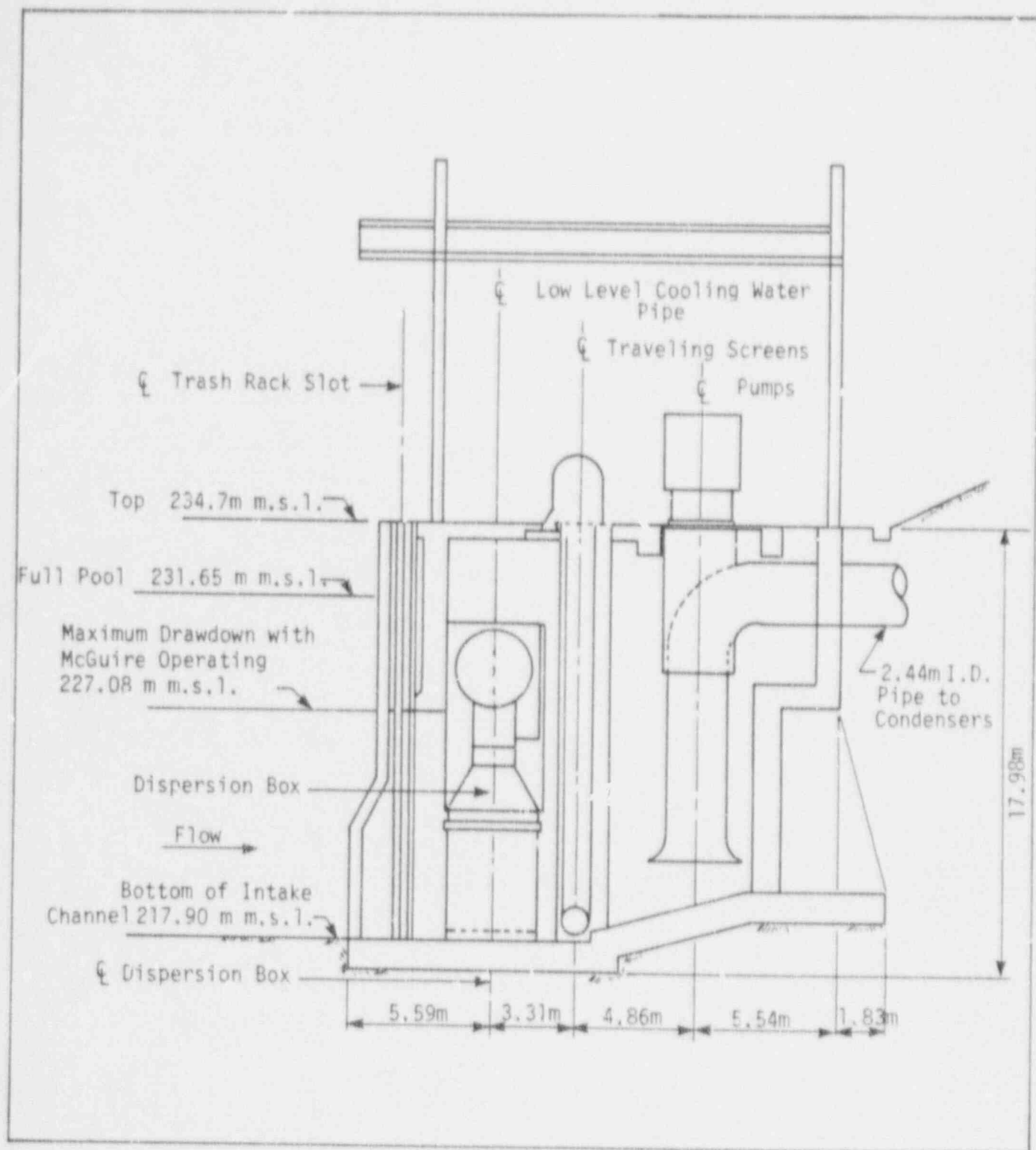


Figure 1-8. Schematic of McGuire Nuclear Station upper-level intake structure.

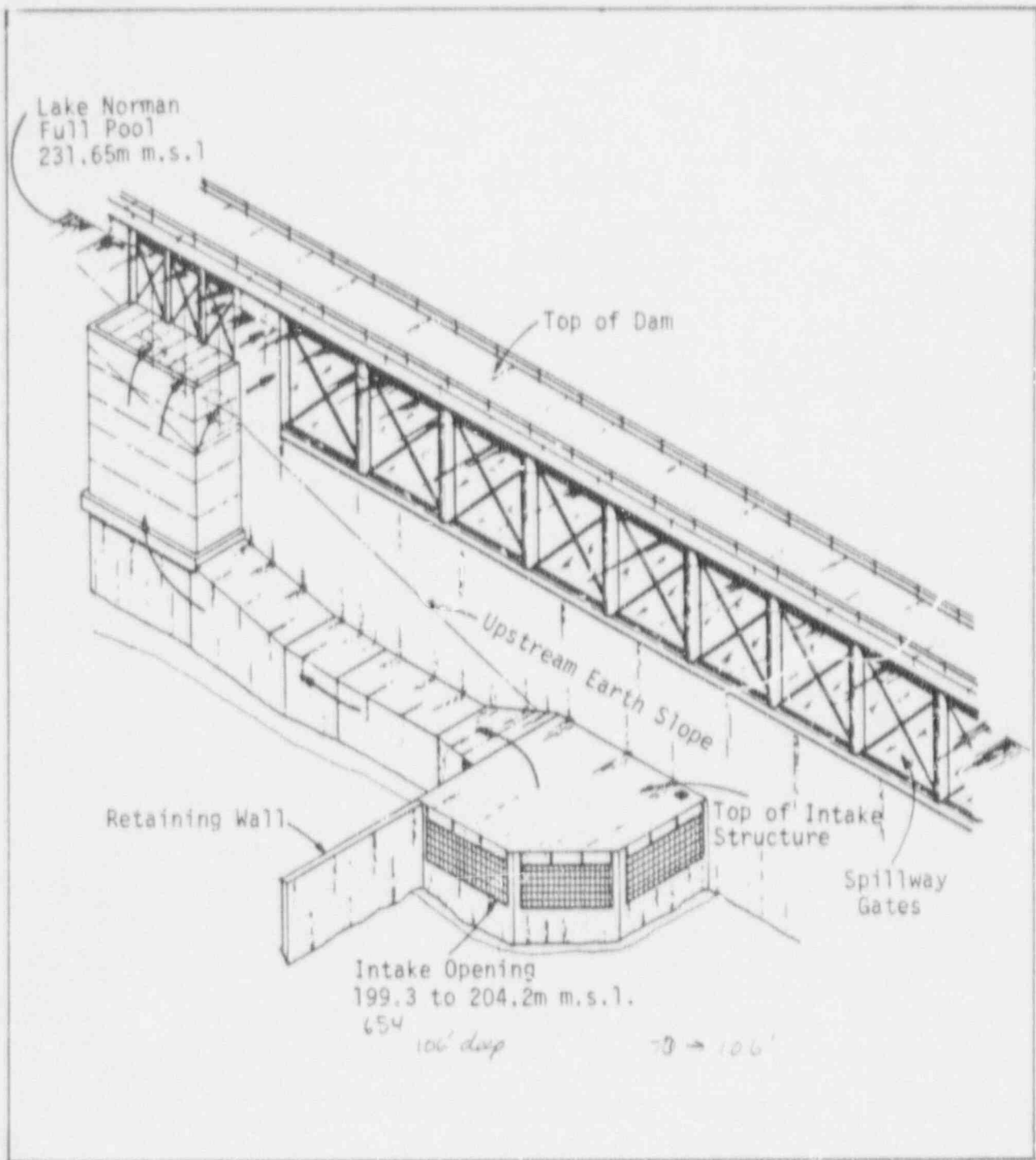


Figure 1-9. Schematic of McGuire Nuclear Station lower-level intake structure on the Lake Norman side of Cowans Ford Dam. (Not drawn to scale)

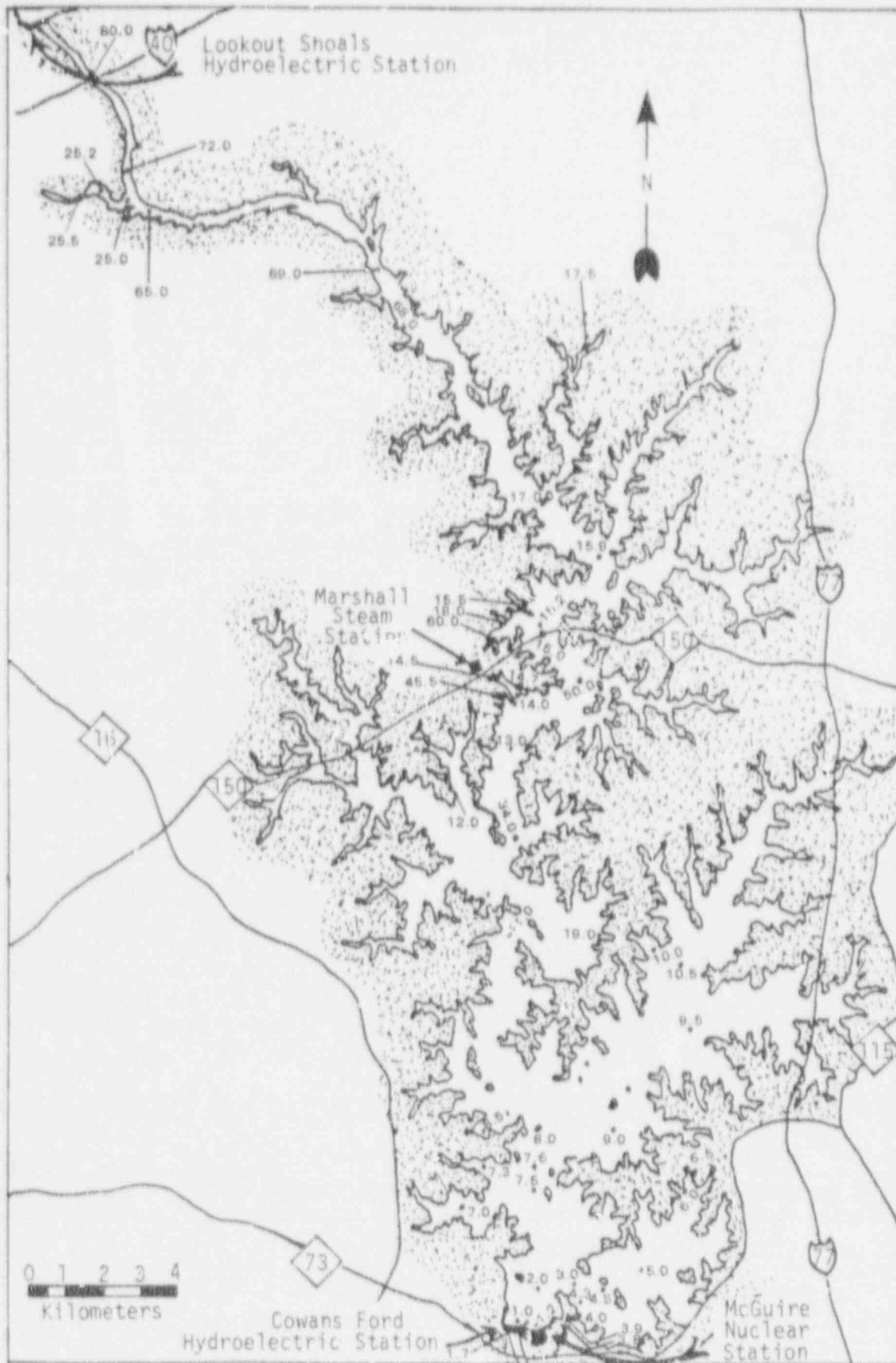


Figure 1-10. Lake Norman sampling locations, 1973 through 1980.

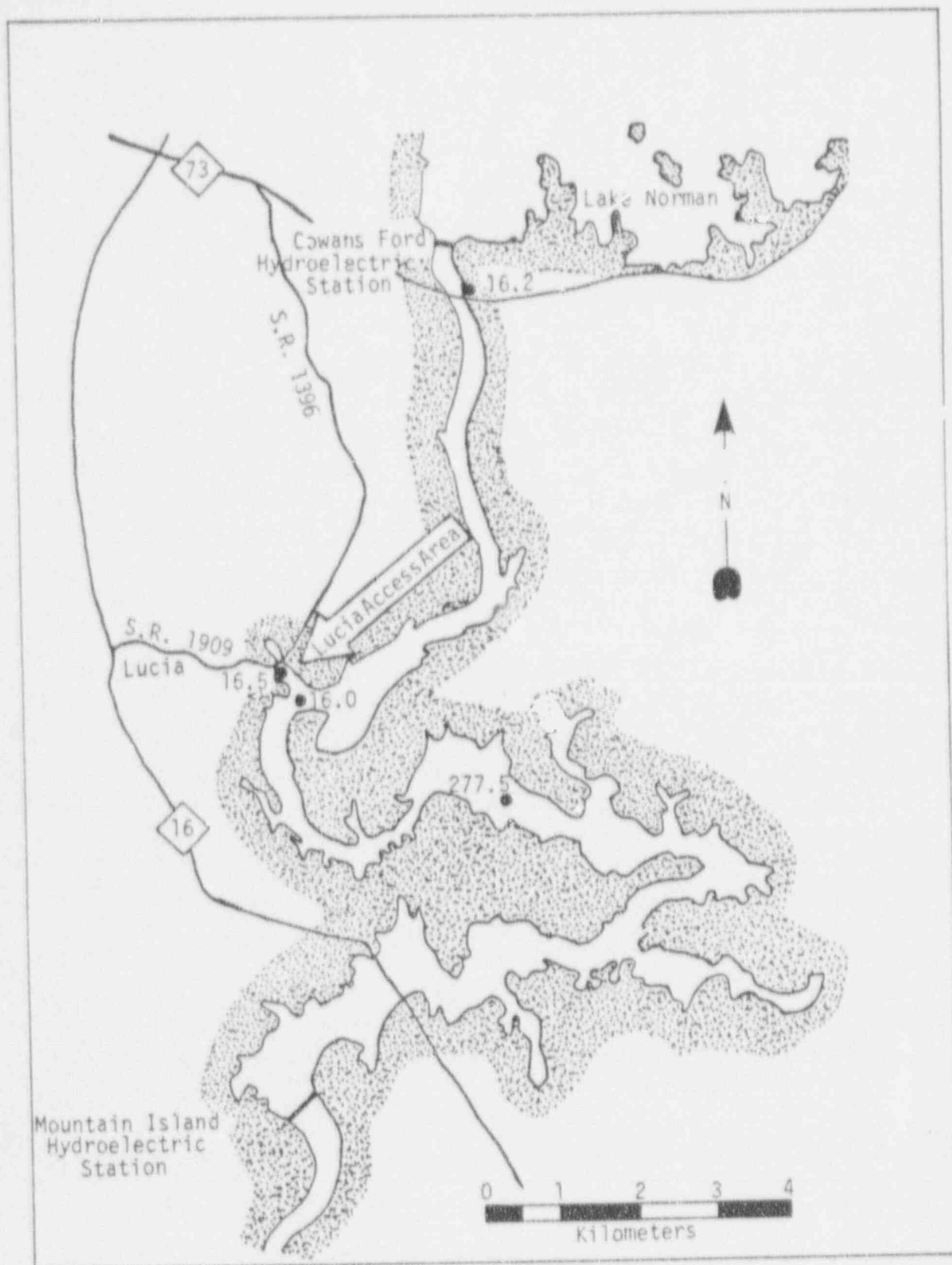


Figure 1-11. Mountain Island Lake sampling Locations (●) 1974 through 1980.

CHAPTER 2. THERMAL REGIMES

R. W. CACCIA, M. C. GRIGGS, AND D. S. RIDDLE

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INTRODUCTION

BACKGROUND

Major changes in physical, chemical, and biological characteristics of a lake are often responses to seasonal changes in meteorology. In the Piedmont Carolinas, lakes follow a seasonal pattern of thermal stratification beginning in April or May and continuing until overturn in October or November. A period of circulation in which the lake is mixed vertically begins in the fall and continues until the onset of stratification. During the circulation period, depending on weather conditions of that particular year, alternate periods of slight stratification and mixing are common (Weiss 1960).

Lakes exhibiting thermal characteristics similar to those in the Piedmont Carolinas can be classified as warm monomictic (Hutchinson 1957). In the Piedmont, lakes are essentially isothermal during winter (December-March). As the spring season begins (April), heat is added to the lake surface by the atmosphere during daylight hours. At night, the lake is unable to dissipate all the added heat to the atmosphere and warms isothermally as heat is mixed from the lake surface to the bottom by wind action and convection (Edinger et al. 1974). The lake thermally stratifies during periods of calm winds as heat is added to the lake surface. It then mixes down slowly, and a warm upper layer forms. If the interface (thermocline) between the upper (epilimnion) and lower (hypolimnion) layers is stable, the lake remains stratified throughout the summer and the epilimnion thickens (Edinger et al. 1974). The lake cools during the fall months (September-December). The stability of the thermocline decreases as convective mixing in the lake increases. Eventually the lake completely mixes (fall overturn) and cools isothermally until the seasonal cycle begins again the following spring.

Duke Power Company began measuring temperature on Lake Norman in August 1963, before the lake reached full pool in 1964. Between 1965 and 1971, Johns Hopkins University and management of Duke Power Company directed a thermal effects research project on Lake Norman (Jensen 1974). The focus of the study was Marshall Steam Station, a four-unit fossil-fueled steam-electric generating station.

Determination of the effects of a skimmer wall at Marshall on the thermal effluent was among the most significant findings of the thermal research project. During stratified periods, April through October, the condenser cooling water was withdrawn from the hypolimnion of the lake. The resulting thermal discharge was approximately the same temperature as receiving waters. As a result, considerable mixing between the effluent and receiving water occurred in the discharge cove and immediately downlake. During the winter months, the temperature of the Marshall effluent was reduced rapidly in the discharge cove. The rapid reduction in temperature was probably due to Lake Norman bottom water flowing toward the discharge structure and mixing upward with the buoyant thermal plume, rather than rapid surface heat dissipation. However, the thermal plume generally remained buoyant as it entered Lake Norman, and was confined to the upper strata of the lake in the immediate discharge area. During the winter months when the Marshall thermal plume was expected to extend over the largest surface area of Lake Norman, the plume was slightly detectable uplake at Location 50.0 and downlake at Location 11.0 (Fig. 1-12).

A study, from February 1973 through January 1974 by Weiss (1975), indicated that the seasonal heating and stratification patterns of Lake Norman were typical of other lakes in Piedmont North Carolina. The weir in front of Cowans Ford Hydroelectric Station intake was found to enhance stratification in the lake during the spring and summer by excluding hypolimnetic water from being discharged to Mountain Island Lake.

Duke Power Company continued to monitor temperatures on Lake Norman after the Johns Hopkins University study (Jensen 1974) was completed. Thermal monitoring in conjunction with the water quality program (Chapter 3), and continuous temperature monitoring were conducted throughout this period. Data collected prior to March 1974 have been reported by Duke Power Company (1976).

OBJECTIVES

The objectives of this study were to:

- 1) define the thermal characteristics in Lake Norman, both spatially and temporally,
- 2) identify those factors influencing the thermal characteristics in Lake Norman,
- 3) establish a thermal data base which may be used to assess the effects on Lake Norman from the operation of existing and future power generating stations.

MATERIALS AND METHODS

MONTHLY WATER TEMPERATURE MONITORING

SAMPLING LOCATIONS AND FREQUENCY

Water, temperatures were measured at monthly intervals, between January 1974 and December 1980, in conjunction with the water quality program (Chapter 3). Locations and the periods each was monitored are tabulated in Table 2-1. Sample locations are presented in Fig. 1-10 and 1-11 and described in Table 1-3.

FIELD PROCEDURES

Temperatures at all locations except Location 16.0 were measured in situ using the thermistor sensor on a Hydrolab Surveyor Model 6D. Thermistor accuracy was $\pm 0.25^{\circ}\text{C}$ (Hydrolab Corporation 1973). Calibration of the system was performed prior to the collection of data and, in most cases, after data collection. Temperatures were measured beginning at 1 m above the bottom, and thereafter at one-meter intervals to the surface (0.3 m). At Location 16.0, temperatures were measured with a thermometer.

CONTINUOUS WATER TEMPERATURE MONITORING

SAMPLING LOCATIONS AND FREQUENCY

Continuous water temperature monitoring was conducted between September 1967 and December 1980. For this study, however, data will be examined for only five locations from January 1976 through December 1980. Sample locations, depths, and the period each location was monitored are shown in Table 2-2.

FIELD PROCEDURES

Water temperatures at each location were monitored with an arrangement of thermistors attached at various depths to a floating buoy. The thermistors were wired to an instrument building on the shore which housed a Leeds and Northrup Speedomax strip chart recorder. Each monitoring system was accurate to $\pm 0.5^{\circ}\text{C}$. The chart recorders were calibrated according to the manufacturer's recommendations at the time of installation and at least every six months thereafter. Strip charts were collected weekly and daily readings for 0600 and 1800 hrs. were recorded.

SUPPLEMENTAL DATA

Various meteorological variables were monitored at or near the McGuire Nuclear Station site, during the study period, to provide supportive data. Monitoring locations are given in Fig. 2-1, and periods of data collection, instrumentation, and methods of data reduction in Table 2-3.

DATA ANALYSES

All thermal data collected on Lake Norman from January 1976 through December 1980, as well as data at Location 1.0 from January 1971 through December 1976 are included in Appendix 2. For this study, we only consider that data collected between January 1976 and December 1979 with the exception of continuous water temperature monitoring data for 1980.

HEAT CONTENT

Heat content, defined for this study as the amount of heat above 0.0°C stored in the lake, was calculated from the monthly temperature monitoring data. Lake Norman was divided into four zones with the following locations representing each zone: (1) the Lower Lake Main Channel Area was represented by Locations 1.0, 2.0 and 7.5; (2) the Ramsey Creek Area by Locations 3.0, 4.5, and 5.0; (3) the Reference Area by Locations 8.0 and 11.0; and (4) the Upper Lake Main Channel Area by Locations 13.0 and 15.0. The assumption that the density of water remains at $1.0\text{ g}\cdot\text{cm}^{-3}$ and the fact that a calorie is equal to the amount of energy required to raise the temperature of 1 g of water by 1°C were used in the calculations. Data for all locations within a zone were averaged to obtain an average temperature for each depth sampled. The average temperature for each depth was averaged with the mean temperature for the depth above to obtain a temperature representative of each one meter stratum in the water column. The representative temperature of each stratum was multiplied by the volume of that stratum to obtain a heat content for each stratum. The strata

from 0 to 10 m and from 10 to 30 m were summed to obtain a heat content for each water mass in each zone. The heat contents for all of the zones were summed to obtain a heat content for the entire lake. A volume-weighted temperature for each water mass was calculated by dividing the heat content by the volume of that water mass. For comparison, a theoretical heat content value for the total lake was calculated by multiplying the total lake volume by the average monthly equilibrium temperature (Ryan-Harlemen 1973). All of the heat content calculations took into consideration the lake elevation recorded on the day of data collection.

HYPOLIMNETIC WARMING RATES

Hypolimnetic warming rates were calculated from data collected with continuous temperature monitors. A linear regression (Helwig and Council 1979) was calculated based on data measured at 25 m between April 1 and August 31 each year. The warming rate was taken as the slope of the regression line.

TEMPERATURE DECAY

Temperatures, measured monthly at the surface (0.3 m) and 5 m depths at locations in the Lake Norman main channel, were normalized to Location 1.0 (values recorded for Location 1.0 were subtracted from all other locations). The normalized temperatures were plotted against distance from the Marshall discharge structure. Plots were prepared for months when the Marshall thermal plume extended over the largest lake surface area (October through March).

EQUILIBRIUM TEMPERATURES

Equilibrium temperatures were calculated, based on the unheated windspeed function and the method developed by Ryan and Harlemen (1973), from data collected at Douglas Municipal Airport in Charlotte, N. C. Mean, maximum and minimum daily equilibrium temperatures were calculated for a 25-year period (1950-1974) prior to the study period. Daily equilibrium temperatures for the 1975 through 1979 study period were also calculated.

RESULTS AND DISCUSSION

THERMAL CHARACTERISTICS

Trends in temperature data collected during the study period, 1975 through 1979, were similar to those previously reported for Lake Norman (Duke Power Company 1976; Jensen 1974; Weiss 1975). Lake Norman temperatures followed a seasonal pattern typical of warm monomictic lakes (Hutchinson 1957).

Thermal stratification typically began in Lake Norman during April and was well established by June (Fig. 2-2 through 2-18). Vertical thermal gradients increased during the summer as the lake surface warmed. Maximum surface temperatures (excluding the Marshall intake cove and Location 16), for each year, were generally measured during July or August and ranged from 27.5 to 32.9°C (Tables 2-4 and 2-5). During August, when the maximum vertical thermal gradient for each year was measured, a metalimnion existed between 6 and 18 m

at deep (>20 m) sample locations (Fig. 2-12 through 2-18). Differences between surface and bottom temperatures at deep locations ranged from 6.3 to 18.5°C during August.

Lake temperatures began to decrease in early fall. Stratification decreased gradually until the lake overturned in November. Cooling and mixing established relatively uniform temperatures from the lake surface to the bottom by December. The lake continued to cool during January and February. Minimum surface temperatures, in the lower areas of the lake, were typically measured during February of each year and ranged from 1.6°C to 8.6°C (Tables 2-4 and 2-5). Lake Norman bottom waters warmed much slower than surface waters after the lake thermally stratified in the spring (Fig. 2-19). A warming rate was calculated for the hypolimnion based upon data collected with continuous monitors at a depth of 25 m at Locations 1.7 and 7.6 between April 1 and August 31 of each year. Sufficient data for the calculations were only available during 1976, 1977, and 1979. Hypolimnetic warming rates of 0.75, 0.72, and 0.78°C·month⁻¹ were calculated for 1976, 1977, and 1979, respectively. These rates were similar to rates reported by Jensen (1974) of 0.73°C·month⁻¹ for Lake Norman bottom waters in the spring before a thermocline developed and 0.66°C·month⁻¹ after a thermocline was established. No continuously recorded data were available for the hypolimnion in the vicinity of Marshall.

Seasonal trends in surface temperatures measured at Location 16.0 on Mountain Island Lake were similar to the trends discussed for locations on Lake Norman. Maximum values were measured at Location 16.0 between July and September each year and ranged from 26.7 to 28.0°C. Minimum surface temperatures were measured during January or February each year and ranged between 2.3 and 8.0°C. Generally, surface temperatures measured at Location 16.0 were slightly cooler during the summer than surface temperatures measured at Location 1.0 (Cowans Ford Hydroelectric Station forebay). During the winter, surface temperatures measured at the two locations were approximately the same (Fig. 2-20).

Year-to-year variations in Lake Norman temperatures were small during the summer throughout the study period (Figures 2-21 through 2-25). The warmest temperatures were measured at most locations during the 1979 summer season.

During the 1976/1977 and 1977/1978 winter seasons, Lake Norman temperatures measured during the first three weeks of February each year were below 4°C, the temperature of maximum density for water (Fig. 2-26). Inverse thermal stratification (bottom temperatures exceeded surface temperatures) was noted at most locations on the lake as surface temperatures decreased to 1.6°C at some locations.

Variations in temperature between locations on Lake Norman were small, excluding temperatures measured at locations near Marshall (Figs. 2-2 through 2-16). Trends in temperature throughout the years at Locations 14.0 and 13.0 were usually warmer than temperatures at other locations. Location 14.0 is in the Marshall discharge cove and Location 13.0 is within 2 km of the Marshall discharge structure (Fig. 1-10). Temperature variations at both locations are primarily influenced by Marshall discharge temperatures and condenser cooling water flow rates.

FACTORS INFLUENCING LAKE NORMAN THERMAL CHARACTERISTICS

LOCAL METEOROLOGY

Thermal characteristics of Lake Norman were basically determined by local meteorology. Annual and seasonal variations in the lakes water temperatures were the result of diurnal cycles in local meteorology. Data indicate that solar radiation was the dominant factor in determining these diurnal cycles. Temperatures measured with continuous monitors at Location 5.0 were plotted to illustrate the diurnal variations in Lake Norman water temperatures (Fig. 2-27). Wind velocity during this 48 h period was low (Fig. 2-28); therefore, mixing due to wind was minimal. Lake surface temperatures began to increase at approximately 1000 each day and reached a maximum value at approximately 1800 (Fig. 2-27). Minimum values were recorded at approximately 0600 each day. Maximum solar radiation values were recorded between 1200 and 1400 each day indicating that increases in lake temperatures typically lagged solar radiation increases by 4 to 6 hours due to the large heat capacity of water. At night, the surface temperatures cooled first to the temperature of layers immediately below the surface. This process continued until the top 2 to 3 m of the lake was isothermal.

Wind movement across surface waters also caused variations in Lake Norman water temperatures (Fig. 2-29). Reid (1961) reported wind has a substantial influence on water movement in a lake and may cause translational movement of surface water when wind force is sufficient to cause whitecaps. Wind-induced circulation of water promotes a vertical transport of heat from the upper layers to the lower layers; the epilimnetic layers lose heat while the hypolimnetic layers gain heat (Hutchinson 1957). In Lake Norman, the wind affected water temperatures at depths well below the lake surface (Fig. 2-30).

Equilibrium temperatures provide a simple approach to heat exchange analyses and are useful in examining long term trends in lake temperatures (Edinger et al. 1974). On a lake receiving no thermal discharge, the mean monthly lake temperature should follow closely the mean monthly equilibrium temperature (Jensen 1974). The lowest mean daily equilibrium temperatures typically occurred during January and February (Fig. 2-31). Mean values for January and February ranged from 2.3 to 8.7°C. The highest mean daily equilibrium temperatures for the 25 yr period typically occurred during July and August and ranged from 27.6 to 30.5°C. Daily equilibrium temperatures for the period varied considerably ranging from a minimum of -10.5°C to a maximum of 40.2°C.

Daily equilibrium temperatures for the study period followed trends similar to the 25-yr mean daily values (Fig. 2-32 through 2-34). Values for the 1975 through 1979 period were generally within the range of the 25-yr maximum and minimum equilibrium temperature. The coldest and hottest months during the study period were January and July 1977, respectively.

Edinger et al. (1974) reported that lake surface temperatures typically lag equilibrium temperatures by one to four weeks. Lake Norman surface temperatures generally lagged equilibrium temperatures by two to three weeks, and followed the same seasonal patterns as equilibrium temperatures. The coolest and warmest

lake surface temperatures during the study period were measured during the 1977 winter and summer seasons which were also the periods when the maximum and minimum equilibrium temperatures occurred.

HYDROLOGY

Hydrological processes greatly influence the thermal structure of a lake, though generally to a lesser extent than meteorology. Hydrology is governed by natural sources such as precipitation and stream inflow, as well as man-induced usages, both consumptive and non-consumptive. The operation of Lookout Shoals and Cowans Ford Hydroelectric Stations, and Marshall Steam Station affected Lake Norman's thermal structure during the study period.

Operation of Cowans Ford Hydroelectric Station affected thermal stratification in Lake Norman in the forebay area during the study period. Stratification patterns in that area were also affected by the skimmer weir located in front of the station intakes. The top of the skimmer weir is located approximately 11 m below the Lake Norman full pool elevation. The weir prevents the colder bottom waters of Lake Norman from being withdrawn from the lake during periods of stratification. Temperatures measured with continuous monitors at Location 1.7 during two 24 h periods illustrate the effect of Cowans Ford Hydroelectric Station operations on thermal patterns in the forebay area (Fig. 2-35 and 2-36). Location 1.7 is approximately 65 m from the dam located on the lake side of the weir.

Temperatures measured in the upper 14 m of the water column at Location 1.7 were immediately affected each time Cowans Ford began operation (Fig. 2-35 and 2-36). The maximum change in temperature was observed between 4 and 14 m in the water column. The cold deep waters mixed with upper warm waters, resulting in a net decrease in temperatures. Temperatures in the top 4 m of the water column were affected by Cowans Ford operation but changes were less than observed for the 4 to 14 m depths. Temperatures measured below 20 m were fairly stable when the station was operating due to the skimmer weir retaining the bottom waters. The increase in surface temperature (Fig. 2-36) was probably due to increases in solar radiation during daylight hours and not station operations. Temperatures at all depths oscillated slightly as Cowans Ford began operating. As station operations stopped, temperature oscillations were pronounced, especially at depths in the middle of the water column. Several hours after Cowans Ford ceased operation, temperatures returned to approximately the same temperature measured prior to operation of the station.

Steam electric generating stations affect lake thermal structures not only by rejecting heat to the lake, but by displacing large volumes of water from one area to another. Stations which utilize bottom waters for condenser cooling purposes also displace large volumes of water from the lake bottom to the surface. When the lake is stratified, the hypolimnion is gradually reduced as the summer progresses.

Temperatures at Location 15.0, in the vicinity of Marshall's skimmer wall, followed trends similar to those temperatures in other areas of Lake Norman (Fig. 2-2, 2-3, and 2-11). Bottom waters at Location 15.0 warmed only slightly faster than bottom waters at other locations. The thermal similarities illustrated represent Marshall Steam Station operational period.

To realize the cumulative effect that Marshall had on the thermal characteristics of Lake Norman, the average temperature profiles for the pre-operational period August 1963, 1964, and 1965, and the operational period August 1970, 1971, and 1972, were plotted for Locations 1.0, 8.0, and 15.0 (Fig. 2-37). These years were chosen due to their similarities in meteorological conditions. The vertical thermal gradient in Lake Norman showed a distinct decrease from pre-operation to operation of Marshall. This change in the thermal gradient is very similar to that found on Lake Keowee after Oconee Nuclear Station became operational (Duke Power Company 1977). On both Lakes Keowee and Norman, the variance in thermal gradient was primarily due to artificial mixing of the lake by the utilization of hypolimnetic waters for condenser cooling purposes.

MARSHALL STEAM STATION

Waste heat is discharged at rates up to $1.7 \cdot 10^{12}$ kcal·month⁻¹ from Marshall when the station is operating at full capacity. This amount of heat could theoretically raise the temperature of the volume of Lake Norman 1.3°C per month if the entire amount were stored in the lake. Heat rejection rates (waste heat) averaged $0.93 \cdot 10^{12}$ kcal·month⁻¹ during the study period (Fig. 2-38 through 2-40). Monthly mean heat rejection rates varied from a minimum of $0.88 \cdot 10^{12}$ kcal·month⁻¹ during 1976 to a maximum of $1.0 \cdot 10^{12}$ kcal·month⁻¹ during 1979. Although daily mean heat rejection rates were erratic, the monthly mean values indicated Marshall operated at relatively consistent levels during the study period.

The Marshall thermal plume was typically observed over the largest area during January and February (Fig. 2-41 through 2-45). Differences between surface temperatures measured during the study period at Location 14.0 and Location 1.0 varied from a minimum of 3.8°C in October 1976 to 11.0°C in January 1979.

The most rapid temperature decays were observed between Locations 14.0 and 13.0 (Fig. 2-41 through 2-45). The majority of excess heat had dissipated before reaching Location 11.0, approximately 6.0 km downlake from the Marshall discharge. Temperatures measured at 5 m depths indicated that most of the Marshall thermal plume was contained within the upper portion of the water column (Fig. 2-41 through 2-45). The maximum temperature difference between the 5 m depths at Location 14.0 and 1.0 was only 3.1°C observed in February 1977.

During spring and summer months (April through September) Marshall discharges are of approximately the same temperature as receiving waters. As a result, the plume mixes deeper during these months versus the fall and winter periods when temperature and thus density differences tend to "float" the warmer water on the receiving waters.

HEAT CONTENT

Heat content analyses are useful in the evaluation of seasonal changes, mixing, and heat storage in lakes (Derecki 1976; Duke Power Company 1977). Local meteorology is the dominant influence on lake heat content and is responsible for its cyclical nature. Other factors such as hydrology and thermal discharges are also important and may cause deviations in normal lake heat content cycles.

Annual cycles in Lake Norman total heat content were relatively consistent during the study period (Fig. 2-46). Minimum values for each year were observed in January or February and ranged from $4.8 \cdot 10^{12}$ kcal (February 1978) to $10 \cdot 10^{12}$ kcal (January 1975). Maximum values were typically observed in July, August, or September and ranged from $28 \cdot 10^{12}$ (July 1977) to $31 \cdot 10^{12}$ kcal (August 1979).

Total lake heat content followed the same cyclical pattern as the theoretical heat content based on mean equilibrium temperatures (Fig. 2-46). Maximum values for the theoretical heat content were much greater than maximum actual heat content values. The Lake Norman epilimnion was affected more by meteorology than other strata of the lake because the thermocline impeded mixing and heat transfer to the hypolimnion. Lower strata were not able to absorb and store as much heat from the atmosphere as the upper layers and did not approach the theoretical heat content after a stable thermocline was present in June.

The cyclical pattern of the actual lake total heat content during 1975 and 1976 followed closely the monthly pattern exhibited by the theoretical lake heat content; however, during 1977, 1978, and 1979 the lake heat content appeared to lag approximately one month behind the theoretical heat content (Fig. 2-46). The differences are probably due to a three-week shift in the Lake Norman sampling schedule from the last week of each month to the first week of each month beginning in January 1977. Monthly mean equilibrium temperatures were used to calculate theoretical heat content and would be most representative of middle of the month values. Since Lake Norman temperatures lagged equilibrium temperatures by two to three weeks, temperatures collected at the end of the month would be reflective of equilibrium temperatures calculated for the middle of the month. Temperatures collected during the first week of the month would be more nearly reflective of mean equilibrium temperatures calculated for the previous month.

Heat rejection rates from Marshall were a small percentage of the total lake heat content during most of the study period (Fig. 2-46). Heat rejected from Marshall contributed most to the heat load of Lake Norman during winter months when the lake heat contents were lowest. Lake temperatures, especially in the area near Marshall, were probably affected more by heat rejected from Marshall during the winter than during other seasons, as evidenced by the actual lake heat content being greater than theoretical (Fig. 2-46).

Volume-weighted temperatures (heat content of a layer of water divided by the volume of the layer) are useful when comparing heat stored within various areas and depths in a lake. The Lake Norman volume-weighted temperatures were approximately the same for the surface to 10 m and 10 m to bottom layers during winter months (December through March); however, as the lake stratified during the summer, the surface to 10 m values were much greater than 10 m to bottom values (Fig. 2-47). During the fall season the surface to 10 m layer cooled rapidly and was approximately the same as the 10 m to bottom values after lake overturn. The thermocline in Lake Norman inhibited mixing and heat transfer from surface to bottom waters. The volume-weighted temperatures for the 10 m to bottom layer lagged the volume-weighted temperature for the surface to 10 m layer during periods when the lake was stratified.

Heat storage within various areas of Lake Norman was evaluated by dividing the lake into four zones: the Lower Lake Main Channel Area, the Ramsey Creek

Area, the Reference Area, and the Upper Lake Main Channel Area. Surface to 10 m and 10 m to bottom, volume-weighted temperatures were calculated for each zone. Spatial variations between volume-weighted temperatures for the total water column in each zone were small (Fig. 2-48 and 2-49). The volume-weighted temperatures calculated for the 10 m to bottom layers in each zone were also approximately the same. Surface to 10 m volume-weighted temperatures for each zone varied the most (Fig. 2-50 through 2-54). The Upper Lake Main Channel Area volume-weighted temperature (surface to 10 m) was typically greater than the surface to 10 m volume-weighted temperature for other zones due to the Marshall thermal discharge. Differences were greatest during winter months, especially January and February. During months when the lake was stratified the surface to 10 m volume-weighted temperatures calculated for the Upper Lake Main Channel Area were approximately the same as values calculated for the other zones. This seasonal variation in surface to 10 m volume-weighted temperatures between the zones was due to the use of hypolimnetic condenser cooling water by Marshall when Lake Norman was stratified. Differences between surface to 10 m volume-weighted temperatures calculated for the other zones were small. Typically the surface to 10 m volume-weighted temperature for the Reference Area was slightly warmer than the Ramsey Creek Area and the Lower Lake Main Channel Area.

SUMMARY

Temperatures on Lake Norman were monitored monthly, at various times during the period from 1974 through 1980, at 21 locations. These temperatures were measured with a Hydrolab Surveyor Model 6-D. In conjunction with the monthly sampling program, continuous hourly sampling was done at one location from 1971 through 1976 and at five other locations from 1976 through 1980. Recorders, attached to thermistor chains, measured temperature profiles in the water strata at these locations.

Temperature data collected on Lake Norman followed seasonal patterns typical of warm monomictic lakes. The lake began to stratify during April. Maximum surface temperatures were measured during July and August and ranged from 27.5 to 32.9°C. The lake began to cool during the fall and vertical stratification decreased. Overturn was typically complete by the end of November as relatively uniform temperatures were established from surface to bottom. Minimum lake surface temperatures, in the lower areas of the lake, were generally measured during February each year and ranged from 1.6 to 8.6°C.

Year to year variations in Lake Norman temperatures were small during the summer season throughout the study period. During the 1976/1977 and 1977/1978 winter seasons, temperatures measured at most locations on Lake Norman were below 4°C for a brief period in February and inverse stratification was observed in the lake.

The thermal characteristics of Lake Norman were primarily determined by local meteorology and followed seasonal meteorological patterns. Annual and seasonal variations in Lake Norman temperatures were the result of diurnal cycles in local meteorology with solar radiation being the dominant factor in determining diurnal cycles. More heat was generally gained by the lake surface during daylight than was dissipated at night during spring and summer seasons resulting in a gradual warming up of the lake. During fall and winter, more heat was

typically dissipated to the atmosphere from the lake surface than was absorbed, resulting in a net daily reduction in lake temperatures. Heat was transferred in the water column during diurnal cycles by convective mixing and wind action.

Thermal characteristics of Lake Norman were also influenced by lake hydrology. Natural sources as well as the operation of Lookout Shoals and Cowans Ford Hydroelectric Stations and Marshall Steam Station affected lake hydrology. The operation of Cowans Ford during spring and summer seasons effected thermal stratification in the vicinity of the station to depths of 20 m. Temperatures measured between 4 and 14 m were affected the most by station operations as mixing at those depths resulted in the greatest changes in temperatures.

Based on temperatures measured at Location 15.0, the Lake Norman hypolimnion in the vicinity of the Marshall intake canal was reduced only slightly, compared to other lake locations, during the summer due to the withdrawal of bottom waters by Marshall. Since Marshall utilizes bottom waters for condenser cooling water, discharge temperatures during the summer were approximately the same as surface temperatures measured at locations out of the influence of the Marshall discharge. Maximum differences between surface temperatures in the discharge cove and those in other areas of the lake were measured between October and March when the lake was nearly isothermal.

The Marshall thermal plume was typically observed over the largest area of Lake Norman during January and February. The largest surface temperature decays were measured between Locations 14.0 and 13.0. The majority of excess heat had dissipated before reaching Location 11.0. During the winter the thermal plume was buoyant and was generally contained within the top 5 m of the water column. Discharge temperatures in the summer were approximately the same as surface receiving waters causing the plume to mix downward to slightly lower depth than in the winter.

Annual cycles in Lake Norman total heat content were relatively consistent during the study period. The heat content for Lake Norman closely followed the annual cycles in equilibrium temperatures.

Spatial variations between volume-weighted temperatures calculated for the total water column in each of the four Lake Norman zones were small. Surface to 10 m volume-weighted temperatures for the Upper Lake Main Channel Area were typically greater than the surface to 10 m volume-weighted temperature for the other zones due to the Marshall thermal discharge. Differences were greatest during winter months. During months when the lake was stratified, the surface to 10 m volume-weighted temperature calculated for the Upper Lake Main Channel Area was approximately the same as values calculated for the other zones. Typically the surface to 10 m volume-weighted temperature for the Reference Area was slightly warmer than surface to 10 m values calculated for the Ramsey Creek Area and the Lower Lake Main Channel Area.

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Table 2-1. Monthly temperature monitoring conducted during the period from January 1974 through December 1980.

<u>Locations</u>	<u>1974</u>	<u>1975</u>	<u>1976</u>	<u>1977</u>	<u>1978</u>	<u>1979</u>	<u>1980</u>
1.0	A	A	A	A	A	A	A
1.2	-	-	-	Jul-Dec	A	A	A
2.0	A	A	A	A	A	A	A
3.0	A	A	A	A	A	A	A
4.0	A	A	A	A	A	A	A
4.5	A	A	A	A	A	A	A
5.0	A	A	A	A	A	A	A
6.0	A	A	A	A	A	A	A
7.0	A	-	-	-	-	-	-
7.5	-	A	A	A	A	A	A
8.0	A	A	A	A	A	A	A
8.5	-	-	-	-	-	May-Dec	A
9.0	A	-	-	-	-	A	A
9.5					Mar-Dec	A	A
10.0	A	A	-	-	-	-	-
11.0	A	A	A	A	A	A	A
12.0	A	-	-	-	-	-	-
13.0	A	A	A	A	A	A	A
14.0	A	A	A	A	A	A	A
14.5	Sep-Nov	Feb-Dec	-	-	-	-	-
15.0	A	A	A	A	A	A	A
15.9	-	-	-	-	Mar-Dec	Jan-May	-
16.0	A	A	A	A	A	A	A
17.0	Jan-Oct	-	-	-	-	-	-
17.5	Jul-Dec	A	-	-	-	-	-
18.0	A	A	-	-	-	-	-
34.0	-	-	-	-	Jun-Dec	Jan-May	-
50.0	-	-	-	-	Jun-Dec	Jan-May	-
60.0	-	-	-	-	Jun-Dec	Jan-May	-

A = Sampled during all 12 months of that year.

- = Not sampled

Table 2-2. Sample locations and depths for continuous water temperature monitoring during the study period.

Location No.	1.0	1.7	4.3	5.0	7.6	9.5
Date Effective	1/71-12/76	12/76-12/80	8/78-12/80	1/76-12/80	1/76-12/80	1/76-12/80
Depth (m)	0.3	0.3	0.3	0.3	0.3	0.3
	3.0	2.0	2.0	2.0	2.0	2.0
	6.1	4.0	4.0	4.0	4.0	4.0
	9.1	6.0	6.0	6.0	6.0	6.0
	12.2	8.0	8.0	8.0	8.0	8.0
	15.2	10.0	10.0	10.0	10.0	10.0
	18.3	12.0	12.0	12.0	12.0	12.0
	21.3	14.0	14.0	14.0	14.0	14.0
	24.4	16.0	16.0	16.0	20.0	16.0
	27.4	20.0	18.0	18.0	25.0	18.0
	30.5	25.0	20.0	20.0	30.0	20.0
	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom

Table 2-3. Meteorological data collection information for the McGuire Nuclear Station Site.

Monitored Variable	Period of Record		Instrument		Method of Data Reduction
	Beginning	Ending	Type	Accuracy	
*Temperature (@ 10 m)	1-29-76	12-31-80	4 lead copper RTD	$\pm 0.5^{\circ}\text{F}$	Avg. hourly to nearest 0.5°F
*Vertical temperature gradient (27.7 m separation from 10 m sensor)	1-29-76	12-31-80	4 lead copper RTD	$\pm 0.5^{\circ}\text{F}$	Avg. hourly to nearest 0.5°F
Rainfall	1-26-76	12-31-80	Belfort weighing rain gage model 5-780	$\pm 0.03"$ from 0-6," $\pm 0.06"$ from 6-12"	Hourly totals to nearest 0.01"
*Dew Point Temperature (@10 m)	1-29-76	12-31-80	EG&G Model 110 Hygrometer	$\pm 0.5^{\circ}\text{F}$	Avg. hourly to nearest 0.5°F
Solar Radiation	4-21-75	12-31-80	Belfort Model 53850 Pyrheliograph	$\pm 5\%$	Total $\text{ly}\cdot\text{d}^{-1}$
	9-14-77	12-31-78	Eppler Model 8-48	± 0.31 $\text{ly}\cdot\text{min}^{-1}$	Total $\text{ly}\cdot\text{h}^{-1}$ to nearest 0.21 ly
	1-1-78	12-31-80	Eppler Model 8-48 Pyranometer	± 0.31 $\text{ly}\cdot\text{min}^{-1}$	Total $\text{ly}\cdot\text{h}^{-1}$ to nearest 0.11 ly

Monitored Variable	Period of Record		Instrument		Method of Data Reduction
	Beginning	Ending	Type	Accuracy	
*Wind Speed (low level @ 10 m)	1-29-76	12-31-80	Teledyne Geotech Series 40	+0.5 mph	30 min. avg. preceeding each hour to nearest 0.1 mph
*Wind Speed (High level @ 41 m)	1-29-76	12-31-80	Packard-Bell Model 101 Wind System	+0.5 mph	30 min. avg. preceeding each hour to nearest 0.1mph
*Wind Direction (High level @ 41 m)	1-29-76	12-31-80	Packard-Bell Model 101 Wind System	+5°	30 min avg. preceeding each hour to nearest 5°
*Wind Direction (Low Level @ 10 m)	1-29-76	12-31-80	Teledyne Geotech Series 40	+5°	30 min avg. preceeding each hour to nearest 5°
*Located on Permanent Meteorological Tower at McGuire Nuclear station. Other variables were monitored within 1 km from McGuire.					

Table 2-4. Maximum and minimum surface water temperatures measured with continuous monitors on Lake Norman.

Location	Minimum/Maximum Temperatures (°C)								
	1971	1972	1973	1974	1975	1976	1977	1978	1979
1.0	$\frac{5.0}{29.4}$	$\frac{6.7}{31.7}$	$\frac{6.1}{31.7}$	$\frac{8.3}{29.0}$	$\frac{6.5}{32.5}$	$\frac{5.2}{31.0}$			
1.7							$\frac{2.0}{32.6}$	$\frac{3.2}{31.6}$	$\frac{4.4}{32.1}$
4.3						$\frac{*}{*}$	$\frac{*}{*}$	$\frac{*}{30.1}$	$\frac{4.0}{32.3}$
5.0						$\frac{5.0}{31.3}$	$\frac{1.6}{*}$	$\frac{1.6}{31.6}$	$\frac{3.7}{31.8}$
7.6						$\frac{5.7}{*}$	$\frac{1.9}{*}$	$\frac{3.2}{31.5}$	$\frac{4.1}{*}$
9.5						$\frac{4.7}{31.1}$	$\frac{1.6}{32.9}$	$\frac{2.6}{32.1}$	$\frac{3.8}{*}$

* Insufficient number of observations to warrant reporting.

Table 2-5. Maximum and minimum surface water temperatures measured monthly in Lake Norman.

Location	Surface Minimum/Maximum Temperatures (°C)				
	1975	1976	1977	1978	1979
1.0	7.7/28.9	6.1/28.5	2.5/28.1	3.5/29.1	5.0/29.2
1.2			*/28.1	3.5/28.7	5.0/29.3
2.0	7.7/29.0	6.4/28.1	2.4/27.8	3.7/28.5	5.0/29.3
3.0	7.7/29.5	6.4/28.0	2.5/27.8	3.2/28.1	5.0/29.8
4.0	7.6/29.1	6.1/28.4	2.3/28.2	2.7/28.9	5.0/30.2
4.5	7.6/29.1	6.4/28.0	2.7/28.0	2.8/29.0	5.0/30.1
5.0	7.5/29.6	6.4/28.1	2.4/28.3	2.9/28.5	4.3/30.9
6.0	7.7/30.3	6.6/28.0	2.6/29.8	2.8/29.2	4.0/30.9
7.5	8.1/29.4	6.3/27.6	2.8/28.2	3.7/28.3	5.4/30.3
8.0	7.8/29.0	6.5/28.0	2.7/27.9	3.7/28.3	5.4/30.1
8.5					5.1/30.5
9.5				4.3/28.9	5.0/29.8
10.0	7.8/30.4				
11.0	8.6/30.4	7.0/28.1	3.7/28.9	4.3/27.7	6.8/30.8
13.0	11.0/30.5	9.3/28.1	9.1/29.4	6.6/27.5	9.9/32.0
14.0	15.8/31.2	14.6/30.5	12.3/30.6	10.2/27.6	13.6/30.6
14.5	16.4/30.3				
15.0	9.0/30.5	7.6/28.3	5.8/29.4	2.7/27.6	7.0/31.4
15.9				*/27.7	4.4/*
16.0	8.0/28.0	5.7/27.2	2.3/27.2		5.6/26.7
17.5	9.0/31.0				
18.0	9.0/28.8				
34.0				*/27.6	7.4/*
50.0				*/27.6	7.6/*
60.0				*/20.0	5.1/*

*Insufficient sample period to justify reporting.

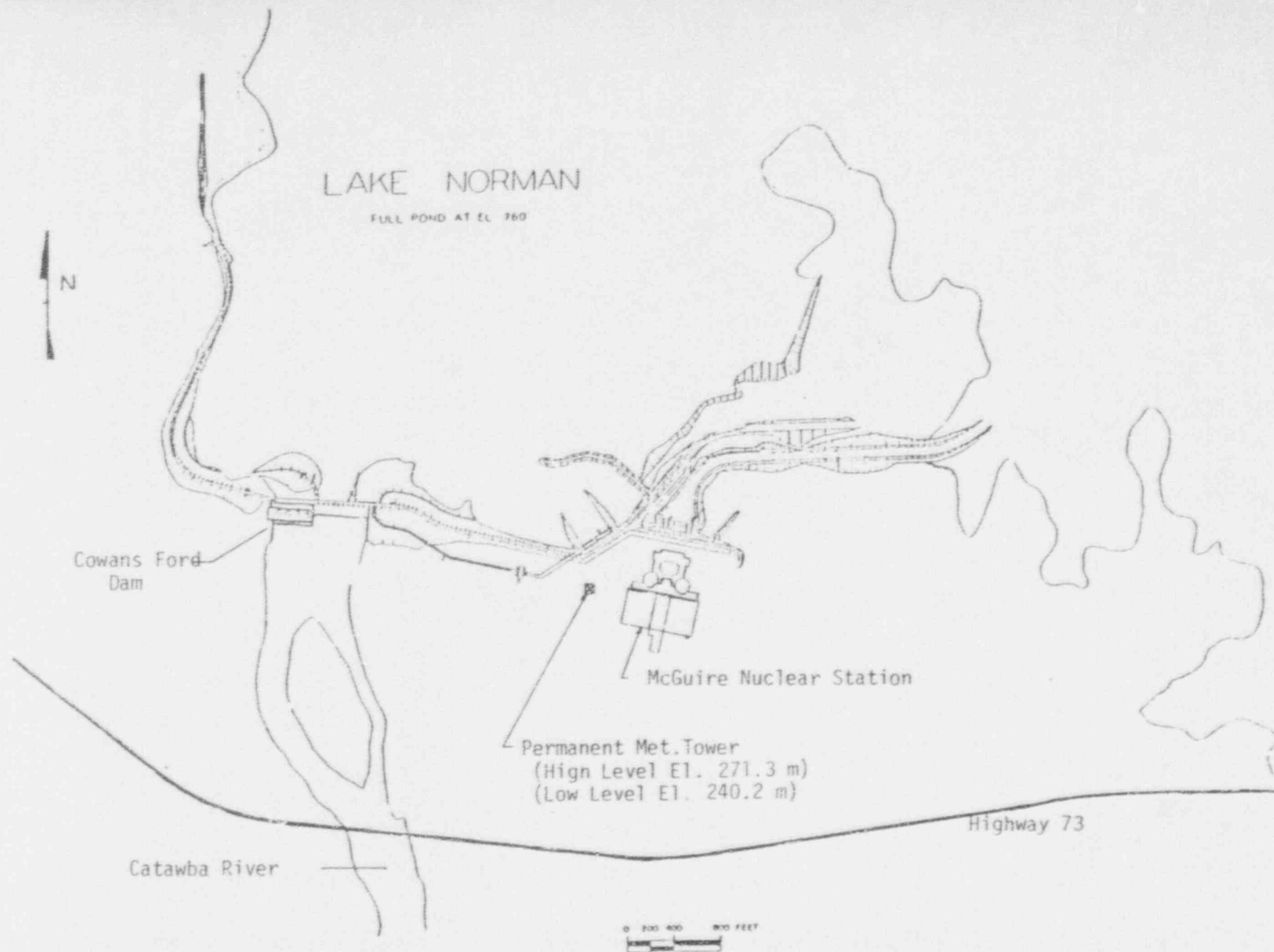


Figure 2-1. Location of the Permanent Meteorological Tower at McGuire Nuclear Station

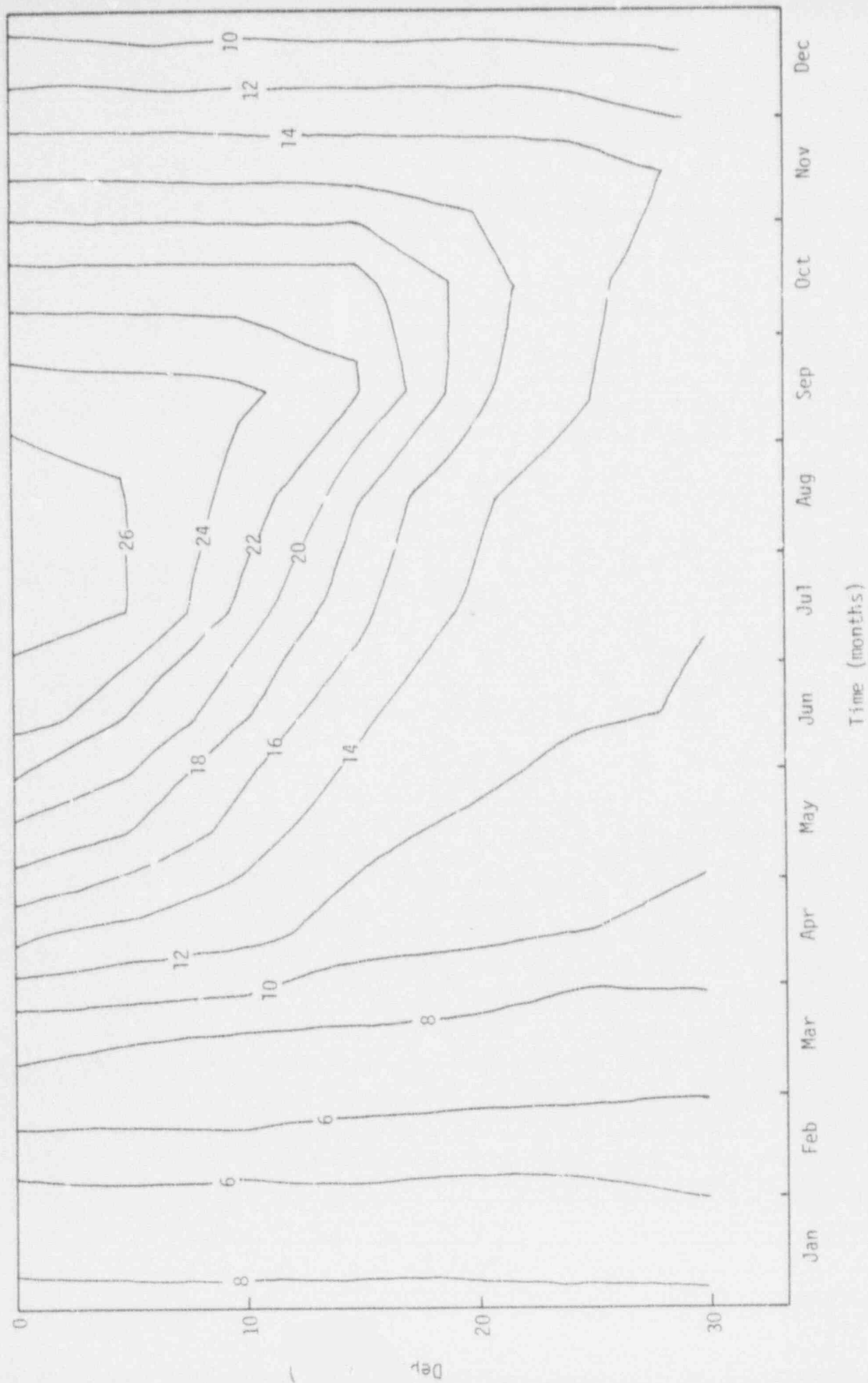


Figure 2.2. Mean temperature isopleths ($^{\circ}\text{C}$) for data measured from 1975 through 1979 at Location 2.0, Lake Norman, NC.

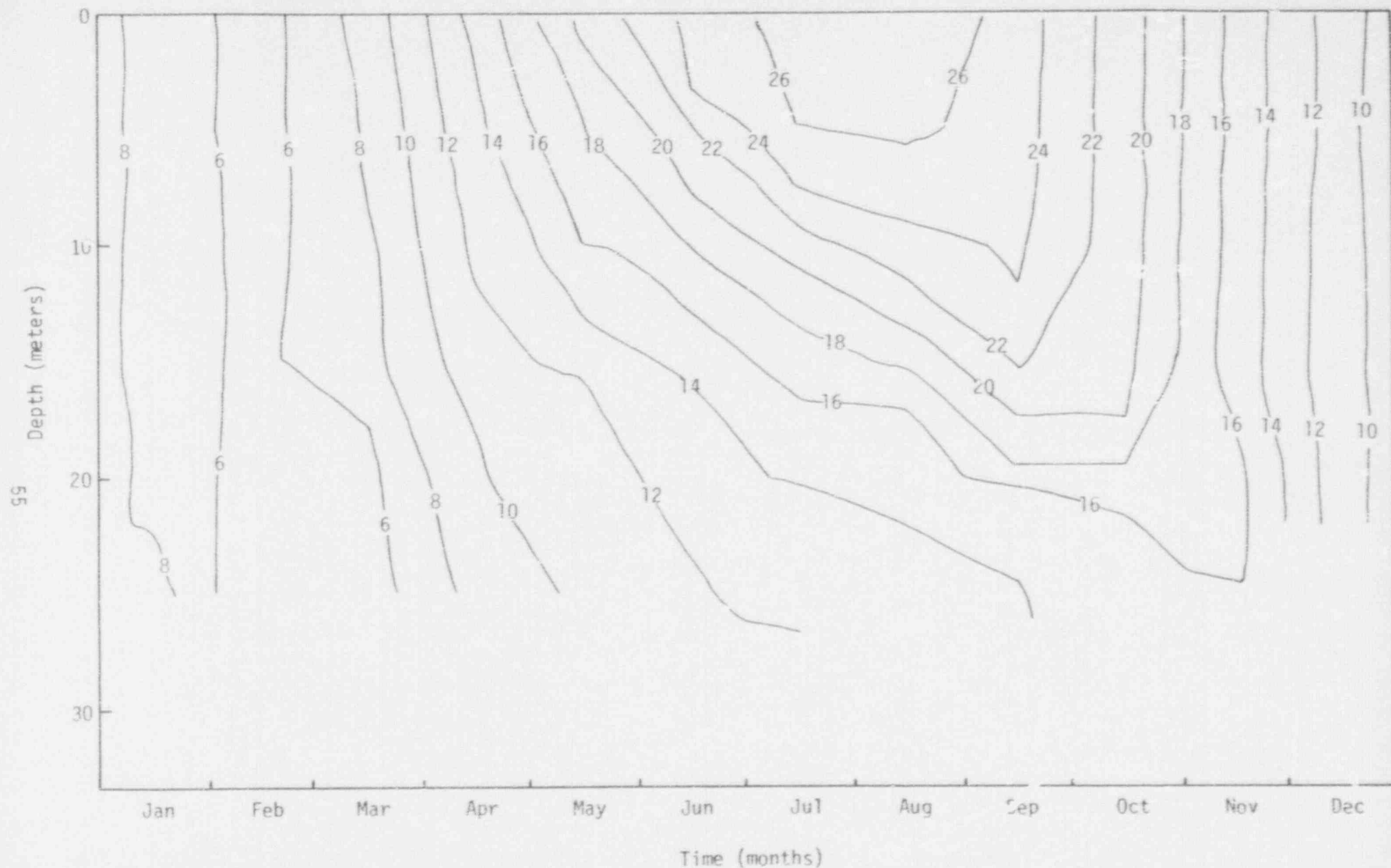


Figure 2-3. Mean temperature isopleths (°C) for data measured from 1975 through 1979 at location 3.0, Lake Norman, NC.

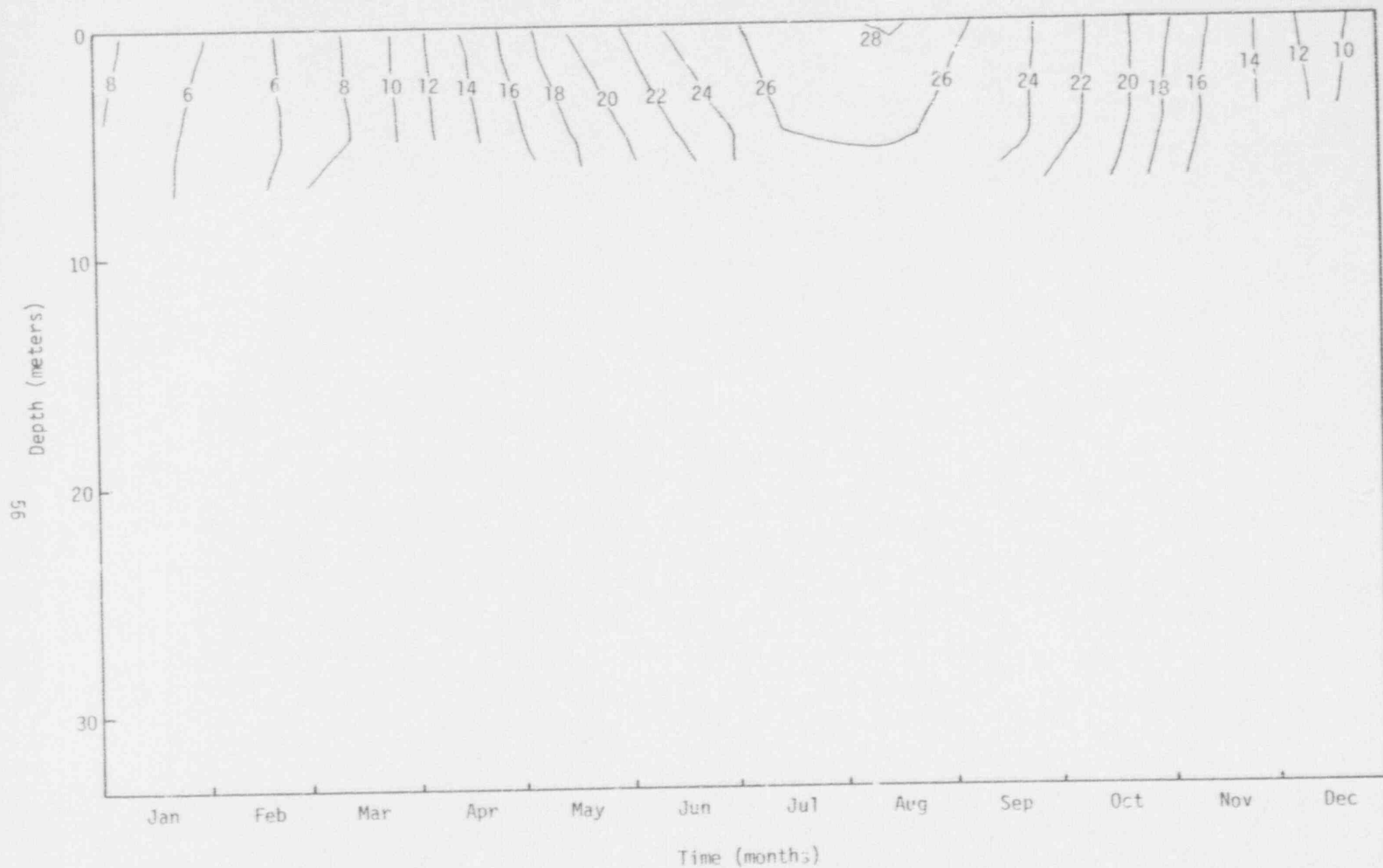


Figure 2-4. Mean temperature isopleths ($^{\circ}\text{C}$) for data measured from 1975 through 1979 at Location 4.0, Lake Norman, NC.

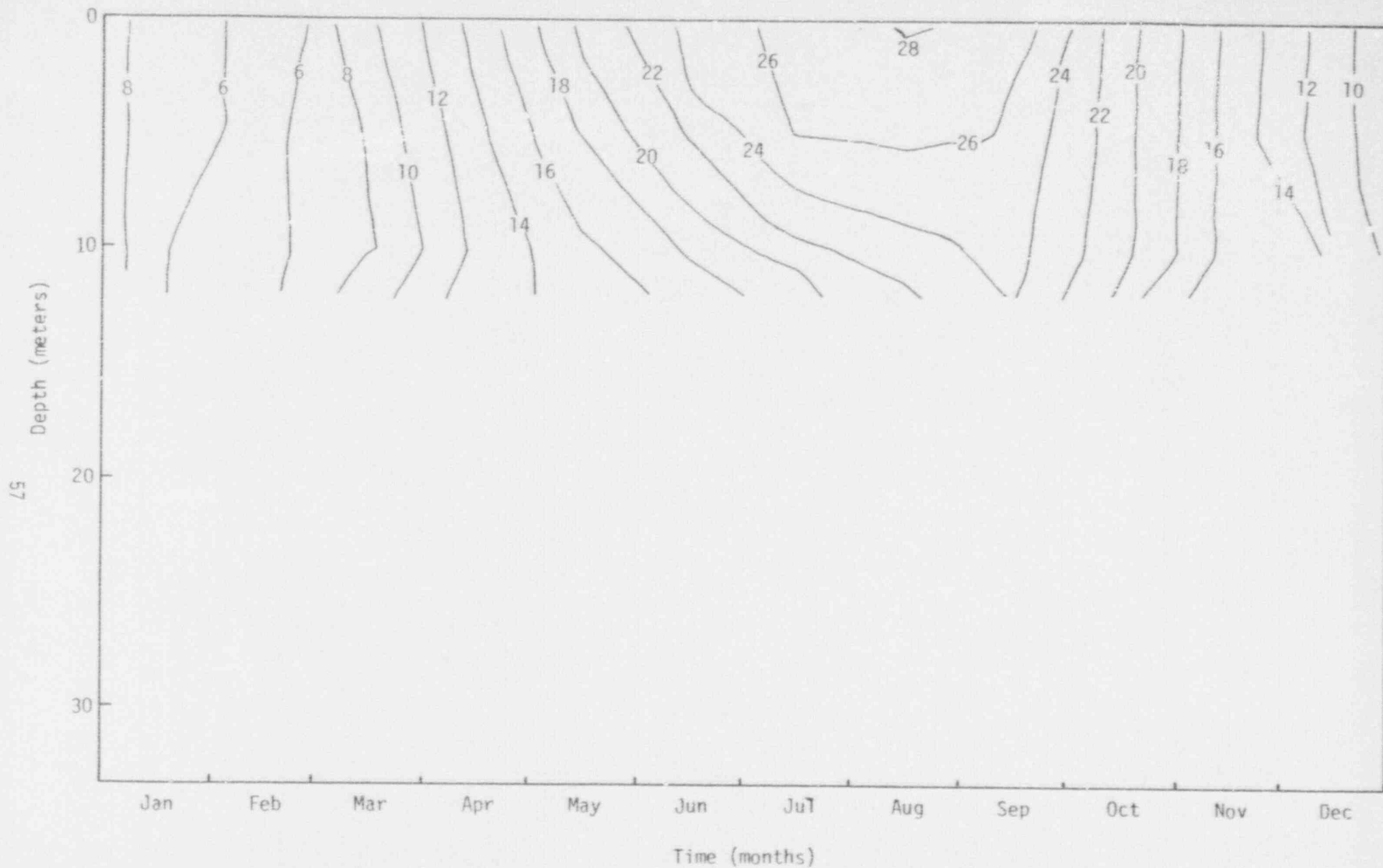


Figure 2-5. Mean temperature isopleths ($^{\circ}\text{C}$) for data measured from 1975 through 1979 at Location 4.5, Lake Norman, NC.

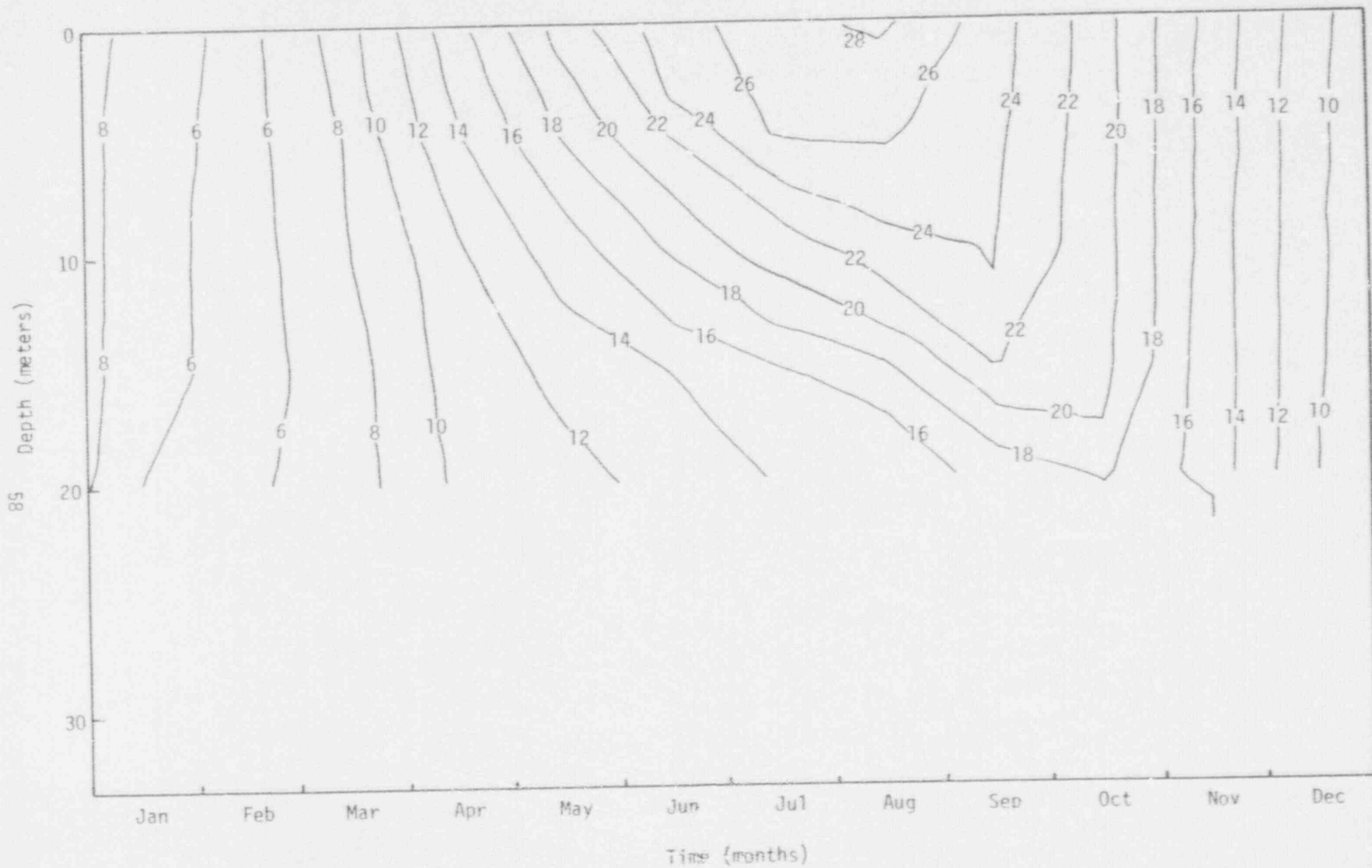


Figure 2-6. Mean temperature isopleths ($^{\circ}\text{C}$) for data measured from 1975 through 1979 at Location 5.0, Lake Norman, NC.

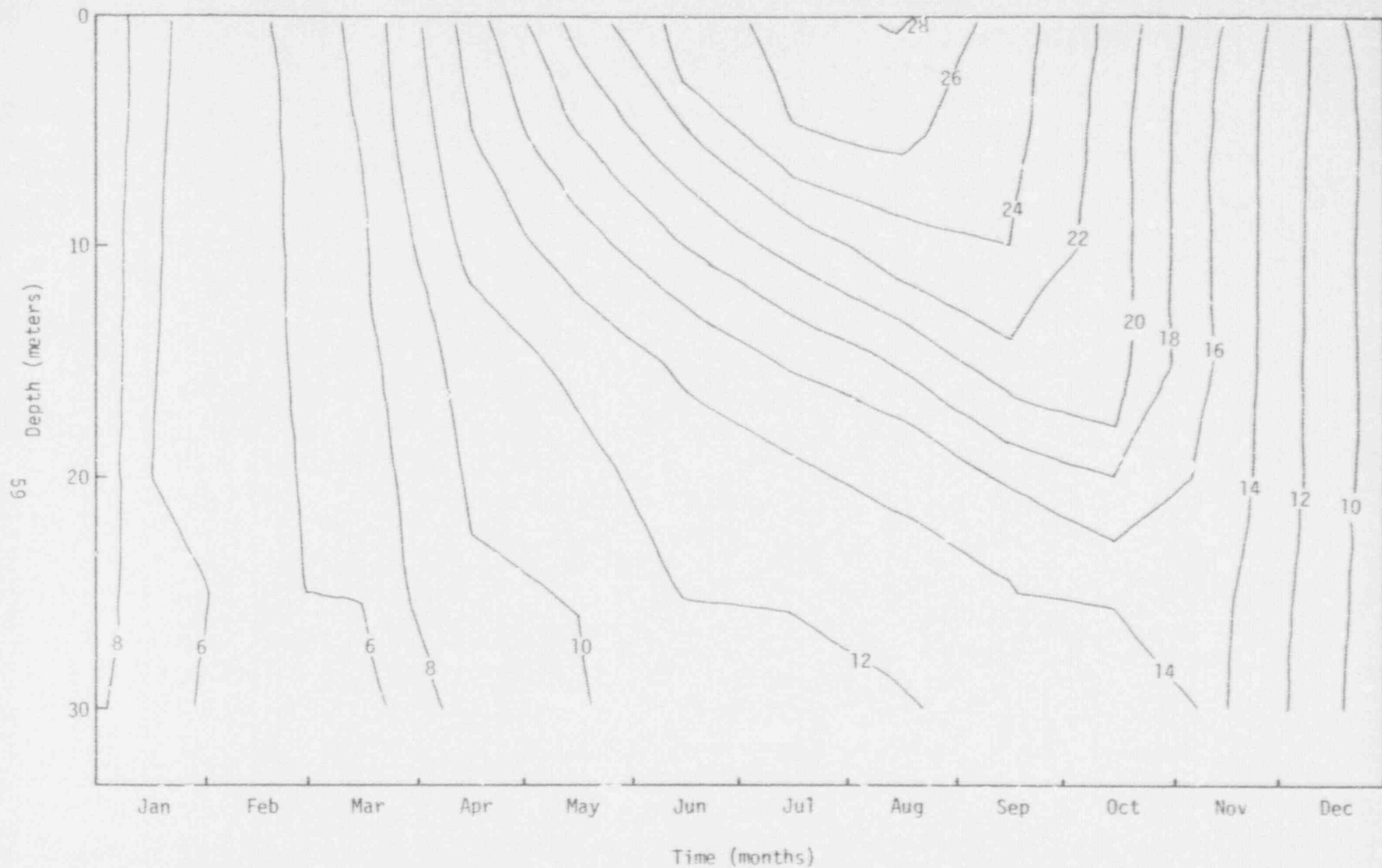


Figure 2-7. Mean temperature isopleths ($^{\circ}\text{C}$) for data measured from 1975 through 1979 at Location 8.0, Lake Norman, NC.

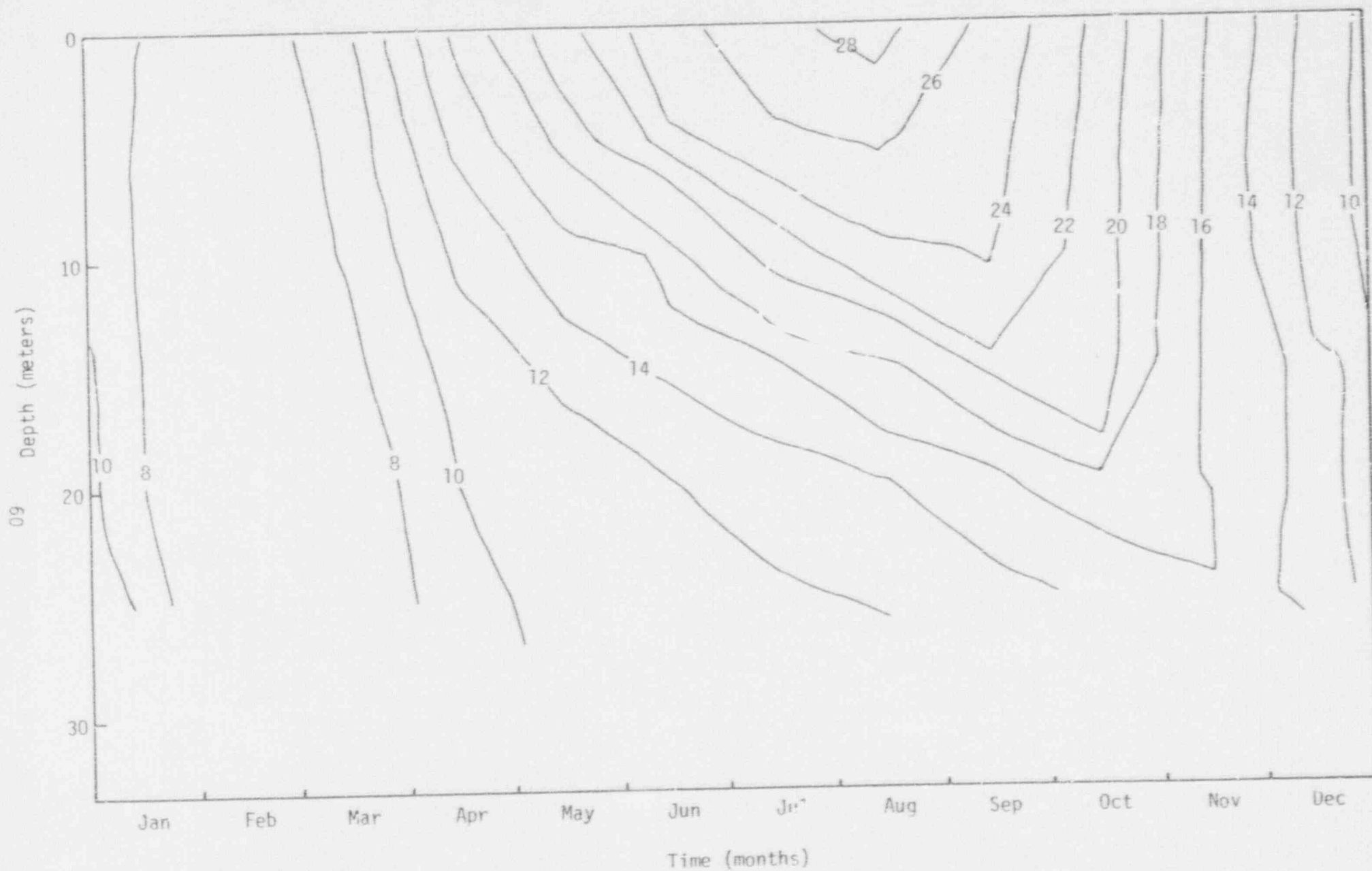


Figure 2-8. Mean temperature isopleths (°C) for data measured from 1975 through 1979 at Location 11.0, Lake Norman, NC.

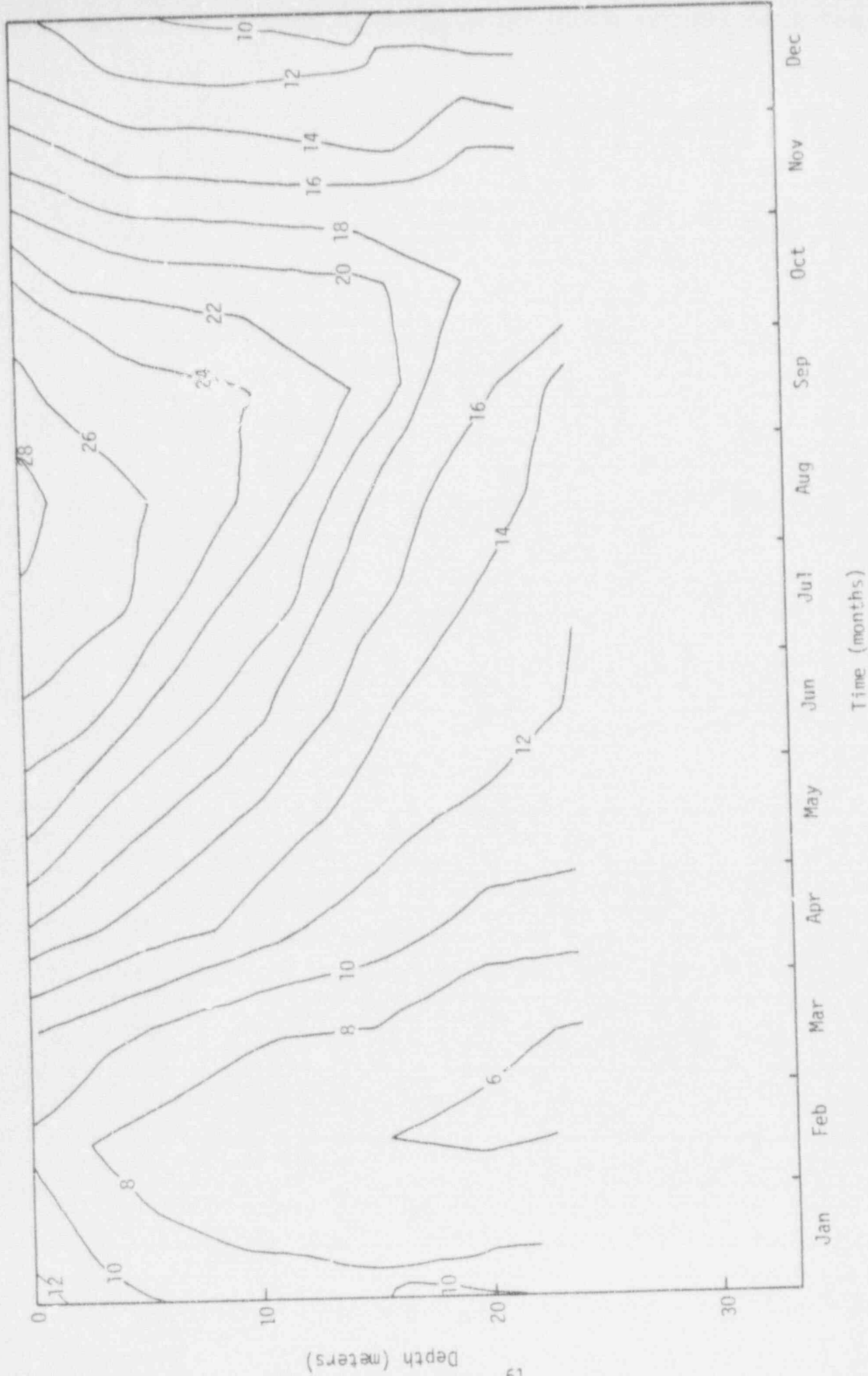


Figure 2-9. Mean temperature isopleths ($^{\circ}\text{C}$) for data measured from 1975 through 1979 at Location 13.0, Lake Norman, NC.

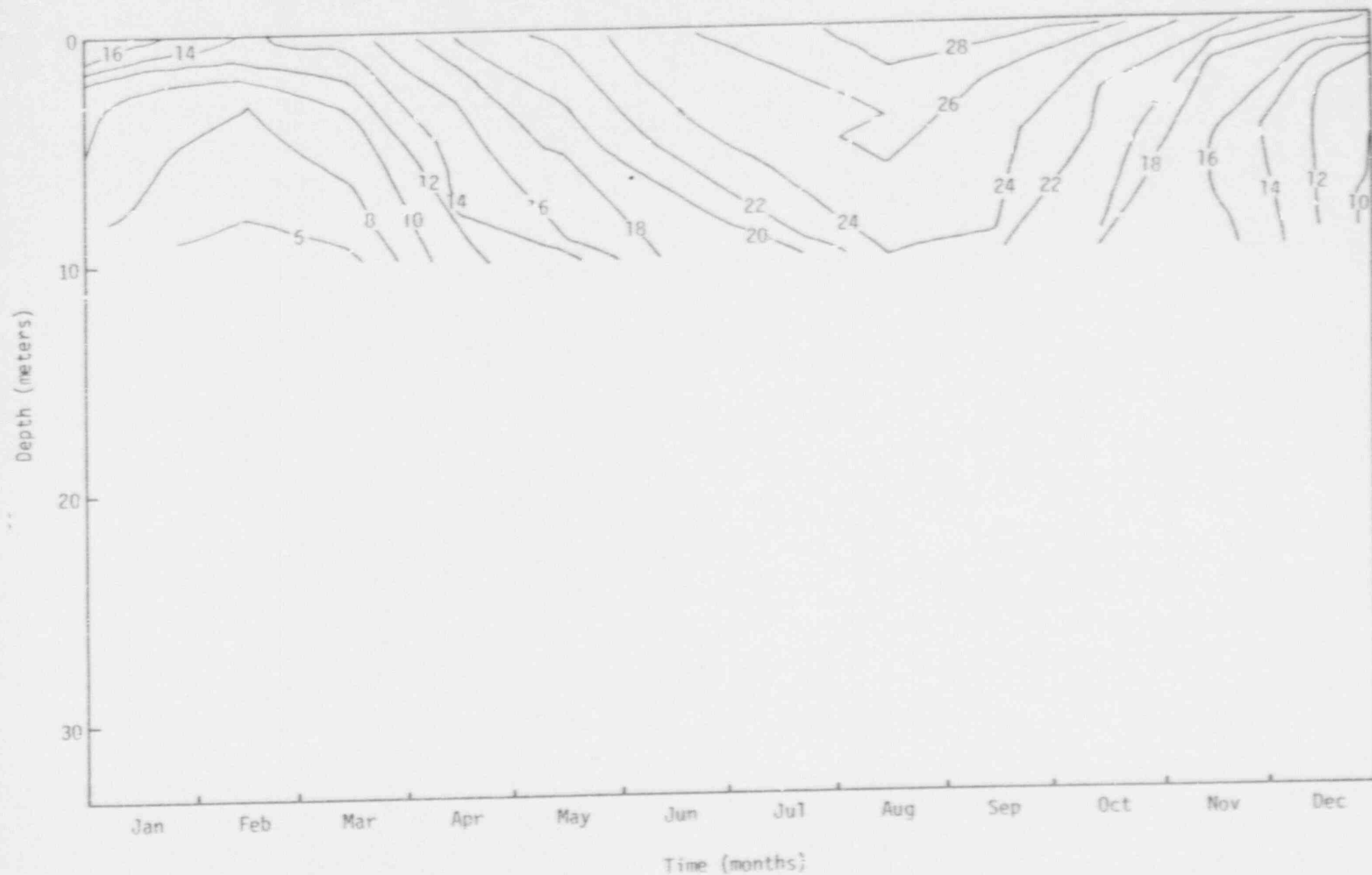


Figure 2-10. Mean temperature isopleths ($^{\circ}\text{C}$) for data measured from 1975 through 1979 at Location 14.0, Lake Norman, NC.

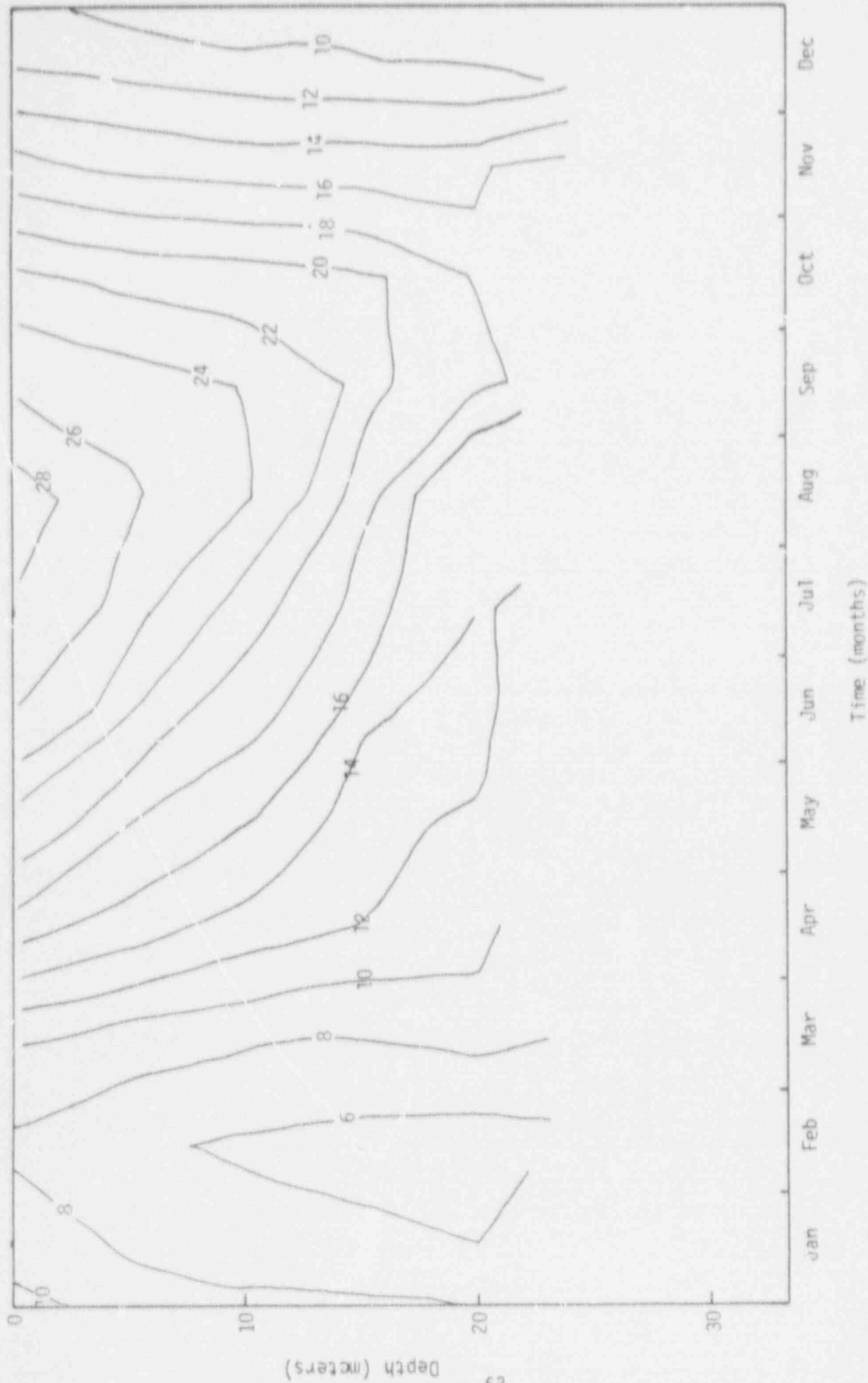


Figure 2-11. Mean temperature isopleths ($^{\circ}\text{C}$) for data measured from 1975 through 1979 at Location 15.0, Lake Norman, NC.

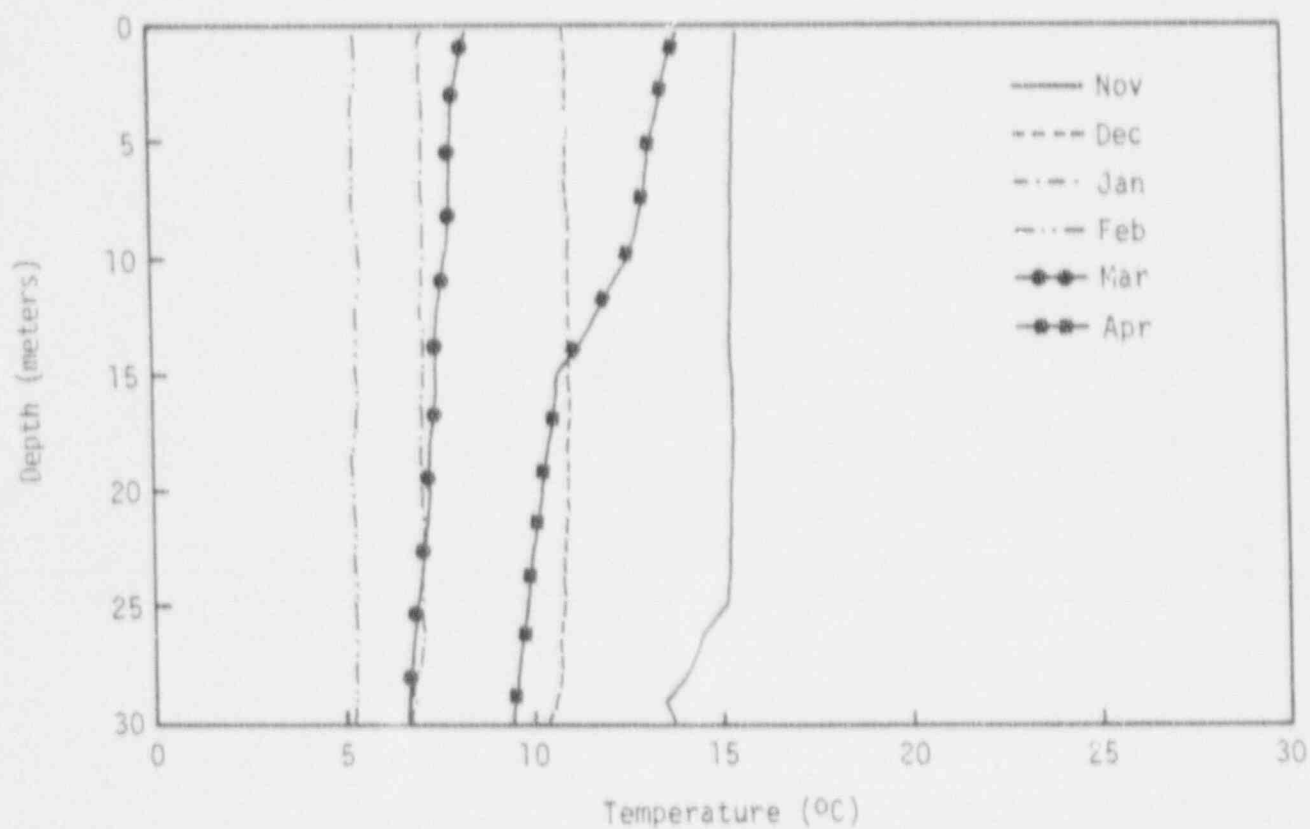
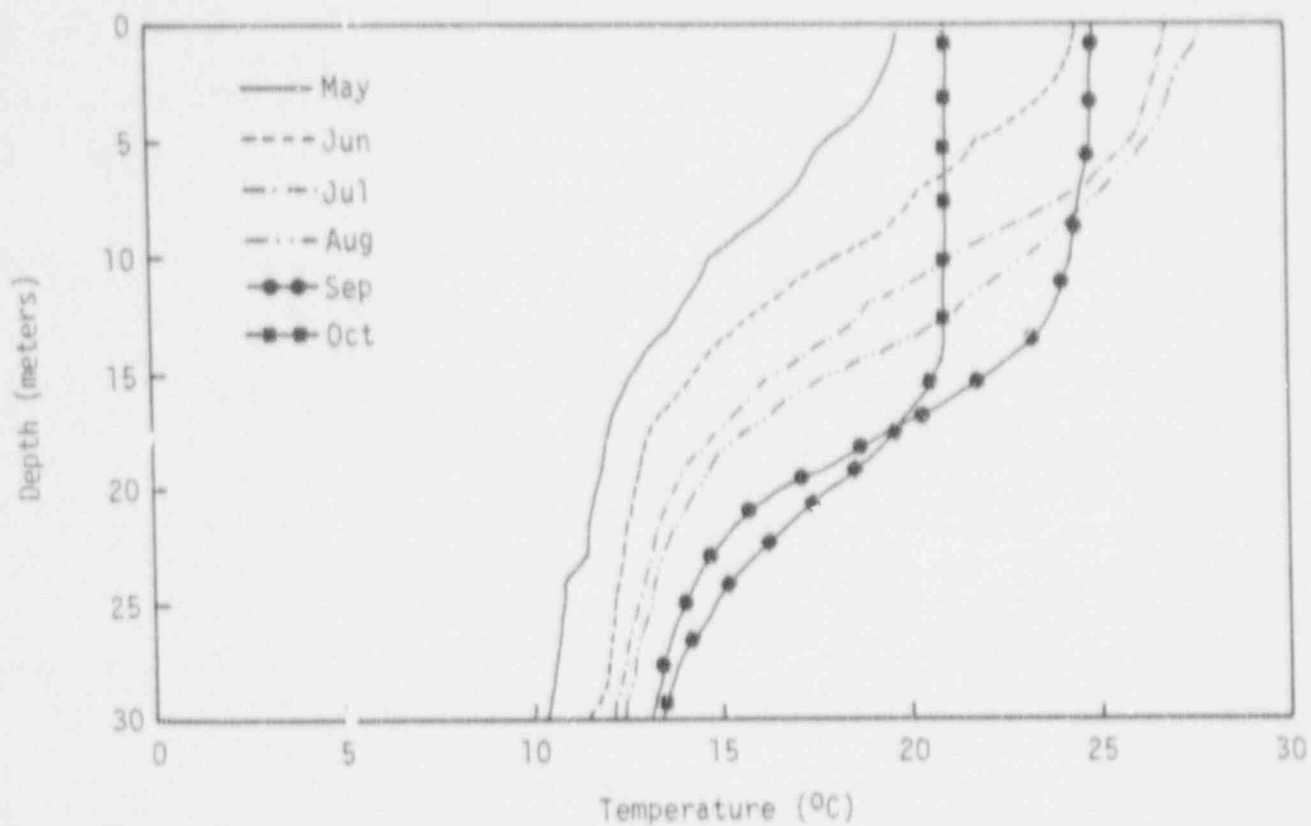


Figure 2-12. Mean monthly temperature profiles for data measured from 1975 through 1979 at Location 2.0, Lake Norman, NC.

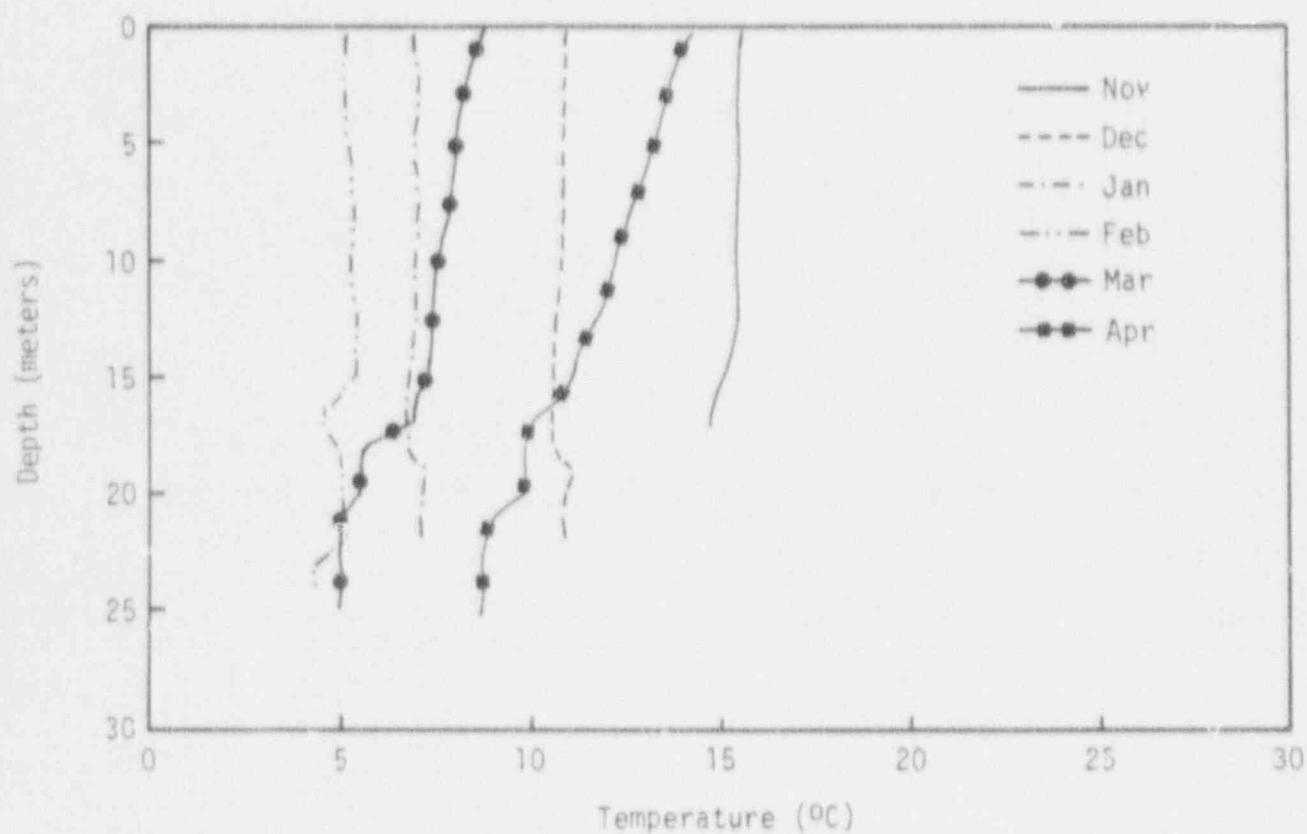
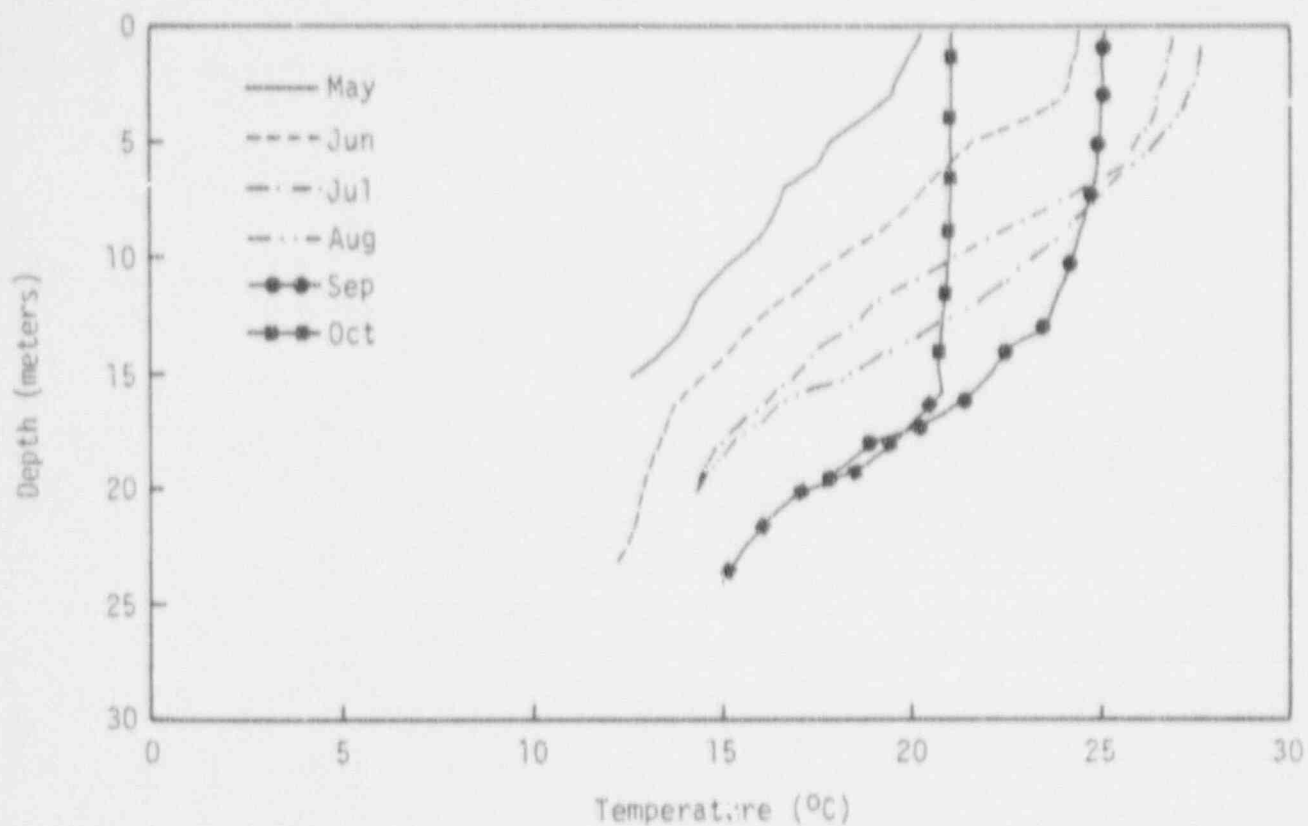


Figure 2-13. Mean monthly temperature profiles for data measured from 1975 through 1979 at Location 3.0, Lake Norman, NC.

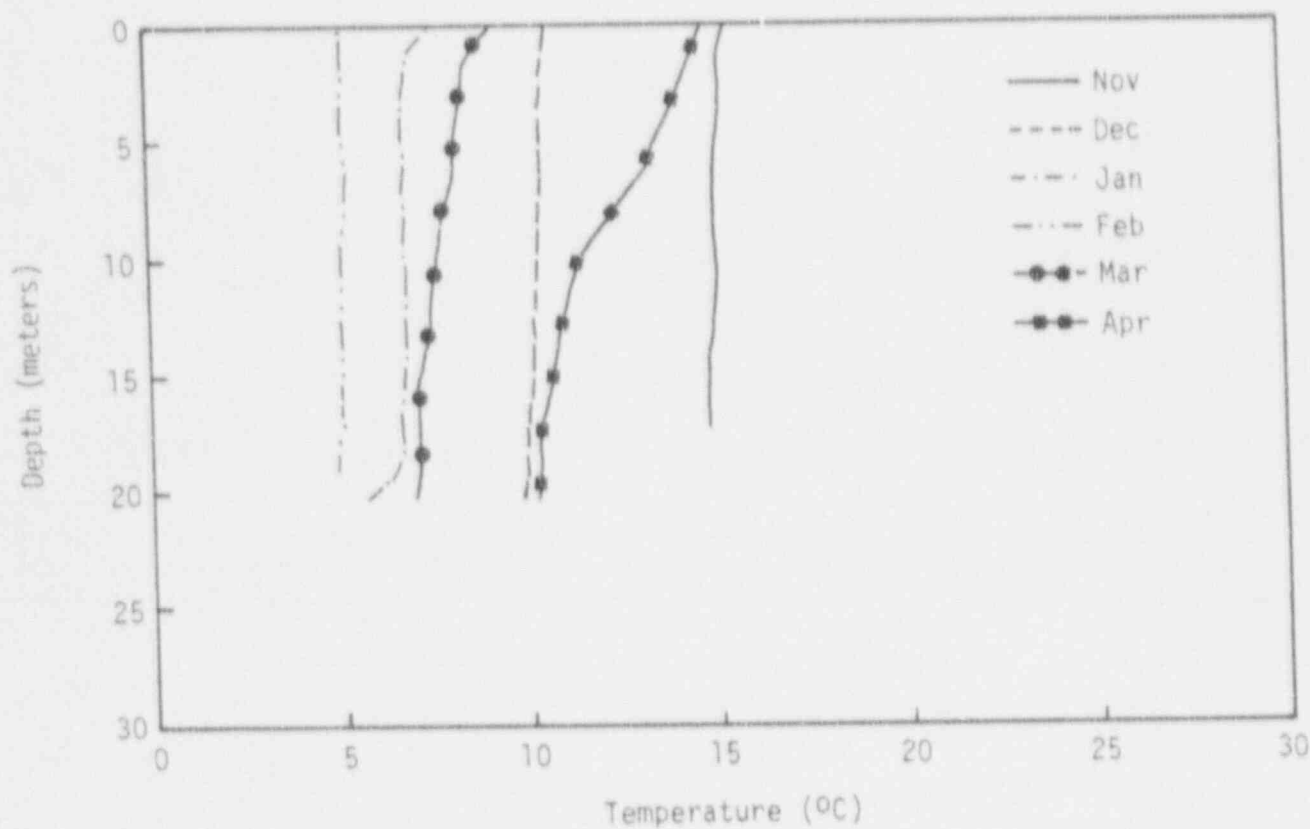
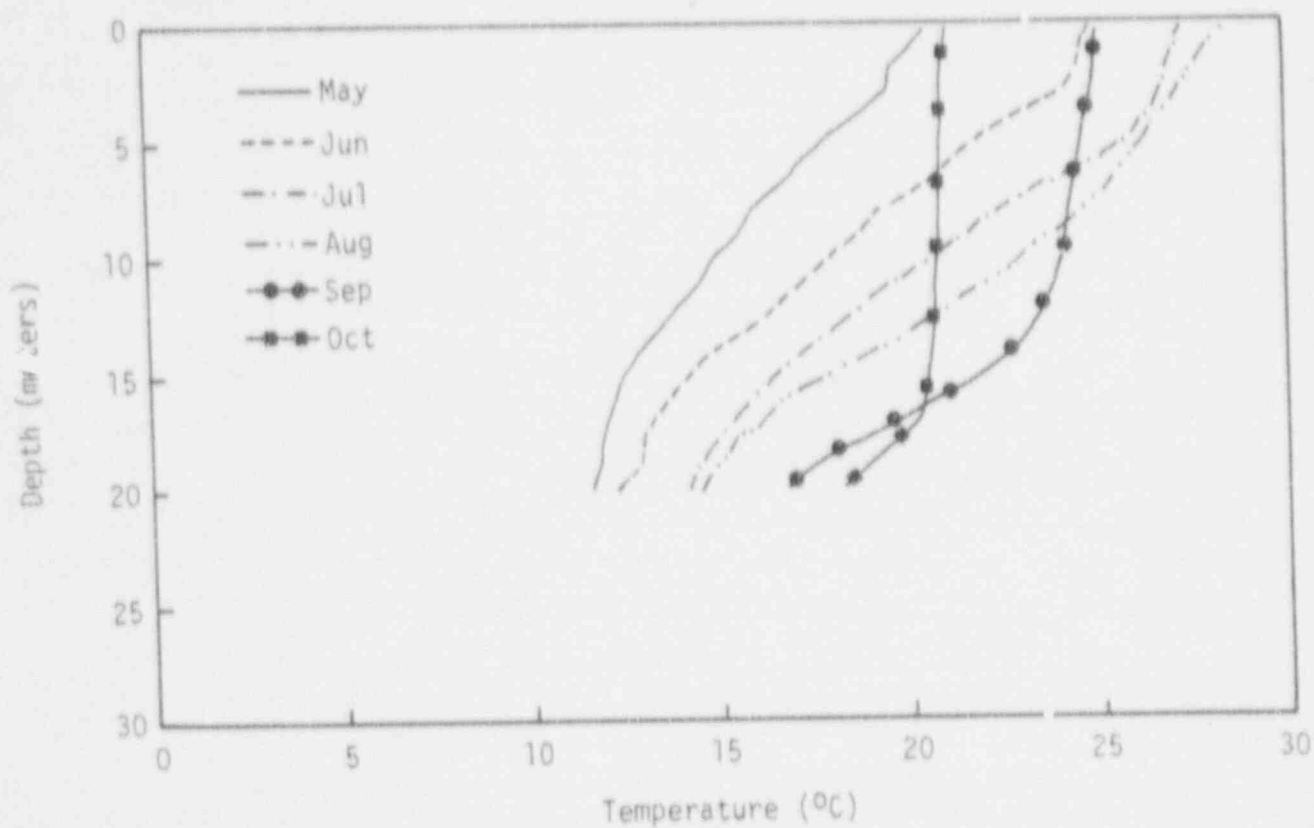


Figure 2-14. Mean monthly temperature profiles for data measured from 1975 through 1979 at Location 5.0, Lake Norman, NC.

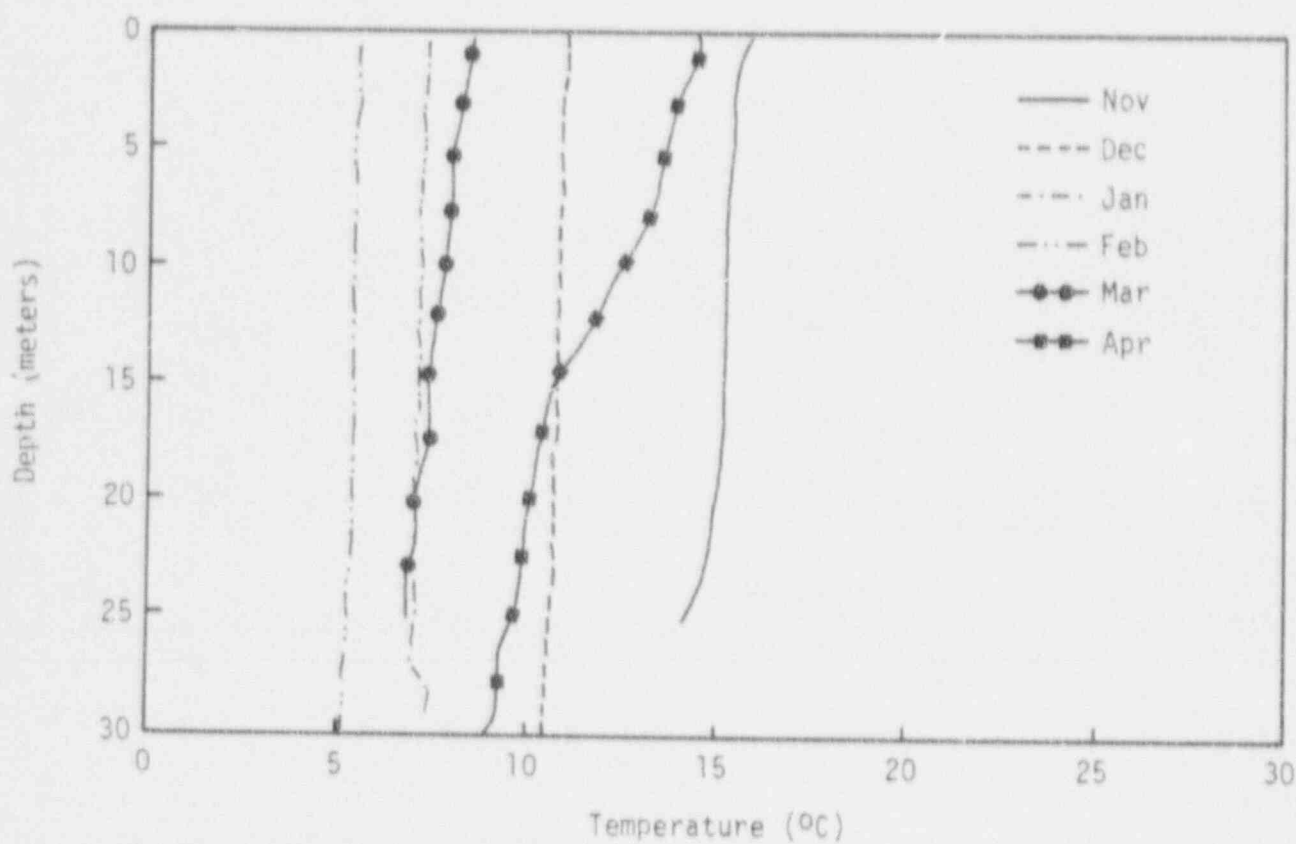
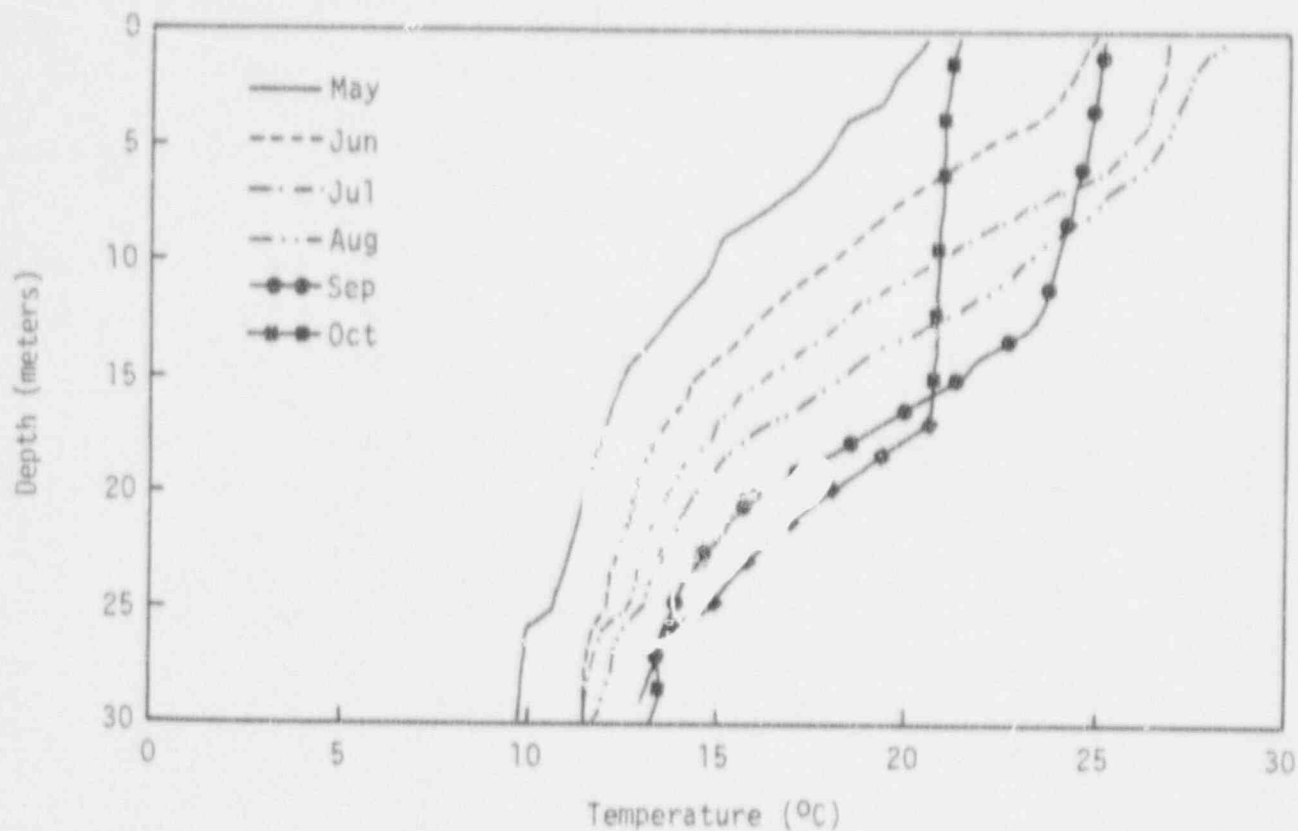


Figure 2-15. Mean monthly temperature profiles for data measured from 1975 through 1979 at Location 8.0, Lake Norman, NC.

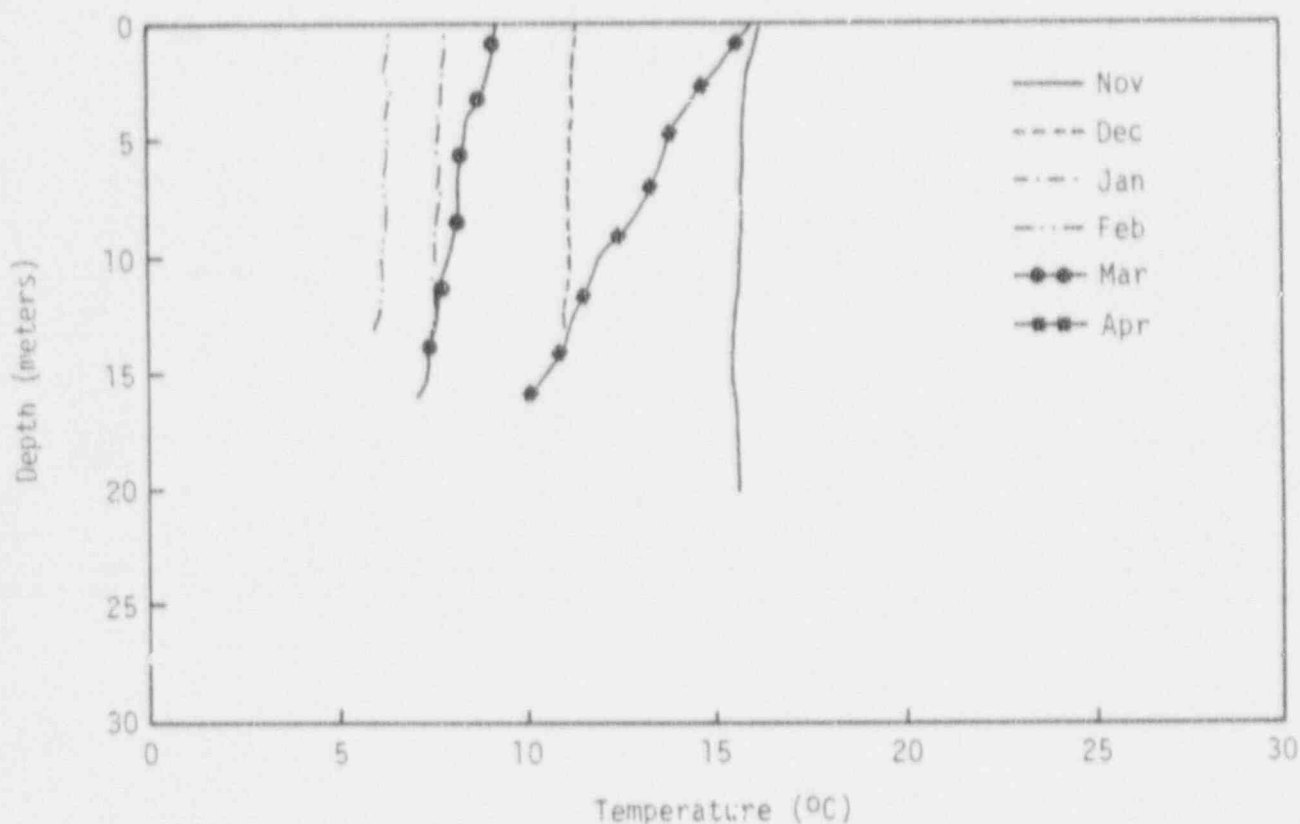
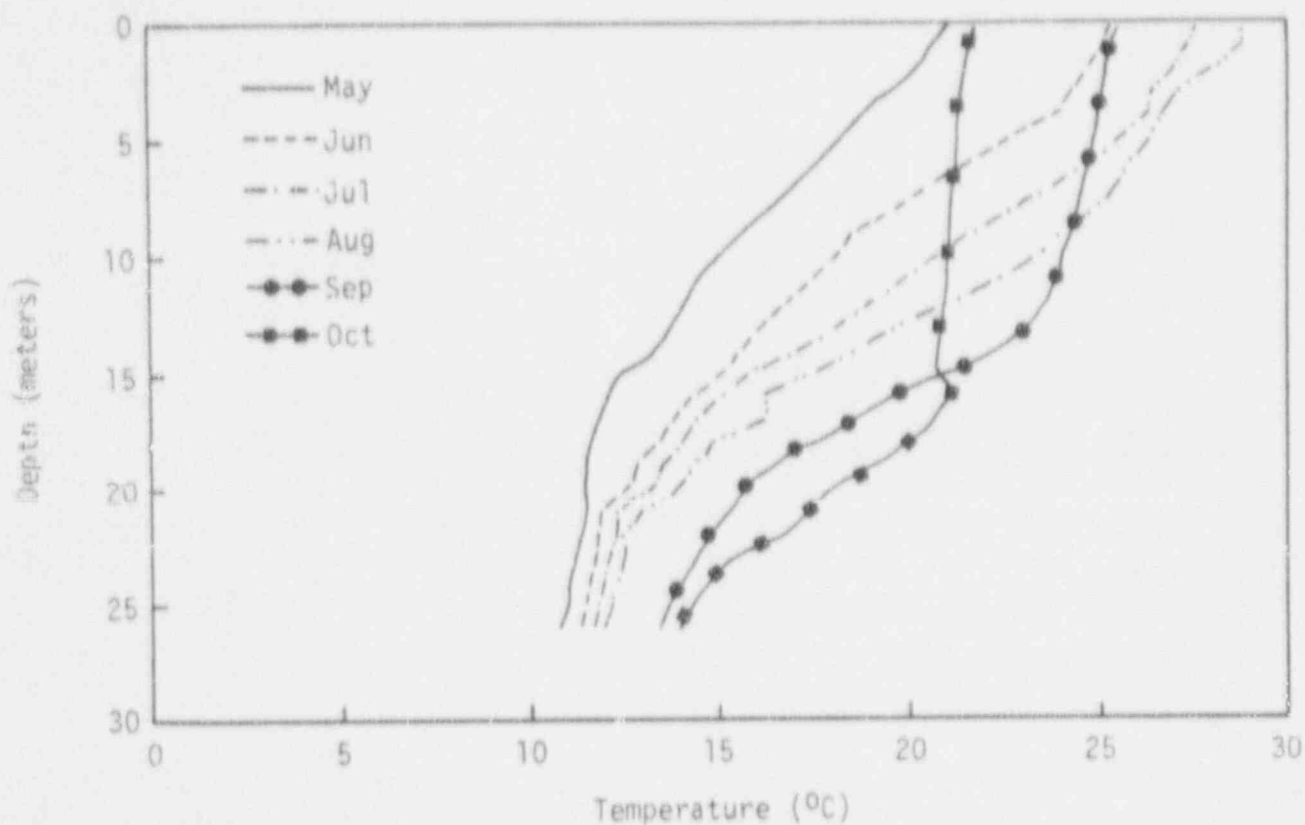


Figure 2-16. Mean monthly temperature profiles for data measured from 1975 through 1979 at Location 11.0, Lake Norman, NC.

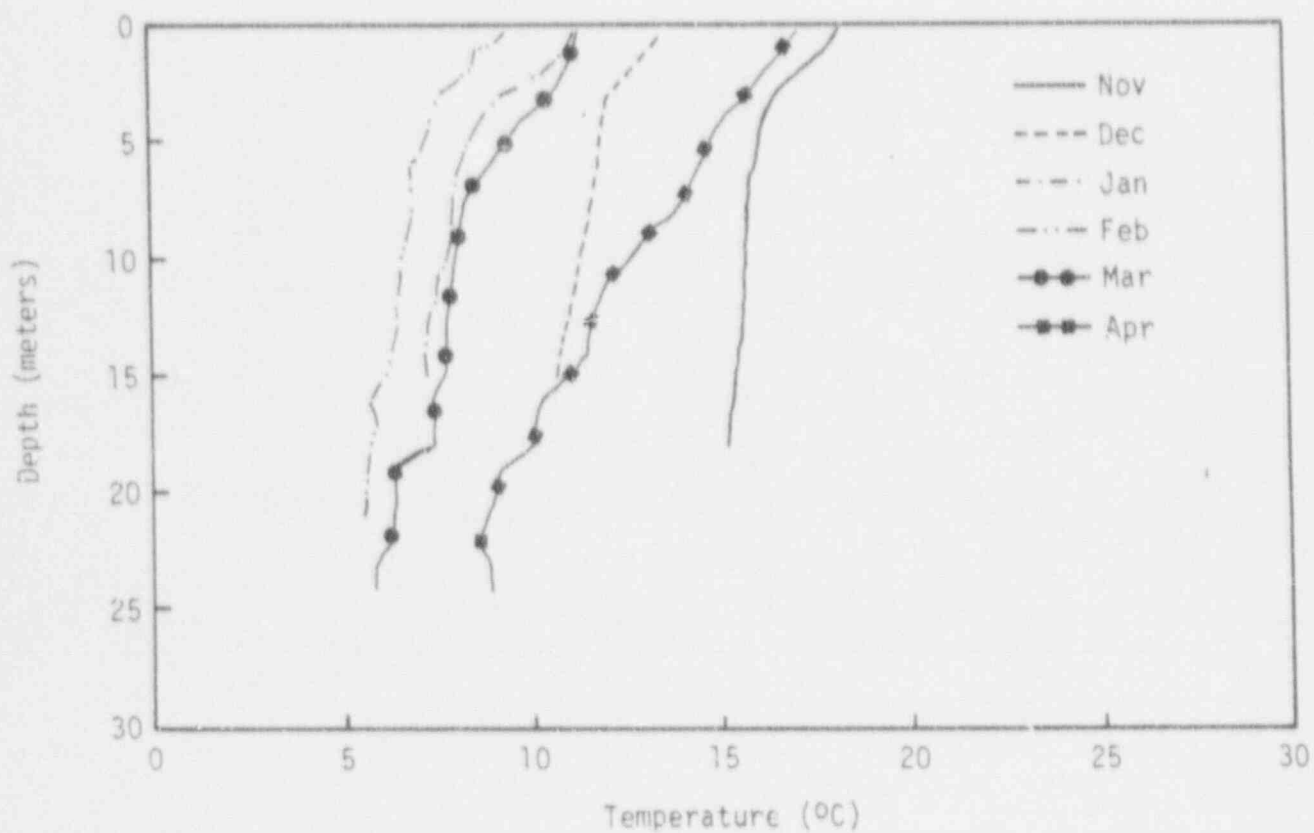
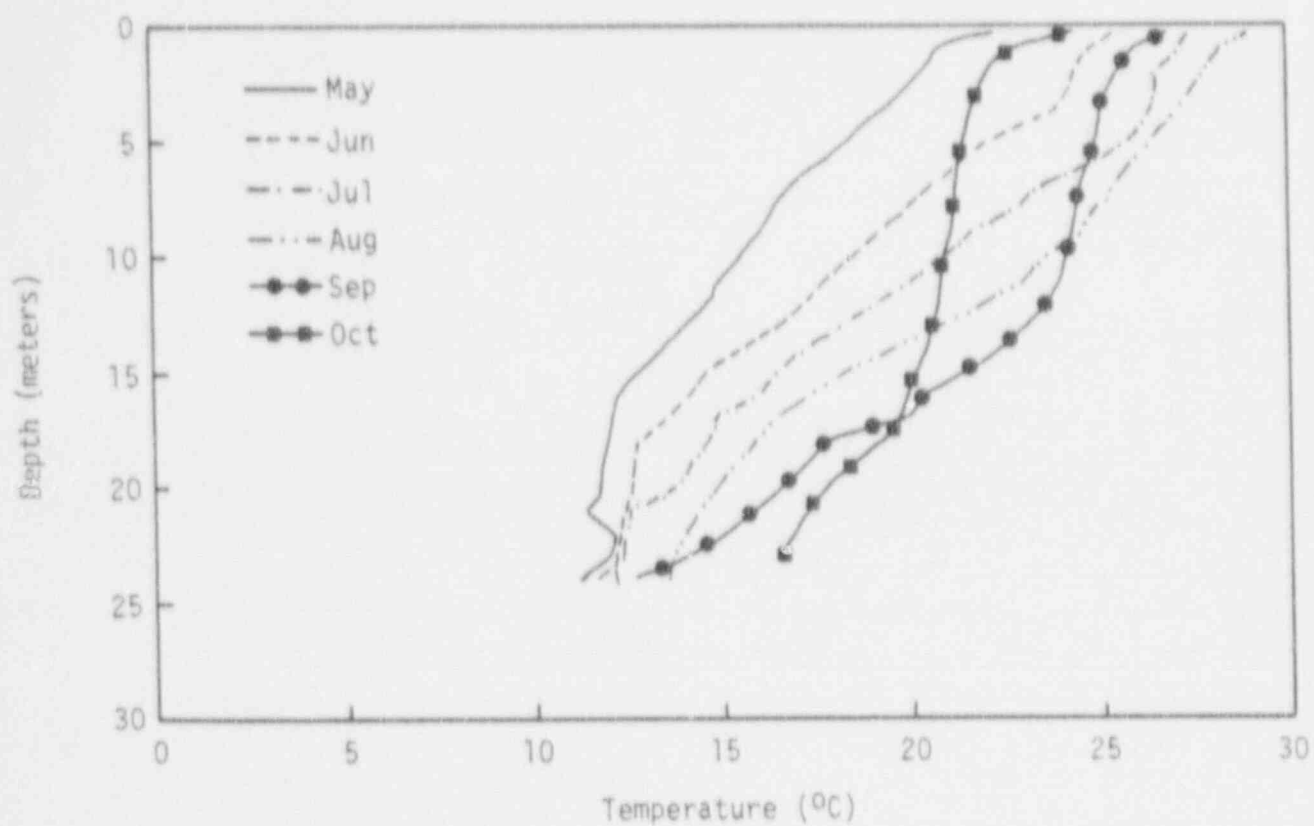


Figure 2-17. Mean monthly temperature profiles for data measured from 1975 through 1979 at Location 13.0, Lake Norman, NC.

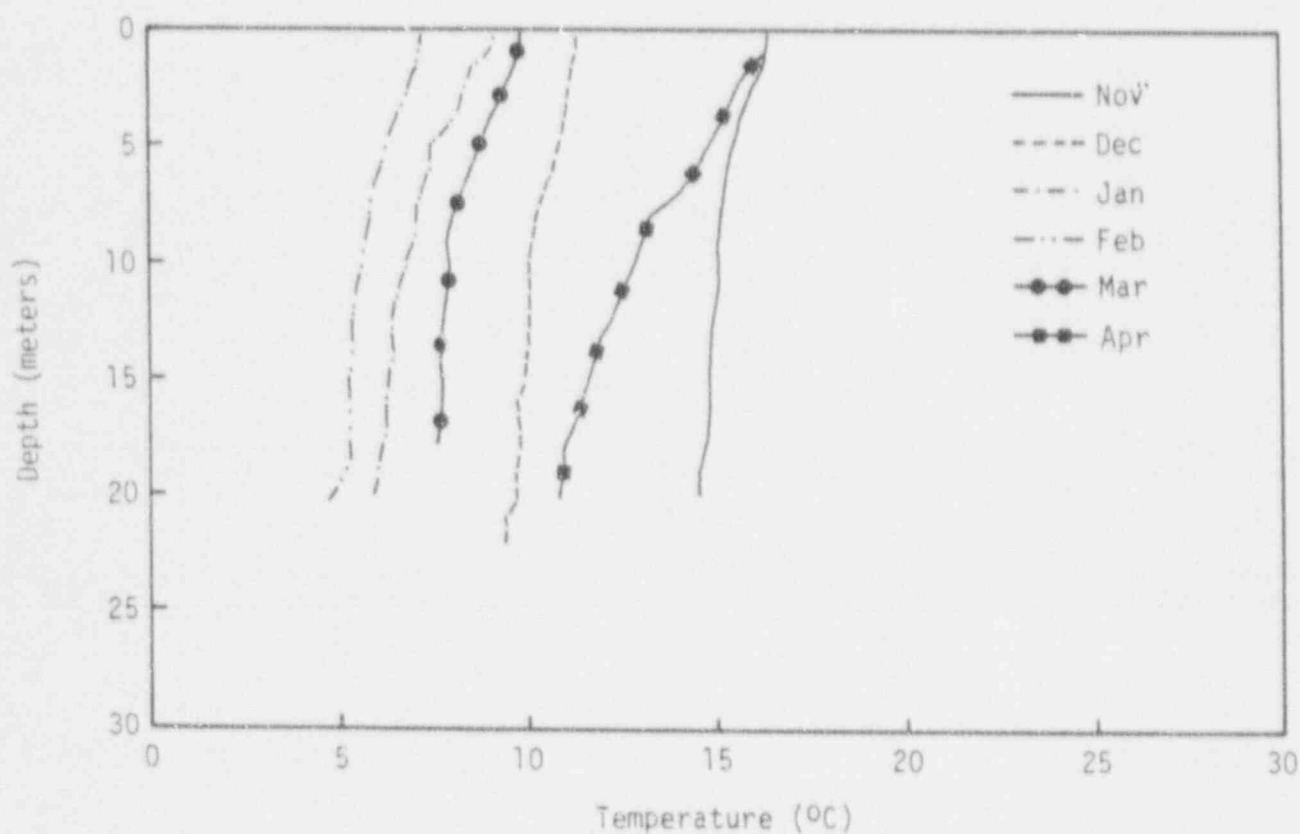
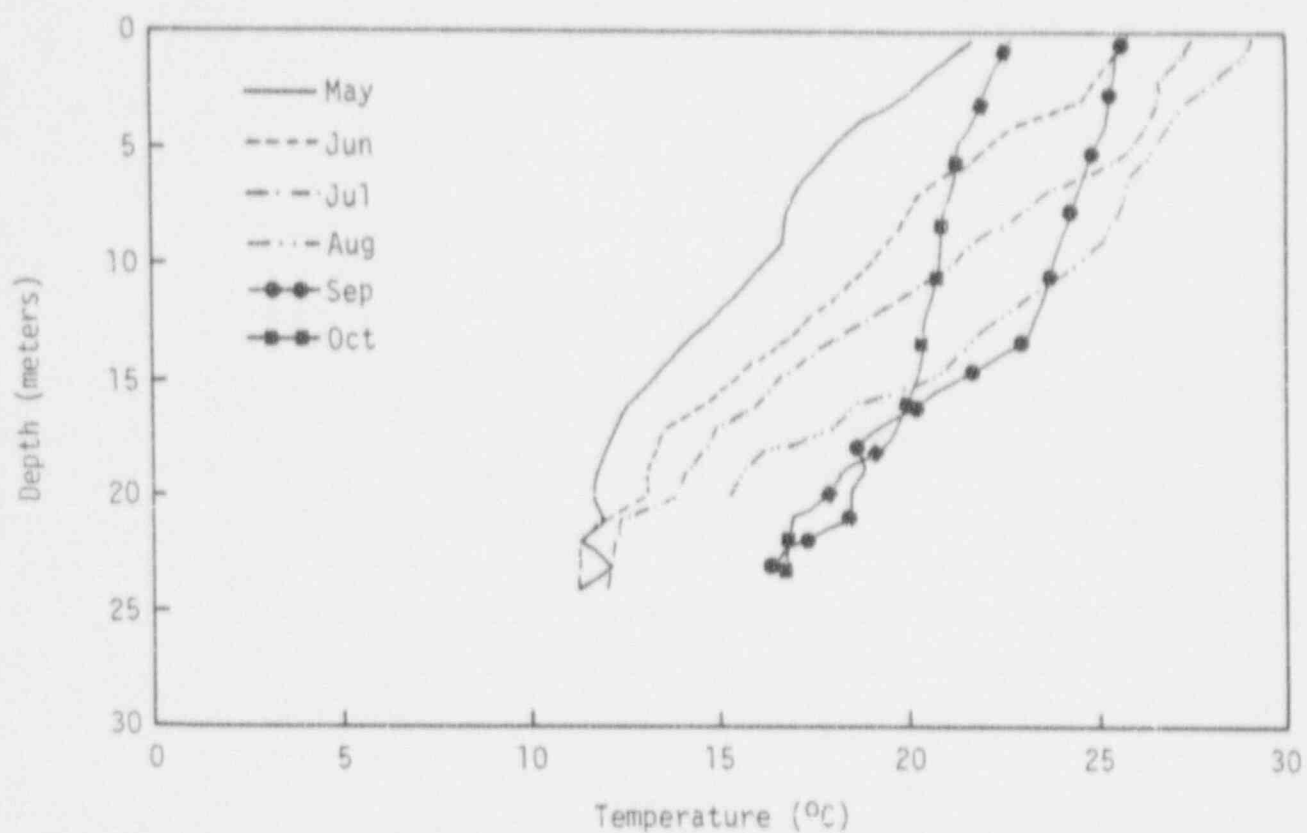


Figure 2-18. Mean monthly temperature profiles for data measured from 1975 through 1979 at Location 15.0, Lake Norman, NC.

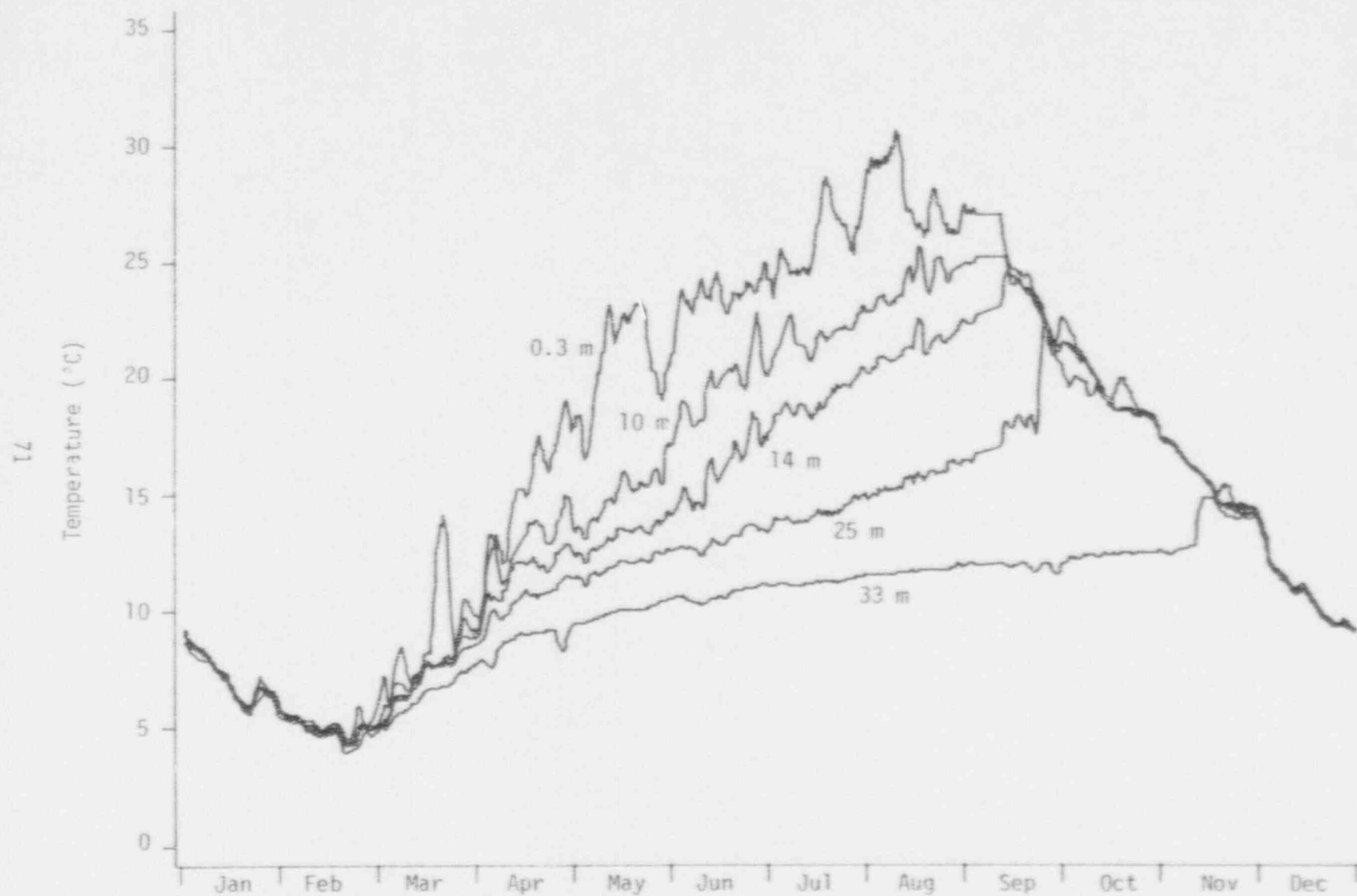


Figure 2-19. Temperatures measured at Location 1.7 by continuous monitors during 1979, Lake Norman, NC.

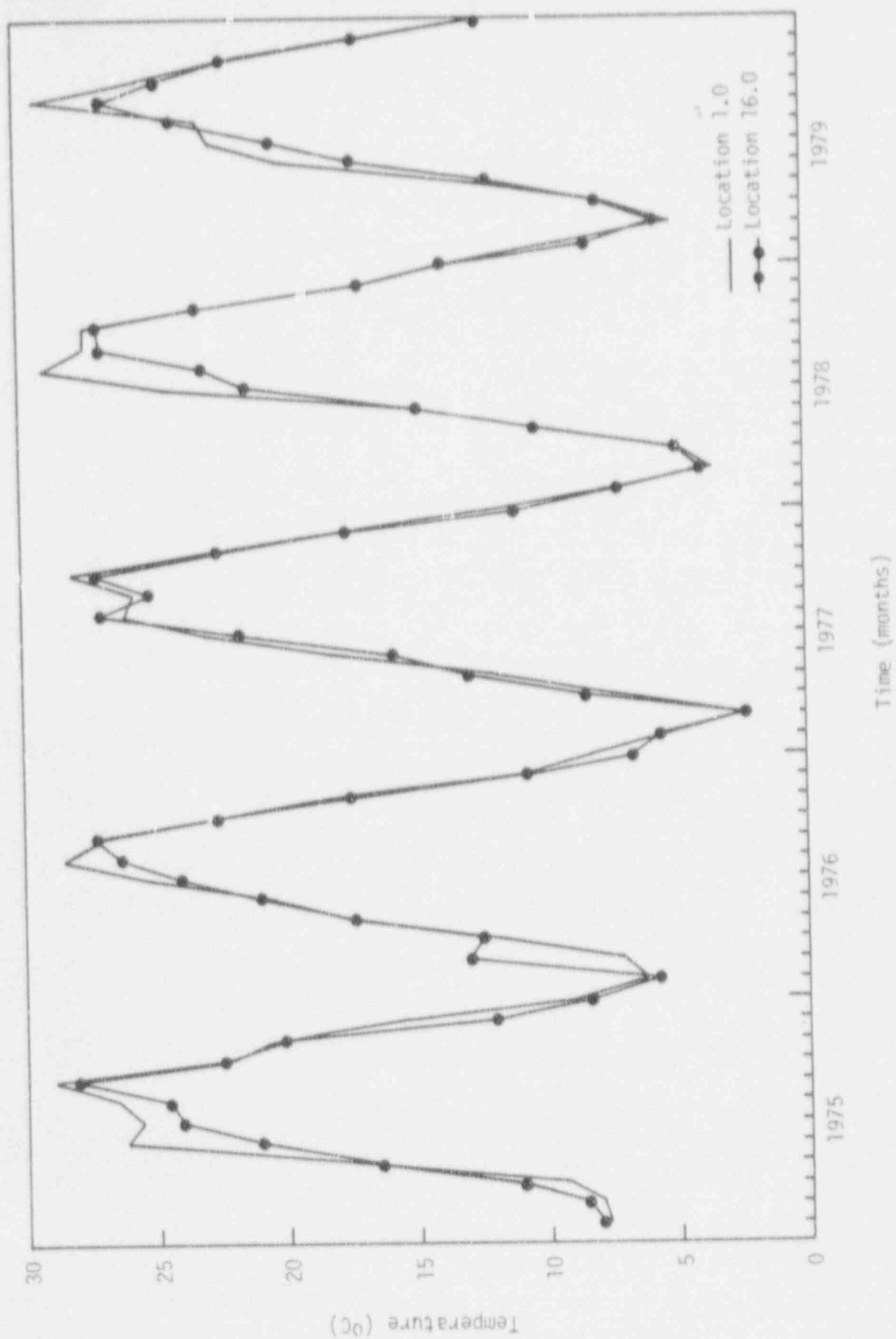


Figure 2-20. Surface temperatures measured at Locations 1.0 and 16.0 during monthly water temperature monitoring on Lake Norman.

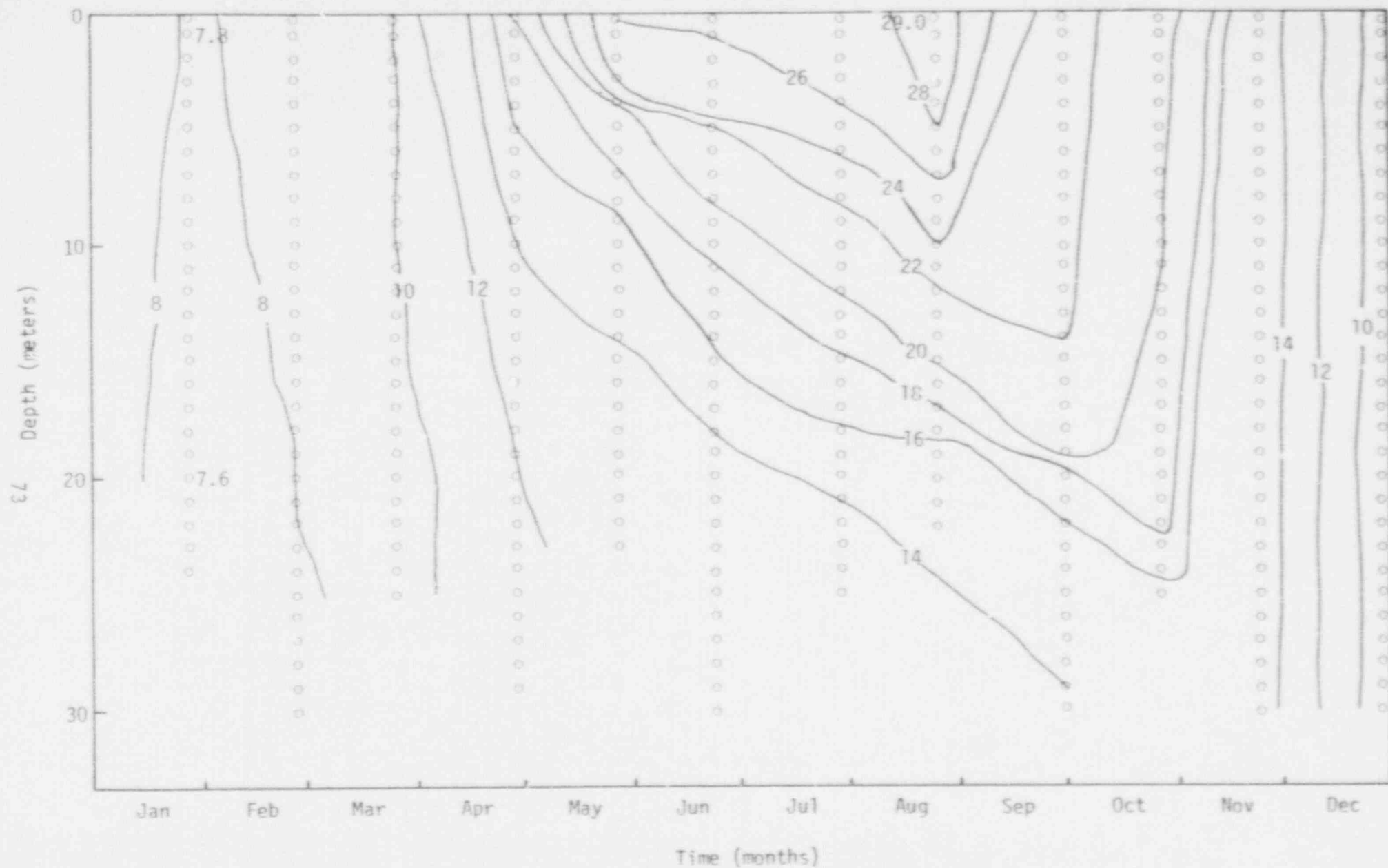


Figure 2-21. Temperature isopleths (°C) for Location 8.0 on Lake Norman during 1975.

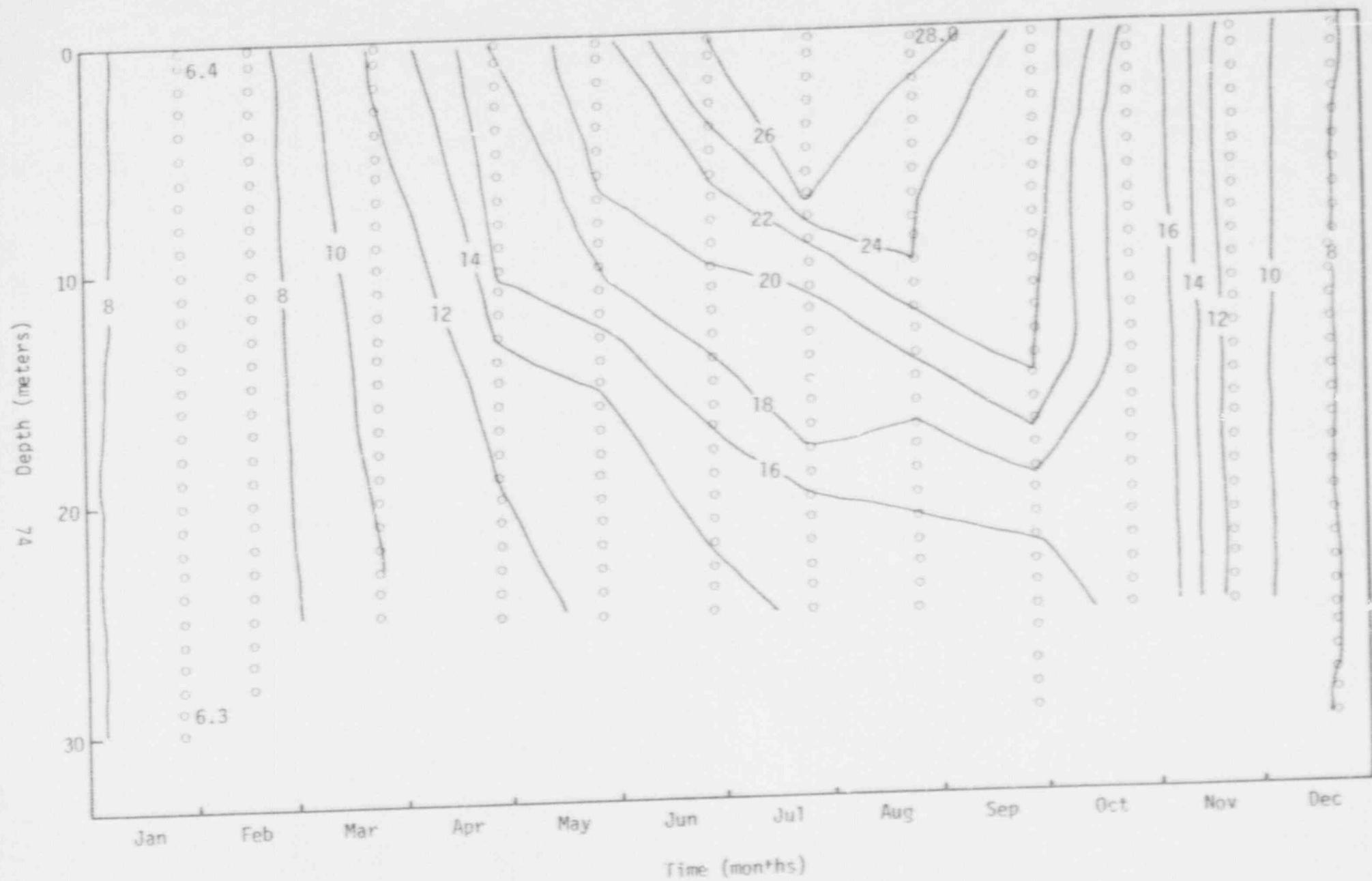


Figure 2-22. Temperature isopleths ($^{\circ}\text{C}$) for Location 8.0 on Lake Norman during 1976.

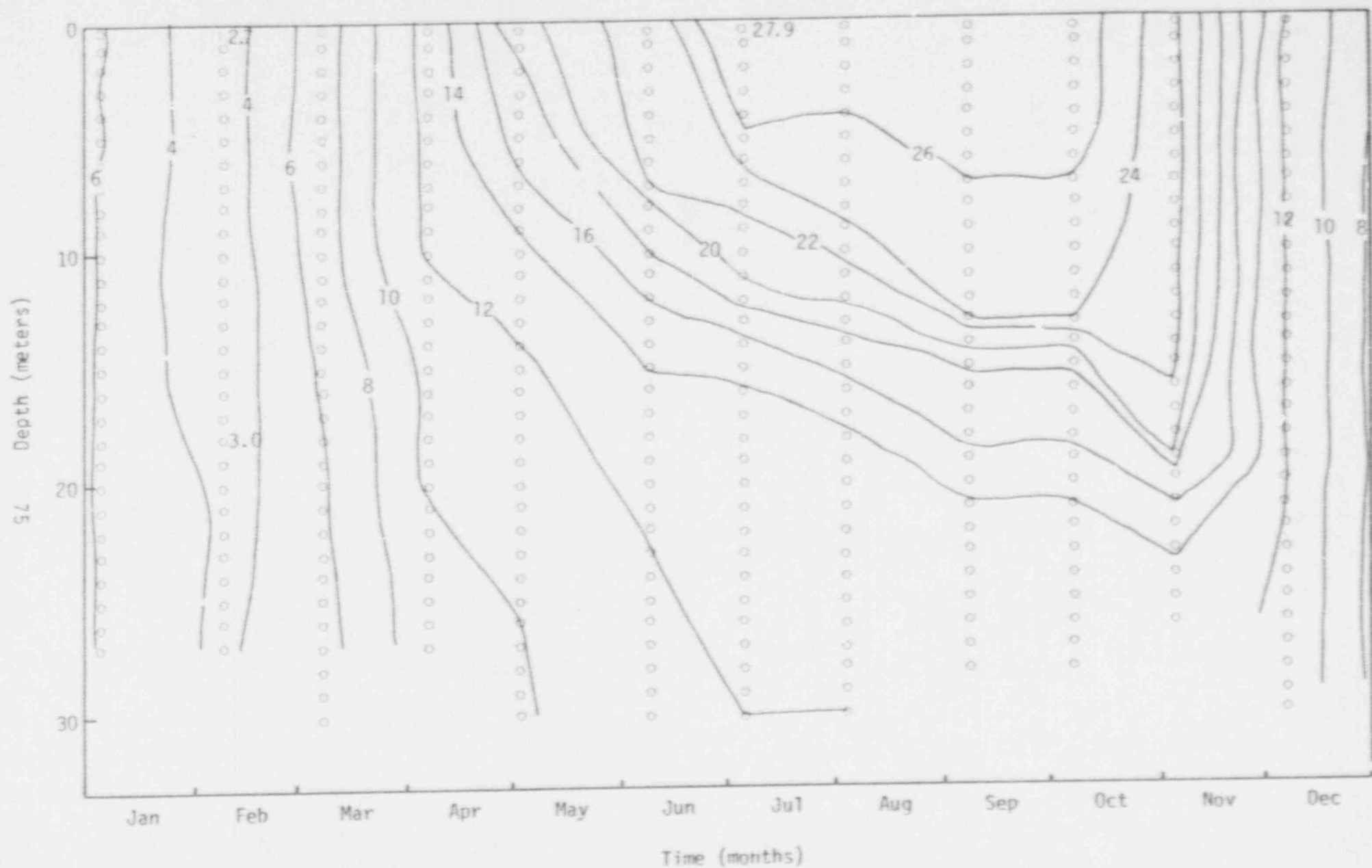


Figure 2-23. Temperature isopleths ($^{\circ}\text{C}$) for Location 8.0 on Lake Norman during 1977.

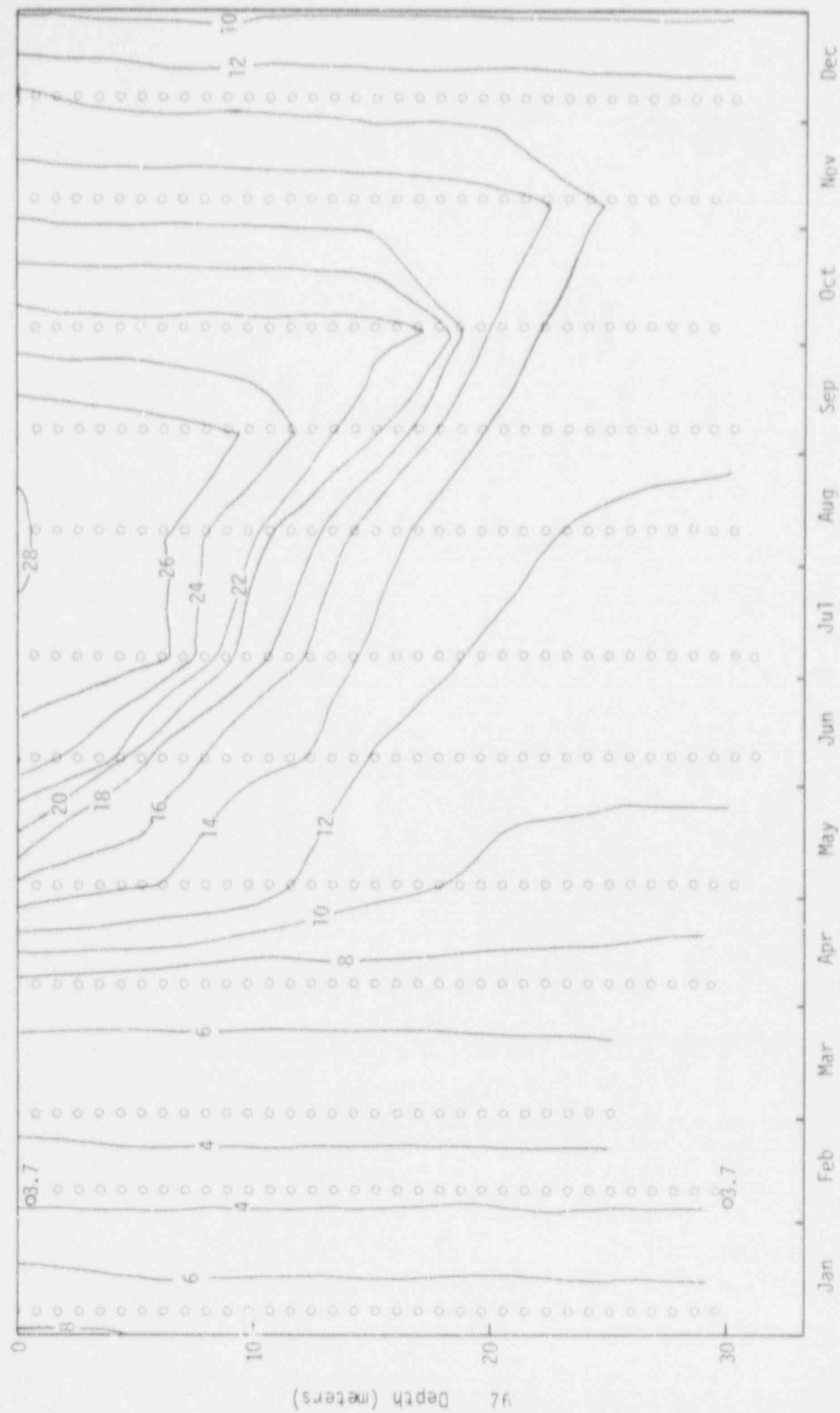


Figure 2-24. Temperature isopleths ($^{\circ}\text{C}$) for Location 8.0 on Lake Norman for 1978.

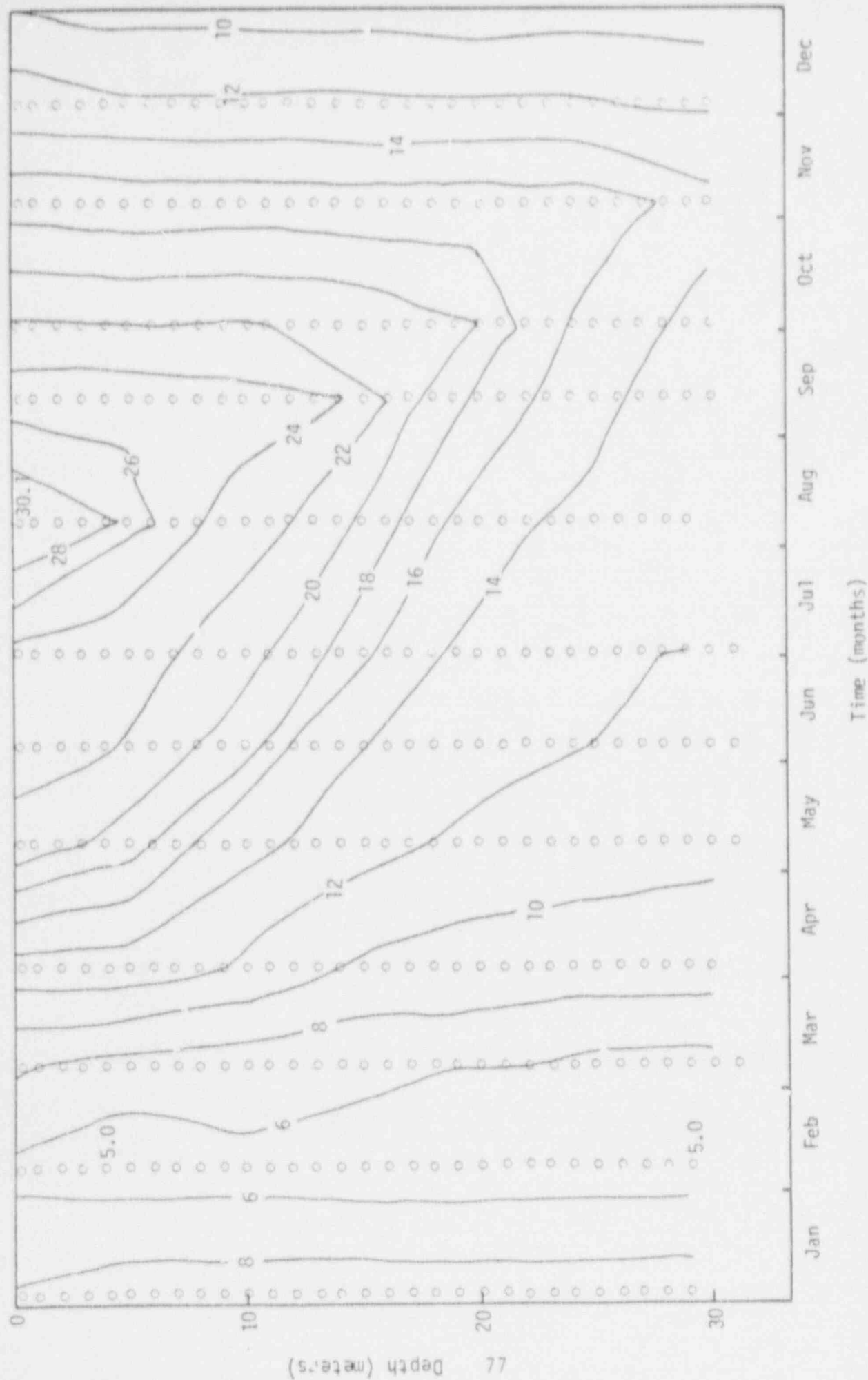


Figure 2-25. Temperature isopleths ($^{\circ}\text{C}$) for Location 8.0 on Lake Norman during 1979.



Figure 2-26. Mean temperatures measured at Location 1.7 by continuous monitors during February 1977 and 1978 (mean of twice daily values) on Lake Norman.

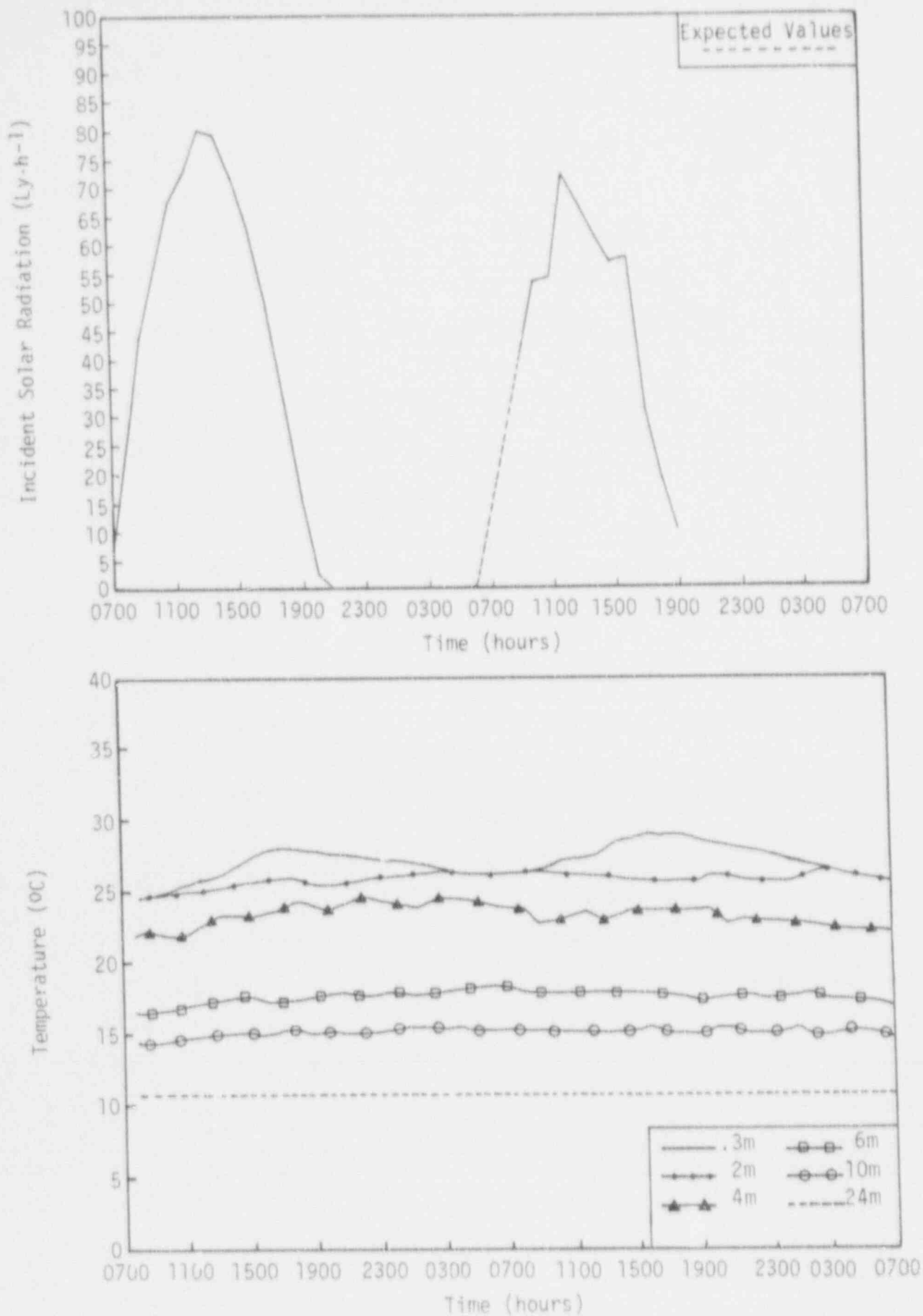


Figure 2-27. Incident solar radiation data (Eppley Model 8-48 Pyranometer) collected near the McGuire site and temperature variability at Location 5.0 on Lake Norman from 1 through 3 June 1978.

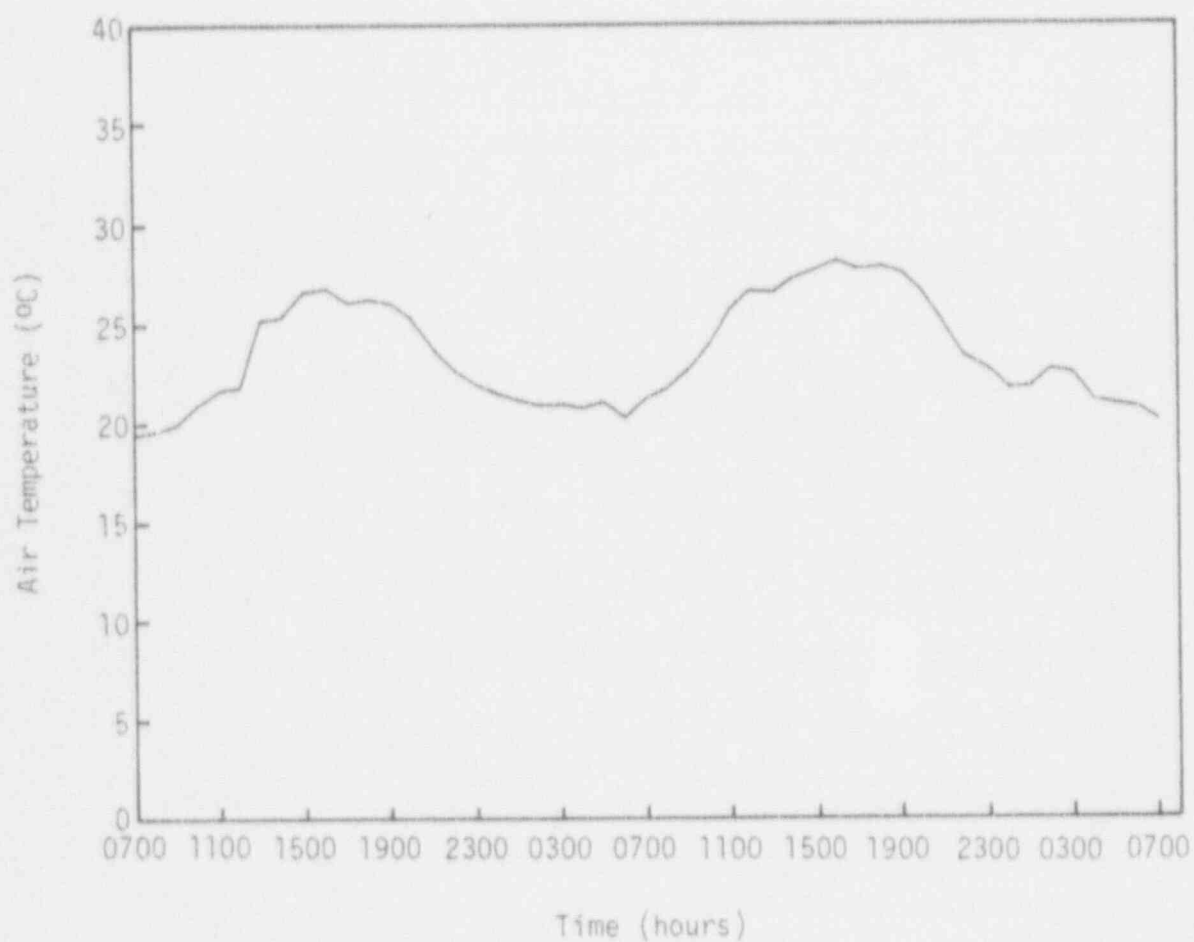
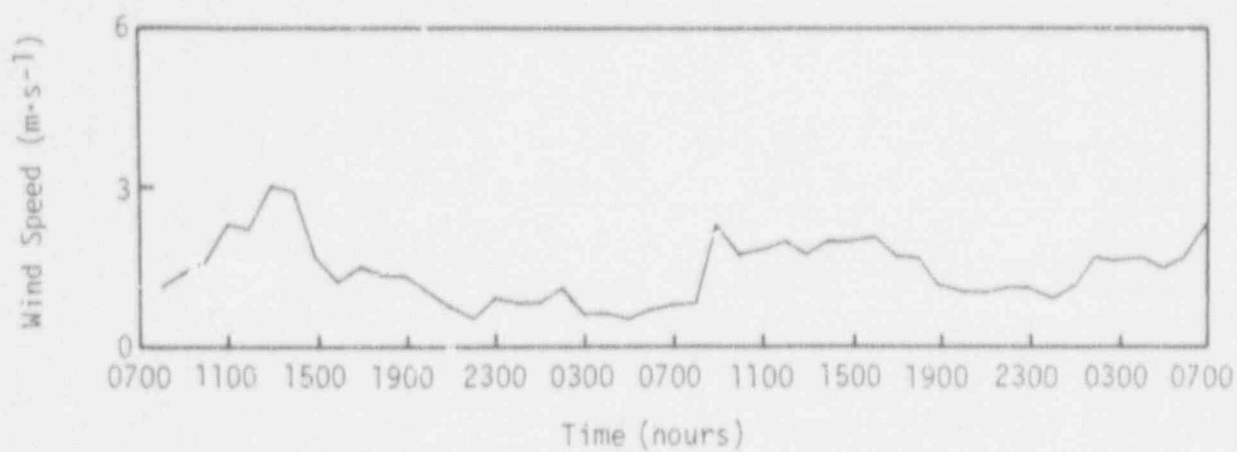


Figure 2-28. Lower level wind speed and air temperature data collected from the McGuire site from 1 through 3 June 1975.

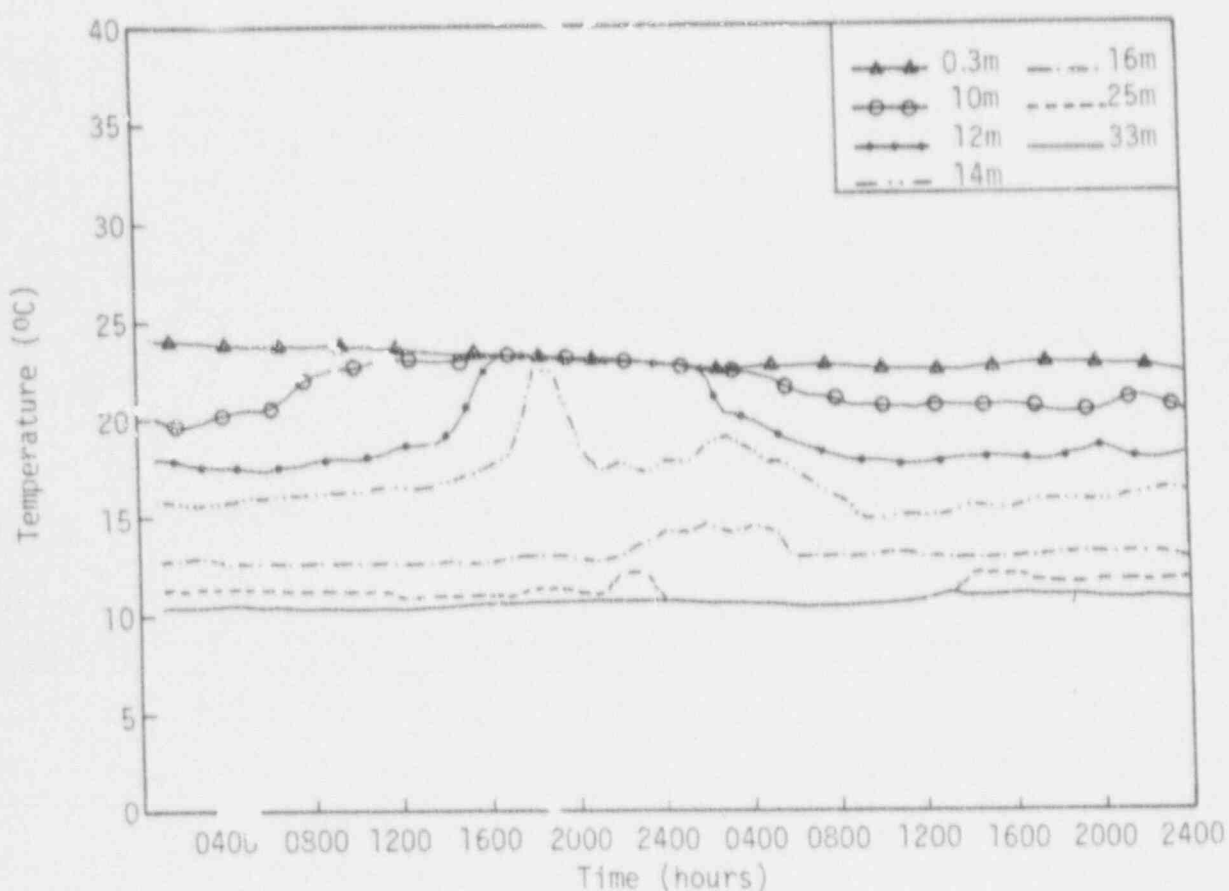
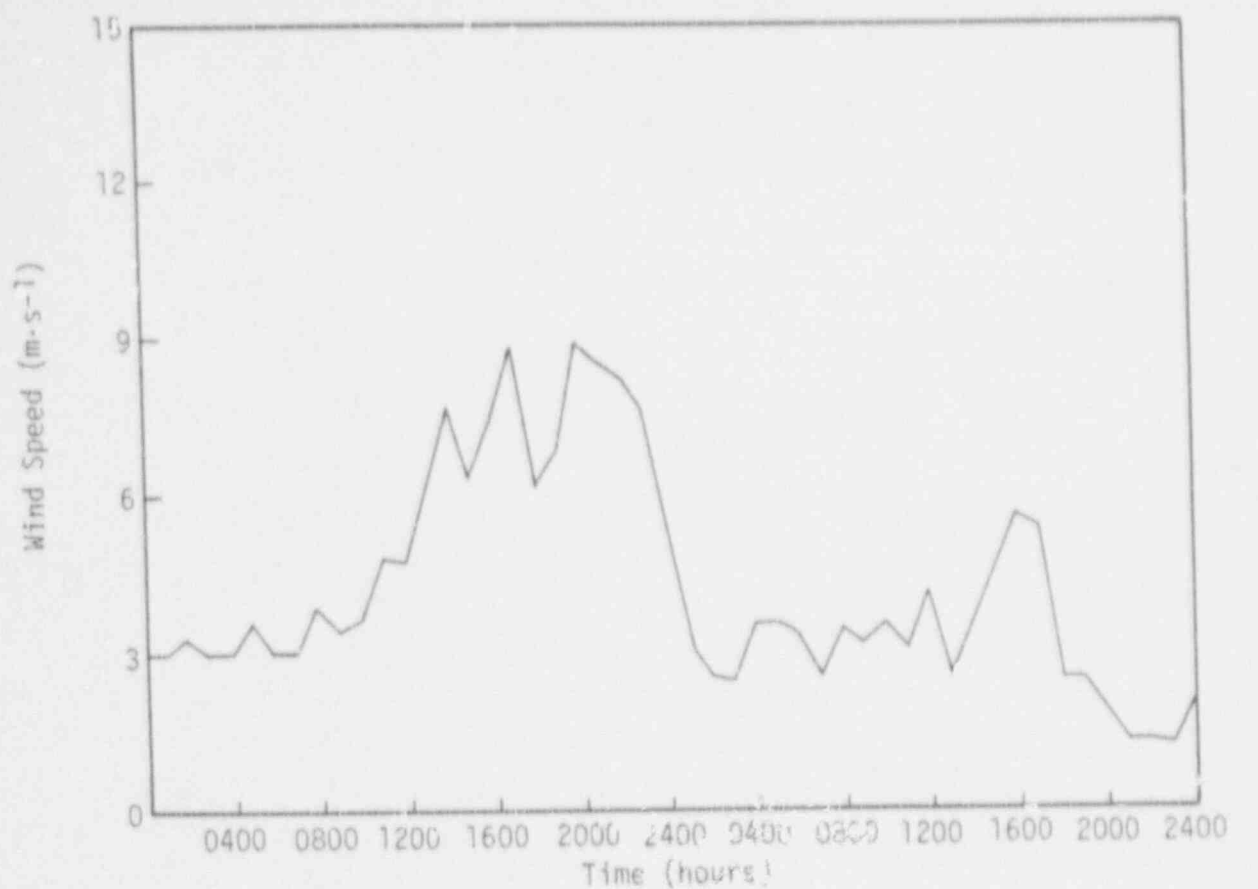


Figure 2-29. Wind speed data from the McGuire site and water temperature variability at Location 1.7 on 16 and 17 June 1979.

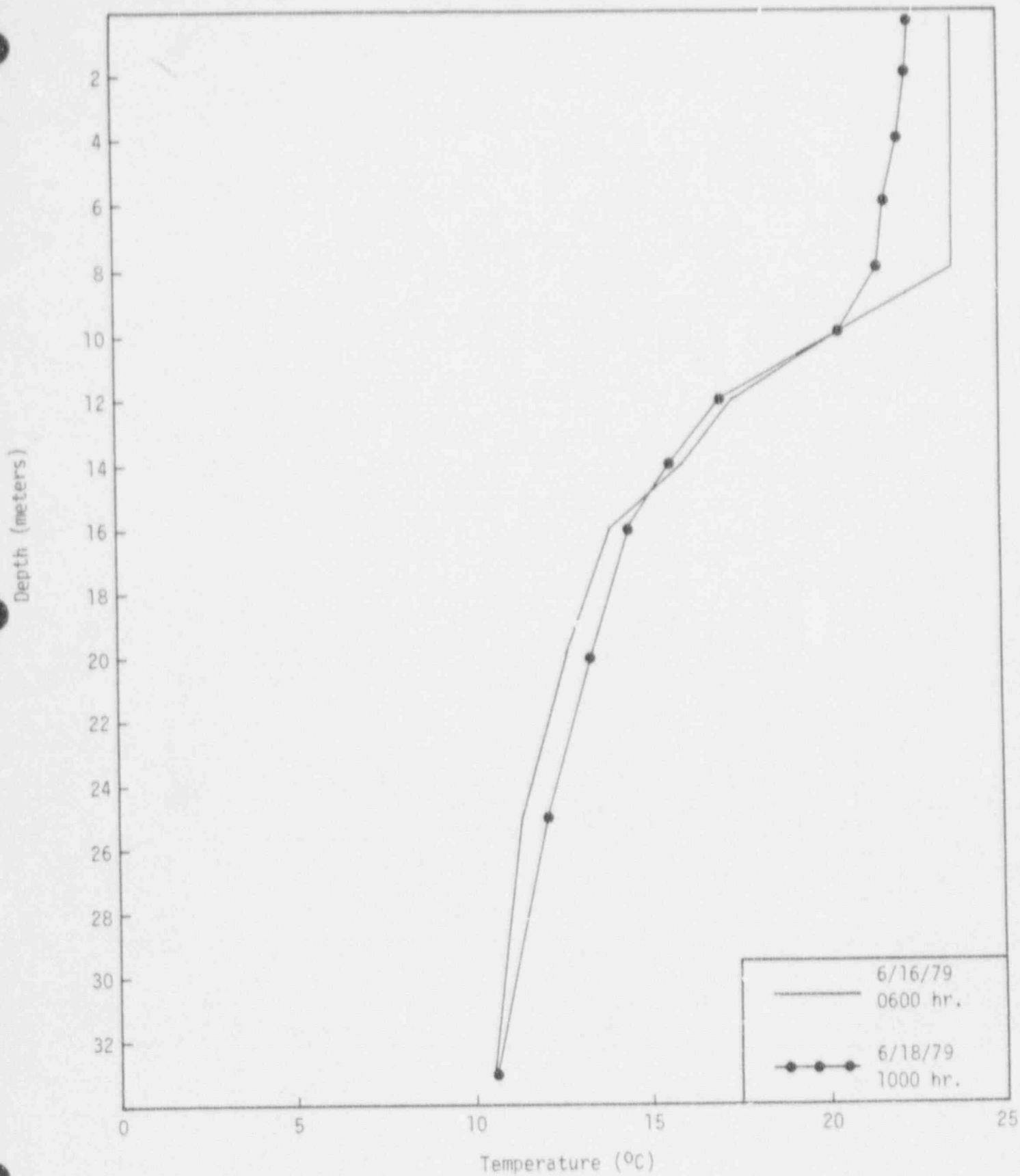


Figure 2-30. Water temperature variability at Location 1.7 on Lake Norman before and after periods of high winds of up to 9.0 m.sec⁻¹.

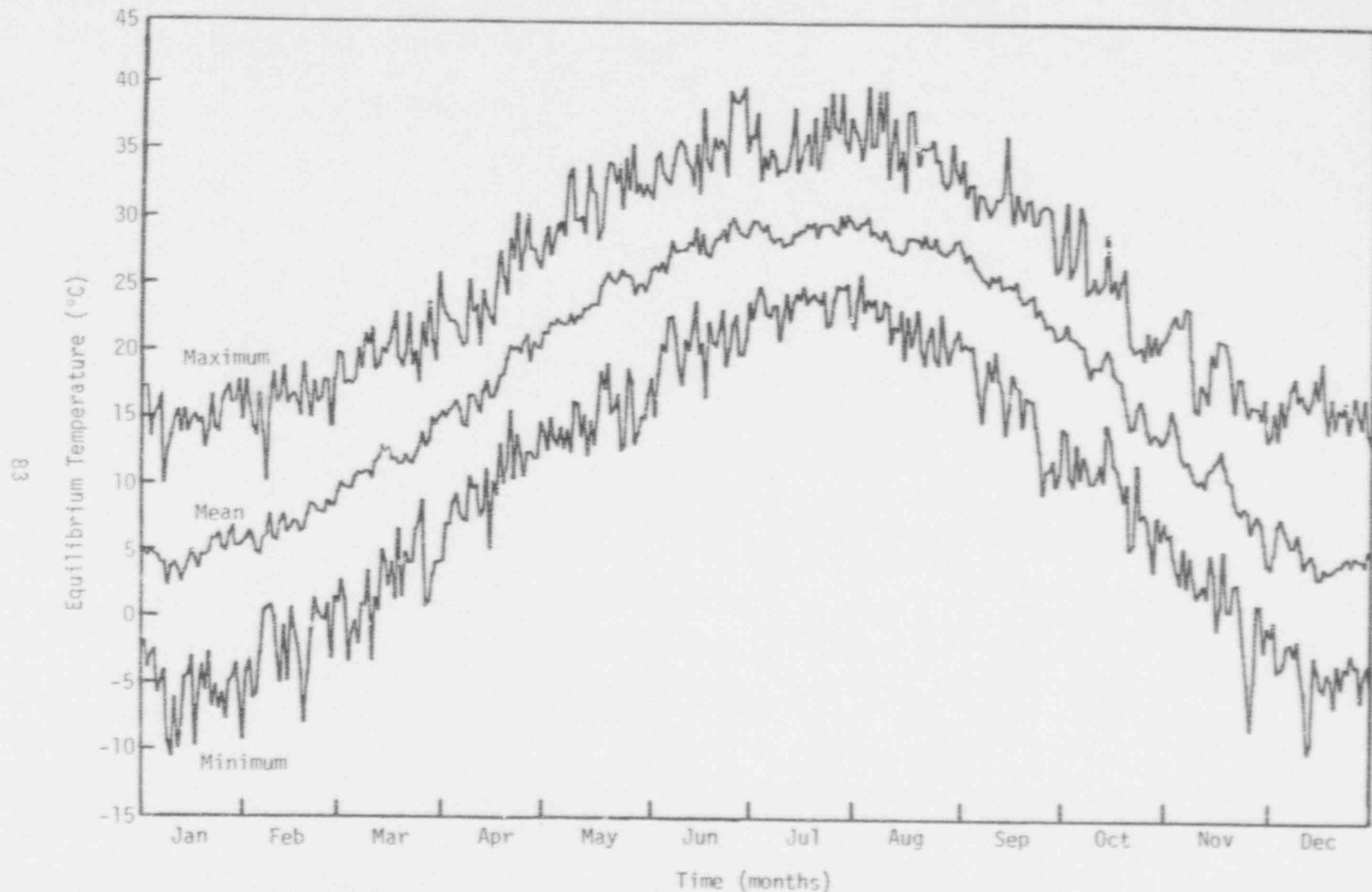


Figure 2-31. Twenty-five year (1950 through 1974) daily minimum, mean, and maximum equilibrium temperatures calculated from data from Douglas Municipal Airport, Charlotte, NC, using the unheated model of Ryan and Harleman (1973).

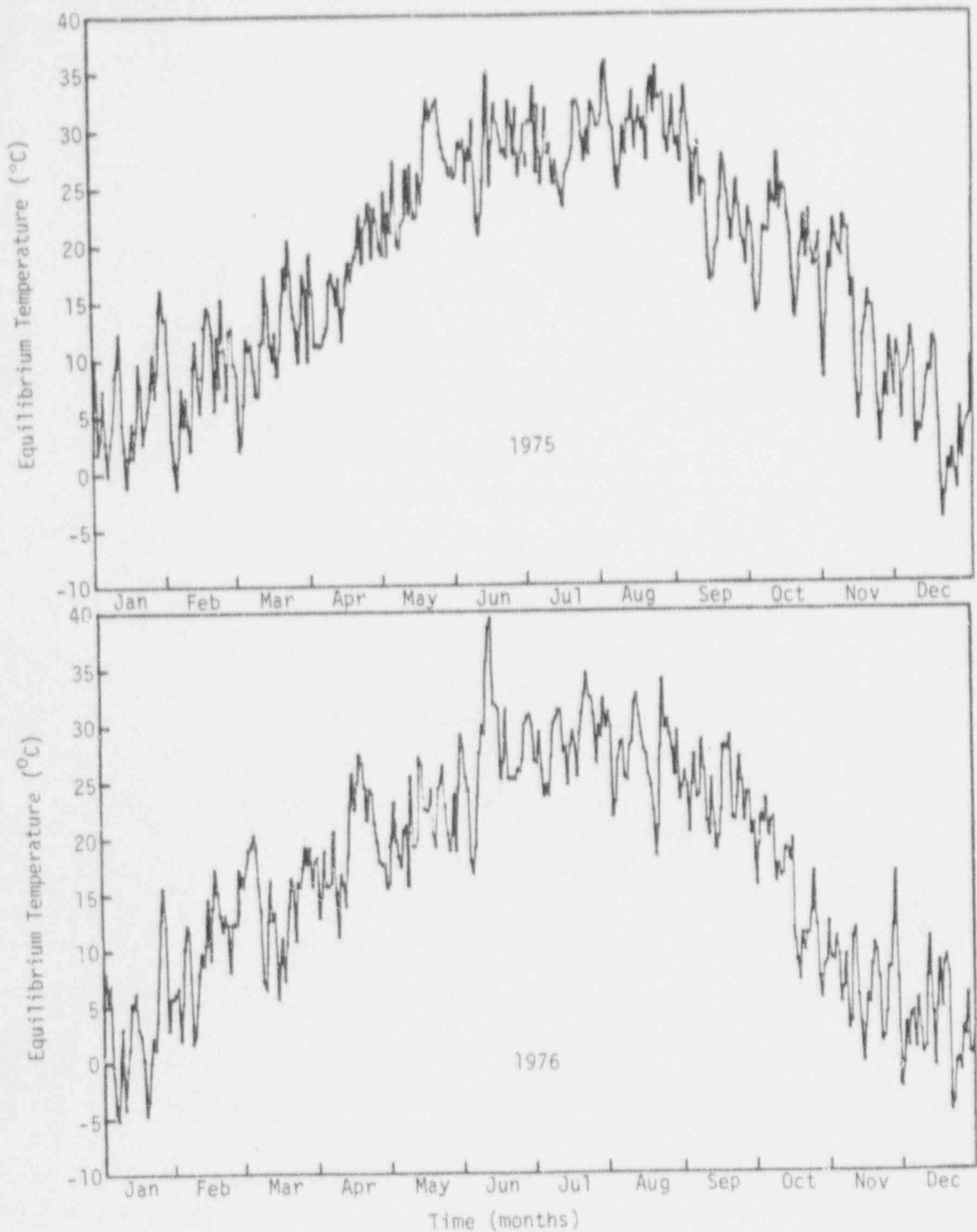


Figure 2-32. Daily mean equilibrium temperatures for 1975 and 1976 calculated from data from Douglas Municipal Airport, Charlotte, NC, using the unheated model of Ryan and Harleman (1973).

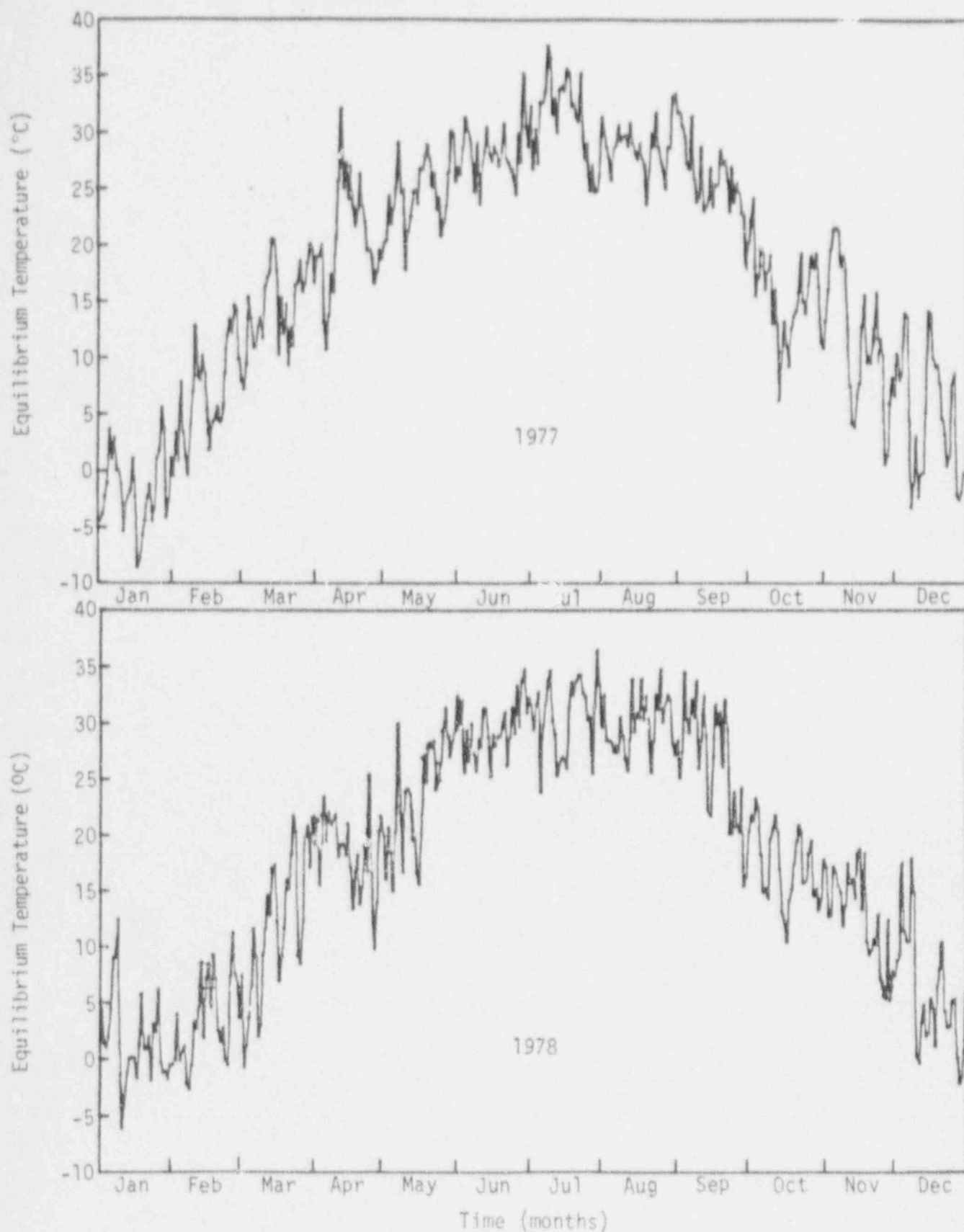


Figure 2-33. Daily mean equilibrium temperatures for 1977 and 1978 calculated from data from Douglas Municipal Airport, Charlotte, NC, using the unheated model of Ryan and Harleman (1973).

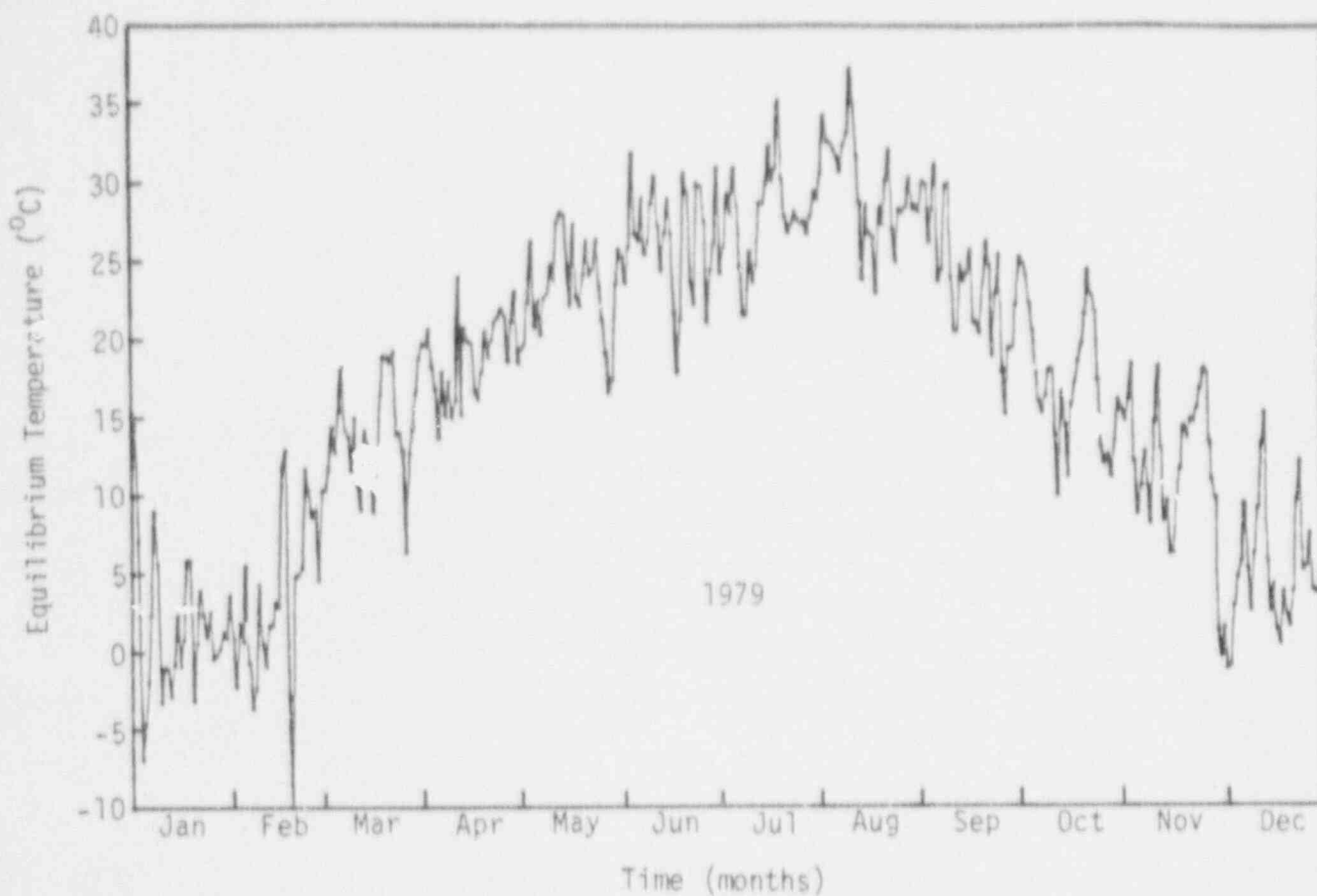


Figure 2-34. Daily mean equilibrium temperatures for 1979 calculated from data from Douglas Municipal Airport, Charlotte, NC, using the unheated model of Ryan and Harleman (1973).

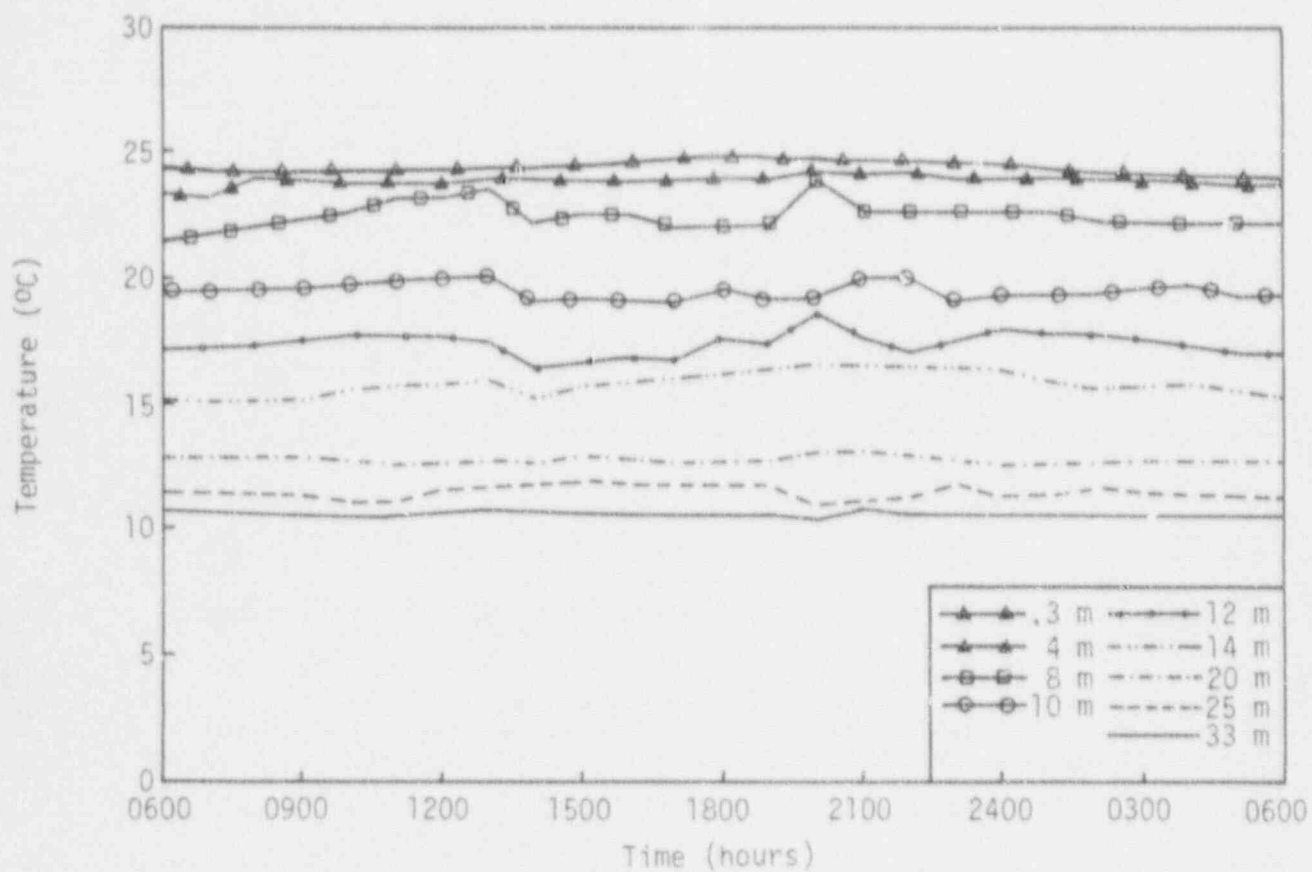
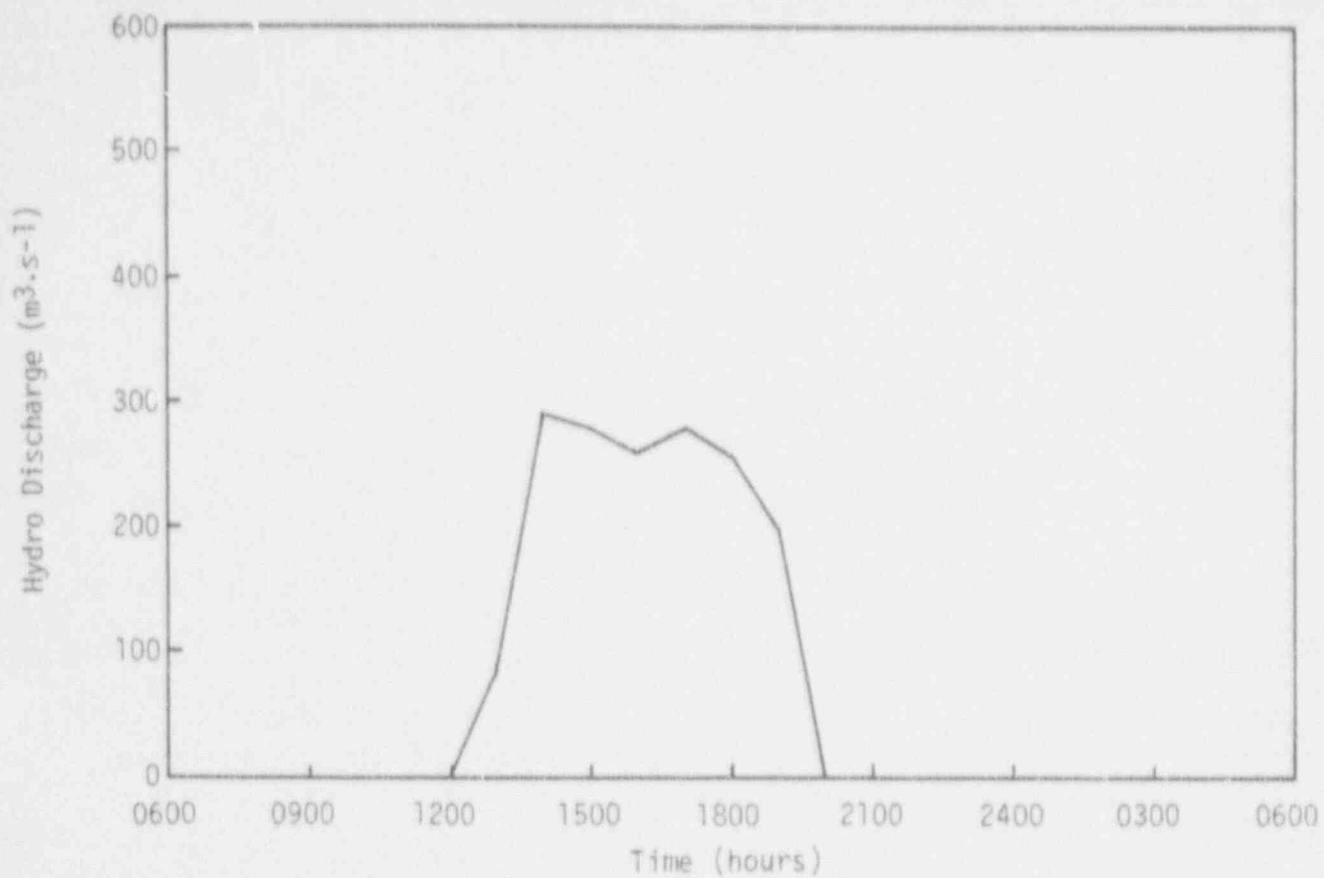


Figure 2-35. Cowans Ford hydro discharge and water temperature variability at Location 1.7 on 14 and 15 June 1979.

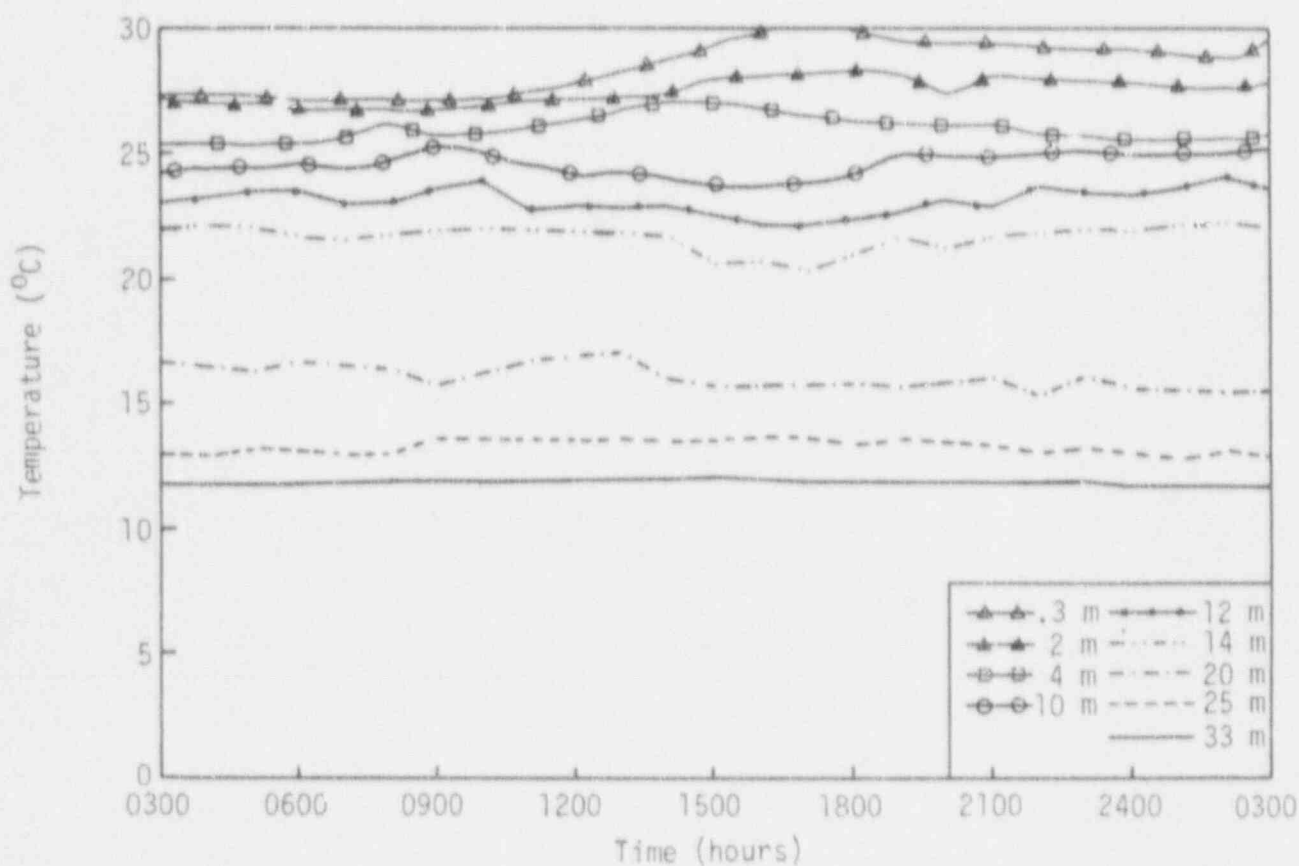
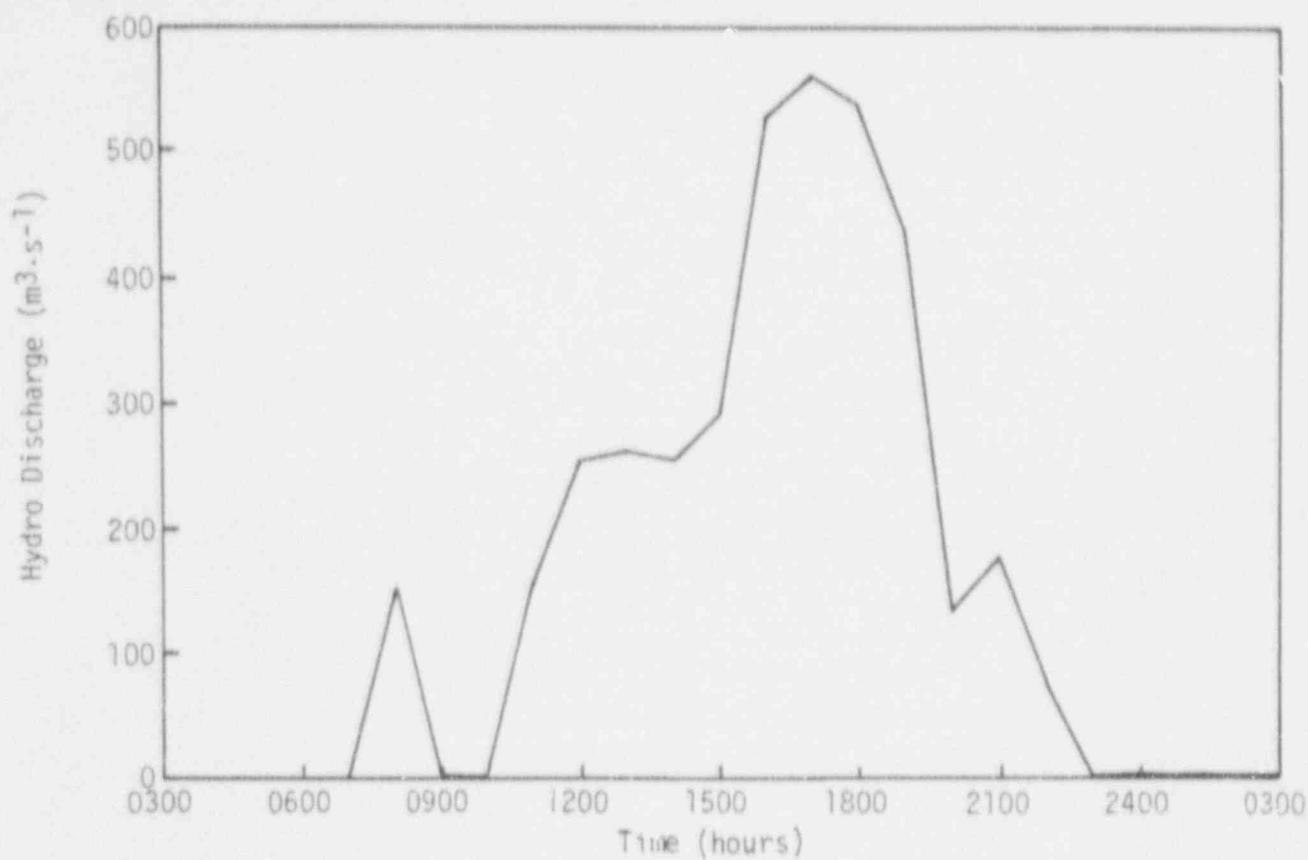


Figure 2-36. Cowans Ford Hydro discharge and temperature variability at Location 1.7 on 20 and 21 August 1970.

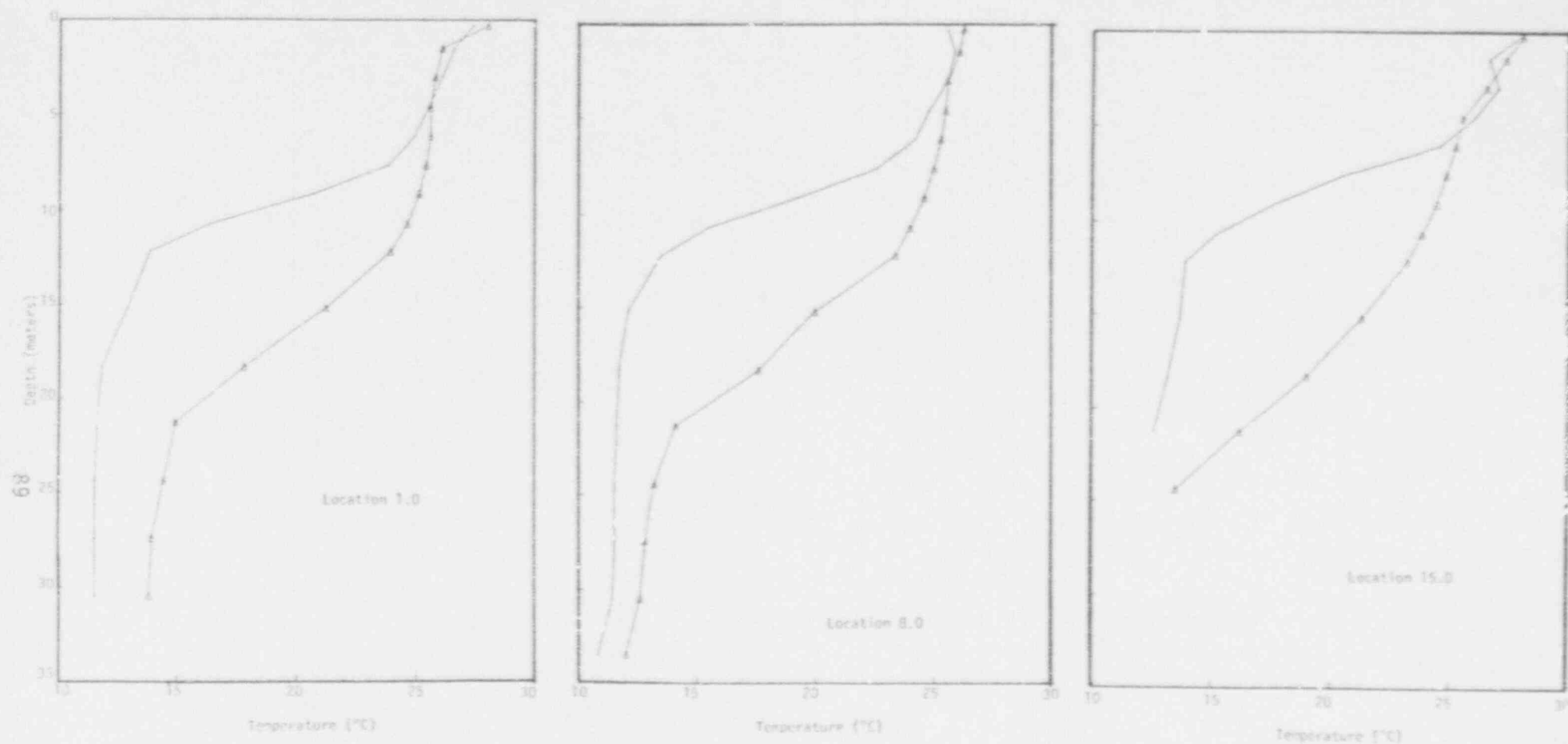


Figure 2-37. Vertical temperature profiles at Locations 1.0, 8.0, and 15.0 on Lake Norman. The profile at Location 8.0 for the operational period was determined from 1970 and 1971 data only. (August 1962-1965, pre-operational period —; August 1970-1972, operational period Δ — Δ)

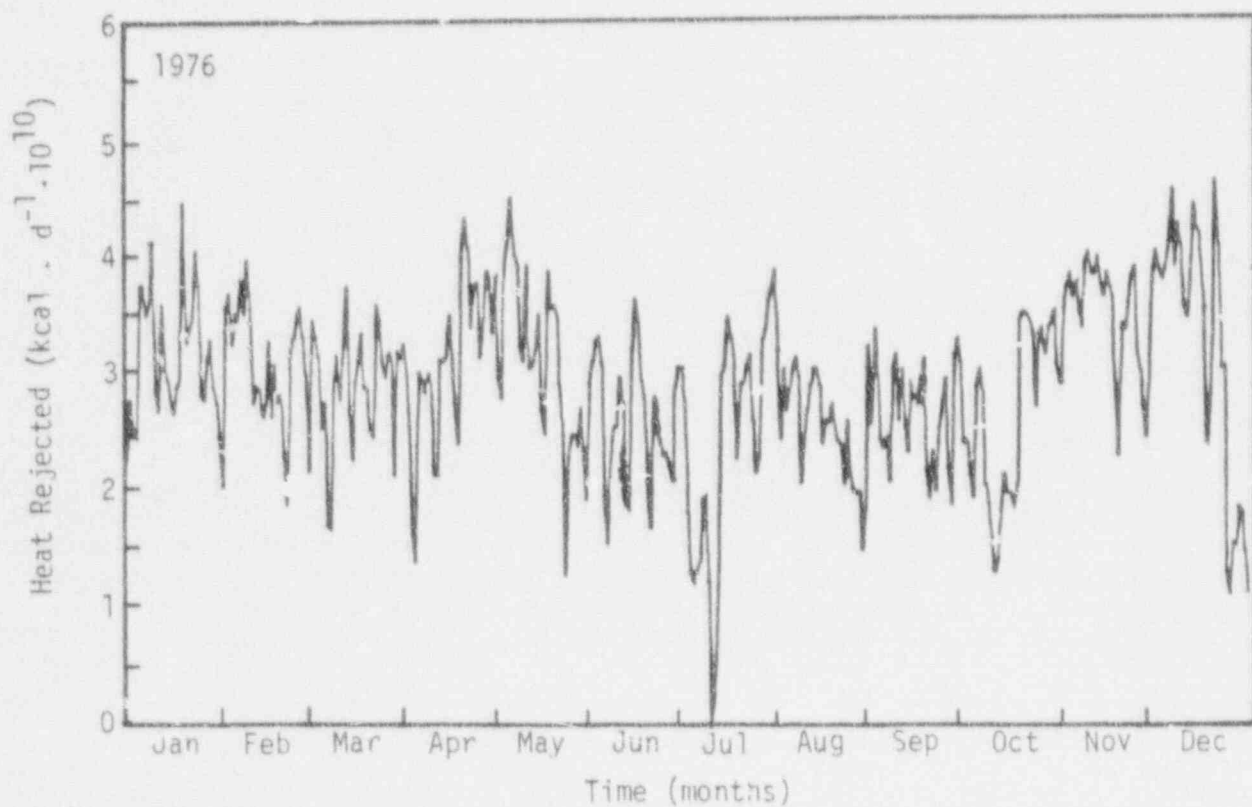
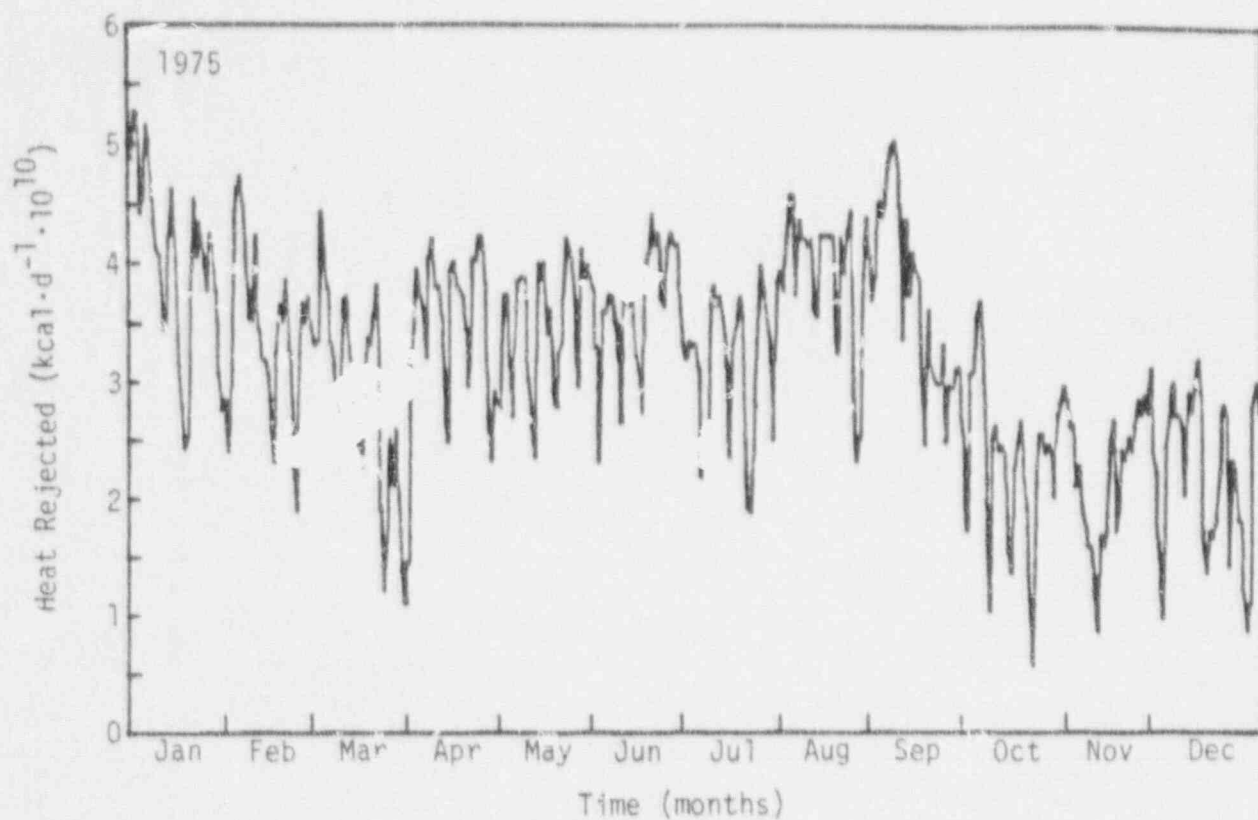


Figure 2-38. Mean daily heat rejection rates from Marshall Steam Station for 1975 and 1976.

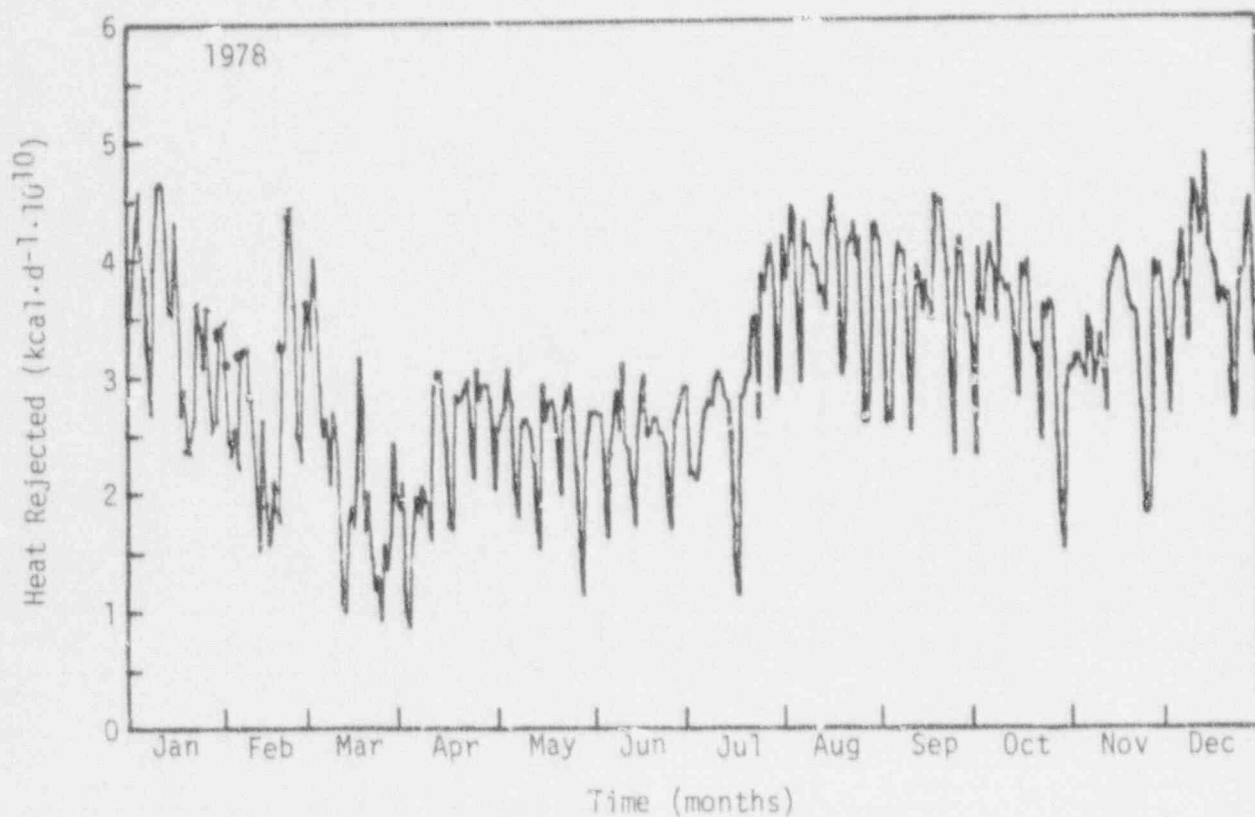
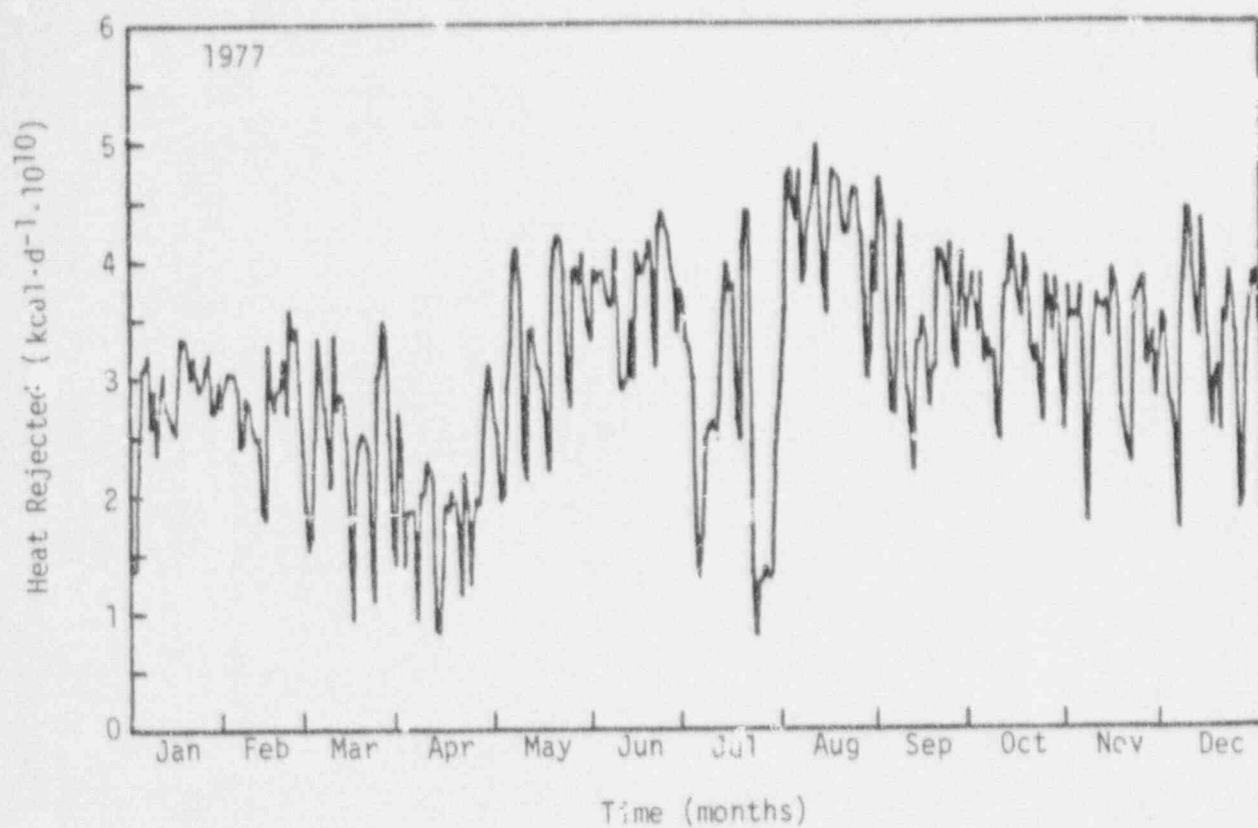


Figure 2-39. Mean daily heat rejection rates from Marshall Steam Station for 1977 and 1978.

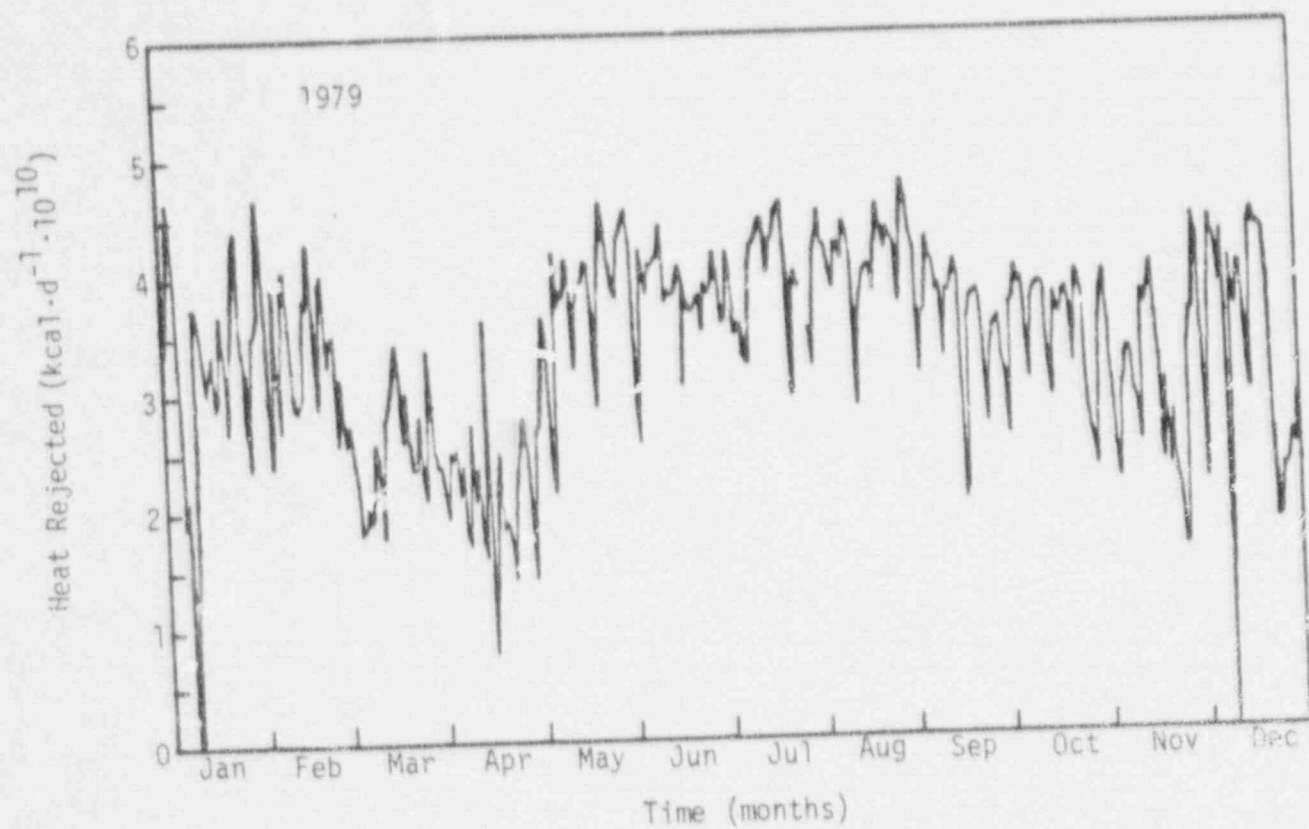


Figure 2-40. Mean daily heat rejection rates from Marshall Steam Station for 1979.

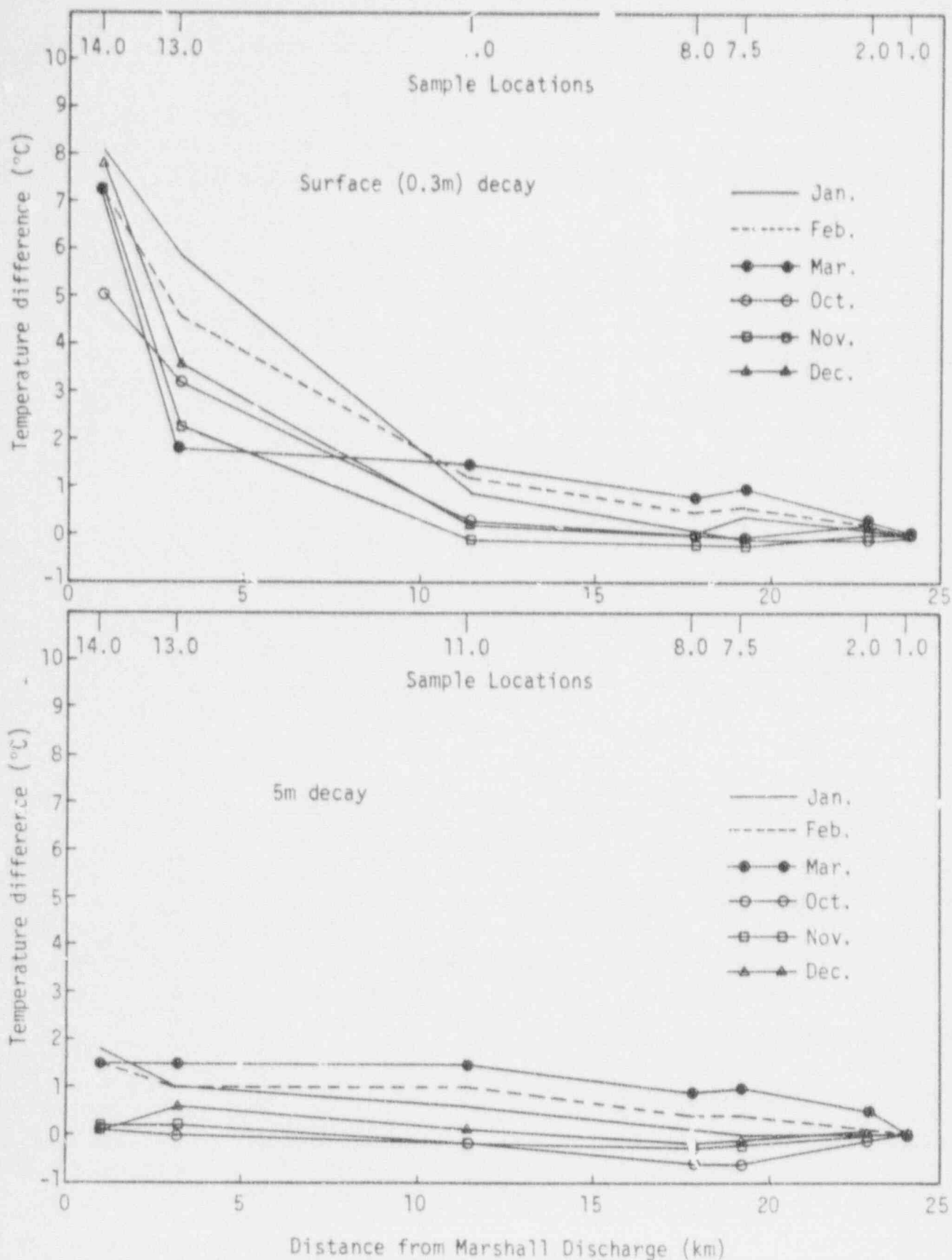


Figure 2-41. Temperature decay at surface (0.3 m) and 5 m depths measured on Lake Norman during 1975. The plotted values were normalized to the temperatures at Location 1.0.

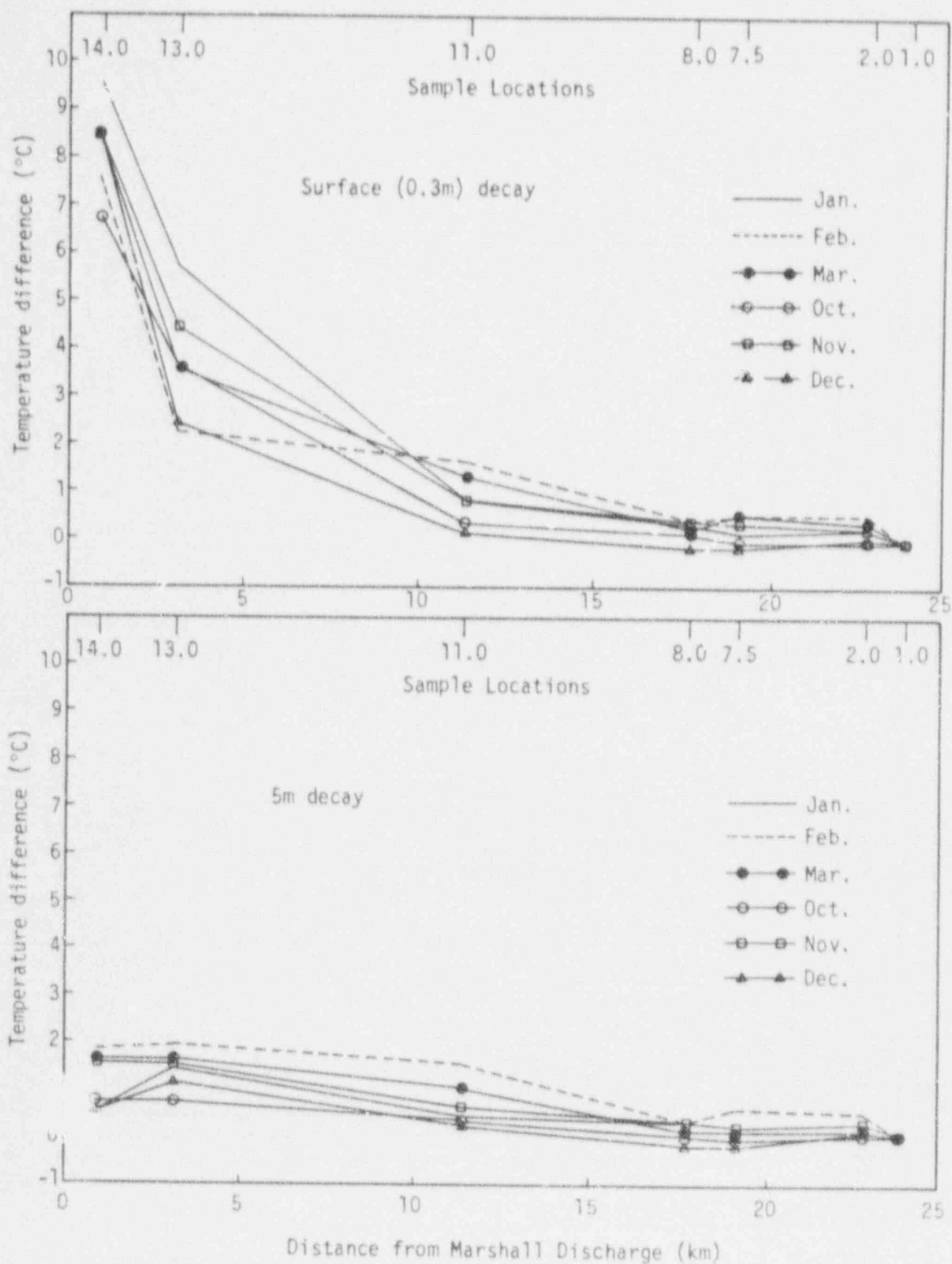


Figure 2-42. Temperature decay at surface (0.3 m) and 5 m depths measured on Lake Norman during 1976.

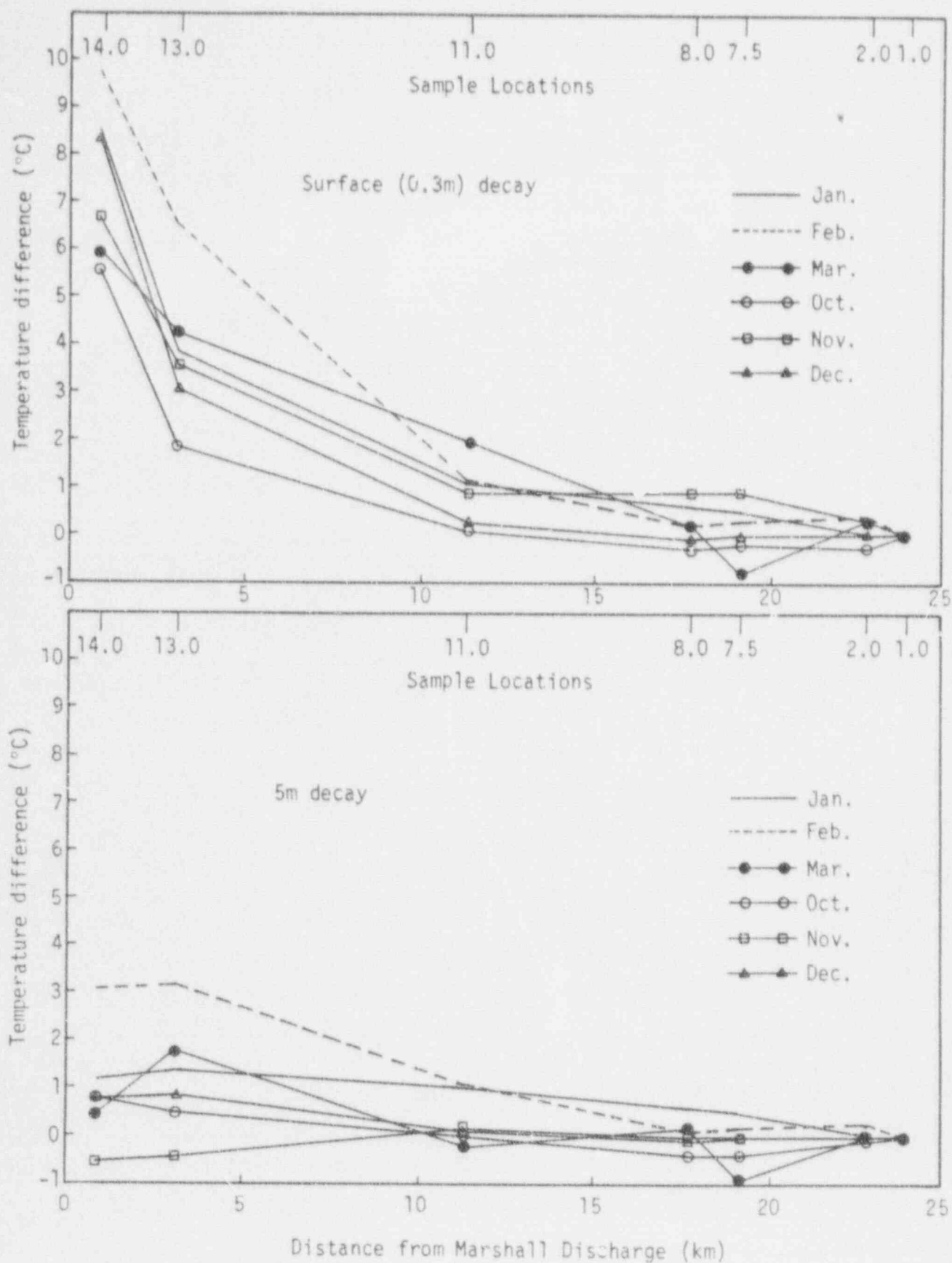


Figure 2-43. Temperature decay at surface (0.3 m) and 5 m depths measured on Lake Norman during 1977.

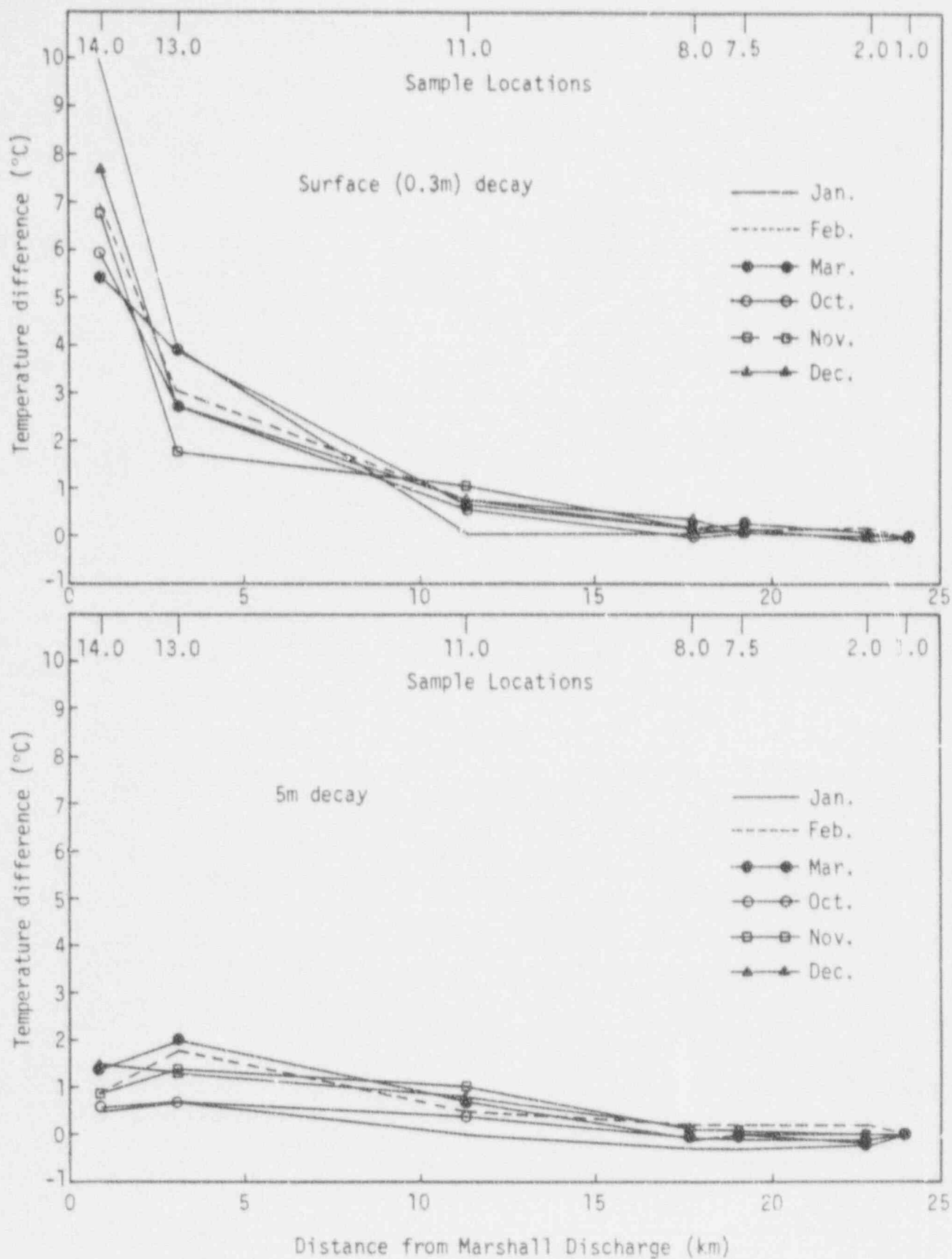


Figure 2-44. Temperature decay at surface (0.3 m) and 5 m depths measured on Lake Norman during 1978.

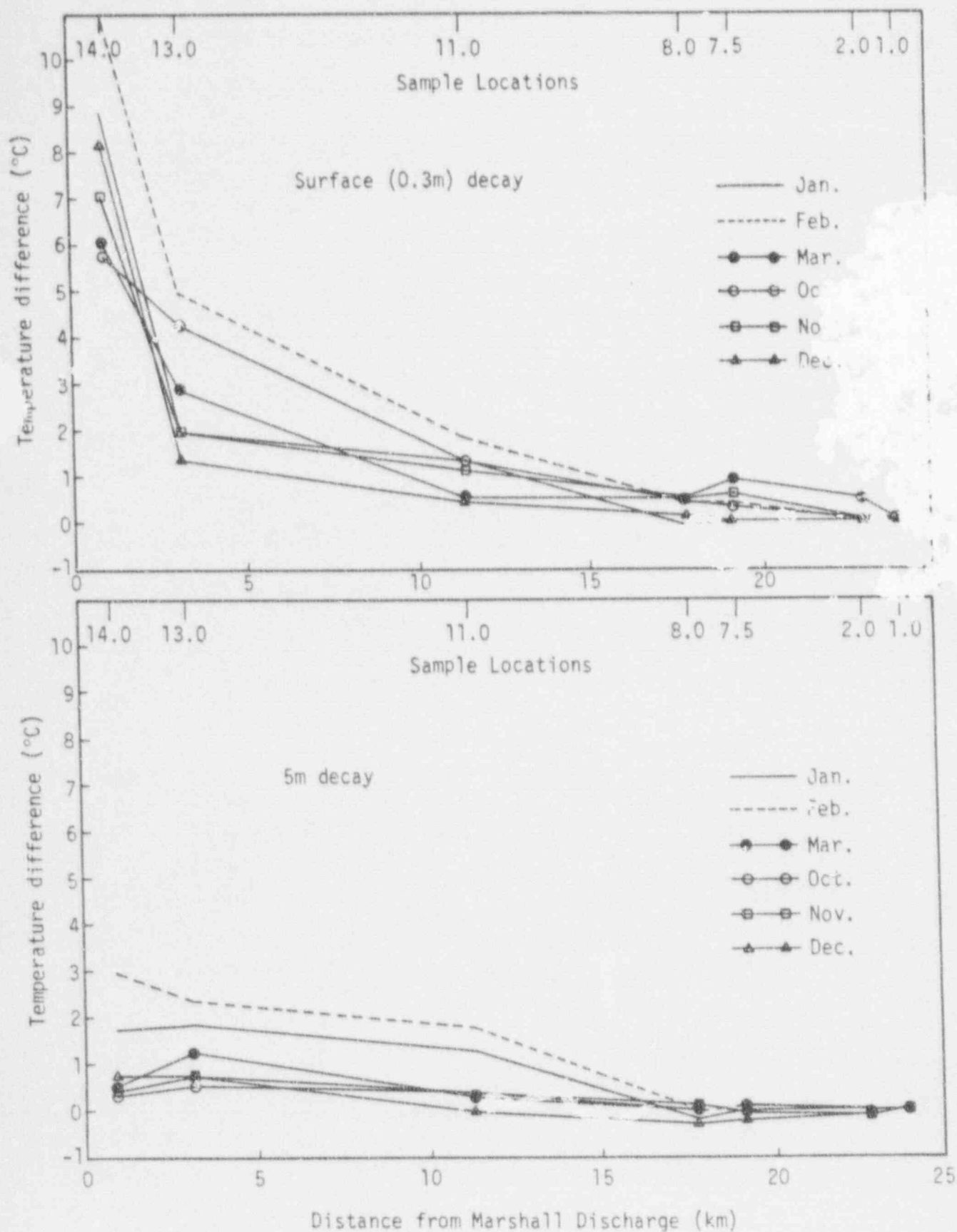


Figure 2-45. Temperature decay at surface (0.3 m) and 5 m depths measured on Lake Norman during 1979.

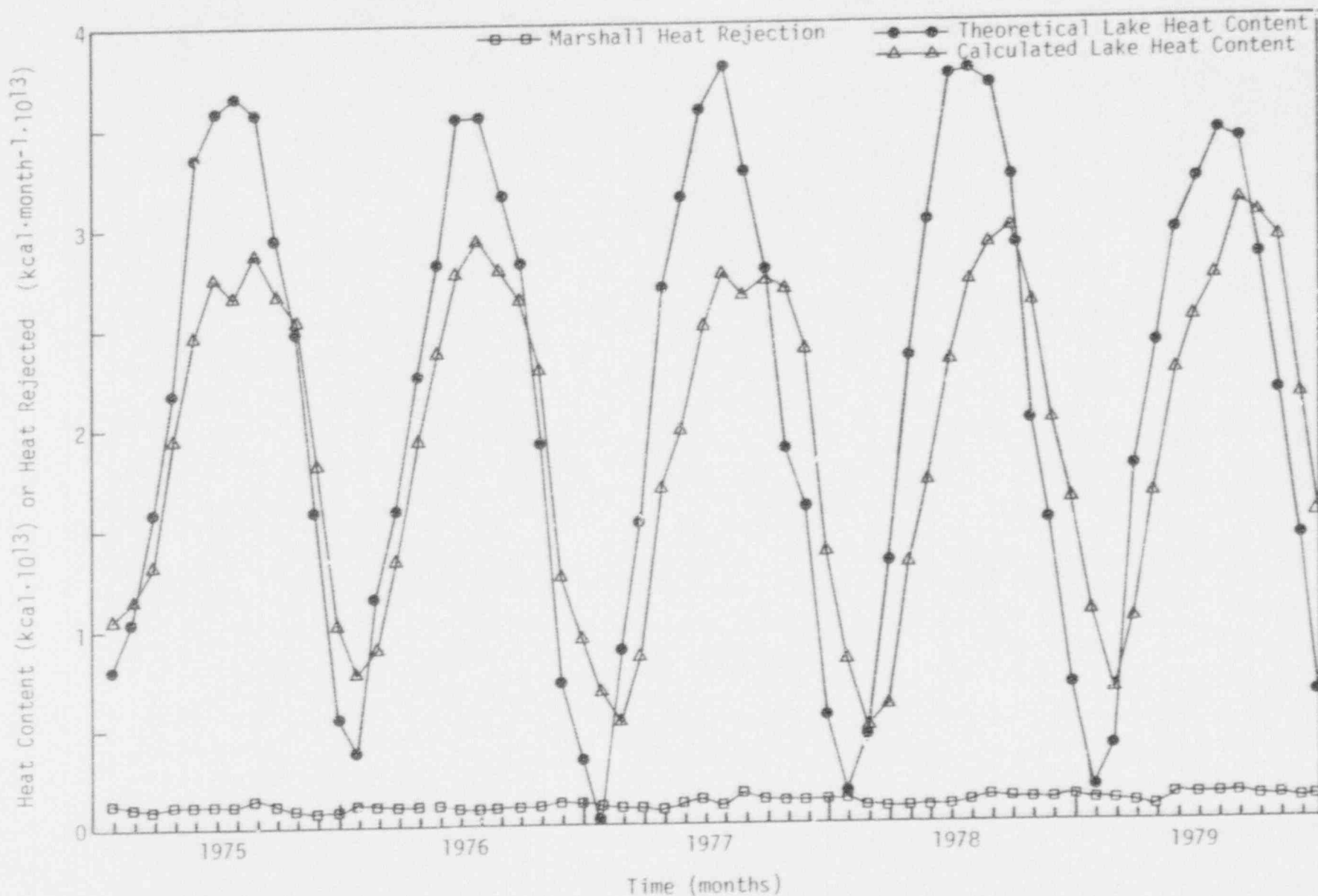


Figure 2-46. Heat content considerations for Lake Norman for the period 1975 through 1979. The theoretical heat content is based on monthly mean equilibrium temperatures.

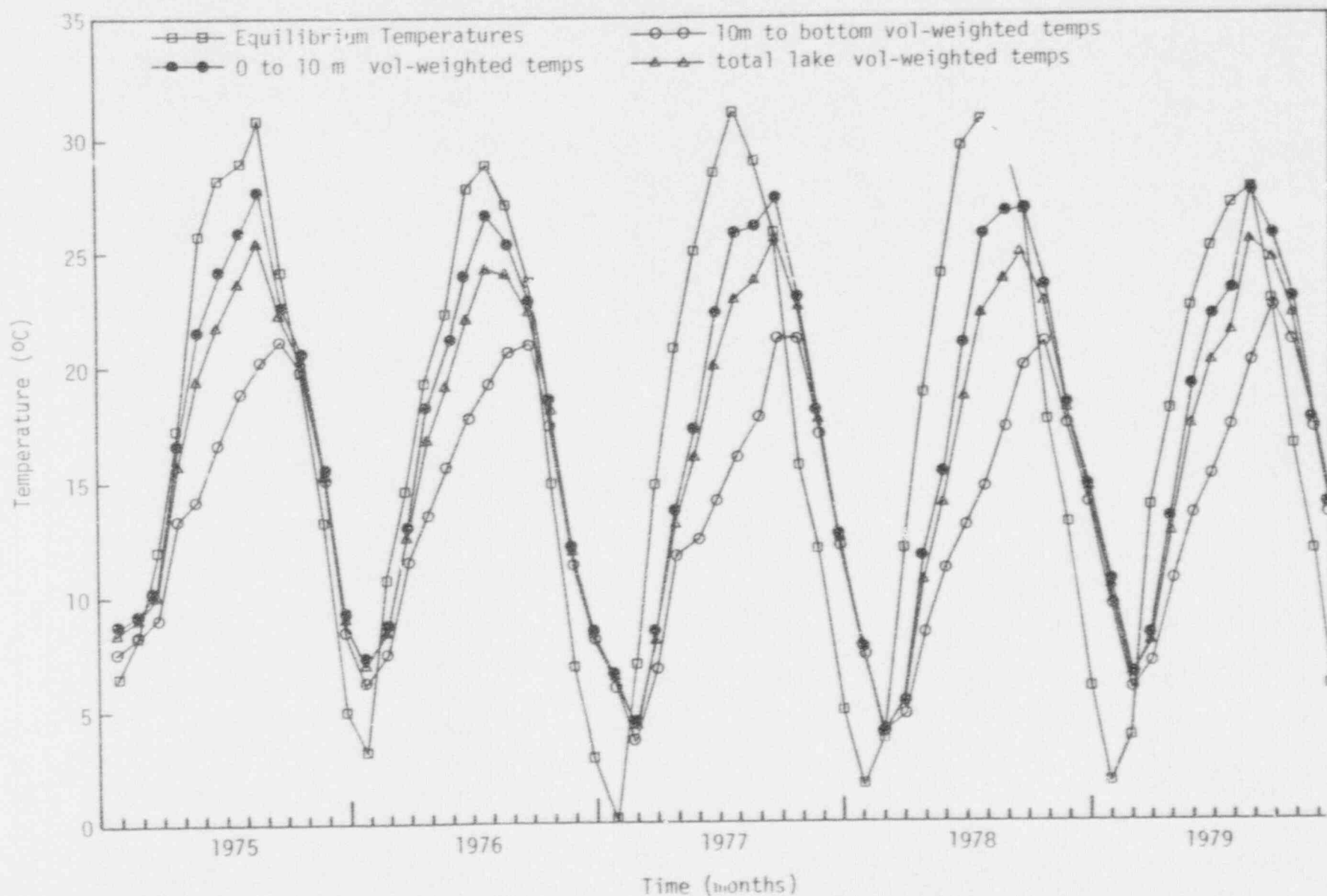


Figure 2-47. Lake Norman volume-weighted temperatures and monthly mean equilibrium temperatures.

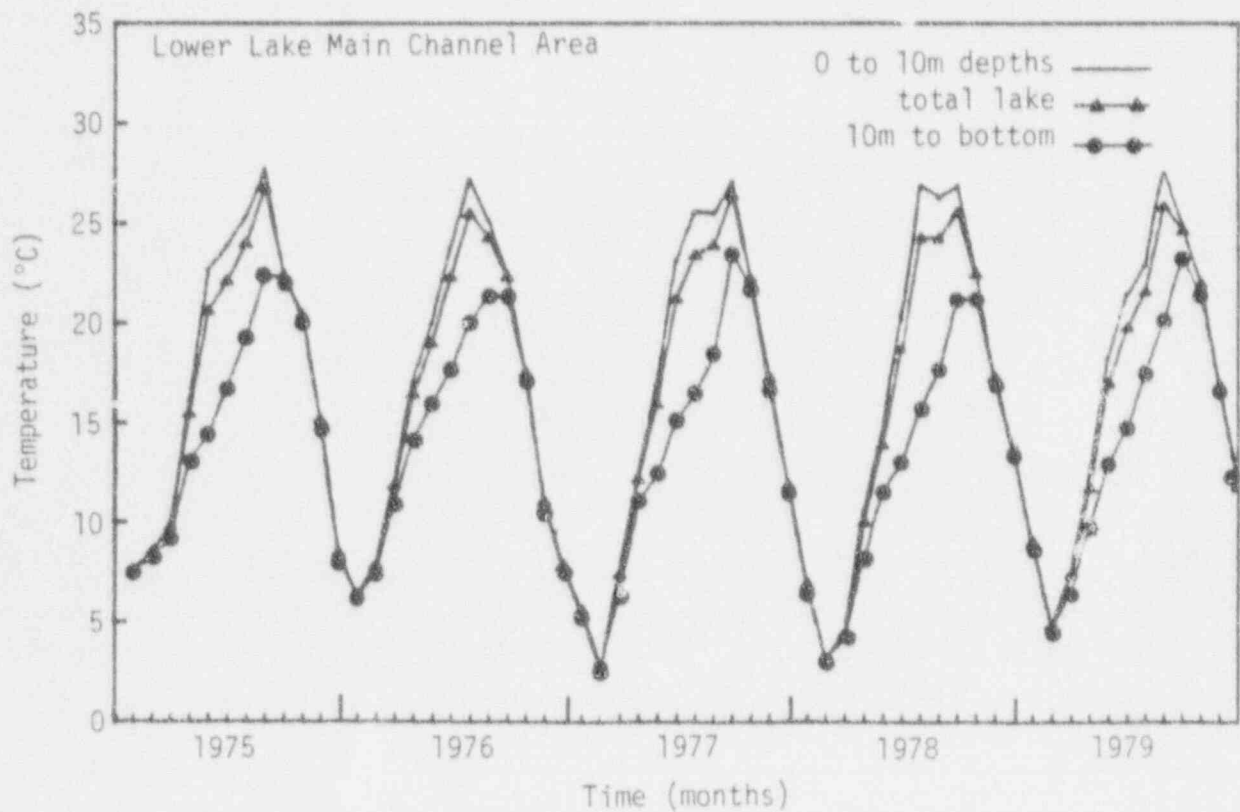
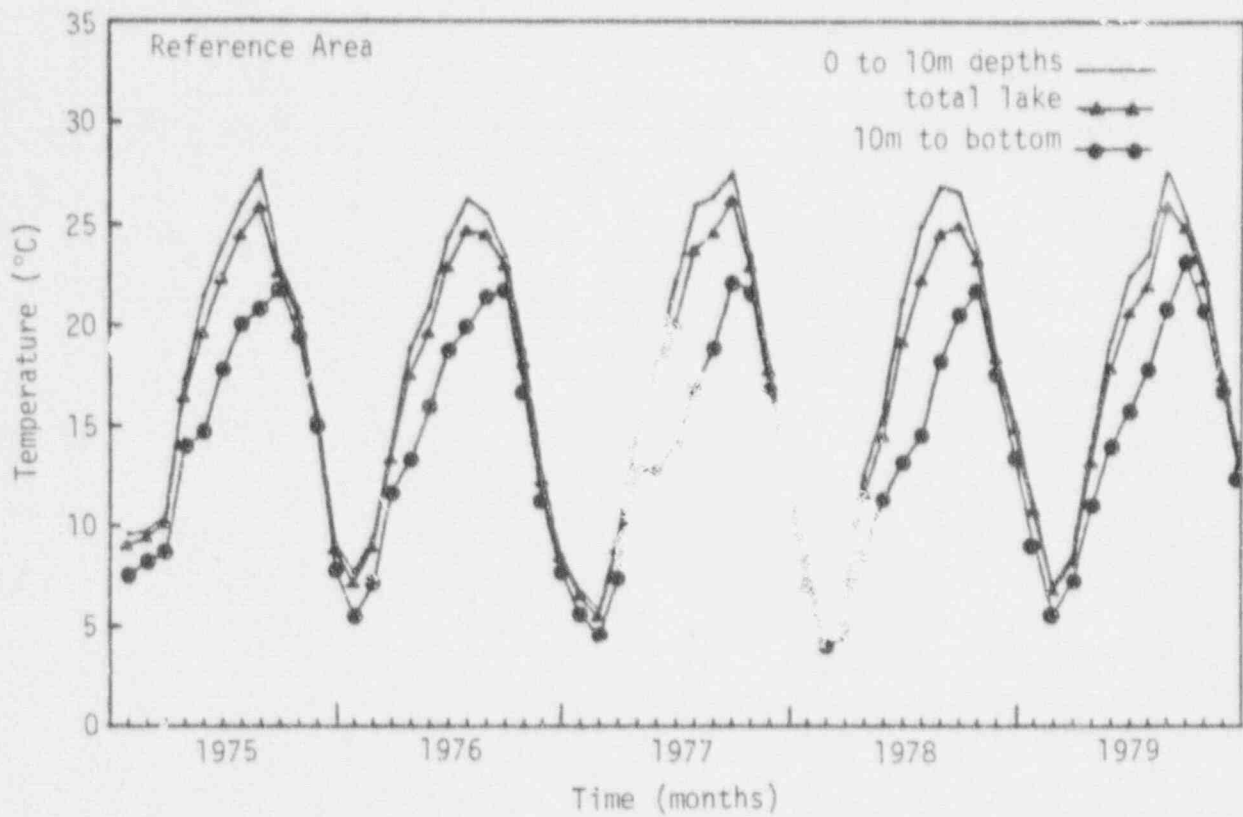


Figure 2-48. Volume-weighted temperatures for the Reference Area and the Lower Lake Main Channel Area of Lake Norman during the study period.

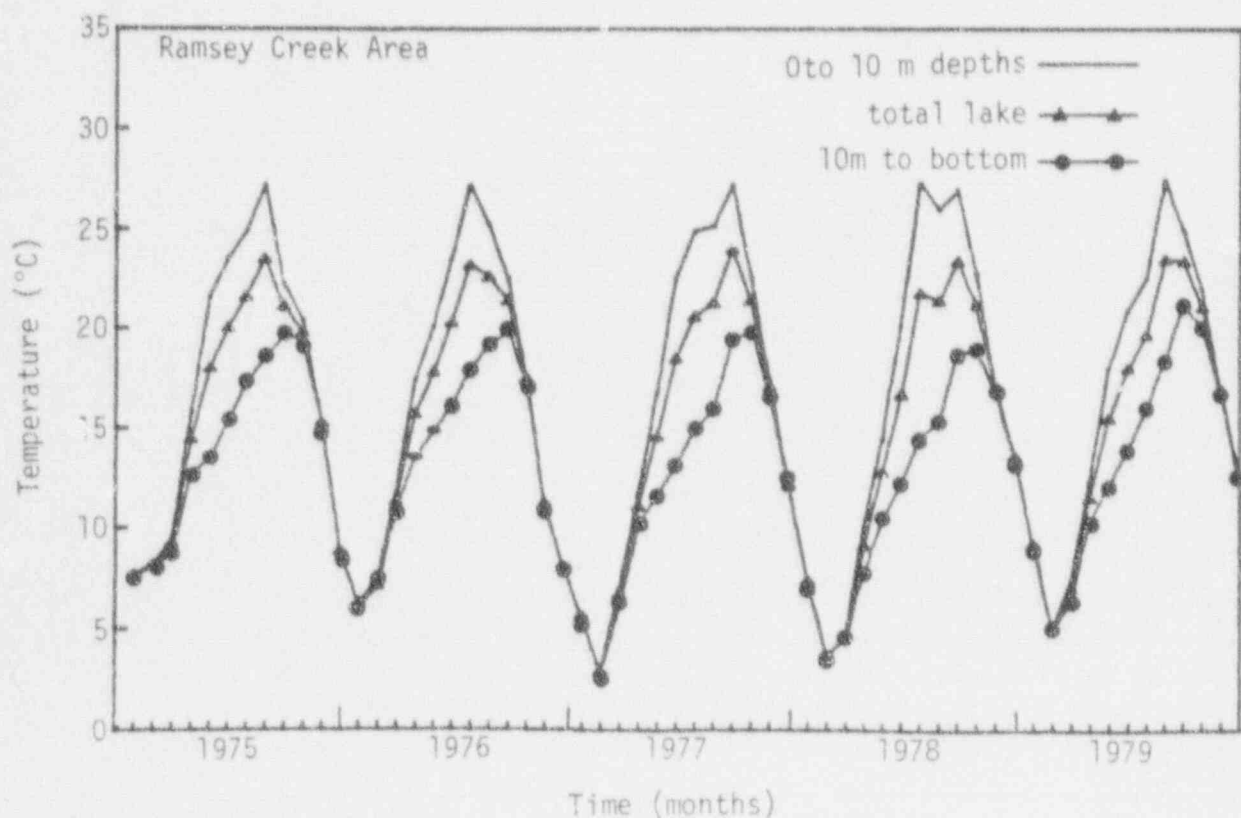
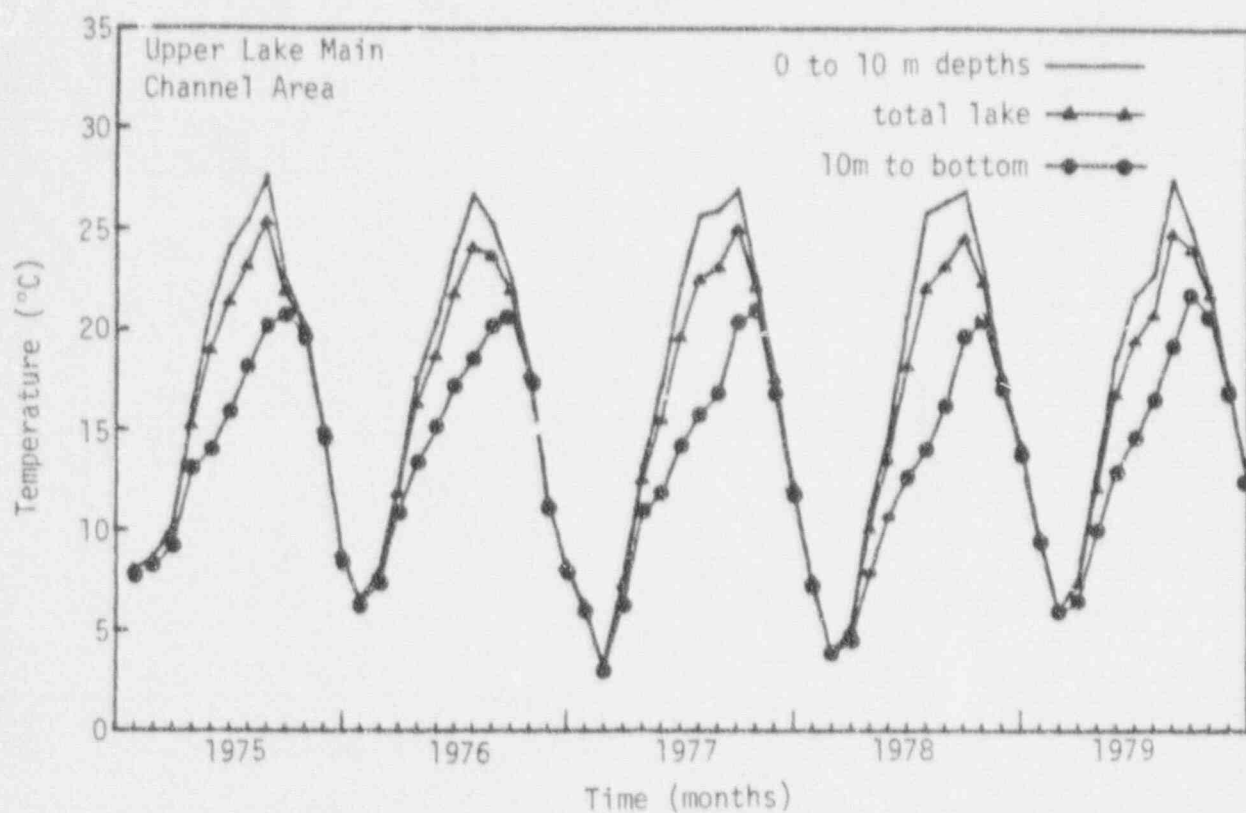


Figure 2-49. Volume-weighted temperatures for the Upper Lake Main Channel Area and the Ramsey Creek Area of Lake Norman during the study period.

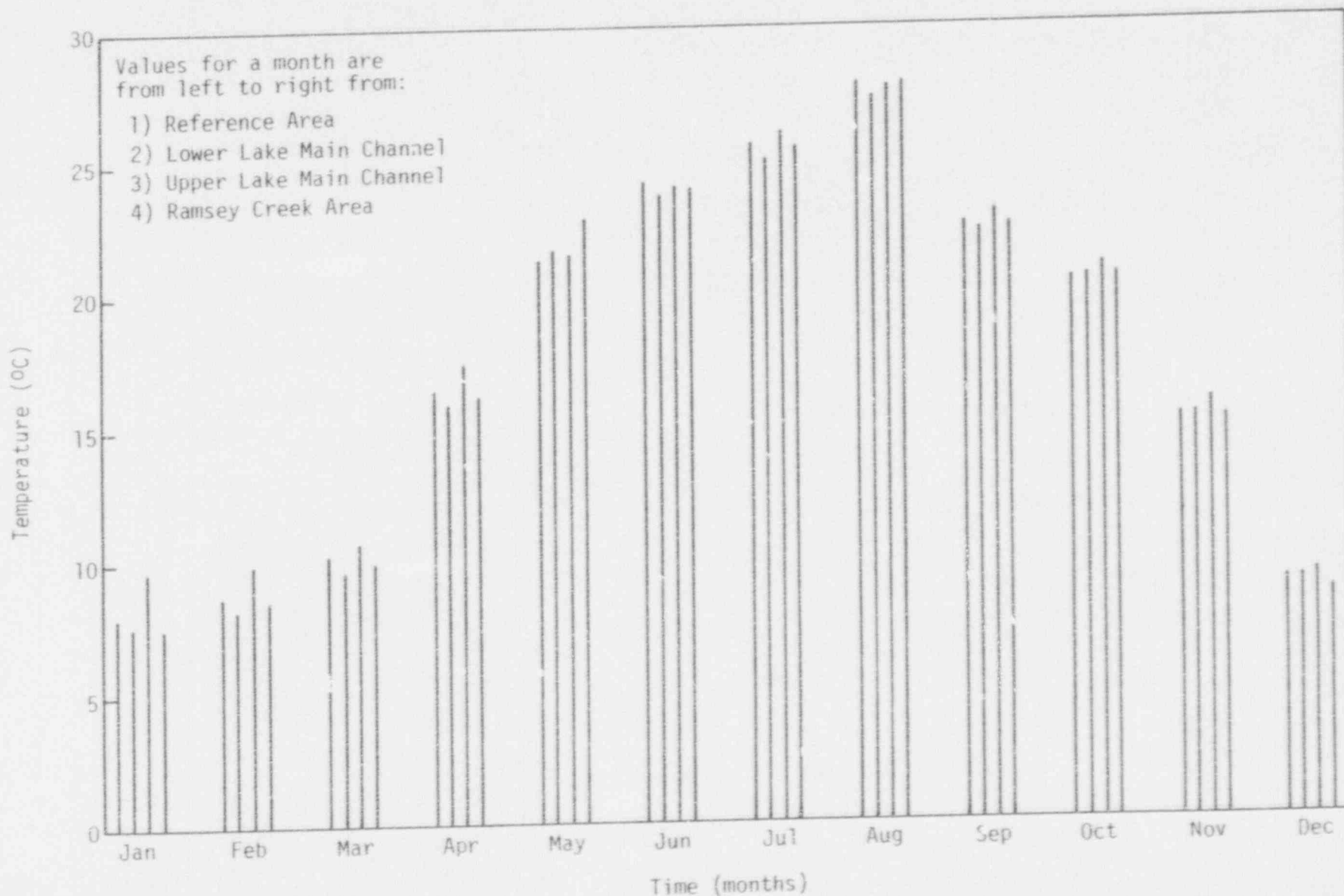


Figure 2-50. Volume-weighted temperature (0.3 to 10 m depth) comparisons for four zones in Lake Norman in 1975.

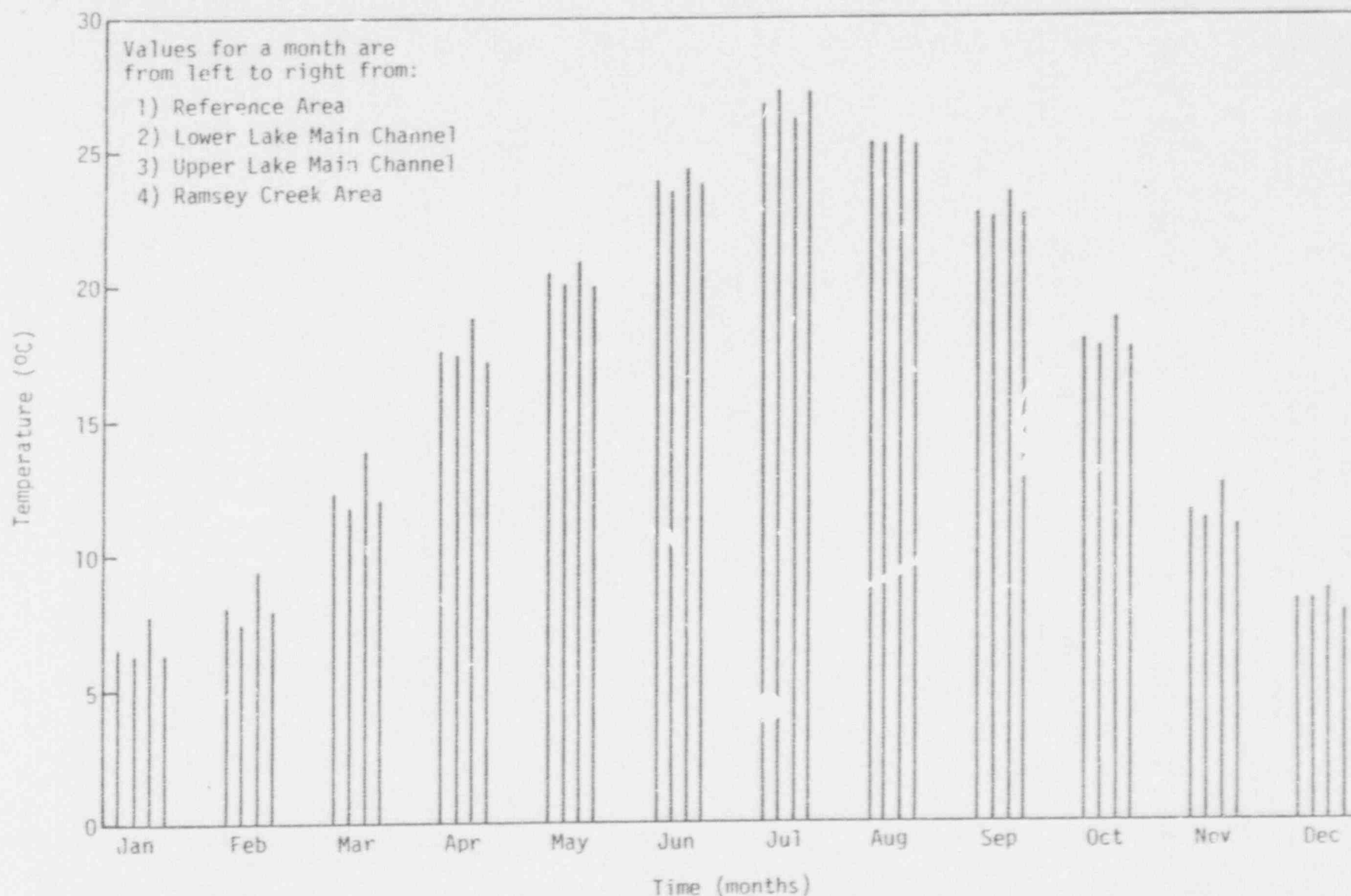


Figure 2-51. Volume-weighted temperature (0.3 to 10 m depth) comparisons for four zones in Lake Norman in 1976.

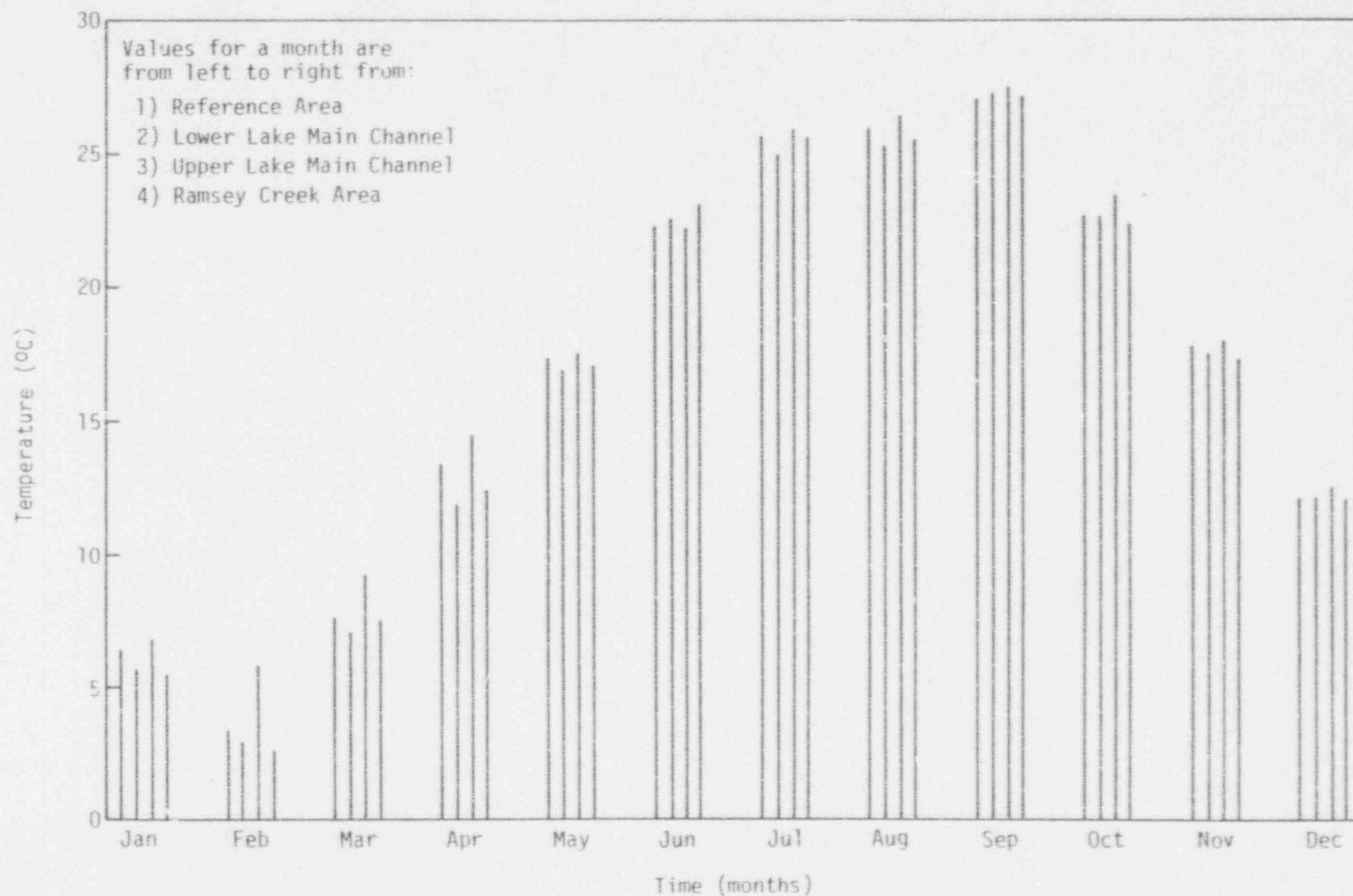


Figure 2-52. Volume-weighted temperature (0.3 to 10 m depth) comparisons for four zones in Lake Norman in 1977.

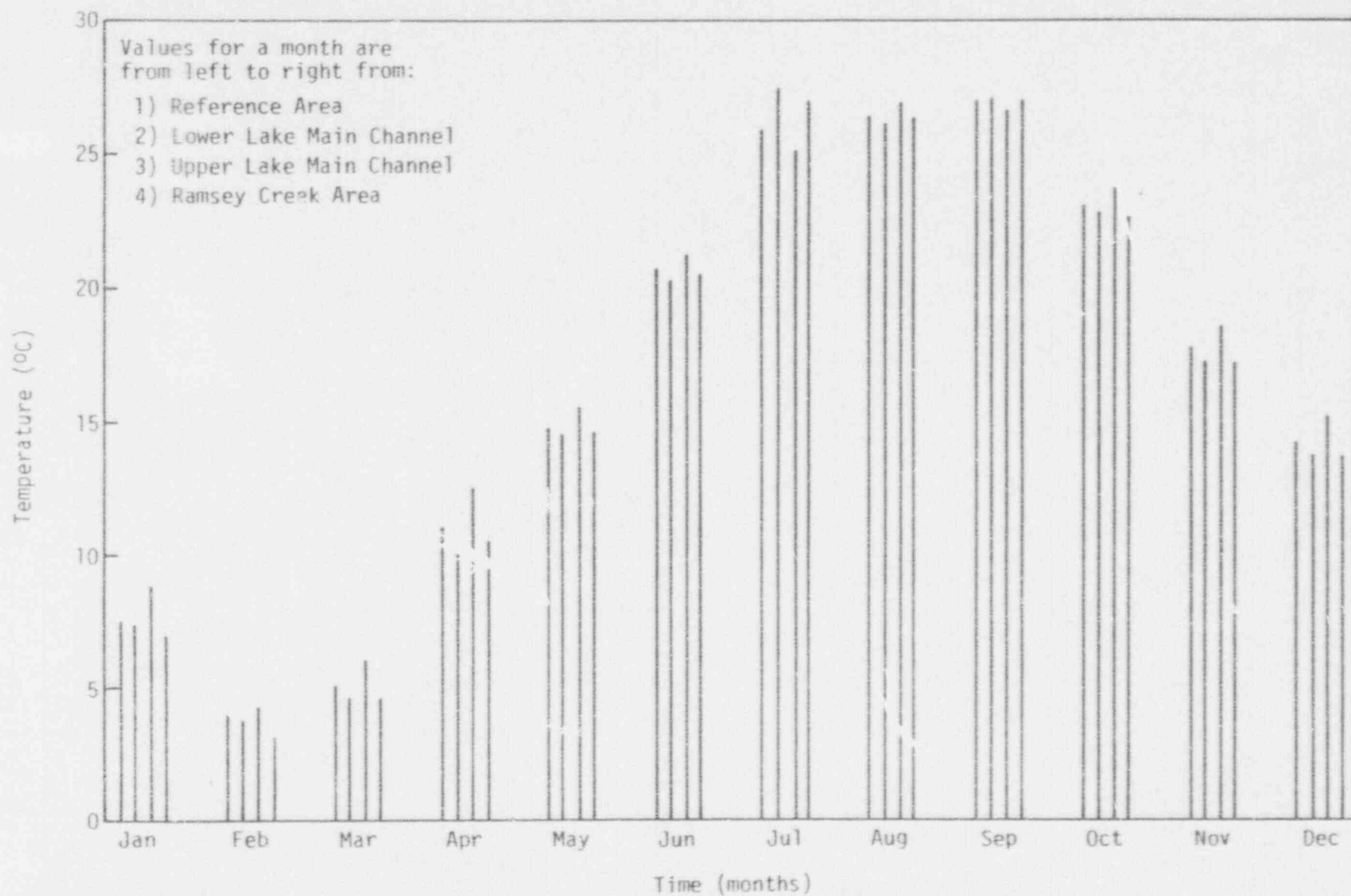


Figure 2-53. Volume-weighted temperature (0.3 to 10 m depth) comparisons for four zones in Lake Norman in 1978.

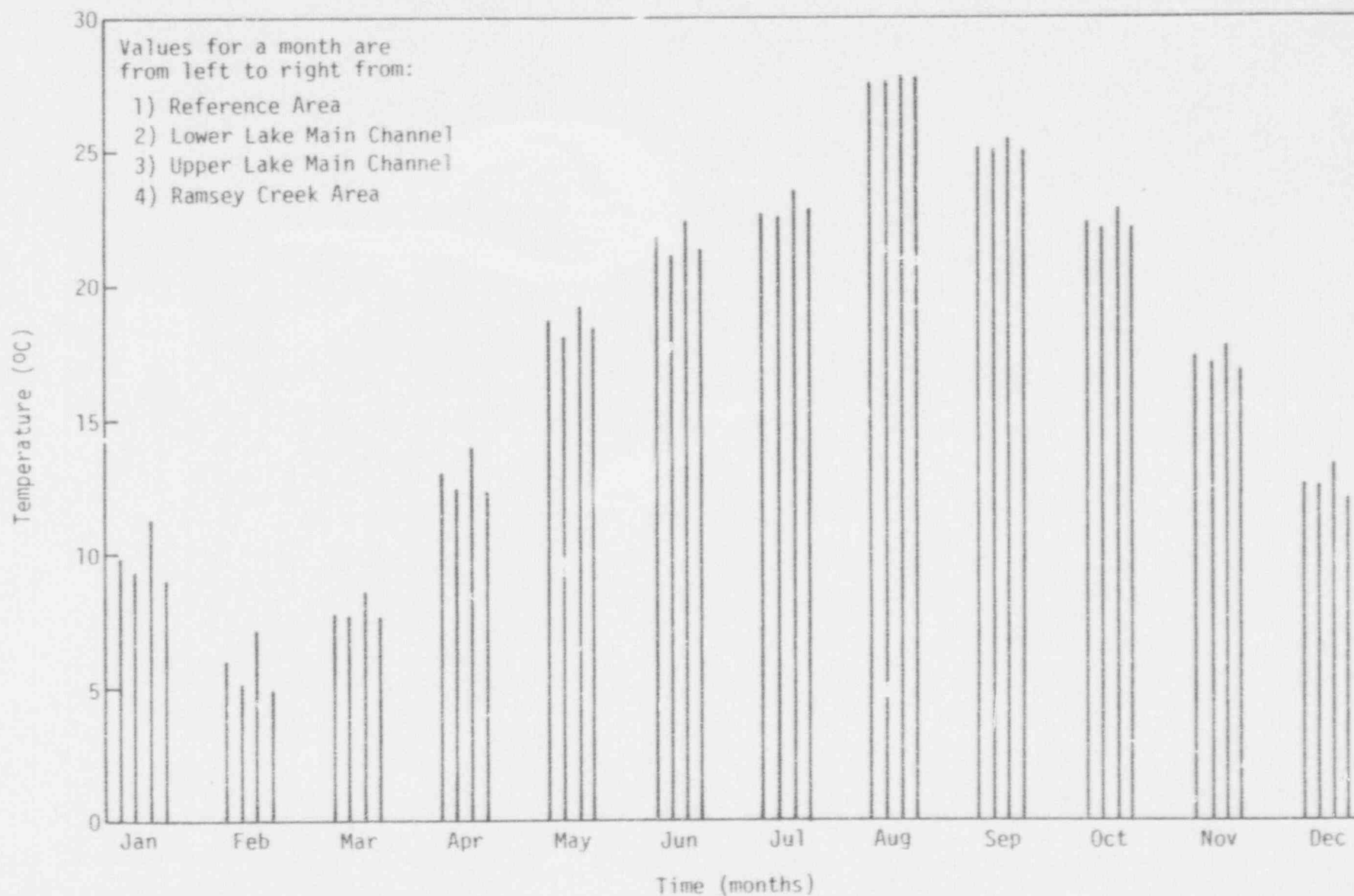


Figure 2-54. Volume-weighted temperature (0.3 to 10 m depth) comparisons for four zones in Lake Norman in 1979.

CHAPTER 3. WATER CHEMISTRY
J. C. PERKINS AND T. L. WHISENANT

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INTRODUCTION

BACKGROUND

The physicochemical characteristics of Lake Norman have been documented by previous water quality studies (Bowling and Flowe 1977; Duke Power Company 1976; Jensen et al. 1974; Weiss et al. 1975). These studies showed similar trends for the variables measured. The general water quality of Lake Norman reflected the lithology of the Catawba River drainage area. Waters associated with the metamorphic rock types described in Chapter 1 are typically low in dissolved solids. The mineral composition of Lake Norman was dominated by sodium, calcium, and bicarbonate. Total hardness concentrations ranged from 8 to 15 $\text{mg-CaCO}_3 \cdot \text{L}^{-1}$ (Duke Power Company 1976). Alkalinity values in Lake Norman were generally less than 25 $\text{mg-CaCO}_3 \cdot \text{L}^{-1}$. These hardness and alkalinity values indicate that Lake Norman is a soft water lake. Fluctuations in pH were common due to the low buffering capacity of Lake Norman water with pH values fluctuating between 6 and 8 pH units (Duke Power Company 1976; Jensen et al. 1974).

Because oxygen solubility increases with decreasing temperatures, the highest dissolved oxygen (DO) levels were observed during the winter months. The DO concentrations were generally at or above 7.0 $\text{mg} \cdot \text{L}^{-1}$ throughout the water column from December through April (Duke Power Company 1976; Jensen et al. 1974; Weiss et al. 1975). Hypolimnetic oxygen depletion began in June with anoxic conditions being observed in the bottom waters from August through October.

Inorganic nitrogen levels were dominated from December through May by nitrate plus nitrite while ammonia was the dominant nitrogen form from August through November in the bottom waters. Nitrate plus nitrite concentrations ranged from less than 0.010 to 0.50 $\text{mg-N} \cdot \text{L}^{-1}$ with an average annual mean of approximately 0.25 $\text{mg-N} \cdot \text{L}^{-1}$. Ammonia concentrations for Lake Norman waters ranged from less than 0.010 to 3.1 $\text{mg-N} \cdot \text{L}^{-1}$ with an average annual mean of approximately 0.20 $\text{mg-N} \cdot \text{L}^{-1}$ (Duke Power Company 1976; Jensen et al. 1974).

Orthophosphate concentrations for Lake Norman waters were around 0.005 $\text{mg-P} \cdot \text{L}^{-1}$. Silica, a nutrient source for diatoms, ranged from 5 to 8 $\text{mg-Si} \cdot \text{L}^{-1}$ before impoundment (1939 to 1961). Following impoundment of Lake Norman silica values ranged from 2 to 5 $\text{mg-Si} \cdot \text{L}^{-1}$ in the surface waters. The decrease in silica concentrations was attributed, in part, to diatom uptake (Duke Power Company 1976).

OBJECTIVES

The objectives of this study were to:

- 1) document the physicochemical characteristics of Lake Norman with regard to dissolved oxygen, pH, alkalinity, turbidity, conductivity, minerals, nutrients, and trace metals,
- 2) describe the vertical and horizontal distribution of the physicochemical variables, and
- 3) examine seasonal trends of the physicochemical variables.

MATERIALS AND METHODS

SAMPLING LOCATIONS AND FREQUENCY

Twenty eight locations were sampled on Lake Norman from 1974 through 1980 (Table 3-1; Fig. 1-10 and 1-11). This report summarizes data collected from January 1975 through December 1979 at the following locations: 1.0, 1.2, 2.0, 3.0, 4.0, 4.5, 5.0, 6.0, 7.5, 8.0, 11.0, 13.0, 14.0, 15.0, and 16.0. All samples were collected monthly during this period except for trace metals which were generally collected on a quarterly basis. During 1975 and 1976, sampling was performed the last week of the month. Beginning in 1977, sampling was performed the first week of the month. This sampling change caused an apparent shift of approximately one month in the temporal trends of some variables.

FIELD PROCEDURES

Profile measurements of DO, pH, and specific conductance were obtained in-situ using a Hydrolab Surveyor Model 6D water quality analyzer. In September 1976, oxidation-reduction potential was added to the in-situ measurements. Profiles were taken at one meter intervals from surface (0.3 m) to 1 m off the bottom, at all locations, throughout the five year study period (1975 through 1979). The manufacturer's recommended calibration procedures were performed before each monthly sampling. Methods for the measurements of these variables are presented in Table 3-2.

LABORATORY PROCEDURES

A diaphragm pump was used to collect the samples analyzed in the laboratory. Beginning in June 1977, duplicate samples were collected near the surface and bottom of all locations. Prior to July 1978 profile samples were collected at all locations for nutrient and mineral analyses. Examination of past data indicated that more locations than necessary were being sampled to adequately characterize the water column. Beginning in July 1978 the number of locations profiled were decreased to the following: 2.0, 3.0, 5.0, 8.0, and 15.0.

Samples for nutrient determination were collected in acid washed linear polyethylene bottles, stored on ice, and returned to the laboratory. Samples for metal analyses except mercury, were collected in acid washed linear polyethylene bottles containing 0.5% HNO_3 as a preservative. Mercury samples were preserved with 1% HNO_3 . The analytical methods, references, and preservatives for each variable are listed in Table 3-2. All analytical methods were approved by the USEPA (1974).

New techniques for various analyses were employed to lower the analytical detection limits and increase laboratory efficiency. The method changes are documented in Table 3-2. The limit of determination (Currie 1968) and detection limits, which were determined on the majority of variables, are also documented in Table 3-2. The precision and accuracy of the data were affirmed in accordance with the procedures outlined by the USEPA (1972).

DATA ANALYSES

All physicochemical data collected from 1974 through 1980 is given in Appendices 3.1 through 3.34. This chapter will discuss data collected from 1975 through 1979. In summarizing the large amount of data collected from 1975 through 1979 the following locations were grouped into specific areas: Ramsey Creek area (Locations 3.0, 4.5, and 5.0), Lower Main Channel area (Locations 1.0, 2.0, and 7.5), Reference area (Locations 8.0 and 11.0), Upper Main Channel area (Locations 13.0 and 15.0). The following areas consist of only one location: McGuire Intake area (Location 1.2), McGuire Discharge area (Location 4.0) and Catawba River area (Location 16.0). These groupings were based primarily on the geographic areas of each location. However, the variability (standard deviation, maximum, minimum, median) of each location within an area also aided in grouping the locations. Unless defined differently in the remainder of the chapter, "surface waters" refers to depths from 0.3 to 2 m and "bottom waters" to depths equal to or greater than 20 m. In discussing seasonal variability the following monthly divisions were made: winter (December through February), spring (March through May), summer (June through August), and fall (September through November).

Bicarbonate values were calculated from alkalinity values using Hem's (1970) factor. Carbon dioxide concentrations were derived from Stumm and Morgan (1970) as follows:

$$pK_1 = [6.572 - 0.01 (\text{TEMP})] - \frac{2.04 \times 10^{-3} \sqrt{\text{COND}}}{[(1 + (5.73 \times 10^{-3} \sqrt{\text{COND}}))]}$$

$$pK_2 = [10.614 - 0.012 (\text{TEMP})] - \frac{8.18 \times 10^{-3} \sqrt{\text{COND}}}{[(1 + (5.73 \times 10^{-3} \sqrt{\text{COND}}))]}$$

$$[H] = 10^{-pH}$$

$$K_1 = 10^{-pK_1}$$

$$K_2 = 10^{-pK_2}$$

$$\text{mmole CO}_2 \cdot \ell^{-1} = \text{ALKALINITY} \left(\frac{[H]}{K_1(1 + \frac{2K_2}{[H]})} \right)$$

$$\text{mg CO}_2 \cdot \ell^{-1} = (44) \text{ mmole CO}_2 \cdot \ell^{-1}$$

Where TEMP = °C

COND = $\mu\text{mho} \cdot \text{cm}^{-1}$

ALKALINITY = $\text{meq} \cdot \ell^{-1}$

Water chemistry and meteorological data were subjected to Pearson's correlation analysis (Helwig and Council 1970). Only results with $p < 0.05$ were considered statistically significant. Standard deviation is denoted by "s".

RESULTS AND DISCUSSION

GENERAL WATER QUALITY VARIABLES

DISSOLVED OXYGEN

Previous aquatic chemistry studies performed on Lake Norman reported DO trends similar to those observed during this study (Table 3-3). Dissolved oxygen concentrations in Lake Norman followed seasonal patterns typical of other Piedmont Carolina reservoirs (Bowling and Flowe 1977; Katnik et al. 1974). Lowest DO values generally occurred from July through October and the highest concentrations occurred in February and March (Figure 3-1). Depletion of DO concentrations in Lake Norman began in late April with reoxygenation of the water column occurring by late November. The mean DO concentration in Lake Norman was $7.7 \text{ mg} \cdot \text{l}^{-1}$ ($s = 3.6$) with annual means ranging from $7.3 \text{ mg} \cdot \text{l}^{-1}$ ($s = 3.3$) in 1975 to $7.8 \text{ mg} \cdot \text{l}^{-1}$ ($s = 3.5$) in 1978. Dissolved oxygen concentrations in Lake Norman generally ranged from 8.0 to $12.0 \text{ mg} \cdot \text{l}^{-1}$ from December through April (Fig. 3-2 through 3-5) indicating thorough vertical mixing throughout this period.

As thermal stratification developed in May, a reduction in DO concentrations was observed in the bottom waters. Thermal density gradients forming in the water column limited mixing of epilimnetic and hypolimnetic waters. Thus, as biological respiration and chemical oxidation continued, DO concentrations in the bottom waters steadily decreased throughout the summer and early fall. From July through October, bottom DO values were less than $5.0 \text{ mg} \cdot \text{l}^{-1}$ (Fig. 3-2 through 3-5). By November, destratification was well underway and only the bottom 1 to 3 m of the deepest locations exhibited low DO concentrations (Fig. 3-6).

From 1975 through 1979 all locations except 13.0 and 14.0 exhibited DO concentrations above $5.0 \text{ mg} \cdot \text{l}^{-1}$ at the surface. From July through October, Location 14.0 exhibited surface DO concentrations generally at or below $5.0 \text{ mg} \cdot \text{l}^{-1}$. The hypolimnetic water used for condenser cooling at Marshall Steam Station was the reason for the low DO at Location 14.0. Only during September 1977 and October 1978 were surface DO values at Location 13.0 below $5.0 \text{ mg} \cdot \text{l}^{-1}$. A concentration of $4.1 \text{ mg} \cdot \text{l}^{-1}$ and $4.2 \text{ mg} \cdot \text{l}^{-1}$ was recorded in September 1977 and October 1978, respectively, at Location 13.0. In October 1978, as a result of Marshall Steam Station using hypolimnetic water for condenser cooling, the DO at Locations 13.0 and 14.0 was between 3.0 and $4.5 \text{ mg} \cdot \text{l}^{-1}$ from 0.3 through 8 meters (Fig. 3-7). The decrease in DO in this general area of Lake Norman was also documented by Jensen et al. (1974). Dissolved oxygen concentrations at Locations 11.0 and 15.0 may also have been affected in October of 1978 by Marshall's operation (Fig. 3-7). However, fish and other oxygen requiring organisms were probably not adversely affected by the oxygen levels observed at these locations.

Mean DO values for July through September were calculated over the study period to give an overall indication of DO trends in the vicinity of McGuire Nuclear Station. Locations in the vicinity of McGuire exhibited DO concentrations above $5.0 \text{ mg} \cdot \text{l}^{-1}$ from surface (0.3 meters) through 5.0 meters (Fig. 3-8 through 3-10). Due to biological respiration and chemical oxidation depleting DO, the concentrations at 10 m were at or below $5.0 \text{ mg} \cdot \text{l}^{-1}$ from July through August (Fig. 3-8 through 3-10).

Oxygen saturation values in the surface waters of Lake Norman ranged from 50 to 140% with 42% of the values being greater than 100%. From March through August the surface waters exhibited oxygen saturation values generally around 100% (Fig. 3-11). Bottom water oxygen saturation values ranged from 0 to 110% with less than 1% of the values being above 100%. Maximum surface to bottom differences occurred from July through October (Fig. 3-11) and reflected natural processes of photosynthesis and reaeration in the surface waters and respiration and oxidation in the bottom waters.

ALKALINITY AND pH

Alkalinity values, an indicator of bicarbonate concentrations (Wetzel 1975), indicate that Lake Norman is a soft water lake. Annual means ranged from 11 mg-CaCO₃·ℓ⁻¹ (s = 2) in 1978 to 14 mg-CaCO₃·ℓ⁻¹ (s = 5) in 1975. These alkalinity values were similar to those reported in Lake Wylie (Katnik et al. 1974) and in Lakes Keowee and Hartwell (Duke Power Company 1977). The range of alkalinity values in Lake Norman was from 5 to 40 mg-CaCO₃·ℓ⁻¹ with an overall mean of 12 mg-CaCO₃·ℓ⁻¹ (s = 3.0). Little difference was observed between surface and bottom alkalinity values (Fig. 3-12) except during the fall, when bottom alkalinities increased. This increase in alkalinity concentrations was due to carbon dioxide reacting with carbonates of calcium and magnesium to form bicarbonate (Hutchinson 1957). This increase in bicarbonate concentration during the fall generally kept the bottom pH from falling below 6.0 (Fig. 3-12).

Due primarily to the geology of the area, pH values in Lake Norman waters are slightly acidic. The mean pH value from 1975 through 1979 was 6.7 (s = 0.5), with annual means ranging from 6.5 (s = 0.6) in 1975 to 6.7 (s = 0.4) in 1977. Highest surface pH values generally occurred during the summer when photosynthetic activity was greatest. This trend was observed in Lake Wylie, (Katnik et al. 1974) and in Lakes Keowee and Hartwell (Duke Power Company 1977). Surface to bottom pH differences were greatest during the summer (Figure 3-12). This was attributed to an increase in carbon dioxide, due to biological respiration, lowering the pH of the bottom waters (Fig. 3-13). Photosynthetic activity and reaeration of the surface waters prevented any major increase in carbon dioxide in the surface waters. Alkalinity and pH values exhibited small spatial differences (Tables 3-4 and 3-5). Previous aquatic studies on Lake Norman reported similar alkalinity and pH values (Table 3-3).

TURBIDITY

Turbidity, an indicator of suspended particulate matter, ranged from 1 to 74 NTU in Lake Norman. The overall mean turbidity value was 17 NTU (s = 14), with annual means ranging from 12 NTU (s = 12) in 1977 to 21 NTU (s = 15) in 1975. The higher surface turbidity values were generally observed during the winter and early spring, while July through October were periods of low surface turbidities (Fig. 3-14). Historical records (1941-1970) indicated that the mean wind speed was lowest from July through October ranging from 10.6 to 11.4 K·H⁻¹. Highest wind speed values were recorded from January through April (12.8 to 15.2 K·H⁻¹) (NOAA 1979). Surface turbidity values correlated with wind speed (r = 0.51) indicating that wind speed directly influences turbidity values in Lake Norman.

Due to inputs from the Catawba River and Marshall Steam Station's use of hypolimnetic water, highest turbidity values occurred in the Upper Main Channel

area (Fig. 3-15 and Tables 3-4 and 3-5). Turbidity values decreased with distance from the Upper Main Channel area due to settling of particulate matter (Fig. 3-16).

MINERAL COMPOSITION

Mineral composition and variability in Lake Norman were attributed to geological processes involving the physical and chemical weathering of soils and bedrock outcroppings. Feldspars (orthoclase $[K(AlSi_3O_8)]$, plagioclase $[Ca,Na(AlSi_3O_8)]$), quartz (SiO_2), and olivine $[Mg_2, Fe_2(SiO_4)]$ are the most commonly occurring minerals. Surface waters associated with such metamorphic rock types are generally characterized by low solute concentrations (Hem 1970). Lake Norman waters, exhibiting a hardness value of approximately $10 \text{ mg-CaCO}_3 \cdot \text{L}^{-1}$ exemplified a soft water lake.

Bicarbonate was the major ion in Lake Norman. Sodium, chloride, calcium, magnesium, silica, and potassium were also abundant constituents in Lake Norman waters (Fig. 3-17). Minor constituents included aluminum, iron, and manganese. Except for aluminum, no substantial yearly variability was observed in the concentrations of the various minerals. Aluminum concentrations appeared to be associated with increases in turbidity. However, no statistical correlation was observed between aluminum and turbidity, probably due to aluminum being analyzed from quarterly composites.

IRON AND MANGANESE

Both iron and manganese possess similar chemical properties and are important as micronutrients of freshwater flora and fauna (Wetzel 1975) and as indicators of oxidation-reduction processes. Although the concentrations of these micronutrients were generally low throughout most of the year, the concentration of iron and manganese during the fall are higher in the bottom waters.

The mean iron concentration for the study period 1975 through 1979 was $0.8 \text{ mg} \cdot \text{L}^{-1}$ ($s = 0.9$), with annual means ranging from $0.5 \text{ mg} \cdot \text{L}^{-1}$ ($s = 0.7$) in 1976 to $1.1 \text{ mg} \cdot \text{L}^{-1}$ ($s = 0.9$) in 1975. Iron values in the bottom waters were consistently high in the fall of each year (Fig. 3-18) and were associated with anoxic conditions. The anoxic conditions were conducive for iron ions to diffuse from the sediment into the water column (Wetzel 1975). Due to increased runoff associated with rainfall, surface iron values were highest during the winter and spring (Fig. 3-18). The correlation of iron with turbidity ($r = 0.72$) in the surface waters indicates the major source of iron in the surface waters was from suspended particulate matter.

The Piedmont soils of the Catawba River drainage basin are a major source of iron to Lake Norman. This was reflected in the higher iron concentrations in the Upper Main Channel area of Lake Norman (Fig. 3-19, Tables 3-4 and 3-5). The deep water areas of Lake Norman consisting of the Upper Main Channel area, the Reference area, and the Lower Main Channel area exhibited two annual peaks in iron concentrations (Fig. 3-19). Iron concentrations peaked during spring due to increased suspended particulate matter in surface waters. A fall peak was observed due to diffusion of iron from the sediments into the bottom waters. Generally, the other lake areas showed high iron concentrations only in the spring (Fig. 3-19).

The mean manganese concentration for the study period 1975 through 1979 was $0.21 \text{ mg} \cdot \text{L}^{-1}$ ($s = 0.54$) with annual means ranging from $0.16 \text{ mg} \cdot \text{L}^{-1}$ ($s = 0.53$) in 1978 to $0.27 \text{ mg} \cdot \text{L}^{-1}$ ($s = 0.67$) in 1977. Surface concentrations of manganese were low throughout the study period (Fig. 3-18). Manganese concentrations were highest in the bottom waters usually from September through November (Fig. 3-18) when the reducing conditions were conducive for manganese ions to diffuse from the sediment into the water column. Manganese concentrations in the bottom waters correlated inversely with dissolved oxygen concentrations ($r = -0.58$) and oxidation-reduction potential ($r = -0.75$). Manganese concentrations were highest during the fall in the Upper Main Channel area, Reference area, and Lower Main Channel area (Fig. 3-20). The Ramsey Creek area to a lesser degree also exhibited this increase in manganese concentration in the fall (Fig. 3-20).

SPECIFIC CONDUCTANCE

Specific conductance is an indicator of ionized substances in fresh water (Wetzel 1975). The mean specific conductance value for the study period 1975 through 1979 was $40 \text{ } \mu\text{mho} \cdot \text{cm}^{-1}$ ($s = 6$), with specific conductance values ranging from 23 to $92 \text{ } \mu\text{mho} \cdot \text{cm}^{-1}$. Surface conductivities generally ranged from 40 to $45 \text{ } \mu\text{mho} \cdot \text{cm}^{-1}$ (Fig. 3-21) indicating uniform mixing of dissolved solids in the surface water throughout each year. Previous studies on Lake Norman reported similar conductivity values (Table 3-3). Surface to bottom differences in conductivity were greatest during October and November (Fig. 3-21) as a result of ions (iron and manganese, etc.) diffusing from the sediment into the water column. Inputs of dissolved substances into the Catawba River (surface runoff, etc.) were indicated by the relatively high specific conductance values recorded at the Catawba River area (Fig. 3-22, Tables 3-4 and 3-5).

AQUATIC NUTRIENTS

INORGANIC NITROGEN

The mean nitrate plus nitrite concentration for the study period 1975 through 1979 was $0.26 \text{ mg-N} \cdot \text{L}^{-1}$ ($s = 0.14$), with annual means ranging from $0.22 \text{ mg-N} \cdot \text{L}^{-1}$ ($s = 0.11$) in 1976 to $0.34 \text{ mg-N} \cdot \text{L}^{-1}$ ($s = 0.17$) in 1978. Maximum concentrations of nitrate plus nitrite generally occurred in winter and spring in both the surface and bottom waters (Fig. 3-23). These high concentrations were associated with oxidizing conditions that prevailed in Lake Norman waters during this part of the year (Wetzel 1975). During the summer, nitrate plus nitrite concentrations decreased from the high spring values due to nutrient utilization (Chapter 4) which was accompanied by increased rates of bacterial decomposition and lower redox potential. The minimum nitrate plus nitrite concentrations occurred during late summer and fall (Fig. 3-23) and were associated with reducing conditions in Lake Norman bottom waters. These trends were also observed in Lakes Keowee and Hartwell (Duke Power Company 1977). Little spatial variability in nitrate plus nitrite was observed in the study area (Fig. 3-24, Tables 3-4 and 3-5).

The mean ammonia concentration for the study was $0.15 \text{ mg-N} \cdot \text{L}^{-1}$ ($s = 0.17$). The highest values occurred when reducing conditions were prevalent and dissolved oxygen concentrations were low, generally in October and November. Ammonia concentrations in the bottom waters were inversely correlated with oxidation-reduction

potential ($r = -0.62$). Little spatial variability of ammonia concentrations was observed in the study area (Fig. 3-25, Tables 3-4 and 3-5). As with nitrate plus nitrite concentrations, ammonia concentrations in Lake Norman were similar to those reported in previous studies performed on Lake Norman (Table 3-3).

PHOSPHORUS

The temporal trends of total phosphorus and orthophosphate were similar. However, because 64% of orthophosphate values were less than the analytical detection limit of $0.005 \text{ mg-P} \cdot \ell^{-1}$, no significant correlation with total phosphorus concentrations was observed. The mean total phosphorus concentration for the study period 1975 through 1979 was $0.020 \text{ mg-P} \cdot \ell^{-1}$, with annual means ranging from $0.013 \text{ mg-P} \cdot \ell^{-1}$ ($s = 0.009$) in 1977 to $0.028 \text{ mg-P} \cdot \ell^{-1}$ ($s = 0.016$) in 1975. Surface concentrations of total phosphorus were highest in the spring and were associated with runoff. Concentrations of total phosphorus in the bottom waters were high in the spring and in the fall (Fig. 3-23). The higher total phosphorus concentrations in the spring corresponded to periods of increased turbidity due to rainfall. The hypolimnetic increases in total phosphorus in the fall were due to the release of orthophosphate from the sediment during anoxic conditions (Golterman 1975).

The greatest variability in total phosphorus concentrations was exhibited in the Catawba River area (Figure 3-26). Highest total phosphorus concentrations in Lake Norman were observed in the Upper Main Channel area (Fig. 3-26), with a gradual decrease in total phosphorus with distance downstream from the Upper Main Channel area. Total phosphorus concentrations exhibited trends similar to other reservoirs (Duke Power Company 1977; Weiss et al. 1975), with total phosphorus concentrations in Lake Norman gradually decreasing over the years (Table 3-3). Reasons for this apparent decrease in Lake Norman may be due to the adsorption of phosphorus onto suspended clay particles which settle to the lake sediment (Golterman 1973).

SILICA

The mean silica concentration for the study period 1975 through 1979 was $3.6 \text{ mg-Si} \cdot \ell^{-1}$ ($s = 0.5$), with annual means ranging from $3.2 \text{ mg-Si} \cdot \ell^{-1}$ ($s = 0.5$) in 1977 to $4.1 \text{ mg-Si} \cdot \ell^{-1}$ ($s = 1.0$) in 1979. Highest silica concentrations were generally observed from October through February (Fig. 3-27). These higher silica concentrations were probably due to a decrease in diatom productivity since silica is removed from lake waters during the development of diatom populations (Hutchinson 1957). Due to the assimilation of silica by diatoms (Chapter 4) and subsequent sedimentation of diatoms (Wetzel 1975), silica concentrations decreased during spring (Fig. 3-27) and remained low in the surface waters until destratification of the water column in October and November. Silica concentrations exhibited similar spatial trends throughout the sampling areas of Lake Norman (Fig. 3-28, Tables 3-4 and 3-5).

TRACE METALS

Copper, cadmium, mercury, zinc, and lead were monitored to evaluate the trends in trace element concentrations of Lake Norman. Trace metals are those metals with concentrations usually not exceeding $1 \text{ mg} \cdot \ell^{-1}$ (Rubin 1974).

Copper concentrations ranged from 1.0 to 16 $\mu\text{g}\cdot\text{L}^{-1}$ with an overall mean of 3.4 $\mu\text{g}\cdot\text{L}^{-1}$. Copper concentrations were generally highest during the summer (Fig. 3-29) and were attributed to hypolimnetic increases associated with dissolution of copper-containing organic compounds from the sediment (Hutchinson 1957). Cadmium concentrations ranged from 0.1 to 0.5 $\mu\text{g}\cdot\text{L}^{-1}$ with an overall mean of 0.2 $\mu\text{g}\cdot\text{L}^{-1}$. Generally, where seasonal changes were detected, highest concentrations were observed during the spring and summer (Fig. 3-29). The seasonal trends observed for copper and cadmium were typical of the trends observed in Lake Keowee (Duke Power Company 1977).

Mercury concentrations ranged from less than 0.1 to 0.3 $\mu\text{g}\cdot\text{L}^{-1}$. Generally, mercury concentrations were below the analytical detection limit of 0.1 $\mu\text{g}\cdot\text{L}^{-1}$. Mercury concentrations in fresh water are usually inorganically complexed and removed from the active mercury cycle (Schindler and Alberts 1977). Mercury may be adsorbed by clays, sands, or oxides in sediment resulting in relatively low levels of mercury in water (Schindler and Alberts 1977).

Zinc concentrations ranged from 1.0 to 48 $\mu\text{g}\cdot\text{L}^{-1}$ with an overall mean of 11 $\mu\text{g}\cdot\text{L}^{-1}$. Where seasonal changes were detected, the highest concentrations of zinc usually occurred during the fall and/or winter (Fig. 3-29). Lead concentrations ranging from less than 2.0 to 3.8 $\mu\text{g}\cdot\text{L}^{-1}$ showed little variability over the period 1977 through 1979.

SUMMARY

In characterizing Lake Norman waters 28 locations were sampled from 1974 through 1980. Thirteen of these locations were sampled monthly during the entire study period. Some analytical methods were changed and/or updated during the period to obtain lower detection limits and increase laboratory efficiency.

The physicochemical characteristics of Lake Norman waters reflect the lithology of the basin. Lake Norman waters were characterized by slightly acidic pH values, low hardness, stable mineral composition, and generally low nutrient and trace metal concentrations. Little yearly variation existed in variables analyzed from 1975 through 1979. Previous Lake Norman studies manifested similar variation in the physicochemical variables observed during this study. Spatial characteristics in Lake Norman indicated that variables related to runoff (turbidity, iron, orthophosphate, and total phosphorus) were highest in the Upper Main Channel area with concentrations decreasing with distance downstream from this area. Greatest overall variability was generally observed in the Catawba River area. Surface turbidity values were highest during winter and spring with lowest values being observed during the summer and fall.

Dissolved oxygen concentrations exhibited seasonal trends typical of Piedmont Carolina waters with highest values occurring from December through April and lowest concentrations from July through October. Except for Locations 13.0 and 14.0 near the Marshall Steam Station discharge, dissolved oxygen concentrations in the surface waters were above 5.0 $\text{mg}\cdot\text{L}^{-1}$ throughout the year. Generally, Location 14.0 exhibited surface DO concentrations at or below 5.0 $\text{mg}\cdot\text{L}^{-1}$ from July through October. Only during September 1977 and October 1978 were surface DO values less than 5.0 $\text{mg}\cdot\text{L}^{-1}$ at Location 13.0. Anoxic conditions existed in the hypolimnion from August through October and were accompanied by increased concentrations of ammonia, iron, manganese, and alkalinity. Following destratification in November, all effects of summer anoxia had dissipated from Lake Norman.

waters. Nutrient concentrations exhibited seasonal cycles typical of Piedmont Carolina waters with nitrate plus nitrite being the dominant nitrogen species in winter and spring, and ammonia the dominant species during fall. Total phosphorus concentrations exhibited seasonal trends similar to turbidity with highest concentrations being observed in the winter and spring and lowest concentration in the summer.

Cadmium, copper, lead, mercury, and zinc were monitored to assess trends in the trace metals concentration in Lake Norman. Changes in cadmium, zinc and copper concentrations were associated with changes in oxidation-reduction potential. Lead and mercury concentrations showed little variability with concentrations generally at the analytical detection limit.

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Table 3-1. Locations sampled and types of variables analyzed from 1974 through 1980.

Locations	1974	1975	1976	1977	1978	1979	1980
1.0	***	***5	***4	***4	***4	***4	***4
1.2	0000	0000	0000	7770	***0	***0	***0
2.0	***7	***4	***4	***2	***0	***0	***0
3.0	***7	***4	***4	***4	***0	***0	***0
4.0	***7	***4	***4	***2	***4	***4	***4
4.5	***	***5	***3	***4	***0	***0	***0
5.0	***7	***4	***4	***2	***0	***0	***0
6.0	***7	***4	***4	***2	***0	***0	***0
7.0	***7	0000	0000	0000	0000	0000	0000
7.5	0000	***4	***4	***2	***0	***0	***0
8.0	***	***5	***4	***4	***4	***4	***4
9.0	***7	0000	0000	0000	0000	0000	0000
9.5	0000	0000	0000	0000	*000	*550	***0
10.0	***7	***4	0000	0000	0000	0000	0000
11.0	***7	***4	***4	***2	***0	***0	***0
12.0	***7	0000	0000	0000	0000	0000	0000
13.0	***7	***4	***4	***2	***0	***0	***0
14.0	***	***5	***4	***4	***4	***4	***4
14.5	3222	***4	0000	0000	0000	0000	0000
15.0	***7	***4	***4	***4	***0	***0	***0
15.9	0000	0000	0000	0000	7772	5551	0000
16.0	***7	***4	***4	***4	***0	***0	***0
17.0	1119	0000	0000	0000	0000	0000	0000
17.5	6666	***5	0000	0000	0000	0000	0000
18.0	***	***5	0000	0000	0000	0000	0000
34.0	0000	0000	0000	0000	7770	5550	0000
50.0	0000	0000	0000	0000	7000	5000	0000
60.0	0000	0000	0000	0000	7000	5000	0000

Each digit in the four digit code represents a different group of variables sampled that year as follows: 1st digit - physical variables; 2nd digit - nutrients; 3rd digit - minerals; 4th digit - trace metals. The value of a digit represents the number of times that group of variables was sampled at a location during that year. A number is shown even if only one of the variables of a group was sampled. An asterisk (*) indicates a group of variables were sampled more than nine times in a year. For more detail, see Appendix 3.1 through 3.34.

Table 3-2. Analytical methods for chemical and physical constituents measured on Lake Norman from 1975 through 1980.

Variables	Method	Time Period	Preservation	Detection Limit	Limit of Determination
Alkalinity, total	Electrometric titration to a pH of 5.1 ¹	1/1975-12/1980	4°C	1 mg-CaCO ₃ -l ^{-1*}	
Aluminum	Atomic absorption/HGA ¹ Atomic absorption/DA ¹	1/1975-7/1978 8/1978-12/1980	0.5% HNO ₃	0.2 mg-l ⁻¹	0.6 mg-l ⁻¹
Ammonia	Automated phenate ¹ Automated salicylate/nitroprusside ¹	1/1975-2/1976 5/1977-12/1980 6/1976-4/1977	4°C	0.006 mg-N-l ⁻¹	0.009 mg-N-l ⁻¹
Cadmium	Atomic absorption/HGA ¹	1/1975-12/1980	0.5% HNO ₃	0.11 µg-l ⁻¹	0.27 µg-l ⁻¹
Calcium	Atomic absorption/DA ¹	1/1975-12/1980	0.5% HNO ₃	0.06 mg-l ⁻¹	0.06 mg-l ⁻¹
Chloride	Specific ion electrode ² Automated ferri-yanide ¹	1/1975-6/1976 7/1976-12/1980	4°C	0.2 mg-l ⁻¹	0.3 mg-l ⁻¹
Chromium	Atomic absorption/HGA ¹	1/1975-12/1980	0.5% HNO ₃	0.6 µg-l ⁻¹	1.0 µg-l ⁻¹
Conductance, specific	Temperature compensated nickel electrode ¹	1/1975-12/1980	In-situ	1 µmho/cm ^{-1*}	
Copper	Atomic absorption/HGA ¹	1/1975-12/1980	0.5% HNO ₃	0.7 µg-l ⁻¹	1.0 µg-l ⁻¹
Iron, dissolved	Atomic absorption/DA ¹	1/1975-12/1980	0.5% HNO ₃	0.1 mg-l ⁻¹	0.2 mg-l ⁻¹
Iron, total	Atomic absorption/DA ¹	1/1975-12/1980	0.5% HNO ₃	0.1 mg-l ⁻¹	0.2 mg-l ⁻¹
Lead	Atomic absorption/HGA ¹	1/1975-12/1980	0.5% HNO ₃	2 µg-l ⁻¹	3.2 µg-l ⁻¹
Magnesium	Atomic absorption/DA ¹	1/1975-12/1980	0.5% HNO ₃	0.007 mg-l ⁻¹	0.01 mg-l ⁻¹
Manganese	Atomic absorption/DA ¹	1/1975-12/1980	0.5% HNO ₃	0.02 mg-l ⁻¹	0.06 mg-l ⁻¹
Mercury, total	Flameless atomic absorption ¹	1/1975-12/1980	1.0% HNO ₃	0.1 µg-l ⁻¹	ND
Nickel	Atomic absorption/HGA ¹	1/1975-12/1980	0.5% HNO ₃	0.6 µg-l ⁻¹	0.9 µg-l ⁻¹
Nitrate + Nitrite	Automated cadmium reduction ¹	1/1975-12/1980	4°C	0.005 mg-N-l ⁻¹	0.008 mg-N-l ⁻¹
Orthophosphate	Automated ascorbic acid reduction ¹	1/1975-12/1980	4°C	0.005 mg-P-l ⁻¹	0.008 mg-P-l ⁻¹
Oxidation-reduction potential	Silver-silver chloride electrode ³	9/1976-12/1980	In-situ	10 mv*	
Oxygen, dissolved	Temperature compensated polarographic cell ¹	1/1975-12/1980	In-situ	0.1 mg-l ^{-1*}	
pH	Temperature compensated glass electrode ¹	1/1975-12/1980	In-situ	0.1*	
Phosphorus, total	Persulfate digestion followed by automated ascorbic acid reduction ¹	1/1975-12/1980	4°C	0.004 mg-P-l ⁻¹	0.006 mg-P-l ⁻¹
Potassium	Atomic absorption/DA ¹	1/1975-12/1980	0.5% HNO ₃	0.03 mg-l ⁻¹	0.06 mg-l ⁻¹
Silica	Automated molybdisilicate ¹	1/1975-12/1980	4°C	1.2 mg-Si-l ⁻¹	0.3 mg-Si-l ⁻¹
Sodium	Atomic absorption/DA ¹	1/1975-12/1980	0.5% HNO ₃	0.03 mg-l ⁻¹	0.06 mg-l ⁻¹
Temperature	Thermistor thermometer ¹	1/1975-12/1980	In-situ	0.1°C*	
Turbidity	Jackson turbidity ¹ Nephelometric turbidity ¹	1/1975-5/1978 6/1978-12/1980	4°C	1 NTU*	
Zinc	Atomic absorption/HGA ¹ Atomic absorption/DA ¹	1/1975-12/1979 1/1980-12/1980	0.5% HNO ₃	0.7 µg-l ⁻¹ 10 µg-l ⁻¹	1.0 µg-l ⁻¹ 40

* - Detection limit and limit of determination were not determined on these variables; instead instrument sensitivity is given.
 ND = Not determined. ¹USEPA 1974 ²Technicon Ind. Systems 1972 ³Marion Research 1970 ⁴Hydrolab Corp. 1973

Table 3-3. Mean (\bar{X}) and range (R) concentrations of water quality variables sampled during three studies performed on Lake Norman. All variables were measured in the vicinity of Location 2.0 and/or 7.5 near the surface (0-2 m).

LAKE NORMAN STUDIES				
VARIABLES		Jensen et al. 1974 (7/68-11/71)	Duke Power Co. 1976 (8/73-6/74)	Duke Power Co. 1981 (1/75-11/79)
Dissolved Oxygen ($\text{mg}\cdot\text{l}^{-1}$)	\bar{X}	9.1	9.0	9.4
	R	7.4-11.5	6.7-12.1	5.7-12.8
pH	\bar{X}	6.8	7.1	7.1
	R	6.2-7.3	6.7-8.0	5.8-8.6
Alkalinity ($\text{mg}\cdot\text{CaCO}_3\cdot\text{l}^{-1}$)	\bar{X}	12	11	11
	R	5-18	9-14	5-28
Turbidity ^a	\bar{X}	5	12	11
	R	3-12	5-24	2-60
Conductivity ($\mu\text{mho}\cdot\text{cm}^{-1}$)	\bar{X}	38	40	40
	R	27-60	29-49	28-49
Nitrate-Nitrite-N ($\text{mg}\cdot\text{N}\cdot\text{l}^{-1}$)	\bar{X}	0.16	0.19	0.22
	R	0.010-0.43	0.020-0.34	0.021-0.56
Ammonia-N ($\text{mg}\cdot\text{N}\cdot\text{l}^{-1}$) ^a	\bar{X}	0.11	0.035	0.13
	R	0.01-0.27	0.014-0.15	0.006-0.82
Total Phosphorus ($\text{mg}\cdot\text{P}\cdot\text{l}^{-1}$) ^a	\bar{X}	0.053	0.022	0.013
	R	<0.053-0.086	0.010-0.031	<0.005-0.051
Silica ($\text{mg}\cdot\text{Si}\cdot\text{l}^{-1}$)	\bar{X}	3.1	4.3	3.4
	R	2.0-4.2	3.5-5.7	2.0-4.8
Iron ($\text{mg}\cdot\text{l}^{-1}$)	\bar{X}	0.7	0.4	0.5
	R	0.2-2.3	0.02-1.1	0.1-2.4

*Jackson Turbidity Units were reported in the Jensen (1974) and Duke Power Company (1976) studies. Nephelometric Turbidity Units were reported in the Duke Power Company (1981) study.

^aAnalytical methodologies may have contributed to observed differences in these variables. Percent transmittance was converted to JTU values in the Jensen (1974) study while a turbidimeter was used in the Duke Power Company (1976, 1981) studies. Ammonia concentrations were determined colorimetrically in the Jensen et al. (1974) and Duke Power Company (1981) studies while a gas diffusion electrode was used in the Duke Power Company (1976) study. The analytical detection limit for total phosphorus was $0.053 \text{ mg}\cdot\text{P}\cdot\text{l}^{-1}$ in the Jensen et al. 1974 study.

Table 3-4. Surface (0-2 m) means (\bar{x}) and ranges (R) of selected variables sampled from 1975 through 1979 at various locations in the study area.

	Upper Main Channel Area	Reference Area	Lower Main Channel Area	McGuire Intake Area	McGuire Discharge Area	Ramsay Creek Area	Catahoula River Area
Dissolved Oxygen ($\text{mg} \cdot \text{l}^{-1}$)	\bar{x} 9.0 R 4.1 - 13.2	\bar{x} 9.2 R 5.3 - 13.2	\bar{x} 9.4 R 5.7 - 12.8	\bar{x} 9.1 R 7.1 - 12.4	\bar{x} 9.3 R 6.6 - 12.6	\bar{x} 9.2 R 5.9 - 12.8	\bar{x} 8.9 R 5.0 - 13.4
pH	\bar{x} 6.9 R 5.8 - 8.6	\bar{x} 7.1 R 6.0 - 8.4	\bar{x} 7.1 R 5.8 - 8.6	\bar{x} 7.2 R 6.5 - 8.5	\bar{x} 7.1 R 6.0 - 8.5	\bar{x} 7.2 R 5.9 - 8.6	\bar{x} 6.9 R 5.9 - 7.6
Alkalinity ($\text{mg} \cdot \text{CaCO}_3 \cdot \text{l}^{-1}$)	\bar{x} 12 R 9 - 25	\bar{x} 12 R 6 - 29	\bar{x} 11 R 5 - 28	\bar{x} 11 R 3 - 13	\bar{x} 12 R 6 - 25	\bar{x} 11 R 6 - 26	\bar{x} 12 R 5 - 20
Turbidity (NTU)	\bar{x} 16 R 2 - 72	\bar{x} 14 R 2 - 64	\bar{x} 11 R 2 - 60	\bar{x} 10 R 2 - 30	\bar{x} 12 R 2 - 52	\bar{x} 10 R 2 - 36	\bar{x} 12 R 3 - 40
Conductivity ($\mu\text{mho} \cdot \text{cm}^{-1}$)	\bar{x} 40 R 29 - 56	\bar{x} 40 R 30 - 50	\bar{x} 40 R 28 - 49	\bar{x} 42 R 28 - 48	\bar{x} 39 R 29 - 46	\bar{x} 39 R 29 - 49	\bar{x} 47 R 23 - 70
Nitrate-Nitrite-N ($\text{mg} \cdot \text{N} \cdot \text{l}^{-1}$)	\bar{x} 0.24 R 0.012 - 0.61	\bar{x} 0.23 R 0.018 - 0.56	\bar{x} 0.22 R 0.021 - 0.55	\bar{x} 0.22 R 0.044 - 0.52	\bar{x} 0.23 R 0.008 - 0.96	\bar{x} 0.20 R 0.006 - 0.62	\bar{x} 0.24 R 0.051 - 0.66
Ammonia-N ($\text{mg} \cdot \text{N} \cdot \text{l}^{-1}$)	\bar{x} 0.13 R 0.016 - 0.51	\bar{x} 0.11 R 0.006 - 0.54	\bar{x} 0.13 R 0.006 - 0.82	\bar{x} 0.11 R 0.016 - 0.72	\bar{x} 0.11 R 0.019 - 0.86	\bar{x} 0.11 R 0.010 - 1.3	\bar{x} 0.16 R 0.006 - 0.64
Orthophosphate ($\text{mg} \cdot \text{P} \cdot \text{l}^{-1}$)	\bar{x} 0.005 R <0.005 - 0.028	\bar{x} <0.005 R <0.005 - 0.024	\bar{x} <0.005 R <0.005 - 0.039	\bar{x} <0.005 R <0.005 - 0.019	\bar{x} <0.005 R <0.005 - 0.030	\bar{x} <0.005 R <0.005 - 0.036	\bar{x} 0.010 R <0.005 - 0.013
Total Phosphorus ($\text{mg} \cdot \text{P} \cdot \text{l}^{-1}$)	\bar{x} 0.022 R <0.005 - 0.067	\bar{x} 0.015 R <0.005 - 0.076	\bar{x} 0.013 R <0.005 - 0.051	\bar{x} 0.010 R <0.005 - 0.035	\bar{x} 0.013 R <0.005 - 0.060	\bar{x} 0.012 R <0.005 - 0.047	\bar{x} 0.016 R <0.005 - 0.034
Silica ($\text{mg} \cdot \text{Si} \cdot \text{l}^{-1}$)	\bar{x} 3.7 R 2.2 - 5.2	\bar{x} 3.5 R 2.0 - 4.9	\bar{x} 3.4 R 2.0 - 4.8	\bar{x} 2.3 R 2.0 - 4.7	\bar{x} 3.3 R 2.0 - 4.6	\bar{x} 3.3 R 2.0 - 4.8	\bar{x} 3.5 R 2.4 - 5.5
Iron ($\text{mg} \cdot \text{l}^{-1}$)	\bar{x} 0.9 R 0.1 - 4.9	\bar{x} 0.7 R 0.1 - 3.9	\bar{x} 0.5 R 0.01 - 2.4	\bar{x} 0.4 R 0.1 - 1.6	\bar{x} 0.6 R 0.1 - 3.0	\bar{x} 0.5 R 0.04 - 2.8	\bar{x} 0.6 R 0.1 - 2.9
Calcium ($\text{mg} \cdot \text{l}^{-1}$)	\bar{x} 2.8 R 1.0 - 4.0	\bar{x} 2.8 R 1.1 - 4.2	\bar{x} 2.7 R 1.1 - 4.2	\bar{x} 2.6 R 2.1 - 3.3	\bar{x} 2.8 R 1.1 - 4.4	\bar{x} 2.7 R 1.1 - 4.3	\bar{x} 2.9 R 1.1 - 4.3
Magnesium ($\text{mg} \cdot \text{l}^{-1}$)	\bar{x} 1.2 R 0.6 - 1.2	\bar{x} 1.1 R 0.6 - 1.6	\bar{x} 1.1 R 0.6 - 1.5	\bar{x} 1.1 R 0.9 - 1.2	\bar{x} 1.1 R 0.6 - 1.5	\bar{x} 1.1 R 0.6 - 1.5	\bar{x} 1.1 R 0.6 - 1.5
Manganese ($\text{mg} \cdot \text{l}^{-1}$)	\bar{x} 0.33 R 0.01 - 0.96	\bar{x} 0.08 R 0.01 - 0.90	\bar{x} 0.06 R 0.01 - 0.41	\bar{x} 0.03 R 0.01 - 0.12	\bar{x} 0.04 R 0.01 - 0.25	\bar{x} 0.04 R <0.01 - 0.30	\bar{x} 0.04 R 0.01 - 0.25

Table 3-5 . Bottom (>20 m) means (\bar{X}) and ranges (R) of selected variables sampled from 1975 through 1979 at various locations in the study area. Areas less than 20 meters deep were not included in table.

		Upper Main Channel Area	Reference Area	Lower Main Channel Area	Ramsey Creek Area
Dissolved Oxygen ($\text{mg}\cdot\text{l}^{-1}$)	\bar{X} R	6.1 0.0 - 11.8	5.7 0.0 - 12.2	6.1 0.0 - 13.2	6.3 0.0 - 12.1
pH	\bar{X} R	6.5 5.4 - 7.6	6.5 5.4 - 7.4	6.5 5.5 - 7.4	6.5 5.4 - 7.4
Alkalinity ($\text{mg}\cdot\text{CaCO}_3\cdot\text{l}^{-1}$)	\bar{X} R	12 9 - 40	13 7 - 29	13 6 - 34	12 6 - 27
Turbidity (NTU)	\bar{X} R	32 4 - 74	26 3 - 74	24 2 - 74	22 4 - 52
Conductivity ($\mu\text{mho}\cdot\text{cm}^{-1}$)	\bar{X} R	43 28 - 82	43 29 - 92	41 28 - 82	48 24 - 62
Nitrate-Nitrite-N ($\text{mg}\cdot\text{N}\cdot\text{l}^{-1}$)	\bar{X} R	0.32 0.005 - 0.75	0.30 0.008 - 0.71	0.30 0.005 - 0.67	0.30 0.01 - 0.76
Ammonia-N ($\text{mg}\cdot\text{N}\cdot\text{l}^{-1}$)	\bar{X} R	0.20 0.030 - 1.0	0.17 0.006 - 0.94	0.18 0.006 - 1.0	0.13 0.010 - 0.95
Orthophosphate ($\text{mg}\cdot\text{P}\cdot\text{l}^{-1}$)	\bar{X} R	0.007 <0.005 - 0.036	0.005 <0.005 - 0.043	0.005 <0.005 - 0.051	0.005 <0.005 - 0.022
Total Phosphorus ($\text{mg}\cdot\text{P}\cdot\text{l}^{-1}$)	\bar{X} R	0.034 0.005 - 0.14	0.020 <0.005 - 0.057	0.021 <0.005 - 0.15	0.017 <0.005 - 0.067
Silica ($\text{mg}\cdot\text{Si}\cdot\text{l}^{-1}$)	\bar{X} R	3.9 2.8 - 5.3	3.7 2.5 - 4.8	3.7 2.5 - 4.8	3.5 2.3 - 4.4
Iron ($\text{mg}\cdot\text{l}^{-1}$)	\bar{X} R	1.7 0.2 - 5.5	1.3 0.1 - 4.3	0.6 0.1 - 4.5	1.0 0.2 - 4.7
Calcium ($\text{mg}\cdot\text{l}^{-1}$)	\bar{X} R	2.9 1.1 - 5.8	2.9 1.1 - 5.5	3.0 1.0 - 7.5	3.0 1.1 - 5.2
Magnesium ($\text{mg}\cdot\text{l}^{-1}$)	\bar{X} R	1.1 0.6 - 1.6	1.1 0.6 - 1.6	1.1 0.6 - 1.6	1.1 0.6 - 1.6
Manganese ($\text{mg}\cdot\text{l}^{-1}$)	\bar{X} R	0.48 0.01 - 3.9	0.58 0.01 - 4.3	0.56 0.01 - 5.2	0.30 0.01 - 2.8

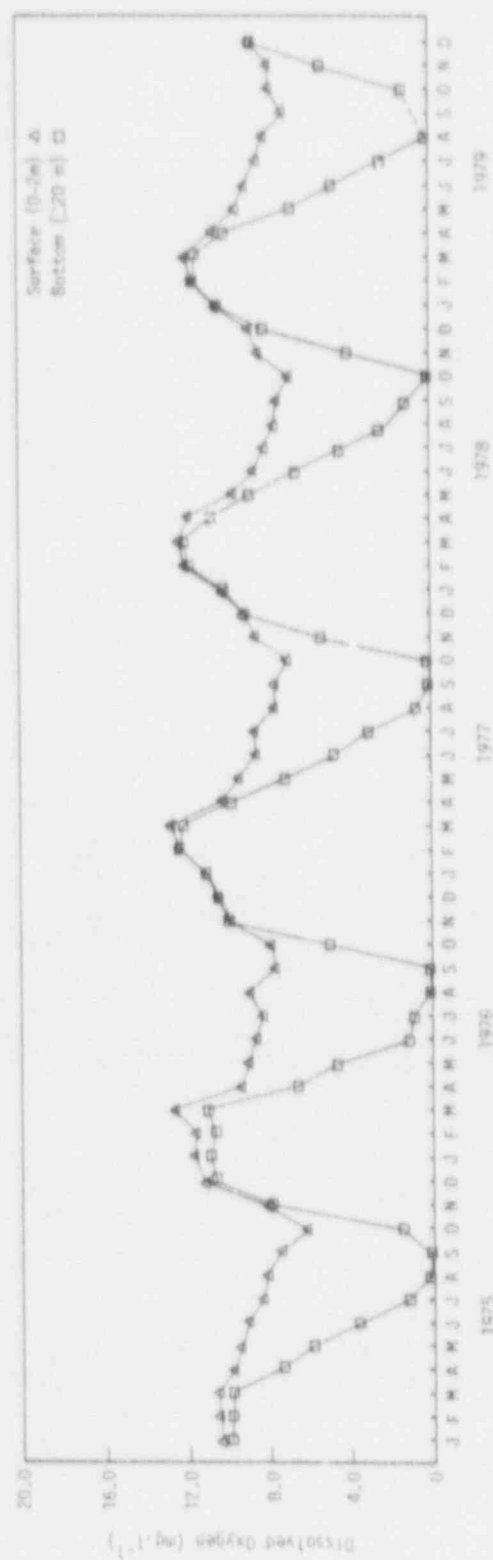


Figure 3-1. Mean dissolved oxygen concentrations in Lake Norman from 1975 through 1979. Dashed lines indicate missing data.

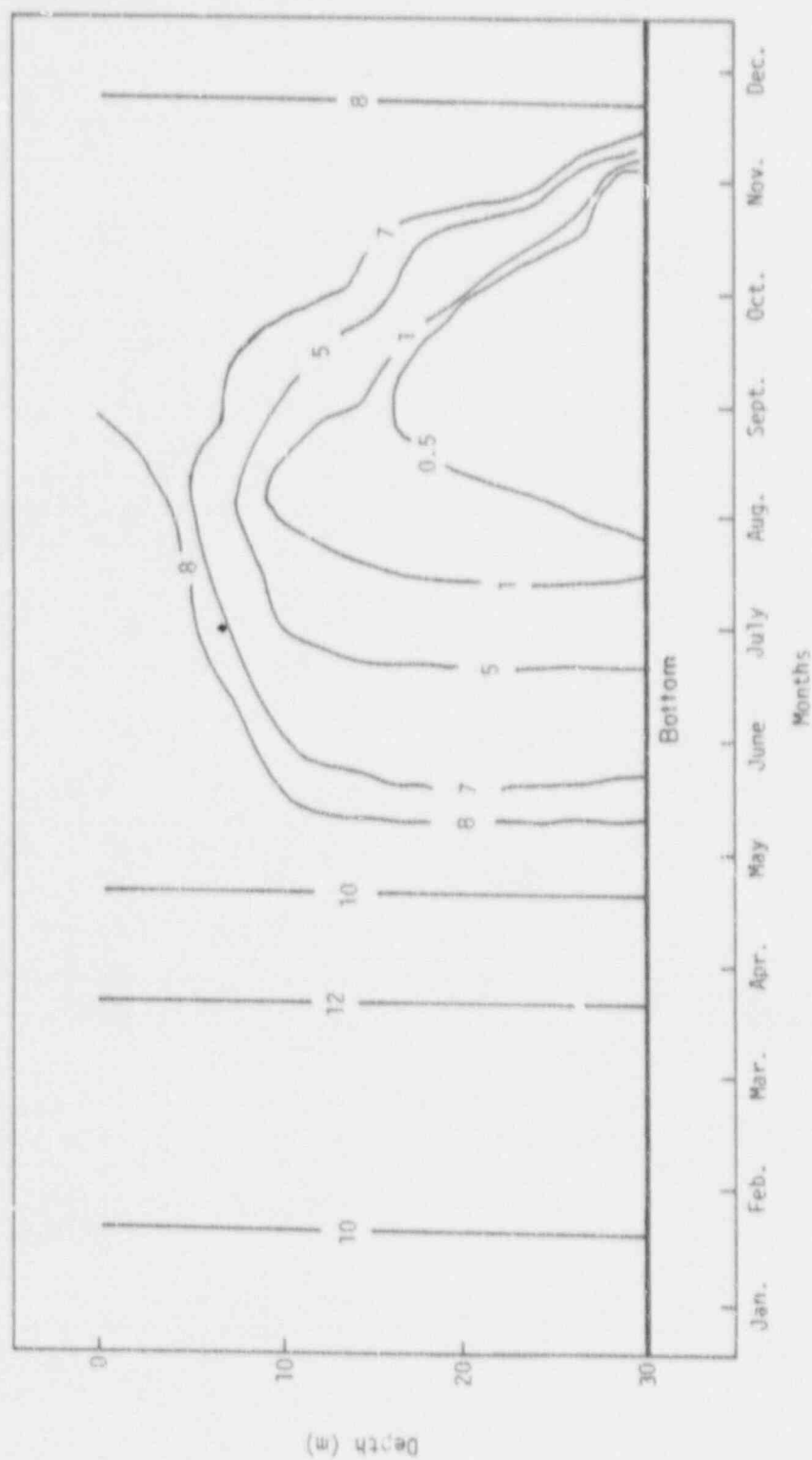


Figure 3-2. Mean dissolved oxygen values ($\text{mg}\cdot\text{l}^{-1}$) at Location 2.0 from 1977 through 1979.

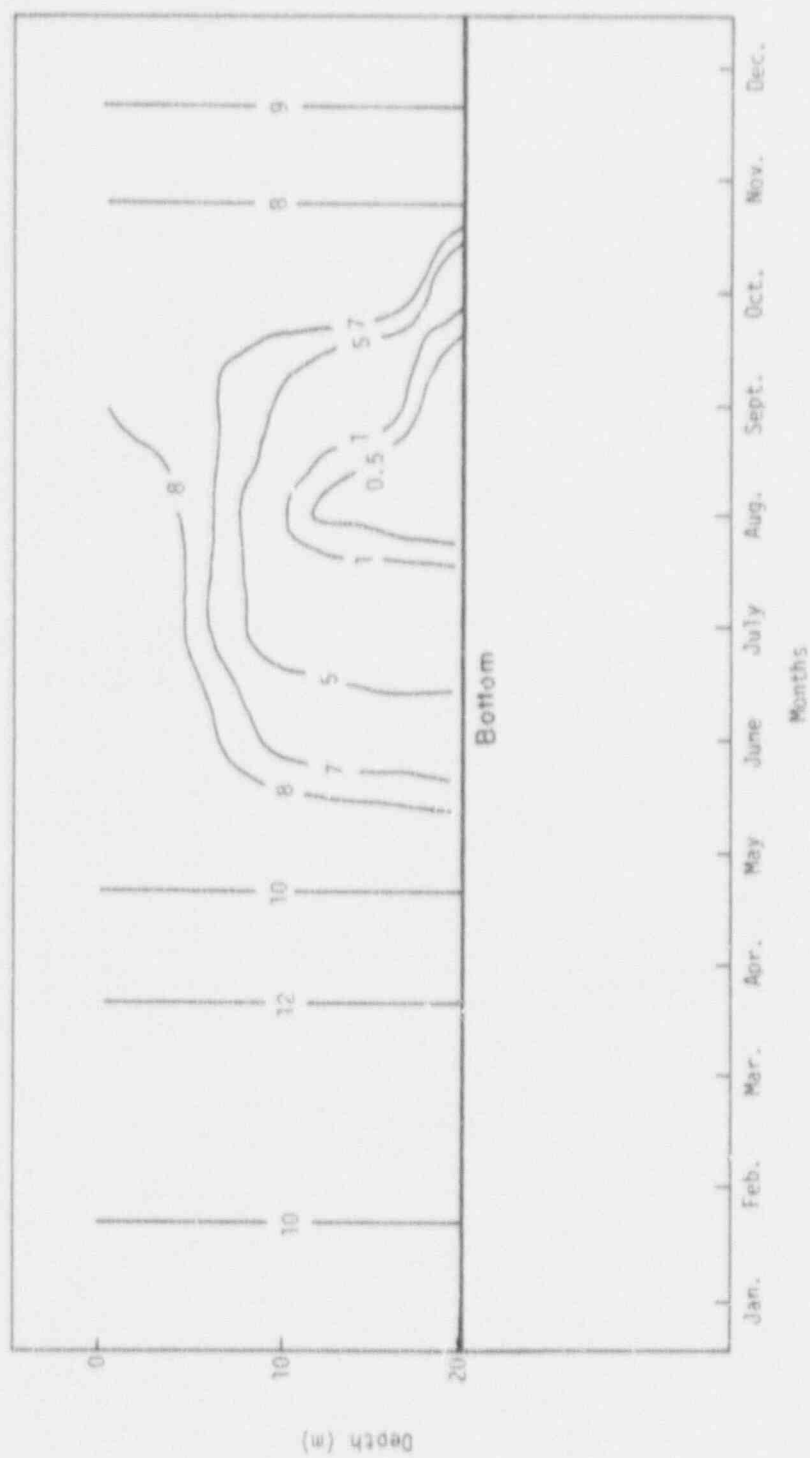


Figure 3-3. Mean dissolved oxygen values ($\text{mg}\cdot\text{l}^{-1}$) at Location 5.0 from 1977 through 1979.

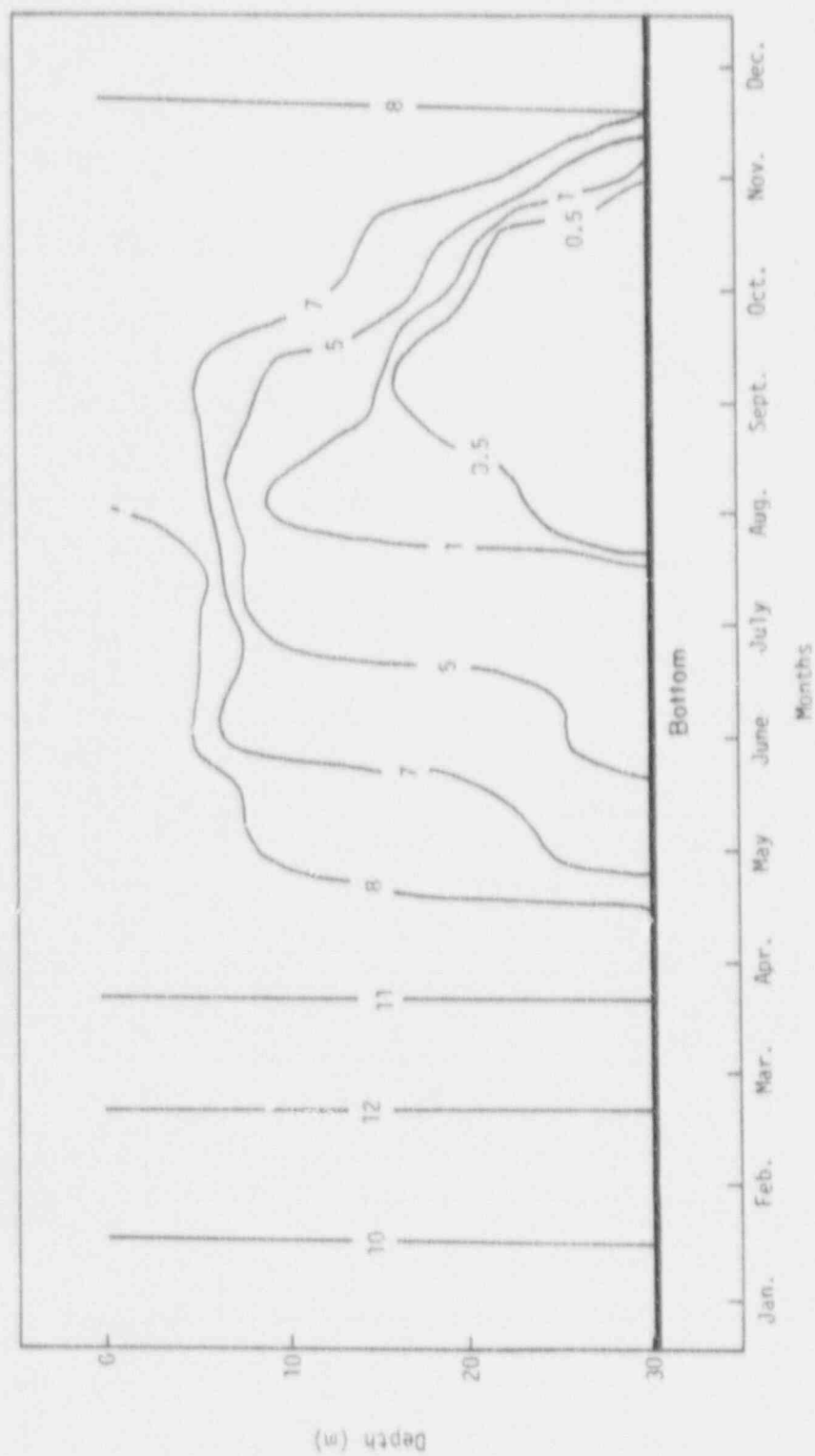


Figure 3-4. Mean dissolved oxygen values (mg.l^{-1}) at Location 8.0 from 1977 through 1979.

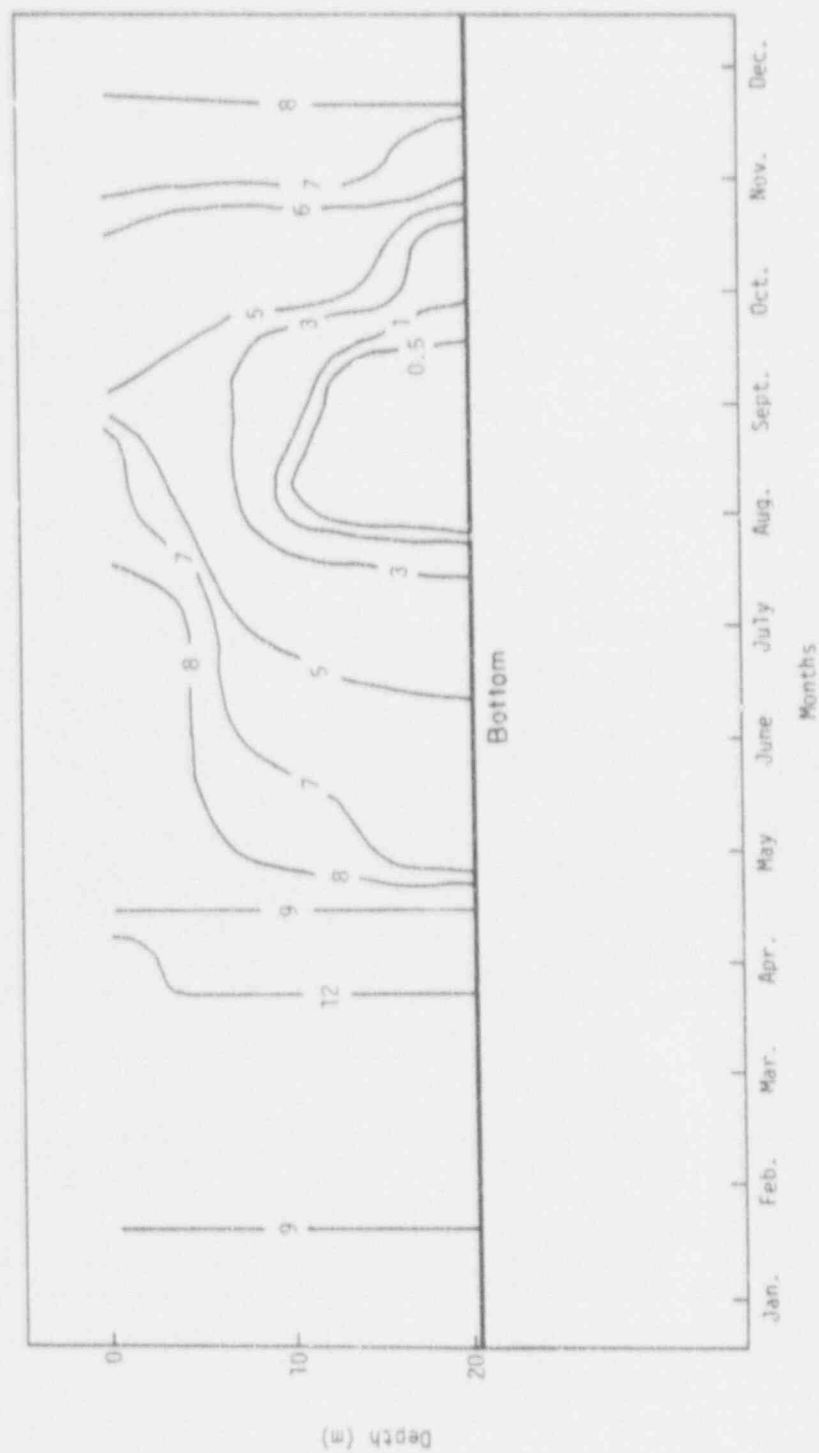


Figure 3-5. Mean dissolved oxygen values (mg.l⁻¹) at Location 13.0 from 1977 through 1979.

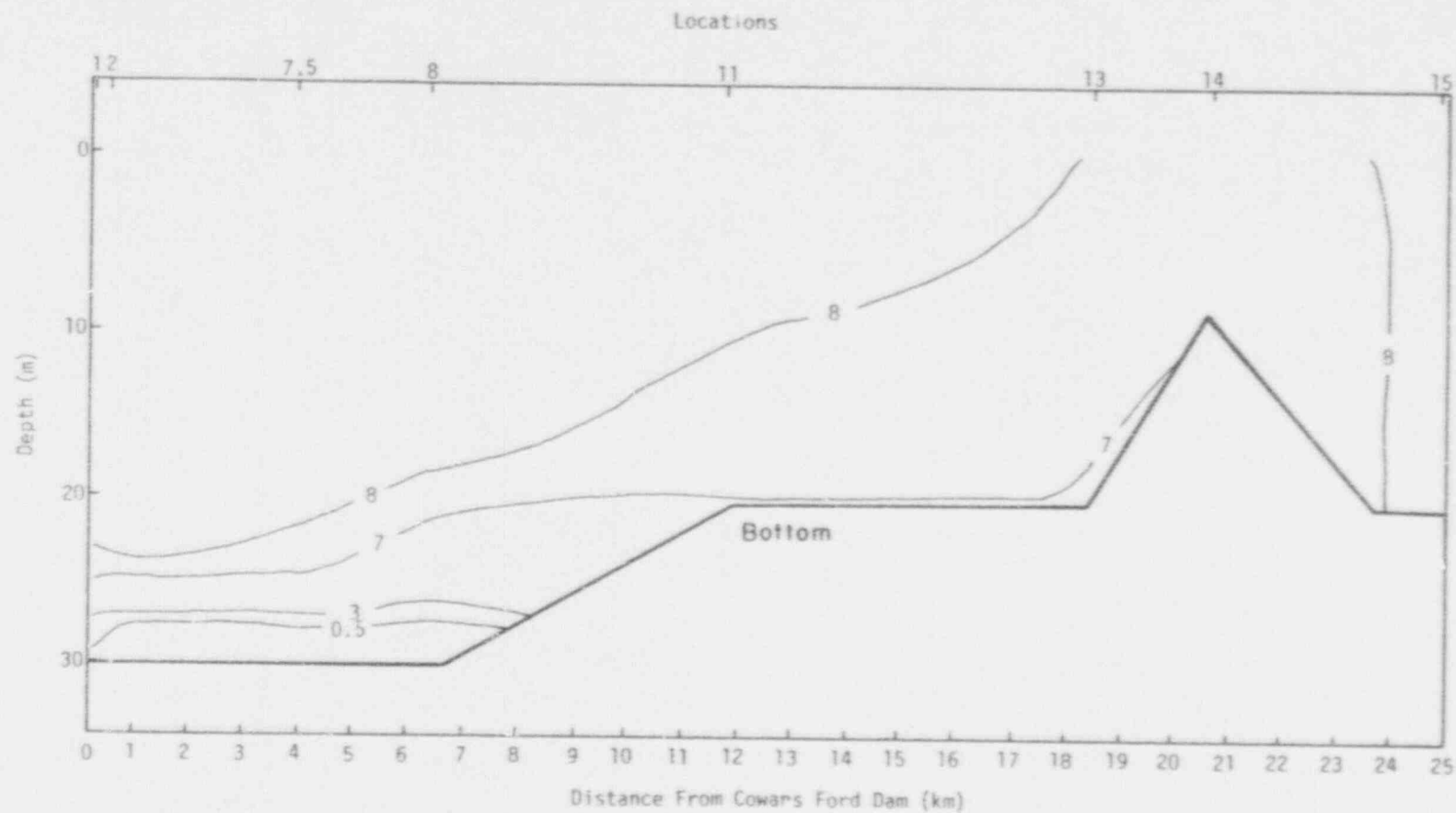


Figure 3-6. Mean dissolved oxygen values ($\text{mg}\cdot\text{l}^{-1}$) at main channel locations on Lake Norman during the latter stages of destratification during November 1977 through 1979.

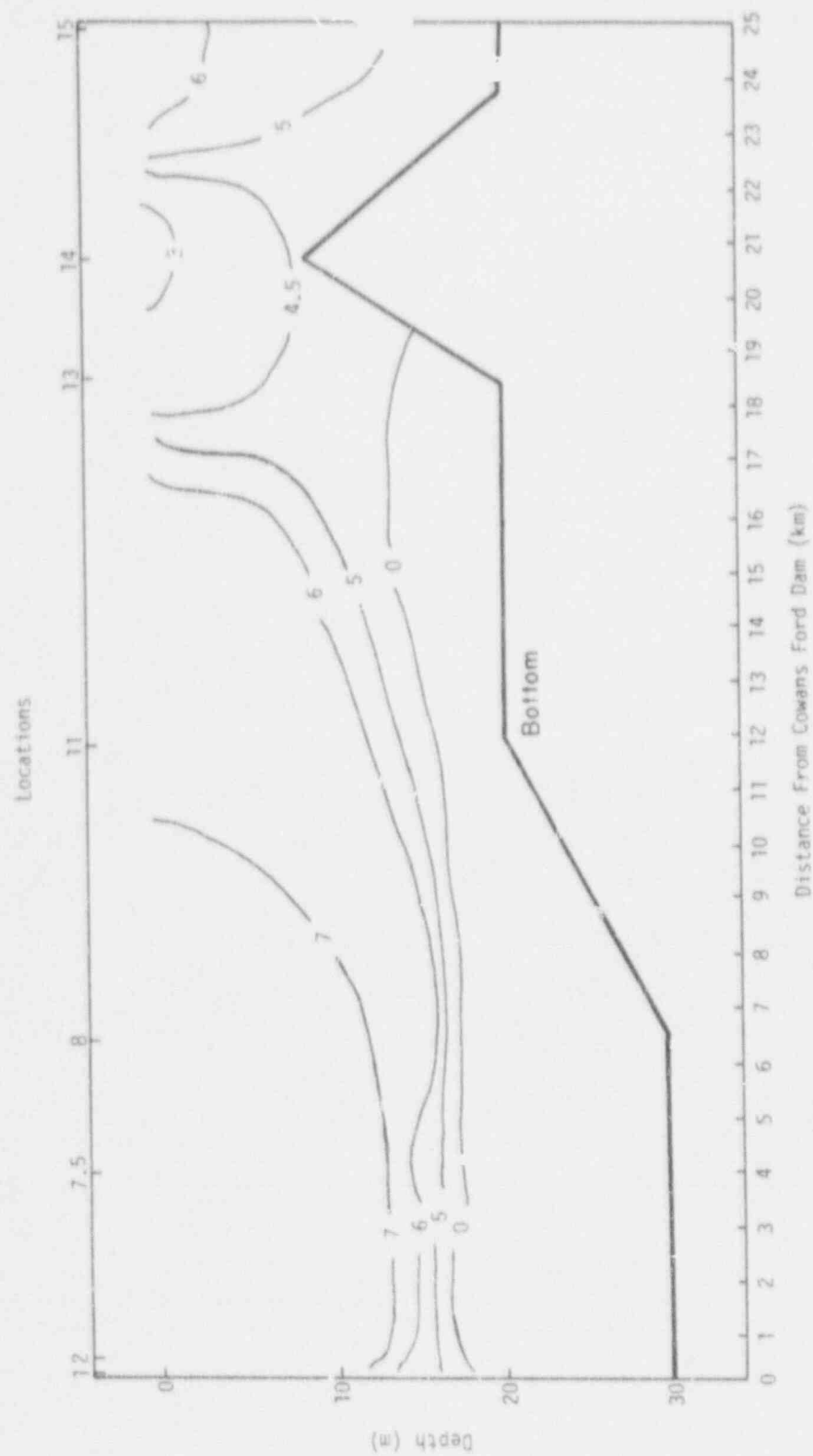


Figure 3-7. Dissolved oxygen values ($\text{mg}\cdot\text{l}^{-1}$) at main channel locations on Lake Norman during October 1978.

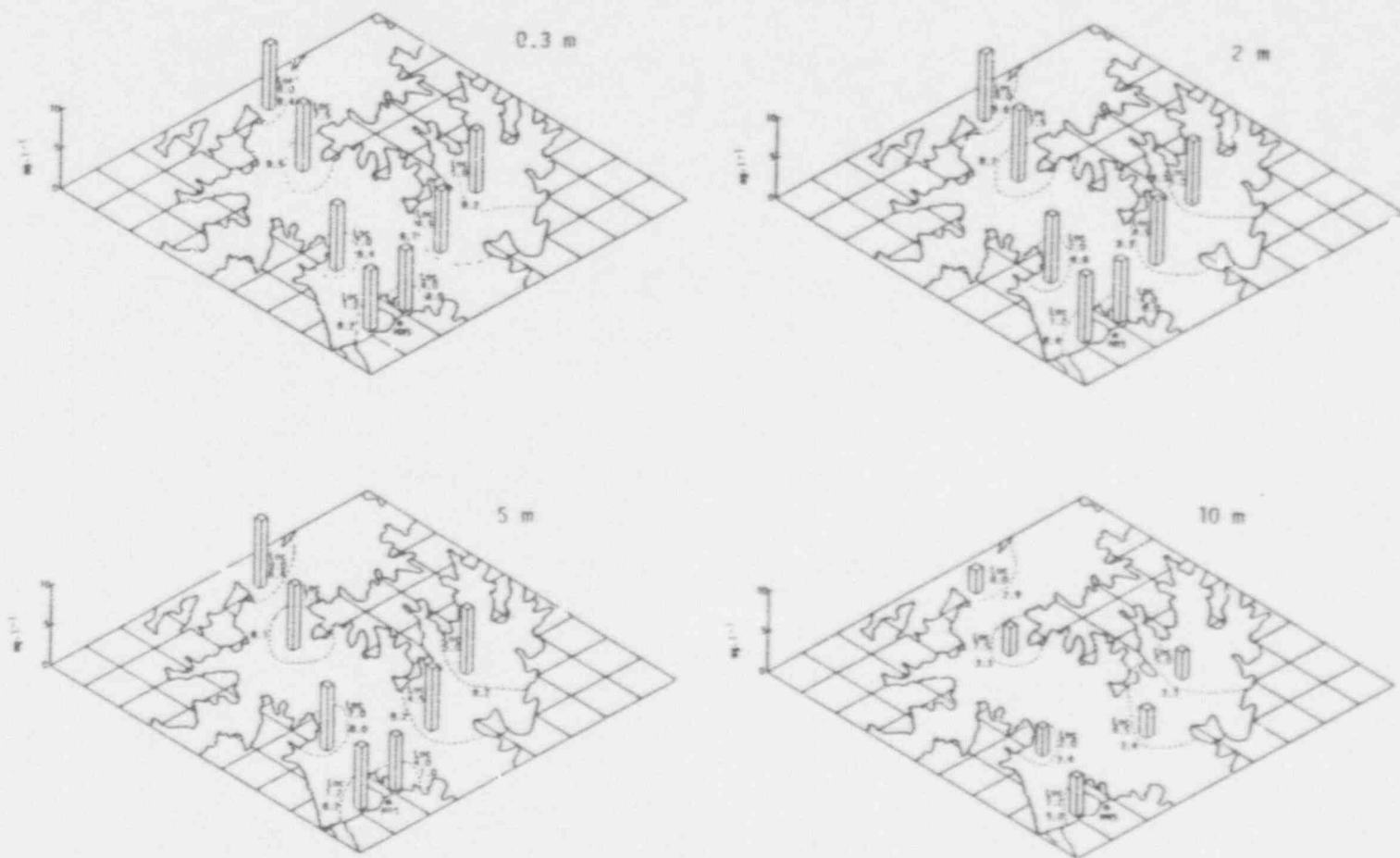


Figure 3-8. Mean dissolved oxygen concentrations ($\text{mg}\cdot\text{l}^{-1}$) at 0.3, 2, 5, and 10 m during July (1975-1979) at locations in the vicinity of McGuire Nuclear Station (MNS).

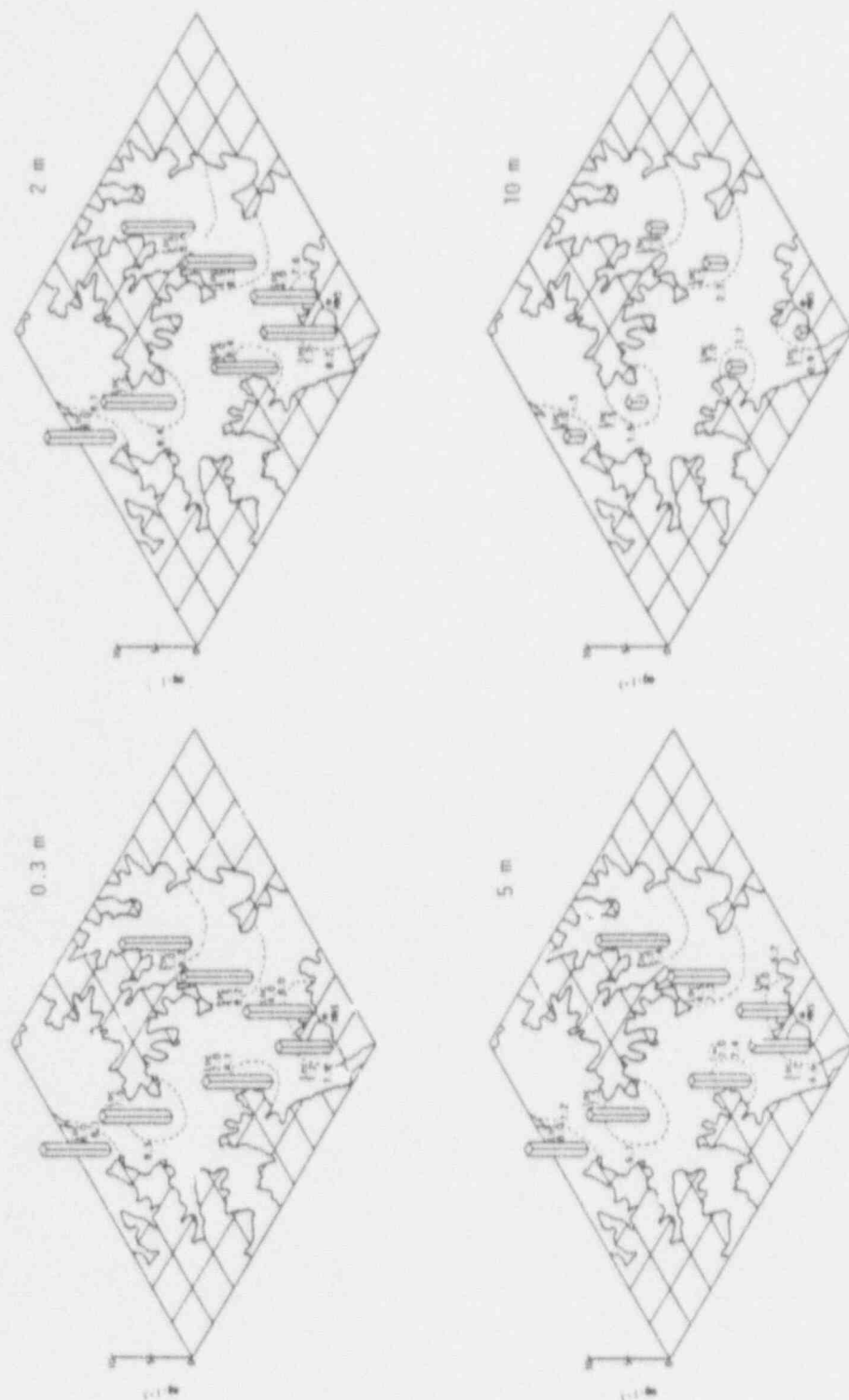


Figure 3-9. Mean dissolved oxygen concentrations (mg·l⁻¹) at 0.3, 2, 5, and 10 m during August 1975 through 1979 at locations in the vicinity of the McGuire Nuclear Station (MNS).

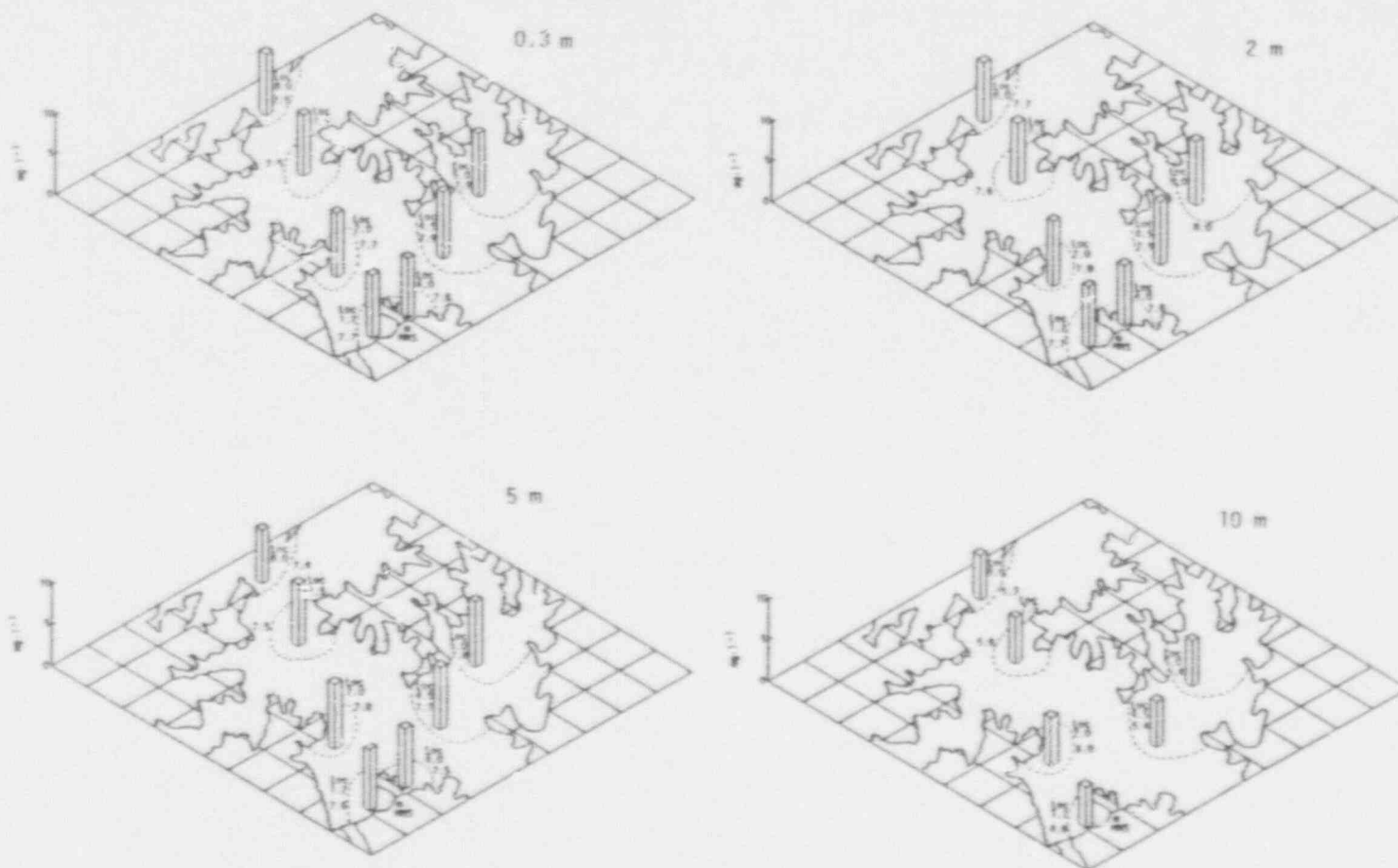


Figure 3-10. Mean dissolved oxygen concentrations ($\text{mg}\cdot\text{l}^{-1}$) at 0.3, 2, 5, and 10 m during September 1975 through 1979 at locations in the vicinity of the McGuire Nuclear Station (MNS).

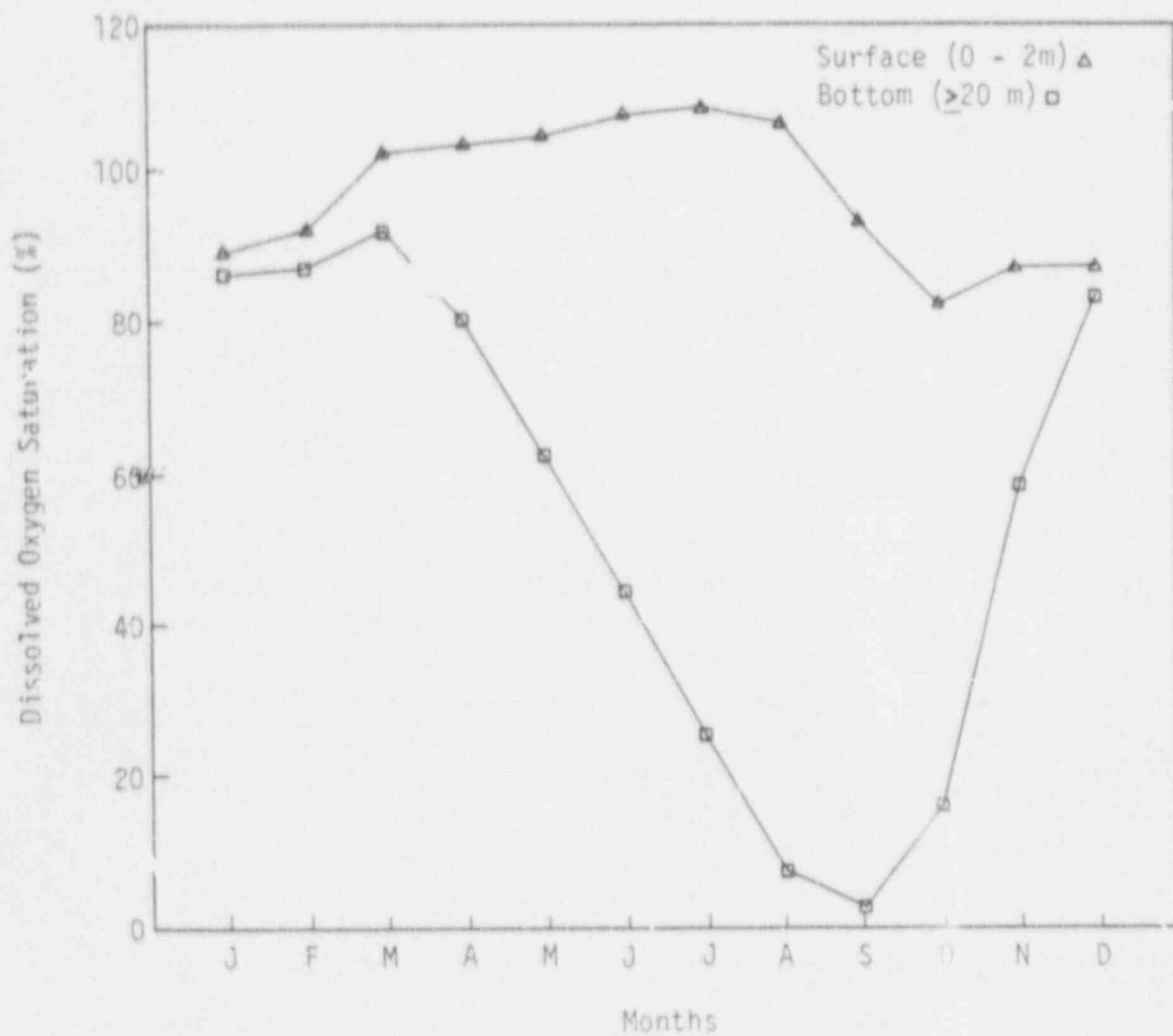


Figure 3-11. Mean percent dissolved oxygen saturation in the surface and bottom waters of Lake Norman from 1975 through 1979.

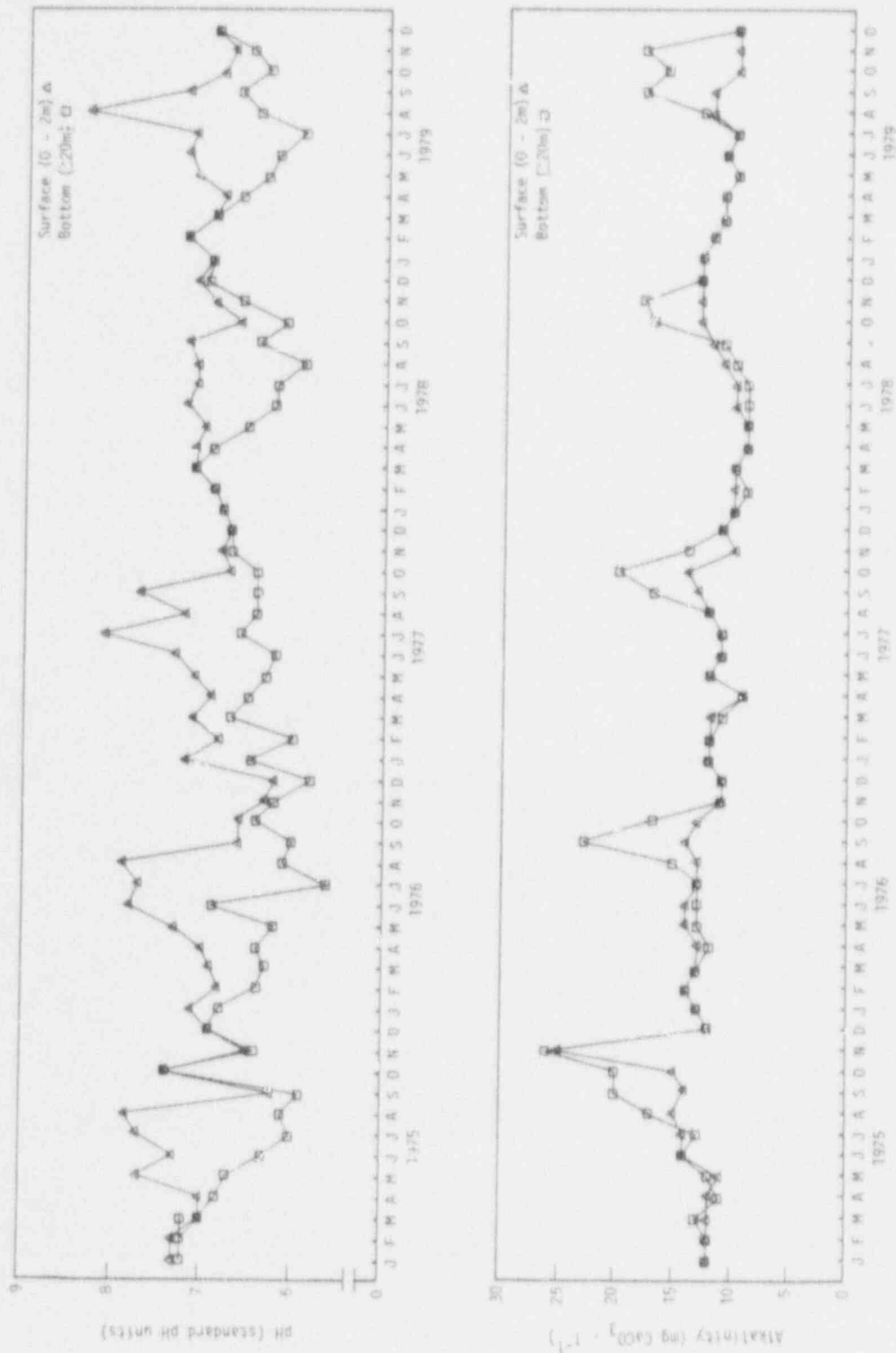


Figure 3-12. Mean pH (standard units) and alkalinity (mgCaCO₃ · l⁻¹) values in Lake Norman from 1975 through 1979.

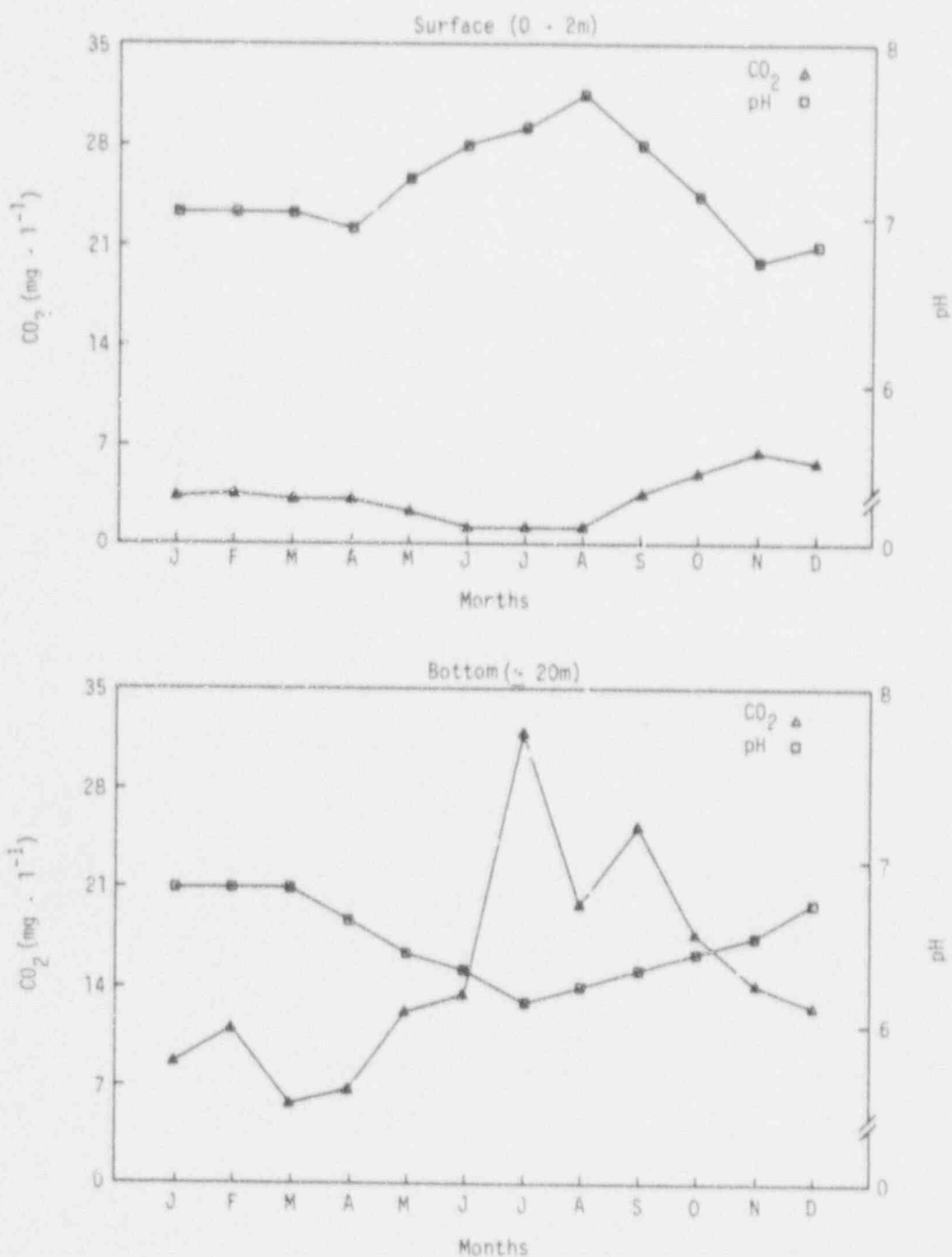


Figure 3-13. Mean carbon dioxide and pH values in the surface and bottom waters of Lake Norman from 1975 through 1979.

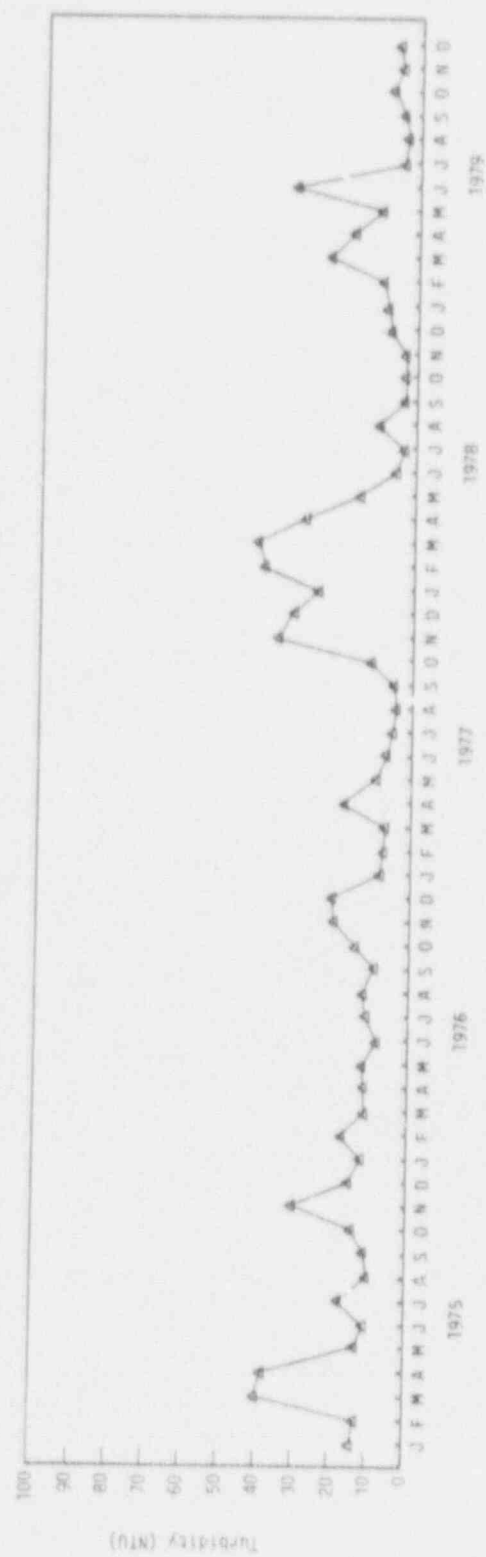


Figure 3-14. Mean turbidity values (NTU) in Lake Norman surface waters from 1975 through 1979.

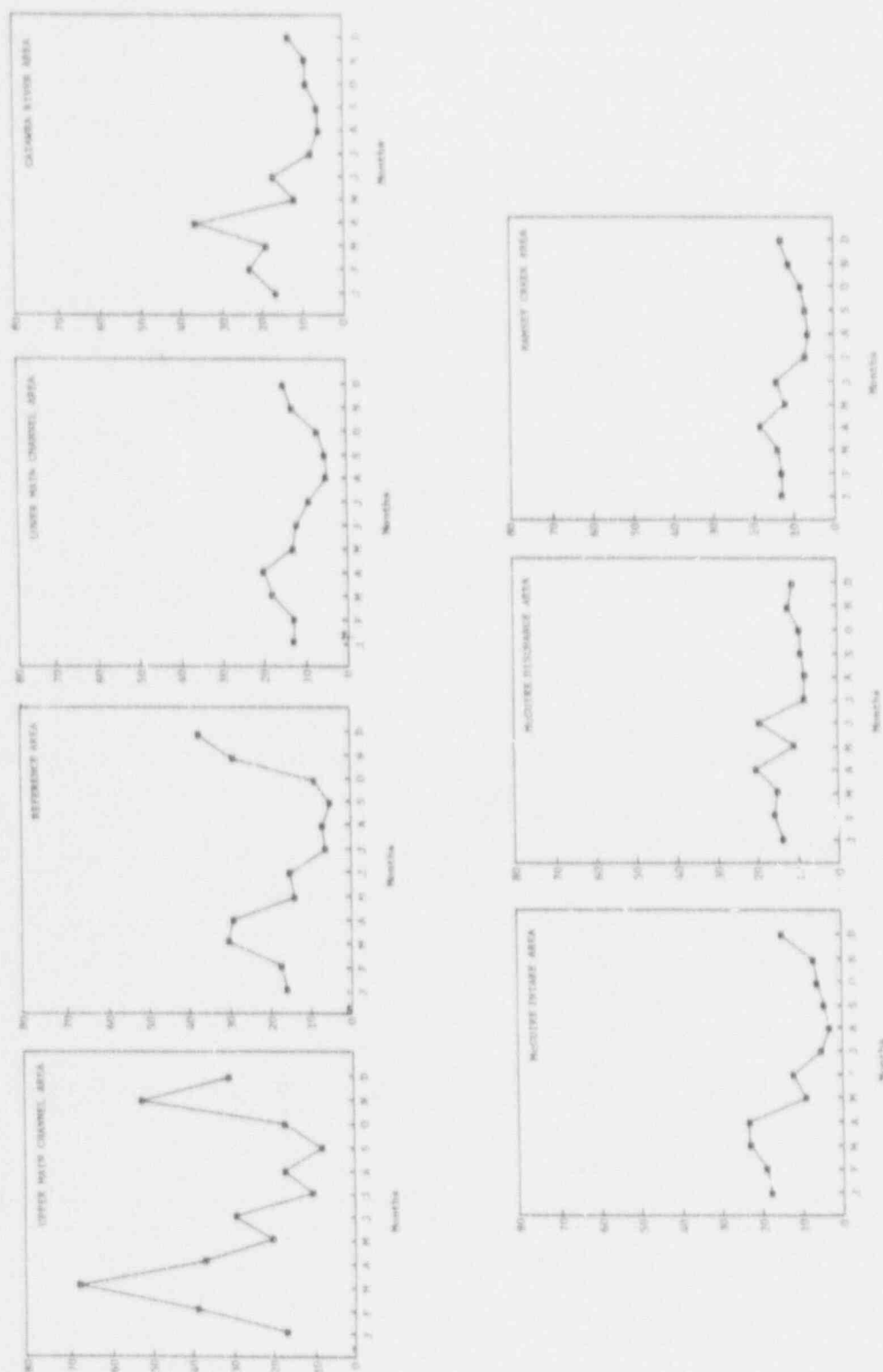


Figure 3-15. Mean turbidity values (NTU) in selected areas of Lake Norman from 1975 through 1979.

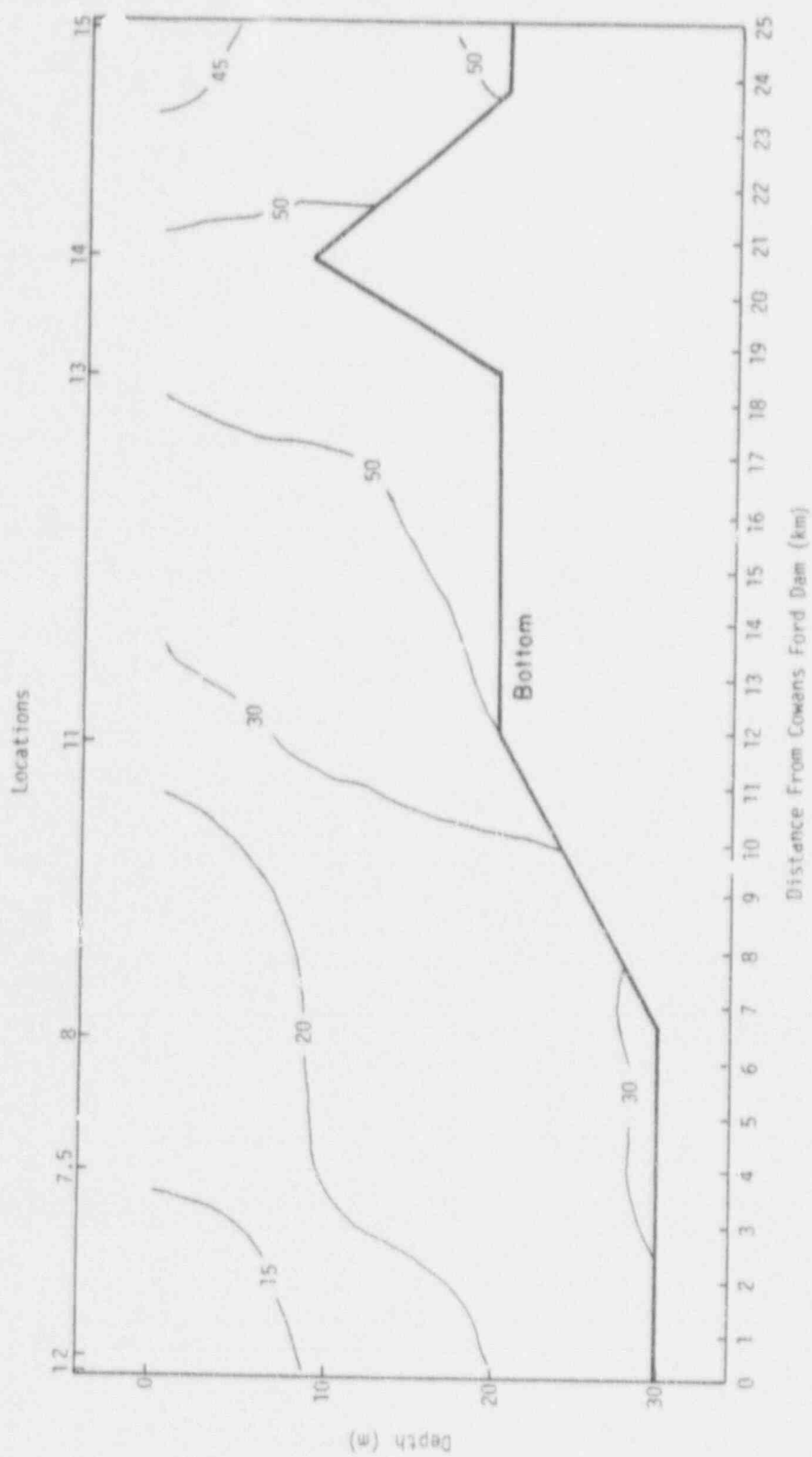


Figure 3-16. Mean turbidity values (NTU) in Lake Norman rain channel locations during February 1977 through 1979.

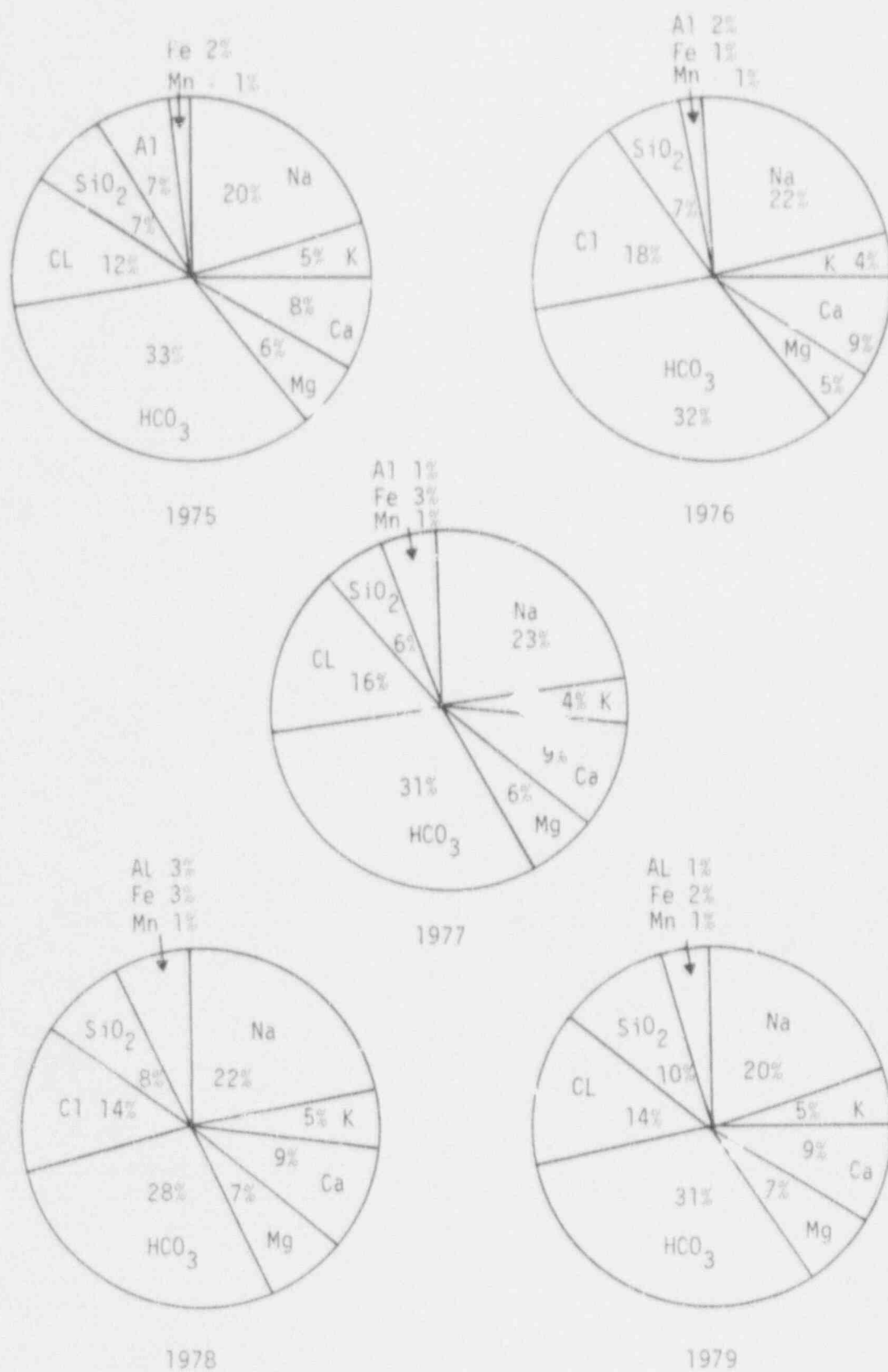


Figure 3-17. Mean mineral composition (%) in Lake Norman 1975 through 1979 expressed as percent of total concentration (mmol·l⁻¹) of Al, Fe, Mn, SiO₂, HCO₃, Mg, Ca, K, and Na.

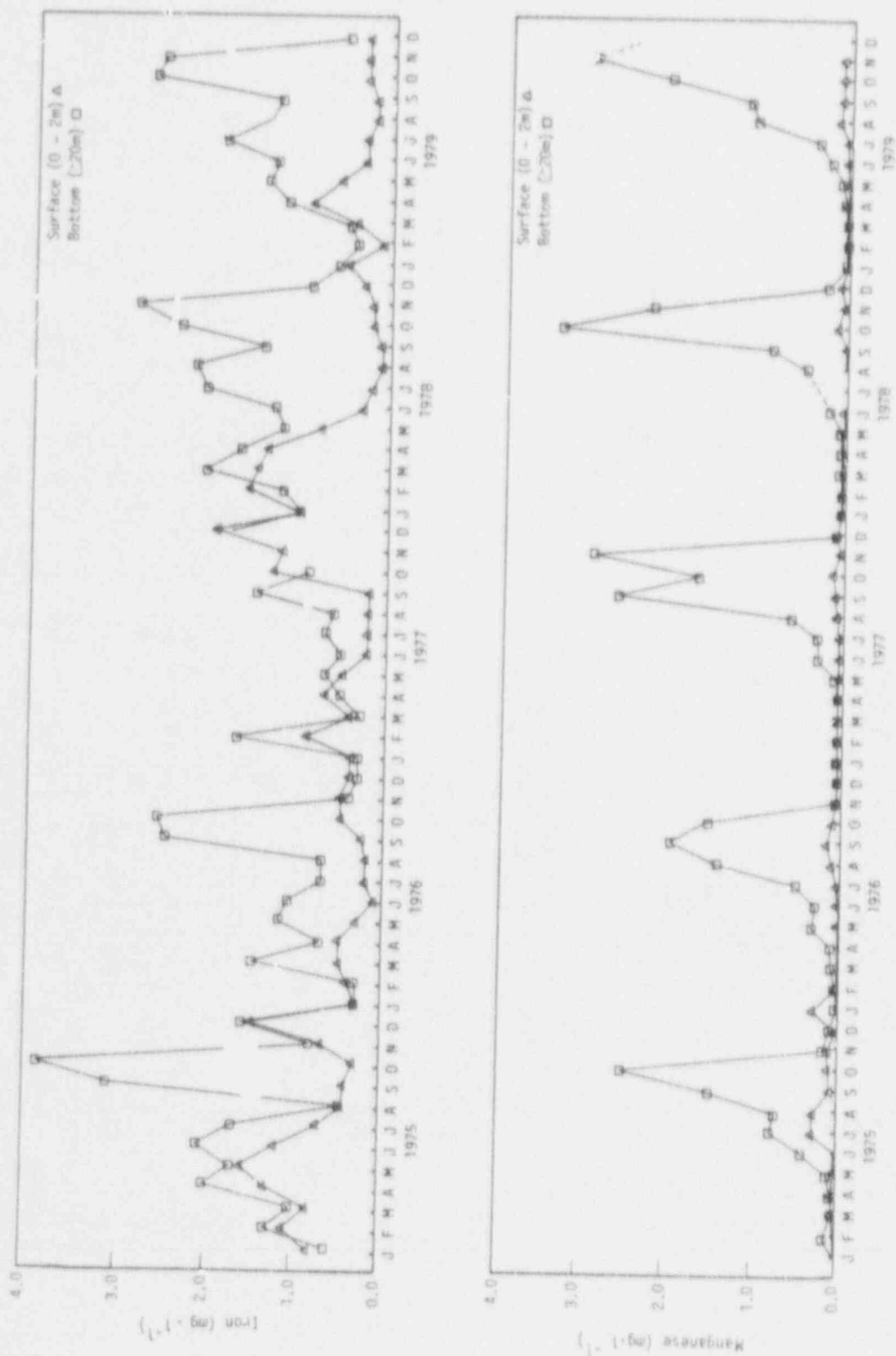


Figure 3-18. Mean iron and manganese concentrations (mg.l⁻¹) in Lake Norman from 1975 through 1979. Dashed lines indicate missing data.

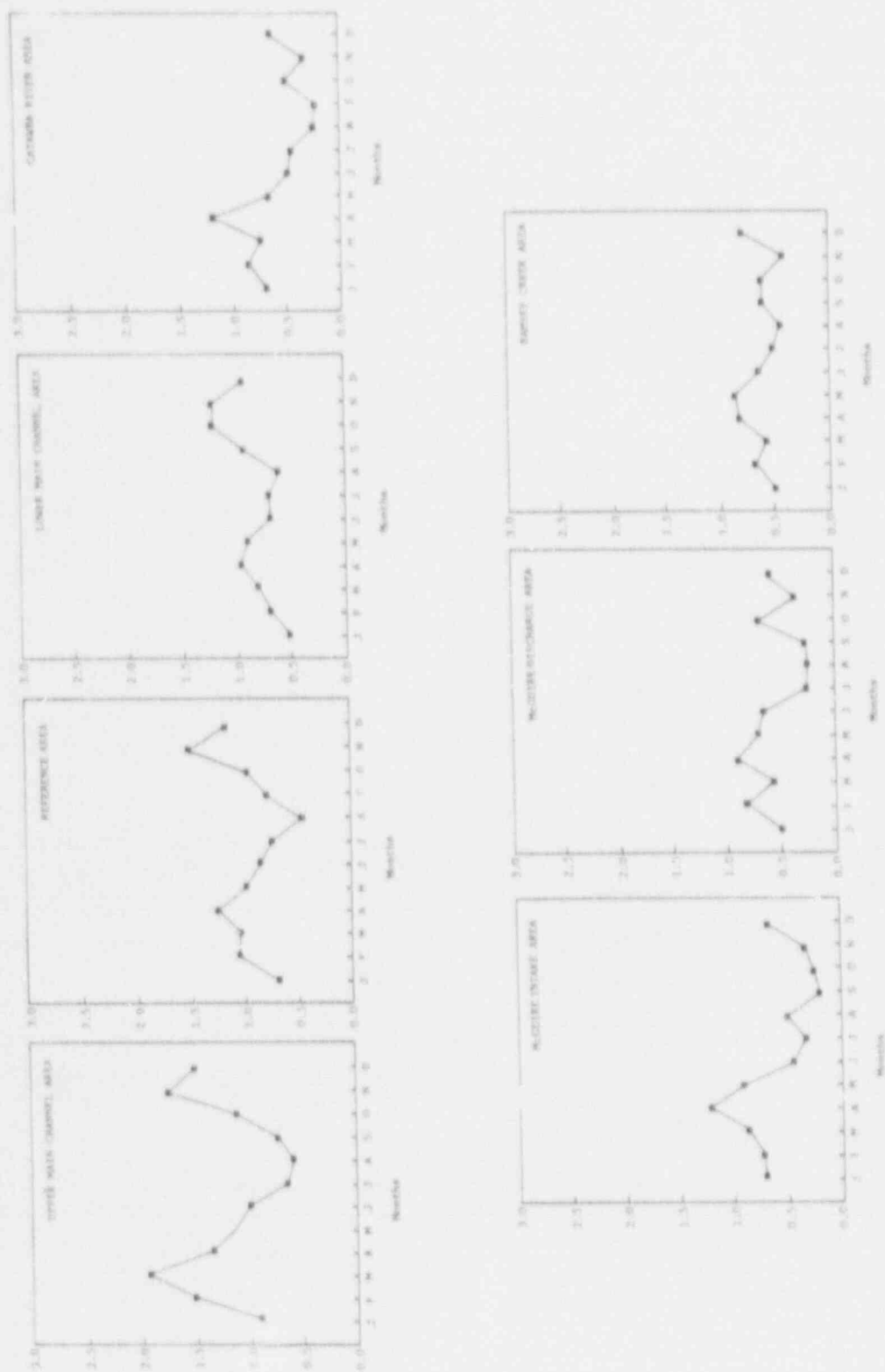


Figure 3-19. Mean iron concentrations (mg/l) in selected areas of Lake Norman from 1975 through 1979.



Figure 3-20. Mean manganese concentrations (mg.l⁻¹) in selected areas of Lake Korman from 1975 through 1979.

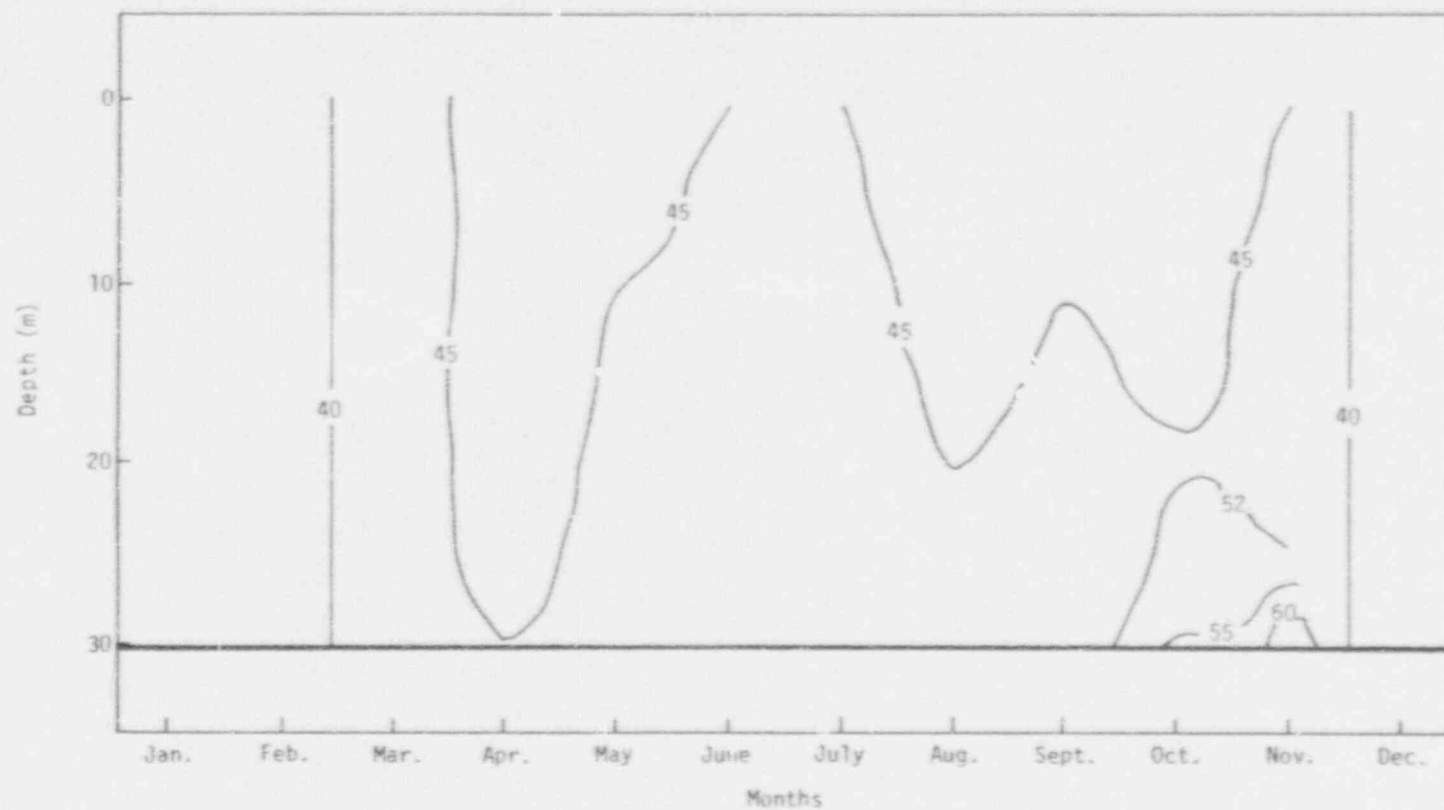


Figure 3-21. Mean specific conductance values ($\mu\text{mho}\cdot\text{cm}^{-1}$) observed in Lake Norman from 1977 through 1979.

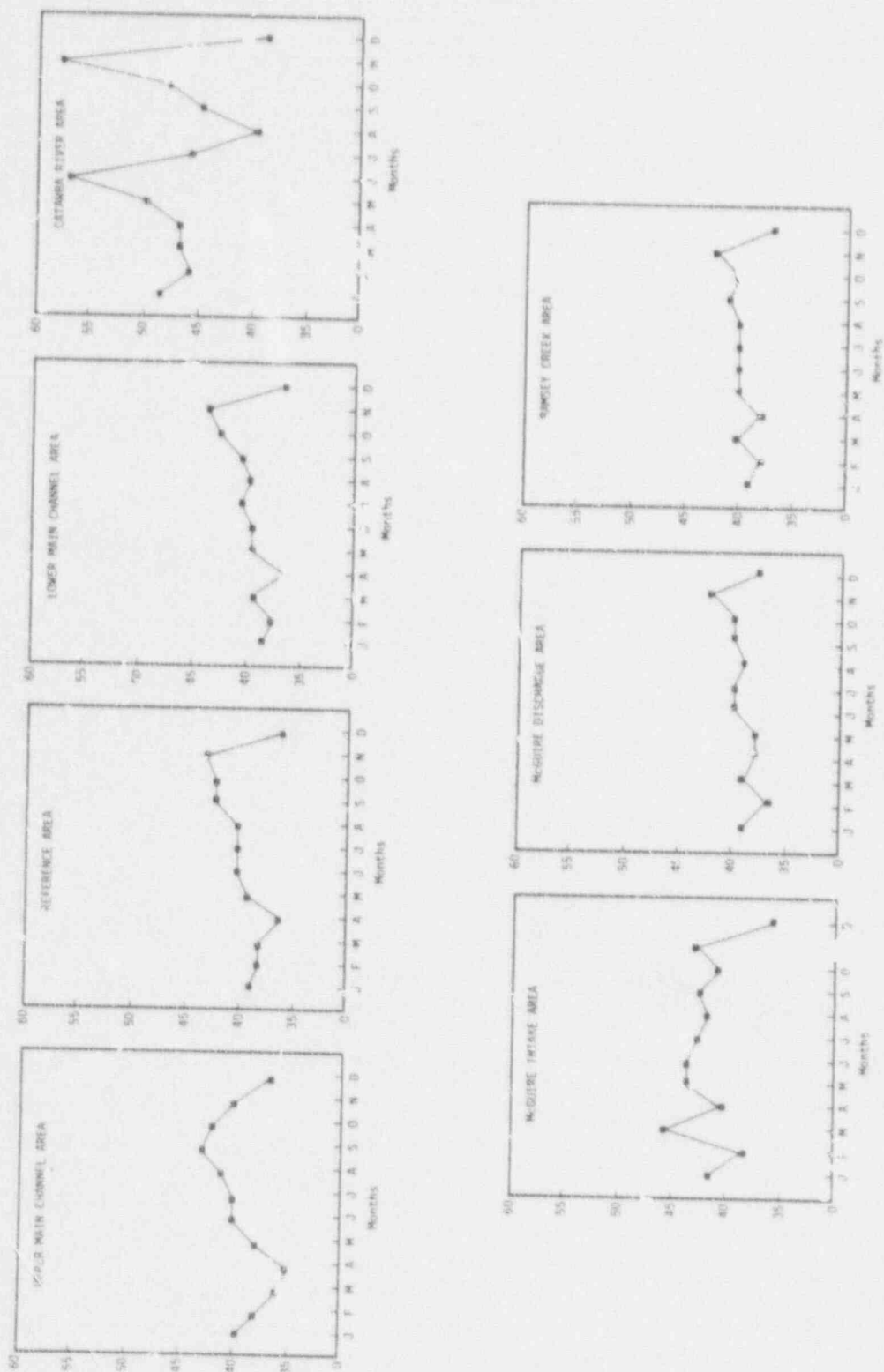


Figure 3-22. Mean specific conductance values ($\mu\text{mho}\cdot\text{cm}^{-1}$) in selected areas of Lake Norman from 1975 through 1979.

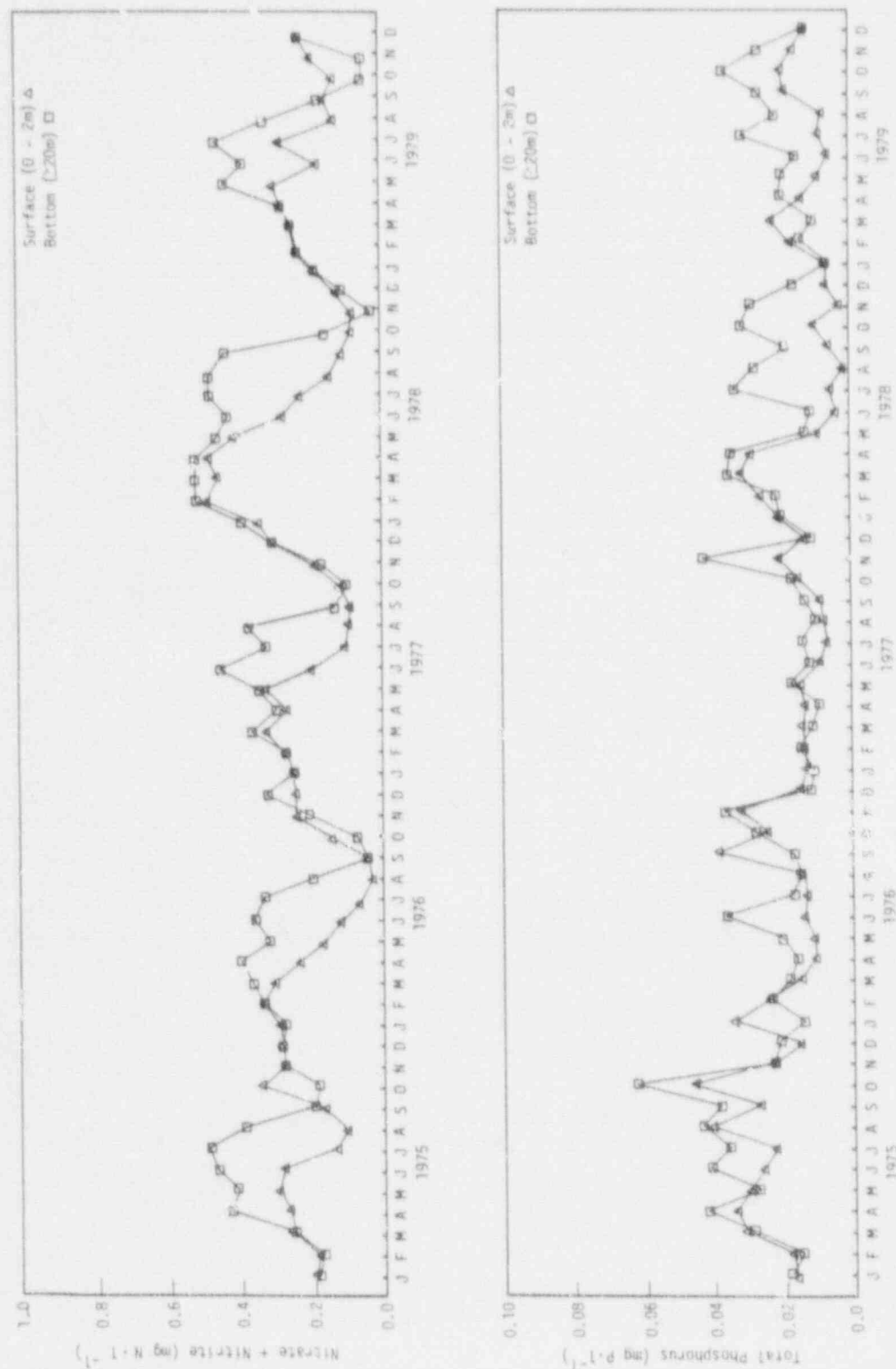


Figure 3-23. Mean nitrate plus nitrite and total phosphorus concentrations (mg · l⁻¹) in Lake Norman from 1975 through 1979.

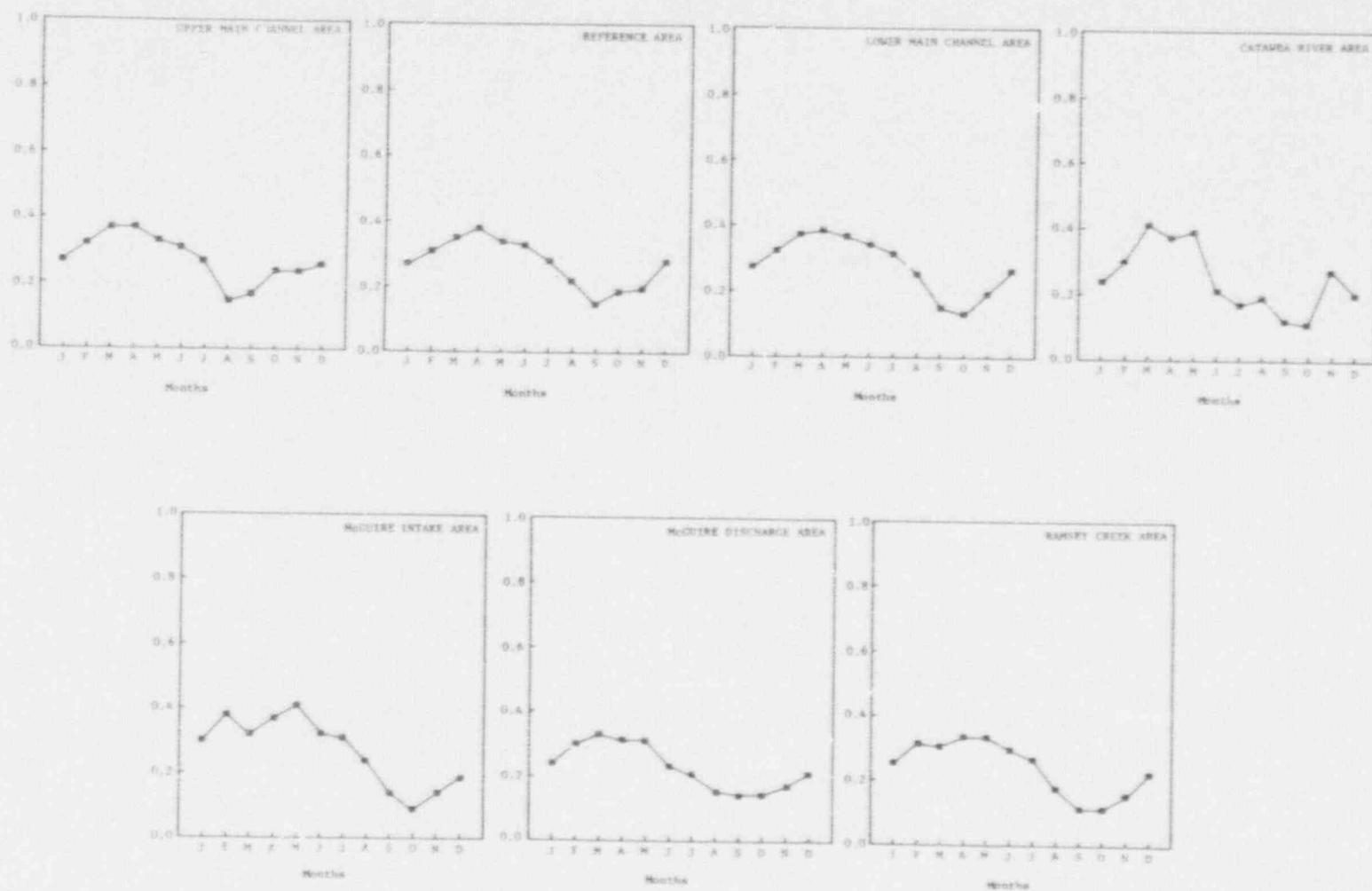


Figure 3-24. Mean nitrate plus nitrite concentrations (mg-l⁻¹) in selected areas of Lake Norman from 1975 through 1979.



Figure 3-25. Mean ammonia concentrations (mg·l⁻¹) in selected areas of Lake Norman from 1975 through 1979.



Figure 3-26. Mean total phosphorus concentrations (mg.l-1) in selected areas of Lake Norman from 1975 through 1979.

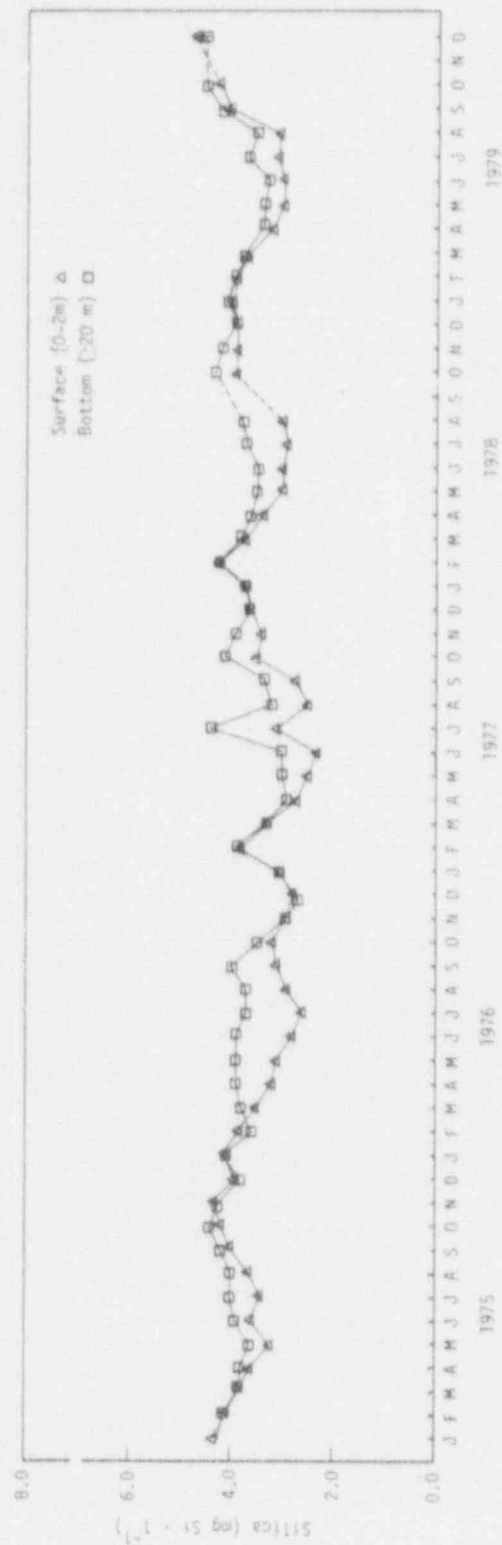


Figure 3-27. Mean silica concentrations ($mg\ l^{-1}$) in Lake Norman from 1975 through 1979. Dashed lines indicate missing data.

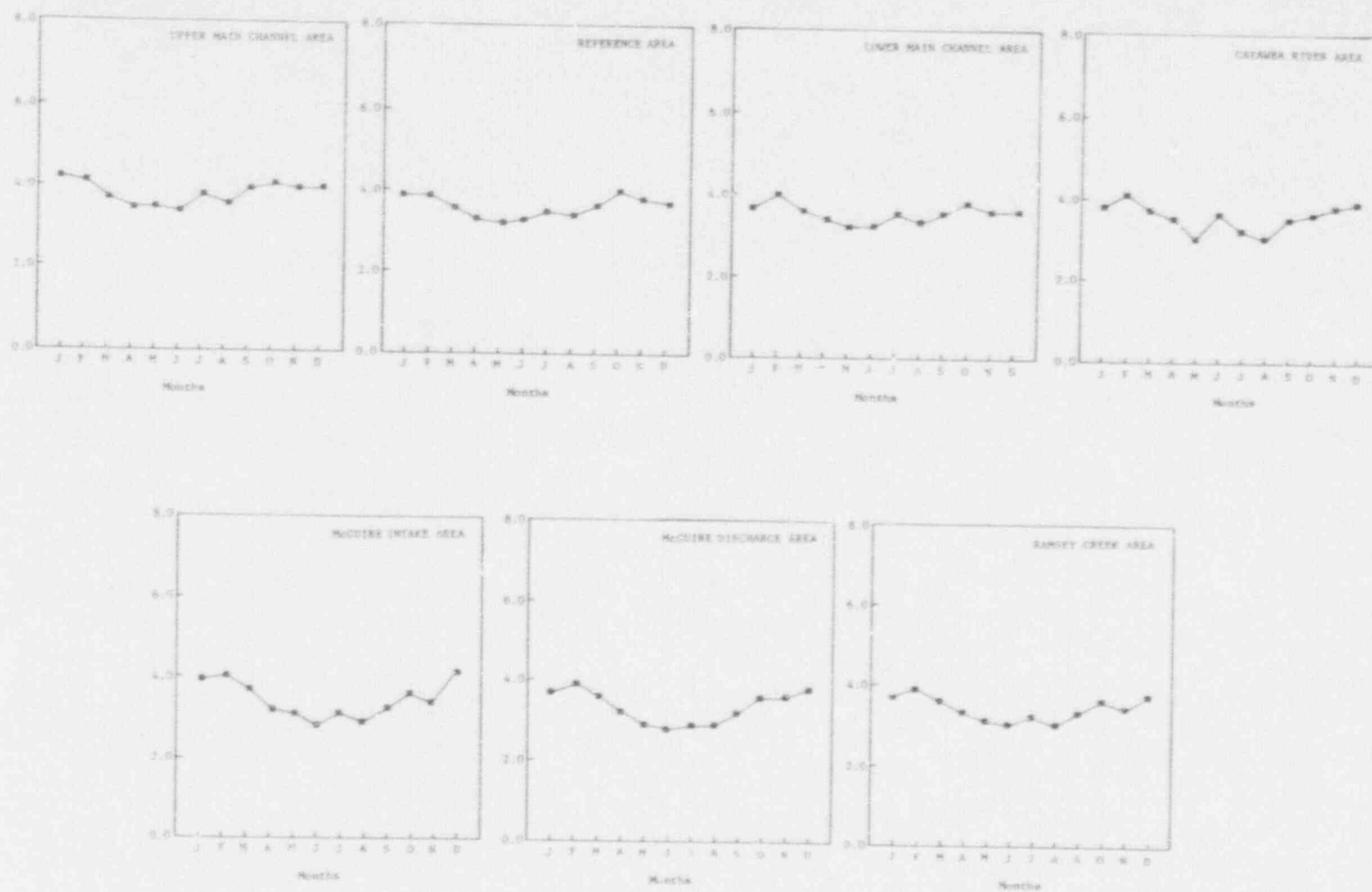


Figure 3-28. Mean silica concentrations (mg·l⁻¹) in selected areas of Lake Norman from 1975 through 1979.

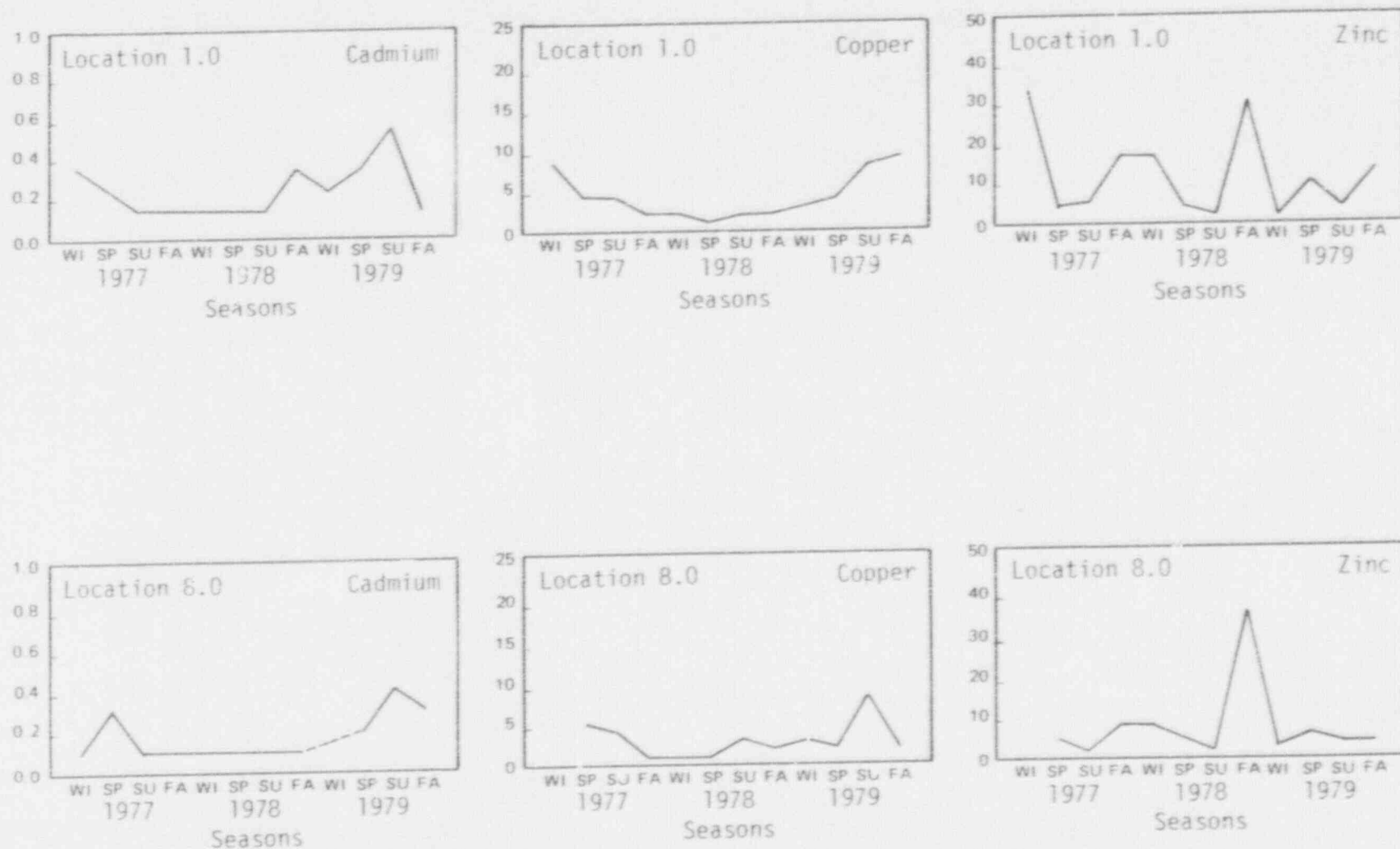


Figure 3-29. Mean seasonal variation of cadmium, copper, and zinc ($\mu\text{g}\cdot\text{l}^{-1}$) from 1977 through 1979 at Location 1.0 and Location 8.0. Dashed lines indicate missing data.

CHAPTER 4. PHYTOPLANKTON

M. S. RODRIGUEZ

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INTRODUCTION

BACKGROUND

Phytoplankton are the algae of open water communities. In relatively large, deep, impounded systems phytoplankton generally account for the majority of autotrophic production (Wetzel 1975). This is particularly true of systems such as Lake Norman, where fluctuating water levels and unfavorable substrates limit the development of extensive macrophytic and periphytic communities. In Lake Keowee, a South Carolina piedmont reservoir of relatively similar size, retention time, and substrate type, phytoplankton accounted for approximately 98% of primary production (Rodgers 1974). Thus the phytoplankton in Lake Norman may represent the major autochthonous source of organic matter for consumption by the heterotrophic component of the community.

Weiss et al. (1975) described the mean standing crops and primary productivity of Lake Norman as similar to other impoundments on the Catawba River system. The phytoplankton community in the vicinity of McGuire Nuclear Station was described as low in abundance, highly diverse, and dominated by green algae and diatoms. Maximum abundance occurred in mid summer. Menhinick and Jensen (1974) found similar results in the vicinity of Marshall Steam Station, with the exception that seasonal maxima appeared to occur during the colder months (November through March). Weiss and Kuenzler (1976) classified Lake Norman as oligo-mesotrophic, while the U. S. Environmental Protection Agency (1975) described it as slightly eutrophic.

Several studies have examined the effects of the operation of electric generating facilities on the phytoplankton of southern reservoirs. The major identifiable impacts appear to be related to water movement. Among steam stations with surface-water intakes, studies indicate that homogeneity among sampling locations increased during station operation (Weiss and Anderson 1978). Among steam stations with hypolimnetic intakes, the primary impact of station operation appeared to be a dilution of epilimnetic populations in the discharge area with less abundant hypolimnetic populations (Duke Power Company 1977; Smith et al. 1974). The hydromechanics of the condenser cooling water system of Plant Allen, a steam station located on Lake Wylie, North Carolina, resulted in the redistribution of algal populations from one area to an area with typically dissimilar populations, and in addition created increased retention times of phytoplankton in an eddy upstream of the discharge (Wilde and Paulishen 1974; Weiss et al. 1975).

The observation of steam station effects which were directly attributable to increased temperatures was generally limited to studies of phytoplankton entrained through condenser cooling water systems. Gurtz and Weiss (1972), studying phytoplankton entrained at Plant Allen, observed depressed productivity following condenser passage, with the degree of depression related to initial temperature and the magnitude of temperature increase. However, delayed growth stimulation appeared to occur following the initial decrease in productivity. Knight (1973), working at the same location, documented decreased abundance and diversity in entrained populations. Entrainment studies at Oconee Nuclear Station, Lake Keowee, South Carolina (Duke Power Company 1977) and at Marshall Steam Station, Lake Norman, North Carolina (Smith et al. 1974) indicated that condenser passage had very little impact on phytoplankton populations.

OBJECTIVES

The objectives of this study were to:

1. document the taxonomic composition of the Lake Norman phytoplankton community,
2. describe seasonal patterns in phytoplankton abundance and taxonomic composition in Lake Norman,
3. examine vertical and horizontal distribution patterns in Lake Norman phytoplankton populations, and
4. characterize rates of production by phytoplankton in Lake Norman under various environmental conditions.

MATERIALS AND METHODS

SAMPLING LOCATIONS, FREQUENCY, AND PARAMETERS

Sampling of the phytoplankton populations and chlorophyll concentrations of Lake Norman was initiated in July 1973. The sampling history of each location is documented in Table 4-1. Locations are described in Table 1-3 and mapped in Fig. 1-10 and 1-11. Population and chlorophyll data from 1973 are presented and discussed in the McGuire Nuclear Station Environmental Report (Duke Power Company 1976).

From January 1974 through February 1975 duplicate euphotic zone composite population and chlorophyll samples were collected monthly at Locations 2.0, 3.0, 4.5, 5.0, 6.0, 7.5, 10.0, 11.0, 13.0, and 16.0. In addition, duplicate population and chlorophyll samples were collected monthly at the depth of 1% light penetration, at one-half that depth, at the surface, and at 1 m above lake bottom at Locations 1.0, 4.0, and 8.0, to examine the vertical distribution of the phytoplankton. Locations 1.0 through 7.5 were selected to characterize the area of the lake predicted to be within the thermal influence of McGuire Nuclear Station, while Locations 8.0, 10.0, 11.0, and 13.0 were intended to act as references and to characterize the northern area of Lake Norman. Location 16.0 was chosen to monitor populations downstream of Cowans Ford Dam in Mountain Island Lake.

Euphotic zone composite population samples were collected weekly at Locations 1.0, 4.0, and 8.0 from April 1974 through September 1975 to document short-term variability in the phytoplankton community. Long-term variability in phytoplankton biomass was examined through the monthly collection of chlorophyll samples from March 1975 through September 1977. From March 1975 through November 1975 duplicate euphotic zone composite chlorophyll samples were collected at Locations 1.0, 2.0, 3.0, 4.0, 4.5, 5.0, 6.0, 7.5, 8.0, 10.0, 11.0, 13.0, and 16.0. Sampling at Locations 7.5, 10.0, 11.0, and 13.0 was discontinued in December 1975, and sampling at Location 6.0 was discontinued in October 1976. Justification for deleting these locations from the monitoring program is contained in the McGuire Nuclear Station Environmental Report (Duke Power Company 1976). In March

1977, sampling at Locations 1.0, 3.0, 5.0, and 8.0 was modified such that duplicate chlorophyll samples were collected at three or more discrete depths within the water column, in order to obtain further data on vertical distribution of the phytoplankton. This program continued through September 1977.

Beginning in October 1977, and continuing through December 1980, duplicate euphotic zone composite population and chlorophyll samples were collected monthly at Locations 1.0, 1.2, 2.0, 3.0, 3.9, 4.0, 4.5, 5.0, 8.0, and 16.0. In addition, duplicate discrete samples were collected at a depth 1 m above the lake bottom at Locations 1.0, 3.0, and 8.0. Location 1.2 was added to the monitoring program to characterize populations in the immediate area of McGuire's upper-level intake, while Location 3.9 was added to characterize populations in the McGuire discharge canal.

Two studies were conducted to examine rates of primary production. From February 1974 through January 1975 primary productivity was measured monthly at Locations 1.0 and 4.0, and from January 1978 through January 1979 primary productivity was measured weekly at Locations 3.0 and 8.0 and quarterly at Location 1.0. Quarterly measurements continued at Locations 1.0, 3.0, and 8.0 from 1979 through 1980. The initial study was conducted to characterize productivity in the vicinity of the McGuire intake and discharge. The second study, beginning in 1978, was conducted to compare productivity at a reference location (8.0) to locations within the area of McGuire's projected thermal influence (3.0 and 1.0). Population and chlorophyll samples were collected at discrete depths in conjunction with the more recent productivity study.

Because of the potential impact of McGuire's operation on the operation of Marshall Steam Station (located approximately 23 km uplake from Cowans Ford Dam on Lake Norman), an additional sampling program was initiated at locations in the vicinity of Marshall Steam Station. From June 1978 through May 1979 population and chlorophyll samples were collected twice each month at Locations 11.0, 13.0, 14.0, 15.0, 15.9, 34.0, 50.0, and 60.0. Beginning in June 1979 and continuing through December 1980, population and chlorophyll samples were collected monthly at Locations 11.0, 13.0, and 34.0. Samples collected at all locations except 14.0 consisted of either euphotic zone composites, or composites of water collected at 0.3 and 5.0 m. Surface samples were collected at Location 14.0.

The Results and Discussion section of this chapter is based primarily on the following data: monthly chlorophyll data from Locations 1.0 through 8.0, 1975 through 1979; monthly chlorophyll data from Locations 11.0 through 60.0, June 1978 through May 1979; monthly population data from Locations 1.0 through 8.0, January 1978 through December 1979; monthly population data from Locations 11.0 through 60.0, June 1978 through May 1979; monthly population data from Locations 1.0 through 13.0, March 1974 through February 1975; weekly chlorophyll and population data from Locations 3.0 and 8.0, January 1978 through January 1979; and weekly productivity data from Locations 3.0 and 8.0, January 1978 through January 1979. All data are included in Appendix 4.

PROCEDURES

STANDING CROP

Field Procedures

Measurement Of Light Penetration

Light penetration was measured at each location on each sample date. From 1974 through 1976 a Montedoro-Whitney Model LMD-8A solar illuminance meter was used to determine the depth to which 1% of incident solar radiation penetrated. In February 1977, the Montedoro-Whitney meter was replaced with a Kahlsico Model 268WA310 radiometric submarine photometer, preferable to the Montedoro-Whitney meter because it measures energy flux ($\mu\text{Watts}\cdot\text{m}^{-2}$) within the photosynthetically active range of the spectrum (400 to 700 nm), while the Montedoro-Whitney measures the sum of visible and infrared radiation. Meters such as the Kahlsico Model 268WA310 and the Licor Model LI-185A thus provide more accurate estimates of the amount of solar radiation actually available for photosynthesis. In September 1978 a Licor Model LI-185A light meter equipped to measure both energy flux and quantum flux ($\mu\text{E}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) in the 400 to 700 nm range became the primary instrument for measuring light penetration. From February 1977 to December 1980, vertical profiles of light intensity at depth intervals were measured at each location on each sampling date.

Sample Collection

All standing crop samples were collected with a van Dorn or Kemmerer water bottle or with a graduated cylinder (surface samples only). Euphotic zone composite samples were prepared by compositing 1-l samples from the depth of 1% light penetration, from one-half that depth and from the surface. The change in instrumentation used for the measurement of light penetration from a Montedoro-Whitney Model LMD-8A to a Kahlsico Model 268WA310 and subsequently to a Licor Model LI-185A probably resulted in the measurement of greater depths of 1% light penetration after January 1977. The Montedoro-Whitney meter measures solar radiation in both the infrared and visible ranges, while the Kahlsico and Licor meters measure in the visible range only. Because infrared radiation is absorbed in water more rapidly than visible light, the Montedoro-Whitney meter probably underestimated the depths of 1% light penetration compared to the Kahlsico and Licor meters. The collection of composite standing crop samples based on the 1% depths estimated by any of the three instruments should result in similar estimates of standing crop whenever the mixed depth is greater than the Kahlsico/Licor 1% depth, since only the mixed layer would be subsampled. Based on 1978 data (Figures 4-30a and 4-30b), the mixed depth exceeded the Kahlsico/Licor 1% depth from September through mid-May. Thus, during this period the use of any of the three meters should produce similar standing crop estimates. However, during the period from mid-May through August, the Montedoro-Whitney meter most frequently estimated the 1% depth to be slightly less than the mixed depth, while the Kahlsico/Licor estimates were most frequently slightly greater than the mixed depth. Composites based on the Montedoro-Whitney estimates thus most frequently represented the epilimnion

only, while composites based on the Kahlsico/Licor 1% depths frequently contained one subsample from the upper metalimnion. Chlorophyll profiles obtained in 1978 (Appendix Tables 4.2-4 and 4.2-5) indicate that the standing crop of the upper metalimnion averaged about 45% less than that of the epilimnion. Thus, the inclusion of one metalimnetic subsample in the composite would produce a mean standing crop estimate approximately 18% less than that which would be obtained using epilimnetic subsamples only. The error inherent in the phytoplankton enumeration technique was approximately 20% (Lund et al. 1958).

Subsamples for the analysis of standing crop parameters were withdrawn from the composite sample. Samples collected to characterize discrete depths were withdrawn directly from the van Dorn or Kemmerer bottle. Population samples consisted of a known volume of water, generally 950 ml, measured in a graduated cylinder and transferred to a glass French square bottle, to which 10 to 20 ml M3 preservative (Meyer 1971) was immediately added. In January and February 1974, a surfactant was also added to the samples. However, the surfactant interacted with the sample and preservative such that the samples could not be analyzed. To prepare samples for the analysis of chlorophyll *a* content, a known volume of water, generally 250 to 500 ml, was filtered in the field through a 47 mm glass fiber filter. Approximately 1 ml of a saturated magnesium carbonate solution was added to each sample during filtration to prevent acidification and decomposition of chlorophyll *a* to phaeopigments (Strickland and Parsons 1972). Filters were stored in darkened centrifuge tubes on ice.

Laboratory Procedures

Population Samples

Population samples were allowed to settle undisturbed at a rate of at least $4 \text{ h} \cdot \text{cm}^{-1}$ of container height (Weber 1973). Supernatants were aspirated off and discarded, and the settling process was repeated in smaller containers until a final known volume of approximately 5 ml was obtained. Samples were diluted when the settling process resulted in a very dense concentration of phytoplankton or other suspended matter.

Subsamples of each concentrate were pipetted into Palmer-Maloney counting cells (Palmer and Maloney 1954) for observation at 500X under phase-contrast illumination. A minimum of 100 phytoplankton units (Lund et al. 1958) were identified and enumerated for each subsample, over a known area of the counting cell.

Prior to 1977, phytoplankton units were defined as follows: for diatoms (Bacillariophyceae) one cell was counted as one unit; for all other classes, one unit was defined as one cell for unicellular species, one colony for colonial species, and one 18- μm length for filamentous species. Beginning in 1977, each entire filament of a non-diatom species was defined as one unit. To aid comparability, all data collected prior to 1977 and reported here have been converted to the latter definition of units as follows. Where possible, a mean filament length for each non-diatom filamentous species was obtained, and divided by 18 to obtain a mean number of 18- μm lengths per filament. Each count of a filamentous species made prior to 1977 was then divided by the mean number of 18- μm lengths per filament to obtain an approximate number of filaments observed. Where it was not possible to obtain a mean filament length (as when a species was very rarely observed), the mean number of 18- μm lengths recorded per filament observation was obtained and used in the same manner as mean number of 18- μm lengths per filament above.

Taxonomic identifications were carried out to the lowest practicable taxon, generally species or genus. Major taxonomic references included Bourrelly (1968, 1972), Cocke (1967), Eddy (1930), Huber-Pestalozzi (1941, 1968), Hustedt (1930), Kim (1967), Patrick and Reimer (1966), Prescott (1962), Weber (1971), and Whitford and Schumacher (1973). Dr. Larry A. Whitford and Dr. Charles W. Reimer were retained as taxonomic consultants and confirmed identifications of many of the species observed.

From 1 to 30 cells of each species were measured with an ocular micrometer, depending on frequency of occurrence, and the mean cell dimensions for each species were calculated. For colonial species, the number of cells per colony was also recorded for several colonies, and the mean number of cells per colony was calculated. For filamentous species, filament dimensions rather than cell dimensions were measured.

Chlorophyll Samples

Filters containing chlorophyll samples were ground with a tissue grinder in a known volume of 90% acetone and stored on ice for at least 15 h. Samples were centrifuged to remove filter fragments and analyzed on a Turner Model 111 fluorometer and/or a Coleman Model 124 double-beam spectrophotometer. Following an initial reading samples were acidified with oxalic or hydrochloric acid, and reread to obtain estimates of true chlorophyll *a* and phaeopigment concentrations (Strickland and Parsons 1972). Samples were not acidified prior to 1975.

Calculations

The depth to which 1% of subsurface incident light penetrated was recorded directly from the Montedoro-Whitney light meter, and was estimated from submarine photometer data by regressing the log of percent subsurface light penetration against depth. Chlorophyll *a* concentrations were calculated according to Strickland and Parsons (1972).

Phytoplankton counts were converted to standing crop estimates expressed as numerical densities. Estimates of standing crop expressed as biovolume were also obtained, by converting the mean dimensions (length, width, depth) for each species to an approximate biovolume per cell or filament, using volume formulae for appropriate geometric solids. For non-filamentous colonial species, the mean number of cells per colony was multiplied by the biovolume per cell to obtain a colonial biovolume estimate. However, all diatom biovolumes were expressed on a per-cell basis. Standing crop estimates expressed as biovolume were obtained by multiplying mean biovolume per phytoplankton unit by the species numerical density. Standing crop estimates for March 1974 through February 1975 were based on mean unit dimensions for that period. Estimates reported for October 1977 through December 1980 were based primarily on mean unit dimensions recorded from October 1977 through September 1978.

PRODUCTIVITY

Field Procedures

During the initial study period (February 1974 through January 1975) primary productivity and rates of community metabolism were estimated monthly by

measuring changes in the dissolved oxygen concentration of samples incubated at 4 to 6 depths for a midday period of 3 to 6 h. Depths were chosen on the basis of light penetration, measured with a Montedoro-Whitney solar illuminance meter. Samples were collected with opaque Kemmerer or van Dorn bottles. From each depth, 2 sets of 2 transparent and 1 opaque 300-ml BOD bottles were filled. One transparent bottle from each set was retained for the determination of initial dissolved oxygen concentration, while the remaining samples were incubated at the depth of collection. All oxygen samples were preserved in the field with 2 ml MnSO_4 solution and 2 ml alkali-iodide-azide solution (APHA et al. 1971). Two series of dawn-to-dusk 4-h incubations were conducted, in May and October 1974.

From January 1978 through January 1979 productivity was estimated weekly using both the oxygen method described above and the ^{14}C method. Samples were collected and incubated at 0.3, 1.0, 2.0, 3.0, 6.0, and 10.0 m. Incubation depths were chosen on the basis of light profile data collected on Lake Norman for the months November 1974 to November 1975, and represented the approximate mean depths of 100, 50, 25, 10, 1 and $<0.1\%$ light penetration. Samples were incubated for 2 to 4 h at midday. An Eppley pyranometer, Model 8-48, continuously recorded incident light. Vertical profiles of light intensity in terms of both energy and quanta were obtained during each incubation with submarine photometers. Vertical profiles of temperature, pH, dissolved oxygen, and conductivity were obtained during each incubation with a Hydrolab Model 6D (Chapter 3).

At each depth, sets of initial, transparent, and opaque 300-ml BOD bottles were filled to examine changes in dissolved oxygen. In addition, sets of transparent and opaque 300-ml BOD bottles were filled and spiked with approximately 5 μCi ^{14}C as sodium bicarbonate. Samples for the analysis of alkalinity, chlorophyll, and nutrients were also collected at each depth. Population samples were collected at 0.3, 3.0, 6.0, and 25.0 m. Duplicate samples were collected approximately every other sampling period.

Laboratory Procedures

Following incubation and fixation, oxygen samples were titrated using the azide modification of the iodometric method to determine initial and final concentrations of dissolved oxygen. Changes in oxygen concentrations in transparent and opaque bottles were used to calculate gross and net productivity and respiration (APHA et al. 1976).

A 1-ml subsample was withdrawn from each ^{14}C -spiked sample and analyzed using liquid scintillation spectrophotometry to check the true activity of the spike (this procedure was not carried out prior to August 1978). To determine ^{14}C uptake for each sample, a 100-ml subsample was filtered onto a membrane filter, and then rinsed with 0.002 N hydrochloric acid to remove excess inorganic ^{14}C . Filters were assayed for radioactivity using a liquid scintillation counter (Beckman Model LS-9000). Filtrates were purged of inorganic ^{14}C and subjected to flash evaporation, in order to concentrate ^{14}C -labeled dissolved organics released by the plankton during incubation. A subsample of the concentrated filtrate was analyzed using the liquid scintillation counter.

Alkalinities were determined by titration to a pre-determined pH end-point (APHA et al. 1976). The appropriate end-point pH was determined for each sampling period by examining the inflection points of the curves resulting from at least two full titrations. The initial pH of each alkalinity sample was recorded. Samples collected for the analysis of total phosphorus, orthophosphate, Kjeldahl nitrogen, ammonia, and nitrate plus nitrite were analyzed as described in Chapter 3.

Calculations

Estimates of carbon uptake ($\text{mg C} \cdot \text{m}^{-3} \cdot \text{h}^{-1}$) from samples spiked with ^{14}C were calculated based on APHA et al. (1976). Opaque bottle rates were subtracted from clear bottle rates. Total available inorganic carbon and carbon dioxide concentrations were calculated based on field measurements of conductivity and temperature, and laboratory measurements of pH and alkalinity, utilizing equations derived from Stumm and Morgan (1970). Carbon uptake rates on an areal basis ($\text{mg C} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$) were obtained by plotting volumetric uptake ($\text{mg C} \cdot \text{m}^{-3} \cdot \text{h}^{-1}$) vs. depth (m), and integrating the resulting curve by planimetry. Daily areal uptake rates ($\text{mg C} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$) were calculated by multiplying hourly areal rates by the ratio of total $\text{ly} \cdot \text{d}^{-1}$ to $\text{ly} \cdot \text{h}^{-1}$ (mean during incubation period). Mean values for $\text{mg C} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$ for each week were calculated utilizing a weekly mean value for $\text{ly} \cdot \text{d}^{-1}$. Annual estimates of production ($\text{g C} \cdot \text{m}^{-2} \cdot \text{yr}^{-1}$) were obtained by adding the weekly mean areal uptake rates ($\text{mg C} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$) for 52 consecutive weeks, and multiplying by $7 \text{ d} \cdot \text{wk}^{-1}$.

Assimilation ratios ($\text{mg C} \cdot \text{mg chl a}^{-1} \cdot \text{h}^{-1}$) were calculated at each depth by dividing uptake rates ($\text{mg C} \cdot \text{m}^{-3} \cdot \text{h}^{-1}$) by the mean concentration of chlorophyll *a* ($\text{mg} \cdot \text{m}^{-3}$), determined spectrophotometrically. For depths $\leq 3 \text{ m}$, values for the mean concentration of chlorophyll *a* in the upper 3 m were used; for 6 and 10 m, values for chlorophyll *a* concentrations at those discrete depths were used. Photosynthetic efficiencies, or carbon uptake rates per unit chlorophyll *a* per unit light, were determined from the slope of the initial linear portion of the plot of photosynthesis ($\text{mg C} \cdot \text{mg chl a}^{-1} \cdot \text{h}^{-1}$) vs. light intensity ($\mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$), for each set of incubations. Mean light intensity at each incubation depth was determined by subtracting reflected light from total incoming solar radiation during the incubation, converting to photosynthetically active radiation (Vollenweider 1974), multiplying by the percent penetration of subsurface incident light to the desired depth, and dividing by the length of the incubation period. Where necessary, data expressed as $\text{ly} \cdot \text{h}^{-1}$ were converted to $\mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ using a conversion factor of $52.8: (\mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1})/(\text{ly} \cdot \text{h}^{-1})$ (Harris 1978).

Respiration rates could not be calculated directly from ^{14}C data. However, apparent respiration rates (R') were back-calculated, based on uptake rates and changes in algal standing crop expressed as carbon. Algal biovolumes were converted to estimates of algal carbon utilizing the equations of Strathmann (1967). The year was divided into several time periods, generally 2 to 5 weeks in length, during which concentrations of algal carbon in the mixed layer of the lake either consistently increased, decreased, or remained stable. For each time period, the net change in algal carbon in the mixed layer was calculated and divided by the number of days in the time period. This quantity was then subtracted from the mean daily areal photosynthetic rate during the time period, resulting in an estimate of daily apparent respiration in the mixed layer per square meter of lake surface. This estimate was in turn

divided by the depth in meters of the mixed layer, and by $24 \text{ h} \cdot \text{d}^{-1}$, to obtain an estimate of apparent respiration as $\text{mg C} \cdot \text{m}^{-3} \cdot \text{h}^{-1}$.

DATA ANALYSES

Differences in total abundance among locations were examined on an annual basis with Friedman's analysis (Conover 1971), using mean abundance values for each month at each location. Separate analyses were performed on chlorophyll a, algal density, and algal biovolume data.

Differences in mean annual taxonomic composition among locations were examined with cluster analysis (Helwig and Council 1979). Variables used in this analysis were the mean annual densities at each location of six taxonomic groups: the Chlorophyceae, Bacillariophyceae, Cryptophyceae, Myxophyceae, Dinophyceae, and a group representing all other classes combined. In order to examine the relative importance of temporal variation in taxonomic composition as compared to spatial variation, a cluster analysis was performed using as variables the percent composition of the five major taxonomic classes plus unidentified algae, observed at each location during each month in 1978.

Individual linear regressions (Helwig and Council 1979) were used to examine the relationships between the following parameters: maximum assimilation ratio (AR_{max}) and temperature; AR_{max} and total phosphorus; AR_{max} and total nitrogen; and log of the percent subsurface light penetration and depth.

RESULTS AND DISCUSSION

COMMUNITY COMPOSITION

Ten classes and 306 species and varieties of phytoplankton were observed in samples collected from Lake Norman from October 1977 through December 1979 (Table 4-2). Distribution of species in classes was as follows: Chlorophyceae, 148 species and varieties; Bacillariophyceae, 54; Chrysophyceae, 27; Haptophyceae, 1; Xanthophyceae, 3; Cryptophyceae, 9; Myxophyceae, 28; Euglenophyceae, 13; Dinophyceae, 22; and Chloromonadophyceae, 1. In terms of abundance, the major classes were the Bacillariophyceae, dominant from late fall through mid spring; the Cryptophyceae, abundant in late spring; and the Chlorophyceae and Dinophyceae, dominant from summer through mid fall. The Myxophyceae were an important component of warm weather populations in 1974, but did not recur in large numbers in 1978 or 1979. The Haptophyceae and Chrysophyceae were occasionally abundant at isolated locations for short periods of time. Genera which consistently constituted a significant part of the total density or biovolume were Nannochloris, Rhodomonas, Melosira, and Peridinium. Community composition was similar to that observed for Lake Norman by Weiss et al. (1975).

LOCATION COMPARISONS

TOTAL ABUNDANCE

Differences in total abundance among downlake locations (1.0 through 8.0) were examined utilizing Friedman's analysis on 5 years of monthly chlorophyll data

(1975 through 1979). Significant location differences were detected only in 1976 and 1979 (Table 4-3). During these years, Location 8.0 exhibited highest mean annual chlorophyll concentrations ($4.6 \text{ mg} \cdot \text{m}^{-3}$ in 1976 and $3.6 \text{ mg} \cdot \text{m}^{-3}$ in 1979). These values did not exceed those observed at other downlake locations by more than $1.5 \text{ mg} \cdot \text{m}^{-3}$, indicating that, although at times significant, variation among downlake locations was not substantial on an annual basis (Fig. 4-1).

Lakewide differences in total abundance were examined utilizing chlorophyll data from uplake as well as downlake locations, collected from January through December 1974 and from June 1978 through May 1979. Significant differences among locations were detected, with uplake locations and Location 8.0 consistently exhibiting higher chlorophyll concentrations than downlake locations (Fig. 4-2 and Table 4-3). Location 34.0, the highest ranked location (Table 4-3), exhibited a mean annual chlorophyll concentration of $5.0 \text{ mg} \cdot \text{m}^{-3}$, while the lowest ranked location (1.2) exhibited a mean annual chlorophyll concentration of $2.0 \text{ mg} \cdot \text{m}^{-3}$, indicating that differences between uplake and downlake locations were somewhat more substantial than among downlake locations alone (Fig. 4-2). Higher chlorophyll concentrations uplake may have been the result of the higher concentrations of total phosphorus observed uplake (Chapter 3).

Friedman's analysis of biovolume data generally supported the results obtained utilizing chlorophyll data (Table 4-3). However, analysis of density data did not produce consistent relationships among various areas of the lake (Table 4-3).

TAXONOMIC COMPOSITION

Mean annual densities of the major taxonomic classes (Chlorophyceae, Bacillariophyceae, Cryptophyceae, Myxophyceae, Dinophyceae; all other classes were combined and treated as one variable) were compared among locations using cluster analysis (Helwig and Council 1979). Cluster analysis of downlake locations (1.0 through 8.0) and Location 16.0 (Fig. 4-3) revealed that differences in taxonomic composition among locations did occur, largely as the result of differences in the mean annual densities of diatoms, which were highest at Location 8.0 and lowest at locations in the Ramsey Creek area. This was particularly evident in 1979, when diatom densities were as much as 50% lower at Ramsey Creek locations than at Location 8.0 (Table 4-4).

Cluster analysis based on the mean annual densities observed at all locations, uplake included, from June 1978 through May 1979, revealed that uplake locations maintained higher mean annual densities of diatoms, and lower densities of green algae and unidentified or minor classes of algae, than did downlake locations (Table 4-4 and Fig. 4-4). Diatom densities at Locations 1.0, 2.0, and 8.0 were approximately 20% lower, and at Ramsey Creek locations, approximately 50% lower than those observed uplake. Densities of green algae were approximately 30% lower uplake than downlake, while densities of unidentified or minor classes of algae were 60% lower uplake than downlake (Table 4-4). A cluster analysis based on data from March 1974 through February 1975 isolated uplake locations 11.0 and 13.0, which at that time exhibited higher mean annual densities of cryptophytes and diatoms than exhibited at other locations (Fig. 4-5).

Examination of the mean class densities associated with each cluster (Table 4-4) indicates that, although detectable, taxonomic differences among downlake locations were not substantial, and in fact, were generally outweighed by similarities in temporal variation among locations (Fig. 4-6). As the following discussions of temporal variation and vertical distribution are based on data collected at downlake locations (1.0, 1.2, 2.0, 3.0, 3.9, 4.0, 4.5, 5.0, 8.0), the phytoplankton communities of specific geographical areas will be discussed independently only where instances of large differences in taxonomic composition or total abundance occurred.

TEMPORAL VARIATION

TOTAL ABUNDANCE

Seasonal variation

Mean concentrations of chlorophyll, averaged over a 5-year period and over 7 locations (1.0, 2.0, 3.0, 4.0, 4.5, 5.0, 8.0), yielded little evidence of consistent patterns in the seasonal variation of phytoplankton abundance (Fig. 4-7). The minimum monthly mean chlorophyll concentration was $2.6 \text{ mg} \cdot \text{m}^{-3}$ in May; the maximum was 5.0 in September. Seasonal trends in mean biovolume data averaged over 2 years (1978 and 1979) for Ramsey Creek (Locations 3.0, 4.5, 5.0) and main channel locations (1.0, 2.0, 8.0) were somewhat more substantial (Fig. 4-8 and 4-9); however, maxima did not exceed minima by more than an order of magnitude. This is typical of other oligo- to mesotrophic piedmont Carolina reservoirs (Duke Power Company 1977; Weiss and Anderson 1978; Wilde and Paulishen 1974). In contrast, Wetzel (1975) stated that seasonal biomass maxima of algal populations in temperate lakes are generally on the order of 1000 times higher than seasonal minima.

Patterns in seasonal variation were, however, discernible in biovolume and chlorophyll data when examined on a yearly basis, rather than utilizing 5-year mean data. Chlorophyll concentrations in surface waters, which ranged from 0.3 to $18.0 \text{ mg} \cdot \text{m}^{-3}$, and biovolume, which ranged from <100 to $4000 \text{ mm}^3 \cdot \text{m}^{-3}$ attained mid summer maxima in 1974 (Duke Power Company 1976). This pattern persisted in chlorophyll concentrations at main channel locations through 1976; no consistent seasonal trends were exhibited at Ramsey Creek or McGuire discharge locations during this period (Fig. 4-10). More recently (1978 and 1979), bimodal maxima were observed to occur in spring and in late summer to early fall (Fig. 4-10 and 4-11). Among all downlake locations the fall peak in biovolume varied from 1000 to $2500 \text{ mm}^3 \cdot \text{m}^{-3}$ in 1978 and 1979.

The size of the spring peak, composed primarily of *Melosira italica*, was much more variable, ranging from 800 to $1300 \text{ mm}^3 \cdot \text{m}^{-3}$ in 1978, and from non-existent at Ramsey Creek locations to $3800 \text{ mm}^3 \cdot \text{m}^{-3}$ at main channel locations in 1979. Unlike Ramsey Creek locations, McGuire discharge locations (3.9 and 4.0) did exhibit a small spring peak in 1979, presumably due to the displacement of water from main channel locations through the McGuire Condenser Cooling Water System.

No consistent seasonal trends were observed in algal density, which ranged in surface waters from 300 to $5000 \text{ units} \cdot \text{ml}^{-1}$. Density, however, is not generally considered a good estimate of total algal biomass, due to extreme variation in cell size among species.

Year to year variation

Mean annual chlorophyll concentrations exhibited a net downward trend from 1974 through 1979 (Table 4-5 and Fig. 4-1). Values for downlake locations (1.0 through 8.0) ranged from 5.7 to 7.0 $\text{mg}\cdot\text{m}^{-3}$ in 1975, and from 2.1 to 3.6 $\text{mg}\cdot\text{m}^{-3}$ in 1979. The decline in chlorophyll a concentrations was potentially due to the decrease in mean annual concentrations of total phosphorus which occurred during this time period (Chapter 3).

SEASONAL SUCCESSIONS AND ASSOCIATIONS

The seasonal variation of each of the major taxonomic classes was quite consistent in 1978 and 1979. Densities of the Chlorophyceae peaked in late summer-early fall (Fig. 4-12 and 4-13), attaining maxima up to 2200 $\text{units}\cdot\text{ml}^{-1}$ (200 $\text{mm}^3\cdot\text{m}^{-3}$ of biovolume). The major components of the green algal community during the period of peak abundance were small coccoid greens, such as *Nannochloris* spp. and *Chlorella* spp., and several very small members of the genus *Cosmarium* (less than 10 μm in length). The green algal community was quite diverse during late summer-early fall, with an average of 23 taxa observed at each location, the majority being members of the Chlorococcales. In 1974, the Chlorophyceae peaked in mid summer (Fig. 4-14 and 4-15). Dominants were similar to those observed in 1978 and 1979.

Diatoms reached peak abundance during the spring (Fig. 4-12 and 4-13). Densities as high as 3800 $\text{units}\cdot\text{ml}^{-1}$ and biovolumes up to 3700 $\text{mm}^3\cdot\text{m}^{-3}$ were observed in March 1979. The primary components of the spring diatom pulse were *Melosira italica* and *M. italica* var. *tenuissima*, the year-round dominants of the diatom population. During the period of maximum diatom abundance, rarely more than 11 taxa of diatoms were observed at each location. Other diatoms common during this period were *Asterionella formosa*, *Melosira distans* and *M. distans* var. *alpigena*, *Nitzschia agnita*, *Rhizosolenia* spp., and *Stephanodiscus* spp. As previously stated, no peak in diatom abundance occurred at Ramsey Creek locations in 1979. In 1974, both spring and fall peaks were observed in diatom abundance (Fig. 4-14 and 4-15). While both peaks were of similar size in terms of density, the fall peak was much larger in terms of biovolume. The spring peak was dominated by *Melosira distans* var. *alpigena*, although *M. italica* was also important; the fall peak was dominated by *M. italica* and *M. italica* var. *tenuissima*. Diatom abundances were lower in Ramsey Creek than in the main channel.

Densities of the Cryptophyceae peaked in May in 1978 and 1979 (Fig. 4-12 and 4-13), exhibiting a maximum density of 1500 $\text{units}\cdot\text{ml}^{-1}$ and a maximum biovolume of 300 $\text{mm}^3\cdot\text{m}^{-3}$. *Rhodomonas minuta* was by far the most abundant of the cryptophytes, both at peak density and throughout the year. On the average, five taxa were observed at each location during peak abundance, generally including several species of the genus *Cryptomonas* as well as *Rhodomonas minuta*. In 1974, seasonal trends in the abundance of the cryptophytes were variable, although minima were generally observed during the summer (Fig. 4-14 and 4-15).

Dinoflagellate populations peaked in late summer-early fall in 1978 and 1979 (Fig. 4-12 and 4-13). Densities did not exceed 150 $\text{units}\cdot\text{ml}^{-1}$; the maximum observed biovolume was 2200 $\text{mm}^3\cdot\text{m}^{-3}$. The genus *Peridinium* constituted the major part of the dinoflagellate community. The most frequently observed species

during peak abundance were Peridinium deflandrei, P. inconspicuum, P. lomnickii, P. wisconsinense, and Glenodinium gymnodinium. On the average, six species were observed at each location during peak abundance. A June peak in dinoflagellate abundance was observed at downlake locations (1.0 through 8.0) in 1974 (Fig. 4-14 and 4-15).

Blue-green algae were not observed in substantial numbers in 1978 and 1979. Maximum observed density during this period was 200 units·ml⁻¹ and maximum biovolume approximately 100 mm³·m⁻³. One exception occurred, in September and October 1978, when densities at Location 16.0 reached 900 units·ml⁻¹ and biovolume reached 300 mm³·m⁻³, due to high densities of Oscillatoria lemmermannii. Blue-greens present at other locations peaked in late summer-early fall (Fig. 4-12 and 4-13). In contrast, in 1974 blue-green algae constituted an important component of the total algal community, attaining peak densities and biovolumes of 400 units·ml⁻¹ and 800 mm³·m⁻³, respectively. Peak abundance was observed in May and July (Fig. 4-14 and 4-15). Anabaena wisconsinense accounted for the majority of blue-green algal biovolume. Other species of Anabaena, as well as Anacystis cyanea, were also present. On the average, four taxa were observed at each location during peak abundance in 1974.

Based on the above discussions of relative and total abundance, the recent seasonal variation of the phytoplankton assemblage of Lake Norman in the vicinity of McGuire Nuclear Station can be characterized as follows. Relatively low mid winter biovolumes were dominated by diatoms, primarily Melosira italica. Diatoms, Rhodomonas minuta (a cryptophyte) and small coccoid green algae constituted most of the mid winter algal density. A spring peak in biovolume consisted mostly of Melosira italica, which declined rapidly at the onset of thermal stratification. Rhodomonas minuta then increased to dominate algal densities in May and June, although diatoms and green algae remained important constituents of the relatively low total biovolume and density. The mid summer community was dominated by small green algae in terms of density and by dinoflagellates in terms of biovolume. Both of these classes increased to a late summer-early fall peak, with the dinoflagellates constituting the major percentage of the late summer-early fall peak in total algal biovolume. The diversity in terms of number of species observed at a location reached an annual maximum averaging about 60 species per location during this period (October), as opposed to a late winter-spring minimum of about 30 species per location. The small population of blue-greens, primarily Anabaena spp., other unidentified filamentous blue-green algae, Anacystis spp., and Agmenellum quadriduplicatum also appeared during the late summer-fall period. As overturn progressed, biovolume declined and the typical winter association of diatoms (Melosira italica), cryptophytes (Rhodomonas minuta), and small coccoid greens reappeared.

VERTICAL DISTRIBUTION

The vertical distribution of phytoplankton is a function of turbulence within the mixed layer, the mixing regime of the lake, and the ability of the algae to influence their position in the water column utilizing flagella or the regulation of buoyancy via gas vacuoles. During the period in which Lake Norman was not stratified, vertical distribution of algae based on chlorophyll profiles ranged from uniform to patchy, with no particular water stratum consistently maintaining higher or lower chlorophyll concentrations than any other stratum (Fig. 4-16 and 4-17). The major dominant during this period was a diatom,

Melosira italica, which is subject to relatively rapid sinking (Lund 1954). Thus, it is expected that algal distribution would be fairly uniform during periods of high turbulence, and patchy when mixing rates decreased.

From the onset of stratification in the spring to the initiation of overturn in the fall, populations tended to be increasingly concentrated in the epilimnion (Fig. 4-16 and 4-17). Chlorophyll concentrations in the epilimnion were as much as 30 to 40 times greater than hypolimnetic concentrations, which declined to as low as $0.1 \text{ mg} \cdot \text{m}^{-3}$ (App. Table 4.2-6). Dinoflagellates and very small green algae dominated the epilimnetic populations during the stratified period. Dinoflagellates are large, but motile (possessing flagella) and thus during periods of low turbulence are able to regulate their position in the water column. Small green algae possess large surface to volume ratios and therefore require proportionally less turbulence to prevent loss to the metalimnion. Thus, both major summer dominants were adapted to remain within the upper mixed layer exposed to the light required for autotrophic growth.

The Chlorophyceae were well-distributed in the water column during non-stratified periods, but were heavily concentrated in the epilimnion during the stratified period (Fig. 4-18). The Bacillariophyceae, consisting primarily of Melosira italica, were patchily to uniformly distributed during the non-stratified period. However, during the stratified period diatoms showed a marked peak density in the hypolimnion. Densities in the hypolimnion declined rapidly when anoxia was attained (Fig. 4-19).

During periods of peak abundance, cryptophytes were concentrated in surface waters, even when the lake was not stratified. In addition, vertical distribution within the upper 6 m was quite patchy (Fig. 4-20). During periods of peak abundance and throughout the stratified period, the motility of the major genera was apparently an important factor in regulating distribution of the Cryptophyceae.

Dinoflagellate peak abundances were restricted to epilimnetic waters. Vertical distribution within the upper mixed layer was quite patchy, and dinoflagellates were frequently concentrated at the surface or at 3 m (Fig. 4-21). Vertical migration by dinoflagellates in apparent response to light intensity has been documented by Harris (1978).

Blue-green algae were not a significant component of the algal population in 1978-79. However, vertical distribution data from 1974-75 (Fig. 4-22) indicate that the Myxophyceae were generally confined to surface waters, with maximum abundance at the surface or in the mid-euphotic zone. The dominant species was Anabaena wisconsinense, which possesses gas vacuoles. Gas vacuoles can provide buoyancy to blue-green algal cells, allowing them to remain within the upper mixed layer. Vertical distribution data from 1978-79 (Fig. 4-23) also illustrate the concentration of blue-green algae in surface waters, particularly in the top 3 m.

PRIMARY PRODUCTIVITY

Measurements made utilizing the transparent-opaque bottle dissolved oxygen technique (App. Tables 4.3-1, 2, 3, 8, 9, and 10) provided results too variable to give significant information on the primary productivity of Lake Norman. Thus, all the results in this section are based on the ^{14}C uptake method (App. Table 4.3-4 and 4.3-5).

Annual production in Lake Norman was approximately $110 \text{ g C} \cdot \text{m}^{-2} \cdot \text{yr}^{-1}$ at Location 3 and $130 \text{ g C} \cdot \text{m}^{-2} \cdot \text{yr}^{-1}$ at Location 8. Carbon fixation rates on a daily basis ranged from 8 to $860 \text{ mg C} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$, averaging $210 \text{ mg C} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$ at Location 3 and $330 \text{ mg C} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$ at Location 8. Daily fixation rates varied seasonally (Fig. 4-24), peaking in midsummer and declining to a midwinter minimum.

Utilizing Wetzel's (1975) system of classification, lower Lake Norman can be classified as oligo-mesotrophic, based on measurements of mean primary productivity, phytoplankton biovolume and biomass, chlorophyll *a*, dominant classes of phytoplankton, light extinction coefficients, total organic carbon, total phosphorus, total nitrogen, and total inorganic solids. This classification agrees with that proposed for Lake Norman by Weiss and Kuenzler (1976).

Maximum carbon uptake rates in the water column (P_{max}) ranged from 0.3 to $28.0 \text{ mg C} \cdot \text{m}^{-3} \cdot \text{h}^{-1}$ (Fig. 4-25). Other than very low values observed in January and February 1978, no seasonal trends were evident. Maximum assimilation ratios in the water column (AR_{max}) ranged from 0.2 to $12.0 \text{ mg C} \cdot \text{mg chl} \cdot \text{h}^{-1}$ (Fig. 4-26). Assimilation ratios gradually increased from a winter minimum to a mid May-early June maximum of approximately $12 \text{ mg C} \cdot \text{mg chl} \cdot \text{h}^{-1}$. Values fluctuated from 4 to $8 \text{ mg C} \cdot \text{mg chl} \cdot \text{h}^{-1}$ through mid August, then stabilized at approximately $3 \text{ mg C} \cdot \text{mg chl} \cdot \text{h}^{-1}$. Beginning in late September, assimilation ratios gradually increased to a peak of approximately $6 \text{ mg C} \cdot \text{mg chl} \cdot \text{h}^{-1}$, then declined to a winter mean of 3 to $4 \text{ mg C} \cdot \text{mg chl} \cdot \text{h}^{-1}$. An isolated increase in the assimilation ratio was observed at Location 8 on December 6.

Phytoplankton standing crops at a given location are the result of reproduction, death, immigration and emigration. Reproduction and growth rates are, in turn, controlled by light, temperature, nutrient availability and the specific physiological characteristics of the dominant algae in the population, while death rates are controlled by the above factors plus predation. Immigration to, and emigration from the population may occur horizontally due to the movement of water through the reservoir, and vertically due to sinking or turbulent resuspension of the phytoplankton. Algal motility or buoyancy may also contribute to immigration and emigration.

GROWTH AND REPRODUCTION

Photosynthetic rates were measured in-situ in Lake Norman via the ^{14}C method, to approximate the potential for algal growth and reproduction. Information about the factors controlling photosynthetic rates can be gained by examining three characteristics of the curve which results when photosynthetic rates are plotted against light intensity (Fig. 4-27). This plot is generally referred to as a P vs. I curve. Because community photosynthesis is dependent on the amount of chlorophyll initially present in the populations, photosynthetic rates are here expressed as assimilation ratios ($\text{mg C} \cdot \text{mg chl} \cdot \text{h}^{-1}$). The first useful characteristic of the P vs. I curve is the initial slope, which is basically a measure of how efficiently the phytoplankton community was utilizing light. Photosynthetic efficiency in this light-limited, linear portion of the curve is a function of adaptation to light, and of the taxonomic composition of the population, in that different taxonomic groups contain different ratios of the various photosynthetic and accessory pigments. Species adapted to low light

intensities generally utilize low light very efficiently but become light-saturated at relatively low light intensities. Thus, high values for the initial slope of the P vs. I curve are thought to correspond to adaptation to low light intensities. The initial slope of the P vs. I curve is generally considered to be temperature-independent (Harris 1978). Photosynthetic efficiencies for Lake Norman, corresponding to the initial slope of the P vs. I curve, evidenced no clear seasonal trends, with the exception of relatively high efficiencies during May (Fig. 4-28). The lack of seasonal trends indicates that no consistent pattern of seasonal adaptation to light was occurring. Rather, fluctuations in efficiency may have been the result of short-term adaptation, which can occur following two or three cloudy days (Harris 1978). In addition, the seasonal succession of various taxonomic classes (Fig. 4-18, 19, 20, 21, 23) did not appear to consistently affect photosynthetic efficiencies. Thus, differing ratios of photosynthetic and accessory pigments did not appear to have a significant impact. The apparently high photosynthetic efficiencies observed in May were probably artifacts of the operational characteristics of the Montedoro-Whitney light meter, which was used on May 3, 10, and 17, 1978. The Montedoro-Whitney meter measures solar radiation in the infrared as well as visible range. Because infrared light is absorbed in the water column much more rapidly than visible light, the Montedoro-Whitney meter overestimates the rapidity of light extinction in the water column as compared to the Licor and Kahlsico meters, which measure only visible light. Estimates of light intensity in the water column based on Montedoro-Whitney measurements of light extinction would thus be low compared to those based on Licor or Kahlsico measurements, resulting in the observation of apparently high photosynthetic efficiencies.

The second characteristic of the photosynthesis vs. light intensity curve is P_{max} (AR_{max} , when expressed per unit chlorophyll *a*), the light-saturated rate of photosynthesis. This is the value at which increasing light intensities fail to cause an increase in photosynthetic rates. By definition, AR_{max} is not light dependent (Fig. 4-27). Temperature and nutrient availability affect the maximum rate of photosynthesis achieved under light-saturating conditions (Harris 1978). In Lake Norman maximum assimilation ratios generally followed a seasonal pattern (Fig. 4-26), increasing from a late winter minimum to a maximum in late May-early June. A second, smaller peak was observed in mid October-early November, followed by a decline, then a sharp peak December 6, after which assimilation ratios dropped immediately to pre-peak levels. As previously stated, AR_{max} is basically a function of temperature and nutrient availability. A linear regression of photosynthetic rate (AR_{max}) with temperature indicated that, from December through May, temperature could account for approximately 72% of the variation in photosynthetic rates. From January through early April, nutrients were irregularly abundant, declining rapidly following the onset of stratification (Fig. 4-29). During the period from December through May, a linear regression of AR_{max} with total phosphorus revealed that total phosphorus could account for only 31% of the variation in AR_{max} ; nitrogen accounted for less than that. Following the onset of stratification, any relationship between temperature and AR_{max} was masked, as temperature continued to increase and AR_{max} underwent a gradual decline. This tends to indicate that AR_{max} was no longer temperature limited, but rather was related to nutrient availability. The changes in concentrations of phosphorus and nitrogen support the idea of nutrient limitation: concentrations of total phosphorus dropped to virtually undetectable levels following the onset of stratification, while concentrations of inorganic nitrogen declined gradually

throughout the summer (Fig. 4-29). Nutrient concentrations remained low until the completion of destratification in the late fall. The increase in AR_{max} during destratification indicates that mixing of nutrient-depleted waters with the relatively nutrient-rich waters of the hypolimnion increased nutrient availability, which in turn increased AR_{max} . Additional evidence lies in the fact that destratification progressed fairly uniformly until about October 18 (Fig. 4-30). A stable thermocline developed at about 22 m, and this was not disrupted at Location 3.0 (a shallower location) until November 1 and at Location 8.0 until November 22. Within 2 weeks following this final disruption, an increase in AR_{max} occurred at both locations, followed by a subsequent decline.

Ample evidence exists in the literature to indicate that, within the context of light and temperature regimes, phosphorus availability generally sets the limits to algal production in lakes (Schindler 1971; Deevey 1972; Schindler and Fee 1974). In Lake Norman, the molar concentrations of total nitrogen and phosphorus during the summer indicate that phosphorus was deficient relative to nitrogen for algal production. Molar ratios of total nitrogen to total phosphorus ranged from 55:1 to 300:1 during the stratified period. Ratios greater than 16:1 suggest phosphorus limitation of production (Redfield et al. 1963). The simultaneous decline in mean annual concentrations of chlorophyll *a* and total phosphorus over a 5-year period, as well as the observation of higher chlorophyll *a* concentrations at uplake locations, where concentrations of total phosphorus were higher, provide additional evidence of the importance of phosphorus in regulating algal production in Lake Norman.

The third characteristic of the photosynthesis vs. light intensity curve is I_k , the saturating light intensity, or the light intensity at the intersection of the line defining the initial slope of the curve, and the horizontal line intersecting P_{max} (Fig. 4-27). The value of I_k is dependent on both the initial slope of the curve and on P_{max} . Thus, I_k is dependent on temperature, nutrient availability, light adaptation, and pigment ratios within the population. No clear pattern emerged in examining the saturation light intensity values from Lake Norman (Fig. 4-31).

Thus, it appears that the maximum growth rates of algae incubated in situ on Lake Norman were dependent on temperature during late winter and early spring. During the remainder of the year nutrient availability, specifically phosphorus availability, appeared to restrict the maximum photosynthetic rates attained by the phytoplankton. Low light limitation of the entire water column, in which subsurface incident intensities were insufficient for algae to attain light-saturated photosynthetic rates, was encountered only three times, on January 25, March 8, and December 20, 1978. This is based on Harris' (1978) contention that saturating light intensities generally approximate $120 \mu E \cdot m^{-2} \cdot s^{-1}$.

The estimation of photosynthetic rates from in-situ suspension of phytoplankton provides a means of assessing the relative importance of temperature, nutrient availability, and light adaptation in regulating photosynthetic rates. However, this method provides no means to assess the effects of vertical circulation which would occur under natural conditions. Phytoplankton, particularly those with no means of controlling their position within the water column (algae without flagella, gas vacuoles, or other means of buoyancy regulation), are subject to sinking and turbulent resuspension, and are generally uniformly distributed within a well-mixed water column. One primary impact of vertical

circulation is to influence the degree to which the phytoplankton are exposed to light. The relationships between the depth of maximum circulation, daily incident light, and the degree of light penetration in the water column regulate the relative rates of production and respiration in the algal community. Sverdrup (1953) quantified these relationships, creating the concept of the critical depth, defined as the theoretical maximum depth to which an algal community can circulate and still increase in abundance due to growth, under given conditions of incident light and light penetration. Thus, if circulation occurs to a depth exceeding the critical depth, respiration will exceed production, preventing increases in algal abundance due to growth.

Based on the calculation of theoretical critical depths (Sverdrup 1953; Parsons et al. 1969) for Lake Norman, it appears likely that light and mixing, in addition to temperature, were important factors in controlling increases in algal abundance from late fall through early spring. Critical depths from January through mid March 1978 and from mid November 1978 through January 1979 averaged less than 5 m (Table 4-7), while circulation was occurring from lake surface to bottom. Mean lake depth is greater than 10 m; at Locations 3.0 and 8.0, the maximum depths are generally greater than 25 m. The dominant algae during this period were diatoms, which do not have flagella or gas vacuoles as means of regulating their position in the water column.

Critical depths began to increase during the spring, as incident solar radiation increased and light extinction coefficients of the water decreased. Also at this time, thermal stratification began to develop, substantially decreasing the maximum depth of circulation. Critical depths rapidly exceeded the depths of maximum circulation of epilimnetic algae (Table 4-7), making it very unlikely that light was limiting increases in algal abundance. This situation persisted throughout the stratified period (May through October). In addition, the dominant algae during the stratified period were either flagellated (primarily dinoflagellates) and thus were potentially able to regulate their position at optimal light intensities, or were very small (small green algae) with increased surface to volume ratios to decrease sinking rates, further reducing the likelihood of growth limitation due to low light intensities.

During the stratified period, the potential also existed for a reduction of algal productivity due to photoinhibition, caused by excessively high light intensities in the epilimnion. Mild photoinhibition was frequently observed at the surface in Lake Norman (Fig. 4-32), but presumably natural populations did not remain suspended at the surface long enough to undergo substantial photoinhibition, due to circulation within the epilimnion. Thus photoinhibition was not considered to be an important factor limiting algal populations.

RESPIRATION, IMMIGRATION, AND EMIGRATION

The rate of change of the phytoplankton standing crop is controlled not only by reproduction and growth, but by respiration, death, grazing, immigration and emigration. Neither phytoplankton loss rates nor immigration were measured in this study; however, values for apparent respiration (R') were back-calculated based on changes in the standing crop of algal carbon in the mixed layer, and on mean daily photosynthetic rates. These values were then used to examine whether photosynthesis and respiration alone could potentially account for observed changes in algal standing crop during any particular time period,

or whether it was necessary to postulate the substantial occurrence of grazing, immigration or emigration. Ratios of apparent respiration (R') to maximum photosynthetic rate (P_{max} , mean for the time period of interest) were compared to published values for the ratio of measured respiration (R) to P_{max} . Measured ranges of $R:P_{max}$ for specific taxonomic classes were obtained from Harris (1978). If the calculated $R':P_{max}$ values for Lake Norman fell within the range of published values for $R:P_{max}$, it was assumed that photosynthesis and respiration alone could potentially account for observed changes in standing crop. As a second means of checking the comparability of $R':P_{max}$ values with those measured by other workers, values for Lake Norman were superimposed in a plot published by Harris (1978) of $R:P_{max}$ values vs. the ratio of euphotic depth to mixed depth (Fig. 4-33). Where $R':P_{max}$ values were close to those predicted by Harris' plot, it was again assumed that photosynthesis and respiration could reasonably have accounted for observed changes in standing crop.

During the period in which the lake was stratified, virtually all changes in algal standing crop as measured by algal carbon could potentially be accounted for by the relative rates of photosynthesis and respiration (Table 4-8). However, when the lake was isothermal, $R':P_{max}$ ratios were uniformly less (0.01-0.02) than those measured by other workers for diatoms (0.04-0.08), which were dominant during the isothermal period. This suggests that populations were increasing too rapidly or were not declining rapidly enough to be explained by the intrinsic photosynthetic and respiratory rates reported in the literature for populations of diatoms. Two potential explanations for this are 1) that passive immigration may have been an important factor in increasing algal abundance, and 2) that Melosira italica, the dominant algal species during the isothermal period, may possess a characteristic $R:P_{max}$ ratio somewhat lower than that reported for other diatoms.

Evidence for the importance of non-metabolic factors such as passive immigration and emigration in the population dynamics of Melosira italica was reported by Lund (1954, 1955) and Knoechel and Kalff (1978). They observed that, due to the comparatively rapid sinking rate of M. italica, the major factors affecting its abundance were turbulence and the mixing regime of the water column. Lund (1954, 1955) observed that Melosira filaments sank rapidly during periods of low turbulence, sinking all the way to the sediments at the onset of stratification. He presented evidence that cells could remain alive and viable on the sediments for periods of up to 3 years, even under anaerobic conditions. When turbulence was sufficient, for example, during destratification, filaments were apparently resuspended in the water column, sometimes in great numbers. In Lake Norman, some of the trends in abundance of M. italica appeared to be associated with water movement and changes in turbulence. A rapid decline in abundance was observed in mid April (Fig. 4-34), following the appearance of initial, unstable thermal stratification. Although this decline could potentially be explained by relative rates of photosynthesis and respiration (Table 4-8), its close correlation with the beginnings of stratification and with a simultaneous decline in turbidity, plus observations from the literature, tend to indicate that Melosira cells were merely sinking rather than dying. This idea is also supported by the observation of what appeared to be a viable population of Melosira italica in the hypolimnion (Fig. 4-34). (Silica limitation did not appear to be a factor in the mid April decline in abundance, as concentrations of silica did not fall below $2.1 \text{ mg} \cdot \text{l}^{-1}$; silica is potentially limiting to the growth of M. italica at concentrations $< 0.8 \text{ mg} \cdot \text{l}^{-1}$ (Lund 1955).) The reappearance of Melosira as a dominant in late fall-early winter corresponded to

the mid and final stages of destratification, with the largest increases occurring in bottom waters immediately following the completion of overturn (Fig. 4-34); this suggests that resuspension was occurring. Passive immigration may also have contributed to the rapid increase in abundance in early spring. Peak abundance occurred earlier at uplake locations in 1979 (no data is available from 1978 at uplake locations), suggesting that an influx of cells from uplake may have contributed to peaks observed at downlake locations (Fig. 4-35). However, most researchers noting early spring increases in populations of *Melosira* attributed these peaks to increasing solar radiation (Lund 1955; Pechlaner 1970; Knoechel and Kalff 1978). It is likely that the spring peak in Lake Norman, also, was primarily the result of a growth response to increasing light intensities. This is particularly evident at uplake locations, where inputs from the Catawba River did not appear to be substantial (Fig. 4-35). However, the spring peak cannot be entirely explained by relative rates of photosynthesis and respiration unless it is assumed that the $R:P_{max}$ value characteristic of *Melosira italica* is somewhat lower than for other diatoms. Assuming that passive immigration was not substantial, the very occurrence of a spring peak in abundance at a time when critical depths were exceeded by mixing depths suggests a reduced $R:P_{max}$ ratio. Evidence for very low respiration rates also lies in the observation of an apparently viable population of *Melosira* in the hypolimnion (below the photosynthetic zone) during the period in which the lake was thermally stratified. Other workers have observed large populations of various species of *Melosira* on the sediments (Lund 1954; Stockner and Lund 1970) or in the hypolimnion below the photosynthetic zone (Talling 1957).

To summarize, the relationship of relative rates of photosynthesis and respiration to the standing crop of phytoplankton was dependent on the mixing regime of the lake. During the period in which Lake Norman was stratified, photosynthesis and respiration could account for all of the observed changes in standing crop, although predation, immigration and emigration were undoubtedly occurring to some extent. Maximum photosynthetic rates and standing crops were in turn apparently limited by the availability of phosphorus. During the period in which the lake was isothermal, maximum photosynthetic rates of populations suspended in-situ were primarily a function of temperature; however, light was apparently an important factor in controlling the growth rates of natural populations subject to circulation to bottom depths. Changes in standing crop during the isothermal period were apparently the result not only of growth and respiration, but of sinking and resuspension and a possible influx of cells from uplake.

SUMMARY

The phytoplankton community was sampled monthly on Lake Norman from March 1974 through February 1975 and from October 1977 through December 1980. Population samples were examined at 500X to determine species composition and abundance. Chlorophyll samples were collected monthly from January 1974 through December 1980. Samples were filtered, extracted in acetone, and analyzed fluorometrically and/or spectrophotometrically. Primary productivity was estimated monthly in 1974 using the in-situ transparent-opaque bottle dissolved oxygen technique, and weekly in 1978, using the in-situ transparent-opaque bottle ^{14}C assimilation technique. Samples to characterize the vertical distribution of the phytoplankton were collected at 10 depths weekly in 1978.

The major taxonomic classes of phytoplankton observed in Lake Norman were the Bacillariophyceae (dominant throughout the winter), the Cryptophyceae (abundant in late spring), and the Chlorophyceae and Dinophyceae (dominant in summer and fall). Ten classes and over 300 species and varieties of phytoplankton were observed, with *Nannochloris*, *Rhodomonas*, *Melosira* and *Peridinium* among the most abundant genera. Blue-green algae (Myxophyceae) were relatively abundant in 1974 but not in 1978 or 1979.

Phytoplankton abundance, as measured by mean annual concentrations of chlorophyll *a*, was fairly consistent among locations south of the Davidson Creek-Catawba River channel confluence, but increased at uplake locations. Differences in taxonomic composition among locations were evident primarily in the distribution of diatoms, which were most abundant uplake and least abundant at Ramsey Creek locations. However, differences in taxonomic composition among downlake locations were generally outweighed by similarities in temporal variation.

Temporal variation in phytoplankton abundance was comparatively low; chlorophyll annual maxima rarely exceeded minima by more than an order of magnitude. During the early phase of the study (1974-1976) annual maxima were observed in mid summer. In 1978 and 1979 a bimodal tendency was observed, with small peaks in early spring and late summer-early fall. Mean annual chlorophyll *a* concentrations declined throughout the study period, possibly due to declining concentrations of total phosphorus.

Seasonal succession of phytoplankton exhibited a consistent pattern in 1978 and 1979. Diatoms, small cryptophytes, and small coccoid green algae dominated late fall and winter populations. Diatoms peaked in early spring, followed by cryptophytes in late spring. Small green algae and dinoflagellates dominated populations during the stratified period. Both greens and dinoflagellates attained maximum abundance in late summer-early fall.

Phytoplankton were patchily to uniformly distributed in the water column during the isothermal period. During the stratified period, phytoplankton were heavily concentrated in the epilimnion, with epilimnetic chlorophyll concentrations as much as 30 to 40 times higher than hypolimnetic concentrations. Cryptophytes, dinoflagellates and blue-green algae attained maximum densities in surface or epilimnetic waters. Green algae were fairly uniformly distributed in the water column during the isothermal period, but were concentrated in the epilimnion during the stratified period. The vertical distribution of diatoms was patchy to uniform during the isothermal period, but diatoms maintained higher densities in the hypolimnion than in the epilimnion during the stratified period.

Lake Norman is probably best characterized as oligo-mesotrophic. From 1975 through 1979 chlorophyll *a* concentrations in surface waters ranged from 0.3 to 18.0 mg·m⁻³, and biovolume ranged from <100 to 4000 mm³·m⁻³. Annual primary production in the downlake area was measured at approximately 120 g C·m⁻²·yr⁻¹. Daily primary production peaked in mid summer, coinciding with maximum day length, light intensity, and light penetration. Production rates of the phytoplankton community were apparently regulated primarily by light and temperature during the isothermal period, and by the availability of phosphorus during the stratified period.

Much of the variation among locations in total abundance and in taxonomic composition was based on the relative distribution of diatoms, primarily Melosira italica, as was most of the variation between years in the size of the spring peak in abundance. In addition, temporal and vertical variation during the isothermal period were largely a function of the distribution of Melosira italica. The distribution and abundance of Melosira italica were functions not only of growth and respiration, but of water movement and turbulence.

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[illegible]

Table 4-2. (continued)

Table 4-2. (continued)

Microvolumes, μm^3	Species	Author
55	<i>armatus</i> var. <i>bicaudatus</i> (Guggliel-Printz)	Chodat
66	<i>bicaudatus</i> (Hansging)	Chodat
64	<i>bijsa</i> (Turp.) Lagerheim	
205	<i>bijsa</i> var. <i>alternans</i> (Reinsch)	Hansging
176	<i>denticulatus</i> Lagerheim	
347	<i>dimorphus</i> (Turp.) Kuetzing	
82	<i>quadricauda</i> (Turp.) Brebisson	
152	<i>quadrifida</i> var. <i>alternans</i> G. M. Smith	
151	<i>quadrifida</i> var. <i>longispina</i> (Chodat) G. M. Smith	
75	<i>spinosus</i> Chodat	
32	spp. Mylen	
261	<i>Schroederia setigera</i> (Schroeder)	Leimmann
528	<i>telanstrum gracile</i> Reinsch	
40	<i>minutum</i> (Naeg.) Collins	
205	<i>westii</i> G. M. Smith	
72	spp. Reinsch	
444	<i>Spinerosystis schroeteri</i> Chodat	
636	<i>Staurastrum chaetoceras</i> Schroeder	
629	<i>curvatum</i> var. <i>elongatum</i> G. M. Smith	
2197	<i>defectum</i> Brebisson	
5265	<i>fasciata</i> G. M. Smith	
265	<i>paradoxum</i> var. <i>cingulum</i> West and West	
490	<i>paradoxum</i> var. <i>parvum</i> W. West	
203	<i>tetracrum</i> Ralfs	
335	spp. Mylen	
128	<i>Tetrandron caudatum</i> (Corda)	Hansging
1437	<i>caudatum</i> var. <i>longispinum</i> Leimmann	
27	<i>enorme</i> (Ralfs)	Hansging
128	<i>minimus</i> (A. Braun)	Hansging
111	<i>pentandricum</i> West and West	
432	<i>regularare</i> var. <i>incus</i> Telling	
199	<i>trigonum</i> (Naeg.) Hansging	
56	<i>trigonum</i> var. <i>gracile</i> (Reinsch)	Detoni
258	spp. Kuetzing	
90	<i>Tetraspora lobulosa</i> Prescott	
102	<i>tetrastrium glabrum</i> (Roll) Aclitrom and Tiffany	
57	<i>tetrastrium</i> (Nordst.) Chodat	
92	<i>Staurigeniaeforme</i> (Schroeder)	Leimmann
212	<i>Tetraspora setigerum</i> (Archer) G. M. Smith	
92	<i>kanthidium</i> spp. Ehrenberg	
92	<i>Achnanthes microcephala</i> (Kuetz.) Grunow	
102	<i>A. minutissima</i> Kuetzing	
111	A. spp.	
5087	<i>Amphiprora costata</i> Hustedt	
8001	A. ornata Baile	
312	<i>Asterionella formosa</i> Hassall	
1908	<i>Attheya zachvatkini</i> J. Brun	
1846	<i>Cocconeis</i> spp. Ehrenberg	
368	<i>Cylotella setigera</i> (Cleve) van Huerck	
392	C. spp. Kuetzing	
498	<i>C. minima</i> Hise ex Rabenhorst	
55	C. ventricosa Kuetzing	
1362	C. spp. Agardh	
475	<i>Denticula</i> spp. Kuetzing	
1640	<i>Eumetia arcus</i> Ehrenberg	
267	<i>E. zanzibarica</i> (Cabejzskis) Koerner	
750	<i>Fragilaria crotensis</i> Kitton	
99	F. spp. Lyngbye	
565	<i>Gomphonema parvum</i> Kuetzing	
1077	<i>G. truncatum</i> var. <i>capitatum</i> (Ehr.) Patrick	
312	G. spp. Agardh	
270	<i>Melosira distans</i> (Ehr.) Kuetzing	
327	<i>M. distans</i> var. <i>alpigena</i> Grunow	
668	<i>M. granulata</i> (Ehr.) Ralfs	
297	<i>M. granulata</i> var. <i>angustissima</i> Mueller	
1206	<i>M. italica</i> (Ehr.) Kuetzing	
386	<i>M. italica</i> var. <i>tenuissima</i> (Grun.) Mueller	
8792	<i>M. varians</i> Agardh	
407	M. spp. Agardh	
257	<i>Nautilia notha</i> Wallace	
54	<i>N. tridentula</i> Krasske	
468	N. spp. Bory	
234	<i>Nitzschia acicularis</i> (Kuetz.) W. Smith	
55	<i>N. digna</i> Hustedt	
205	<i>N. palea</i> (Kuetz.) W. Smith	
3627	<i>Pinnularia biceps</i> Gregory	
350	<i>Rhizolenia erizans</i> H. L. Smith	
1166	<i>R. longiseta</i> Zacharias	
1347	R. spp. Ehrenberg	
1389	<i>Rhodosphecia</i> spp. Grunow	
2155	<i>Stephanodiscus astraea</i> (Ehr.) Grunow	
123	S. spp. Ehrenberg	
703	<i>Sorirella angulata</i> Kuetzing	
1868	S. spp. Turpin	
157	<i>Synedra actinastroides</i> Leimmann	
429	<i>S. acus</i> var. <i>ostentifolius</i> Krueger	
1845	<i>S. delicatissima</i> W. Smith	
1997	<i>S. delicatissima</i> var. <i>angustissima</i> Grunow	
132	<i>S. fasciculata</i> var. <i>truncata</i> (Greville) Patrick	
420	<i>S. nana</i> Meister	
132	<i>S. rumpens</i> Kuetzing	
3733	<i>S. sink</i> (Nitzsch) Ehrenberg	
528	S. spp. Ehrenberg	
1293	<i>Tabellaria fenestrata</i> (Lyngb.) Kuetzing	
26	<i>Chromulina wuerminiana</i> Fisch	
117	C. spp. Chienowsky	
158	<i>Chrysopharella solitaria</i> Preisig and Takahashi	
74	<i>Ciceras</i> spp. Brebisson	

Table 4-2. (continued)

Biovolumes, μm^3

D. spp. Ehrenberg	327
<i>Keulephyrion rubri-kaustleri</i> Conrad	151
K. spp. Pascher	14
<i>Millimonas aculeatus</i> Perty	1141
<i>M. akrocomis</i> var. <i>plusiopsis</i> (Naumann) Krieger	128
<i>M. caudata</i> Ivanoff	4256
<i>M. elongata</i> Reinhardt	5755
<i>M. pseudocrenata</i> Prescott	1272
<i>M. tenebrata</i> Telling	354
M. spp. Perty	802
<i>Millimonas crenata</i> Kiebs	113
O. spp. Wyszotzki	118
<i>Pseudokeulephyrion schilleri</i> Conrad	27
P. spp. Pascher	20
<i>Steltonomus dichotoma</i> Lackey	1174
<i>Synura caroliniana</i> Bourrelly	312
S. sp. Korschikov	1061
S. ovella Ehrenberg	386
S. spp. Ehrenberg	

HAPTOPYCEAE

<i>Chrysoschromulina</i> sp. Lackey	236
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KANTHOPYCEAE

<i>Dichotomococcus</i> spp. Korschikov	29
<i>Heteromastus multicellularis</i> Wawrik	92
<i>Hydrogation capitatum</i> var. <i>longispinum</i> (Muhlb.) Lemmermann	208

CRYPTOPHYCEAE

<i>Cryptomonas erosa</i> Ehrenberg	398
C. erosa var. <i>reflexa</i> Marsson	345
C. marxianii Skuja	844
C. obsoleta Skuja	362
C. ovata Ehrenberg	862
C. phaeolus Skuja	124
C. reflexa Skuja	1667
C. spp. Ehrenberg	241
<i>Phacococcus minuta</i> Skuja	107

HAPTOPYCEAE

<i>Apertium quadruplicatum</i> Brebisson	13
<i>Apertium affinis</i> Lemmermann	175
<i>A. calanella</i> (Kuetz.) Borset and Flahault	105
A. calanella (Kuetz.) Borset and Flahault	3600
A. calanella (Kuetz.) Borset and Flahault	4287
A. calanella (Kuetz.) Borset and Flahault	93
A. calanella (Kuetz.) Borset and Flahault	977
A. calanella (Kuetz.) Borset and Flahault	2212
A. calanella (Kuetz.) Borset and Flahault	975
A. calanella (Kuetz.) Borset and Flahault	70

Biovolumes, μm^3

A. montana f. minor Drouet and Dally	83
A. thermalis (Menegh.) Drouet and Dally	67
A. spp. Meneghini	176
<i>Aphanizomenon flos-aquae</i> (Linnaeus) Bailly	3456
<i>Aphanizomenon clathrata</i> G. S. West	26
<i>Coelosphaerium dubium</i> Grunow in Rabenhurst	3358
C. kuettzingianum Naegeli	14
C. kuettzingianum Unger	422
<i>Gaeylethocopsis fascicularis</i> Lemmermann	52
<i>Gaeylethocopsis apuina</i> Kuettzing	1179
G. lacustris Chodat	3537
G. wickhami Drouet and Dally	354
G. spp. Kuettzing	102
L. spp. Agardh	183
<i>Oscillatoria lemmermannii</i> Woloszyńska	12186
O. rubescens Gracandolle	316
P. -v. Vaucher	754
<i>Spirula subnata</i> Dersted	

EUGLEPHACEAE

<i>Euglena polymorpha</i> Dangeard	10601
E. spp. Ehrenberg	2633
<i>Phacus acuminatus</i> Stokes	817
P. helioides Puchmann	3741
P. lemmermannii (Sw.) Skovtsov	3170
P. lentus (Lemm.) Skovtsov	14166
P. spp. Dujardin	10139
<i>Trachelomonas abrupta</i> (Sw.) Deflandre	2683
T. granulosa Flajole	4013
T. hispida (Perty) Stein	4754
T. lacustris Dnespolski	4075
T. sellingeri (Sw.) Deflandre	8149
T. spp. Ehrenberg	1978

DINOFLAGELLACEAE

<i>Ceratium hirundinella</i> (Muhl.) Schwank	16128
C. hirundinella var. <i>brachyceras</i> (Dall) Deflandre	1181
C. kuettzingianum Kiebs	183
C. kuettzingianum Perty	12138
C. polvisculum (Sw.) Schiller	35-4
C. quadratum (Stein) Stein	9082
C. spp. (Sw.) Stein	3289
C. kuettzingianum Schilling	5713
C. kuettzingianum Stein	2895
C. kuettzingianum Lemmermann	14944
C. kuettzingianum Lefevre	9516
C. kuettzingianum Lemmermann	14437
C. kuettzingianum Woloszyńska	2033
C. kuettzingianum (Perty) Lemmermann	11239
C. kuettzingianum Stein	2132
C. kuettzingianum Stein	4940

Table 4-2. (continued)

	<u>Biolume, μm^2</u>
<u>P. volzii</u> Lemmerman	13752
<u>P. willei</u> Hultfeld-Kass	40911
<u>P. wisconsinense</u> Eddy	32788
<u>P. spp.</u> Ehrenberg	12925
CHLORONADOPHYCEAE	
<u>Gonyostomum</u> spp. Diesing	5659

Table 4-3. Results of Friedman's analysis of phytoplankton total abundance data, 1974 through 1979.

Measure of abundance	Months included in analysis	T	χ^2 critical	Locations ranked by mean rank	Mean annual value of measure of abundance, top and bottom ranked locations	
					Top ranked location	Bottom ranked location
Chlorophyll a	1/74-12/74	29.5	21.0	11, 13, 8, 4.5, 7.5, 5, 10, 6, 2, 1, 16, 4, 3	7.5 mg·m ⁻³	5.4 mg·m ⁻³
	1/75-12/75	18.8	21.0	NSD		
	1/76-12/76	18.5	12.6	8, 5, 2, 3, 4.5, 4, 1	4.6 mg·m ⁻³	3.4 mg·m ⁻³
	1/77-12/77	6.0	12.6	NSD		
	1/78-12/78	13.9	15.5	NSD		
	1/79-12/79	28.7	15.5	8, 2, 1, 1.2, 5, 3, 4.5, 4, 3.9	3.6 mg·m ⁻³	2.2 mg·m ⁻³
Density	6/78-5/79	53.0	25.0	34, 15.9, 11, 15, 8, 50, 13, 1, 2, 4.5, 5, 16, 3, 3.9, 4, 1.2	5.0 mg·m ⁻³	2.0 mg·m ⁻³
	3/74-2/75	56.5	21.0	13, 11, 8, 10, 5, 3, 4.5, 2, 1, 7.5, 6, 4, 16	1433 units·ml ⁻¹	859 units·ml ⁻¹
	1/78-12/78	24.1	15.5	8, 5, 3, 2, 4.5, 1.2, 3.9, 4, 1	1854 units·ml ⁻¹	1452 units·ml ⁻¹
	1/79-12/79	16.4	15.5	8, 2, 1, 3, 1.2, 5, 4.5, 3.9, 4	2413 units·ml ⁻¹	1760 units·ml ⁻¹
	6/78-5/79	26.5	25.0	8, 15.9, 2, 15, 5, 3, 16, 1, 4.5, 1.2, 50, 13, 34, 11, 3.9, 4	1926 units·ml ⁻¹	1361 units·ml ⁻¹
Biovolume	3/74-2/75	9.3	19.7	NSD		
	1/78-12/78	11.2	15.5	NSD		
	1/79-12/79	4.2	15.5	NSD		
	6/78-5/79	37.8	25.0	15.9, 15, 13, 11, 34, 8, 50, 2, 1, 16, 4.5, 5, 3, 1.2, 3.9, 4	1249 mm ³ ·m ⁻³	561 mm ³ ·m ⁻³

NSD = N= significant differences among locations at the 0.05 level of significance.

Table 4-4. Results of cluster analyses comparing sampling locations on the basis of mean annual densities of major taxonomic classes of phytoplankton.

Locations used in analysis	Sampling dates	Maximum standardized distance within a cluster	Locations in cluster	Class densities (units·ml ⁻¹):											
				Chlorophyceae		Bacillariophyceae		Cryptophyceae		Myxophyceae		Dinophyceae		Other Classes	
				Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
1, 1.2, 2, 3, 3.9, 4, 4.5, 5, 8, 16	1/78 through 12/78, monthly	1.64	1, 3.9, 4, 1.2, 2, 3 4.5, 5 8 16	547 584 602 571	514-577 577-590 - -	505 466 631 661	456-517 455-477 - -	307 341 378 232	262-354 301-381 - -	20 18 30 131	19-27 16-29 - -	21 27 19 25	17-25 26-27 - -	213 295 246 296	201-231 273-317 - -
1, 1.2, 2, 3, 3.9, 4, 4.5, 5, 8, 16	1/79 through 12/79, monthly	1.45	1, 2, 1.2 3.9, 4, 16 3, 5, 4.5 8	649 508 640 647	639-661 483-539 605-665 -	707 616 464 929	623-759 566-690 455-474 -	314 275 326 472	280-362 189-332 312-334 -	18 13 17 21	11-21 10-14 15-18 -	23 18 28 19	20-25 13-25 26-30 -	291 252 311 316	289-297 211-287 294-323 -
1, 1.2, 2, 3, 3.9, 4, 4.5, 5, 8, 16, 11, 13, 14, 15, 15.9, 34, 50, 60, 69	6/78 through 5/79, monthly	0.91	1, 2, 16, 8 13, 50, 15, 15.9 11, 34, 14, 69 60 1.2, 3.9, 4, 3, 4.5, 5	409 295 275 114 395	381-446 263-338 157-339 - 355-444	694 790 972 724 442	625-799 746-849 887-995 - 341-525	277 300 188 156 270	232-334 261-337 129-270 - 226-323	46 37 24 6 20	19-119 23-44 3-38 - 14-24	23 13 17 0 22	19-26 9-19 3-27 - 17-26	276 119 89 67 270	258-291 91-150 55-120 - 233-322
1, 2, 3, 4, 4.5, 5, 6, 7.5, 8, 10, 11, 13, 16	3/74 through 2/75, monthly	0.96	1, 4.5, 5, 2, 3, 7.5 4, 10, 8 6 16 11, 13	288 334 319 229 366	226-340 318-354 - - 344-387	323 424 250 375 460	292-361 407-433 - - 440-462	255 270 126 147 471	223-290 225-442 - - 457-485	56 62 50 37 52	51-66 48-77 - - 51-52	28 27 54 16 24	21-37 22-35 - - 21-27	*45 *41 *72 *25 *55	*21-74 *36-44 - - *50-60

* Values represent densities of unidentified algae in this analysis.

Table 4-5. Mean annual abundance at a main channel downlake location (1.0), a McGuire Nuclear Station discharge location (4.0), a Ramsey Creek location (5.0), and at Location 8.0.

Location	Date	Chlorophyll, mg/m^3			Biomass, mg/m^3			Density, or/m^3		
		Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum
1	*1974	5.4	0.6	10.3	7.36	205	1839	1021	534	1395
	1975	5.7	2.6	10.0						
	1976	3.0	1.0	7.4						
	1977	3.7	1.3	5.5						
	1978	2.1	0.5	4.4	6.95	150	2105	1452	667	2116
	1979	2.9	1.1	5.1	7.92	410	2172	2024	1022	3327
4	*1974	5.2	0.6	10.5	6.79	147	1570	891	406	1293
	1975	6.1	3.8	7.8						
	1976	3.6	2.1	6.5						
	1977	3.2	1.2	5.8						
	1978	1.9	0.5	4.4	5.10	183	1079	1558	517	3164
	1979	2.4	0.9	4.6	7.11	302	2200	1760	939	2320
5	*1974	5.9	0.5	13.4	7.13	286	1755	1055	706	1807
	1975	6.1	3.8	14.6						
	1976	3.9	2.3	5.6						
	1977	3.2	1.0	5.5						
	1978	2.6	0.7	7.3	5.92	263	1212	1771	693	3060
	1979	2.3	0.7	4.7	7.08	173	1914	1802	583	3757
8	*1974	6.4	0.6	10.1	7.43	263	1203	1291	743	2029
	1975	7.0	2.7	10.7						
	1976	4.6	1.3	8.2						
	1977	3.5	1.5	5.8						
	1978	2.7	0.7	6.7	7.27	230	1654	1054	725	3760
	1979	3.6	1.4	6.0	10.19	385	3777	2413	1243	4420

* For density and biomass data, mean annual abundance was calculated based on data collected March 1974 through February 1975.

Table 4-6. Primary productivity and production data, Locations 3.0 and 8.0, Lake Norman, January 18, 1978 through January 10, 1979.

Location	Date	P_{max} ($mg \cdot m^{-2} \cdot d^{-1}$) (areally mean)	P_{max} ($mg \cdot m^{-2} \cdot h^{-1}$)	AR_{max} ($mg \cdot chl \cdot a^{-1} \cdot h^{-1}$)	Photosynthetic efficiency ($mg \cdot chl \cdot a^{-1} \cdot h^{-1}$)	I_k ($\mu E \cdot m^{-2} \cdot s^{-1}$)	$mg \cdot chl \cdot a^{-2}$ ($mg \cdot chl \cdot a^{-2} \cdot m^{-2}$)	Algal bio- volume in upper mixed layer	Algal car- bon in upper mixed layer	Chloro- phyll <i>a</i> mean in upper 3m	Algal bio- volume (m ³ density m ⁻³) mean in upper 3m	Algal mean in upper 3m
Jan 18	14	2.7	1.5	118	0.22	60	8.3	538	1.7	1.7	345	627
Jan 25	106	0.8	0.7	-	-	30	4.3	318	1.3	1.3	459	459
Feb 1	-	3.0	1.3	-	-	55	7.7	508	2.2	2.2	241	612
Feb 8	32	2.4	1.3	38	0.59	41	7.5	837	1.9	1.9	285	494
Feb 15	23	3.3	1.5	73	-	60	10.9	568	2.0	2.0	363	800
Feb 22	-	-	-	-	-	61	13.2	727	2.5	2.5	486	1097
Mar 2	193	5.0	1.7	93	0.27	71	19.5	285	3.1	3.1	843	1487
Mar 8	27	7.2	2.2	73	0.43	66	22.8	842	2.9	2.9	975	1585
Mar 15	258	11.0	2.7	78	0.50	112	24.0	942	3.2	3.2	791	1833
Mar 29	210	18.8	3.2	109	0.35	109	33.7	1199	4.1	4.1	1543	2980
Apr 5	148	10.1	2.0	144	0.46	106	37.1	1265	5.0	5.0	1346	2425
Apr 12	140	14.0	3.4	70	0.42	144	37.5	1235	5.1	5.1	1356	2273
Apr 19	210	13.4	5.9	78	-	78	2.6	169	2.2	2.2	659	2023
Apr 26	204	12.0	4.7	-	0.79	69	2.6	197	2.3	2.3	525	1474
May 3	-	10.2	5.2	103	-	89	8.4	547	2.5	2.5	514	1402
May 10	190	8.6	5.9	22	*2.92	89	4.1	355	1.6	1.6	385	1567
May 17	197	8.8	5.9	15	*4.07	15	1.9	221	1.1	1.1	183	946
May 24	292	11.3	12.5	48	-	19	2.0	266	0.7	0.7	772	1130
Jun 7	337	11.6	-	-	-	24	0.3	49	-	-	116	179
Jun 14	546	17.5	11.6	142	1.47	20	0.5	74	1.0	1.0	179	998
Jun 21	401	8.5	5.3	125	1.52	21	0.6	74	1.6	1.6	812	912
Jun 28	511	9.2	5.5	153	0.57	25	3.2	368	1.6	1.6	481	756
Jul 5	546	10.0	6.5	137	0.68	41	1.0	125	1.7	1.7	252	796
Jul 12	993	14.4	4.1	115	0.95	24	2.9	310	2.9	2.9	485	529
Jul 19	696	14.3	4.6	-	-	25	5.3	581	2.2	2.2	85	279
Jul 26	509	11.7	3.4	-	-	46	5.8	626	2.5	2.5	766	641
Aug 2	519	12.0	4.1	148	0.48	74	6.2	657	2.1	2.1	1067	725
Aug 9	432	11.6	5.3	274	0.27	31	9.4	948	3.2	3.2	120	909
Aug 15	501	12.4	8.1	-	-	36	4.0	851	2.2	2.2	803	990
Aug 23	456	12.5	3.1	168	0.55	33	4.5	491	2.1	2.1	776	1163
Aug 30	482	13.0	3.4	97	0.55	49	11.6	1150	4.0	4.0	2005	1231
Sep 6	-	13.0	2.9	-	-	45	8.0	811	3.7	3.7	1205	932
Sep 12	513	14.9	2.5	172	0.24	64	9.0	915	6.3	6.3	1308	3291
Sep 20	429	15.1	1.8	157	0.19	49	9.5	943	5.8	5.8	1658	3426
Sep 27	-	10.8	3.4	-	-	63	21.6	1946	0.8	0.8	224	1426
Oct 4	456	13.1	5.2	26	1.11	52	9.6	979	2.8	2.8	647	837
Oct 11	303	12.0	6.9	154	0.77	47	12.8	1327	2.5	2.5	780	920
Oct 18	-	11.3	5.6	-	-	46	0.4	710	1.8	1.8	518	979
Oct 25	326	11.0	6.1	-	-	61	11.0	804	2.0	2.0	904	1164
Nov 1	277	11.3	4.8	158	0.52	66	11.8	923	2.4	2.4	535	807
Nov 8	989	18.1	7.5	41	2.19	70	9.5	917	2.8	2.8	917	1027
Nov 15	139	12.4	4.1	116	0.40	75	9.7	737	3.9	3.9	426	806
Nov 22	192	11.4	3.1	95	0.50	96	6.1	543	3.5	3.5	755	294
Nov 29	44	6.1	2.7	100	0.22	62	7.4	504	2.1	2.1	240	430

* Montedoro laboratory light source ** Spectrophotometrically determined

Table 4-6. (continued).

Date	$\text{mgC} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$	$\text{mgC} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$ (weekly mean)	P_{max} ($\text{mgC} \cdot \text{m}^{-3} \cdot \text{h}^{-1}$)	P_{max} ($\text{mgC} \cdot \text{mgChl} \cdot \text{a}^{-1} \cdot \text{h}^{-1}$)	Photosynthetic efficiency ($\text{mgC} \cdot \text{mgChl} \cdot \text{a}^{-1} \cdot \text{h}^{-1}$)	I_k ($\mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$)	I_k ($\mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$)	I_k ($\mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$)	Algal bio- volume in upper mixed layer ($\text{m}^3 \cdot 10^{-3} \cdot \text{m}^{-2}$)	Algal car- bon in upper mixed layer ($\text{mg} \cdot \text{m}^{-2}$)	Chloro- phyll <i>a</i> ($\text{mg} \cdot \text{m}^{-3}$) mean in upper 3m	Algal bio- volume (m ³ · m ⁻³) mean in upper 3 m	Algal density (units · ml ⁻¹) mean in upper 3m
Dec 6	224	71	12.0	5.6	0.95	99	45	6.0	385	385	2.2	188	254
13	203	160	10.8	3.6	0.57	105	85	9.3	544	544	3.0	740	752
20	139	469	11.4	3.3	1.43	38	93	9.7	519	519	3.7	378	823
27	171	97	10.9	4.0	0.36	187	78	13.4	657	657	7	531	1025
Jan 3	157	78	9.9	3.4	0.58	97	86	9.7	533	533	9	465	973
10	156	79	9.2	3.2	0.51	84	78	12.4	687	687	2.9	509	950
Location B.0													
Jan 18	23	14	2.5	0.9	0.14	112	67	12.3	868	868	3.0	260	681
25	43	556	0.3	0.2	-	-	50	9.0	430	430	1.5	325	775
Feb 1	-	-	4.0	1.4	-	-	68	9.5	492	492	2.9	388	867
8	59	68	4.6	2.2	1.89	19	52	10.0	514	514	2.1	408	728
15	98	56	5.5	2.3	0.56	52	79	19.0	835	835	2.6	649	1111
22	-	-	-	-	-	-	64	18.9	977	977	3.3	593	1246
Mar 2	-	-	-	-	-	-	92	28.0	1040	1040	4.1	939	1860
8	26	313	3.8	1.2	0.16	80	108	30.3	1019	1019	3.3	1706	1504
15	124	107	12.6	2.8	-	-	126	29.5	1082	1082	4.5	966	1953
21	208	230	13.9	2.3	0.49	75	163	36.3	1307	1307	6.1	1278	2773
29	273	225	27.9	5.2	0.66	125	153	45.2	1619	1619	5.3	1564	2003
Apr 5	340	173	19.6	4.0	-	-	162	43.9	1436	1436	4.9	1545	2477
12	175	146	12.9	3.9	1.23	56	98	6.8	379	379	3.3	1057	2460
19	257	310	15.7	4.9	-	-	80	6.6	394	394	3.2	898	2280
26	304	283	16.6	5.5	0.95	92	87	14.3	772	772	3.0	727	3527
May 3	-	-	13.3	7.8	-	-	33	0.9	752	752	1.7	378	1456
10	215	159	9.1	5.7	*2.56	*17	25	0.9	120	120	1.5	237	946
17	284	248	10.8	5.7	*3.60	*27	19	1.6	166	166	1.9	263	926
24	440	330	10.2	10.2	-	-	18	0.5	73	73	1.0	183	1070
31	346	395	16.8	11.4	-	-	28	0.6	85	85	1.5	156	777
Jun 7	334	418	9.9	5.7	0.84	173	21	0.5	71	71	1.7	129	651
14	440	378	10.0	6.4	0.88	123	28	2.3	251	251	1.4	125	630
21	484	605	12.2	6.3	0.86	119	29	2.1	226	226	1.8	431	1352
28	461	431	10.3	7.9	0.64	205	20	2.6	203	203	1.3	511	693
Jul 5	613	1180	21.8	8.6	0.42	353	47	3.5	407	407	2.5	736	970
12	553	554	12.9	4.8	0.30	280	61	5.6	602	602	2.7	903	1013
19	859	908	16.3	3.5	0.37	141	66	8.1	810	810	4.3	1832	1013
26	606	551	12.6	5.8	-	-	32	4.2	465	465	2.2	845	915
Aug 2	398	613	13.7	4.6	0.78	108	50	5.0	548	548	3.0	992	1036
9	750	613	13.1	5.7	1.19	81	43	2.9	327	327	3.3	522	1671
15	657	679	17.1	6.1	1.30	70	38	3.9	441	441	2.8	774	1188
23	657	604	13.4	3.7	0.41	142	59	7.0	745	745	3.6	1279	1811
30	611	611	14.5	3.3	-	-	55	3.8	351	351	4.4	250	1459
Sep 6	-	-	20.1	3.2	-	-	62	8.8	903	903	6.3	1456	1408
12	615	453	19.1	2.9	0.20	239	73	12.0	1268	1268	6.3	1417	1529
20	805	805	22.6	4.0	0.48	145	49	11.7	1115	1115	5.7	1634	1755
27	-	-	15.6	4.4	-	-	46	13.4	1270	1270	3.5	1105	1004
Oct 4	290	456	12.0	5.4	0.98	94	38	8.7	831	831	2.1	540	798
11	283	282	11.6	6.4	-	181	86	8.3	671	671	1.8	492	906

*Quantum efficiency light action **Specific photosynthesis cellually determined

Table 4-6. (continued).

Date	$\text{mgC} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$	$\text{mgC} \cdot \text{m}^{-2} \cdot \text{d}^{-1}$ (weekly mean)	P_{eq} ($\text{mgC} \cdot \text{m}^{-3} \cdot \text{h}^{-1}$)	AP_{max} ($\text{mgC} \cdot \text{mgChl} \cdot \text{h}^{-1}$)	Photosynthetic efficiency ($\text{mgC} \cdot \text{mgChl} \cdot \text{h}^{-1} \cdot \text{m}^2$) I_0 ($\mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$)	** $\text{mgChl} \cdot \text{a} \cdot \text{m}^{-2}$	Algal bio- volume in upper mixed layer ($\text{m}^3 \cdot \text{kg}^{-1} \cdot \text{m}^{-2}$)	Algal car- bor in upper mixed layer ($\text{mg} \cdot \text{m}^{-2}$)	** Chloro- phyll mean in upper 3m	Algal bio- volume (in upper 3m)	Algal bio- density ($\text{mg} \cdot \text{m}^{-3}$)
Oct 18	-	-	10.9	6.6	-	54	8.3	653	1.7	352	1017
Oct 25	377	327	12.6	5.6	122	50	6.5	520	2.3	301	956
Nov 1	273	264	13.0	4.9	-	57	8.5	657	2.7	390	1130
Nov 8	475	651	15.5	4.9	77	72	5.5	458	3.1	219	722
Nov 15	322	279	19.2	4.7	100	81	7.0	539	4.1	298	940
Nov 22	173	178	9.2	2.9	125	76	6.5	537	2.9	236	677
Nov 29	-	49	3.2	1.5	-	56	6.3	456	2.1	250	773
Dec 6	205	65	13.5	11.9	123	49	7.3	504	1.1	211	682
Dec 13	114	89	9.8	3.5	102	81	10.2	574	2.8	251	816
Dec 20	73	246	7.3	2.1	27	94	12.2	620	3.5	421	905
Dec 27	169	134	11.5	4.0	89	80	14.1	707	2.9	538	964
Jan 3	89	44	6.1	2.0	122	86	13.4	679	3.1	435	918
Jan 10	159	80	9.5	2.6	95	90	14.1	782	3.4	501	1124

**Montgomery light meter **Spectrophotometrically determined

Table 4-7. Physical and chemical data collected at Locations 3.0 and 8.0, Lake Norman, January 10, 1979.

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Location 3.0

Date	Incident light intensity ly-d-1	Incident light intensity during incubation ly-h-1	Average extinction coefficient (k), m ⁻¹	Mean temperature upper 3m, °C	Upper mixed depth based on temperature profiles, m	Upper mixed depth based on temperature on oxygen profiles, m	Critical TN depth, m	Nutrient concentrations in upper mixed layer					Chl a µmole l ⁻¹
								NO ₃ -N µmole l ⁻¹	TP µmole l ⁻¹	PO ₄ µmole l ⁻¹	TIC µmole l ⁻¹	CO ₂ µmole l ⁻¹	
Jan 18	274	45.4	2.00	5.4	25	25	3	40.8	28.9	0.57	BDL	259	65
Jan 25	14	2.5	1.84	5.0	25	5	4	38.3	26.5	0.66	0.17	259	59
Feb 1	*328		2.19	4.0	25	25	4	36.7	27.2	-	0.28	240	51
Feb 8	273	44.7	2.19	3.2	25	25	7	43.9	30.4	0.81	0.72	241	50
Feb 15	340	55.4	2.09	3.7	25	25	4	38.0	30.8	0.81	0.28	245	49
Feb 22	221	-	2.19	4.0	25	25	7	37.7	27.2	0.79	0.19	233	40
Mar 2	*77	-	2.19	4.7	25	25	4	-	30.7	0.74	0.17	226	31
Mar 8	22	5.6	2.09	4.6	25	25	4	-	-	-	-	224	43
Mar 15	436	62.7	1.92	6.0	25	25	8	-	-	-	-	212	28
Mar 21	394	32.1	2.09	7.5	25	25	9	-	-	-	-	222	38
Mar 29	505	56.0	2.19	10.0	25	25	6	-	-	-	-	216	40
Apr 5	526	58.6	2.19	11.3	25	25	8	-	-	-	-	221	45
Apr 12	508	62.0	2.00	15.2	25	25	8	76.1	57.3	0.63	BDL	198	17
Apr 19	*282	44.0	-	15.5	25	25	8	49.3	35.0	0.60	BDL	204	23
Apr 28	646	70.8	1.71	14.3	15	25	16	-	-	-	-	216	33
May 10	*644	64.4	1.71	15.3	13	25	9	44.0	24.0	0.46	0.17	208	26
May 17	494	49.0	1.59	16.6	9	25	13	56.4	28.3	0.41	BDL	210	33
May 24	514	48.6	1.54	17.0	12	25	12	40.7	23.2	0.48	BDL	204	30
Jun 31	*475	61.3	-	23.4	2	25	-	19.5	4.0	0.23	BDL	196	17
Jun 7	*346	29.8	0.89	24.6	3	25	25	32.8	21.3	0.19	BDL	205	14
Jun 14	*699	75.0	0.68	24.2	8	3	18	57.9	20.5	BDL	BDL	214	14
Jun 21	414	47.4	0.61	25.2	4	8	42	28.4	19.3	0.23	BDL	213	16
Jun 28	605	63.8	0.58	26.7	4	6	46	28.3	15.9	0.17	BDL	218	11
Jul 5	247	19.2	0.54	28.1	8	8	49	23.7	12.7	0.21	BDL	223	18
Jul 12	525	51.3	0.55	28.0	7	7	45	23.0	12.4	0.34	BDL	221	14
Jul 19	582	51.4	0.57	27.2	7	7	46	26.3	10.4	BDL	BDL	213	6
Jul 26	581	65.1	0.62	27.6	6	6	38	24.5	10.9	0.22	BDL	214	6
Aug 2	*282	42.5	0.56	27.7	7	7	37	18.3	7.7	BDL	BDL	229	15
Aug 9	*493	56.1	0.61	27.3	5	5	26	20.0	7.9	BDL	BDL	221	6
Aug 15	401	49.5	0.61	27.9	10	6	31	19.7	6.0	BDL	BDL	231	13
Aug 23	*564	69.1	0.61	28.7	7	7	30	19.4	5.3	BDL	BDL	233	9
Aug 30	440	50.5	0.59	28.5	13	7	35	23.1	5.7	0.20	BDL	236	10
Sep 6	-	-	0.63	27.2	13	6	36	19.7	3.7	0.18	BDL	260	79
Sep 12	472	53.3	0.75	27.1	15	7	22	19.3	5.0	BDL	BDL	251	16
Sep 20	218	13.4	0.65	26.8	13	7	18	22.2	5.2	BDL	BDL	248	22
Sep 27	-	-	0.71	24.4	16	16	15	15.8	5.0	BDL	BDL	245	19
Oct 4	295	57.6	0.63	22.9	16	16	21	14.8	4.8	0.18	BDL	292	48
Oct 11	405	41.7	0.78	21.0	19	19	22	16.9	4.2	0.24	BDL	304	47
Oct 18	-	-	0.90	19.3	22	22	17	16.4	3.5	0.19	BDL	295	42
Oct 25	*297	41.2	0.63	18.5	21	21	19	12.6	4.2	0.17	BDL	291	41
Nov 1	282	42.1	0.81	17.6	25	25	16	16.9	3.3	BDL	BDL	314	53
Nov 8	135	12.6	0.65	17.2	25	25	13	15.0	4.0	0.18	BDL	282	29
Nov 15	134	17.3	0.59	16.6	25	25	8	13.9	3.1	BDL	BDL	323	43
Nov 22	*186	31.2	0.87	16.0	25	25	7	18.7	5.0	BDL	BDL	311	45
Nov 29	-	16.9	1.02	14.6	25	25	5	19.7	5.6	0.20	BDL	321	53
												308	47

* Approximation
BDL = Below detection limit

Table 4-7. (continued)

Location 3.0

Date	Incident light intensity ly-d ⁻¹	Incident light intensity during incubation ly-h ⁻¹	Average extinction coefficient (k), m ⁻¹	Mean temperature upper 3m, °C	Upper mixed depth based on temperature profiles, m	Upper mixed depth based on oxygen profiles, m	Critical depth, m	TN μmole-l ⁻¹	Nutrient concentration in upper mixed layer					CO ₂ μmole-l ⁻¹
									NO ₃ +NO ₂ μmole N-l ⁻¹	TP μmole-l ⁻¹	PO ₄ μmole-l ⁻¹	TIC μmole-l ⁻¹		
Dec 6	*245	40.7	1.00	13.5	25	25	3	20.2	6.2	0.21	BDL	314	54	
13	242	38.0	1.12	12.5	25	25	7	21.5	7.1	-	BDL	314	53	
20	27	3.5	1.18	10.9	25	25	4	33.5	9.2	0.20	BDL	302	43	
27	217	35.2	1.15	10.1	25	25	5	26.6	10.6	0.17	0.17	297	45	
Jan 3	*244	48.3	1.12	9.0	25	25	5	-	-	-	-	298	44	
10	222	35.3	1.02	7.6	25	25	5	-	-	-	-	293	40	

Location 8.0

Jan 18	274	38.1	2.30	5.9	28	28	3	45.3	34.4	0.73	0.20	261	69
25	14	2.1	3.07	5.5	28	28	2	40.9	29.8	0.68	BDL	258	63
Feb 1	*328	-	2.30	4.6	28	28	5	49.5	29.0	0.70	0.26	245	52
8	273	48.4	2.19	3.7	28	28	6	43.3	31.7	0.59	0.37	201	-
15	340	38.9	2.30	4.0	28	28	4	35.6	30.9	0.05	0.30	239	46
22	221	-	2.71	4.1	28	28	5	36.9	30.2	1.00	0.19	241	48
Mar 2	*77	-	2.71	5.0	28	28	3	-	32.5	0.99	0.18	236	42
8	22	4.4	2.42	4.6	28	28	4	-	-	-	-	229	44
15	436	56.9	2.42	6.2	28	28	6	-	-	-	-	211	37
21	394	40.4	2.30	7.3	28	28	6	-	-	-	-	226	45
29	505	66.6	2.56	9.8	28	28	5	-	-	-	-	214	42
Apr 5	526	71.2	-	12.0	28	28	4	-	-	-	-	222	41
12	508	67.5	2.00	13.9	6	28	9	-	55.4	0.68	BDL	200	18
19	*282	34.5	-	15.5	7	26	-	48.7	35.6	0.59	BDL	207	27
28	646	71.9	1.77	14.4	18	28	14	-	-	-	-	209	25
May 3	-	-	1.64	15.2	8	28	10	39.6	24.3	0.49	BDL	209	30
10	*644	67.7	1.59	17.2	4	28	13	40.9	29.6	0.41	BDL	208	32
17	434	49.1	1.44	16.8	6	28	13	39.0	24.6	0.50	BDL	205	28
24	514	49.7	0.69	21.1	3	28	36	19.5	5.0	0.22	BDL	208	24
31	*475	67.5	0.98	24.1	2	4	23	35.5	20.0	0.19	BDL	208	13
Jun 7	*346	35.7	0.74	24.1	4	4	25	33.2	20.9	BDL	0.20	200	14
14	*699	79.8	0.70	23.8	7	7	40	58.6	19.7	0.22	BDL	222	24
21	414	53.1	0.64	25.1	6	6	40	25.4	16.3	BDL	BDL	230	22
28	605	69.4	0.60	26.7	4	5	44	25.4	14.1	0.19	BDL	218	7
Jul 5	247	25.2	0.52	27.6	6	6	43	22.9	13.6	BDL	BDL	226	20
12	528	60.0	0.54	27.5	6	6	46	20.4	11.7	0.33	BDL	223	12
19	542	55.0	0.56	27.2	7	6	47	25.1	8.8	0.20	BDL	224	7
26	581	68.2	0.56	28.1	6	6	39	21.2	9.6	0.28	BDL	229	14
Aug 2	*282	49.1	0.61	28.6	9	5	29	18.1	6.0	BDL	BDL	227	6
9	*493	55.9	0.67	27.6	8	-	22	18.4	5.2	BDL	BDL	242	16
15	401	54.5	0.67	28.0	9	-	25	16.1	3.8	0.19	BDL	244	17
23	*564	61.5	0.62	28.4	10	6	39	19.0	3.0	BDL	BDL	252	10
30	440	59.7	0.51	28.3	10	4	39	17.5	2.1	BDL	BDL	248	12
Sep 6	-	-	0.65	27.2	12	6	37	16.2	2.1	0.21	BDL	254	15
12	472	60.1	0.66	27.0	12	8	24	19.4	3.7	BDL	BDL	262	21
20	218	20.6	0.64	26.5	14	9	19	20.9	7.3	BDL	BDL	290	49
27	-	-	0.82	24.5	14	13	16	13.6	3.5	0.17	BDL	311	57
Oct 4	295	44.2	0.79	22.9	17	17	16	16.9	5.1	0.18	BDL	306	55
11	405	51.0	0.94	21.1	19	18	17	16.1	4.8	0.24	BDL	313	51
18	-	-	1.02	19.4	22	21	17	15.8	4.6	0.28	BDL	313	51

* Approximation

BDL - Below detection limit

Table 4-7. (continued)

Date	Incident light intensity during incubation ly-d-1	Incident light intensity during incubation ly-h-1	Average extinction coefficient (k), m-1	Mean temperature upper 3m, °C	Upper mixed depth based on temperature profiles, m	Upper mixed depth based on oxygen profiles, m	Critical TN, m	Nutrient concentration in upper mixed layer				
								NO ₃ -N, $\mu\text{mole l}^{-1}$	TP, $\mu\text{mole l}^{-1}$	PO ₄ , $\mu\text{mole l}^{-1}$	TIC, $\mu\text{mole l}^{-1}$	CO ₂ , $\mu\text{mole l}^{-1}$
Oct 25	*297	37.4	0.77	18.5	22	21	15	13.6	5.0	BDL	341	40
Nov 1	292	46.9	0.81	18.0	24	23	15	17.1	4.3	BDL	303	51
8	135	16.6	0.78	17.4	22	21	11	15.7	4.8	BDL	313	51
15	134	24.4	0.73	17.0	23	23	6	17.5	0.18	BDL	315	52
22	*186	35.3	1.02	16.0	26	25	6	18.6	5.8	BDL	312	52
29	-	17.4	1.21	14.9	28	28	5	22.2	7.1	BDL	339	64
Dec 6	*245	41.6	1.18	14.0	28	28	3	21.5	0.22	BDL	323	58
13	242	42.4	1.35	12.7	28	28	6	23.9	9.9	BDL	326	63
20	27	3.8	1.28	11.0	28	28	3	30.6	12.7	BDL	319	53
27	217	39.3	1.28	10.4	28	28	6	26.5	0.19	BDL	298	47
Jan 3	*244	47.6	1.21	9.1	28	28	5	-	-	-	302	46
10	222	36.5	1.02	8.3	28	28	4	-	-	-	305	48

* Approximation

BDL = Below detection limit

Table 4-8. Calculation of apparent respiration (R') to P_{max} ratios, Locations 3.0 and 8.0, 1978.

Location	Range of dates	Net change in algal carbon in upper mixed layer (mgC·m ⁻² ·d ⁻¹)	Mean daily photosynthesis (mgC·m ⁻² ·d ⁻¹)	Daily apparent respiration (mgC·m ⁻² ·d ⁻¹)	Apparent respiration (mgC·m ⁻² ·h ⁻¹)	Mean P _{max} (mgC·m ⁻² ·h ⁻¹)	R' : P _{max}	Dominant classes	Range of measured R' : P _{max} for dominants (Harris 1978)
3.0	March 8 to April 5	17.6	175	157	0.26	10.42	0.02	BAC	0.04-0.08
3.0	April 5 to May 3	-35.0	176	211	0.35	10.95	0.03	BAC	0.04-0.08
3.0	May 24 to June 7	1.8	441	439	6.86	13.46	0.51	CRP	ND
3.0	June 21 to July 19	19.0	646	627	4.08	11.32	0.36	DIN	0.25-0.80
3.0	August 15 to September 6	20.2	487	46	2.79	13.67	0.20	CHL	0.06-0.25
3.0	September 1 to December 6	-15.4	314	329	0.56	11.90	0.05	DIN	0.06-0.25
3.0	December 6 to December 27	13.0	199	186	0.31	11.28	0.03	BAC	0.04-0.08
8.0	February 8 to February 22	33.1	62	29	0.04	5.03	0.01	BAC	0.04-0.08
8.0	March 15 to March 29	38.4	187	149	0.22	18.10	0.01	BAC	0.04-0.08
8.0	April 5 to May 3	-42.3	228	270	0.84	15.61	0.05	BAC	0.04-0.08
8.0	May 10 to June 7	-1.8	317	314	3.12	11.37	0.27	CRP	ND
8.0	June 21 to July 19	20.9	736	715	5.14	14.71	0.35	DIN	0.25-0.80
8.0	July 19 to August 9	-23.0	672	695	5.27	15.16	0.35	CHL	0.06-0.25
8.0	August 9 to September 12	26.9	592	565	3.92	16.86	0.23	DIN	0.25-0.80
8.0	September 12 to December 27	9.7	134	128	0.19	10.56	0.02	CHL	0.06-0.25
								BAC	0.04-0.08

BAC: Bacillariophyceae
CRP: Cryptophyceae
DIN: Dinophyceae
CHL: Chlorophyceae

ND: No R' : P_{max} values for cryptophytes were available. R' : P_{max} values for these time periods were examined by comparing values to those plotted in Figure 4-33.

*: These values were calculated based on weekly mean incident solar radiation (ly·d⁻¹).

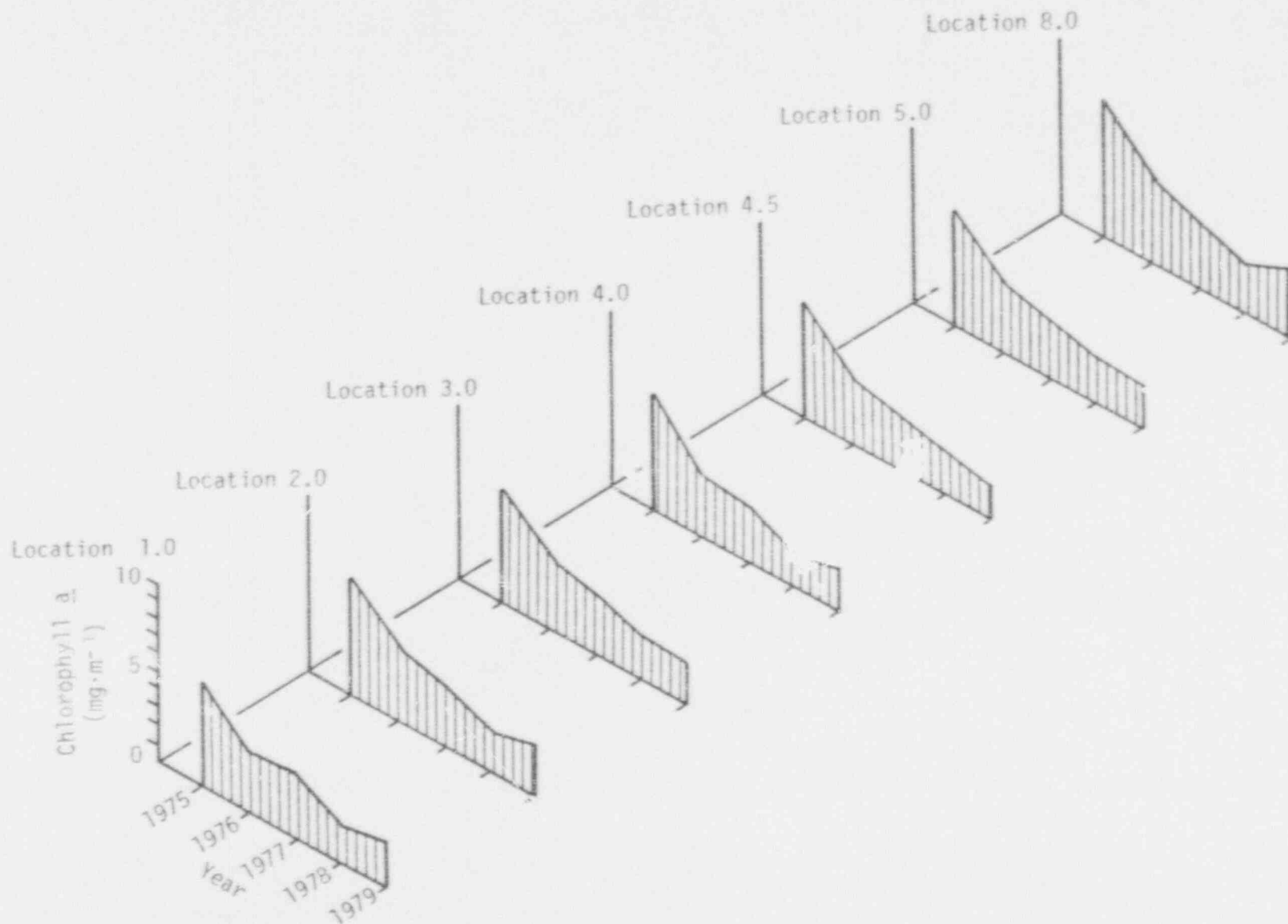


Figure 4-1. Mean annual surface concentrations of true chlorophyll a ($\text{mg}\cdot\text{m}^{-3}$) at seven locations on Lake Norman, 1975 through 1979.

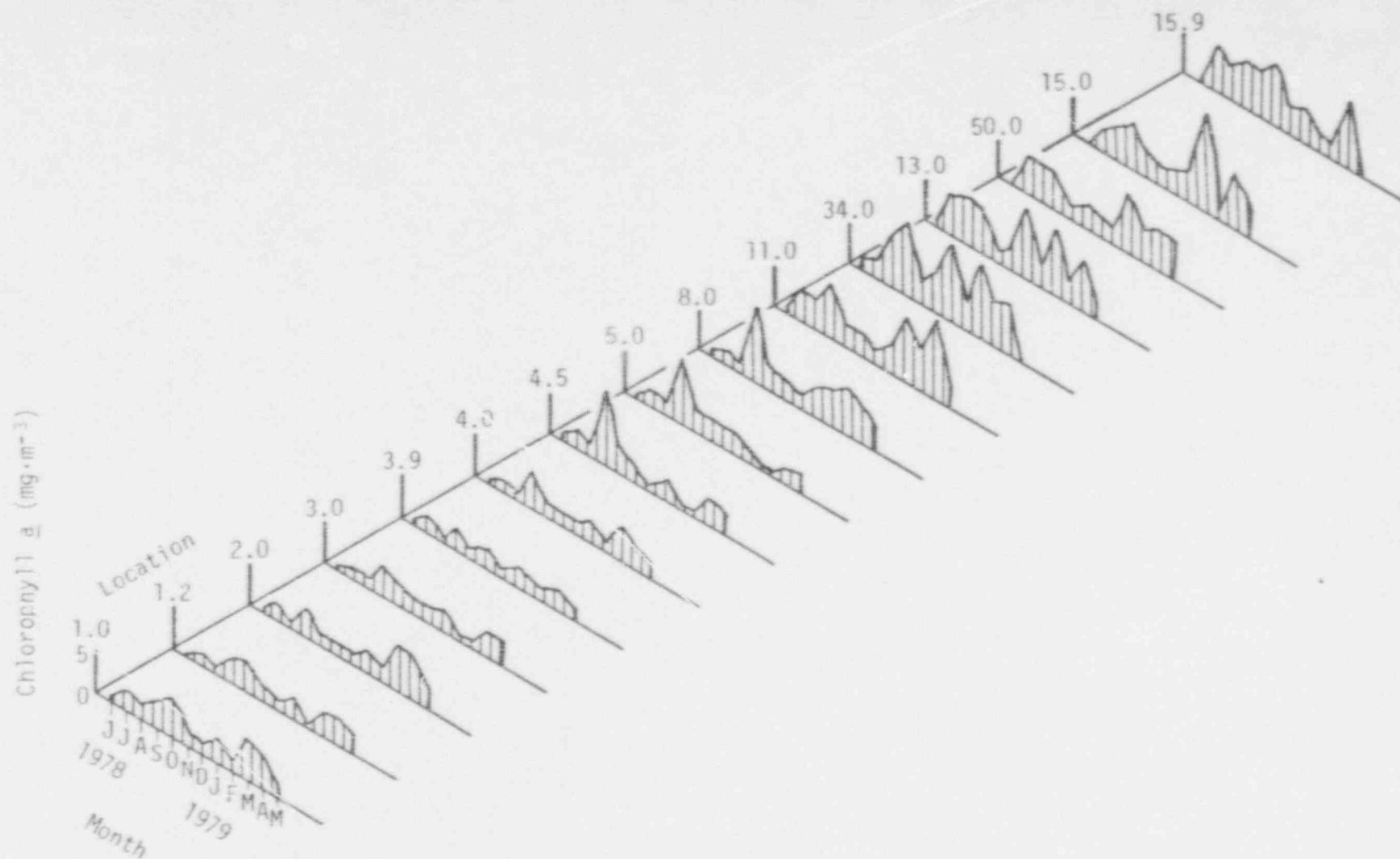


Figure 4-2. Concentrations of true chlorophyll a ($\text{mg} \cdot \text{m}^{-3}$) in surface waters at fifteen locations on Lake Norman, June 1978 through May 1979.

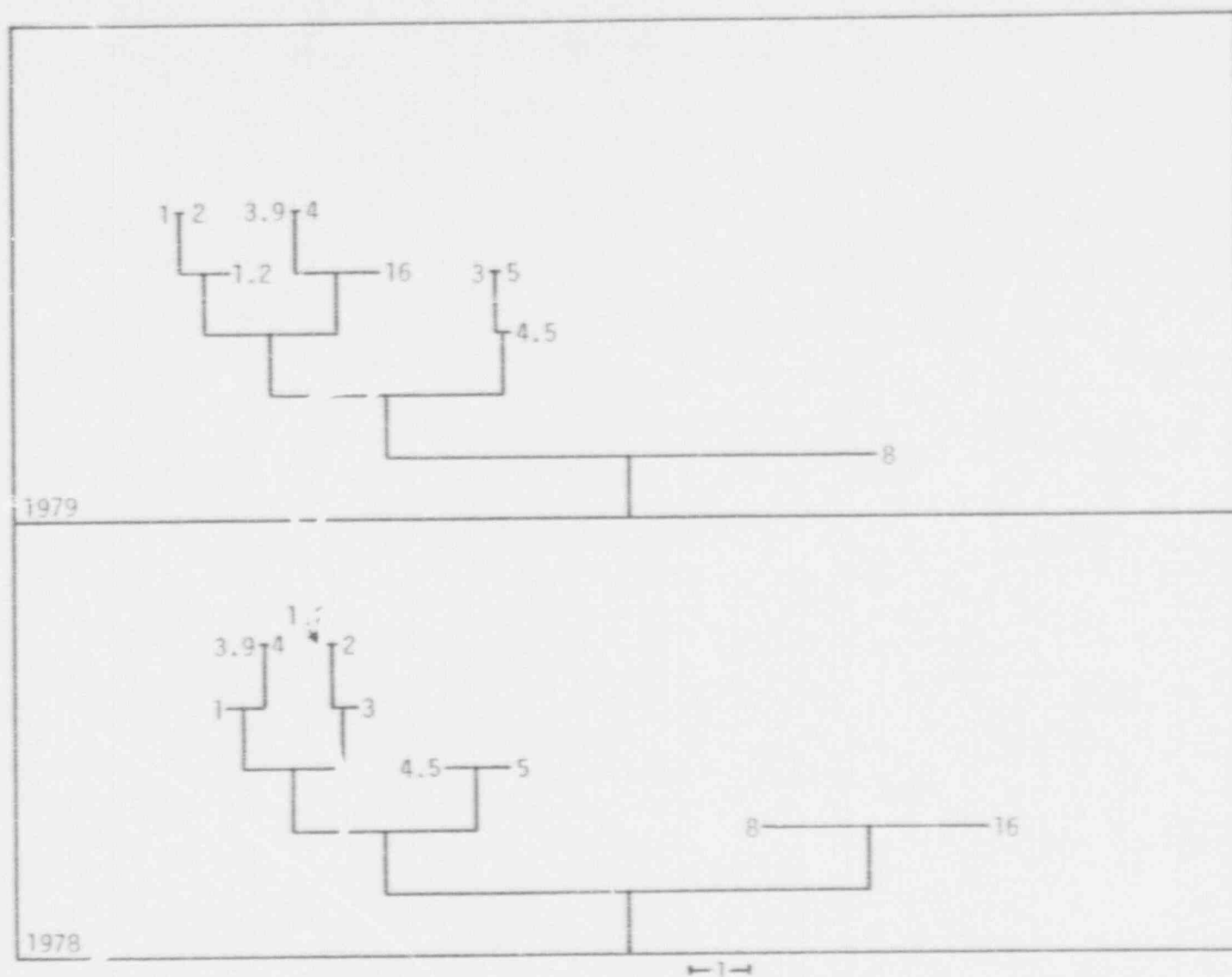


Figure 4-3. Dendrograms based on cluster analysis of Locations 1.0, 1.2, 2.0, 3.0, 3.9, 4.0, 4.5, 5.0, 8.0 and 16.0 on Lake Norman. Analysis is based on mean annual densities of major taxonomic classes. Horizontal distance corresponds to maximum standardized distance within a cluster (Helwig and Council 1979).

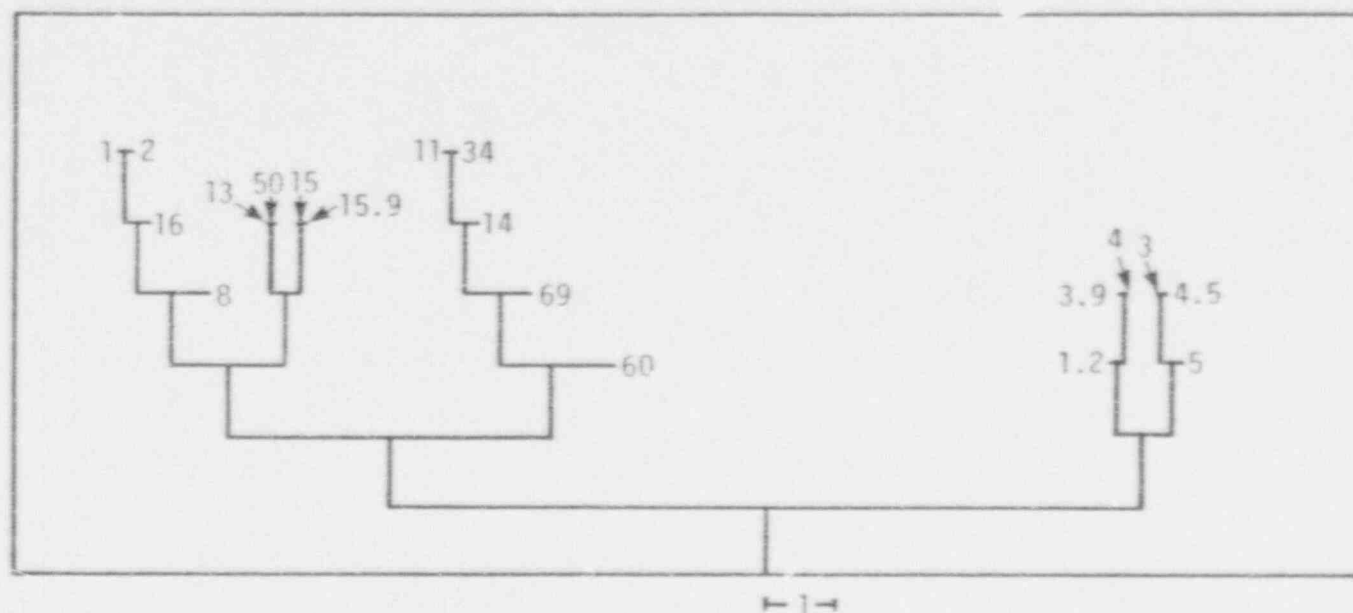


Figure 4-4. Dendrogram based on cluster analysis of Locations 1.0, 1.2, 2.0, 3.0, 3.9, 4.0, 4.5, 5.0, 8.0, 11.0, 34.0, 13.0, 14.0, 15.0, 15.9, 16.0, 50.0, 60.0, and 69.0 on Lake Norman and Mountain Island Lake. Analysis is based on mean annual densities of major taxonomic classes for the year June 1978 through May 1979. Horizontal distance corresponds to maximum standardized distance within cluster (Helwig and Council 1979).



Figure 4-5. Dendrogram based on cluster analysis of Locations 1.0, 2.0, 3.0, 4.0, 4.5, 5.0, 6.0, 7.5, 8.0, 10.0, 11.0, 13.0, and 16.0 on Lake Norman and Mountain Island Lake. Analysis is based on mean annual densities of major taxonomic classes for the year March 1974 through February 1975. Horizontal distance corresponds to maximum standardized distance within cluster (Helwig and Council 1979).

	1978											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.0	1	1	8	1	9	9	3	4	6	4	1	1
1.2	1	1	8	1	9	9	3	4	6	4	1	8
2.0	1	1	8	1	9	9	3	6	6	4	1	1
3.0	2	1	8	1	9	9	3		6	4	1	1
3.9	1	4	8	1	9	9	5	4	6	4	1	8
4.0	2	1	1	8	9	9	5	4	6	4	8	1
4.5	1	4	8	1	9	9	5	4	6	4	1	8
5.0	2	1	1	1	9	9	5	6	6	6	1	1
8.0	1	1	8	1	9	9	5	6	6	4	1	1
16.0	1	9	8	8	2	9	3	6	6	7	3	8

% composition by density, mean within cluster

Cluster No.	CHL	BAC	CHR	CRP	MYX	DIN	UNID	
1	31	40	3	15	<1	1	9	CHL Chlorophyceae
2	25	31	3	31	<1	<1	11	BAC Bacillariophyceae
3	28	18	16	21	1	3	11	CHR Chrysophyceae
4	46	26	5	7	1	4	8	CRP Cryptophyceae
5	41	15	21	9	1	3	9	MYX Myxophyceae
6	58	13	6	5	3	3	9	DIN Dinophyceae
7	32	9	3	3	40	4	6	UNID Unidentified
8	22	56	3	11	1	<1	6	
9	16	14	4	52	4	<1	9	

Figure 4-6. Results of cluster analysis on percent composition by density of all algal classes plus unidentified algae, January through December, 1978. Number in cell indicates cluster into which location-date combination fell.

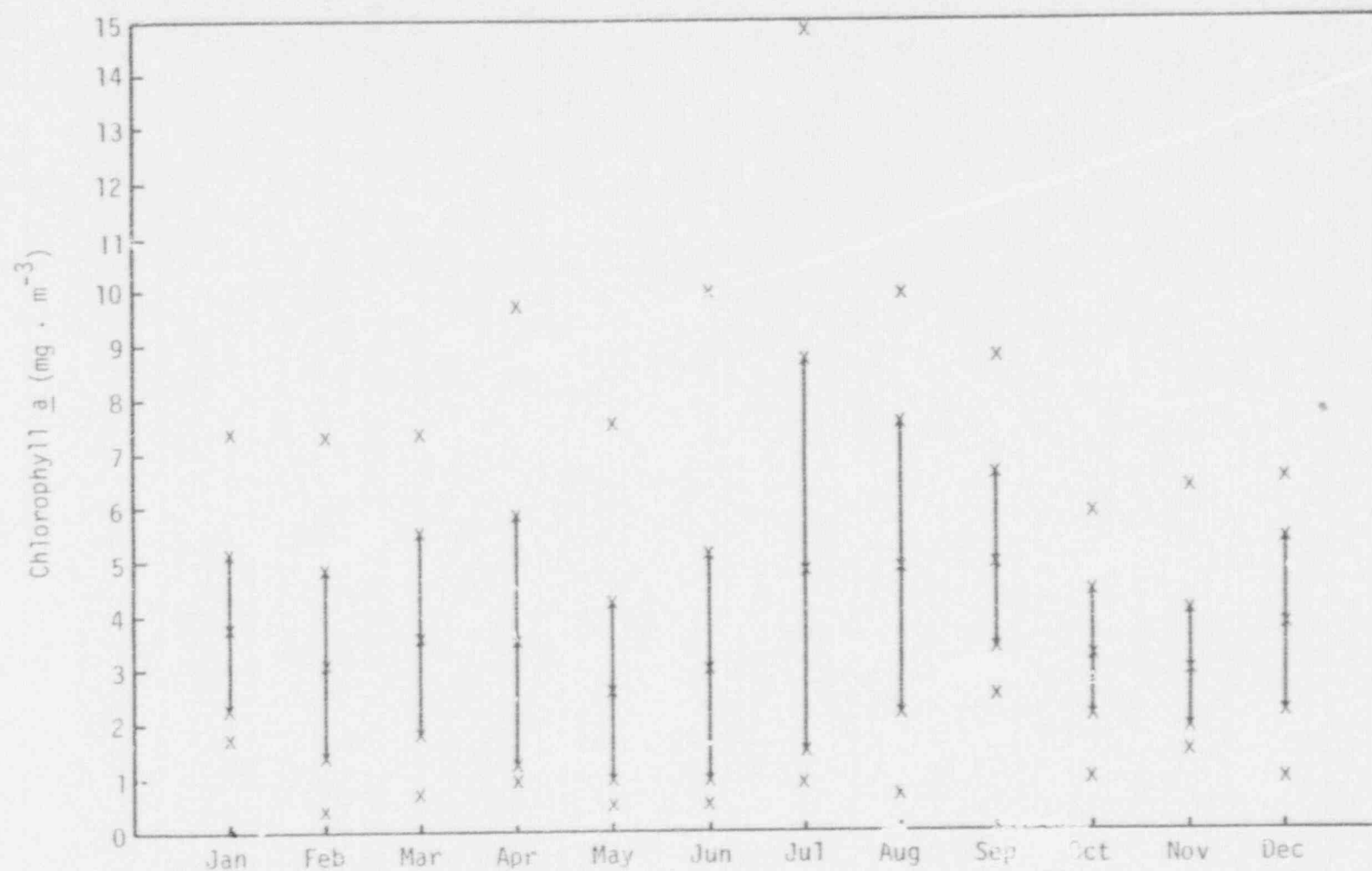


Figure 4-7. Monthly mean concentrations of true chlorophyll a ($\text{mg} \cdot \text{m}^{-3}$) in surface waters, averaged over a five-year period (1975-1979), utilizing data from Locations 1.0, 2.0, 3.0, 4.0, 4.5, 5.0, and 8.0 on Lake Norman. Means are bounded by one standard deviation (x—x) and by the range of observed values (x x).

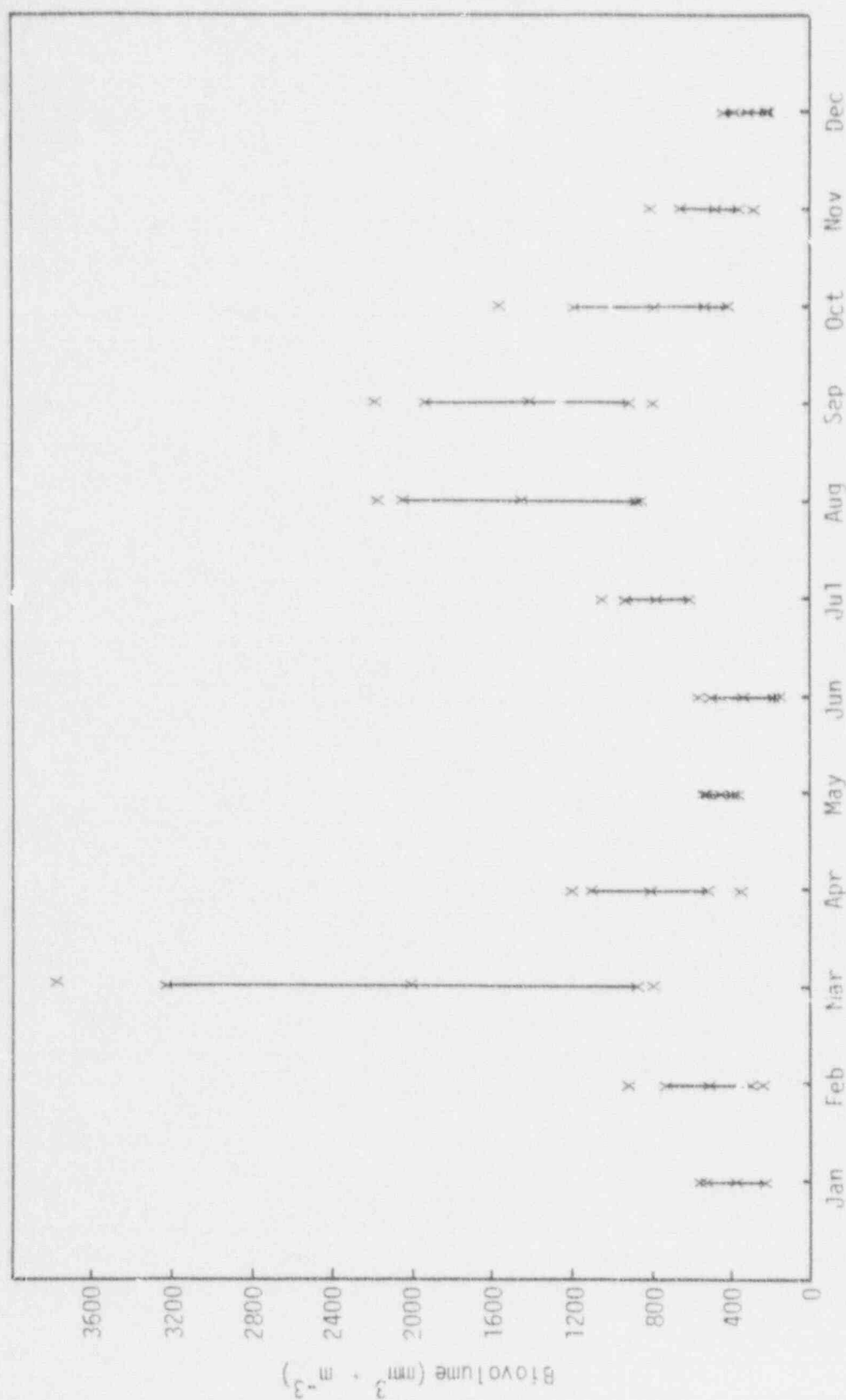


Figure 4-8. Monthly mean biovolume concentrations ($\text{mm}^3 \cdot \text{m}^{-3}$) in surface waters, averaged over a two-year period (1978-1979), at three main channel locations (1.0, 2.0, 8.0) on Lake Norman. Means are bounded by or , standard deviation ($x - x$) and by the range of observed values ($x - x$).

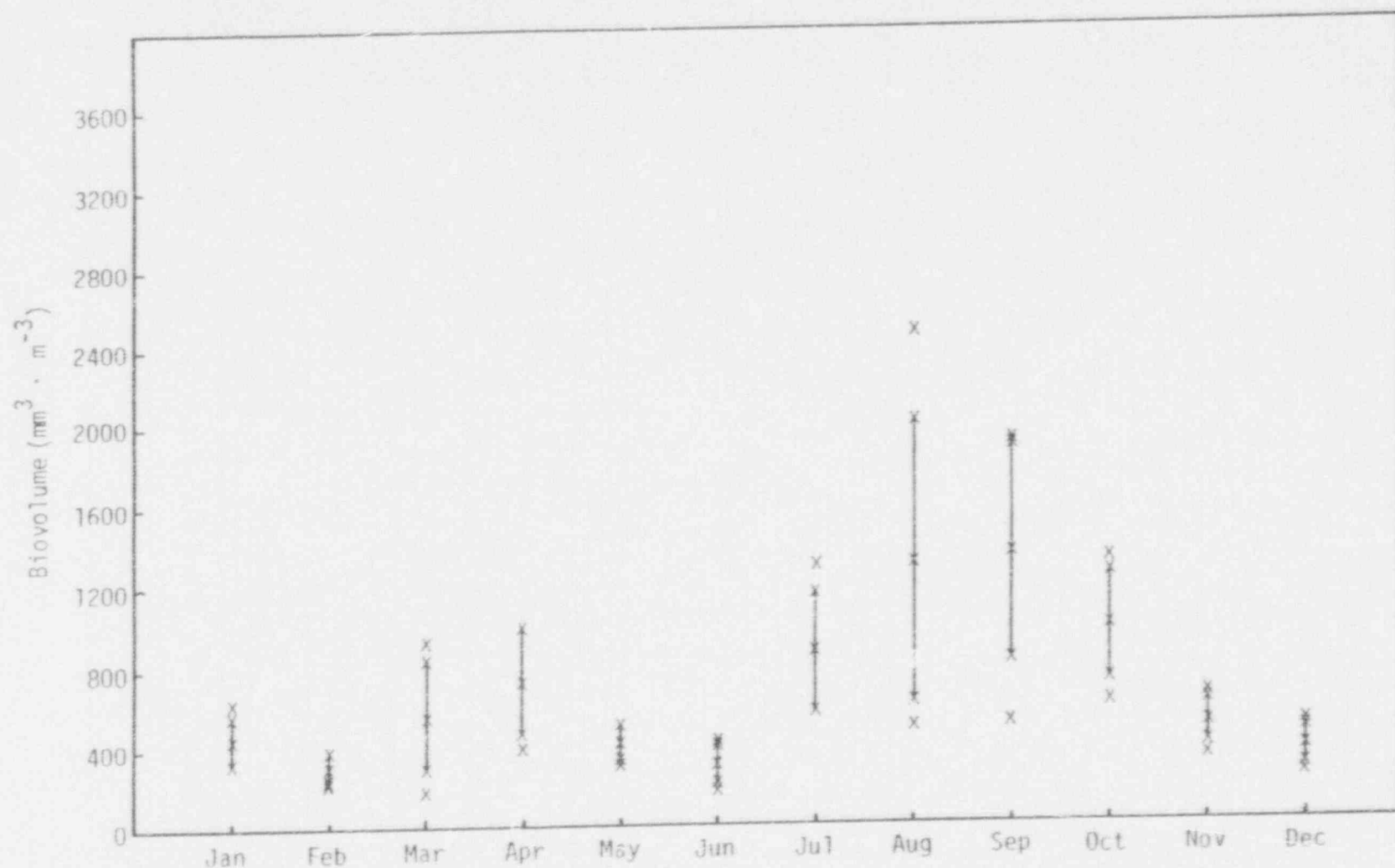


Figure 4-9. Monthly mean biovolume concentrations ($\text{mm}^3 \cdot \text{m}^{-3}$) in surface waters, averaged over a two-year period (1978-1979), at three Ramsey Creek locations on Lake Norman (Locations 3.0, 4.5, and 5.0). Means are bounded by one standard deviation (x—x) and by the range of observed values (x x).

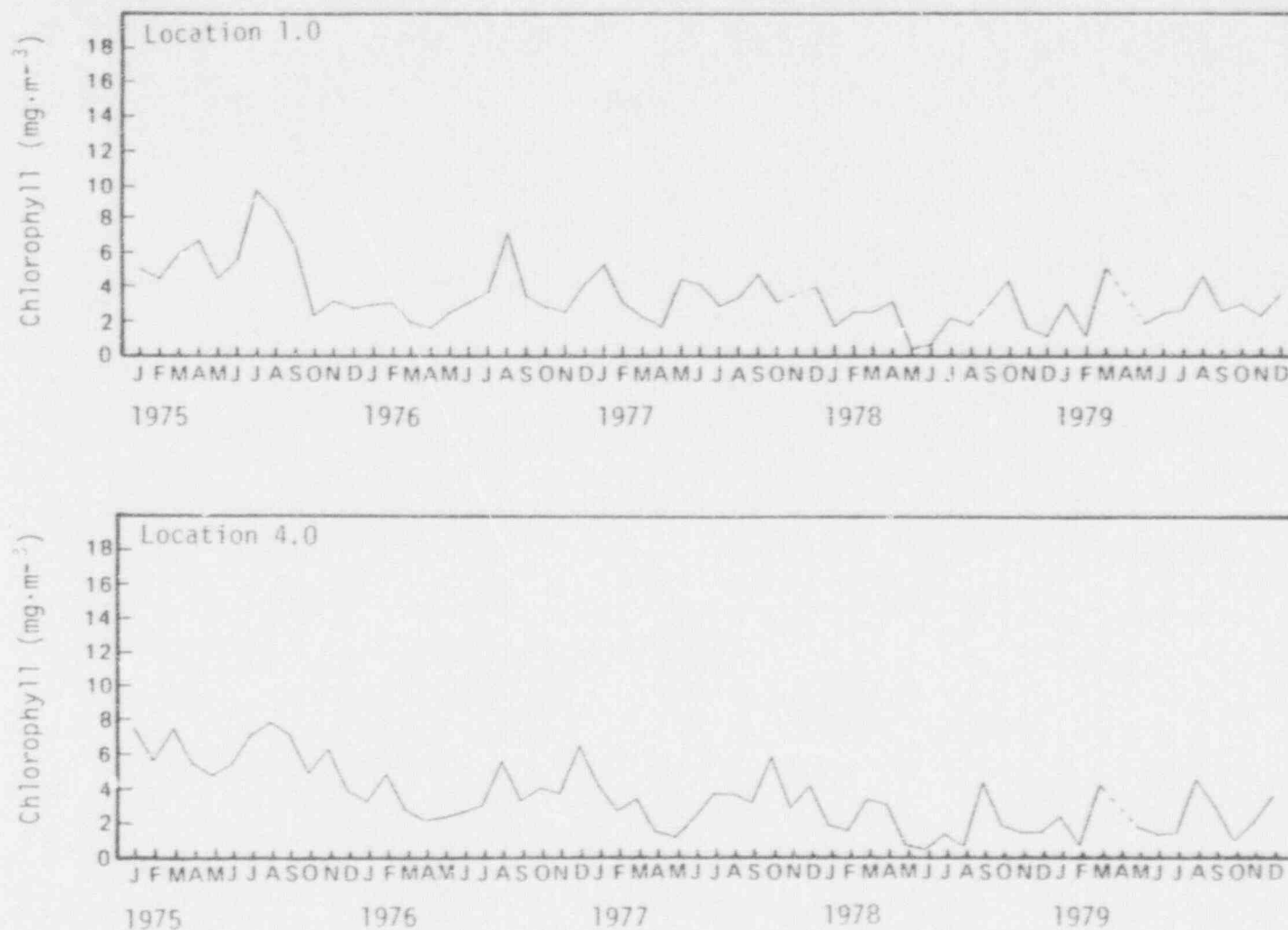


Figure 4-10. Concentrations of chlorophyll a ($\text{mg}\cdot\text{m}^{-3}$) in surface waters at Locations 1.0, 4.0, 5.0 and 8.0 on Lake Norman, 1975 through 1979. Broken line indicates missing data.

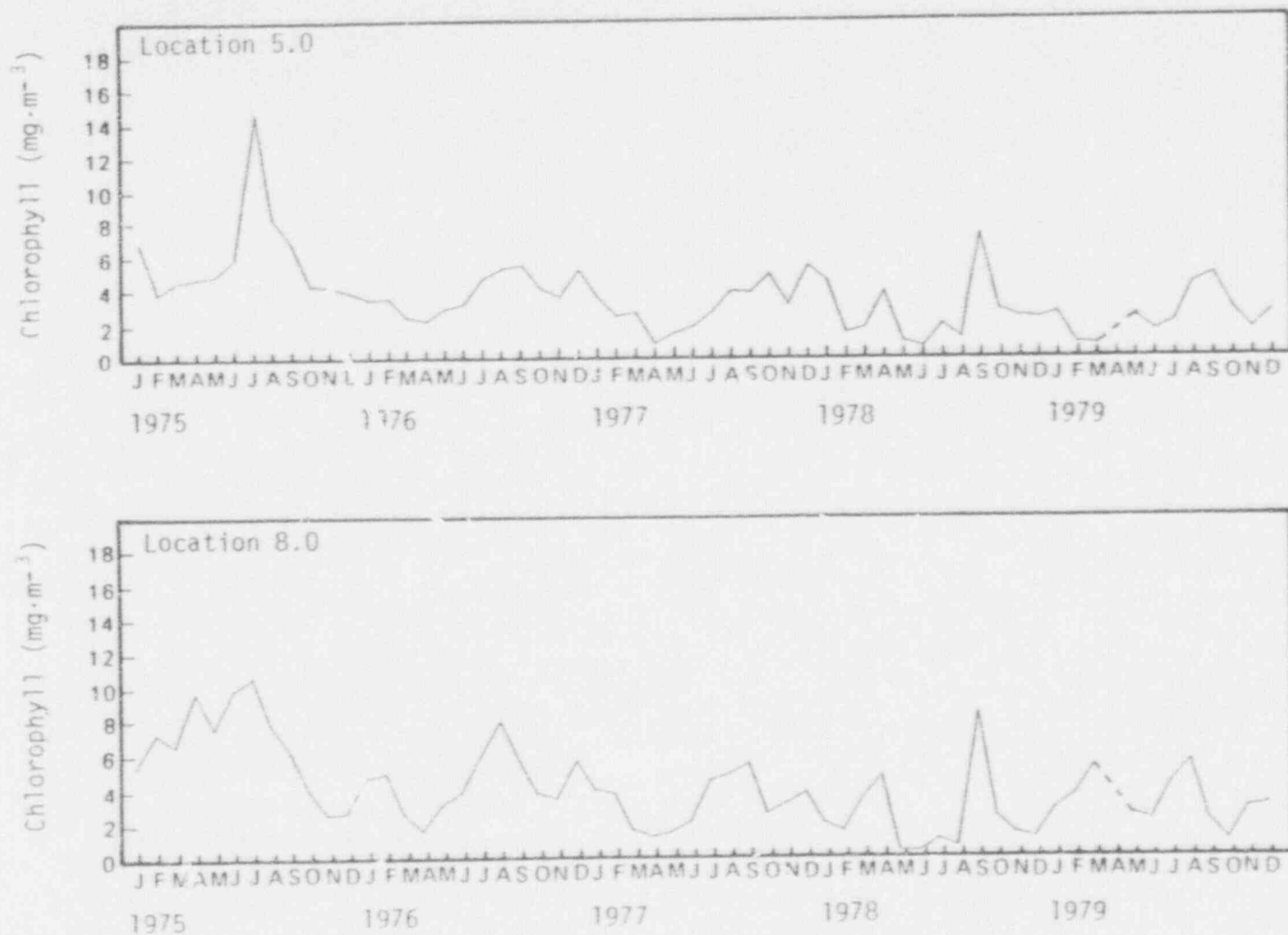


Figure 4-10 (continued)

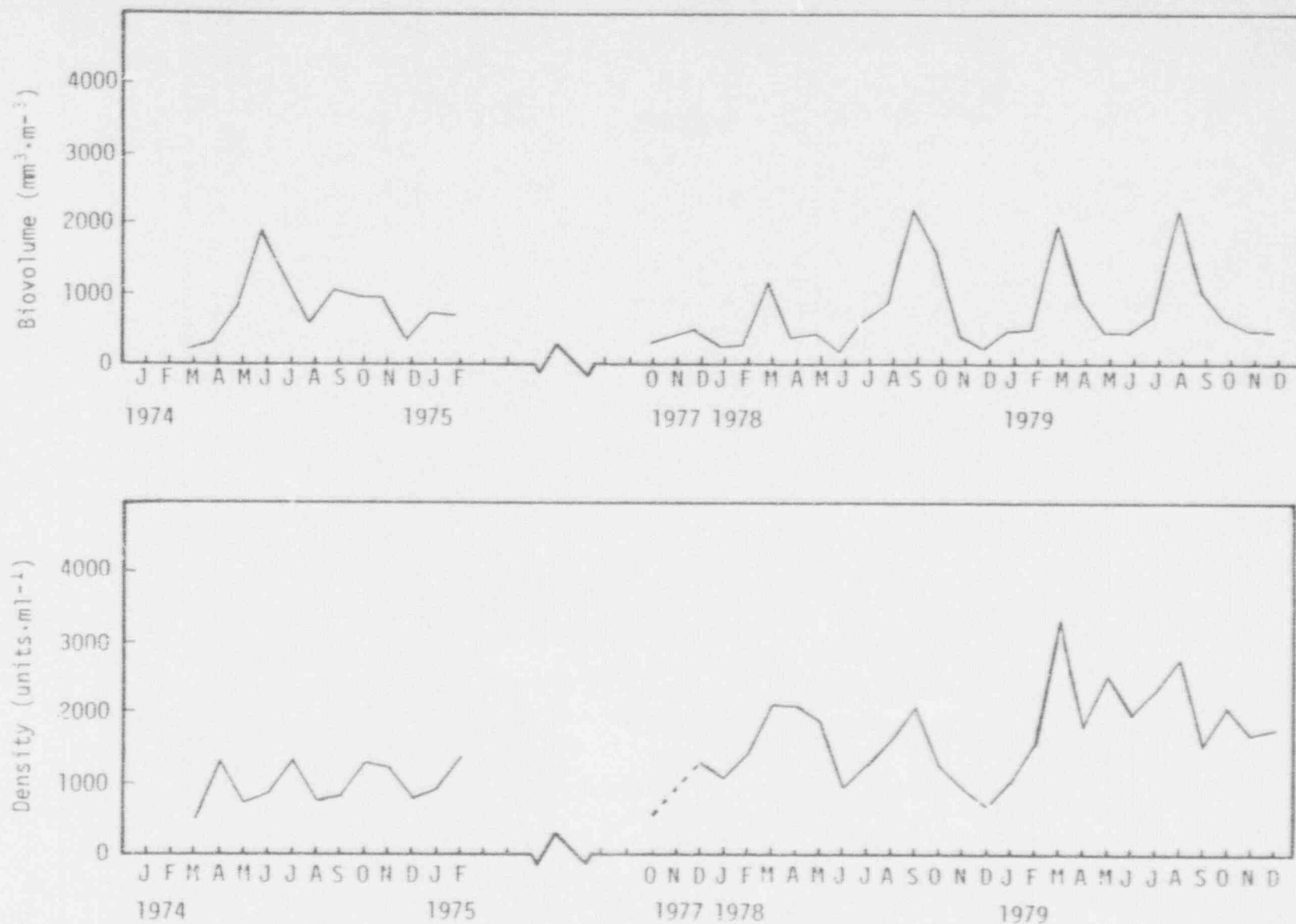


Figure 4-11a. Total algal biovolume ($\text{mm}^3 \cdot \text{m}^{-3}$) and density ($\text{units} \cdot \text{ml}^{-1}$) at Location 1.0 on Lake Norman, March 1974 through February 1975, and October 1977 through December 1979. Broken line indicates missing data.

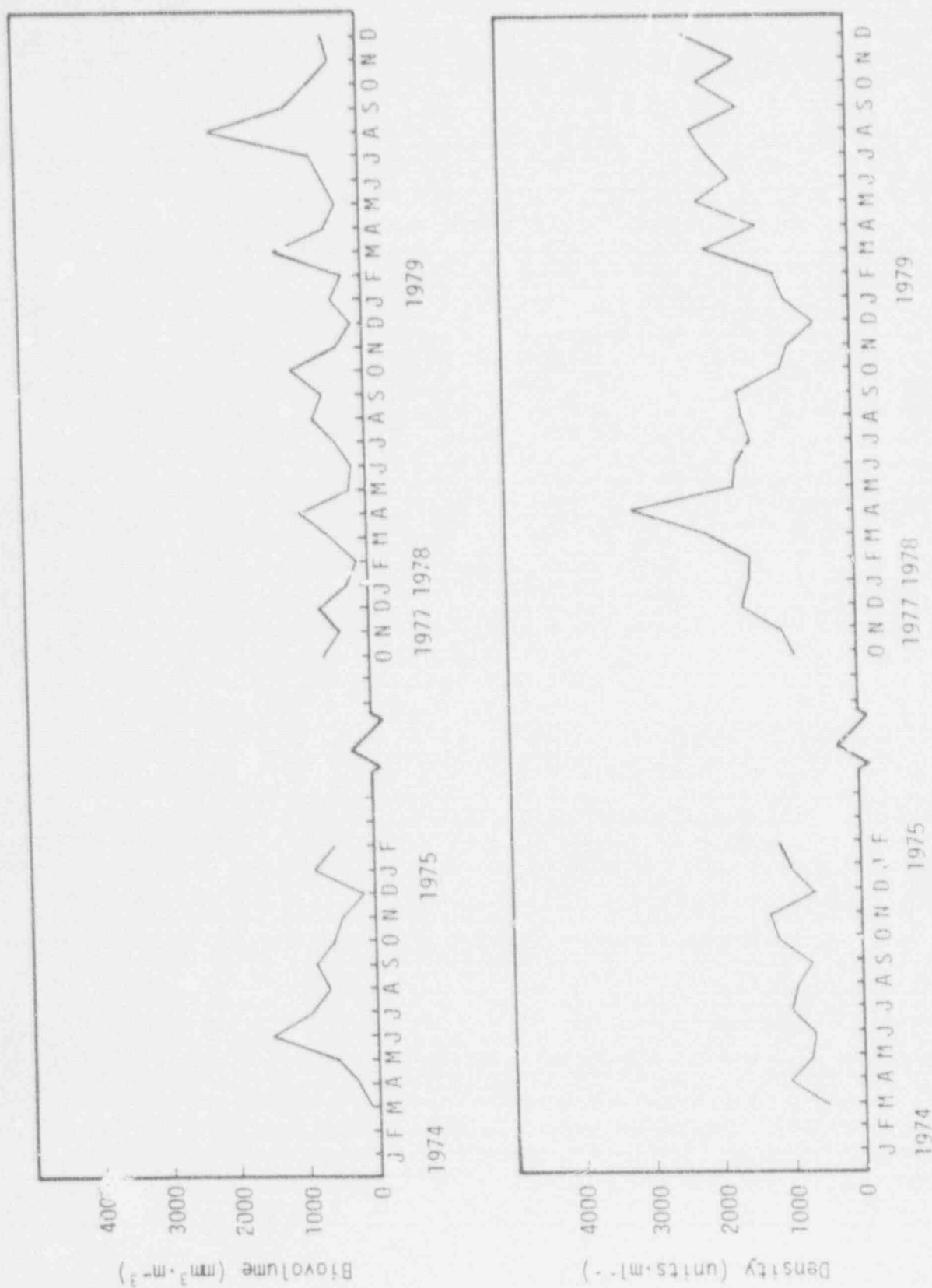


Figure 4-11b. Total algal biovolume ($\text{mm}^3 \cdot \text{m}^{-3}$) and density (units $\cdot \text{ml}^{-1}$) at Location 4.0 on Lake Norman, March 1974 through February 1975, and October 1977 through December 1979.

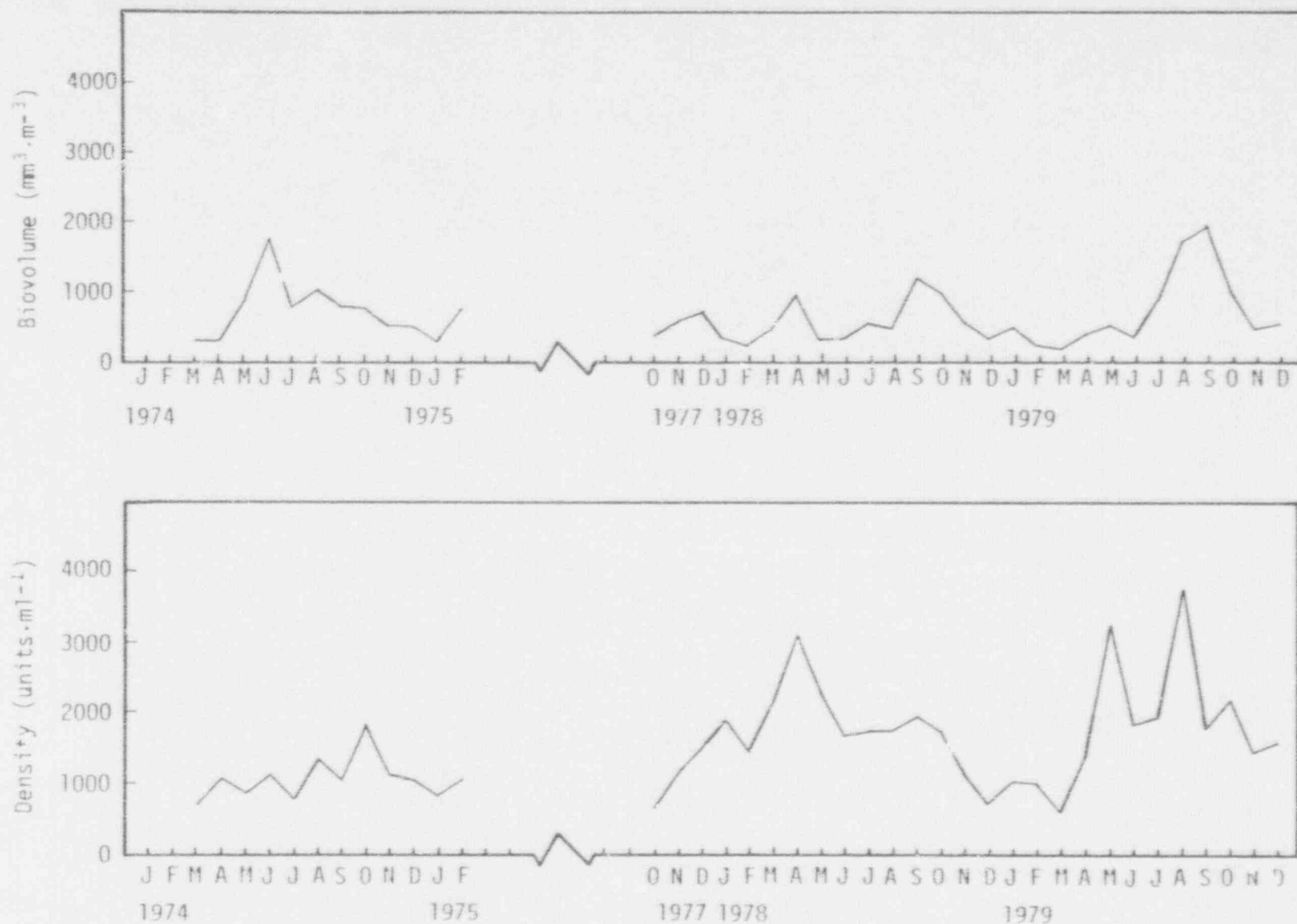


Figure 4-11c. Total algal biovolume ($\text{mm}^3 \cdot \text{m}^{-3}$) and density ($\text{units} \cdot \text{ml}^{-1}$) at Location 5.0 on Lake Norman, March 1974 through February 1975, and October 1977 through December 1979.

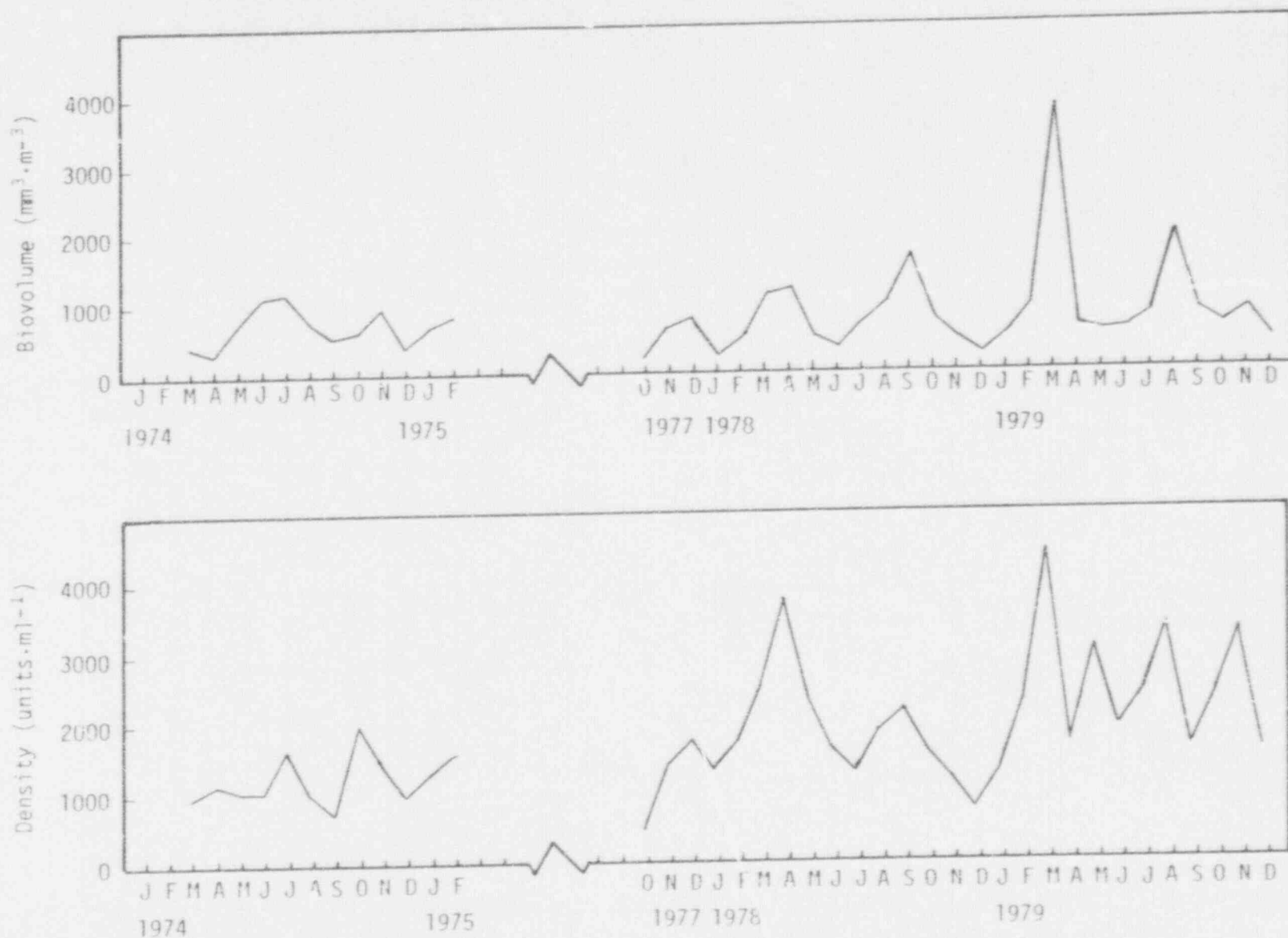


Figure 4-11d. Total algal biovolume ($\text{mm}^3 \cdot \text{m}^{-3}$) and density ($\text{units} \cdot \text{ml}^{-1}$) at Location 8.0 on Lake Norman, March 1974 through February 1975, and October 1977 through December 1979.

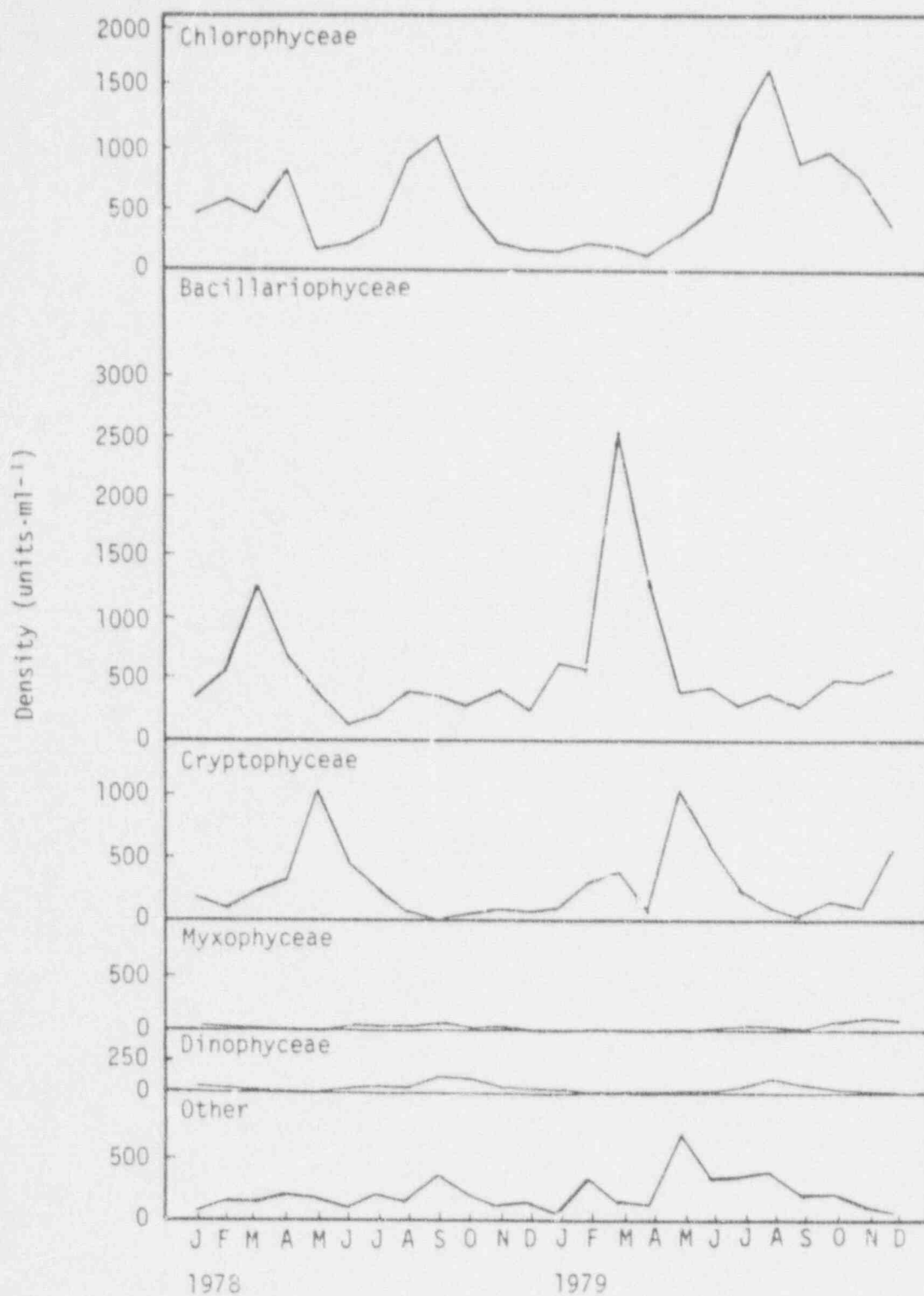


Figure 4-12a. Density (units·ml⁻¹) of major taxonomic classes of phytoplankton in surface waters at Location 1.0, Lake Norman, January 1978 through December 1979.

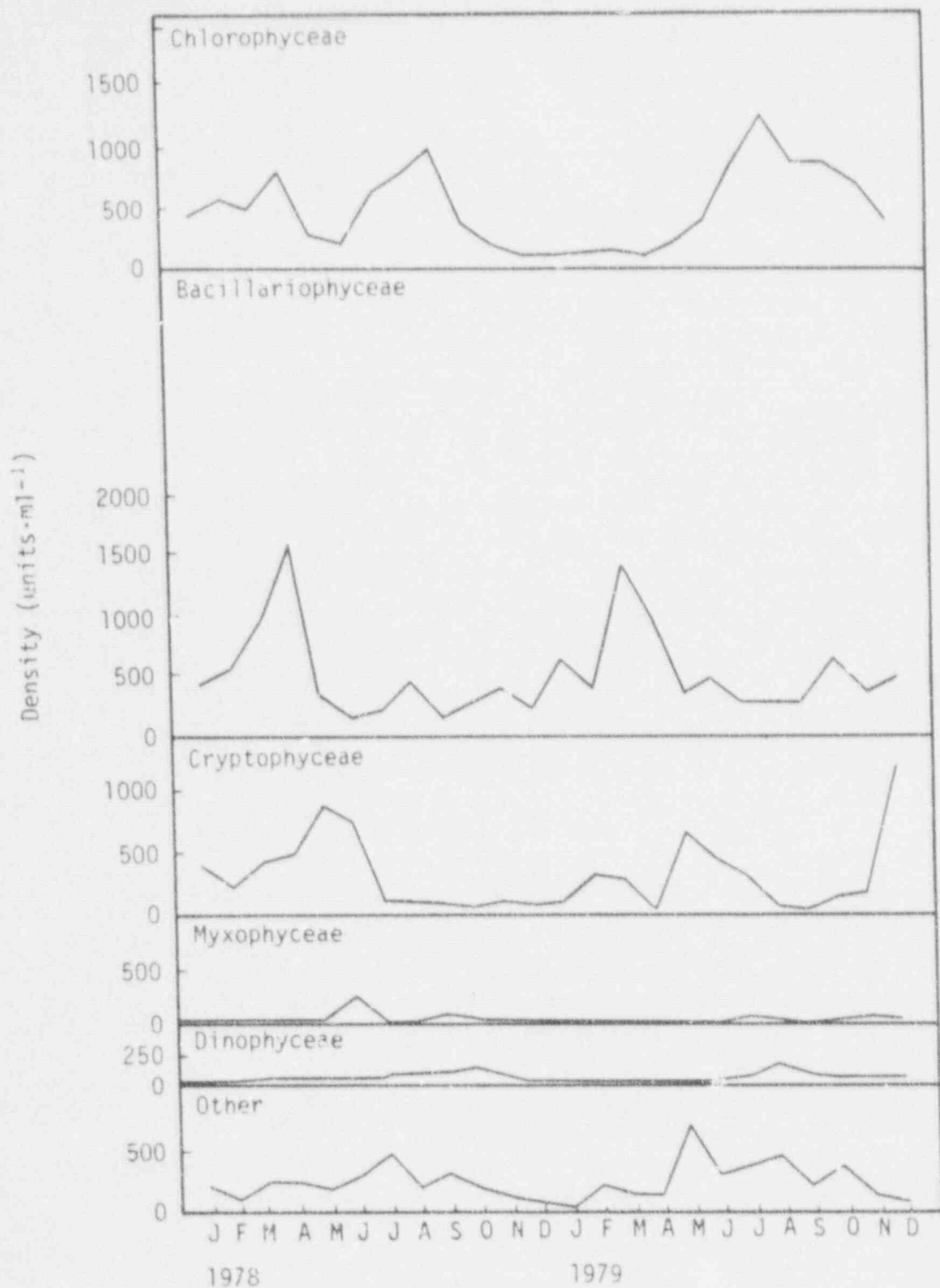


Figure 4-12b. Density (units·ml⁻¹) of major taxonomic classes of phytoplankton in surface waters at Location 4.0, Lake Norman, January 1978 through December 1979.

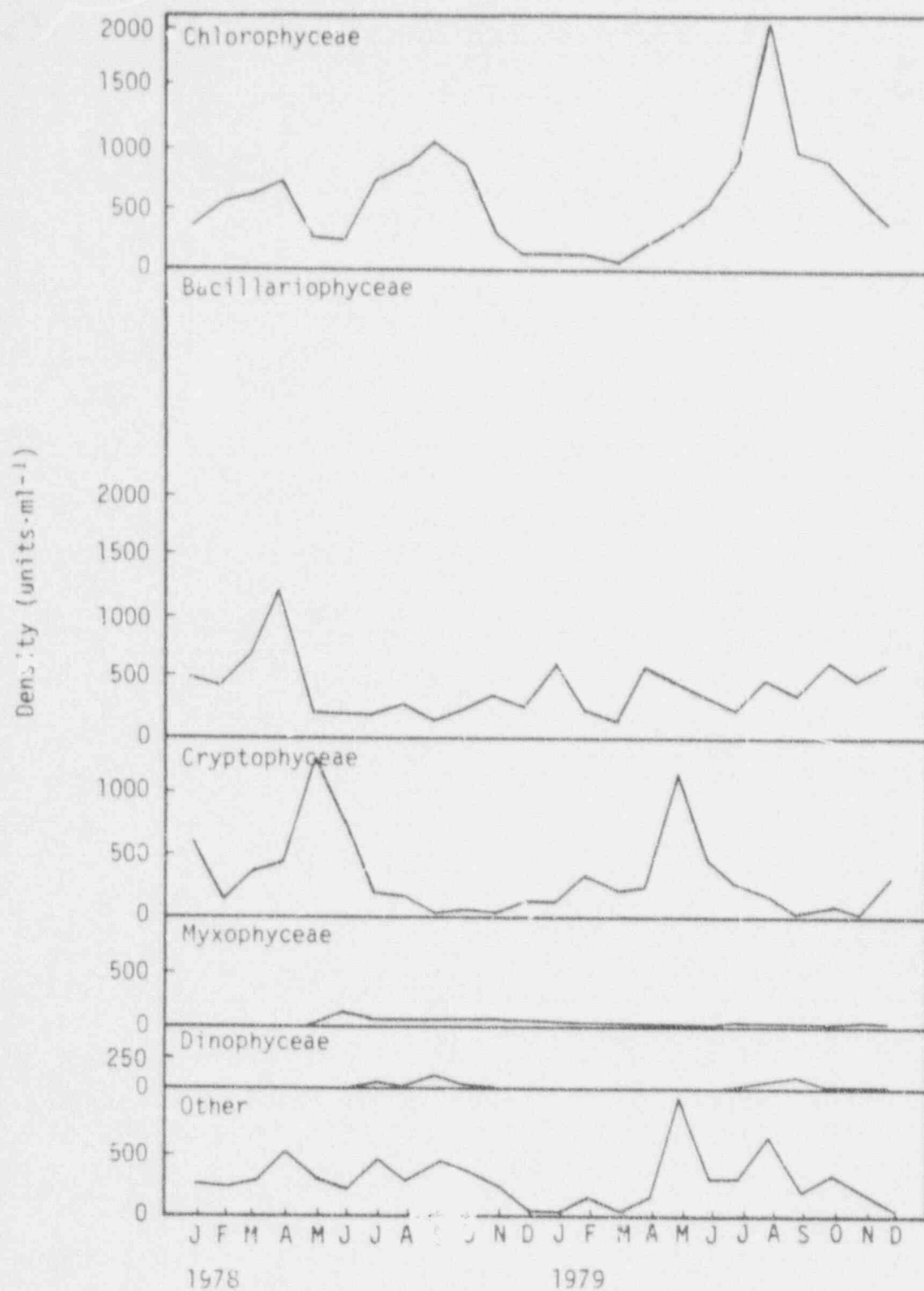


Figure 4-12c. Density (units·ml⁻¹) of major taxonomic classes of phytoplankton in surface waters at Location 5.0, Lake Norman, January 1978 through December 1979.

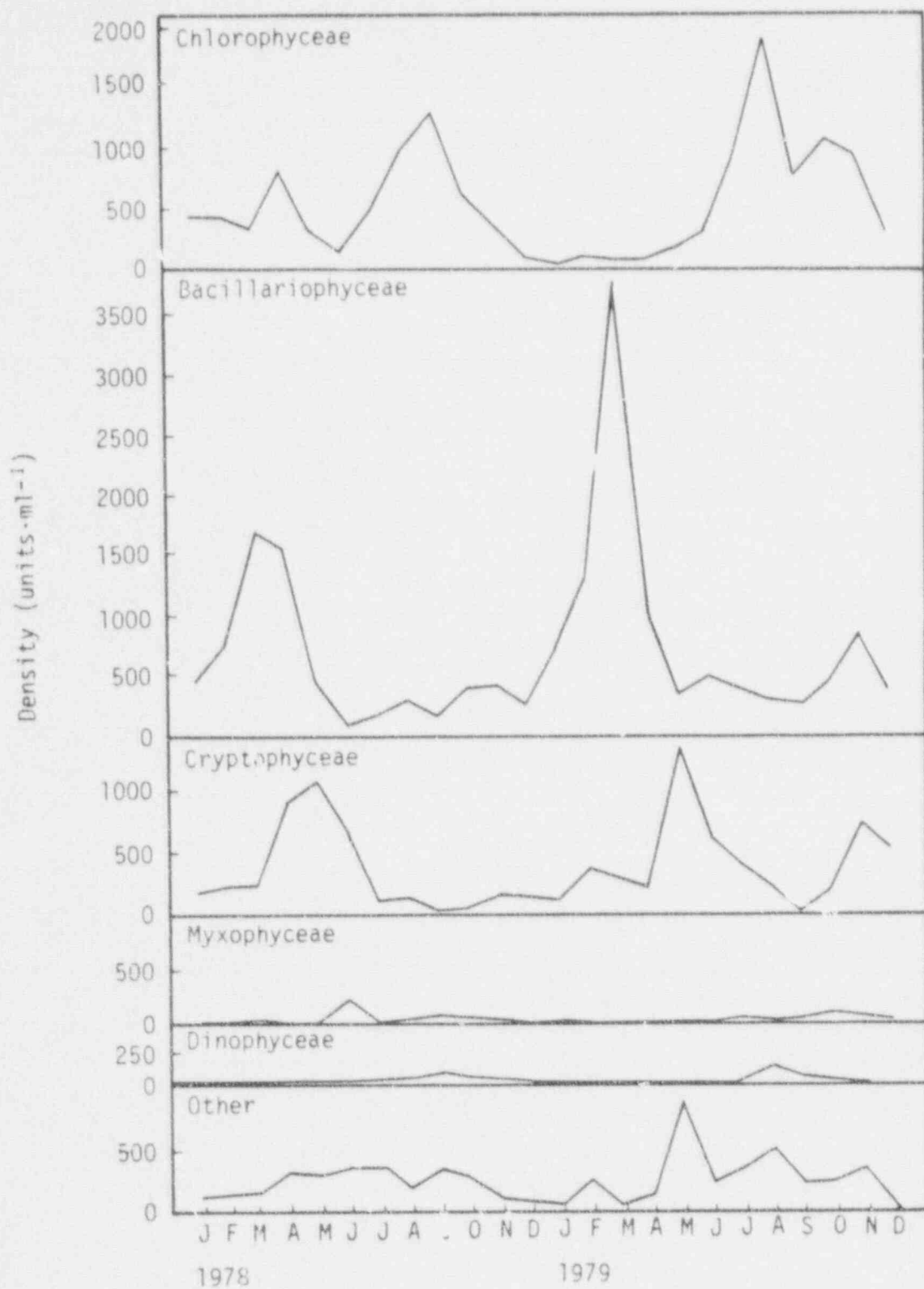


Figure 4-12d. Density (units·ml⁻¹) of major taxonomic classes of phytoplankton in surface waters at Location 8.0, Lake Norman, January 1978 through December 1979.

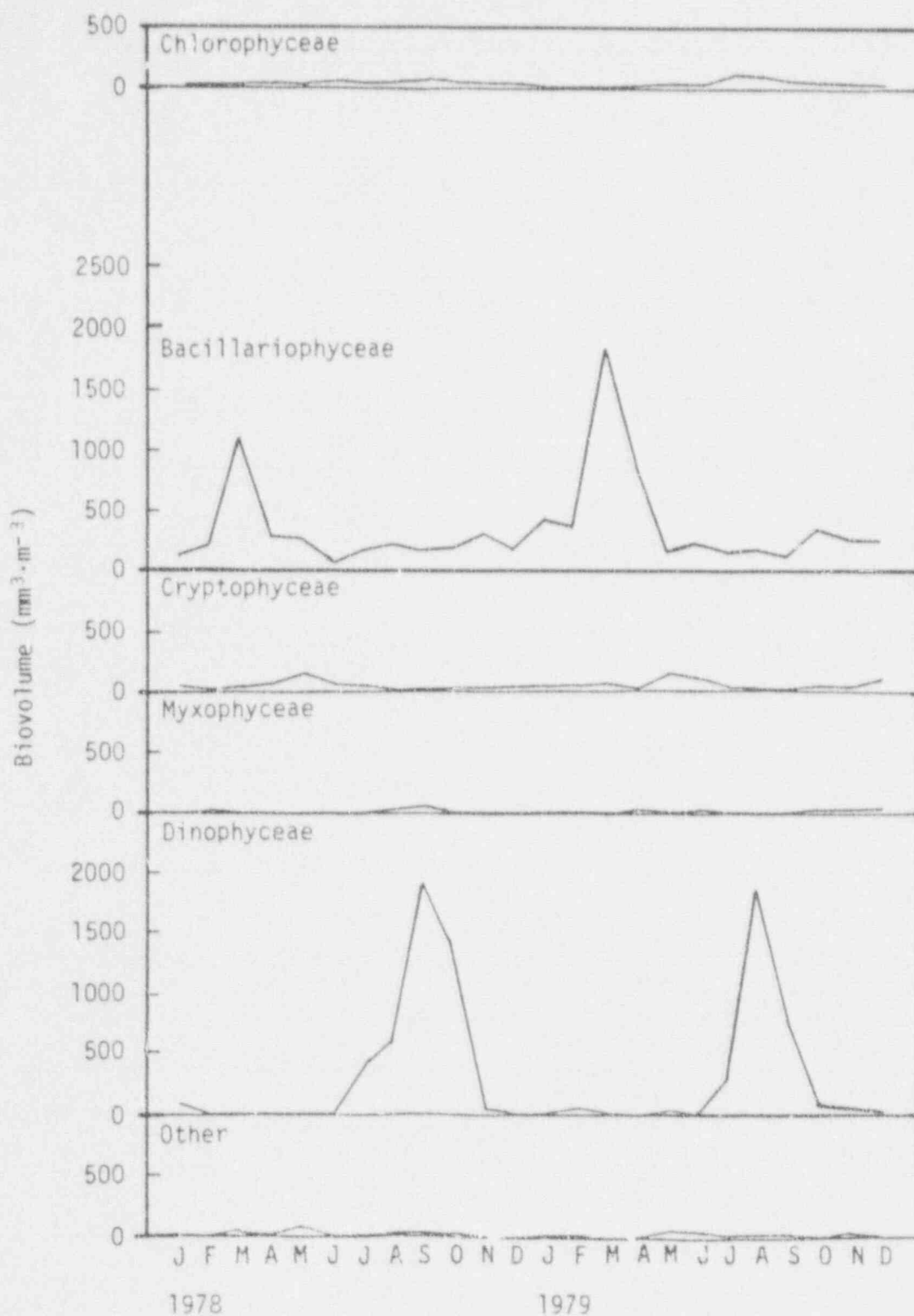


Figure 4-13a. Biovolume (mm³·m⁻³) of major taxonomic classes of phytoplankton in surface waters at Location 1.0, Lake Norman, January 1978 through December 1979.

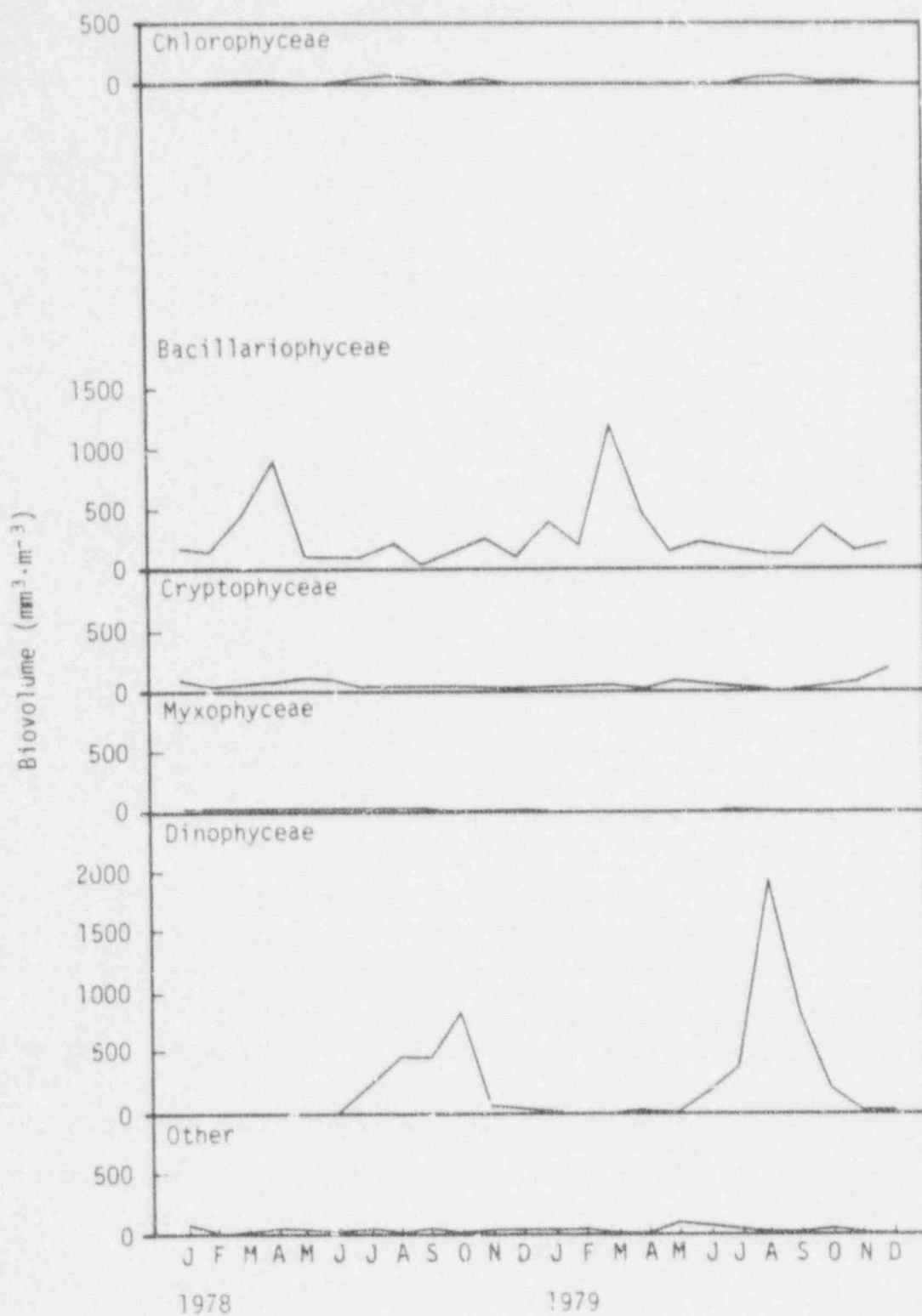


Figure 4-13b. Biovolume (mm³·m⁻³) of major taxonomic classes of phytoplankton in surface waters at Location 4.0, Lake Norman, January 1978 through December 1979.

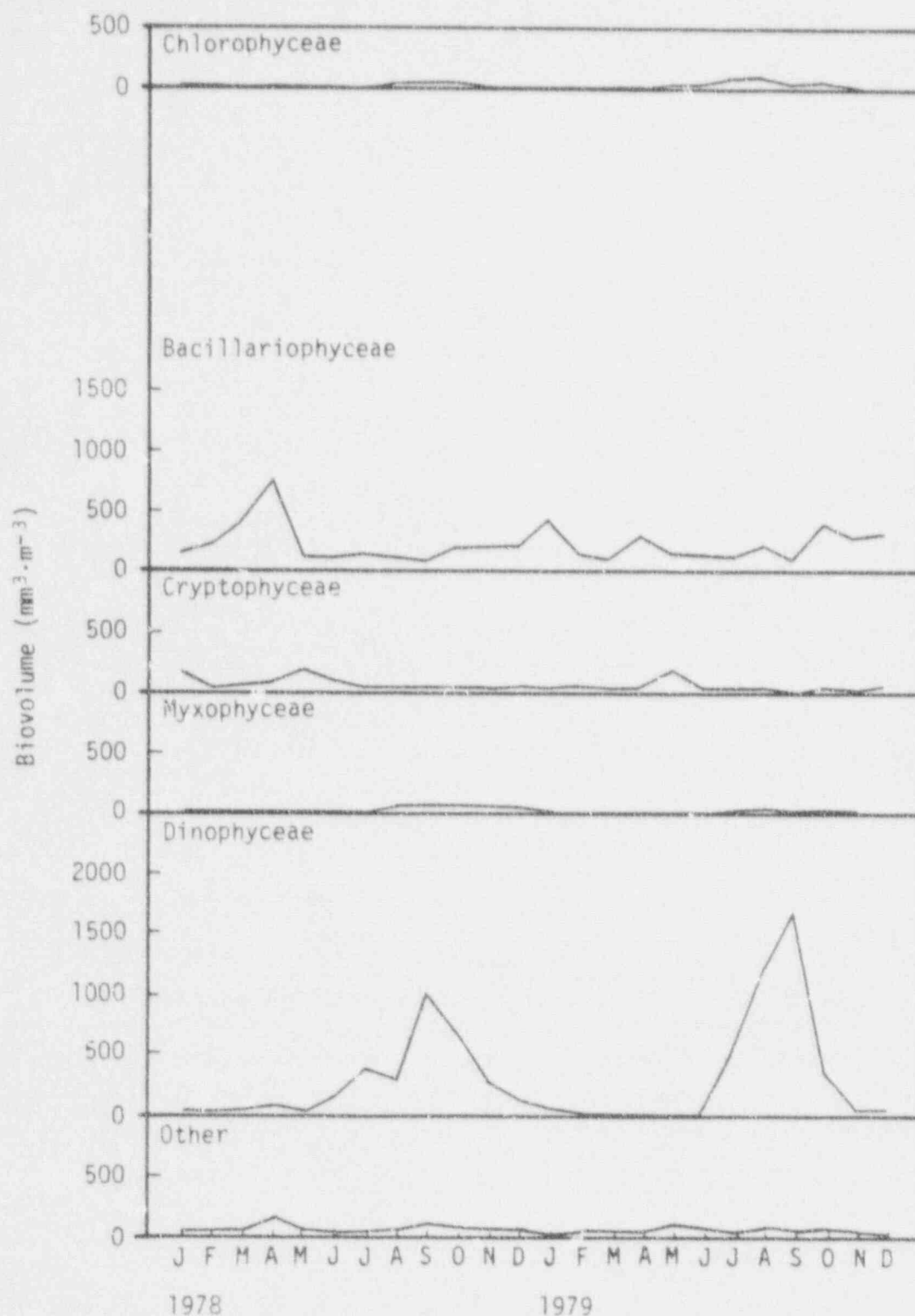


Figure 4-13c. Biovolume (mm³·m⁻³) of major taxonomic classes of phytoplankton in surface waters at Location 5.0, Lake Norman, January 1978 through December 1979.

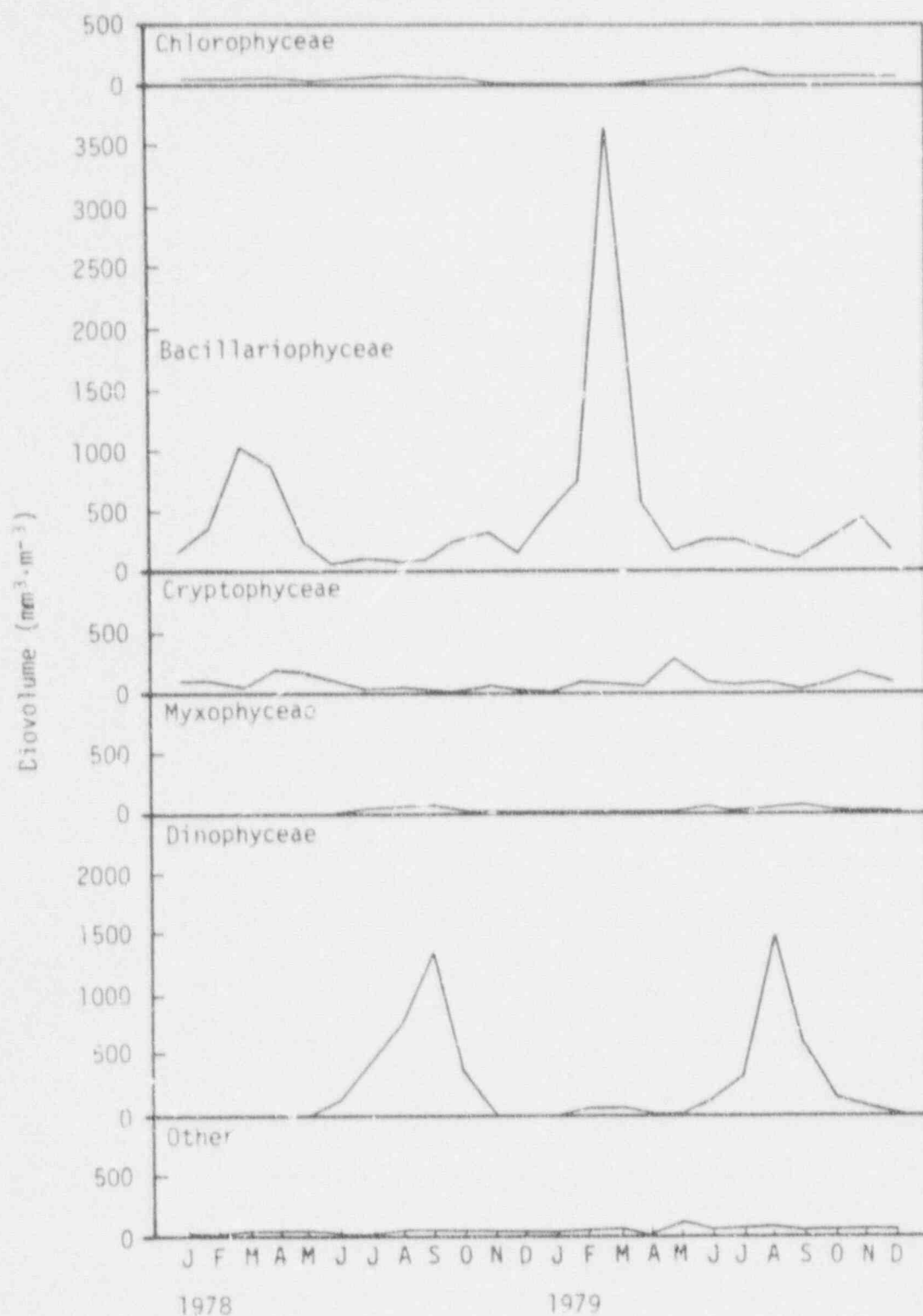


Figure 4-13d. Biovolume (mm³·m⁻³) of major taxonomic classes of phytoplankton in surface waters at Location 8.0, Lake Norman, January 1978 through December 1979.

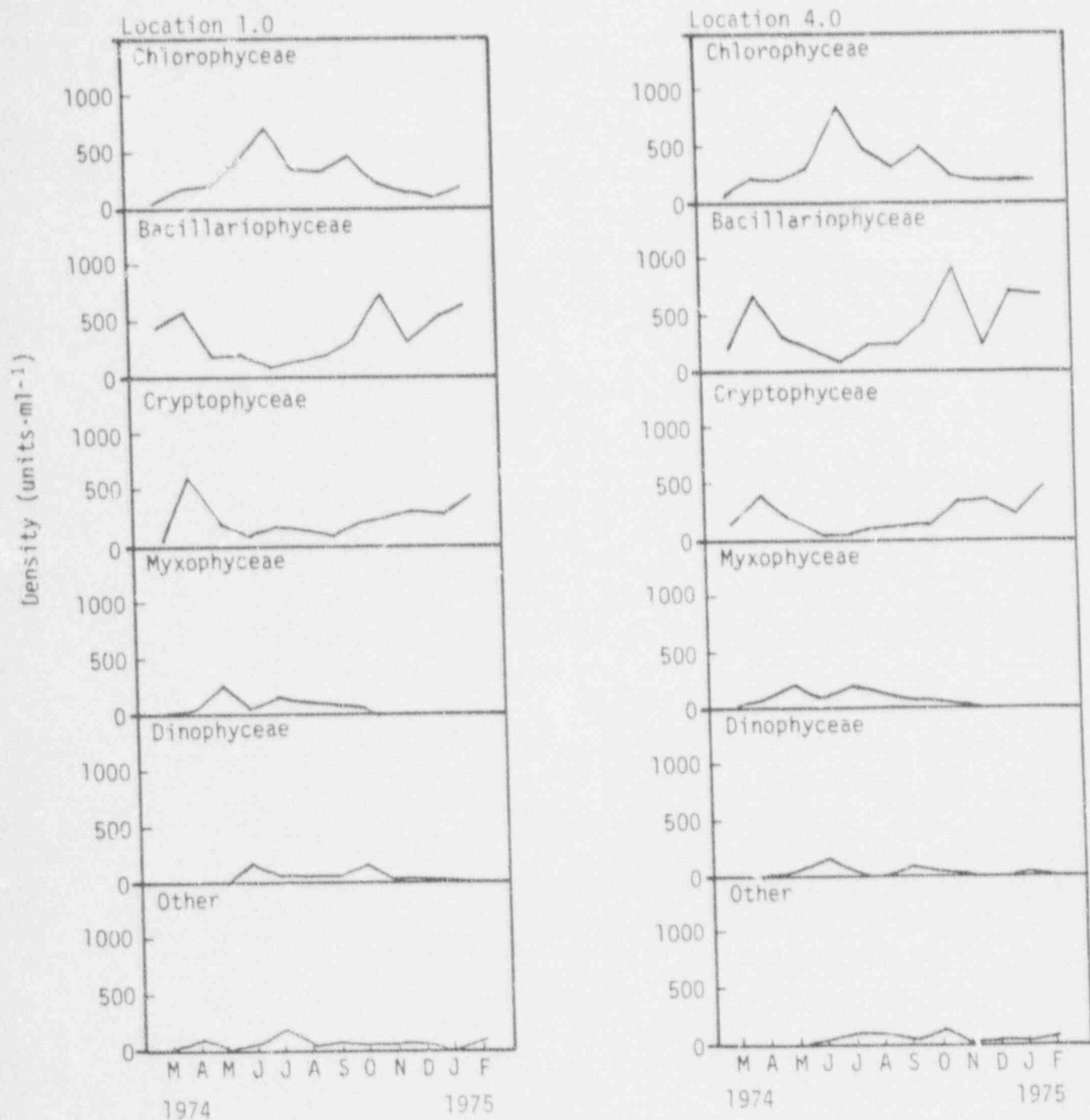


Figure 4-14a. Density (units·ml⁻¹) of major taxonomic classes of phytoplankton in surface waters at Locations 1.0 and 4.0, Lake Norman, March 1974 through February 1975.

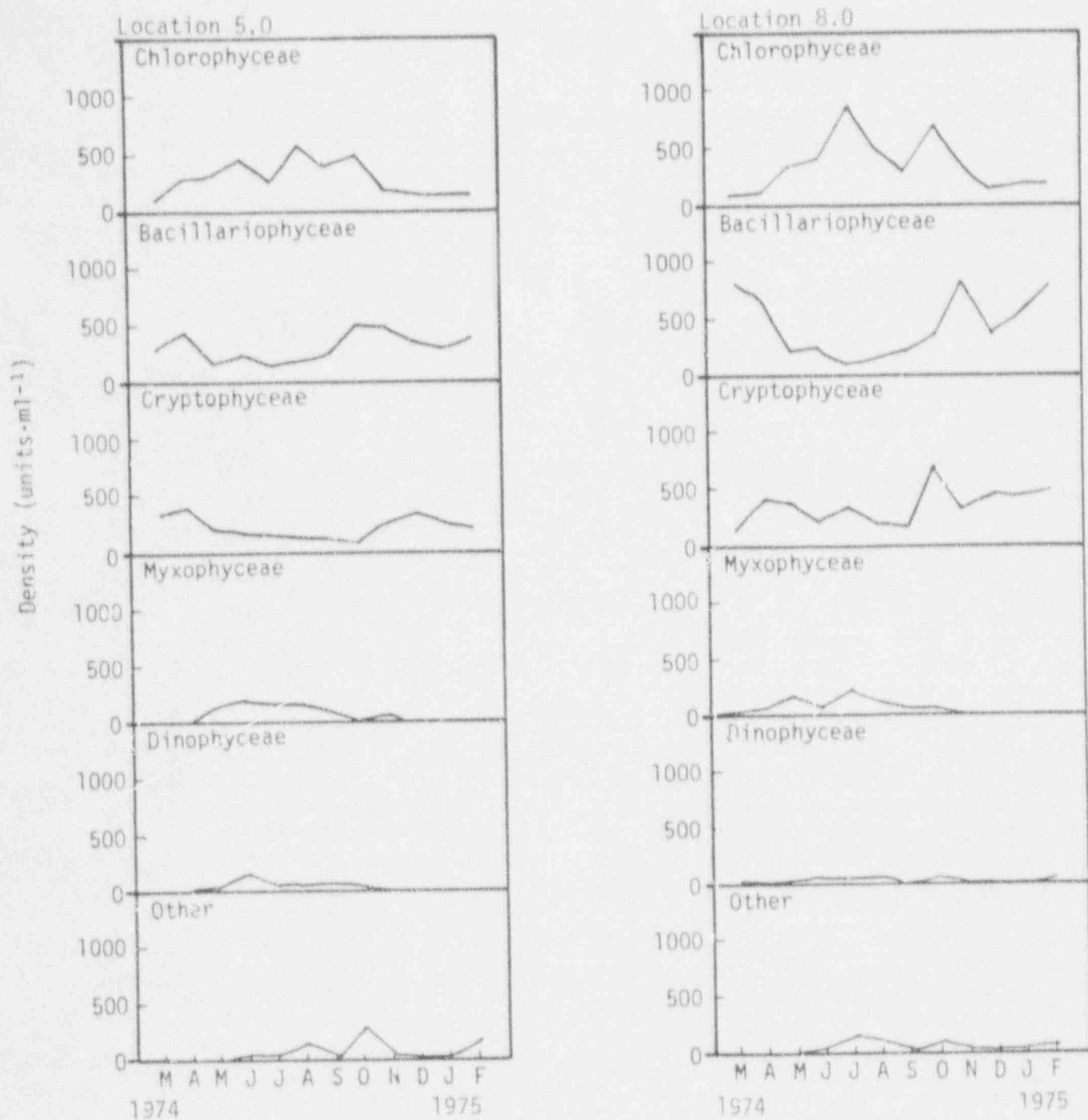


Figure 4-14b. Density (unit·ml⁻¹) of major taxonomic classes of phytoplankton in surface waters at Locations 5.0 and 8.0, Lake Norman, March 1974 through February 1975.

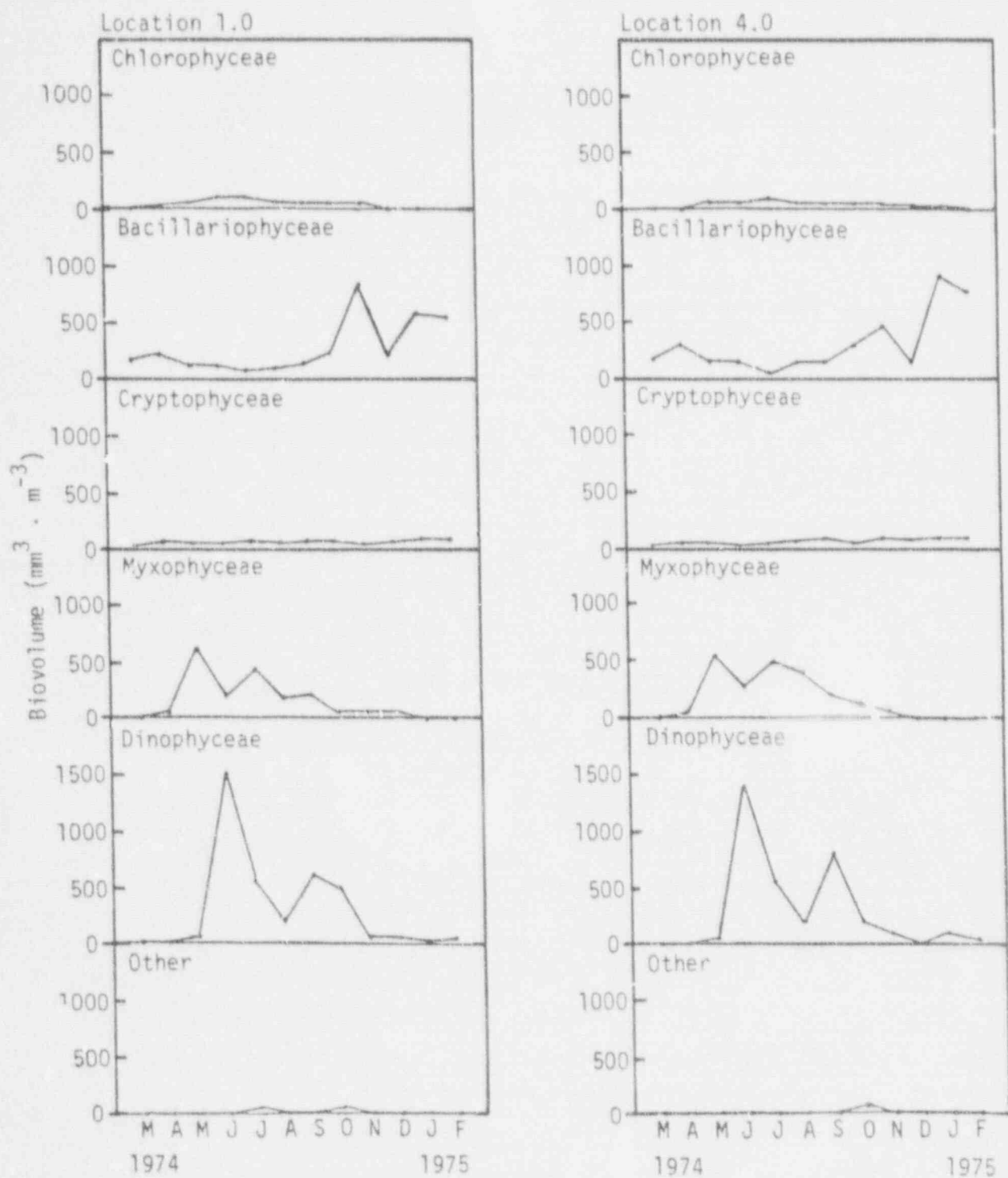


Figure 4-15a. Biovolume (mm³ · m⁻³) of major taxonomic classes of phytoplankton in surface waters at Locations 1.0 and 4.0, Lake Norman, March 1974 through February 1975.

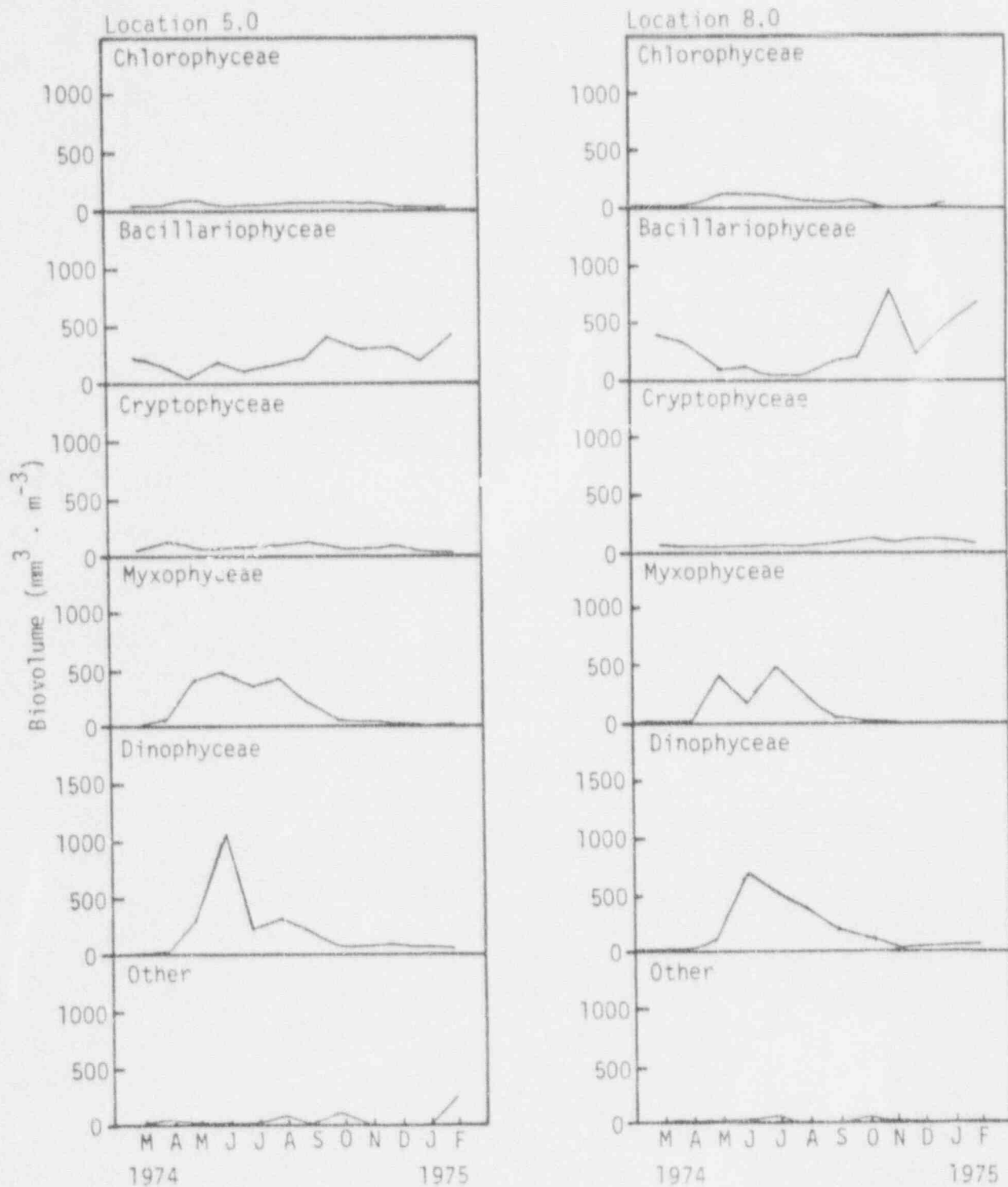


Figure 4-15b. Biovolume ($\text{mm}^3 \cdot \text{m}^{-3}$) of major taxonomic classes of phytoplankton in surface waters at Locations 5.0 and 8.0, Lake Norman, March 1974 through February 1975.

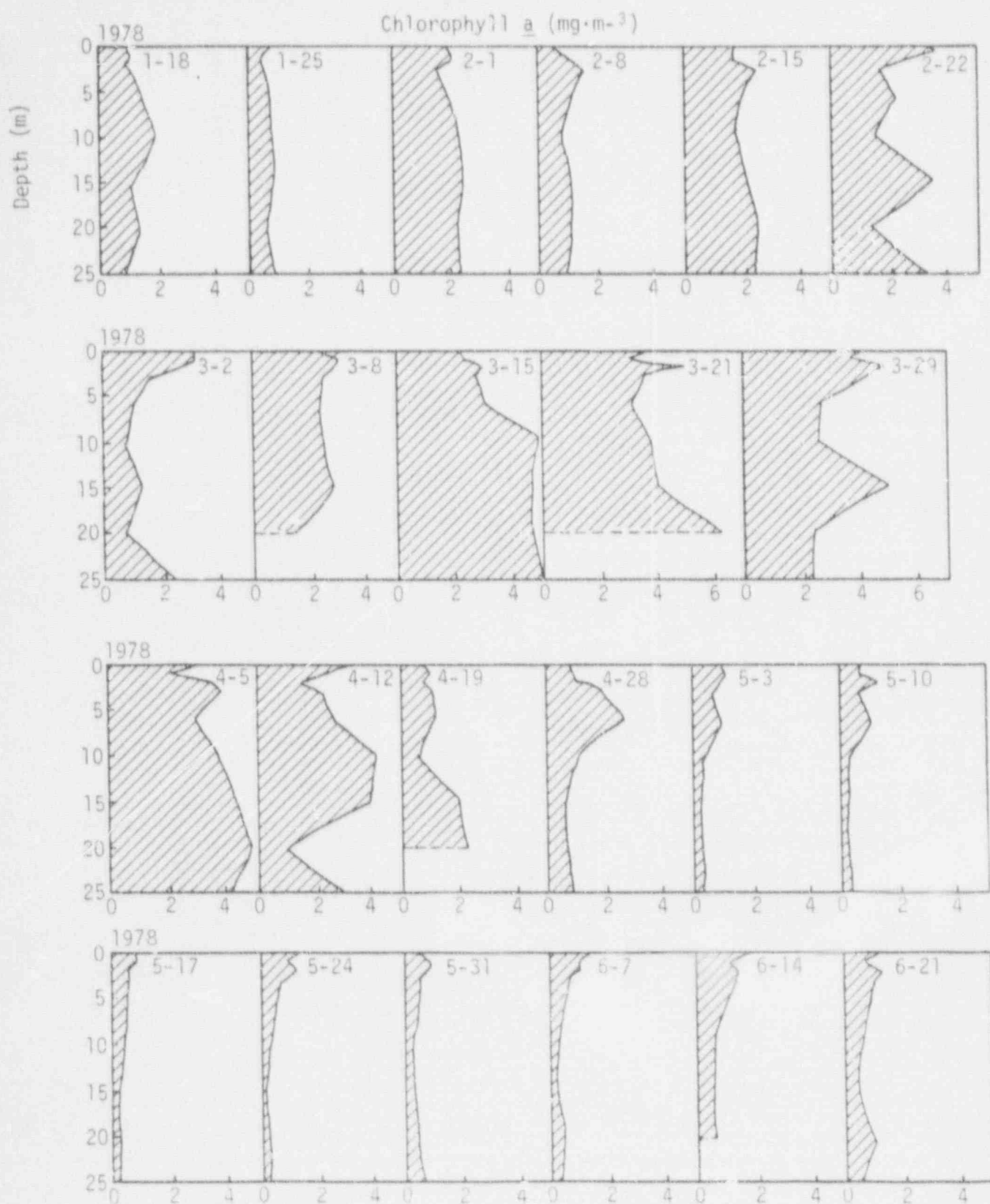


Figure 4-16. Vertical distribution of chlorophyll *a* ($\text{mg}\cdot\text{m}^{-3}$) at Location 3.0 on Lake Norman, January 18, 1978 through January 10, 1979. Numbers in each cell represent month-day.

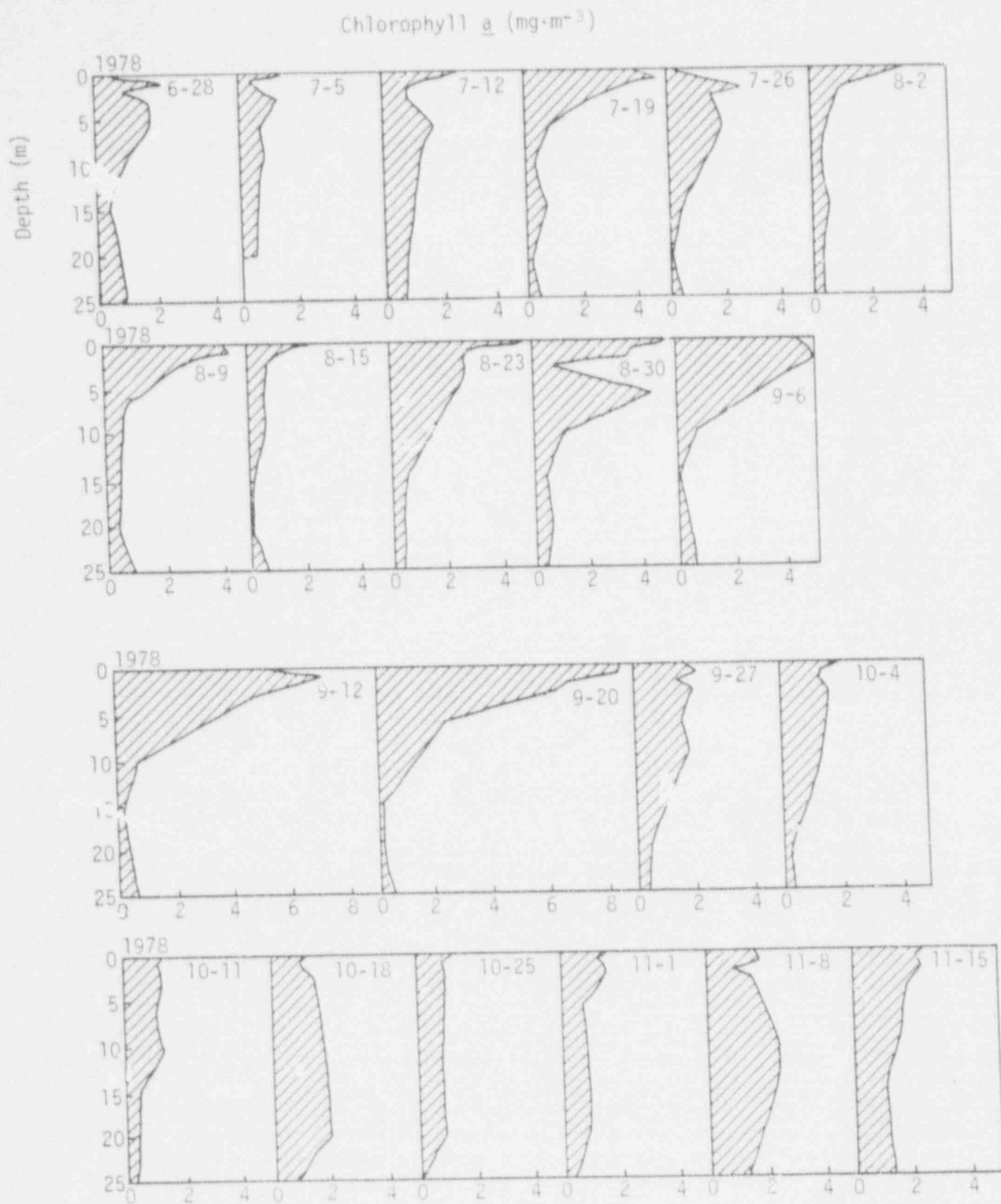


Figure 4-16 (continued)

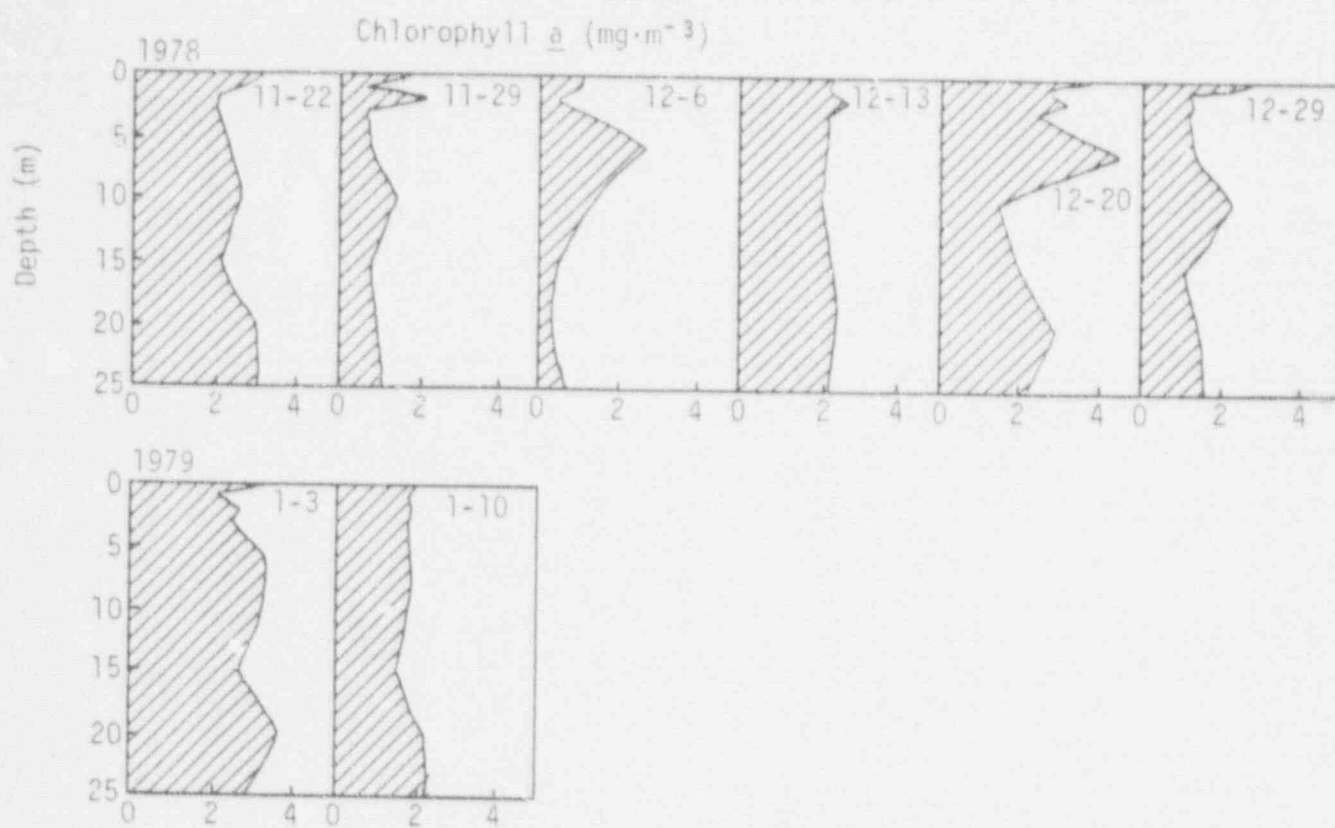


Figure 4-16 (continued)

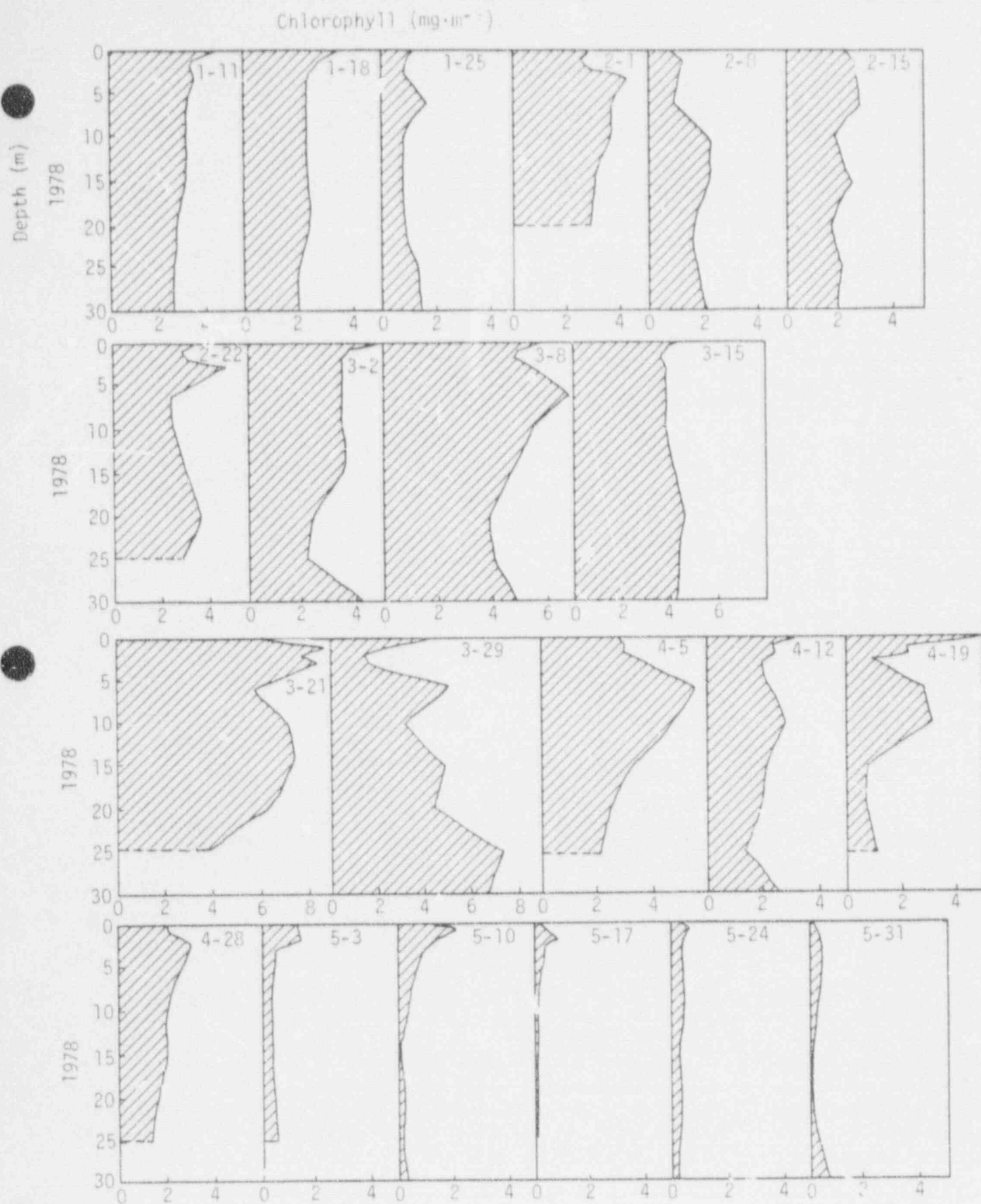


Figure 4-17. Vertical distribution of chlorophyll a ($\text{mg} \cdot \text{m}^{-3}$) at Location 8.0 on Lake Norman, January 11, 1978 through January 10, 1979. Numbers in each cell represent month-day.

Chlorophyll ($\text{mg} \cdot \text{m}^{-3}$)

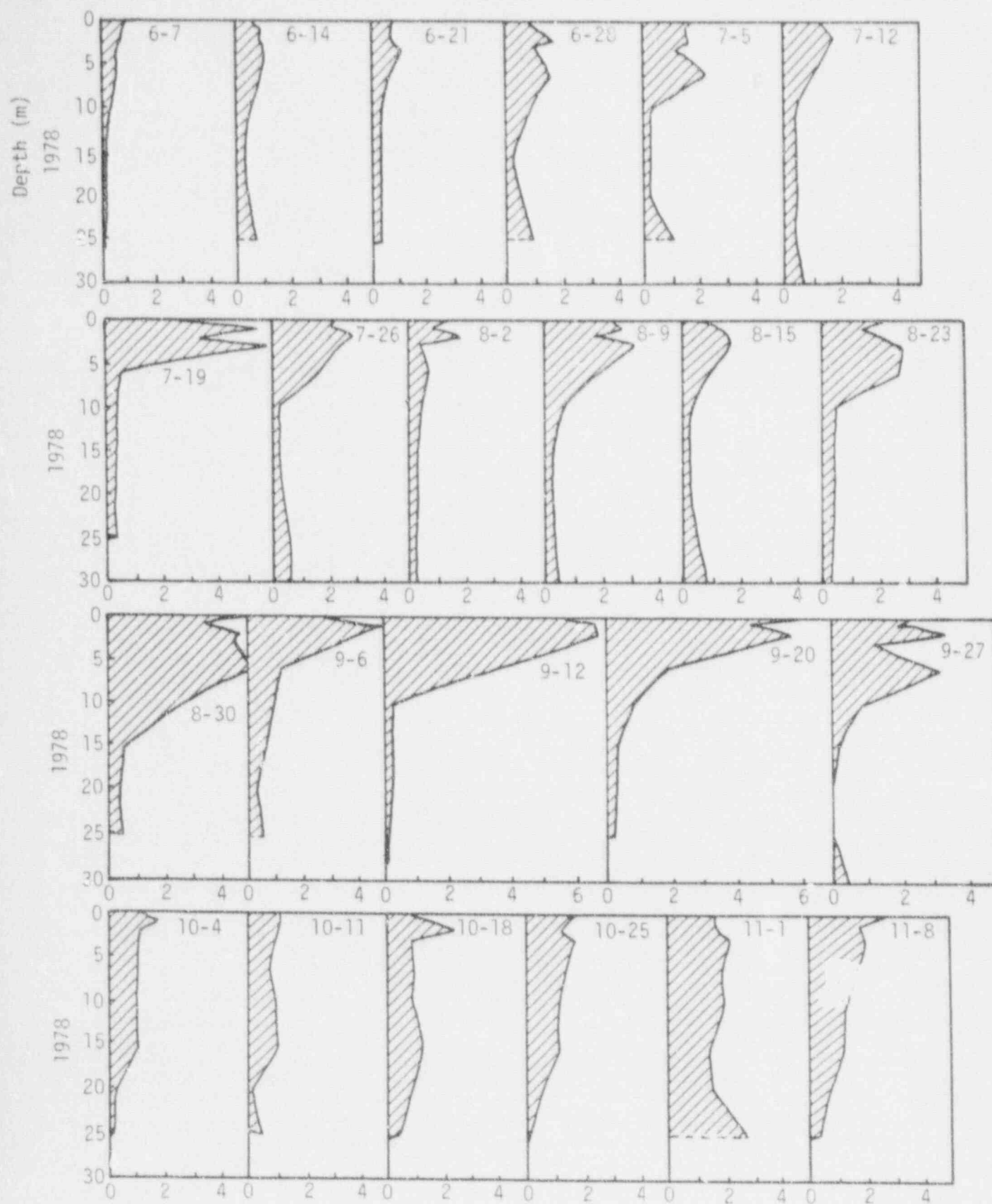


Figure 4-17 (continued)

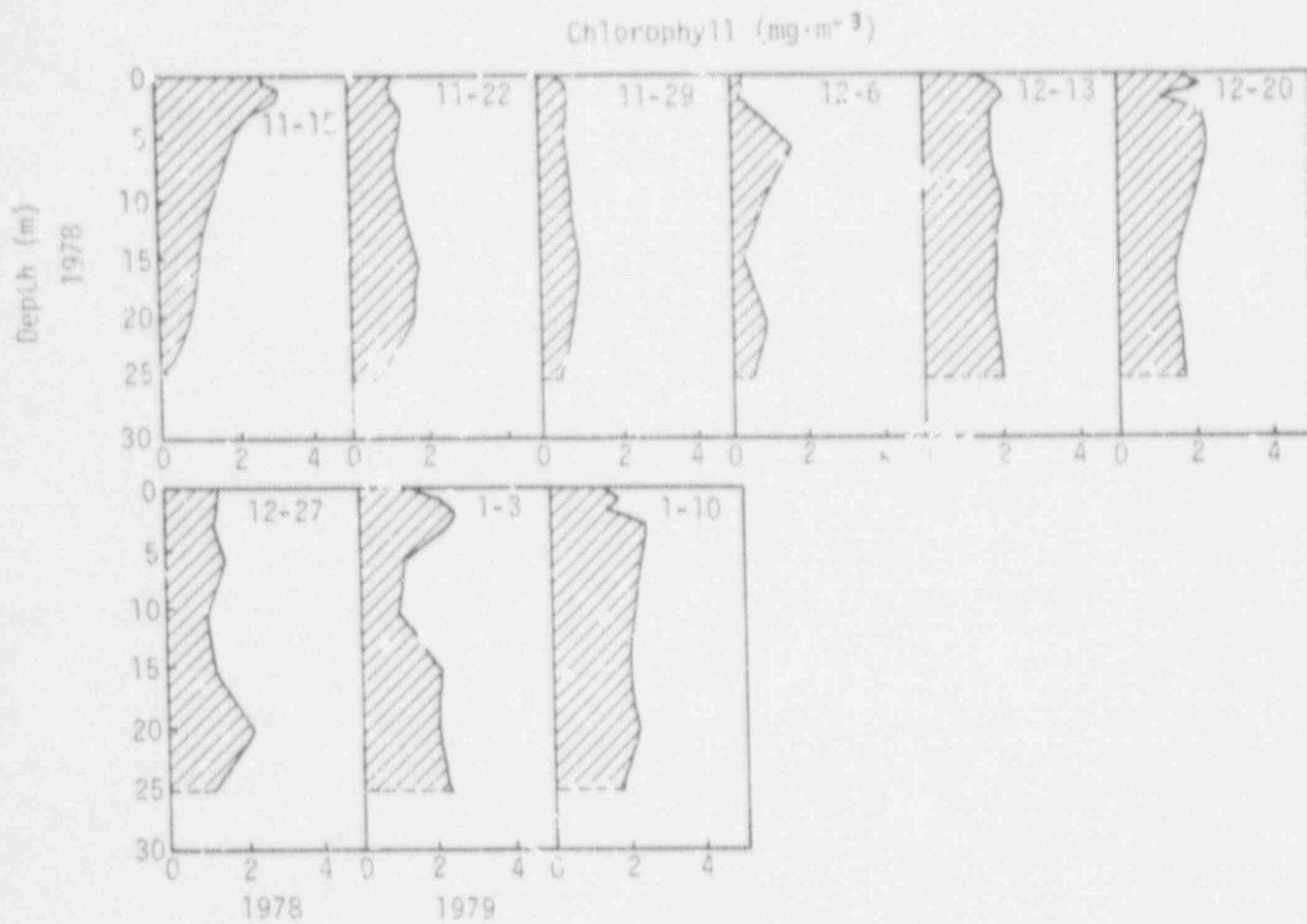


Figure 4-17 (continued)

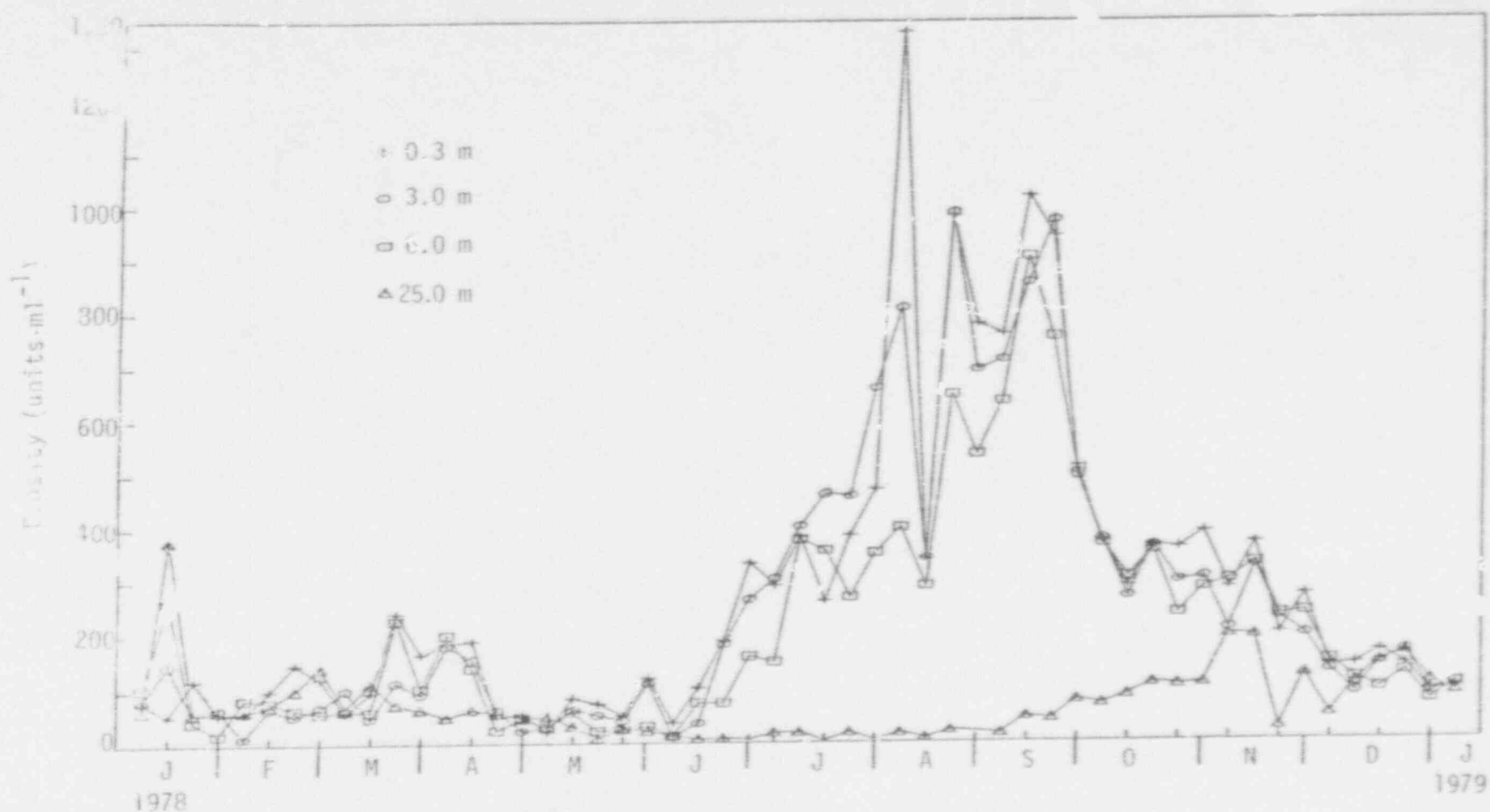


Figure 4-18a. The vertical distribution of the Chlorophyceae, in terms of density, at Location 8.0, Lake Norman, January 11, 1978 through January 10, 1979.

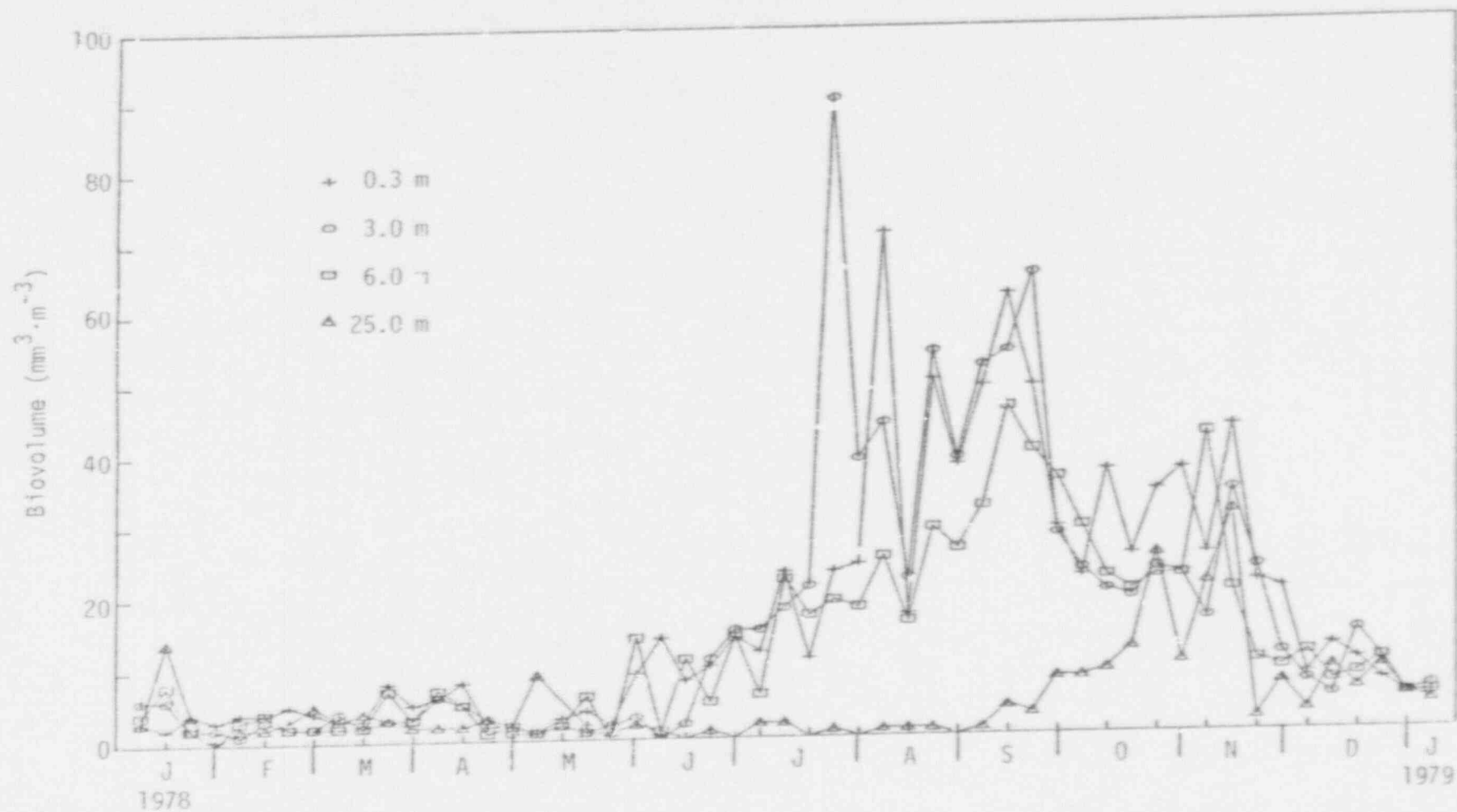


Figure 4-18b. The vertical distribution of the Chlorophyceae, in terms of biovolume, at Location 8.0, Lake Norman, January 11, 1978 through January 10, 1979.

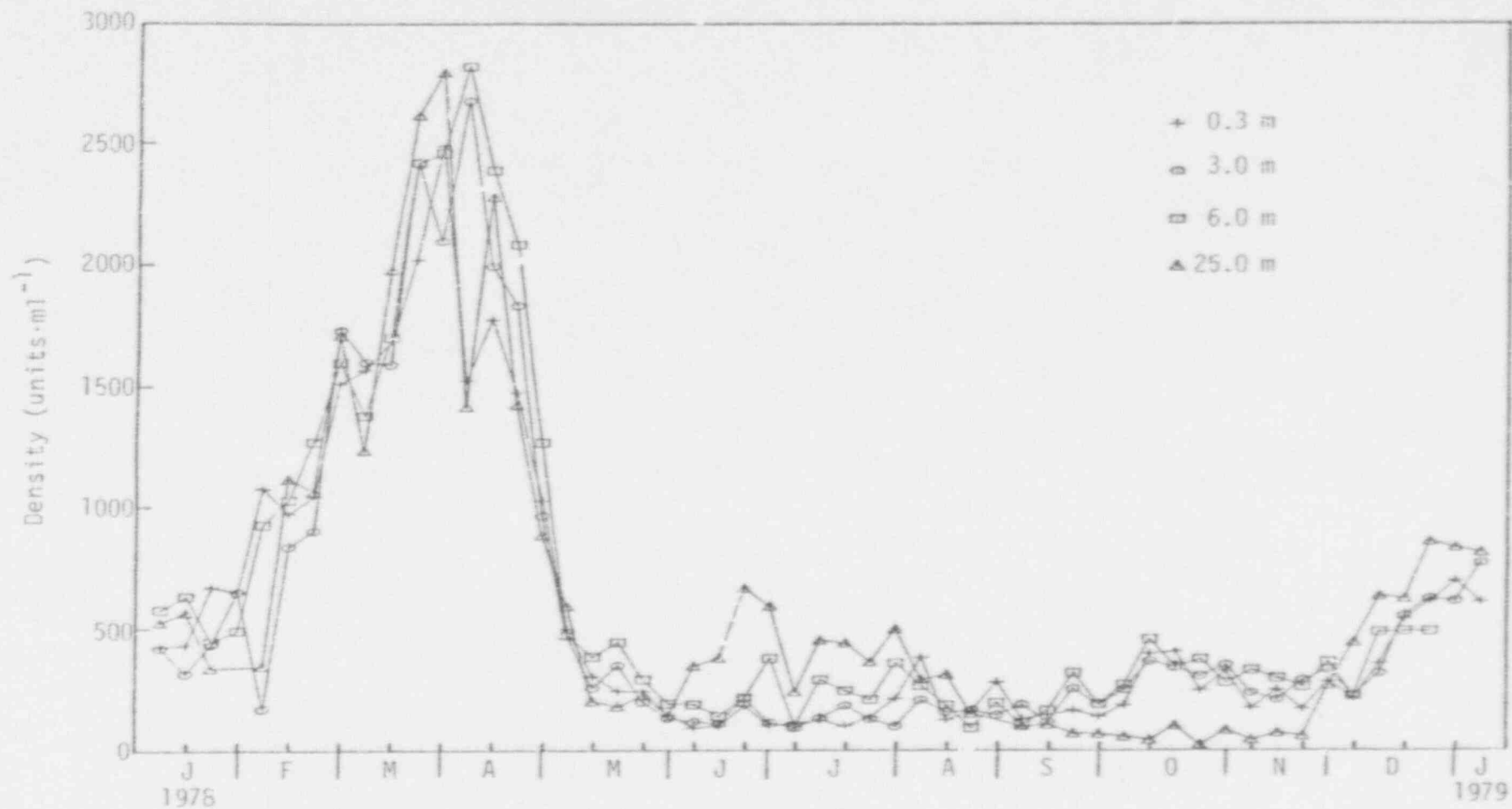
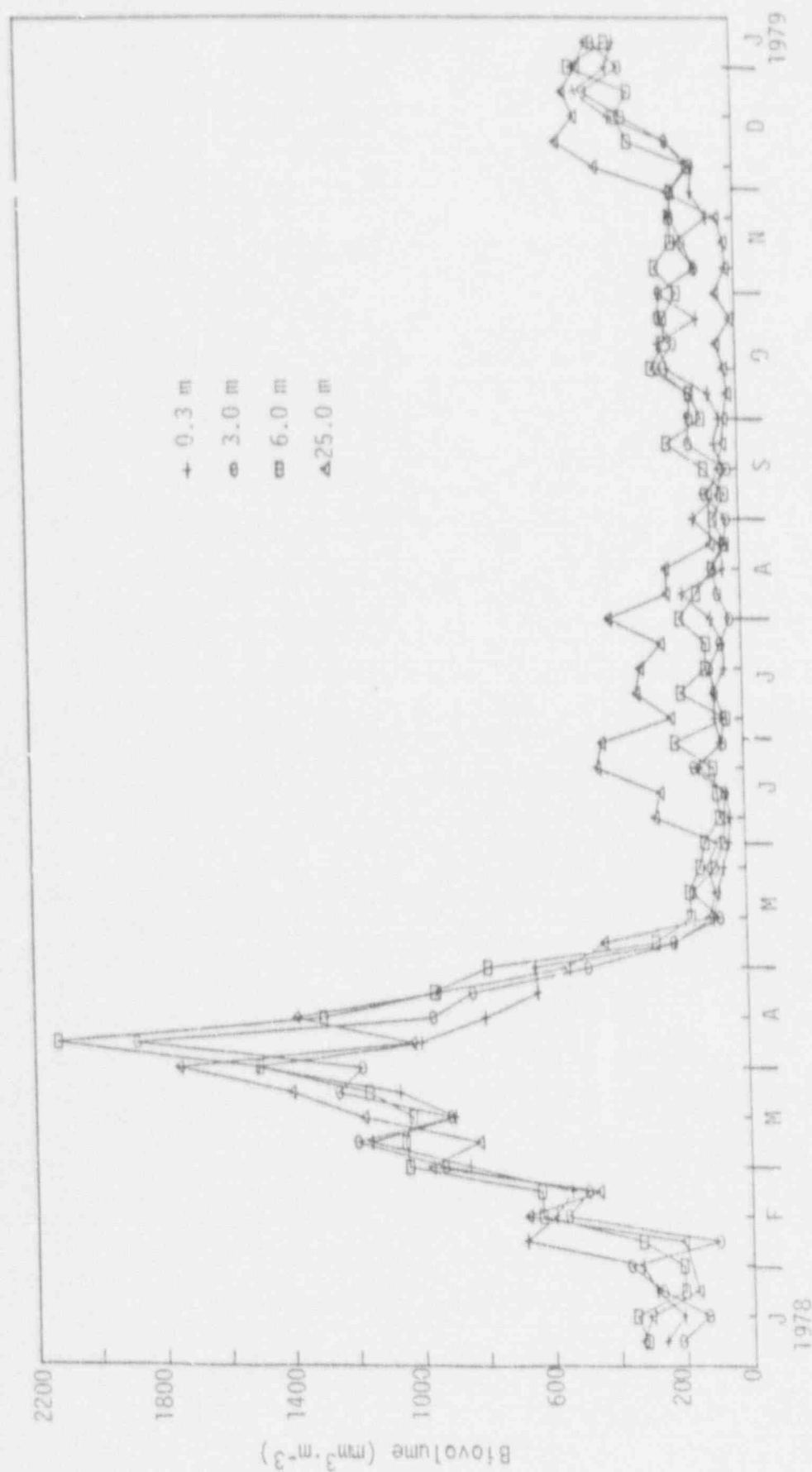


Figure 4-19a. The vertical distribution of the Bacillariophyceae, in terms of density, at Location 8.0, Lake Norman, January 11, 1978 through January 10, 1979.



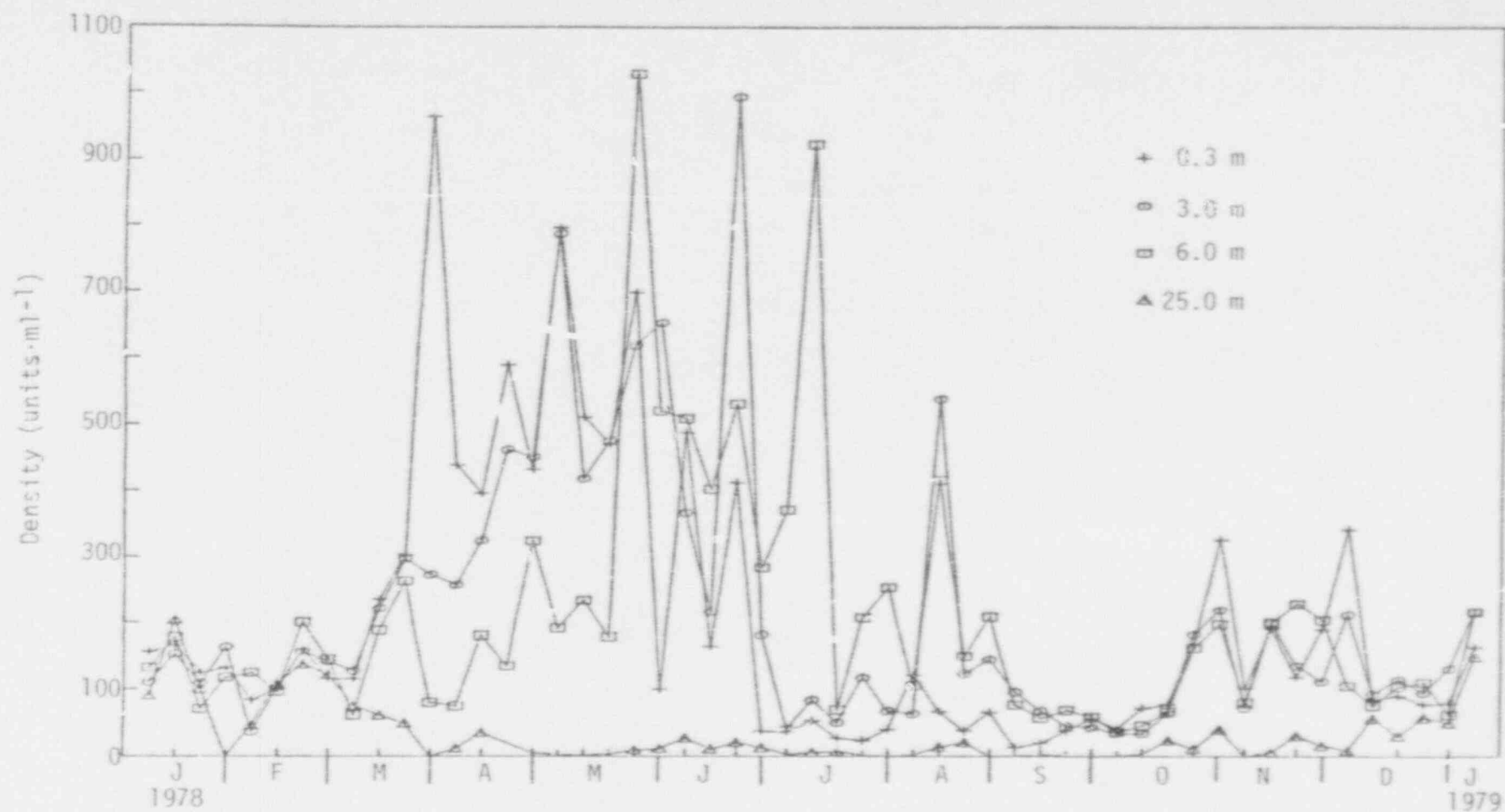


Figure 4-20a. The vertical distribution of the Cryptophyceae, in terms of density, at Location 8.0, Lake Norman, January 11, 1978 through January 10, 1979.

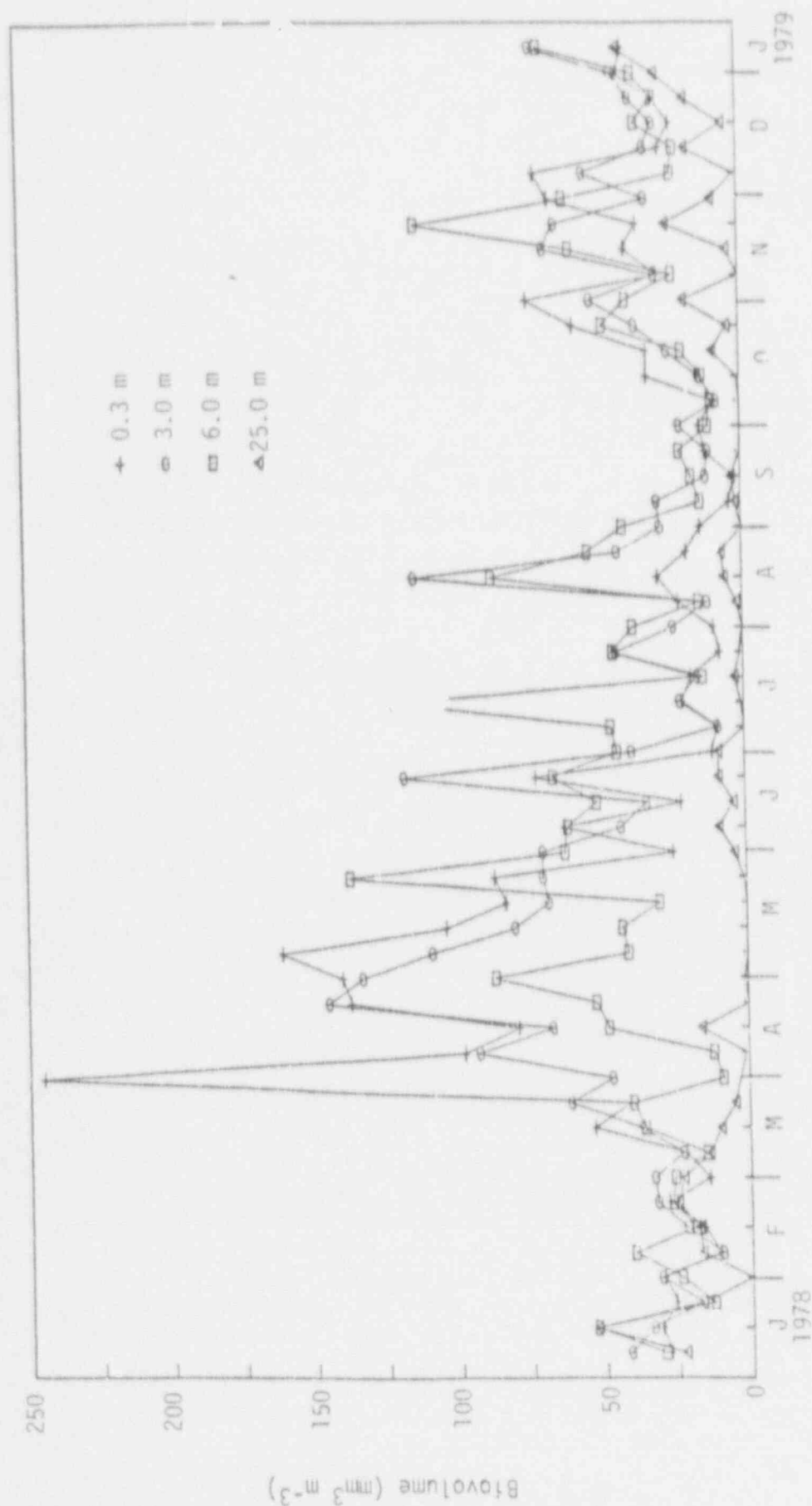


Figure 4-20b. The vertical distribution of the Cryptophyceae, in terms of biovolume, at Location 8.0, Lake Norman, January 11, 1978 through January 10, 1979.

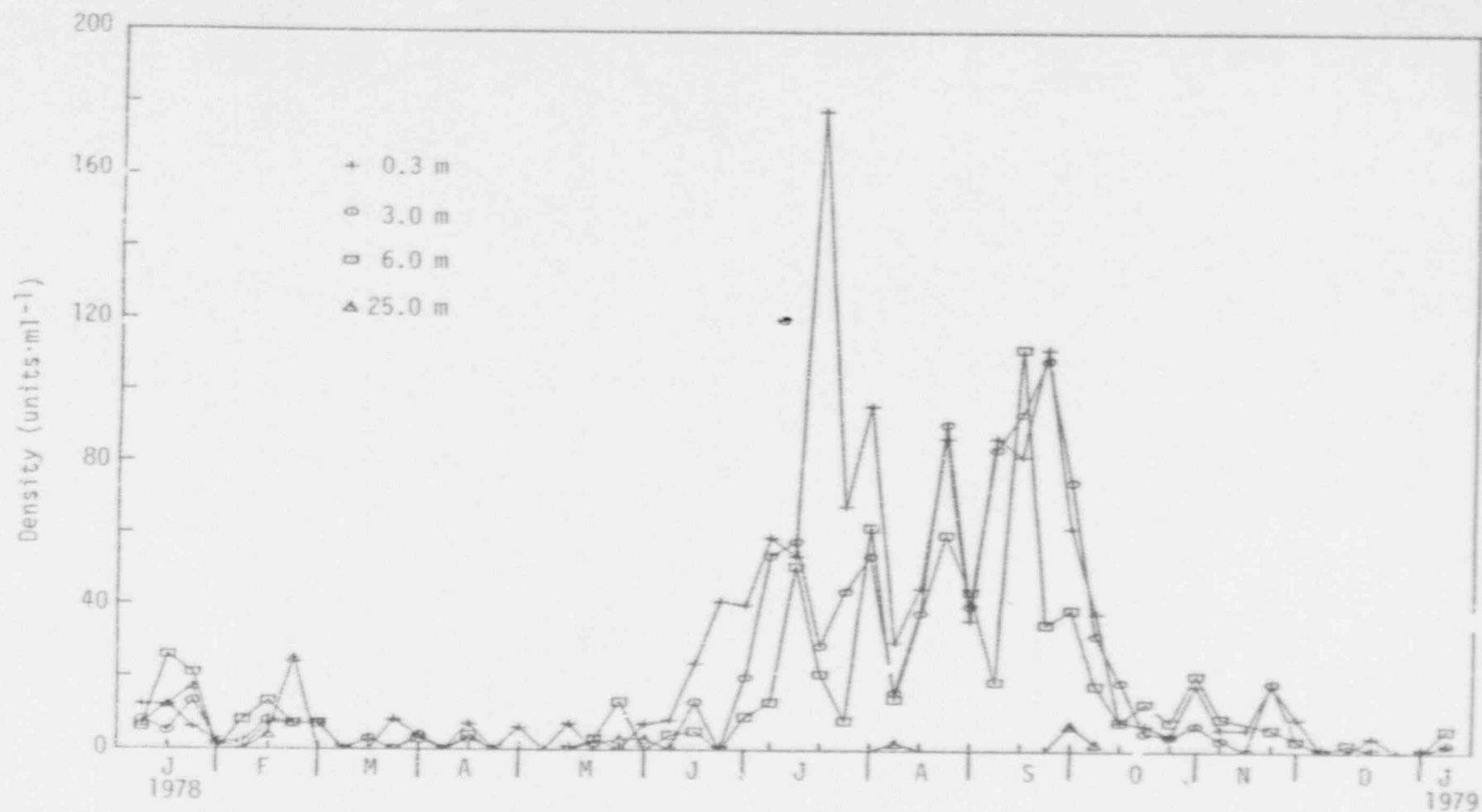


Figure 4-21a. The vertical distribution of the Dinophyceae, in terms of density, at Location 8.0, Lake Norman, January 11, 1978 through January 10, 1979.

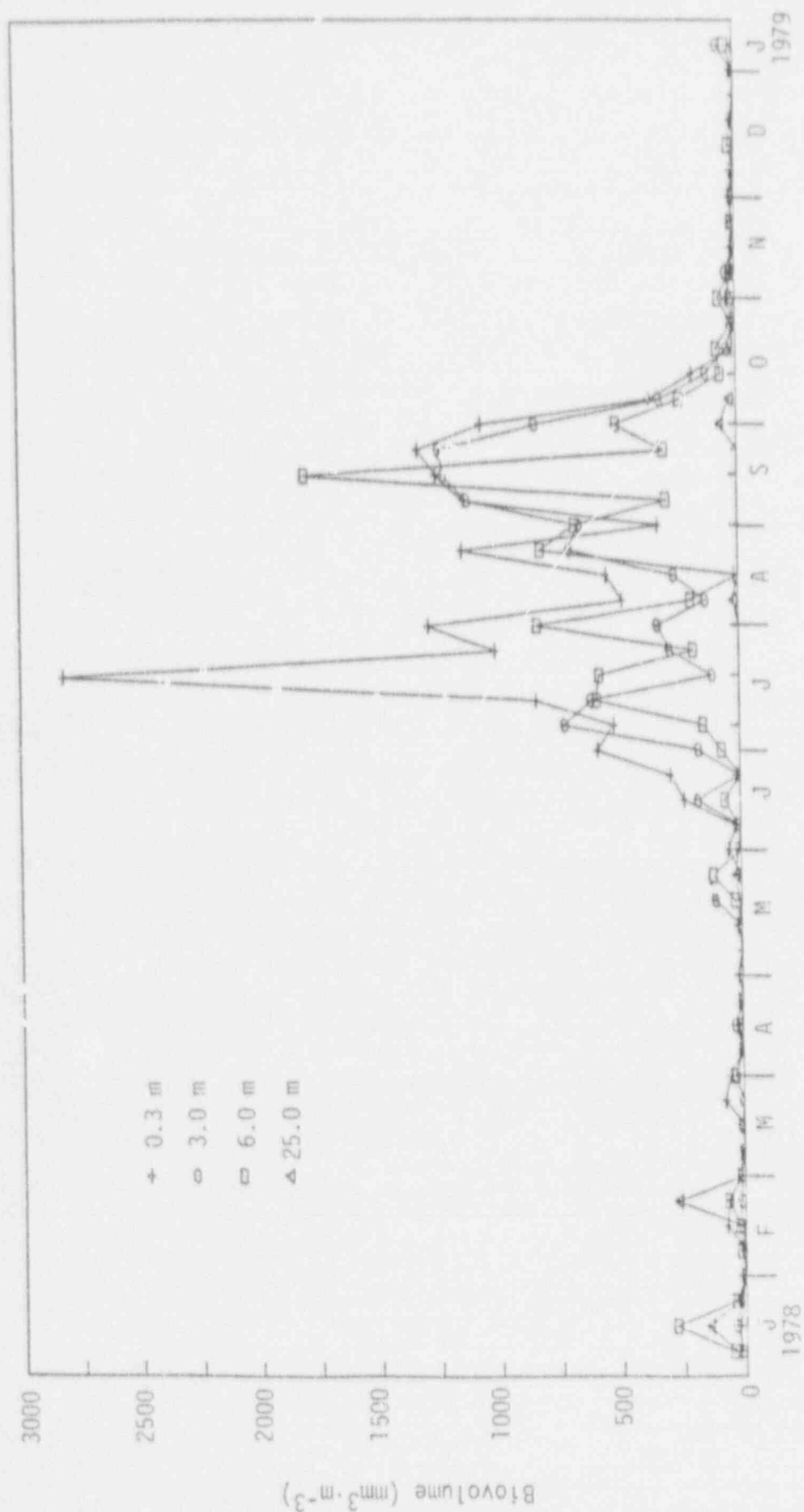


Figure 4-21b. The vertical distribution of the Dinophyceae, in terms of biovolume, at Location 8.0, Lake Norman, January 11, 1978 through January 10, 1979.

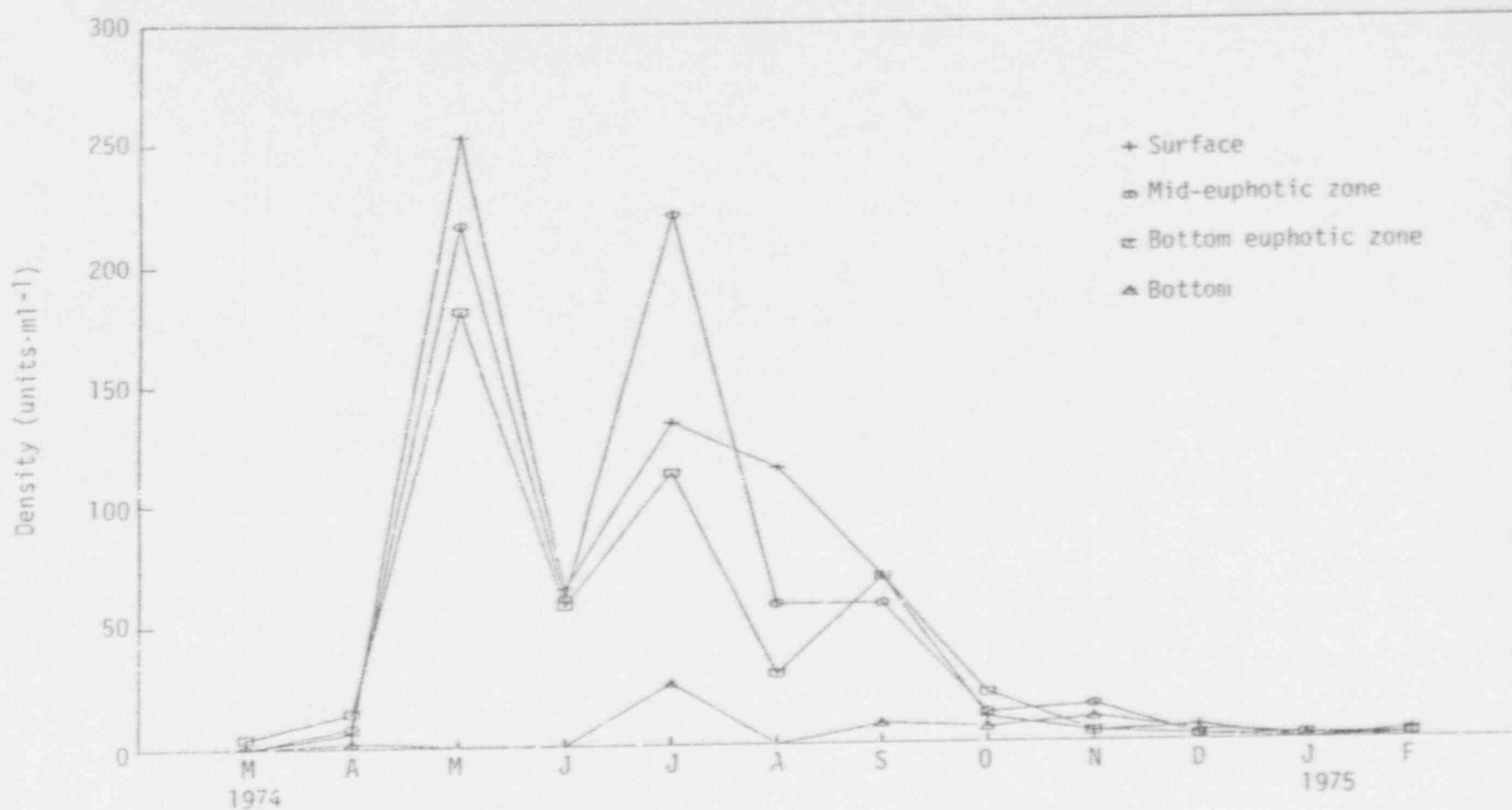


Figure 4-22. Vertical distribution of the Myxophyceae, in terms of density, at Location 1.0, Lake Norman, March 1974 through February 1975.

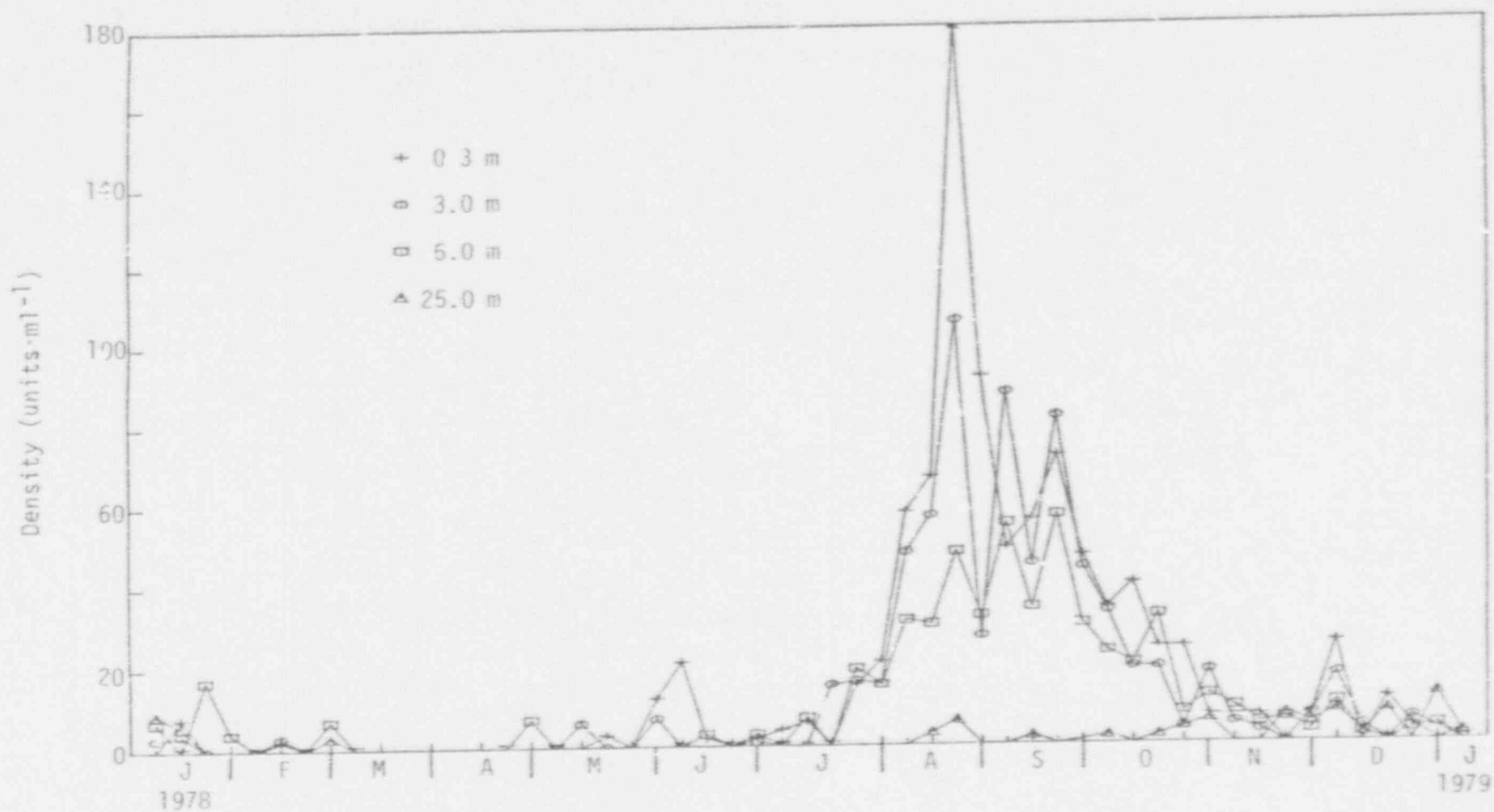


Figure 4-23a. The vertical distribution of the Myxophyceae, in terms of density, at Location 8.0, Lake Ilorman, January 11, 1978 through January 10, 1979.

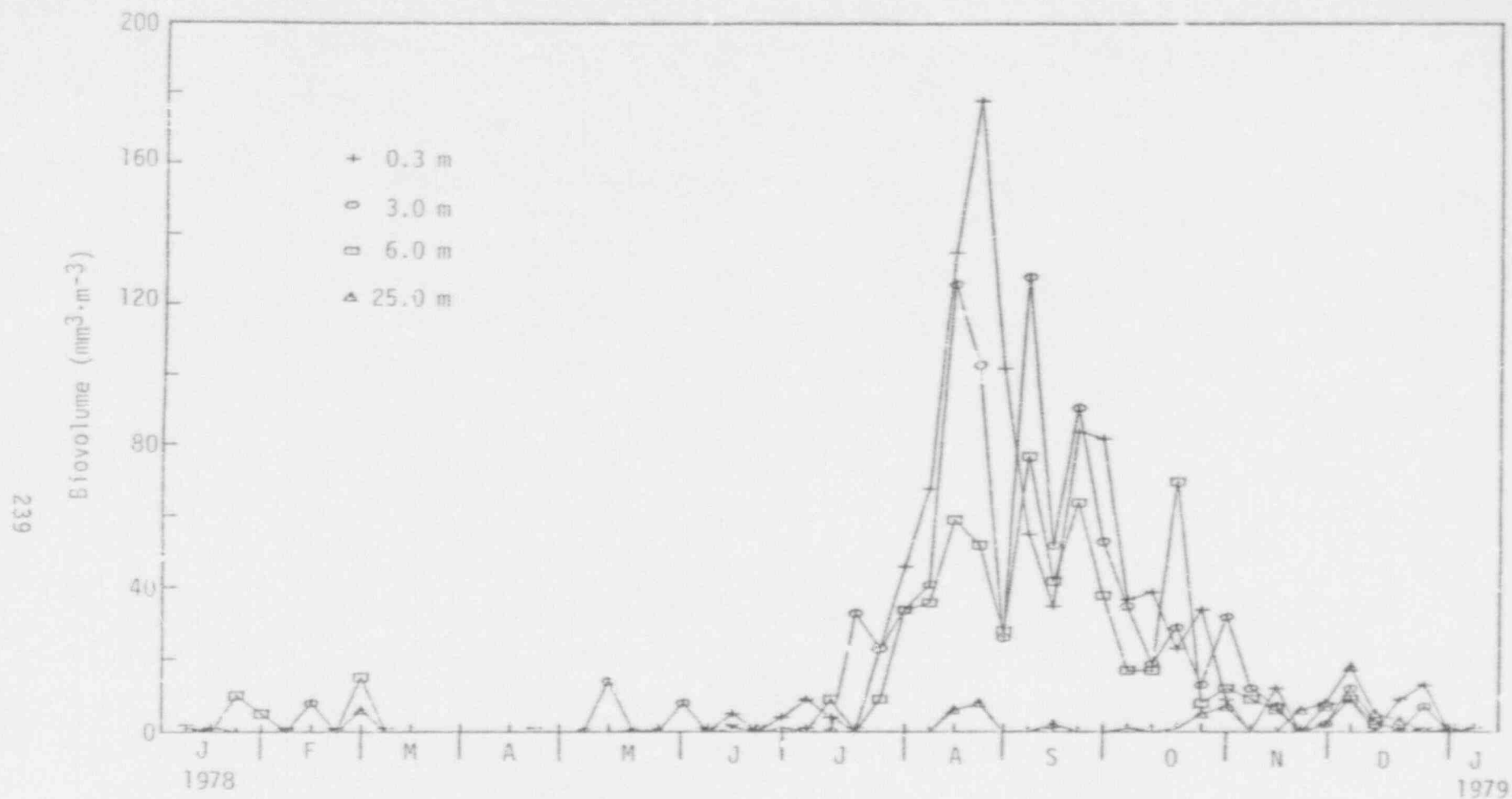


Figure 4-23b. The vertical distribution of the Myxophyceae, in terms of biovolume, at Location 8.0, Lake Herman, January 11, 1978 through January 10, 1979.

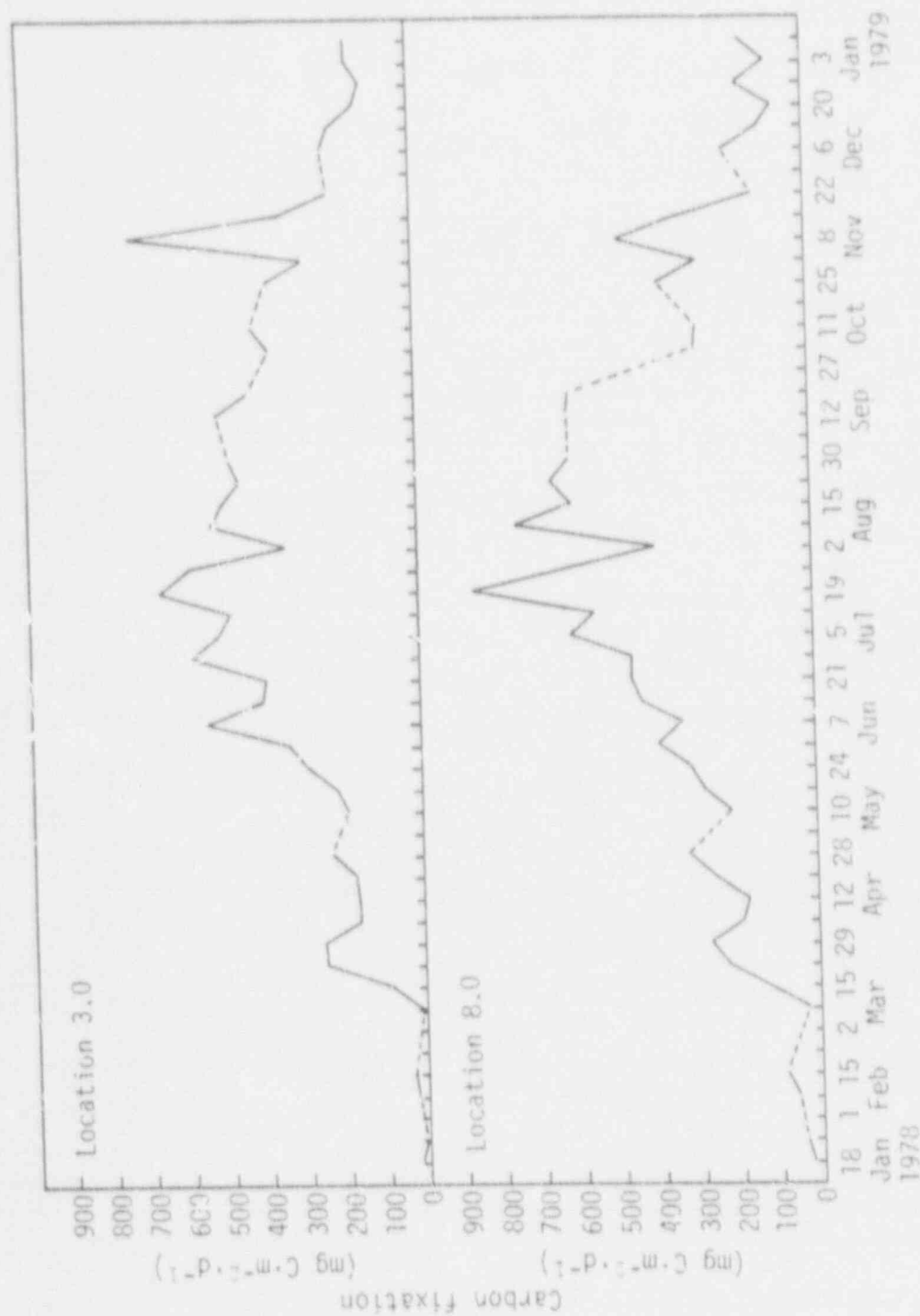


Figure 4-24. Daily carbon fixation rates (mg C·m⁻²·d⁻¹) on Lake Norman, January 18, 1978 through January 10, 1979. Broken line indicates an interval of two weeks or more between observations.

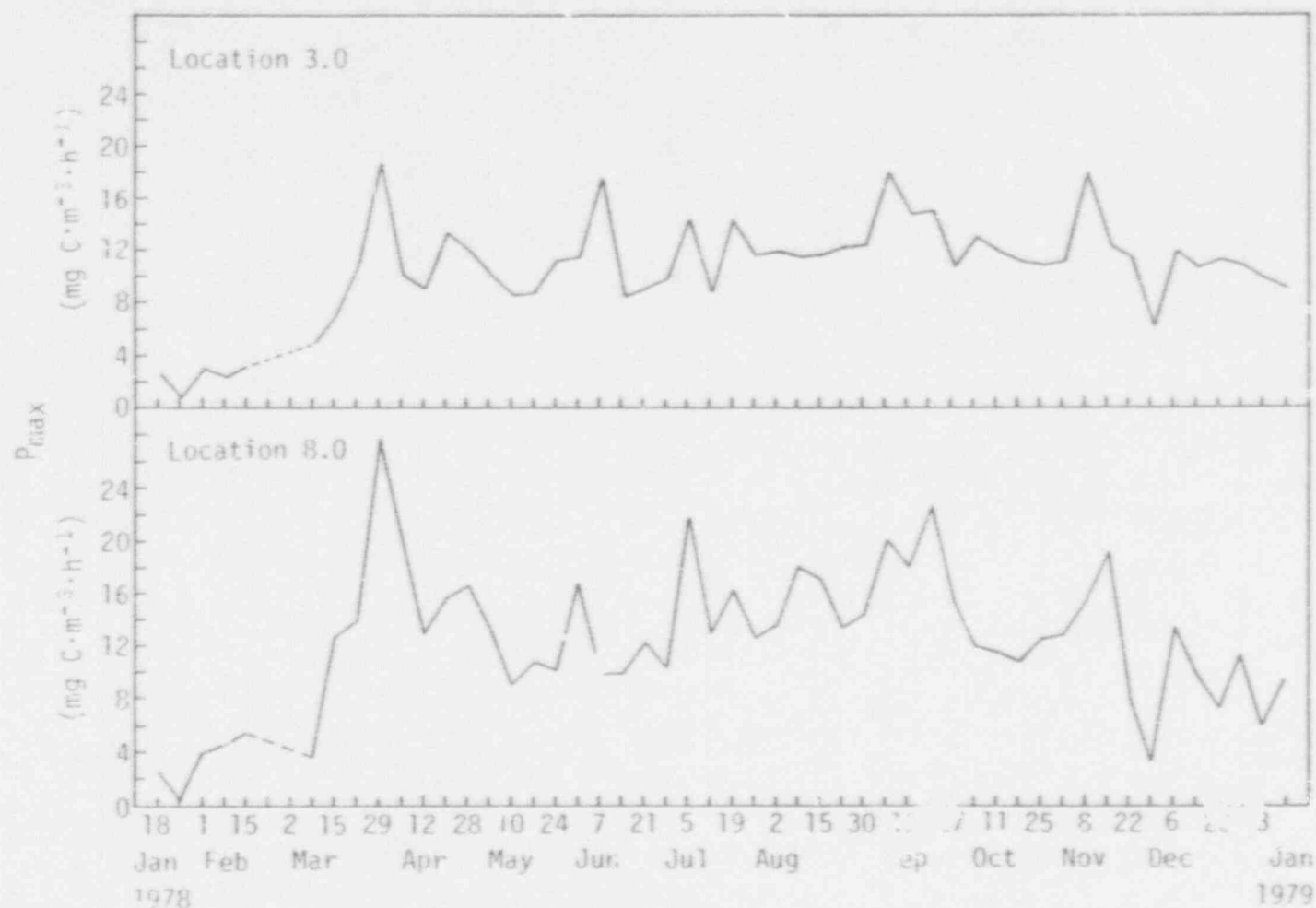


Figure 4-25. Maximum photosynthetic rates (P_{max}) ($\text{mg C} \cdot \text{m}^{-3} \cdot \text{h}^{-1}$) on Lake Norman, January 18, 1978 through January 10, 1979. Broken line indicates an interval of two weeks or more between observations.

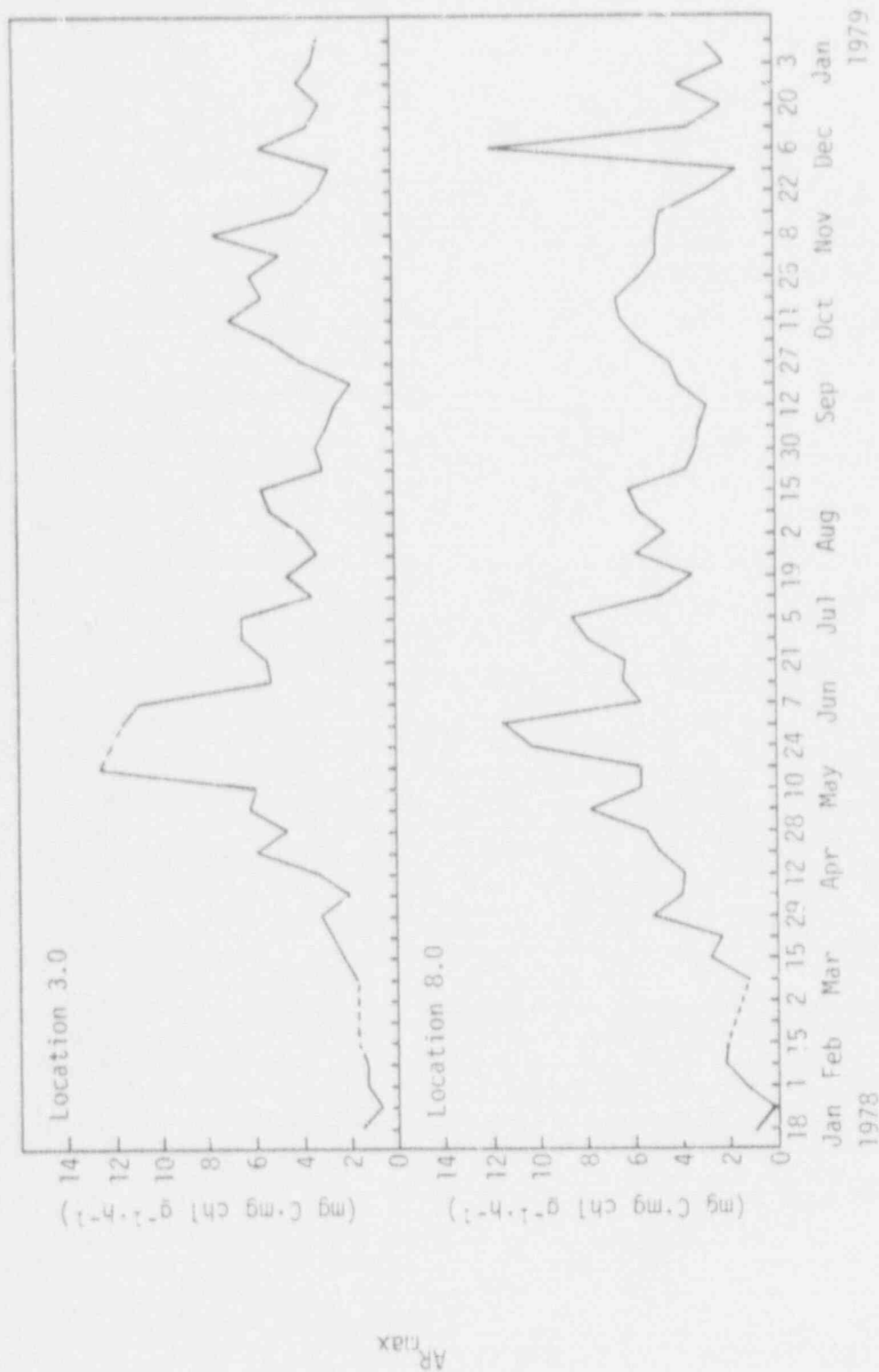


Figure 4-26. Maximum assimilation ratios (AR_{max}) (mg C·mg chl a^{-1} ·h $^{-1}$) on Lake Norman, January 18, 1978 through January 10, 1979. Broken line indicates an interval of two weeks or more between observations.

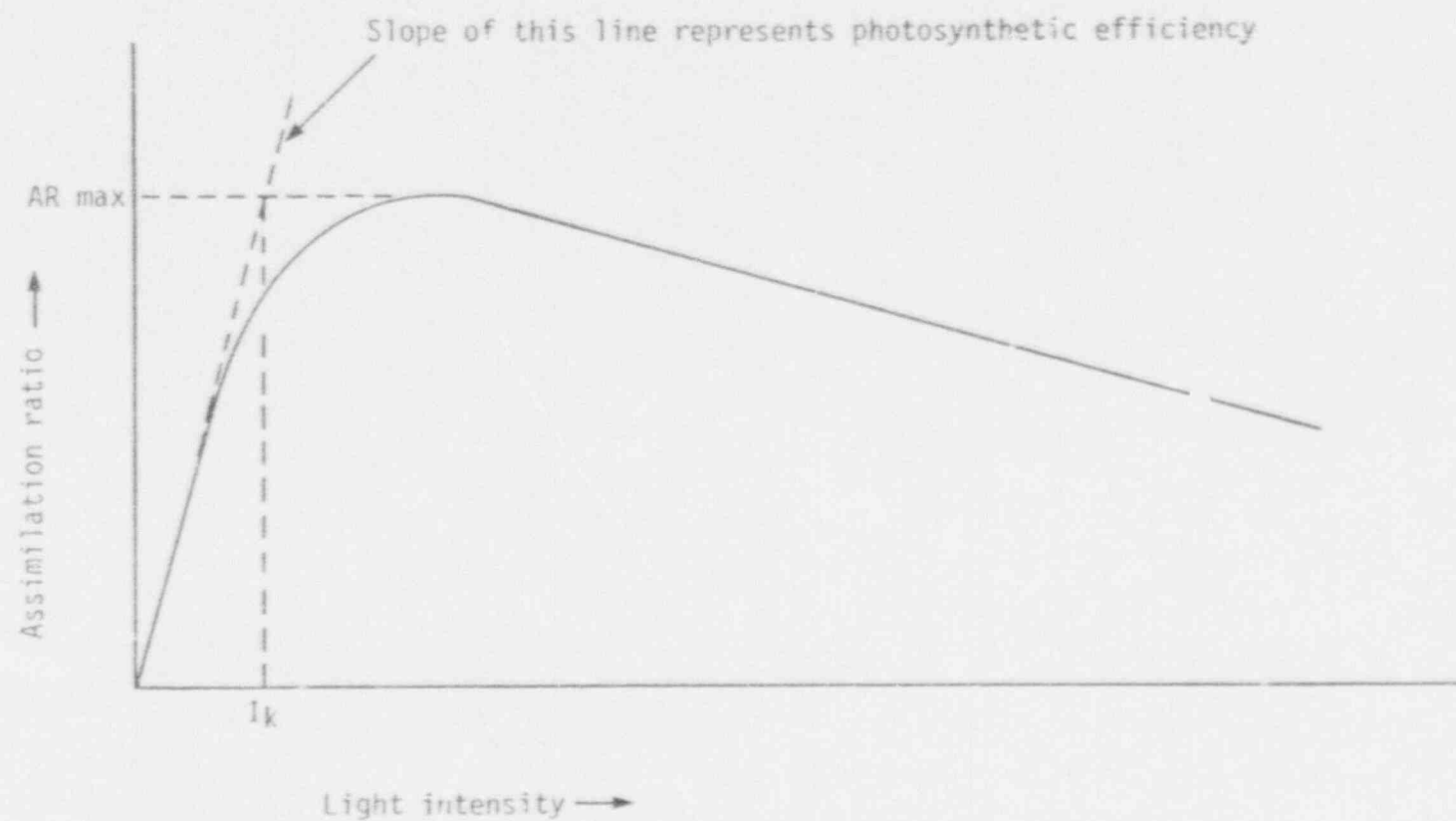


Figure 4-27. Example of a photosynthesis ($\text{mg C} \cdot \text{mg chl a}^{-1} \cdot \text{h}^{-1}$) vs. light ($\mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$) curve (P vs. I curve).

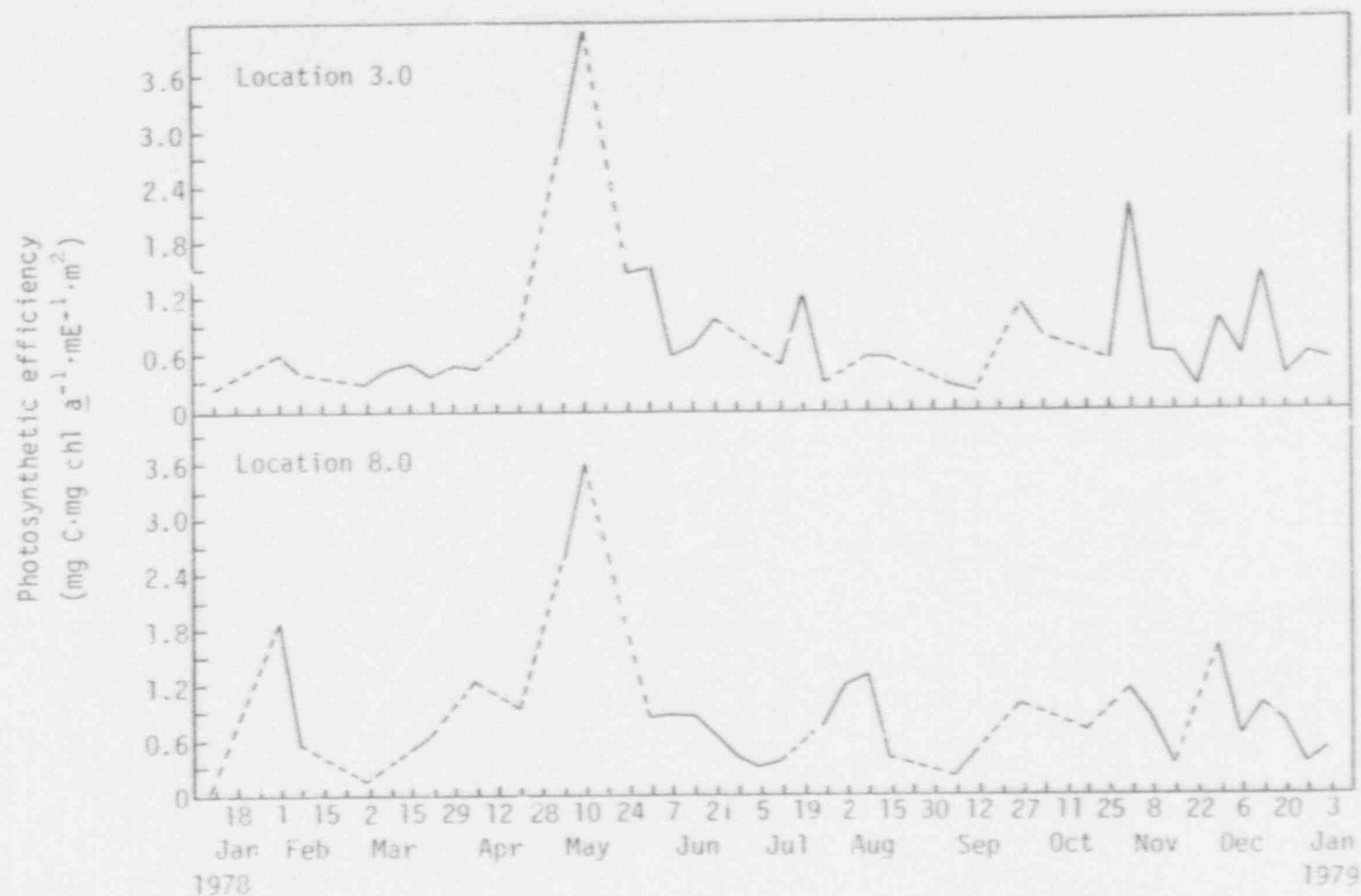


Figure 4-28. Photosynthetic efficiencies ($\text{mg C} \cdot \text{mg chl a}^{-1} \cdot \text{mE}^{-1} \cdot \text{m}^2$) on Lake Norman, January 18, 1978 through January 10, 1979. Broken line indicates an interval of two weeks or more between observations.

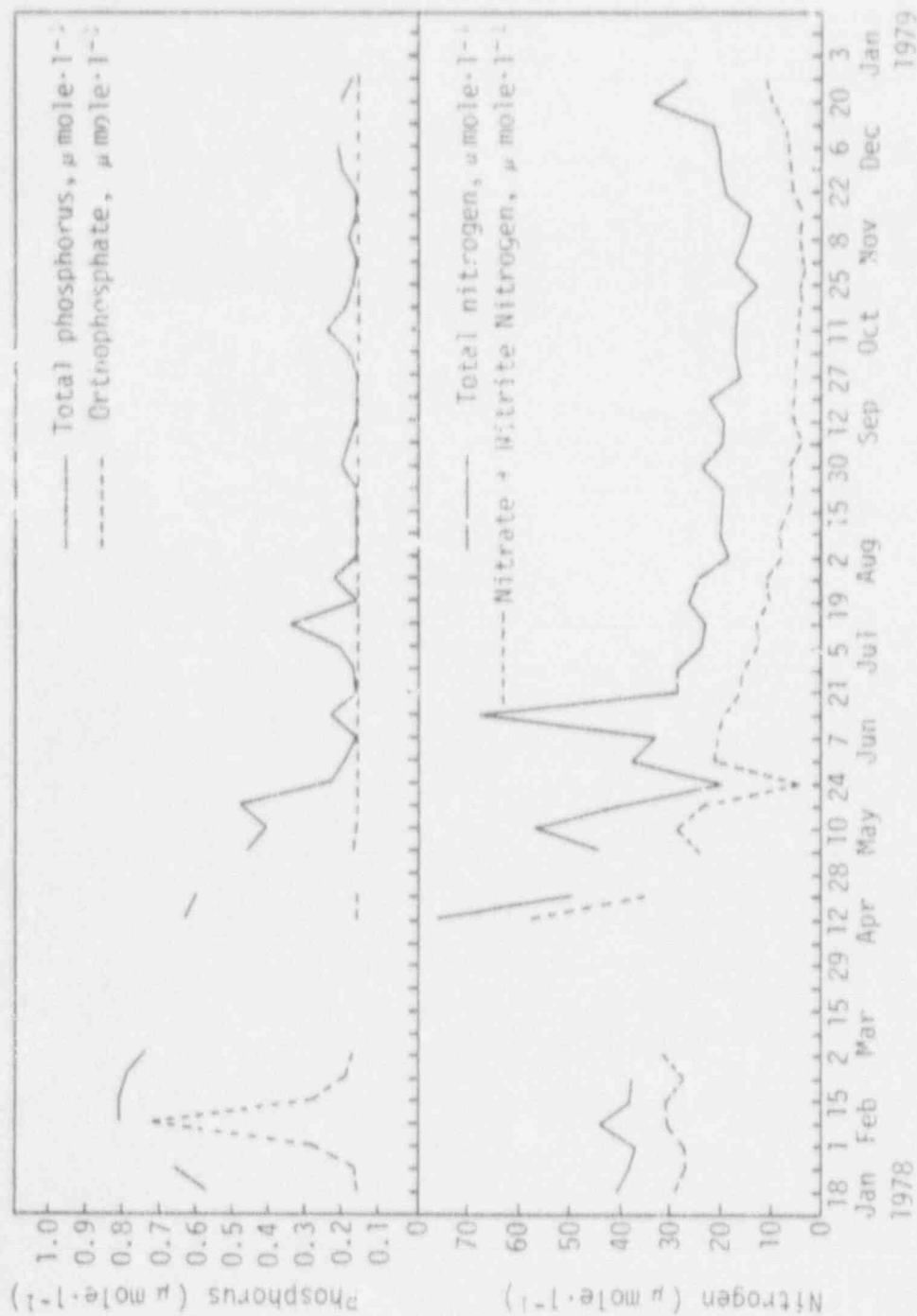


Figure 4-29a. Concentrations of phosphorus and nitrogen ($\mu\text{mole}\cdot\text{l}^{-1}$) in the upper mixed layer of Lake Norman at Location 3.0, January 13, 1978 through January 10, 1979. Detection limit for phosphorus was $0.16 \mu\text{mole}\cdot\text{l}^{-1}$ and for nitrogen was $0.36 \mu\text{mole}\cdot\text{l}^{-1}$.

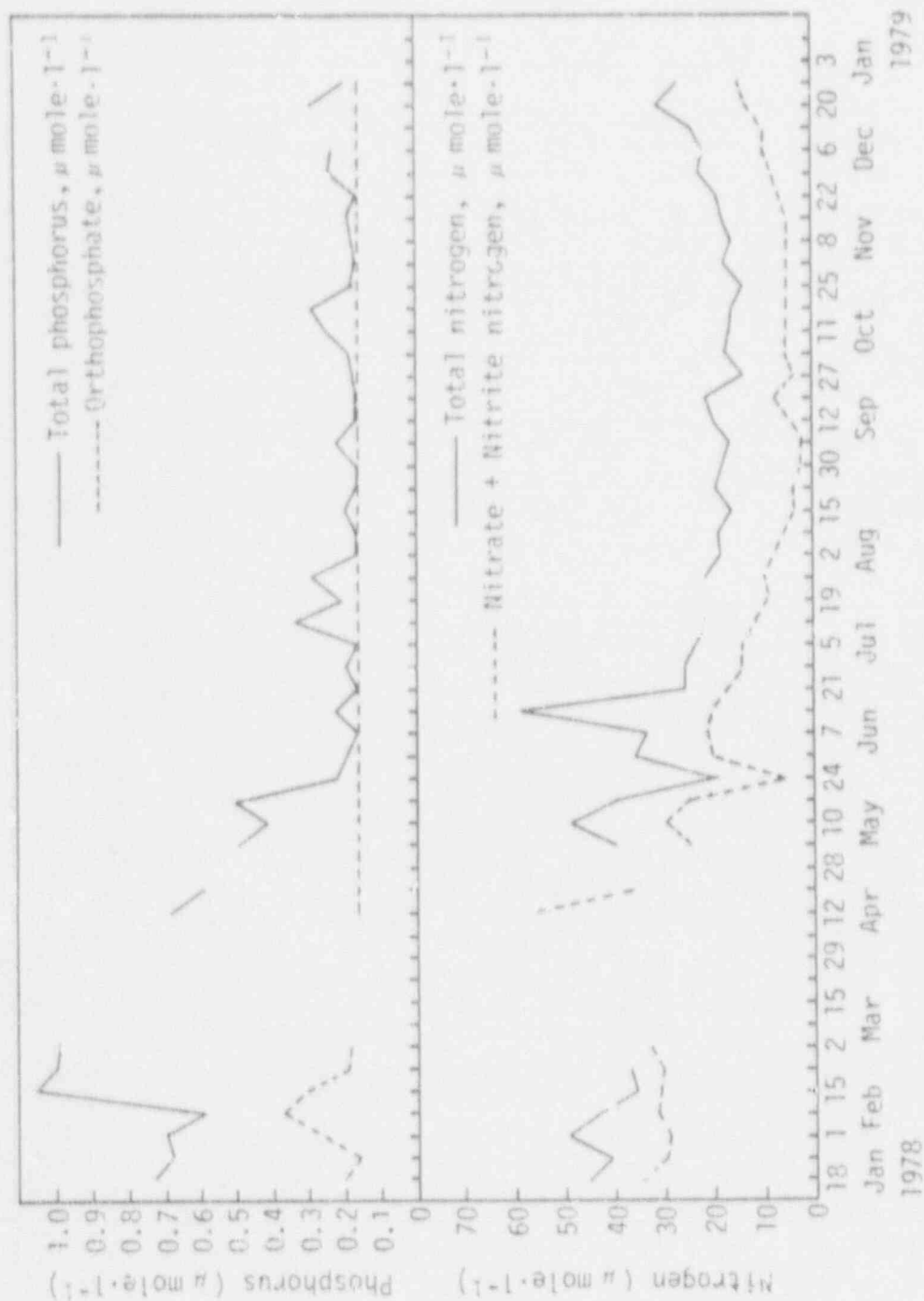


Figure 4-29b. Concentrations of phosphorus and nitrogen ($\mu\text{mole}\cdot\text{l}^{-1}$) in the upper mixed layer of Lake Norman at Location 8.0, January 18, 1978 through January 10, 1979. Detection limit for phosphorus was $0.16 \mu\text{mole}\cdot\text{l}^{-1}$ and for nitrogen was $0.36 \mu\text{mole}\cdot\text{l}^{-1}$.

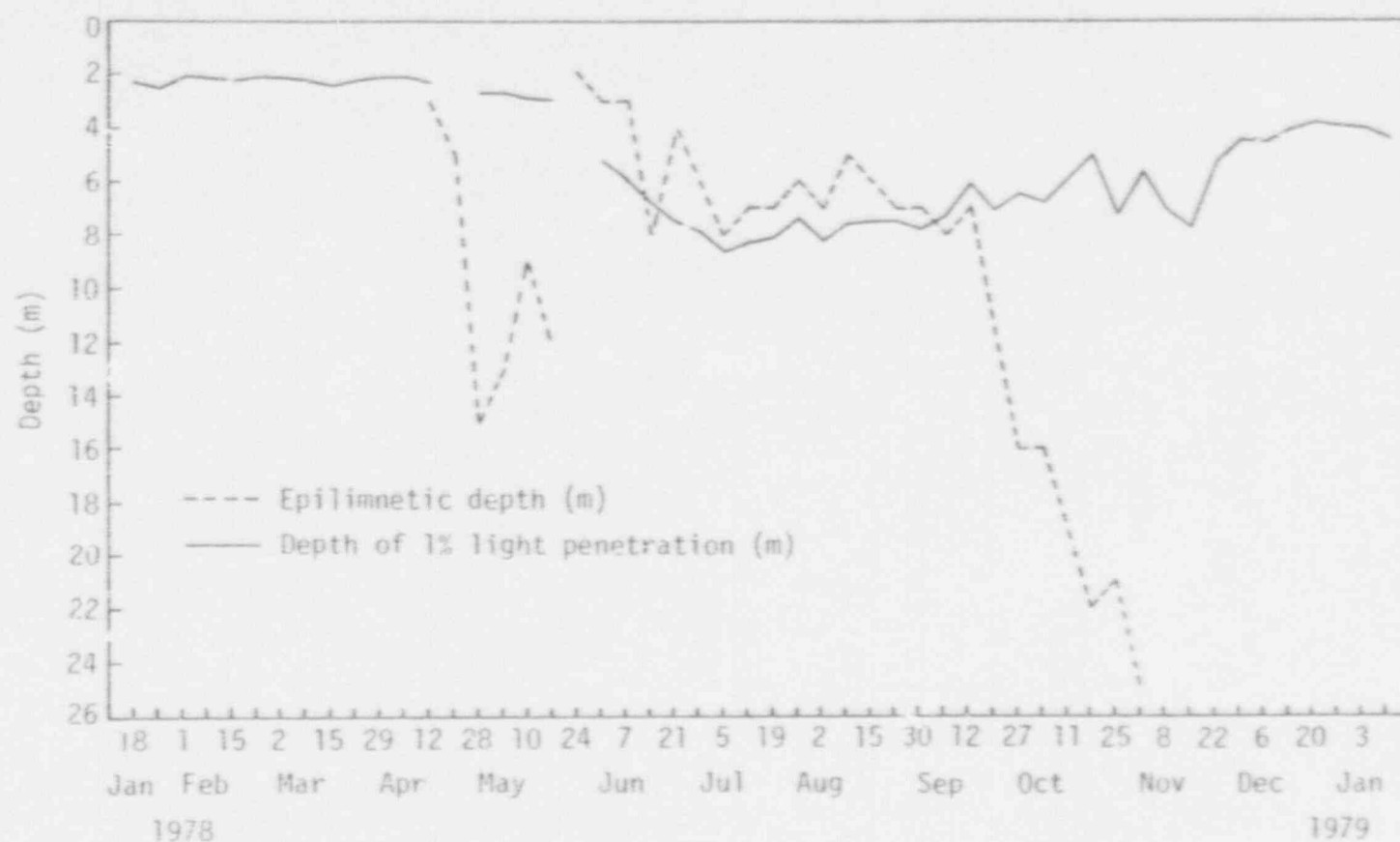


Figure 4-30a. Approximate depth (m) of the epilimnion based on vertical profiles of temperature and dissolved oxygen, and the maximum depth (m) to which one percent of subsurface incident light penetrated at Location 3.0, Lake Norman, January 18, 1978 through January 10, 1979.

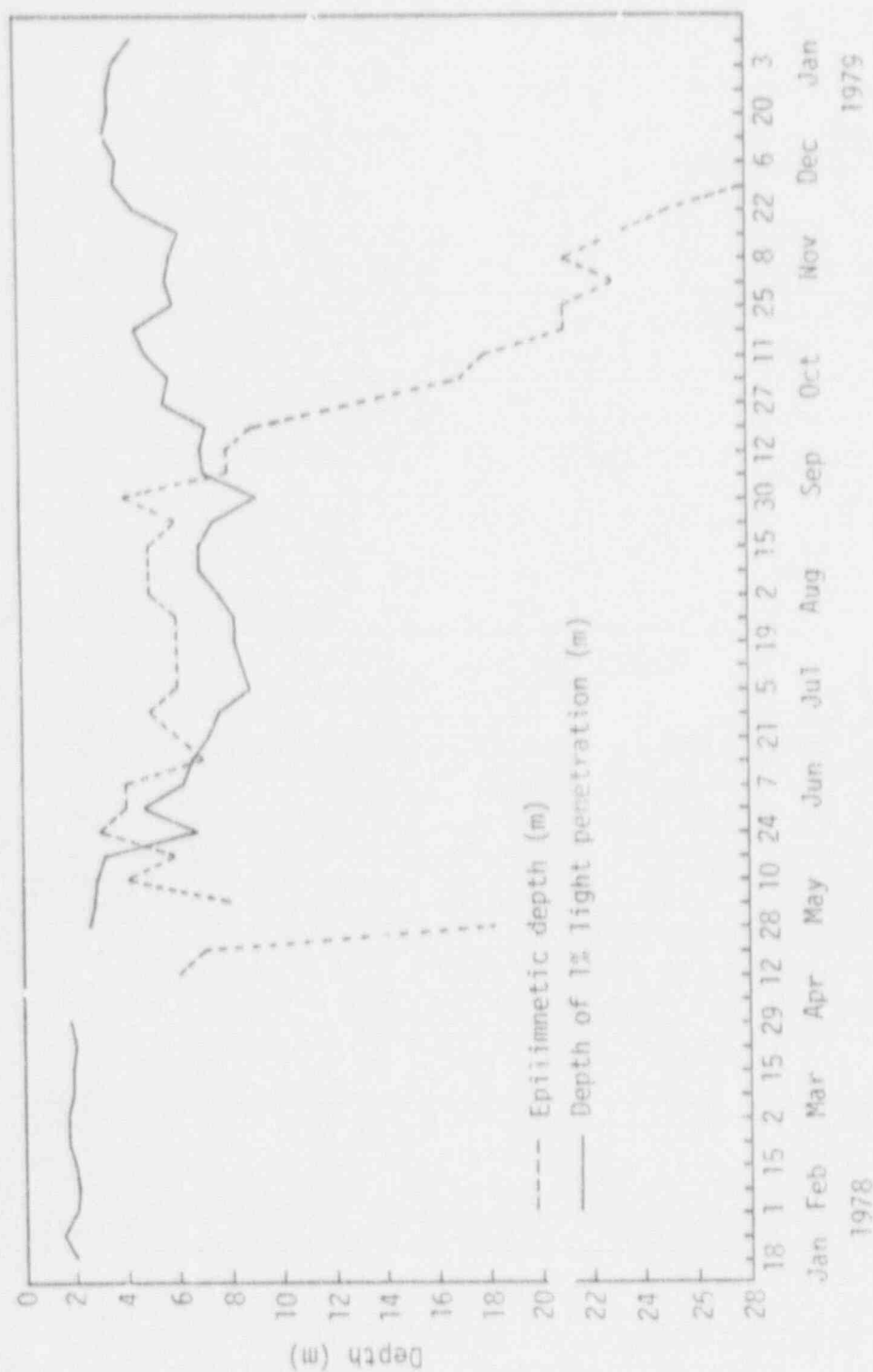


Figure 4-30b. Approximate depth (m) of the epilimnion based on vertical profiles of temperature and dissolved oxygen, and the maximum depth (m) to which one percent of subsurface incident light penetrated at Location 8.0, Lake Norman, January 18, 1978 through January 10, 1979.

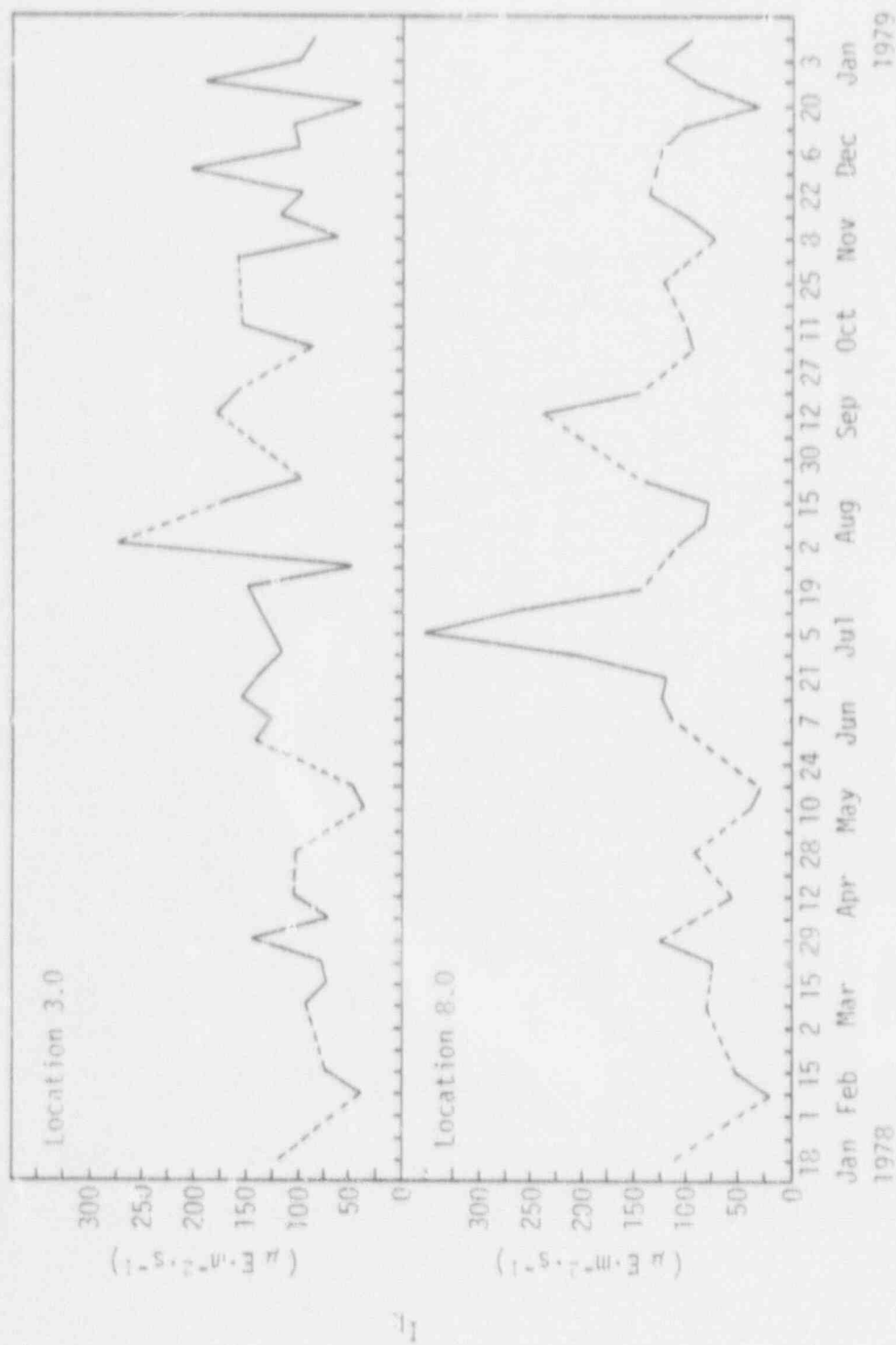


Figure 4-31 Saturating light intensities (I_k) ($\mu E \cdot m^{-2} \cdot s^{-1}$) on Lake Norman, January 18, 1978 through January 10, 1979. Broken line indicates an interval of two weeks or more between observations.

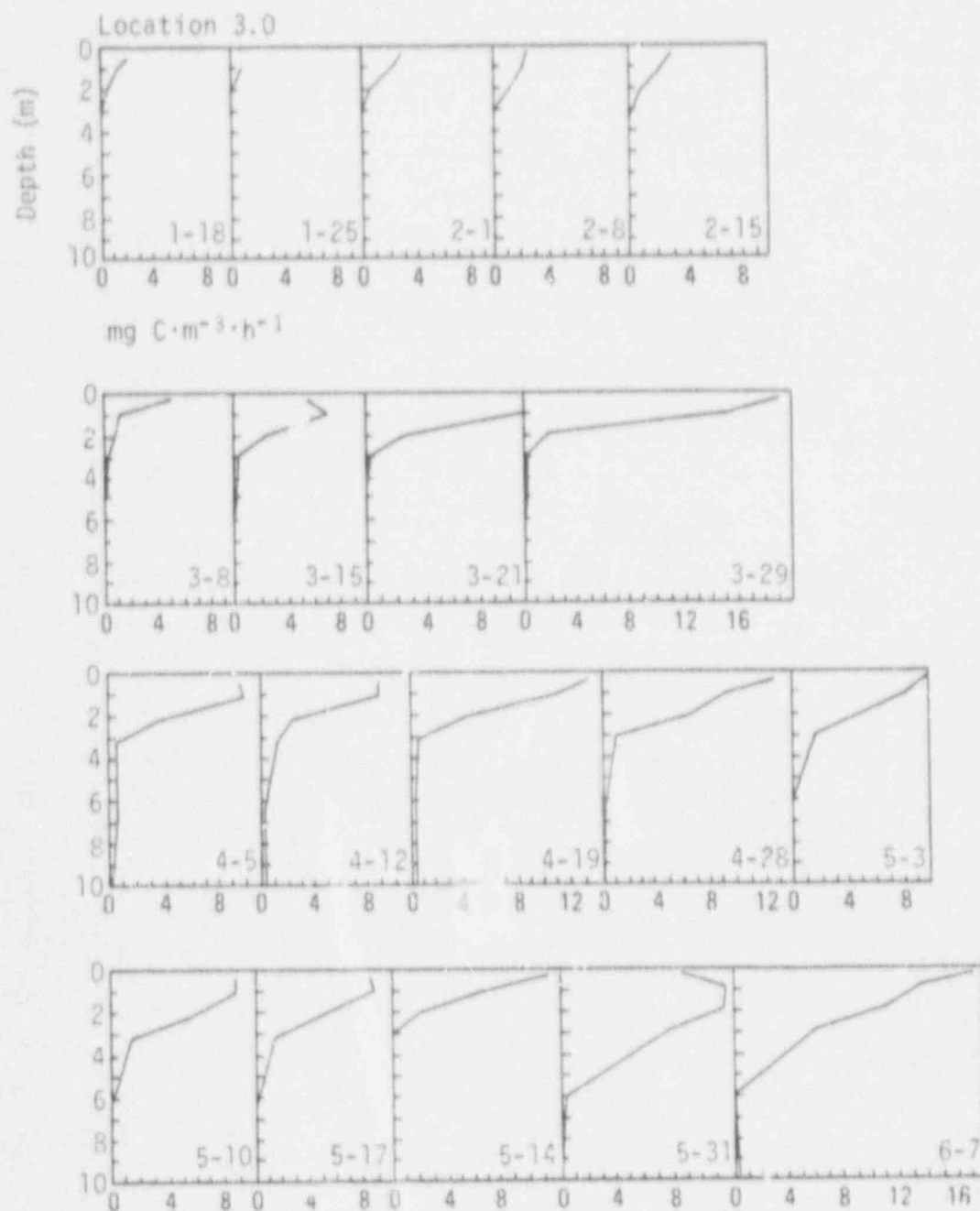


Figure 4-32. Carbon uptake rates ($\text{mg C} \cdot \text{m}^{-3} \cdot \text{h}^{-1}$) vs. depth (m) at Locations 3.0 and 8.0, Lake Norman, January 18, 1978 through January 10, 1979. Numbers in each cell represent month-day.

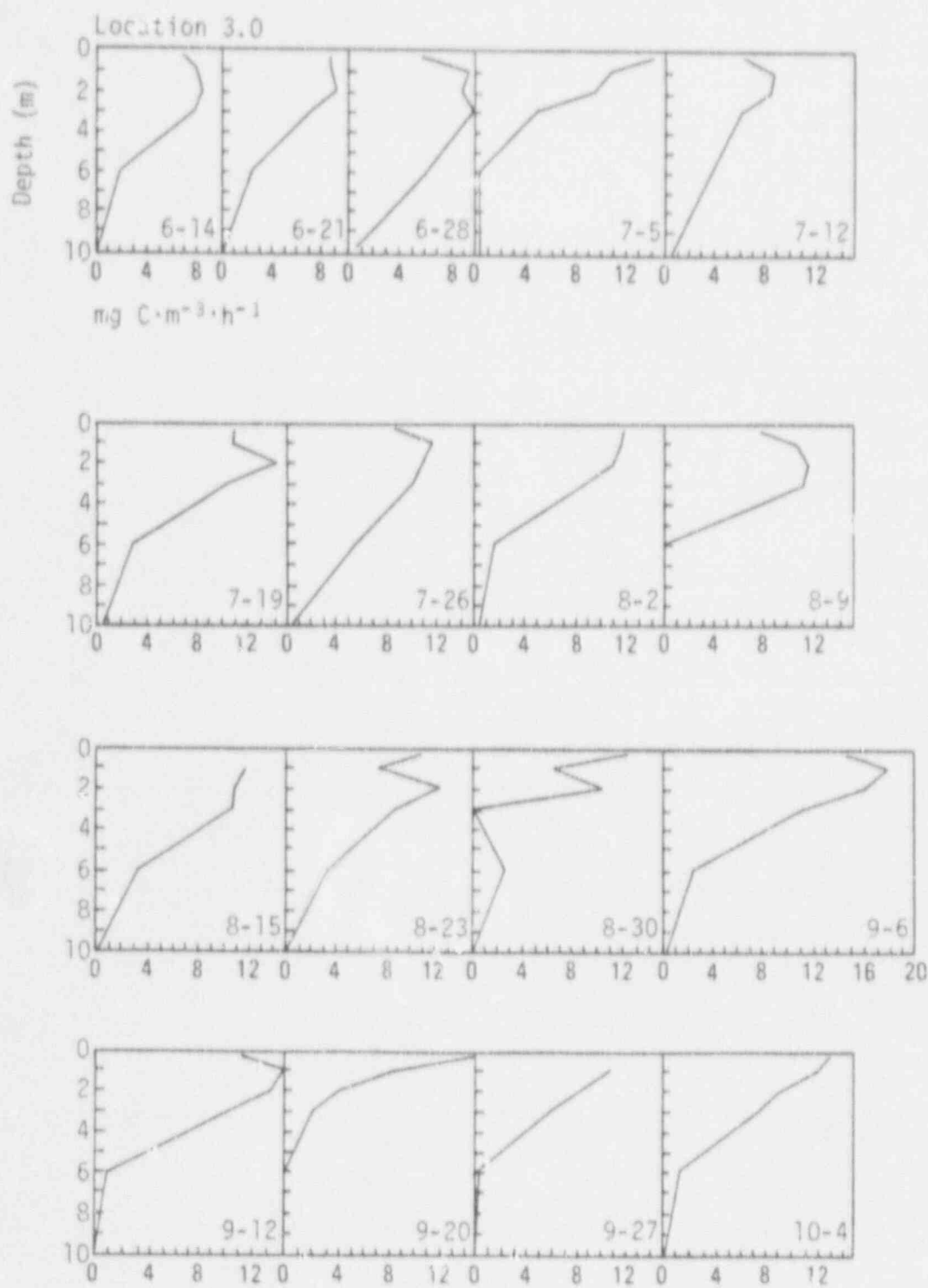


Figure 4-32 (continued)

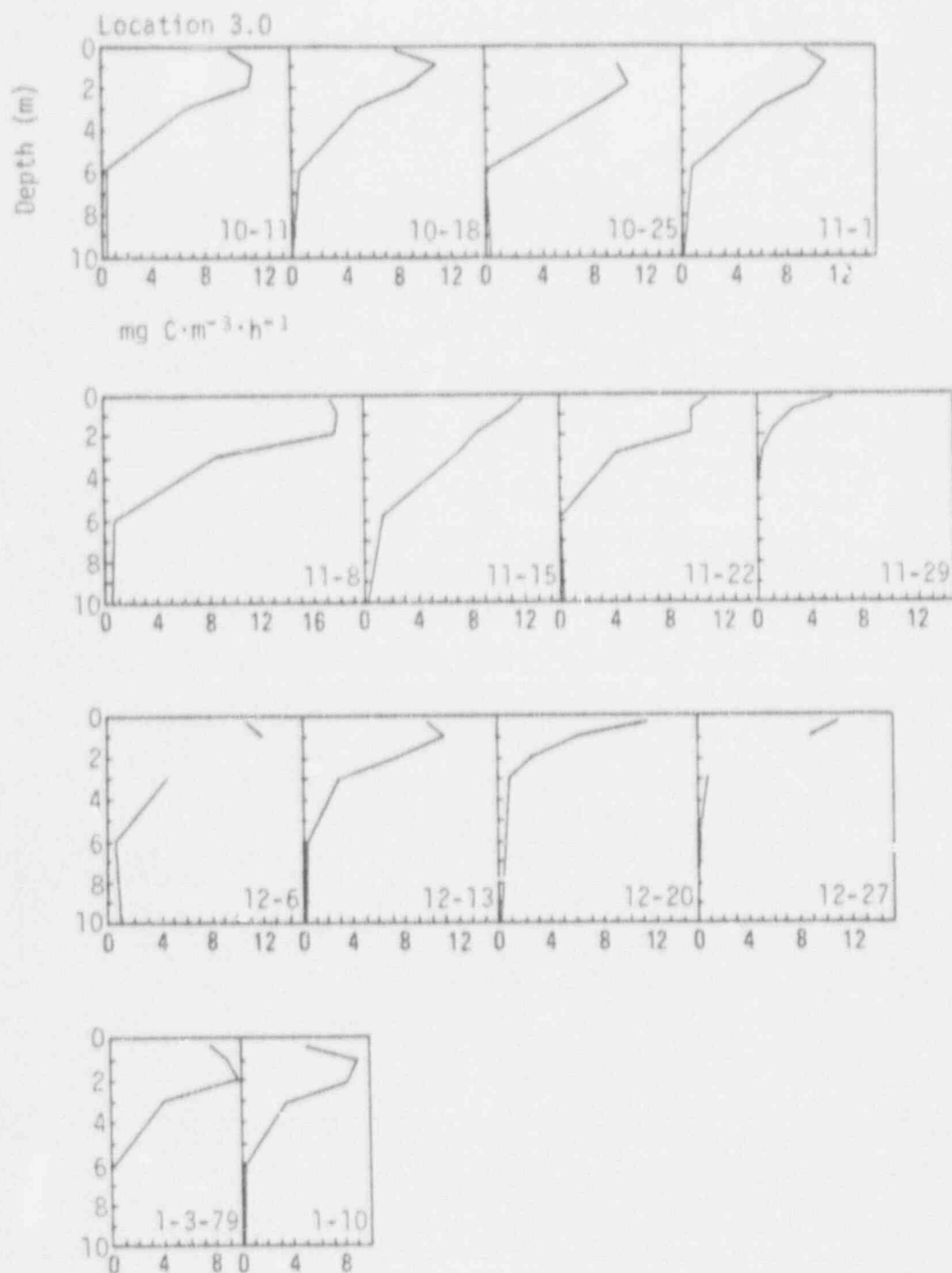


Figure 4-32 (continued)

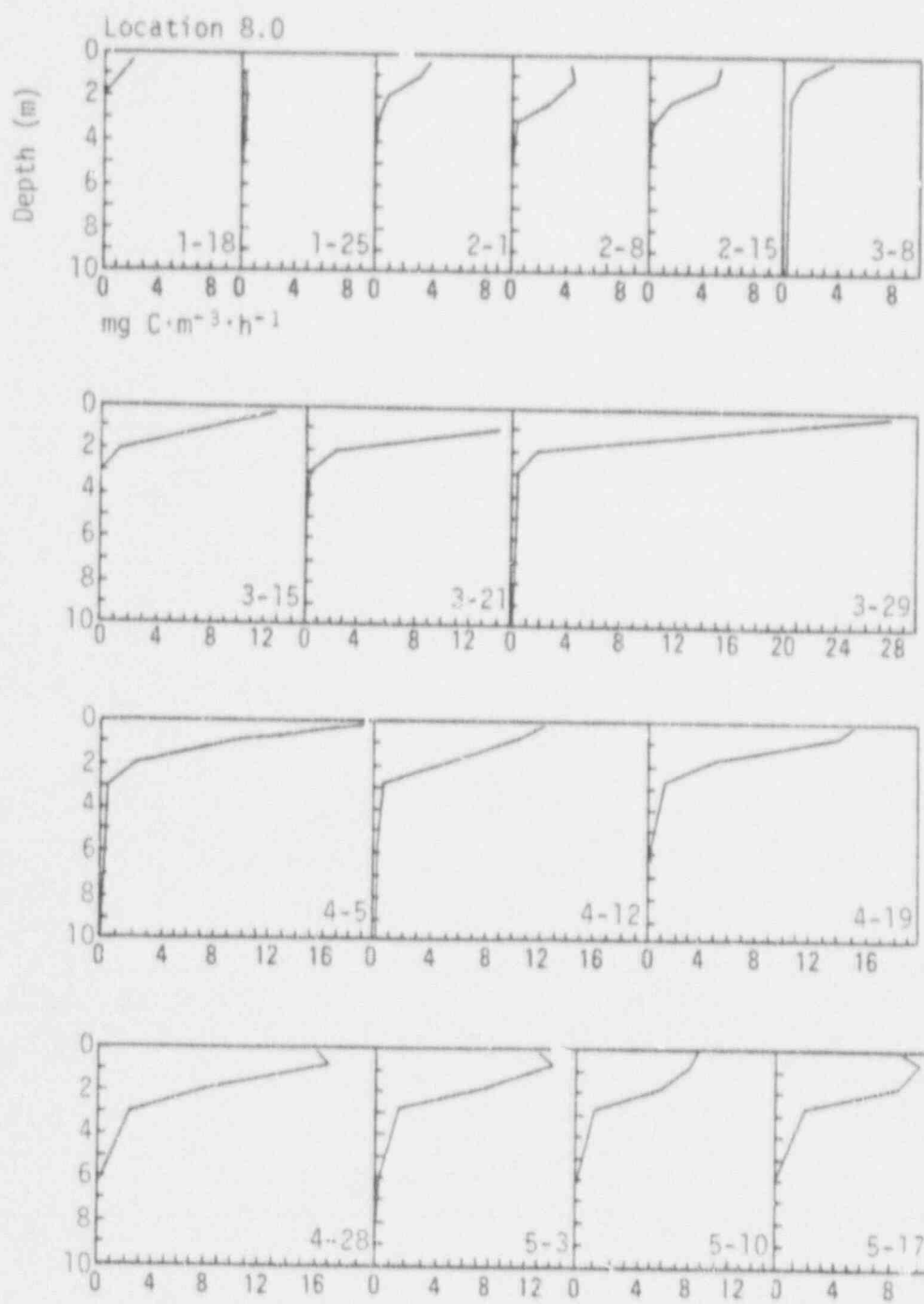


Figure 4-32 (continued)

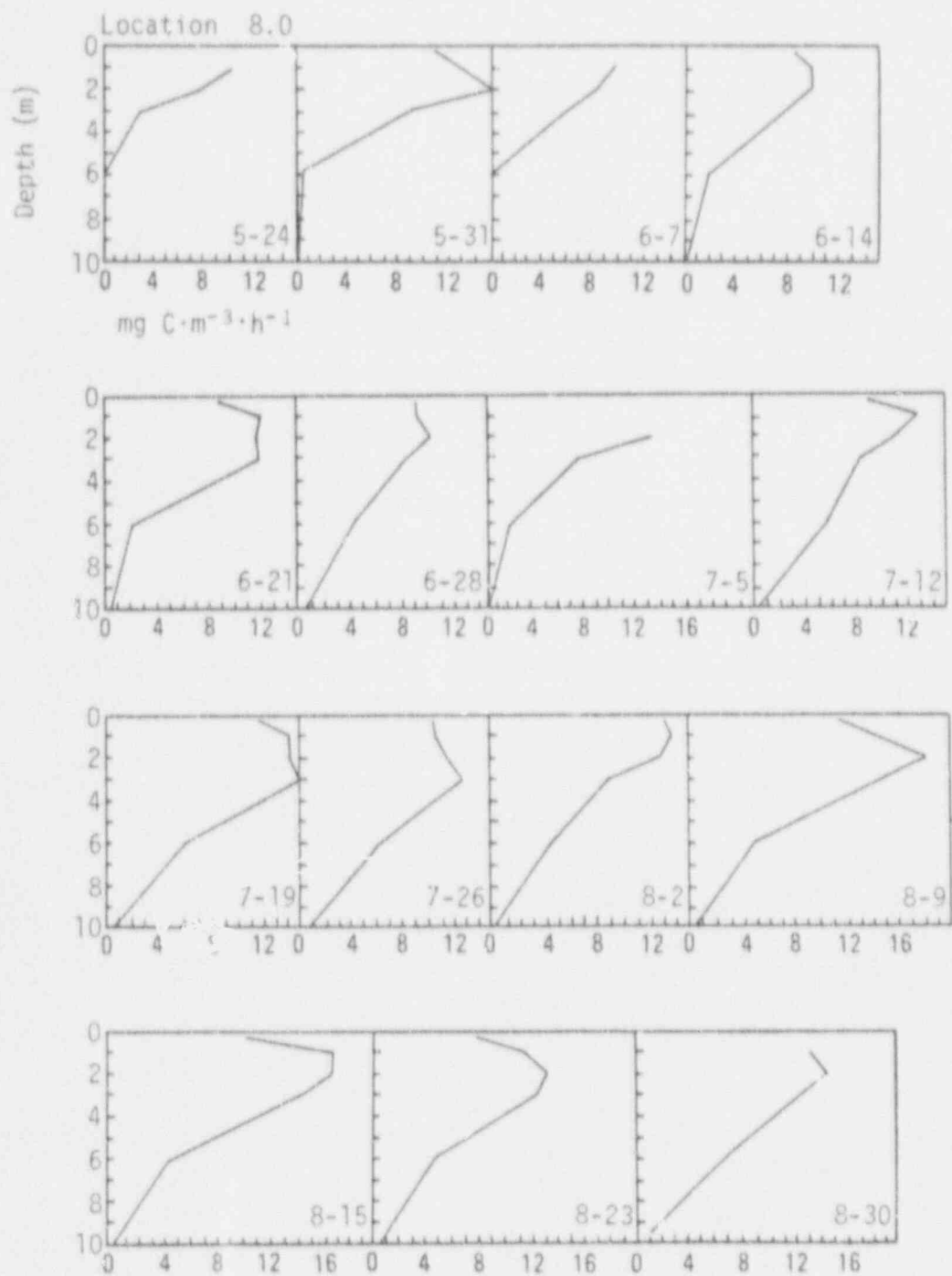


Figure 4-32 (continued)

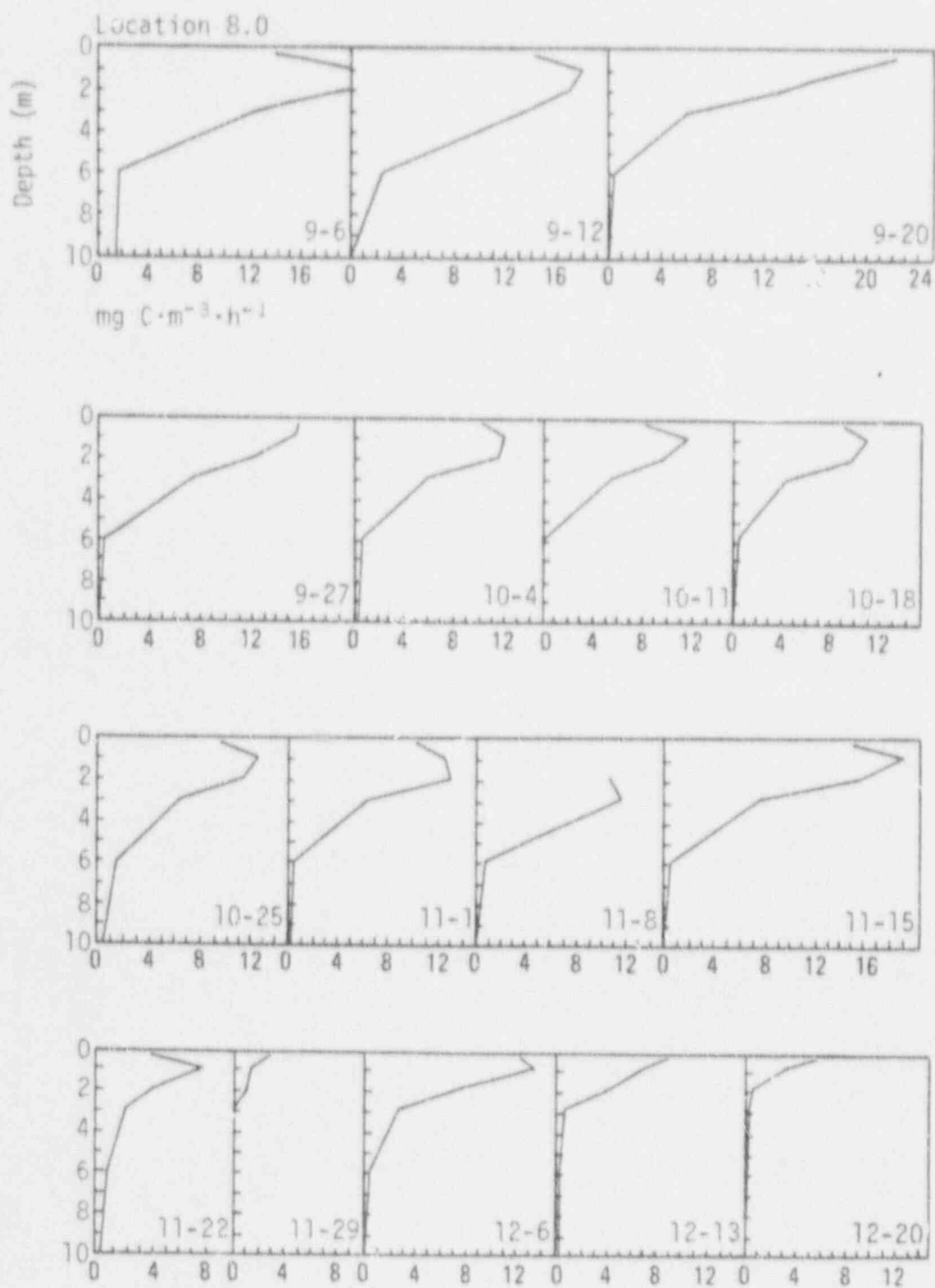
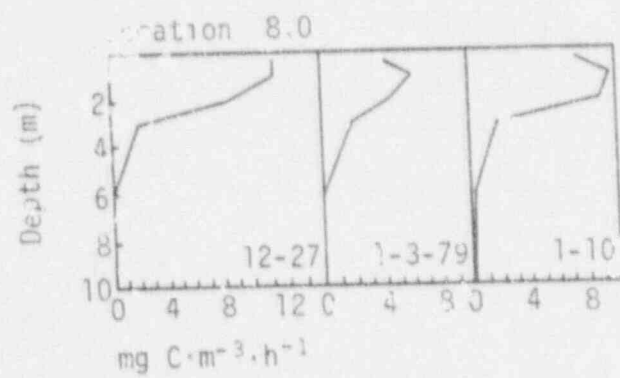
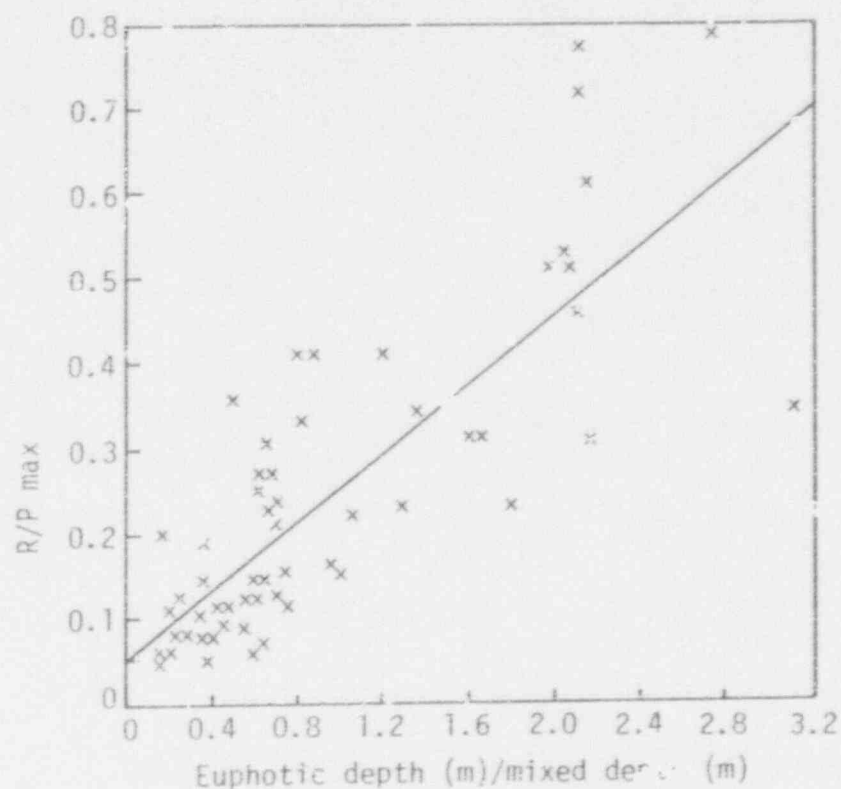
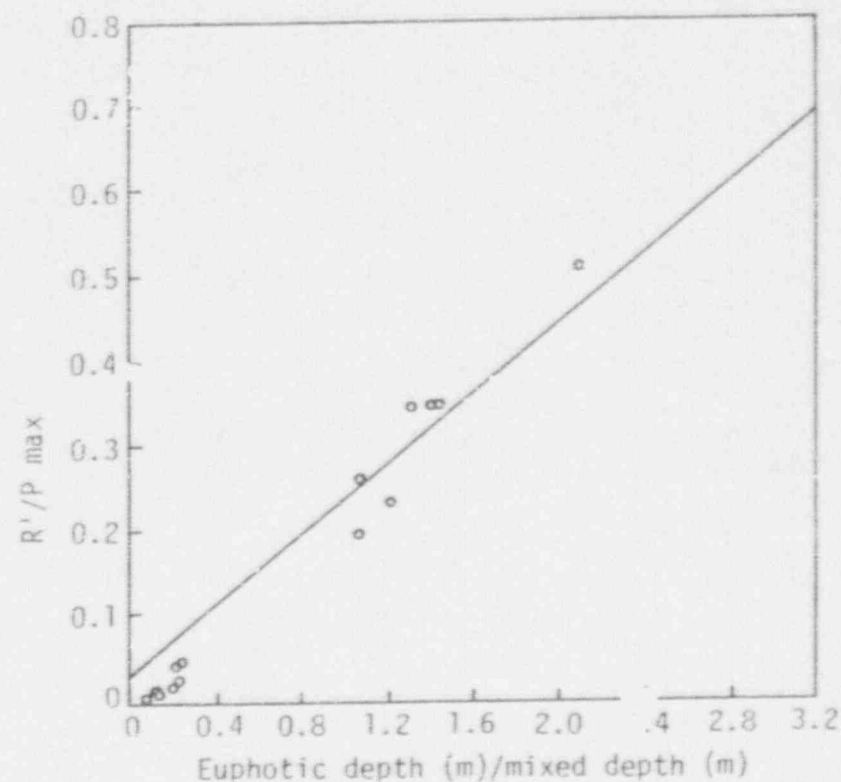


Figure 4-32 (continued)





Data and plot reproduced from Harris (1978)



Harris' (1978) regression line (from plot at left) superimposed on plot of data from Locations 3.0 and 8.0, Lake Norman (Table 4-8).

Figure 4-33. A comparison of R'/P_{max} values calculated for Lake Norman to R/P_{max} values (Harris 1978) measured for algal populations in other aquatic systems under similar relative conditions of light penetration and mixing depth.

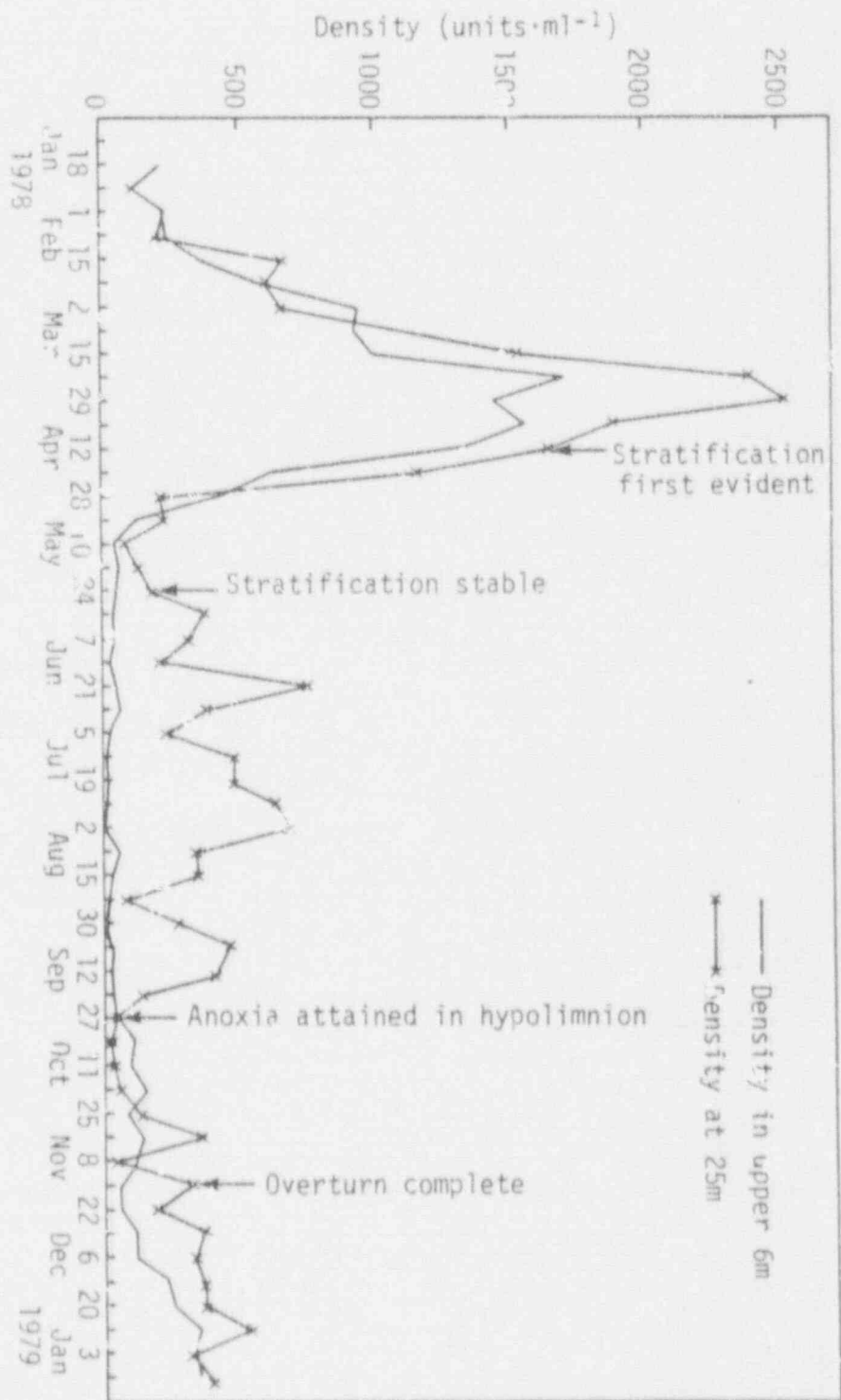


Figure 4-34a. Density (units·ml⁻¹) of *Melosira italica* plus *M. italica* var. *tenuissima* observed at Location 3.0, Lake Norman, January 18, 1978 through January 10, 1979.

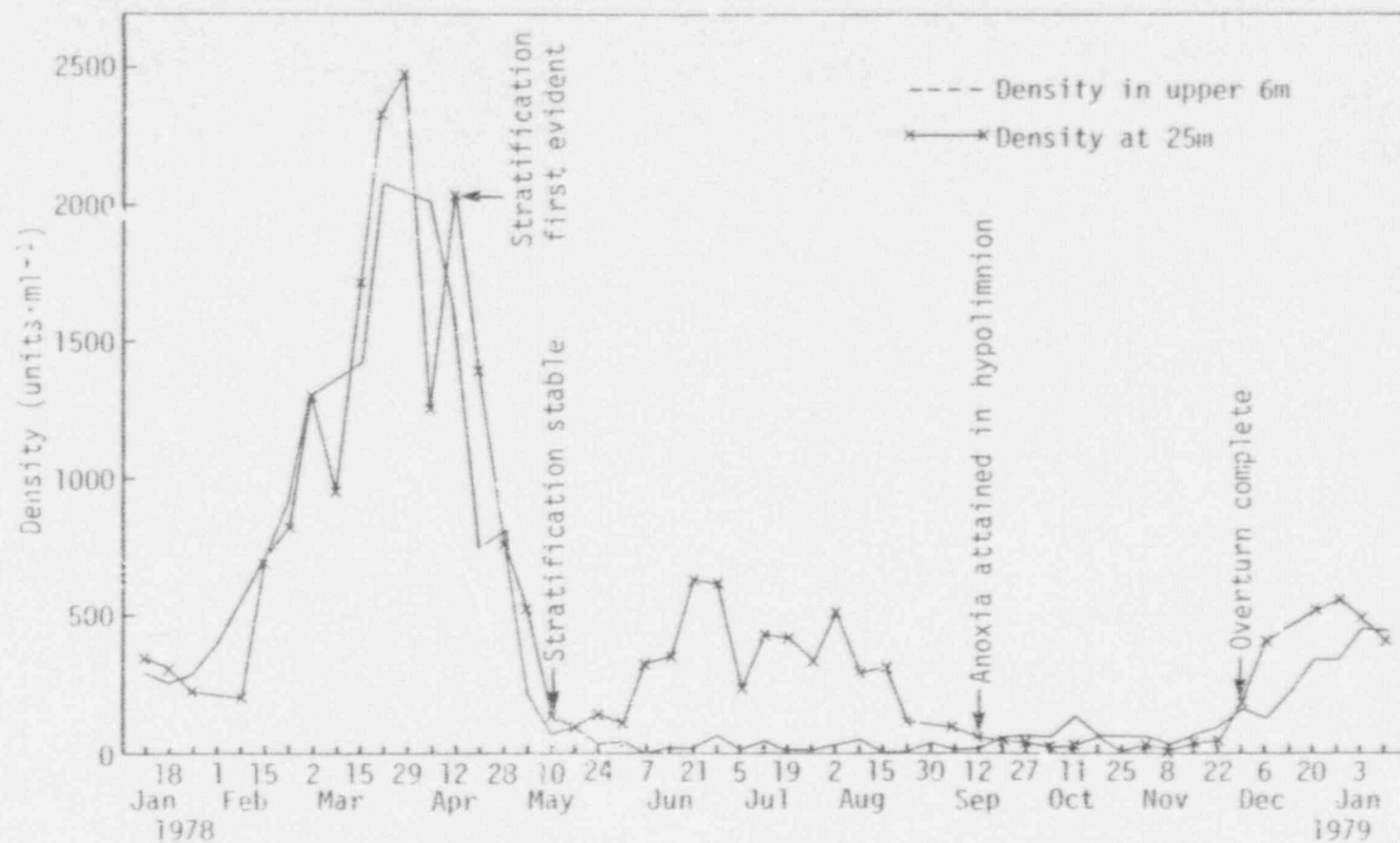


Figure 4-34b. Density (units·ml⁻¹) of *Melosira italica* plus *M. italica* var. *tenuissima* observed at Location 8.0, Lake Norman, January 11, 1978 through January 10, 1979.

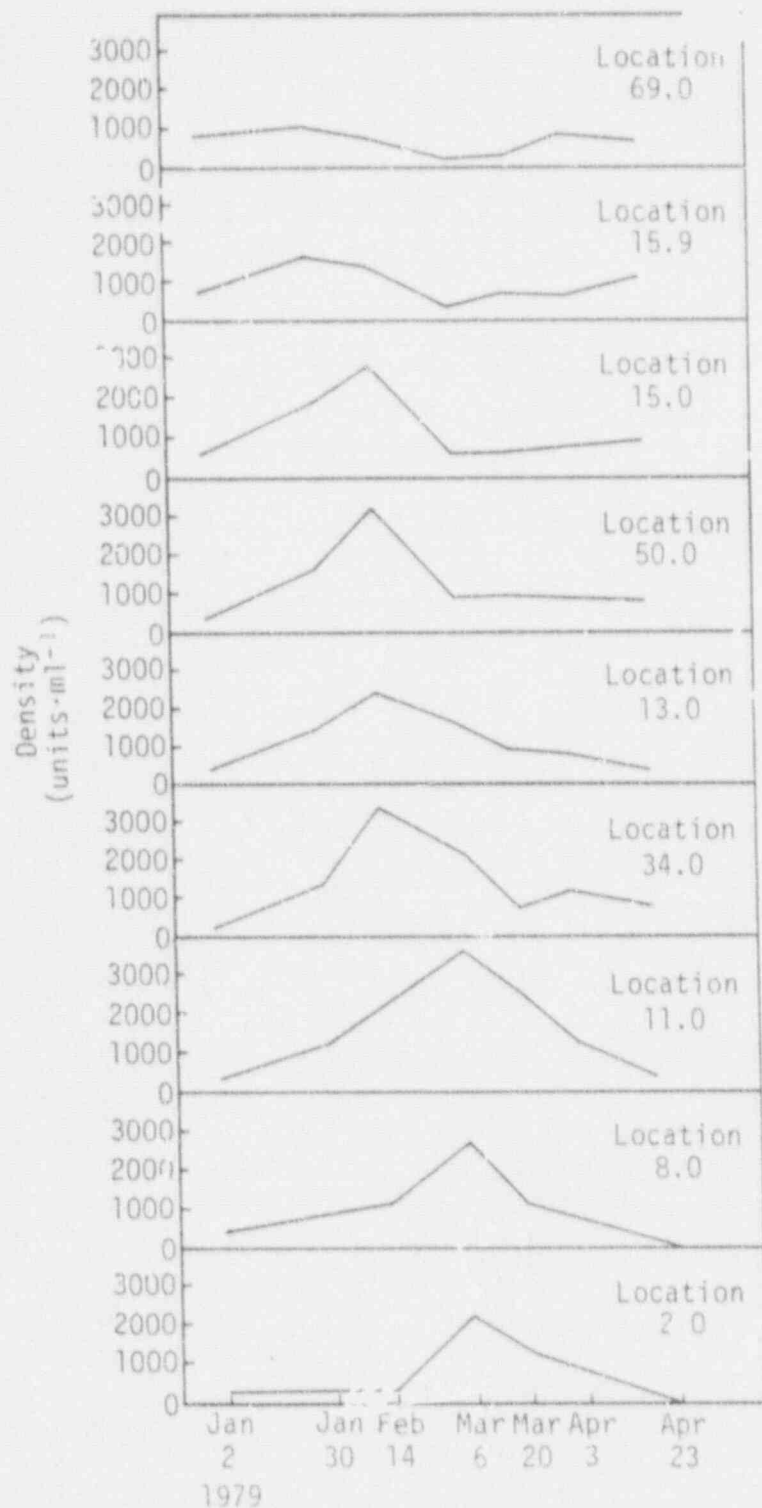


Figure 4-35. Density (units·ml⁻¹) of *Melosira italica* plus *M. italica* var. *tenuissima* during the period of maximum abundance, at nine locations on Lake Norman.

LAKE NORMAN SUMMARY

VOLUME II

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CHAPTER 5. PHYTOPLANKTON BIOASSAY

C. M. WISEMAN AND J. E. HOGAN

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INTRODUCTION

BACKGROUND

Phytoplankton bioassay has been used for determining factors affecting phytoplankton growth in a water body. Various techniques have been used for conducting these bioassays. One technique utilizes the growth responses of a uni-algal population grown in autoclaved and/or filtered lake water (U. S. Environmental Protection Agency 1971). This test enables direct comparison of the results of bioassays from different waters. Two investigators have examined major nutrient factors affecting algal growth on Lake Norman using this technique (U. S. Environmental Protection Agency 1975; Weiss 1976). Both investigators indicated phosphorus limitation at all locations examined on this lake, and at all times of the year. However, applications of this technique to natural populations are limited, since a single test species cannot be expected to adequately represent a natural association of many algal taxa.

An alternative technique is the use of natural phytoplankton populations from the study area (Barlow et al. 1973). The growth responses of the indigenous algal species are used to assess the effect of nutrient supply, light, temperature, and other factors. Changes in metabolic, chemical, and taxonomic characteristics of these mixed populations are used to assess the effects of the test conditions. However, a major disadvantage of using indigenous phytoplankton populations is in the enclosure of a sample in a container, where due to the confinement, certain species are unable to survive (Fogg 1965). Small-scale turbulence is important for the supply of nutrients to the algal cell, and is likely to be different in an enclosed container from that in open water. Turbulence can be critical for the survival of all but the most robust of algae (Fogg 1965). Competition among species is another problem associated with bottle tests that use many species. Although phytoplankton species co-exist in a natural water, almost invariably one or two species will outgrow the others when enclosed in a container (Fogg 1965). Therefore, results from algal assays may be used in making general comparisons, but they are not intended to be used as absolute predictors of phytoplankton growth response.

Algal standing crops in freshwater systems may be limited by physical, chemical, or biological factors such as light, temperature, nutrients, or predation. The effects of these factors are variable and can change with the time of year, influx of nutrients from runoff, fluctuations in water level, and taxonomic composition.

McGuire Nuclear Station may be an additional factor affecting algal growth in Lake Norman near the station (Duke Power Company 1976). The use of up to 44% hypolimnetic water by McGuire during the warmest months will result in slightly higher nutrient concentrations in the epilimnetic water of the immediate discharge area compared to pre-operational levels. Also, the steam condenser cooling water discharge will increase the mixing zone temperature above pre-operational levels. Vertical and horizontal water movements will also increase as a result of the discharge of cooling water.

OBJECTIVES

The objectives of this study were to:

1. examine the effect on phytoplankton of the expected increase in lake temperature due to operation of McGuire Nuclear Station,
2. examine the effect on phytoplankton of the expected surface water concentrations of nitrate, ammonia, and orthophosphate resulting from hypolimnetic water used for partially cooling the steam condensers of McGuire, and
3. examine the effect on phytoplankton at different light levels.

MATERIALS AND METHODS

SAMPLING LOCATIONS AND FREQUENCY

Bioassays were conducted monthly from April 1974 through June 1975 using water collected at Locations 1.0, 3.0, 4.0, 6.0, 7.5, and 10.0. Bioassay sampling frequency was changed to quarterly in June 1975. Location 10.0 was deleted in May 1975 and location 7.5 was replaced by Location 8.0 in January 1976 (Duke Power Company 1976). Profiles of temperature, chlorophyll fluorescence, and light intensity were taken weekly at Locations 1.0, 4.0, and 7.5 from May 1974 through November 1975. Sampling frequency for these profiles was changed in January 1976 to one week prior to an assay and each week an assay was incubated. The bioassay sampling history is documented in Table 5-1. Sampling locations are shown in Figure 1-10.

FIELD PROCEDURES

Water samples were taken at one-meter intervals from surface to 15 m, or bottom if shallower, using a non-metallic van Dorn sampler. The temperature of each sample was recorded and then the sample was transported to the laboratory. A Lambda quantum sensor Model LI192S was used for measuring photosynthetically active radiation (PAR) at one-meter intervals from the surface to the depth at which the readings were less than $1.0 \mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$.

The week prior to the beginning of a nutrient bioassay a water sample was taken at the depth of the McGuire lower-level intake structure. The sample was analyzed for nitrate plus nitrite-nitrogen, ammonia-nitrogen, and total phosphorus. These concentrations were used to determine and prepare nutrient spikes.

Duplicate samples collected for each bioassay from the surface (0.3 m), mid-euphotic, and bottom euphotic depths at each location were composited. Prior to January 1977 only the euphotic zone composite sample was collected at each location. The depth for the bottom of the euphotic zone at each location was taken as one percent of the surface PAR.

LABORATORY PROCEDURES

The bioassays followed a modification of the Algal Assay Procedure Bottle Test (United States Environmental Protection Agency 1971). The modification consisted of using untreated lake water containing natural phytoplankton populations instead of unialgal cultures. The experimental design is presented in Figure 5-1.

A set of flasks for each replicate at any given location was separated into four nutrient treatment groups. The replicate flasks within the first treatment group (+N) received, in addition to the ambient concentration, a nitrate-N plus ammonia-N spike (as NaNO_3 and NH_4Cl , respectively) at the concentration found at the McGuire lower-level intake structure the previous week. The second treatment group (+P) was spiked, in addition to ambient levels, with the concentration of total phosphorus as orthophosphate (as KH_2PO_4), found at the lower-level intake. The concentration of total phosphorus, in the form of orthophosphate, was used due to the rapid cycling of phosphorus between organisms and water (Lean 1973) and the ease of working with only orthophosphate. A third treatment group (+N+P) received the above concentrations of ammonia, nitrate, and phosphorus, in addition to ambient levels. The fourth (control) treatment group received no nutrient spike. During winter and spring when the McGuire lower-level intake is not expected to be used, only a thermal assay was employed, except from May 1974 through December 1974 when nutrient assays were also conducted.

These four sets of flasks were placed in an incubator and illuminated by cool-white fluorescent lights at an intensity of $125 \pm 15 \mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$. An identical group of four sets of flasks were placed in the same incubator and illuminated at $25 \pm 5 \mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$. These PAR levels correspond approximately to 12 and 2%, respectively, of incident PAR on the lake surface on a clear day. The same laboratory procedure was repeated for the second replicate.

The incubator lighting was cyclic and set to approximate the current local photoperiod at the time of sample incubation. The incubator temperature was set to the expected maximum monthly average temperature of McGuire's condenser cooling water discharge, with a range of about $\pm 2^\circ\text{C}$ from the selected temperature.

The flasks were incubated about fourteen days. Prior to incubation, initial measurements were made of relative chlorophyll *a* fluorescence, nutrients (total phosphorus, and filterable orthophosphate, ammonia, nitrate + nitrite, and silica), particulate organic carbon (POC), and algal cell densities. These variables were re-evaluated on the final day of the assay. Methods for nutrient analyses are given in Table 3-2. Samples for POC analyses were filtered through a Reeve Angel glass fiber filter. Filters were sealed in ampules and analyzed on an Oceanography International Carbon analyzer. Chlorophyll *a* fluorescence was measured on a Turner Model 111 fluorometer equipped with a F4T4 lamp and Corning CS5-60 primary and CS2-64 secondary filters. All measurements were made relative to the 10X window setting, using dilution of the sample if necessary, in order to give a linear response in Turner Fluorescence Units (TFU). Algal cell densities were determined by microscope counts. Ten milliliters of sample were centrifuged and drawn down to approximately 0.5 ml. A subsample of this concentrate was transferred to a Palmer-Maloney counting cell, and a minimum of one hundred algal cells were identified

and enumerated under 500X magnification. Counts were in a known volume of the Palmer-Maloney cell, and converted to cells per milliliter.

EXPERIMENTAL DESIGN CONSIDERATIONS

In the design of this test, no effort was made to remove zooplankton from the water sample. Predation by zooplankton in the flasks may have affected the final phytoplankton standing crop; however, no zooplankton were ever observed in the flasks and predation was considered inconsequential. It also should be noted that the taxonomic composition of most of the samples at the end of the incubation period, consisted of a dominant coccoid green algae population. This domination by coccoid greens probably resulted from the competition among the indigenous species imposed by the bottle test, as discussed earlier. As a result the growth responses of the algae discussed in the following sections are based on this algal population. The total phosphorus concentration of the sample was used for the spike, although orthophosphate is considered the form used by phytoplankton. By using the total phosphorus concentration, and assuming all of it was biologically available, a worst case situation was evaluated for phytoplankton response. In the evaluation of temperature effects, there were no samples incubated under incubator conditions, and at ambient lake temperatures. Instead samples collected in the field at the time the assay ended were used as the controls in the comparison with incubated samples.

DATA ANALYSES

Statistical and graphical analyses were performed on data collected from January 1977 through November 1979 at Locations 1.2, 3.0, 4.0, and 8.0. All data collected from 1974 through 1980 are in Appendix 5. Homogeneity of variances was tested using Bartlett's test (Zar 1974); heteroscedastic data were transformed and retested. However, due to the heteroscedasticity of the transformed data, non-parametric and descriptive tests were generally indicated. Since natural populations were used in these tests a corrected final value for each growth response variable was calculated by subtracting initial values from the final values for all treatments. This allowed only the net increase in the growth response due to the treatment to be evaluated. In the evaluation of temperature effects, the field chlorophyll *a* fluorescence value is a mean of chlorophyll *a* fluorescence values from bottom euphotic, mid-euphotic and surface depths on the sampling date most closely corresponding to final day of the assay.

The percent increase of particulate organic carbon and algal cell density over the incubation period was determined by the following equation:

$$\text{Percent increase} = \frac{(Y_f - Y_i) * 100}{Y_i}$$

where Y_i = value of treatment variable on initial day of incubation
 Y_f = Value of treatment variable on final day of incubation
100 = conversion to percent

The Kruskal Wallis test (Helwig and Council 1979) was used to examine differences between field and laboratory growth responses.

RESULTS AND DISCUSSION

Temperature, light, and nutrients were examined as to their importance to the phytoplankton growth response in these bioassays. Temperature was determined to be the single most important factor over the course of a year, with nutrients exerting a generally lesser influence.

Analysis of light effects indicates there was no significant difference in algal growth response between the two light levels tested. The similar response of algae at both light intensities indicates probable light adaptation of the algae. Light adaptation to a different intensity has been shown to occur within one algal generation (Harris 1978) and several generations likely occurred during the course of a 14-d assay.

TEMPERATURE

Chlorophyll *a* fluorescence mean values were higher in the assay control samples at the end of the 14-d incubation period than in the samples collected in the field near the end of the assay (Table 5-2). This difference in chlorophyll *a* fluorescence between field and incubated samples was statistically significant as categorized by temperature ranges (Table 5-2). The *in vivo* fluorescence of the incubated samples increased as a response to temperature because no added nutrients were present in the control samples and all other factors were equal. The response is related to both the lake temperature at the time of sample collection and the temperature increase as a result of the incubation process. As the lake temperature increased, the fluorescence response generally declined; as the temperature difference between lake and incubator increased, the fluorescence response generally increased (Fig. 5-2). However, the two parameters lake temperature and temperature difference, are related in that at low values of one parameter, only high values of the other parameter were tested, and vice versa. The net increase in chlorophyll *a* fluorescence, however, indicates the temperature difference between the lake and incubator was probably the more important factor in determining the fluorescence growth response of assayed algae because of the higher net increase for temperature difference compared to lake temperature (Table 5-2). Smith et al. (1974) in a carbon-14 production study of the response of Lake Norman phytoplankton to temperature increases observed similar results.

Moreover these investigators (Smith et al. 1974) noted that in July and February, production rates reached an optimum and declined with increasing temperature above ambient. Results of the present study indicate a similar phenomenon at low ambient lake temperatures with correspondingly high increases in incubator temperatures (Fig. 5-2). No similar decline was observed at high lake temperatures because only relatively small temperature increases as a result of incubation were tested.

NUTRIENTS

Mean values of chlorophyll *a* fluorescence, POC, cell density, and percent increase of POC and cell density over the study period were generally higher in the samples to which both nitrogen and phosphorus were added compared to other nutrient treat-

ments (Fig. 5-3 through 5-5 and Table 5-3). The addition of phosphorus alone produced the next greatest response from these variables. The response in the control and in the nitrogen treatment were lower and usually very similar to each other.

Based on the above observations it is evident that of the two major nutrients, nitrogen and phosphorus, the latter exhibited more influence on the growth of Lake Norman algae in a laboratory incubator. The laboratory response to phosphorus may not be indicative of the in-situ lake response, however. The principal reason lies in the forms of phosphorus encountered in laboratory and field situations. The amount of phosphorus added to samples was based on the concentration of total phosphorus in the lake water at the time of the assay. However, when the phosphorus was actually added to the samples, it was added as soluble orthophosphate. Gerhold (1974) found that total phosphorus overestimated, and that both soluble orthophosphate and total soluble phosphorus underestimated, the biologically available portion of phosphorus in waters from Lake Wylie, a reservoir downstream from Lake Norman. Assuming these results are generally applicable to Lake Norman because both lakes are formed primarily on the Catawba River, then the response to phosphorus of Lake Norman algae in the laboratory was probably an overestimation of the response to nutrients. A further reason is that the assays were designed to assess worst case conditions due to nutrients because only 44% hypolimnetic water can be discharged yet 100% of the hypolimnetic nutrient concentrations were tested.

The growth response variables sometimes showed less response in the nutrient treatments than in the control treatment. This negative response was interpreted to mean no effect was attributed to the nutrient additions. Although this response could imply that the nutrient addition had a toxic effect on growth, this did not seem to be the case since large net increases in growth were apparent in the combined nutrient treatments. A more likely explanation is in the extreme variability of the data and the error associated with the measurement of the growth response variables at the usually low level of responses.

SUMMARY

The effects of light, temperature, and nutrients on algae were investigated on Lake Norman. The growth response variables chlorophyll a fluorescence, algal cell density, and particulate organic carbon were evaluated from results of bottle test bioassays of indigenous species of phytoplankton at several locations on Lake Norman from 1974 through 1980.

A comparison between chlorophyll a fluorescence in the lake and the net increase in the laboratory nutrient controls was used to investigate the effects of increased temperature on algal growth. Algal growth response was related to both lake temperature at the time of collection and temperature increase from lake to incubator. The latter was the more important factor in determining the response, however.

The addition of phosphorus as orthophosphate to Lake Norman waters resulted in algal production greater than that occurring with the addition of nitrogen as nitrate or ammonia. These observations indicate phosphorus exhibited more influence than nitrogen on the growth response of laboratory-incubated algae.

from the sampled locations on Lake Norman. However, literature reviews indicate that the responses measured under laboratory conditions may be an overestimation of responses that would be observed in the field.

Tested light conditions indicated light adaptation generally occurred in the low level light treatments. The growth responses at both light levels were generally the same.

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Table 5-1. Bioassay sampling history at locations on Lake Norman from 1974 through 1980.

Location		1.0	1.2	3.0	4.0	6.0	7.5	8.0	10.0
	May	BW		B	BW	B	BW		B
	Jun	BW		B	BW	B	BW		B
1	Jul	BW		B	BW	B	BW		B
9	Aug	BW		B	BW	B	BW		B
7	Sep	BW		B	BW	B	BW		B
4	Oct	BW		B	BW	B	BW		B
	Nov	BW		B	BW	B	BW		B
	Dec	BW		B	BW	B	BW		B
	Jan	TW		T	TW	T	TW		T
	Feb	TW		T	TW	T	TW		T
	Mar	BW		B	BW	B	BW		B
1	Apr	W			W		W		
9	May	BW		B	BW	B	BW		B
7	Jun	BW		B	BW		BW		
5	Jul	W			W		W		
	Aug	W			W		W		
	Sep	BW		B	BW		BW		
	Oct	W			W		W		
	Nov	W			W		W		
1	Feb	TP		T	TP			TP	
9	Apr	TP		T	TP			TP	
7	Jul	BP		B	BP			BP	
6	Oct	BP		B	BP			BP	
1	Jan	TP		T	TP			TP	
9	Apr	TP		T	TP			TP	
7	Jul	BP		B	BP			BP	
7	Oct	BP		B	BP			BP	
1	Jan		TP	T	TP			TP	
9	Apr		TP	T	TP			TP	
7	Jul		BP	B	BP			BP	
8	Oct		BP	B	BP			BP	
1	Jan		TP	T	TP			TP	
9	Apr		TP	T	TP			TP	
7	Jul		BP	B	BP			BP	
9	Nov		BP	B	BP			BP	
1	Jan		TP	T	TP			TP	
9	Apr		TP	T	TP			TP	
8	Jul		BP	B	BP			BP	
0	Oct		BP	BP	BP			BP	

Legend

B - Laboratory Thermal-Nutrient Bioassay

W - Weekly lake profiles of temperature, chlorophyll a fluorescence, and light intensity

P - Profiles of lake temperature, chlorophyll a fluorescence, and light intensity taken one week prior to an assay and each week an assay is incubated

T - Laboratory Thermal Bioassay

Table 5-2. Relationship of the chlorophyll a fluorescence response to field and incubator conditions for various lake temperatures and incubator temperature increases. The incubator data are mean values of the corrected final fluorescences.

	Temperature Range (°C)	N	Chlorophyll a fluorescence				\bar{y}^2
			Field	Incubator		Mean Net Increase*	
Ambient lake temperature at time of sample collection	5.5 - 9.0	12	35	91	86	54	10.4
	11.9 - 17.0	24	36	85	69	41	
	20.5 - 25.0	24	20	75	97	66	
	27.5 - 28.5	12	49	62	67	16	
Increase in temperature upon incubation	17.8 - 19.5	12	38	156	196	138	29.3 [†]
	13.3 - 16.8	30	33	78	62	37	
	8.6 - 10.7	18	18	42	44	25	
	6.8 - 7.0	12	49	63	67	16	

*Mean net increase is the fluorescence response for the mean incubator value $((\text{low} + \text{high light})/2)$ less the field value.

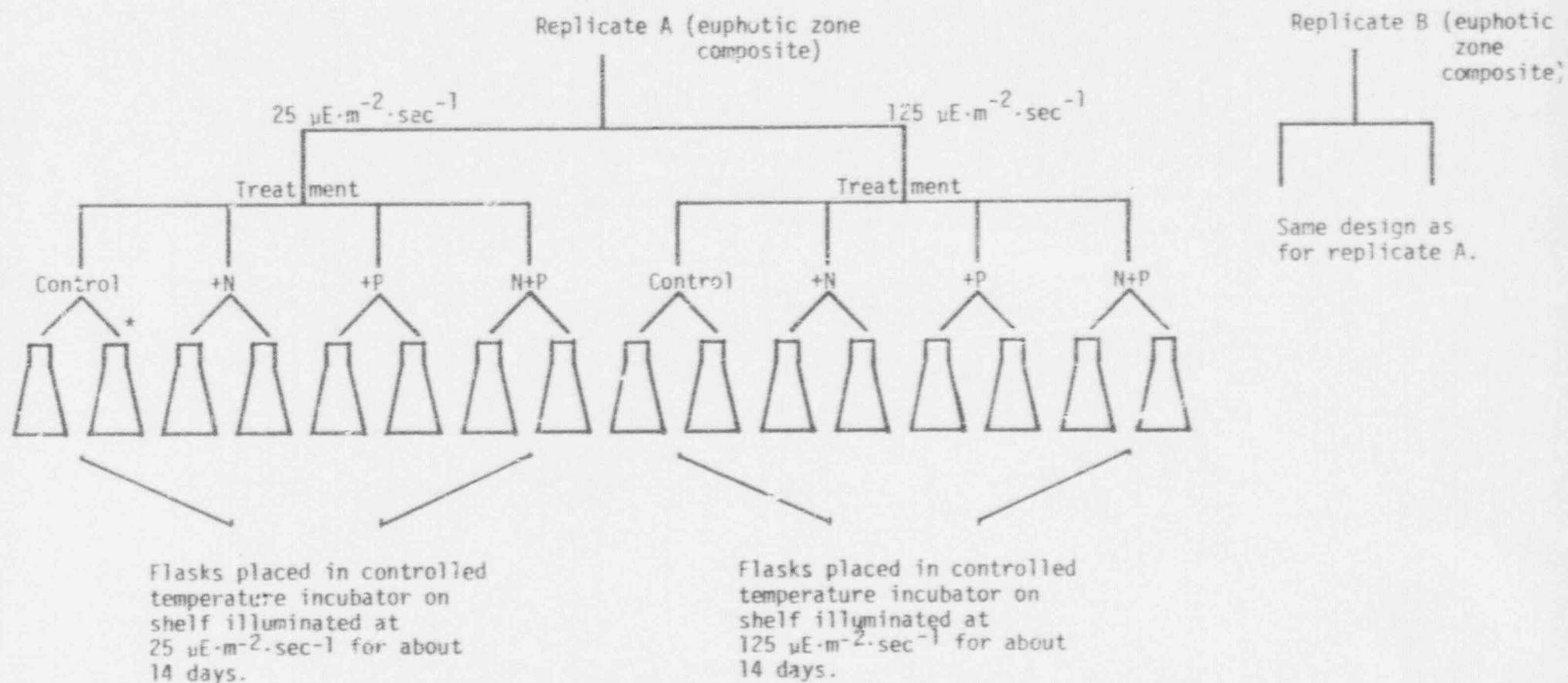
[†]significant at 0.05 level

Table 5-3. Mean net increase (%) in algal cell density and particulate organic carbon for various temperature increases (change between ambient lake temperature and incubator temperature) for quarterly thermal-nutrient bioassays ($125 \mu\text{E}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) from Lake Norman (Locations 1.2, 3.0, 4.0, and 8.0), 1977 through 1979. The levels of treatment were: N - nitrogen spike, P - phosphorus spike, and N+P - nitrogen plus phosphorus spike.

Change in Temperature (°C)	Variable/Treatment	Control	N	P	N+P
6.8-7.0	Cell Density	1836	1591	5336	12180
	POC	73	67	153	142
8.6-10.7	Cell density	885	1220	2588	6976
	POC	155	168	327	448
13.3-16.8	Cell density	1416	2045	3999	5083
	POC

Note: an ellipsis (...) indicates missing data.

Figure 5-1. Experimental design for a thermal-nutrient bioassay for one location on Lake Norman. For a thermal assay only the control treatment is incubated for each replicate. Prior to January 1977 only one euphotic zone composite was collected at each location.



*Each flask is filled with 100 ml of composite sample.

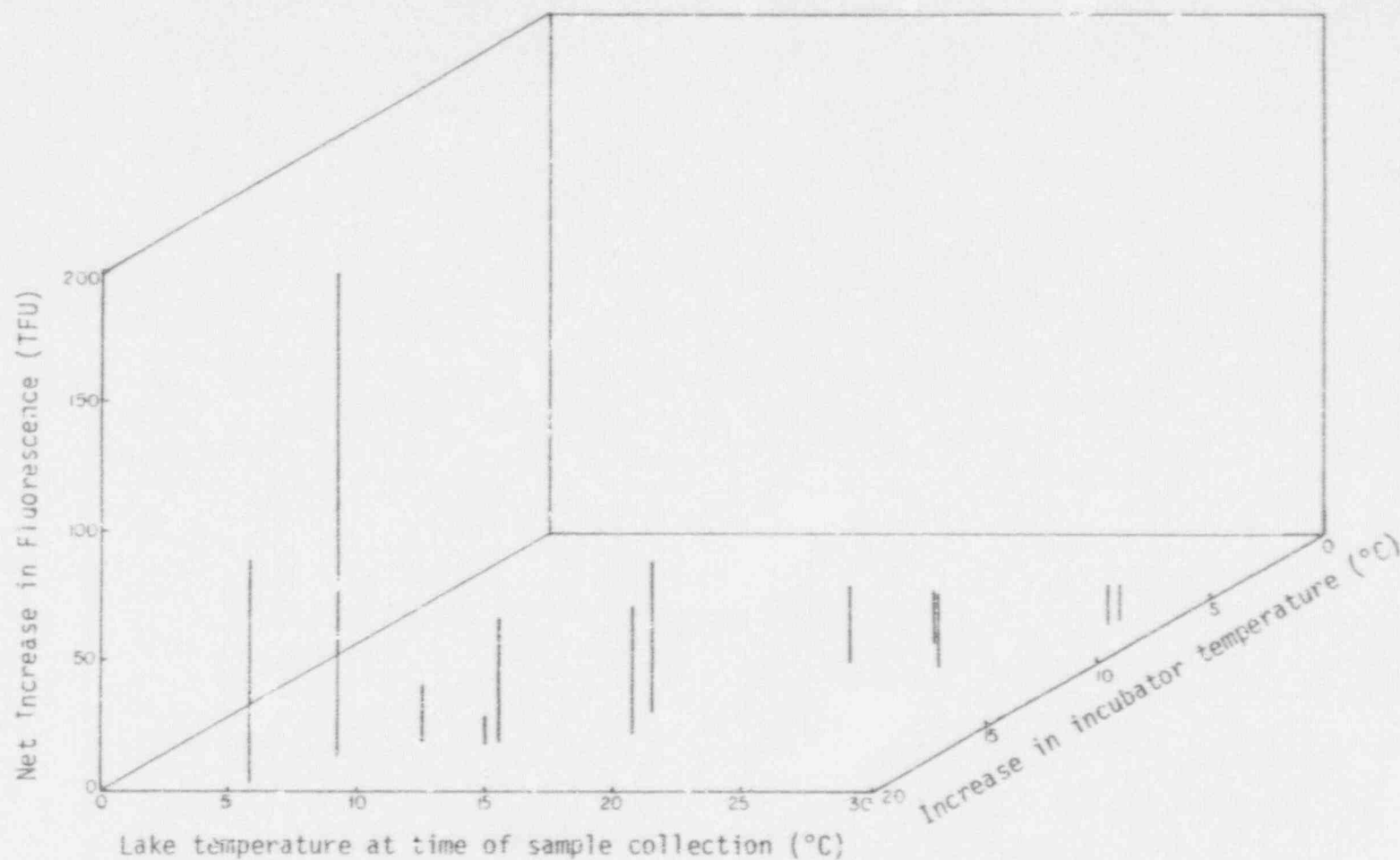


Figure 5-2. Net increase in chlorophyll *a* fluorescence of incubated water compared to ambient lake water near the end of the 14-d incubation period, as related to lake temperature at the time of incubated sample collection and to the increase in temperature resulting from incubation. Each vertical line represents the mean net increase in chlorophyll *a* for each quarterly assay from Lake Norman, 1977 through 1979.

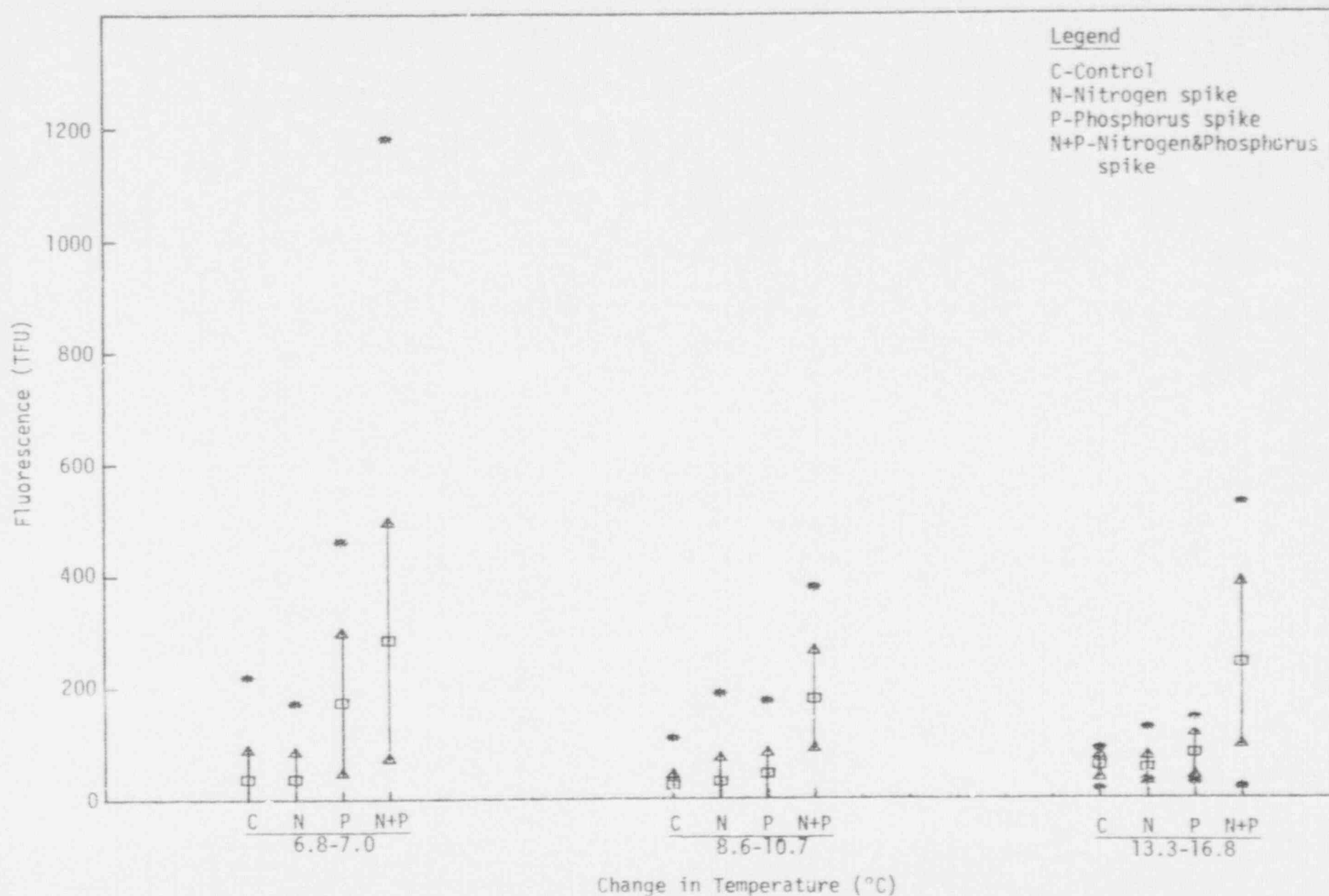


Figure 5-3. Mean (\square) Chlorophyll a fluorescence (TFU) for various temperature increases (change between ambient lake temperature and incubator temperatures) for quarterly thermal-nutrient bioassays ($125 \mu\text{E}\cdot\text{m}^{-2}\cdot\text{sec}^{-1}$ light intensity) from Lake Norman (Locations 1.2, 3.0, 4.0 and 8.0) 1977 through 1979. Each mean is bounded by \pm one standard deviation (Δ) the range (*).

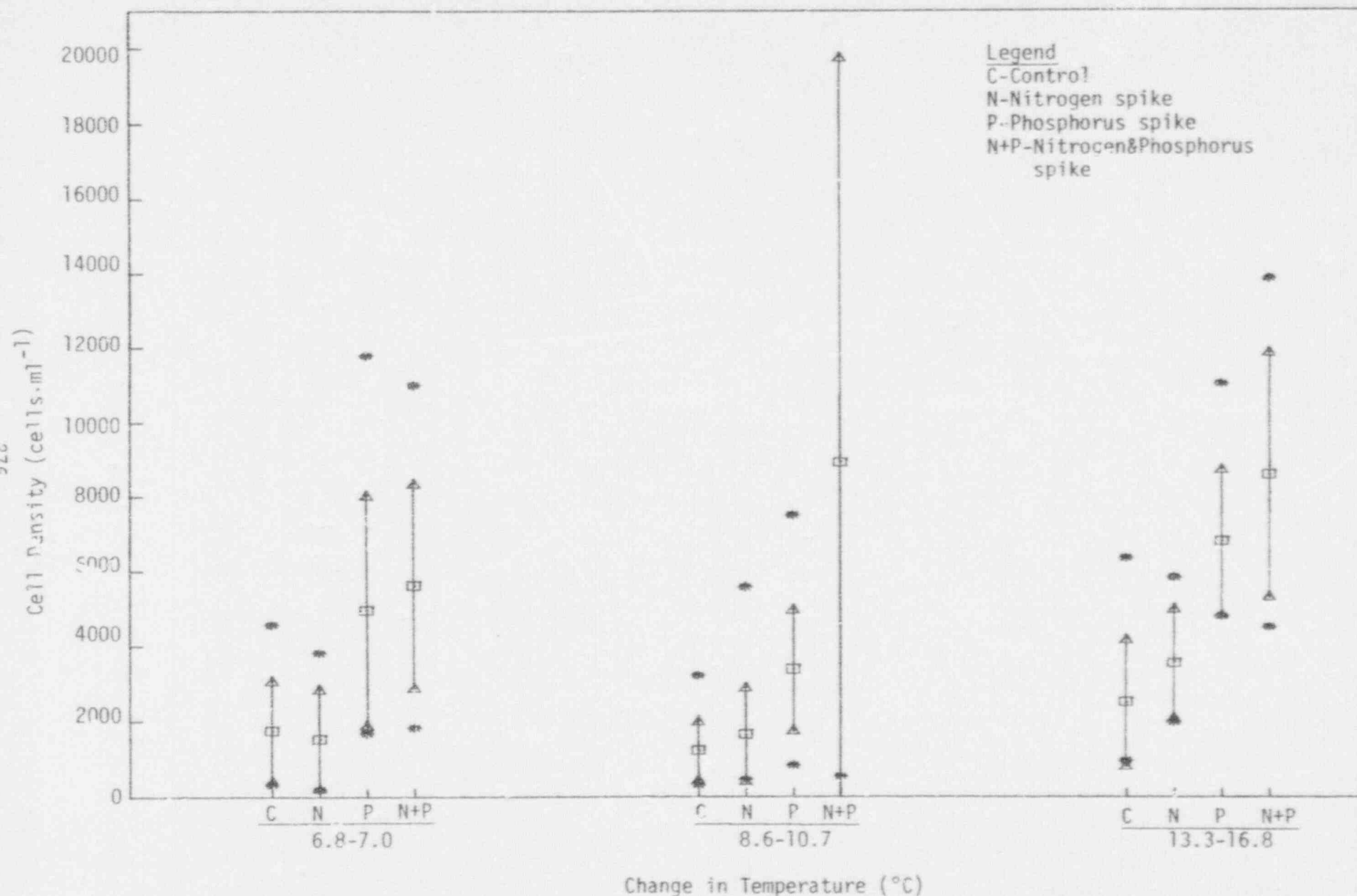


Figure 5-4. Mean (□) algal cell density ($\text{cells} \cdot \text{ml}^{-1}$) for various temperature increases (change between ambient lake temperature and incubator temperatures) for quarterly thermal-nutrient bioassays ($125 \mu\text{E} \cdot \text{m}^{-2} \cdot \text{sec}$ light intensity) from Lake Norman (Locations 1.2, 3.0, 4.0 and 8.0) 1977 through 1979. Each mean is bounded by + one standard deviation (Δ) and the range (*).

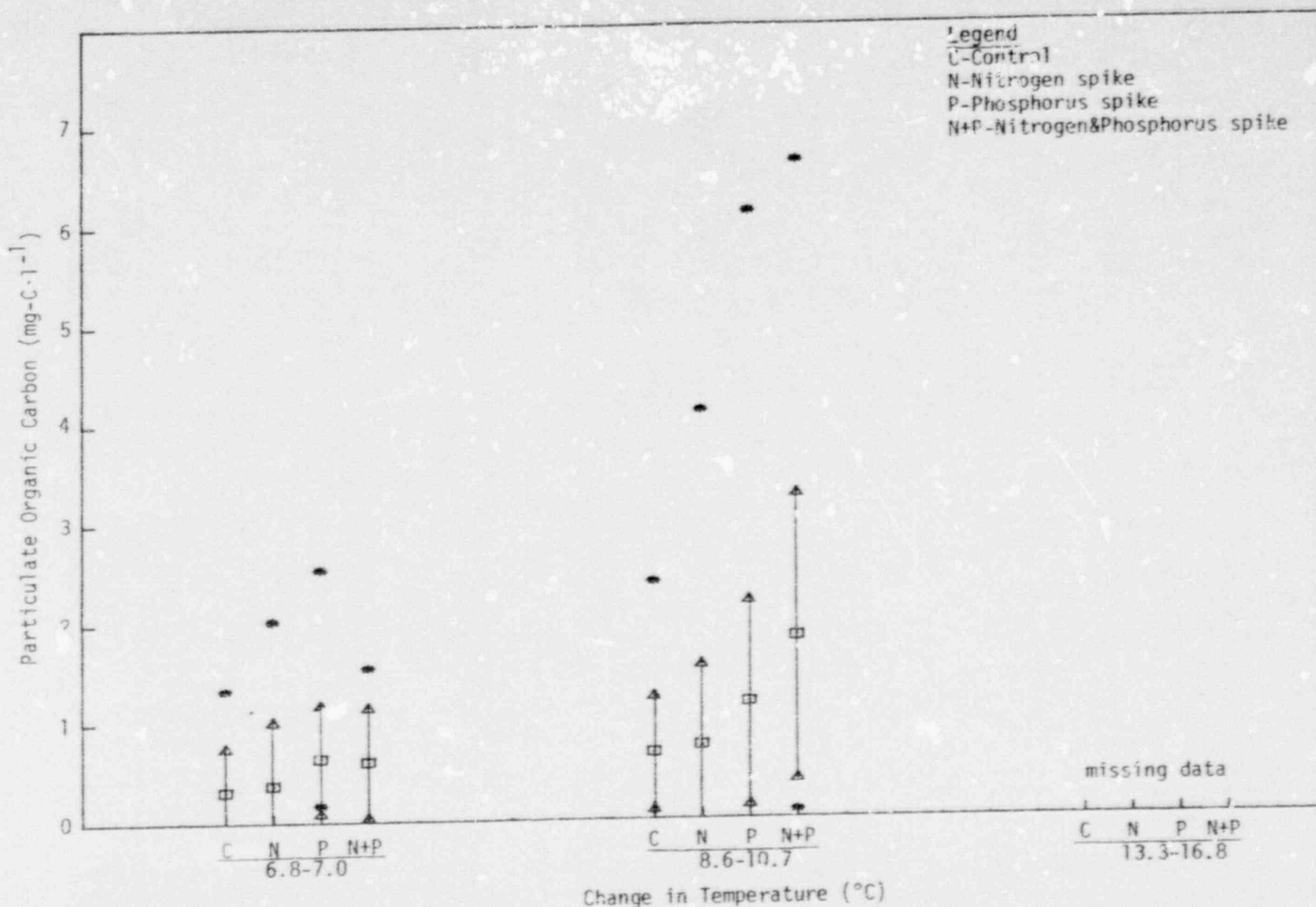


Figure 5-5. Mean (\square) particulate organic carbon ($\text{mg-C}\cdot\text{l}^{-1}$) for various temperature increases (change between ambient lake temperature and incubator temperatures) for quarterly thermal-nutrient bioassays ($125 \mu\text{E}\cdot\text{m}^{-2}\cdot\text{sec}^{-1}$) from Lake Norman (Locations 1.2, 3.0, 4.0 and 8.0), 1977 through 1979. Each mean is bounded by \pm one standard deviation (\triangle) and range (\bullet).

CHAPTER 6. PERIPHYTON

J. E. DERWORT

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INTRODUCTION

BACKGROUND

The term "periphyton" was originally used to describe all organisms attached to submerged artificial substrates and later included all organisms growing on submerged objects (Behning 1924, 1928). In the present work, the term periphyton is used to describe the algal portion of attached communities on submerged substrates (Wetzel and Westlake 1969).

The importance of periphyton on natural substrates as an autotrophic component in large, deep lakes with a small littoral to limnetic ratio has been found to be considerably less than that of phytoplankton (Wetzel 1964). Rodgers (1974) found that the periphyton on the sediments of a large, deep, oligotrophic reservoir (Lake Keowee, SC) constituted less than 2% of the estimated annual production of autotrophs. However, periphyton from fixed, uniform, artificial substrates have been used to estimate the effects of environmental changes on algal growth potential (Odum 1971).

Environmental factors which affect periphyton on artificial substrates in lentic habitats include light, temperature, and nutrient concentration and availability (Benson 1967; Brown 1973; Weiss 1974). Previous studies have indicated that the interrelated physical variables of light and temperature are the major factors influencing the seasonal distribution of periphyton on artificial substrates in lentic habitats (Duke Power Company 1976, 1977; Hynes 1970; Lund 1965). Studies on Lake Norman, NC, have shown that maximum periphyton accumulation rates occurred during periods of warm temperatures and high light intensity (Duke Power Company 1976; Weiss 1974). Weiss (1974), in a study near Marshall Steam Station on Lake Norman pointed out that depth (presumably light intensity) affects the standing crop of periphyton on artificial substrates to the greatest extent. Results of a five-year study of the operational effects of Oconee Nuclear Station on the periphyton of Lake Keowee, SC (Duke Power Company 1977) showed that warmer temperatures and greater nutrient availability as a result of current in the discharge canal brought about higher rates of organic accumulation and greater periphyton standing crops in the discharge area than at other locations. Also, due to the slightly more acidic hypolimnetic water, acidophilous algae were found in greater numbers in the discharge than at other locations.

Because periphyton on artificial substrates are not as subject to certain physical variables (e.g., vertical mixing) as are phytoplankton, they reflect seasonal changes in light, temperature, and nutrients. Also, periphyton communities on artificial substrates placed at selected locations on reservoirs have been used to determine the effects of man-induced changes in water quality on the algal component of autotrophic communities (Butcher 1946; Duke Power Company 1977; Jackson 1974; Weiss 1974).

OBJECTIVES

The objectives of this study were to:

- 1) document the taxonomy of Lake Norman periphyton from artificial substrates,

- 2) describe the seasonal patterns of periphyton standing crop from artificial substrates, and
- 3) examine spatial patterns of periphyton standing crop on artificial substrates prior to the operation of McGuire Nuclear Station.

MATERIALS AND METHODS

FIELD PROCEDURES

Monthly periphyton sampling was initiated at Locations 1.0, 3.0, 4.0, and 6.0 in February 1973. Location 10.0 was added to the sampling program in June 1973. Materials and methods used from the initiation of sampling through March 1975 were presented previously by Duke Power Company (1976). All location additions and deletions, and changes in field and laboratory procedures are presented in Table 6-1, and location descriptions are presented in Chapter 1 (Table 1-3, Figs. 1-10 and 1-11).

Beginning in April 1975, glass microscope slides (2.5 x 7.5-cm) were used as artificial substrates (Table 6-1). Eight slides were placed in a Periphytometer IITM cartridge, and suspended horizontally at 1.5 m for an exposure period of approximately four weeks (Cooke 1956; Newcomb 1949; Weiss 1974; Wetzel 1964). Four to six slides, to be analyzed for organic accumulation, were placed in a metal slide rack and allowed to air dry. The remaining slides were stored for diatom community composition analysis.

In May 1976 sampling began at Location 8.0, and slide orientation was changed from horizontal to vertical (Patrick et al. 1954; Squires et al. 1973). Locations 16.0 (in Mountain Island Lake) and 1.2 (McGuire Nuclear Station intake) were added to the sampling program in May and October 1977, respectively. Slides at Location 16.0 were placed at or near the surface due to the shallow and variable depth. Locations 15.9 and 34.0 were added on 1 June 1978, and Locations 13.0 and 14.0 were added on 29 June 1978 (Table 6-1).

Additional slides were collected for pigment analyses starting in May 1977. Two slides, to be used for total community composition analyses (diatoms and non-diatoms), were placed in 60-ml, wide-mouth bottles and preserved in the field with M3 preservative (Meyer 1971). Three slides, to be used for chlorophyll analyses, were placed in darkened 60-ml, wide-mouth bottles, and were crushed with a stainless steel rod. Ten milliliters of 90% acetone were added to extract the chlorophyll, and the bottles were placed on ice in the dark until returned to the laboratory. Three slides were used for organic accumulation analysis.

Sediments from Locations 4.0 and 6.0 were collected on a seasonal basis from the summer of 1974 through the summer of 1979. Community composition on natural substrates was compared with community composition on artificial substrates.

PHYSICOCHEMICAL MEASUREMENTS

Physicochemical data were obtained from water chemistry studies (Chapter 3). Solar radiation data were obtained from a pyranometer located at the Duke Power Environmental Laboratories near Lake Norman, NC.

LABORATORY PROCEDURES

Periphyton from exposed glass slides were analyzed by the ash-free dry weight procedures in American Public Health Association et al. (1971) with the exception that each slide was placed in a numbered, pre-weighed Pyrex(R) tube rather than scraped into a crucible (Lawson et al. 1978). This technique minimized handling error. The ash-free dry weights (representing total accumulated organic mass) were expressed as grams per square meter ($\text{g}\cdot\text{m}^{-2}$). The organic accumulation rates (representing accumulated organic mass per unit of time) were expressed as milligrams per square meter per day ($\text{mg}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$).

Algal species composition and relative abundance were analyzed from duplicate preserved slides. Samples were mixed in a Waring(R) blender to ensure even distribution of organisms (Weber 1973), and the sample volume was measured and recorded. After uniformly resuspending the scraped algae, a 0.1-ml aliquot from the sample was placed in a Palmer-Maloney counting slide (Palmer and Maloney 1954). Non-diatom organisms were counted and identified to the lowest practicable taxonomic level under 500X phase contrast illumination. Unicellular forms were enumerated as each cell, colonial forms as each colony, and filamentous forms were recorded as 18- μm lengths. Diatoms observed under 500X were counted as each frustule, with or without cell contents, regardless of taxon. In each sample, a total of 100 to 500 units was counted and the number of fields or transects examined was recorded. Counts of all algae, excluding empty diatom frustules, were converted to densities and expressed as units per square meter ($\text{units}\cdot\text{m}^{-2}$).

Diatom slides were prepared using the nitric acid cleaning method of Hohn and Hellerman (1963) and were counted under oil immersion at 1250X (phase contrast illumination). When practical, at least 500 valves per sample were counted and each was identified to the lowest practicable taxon. The proportion of each diatom taxon in the sample was calculated, and multiplied by the total density of diatom cells with cell contents observed under 500X to obtain the densities of diatom taxa in $\text{units}\cdot\text{m}^{-2}$. Sediment samples were counted using the same procedures, with the exception that only the relative abundance of algal taxa could be calculated.

Taxonomic keys used for the identification of algae included Cleve-Euler (1953), Cocke (1967), Hustedt (1930), Kim (1967), Patrick and Reimer (1966, 1975), Prescott (1962), Smith (1950), Taft and Taft (1971), Tiffany and Britton (1952), Van Heurck (1896), Weber (1971), and Whitford and Schumacher (1973). Dr. Larry Whitford and Dr. Charles Reimer were retained as consultants to confirm the identifications of non-diatoms and diatoms, respectively.

The mean biovolume of each species was calculated by applying the average cell dimensions, measured over the period of the study to the volume formula of an approximate geometric solid (Cowell 1960; Hohn 1969). This value was then multiplied by the respective numerical density to obtain a biovolume estimate in cubic millimeters per square meter ($\text{mm}^3\cdot\text{m}^{-2}$). Equations formulated by Strathman (1967) were used to convert total biovolume to algal carbon.

Prior to blending the samples, *Sida crystallina* O. F. Muller (Ward and Whipple 1959), the most apparent and common microinvertebrate observed on sample

slides, was enumerated by counting a 1-ml aliquot under 78X. The density of this organism was calculated on the basis of units·m⁻². Dry weights and ash-free dry weights for *Sida crystallina* were calculated based on equations developed by Duke Power biologists and those of Strickland (1960) and were expressed as mg·m⁻².

Samples for pigment analyses were held in the dark at <0° C for at least seven days prior to analyses to aid in chlorophyll extraction. Chlorophyll *a* and phaeopigment concentrations were determined with a Coleman 124 double beam spectrophotometer, using methods and calculations outlined in Strickland and Parsons (1972).

DATA ANALYSES

Data from March 1973 through December 1980 are presented in Appendix 6.1. The two years of data analyzed in the text represents the most complete period of data with respect to locations sampled and variables analyzed.

An index of dominance was calculated for each exposure period using a modified method of Simpson (1949). Species comprising 5% or more of the density or biovolume at some time during the study, and all classes, regardless of percent composition, were analyzed with the dominance index:

$$C_j = \sum_{i=1}^n \left(\frac{N_{ij}}{N_i} \right)^2 \cdot R_{ij} \cdot F_j^2$$

where: *n* = number of exposure periods

i = exposure period

C_j = index of dominance of *j* th taxon over all exposure periods

N_{ij} = density and/or biovolume of *j* th taxon in *i* th exposure period

N_i = density and/or biovolume of all taxa in the *i* th exposure period

R_{ij} = inverse rank of $C_{ij} = \left(\frac{N_{ij}}{N_i} \right)^2$ for *i* th exposure period, and

F_j = frequency of *j* th taxon for all exposure periods

RESULTS AND DISCUSSION

COMMUNITY COMPOSITION

Four hundred thirty-one algal taxa were identified from artificial and natural substrate samples collected in Lake Norman and Mountain Island Lake, including 9 classes, 94 genera, and 365 species (Tables 6-2 and 6-3; App. Table 6.1-1).

Diatoms (Bacillariophyceae) were the most abundant algae, ranking number 1 by dominance index for density and biovolume at all locations, for lower lake locations (Locations 1.0, 1.2, 3.0, 4.0, 6.0, and 8.0), for upper

lake locations (Locations 13.0, 14.0, 15.9, and 34.0), and for Location 16.0 in Mountain Island Lake. Diatoms generally contributed over two-thirds to the total density and over three-fourths to the total biovolume in all areas of the study, with the exception of Location 16.0, where diatoms constituted only a little over one-half of the total biovolume (Table 6-4). A previous study at Lake Keowee, SC, also found that the periphyton was composed primarily of diatoms (Duke Power Company 1977).

The green algae (Chlorophyceae) and blue-green algae (Myxophyceae) were ranked numbers 2 and 3, respectively, for density and biovolume indices at all locations. The Chlorophyceae were more important, in terms of biovolume, at Location 16.0 where they constituted nearly 50% of the total biovolume, due primarily to the presence of Stigeoclonium spp., a filamentous taxon which was abundant during April and May. The Myxophyceae were more abundant at upper lake locations and ranked number 2 by density dominance index among these locations, due primarily to the abundance of a filamentous blue-green, Lyngbya ochracea, during June and July. Even though the Chlorophyceae often constituted a substantial portion of the total densities at uplake locations during the summer, they seldom contributed over 5% to the total biovolume at any location on any sample date. The other classes, with the exception of the Dinophyceae, had dominance indices of less than 3.0, constituted less than 1.0% of the total density and biovolume, and were considered inconsequential. Although the dinoflagellates exhibited relatively high biovolume dominance indices (69.9 for all locations combined, 48.9 for lower lake locations), these indices were due to the presence of a few very large taxa which occurred infrequently within certain sample periods. Generally, the Dinophyceae ranked low (5 to 7) by monthly dominance rank, or were not present at all (Table 6-4). Diatoms, green algae, and blue-green algae were generally most abundant from May through June, and least abundant from February through March.

Achnanthes microcephala, an ubiquitous, eurytrophic diatom (Patrick and Reimer 1966), was the dominant species by density and biovolume dominance indices at all locations (Table 6-5). This species was also the dominant taxon found in a study of Lake Keowee, SC (Duke Power Company 1977). Most of the diatoms ranked by the indices, as well as Lyngbya ochracea and Nannochloris spp., have been described as ubiquitous and cosmopolitan (Cocke 1967; Lowe 1974; Prescott 1962). Members of the genus Mougeotia have been described as commonly lentic (Prescott 1962), and certain members of this genus have often been found in areas of low pH (Duke Power Company 1977; Hendrey 1976; Muller 1980). Stigeoclonium spp., a rheophyllous, cool water taxon common in North Carolina streams (Whitford and Schumacher 1963), ranked high by the dominance indices at Location 16.0. This taxon was also abundant in the Broad River (Lawson and Buetow 1978).

Seasonal variations in species composition were similar among all locations during the study. Smaller taxa, predominantly Achnanthes microcephala ($128 \mu\text{m}^3$), dominated periphyton communities from May through December. Nannochloris spp. ($12 \mu\text{m}^3$) and Lyngbya ochracea ($18 \mu\text{m}^3$) were important numerically (ranking between 1 and 3 by monthly density dominance index) during exposure periods from June through August. During January through April, taxa such as Synedra rumpens ($229 \mu\text{m}^3$), Gomphonema parvulum ($285 \mu\text{m}^3$), and the large centrate, Melosira varians ($7800 \mu\text{m}^3$) often became dominant, ranking from

1 to 3 by monthly density and biovolume indices. Certain large filamentous green algae were also important periodically throughout the study. Stigeoclonium spp. ($650 \mu\text{m}^3$) was important at Location 16.0 in April 1978 and May 1979, and Mougeotia sp. B, ($728 \mu\text{m}^3$) was important among lake locations in June 1978 and 1979, and October 1978. Certain larger taxa such as Synedra ulna ($4500 \mu\text{m}^3$), Mougeotia sp. B, and S. delicatissima ($2700 \mu\text{m}^3$) were more important at upper lake locations than other locations during certain periods (Table 6-5).

Periphyton communities on natural substrates collected at Locations 4.0 and 6.0 were also composed primarily of diatoms (82.0%), while green algae and blue-green algae ranked 2 and 3, respectively (Table 6-6). Only 23 taxa, mostly of rare (<6.8%) occurrence (Table 6-2), were found exclusively on natural substrates (App. Table 6.1-2).

Achnanthes microcephala also dominated natural substrate samples and ranked number 1 during all seasons. Navicula notha, Anomoeoneis vitrea, and Lyngbya ochracea, although ranked by density dominance index for artificial substrates in certain areas, were ranked higher for natural substrates (Table 6-5). The other species presented in Table 6-5, while commonly found on artificial substrates, were relatively more abundant on natural substrates.

STANDING CROP

Standing crop has been defined by Strickland (1960) as "the instantaneous value of the amount of living plant material present in the water"; the "plant material" in this case being algae. A number of variables have been measured in an effort to estimate algal standing crop, including ash-free dry weight, density, biovolume, pigment concentration, and algal carbon (Harris 1978; Lawson et al. 1978; Lawson and Buetow 1978; Mullins et al. 1966; Strathman 1967; Strickland 1960). Algal carbon, calculated from biovolume measurements (Strathman 1967) and chlorophyll *a* (Strickland and Parsons 1972) have been considered better estimates of algal standing crop than density or ash-free dry weight, since the measurement of these variables represents the "amount of living plant material" in terms of the size or biovolume of individuals (algal carbon) or by direct measurement of a common and unique algal constituent (chlorophyll *a*).

The results of Weiss's (1974) study of total organic accumulation (measured by the dichromate oxidation method) were similar, on a seasonal basis, to the organic accumulation results (using ash-free dry weights) presented in this study. However, errors associated with the use of ash-free dry weight measurements as indicators of autotrophic standing crop have occurred due to the inclusion of non-algal matter such as detritus and aquatic invertebrates (Duke Power Company 1977; Lawson et al. 1978; Lawson and Buetow 1978). Total ash-free dry weights (Tables 6-7 and 6-8) and the ash-free dry weights of Sida crystallina, algae, and organic non-algal material (detritus, extracellular material, dead cells, etc.) were compared on a seasonal basis (Fig. 6-1). The ash-free dry weights of algae and S. crystallina were calculated as described earlier. The ash-free dry weights of organic non-algal material were arrived at by subtracting algal and S. crystallina ash-free dry weights from total ash-free dry weights. Although the ash-free dry weights of all variables followed similar trends, total ash-free dry weights ranged

from 8 to 37 times greater than algal ash-free dry weights (Fig. 6-1). Also, ash-free dry weights from the 1973-1974 (Duke Power Company 1976) and 1975-1976 sampling periods were generally greater than ash-free dry weights from the 1977-1979 sampling periods (Tables 6-7 and 6-8; Fig. 6-2; App. Table 6.1-3). This difference was probably due to the use of horizontal substrates during all of the 1973-1974 sampling periods (Duke Power Company 1976), and during most of the 1975-1976 sampling periods (Table 6-1). Horizontal substrates tend to have greater amounts of organic accumulation from non-algal matter (invertebrates and detritus) and pseudoperiphyton which settle on to the exposed surfaces of slides (Castenholz 1960; Foris 1976). These data indicate that ash-free dry weights, although of use in determining total organic accumulation, do not provide an accurate estimate of autotrophic material on the substrates.

Algal densities have been used to estimate algal standing crop by representing the "amount of living plant material" in terms of individuals per unit of area. However, the sizes (i.e., biovolumes) of the individuals counted in this study varied more than four orders of magnitude: from $1 \mu\text{m}^3$ (*Coccolithus* spp.) to approximately $45,000 \mu\text{m}^3$ (*Peridinium aciculiferum*). Densities in this study exhibited considerable variation among years, months, and locations when compared to mean cell sizes (Figs. 6-3 and 6-4). Therefore, biovolumes (Table 6-9; Fig 6-5; App. Table 6.1-1), which reflect algal carbon (Strathman 1967), have been considered better estimates of standing crop than densities due to extreme variations in biovolume among different species (Lawson and Buetow 1978; Vollenweider 1974).

Maximum algal carbon and chlorophyll *a* values occurred in May and June, while minimum values typically occurred in February and March (Table 6-10; Figs. 6-6 through 6-9; App. Table 6.1-3). During May and June, when light intensities and temperatures were high, stratification had begun to develop, but nutrient values were still high relative to late summer concentrations. During part of the isothermal period (February through March), nutrient values were higher than those of the May through June, or July through September periods, but light intensities and temperatures were low (Table 6-11). However, periphyton standing crops declined throughout the summer months (July through September). This may indicate low nutrient availability, since light and temperature remained high, or the possibility of predation by invertebrates, since total ash-free dry weights did not decline as rapidly as algal ash-free dry weights (Fig. 6-1).

The tendency for species mean cell sizes to increase during the period of low light and temperature (Figs. 6-4 and 6-7), indicates that turnover rate and/or growth declined due to the effects of low light and temperature. However, with the onset of increased standing crops in May, cell size rapidly decreased, possibly indicating a dependence on nutrient availability, since maximum metabolic and nutrient uptake rates are typically exhibited by small cells with high surface to volume ratios (Harris 1978).

A comparison of epilimnetic phytoplankton carbon ($\text{mg}\cdot\text{m}^{-2}$, from weekly measurements at Locations 3.0 and 8.0) (Chapter 4) with periphyton carbon ($\text{mg}\cdot\text{m}^{-2}$) during the isothermal period (November through April) indicate the effects of vertical mixing on the phytoplankton (Fig. 6-7). The periphyton standing

crop was lowest throughout most of the isothermal period, reflecting low light and temperature conditions, while the phytoplankton standing crops were influenced by vertical mixing which results in the resuspension of algae (Chapter 4). The March-April peak in phytoplankton standing crop (primarily *Melosira* spp.) was probably due to the effects of increased light and temperature, and/or vertical mixing throughout the water column. However, with the onset of lake stratification in May and June, the phytoplankton standing crops declined, since organisms settled into the hypolimnion. In contrast, the periphyton increased rapidly due to the relatively high nutrient availability and increased light and temperature. The August-September peak in phytoplankton standing crops was not reflected by the periphyton, which could indicate the effects additional physical and chemical factors coupled with the possibility of selective invertebrate predation on periphyton communities. Therefore, phytoplankton tend to reflect seasonal changes in light, temperature, nutrients, and mixing, while periphyton on artificial substrates suspended at a given depth, tend to minimize effects of vertical mixing, but are useful indicators of algal responses to light, temperature, and nutrients.

Although algal carbon and chlorophyll *a* values were often higher at upper lake locations than at other locations, these variations were generally small when compared with seasonal variations (Figs. 6-3 through 6-9), and were probably due to spatial variations of turbidity with subsequent nutrient and light effects. Variability at Location 16.0 could have been due to several factors: exposure of substrates at the surface, periodic fluctuations in current, and increased nutrient availability due to current and runoff.

SUMMARY

Periphyton samples from artificial substrates suspended at 1.5 m for an exposure period of approximately four weeks were collected from locations in Lake Norman, NC, from March 1973 through December 1980. The data presented and analyzed in this report include primarily standing crop and community composition data from Locations 1.0, 1.2, 3.0, 4.0, 6.0, 8.0 and 16.0 for the period 8 July 1977 through 6 July 1979, and Locations 13.0, 14.0, 15.9, and 34.0 for the period 1 June 1978 through 6 July 1979. All data including data not summarized in this report are presented in the appendix to this chapter.

Bacillariophyceae was the dominant class of algae observed during the study, comprising over two-thirds of the total densities and three-fourths of the total biovolumes at all locations, with the exception of Location 16.0, where diatoms constituted a little over one-half of the total biovolume. The Chlorophyceae, predominantly *Nannochloris* spp., ranked second in overall importance, but were more important in terms of biovolume at Location 16.0 due to the abundance of *Stigeoclonium* spp. during April and May sampling periods. The Myxophyceae, dominated by *Lyngbya ochracea*, ranked third in overall importance, but were more abundant at upper lake locations than at lower lake locations and Location 16.0.

Most of the taxa ranked by dominance index have been characterized as ubiquitous and cosmopolitan and few differences were noted in species composition

between upper lake locations, lower lake locations, and Location 16.0, with the exceptions that certain larger taxa were more important in the upper lake, and *Stigeoclonium* spp. was a major taxon at Location 16.0. *Achnanthes microcephala*, a small pennate diatom, was the dominant species at all locations on artificial and natural substrates. Smaller taxa dominated the periphyton from May through December, with increasingly larger forms becoming more predominant from December through April. Therefore, mean unit size tended to show an inverse seasonal relationship with standing crop variables.

Algal carbon and chlorophyll *a* were the best available estimates of periphyton algal standing crop. Ash-free dry weights overestimated autotrophic accumulation due to the inclusion of non-algal matter (invertebrates and detritus), and densities generally showed variability based on extreme variations in cell size, with large fluctuations of units per square meter corresponding to small variations in biomass.

Maximum algal carbon and chlorophyll *a* values occurred in May and June, when light, temperature, and nutrients were high. Minimum values occurred in February and March, when nutrients were high, but light and temperature were low. Although light and temperature were high during the summer, standing crop values decreased, possibly due to low nutrient availability as evidenced by the increase in the number of cells with high surface to volume ratios, and/or increased predation. Therefore, growth was primarily a function of light and temperature, except during late summer (July through September) when low nutrient availability and/or increased predation may have brought about a decrease in standing crops. Major class standing crops followed the same seasonal trends as periphyton standing crop. Periphyton were useful indicators of algal responses to seasonal changes in light, temperature, and nutrients since they were not subject to vertical mixing as were the phytoplankton.

Differences among locations in the upper lake and the lower lake were minimal compared to seasonal differences and were probably due to small variations in turbidity and nutrient availability. Variability at Location 16.0 was probably due to such factors as exposure depth, current fluctuation and nutrient availability.

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Table 6-1. Periphyton sampling history at locations on Lake Norman, from February 1973 through December 1980.

Sampling Program	Locations											
	1.0	1.2	3.0	4.0	6.0	8.0	10.0	13.0	14.0	15.9	16.0	34.0
February - May 1973 Ash-free dry weight (HP)	M2		M2	M2	M2							
June 1973 - April 1975 Same as above	M2		M2	M2	M2		M2					
May 1975 - January 1976 Ash-free dry weight (HG)	M2		M2	M2	M2		M2					
February - April 1976 Same as above	M2		M2	M2	M2							
May 1976 - January 1977* Ash-free dry weights (VG)	M2		M2	M2	M2	M2						
April 1977 - September 1977 Ash-free dry weight, chlorophyll, community composition (VG)	M2		M2	M2	M2	M2					M2	
October 1977 - May 1978 Same as above	M2	M2	M2	M2	M2	M2					M2	
June 1978 - July 1979 Same as above	M2	M2	M2	M2	M2	M2		M2	M2	M2	M2	M2
July 1979 - December 1980 Same as above	M2	M2	M2	M2	M2	M2					M2	
July 1974 - July 1979 Community composition (NS)				Q1	Q1							

*Sampling discontinued at all locations from January through April 1977. Data from May and June are presented in App. Tables 6.1-1 and 6.3-3.

M - Monthly

Q - Quarterly

HP- Horizontal plexiglass substrates

HG- Horizontal glass substrates

VG- Vertical glass substrates

NS- Natural substrates

1 - No replication

2 - Duplicate samples collected

Table 6-2. Distribution of taxa among algal classes from all periphyton samples collected in Lake Norman and Mountain Island Lake.

	<u>Genera</u>	<u>Species</u>
Bacillariophyceae	31	216
Chlorophyceae	36	80
Myxophyceae	12	40
Chrysophyceae	7	10
Euglenophyceae	2	7
Dinophyceae	2	6
Cryptophyceae	2	4
Xanthophyceae	1	1
Haptophyceae	1	1
Total	94	365

Table 6-3 (continued)

<i>Phymatopteris</i> var. <i>seazonica</i> (Rabenh.) Detoni	1.1	*	N. <i>laevis</i> Hantz.	1.8	*
<i>Phymatopteris</i> (Thwaites) Detoni	1.8	9.1	N. <i>dentata</i> Grun.	13.1	*
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>distans</i> (Kütz.) Grun.	0.4	15.9
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>filiformis</i> (W. Smith) Schott	0.4	*
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>fruticulosa</i> Grun.	1.3	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	42.0	40.9	N. <i>fruticulosa</i> (Kütz.) Grun.	5.1	6.8
<i>Phymatopteris</i> (Thwaites) Detoni	8.0	*	N. <i>fruticulosa</i> var. <i>perpusilla</i> (Rabenh.) Grun.	1.8	*
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>gracilis</i> Hantz.	3.3	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	3.9	2.3	N. <i>graciloides</i> Grun.	0.4	*
<i>Phymatopteris</i> (Thwaites) Detoni	1.2	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	9.8	27.3	N. <i>graciloides</i> Hiltz	0.4	*
<i>Phymatopteris</i> (Thwaites) Detoni	4.0	*	N. <i>graciloides</i> Hiltz	0.4	*
<i>Phymatopteris</i> (Thwaites) Detoni	1.4	*	N. <i>graciloides</i> Hiltz	0.4	*
<i>Phymatopteris</i> (Thwaites) Detoni	2.9	*	N. <i>graciloides</i> Hiltz	0.4	*
<i>Phymatopteris</i> (Thwaites) Detoni	1.4	*	N. <i>graciloides</i> Hiltz	0.4	*
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	*
<i>Phymatopteris</i> (Thwaites) Detoni	93.8	57.3	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	2.1	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.7	2.3	N. <i>graciloides</i> Hiltz	0.4	*
<i>Phymatopteris</i> (Thwaites) Detoni	99.6	80.4	N. <i>graciloides</i> Hiltz	0.4	*
<i>Phymatopteris</i> (Thwaites) Detoni	1.1	*	N. <i>graciloides</i> Hiltz	0.4	*
<i>Phymatopteris</i> (Thwaites) Detoni	0.7	*	N. <i>graciloides</i> Hiltz	0.4	*
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	*
<i>Phymatopteris</i> (Thwaites) Detoni	25.1	*	N. <i>graciloides</i> Hiltz	0.4	*
<i>Phymatopteris</i> (Thwaites) Detoni	5.1	*	N. <i>graciloides</i> Hiltz	0.4	6.8
<i>Phymatopteris</i> (Thwaites) Detoni	1.1	*	N. <i>graciloides</i> Hiltz	0.4	11.4
<i>Phymatopteris</i> (Thwaites) Detoni	8.0	*	N. <i>graciloides</i> Hiltz	0.4	20.4
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	*
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	*
<i>Phymatopteris</i> (Thwaites) Detoni	1.8	2.3	N. <i>graciloides</i> Hiltz	0.4	4.5
<i>Phymatopteris</i> (Thwaites) Detoni	9.1	2.3	N. <i>graciloides</i> Hiltz	0.4	*
<i>Phymatopteris</i> (Thwaites) Detoni	94.0	63.8	N. <i>graciloides</i> Hiltz	0.4	*
<i>Phymatopteris</i> (Thwaites) Detoni	1.8	11.4	N. <i>graciloides</i> Hiltz	0.4	4.5
<i>Phymatopteris</i> (Thwaites) Detoni	21.6	75.0	N. <i>graciloides</i> Hiltz	0.4	4.5
<i>Phymatopteris</i> (Thwaites) Detoni	39.6	91.4	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	65.8	34.1	N. <i>graciloides</i> Hiltz	0.4	*
<i>Phymatopteris</i> (Thwaites) Detoni	70.9	36.4	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	83.6	18.2	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	1.1	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	1.1	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	2.2	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	8.0	18.2	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	1.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	3.6	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	3.2	15.9	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	1.1	4.5	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	44.0	20.4	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	3.6	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.7	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	1.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.7	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.7	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	5.1	15.9	N. <i>graciloides</i> Hiltz	0.4	4.5
<i>Phymatopteris</i> (Thwaites) Detoni	0.7	*	N. <i>graciloides</i> Hiltz	0.4	4.5
<i>Phymatopteris</i> (Thwaites) Detoni	0.7	*	N. <i>graciloides</i> Hiltz	0.4	4.5
<i>Phymatopteris</i> (Thwaites) Detoni	2.2	9.1	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	2.9	2.3	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	10.5	22.1	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	2.9	2.3	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	1.1	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	2.5	2.3	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	1.1	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.7	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	79.3	90.9	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	5.8	6.8	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3
<i>Phymatopteris</i> (Thwaites) Detoni	0.4	*	N. <i>graciloides</i> Hiltz	0.4	2.3

Table 6-3 (continued)

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Division Cyanophyta

Class Myxophyceae

<i>Agmenellum guardriduplicatum</i> Bréb.	4.2	*
<i>A. thermale</i> (Kütz.) Drouet and Daily	0.9	*
<i>Anabaena</i> sp.	8.8	2.3
<i>Anacystis cyanea</i> Drouet and Daily	0.5	*
<i>A. incerta</i> Drouet and Daily	0.5	*
<i>A. montana</i> (Light.) Drouet and Daily	1.8	*
<i>A.</i> sp.	0.9	6.8
<i>Calothrix</i> sp.	1.4	2.3
<i>Chroococcus limneticus</i> Lemm.	1.4	4.5
<i>Coccochloris</i> sp.	6.5	2.3
<i>Coelosphaerium naegelianum</i> Unger	0.5	*
<i>Dactylococcopsis raphidioides</i> Hansg.	1.4	*
<i>Lyngbya ochracea</i> Thur.	63.0	4.5
<i>L. subtilis</i> W. West	4.6	*
<i>L. subtilissima</i> Kütz.	0.5	*
<i>L. thermalis</i> Rabh.	0.5	*
<i>L. versicolor</i> Gomont	1.4	*
<i>L.</i> sp.	9.7	70.4
<i>Oscillatoria acutissima</i> Kuff.	0.5	*
<i>O. ambigua</i> Gomont	1.8	*
<i>O. amphibia</i> Ag.	4.2	*
<i>O. angustissima</i> West and West	1.4	*
<i>O. articulata</i> Guard.	13.0	11.4
<i>O. chlorina</i> Kütz.	*	4.5
<i>O. formosa</i> Bory	0.5	*
<i>O. geminata</i> Meneg.	50.0	38.6
<i>O. lacustris</i> (Kleb.) Geit.	0.9	*
<i>O. limnetica</i> Lemm.	6.0	2.3
<i>O. numidica</i> Gomont	1.8	*
<i>O. splendida</i> Grev.	1.4	*
<i>O. subsalsala</i> Ag.	0.5	*
<i>O. subtilissima</i> Kütz.	1.8	*
<i>O. tenuis</i> Ag.	14.8	4.5
<i>O.</i> sp.	17.1	9.1
<i>Phormidium angustissimum</i> West and West	27.3	27.3
<i>P. retzii</i> (Ag.) Gomont	0.9	*
<i>P. tenue</i> (Meneg.) Gomont	0.9	*
<i>P. valderianum</i> (Dep.) Gomont	3.7	*
<i>P.</i> sp.	0.9	9.1
<i>Spirulina subsalsala</i> Oerst.	0.9	2.3

Division Euglenophyta

Class Euglenophyceae

<i>Euglena</i> spp.	3.7	2.3
<i>Trachelomonas hispida</i> (Perty) Stein	0.9	2.3
<i>T. hispida</i> var. <i>duplex</i> Defl.	0.5	*
<i>T. pulchella</i> Drez.	0.5	*
<i>T. pulcherrima</i> Playf.	0.5	*
<i>T. superba</i> (Swir.) Defl.	0.5	*
<i>T. volvocina</i> Ehr.	2.8	2.3
<i>T.</i> spp.	1.8	*

Division Pyrrophyta

Class Dinophyceae

<i>Glenodinium</i> spp.	1.4	*
<i>Peridinium aciculiferum</i> Lemm.	3.2	*
<i>P. inconspicuum</i> Lemm.	0.5	*
<i>P. pusillum</i> (Pen.) Lemm.	9.7	2.3
<i>P. wisconsinense</i> Eddy	0.9	*
<i>P.</i> spp.	5.6	2.3

¹Artificial substrate samples include those collected monthly for the periods 30 May 1975 through 2 December 1976, and 8 July 1977 through 6 July 1979. Natural substrate samples include those collected seasonally from summer 1974 through summer 1979.

* indicates not observed

TABLE 6-4. Rank of classes according to density and biovolume, based on an index of dominance, and average percent composition for periphyton from all locations, lower lake locations¹, upper lake locations², and Mountain Island Lake (Location 16.0).

		NORTHERLY DOMINANCE RANK ³															Dominance Index	Percent Composition
		1977					1978					1979						
DENSITY INDEX	All Locations	L	A	S	M	D	L	A	S	M	D	L	A	S	M	D		
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5		
DENSITY INDEX	Bacillariophyceae	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	61568.8	88.0
	Chlorophyceae	2	2	2	3	2	2	2	2	3	2	2	2	2	2	2	1448.8	17.0
	Myxophyceae	3	3	3	2	3	3	3	3	2	3	3	3	3	3	2	806.6	14.0
	Chrysophyceae	4	4	4	4	4	4	4	4	5	4	4	4	4	4	4	1.4	0.5
	Cryptophyceae	5	5	5	4	5	4	4	4	4	4	5	4	4	4	5	0.4	0.2
	Euglenophyceae	7	7	7	7	7	6	5	7	7	6	6	7	6	6	7	<0.1	<0.1
	Dinophyceae	6	6	4	5	6	4	5	7	7	6	6	7	5	6	6	<0.1	<0.1
	Xanthophyceae																<0.1	<0.1
BIOVOLUME INDEX	Bacillariophyceae	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	69437.8	77.9
	Chlorophyceae	2	2	4	2	2	2	2	2	2	2	2	2	2	2	2	1779.5	17.2
	Myxophyceae	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	109.4	2.6
	Dinophyceae	4	3	2	4	4	4	5	4	4	4	4	4	4	4	4	69.9	1.5
	Cryptophyceae	6	5	4	5	6	4	4	4	4	4	4	4	4	4	4	0.6	0.4
	Euglenophyceae	5	4	6	5	6	4	4	4	5	5	5	4	4	4	4	0.3	0.2
	Chrysophyceae	7	7	7	7	7	6	5	7	7	5	6	7	5	6	7	<0.1	0.1
	Xanthophyceae	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	<0.1	<0.1
DENSITY INDEX	Lower Lake Locations	L	A	S	1978					1979					Dominance Index	Percent Composition		
	Locations	L	A	S	M	D	L	A	S	M	D	L	A	S			M	D
	Bacillariophyceae	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	57781.2	68.5
	Chlorophyceae	2	2	2	3	2	2	2	2	2	2	2	2	2	2	2	1643.8	19.9
	Myxophyceae	3	3	3	2	3	3	3	3	3	3	3	3	3	3	3	507.2	11.4
	Chrysophyceae	4	4	5	4	5	4	4	4	4	4	4	4	4	4	4	0.5	0.3
	Cryptophyceae	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	0.1	0.2
	Euglenophyceae	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	<0.1	<0.1
BIOVOLUME INDEX	Bacillariophyceae	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	64750.0	82.8
	Chlorophyceae	2	2	4	2	2	2	2	2	2	2	2	2	2	2	2	674.8	12.5
	Myxophyceae	3	4	3	2	3	3	3	3	3	3	3	3	3	3	3	61.5	2.3
	Dinophyceae	4	3	2	4	4	4	4	4	4	4	4	4	4	4	4	48.9	1.9
	Cryptophyceae	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	0.9	0.2
	Euglenophyceae	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	0.2	0.2
	Chrysophyceae	7	7	7	7	7	6	5	4	6	7	7	5	6	7	5	0.1	0.1
	Xanthophyceae	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	<0.1	<0.1
DENSITY INDEX	Location 16.0	L	1978					1979					Dominance Index	Percent Composition				
	Locations	L	A	S	M	D	L	A	S	M	D	L			A	S	M	D
	Bacillariophyceae	1	1	MS ⁴	1	MS	1	1	1	1	1	1	1	1	1	1	24872.4	69.8
	Chlorophyceae	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	1088.8	27.8
	Myxophyceae	3	4	3	3	3	3	3	3	3	3	3	3	3	3	3	27.5	5.8
	Chrysophyceae	4	2	4	4	4	4	4	4	4	4	4	4	4	4	4	2.5	1.3
	Cryptophyceae	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	0.1	0.1
	Dinophyceae	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	<0.1	<0.1
BIOVOLUME INDEX	Bacillariophyceae	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	18192.4	50.8
	Chlorophyceae	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2592.1	47.2
	Myxophyceae	3	4	3	3	3	3	3	3	3	3	3	3	3	3	3	18.0	1.3
	Chrysophyceae	4	3	4	4	4	4	4	4	4	4	4	4	4	4	4	0.5	0.4
	Cryptophyceae	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	0.1	0.1
	Dinophyceae	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	<0.1	<0.1
	Euglenophyceae	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	<0.1	<0.1
	Xanthophyceae	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	<0.1	<0.1
DENSITY INDEX	Upper Lake Locations	L	1978					1979					Dominance Index	Percent Composition				
	Locations	L	A	S	M	D	L	A	S	M	D	L			A	S	M	D
	Bacillariophyceae	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7098.0	69.0
	Myxophyceae	2	2	2	3	2	2	2	2	2	2	2	2	2	2	2	186.5	21.2
	Chlorophyceae	3	3	3	2	3	3	3	3	3	3	3	3	3	3	3	72.8	9.0
	Cryptophyceae	4	4	4	5	4	5	4	4	4	4	4	4	4	4	4	<0.1	0.3
	Chrysophyceae	5	5	5	4	5	4	4	4	4	4	4	4	4	4	4	<0.1	0.2
	Dinophyceae	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	<0.1	<0.1
BIOVOLUME INDEX	Bacillariophyceae	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9217.5	84.4
	Chlorophyceae	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	131.1	12.5
	Myxophyceae	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2.9	2.0
	Dinophyceae	4	3	4	4	4	4	4	4	4	4	4	4	4	4	4	0.3	0.5
	Cryptophyceae	5	5	5	4	5	4	4	4	4	4	4	4	4	4	4	0.2	0.4
	Euglenophyceae	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	<0.1	0.1
	Chrysophyceae	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	<0.1	<0.1
	Xanthophyceae	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	<0.1	<0.1

¹Lower lake locations include locations 1.0, 1.2, 3.0, 4.0, 6.0 and 8.0

²Upper lake locations include locations 16.0, 12.0, 14.0, and 15.0

³Blank indicate class not present

⁴Sample missing

TABLE 6-5. Rank of dominant species according to density and biovolume, based on an index of dominance, for periphyton from all locations, lower lake locations¹, upper lake locations², and Mountain Island Lake (Location 16.0).

		MONTHLY DOMINANCE RANK ³																								Dominance Index		
		1977						1978						1979														
All Locations		J	A	S	O	N	D	J	F	M	A	M	J	J	J	A	O	N	D	J	F	M	A	M	J	J		
DENSITY INDEX	<i>Achnanthes microcephala</i>	1	1	1	3	1	1	1	3	4	4	2	1	2	1	1	1	1	1	2	3	4	2	1	1	1	19124.4	
	<i>Gomphonema parvulum</i>			7		2	2	2	1	3	1	1	3	6			10	2	2	1	2	2	1	2	4	5	2708.2	
	<i>Synedra rumpens</i>			5	4	4	3	3	2	1	3	3					8	4	3	7	6	6	3	5	7	6	657.5	
	<i>Melosira varians</i>								4	2	6									8	1	1	6				182.7	
	<i>Nannochloris</i> sp.	2							6					1	3	2	3						7		3	2	119.4	
	<i>Lyngbya ochracea</i>		7		2	6							6	2	3	2	3	4			11			8	2	3	112.0	
	<i>Gomphonema gracile</i>		3	2	3	3	4	4	6								6	9		6							9.3	
	<i>Stigeoclonium</i> sp.										2	5												3			5.4	
	<i>Mougeotia</i> sp. B		8		6										5			5	8		4	7	11	12	4	8	7	3.6
	<i>Synedra ulna</i>											4						13	5		3	4	8	9				3.0
BIOVOLUME INDEX	<i>Achnanthes microcephala</i>	1	1	2	2	4	2	2	6	7	7	9	1	1	1	1	1	1	3	4	7	6	6	3	1	1	11370.3	
	<i>Melosira varians</i>					8		1	1	1	2	3			8			12	13	2	1	1	1	5	13		8917.8	
	<i>Gomphonema parvulum</i>			7		2	1	3	2	4	3	2	2	13	11			2	2	3	3		2	2	4	2	1063.3	
	<i>Synedra ulna</i>		2			5	5	8	5	3	5	1	5		6	2	2	3	1		2	2	3	7			691.2	
	<i>Gomphonema gracile</i>	2	3		1	1	3	4		6		12	6		10	6	5	5	5	6				10	10	7	844.5	
	<i>Synedra delicatissima</i>													10	2	3	8	9	4	1	13		5	12	8		307.8	
	<i>Stigeoclonium</i> sp.	3		3	8			6			1	5		11	5	5								1	9	8	214.6	
	<i>Synedra rumpens</i>		5	4	4	3	4	7	3	2	6	7		4	3	18		6	7		5	9	9		5	5	168.9	
	<i>Mougeotia</i> sp. B		12										4	2		9		7	9	7	8		8	6	2	4	122.8	
	<i>Gomphonema acuminatum</i>		8	5	6			10				4			15		3	11	10		10	9		10		9		39.4
Lower Lake Locations		J	A	S	O	N	D	J	F	M	A	M	J	J	J	A	O	N	D	J	F	M	A	M	J	J	Dominance Index	
DENSITY INDEX	<i>Achnanthes microcephala</i>	1	1	1	1	1	1	1	3	4	3	1	1	2	1	1	1	1	1	1	2	2	2	1	1	1	18727.5	
	<i>Gomphonema parvulum</i>			7		2	2	2	1	3	1	2	3					2	2	2	1	3	1	2			1283.9	
	<i>Synedra rumpens</i>			5	4	4	3	3	2	2	2	3					7	3		6	4	7	4				211.2	
	<i>Nannochloris</i> sp.	2												1	2	2	2								2	2	80.0	
	<i>Melosira varians</i>							4	4	1	4									10	1	5					46.8	
	<i>Lyngbya ochracea</i>		5		2	6						4	2	3	3	3	5				9			4	3		36.5	
	<i>Gomphonema gracile</i>		3	2	3	3	4	5		5										4							9.9	
	<i>Navicula notha</i>	5	2	6										4	4	4	4	5							3	6	4.6	
	<i>Tabellaria flocculosa</i>																			3	3	8			6		1.4	
	<i>Amphioneis vitrea</i>		7	3												6	3					5						1.1
BIOVOLUME INDEX	<i>Achnanthes microcephala</i>	1	1	2	3	4	2	2	6	5	5	6	1	1	1	1	2	1	1	2	6	4	5	1	1	1	10819.0	
	<i>Melosira varians</i>					9		1	1	1	1	3								1	1	1					1770.3	
	<i>Gomphonema parvulum</i>			7		2	1	3	2	3	2	2	2					6	2	1	2		2	2	6	6	909.3	
	<i>Gomphonema gracile</i>	2	3	1	1	3		5		4		9	6				8	11	5	3						7	316.5	
	<i>Synedra ulna</i>		3			5	5	7	5	2	3	1	5			11	6			5	7	3	8				233.6	
	<i>Synedra rumpens</i>		5	4	4	3	4	4	3		4	5		5		13		5	4	4	8	8	4				119.9	
	<i>Mougeotia</i> sp. B		9										4	2		10	3			4	8			2	8		63.7	
	<i>Gomphonema acuminatum</i>		7	5	6			9					4			6		1	3	7	8	11		7		3	62.5	
	<i>Tabellaria flocculosa</i>		10										8	7						5	3			7	3	5	18.4	
	<i>Synedra delicatissima</i>																	9	12	2	7	12		6	6	7	13.7	

Table 6-5 (continued)

		MONTHLY DOMINANCE RANK ¹																								Dominance Index	
		1977						1978										1979									
Location 16.0		J	A	S	O	N	D	J	F	M	A	M	J	J	A	O	N	D	J	F	M	A	M	J	J		
DENSITY INDEX	<i>Achnanthes microcephala</i>	1	1	MS	1	MS	1	2	3	4	4	2	MS	1	1	1	1	1	1	MS	2	5	3	3	1	1	4810.4
	<i>Gomphonema parvulum</i>						2	1	1	3	1	1		2					2		1	3	1	2	2	3	1250.8
	<i>Synedra rumpens</i>						3		2	1	3	3								4	4	2			2	139.7	
	<i>Stigeoclonium</i> sp.										2	4											1			14.4	
	<i>Melosira varians</i>							4	2	6												1				8.2	
	<i>Nannochloris</i> sp.						6							2	2											1.6	
	<i>Anomoeoneis vitrea</i>	3					7								4	2					6					1.3	
	<i>Lyngbya ochracea</i>				2											3	5									0.5	
	<i>Mougeotia</i> sp. B.				3													3			3					0.2	
<i>Melosira italica</i>																					2				0.1		
BIOVOLUME INDEX	<i>Achnanthes microcephala</i>	1	1		2		2			3				1	1	2	1	1	1			9		1	1	1419.0	
	<i>Gomphonema parvulum</i>					1		1	2		2	4		3				5	2		1	2	2	3	4	444.0	
	<i>Stigeoclonium</i> sp.	3		3				2			1	1		2	2	1							1	2		216.6	
	<i>Melosira varians</i>							3	1	1	3	3		4	3						1	5				203.5	
	<i>Gomphonema gracile</i>	2	4		1		3							5			5	3	4					4		46.6	
	<i>Synedra rumpens</i>						4		4	4	2	6		4				5		5	7			3		36.9	
	<i>Mougeotia</i> sp. B.																3	2		2				5	2	5.5	
	<i>Synedra ulna</i>					5		3												3	2	3				1.1	
	<i>Mougeotia</i> sp. A.																	6	2	3						1.4	
	<i>Synedra pulchella</i>								4	2																0.6	
Upper Lake Locations		1978						1979															Dominance Index				
		J	A	S	O	N	D	J	F	M	A	M	J	J	A	O	N	D	J	F	M	A	M	J	J		
DENSITY INDEX	<i>Achnanthes microcephala</i>	1	1	1	1	1	2									6	2	2	1	1						864.0	
	<i>Gomphonema parvulum</i>						5	2	1				2	3	2	5	1	3	2							367.2	
	<i>Melosira varians</i>												4	1	1	1										63.0	
	<i>Lyngbya ochracea</i>	2	2	2	7													7	2	3						33.8	
	<i>Synedra ulna</i>						9	4					1	2	3											10.7	
	<i>Synedra rumpens</i>						3	4	7									4	4	4						2.2	
	<i>Mougeotia</i> sp. B.						6	8					3	4		7	3	5	6							2.1	
	<i>Nannochloris</i> sp.	3	3	3													3									1.7	
	<i>Gomphonema gracile</i>						2	9																		0.6	
	<i>Eunotia curvata</i>						5	5	5				5					5	8	7						0.2	
BIOVOLUME INDEX	<i>Achnanthes microcephala</i>	1	1	1	3	3	4													1	1					372.8	
	<i>Synedra ulna</i>			5	2		1						1	2	2	3	4									197.0	
	<i>Melosira varians</i>												2	1	1	1	3	10								173.5	
	<i>Gomphonema parvulum</i>						7				1	2	4					2	2	2						59.3	
	<i>Gomphonema gracile</i>						6	5	2	5	7							7	7	7						17.7	
	<i>Mougeotia</i> sp. B.							5	7	6			5		2				3	4						9.4	
	<i>Synedra rumpens</i>	2	4								6	3							4	5						8.2	
	<i>Eunotia curvata</i>										6	4	5						5	5	3					7.9	
	<i>Synedra delicatissima</i>	5	2	3	4	8														7						6.8	
	<i>Mougeotia</i> sp. A.						2													1						4.0	

¹Lower lake locations include Locations 1.0, 1.2, 3.0, 4.0, 6.0 and 8.0.²Upper lake locations include Locations 34.0, 13.0, 14.0, and 15.9.³Blanks indicate taxon constituted less than 5.0% of total density or biovolume.⁴Sampler missing.

TABLE 6-6. Rank of classes and dominant species according to density, based on an index of dominance for periphyton observed on natural substrates collected seasonally¹ at Locations 4.0 and 6.0 from the summer of 1974 through the summer of 1979.

SEASONAL DOMINANCE RANK ²																							
Classes	1974		1975				1976				1977				1978				1979			Dominance Index	Percent Composition
	SU	F	W	S	SU	F	W	S	SU	F	W	S	SU	F	W	S	SU						
Bacillariophyceae	1	1	1	1	1	1	1	1	1	1	NS ³	1	1	1	1	1	1	1	1	1	21856.0	82.0	
Chlorophyceae	3	3	2	3	3	2	2	2	3	3		3	2	2	2	2	2	3	2	2	136.7	10.8	
Myxophyceae	2	2		2	2	3	3	3	2	2		2	3	3	3	3	3	2	3	3	120.1	6.9	
Chrysophyceae	5			4	4		4					4	4	4		4				4	<0.1	0.1	
Dinophyceae	4					4															<0.1	<0.1	
Euglenophyceae			3		5																<0.1	<0.1	
Species																							
Achnanthes																							
microcephala	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	6988.0		
Navicula notha		4	2		4	2	2	3		3		2	2		3	3		2		2	149.7		
Anomoeoneis vitrea		3			2	6	3		5			3	4	9		4	2	5		2	58.3		
Lyngbya ochracea	2	2		5	3				4	2		4	5				4	4		4	16.4		
Navicula																							
subtilissima						7			2					8		2		5	3		5.4		
Cymbella																							
microcephala																					2.6		
Melosira granulata									3			5	6				3			3	1.5		
M. distans							4			7			5								0.2		
Cymbella minuta										4						2		6			0.1		

¹ W (Winter) = January, February and March.
 S (Spring) = April, May, and June.
 SU (Summer) = July, August, and September.
 F (Fall) = October, November, and December.

² Blank indicates class not present during that period, or species constituted less than 5% of the relative density during that period.

³ Not sampled.

Table 6-7. Periphyton organic accumulation rates ($\text{mg}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$) and, in parentheses, ash-free dry weights ($\text{g}\cdot\text{m}^{-2}$) for locations on Lake Norman, NC¹ from 30 May 1975 through 5 December 1976².

		Locations						
	Location Number	1.0	4.0	5.0	6.0	8.0	10.0	Monthly
	Distance (km) from MNS ³	4.0	0.7	1.5	4.2	7.0	12.0	Mean
Date	Exposure period (days)							
30 May 75	30	249.8 (7.49)	204.2 (6.12)	153.6 (4.61)	292.6 (8.78)	NS ⁿ	222.2 (6.66)	224.5 (6.73)
30 June 75	31	142.0 (4.41)	115.8 (3.59)	144.7 (4.49)	235.0 (7.28)	NS	238.8 (7.40)	175.3 (5.43)
31 July 75	31	135.4 (4.20)	118.2 (3.66)	160.6 (4.98)	146.7 (4.55)	NS	66.2 (2.05)	125.4 (3.89)
29 Aug 75	29	104.3 (3.02)	104.5 (3.03)	MS ⁵	103.9 (3.01)	NS	187.3 (5.43)	125.0 (3.62)
30 Sep 75	32	82.4 (2.64)	58.2 (1.86)	125.2 (4.01)	90.1 (2.88)	NS	322.3 (10.31)	135.6 (4.34)
3 Nov 75	29	8.9 (0.26)	148.7 (5.06)	MS	111.8 (3.80)	NS	NS	89.8 (3.04)
28 Nov 75	25	72.3 (1.81)	65.6 (1.64)	6.8 (0.17)	95.0 (2.37)	NS	87.5 (2.19)	65.4 (1.64)
31 Dec 75	33	17.6 (0.58)	38.8 (1.28)	23.2 (0.76)	25.6 (0.84)	NS	SD ⁶	26.3 (0.86)
31 Jan 76	31	8.3 (0.26)	15.6 (0.49)	28.7 (0.89)	4.3 (0.13)	NS	SD	14.2 (0.44)
27 Feb 76	28	15.4 (0.43)	20.3 (0.57)	MS	24.2 (0.68)	NS	SD	20.0 (0.56)
31 Mar 76	33	14.5 (0.48)	40.4 (1.34)	MS	98.5 (3.25)	NS	SD	51.4 (1.69)
6 May 76	35	36.5 (1.32)	143.2 (5.16)	43.3 (1.56)	178.5 (6.42)	NS	SD	100.4 (3.62)
14 June 76	38	53.3 (2.08)	MS	MS	119.6 (4.67)	73.8 (2.88)	SD	82.2 (3.21)
16 July 76	28	MS	152.8 (5.04)	47.6 (1.37)	MS	38.3 (1.26)	SD	79.6 (2.54)
1 Aug 76	27	86.6 (2.34)	241.5 (6.52)	81.6 (2.20)	146.9 (3.97)	MS ⁷	SD	139.2 (3.76)
9 Sept 76	28	15.5 (0.43)	58.8 (1.65)	41.0 (1.15)	55.7 (1.56)	13.0 (0.36)	SD	36.8 (1.03)
5 Oct 76	26	10.9 (0.28)	38.5 (1.00)	MS	MS	2.8 (0.07)	SD	17.4 (0.45)
5 Nov 76	31	6.7 (0.21)	18.8 (0.55)	9.1 (0.28)	79.6 (2.47)	2.9 (0.09)	SD	23.4 (0.72)
5 Dec 76	30	37.9 (1.14)	44.2 (1.32)	36.2 (1.09)	70.4 (2.11)	12.2 (0.33)	SD	40.2 (1.20)
Location Mean		69.8 (1.85)	90.4 (2.77)	69.4 (2.29)	110.5 (3.46)	23.8 (0.84)	187.4 (5.67)	

¹Locations are listed according to distance from the McGuire Nuclear Station (MNS) discharge.

²Dates listed specify the end of each exposure period.

³Distances were measured via the main channel.

⁴Sampling not initiated

⁵Sampler missing

⁶Sampling discontinued

Table 6-8. Periphyton organic accumulation rates ($\text{mg}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$) and in parentheses, ash-free dry weights ($\text{g}\cdot\text{m}^{-2}$) for locations on Lake Norman¹ and Mountain Island Lake (16.0), NC, from 8 July 1977 through 6 July 1979².

		Lower Lake Locations							Upper Lake Locations			
		16.0	1.0	1.2	4.0	1.0	6.0	8.0	25.0	12.0	14.0	15.0
Distance (km) from MMS ³		12.0	4.0	3.2	0.7	1.5	4.7	7.0	16.9	19.7	21.7	29.9
Distance (km) from MGS		31.1	21.1	21.1	22.0	19.6	22.6	15.9	4.0	3.2	1.2	7.0
Date	Exposure period (days)	Monthly Mean							Monthly Mean			
8 July 77	30	53.7 (1.54)	59.4 (1.78)	NS ⁴	163.9 (4.97)	159.8 (4.79)	130.1 (3.90)	NS ⁵	128.4 (3.85)	NS	NS	NS
5 Aug 77	28	54.1 (1.59)	94.9 (2.84)	NS	130.9 (3.87)	126.4 (3.79)	97.8 (2.97)	131.3 (3.88)	104.7 (3.21)	NS	NS	NS
1 Sept 77	27	NS	28.2 (0.76)	NS	91.8 (2.40)	72.0 (1.94)	NS	40.9 (1.22)	60.2 (1.67)	NS	NS	NS
4 Oct 77	33	23.4 (0.70)	52.2 (1.04)	NS	NS	90.8 (2.69)	218.4 (6.55)	61.8 (1.84)	115.0 (3.42)	NS	NS	NS
2 Nov 77	29	NS	66.5 (1.94)	29.8 (0.86)	37.9 (1.06)	41.8 (1.23)	81.2 (2.39)	25.0 (0.72)	43.7 (1.28)	NS	NS	NS
7 Dec 77	35	33.2 (1.00)	28.0 (0.80)	69.1 (2.07)	36.7 (1.09)	64.7 (1.93)	22.2 (0.67)	23.7 (0.70)	52.4 (1.57)	NS	NS	NS
5 Jan 78	29	32.2 (0.94)	14.4 (0.42)	2.8 (0.08)	20.6 (0.60)	8.7 (0.25)	18.7 (0.54)	12.0 (0.35)	6.8 (0.20)	NS	NS	NS
2 Feb 78	26	1.3 (0.04)	1.3 (0.04)	2.1 (0.06)	1.1 (0.03)	0.3 (0.01)	6.6 (0.18)	NS	NS	NS	NS	NS
2 Mar 78	26	8.1 (0.24)	2.2 (0.09)	7.2 (0.20)	5.4 (0.15)	3.9 (0.11)	11.0 (0.33)	9.0 (0.26)	6.4 (0.19)	NS	NS	NS
1 Apr 78	32	35.3 (1.07)	27.1 (0.81)	43.4 (1.29)	23.9 (0.70)	14.0 (0.41)	37.0 (1.08)	11.0 (0.32)	26.1 (0.78)	NS	NS	NS
1 May 78	28	34.2 (0.99)	40.2 (1.12)	28.9 (0.85)	29.6 (0.85)	NS	48.4 (1.36)	19.2 (0.56)	31.5 (0.90)	NS	NS	NS
1 June 78	31	NS	85.2 (2.54)	95.4 (2.86)	61.7 (1.81)	102.6 (3.08)	69.4 (2.07)	76.0 (2.23)	81.7 (2.42)	NS	NS	113.2 (3.40)
29 June 78	28	16.7 (0.45)	74.5 (2.10)	48.4 (1.35)	64.9 (1.96)	173.8 (5.14)	91.0 (2.65)	103.0 (3.00)	93.5 (2.72)	107.2 (3.19)	NS	113.2 (3.40)
28 July 78	29	NS	NS	107.7 (3.12)	12.4 (0.35)	131.3 (3.85)	129.7 (3.79)	8.8 (0.26)	78.0 (2.26)	88.8 (2.60)	45.7 (1.32)	131.0 (3.80)
20 Aug 78	33	47.4 (1.36)	2.1 (0.06)	220.4 (6.61)	35.3 (1.05)	84.7 (2.48)	17.3 (0.51)	31.0 (0.91)	65.3 (1.93)	76.0 (2.23)	36.9 (1.07)	106.5 (3.15)
6 Oct 78	36	35.6 (1.05)	15.2 (0.45)	71.1 (2.07)	130.4 (3.80)	108.3 (3.18)	77.0 (2.27)	19.8 (0.58)	72.1 (2.12)	28.9 (0.84)	41.4 (1.20)	128.2 (3.75)
6 Nov 78	31	32.8 (0.95)	5.4 (0.15)	26.6 (0.78)	NS	17.8 (0.52)	115.9 (3.38)	11.5 (0.33)	35.4 (1.04)	23.4 (0.69)	53.2 (1.55)	154.1 (4.50)
6 Dec 78	30	11.8 (0.34)	3.9 (0.11)	11.4 (0.33)	22.5 (0.65)	52.7 (1.54)	14.4 (0.42)	12.5 (0.36)	13.0 (0.38)	29.8 (0.88)	25.2 (0.74)	NS
5 Jan 79	30	NS	3.8 (0.11)	0.2 (0.01)	44.9 (1.30)	21.7 (0.63)	12.8 (0.37)	12.4 (0.36)	17.3 (0.51)	13.4 (0.39)	14.0 (0.41)	17.4 (0.51)
5 Feb 79	31	33.4 (1.00)	2.6 (0.08)	4.7 (0.14)	15.4 (0.45)	12.4 (0.36)	11.6 (0.34)	9.6 (0.28)	9.6 (0.28)	15.1 (0.44)	18.9 (0.55)	10.8 (0.31)
6 Mar 79	29	12.0 (0.35)	43.5 (1.28)	7.0 (0.20)	24.2 (0.70)	43.0 (1.25)	9.8 (0.28)	20.5 (0.60)	13.0 (0.38)	29.3 (0.85)	8.2 (0.24)	130.6 (3.80)
5 Apr 79	30	9.6 (0.28)	6.0 (0.17)	17.0 (0.50)	266.3 (7.89)	18.1 (0.53)	22.4 (0.64)	3.4 (0.10)	55.6 (1.63)	7.3 (0.21)	33.4 (0.97)	153.4 (4.50)
4 May 79	29	75.4 (2.22)	64.2 (1.88)	40.1 (1.17)	NS	49.0 (1.43)	25.2 (0.74)	41.4 (1.20)	54.7 (1.59)	17.3 (0.51)	108.5 (3.15)	40.1 (1.17)
4 June 79	31	17.7 (0.51)	23.6 (0.69)	52.0 (1.53)	14.9 (0.43)	111.1 (3.23)	102.0 (2.98)	112.3 (3.28)	105.6 (3.08)	102.2 (2.98)	91.8 (2.68)	20.9 (0.61)
6 July 79	32	19.7 (0.58)	140.4 (4.11)	11.6 (0.33)	38.2 (1.12)	47.5 (1.39)	15.1 (0.44)	174.8 (5.14)	47.4 (1.39)	64.0 (1.88)	42.7 (1.25)	78.8 (2.30)
Location MMS		29.9 (0.88)	42.8 (1.28)	17.0 (0.50)	62.5 (1.85)	63.8 (1.89)	46.6 (1.37)	40.4 (1.19)	45.0 (1.33)	43.9 (1.28)	39.7 (1.16)	89.7 (2.60)

¹Locations are listed according to distance from Perkins Nuclear Station (MMS) and Marshall Steam Station (MS) discharges.

²Dates listed specify the end of each exposure period.

³Distances were measured via the main channel.

⁴Sampling not initiated.

⁵Sample missing.

Table 6-10. Periphyton α -chlorophyll a ($\text{mg}\cdot\text{m}^{-2}$) and, in parentheses, algal carbon ($\text{mg}\cdot\text{m}^{-2}$) from locations on Lake Norman¹ and Mountain Island Lake (16.0), NC, from 8 July 1977 through 6 July 1979².

	Lake Norman Locations							Mountain Island Lake Locations			
	16.0	1.0	1.2	4.0	5.0	6.0	8.0	16.0	11.0	14.0	15.4
Distance (km) from MS ³	12.0	4.0	3.2	0.7	1.5	4.2	7.0	18.5	15.1	21.7	29.9
Distance (km) from MS ⁴	21.1	21.3	21.1	22.0	19.8	22.4	15.5	6.0	5.2	1.2	7.0
Date	Exposure period (days)	Monthly Mean						Monthly Mean			
8 July 77	30	4.42 (85.8)	MS ⁵	MS ⁵	1.00 (49.8)	1.57 (118.4)	1.15 (46.2)	MS	1.31 (51.2)	MS	MS
5 Aug 77	29	3.87 (91.7)	5.55 (131.2)	MS	4.07 (112.2)	1.45 (12.4)	1.80 (32.2)	21.30 (125.8)	MS	MS	MS
1 Sept 77	28	MS	1.31 (36.1)	MS	1.36 (35.8)	1.35 (106.7)	MS	0.46 (9.4)	1.13 (44.9)	MS	MS
4 Oct 77	31	3.41 (47.8)	3.70 (11.0)	MS	2.82 (102.2)	4.70 (117.5)	2.90 (45.0)	5.05 (78.2)	MS	MS	MS
2 Nov 77	29	MS	C 14 (10.6)	0.62 (17.0)	1.87 (26.8)	0.42 (8.6)	0.81 (17.5)	0.74 (7.5)	MS	MS	MS
7 Dec 77	35	8.19 (52.2)	1.92 (10.6)	6.35 (32.3)	0.69 (27.0)	3.99 (34.6)	5.86 (4.8)	0.24 (21.8)	3.14 (2.3)	MS	MS
5 Jan 78	29	0.23 (7.6)	0.07 (1.6)	0.91 (5.0)	0.71 (13.9)	0.20 (16.6)	1.05 (18.8)	0.14 (2.6)	0.45 (8.1)	MS	MS
2 Feb 78	28	0.04 (0.3)	0.15 (0.9)	0.23 (4.0)	0.44 (2.4)	0.35 (2.6)	0.37 (1.2)	MS	0.28 (2.3)	MS	MS
2 Mar 78	28	0.09 (4.6)	0.11 (4.4)	0.30 (10.9)	0.13 (5.7)	0.17 (5.7)	0.22 (7.5)	0.08 (1.7)	0.15 (4.0)	MS	MS
3 Apr 78	32	2.92 (42.4)	3.16 (32.1)	2.89 (38.6)	1.06 (28.3)	1.25 (22.6)	1.97 (29.5)	0.59 (22.2)	1.82 (28.9)	MS	MS
1 May 78	28	1.95 (87.4)	3.32 (52.7)	4.02 (20.1)	4.24 (36.6)	MS	4.07 (38.6)	3.68 (31.4)	3.85 (33.4)	MS	MS
1 June 78	31	MS	13.86 (152.4)	15.44 (212.0)	9.39 (93.6)	17.40 (165.5)	9.54 (172.4)	15.81 (31.4)	12.45 (146.2)	MS	MS
29 June 78	28	1.73 (57.0)	4.31 (141.9)	4.31 (184.2)	2.81 (63.4)	8.67 (187.1)	4.18 (106.1)	15.94 (112.3)	7.15 (141.0)	MS	MS
28 July 78	29	2.43 (78.8)	MS	3.83 (98.5)	1.43 (28.8)	6.03 (81.7)	3.61 (32.4)	1.14 (25.6)	3.7 (57.2)	20.24 (141.3)	12.95 (135.8)
30 Aug 78	31	1.26 (67.4)	1.07 (5.8)	20.47 (84.4)	1.17 (50.2)	4.21 (114.6)	1.12 (28.8)	4.06 (46.2)	4.80 (51.1)	9.52 (122.7)	8.02 (24.6)
6 Oct 78	36	5.72 (121.5)	2.70 (51.3)	4.24 (181.2)	3.56 (102.4)	2.06 (32.1)	7.23 (299.3)	3.56 (94.1)	3.89 (101.8)	2.06 (29.3)	1.64 (43.1)
6 Nov 78	31	3.90 (94.2)	0.58 (18.2)	1.14 (19.4)	MS	1.48 (40.6)	4.82 (105.1)	1.49 (19.0)	1.4 (40.1)	11.95 (136.1)	22.18 (178.1)
6 Dec 78	30	2.52 (50.3)	1.08 (9.8)	1.87 (25.8)	4.01 (27.2)	1.12 (13.2)	0.32 (8.2)	1.61 (14.0)	1.1 (16.4)	8.15 (75.0)	6.54 (57.8)
5 Jan 79	30	MS	2.10 (25.2)	2.06 (20.8)	3.21 (61.6)	6.6 (72.5)	0.35 (18.7)	1.68 (17.7)	2.81 (26.0)	1.55 (51.2)	2.29 (71.2)
5 Feb 79	31	0.16 (10.2)	0.10 (5.0)	0.05 (4.3)	0.03 (15.4)	0.38 (3.3)	0.16 (6.1)	0.10 (7.8)	0.11 (7.0)	5.29 (49.6)	4.01 (94.1)
6 Mar 79	29	0.07 (8.3)	0.47 (12.4)	0.30 (28.2)	0.70 (24.0)	0.31 (5.1)	0.52 (16.8)	0.38 (44.6)	1.28 (121.0)	0.45 (66.8)	2.06 (47.4)
5 Apr 79	30	1.06 (47.2)	5.17 (57.2)	1.31 (32.9)	3.45 (206.8)	0.87 (28.6)	0.48 (24.8)	0.92 (38.6)	2.37 (64.8)	0.49 (40.1)	0.31 (14.3)
4 May 79	29	17.81 (470.0)	7.92 (112.0)	8.15 (246.1)	71.72 (440.2)	9.02 (115.0)	5.74 (115.1)	1.72 (10.2)	9.18 (126.4)	30.57 (691.8)	31.39 (280.0)
4 June 79	31	3.66 (68.5)	9.42 (247.0)	9.30 (109.9)	6.55 (196.7)	25.28 (295.6)	11.03 (159.5)	31.14 (216.0)	15.45 (264.6)	34.44 (283.0)	40.11 (41.0)
6 July 79	32	2.61 (28.4)	5.72 (93.2)	6.77 (98.1)	7.35 (48.2)	7.01 (107.0)	11.37 (101.8)	26.39 (194.4)	11.01 (104.0)	19.30 (213.2)	25.05 (194.1)
Location Mean		1.23 (100.9)	3.48 (52.1)	4.49 (83.0)	3.50 (74.0)	4.18 (64.1)	7.41 (68.6)	6.21 (45.6)	10.79 (181.4)	13.89 (123.4)	6.23 (66.4)

¹ Locations are listed according to distance from McGuire Marine Station (100) and Marshall Steam Station (155) discharges.

² Dates listed specify the end of each exposure period.

³ Distances were measured via the main channel.

⁴ Sampler missing.

⁵ Sampling not initiated.

Table 6-11. Mean light intensities, temperatures, and nutrient concentrations at two locations (3.0 and 8.0) on Lake Norman, NC, during selected periods of 1978. Means are based on values from samples collected weekly.

	1 Feb.-29 Mar.		3 May-23 Jun.		5 Jul.-27 Sep.	
	<u>X</u>	<u>S</u>	<u>X</u>	<u>S</u>	<u>X</u>	<u>S</u>
Light Intensity ($L_y \cdot d^{-1}$)	287.40	159.60	523.40	119.00	433.40	130.30
Temperature ($^{\circ}C$)	5.40	2.00	21.70	4.10	27.50	1.10
Total Nitrogen ($\mu mole \cdot l^{-1}$)	40.20	4.80	37.70	13.20	20.20	3.10
Total Phosphorus ($\mu mole \cdot l^{-1}$)	0.83	0.15	0.32	0.14	0.10	0.12

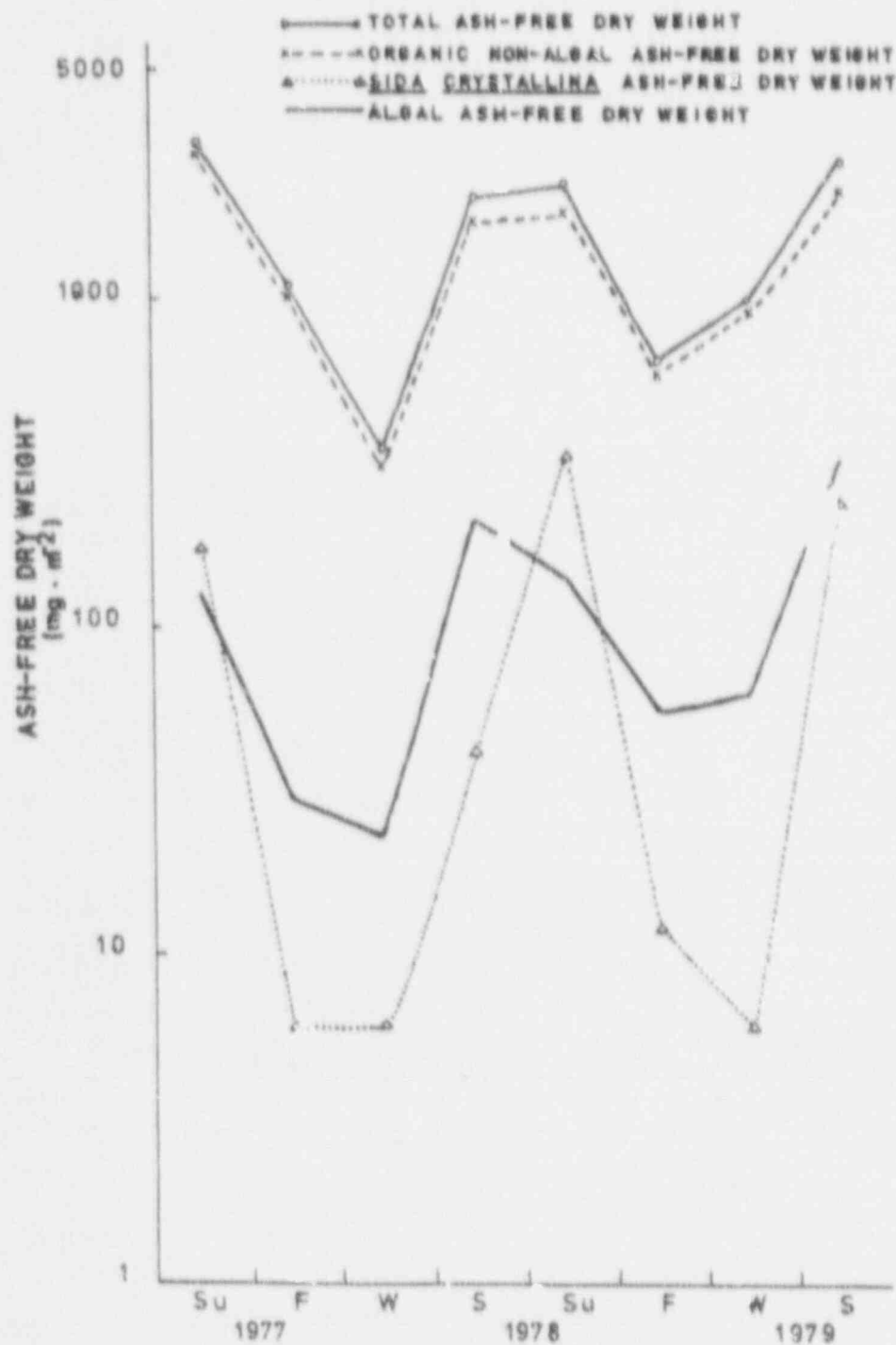


Figure 6-1. A seasonal comparison of total, organic non-algal material, *Sida crystallina*, and algal ash-free dry weights averaged from all lower lake locations on Lake Norman, NC for each season from the summer of 1977 through the spring of 1979.

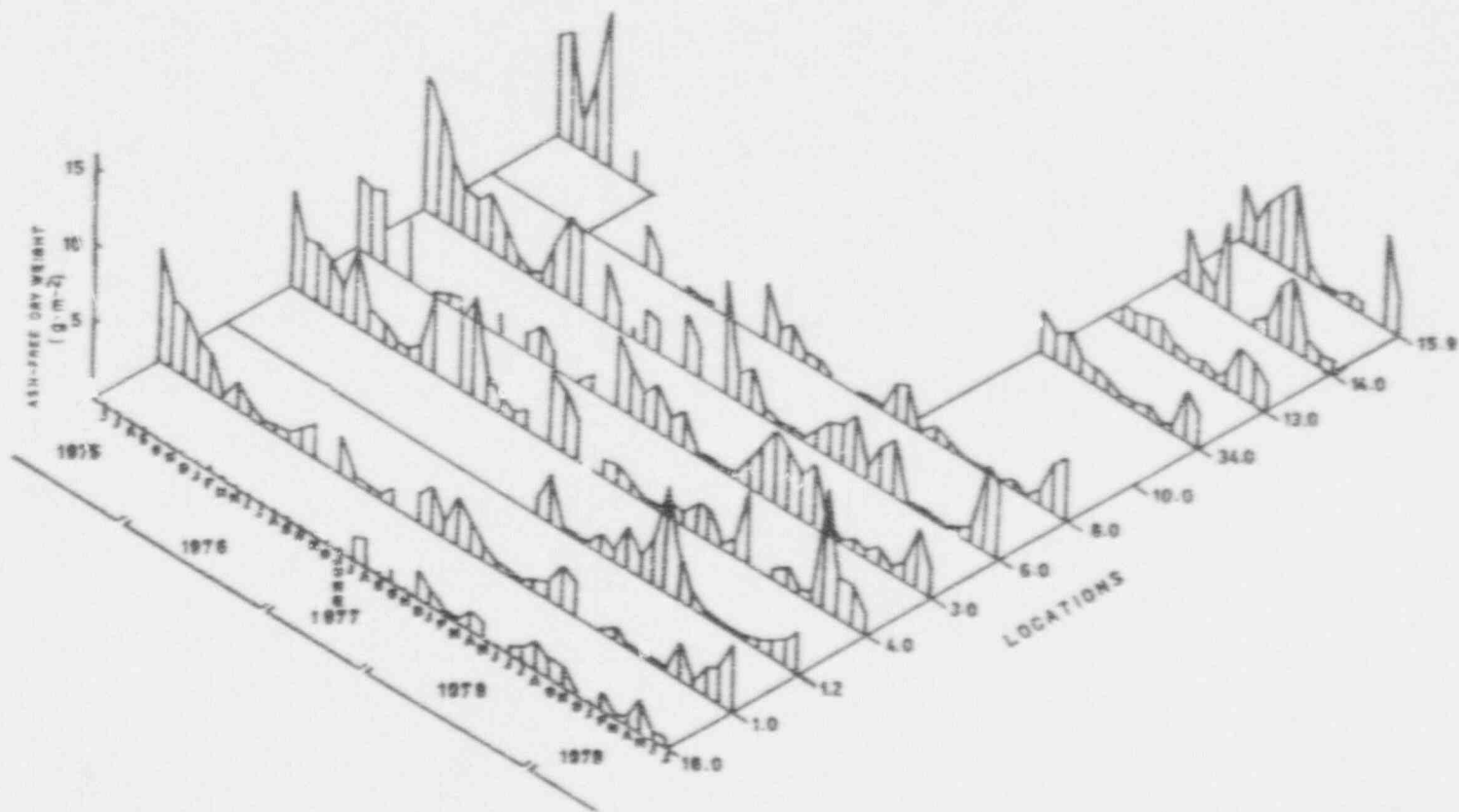


Figure 6-2. Periphyton ash-free dry weights for locations on Lake Norman and Mountain Island Lake, NC from 30 May 1975 through 5 December 1976, and from 8 July 1977 to 6 July 1979.

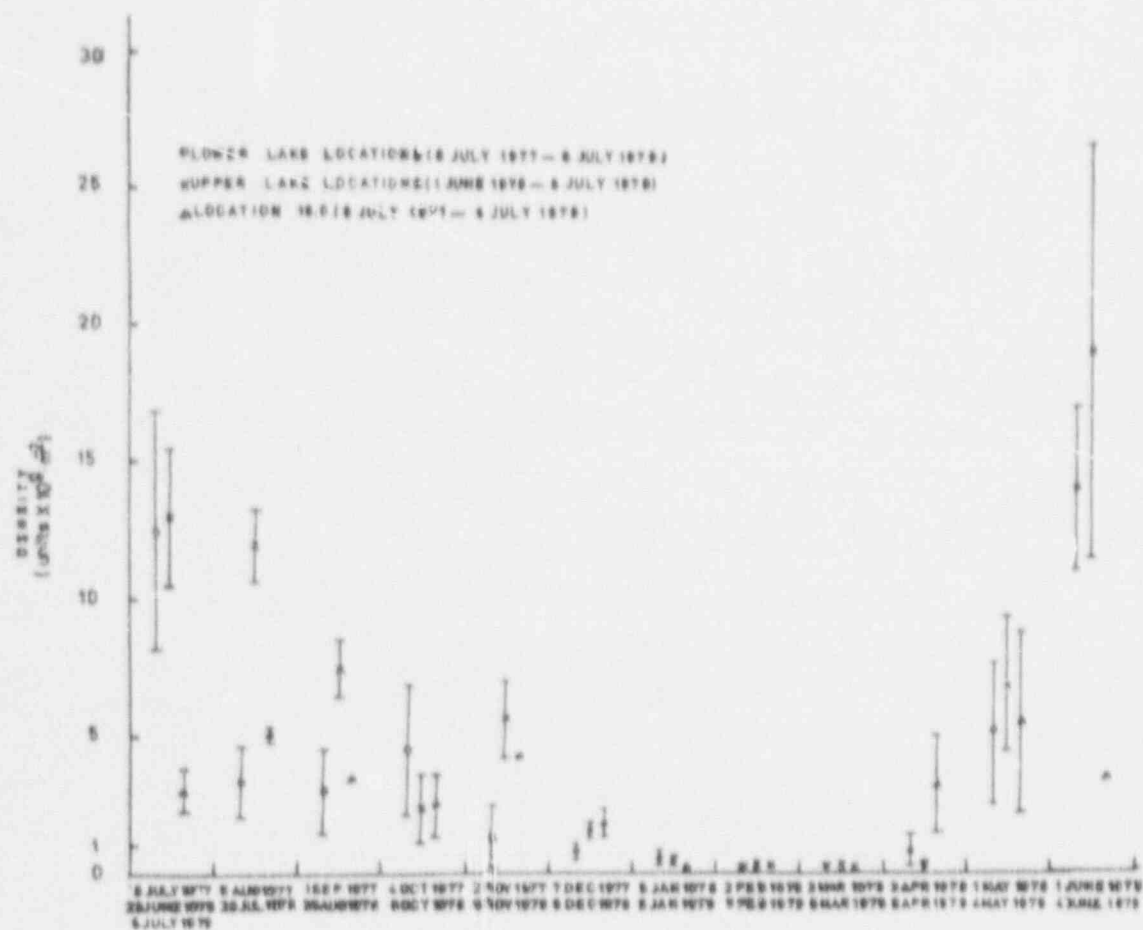


Figure 6-3. The seasonal distribution, averaged for all years, of the means and standard deviations of total densities for areas of Lake Norman, NC from 8 July 1977 to 6 July 1979.

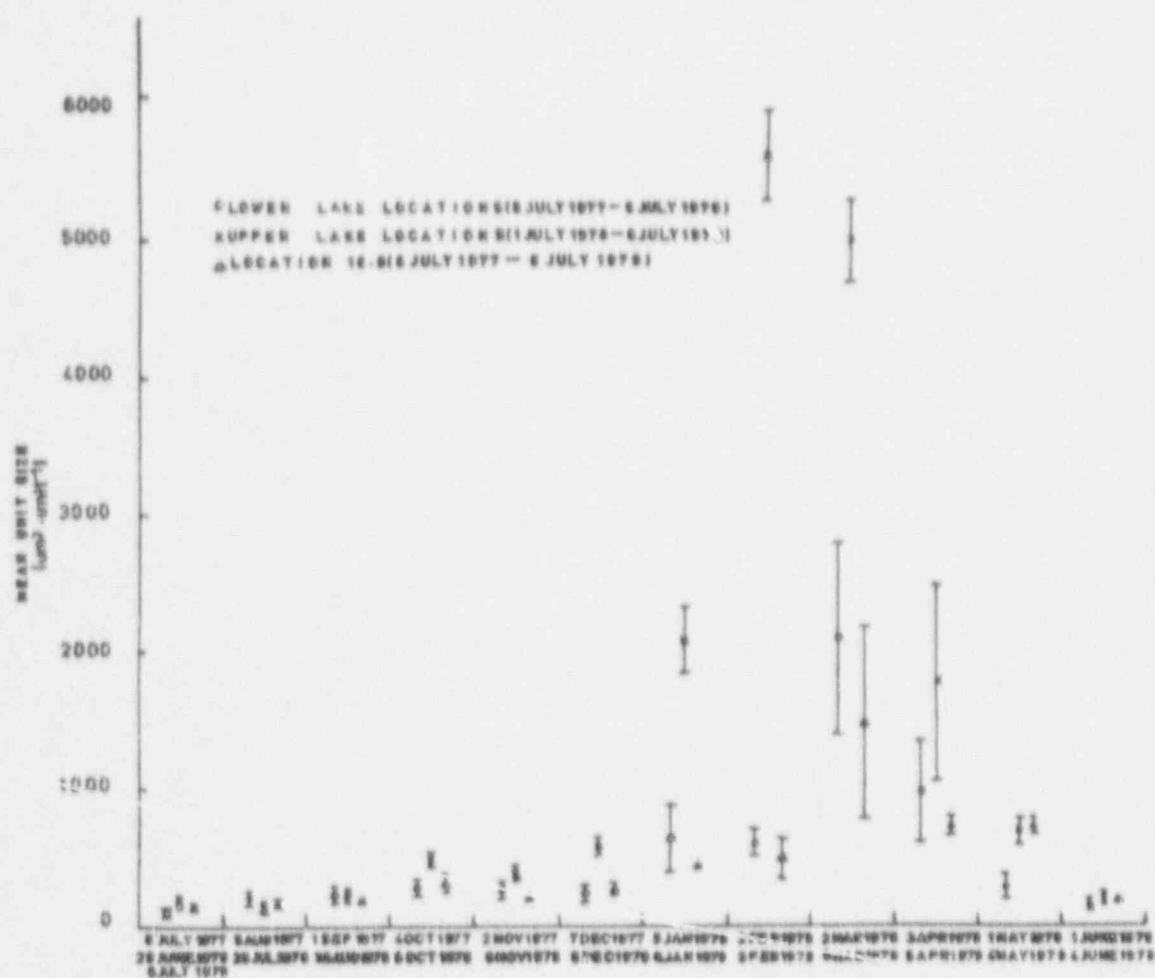


Figure 6-4. The seasonal distribution, averaged for all years, of the means and standard deviations of mean unit sizes for areas of Lake Norman, NC from 7 July 1977 to 6 July 1979.

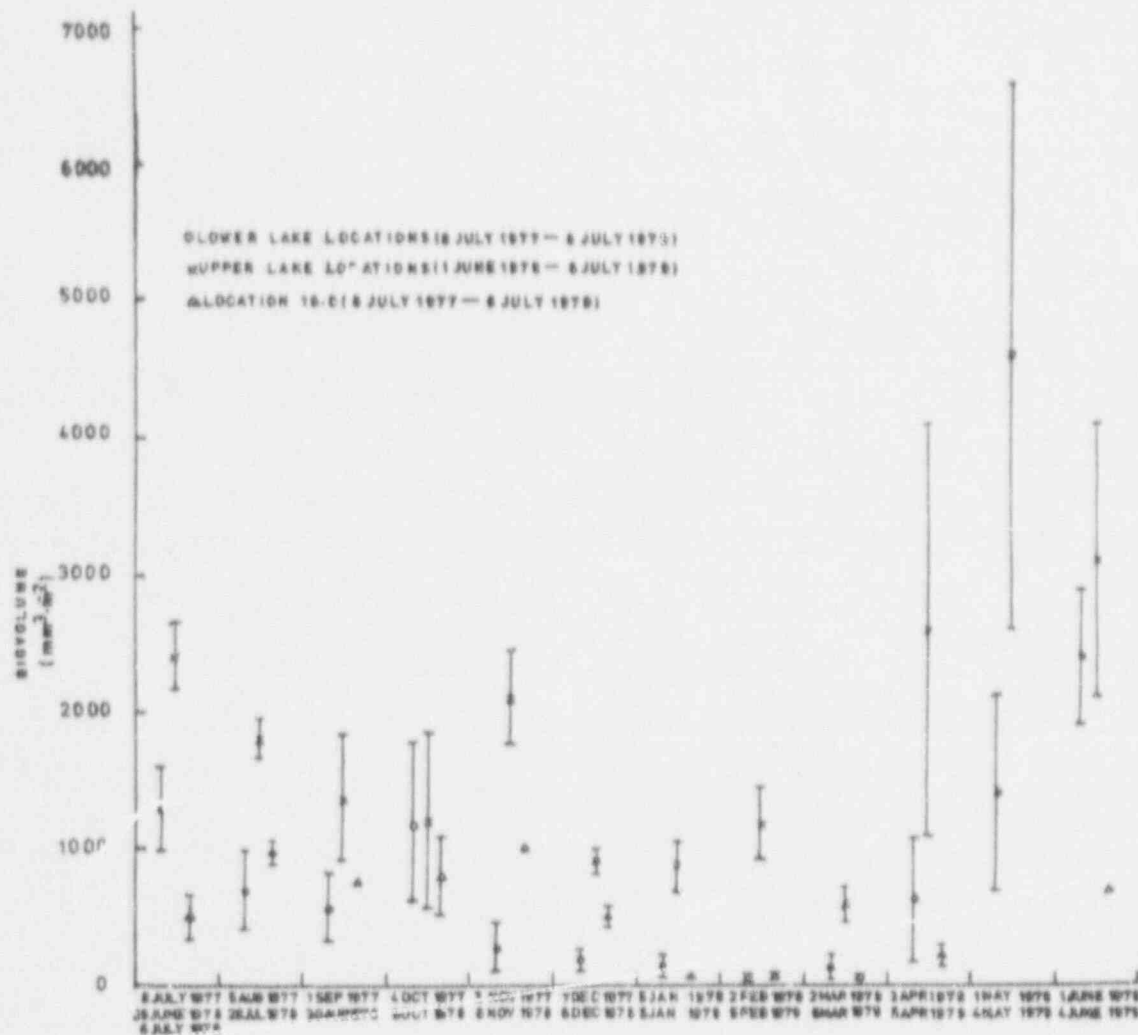


Figure 6-5. The seasonal distribution, averaged for all years, of the means and standard deviations of total algal biovolumes for areas of Lake Norman, NC from 8 July 1977 to 6 July 1979.

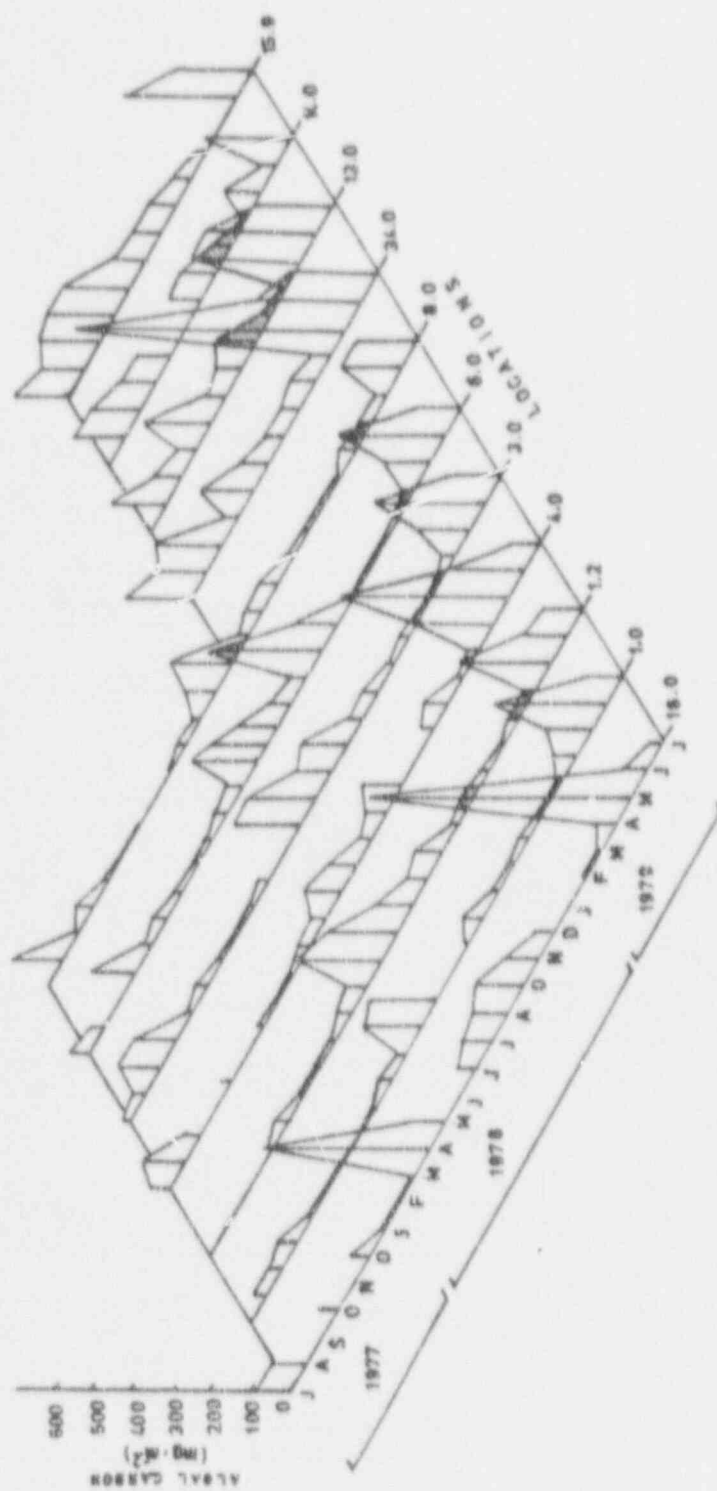


Figure 6-6. Periphyton algal carbon for locations on Lake Norman and Mountain Island Lake, NC from 8 July 1977 to 6 July 1979.

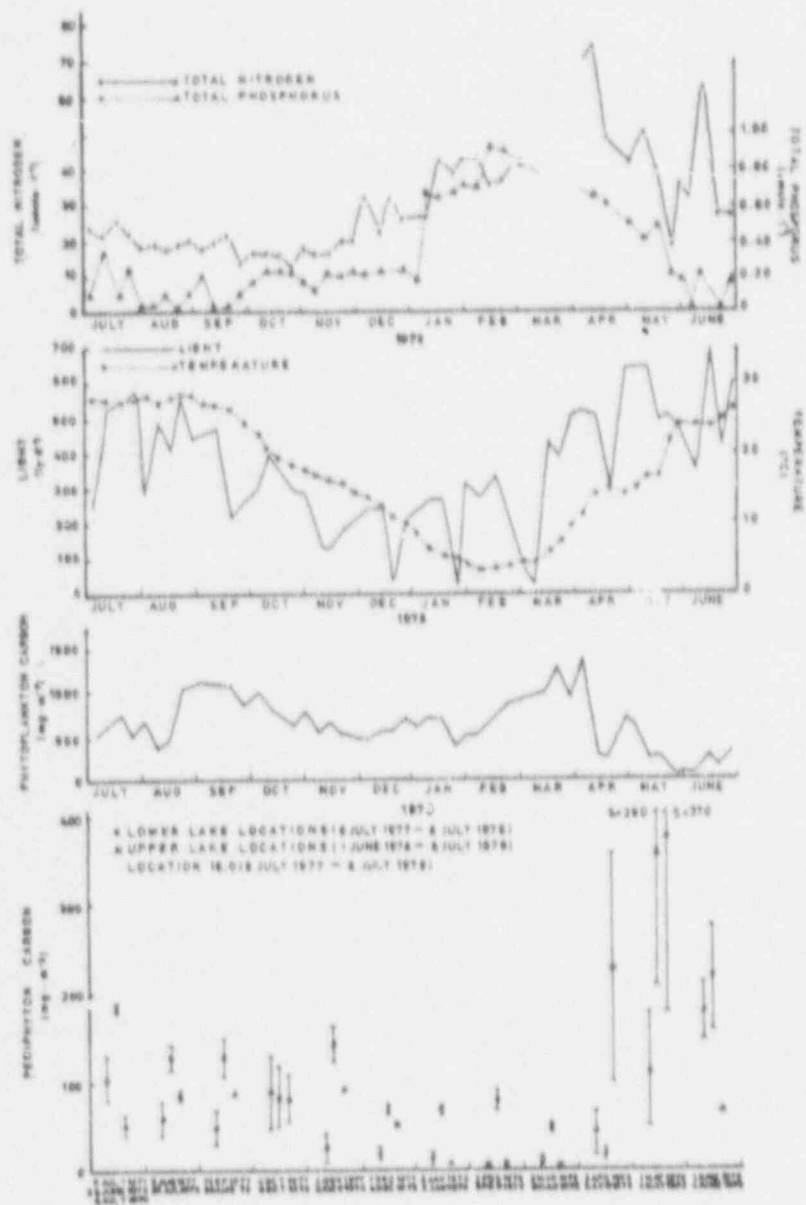


Figure 6-7. A comparison of physicochemical variables and phytoplankton carbon from samples collected at Locations 3.0 and 8.0 in 1978 with the seasonal distribution, averaged for all years, of the means and standard deviations of periphyton carbon for areas in Lake Norman, NC, from 8 July 1977 to 6 July 1979.

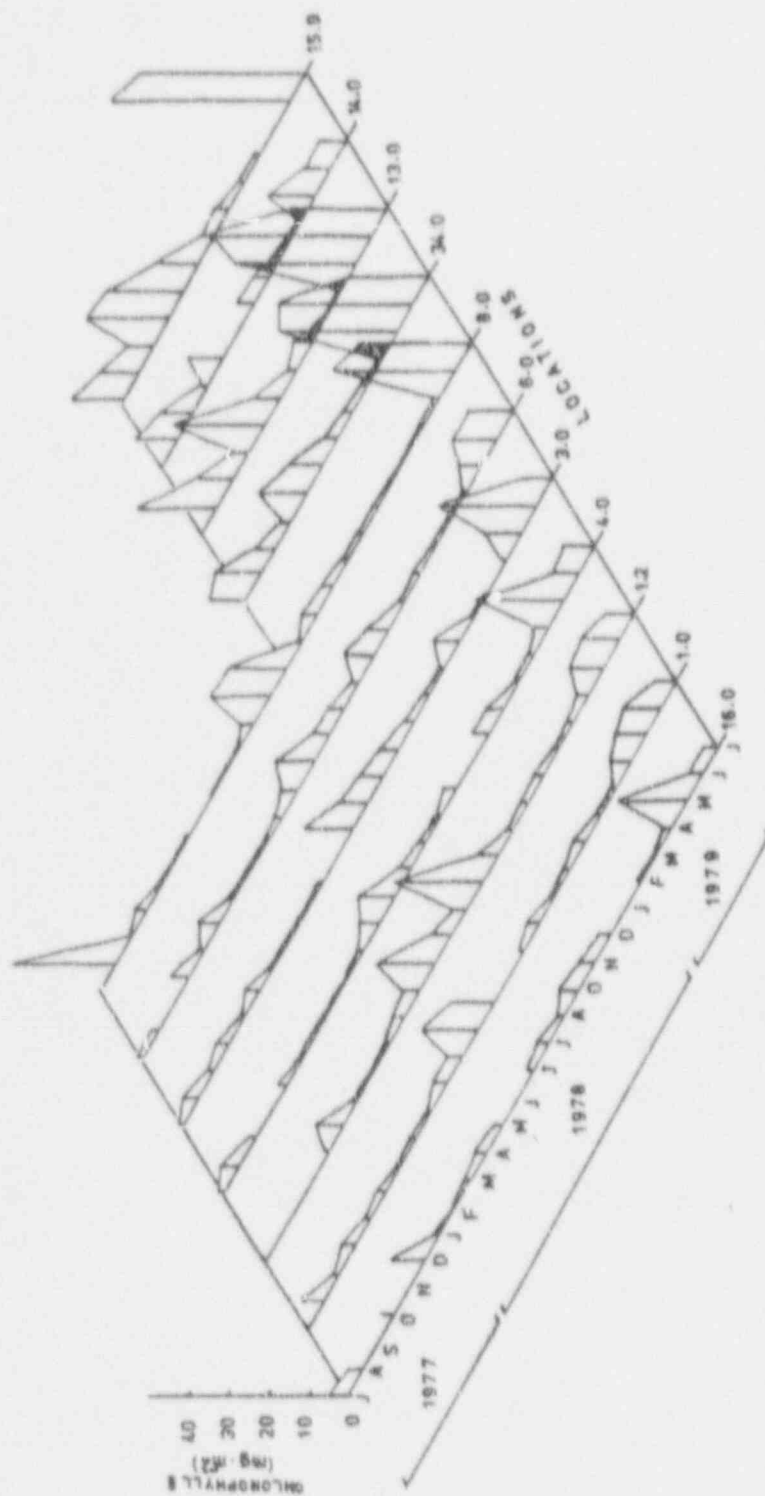


Figure 6-8. Periphyton chlorophyll *a* for locations on Lake Norman and Mountain Island Lake, NC from 8 July 1977 to 6 July 1979.

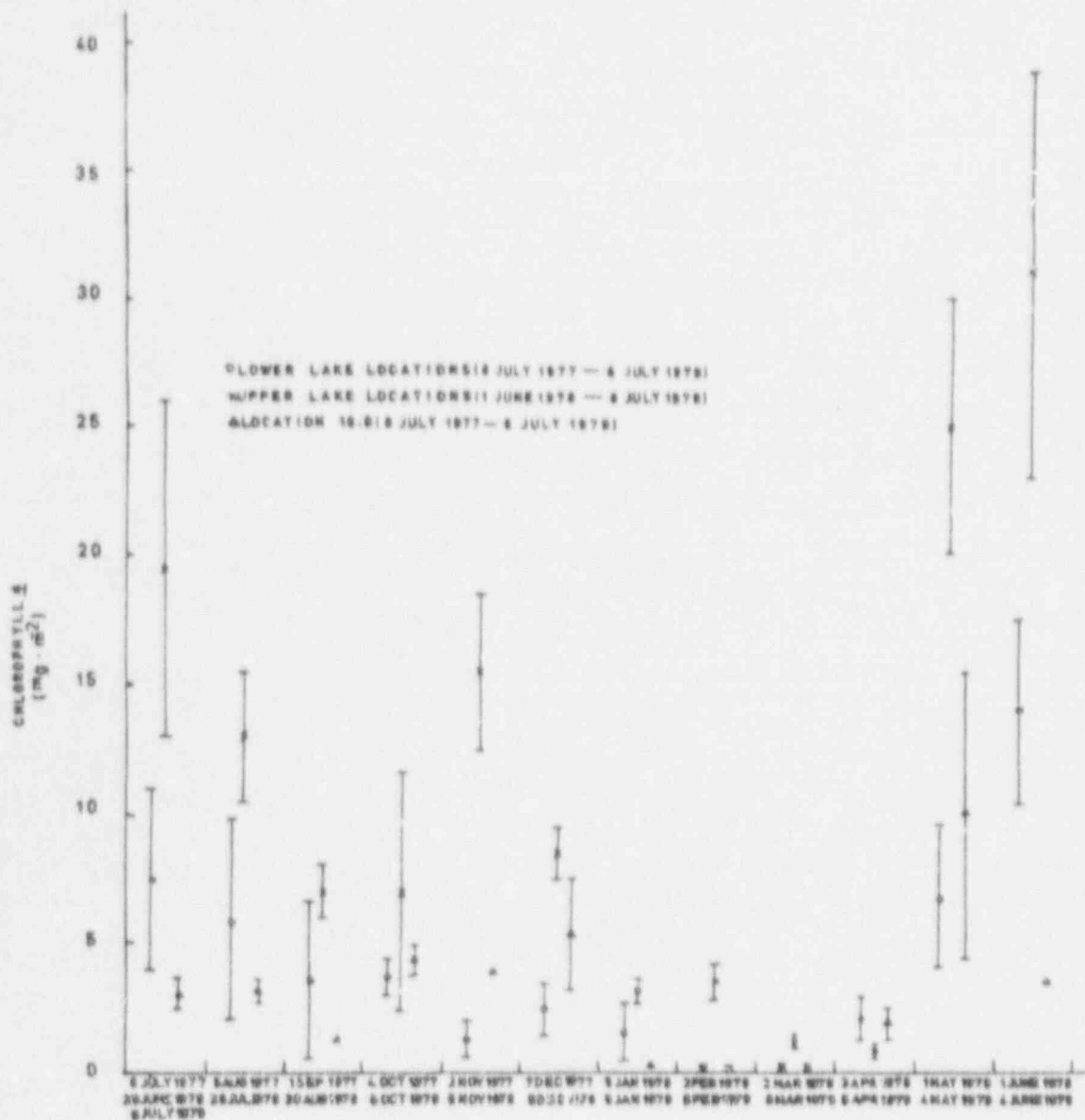


Figure 6-9. The seasonal distribution, averaged for all years, of the means and standard deviations of true chlorophyll *a* for areas of Lake Norman, NC from 8 July 1977 to 6 July 1979.

CHAPTER 7. MACROPHYTES

J. E. DERWORT

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INTRODUCTION

BACKGROUND

Macrophytes have been defined as macroscopic aquatic plants inhabiting the littoral zone of a body of water (Odum 1971), and consist primarily of aquatic flowering plants, but also include bryophytes, ferns, and larger algae (Vollenweider 1974). Macrophytes have also been described as "habitat formers" (Wood 1967), because they provide substrate for periphytic algae and attached invertebrates, and are a source of food and shelter for invertebrates, fish, birds, and mammals (Odum 1956).

As primary producers in aquatic ecosystems, macrophytes add to the supply of organic material and oxygen; upon their death, oxygen is utilized, while carbon dioxide and nutrients are released via decomposition. Macrophytes have been found to be the major primary producers in certain shallow, eutrophic lakes and ponds of the temperate zone (Wetzel 1964); however, in deep, oligotrophic lakes, their contribution to autotrophic production is usually negligible (Odum 1971; Westlake 1965). Rodgers (1974) found that macrophytes utilized approximately 1% of the littoral substrates in Lake Keowee, SC, and contributed only 0.001% to the total mean annual primary production in that lake.

During 1973 and 1974, beds of macroscopic algae (charophytes) were observed on silty substrates at 0.3 to 1.5 m in certain protected coves in Lake Norman, NC. As a result of these observations, questions arose as to the abundance and importance of these macrophytes, especially with regard to oxygen depletion during periods of macrophyte death and subsequent decomposition (Duke Power Company 1976).

OBJECTIVES

The objectives of this study were to:

- 1) determine the taxa composition of macrophytes, and
- 2) assess the importance of macrophytes in terms of biomass and oxygen depletion in the Ramsey Creek Arm of Lake Norman.

MATERIALS AND METHODS

FIELD PROCEDURES

Aerial photographs were taken on 6 March 1975 and 11 September 1978 along the Lake Norman shoreline, specifically in the Ramsey Creek area (Fig. 7-1), to determine the extent of macrophyte beds. Likely habitats for macrophytes were considered as those areas on the aerial photographs which appeared dark or shaded in contrast to the red color associated with the normal bare substrate. Aerial photos have been used by a number of investigators to pinpoint macrophyte habitats (Edwards and Brown 1957; Vollenweider 1974; Wetzel 1964).

Actual visits to the photographed sites were made on 7 March and 2 May 1975, 5 October 1976, 7 July 1977, and 29 September 1978. Samples collected prior

to 29 September 1978 were from 0.3 to 5.0 m depths near Locations 4.0 and 6.0. Macrophytes from these samples were returned to the laboratory for identification. Samples collected on 29 September 1978 were collected with a modified Petersen dredge at depths from 0.5 to 1.5 m from the locations marked on Fig. 7-1. These locations were selected for sampling because they appeared, from aerial photographs, to be areas of high macrophyte densities. The samples were washed thoroughly in a bucket with a 0.5-mm mesh screen prior to returning to the laboratory.

LABORATORY PROCEDURES

Specimens from all collections were examined under a dissecting microscope at 20 to 40X. Taxonomic keys used for the identification of macrophytes included Wood (1967) and Radford et al. (1968).

Biomass was estimated from samples collected on 29 September 1978. The dry and ash-free dry weight methods of American Public Health Association et al. (1976) and Vollenweider (1974) were used to estimate biomass in grams per square meter ($\text{g}\cdot\text{m}^{-2}$).

RESULTS AND DISCUSSION

Chara sp., a macroscopic alga (Charophyceae), was observed prior to 1975 on silty substrates in coves of the Ramsey Creek Arm of Lake Norman. This charophyte was found at depths of 0.3 to 1.5 m (Duke Power Company 1976). Aerial surveys in March 1975 and September 1978 revealed that certain areas in the Ramsey Creek Arm of Lake Norman were likely habitats for macrophytes.

Two genera of submerged aquatic macrophytes were found near Location 6.0 in May 1975. *Nitella* sp., another charophyte, was observed in samples from depths of 1.0, 3.0, and 5.0 m. *Potamogeton* sp. (Potamogetonaceae), a rooted pond weed, was observed in samples from depths of 2.0 to 3.5 m. *Nitella* sp. was again observed near Location 6.0 from depths of 0.5 to 2.0 m in October 1976 and July 1977. Samples taken in September 1978 were from five locations chosen from aerial photographs as areas of apparent macrophyte growth (Fig. 7-1). These samples consisted primarily of the sedge *Eleocharis* sp. (Cyperaceae), a widespread, shallow-water plant important in the marginal vegetation of lakes (Corillion 1957 in Hutchinson 1975) and *Nitella* *hyalina* (DC) Ag., a halophobic charophyte often found in circumneutral water (Hutchinson 1975). These macrophytes were generally observed in sparse, scattered clumps.

Available substrate for macrophyte growth was assumed to be all substrate to a depth of 6.0 m from full pond (Wood 1967). Also, since macrophytes were observed in sparse, scattered clumps, the assumption was made that macrophytes occupied 10% of the available substrate (utilized available substrate).

Ash-free dry weights from samples collected in September 1978 ranged from $12.1 \text{ g}\cdot\text{m}^{-2}$ at Location A to $38.8 \text{ g}\cdot\text{m}^{-2}$ at Location C (Table 7-1). In order to estimate the relative contribution of autochthonous input from macrophytes, ash-free dry weights were converted to carbon using Vollenweider's (1974) equations. Based on biomass measurements and utilized available substrate, the instantaneous production of macrophytes was approximately 5.0 metric tons

carbon. The instantaneous biomass of periphyton, calculated from natural substrate standing crops collected in September 1978 at Locations 4.0 and 6.0 in Ramsey Creek (Chapter 6) and converted to carbon using Strathman's (1967) equations, was $100 \text{ mgC} \cdot \text{m}^{-2}$. Assuming available substrate to a depth of 6.0 m, the total instantaneous biomass of periphyton in Ramsey Creek was estimated as 0.45 metric tons carbon. The estimated total annual carbon production of phytoplankton in Ramsey Creek (calculated from weekly primary production data for Location 3.0 presented in Chapter 4) was approximately 1500 metric tons. By estimating total biomass contributed per year by macrophytes (turnover rate = $2 \text{ times} \cdot \text{yr}^{-1}$), periphyton (turnover rate = $52 \text{ times} \cdot \text{yr}^{-1}$), and phytoplankton, the 10.0 metric tons carbon input per year from macrophytes was less than 1.0% that of periphyton and phytoplankton (1523.4 metric tons carbon per year).

Table 7-1. Macrophyte ash-free dry weights from samples collected at Locations in the Ramsey Creek Arm of Lake Norman, NC for 29 September 1978.

<u>Location</u>	<u>Depth (m)</u>	<u>Ash-Free Dry Weight ($\text{g} \cdot \text{m}^{-2}$)</u>
A	0.5	12.1
B	0.5	17.6
C	0.5	38.8
D	0.5	26.2
E	1.5	24.6
		Mean = $\overline{23.9}$
		Standard Deviation = 10.7

Based on the above estimates (biased toward the macrophytes), and on the equations of Stumm and Morgan (1970), complete macrophyte decomposition utilized approximately $0.7 \text{ mg} \cdot \text{l}^{-1}$ of oxygen annually in the Ramsey Creek Arm of Lake Norman. Phytoplankton and periphyton decomposition, however, was estimated to use approximately $23.3 \text{ mg} \cdot \text{l}^{-1}$ of oxygen per year, or nearly 97% of the oxygen used by autochthonous decomposition. Therefore, macrophyte contribution to lake metabolism, especially with regard to oxygen depletion during the decay process, was negligible compared to the other autotrophic components. In addition, during several sampling periods, macrophytes were observed washed up on shore. This along with lake drawdown, would permit aerobic decomposition utilizing atmospheric oxygen rather than consuming dissolved oxygen within the lake.

SUMMARY

During 1973 and 1974, beds of macrophytes were observed in the Ramsey Creek Arm of Lake Norman. Aerial photographs taken in 1975 and 1978 revealed that certain areas in the Ramsey Creek Arm of Lake Norman were likely habitats for macrophytes. Samples for taxonomic determinations were collected in Ramsey Creek at least once each year from 1973 to 1978. Samples collected in 1978 were used to estimate total annual carbon input from macrophytes in Ramsey Creek.

Four genera of submerged aquatics were identified from samples collected in Ramsey Creek. *Eleocharis* sp., a sedge, and the charophyte *Nitella* sp. were the most common forms observed.

Based on utilized available substrate, aerial photographs, and subsequent macrophyte standing crop estimates from samples collected in September 1978, macrophytes contributed less than 1% to the total annual autotrophic production in the Ramsey Creek Arm of Lake Norman. Therefore, macrophyte contribution to lake metabolism was negligible, especially with regard to oxygen depletion, since it was estimated that macrophytes utilized approximately 3% of the total oxygen utilized by all autotrophs during decomposition. Also, lake drawdown and macrophyte deposition on the shore probably permitted considerable atmospheric, aerobic decomposition.

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Figure 7-1. Maps of Lake Norman, NC (top) and the Ramsey Creek Arm (bottom) of Lake Norman showing macrophyte sampling locations for 29 September 1978.

CHAPTER B. ZOOPLANKTON

R. E. HAMME

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INTRODUCTION

BACKGROUND

The zooplankton considered in this report are the copepod and cladoceran microcrustaceans, and the rotifers. Although these organisms are capable of varying degrees of movement, they generally are transported with water currents. Many zooplankton are consumers of algae, bacteria, and detritus, and in turn, recycle nutrients. Zooplankton are also important in the diets of some benthic organisms and both larval and adult fish.

Zooplankton communities in temperate lakes are often characterized by annual bimodal density distributions and population succession cycles (Hutchinson 1967; Pennak 1946, 1957; Ruttner-Kolisko 1974). Temperature and food supply are generally considered the two most important influencing factors. Temperature affects zooplankton populations by regulating time of occurrence, reproduction, and development rates, while food supply affects fertility by influencing brood size (Edmondson 1965; Edmondson and Winberg 1971; Hofmann 1977; Winberg 1971). Additional factors which influence zooplankton populations include water movements, predation, turbidity, and water quality parameters.

Duke Power Company (1976), Menhinick and Jensen (1974), and Weiss et al. (1975) found that crustacean densities in Lake Norman exhibited a general seasonal trend of spring maxima with lower densities in the summer and fall. Rotifer densities exhibited similar spring trends and a pronounced increase in population densities during the fall. Menhinick and Jensen (1974) noted that zooplankton densities were lower in the Marshall Steam Station intake and discharge coves compared to the remainder of the lake, particularly during the periods of lake stratification. This was attributed to the use of hypolimnetic condenser cooling water which contained few zooplankton. A similar effect was observed by Duke Power Company (1977) in Lake Keowee, S. C. who concluded, with this exception, that zooplankton populations were essentially uniformly distributed in Lake Norman. Weiss et al. (1975) and Duke Power Company (1976) reported similar trends although Duke Power Company (1976) noted slightly higher zooplankton densities in the Davidson and Ramsey Creek Arms than in the main channel areas.

OBJECTIVES

Within the overall objectives stated in Chapter 1, the specific objectives of this study were to:

- 1) determine the zooplankton community composition in Lake Norman, and
- 2) determine the seasonal and spatial variability of the zooplankton.

MATERIALS AND METHODS

FIELD PROCEDURES

ZOOPLANKTON DENSITY

A summary of the sampling locations, depths, replication, equipment, and frequency of zooplankton collections is presented in Table 8-1. Sampling locations are described in Table 1-3 and shown in Fig. 1-10 and 1-11.

Two types of 76- μ m mesh net sampling devices were used to collect zooplankton density samples. A Clarke-Bumpus sampler was used from January 1974 through July 1974. Beginning in August 1974 and continuing through December 1980, a 0.5-m diameter oceanographic style net was used to collect the samples. Both devices were equipped with a calibrated flowmeter which was used to calculate sample volumes. Depending upon the water depth, these devices were towed from 10 m to the surface and/or bottom to the surface. Only surface tows were collected at Location 16.0. Two replicate samples were collected from January 1974 through September 1976. Three replicate samples were collected from October 1976 through September 1980, after which single samples were collected.

VERTICAL DISTRIBUTION

Discrete depth samples were collected monthly as outlined in Table 8-2. Prior to August 1975, single samples were collected at 3-m depth intervals from the surface to 15 m and from 1 m above the bottom. A Homelite Model XL water pump with an in-line flowmeter was used to collect these samples from January through March 1974. The pump was replaced with a Clarke-Bumpus sampler in March which was used through July 1974. A plankton trap (Schindler 1969), with a capacity of approximately 30 l, was used to collect discrete depth samples from October 1975 through December 1980. Beginning in October 1977, discrete depth samples were collected at the locations listed in Table 8-2 at 2-m depth intervals from 0.3 to 10 m. Samples in the McGuire intake areas were collected from depths corresponding to the upper and lower elevations of the two intake structures.

From April 1979 through March 1980, a 76- μ m mesh, 0.5-m diameter oceanographic style net equipped with a flowmeter and a combination opening and closing device was used to collect samples from the bottom to 10 m and from 10 m to the surface, which are designated the lower and upper depth regions, respectively. These samples were collected in triplicate at Locations 5.0 and 8.0.

SAMPLE PRESERVATION

All samples were rinsed into vials and preserved in a sugar-formalin solution. Beginning in November 1974, this procedure was modified by rinsing the samples into vials containing 1.0 ml of a 5.0% L-phenylephrine HCl solution and then preserving with sugar-formalin solution 15 minutes later. The L-phenylephrine HCl solution acted as a relaxant and facilitated rotifer identification. Rose bengal stain was also added to the sugar-formalin solution as an enumeration aid.

LABORATORY PROCEDURES

Zooplankton samples were concentrated or diluted to a known volume depending upon the density of zooplankton, phytoplankton, and suspended particles. From this sample, aliquots were withdrawn, placed in a counting chamber and the zooplankton enumerated and identified to the lowest practicable taxonomic level. Two aliquots were enumerated from January 1974 through September 1976 and only one was enumerated from October 1976 through December 1980. When practicable, at least 100 rotifers and 100 crustaceans were enumerated in each aliquot. Due to different dilution/concentration requirements, separate aliquots were usually counted for these groups. All raw values were converted to zooplankton

densities expressed as the number of organisms per cubic meter ($\text{no} \cdot \text{m}^{-3}$). Principal taxonomic references were Ahlstrom (1940, 1943), Brooks (1957, 1959), Edmondson (1959), Ruttner-Kolisko (1974), Smirnov (1974), Voigt (1956), Wilson (1959), Wilson and Yeatman (1959) and Yeatman (1944, 1959).

DATA ANALYSES

Zooplankton densities were analyzed to determine trends in community composition and abundance, as outlined in Table 8-3. The data used in these analyses are presented in Appendix 8.1, 8.2, and 8.3. Seasons, where used, are the calendar seasons. Biomass estimates were derived from density values using the mean biomass per individual as developed by Horton and Carter (personal communication). The methods and data used to investigate the relationship between zooplankton density and various other biological and physical data (e.g., total phytoplankton density, total phytoplankton biovolume, temperature, and turbidity) are shown in Table 8-3.

RESULTS AND DISCUSSION

COMMUNITY COMPOSITION

A total of 134 taxa was identified in the samples collected from Lake Norman (Table 8-4). The crustaceans generally dominated the zooplankton density from the winter through early summer, while the rotifers were the major forms during the summer and fall (Fig. 8-1). However, the crustaceans dominated the zooplankton biomass throughout the year. Throughout the sampling period, crustacean densities were dominated by the immature copepod life stages. Rotifer taxa important on a numerical basis included Keratella spp., Polyarthra vulgaris, Synchaeta spp., Conochilus unicornis, Collotheca spp., Trichocerca porcellus, Asplanchna spp., and Ptygura spp. Important copepod species included Diaptomus mississippiensis, Mesocyclops edax, Tropocyclops prasinus, and Cyclops thomasi and the major cladocerans were Bosmina longirostris, Daphnia parvula, D. ambigua, and Holopedium gibberum.

From January through March, the immatures dominated the copepods, and a few Cyclops thomasi and Tropocyclops prasinus adults were also present. During this time, Bosmina longirostris dominated the cladocerans, while the rotifers were dominated by Polyarthra vulgaris, Keratella spp., Trichocerca porcellus, and Synchaeta spp. (Fig. 8-2 and 8-3). In April and May, immature copepods, Diaptomus mississippiensis, Cyclops thomasi and later Mesocyclops edax, Bosmina longirostris, Daphnia parvula, Keratella spp., Polyarthra vulgaris, Trichocerca porcellus, and Conochilus unicornis dominated the respective major zooplankton taxa. Immature copepods, Holopedium gibberum and Bosmina longirostris dominated the crustaceans during the summer months while the major rotifers were dominated by Keratella spp., Ptygura spp., and Polyarthra vulgaris. Fall populations consisted primarily of immature copepods, Bosmina longirostris, Diaphanosoma leuchtenbergianum, Conochilus unicornis, Ptygura spp., Synchaeta spp., Keratella spp., and Polyarthra vulgaris. As a result, the Lake Norman zooplankton community at any particular time was generally composed of one to three major cladoceran and/or copepod species and one to five major rotifer taxa. This assemblage of species was generally most diverse in terms of number of taxa in the late winter and spring months and least diverse in the late summer and fall months. These patterns were similar to those reported by Pennak (1957), Ruttner-Kolisko (1974), and Weiss et al. (1975).

Crustacean populations demonstrated consistent cycles of occurrence and peak densities. Bosmina longirostris, which Kwick and Carter (1975) found capable of development at lower temperatures than most limnetic cladocerans, was the first cladoceran species to attain high densities in the early spring (March or April) (Fig. 8-2). Daphnia parvula attained a population peak within two weeks of B. longirostris. D. ambigua followed in late April and Holopedium gibberum in May. Diaphanosoma leuchtenbergi and Leptodora kindtii had population increases in late September and October. Similarly, the adult copepods (Fig. 8-2) generally followed a pattern beginning with Tropocyclops prasinus in early Spring and continuing with peaks of Cyclops thomasi, Diaptomus mississippiensis and D. birgei within the same month. Mesocyclops edax reached maximum density in late spring or early summer. The yearly occurrence of these cycles and the resultant associations indicate that temperature, and possibly food supply were the principle factors affecting species occurrence and relative abundance, as suggested by Edmondson and Winberg (1971), Kamps (1978), Kwick and Carter (1975), and Winberg (1971).

Seasonal trends of rotifer abundance and species composition were more complex, probably due to the strong genetic seasonal adaptation of rotifers (King 1977; Ruttner-Kolisko 1974; Snell 1977), and/or the difficulty of species identification (e.g., Collotheca spp., Keratella spp., Synchaeta spp.). However, some general trends were evident (Fig. 8-3). Polyarthra vulgaris, Synchaeta spp., and Keratella spp. were generally present throughout the year. The winter-spring assemblage was primarily composed of Polyarthra vulgaris, Synchaeta spp., Collotheca spp., Trichocerca porcellus, Keratella spp., and Conochilus spp. Of these, Keratella spp., Synchaeta spp., and Collotheca spp. were abundant during the warmer months as well. Ploesoma spp., Ptygura spp., and Conochilus spp. were also important components of the summer rotifer population assemblage. Several taxa of lesser numerical importance were also characteristic of the summer and fall months. These included Macrochaetus spp., Hexarthra spp., and Trichocerca capucina. In general, the rotifer assemblage found in Lake Norman was similar to that described by Ruttner-Kolisko (1974) as characteristic of oligotrophic lakes.

STANDING CROP

VERTICAL DISTRIBUTION

Zooplankton densities appeared to be relatively evenly distributed throughout the upper 10 m of the water column (Fig. 8-4). Densities were generally higher in this region than they were below 10 m throughout the year (Fig. 8-5). This trend was due primarily to the rotifer densities which were always at least one order of magnitude higher in the upper 10 m even in the absence of lake stratification. This indicates that the rotifers were capable of actively maintaining their position in the water column even during the winter periods of vertical mixing. A similar distribution of rotifers was noted during turnover of Lake Windermere, England and attributed to active vertical migration in response to the light gradient (Ruttner-Kolisko 1974).

HORIZONTAL DISTRIBUTION

Zooplankton horizontal heterogeneity in natural lakes is a result of interaction between vertical migration and wind induced water movements (George and Edwards 1976). Of possibly greater importance in Lake Norman were water movements resulting from river inflow, Marshall Steam Station operation, and operation

of Cowans Ford Hydroelectric Station. The most pronounced example of these effects was evident in the vicinity of Marshall. The use of hypolimnetic water, which contains relatively low zooplankton densities, for condenser cooling and its subsequent discharge onto the surface of Lake Norman resulted in a dilution of zooplankton densities at nearby sampling locations (Fig. 8-6). A similar effect was documented at Oconee Nuclear Station (Duke Power Company 1977) and previously at Marshall by Menhinick and Jensen (1974). Zooplankton total densities at Location 14.0 (Table 8-5) (Marshall discharge) were lower than at any other sampling location on the lake with the exception of the Marshall intake. Densities at Location 13.0, located in the main channel immediately downstream from the Marshall discharge canal, were also low, but densities were higher at Locations 34.0 and 50.0 (downstream and upstream of Location 13.0, respectively). These values indicate either rapid recovery and/or less dilution by hypolimnetic water at these locations.

Zooplankton densities in the upper 10 m of the water column in the main channel were generally higher midlake (Location 8.0) than they were either downlake (Locations 1.0 and 2.0) or in the vicinity of Marshall (Location 13.0). Locations 15.0 and 15.9 generally supported the greatest number of zooplankton (Fig. 8-6). Ramsey Creek sampling locations, with the exception of Location 6.0 (Locations 3.0, 3.9, 4.0, 4.5, 5.0), generally supported lower zooplankton densities than the main channel locations (Table 8-5). This general trend was also reported for the phytoplankton standing crop (Chapter 4).

A principal components analysis (Helwig and Council 1979) was used to examine the relative similarities among locations in terms of the relative abundance of rotifer, cladoceran, and copepod densities. Data from the 10 m to surface tows collected from June 1978 through May 1979 were used for this analysis. The resultant analysis grouped the sampling locations as follows: the downlake and Ramsey Creek Locations 1.0, 1.2, 3.0, 3.9, 4.0, 4.5, and 5.0; the mid to uplake Locations 8.0, 34.0, 13.0, and 50.0; Locations 15.0 and 15.9; Locations 16.0 and 60.0; Location 2.0; and Location 6.0 (Fig. 8-7). Although the differences in mean location densities, with the exception of Locations 16.0 and 60.0, were small (less than three-fold), the rotifer and cladoceran densities were generally higher in the uplake cluster and the copepod densities were generally higher in the downlake cluster (Table 8-5, Fig. 8-6). As shown in Fig. 8-7, there may have been a relationship between phytoplankton standing crop as indicated by total biovolume and the zooplankton composition within the various clusters.

SEASONAL VARIATION

In general, the zooplankton community in Lake Norman was bimodal exhibiting a higher spring density with a secondary fall pulse as is characteristic of other piedmont lakes (Duke Power Company 1977; Weiss et al. 1975). As shown by the mean monthly density values of the cladocerans, copepods, and rotifers, for all three years of the 0.5-m net samples (Fig. 8-8), rotifers were variable in their annual density distributions, while the cladocerans and copepods exhibited a unimodal, spring peak. Typically, April tended to be the month of highest rotifer densities while the cladocera reached maximum abundance in April or June, and the copepods peaked in March. The fall increase of cladocerans generally occurred in September or October.

The monthly mean densities of the various major taxonomic groups did not vary by more than one order of magnitude (Fig. 8-8). However, variations

within each month between the different locations and study years were as high as three orders of magnitude between the maximum and minimum values. With the exception of the cladocerans, the variation in biomass was generally less or similar to the variation in density indicating that the taxa contributing to the density variability were generally the smaller forms. Rotifer biomass, in fact, was relatively constant despite fairly large variations in density. The large cladoceran biomass from April through June was due primarily to Daphnia spp. and Holopedium gibberum.

Densities of crustacean filter feeders and rotifer current feeders during the winter and spring generally lagged the phytoplankton total density by one month (Fig. 8-9). Zooplankton and phytoplankton followed similar trends during the summer and fall of 1978. The one month lag-time in the winter and spring and absence of a lag-time in the summer and fall were probably due to the effects of temperature on zooplankton development times as reviewed by Edmondson and Winberg (1971), and Winberg (1971). These comparisons suggest that phytoplankton were influencing, to some degree, the current feeding rotifer and the filter feeding cladoceran population levels.

Most of the discrepancies in the relationship between the phytoplankton and zooplankton density trends occurred during the summer and fall. The generally low crustacean densities and the dominance of the crustaceans by the smaller species may be attributed to two major factors. Predation levels, based on densities of fish (Chapter 10) and limnetic Chaoborus spp. (Eaton, personal communication), were high during these periods and may have contributed to these crustacean community characteristics by size selective predation as described by Anderson and Raasveldt (1974), Brooks and Dodson (1965), and Vingard and Menger (1980). Thermal stratification (Chapter 3), with the attendant changes in food supply and temperature may alter crustacean community density and structure as described by Threlkeld (1979).

YEAR TO YEAR VARIATION

Year to year variation in zooplankton populations was most evident in maximum densities as shown in Fig. 8-10 for the October 1977 through September 1979 sampling period. Although major differences in phytoplankton or predator populations were not evident between the two study years (Chapters 4 and 10 respectively), differences did occur in temperature, which influences population development, and turbidity (Fig. 8-10). The mean water temperature in the upper 10 m was less than 5°C in January and February of 1978, while in 1979, the temperature remained below 5°C for only a short period in February (Chapter 3). Mean water temperatures in the upper 10 m increased to greater than 25°C during July 1978 and remained above 25°C until September while temperatures exceeded 25°C only during August in 1979. Turbidity, which may adversely affect zooplankton densities by interfering with feeding (Benson and Cowell 1967), was higher throughout the winter in 1978 than it was in 1979. The lower zooplankton densities in 1978 were probably attributable to the combination of relatively high turbidity and the prolonged low temperatures in 1978. The differences in the summer densities were possibly due to the temperature characteristics of the respective years.

SUMMARY

The zooplankton community of Lake Norman was sampled from July 1973 through December 1980. Samples were collected with metered nets, a pump, a Clarke-Bumpus apparatus and a plankton trap to characterize the zooplankton standing crop and the horizontal and vertical distribution within Lake Norman. The data analyzed in this report included monthly standing crop data from August 1974 through July 1975 and October 1977 through September 1979; weekly standing crop data from August 1974 through December 1976; and vertical distribution data collected with a plankton trap from October 1977 through September 1979.

The Lake Norman zooplankton community, at any particular point in time, was characterized by one to three major (in terms of density) cladoceran and copepod taxa, and three to five rotifer taxa. Typically, the cladocerans progressed from a Bosmonia longirostris peak in early spring, through Daphnia parvula, D. ambigua, and Holopedium gibberum by late spring, and to Diaphanosoma leuckithenbergianum and Leptodora kindtii in the early fall. The copepods, Tropocyclops prasinus, Cyclops thomasi, Diaptomus mississippiensis and D. birgei all attained maximum densities in the early to mid spring, and Mesocyclops edax followed in late spring. The rotifers did not follow as consistent a cycle, probably due to the genetic character of rotifer adaptation. In general, major winter-spring taxa included Polyarthra vulgaris, Synchaeta spp., Collotheca spp., Trichocera porcellus and Conochilus spp., Ptygura spp., Ploesoma spp., Conochilus spp., Keratella spp., Conochiloides spp., and Synchaeta spp. were abundant during the warmer months. The seasonal occurrence of the various zooplankton taxa was probably a function of temperature.

Zooplankton populations, particularly the rotifers, tended to be concentrated in the upper 10 m of the water column. The crustaceans were more variable in their vertical distribution but were also more abundant in the upper 10 m during the periods of maximum densities.

Differences among sampling locations were small (not more than three-fold on an annual basis). However, cladocerans and rotifers were generally more abundant uplake while copepods formed a larger component of the zooplankton community downlake. A localized dilution effect of zooplankton densities was noted in the vicinity of the Marshall Steam Station discharge canal. This was due to the discharge of hypolimnetic water, containing low densities of zooplankton onto the surface of Lake Norman. The Marshall intake cove and the Cowans Ford tailrace supported much lower densities than did the open lake locations.

While mean annual densities of all sampling locations did not vary by more than threefold, densities at a given location varied as much as three orders of magnitude on an annual basis. The zooplankton community was generally bimodal in its annual density distribution; maximum densities occurred in the spring with a secondary late summer-fall pulse. The rotifers generally attained population peaks in April and September or October while the crustaceans attained high densities only in the spring. The densities of filter feeding crustaceans and the current feeding rotifers appeared to be somewhat influenced by the total phytoplankton density, as was evidenced by corresponding trends of the respective concentrations. The large drop in crustacean densities after the spring pulse was probably due to a combination of predation, a shift in food characteristics and increased temperature.

Year to year differences were probably due to differences in temperature and turbidity. Low temperatures and high turbidity could have reduced zooplankton populations by delaying diapause release, reducing fecundity, increasing development rates, and reducing feeding rates. These may have caused the noted differences between the winter-spring populations observed in 1978 and 1979. Warmer temperatures during the summer of 1978 were probably responsible for the development of the late summer zooplankton pulse observed that year. Biological factors did not show any major differences that could have accounted for the observed differences in the zooplankton populations between the last two study years.

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Table 8-1. Zooplankton standing crop sampling summary for Lake Norman, NC, January 1974 through December 1980.

Sampling Frequency	Dates	Locations	Depths	Devices	Sample Replication
Monthly	Jan 1974 through Jul 1974	1.0, 2.0, 3.0, 4.0, 4.5, 5.0, 6.0, 7.5, 8.0, 10.0, 11.0, 13.0, 16.0	Bottom to surface and 10 m to surface	Clarke-Bumpus	Duplicate
	Aug 1974 through Jul 1975	"	"	0.5 m net	"
	Oct 1977 through May 1978	1.0, 1.2, 2.0, 3.0, 3.9, 4.0, 4.5, 5.0, 6.0, 8.0, 16.0	"	"	Triplicate
	Jun 1978 through May 1979 ¹	1.0, 1.2, 2.0, 3.0, 3.9, 4.0, 4.5, 5.0, 6.0, 8.0, 13.0, 14.0, 15.0, 15.9, 16.0, 34.0, 50.0, 60.0	"	"	"
	Jun and Jul 1979	1.0, 1.2, 2.0, 3.0, 3.9, 4.0, 4.5, 5.0, 6.0, 8.0, 16.0	"	"	"
	Aug 1979 through Jul 1980 ²	1.0, 1.2, 2.0, 3.0, 3.9, 4.0, 4.5, 5.0, 6.0, 8.0, 14.0, 15.9, 16.0, 34.0	"	"	"
	Aug 1980 through Dec 1980	1.0, 1.2, 2.0, 3.0, 3.9, 4.0, 4.5, 5.0, 6.0, 8.0, 16.0	"	"	"
Weekly	14 Aug 1974 through 31 Jul 1975	1.0, 4.0, 8.0	10 m to surface	0.5 m net	Duplicate
	Aug 1975 through 31 Sep 1976	"	10 m to surface and Bottom to surface	"	"
	Oct 1976 through 31 Dec 1976	"	"	"	Triplicate

¹ Locations 13.0, 14.0, 15.0, 15.9, 34.0, 50.0, and 60.0 were added to collect 12 months of data from uplake locations.

² The uplake locations 14.0, 15.9, and 34.0 were added to collect an additional 12 months of uplake data.

Table 8-2. Zooplankton vertical distribution sampling summary for Lake Norman, NC, January 1974 through December 1980.

Study	Dates	Locations	Depths (m)	Device	Sample Replication
Monthly Discrete	Jan 1974 through Mar 1974	1.0, 4.0, 8.0	0.0, 3.0, 6.0, 9.0, 1.2, 15.0 and 1 m above bottom	Metered pump	None
	Apr 1974 through Jul 1975	" " "	" " "	Clarke Bumpus	" "
	Oct 1974 through Jul 1975	" " "	" " "	Plankton trap	" "
	Oct 1977 through Dec 1980	1.0, 1.2, 4.5, 8.0	0.3, 2.0, 4.0, 6.0, 8.0, 10.0 @ Locations 4.5 and 8.0. Depths corresponding to the intake structures @ Locations 1.0 and 1.2	" "	Duplicate
Monthly Depth Region Distribution Samples	Apr 1979 through Mar 1980	5.0, 8.0	Bottom to 10 m 10 m to surface	0.5 m net w/opening and closing device	Triplicate

Table 8-3. Zooplankton data analysis summary for Lake Norman, NC, data from January 1974 through December 1980.

Analysis	Procedure	Study	Dates	DATA USED		Taxa
				Locations	Depths (m)	
Zooplankton Seasonal Succession	Calculation of times of year densities and percentage composition.	Weekly standing crop	Aug 1974 through Dec 1976	1.0, 4.0, 8.0	Shallow (10-S + shallower)	All major taxa
Vertical Distribution	Graphical - plotted total taxa densities for each depth region	Depth region vertical distribution	Apr 1979 through Mar 1980	5.0, 8.0	Bottom to 10 m, 10 m to surface	Total Zooplankton, Rotifera, Cladocera, Copepoda
Location Comparisons	Plotted means of locations, depths, years by month	Discrete depth samples	Oct 1977 through Sep 1979	4.5, 8.0	0.3, 2.0, 4.5, 6.0, 8.0 and 10.0	Rotifera, Cladocera, Copepoda
	Plotted means of 1 year's densities at all locations	Monthly density samples	Apr 1979 through May 1979	All listed for this time period in Table 6-1	Shallow (10-S + shallower)	Total Zooplankton, Rotifera, Cladocera, Copepoda
	Maximum, minimum, standard deviation	"	Aug 1974 through July 1975	"	"	"
Temporal Trends by month (average year)	Principal components with in SAS (Helwig & Council 1979), based on mean densities over the year at each location	"	Apr 1978 through May 1979	"	"	Cladocera, Rotifera, Copepoda with total phytoplankton biovolume
	Plotted means, minimums, maximums, standard deviations for each calendar month based on 3 years of data for density and biomass	"	Aug 1974 through Jul 1975	"	"	"
	Plot of standing crops, means of locations over time for density and biomass	"	Oct 1977 through Sep 1979	1.0, 1.2, 3.0, 3.9, 4.0, 4.5, 5.0	"	"
Zooplankton - Phytoplankton Relationships	Plot of standing crops, means of locations over time for density and biomass	"	Oct 1977 through Sep 1979	1.0, 1.2, 3.0, 3.9, 4.0, 4.5, 5.0	"	Rotifera, Cladocera, Copepoda
	Plot of mean zoo. standing crops against mean phyto. standing crops	"	Oct 1977 through Sep 1979	1.0, 1.2, 3.0, 3.9, 4.0, 4.5, 5.0	"	Filter feeding Cladocera, Current feeding Rotifera, total phytoplankton density
Zooplankton Density year to year variation	Comparison of zooplankton density plots to temperature and turbidity data	"	"	"	"	"

* S = Surface

Table 8-4. Zooplankton taxa encountered in Lake Norman, NC, January 1974 through December 1980.

Phylum Arthropoda

Class Crustacea

Order Cladocera

Family Bosminidae

Bosmina longirostris (O. F. Müller)

Family Chydoridae

Alona affinis (Leydig)

A. costata Sars

A. guttata Sars

A. quadrangularis (O. F. Müller)

A. setulosa Megard

Camptocercus sphaericus (O. F. Müller)

C. spp.

Chydorus sphaericus (O. F. Müller)

Disparalona acutirostris (Birge)

D. rostrata (Koch)

Kurzia latissima (Kurz)

Leydigia leydigi (Schoedler)

Family Daphnidae

Ceriodaphnia lacustris Birge

C. quadrangula (O. F. Müller)

C. reticulata (Jurine)

C. spp.

Daphnia ambigua Scourfield

D. catawba Coker

D. galeata mendotae Birge

D. parvula Fordyce

D. (immature) spp.

Moina micrura Kurz

M. spp.

Simocephalus expinosus (Koch)

S. vetulus Schoedler

S. spp.

Family Holopedidae

Holopedium gibberum Zaddach

Family Leptodoridae

Leptodora kindtii (Focke)

Family Macrothricidae

Ilyocryptus sordidus (Lieven)

I. spinifer Herrick

Family Sidae

Diaphanosoma leuchtenbergianum Fischer

Sida crystallina (O. F. Müller)

Order Copepoda

nauplii

Suborder Calanoida

calanoid copepodites

Family Diaptomidae

Diaptomus birgei Marsh

D. mississippiensis Marsh

D. pallidus Herrick

- Suborder Cyclopoida
 - cyclopoid copepodites
 - unidentified cyclopoids
- Family Cyclopidae
 - Cyclops thomasi S. A. Forbes
 - C. vernalis Fischer
 - Ergasilus spp.
 - Eucyclops agilis (Koch)
 - E. prionophorus Kiefer
 - Mesocyclops edax (S. A. Forbes)
 - Orthocyclops modestus (Herrick)
 - Tropocyclops prasinus (Fischer)
- Suborder Harpacticoida
 - harpacticoid copepodites
 - unidentified harpacticoids
- Family Canthocamptidae
 - Atthyella spp.
 - Canthocamptus assimilis Kiefer
- Phylum Rotifera
 - unidentified rotifers
- Class Bdelloidea
 - Order Bdelloida
 - unidentified bdelloids
- Class Monogononta
 - Order Collothecaceae
 - Family Collothecidae
 - Collotheca balatanica Varga
 - C. discophora (Skorikov)
 - C. libera (Zacharias)
 - C. mutabilis (Hudson)
 - C. spp.
 - Order Flosculariaceae
 - Family Conochilidae
 - Conochilus unicornis (Rousselet)
 - C. spp.
 - Conochiloides coenobasis Skorikov
 - C. natans (Seligo)
 - C. spp.
 - Family Flosculariidae
 - Ptygura libera Myers
 - P. spp.
 - Family Hexarthridae
 - Hexarthra mira (Hudson)
 - H. spp.
 - Family Testudinellidae
 - Filinia longiseta (Ehrenberg)
 - F. spp.
 - Order Ploima
 - Family Asplanchinidae
 - Asplanchna amphora Hudson
 - A. priodonta Gosse
 - A. spp.

Family Brachionidae

Subfamily Brachioninae

Anuraeopsis spp.Brachionus angularis GosseB. calicyflorus PallasB. caudatus Barrois and DadayB. havanaensis RousseletB. patulus O. F. MullerB. spp.Dipleuchlanis spp.Euchlanis calpidia MyersE. spp.Kellicottia bostoniensis (Rousselet)Keratella americana CarlinK. cochlearis (Gosse)K. crassa AhlstromK. earlinae AhlstromK. spp.Macrochaetus subquadratus PertyM. spp.Notholca acuminata (Ehrenberg)N. labis GosseN. spp.Platytia quadricornis (Ehrenberg)Trichotria spp.

Subfamily Colurinae

Colurella spp.Lepadella spp.

Family Gastropidae

Chromogaster ovalis (Bergendal)C. spp.Gastropus stylifer ImhovG. spp.

Family Lecanidae

Lecane acronycha Harring & MyersL. depressa HarringL. flexilis (Gosse)L. halictysta Harring & MyersL. luna (O. F. Muller)L. nana (Murray)L. ploenenis (Voight)L. saginata Harring & MyersL. spp.Monostyla lunaris EhrenbergM. quadridentata EhrenbergM. stenroosi (Meissner)M. spp.

Family Notommatidae

unidentified Notommatidae

Cephalodella spp.Eothinia spp.

Family Synchaetidae

Ploesoma hudsoni (Imhof)P. truncatum (Levander)P. spp.Polyarthra euryptera (Wierzejski)P. vulgaris CarlinSynchaeta oblonga EhrenbergS. pectinata EhrenbergS. spp.

Family Trichocercidae

Trichocerca capucina (Wierz)T. chattoni (De Beauchamp)T. cylindrica (Imhof)T. longiseta (Schank)T. multicornisT. platessa MyersT. porcellus (Gosse)T. similis (Wierzejski)T. stylata (Gosse)

Table 8-5. Principal components coefficients of major taxa, the proportion of variance accounted for by each principal component, and the yearly mean densities (No. $\times 10^3 \cdot m^{-3}$) at all Lake Norman, NC, sampling locations, June 1978 through May 1979.

	Principal Component	
	1	2
Rotifera	0.46	-0.16
Cladocera	0.41	-0.62
Copepoda	0.34	0.97
Proportion of variance accounted for by principal component	0.67	0.25

Location	Yearly Mean Densities (No. $\times 10^3 \cdot m^{-3}$)		
	Cladocera	Copepoda	Rotifera
1.0	7.6	34.0	52.0
1.2	5.7	33.0	49.0
2.0	7.0	47.0	68.0
3.0	6.2	40.0	56.0
3.9	6.6	34.0	66.0
4.0	6.3	35.0	57.0
4.5	6.2	36.0	72.0
5.0	5.6	39.0	66.0
6.0	7.8	44.0	100.0
8.0	8.9	33.0	78.0
13.0	9.7	26.0	60.0
14.0	10.0	31.0	47.0
15.0	13.0	33.0	110.0
15.9	10.0	32.0	130.0
16.0	2.4	14.0	29.0
34.0	10.0	29.0	70.0
50.0	10.0	31.0	69.0
60.0	3.2	17.0	22.0

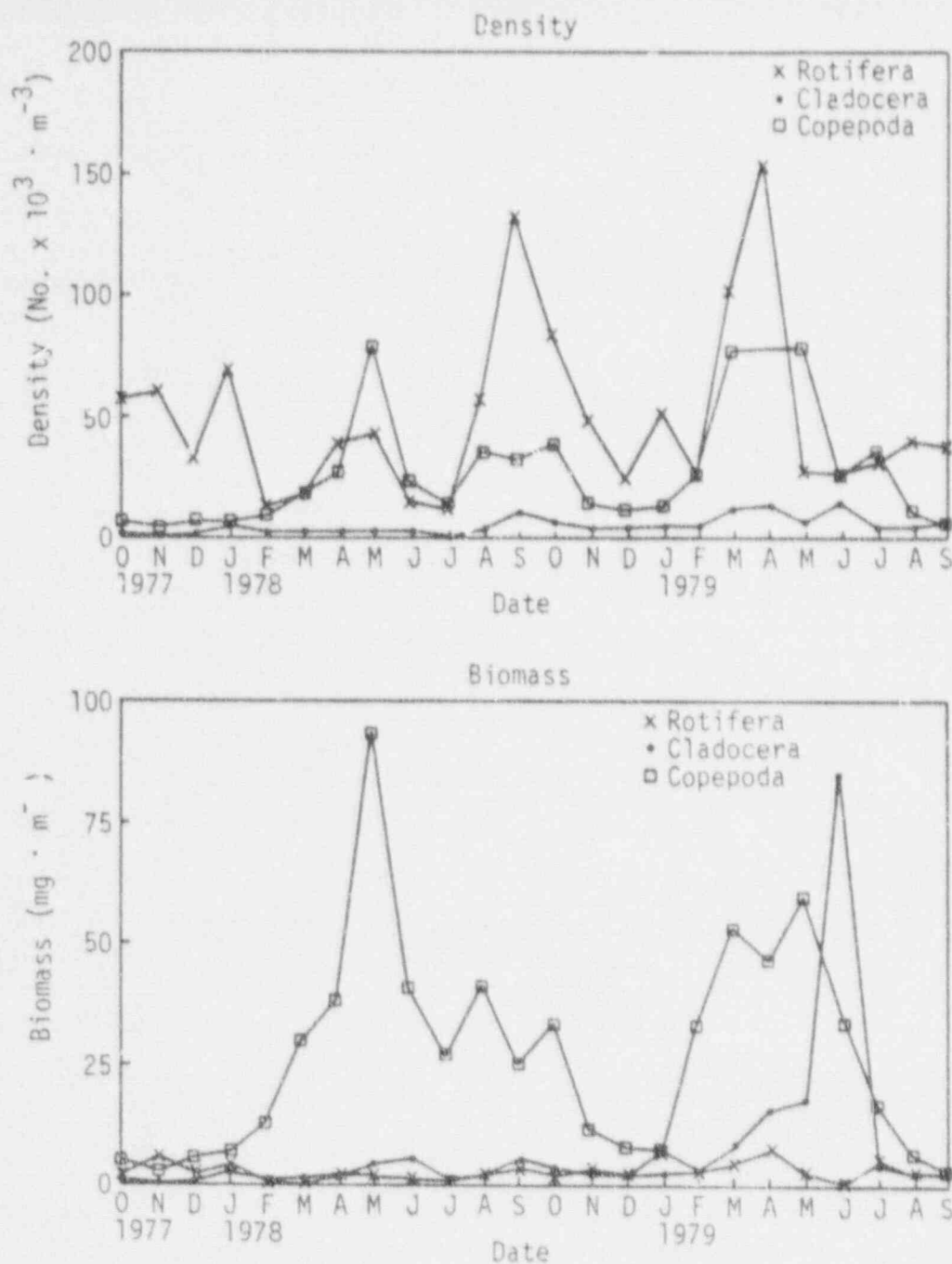


Figure 8-1. Mean Rotifera, Cladocera, and Copepoda standing crops in density (No. $\times 10^3 \cdot m^{-3}$) and biomass (mg $\cdot m^{-3}$) from the shallow depth samples at Locations 1.0, 1.2, 3.0, 3.9, 4.0, 4.5, and 5.0 on Lake Norman, NC, October 1977 through September 1979.

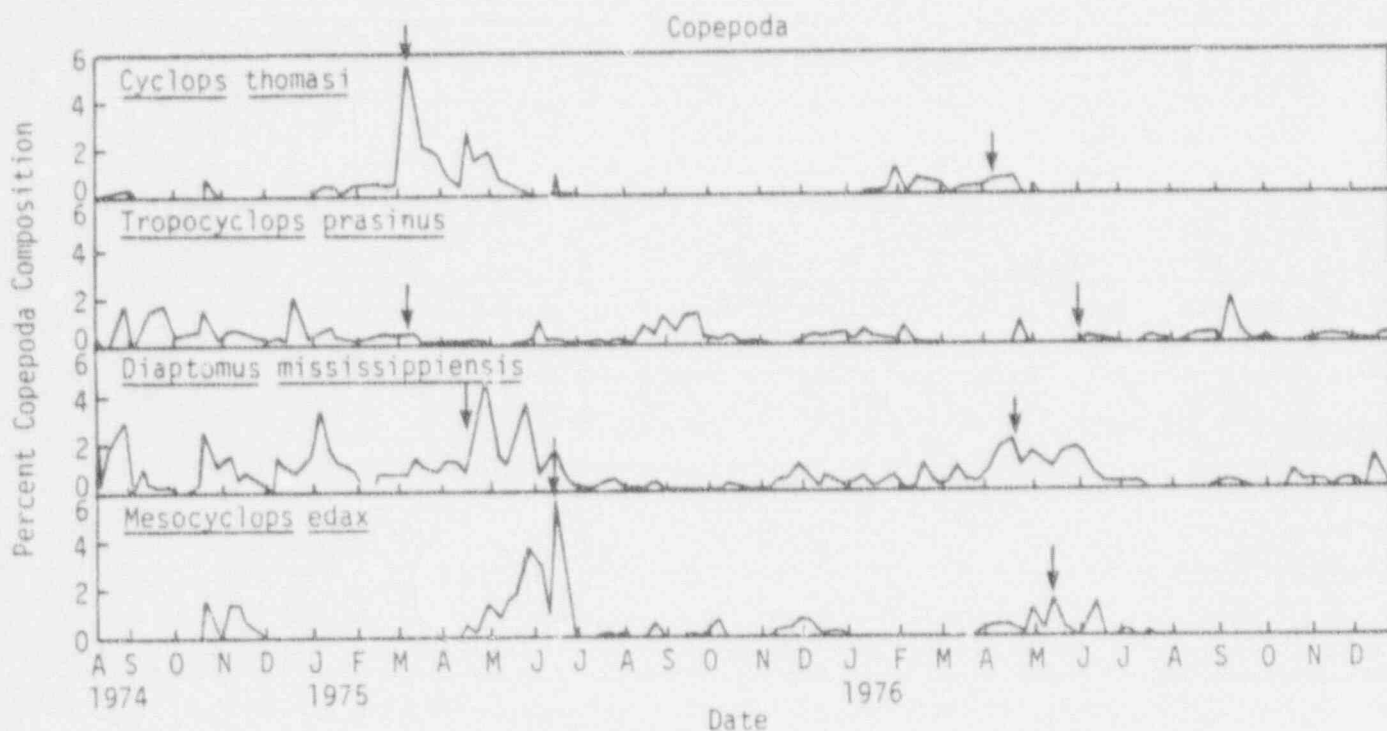
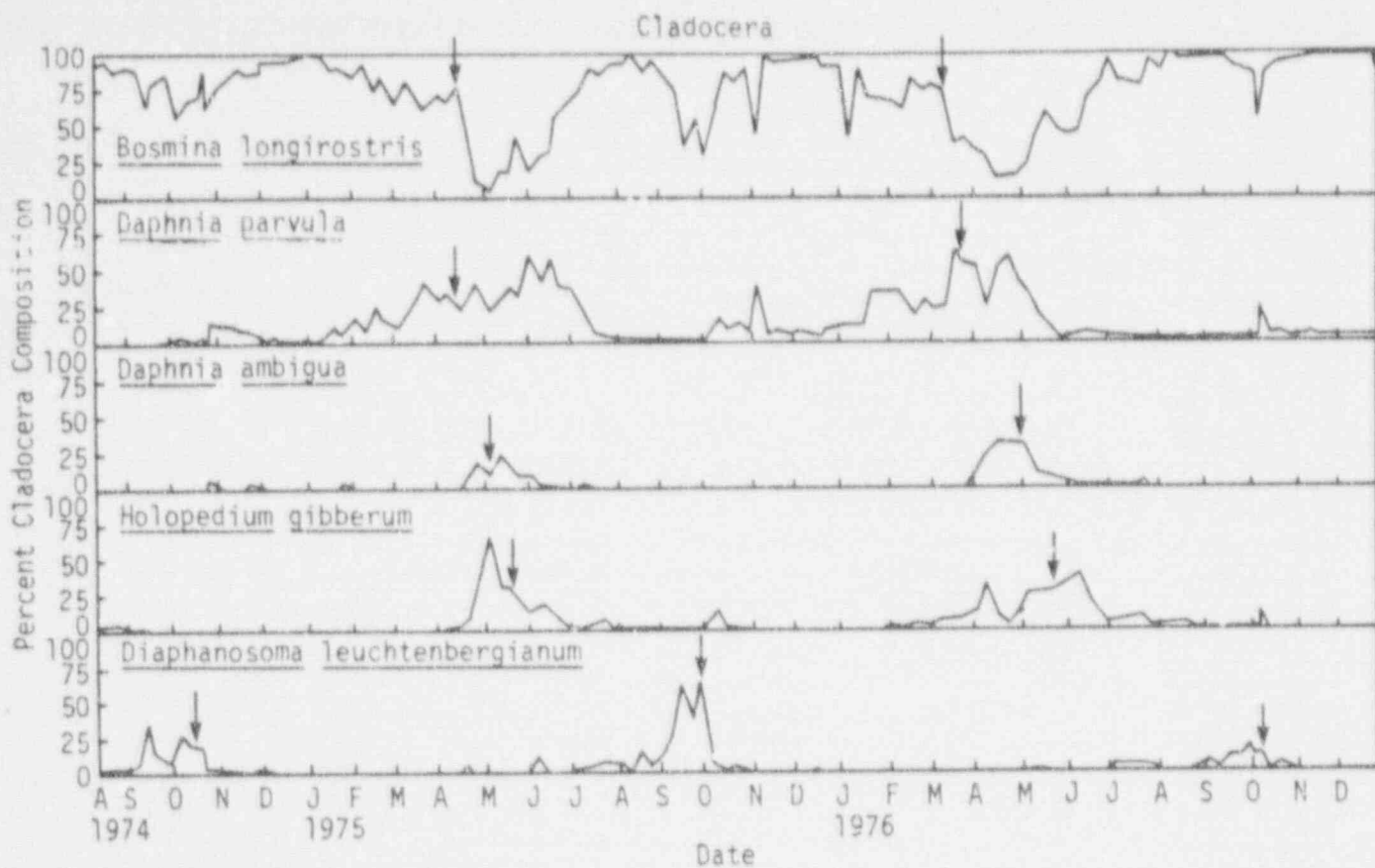


Figure 8-2. Percent composition of total Cladocera and Copepoda for major Cladoceran and Copepod taxa, respectively, in Lake Norman, NC, during the weekly standing crop study, 15 August 1974 through 31 December 1976. Values represent the mean percentage value from the shallow depth samples collected at Locations 1.0, 4.0, and 8.0. Arrows indicate the times of peak densities (No·m⁻³).

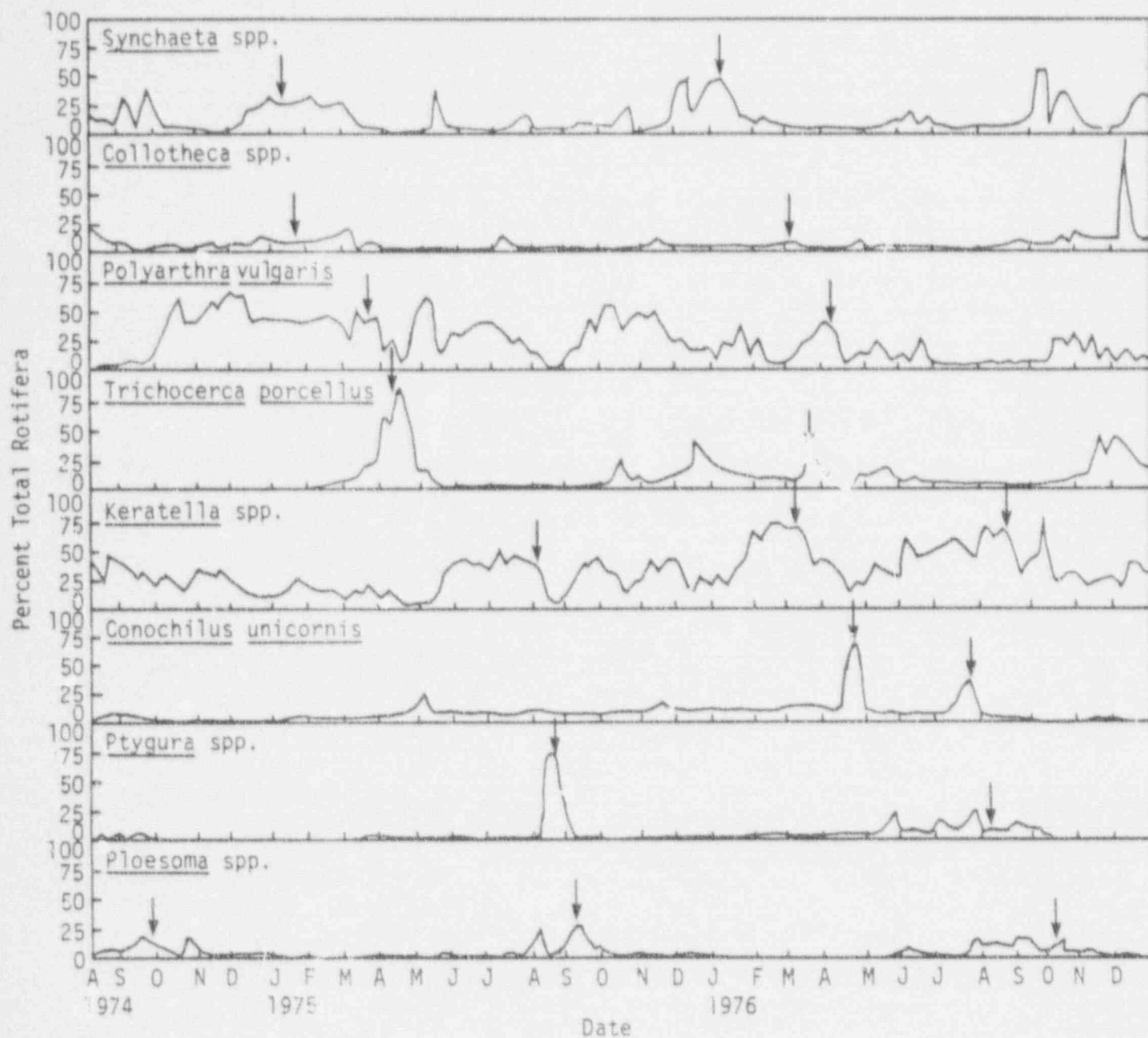


Figure 8-3. Percent composition of total Rotifer for major Rotifer Taxa in Lake Norman, NC during the weekly standing crop study, 15 August 1974 through 31 December 1976. Values represent the mean percentage value from the shallow depth samples collected at Locations 1.0, 4.0, and 8.0. Arrows indicate the times of peak densities ($\text{No} \cdot \text{m}^{-3}$).

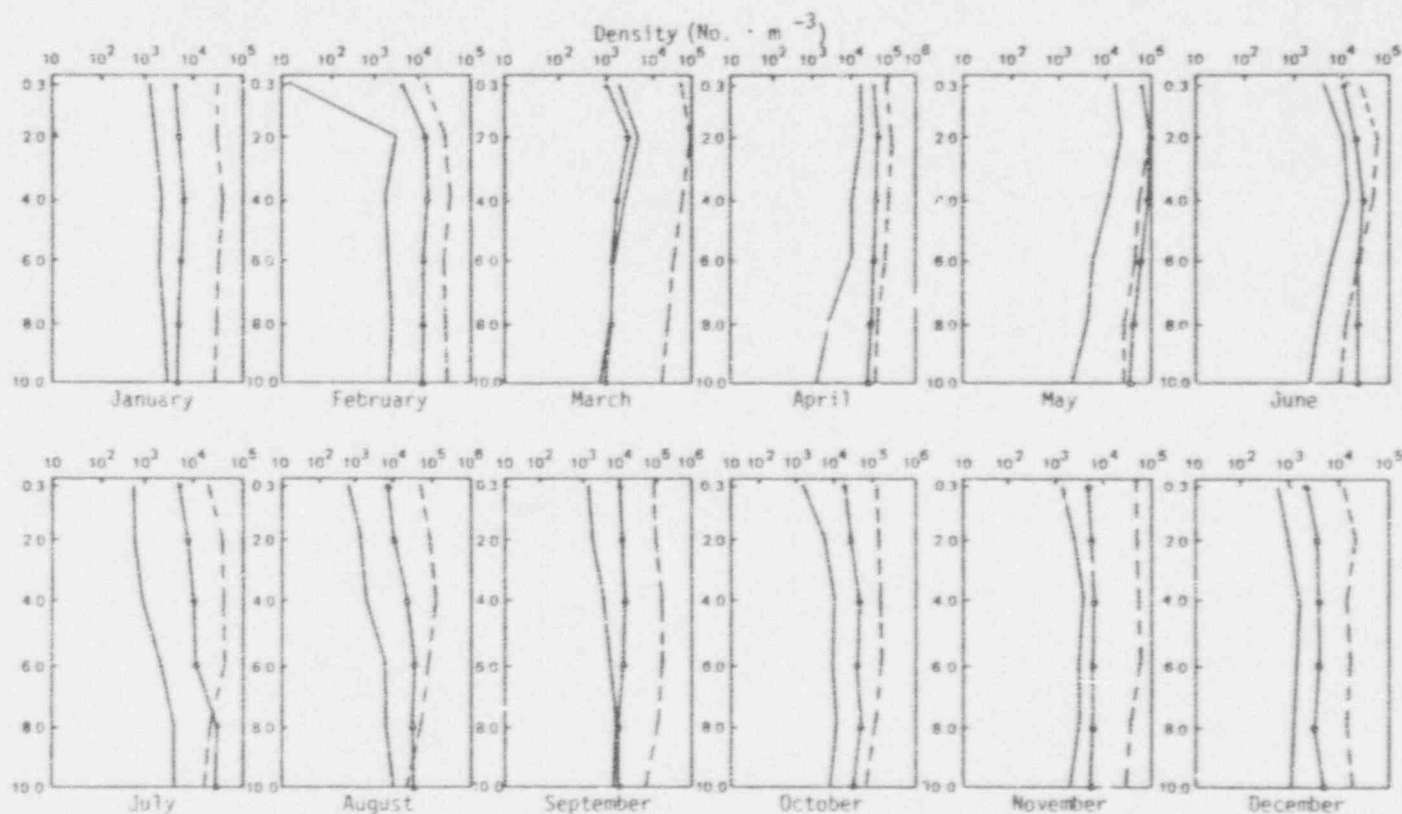


Figure 8-4. Mean monthly vertical distribution of the Rotifera (-----), Cladocera (——), and Copepoda (·——) in the upper 10 m of the water column in Lake Norman, NC. Values represent the mean monthly density estimates (No·m⁻³) for Locations 4.5 and 8.0, October 1977 through September 1979.

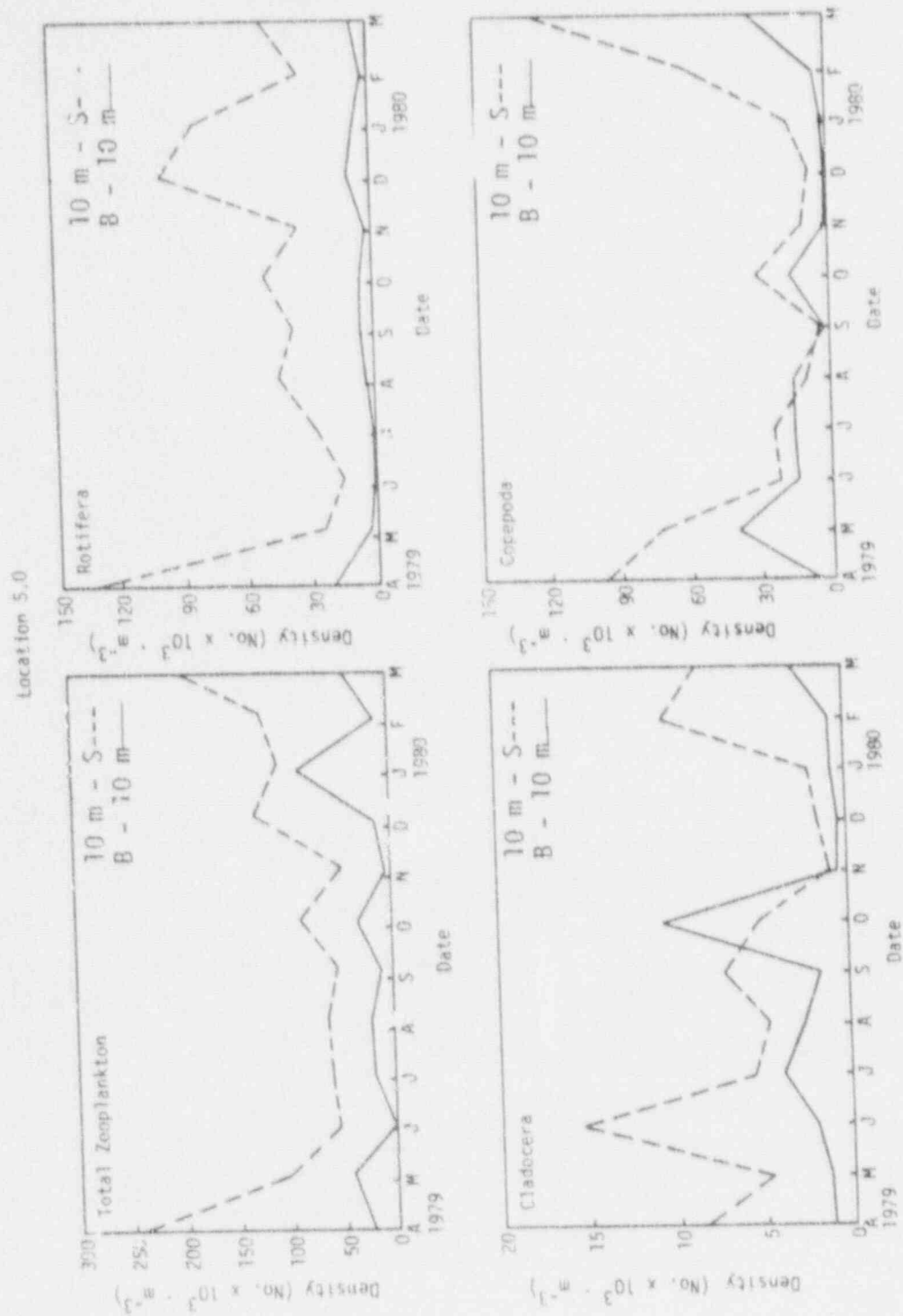


Figure 8-5. Density ($No. \times 10^3 \cdot m^{-3}$) trends of total zooplankton, Rotifera, Cladocera, and Copepoda at Locations 5.0 and 8.0 in the 10 m to surface (S) and 10 m to 10 m depth (B) zones, Lake Norman, NC, April 1979 through March 1980.

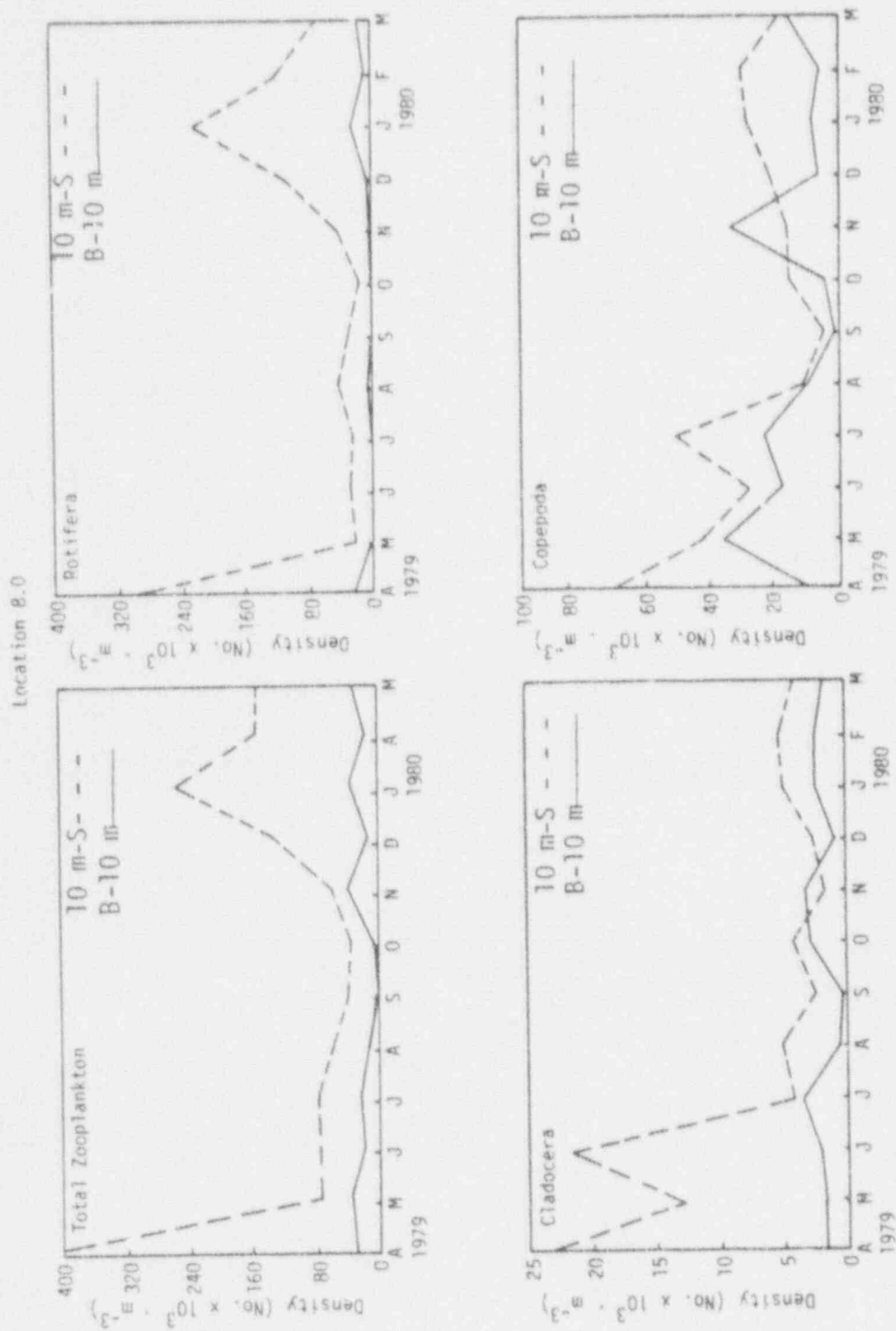


Figure 8-5. (Continued)

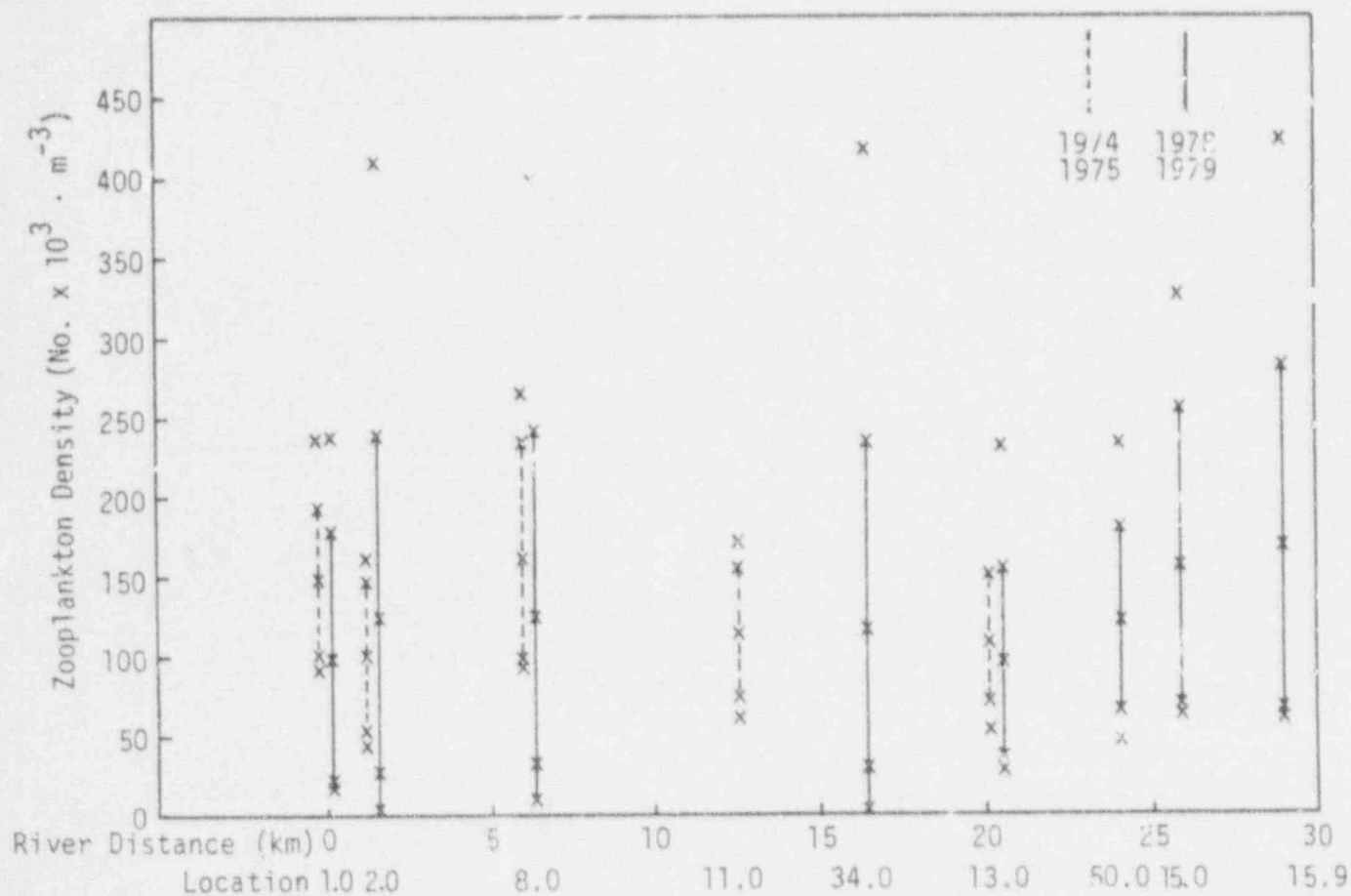


Figure 8-6. Mean yearly zooplankton densities (No. $\times 10^3 \cdot m^{-3}$) at the main channel sampling locations on Lake Norman, NC, August 1974 through July 1975 (.....) and June 1978 through May 1979 (——). Mean values are bounded by standard deviation (x. — x) and range (x x).

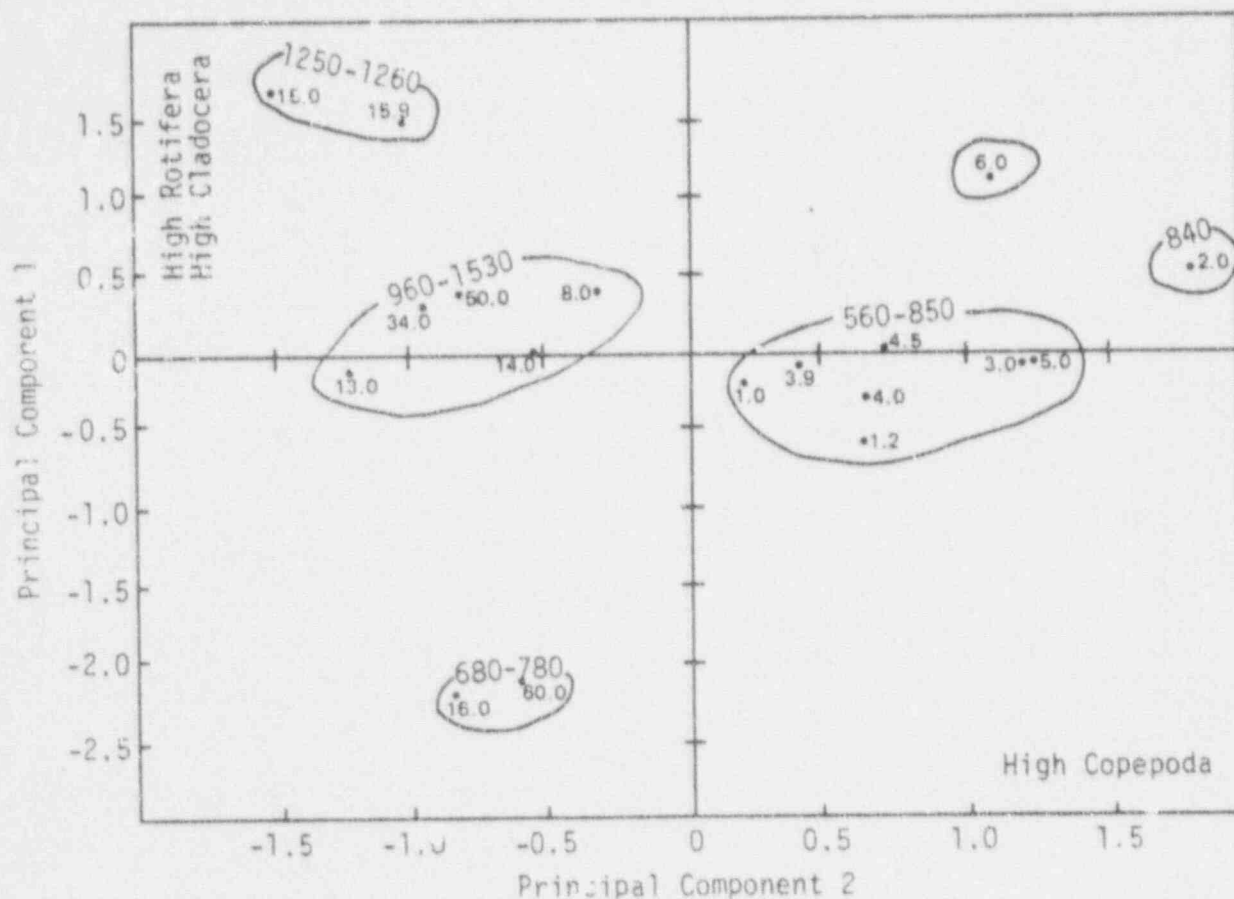


Figure 8-7. Principal components ordination of sampling locations on Lake Norman, NC, of the Rotifera, Cladocera, and Copepoda, June 1978 through May 1979 using the yearly mean densities from the shallow depth samples. Numbers in the cluster boundaries indicate the total phytoplankton biovolume ($\text{mm}^3 \cdot \text{m}^{-3}$) for the locations within the clusters (no phytoplankton data was available for Location 6.0).

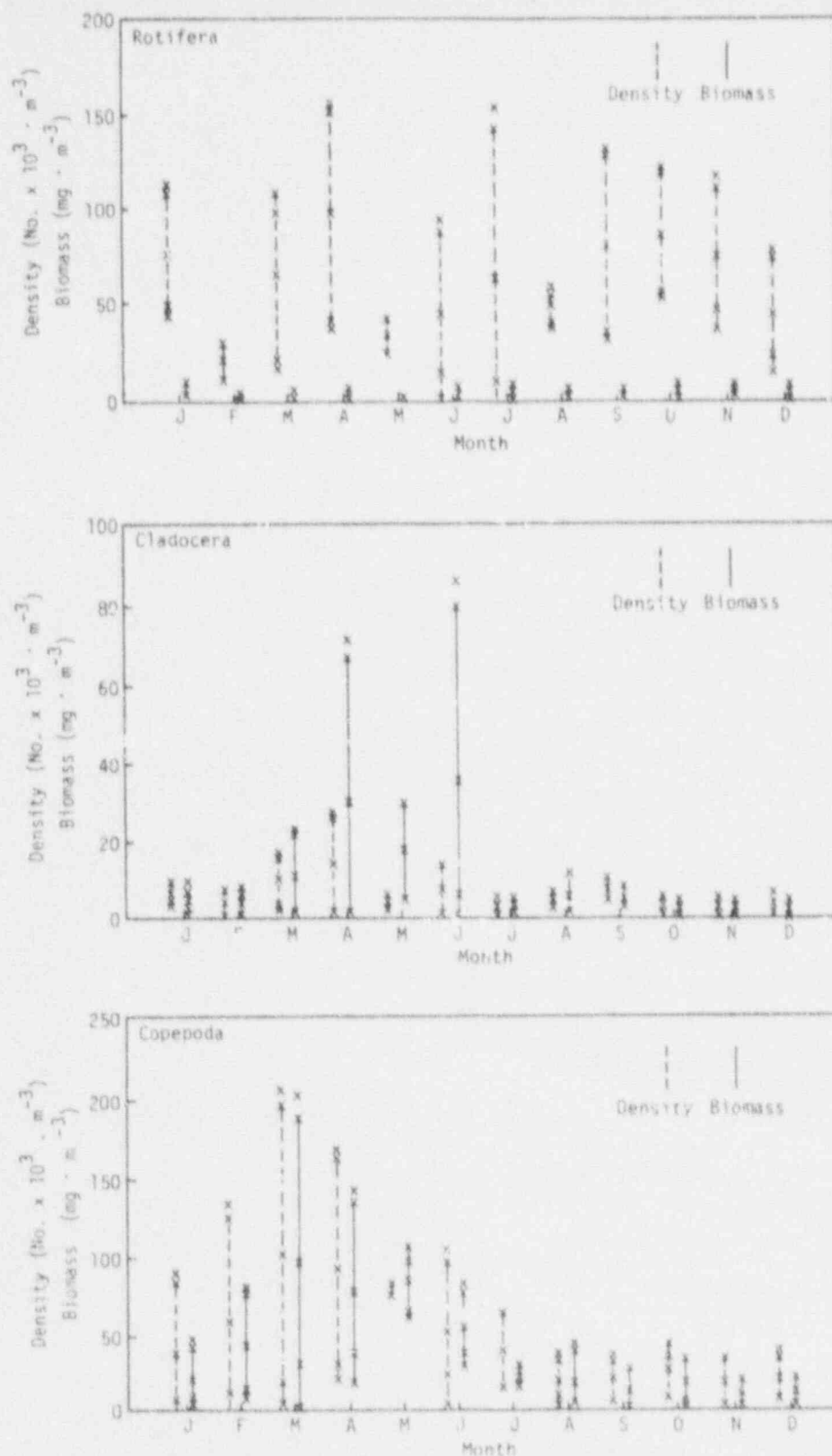


Figure 8-8. Mean standing crop in density ($\text{No.} \times 10^3 \cdot \text{m}^{-3}$) and biomass ($\text{mg} \cdot \text{m}^{-3}$) of the Rotifera, Cladocera, and Copepoda from the shallow depth samples collected at Lake Norman, NC Locations 1.0, 3.0, 4.0, 4.5, and 5.0 from August 1974 through July 1975, (-----) and Locations 1.0, 1.2, 3.0, 3.9, 4.0, 4.5, and 5.0 from October 1977 through September 1979 (——). Mean values are bounded by one standard deviation (x—x) and range (x x).

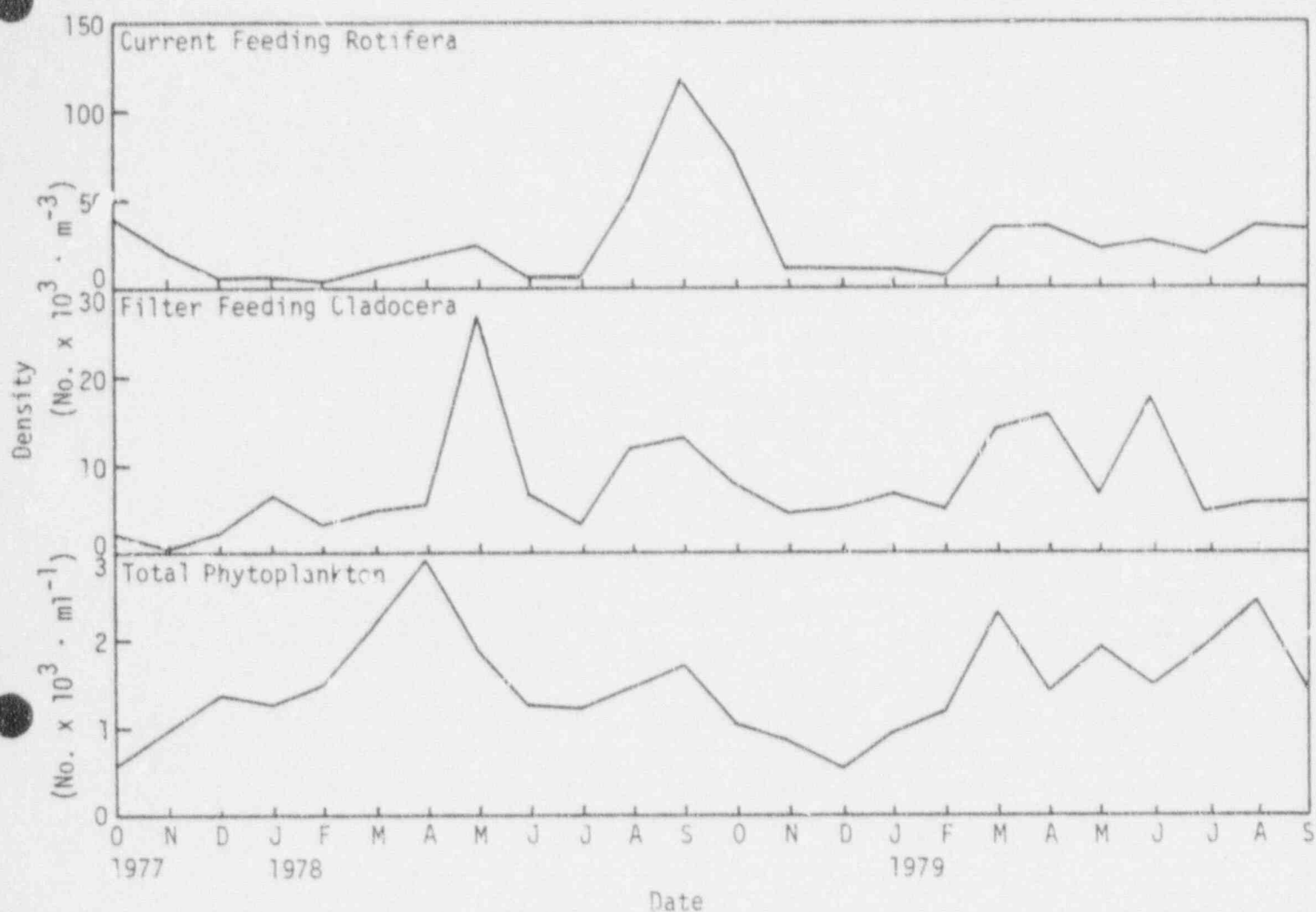


Figure 8-9. Mean population density trends of the current feeding Rotifera and filter feeding Crustacea (No. $\times 10^3 \cdot m^{-3}$) and total phytoplankton (No. $\times 10^3 \cdot m^{-1}$) from Locations 1.0, 1.2, 3.0, 3.9, 4.0, 4.5, and 5.0 on Lake Norman, NC, October 1977 through September 1979.

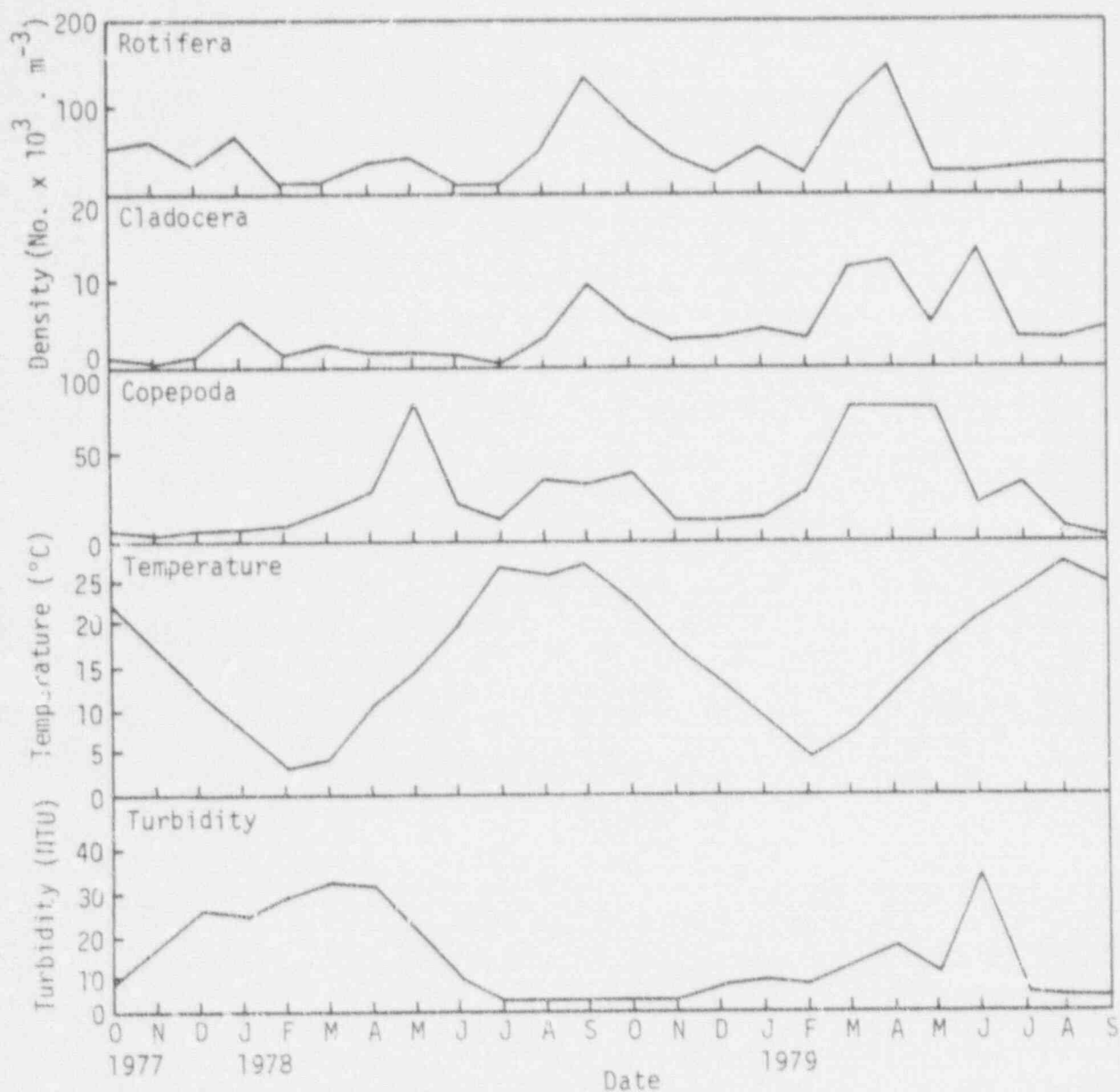


Figure 8-10. Mean zooplankton densities (No. $\times 10^3 \cdot m^{-3}$), temperature ($^{\circ}C$), and turbidity (NTU) in the upper 10 m of the water column at Locations 1.0, 1.2, 3.0, 3.9, 4.0, 4.5, and 5.0 on Lake Norman, NC, October 1977 through September 1979.

CHAPTER 9. BENTHIC MACROINVERTEBRATES

T. J. WILDA

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INTRODUCTION

BACKGROUND

Benthic macroinvertebrate communities in lakes and reservoirs are comprised of abundant and diverse populations which exhibit heterogeneous spatial and temporal distribution patterns. Many of the factors which influence these patterns are, at best, poorly understood. Perhaps the most obvious overall determinants of invertebrate distribution are the morphometry of the lake basin (Brinkhurst 1974) and the stratification patterns of the lake (Jonasson 1978). Considerable variation in the distribution of benthic organisms is also attributable to patchiness of the substrate (Wetzel 1975). In shallow-water (littoral) areas, the well-oxygenated water and variable sediments provide a wide array of microhabitats which are exploited by a diverse assemblage of species. Deep-water (profundal) areas receive the greatest amount of sedimentation, and are usually characterized by soft, uniform, fine-particle sediments, and the dominance of a few species which tolerate the low oxygen tension during stratification. Sublittoral benthic communities exhibit considerable variation, due to substrate heterogeneity and the seasonal emigration and immigration of motile littoral and profundal species.

Other factors which influence the abundance and distribution of benthic invertebrates in lentic habitats include quality and availability of food, temperature, and predation (Macan 1961). Of these factors, the availability of food is perhaps the most important (Brinkhurst 1974). Benthic organisms feed on plankton, periphyton, macrophytes, bacteria, detritus, and other invertebrates. Fundamentally, they transform living and decaying organic matter into food for larger carnivores, such as fish. Invertebrate feeding "types" may vary in relation to depth, with herbivores dominant in littoral areas, and detritivores dominant at sublittoral and profundal depths. Facultative carnivores may follow the distribution of prey species over various depths. Invertebrate respiration, feeding rates, reproduction, and the length of life cycles are also strongly influenced by temperature. Fish predation may impact macroinvertebrate communities directly, or indirectly by controlling the amount of planktonic debris which sinks to the bottom (Lellak 1966).

Previous benthic studies on Lake Norman, summarized by Koss et al. (1974) and Duke Power Company (1976), revealed that chironomids, chaoborids, and oligochaetes were the dominant macroinvertebrates. These groups are also dominant in other Catawba River reservoirs (Steffen and Milligan 1974). Duke Power Company (1976) identified four pre-existing stresses on Lake Norman macroinvertebrates: fluctuating water levels, thermal discharges from Marshall Steam Station, sedimentation, and the application of No. 2 diesel oil for mosquito control. A study of the effects of oil treatment on the Lake Norman benthic community in oil-treated and untreated coves indicated that oiling may decrease the density of the subfamily Chironominae (Appendix 9.1). A subsequent evaluation of the southern portion of Lake Norman determined that area contains negligible mosquito habitat (Appendix 9.2). Oil application to the McGuire Nuclear Station mixing zone was abated in 1977. Duke Power Company has also evaluated the need for replicate sampling with a modified Petersen grab in Lake Norman (Appendix 9.3), and compared grab sampling to artificial substrate sampling (Appendix 9.4). Based on the results of these studies, artificial substrate sampling was discontinued in Lake Norman. Another study was conducted from March 1974 to October 1977 to determine the depth distribution of macroinvertebrates in Lake Norman (Appendix 9.5).

OBJECTIVES

The objectives of this study were to:

1. describe the substrate at benthic sampling locations,
2. determine the taxonomic composition of macroinvertebrates in Lake Norman,
3. describe the distribution, relative abundance, and standing crop biomass of sublittoral and profundal benthic macroinvertebrates, and
4. qualitatively characterize the littoral benthic community.

MATERIALS AND METHODS

SAMPLING LOCATIONS AND FREQUENCY

Benthic invertebrates were sampled quarterly, except during 1974, when monthly collections were taken from March through July (Table 9-1). Since 1974, several changes in sampling locations were made in order to coordinate the sampling effort with other biological groups. Locations 1.0, 10.0, and 277.5 were deleted from the original sampling program: Location 8.0 was chosen to replace Location 1.0 in order to establish a reference profundal location outside the McGuire thermal mixing zone; Location 8.5 was chosen as a reference sublittoral location to replace Location 10.0; and downstream from Cowans Ford Dam, Location 277.5 was replaced by Location 16.0. Location 16.2 was established at the mouth of the effluent canal from McGuire wastewater treatment systems (Fig. 9-1). Locations 12.0 and 14.0 were situated in the uptake area to assess the impact of Marshall Steam Station on the benthic community (Fig. 9-2). Location 3.9 was established in the McGuire condenser cooling water discharge canal.

FIELD PROCEDURES

Three replicate modified Petersen grabs, each sampling an area of 258 cm², were collected at all locations except Locations 4.0 and 12.0, where 10 replicates were collected during 1974 and 1975. An additional grab was frequently collected for analyses of substrate particle size. Sublittoral collections were made at depths ranging from 6 to 11 m at Locations 1.2, 3.0, 3.9, 4.0, 5.0, 6.0, 7.3, 8.5, 10.0, 12.0, and 14.0. Profundal depths of 26 to 36 m were sampled at Locations 1.0, 2.0, and 8.0. Locations downstream from Cowans Ford Dam were sampled at depths of approximately 1 m, depending on water level and hydroelectric generation. Qualitative littoral samples were collected at depths of 0.1 to 1.0 m with a circular-frame, 1000- μ m mesh sweep net used at a constant effort of 2 min. During 1976 only, core sampling was substituted for sweep netting at all littoral areas (Table 9.1). Triplicate cores, each with an area of 45.6 cm² and penetrating 5 cm into the substrate, were taken at 0.5-m depths to quantitatively estimate littoral populations. Cores were not substituted for sweep nets at Location 16.2, however, because of the unsuitable substrate.

Sediment temperatures of grab samples were taken with a mercury bulb thermometer. A qualitative description of the sediments and depth of grab sampling was recorded in the field. All benthic samples were sieved in 500- μ m mesh wash buckets, and the residue was preserved in 70% EtOH containing rose bengal stain. The use of rose bengal stain was initiated in November 1974.

LABORATORY PROCEDURES

Organisms were sorted from the preserved samples under a 2X illuminated magnifying lens. During 1974, a sugar flotation technique (Anderson 1959) was used to aid in sorting samples. This technique was discontinued in favor of staining, however, because many organisms (particularly oligochaetes) which did not float in the sugar solution were more efficiently sorted with the aid of the stain in conjunction with a 2X lens. Organisms were counted, weighed by major taxonomic group (blotted wet weight to 0.1 mg), and identified using appropriate microscopic techniques and taxonomic references. Chironomids were mounted on microscope slides in either CMC-10, Euparal, or Hydramount. Oligochaetes were mounted in either Amman's lactophenol or CMCP-9AB. The taxonomic references used in macro-invertebrate identifications are found in Appendix 9.5. Sediment samples for particle size analysis were sent to Duke Power Company's soils laboratory, where they were analyzed by American Society for Testing and Materials (1972) procedures.

DATA ANALYSES

Results from modified Petersen grab and core samples are presented as estimated density ($\text{no} \cdot \text{m}^{-2}$) and standing crop biomass ($\text{mg} \cdot \text{m}^{-2}$), based on a mean of three replicates. Mean densities from Locations 4.0 and 12.0 in 1974 and 1975 were based on ten replicates. Data from all locations except Location 277.5 were analyzed for the period of 1974 through 1978. All data through 1980 have been appended (Appendices 9.8 - 9.11).

The mean annual density and standing crop biomass (based on grab samples from four sample periods per year) of chironomids, chaoborids, oligochaetes, and total benthos were analyzed with a SAS computer program (Helwig and Council 1979) using principal components and cluster analyses (Green 1979). Organisms of these three taxa are dominant members of the Lake Norman benthic community (Duke Power Company 1976).

Sediment particle size gradation curves were analyzed according to the methods of Folk and Ward (1957). This consisted of transforming the mean particle size in millimeters to $-\log_2$, known as phi (ϕ) units. Sands are -1 to 4ϕ , silts 4 to 8ϕ , and clays $>8\phi$. The percent composition of descriptive sediment fractions was also calculated. Standard statistics in phi units, including mean particle size (M_z), inclusive graphic standard deviation (τ_1), inclusive graphic skewness (SK_1), and graphic kurtosis (K_G) were calculated for all sediment samples, where

$$M_z = \frac{\phi_{16} + \phi_{50} + \phi_{84}}{3}, \quad \tau_1 = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{5} - \phi_{5}}{6.6},$$

$$SK_1 = \frac{\phi_{16} + \phi_{84} - 2\phi_{50}}{2(\phi_{84} - \phi_{16})} + \frac{\phi_{5} + \phi_{95} - 2\phi_{50}}{2(\phi_{95} - \phi_{5})}, \text{ and}$$

$$K_G = \frac{\phi_{95} - \phi_{5}}{2.44(\phi_{75} - \phi_{25})}.$$

RESULTS AND DISCUSSION

SEDIMENT ANALYSIS

Most of the sediments at the benthic sampling locations in Lake Norman were grouped within a range of 20 to 40% sand, 40 to 60% silt, and 20 to 35% clay, which would classify the substrate in general as medium to coarse silt (Fig. 9-3 and 9-4). Location 10.0, which had 50% sand, 30% silt, and 20% clay, was the only sampling location in the downlake area for which mean composition was not within the ranges given above. Locations 14.0 (in the Marshall Steam Station discharge canal), 16.0, and 16.2 (below Cowans Ford Dam) had more than 70% sand and less than 5% clay. These stations were subject to scouring by high flow rates. Results of all particle size analyses are presented in Appendix 9.11.

TAXONOMIC COMPOSITION

Oligochaetes (primarily Limnodrilus hoffmeisteri and Ilyodrilus templetoni), chaoborids (Chaoborus punctipennis), and chironomids (Chironomus and Procladius) were usually the only organisms collected at the profundal locations (Fig. 9-5). These taxa commonly dominate the profundal fauna of lakes (Borutsky 1939a; Brinkhurst 1974; Eggleton 1931; Jonasson 1978; Kajak 1961).

Oligochaetes, chironomids, and chaoborids also dominated the benthos at sublittoral locations in the vicinity of McGuire (Fig. 9-5). The chironomid genera most commonly collected were members of the subfamilies Chironominae (Tanytarsus, Cladotanytarsus, Chironomus, and Stictochironomus) and Tanypodinae (Helotanytus and Procladius). Collections of large numbers of small polychaetes (Manayunkia speciosa) occasionally caused high densities but added little to the total biomass. The large proportion of "Others" in the biomass at the sublittoral locations reflect occasional collections of a few large Hexagenia (Ephemeroptera) nymphs or Asiatic clams (Corbicula).

The density of Corbicula in Lake Norman has increased dramatically over the period examined (Fig. 9-6). The clams, which are highly adaptable and have little competition in freshwater impoundments (Sinclair and Isom 1963), will probably continue to increase in density in Lake Norman. They have a great potential to be a nuisance organism because of their ability to enter and clog waterlines (Goss and Cain 1975) such as those at Marshall Steam Station, McGuire Nuclear Station, and municipal water intakes on Lake Norman.

Oligochaetes and chaoborids were the dominant organisms collected at Location 14.0 in the Marshall discharge canal. Chaoborids and chironomids were dominant at Location 12.0, the only other sampling location in the vicinity of Marshall (Fig. 9-7). Oligochaetes and chironomids were also dominant at Locations 16.0 and 16.2, downstream from Cowans Ford Dam (Fig. 9-8). Taxa collected at all locations by all sampling methods are listed in Table 9-2.

COMMUNITY VARIATION

ORDINATION OF BENTHIC COMMUNITIES

The ordination of all sublittoral locations on Lake Norman indicated that Locations 12.0 and 14.0 were dissimilar from each other and from most of the other

sublittoral locations on the lake (Fig. 9-9). The highest loadings of principal component (PC) 1 were positive on the density of chironomids and negative on the density and biomass of chaoborids (Table 9-3). Principal component 2 loaded most heavily on the density and biomass of oligochaetes. The relatively low magnitudes of the coefficients of the other organisms indicates that PC 2 is probably related to variables which would be favorable to oligochaete populations.

The profundal (1.0, 2.0, and 8.0) and sublittoral (1.2, 3.0, 4.0, 5.0, 6.0, 7.3, 8.5, and 10.0) locations in the vicinity of McGuire tended to be dissimilar based on PC coefficients (Fig. 9-10). The highest loadings of PC 1 were positive on the density and biomass of oligochaetes and chaoborids. Since both of these organisms were dominant profundal forms, PC 1 probably relates to factors involved with increasing depth in the aquatic environment. Principal component 2 loaded most heavily on the density of the total benthos. Location 3.0 (1975) did not fall within the groupings for other locations because of extremely high numbers of chironomids collected in January and April samples.

PROFUNDAL COMMUNITY VARIATION

The density and biomass fluctuations of Chaoborus punctipennis at profundal locations reflect the life cycle of the phantom midges (Fig. 9-11). The larvae migrate to deeper water in the fall. The migration is reversed in the spring, when larvae move to shallower depths where metamorphosis to adults takes place (Borutsky 1939a; Kajak 1961). Although the lowest densities of chaoborids coincide with the periods of low dissolved oxygen in the profundal zone (Fig. 9-12), oxygen concentrations are thought to have little effect on the distribution of the organisms (Brinkhurst 1974; LaRow and Marzolf 1970; MacDonald 1956; Wetzel 1975). Their movement seems to be most closely related to light intensity (Brinkhurst 1974).

Chironomid density and biomass were usually highest in January or April and lowest in July or October (Fig. 9-13, Table 9-4). This may be due to the low dissolved oxygen concentrations in July and October (Fig. 9-12) and to the presence of large late-instar chironomids in January and April, and their subsequent emergence in the summer and fall. Low densities of chironomids in the profundal zone of other lakes (Brinkhurst 1974; Eggleton 1931) have also been attributed to low oxygen availability (Fig. 9-12). Borutsky (1939b) reported that Chironomus plumosus larvae migrated to shallower water with the onset of stagnation in the profundal zone of a Russian lake.

The biomass and density of oligochaetes tended to be lowest in January when those of chironomids were generally highest (Fig. 9-14). This may be attributed to competition between the two taxa, and to predation on oligochaetes by Chaoborus and Procladius larvae (Loden 1974; Rinne 1978). The lack of any seasonal pattern of total benthic density or biomass (Fig. 9-15) may reflect this inverse relationship between oligochaetes and their competitors and predators.

SUBLITTORAL COMMUNITY VARIATION

Locations in the Vicinity of McGuire Nuclear Station

Locations 1.2 and 4.0 were apparently affected by construction activities around the McGuire site. Dredging of the McGuire upper-level intake forebay near Location

1.2 was initiated in October 1975 and completed in March 1977. Density and biomass of most benthic organisms at Location 1.2 were reduced in 1977; samples collected in 1978 indicate that the fauna had recovered to levels observed in 1974 and 1975 (Figs. 9-16, 9-17). A cofferdam located at what is now the mouth of the McGuire discharge canal, adjacent to Location 4.0, was breached in December 1975. Draglining of the canal was completed in March 1977. Density and biomass at Location 4.0 were low during the period from January 1976 through April 1977, but had apparently recovered in July 1977 (App. 9.5, 9.6, 9.7).

Chaoborid density and biomass fluctuations at sublittoral locations exhibited trends similar to those described for the profundal locations, with lowest density and biomass generally found in July, and highest in January (Figs. 9-18, 9-19). The mean density of *C. punctipennis* collected was lower at sublittoral locations than at profundal locations for every sampling period except July (Table 9-4). This indicates that the sublittoral depths are suitable for a portion of the population during its spring and fall migrations and during the summer.

Chironomid density was usually highest in January and lowest in July or October; biomass was usually highest in January or April (Figs. 9-20; 9-21). Monthly sampling for chironomids in a separate study on Lake Norman in 1978 indicated that densities in January were among the highest of the year, and those in October were among the lowest (Duke Power Company, unpublished data). The declining densities in April and July were due to the maturation and subsequent emergence of chironomids. The midge larvae in October probably occurred in greater densities, but as early instars too small to be retained by the mesh used for sampling.

The density of chironomids was usually highest at Location 3.0 and lowest at Location 1.2, although the relative densities among the sample locations may be expected to change due to natural ecosystem variations. Schneider (1965) pointed out that there is much more chance for fluctuation in populations of amphibiotic taxa because they are subject to influences from both terrestrial and aquatic environments. For example, species with winged adult stages may be concentrated or dispersed by wind during mating flights. This may result in different distributions and densities from year to year.

Density and biomass of oligochaetes at Locations 1.2, 3.0, 4.0, 5.0, and 10.0 followed temporal distribution patterns similar to those for chironomids, with highest numbers found in January and lowest in October (Figs. 9-22, 9-23). At Locations 6.0 and 7.3, the trend was reversed, with lows in January and highs in October. The reason for these different trends is not clear.

Locations in the Vicinity of Marshall Steam Station

Location 12.0, where chaoborids were dominant, was shallower than the locations in the vicinity of McGuire, and mean sediment temperatures were higher at Location 12.0 for every sampling period except October (Table 9-5, Appendix 9.8). Other studies have explained the distribution of various species of *Chaoborus* based on behavioral differences between instars, presence of food organisms, and presence of predators (Kajak and Rybak 1979; LaRow and Marzolf 1970; MacDonald 1956).

Location 14.0 in the Marshall discharge canal differed from other sublittoral locations in that oligochaetes dominated the density and biomass. Alston et al. (1978) and Lenat (1978) also found high oligochaete densities in heated

water discharges. The high density of oligochaetes in the Marshall discharge may be due to the substrate differences already discussed because mean sediment temperatures were not much different at Locations 14.0 and 12.0 (Table 9-5). Sand substrates, such as Location 14.0, are not usually selected by oligochaetes, although they are sometimes found in such substrates (Johnson and Matheson 1968). It may be that the substrate is unsuitable for other organisms such as chironomids and chaoborids which compete with or prey upon oligochaetes, thus accounting for the high density of worms at Location 14.0.

Chironomid density and biomass at Location 12.0 followed the general trend described for other sublittoral locations. However, after decreasing from peak numbers in January, chironomid density and biomass increased sharply in October (Fig. 9-24). The same general trend, although less consistent, was observed at Location 14.0.

The density and biomass fluctuations of chaoborids at Location 12.0 differed from those described for other sublittoral locations in that they declined from January to April, increased in July, and then peaked in October (Fig. 9-25). The mean density of chaoborids collected in October was nearly five times greater than that in January (Table 9-6). At the sublittoral locations in the vicinity of McGuire the mean October density was only slightly greater than that of January. The fluctuations of chaoborid density at Location 14.0 were similar to those at Location 12.0, with a peak in October. However, there was an additional peak in April when the biomass was highest.

Oligochaete density at Location 14.0 was usually lowest in October when the density of chaoborids was highest (Fig. 9-26). There was no obvious trend in the fluctuation of oligochaetes at Location 12.0. Fluctuations of the total benthos at Locations 14.0 and 12.0 generally reflected the fluctuations of oligochaetes and chaoborids, respectively (Fig. 9-27).

Locations Downstream from Cowans Ford Dam

Locations 16.0 and 16.2 were dominated by oligochaetes and chironomids. Chaoborids, which are basically lentic organisms, contributed little to the biomass or density at either location (Table 9-7). Density and biomass of oligochaetes, chironomids, and total benthos were almost always higher at Location 16.2 at the mouth of the McGuire wastewater treatment system effluent canal than downstream at Location 16.0 (Figs. 9-28, 9-29, 9-30). This may be due to less scouring influence of flow from Cowans Ford Hydroelectric Station on Location 16.2, and to increased nutrient levels from the McGuire wastewater treatment system discharge canal. Irregular discharge from hydroelectric stations cause fluctuating water levels and currents downstream which in turn have been shown to cause low diversity and density of benthic organisms (Covich et al. 1978; Fisher and LaVoy 1972).

LITTORAL BENTHIC COMMUNITY

The littoral zone usually supports the most diverse fauna, although a fluctuating water level can reduce the number of organisms in the littoral zone of a reservoir (Brinkhurst 1974; Cowell and Hudson 1968; Hynes 1961; Moon 1935; Mundie 1957). The number of taxa collected in sweep nets in Lake Norman was not clearly related to water level fluctuations (Fig. 9-31). It is not possible to discern seasonal fluctuations in the diversity of the littoral fauna because of the possible effects of a fluctuating water level, the complex life histories of the benthic

organisms relative to the sampling schedule, and mesh selectivity.

Sweep net Locations 1.2 and 3.0 yielded the lowest number of taxa (Fig. 9-32). The only areas suitable for sweep netting at both locations were hardpan clay, which is poorly suited to benthic invertebrates.

Oligochaetes and chironomids were the dominant organisms collected in core samples in 1976 and in all sweep net samples. Based on 1976 core samples, littoral density fluctuations were the same as those at sublittoral locations, with peaks in January and minimum density in October. Highest biomass occurred in April, and the minimum biomass coincided with the minimum density in October. Temporal changes in total macroinvertebrate density reflected primarily fluctuations in the density of chironomids. Figures representing the density and biomass of major taxa collected in core samples are presented in Appendix 9.10.

Chironomids, oligochaetes, and "Others" composed 43, 29, and 27%, respectively, of the density in core samples. The subfamily Chironominae composed 83% of the Chironomids, and the genera Tanytarsus, Cladotanytarsus, Pagastiella, and Cryptochironomus were most common. The "Others" category was dominated by Corbicula (Pelecypoda), Palpomyia complex (Ceratopogonidae), Manyunkia speciosa (Polychaeta), and Prostoma (Nemertinea). Densities of each taxon collected in cores at each location are presented in Appendix 9.10. Taxa collected in each sweepnet sample are presented in Appendix 9.9.

SUMMARY

Petersen grab sampling for benthic macroinvertebrates was conducted quarterly (except in 1974, when monthly collections were taken from March through July) at sublittoral and profundal locations on Lake Norman and downstream from Cowans Ford Dam. Sweep net samples were collected at littoral depths on each sample date except during 1976 when core samples were substituted for sweep net samples. An additional Petersen grab sample for sediment size analysis was frequently collected at each sample location.

The sediment at most of the sampling locations on Lake Norman was classified as medium to coarse silt. Locations scoured by flowing water (14.0, 16.0, and 16.2) had a higher proportion of sand than other locations.

Chironomids, oligochaetes, and chaoborids dominated the benthos of Lake Norman. The density of Asiatic clams (Corbicula) increased dramatically during the study period. They have a great potential to be a nuisance because of their ability to clog waterlines such as those at McGuire Nuclear Station and Marshall Steam Station. Oligochaetes and chironomids dominated the profundal locations and the sublittoral locations in the vicinity of McGuire, respectively. Oligochaetes also dominated at Location 14.0 in the Marshall discharge canal. Chaoborids were dominant at Location 12.0 which is the only other location in the vicinity of Marshall. Chironomids and oligochaetes were dominant at Locations 16.0 and 16.2, below Cowans Ford Dam.

Chaoborid density was highest at profundal locations in January and lowest in July, reflecting the organisms' migration pattern. Chironomid density was also highest in the profundal samples in January and lowest in July or October when dissolved oxygen concentration was lowest. There was an inverse relationship between oligochaete density and the densities of chaoborids and chironomids.

Chaoborid density at McGuire sublittoral locations followed a pattern similar to that at profundal locations, indicating that the sublittoral depths were suitable for a portion of the population during spring and fall migrations. Chironomid and oligochaete densities at McGuire sublittoral locations were usually highest in January and lowest in July and October.

Chaoborid density at Location 12.0 decreased from January to April, increased in July, and peaked in October. Chironomid density fluctuations at Location 12.0 were similar to those at other sublittoral locations except that there was a sharp increase in October. Chaoborid density at Location 14.0 was similar to that at Location 12.0, although there was an additional peak in April. Oligochaete density at Location 14.0 was usually lowest in October. There was no obvious trend in the fluctuation of oligochaetes at Location 12.0.

Density and biomass of oligochaetes, chironomids, and total benthos were almost always higher at Location 16.2 than at Location 16.0. This is probably because there was less scouring influence from the Cowans Ford Hydroelectric Station discharge at Location 16.2.

The number of taxa collected in sweep net samples in the littoral zone was not clearly related to water level fluctuations. Locations 1.2 and 3.0 yielded the fewest number of taxa in sweep nets, probably because of the hardpan clay substrate. Based on 1976 core samples, littoral density fluctuations were the same as those for sublittoral locations, with the highest numbers being collected in January and the lowest in October. Chironomids (primarily Tanytarsus, Cladotanytarsus, Pagastiella, and Cryptochironomus), oligochaetes, and "Others" (primarily Corbicula, Palpomyia [Ceratopogonidae] and Manayunkia speciosa [Polychaeta]) were dominant in littoral samples.

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Table 9-1. Macroinvertebrate sampling locations, techniques, and dates on Lake Norman and the Catawba River downstream from Cowans Ford Dam, 1974 through 1980.

	1.0	1.1	2.0	3.0	3.1	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0
1975	11-23 Jan	Gr	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN				
	17-20 Mar	Gr	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN				
	22-24 Apr	Gr	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN				
	28-30 May	Gr	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN				
	24-26 Jun	Gr PS	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN				
	23-25 Jul	Gr PS	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN				
1976	24-26 Sept	Gr PS	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN				
	22-24 Nov	Gr PS	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN				
	11-13 Jan	Gr PS	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN				
	15-19 Apr	Gr PS	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN				
	14-17 Jul	Gr PS	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN				
	13-15 Oct	Gr PS	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN				
1977	24-26 Jan		Gr CO	Gr CO		Gr CO	Gr CO	Gr CO		Gr CO	Gr CO	Gr CO	Gr			Gr CO	Gr SN		
	29-30 Apr		Gr CO	Gr CO		Gr CO	Gr CO	Gr CO		Gr CO	Gr CO	Gr CO	Gr	Gr		Gr CO	Gr SN		
	24-26 Jul		Gr CO	Gr CO		Gr CO	Gr CO	Gr CO		Gr CO	Gr CO	Gr CO	Gr	Gr		Gr CO	Gr SN		
	25-27 Oct		Gr CO	Gr CO		Gr CO	Gr CO	Gr CO		Gr CO	Gr CO		Gr	Gr		Gr CO	Gr		
1978	4-5 Jan		Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr	Gr			Gr SN	Gr SN		
	4-6 Apr		Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr	Gr			Gr SN	Gr SN		
	9-7 Jul	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr	Gr			Gr SN	Gr SN		
	3-5 Oct	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr	Gr			Gr SN	Gr SN		
1979	3-5 Jan	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr PS	Gr PS			Gr SN	Gr SN		
	3-5 Apr	Gr SN	Gr SN	Gr SN		Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr	Gr			Gr SN	Gr SN		
	5-7 Jul	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN		
	2-4 Oct	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN		
1980	2-3 Jan	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN		
	2-3 Apr	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN		
	2-3 Jul	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN		
	1-2 Oct	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN		
1981	21-23 Jan	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN		
	8-10 Apr	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN		
	2-8 Jul	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN		
	4-7 Oct	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN	Gr SN		

Gr = modified Petersen grab
 SN = sweep net
 CO = core
 PS = particle size analysis

Table 9-2. Benthic macroinvertebrates collected by all sampling methods at all locations on Lake Norman and below Cowans Ford Dam from 1974 through 1980.

	Locations in the vicinity of McGuire Nuclear Station	Locations in the vicinity of Marshall Steam Station	Locations downstream from Cowans Ford Dam
Coelenterata			
Hydrozoa			
Hydroida	X	X	
Hydridae	X		
Hydra spp.		X	X
Platyhelminthes			
Turbellaria	X	X	
Nemertinea			
Enopla			
Hoploneurtea			
Tetrastemmatidae			
Prostoma spp.	X	X	X
Ectoprocta			
Gymnolaemata			
Ctenostomata			
Paludicellidae			
Pottsiella erecta	X		
Phylactolaemata			
Plumatellina			
Lophopodidae			
Pectinatella magnifica	X	X	X
Plumatellidae		X	
Nematoda	X	X	X
Annelida			
Oligochaeta	X	X	X
Haplotaxida			
Tubificoidae			
Enchytraeidae	X	X	X
Tubificidae	X	X	X
Limnodrilus spp.	X	X	X
L. hoffmeisteri	X	X	X
L. udekemianus			X
Aulodrilus spp.	X		
A. limnobius	X	X	X
A. pigueti	X	X	X
A. pluriseti			X
Illyodrilus templetoni	X	X	X
Bothrioneurum vejdozkyanum	X	X	X
Naididae			
Arctonais lomondi		X	X
Dero spp.			X
D. digitata			X
D. flabelliger			X
Nais communis	X	X	X
N. elinguis	X		
N. pardalis	X	X	
N. variabilis	X	X	X
Frisina spp.	X		
F. osborni	X		
Stylaria fossularis	X		

Table 9-2. Continued

	Locations in the vicinity of McGuire Nuclear Station	Locations in the vicinity of Marshall Steam Station	Locations down- stream from Cowans Ford Dam
<u>Veiduvskyella comata</u>	X		
Lumbriculida			
Lumbriculidae			
<u>Lumbriculus variegatus</u>	X		X
Hirudinea		X	
Polychaeta			
Sedentaria			
Sabellidae			
<u>Monayunkia speciosa</u>	X		X
Mollusca			
Pelecypoda	X	X	X
Heterodonta			
Corbiculidae			
<u>Corbicula</u> spp.	X	X	X
Sphaeriidae			
<u>Sphaerium</u> spp.			X
Gastropoda			
Pulmonata			
Lymnaeidae			X
<u>Lymnaea</u> spp.			X
Physidae			
<u>Physa</u> spp.	X		X
Planorbidae	X		X
<u>Gyraulus</u> spp.	X		
Ancylidae			X
<u>Ferrissia</u> spp.			
Arthropoda			
Arachnida			
Acariformes			
Prostigmata			
Hydrachnellae	X	X	X
Crustacea			
Malacostraca			
Amphipoda			
Talitridae			X
<u>Hyalolella azteca</u>			
Insecta			
Apterygota			
Ephemeroptera	X		
Baetidae			
<u>Baetis</u> spp.			X
Caenidae			
<u>Caenis</u> spp.	X	X	X
Ephemeridae			
<u>Hexagenia</u> spp.	X	X	X
Heptageniidae			
<u>Heptagenia</u> spp.			X
Leptophlebiidae	X		
Trichoptera			
Polycentropodidae			
<u>Cyrneilus</u> spp.	X		
<u>Leureclipsis</u> spp.	X		
<u>Nyctiophylax</u> spp.	X	X	
<u>Polycentropus</u> spp.	X	X	

Table 9-2. Continued

	Locations in the vicinity of McGuire Nuclear Station	Locations in the vicinity of Marshall Steam Station	Locations down- stream from Cowans Ford Dam
Hydropsychidae			X
Cheumatopsyche spp.			X
Hydropsyche spp.	X		X
Leptoceridae	X		X
Ceraclea spp.			X
Mystacides spp.	X		
Nectopsyche spp.	X		
Oecetis spp.	X	X	X
Hydroptilidae	X	X	
Agraylea spp.	X		
Hydroptila spp.	X		
Ochrotrichia spp.	X		X
Orthotrichia spp.	X		X
Oxyethira spp.	X	X	X
Odontia			
Anisoptera	X		
Gomphidae	X		X
Dromogomphus spp.	X		X
Gomphus spp.	X	X	X
Macromiidae		X	
Didymops spp.	X		
Macromia spp.	X		X
Libellulidae			
Libellula spp.		X	X
Perithemis spp.			
Sympetrum spp.	X		
Corduliidae			X
Epicordulia spp.			X
Zygoptera			X
Lestidae			
Coenagrionidae	X	X	
Anomalagrion spp.			X
Argia spp.	X		X
Enallagma spp.	X		X
Ishnura spp.	X		X
Megaloptera			
Sialidae			
Sialis spp.	X	X	X
Coleoptera			
Dytiscidae		X	
Gyrinidae	X		
Gyrinus spp.	X		
Halplidae			
Halplus spp.			X
Peltodytes spp.	X		X
Helodidae	X		
Hydrophilidae	X		
Berosus spp.			X
Diptera	X	X	X
Anthomyiidae			X

Table 9-2. Continued

	Location in the vicinity of McGuire Nuclear Station	Locations in the vicinity of Marshall Steam Station	Locations down- stream from Cowans Ford Dam
Athericidae			
Atheri spp.			X
Cecidomyiidae			X
Chaoboridae			
Chaoborus punctipennis	X	X	X
Chironomidae			
Chironominae			
Chironomini			
Chironomus spp.	X	X	X
Cryptochironomus spp.	X	X	X
C. ponderosus	X	X	X
Cryptotendipes spp.	X	X	X
Cladopelma spp.	X	X	X
Demicryptochironomus spp.	X	X	X
Dicrotendipes spp.	X	X	X
D. modestus		X	
D. neoradeatus	X	X	X
D. nervosus	X	X	
Einfeldia spp.		X	
Endochironomus spp.	X	X	X
E. nigricans	X	X	X
E. subtendens	X	X	X
Glyptotendipes spp.	X	X	X
G. lobiferous		X	X
Goeldichironomus spp.	X		X
Harnischia spp.	X	X	X
H. curtilamelata	X		
Lauterborniella spp.		X	X
Microchironomus spp.	X	X	X
Microtendipes spp.	X		X
Nilodorum spp.	X		X
Nilothauma spp.	X	X	X
Pagastiella spp.	X	X	X
Parachironomus spp.	X		X
P. pectinatellae	X		
Paracladopelma spp.	X		
Paralauterborniella spp.			X
P. nigrohalterale	X		X
Paratendipes spp.			X
P. connectens			X
Phaenopsectra (Phaenopsectra) gr.	X	X	
P. (tribelos) gr.	X	X	X
Polypedilum spp.	X	X	X
P. (nubeculosum) gr.	X	X	X
P. (tripodura) gr.	X	X	X
Pseudochironomus spp.	X	X	X
P. fulviventris	X		
Robackia spp.	X		
R. demijerrei	X	X	X
Stenochironomus spp.	X	X	
Stictochironomus spp.	X	X	X
Xenochironomus spp.			X
Tanytarsini			
Cladotanytarsus spp.	X	X	X
Microsectra spp.	X	X	X

Table 9-2. Continued

	Locations in the vicinity of McGuire Nuclear Station	Locations in the vicinity of Marshall Steam Station	Locations down- stream from Cowans Ford Dam
<u>Paratanytarsus</u> spp.	X		
<u>Stempellina</u> spp.	X	X	X
<u>Tanytarsus</u> spp.	X	X	X
<u>Orthocladinae</u>			
<u>Cardiocladius</u> spp.	X		
<u>Chaetocladius</u> spp.			X
<u>Cricotopus</u> spp.	X	X	X
<u>Epicoelcladius</u> spp.	X		X
<u>Gymnometriocnemus</u> spp.		X	
<u>Hydrobaenus</u> spp.	X	X	
<u>Limnophyes</u> spp.	X		X
<u>Metriocnemus</u> spp.	X	X	
<u>Nanocladius</u> spp.	X	X	
<u>N. alternatheras</u>		X	
<u>N. anderseni</u>	X		X
<u>N. incomptus</u>			X
<u>N. rectinervis</u>	X		
<u>Orthocladus</u> spp.	X	X	X
<u>Parakiefferiella</u> spp.	X	X	X
<u>Parametriocnemus</u> spp.			X
<u>Psectrocladius</u> spp.	X	X	X
<u>Pseudorthocladus</u> spp.			X
<u>Pseudosmittia</u> spp.	X	X	X
<u>Smittia</u> spp.	X	X	
<u>Trichocladius</u> spp.	X		
<u>Zalutschia zalutschicola</u>	X	X	
<u>Tanypodinae</u>			
<u>Pentaneurini</u>			
<u>Ablabesmyia</u> spp.	X	X	X
<u>A. americana</u>			X
<u>A. annulata</u>	X	X	
<u>A. aspera</u>	X		
<u>A. cinctipes</u>	X	X	
<u>A. hauberi</u>	X		
<u>A. mallochii</u>	X	X	X
<u>A. ornata</u>	X	X	
<u>A. parajontia</u>	X	X	
<u>Clinotanypus pingus</u>			X
<u>Lersia</u> spp.	X		
<u>Tanypus</u> spp.		X	
<u>T. concavus</u>		X	
<u>T. stellatus</u>		X	
<u>Thienmannimyia</u> gr.	X		
<u>Coelotanypodini</u>			
<u>Cocintanypus</u> spp.	X	X	X
<u>C. concinnus</u>	X	X	
<u>C. scapularis</u>	X	X	
<u>C. tricolor</u>	X	X	
<u>Macropelopiini</u>			
<u>Procladius</u> spp.	X	X	X
<u>P. bellus</u>	X	X	

Table 9-2. Continued

	Locations in the vicinity of McGuire Nuclear Station	Locations in the vicinity of Marshall Steam Station	Locations down- stream from Cowans Ford Dam
Ceratopogonidae	X	X	X
Alluaudomyia spp.	X	X	X
Atrichopogon spp.	X		
Dasyhelea spp.	X	X	X
Palpomyia complex	X	X	X
Stilobezzia spp.			X
Dolichopodidae	X	X	
Hydrophorus spp.	X		X
Ephydriidae	X		
Muscidae	X		
Sciaridae		X	
Sciara spp.	X	X	X
Syrphidae			X
Tabanidae			
Tipulidae	X	X	
Dicranota spp.	X		
Gonomyia spp.	X		
Hexatoma spp.	X		
Limnoria spp.		X	X
Limnophila spp.	X		X
Ormosia spp.	X	X	X
Tipula spp.	X	X	

Table 9-3. Principal components coefficients of major taxa and total benthos calculated from quarterly sampling on Lake Norman from 1974 through 1978.

	All Sublittoral Locations (See Fig. 9-9) Principal Component		Profundal and Sublittoral Locations in Area of McGuire (See Fig. 9-10) Principal Component	
	1	2	1	2
Density Chironomidae ($\text{no} \cdot \text{m}^{-2}$)	0.82	0.19	-0.69	0.51
Biomass Chironomidae ($\text{mg} \cdot \text{m}^{-2}$)	0.39	-0.32	-0.41	-0.02
Density Chaoboridae ($\text{no} \cdot \text{m}^{-2}$)	-0.71	-0.17	0.68	-0.26
Biomass Chaoboridae ($\text{mg} \cdot \text{m}^{-2}$)	-0.79	-0.01	0.81	-0.19
Density Oligochaeta ($\text{no} \cdot \text{m}^{-2}$)	-0.23	0.92	0.69	0.63
Biomass Oligochaeta ($\text{mg} \cdot \text{m}^{-2}$)	-0.38	0.86	0.79	0.53
Density Total Benthos ($\text{no} \cdot \text{m}^{-2}$)	0.56	0.59	-0.12	0.92
Biomass Total Benthos ($\text{mg} \cdot \text{m}^{-2}$)	0.41	0.15	-0.16	0.44
Proportion of Variance Accounted for by Each Principal Component	0.33	0.27	0.36	0.26

Table 9-4. Mean (± 1 standard deviation)(upper values)and range (lower values) of density and biomass of major taxa and all organisms collected in modified Petersen grab samples at Lake Norman profundal locations and sublittoral locations in the vicinity of McGuire Nuclear Station from 1974 through 1978.

	Profundal location *					Sublittoral location +				
	Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct		
No. Chironomids-m ⁻²	174 (+ 273)	87 (+ 86)	21 (+ 42)	3 (+ 10)	2074 (+ 3111)	1044 (+ 1624)	324 (+ 420)	365 (+ 396)		
mg. Chironomids-m ⁻²	298 (+ 353)	416 (+ 495)	46 (+ 100)	2 (+ 8)	1114 (+ 2034)	625 (+ 518)	287 (+ 347)	267 (+ 302)		
	0 - 1521	0 - 312	0 - 195	0 - 39	0 - 21099	0 - 10023	0 - 2808	0 - 2184		
No. Chaoborids-m ⁻²	718 (+ 416)	251 (+ 298)	26 (+ 37)	468 (+ 325)	241 (+ 247)	169 (+ 175)	92 (+ 156)	271 (+ 410)		
mg. Chaoborids-m ⁻²	909 (+ 429)	289 (+ 329)	22 (+ 32)	388 (+ 252)	232 (+ 247)	225 (+ 250)	103 (+ 249)	149 (+ 241)		
	109 - 2012	0 - 1326	0 - 105	0 - 924	0 - 1088	0 - 1256	0 - 1872	0 - 1505		
No. Zygochaetes-m ⁻²	838 (+ 645)	2491 (+ 1831)	1791 (+ 1263)	1564 (+ 1218)	362 (+ 509)	267 (+ 357)	283 (+ 500)	186 (+ 365)		
	0 - 2886	780 - 7917	195 - 4914	39 - 3783	0 - 2691	0 - 1560	0 - 3081	0 - 1872		
mg. Zygochaetes-m ⁻²	1810 (+ 1734)	3012 (+ 2069)	2780 (+ 2663)	2393 (+ 1962)	81 (+ 119)	80 (+ 111)	97 (+ 252)	62 (+ 113)		
	0 - 7028	807 - 6962	121 - 9574	31 - 6747	0 - 585	0 - 624	0 - 2360	0 - 636		
No. All Organisms-m ⁻²	1703 (+ 887)	2864 (+ 1780)	1859 (+ 1254)	2049 (+ 1311)	3018 (+ 3035)	2208 (+ 2688)	797 (+ 821)	1024 (+ 885)		
	312 - 4212	780 - 7956	234 - 4914	78 - 4502	16 - 16770	0 - 12714	39 - 6006	0 - 4446		
mg. All Organisms-m ⁻²	2970 (+ 1872)	4900 (+ 2200)	2864 (+ 2628)	3124 (+ 2263)	5154 (+ 29700)	4189 (+ 18026)	1399 (+ 2491)	3282 (+ 24135)		
	468 - 9458	916 - 8514	164 - 9574	51 - 8900	8 - 31 948	0 - 195550	20 - 16481	0 - 253867		

* Profundal locations include locations 1.0, 2.0, and 8.0.

+ Sublittoral locations include locations 1.2, 3.0, 4.0, 5.0, 6.0, 7.3, 8.5 and 10.0.

Table 9-5 Mean sediment temperatures (°C) at sublittoral sampling locations in the vicinity of McGuire Nuclear Station and Marshall Steam Station, based on samples collected from 1974 through 1978.

	<u>Jan</u>	<u>Apr</u>	<u>Jul</u>	<u>Oct</u>
McGuire Locations	7.8	13.3	23.4	21.4
Location 12.0	8.2	14.2	25.6	20.0
Location 14.0	8.4	14.0	26.0	20.4

Table 9-6. Mean (\pm 1 standard deviation) (upper values) and range (lower values) of density and biomass of major taxa and all organisms collected in modified Petersen grab samples at sublittoral locations in the vicinity of Marshall Steam Station from 1974 through 1978.

		Location 12.0					Location 14.0				
		Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct		
No. Chironomids $\cdot m^{-2}$		406 (\pm 264)	270 (\pm 215)	71 (\pm 77)	173 (\pm 157)	203 (\pm 238)	96 (\pm 155)	65 (\pm 95)	95 (\pm 98)		
mg. Chironomids $\cdot m^{-2}$		78 - 1287	0 - 1053	0 - 312	0 - 468	0 - 397	0 - 468	0 - 312	0 - 351		
		850 (\pm 438)	487 (\pm 553)	65 (\pm 98)	246 (\pm 179)	141 (\pm 195)	97 (\pm 119)	32 (\pm 47)	78 (\pm 94)		
		4 - 1677	0 - 2579	0 - 390	0 - 757	0 - 792	0 - 359	0 - 156	0 - 296		
No. Chaoborids $\cdot m^{-2}$		523 (\pm 323)	262 (\pm 275)	748 (\pm 462)	2582 (\pm 893)	120 (\pm 35)	372 (\pm 321)	36 (\pm 37)	1209 (\pm 861)		
mg. Chaoborids $\cdot m^{-2}$		0 - 1326	0 - 1014	39 - 1560	1170 - 3978	0 - 468	39 - 1170	0 - 117	117 - 2652		
		469 (\pm 261)	478 (\pm 601)	498 (\pm 226)	1140 (\pm 511)	148 (\pm 171)	692 (\pm 775)	51 (\pm 90)	1089 (\pm 1002)		
		0 - 1002	0 - 2414	4 - 897	234 - 2461	0 - 554	4 - 2414	0 - 351	125 - 3845		
No. Oligochaetes $\cdot m^{-2}$		163 (\pm 388)	274 (\pm 567)	46 (\pm 108)	22 (\pm 52)	2702 (\pm 1363)	1191 (\pm 826)	1893 (\pm 1210)	858 (\pm 568)		
mg. Oligochaetes $\cdot m^{-2}$		0 - 1560	0 - 2067	0 - 429	0 - 195	0 - 4251	273 - 2535	156 - 4641	78 - 2379		
		56 (\pm 156)	80 (\pm 153)	24 (\pm 84)	75 (\pm 42)	2649 (\pm 2124)	1058 (\pm 773)	1972 (\pm 1725)	137 (\pm 895)		
		0 - 725	0 - 511	0 - 398	0 - 47	0 - 6240	58 - 2660	78 - 4797	165 - 3237		
No. All Organisms $\cdot m^{-2}$		1140 (\pm 559)	893 (\pm 706)	900 (\pm 497)	2814 (\pm 915)	2595 (\pm 1544)	1742 (\pm 1120)	2907 (\pm 1744)	2201 (\pm 1071)		
mg. All Organisms $\cdot m^{-2}$		468 - 3003	117 - 3003	273 - 2028	1248 - 4251	117 - 4992	624 - 3627	234 - 4836	234 - 3783		
		1679 (\pm 1239)	1098 (\pm 898)	627 (\pm 227)	1437 (\pm 537)	3194 (\pm 2271)	1825 (\pm 974)	2070 (\pm 1820)	2603 (\pm 1596)		
		335 - 6782	58 - 3709	160 - 1092	332 - 2886	58 - 6423	187 - 3412	195 - 5413	304 - 6295		

Table 9-7. Mean (\pm standard deviation)(upper values) and range (lower values) of density and biomass of major taxa and all organisms collected in modified Petersen grab samples at locations downstream from Cowans Fird Dam from 1974 through 1978.

		Location 16.0									
		Location 16.0					Location 16.2				
		Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct		
No. Chironomids $\cdot m^{-2}$		423 (\pm 585) 0 - 1794	398 (\pm 379) 78 - 1170	1004 (\pm 949) 117 - 3081	552 (\pm 362) 78 - 1209	39 (\pm 66) 0 - 195	3334 (\pm 6275) 0 - 19695	1173 (\pm 1089) 0 - 2613	348 (\pm 255) 0 - 1052		
mg. Chironomids $\cdot m^{-2}$		416 (\pm 543) 0 - 1560	222 (\pm 249) 4 - 722	392 (\pm 412) 47 - 1470	285 (\pm 347) 31 - 1291	17 (\pm 34) 0 - 121	2870 (\pm 6023) 0 - 17265	1006 (\pm 1497) 0 - 3958	119 (\pm 122) 0 - 335		
No. Chaoborids $\cdot m^{-2}$		49 (\pm 106) 0 - 351	39 (\pm 78) 0 - 234	68 (\pm 140) 0 - 429	26 (\pm 38) 0 - 117	3 (\pm 11) 0 - 39	16 (\pm 26) 0 - 78	16 (\pm 31) 0 - 78	23 (\pm 48) 0 - 156		
mg. Chaoborids $\cdot m^{-2}$		117 (\pm 259) 0 - 819	25 (\pm 47) 0 - 136	29 (\pm 62) 0 - 195	10 (\pm 18) 0 - 55	1 (\pm 3) 0 - 12	23 (\pm 39) 0 - 113	15 (\pm 30) 0 - 78	16 (\pm 44) 0 - 152		
No. Oligochaetes $\cdot m^{-2}$		202 (\pm 373) 0 - 1014	1260 (\pm 1946) 39 - 5070	510 (\pm 405) 78 - 1404	1524 (\pm 1856) 39 - 5109	348 (\pm 772) 0 - 2691	416 (\pm 493) 0 - 1521	1424 (\pm 1442) 0 - 4953	1917 (\pm 1050) 79 - 3939		
mg. Oligochaetes $\cdot m^{-2}$		289 (\pm 762) 0 - 2691	355 (\pm 400) 4 - 1053	242 (\pm 250) 4 - 858	398 (\pm 306) 27 - 1314	266 (\pm 660) 0 - 2258	342 (\pm 693) 0 - 2484	520 (\pm 475) 0 - 1365	366 (\pm 285) 47 - 874		
No. All Organisms $\cdot m^{-2}$		1105 (\pm 1721) 0 - 5109	2055 (\pm 2443) 390 - 6903	1703 (\pm 1067) 546 - 3978	2512 (\pm 2062) 702 - 6396	429 (\pm 863) 0 - 3081	3936 (\pm 7324) 78 - 20982	3289 (\pm 2951) 117 - 9282	1596 (\pm 1254) 624 - 4407		
mg. All Organisms $\cdot m^{-2}$		1333 (\pm 2573) 0 - 6864	772 (\pm 518) 140 - 1669	1077 (\pm 730) 214 - 2792	720 (\pm 2402) 144 - 8349	348 (\pm 687) 0 - 2333	3696 (\pm 6116) 20 - 17967	1814 (\pm 1924) 62 - 5589	599 (\pm 330) 226 - 1182		

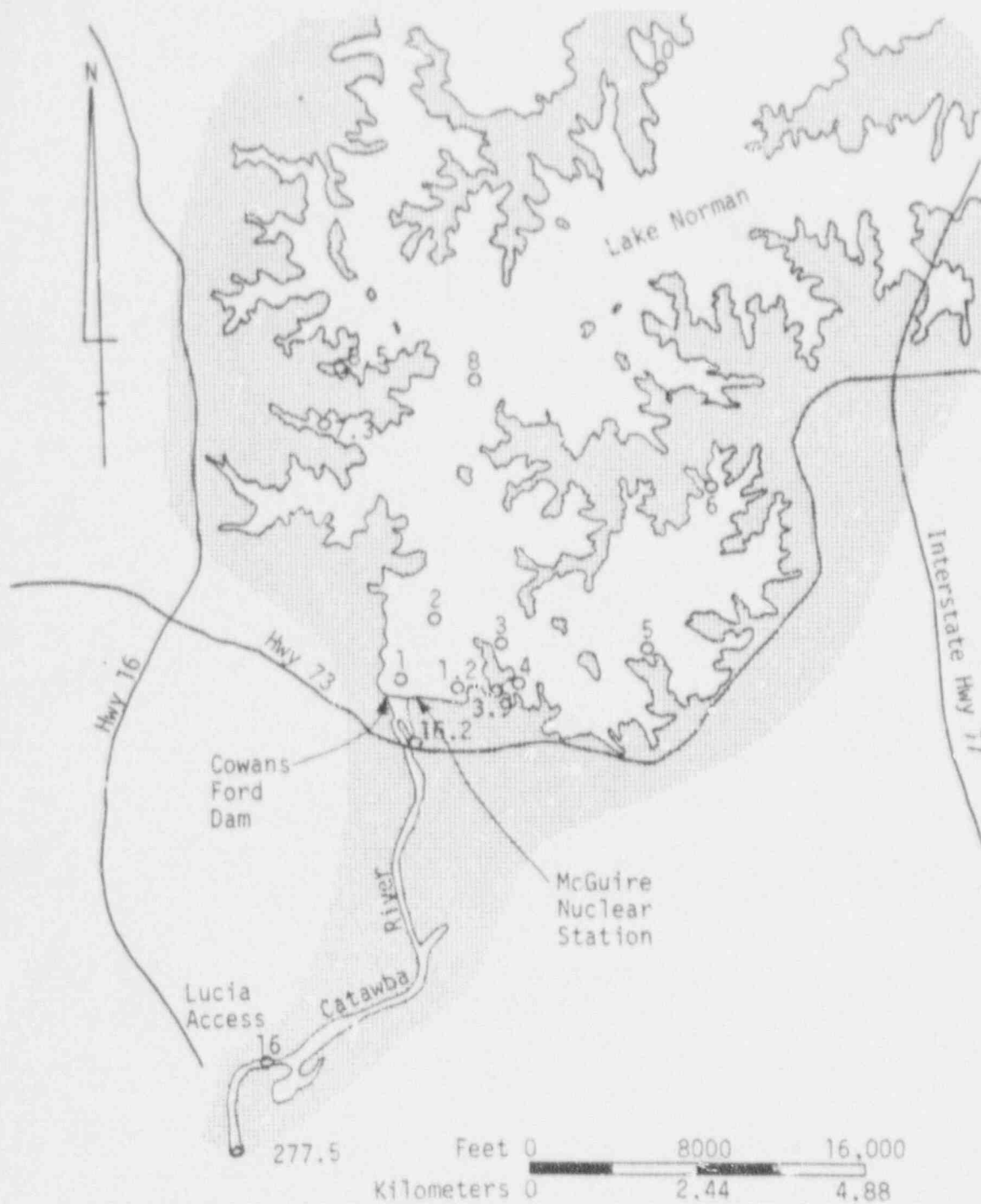


Figure 9-1. Benthic macroinvertebrate sampling locations on Lake Norman in the vicinity of McGuire Nuclear Station and the Catawba River downstream from Cowans Ford Dam.

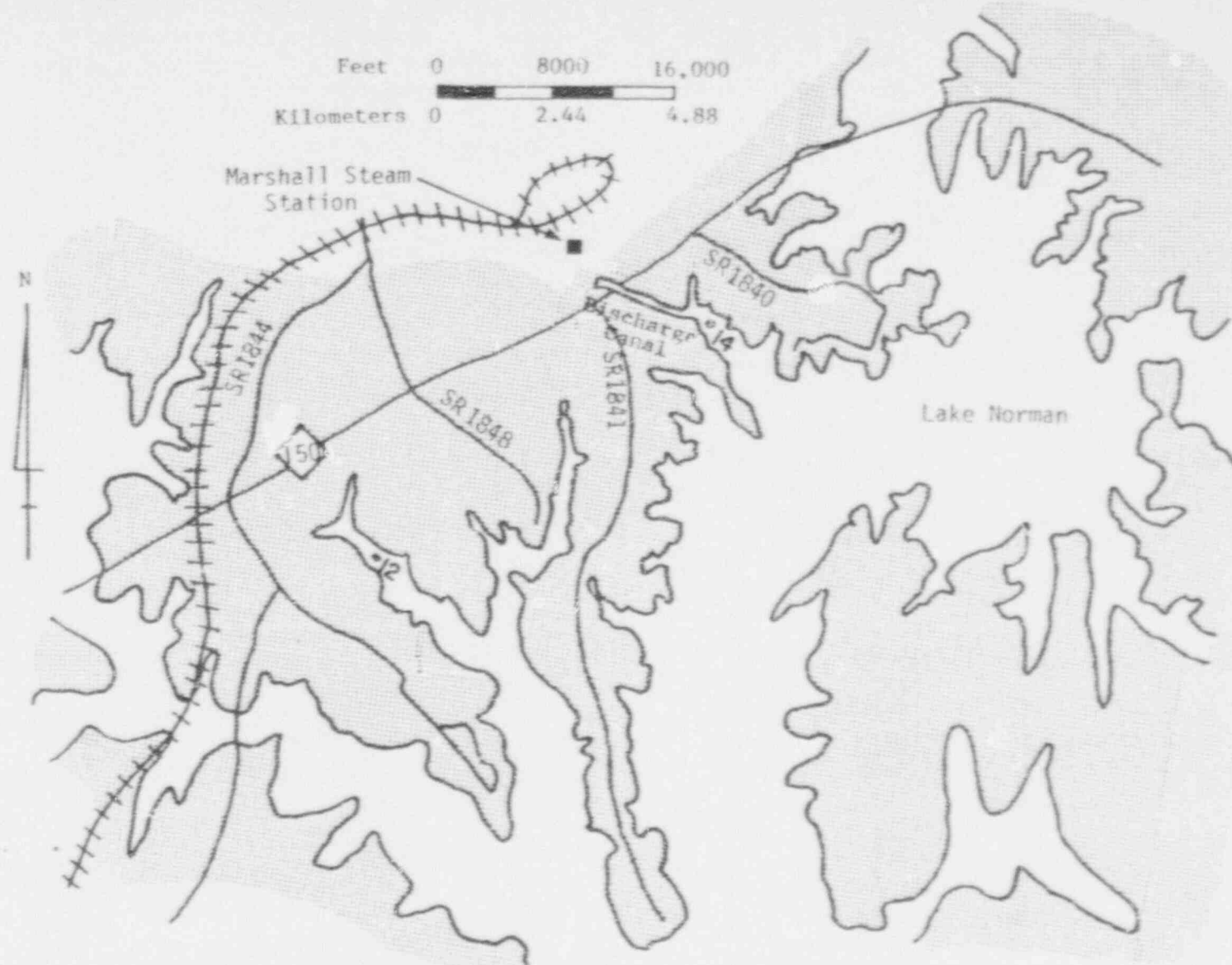


Figure 9-2. Benthic macroinvertebrate sampling locations on Lake Norman in the vicinity of Marshall Steam Station.

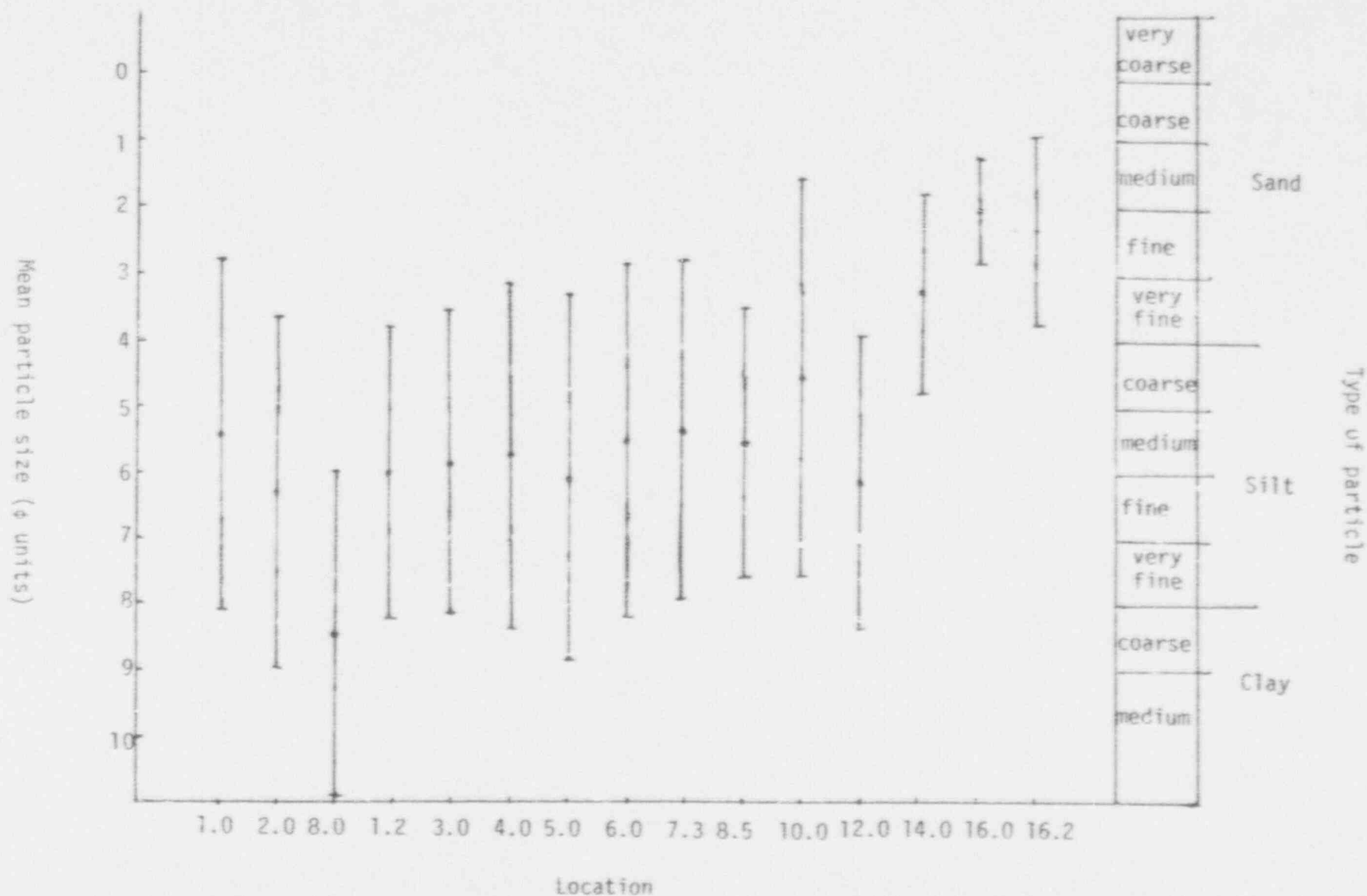


Figure 9-3. Mean substrate particle size (dots) and inclusive graphic standard deviation (vertical lines) of sediments collected at locations on Lake Norman and downstream from Cowans Ford Dam. Values are based on grand means of all sediment analyses from 1974 through 1978.

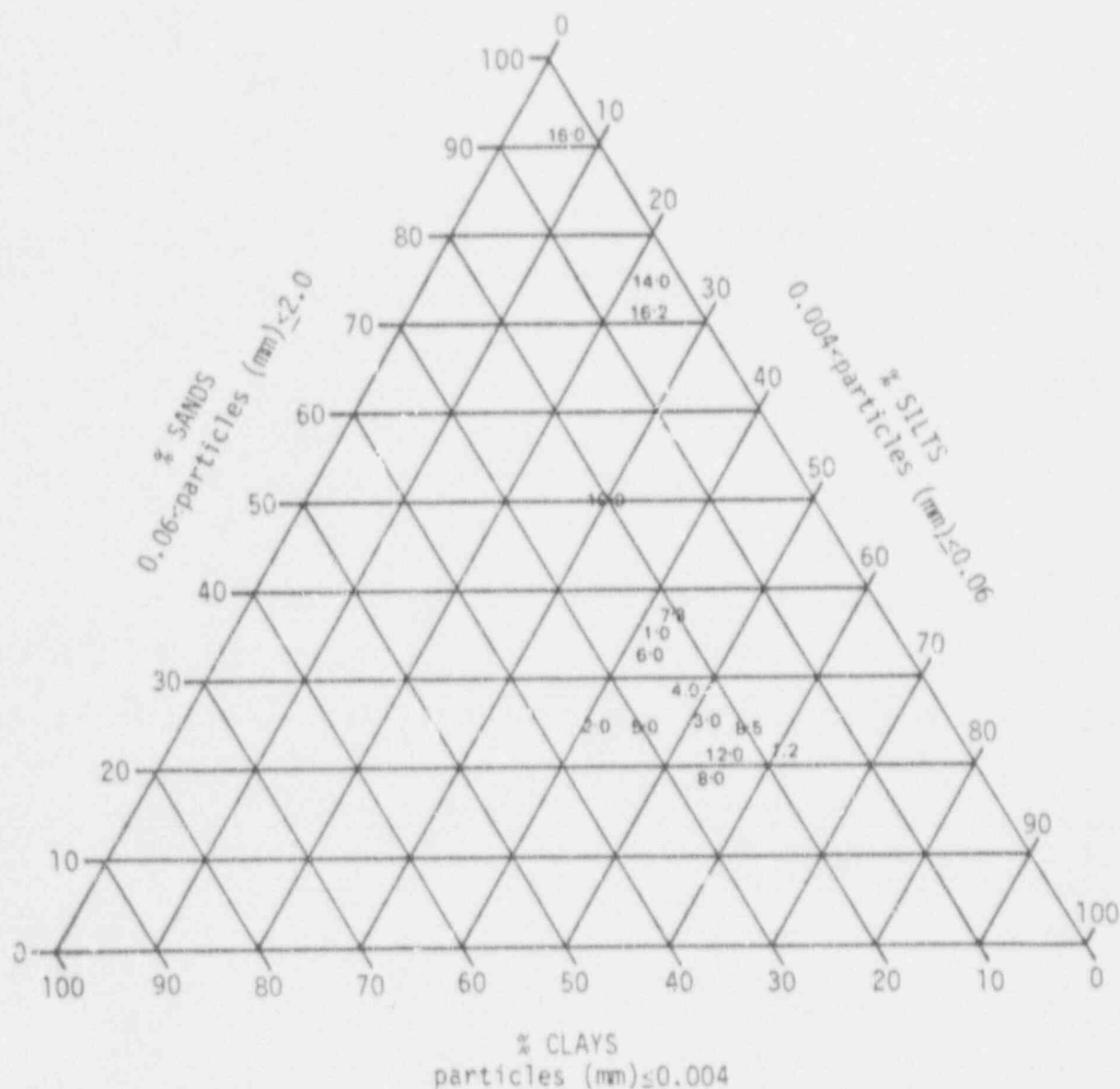
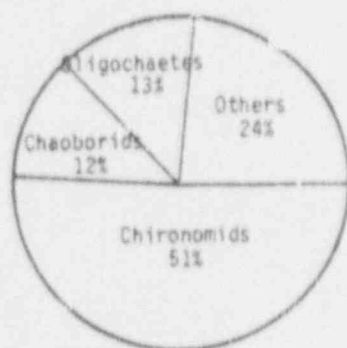
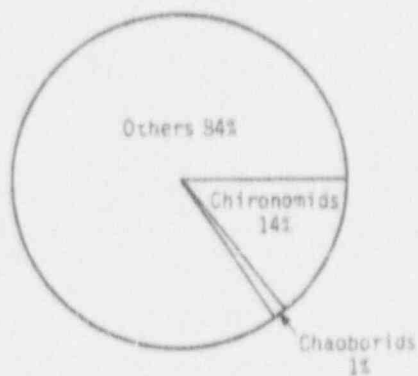


Figure 9-4. Proportions of the major substrate components at all locations sampled for benthic organisms on Lake Norman and below Cowans Ford Dam. Values represent means for all particle size analyses from 1974 through 1978. Numbers on the grid refer to sample locations.



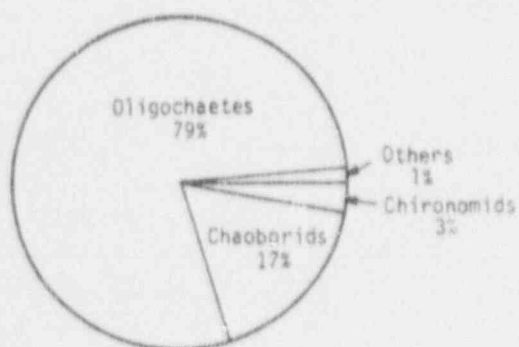
Density



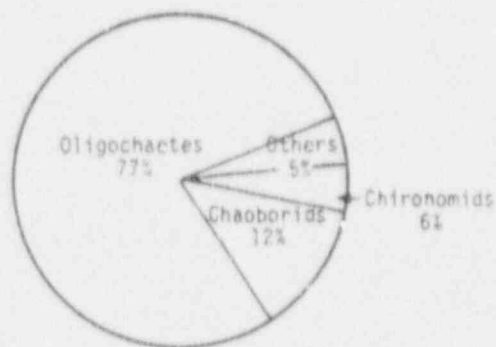
Biomass*

Sublittoral Locations

*Oligochaetes composed < 1% of the biomass.



Density



Biomass

Profundal Locations

Figure 9-5. Mean percent composition ($\text{No.}\cdot\text{m}^{-2}$ and $\text{mg}\cdot\text{m}^{-2}$) of macroinvertebrates collected in modified Petersen grab samples at Lake Norman profundal and sublittoral locations in the vicinity of McGuire Nuclear Station from 1974 through 1978.

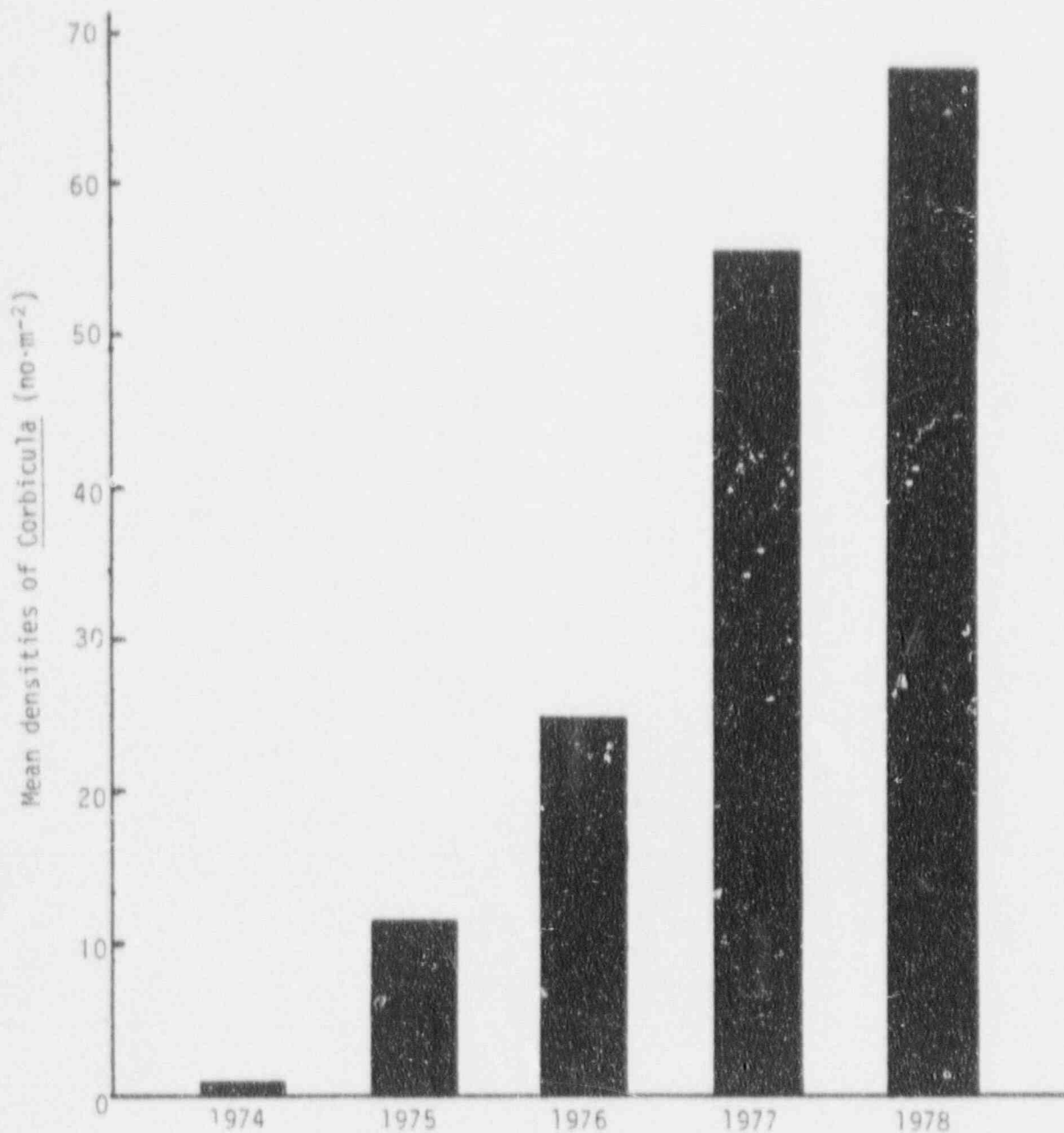


Figure 9-6. Mean annual densities of *Corbicula* collected on all Lake Norman locations from 1974 through 1978. Mean annual densities are based on sampling schedule shown in Table 9-1. Three replicate Petersen grabs were taken per sample date at each location except for 1974 and 1975 when 10 replicates were taken at Locations 4.0 and 12.0.

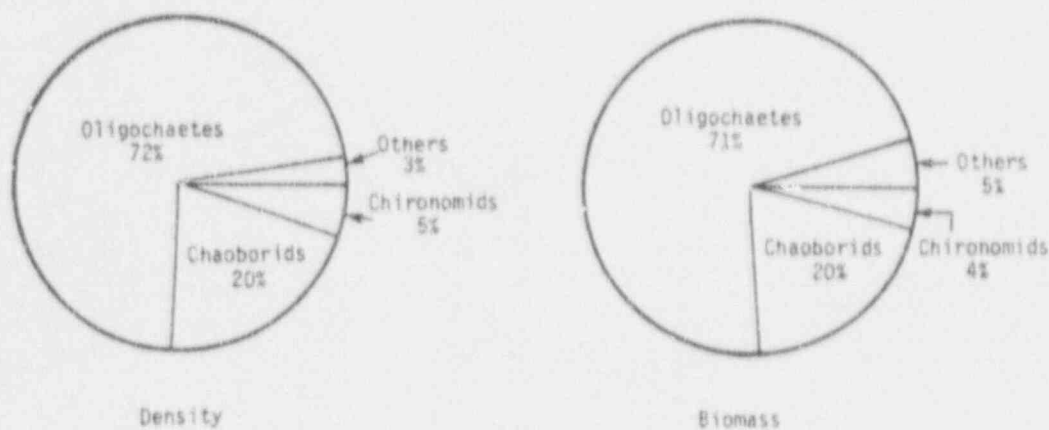
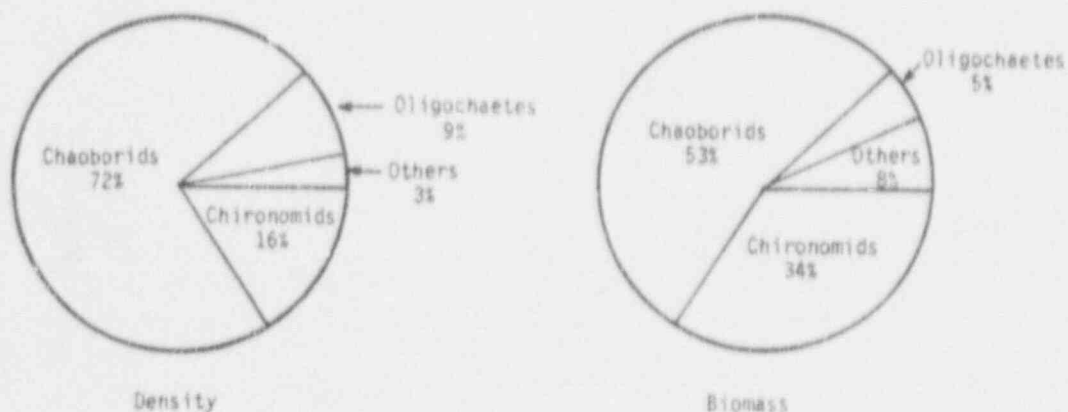
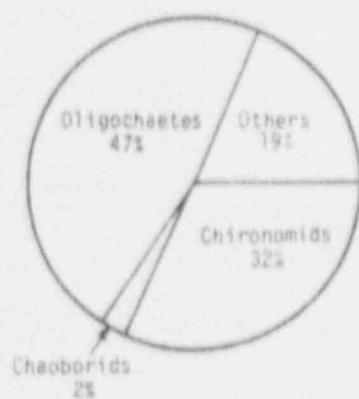
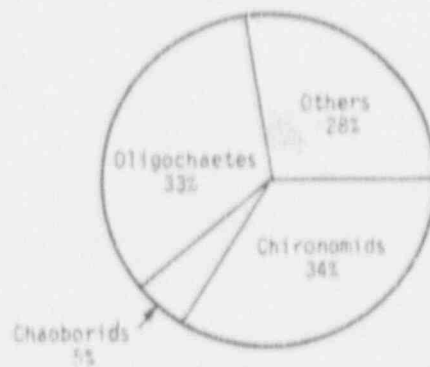


Figure 9-7. Mean percent composition ($\text{No} \cdot \text{m}^{-2}$ and $\text{mg} \cdot \text{m}^{-2}$) of macroinvertebrates collected in modified Petersen grab samples at Lake Norman locations in the vicinity of Marshall Steam Station from 1974 through 1978.

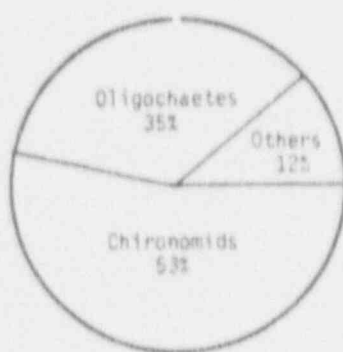


Density

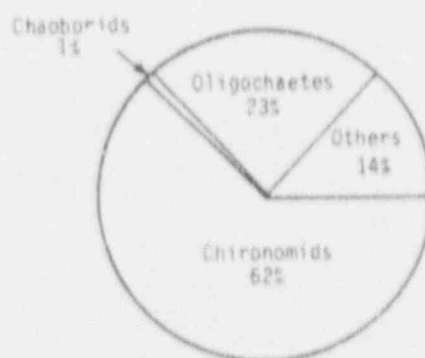


Biomass

Location 16.0



Density*



Biomass

Location 16.2

*Chaoborids composed <0.1% of the density.

Figure 9-8. Mean percent composition ($\text{No.}\cdot\text{m}^{-2}$ and $\text{mg}\cdot\text{m}^{-2}$) of macroinvertebrates collected in Petersen grab samples at locations below Cowans Ford Dam from 1974 through 1978.

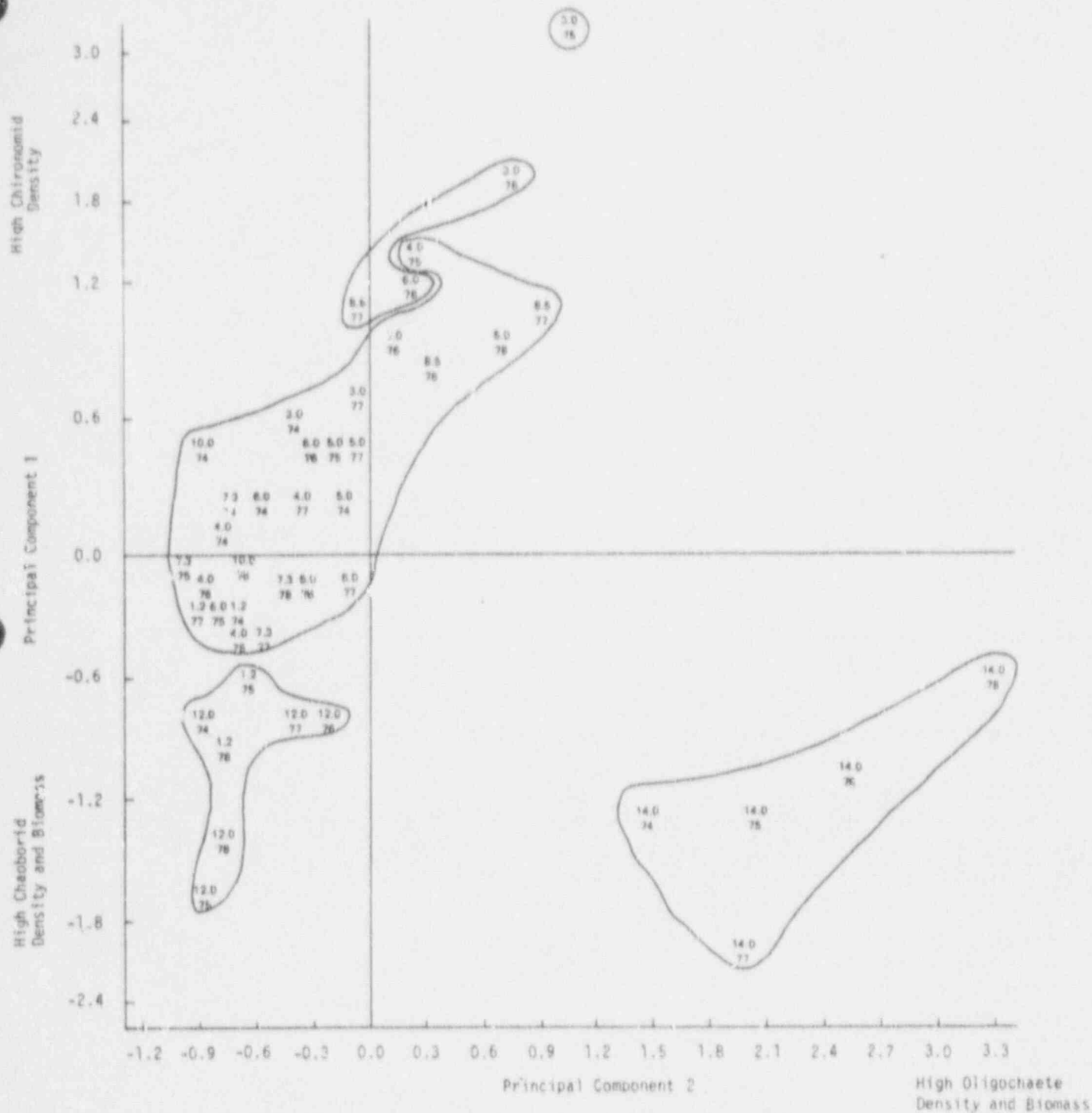


Figure 9-9. Cluster analysis of principal components of all Lake Norman sublittoral sampling locations. Upper number refers to location and the lower number to sample year.

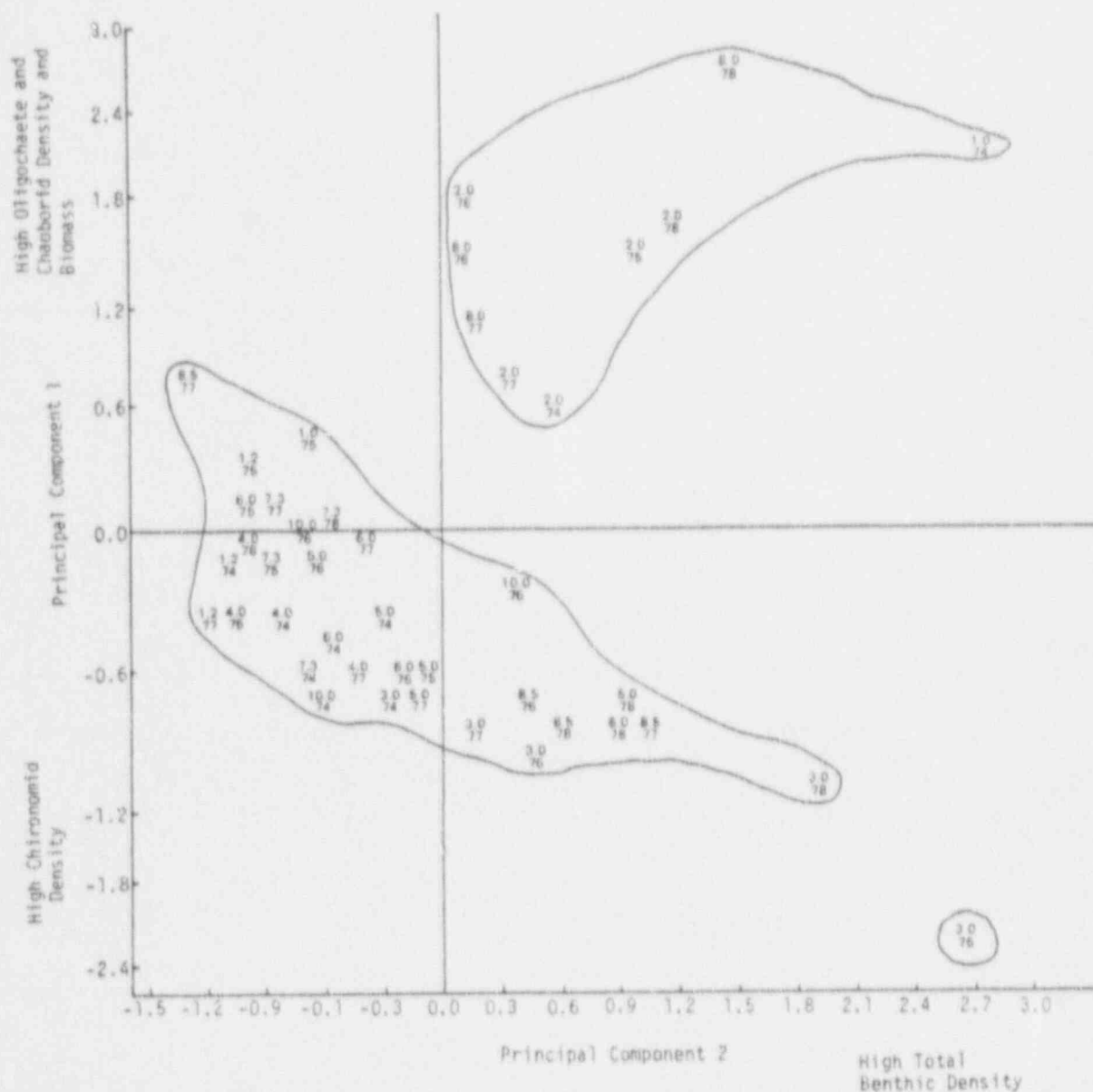


Figure 9-10. Cluster analysis of principal components of Lake Norman profundal and sublittoral benthos sampling locations in the vicinity of McGuire Nuclear Station. Upper number refers to location and the lower number to sample year.

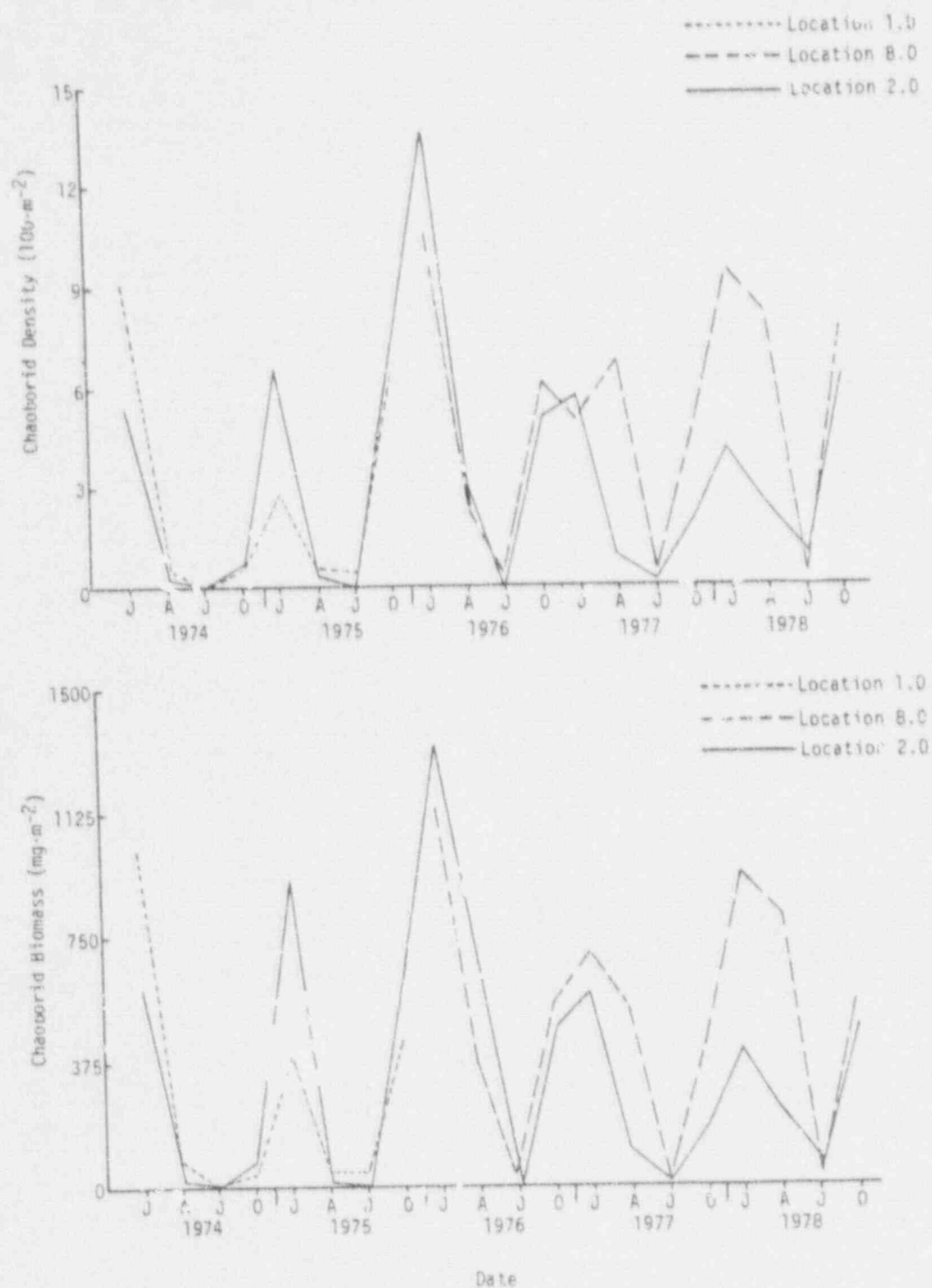


Figure 9-11. Density and biomass of chaoborids collected in modified Petersen grab samples at profundal locations on Lake Norman from 1974 through 1978.

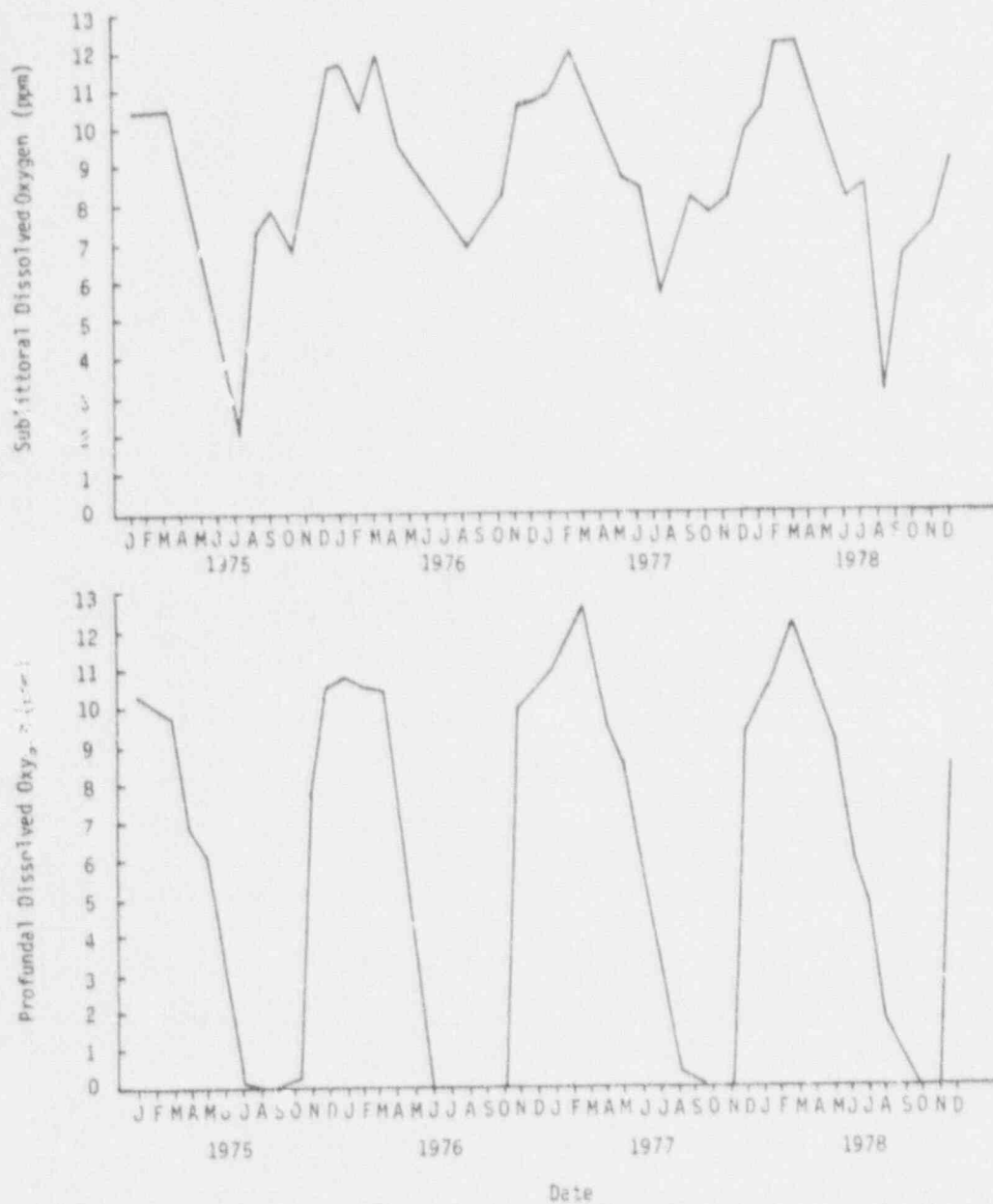


Figure 9-12. Dissolved oxygen concentrations at one meter from the bottom at a Lake Norman profundal location (Location 8.0) and a sublittoral location (Location 4.0) from 1975 through 1978.

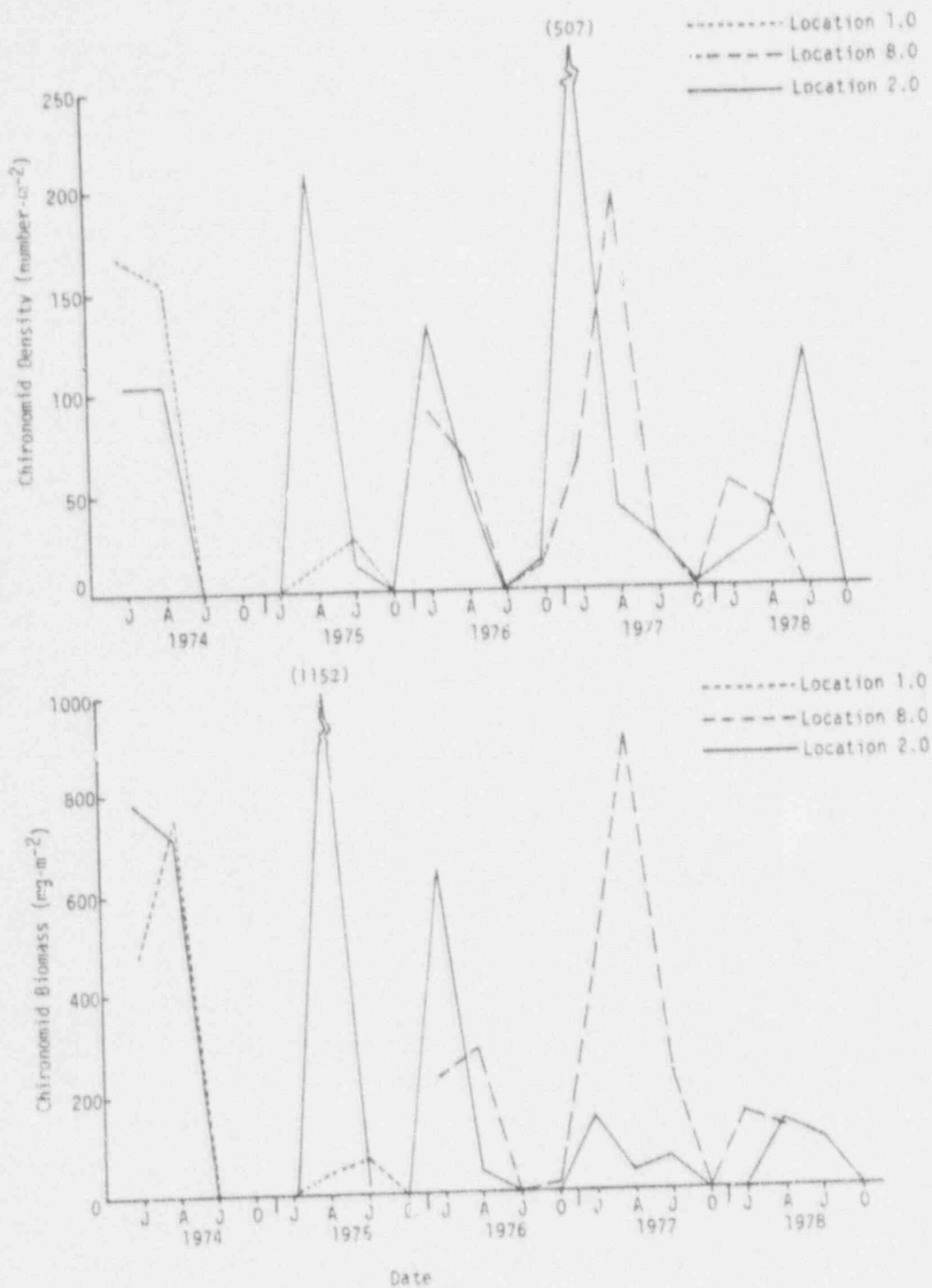


Figure 9-13. Density and biomass of chironomids collected in modified Petersen grab samples at profundal locations on Lake Norman from 1974 through 1978.

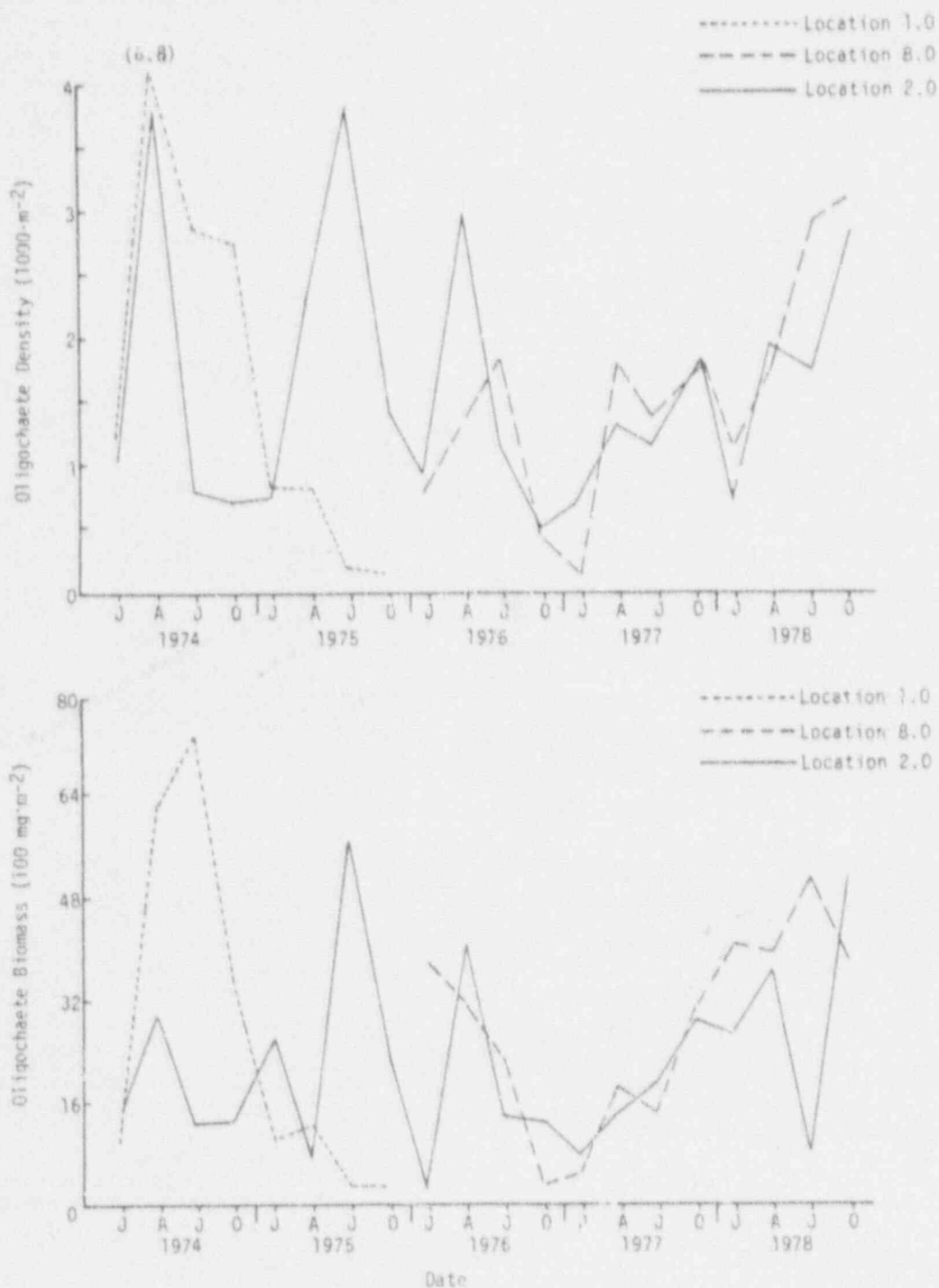


Figure 9-14. Density and biomass of oligochaetes collected in modified Petersen grab samples at profundal locations on Lake Norman from 1974 through 1978.

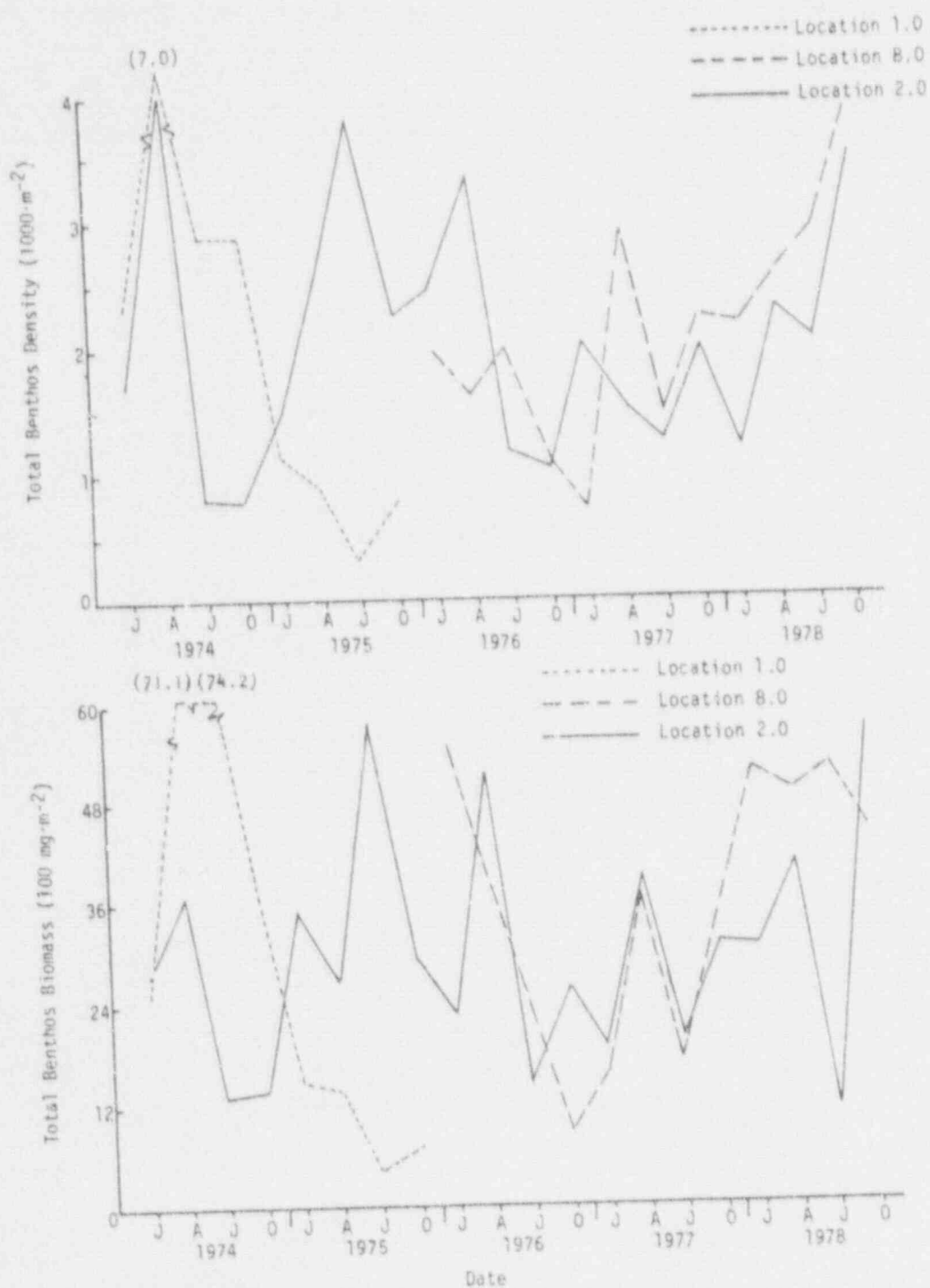


Figure 9-15. Density and biomass of all benthic organisms collected in modified Petersen grab samples at profundal locations on Lake Norman from 1974 through 1978.

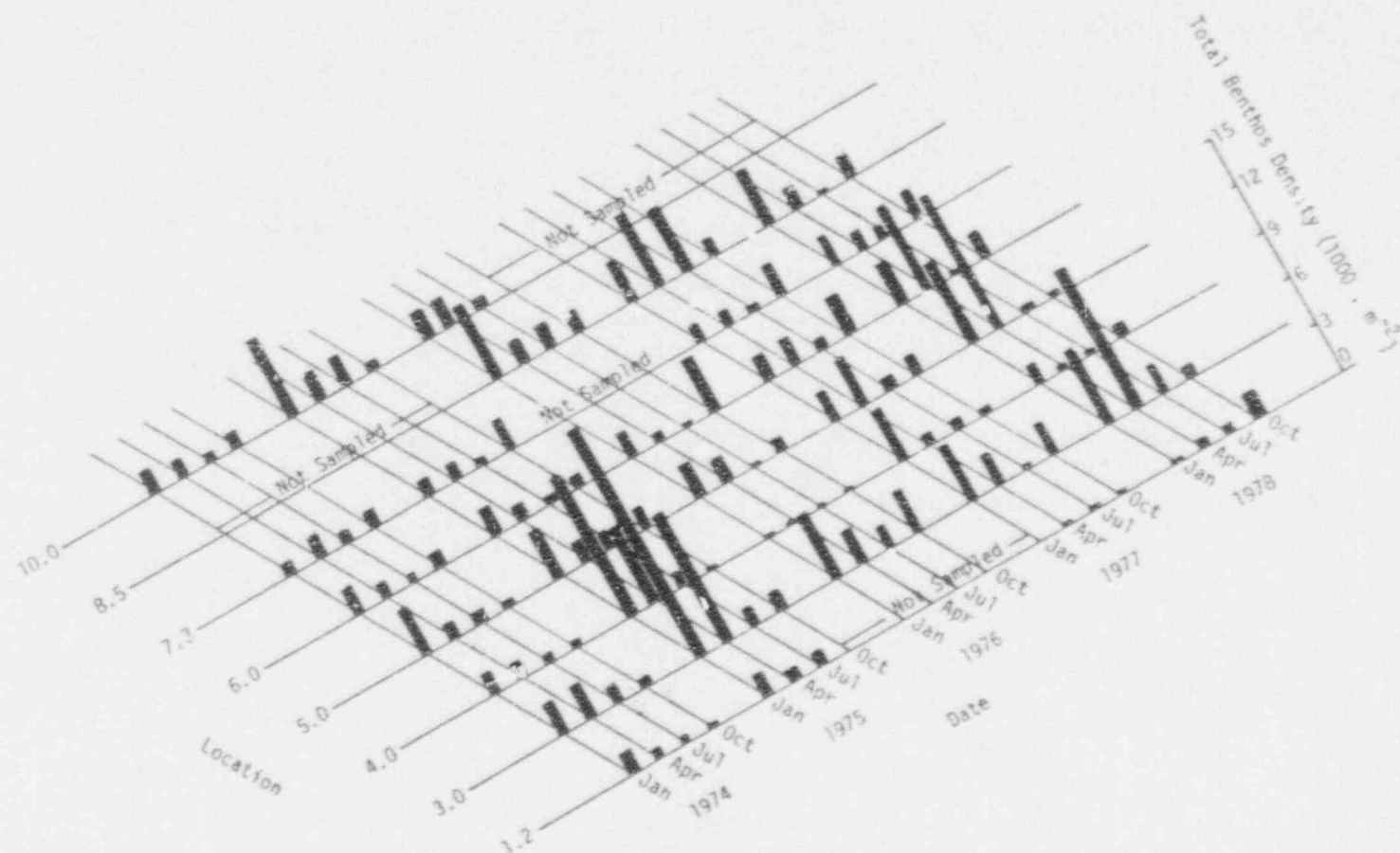


Figure 9-16. Density of all benthic organisms collected in modified Petersen grab samples at Lake Norman sublittoral locations in the vicinity of McGuire Nuclear Station from 1974 through 1978.

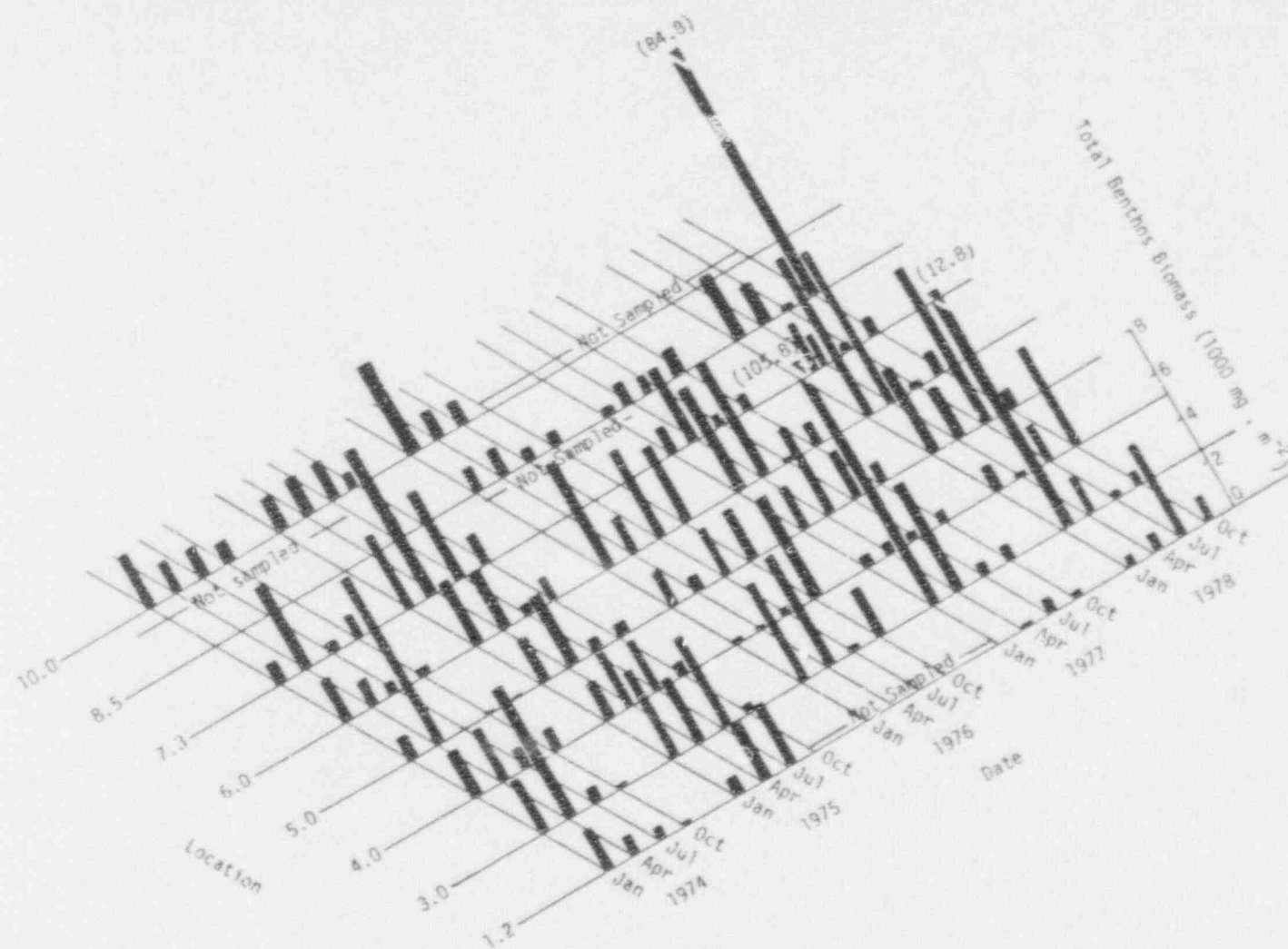


Figure 9-17. Biomass of all benthic organisms collected in modified Peterson grab samples at Lake Norman sublittoral locations in the vicinity of McGuire Nuclear Station from 1974 through 1978.

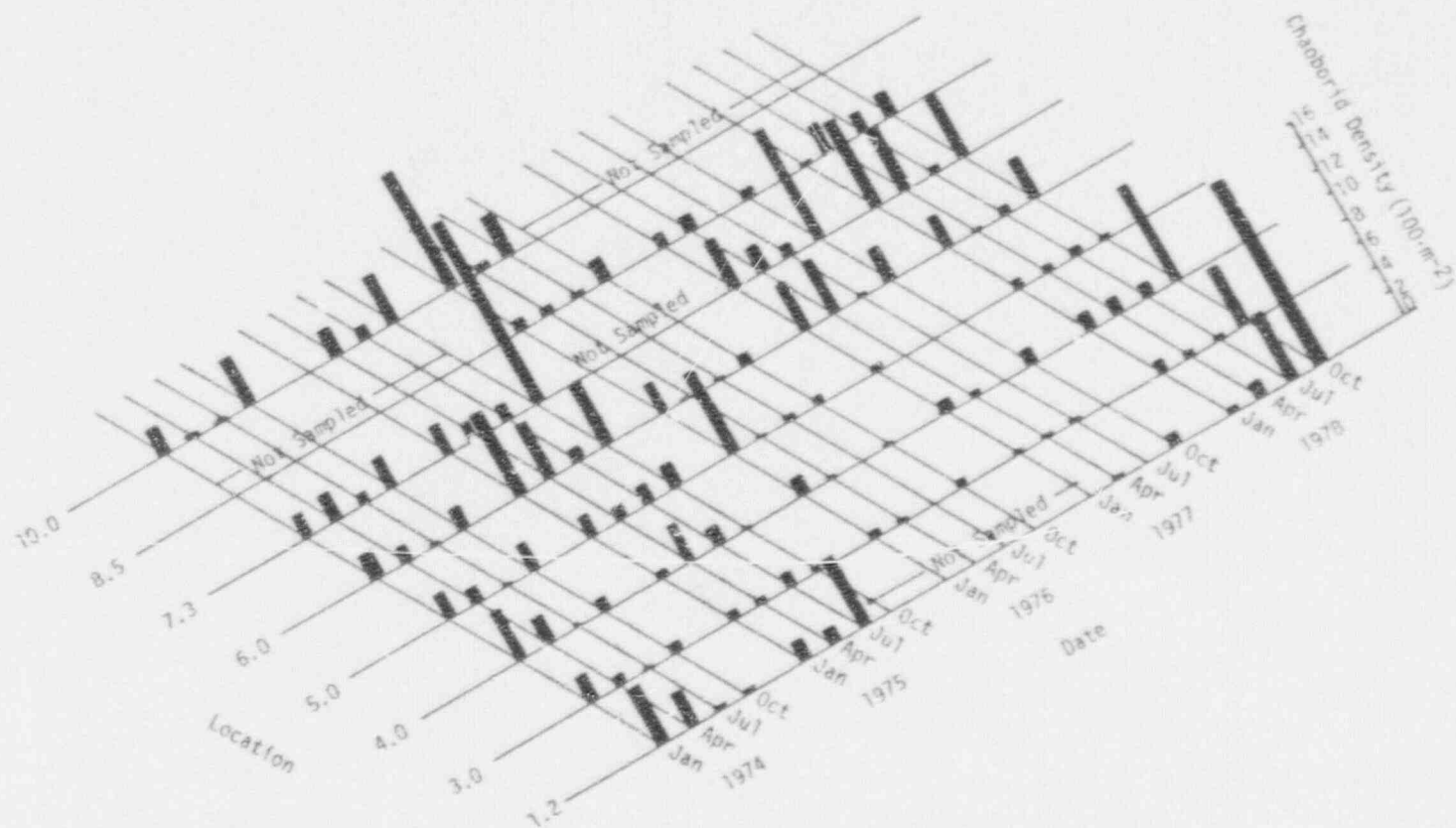


Figure 9-18. Density of chaoborids collected in modified Petersen grab samples at Lake Norman sublittoral locations in the vicinity of McGuire Nuclear Station from 1974 through 1978.

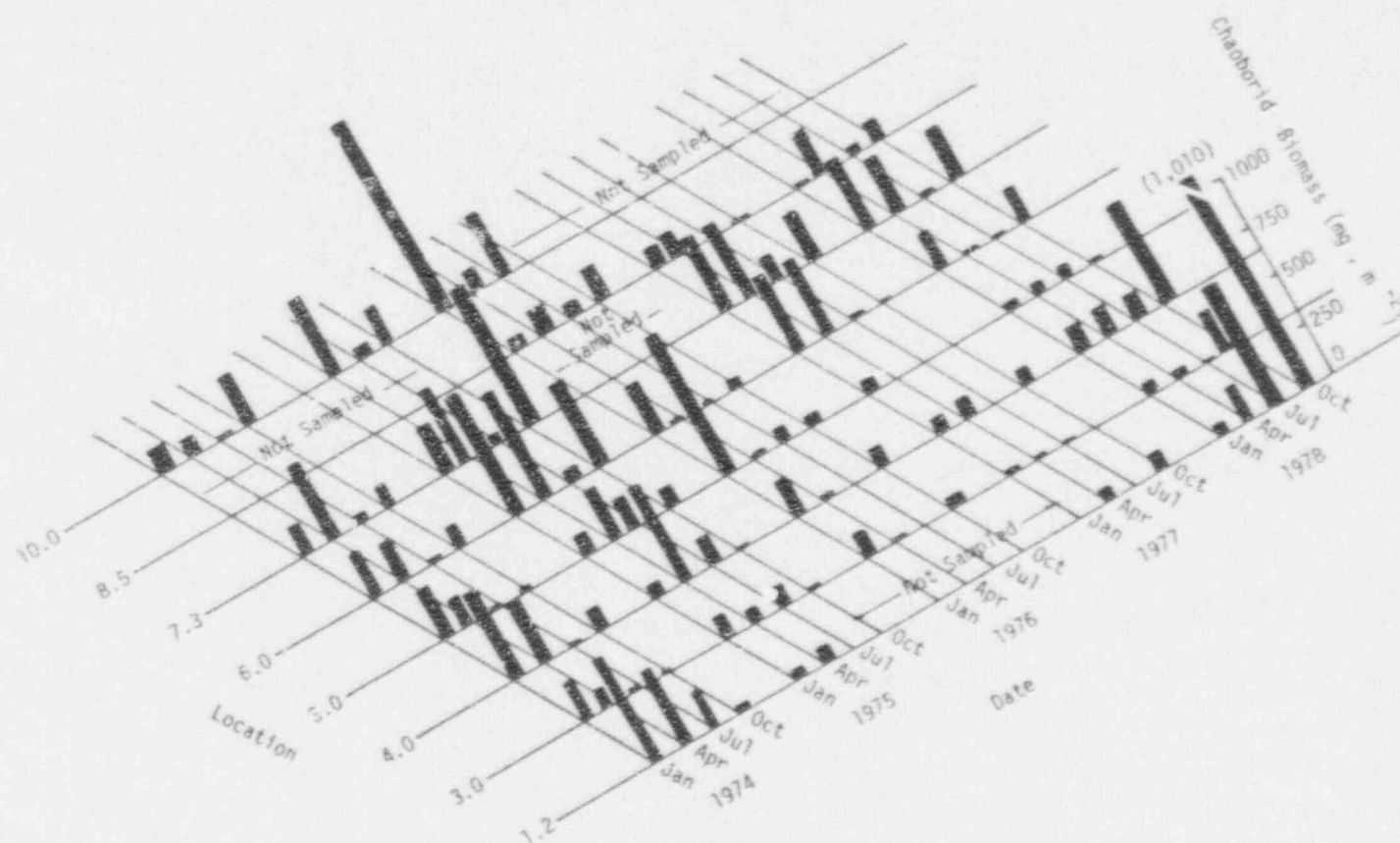


Figure 9-19. Biomass of chaoborids collected in modified Petersen grab samples at Lake Norman sublittoral locations in the vicinity of McGuire Nuclear Station from 1974 through 1978.

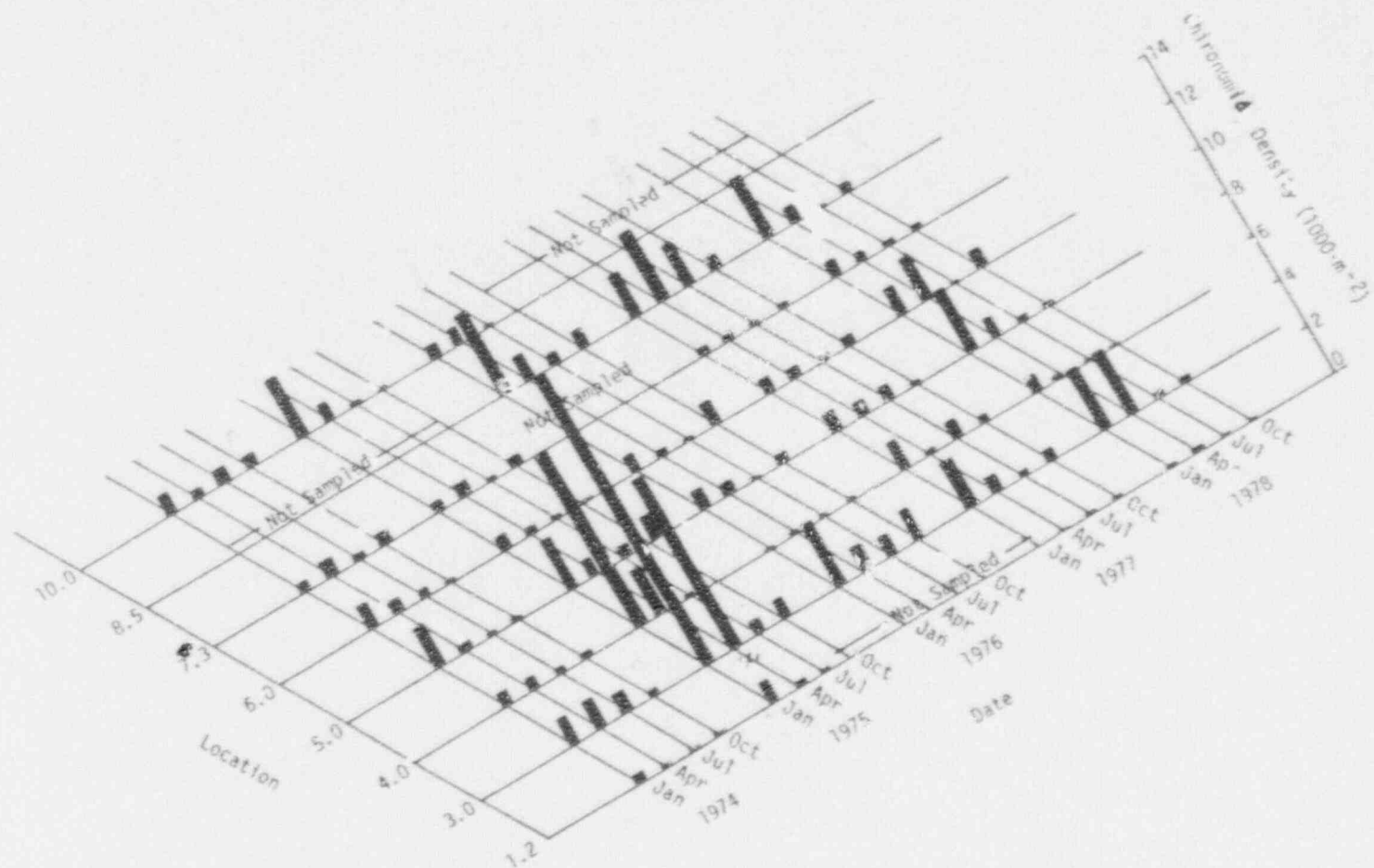


Figure 9-20. Density of chironomids collected in modified Petersen grab samples at Lake Norman sublittoral locations in the vicinity of McGuire Nuclear Station from 1974 through 1978.

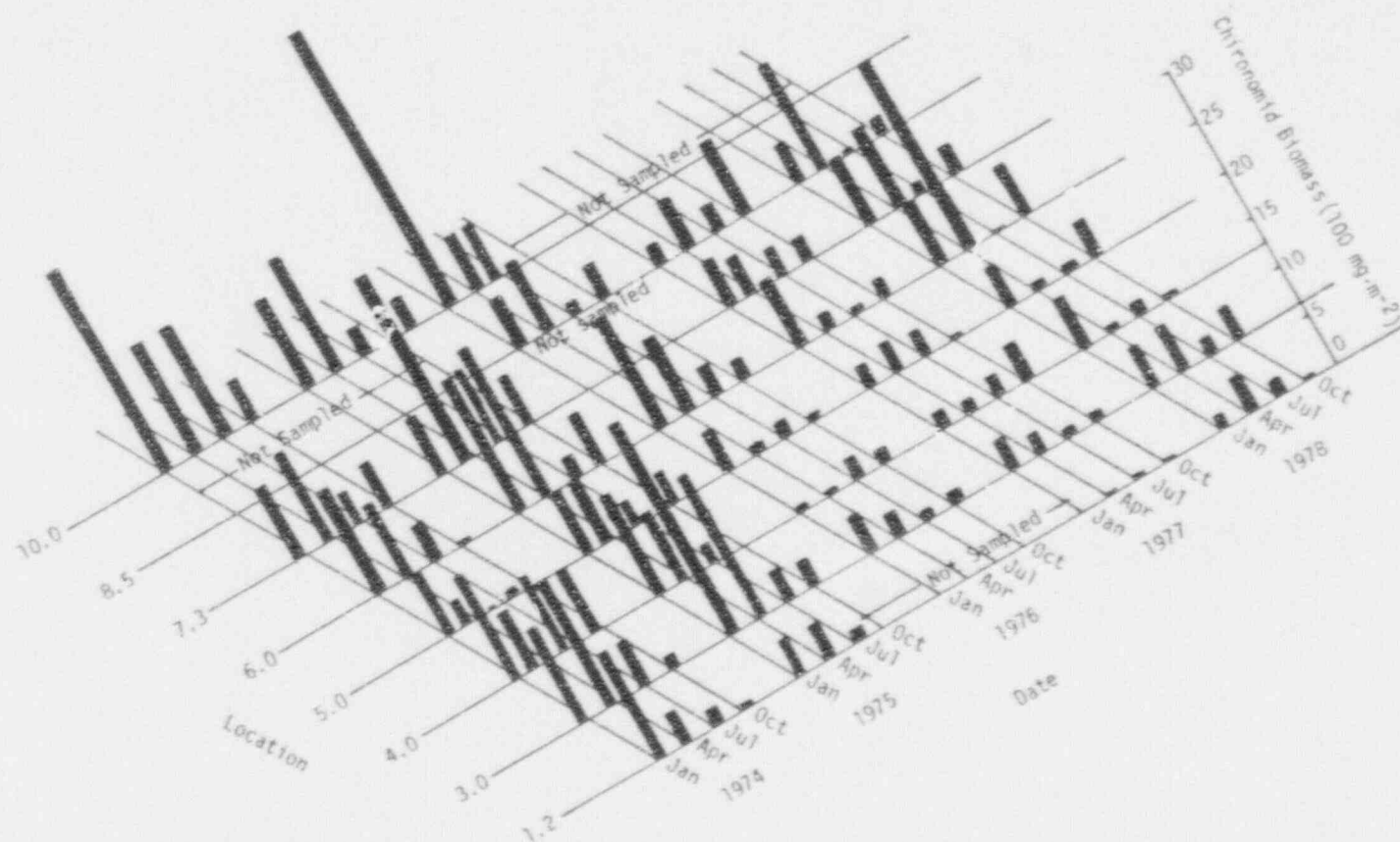


Figure 9-21. Biomass of chironomids collected in modified Petersen grab samples at Lake Norman sublittoral locations in the vicinity of McGuire Nuclear Station from 1974 through 1978.

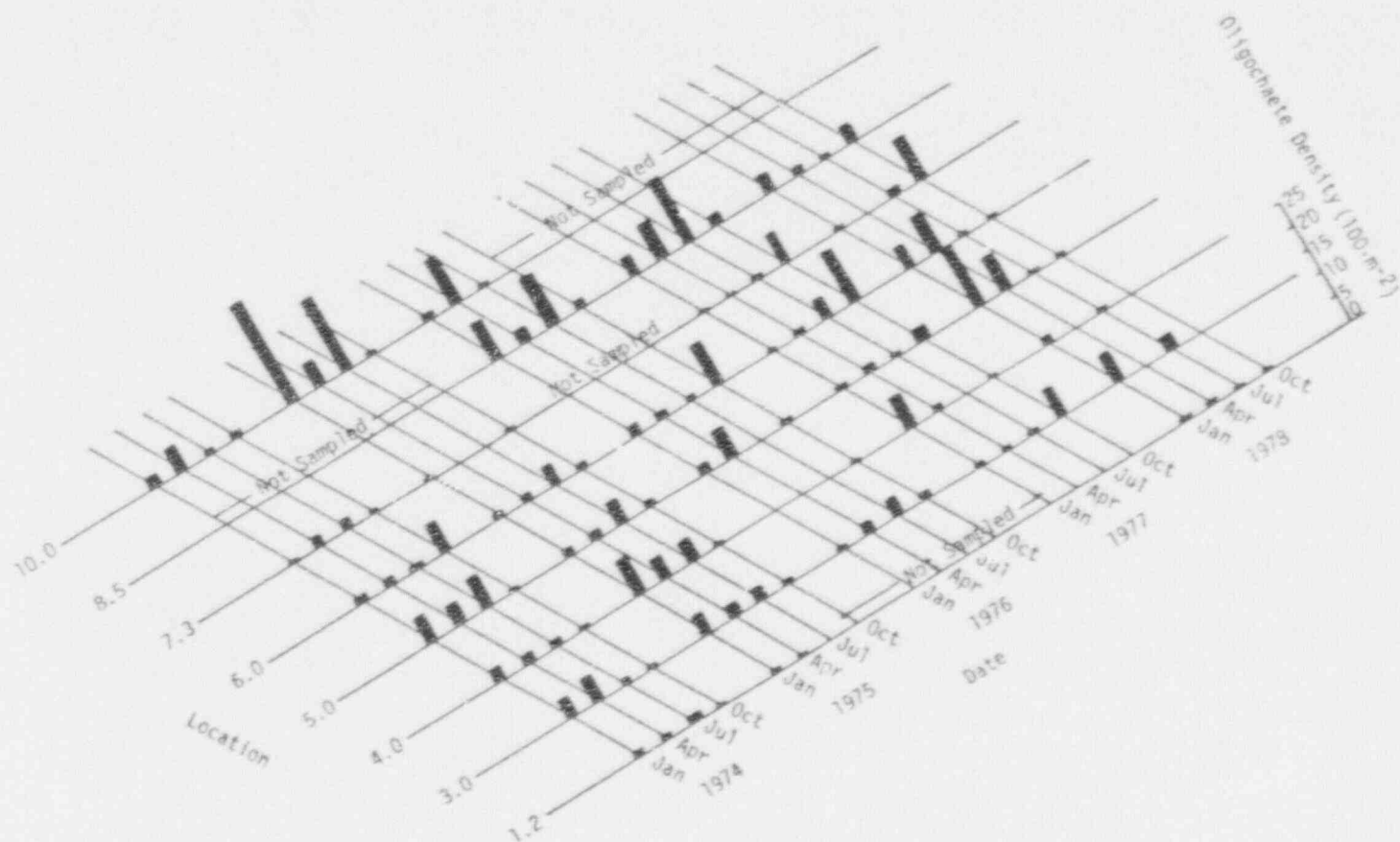


Figure 9-22. Density of oligochaetes collected in modified Petersen grab samples at Lake Norman sublittoral locations in the vicinity of McGuire Nuclear Station from 1974 through 1978.

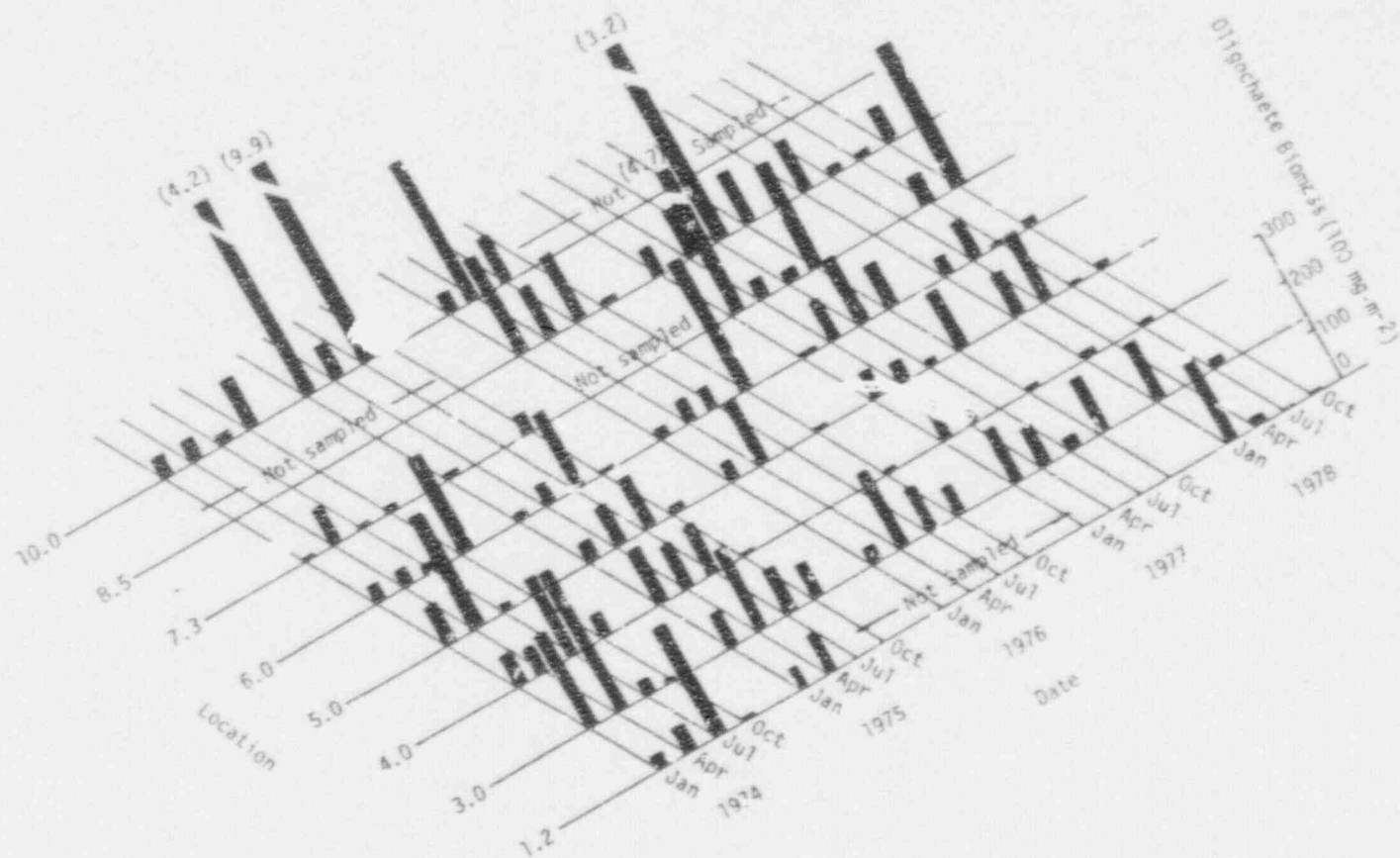


Figure 9-23. Biomass of oligochaetes collected in modified Petersen grab samples at Lake Norman sublittoral locations in the vicinity of McGuire Nuclear Station from 1974 through 1978.

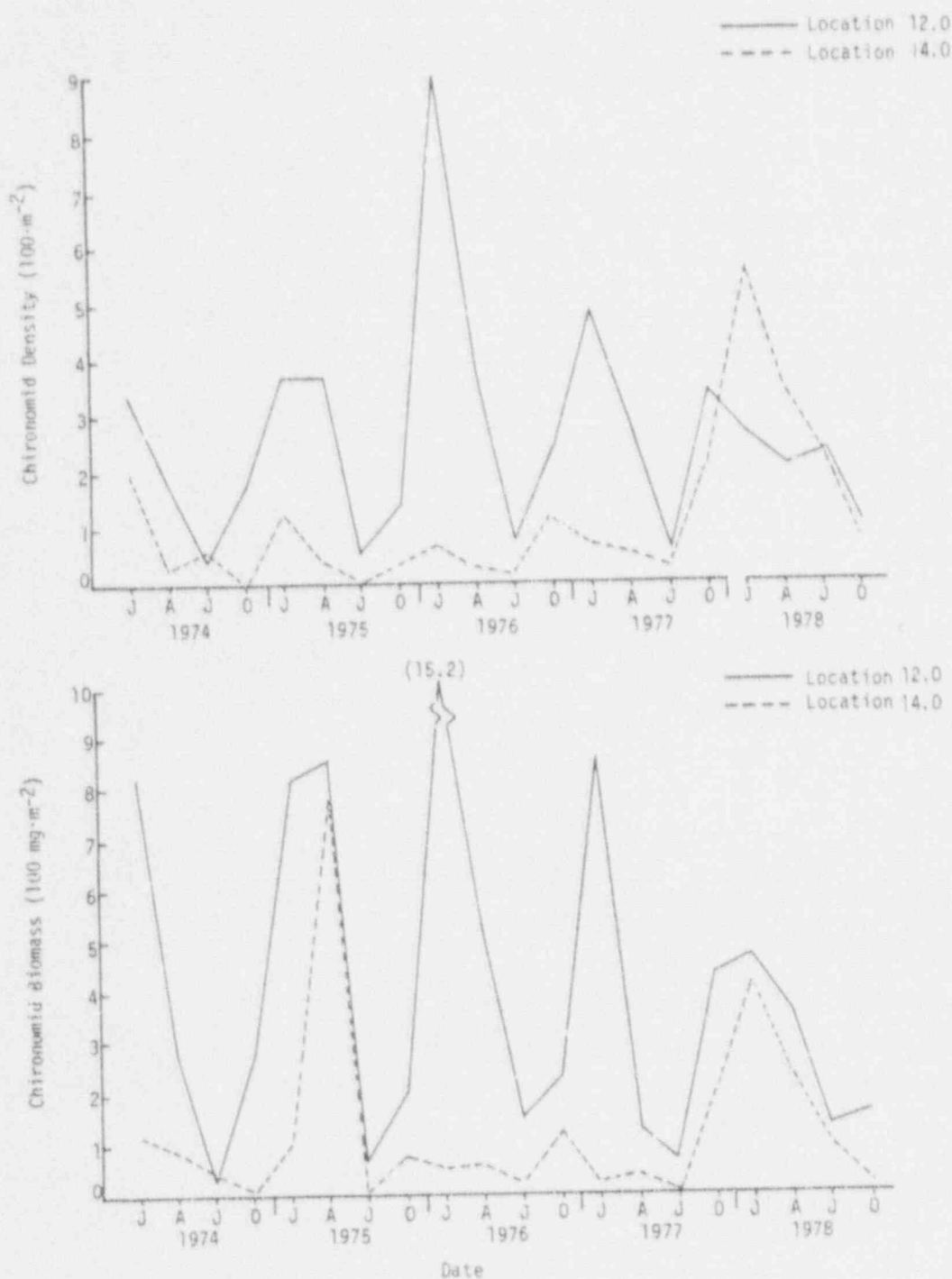


Figure 9-24. Density and biomass of chironomids collected in modified Petersen grab samples at Lake Norman sublittoral locations in the vicinity of Marshall Steam Station from 1974 through 1978.

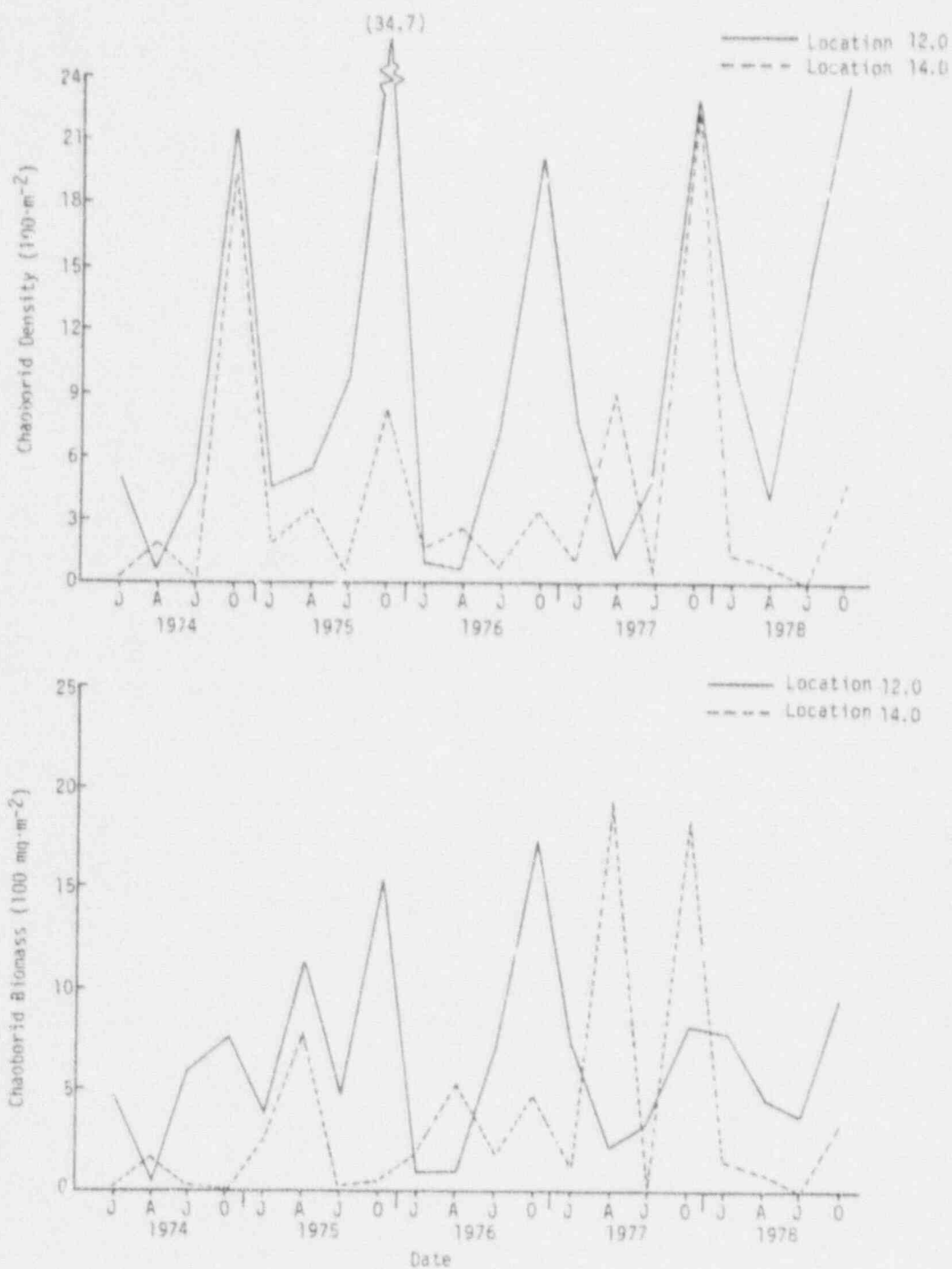


Figure 9-25. Density and biomass of chaoborids collected in modified Petersen grab samples at Lake Norman sublittoral locations in the vicinity of Marshall Steam Station from 1974 through 1978.

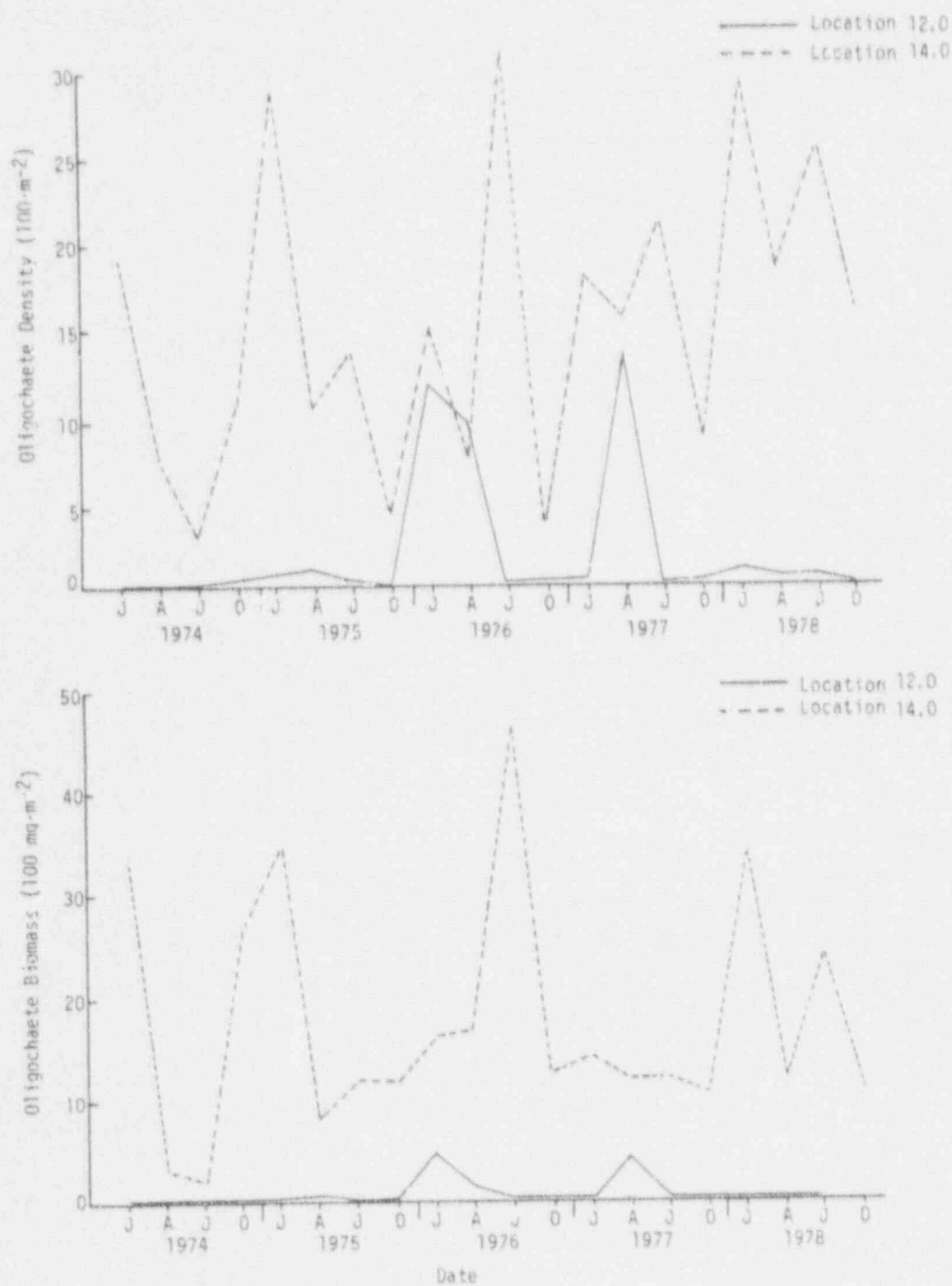


Figure 9-26. Density and biomass of oligochaetes collected in modified Petersen grab samples at Lake Norman sublittoral locations in the vicinity of Marshall Steam Station from 1974 through 1978.

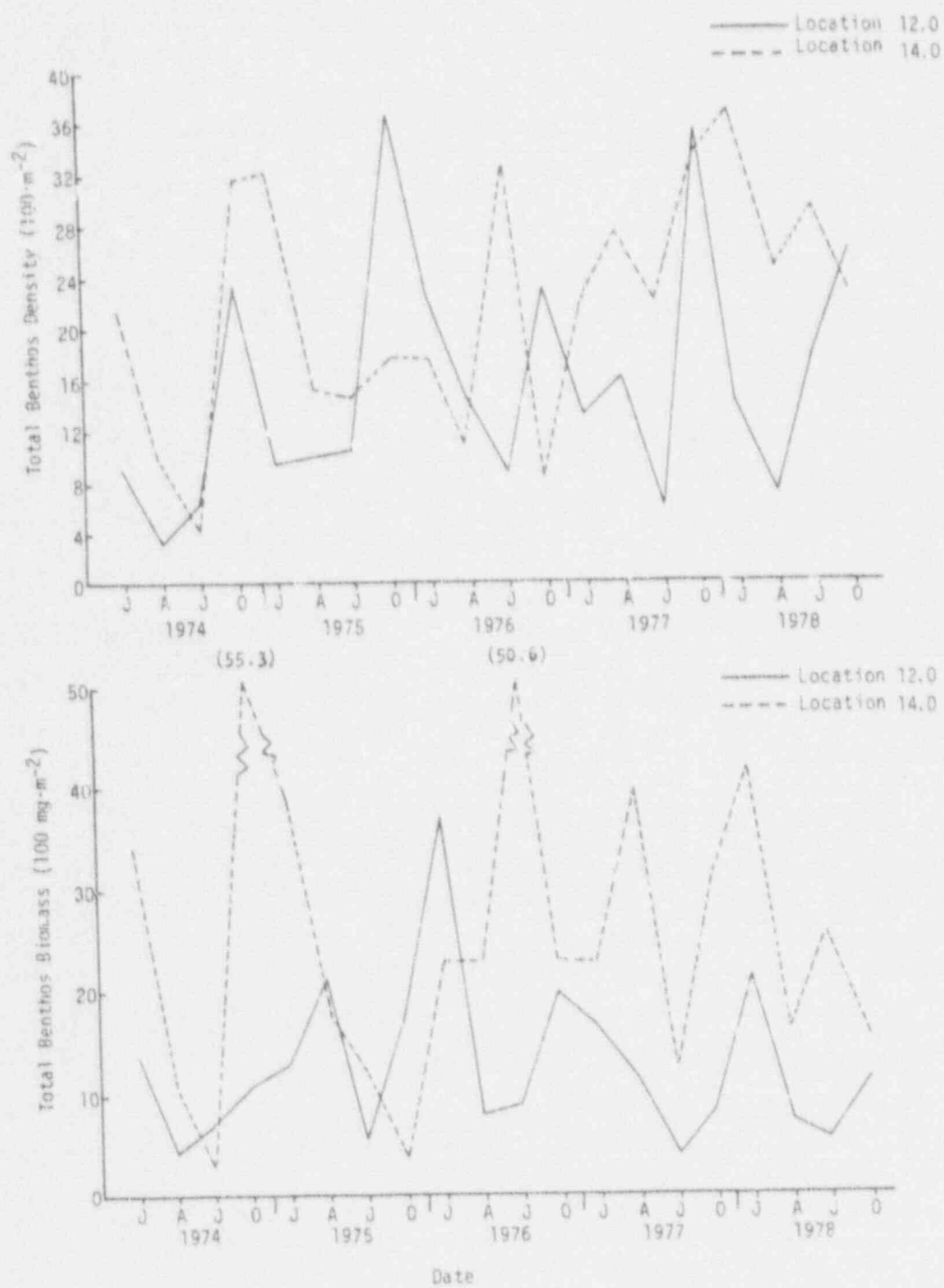


Figure 9-27. Density and biomass of all benthic organisms collected in modified Petersen grab samples at Lake Norman sublittoral locations in the vicinity of Marshall Steam Station from 1974 through 1978.

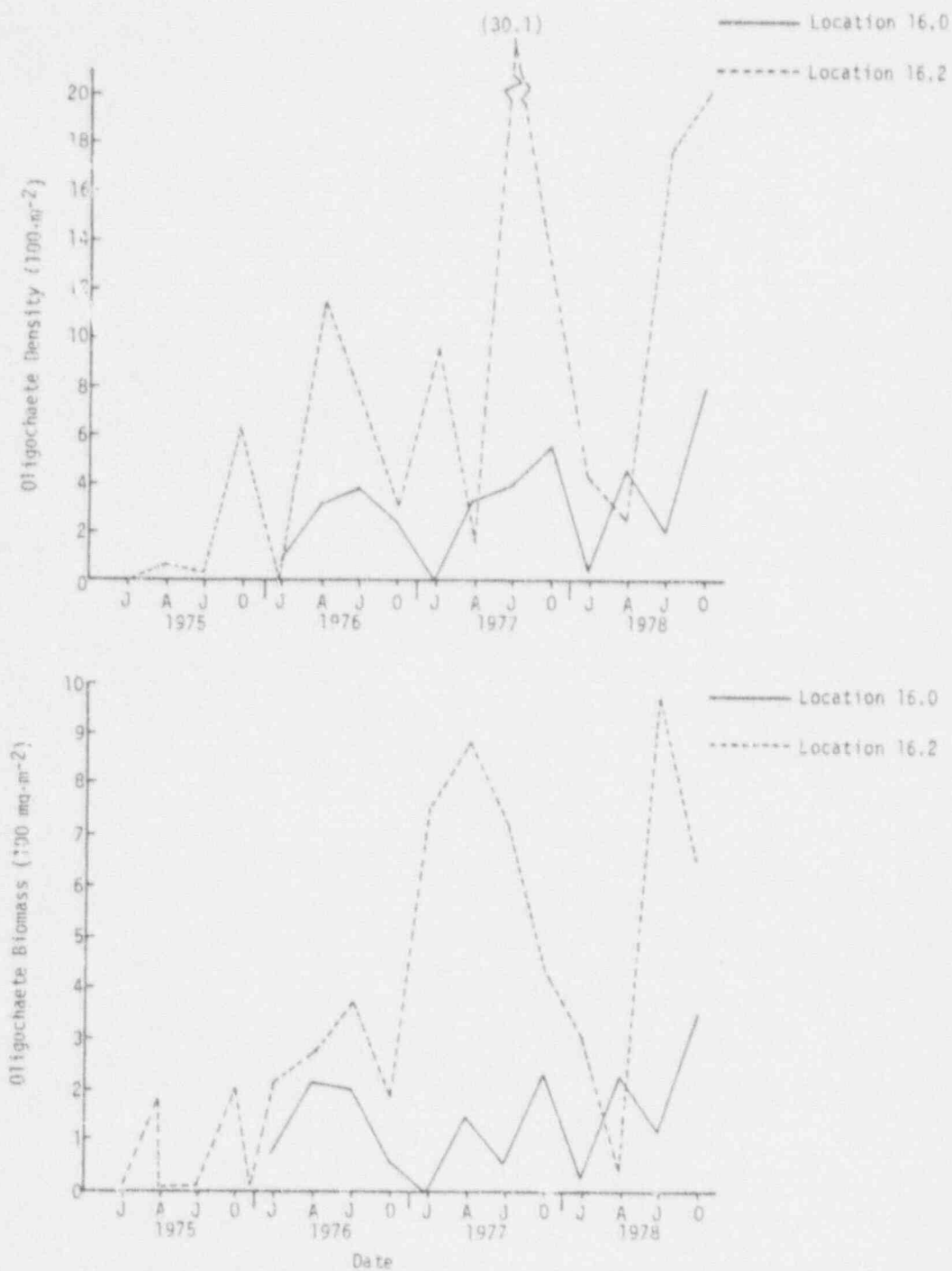


Figure 9-28. Density and biomass of oligochaetes collected in modified Petersen grab samples at locations downstream from Cowans Ford Dam from 1974 through 1978.

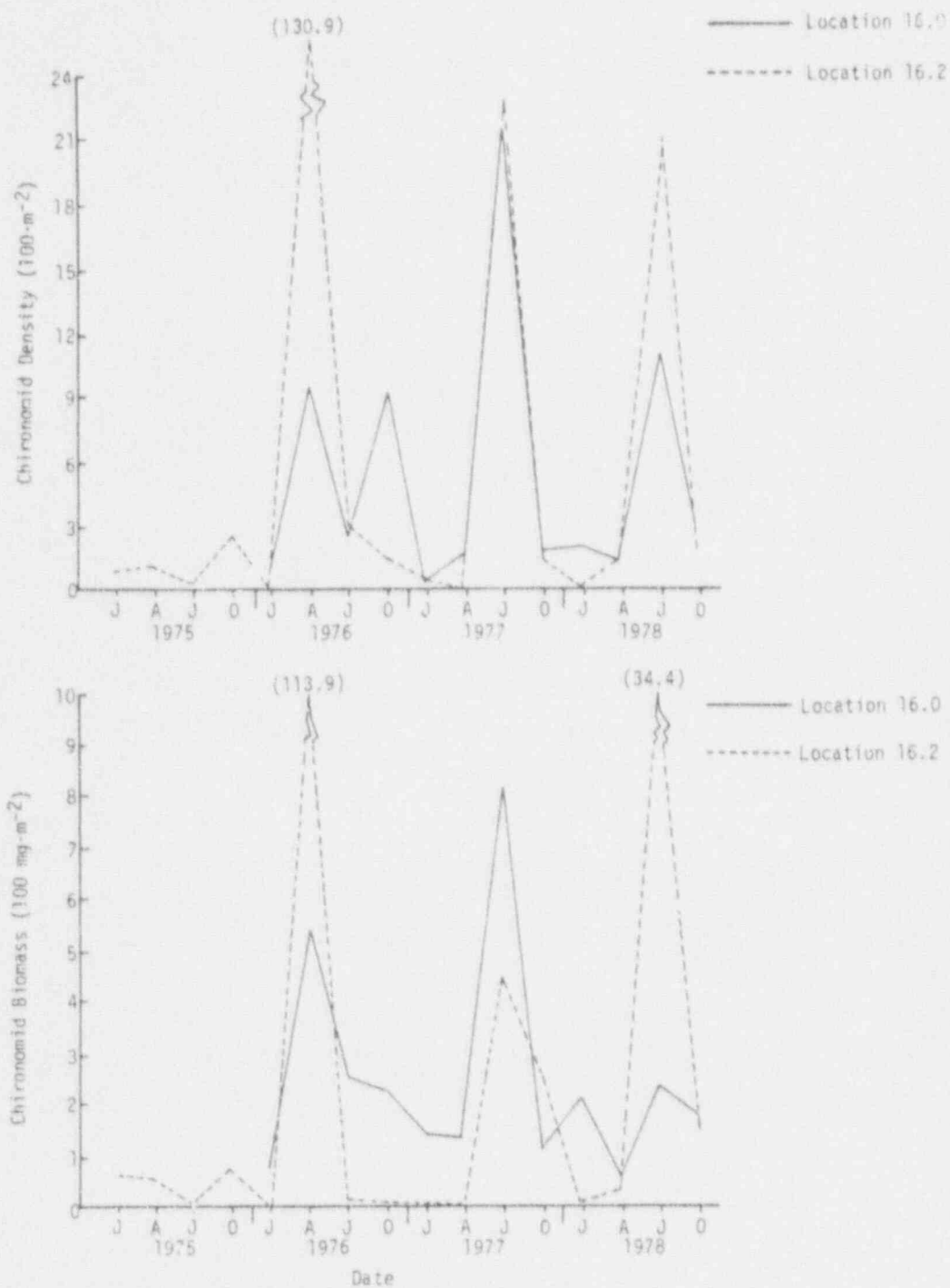


Figure 9-29. Density and biomass of chironomids collected in modified Petersen grab samples at locations downstream from Cowans Ford Dam from 1974 through 1978.

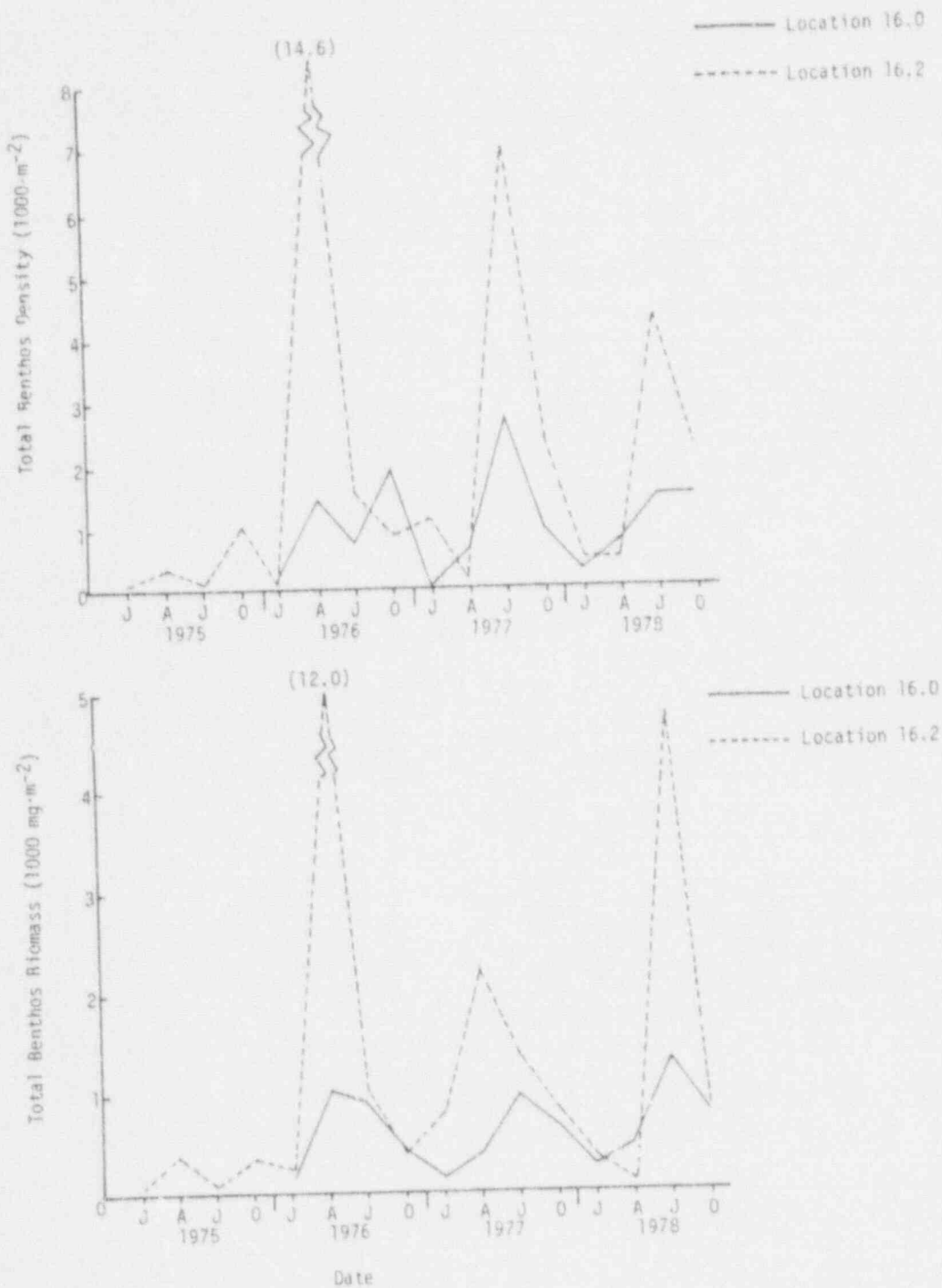


Figure 9-30. Density and biomass of all benthic organisms collected in modified Petersen grab samples at locations downstream from Cowans Ford Dam from 1974 through 1978.

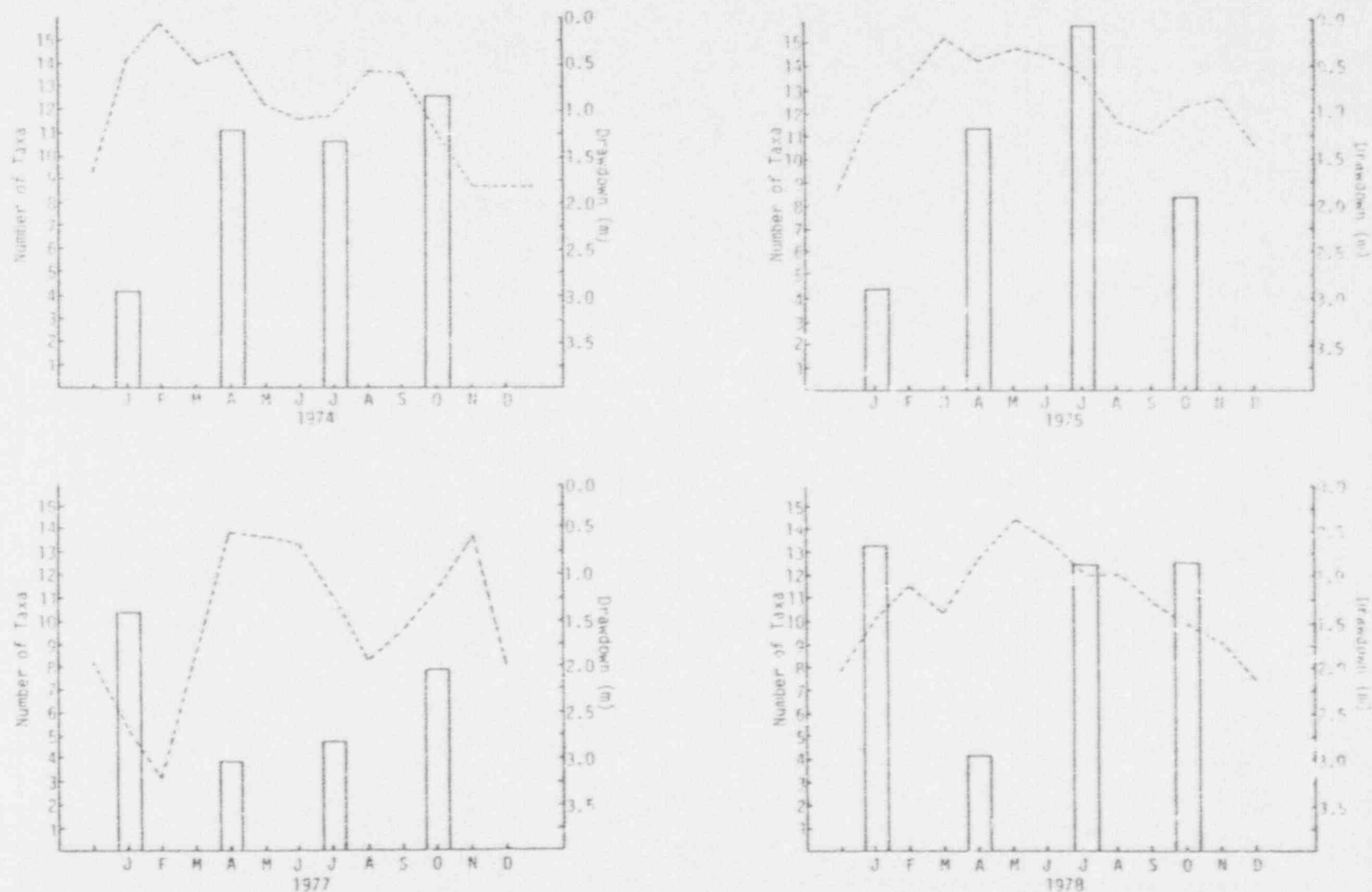


Figure 9-31. Total number of taxa collected at all Lake Norman sweep net locations and drawdown (----) of Lake Norman in meters below full pond. No sweep net data were collected on Lake Norman in 1976.

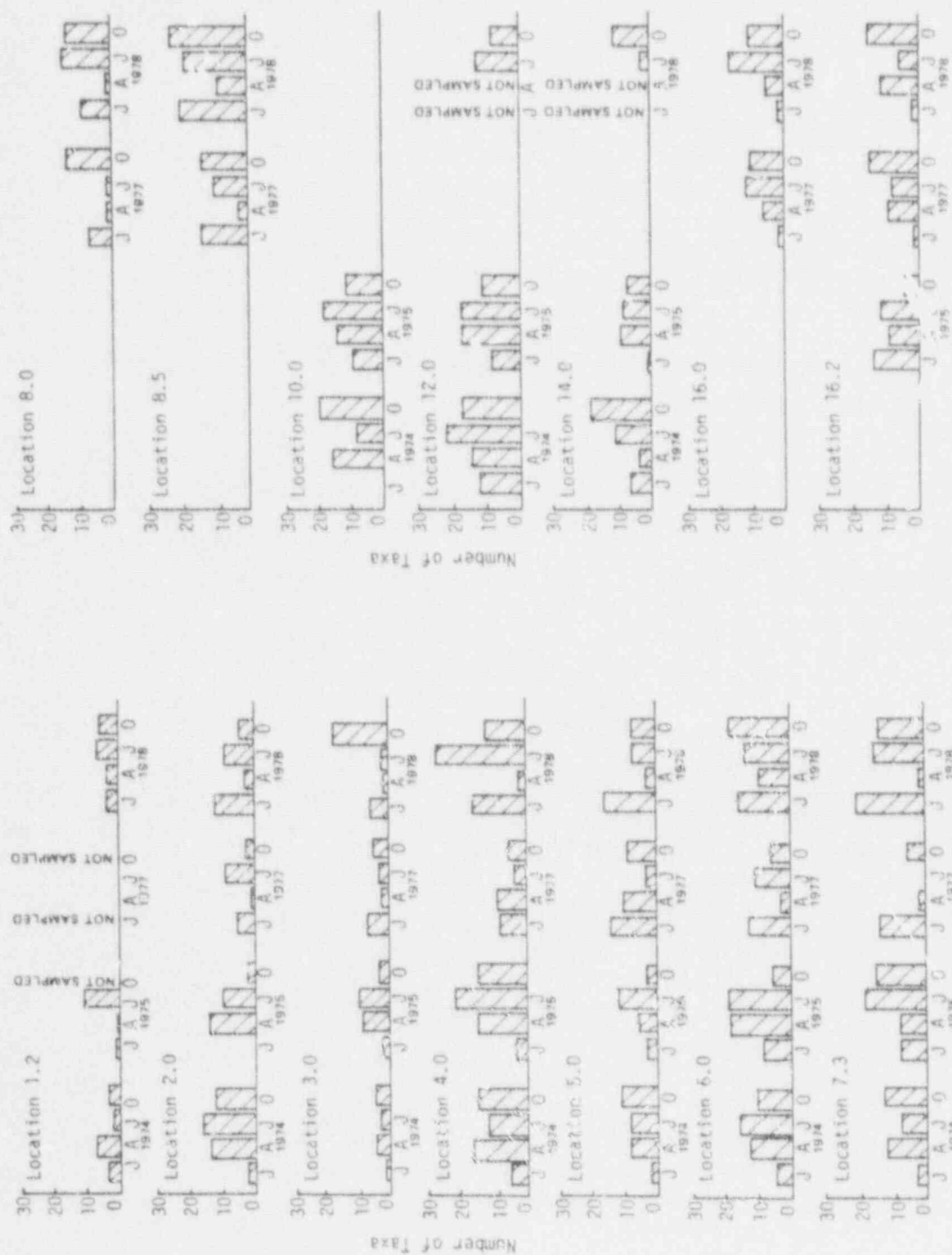


Figure 9-32. Number of taxa collected each quarter in sweep net samples at Lake Norman sampling locations in 1974, 1975, 1977, and 1978.

CHAPTER 10. FISH

J. R. SILER, R. E. LEWIS, B. K. BAKER, R. A. HANSEN, AND G. E. VAUGHAN

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INTRODUCTION

BACKGROUND

Lake Norman, a 13,156-ha reservoir, was impounded in 1963. Jenkins (1972) predicted the Lake Norman sport fish harvest to be approximately 240,620 kg at age 10 years compared with 147,550 kg at age 50 years. A creel survey conducted at age 15 years revealed that Jenkins' predictions were high; the total harvest estimate was only 64,243 kg (Appendix 10.1). Since impoundment, threadfin shad, channel catfish, flathead catfish, blue catfish, striped bass, smallmouth bass, and sauger have been introduced. Of these, smallmouth bass, and sauger have been unsuccessful. Largemouth bass, crappie, striped bass, and white bass dominate the fishery and comprise 88% of the Lake Norman sport fish harvest (Appendix 10.1).

Lake Norman has been the site of extensive research concerning the effects of power plant operations on fishes. Studies pertaining to the effects of Marshall Steam Station on fishes began in July 1968 (Miller and DeMont 1974). Marshall provides both benefits and detriments to the fish community and the fishery. The Marshall condenser cooling water discharge provides not only a substantial winter fishery (Miller and DeMont 1974) as both sport and prey species are attracted to the warmer water, but generally a productive fishery throughout the year (Appendix 10.1). If not for the heated discharges from Marshall, the Lake Norman winter water temperatures would severely limit threadfin shad, an extremely important prey species. In fact, North Carolina waters which have maintained threadfin shad since their initial introduction are those that receive heated effluents from steam plants (McNaughton 1966). In addition to the positive effects on threadfin shad, conditions at Marshall are also conducive to better bluegill and largemouth bass growth as compared to other areas on Lake Norman (Appendix 10.2; Miller and DeMont 1974). Growth of yellow perch, a coolwater species, was generally similar throughout Lake Norman. The warmer water temperatures at Marshall did not inhibit growth of yellow perch (Appendix 10.2).

In January 1970, gas-bubble disease was first observed in fishes in the Marshall discharge area (DeMont and Miller 1971) and by the winter of 1970-1971 the incidence appeared to have increased. However, by the winter of 1971-1972 gas-bubble disease had diminished because of a reduction in condenser cooling water ΔT (i.e., the temperature difference between discharge and intake water) (Adair and Hains 1974; Miller 1974). Epistylis, a stalked ciliated protozoan that attaches to the bony parts of fishes, was recognized as a problem in Piedmont North Carolina reservoirs in 1973 (Chapman et al. 1976). The 1975 incidence of infestation of Lake Norman fishes was low, but fishes with conspicuous infestations were aesthetically unpleasing to fishermen and often rejected (Lewis et al. 1977). Epistylis infestations are generally restricted to summer and fall; however, incidences on largemouth bass were found at Marshall discharge during winter and spring. No fish kills on Lake Norman have been attributed to Epistylis.

The food habits of four species of fish inhabiting the littoral zone of lower Lake Norman were examined during spring of 1975 through winter of 1976 (Appendix 10.3). Bluegill, redear sunfish, and yellow perch diets were similar and quite seasonal with primary foods being fish eggs, benthic invertebrates, terrestrial insects, and zooplankton. Largemouth bass were much less seasonal

in food habits and were dependent on various fish species throughout the year. Invertebrates were predominant food items in bass of 50 mm or less.

During periods of hydroelectric generation, portions of the standing crops of fishes may be entrained through the turbines of Cowans Ford Hydroelectric Station (Duke Power Co. 1976). A similar situation exists at the Marshall intake where fishes, mostly threadfin shad, can be either impinged on the intake screens (Edwards et al. 1976) or entrained through the plant.

OBJECTIVES

The objectives of this study were to:

- 1) determine species composition, standing crops, and relative abundance of fishes in Lake Norman, and
- 2) determine the reproductive success and spawning periods of selected fish species.

MATERIALS AND METHODS

This chapter summarizes data collected from August 1973 through December 1980 on Lake Norman and the Catawba River around McGuire and Marshall. The data presented in this summary do not include all collections. The portion presented is identified in the following sections.

ELECTROFISHING

A boat-mounted Smith-Root Mark IV Electrofisher was used to sample four sublocations at each location. A mean was derived from the four sublocations with relative abundance reported as mean number of fish per 150 m of shoreline (at an average lake level of 230 m m.s.l.).

From January 1974 through December 1975, alternating current (a.c.) electrofishing was employed. In December 1975, a study comparing 400 to 600 V a.c. electrofishing with 450 to 850 V pulsed direct current (d.c.) electrofishing indicated that pulsed d.c. electrofishing was more efficient in obtaining a representative sample with the least harm to the fish. As a result, pulsed d.c. was used from 1976 through 1980.

Quarterly samples (January, April, July, and October) from Locations 1.2, 4.0, 6.5, and 10.0 during 1974 through 1975, Locations 1.2, 4.0, 6.0, and 8.5 during 1976 through 1979, and Locations 13.0, 14.5, 14.7, 15.5, and 19.0 (Fig. 1-10) during June 1978 through May 1979 were included in analyses. Monthly collections from June 1978 through May 1979 at Locations 1.2, 3.7, 3.9, 4.0, 5.0, 6.0, 8.5, and 16.0 (Fig. 1-10, 1-11) were also included. Certain blocks of data were deleted from analyses because of changes in study design (the complete electrofishing sampling program is presented in Table 10-1; all electrofishing data are included in Appendix 10.4). For convenience, Locations 6.0 and 6.5 and Locations 10.0 and 8.5 will be referred to as Locations 6.5/6.0 and 10.0/8.5, respectively. A change from Locations 10.0 to 8.5 and 6.5 to 6.0 was made to better coordinate sampling with other environmental studies. These changes,

when appropriate, were also made for gill net, rotenone, and ichthyoplankton sampling. January, April, July, and October samples represented winter, spring, summer, and fall quarters, respectively.

Total numbers and individual total lengths for each species, and surface water temperatures were recorded at each sublocation. All fish were returned to the water except those retained for life history studies.

GILL NETS

Three experimental gill nets measuring 27 m in length and consisting of alternating 3-m panels of 2.5, 3.8, and 5.1-cm bar mesh were set perpendicular to the shoreline at approximately 1430 h and retrieved the following morning at approximately 0800 h. Accurate records of time-in-water for each net set were maintained, but catches were expressed as fish·gill net set⁻¹ (approximately 17.5 h), because time-in-water generally varied less than 0.5 h. A water temperature profile was taken with a Hydrolab Model TDO-2 or a Yellow Spring Instrument's telethermometer at 1-m intervals from surface to bottom near the center net at each location. Total number and total weight were recorded for each species; total lengths, mesh size, and distance from shore were recorded for each individual.

Quarterly samples (January, April, July, and October) from Locations 4.0, 6.5, and 10.0 from 1974 through 1975, Locations 4.0, 6.0, and 8.5 from 1976 through 1979, and Locations 13.0, 14.7, 15.5, and 19.0 (Fig. 1-10) from July 1978 through April 1979 were included in analyses. Monthly collections from June 1978 through May 1979 at Locations 3.0, 4.0, 5.0, 6.0, and 8.5 were also included. Certain blocks of data were deleted from the analyses because of changes in study design (the complete gill net sampling program is presented in Table 10-1; all gill net data are included in Appendix 10.5).

ROTENONE

Rotenone sampling locations were mapped using an alidade, plane table, and sounding line to estimate the area and volume of each cove. Equations were determined for each cove to estimate area and volume based on lake level. The amount of rotenone to be applied and the sample area was determined from the lake level on the day rotenone was applied.

A 1-cm bar mesh block net was positioned at a fixed point across the mouth of each cove the morning of the day rotenone was applied. SCUBA divers checked the net to ensure proper contact with the bottom. Water temperature and dissolved oxygen profiles were taken with a Hydrolab Model TDO-2 at the mouth of each cove. Rotenone was applied at a concentration of 1 mg·l⁻¹ using a pump and perforated hose. On the first day all fishes collected were identified, counted, and measured, and total weight of each 2-cm length class was determined. The following morning fishes were collected, identified, counted, and measured. Weights for fishes collected on the second day were estimated from first day mean weights of respective size classes. The block net was then removed and the sequence repeated at another location. On the third day, fishes were picked up and buried. These fishes were not used in the standing crop estimates since they could have moved into the area following removal of the block net. Locations 4.0, 6.0, and 10.0 (Fig. 1-10) were sampled the first full week of

August in 1973 and 1975. Samples at these locations in 1974 were taken the last week of June. Locations 4.0, 6.0, and 8.5 (Fig. 1-10) were sampled during the first full week of August from 1976 through 1980. Sampling locations from 1973 through 1977 were approximately 0.4 ha in size and were sampled utilizing the previously discussed procedure. Additional locations were sampled, but these were deleted from analyses because they were not sampled every year (the complete rotenone sampling scheme is presented in Table 10-1; all rotenone data are included in Appendix 10.6).

During 1978 an additional 0.8 ha (cove sizes vary with lake elevation) area was sampled at each location, but the 0.4-ha sublocations (reference to size is for convenience) were separated by an additional block net in order to preserve the integrity of the 0.4-ha data throughout the study period. Data from the 0.8-ha sublocations were combined with those from the 0.4-ha sublocations to yield the 1.2-ha estimates. With this additional area, block nets were left in until the end of the second day in order to allow more time for processing the larger numbers of fish collected.

Uplake Locations 14.7, 19.0, and 68.0 (Fig. 1-10) were added to the study in 1978. Sampling was similar to that previously described, except the 1.2 ha area rotenoned was not partitioned into 0.4 and 0.8-ha sublocations. The coves were sampled during the second week of August.

MIDWATER TRAWL

A Tucker Trawl (Hopkins et al. 1973) was fished from the bow of a 6.7-m Dura-Craft boat modified for trawling. Samples were taken obliquely from the surface to a depth of 18 m. A 3-mm woven mesh net was used for collections made from July 1978 through March 1979 and during October 1979. A 6-mm woven mesh net was used during April and July 1979 and during January and April 1980. Mesh size was increased to obtain faster trawl speeds required for collection of larger shad. A 2 x 3-m trawl frame was used from July 1978 through March 1979 and a 1.5 x 2-m frame during the remainder of the sample period. Trawl frame size was decreased for ease of operation in the field.

Wire angle, trawl angle, boat speed, sample duration, and length of cable below water were needed for estimation of sample volume. Prior to sampling, wire angle to trawl angle relationships were established for each trawl. An inclinometer was affixed across the mouth of the trawl to define the relationship between trawl angle and wire angle for a range of operating speeds. A flowmeter was attached to the boat to estimate boat speed. Wire angle, trawl angle, and boat speed were recorded for each $0.2 \text{ m} \cdot \text{s}^{-1}$ increase in speed from 0.5 to $2.0 \text{ m} \cdot \text{s}^{-1}$. The wire angle to trawl angle relationship was used to predict trawl angle from wire angle readings during actual field collections. A metering device affixed to the winch measured the length of wire used while fishing the trawl. Wire angle, boat speed, length of wire below water, and sample duration were recorded for each sample. These data were used to estimate the effective opening of the trawl and the volume of water sampled.

Two samples were taken at Locations 1.0, 4.5, 5.0, and 8.0 (Fig. 1-10). Samples were preserved in 10% formalin. All fishes collected were sorted by species into 1-cm length classes, counted, and weighed. Abundance was expressed as

numbers/1000 m³. Monthly samples were collected from July 1978 through April 1979 and quarterly samples (January, April, July, and October) from April 1979 through April 1980 (Table 10-1). Quarterly data from January 1979 through April 1980 are analyzed in this chapter. All midwater trawl data are included in Appendix 10.7.

ICHTHYOPLANKTON

A 0.91-m diameter conical nylon net with a mesh size of 794 μ m and a length of 2.4 m was used to sample larval fishes in Lake Norman. Duplicate 5-min tows were made at the surface of shoreline Locations 1.2, 4.0, 6.0, 8.5, and 10.0 and at the surface and 5 m at channel Locations 1.0, 4.5, 5.0, 8.0, and 10.5 (Fig. 1-10). Due to the proximity of the shoreline and channel areas and for ease of discussion, one location number was chosen to represent each area. These were Locations 1.0 (McGuire intake area Locations 1.2 and 1.0), 4.0 (McGuire discharge area Locations 4.0 and 4.5), 6.0 (Ramsey Creek area Locations 5.0 and 6.0), 8.0 (Catawba River channel area Locations 8.0 and 8.5), and 10.0 (Davidson Creek area Locations 10.0 and 10.5).

A General Oceanics flowmeter mounted in the mouth of the net allowed the estimation of the volume of water filtered in each sample. The samples were preserved with 10% formalin. Larval fish were identified to the lowest practicable taxon and total length was measured to the nearest millimeter. All fishes with the exception of pomoxids, were considered ichthyoplankton if their total length was ≤ 21 mm. Fishes having a total length >21 mm had developed adult characteristics and were considered juveniles. Pomoxids having a total length ≥ 16 mm were considered juveniles, as adult characteristics were then present.

In 1974 and 1975, larval fish tows were made at both shoreline and channel areas of Locations 1.0, 6.0, and 10.0, and at the shoreline area of Location 4.0 (Table 10-1). During 1974, samples were taken once every two weeks with weekly collections made during periods of peak abundance. All samples taken before 30 May 1974 were collected during daylight hours; collections after this date were taken at night. Seining was also used to collect ichthyoplankton during 1974 (App. Table 10.8-11), but proved inefficient and was discontinued. During 1975, larval tows were made weekly from February through September. In addition, diel samples were collected during April, May, and July 1975, at the shoreline area of Location 3.0 and the channel area of Location 4.0. Duplicate 10-min tows were made at surface, 5, 10, and 15-m depths. During 1975, approximately weekly collections were also taken at Locations 14.0, 14.7, 15.2, 15.5, and 45.5 (Fig. 1-10) in the vicinity of Marshall Steam Station and at Locations 25.0, 65.0, 72.0, and 80.0 (Fig. 1-10) below Lookout Shoals Dam. A 0.5-m conical net with 560- μ m nitex mesh was used at Location 25.0 because of the shallow depth.

In 1976, larval fish tows were made at the shoreline and channel areas of Locations 1.0, 6.0, and 8.0, but only at the shoreline area of Location 4.0 (Table 10-1). Additionally, during April and May 1976, SCUBA divers documented centrarchid spawning at shoreline areas of Locations 1.0, 4.0, and 8.0 (App. Table 10.8-12). Two divers swam parallel to the shoreline locating and counting nests at the four 150-m electrofishing sections at each location. One diver searched the 0 to 1.5-m depth interval and the other diver the 1.6 to 3.0-m depth interval.

From 1977 through 1980, larval fish tows were made at shoreline and channel areas of Locations 1.0, 4.0, 6.0, and 8.0 (Table 10-1). The channel area at Location 4.0 was added to create a balanced sampling design and to better describe the relative abundance and distribution of ichthyoplankton in the vicinity of the McGuire Nuclear Station discharge. Also during these years, duplicate 10-min tows were made at surface, 2.5, 5.0, 7.5, 10.0, 12.5, and 15.0-m depths at the channel area of Location 4.0 to determine the vertical distribution of larval fish. In 1977, vertical distribution samples were collected monthly from April through August. Because mostly juvenile fish were collected after June 1977, vertical distribution samples were collected only April, May, and June of succeeding years.

A Hydrolab Model TDO-2 was calibrated and used to measure the water temperature and dissolved oxygen concentration at all locations on each sampling date. The surface water temperature and dissolved oxygen concentration were measured at surface (0.3 m) and 1-m depth intervals of the channel areas and at three points along the trawling path at all shoreline areas. The water temperature and the dissolved oxygen concentration in channel areas were measured to a depth of 5 m in 1974, 7 m in 1975, and 15 m from 1976 through 1980. The depth changes were instituted to document possible changes in ichthyoplankton abundance and distribution that might be correlated with water temperature and dissolved oxygen concentration.

Photoperiod and lake level were recorded for each sampling date. The photoperiod was calculated from the sunrise and sunset chart prepared for Charlotte, North Carolina, by the National Weather Service Office (1965). The lake level was obtained from Duke Power Company's Operations Department. All ichthyoplankton data are included in Appendix 10.0.

Split-plot analysis of variance (Sokal and Rohlf 1969; Helwig and Council 1979) was used to compare abundance of ichthyoplankton by species among sample dates, and to compare shoreline and channel areas of locations. Due to the short spawning period of fish and changes in sampling locations during the early years of the study, analyses were restricted to the peak months of larval fish occurrence during 1977, 1978, and 1979.

Spawning periods were estimated by counting back a calculated number of days from the dates of the first and last collections of larval fish less than or equal to 8 mm total length. Based on the number of incubation days for a given taxon (Hardy 1978) and assuming a growth rate of 1 mm per day, a one week period was determined for back calculating estimated spawning dates of clupeids, lepomids and pomoxids. For percids, a three week period was used in calculating initiation of spawning and a one week period for determining cessation of spawning.

RESULTS AND DISCUSSION

ADULT AND JUVENILE FISHES

SELECTIVITY

Electrofishing, gill netting, midwater trawling, and rotenone sampling were used to estimate species composition and abundance of fishes. Since catches

using these techniques require different units of measurement, they are not directly comparable. None of these methods provides unbiased estimates for all sizes of a fish species, because physical and behavioral characteristics of a species vary with size. Likewise, no technique was equally effective in sampling a large number of species; therefore, each method serves to define a portion of the fish community. The assumption necessary to interpret the results of these methods is that changes in catch rates reflect changes in the abundance of fish populations or the composition of the fish community.

Electrofishing is an effective and widely used means of sampling fishes. In this study, electrofishing was used for sampling fishes inhabiting areas less than 2-m deep. When comparing electrofishing catches over a period of time and at various locations as in this study, gear selectivity cannot be overlooked. Novotny and Priegel (1974) listed the following factors that affect electrofishing catches: conductivity, clarity, depth, and temperature of the water, size and species of fish, electrofishing boat speed, experience of the electrofishing crew, time of day, and season of the year.

Gill netting is a passive form of sampling, and catches are dependent on fish activity (Lambou 1962; Moyle and Lound 1960). Variables, such as light conditions, barometric pressure, turbidity, water temperature, and water level fluctuations influence fish activity (Berst 1961). The selectivity of nets also varies temporally with the distribution, behavior, and condition of fish (Hamley 1975). In our study, gill nets caught fishes moving near the bottom and within 27 m of the shore. Interpretation of gill net results is a major problem, because it is impossible to partition the catch into that reflected by changes in abundance, activity, and selectivity.

Midwater trawling was used to sample fishes inhabiting the limnetic areas of Lake Norman. Selectivity of the trawl varies with trawling speed and swim speed of fish, which varies with water temperature. Trawling was most effective in sampling young-of-the-year threadfin shad and was generally ineffective for other limnetic species.

Rotenone is the least selective technique used in our sampling program. Rotenone samples are often considered complete censuses; however, fish inhabiting coves are seldom if ever completely collected following the application of rotenone (Krumholz 1950). Certain biases are unavoidable, such as the inherent bias due to predation on dying fish by larger, more predacious species. Thus, the weight of the predator may be enhanced at the expense of the prey species (Krumholz 1950). When using cove rotenone samples to represent the true abundance and species composition in the entire reservoir, young fish are overestimated and harvestable fish are underestimated (Hayne et al. 1967). Because rotenone samples are taken once annually, temporal and statistical variation of results are not estimated. This makes results for schooling species difficult to interpret, since these fishes may occur in cove samples by chance.

FISH COMMUNITY

From August 1973 through December 1980 Duke Power Company collected 40 of the 48 species of fishes reported from Lake Norman, North Carolina (Table 10-2). Two species were associated with changes in classification. Notropis

analostanus chloristius, previously reported from the Catawba River drainage (Gibbs 1963), was considered by Bailey et al. (1970) to be N. chloristius. Etheostoma olmstedii has been removed from synonymy with E. nigrum (Cole 1967) and both were reported in the Catawba River drainage. Reports of E. nigrum were probably E. olmstedii; reports of N. analostanus were probably N. chloristius. Because N. analostanus was reported from samples associated with this study, we now assent to only 39 species from Duke Power Company collections. The disparity among species lists of other investigators and this study may be related to habitat changes due to inundation when Lake Norman was filling, gear selectivity, and misidentification. None of the 48 species reported from Lake Norman is classified as rare, endangered, or threatened according to Deacon et al. (1979). Eleven of these Lake Norman fishes are classified as sport fish by North Carolina Wildlife Resources Commission (1979).

Because of the magnitude of interspecific selection of electrofishing gear and gill nets, rotenone samples gave better estimates of community composition. Samples from 1.2 ha coves were less variable and included more species than 0.4 ha rotenone samples; therefore, the larger coves were more useful for examining composition, but data collected from both were analyzed in this report.

Considerable variability in species composition of rotenone samples was observed among locations within Lake Norman. Some variability was undoubtedly due to the physical characteristics of the coves while some was probably related to physical differences between uplake and downlake areas (i.e., water depth, turbidity, and shoreline development). For example, the composition of the ictalurid crop varied among uplake and downlake locations with midlake Location 19.0 having species characteristic of both areas (Table 10-3). Ictalurid crops composed 9.2% of the uplake total but only 2.7% of the downlake total (Table 10-4). Catostomids were more common uplake and comprised 10.7% of the total standing crop at Location 68.0 and 2.6% of the average downlake crop. Downlake Location 6.0 and uplake Location 19.0, two shallow sandy coves that were physically similar, had similar total standing crops and composition varied little except for carp and threadfin shad (Table 10-3). Locations 4.0 and 14.7, the discharge coves at McGuire and Marshall, respectively, had similar total standing crops, but the composition of the coves was markedly dissimilar. Location 14.7 had the highest crop of largemouth bass and crappie, while Location 4.0 had the lowest crop of bass and a below average crop of crappie. Location 4.0 had by far the highest crops of gizzard shad and yellow perch (Table 10-3). Location 14.7 had a much lower standing crop of redbreast sunfish than other locations.

The fish community of Lake Norman was roughly similar to those of Lakes Hartwell and Clark Hill, South Carolina (Table 10-4). Lakes Hartwell and Clark Hill had higher crops of sunfish and lower crops of gizzard shad, catostomids, and carp than Lake Norman. Variation in composition was more apparent within Lake Norman locations than among Lakes Hartwell and Clark Hill. The major differences between Lake Keowee, South Carolina, and Lake Norman were the high proportion of the Lake Keowee crop that was carp and the absence of gizzard shad in the lake. Furthermore, Lake Keowee had much lower standing crops of all species other than carp. Lake Wylie, a Catawba River reservoir downstream from Lake Norman, had much higher standing crops than Lake Norman for almost all species. Lake Wylie had proportionally higher crops of threadfin shad, ictalurids, and catostomids, but a lower standing crop of carp than Lake Norman (Table 10-4).

TOTAL STANDING CROP

Total standing crops of Lake Norman fishes were similar at uplake and downlake locations and averaged 128 kg/ha downlake and 125 kg/ha uplake (Table 10-4). Variability in total standing crops within uplake and downlake locations was apparent and generally more pronounced than the variation between the average crops of the two areas. Total standing crops at Location 4.0 were generally higher than other downlake locations during 1978 and 1979 when test pumping of the McGuire condenser cooling water system was occurring. Prior to test pumping, Location 4.0 standing crops were commonly lower than other locations (Fig. 10-1), suggesting at least a portion of the increase in the standing crop at Location 4.0 could be attributed to the attraction of fish to the flowing water from McGuire. Of the uplake locations, Location 14.7 had the highest crops followed by Locations 68.0 and 19.0. Variability in standing crops at all locations was associated with the abundance of gizzard shad, carp, and in some cases, schooling species such as threadfin shad or white bass.

For the most part, the total standing crop of harvestable sport fish (as defined in Fig. 10-1) appeared low at all locations (Fig. 10-1). For the 1.2 ha locations, Location 14.7 during 1978 and Locations 4.0, 8.5, and 14.7 during 1979 exhibited relatively high harvestable sport fish crops. The primary components of the sport fish crop at Location 14.7 were largemouth bass and black crappie. High catches of white bass at Locations 4.0 and 8.5 during 1979 accounted for over 50% of the harvestable sport fish.

The total standing crop of Lake Norman fishes was comparable with those of other Carolina reservoirs. Lake Norman standing crops were similar to Lakes Clark Hill and Hartwell and twice the standing crop of Lake Keowee (Table 10-4). Lake Wylie had much higher standing crops than Lake Norman and other cited reservoirs.

FISH POPULATIONS

Clupeids

Clupeids represented a major portion of the Lake Norman fish community. Gizzard shad comprised the major portion of the biomass in littoral areas while threadfin shad dominated the biomass in limnetic areas. Both clupeids are important prey species in southern reservoirs; however, gizzard shad collections in Lake Norman were dominated by individuals too large to be utilized as prey by most piscivorous fishes.

Gizzard shad standing crops were extremely variable, ranging from 0 to 180.5 kg/ha. The contagious distribution of gizzard shad standing crop estimates (Fig. 10-2) indicates their chance occurrence in rotenone samples. Additionally, annual trends in gizzard shad standing crop estimates based on rotenone sampling varied directly with the area of the sample coves which was dependent on the lake elevation. For example, low estimates in 1976 and 1977 and high estimates in 1973 coincided with low and high water levels, respectively. Annual variation in total gill net catches (Fig. 10-3) of gizzard shad was less than the variation observed in rotenone samples, and abundance estimates using gill nets did not parallel rotenone standing crop estimates. Gizzard shad were rarely collected using electrofishing gear (Fig. 10-4).

The additional area rotenoned in 1978 (approximately 0.8 ha) was expected to reduce the influence of water level changes on standing crop estimates and provide more reliable estimates of population trends and better comparisons among locations. Based on the larger rotenone cove size in 1978 and 1979, Locations 4.0 and 14.7 had the highest standing crops of gizzard shad from downlake and uplake locations, respectively. Gizzard shad standing crops were generally similar (considering the extreme variability in catches) between uplake and downlake locations with standing crops averaging 39 kg/ha uplake and 58 kg/ha downlake (the downlake average includes an unusually high estimate, 151 kg/ha, at Location 4.0 during 1978). Differences among locations were more apparent from gill net catches. Gill net catches of gizzard shad were higher at uplake locations than at downlake locations, mainly due to high catches at Location 14.7 and to a lesser degree at Location 13.0. Location 14.7 and adjacent Location 14.5 were the only locations where an appreciable number of gizzard shad was collected using electrofishing gear.

Activity of gizzard shad appeared to govern temporal variation in gill net catches. Catches were closely associated with water temperature. An exception occurred during May when catches were highest and apparently associated with spawning activity. Gizzard shad were rarely collected during January and February when water temperatures were low. One obvious contrariety was Location 14.7 in the Marshall discharge cove where gill net catches remained high throughout the year and increased to the highest rate in January when differences in water temperatures among locations were most apparent. The warmer water temperatures at Location 14.7 during January were associated with the high catches, but catches remained high in July when the discharge temperature at Marshall was equivalent to or less than other locations (Appendix 10.9). During this period, water current was one of the major differences among locations and probably attracted gizzard shad to the Marshall discharge. Water current, resulting from intake pump testing at McGuire Nuclear Station, was also present at Location 4.0. Although this had no effect on gill net catches, which remained generally similar from 1974 through 1979, the standing crop estimates of gizzard shad at Location 4.0 increased relative to other locations after initiation of pumping.

Threadfin shad is an important prey species for most Lake Norman sport fish. Other than in midwater trawl sampling, threadfin shad biomass rarely exceeded that of gizzard shad, which would be expected due to the limnetic habits of threadfin shad. Based on rotenone samples, threadfin shad standing crops were generally less than 5 kg/ha, and except for three extreme observations, varied little among locations and years (Fig. 10-2). Location 6.0 had extremely high standing crops during 1973 and 1974 including the maximum standing crop recorded for a single species (232.5 kg/ha in 1974), but since 1976, estimates at Location 6.0 have ranged from 0 to 0.003 kg/ha. The additional area sampled during 1978 and 1979 resulted in an increase in threadfin shad standing crop estimates at all locations except Location 6.0. Uplake and downlake differences were not readily apparent except at Location 19.0 during 1979 which had standing crops much higher than other coves. Although threadfin shad were uncommon in electrofishing samples, uplake Locations 14.5 and 14.7 had high density estimates, and threadfin shad comprised over 35% of the electrofishing catch at these locations. The major portion of this catch occurred during winter when threadfin shad were attracted to the warm water and possibly the flow of the Marshall discharge.

Threadfin shad dominated the midwater trawl catches. They were most abundant during summer and fall, and catches were dominated by age 0 fish. Densities were lowest in April prior to spawning. This was indicative of the nature of the age structure of the population which is for the most part dominated by the youngest age class.

Jenkins (1972) predicted the Lake Norman clupeid crop to be 61.7 kg/ha and our estimates, based on rotenone samples, were 53.9 kg/ha for all locations, 47.2 kg/ha for uplake locations, and 60.6 kg/ha for downlake locations. Considering clupeids less than 140 mm as the portion available as prey (based on equations from Jenkins and Morais 1977) for the average size of largemouth bass creel by Lake Norman fishermen (330 mm), Lake Norman's clupeid prey crop averaged 6.0 kg/ha, 11% of the average total clupeid crop. Of this, 92.7% was threadfin shad. Uplake locations averaged 5.3 kg/ha of clupeids available as prey to a 330-mm largemouth bass, as compared to the downlake average of 2.7 kg/ha. Although the average clupeid crop is higher downlake, the uplake crop is of a more acceptable size (Fig. 10-5) for the average size class of largemouth bass creel by Lake Norman sport fishermen (Appendix 10.1).

Cyprinids

Seven cyprinids (excluding *Notropis analostanus* which does not occur in Lake Norman) were represented in Lake Norman collections during the study period (Table 10-2). Carp, whitefin shiner, and greenfin shiner were the only cyprinids that contributed substantially to the total catch by numbers or weight.

Carp comprised 5% of the Lake Norman sport fish harvest, and 1.3% of the fishermen surveyed indicated a preference for this species (Appendix 10.1). In rotenone samples, carp biomass averaged 15.5 kg/ha from downlake 0.4 ha cover and generally ranked second to gizzard shad; however, a few large individuals accounted for the high biomass. Young carp were never collected during this study. Standing crop estimates were variable (Fig. 10-2) and population trends were not apparent. Uplake 1.2 ha crops averaged 26.7 kg/ha and were similar to those from 1.2 ha downlake locations. Location 4.0 supported the lowest carp biomass of the downlake 1.2 ha locations as did Location 19.0 for uplake locations. Carp were rarely collected with electrofishing gear (Fig. 10-4) except at Location 16.0, a lotic location on Mountain Island Lake. Carp comprised approximately 5% of gill net catches both uplake and downlake.

Whitefin and greenfin shiners were abundant in electrofishing samples and common in rotenone samples; however, they comprised less than 3 kg/ha of the total biomass of coves. Their standing crops were less variable than other species (Fig. 10-2) but abundance estimates based on electrofishing catches were the most variable (Fig. 10-4). Electrofishing catches were variable among locations and years, but a general decrease in abundance of these cyprinids was observed at Location 6.5/6.0 during 1974 through 1979. A similar decrease was also apparent in cyprinid standing crop estimates at this location. Uplake and downlake locations were generally similar for electrofishing and rotenone catches with the exception of rotenone Location 68.0 which had lower standing crops of cyprinids other than carp and a general absence of greenfin, whitefin, and spottail shiners. Golden shiners were the dominant shiner but occurred in relatively low numbers. At other locations, whitefin shiners

were usually more abundant than greenfin shiners. Cyprinids other than carp were found in stomach contents of catfish, sunfish, largemouth bass, white bass, striped bass, and yellow perch (Duke Power Company unpublished data).

Catostomids

Suckers contributed little to the Lake Norman fishery (Appendix 10.1), as they were rarely caught by fishermen and their size was too large to be utilized as prey. Eight species of suckers were collected from Lake Norman during the study period. Suckers were more common at uplake gill net and rotenone locations than downlake. When spawning, suckers were concentrated in the tailwaters below Lookout Shoals Lake. Quillbacks were the most abundant catostomid collected in gill nets and in downlake rotenone samples, but the shorthead redhorse was more common in uplake rotenone samples. Catostomids rarely occurred in electrofishing samples.

Of the eight species of catostomids collected, quillbacks were the only one collected in numbers large enough to examine population trends and differences in abundance among locations. Quillbacks apparently increased in abundance in Lake Norman to the point of being the dominant species collected in gill nets during the latter part of this study. Mean catches of quillbacks were relatively low (0.3 fish/gill net set) during 1974 but increased steadily through 1979 (1.4 fish/gill net set). Increases in mean catches were most apparent at Location 6.5/6.0. Catches were variable (Fig. 10-3) and differences between uplake and downlake locations were not apparent. Higher catches of quillbacks generally occurred at uplake Location 19.0 and downlake Locations 5.0 and 6.0. Highest catches usually occurred in April while catches were low in January and February.

Quillbacks were rarely collected in 0.4 ha rotenone coves (Fig. 10-2) and made up less than 0.1% numerically of the composition of 1.2 ha rotenone coves. Their abundance in Lake Norman as indicated by gill net catches was high.

Ictalurids

Ictalurids support a commercial fishery and a small sport fishery on Lake Norman. Total commercial catfish harvest was 24,008 kg in 1975 and 12,919 kg in 1976 (North Carolina Wildlife Resources Commission 1977) while the annual sport fish harvest for catfish was 2511 kg (Appendix 10.1). Of the sport fishermen surveyed, only 2.8% indicated a preference for catfish.

Ictalurids occurred in most gill net and rotenone samples, but catch rates were low (Fig. 10-2 and 10-3) and sampling variability appeared greater than the variability among locations and years. Ictalurids were uncommon in electrofishing samples (Fig. 10-4). Ictalurids were more abundant at uplake 1.2 ha locations (mean = 11.4 kg/ha) than at downlake 1.2 ha locations (mean = 3.4 kg/ha). Uplake Location 14.7 supported the highest average ictalurid crop (14.6 kg/ha) while downlake Location 4.0 supported the lowest (1.6 kg/ha). Higher uplake standing crops of ictalurids were also evident from angler harvest (Appendix 10.1).

Ictalurid crops of downlake locations were composed predominately of snail bullheads, flat bullheads, and white catfish. White catfish, channel catfish, and

flathead catfish were the major components of the uplake ictalurid crops (Fig. 10-6). Snail bullheads were not collected at Locations 14.7 and 68.0 where channel and flathead catfish were abundant. Flathead catfish were not collected at downlake locations and only one channel catfish was collected downlake. Location 19.0, situated roughly midway between Locations 8.5 and 14.7 (Fig. 1-10) had species of ictalurids characteristic of downlake locations and the uppermost uplake locations. With the exception of two large flathead catfish, which accounted for 95% of the ictalurid standing crop during 1979, Location 19.0 ictalurid crops were much lower than Locations 14.7 and 68.0. The difference in ictalurid composition between uplake and downlake may be related to spawning requirements of the species. The uplake areas were situated more closely to the Catawba River channel, and upper Lake Norman is more dendritic, more turbid, and generally shallower than the lower lake. Although spawning requirements for many ictalurids are not well documented, some catfish have strict habitat requirements. For example, channel catfish normally will not reproduce in clear ponds or lakes unless spawning enclosures are added (Marzolf 1957); however, channel catfish nests have been constructed in open water in extremely turbid hatchery ponds (Geibel and Murray 1961).

Percichthyids

White and striped bass were very important sport fish as they comprised 29% of the Lake Norman annual sport fish harvest. Striped bass harvest totaled 12,652 kg and white bass totaled 5,916 kg (Appendix 10.1). Of the fishermen surveyed, 18% fished for striped bass and 6% fished for white bass (Appendix 10.1). White bass reproduce successfully in Lake Norman, whereas the striped bass fishery is dependent on annual stockings of approximately 100,000 2-to 5-cm fingerlings.

The abundance of percichthyids was not reflected in any of the collection techniques used because these species are generally pelagic (Cross 1967; Jenkins 1970). White bass were rare in electrofishing collections at all locations except Locations 14.5 and 14.7 in the Marshall discharge cove. Similarly, white and striped bass were more abundant in gill net collections at Location 14.7 than at other locations. Both were also a major component of the sport fish harvest at the Marshall discharge (Appendix 10.1). White bass were consistently collected in 1.2 ha rotenone samples at all locations but striped bass were not. White bass standing crops were notably higher at Location 4.0 and 8.5 than other locations while Location 68.0 had the lowest standing crops.

Centrarchids

Eight species of centrarchids were collected in the sampling program (Table 10-2). Three genera, Lepomis (sunfish), Micropterus (bass), and Pomoxis (crappie), were represented and each will be discussed separately.

Sunfish

Five sunfish species were collected from Lake Norman; however, bluegill and redbreast sunfish dominated the catches. Warmouth and sunfish hybrids were

collected consistently but their numbers were insignificant compared to bluegill and redbreast sunfish. None of the sunfish was important in the total sport fish harvest, as their slow growth and resulting small size (Appendix 10.2) made them unacceptable to fishermen. Of the fishermen interviewed, none indicated a preference for sunfish, and the annual sunfish harvest was estimated as only 1,269 kg or 2% of the total harvest (Appendix 10.1). On the other hand, sunfish were valuable prey for largemouth bass (Appendix 10.3).

Bluegill and redbreast sunfish were common in electrofishing and rotenone samples. Electrofishing samples indicated roughly similar abundance estimates for these species, but rotenone standing crop estimates for bluegill were considerably higher than for redbreast sunfish. This disparity between electrofishing and rotenone samples was probably due to redbreast sunfish being distributed more commonly near shore in areas with little cover where electrofishing was more efficient. Bluegill were generally more abundant in slightly deeper water with dense cover. On the other hand, misidentification of young-of-the-year sunfish, especially during second day rotenone sampling, may account for some differences. Rotenone standing crop estimates were much less variable than electrofishing density estimates (Fig. 10-2 and 10-4); therefore, rotenone sampling was considered a more precise estimator of abundance. Variability in electrofishing catches of sunfish was such that consistent differences among locations and years could not be detected. Rotenone standing crop estimates of redbreast sunfish were fairly stable at downlake locations from 1974 through 1979 with Location 6.0 having consistently higher standing crops than Location 4.0 or 10.0/8.5, which were generally similar. Bluegill crops, on the other hand, were more variable among years with Location 10.0/8.5 having the highest standing crops of downlake locations followed by Location 6.0 and 4.0, respectively. Bluegill standing crops and electrofishing catches were generally similar between uplake and downlake locations. Redbreast sunfish standing crop and electrofishing catch rates downlake were higher than uplake. Location 14.7 had the lowest redbreast sunfish standing crop and abundance estimates of any location.

Largemouth bass

Largemouth bass is the most important sport fish in Lake Norman with the annual harvest estimated at 20,786 kg or 32% of the total harvest. Of the Lake Norman fishermen surveyed, 40% were fishing for largemouth bass (Appendix 10.1). A creel size limit has always been in effect on Lake Norman largemouth bass and has varied between 254 and 305 mm. Since 1974, a creel limit of 8 fish greater than 305 mm has been in effect. More than 60% of the bass harvested were at or just above legal size (Appendix 10.1).

Electrofishing abundance estimates were more variable than 0.4 ha rotenone standing crop estimates (Fig. 10-2 and 10-4). Electrofishing catches were variable among downlake locations and years with consistent differences undetectable. Based on 0.4 ha rotenone samples, Location 6.0 had the highest standing crops of bass except during 1976 and 1977, when sample area and water depth in coves were reduced because of low lake levels. In these years, Location 4.0, the deepest of the 0.4 ha coves, had the highest standing crops of bass. Bass standing crop estimates based on 1.2 ha downlake samples were slightly higher at Location 8.5 followed by Location 6.0 and 4.0, respectively. Other than

Location 14.7, bass crops were generally similar among uplake and downlake locations. The total bass crop at Location 14.7 was much higher than those of other locations, as was the harvestable bass crop (greater than 305 mm) (Fig. 10-7). Similarly, largemouth bass catches using electrofishing gear were also higher at Locations 14.5 and 14.7. Electrofishing catches of bass were higher during March, April, and May when bass were spawning and more abundant in shoreline areas.

Crappie

Both black and white crappie were represented in collections, but black crappie were far more abundant. Crappie comprised 27% of the total fishermen harvest with an estimated annual harvest of 17,292 kg. Of the fishermen surveyed, 20% were fishing for crappie (Appendix 10.1).

Crappie occurred sporadically in gill net, electrofishing, and rotenone catches. Gill net and electrofishing catches generally occurred in spring when crappie were near shore spawning; however, relatively high catches occurred consistently in October at Location 1.2. Rotenone collections of crappie in 0.4 ha coves were generally dependent on the presence of dense cover in the deep portions of the coves. Standing crops of crappie in 1.2 ha coves were also enhanced by abundant cover, but Location 14.7 in the Marshall discharge cove, which had comparably little cover, had by far the highest standing crops of crappie. Location 6.0, the shallowest cove, always had the lowest standing crops of crappie.

Percids

In our collections, percids were represented by two genera and three species: yellow perch, tessellated darter, and swamp darter (Table 10-2). None is a valuable sport fish. Although yellow perch did occur in the creel, their annual harvest was only 27 kg (Appendix 10.1). Yellow perch fisheries in the South are rare, since most yellow perch are too small to be of interest to fishermen (Hackney and Holbrook 1978). No Lake Norman fishermen indicated a preference for yellow perch (Appendix 10.1), and those yellow perch creeled were taken incidentally. Percids were important prey for sport fish.

Darters were uncommon in electrofishing samples but did occur in rotenone samples, although they were insignificant in the total catch by numbers and weight. Yellow perch were common in electrofishing and rotenone samples, but standing crop estimates were usually less than 5 kg/ha. Perch standing crops varied little among locations and years (Fig. 10-2) except Location 4.0 during 1979 which had an unusually high standing crop (36.3 kg/ha), possibly associated with test pumping at McGuire. Locations 6.0 and 19.0, two shallow, sandy coves, had the lowest perch crops. Excluding downlake Location 4.0, standing crops of perch averaged slightly higher uplake (3.8 kg/ha) than downlake (2.8 kg/ha).

Two major concentrations of perch were documented in Lake Norman during early spring in the Marshall discharge canal and in the tailwaters below Lookout Shoals Dam. High concentrations were associated with spawning as the gonads of perch collected were in an advanced stage of development. Ney (1976) indicated that yellow perch have both lotic and lentic spawning populations.

In Lake Norman, both types occurred, and results of larval sampling indicate that larval percids were more abundant in the lentic waters of lower Lake Norman than at Marshall discharge or the tailwaters of Lookout Shoals Dam. Sampling problems associated with sampling the two types of areas may account for the differences in larval fish abundance.

ICHTHYOPLANKTON

SELECTIVITY

As with the adult fishes, gear selectivity was recognized as a source of bias in collecting ichthyoplankton. During 1974, fewer ichthyoplankton were collected during the day than night, indicating net avoidance during the day. Thus, all samples thereafter were collected at night. Contamination of ichthyoplankton from undesired depths when the net was deployed and retrieved was possible. Approximately 10 to 15% of the towing time was used in deploying and retrieving the net when sampling at 5 m. Graser (1977) pointed out that net avoidance by larger ichthyoplankton, as well as avoidance due to propeller wash and turbulence from the net bridle, can bias results. Larvae of shoreline nest building species (e.g., largemouth bass) were not adequately sampled as they were closely associated with the bottom and with cover.

TAXONOMIC COMPOSITION

Fourteen taxa of ichthyoplankton were collected from 1974 through 1980 (Table 10-5). Four of the 14 taxa composed approximately 98% of ichthyoplankton sampled for any location, sublocation, or year (Table 10-6). Clupeids dominated the ichthyoplankton composition of all downlake locations followed by either pomoxids or percids and then lepomids. During 1975, clupeids also dominated the ichthyoplankton composition at locations near Marshall Steam Station followed by lepomids, percids, and pomoxids, respectively (Appendix 10.9). Ichthyoplankton composition in the headwaters of Lake Norman (lotic habitat) was different among locations sampled during 1975. Clupeids dominated the composition (98.6%) at Location 25.0 on Lyles Creek while percids dominated the composition at Locations 65.0, 72.0, and 80.0 (Catawba River channel), composing 52.6, 68.6, and 47.7%, respectively. Clupeids composed between 23.8 and 40.7% of the composition at these three locations.

The most striking variation in ichthyoplankton composition at downlake locations occurred in 1978 when the number of clupeids was lowest of any year and that of lepomids, pomoxids, and percids was generally highest (Table 10-6). The exact reason for this variation is unknown, but peculiarities in zooplankton densities in the limnetic area of Lake Norman were noted in 1978 (Chapter 8). Food availability may have contributed to the change in ichthyoplankton composition.

The composition of the ichthyoplankton community varied between shoreline and channel areas. More clupeids and percids were generally collected in channel areas and more lepomids and pomoxids were generally greater in shoreline areas (Table 10-6). The differences in ichthyoplankton composition between shoreline and channel areas obviously involves behavioral aspects of ichthyoplankton of the four taxa, since adults of these taxa spawn near shore (Burns 1966; Jester and Jensen 1972). Dispersal of larval clupeids from inshore spawning areas, coupled with the fact

that gizzard and threadfin shad spawn in limnetic areas, as well as shoreline areas (Burns 1966; Jester and Jensen 1972), explains the presence of clupeids in the channel locations. Dispersal of leptomids, pomoxids, and percids to limnetic areas has been documented in other studies (Appendix 10.9; Taber 1969; Werner 1969; Waybrant and Shauver 1979).

ABUNDANCE AND DISTRIBUTION

For each taxon studied, considerable variation in ichthyoplankton densities among sample dates, shoreline and channel areas of locations, and years was apparent. This variation was emphasized by the statistical interaction within and among sampling dates, shoreline and channel areas of locations, and years during the peak months of abundance of 1977, 1978, and 1979 (App. Table 10.8-2 through 5).

Clupeids

Clupeids appeared in ichthyoplankton samples from April through August of each year with peak abundances occurring in May and June (App. Fig. 10.8-1). During 1975, time of occurrence and time of peak abundance of uplake and downlake locations was similar, even though two of the uplake locations received heated effluent (Appendix 10.9). Apparently, the higher water temperatures from October through March at the Marshall discharge locations (Chapter 2) did not alter the spawning period of clupeids. Clupeid densities at uplake locations were higher than densities at downlake locations.

Habitat differences among locations probably accounted for some of the variation in clupeid densities. High densities of clupeids occurred at shoreline and channel areas of Location 6.0 throughout the study and Location 10.0 when it was sampled during 1974 and 1975 (Fig. 10-8). Clupeid densities at other locations showed no distinguishable patterns among years; however, habitat differences were evident among locations. Shoreline areas of Locations 6.0 and 10.0 were characterized by gradual sloping clay and sandy banks, Locations 4.0 and 8.0 by moderately steep clay banks, and Location 1.0 by a steep riprap bank. High densities of clupeids were also noted at the shallowest uplake location (Location 15.2) during 1975 (Appendix 10.9). Jester and Jensen (1972) reported that greatest spawning of gizzard shad occurred at a depth of 0.3 to 1.6 m. Threadfin shad have also been observed spawning near shore (Burns 1966). Thus, differences in shoreline area habitat may help explain some of the observed locational differences.

Distribution differences of larval clupeids were apparent throughout the collection period of each year. At all locations except Location 1.0, clupeid densities were highest at the shoreline areas during April and May of each year, but were followed closely by densities at the surface of channel areas. At Location 1.0 during April and May of each year, densities of larval clupeids appeared similar among shoreline and channel areas. Since the steep shoreline area of Location 1.0 was more typical of a limnetic area than a littoral area, the difference in distribution could be related to habitat. During June and July of each year, densities of clupeids collected at the 5-m depth of channel areas were usually similar to the densities in the surface of shoreline and channel areas. During August of each year, densities varied among shoreline and channel areas. No shift in concentration of clupeids from shoreline to channel areas was observed at uplake locations during 1975 (Appendix 10.9).

The changes in distribution throughout each year were probably related not only to the spawning of both gizzard and threadfin shad, but also to the growth and behavior of clupeids. Juvenile gizzard and threadfin shad were identified in collections from May through September of 1977, 1978, and 1979 (Table 10-7). During 1977 highest densities of juvenile gizzard shad occurred earlier than those of threadfin shad, indicating that possibly gizzard shad spawned first or grew faster and were recruited into the collection earlier. However, no relationship was observed between collections of larval clupeid densities and young-of-year recruitment of threadfin shad from rotenone samples (Fig. 10-8). Low densities of threadfin shad were observed in 1978 and no gizzard shad were collected in 1979. Gizzard shad spawned earlier than threadfin shad in Lake Texoma, Oklahoma, but no difference in growth rates of larval stages of the two species was observed (Shelton 1972). During 1977 and 1978, gizzard and threadfin shad densities were highest in Lake Norman at the channel areas, particularly the 5-m depth (Table 10-7). During 1975, Edwards et al. (1977) noted densities of clupeids of 20-mm total length or greater at Location 1.0 on Lake Norman increased at the surface and 5-m depth of the channel area after June 18. During diel sampling in May 1975, most larval clupeids were collected above 5 m (Table 10-8), which was the depth of the thermocline. Lewis and Siler (1980) noted that larval and juvenile clupeids collected during vertical distribution studies in Lake Norman were highest at or near the thermocline from May through August 1977 and had a mean total length of 15 mm or greater. Netsch et al. (1971) also noted a fairly consistent pattern of highest numbers of young gizzard shad at the 5-m depth, which was the approximate upper limit of the "thermocline" in Beaver Reservoir, Arkansas. Thus, changes in distribution and variation in densities of clupeids may be related to growth and behavioral response to environmental conditions.

The estimated spawning period for clupeids varied among years (Table 10-9); however, factors which could potentially explain this variation, such as water temperature, dissolved oxygen concentration, photoperiod, and lake level did not appear to vary greatly among years (Table 10-9; App. Table 10.8-6). Extended spawning periods and/or multiple spawns as indicated by the prolonged collection of larval clupeids of 5 to 8 mm total length (App. Table 10.8-7) may have contributed to the variation among spawning periods for total clupeids (Table 10-9). Both extended and multiple spawning may occur in Lake Norman, as Miller (1960) and Bodola (1966) reported gizzard and threadfin shad spawning at temperatures of 18°C and above, and 10 to 21°C, respectively. Additionally, Miller (1960) and Johnson (1969) reported two spawnings of gizzard and threadfin shad in the same year.

Lepomids

Lepomids were collected from May through August at all downlake locations with densities varying among locations (App. Fig. 10.8-2). Time of occurrence of lepomid larvae at uplake locations during 1975 was similar to that of downlake locations. Densities were slightly higher at locations near Marshall Steam Station (Appendix 10.9). The variation in lepomid densities among locations during each year was probably related to the overlap of spawning periods of several lepomid species, because larvae could be identified only to genus. The spawning periods of the three most abundant lepomid species in Lake Norman (red-breast sunfish, warmouth, and bluegill) not only overlap, but older, larger female bluegill spawn earlier than younger females (Hardy 1978).

Lepomid densities in shoreline areas were usually higher than in channel areas, which were similar among locations (App. Fig. 10.8-2). During 1975, higher densities of lepomids at locations near Marshall Steam Station were also observed in shoreline areas rather than in channel areas, and shoreline densities there were higher than those observed at downlake locations (Appendix 10.9). However, at Marshall and downlake locations rapid dispersal was indicated by the collection of lepomid larvae during May of each year at channel and shoreline areas. Werner (1969) also observed movement of larval lepomids from the littoral to limnetic areas in Crane Lake, Indiana, shortly after yolk-sac absorption. Considerable variation in densities of lepomids in shoreline areas was evident among locations.

The highest densities of lepomids occurred at the shoreline areas of Locations 4.0 and 8.0 in 1978 and Location 4.0 in 1979 (Fig. 10-9). Condenser cooling water discharges from McGuire during test pumping may have contributed to the higher densities at Location 4.0 during 1978 and 1979. The flow of water may have dispersed aggregations of lepomid larvae, thus increasing the chance of collection; however, other factor(s) probably contributed to the greater abundance of larval lepomids, since high densities were also observed at the reference location (Location 8.0).

The estimated spawning period for lepomids varied slightly among years, as did water temperature, dissolved oxygen concentration, photoperiod, and lake level ranges (Table 10-9). However, both lower and upper limits of the water temperature ranges observed during the lepomid estimated spawning periods were higher than the 17 to 27°C range reported by Hardy (1978) for spawning of bluegill, the predominant lepomid in Lake Norman.

Pomoxids

Pomoxids were collected predominantly during April and May each year at all locations, with occasional collections in June (App. Fig. 10.8-3). In 1975, similar trends in occurrence of pomoxids were observed at uplake and downlake locations, although densities were considerably higher at downlake locations. Increased densities of pomoxids were noted at Locations 4.0 and 8.0 during 1977 and Locations 1.0, 4.0, and 8.0 during 1978 (Fig. 10-10). Densities of pomoxids at Location 6.0 varied much less through the years than at other locations. This yearly variability of pomoxids among locations may be related to the habitat differences among locations; however, the high densities of pomoxids at all locations in 1978 suggest other contributing factors. No relationship between number of young-of-year and densities of larval pomoxids was observed (Fig. 10-10). Only slight changes were observed in the estimated spawning period, water temperature, dissolved oxygen concentration, photoperiod, and lake level ranges in 1978 from other years (Table 10-9). As was noted earlier, peculiarities in zooplankton densities in 1978 may have enhanced the survival of pomoxids.

Although densities of pomoxids were highest in shoreline areas, initial collections of larvae occurred simultaneously at both shoreline and channel areas. For all years except 1974, collection of pomoxids from April through mid-May were highest at the surface of both shoreline and channel areas. From late May through June, the channel areas were usually higher, particularly at 5 m. During 1974, pomoxids collected at the 5-m depth made up a larger

proportion of the catch than during other years. This was probably caused by sampling during the day which resulted in net avoidance by larvae. During the 20 May 1975 diel study, densities of pomoxids were highest at the 5-m depth during the day and the surface of shoreline and channel areas during the night, indicating possible diel movement (Table 10-8). However, other factors can affect the distribution of larval pomoxids, as is evident by the fact that Lewis and Siler (1980) noted an increase in size of pomoxids with a shift in density from surface to deeper strata (at or near the thermocline) during 1977 and 1978 at the channel area of Location 4.0.

Pomoxids spawned during April and May of each year at water temperatures ranging from 12 to 27°C. Initiation of spawning of black crappie (the predominant pomoxid species in Lake Norman) has been reported in March and early April in North and South Carolina, respectively, and at water temperatures ranging from 16 to 21°C (Hardy 1978).

Percids

Percids were collected from April through June of each year and occasionally during July and August (App. Fig. 10.8-4). During 1975, percids were collected from April through June at Marshall locations (Appendix 10.9), and densities were considerably lower than those of downlake locations. Collections of percids during July and August at downlake locations may be related to spawning of *Etheostoma* spp. rather than an extended spawning period of *Perca flavescens* (the dominant percid species in Lake Norman). The spawning periods for the darters in Lake Norman have not been described.

As compared to other years, percid density during 1978 was considerably higher at Location 1.0 and slightly higher at Location 4.0. Densities at other locations during 1978 varied within the range of densities observed during other years. No relationship between young-of-year and larval percid densities was observed (Fig. 10-11).

Although most percids were collected at shoreline areas, initial collection of larvae of 5 to 8 mm total length at shoreline and channel areas indicated rapid dispersal after yolk sac absorption (App. Table 10-7). Densities of percids were usually highest at the shoreline areas in April, varied between shoreline and channel areas during May, and peaked at the 5-m channel areas during June and July. During 1975, a similar trend in distribution of percids at Marshall locations was evident (Appendix 10.9). Additionally, percid densities collected in diel samples in 1975 were highest at the shoreline area on 23 April, but by 20 May the percids were most numerous at the 5-m channel areas (Table 10-7).

These changes in horizontal and vertical distribution may possibly be related to growth of percids and water temperature. During vertical distribution studies on Lake Norman in 1977 and 1978, percids averaging >15 mm were generally collected from the cooler deep strata (Lewis and Siler 1980). A shift of densities of larval *Perca flavescens* from the surface to deeper strata was also observed by Waybrant and Shauver (1979) throughout the larval collection period in Lake Erie, Michigan.

The estimated spawning period of percids varied among years, but could not be related to physicochemical factors (Table 10-9). The water temperature

ranges observed in this study exceeded the spawning water temperature range of 6 to 21°C reported by Hokanson (1977) for *Perca* spp. However, Hokanson (1977) did note an adaptation to different water temperature regimes by shifting spawning temperatures with only a slight change in spawning time for *Perca* spp. *Perca flavescens* was the most abundant adult percid collected by rotenone in Lake Norman, followed by *Etheostoma fusiforme* and *Etheostoma olmstedi*. The yearly variation in the estimated spawning periods could have been related to the spawning of the two species of darters.

Other Taxa

Other taxa of ichthyoplankton were also collected during the study, but their numbers were extremely low when compared to the previously discussed taxa. The sporadic occurrence of these taxa was likely not an indication of poor spawning success but rather selectivity of sampling gear. Adult minnows, suckers, largemouth bass, and catfish were relatively abundant in shoreline electrofishing or gill net catches during their respective spawning periods (App. Tables 10.4 and 10.5), but their larvae were infrequently collected. Several schools of larval largemouth bass were observed by SCUBA divers at Locations 1.2, 4.0, and 10.0 in April and May 1976, further verifying the aforementioned sampling bias (App. Table 10.8-12). Gear selectivity was particularly evident at locations just below Lookout Shoals Dam. Adult suckers and white bass in spawning condition were abundant in electrofishing surveys below Lookout Shoals Dam during March, April, and May, but very few larvae of these species were collected (App. Table 10.5).

Young-of-year catfish and largemouth bass, important commercial and sport fish in Lake Norman, were well represented in rotenone collections each year (Table 10-10), indicating successful reproduction.

SUMMARY

Electrofishing, gill netting, midwater trawling, and cove rotenone sampling were used to estimate species composition and abundance of Lake Norman fishes. Larval trawling was used to monitor the reproductive success and spawning periods of selected fish taxa. Rotenone sampling provided more consistent estimates of the abundance of a larger number of species than the other techniques combined. Studies were conducted from August 1973 through 1980. Samples were collected proximal to Marshall Steam Station and McGuire Nuclear Station, but most of the sampling was done in the vicinity of McGuire.

In this study, 39 species were collected from Lake Norman, and none was considered rare, endangered, or threatened. Generally, the fish community of littoral areas was dominated by gizzard shad, and the limnetic sampling areas were dominated by threadfin shad. The gizzard shad population was mainly composed of individuals that were too large to be utilized by the majority of Lake Norman predator fishes. Generally, threadfin shad were an acceptable size for almost all Lake Norman predator fishes. Gizzard shad, carp, sunfish, catfish, largemouth bass, and yellow perch, in decreasing order, were important contributors to the total biomass of coves.

Sampling locations were partitioned into uplake and downlake locations; uplake locations were associated with Marshall sampling and downlake locations were

associated with McGuire sampling. The estimated fish biomass of sampling locations averaged 128 kg/ha downlake and 125 kg/ha uplake. Despite the similarity in the average biomass estimates, variability among individual coves was apparent. Variation in biomass estimates among individual coves was mainly due to differences in the physical characteristics of locations. Biomass estimates of total fish and harvestable sport fish in areas adjacent to McGuire and Marshall discharges were higher than other areas. These high estimates were attributed to the operation of Marshall and the test pumping of the condenser cooling water system at McGuire. Major differences in the fish communities of uplake and downlake areas were:

- 1) the species of catfish present at uplake areas were markedly different from those of downlake areas,
- 2) catfish composed 9.2% of the uplake fish community, but only 2.7% of the downlake fish community,
- 3) white bass were more common and generally the most abundant sport fish at downlake coves while largemouth bass were the most abundant sport fish at uplake coves; this contradicted the results of the creel survey (Appendix 10.1) in that harvest of both species were higher uplake,
- 4) threadfin shad were more abundant at uplake coves than downlake coves; gizzard shad were more abundant at downlake coves than at uplake coves.

Differences in species composition that were specific to individual locations were also apparent. Redbreast sunfish and bluegill were the dominant sunfish at all locations except at Marshall where redbreast sunfish crops were noticeably lower than at other locations. Marshall (Location 14.7) also had extremely high standing crops of crappie and harvestable largemouth bass. Location 68.0, the most uplake location, had much higher crops of catostomids than other locations. After initiation of test pumping at McGuire, yellow perch crops increased markedly and were much higher than at other locations.

Clupeids, lepomids, pomoxids, and percids comprised approximately 98% of the catch of larval fish. Other species were not sampled effectively. Furthermore, catch rates of larval lepomids, because of their shoreline habits, were probably not indicative of larval lepomid abundance in the lake. At downlake locations, clupeids were the dominant taxon collected, followed by pomoxids or percids, and then lepomids. At locations near Marshall Steam Station, clupeids were also the dominant taxon collected but were followed by lepomids and percids. Pomoxid densities near Marshall were considerably lower than downlake densities. At Marshall locations, densities of larval clupeids and lepomids were higher than at downlake locations. Larval percids were more abundant in downlake collections. Usually, newly hatched larval fish were more abundant in shoreline areas. Rapid dispersal from shoreline areas occurred as the larvae grew, and larger larvae were generally more abundant in the channel areas. Redistribution was possibly associated with initiation of feeding, higher food requirements, development of a thermocline, warming of the reservoir, and/or avoidance of predation. During the six years of this study, no relationship was apparent between the number of larvae collected and the number of young-of-year present in August rotenone samples. Apparently year class strength or the development of a dominant year class is not related to the number of larvae collected, at least for the larval fish abundances encountered during this study.

The estimated spawning periods of clupeids, lepomis, pomoxids, and percids varied only slightly among the years of this study. Even though water temperatures in the heated discharge at Marshall during early spring were slightly higher than ambient lake temperatures, no noticeable difference was observed in spawning times or duration of spawning.

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Table 10-1. Frequency and type of sampling used in fishery studies in Lake Norman, North Carolina. Frequency abbreviations: W=weekly, B=once every two weeks, M=monthly, Q=quarterly, Y=yearly. Type of sampling abbreviations: E=electrofishing, GN=gillnetting, R=rotenone, LT=larval trawling, MT=midwater trawling. Larval trawling was conducted primarily during spring and summer.

Locations	Year							
	1973	1974	1975	1976	1977	1978	1979	1980
1.0		W&B-LT	W&B-LT	B-LT	B-LT	B-LT, M-MT*	B-LT, Q-MT	B-LT, Q-MT
1.2		M-E, W&B-LT	Q-E, W&B-LT	Q-E, B-LT	Q-E, B-LT	M-E, B-LT	M-E, B-LT	M-E, B-LT
2.0		M-GN	Q-GN					
3.0		M-E, M-GN				M-E, M-GN	M-E, M-GN	M-E, M-GN
3.8								M-F
3.9						M-E	M-E	
4.0	Y-R	M-E, M-GN W&B-LT, Y-R	Q-E, Q-GN, W&B-LT, Y-R	Q-E, Q-GN, B-LT, Y-R	Q-E, Q-GN, B-LT, Y-R	M-E, M-GN, B-LT, Y-R	M-E, M-GN, B-LT, Y-R	M-E, M-GN, B-LT, Y-R
4.5						B-LT, M-MT*	B-LT, Q-MT	B-LT, Q-MT
5.0		M-E, M-GN, W&B-LT	W&B-LT	B-LT	B-LT	M-E, M-GN, B-LT, M-MT*	M-E, M-GN, B-LT, Q-MT	M-E, M-GN, B-LT, Q-MT
6.0	Y-R	W&B-LT, Y-R	W&B-LT, Y-R	Q-E, Q-GN, B-LT, Y-R	Q-E, Q-GN, B-LT, Y-R	M-E, M-GN, B-LT, Y-R	M-E, M-GN, B-LT, Y-R	M-E, M-GN, B-LT, Y-R
6.5		M-E, M-GN	Q-E, Q-GN					
7.3	Y-R	M-E, M-GN, Y-R	Y-R	Y-R	Y-R			
8.0				B-LT	B-LT	B-LT, M-MT*	B-LT, Q-MT	B-LT, Q-MT
8.5				Q-E, Q-GN, Y-R, B-LT	Q-E, Q-GN, Y-R, B-LT	M-E, M-GN, Y-R, B-LT	M-E, M-GN, Y-R, B-LT	M-E, M-GN, Y-R, B-LT
9.0	Y-R	M-E, M-GN, Y-R	Y-R					
10.0	Y-R	M-E, M-GN, Y-R, W&B-LT	Q-E, Q-GN, Y-R, W&B-LT					
10.5		W&B-LT	W&B-LT					
13.0						M-E*, Q-GN*	M-E*, Q-GN*	
14.0			W&B-LT					
14.5			W&B-LT			M-E*	M-E*	
14.7						M-E*, Q-GN*, Y-R	M-E*, Q-GN*, Y-R	Y-R
15.2			W&B-LT					
15.5			W&B-LT			M-E*, Q-GN*	M-E*, Q-GN*	
16.0				Q-E	Q-E	M-E	M-E	M-E
16.5		M-E	Q-E					
17.5		Q-E						
19.0						M-E*, Q-GN*, Y-R	M-E*, Q-GN*, Y-R	Y-R
25.0			W-LT					
25.2			W-LT					
25.5			W-LT					
45.5			W&B-LT					
65.0			W-LT					
68.0						Y-R	Y-R	Y-R
72.0			W-LT					
80.0			W-LT					

*sampled only part of the year

Table 10-2. Scientific and common names of fishes collected from Lake Norman, North Carolina.

Family Species	Common Name	Reference
Lepisosteidae		
<i>Lepisosteus osseus</i> (Linnaeus)	Longnose gar	1,2,3,4
Amiidae		
<i>Amia calva</i> Linnaeus	Bowfin	5
Clupeidae		
<i>Dorosoma cepedianum</i> (Lesueur)	Gizzard shad	1,2,3,4
<i>Dorosoma petenense</i> (Gunther)	Threadfin shad	1,2,3,4
Cyprinidae		
<i>Cyprinus carpio</i> (Linnaeus)	Carp	1,2,3,4
<i>Hybognathus regius</i> (Girard)	Eastern silvery minnow	1,3
<i>Nocomis biguttatus</i> (Girard)	Bluehead chub	1
<i>Notemigonus crysoleucas</i> (Mitchell)	Golden shiner	1,2,3
<i>Notropis analostanus</i> (Girard)	Satinfin shiner	2,3
<i>Notropis chloristius</i> (Jordan and Brayton)	Greenfin shiner	1,2
<i>Notropis galacturus</i> (Cope)	Whitetail shiner	4
<i>Notropis hudsonius</i> (Clinton)	Spottail shiner	1,3
<i>Notropis niveus</i> (Cope)	Whitefin shiner	1,3
<i>Semotilus atromaculatus</i> (Mitchell)	Creek chub	2
Catostomidae		
<i>Carpiodes carpio</i> (Rafinesque)	River carpsucker	2
<i>Carpiodes cyprinus</i> (Lesueur)	Quillback	1,2,3
<i>Catostomus commersoni</i> (Lacépède)	White sucker	1,2,3,4
<i>Erimyzon oblongus</i> (Mitchell)	Creek chubsucker	1,3
<i>Ictalobus bubalus</i> (Rafinesque)	Smallmouth buffalo	4
<i>Moxostoma anisurum</i> (Rafinesque)	Silver redhorse	1,2,3
<i>Moxostoma macrolepidotum</i> (Lesueur)	Shorthead redhorse	1,2,3
<i>Moxostoma pappillosum</i> (Cope)	Suckermouth redhorse	1,2,3
<i>Moxostoma robustum</i> (Cope)	Smallfin redhorse	1,2,3
<i>Moxostoma rupiscartes</i> Jordan and Jenkins	Striped jumprock	1
Ictaluridae		
<i>Ictalurus brunneus</i> (Jordan)	Snail bullhead	1,2,3
<i>Ictalurus catus</i> (Linnaeus)	White catfish	1,2,3,4
<i>Ictalurus furcatus</i> (Lesueur)	Blue catfish	2
<i>Ictalurus melas</i> (Rafinesque)	Black bullhead	1,2
<i>Ictalurus natalis</i> (Lesueur)	Yellow bullhead	2,4
<i>Ictalurus nebulosus</i> (Lesueur)	Brown bullhead	1,2,3,4
<i>Ictalurus platycephalus</i> (Girard)	Flat bullhead	1,2,3
<i>Ictalurus punctatus</i> (Rafinesque)	Channel catfish	1,2
<i>Pylodictis olivaris</i> (Rafinesque)	Flathead catfish	1,2
Poeciliidae		
<i>Gambusia affinis</i> (Baird and Girard)	Mosquitofish	1,2,3
Percichthyidae		
<i>Morone chrysops</i> (Rafinesque)	White bass	1,2,3,4
<i>Morone saxatilis</i> (Walbaum)	Striped bass	1,2,3
Centrarchidae		
<i>Lepomis auritus</i> (Linnaeus)	Redbreast sunfish	1,2,3,4
<i>Lepomis gibbosus</i> (Linnaeus)	Pumpkinseed	2,3,4
<i>Lepomis gulosus</i> (Cuvier)	Warmouth	1,2,3,4
<i>Lepomis macrochirus</i> Rafinesque	Bluegill	1,2,3,4
<i>Lepomis microlophus</i> (Gunther)	Redear	1
<i>Micropterus salmoides</i> (Lacépède)	Largemouth bass	1,2,3,4
<i>Pomoxis annularis</i> Rafinesque	White crappie	1,2,3,4
<i>Pomoxis nigromaculatus</i> (Lesueur)	Black crappie	1,2,3,4
Percidae		
<i>Etheostoma fusiforme</i> (Girard)	Swamp darter	1,2,3
<i>Etheostoma nigrum</i> Rafinesque	Johnny darter	2
<i>Etheostoma olmstedti</i> Storer	Tessellated darter	1,3
<i>Perca flavescens</i> (Mitchell)	Yellow perch	1,2,3,4

1. Duke Power Reference Collection (as of December 1980)

2. Miller and DeMont (1974)

3. Duke Power Company (1976)

4. McNaughton (1966)

5. Roy Miller, North Carolina Wildlife Resources Commission (Personal communication)

Table 10-3. Mean standing crops and species composition of 1.2 ha rotenone sampling locations on Lake Norman, NC during 1978 and 1979.

Species	DOWNLAKE LOCATIONS			UPLAKE LOCATIONS		
	Kg/ha	%	6.0	Kg/ha	%	68.0
Longnose gar	98.6	60.2	0.01	0.01	0.01	24.1
Gizzard shad	2.8	1.7	27.5	32.3	35.1	3.9
Threadfin shad	15.8	9.6	0.1	0.1	3.7	39.4
Carp	0.004	<0.01	29.3	34.4	24.4	0.001
Eastern silvery minnow	0.002	<0.01	0.02	0.02	0.01	0.1
Golden shiner	0.1	0.06	0.001	<0.01	<0.01	0.001
Greenfin shiner	0.1	0.06	0.07	0.08	0.05	0.001
Spottail shiner	0.1	0.06	0.06	0.07	0.03	0.001
Whitefin shiner	0.1	0.06	0.2	0.2	0.1	0.001
Quillback	3.3	2.0	1.8	2.1	2.6	4.1
Silver redhorse			0.7	0.8	0.4	2.5
Shorthead redhorse						4.0
Smallfin redhorse						0.07
Snail bullhead	0.3	0.2	0.5	0.6	1.2	1.9
White catfish	0.3	0.2	1.6	1.9	1.2	
Brown bullhead	1.0	0.6	0.02	0.02	1.1	0.2
Flat bullhead			1.9	2.2	0.01	7.8
Channel catfish						0.4
Flathead catfish						0.001
Mosquitofish	13.2	8.1	0.04	0.05	0.04	0.02
White bass	0.03	0.02	1.8	2.1	5.9	0.01
Striped bass	3.2	2.0	5.3	6.2	2.0	2.3
Redbreast sunfish						0.01
Pumpkinseed	0.5	0.3	0.6	0.7	1.0	1.3
Warmouth	3.3	2.0	7.2	8.5	8.4	13.7
Bluegill						11.0
Redear						
Sunfish hybrid	0.004	<0.01	0.04	0.05	0.1	6.9
Largemouth bass	2.4	1.5	4.6	5.4	4.1	1.1
White crappie	0.3	0.2	0.01	0.01	1.2	3.1
Black crappie	1.1	0.7	0.04	0.05	3.5	<0.001
Swamp darter	0.005	<0.01	0.04	0.05	0.02	0.01
Tessellated darter	0.03	0.02	0.03	0.04	0.02	0.01
Unidentified darter						
Yellow Perch	17.3	10.6	1.6	1.9	2.6	4.5
Total	163.8	100.1	85.1	99.9	99.8	125.1
						100

Table 10-4. Standing crops and species composition of five North and South Carolina reservoirs.

Species	Lake Norman ¹ (uplake)		Lake Norman ¹ (downlake)		Lake Wylie, ² NC/SC		Lake Keowee, ³ SC		Lake Hartwell, ⁴ SC		Lake Clark Hill, ⁴ SC	
	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%
Gar			<0.1	<0.1	1.7	0.4					0.1	0.1
Gizzard shad	38.8	31.2	58.0	45.2	161.4	35.5			19.6	17.6	18.5	19.1
Threadfin shad	8.4	6.7	2.7	2.1	47.8	10.5	0.6	1.1	7.0	6.3	4.1	4.2
Carp	26.7	21.4	26.1	20.2	18.8	4.1	34.8	65.2	18.9	16.9	13.4	13.9
Minnows	0.3	0.2	0.3	0.2	0.6	0.1	0.3	0.6				
Suckers	5.0	4.0	3.3	2.6	56.2	12.4	0.5	0.9	0.4	0.4	0.6	0.6
Catfish	11.4	9.2	3.4	2.7	59.0	13.0	3.1	5.8	3.8	3.4	11.3	11.7
Temperate bass	1.0	0.8	8.2	6.4	3.9	0.9	0.1	0.2	0.4	0.4		
Sunfish	13.3	10.7	12.0	9.4	67.4	14.8	9.0	16.9	34.1	30.6	37.5	38.8
Largemouth bass	8.9	7.1	4.2	3.3	32.6	7.2	2.5	4.7	6.8	6.1	5.8	6.0
Crappie	6.9	5.5	2.6	2.0	0.5	0.1	1.4	2.6	5.3	4.7	0.8	0.8
Perch	3.8	3.1	7.5	5.8	4.4	1.0	1.1	2.1	15.0	13.4	4.1	4.2
Others									0.3	0.3	0.5	0.5
Total	124.5	99.9	128.3	99.9	454.3	100.0	53.4	100.1	111.6	100.1	96.7	99.9

¹ Average of three 1.2 ha coves sampled during 1978 and 1979 (present study).

² Average of three 1.2 ha coves sampled during 1979 and 1980 (Duke Power Company unpublished data).

³ Average of four coves sampled from 1977 through 1979 (Southeast Reservoir Investigations unpublished data).

⁴ Average of three coves on Lake Hartwell and two coves on Lake Clark Hill during 1968 (Clugston 1973).

Table 10-5. List of fish taxa collected in ichthyoplankton samples from 1974 through 1980 in Lake Norman, North Carolina.

Scientific Name	Common Name
Clupeidae	
<u>Dorosoma</u> spp.	
<u>D. cepedianum</u>	Gizzard shad
<u>D. petenense</u>	Threadfin shad
Cyprinidae	
<u>Cyprinus carpio</u>	Carp
<u>Notropis</u> spp.	Minnows
Catostomidae	
Ictaluridae	
<u>Ictalurus brunneus</u>	Snail bullhead
<u>I. catus</u>	White catfish
<u>I. platycephalus</u>	Flat bullhead
Percichthyidae	
<u>Morone chrysops</u>	White bass
Centrarchidae	
<u>Lepomis</u> spp.	Sunfish
<u>Micropterus salmoides</u>	Largemouth bass
<u>Pomoxis</u> spp.	Crappie
Percidae	

Table 10-6. Composition of larval fish collected from 1974 through 1979 in Lake Norman, NC. SS = surface of shoreline area, SC = surface of channel area, and FMC = 5 m depth of channel area. Number in parentheses is number of tows taken from April through September of each year.

Year	Location	Sublocation	TAXA									
			Clupeids		Lepomids		Pomoxids		Percids		Other	
			Total Number	%	Total Number	%	Total Number	%	Total Number	%	Total Number	%
1974(38)	1	SS	6978	97.4	50	0.7	22	0.3	88	1.2	23	0.3
"	1	SC	5178	94.8	22	0.4	46	0.8	208	3.8	8	0.1
"	1	FMC	17206	97.1	84	0.5	222	1.3	198	1.1	8	<0.0
"	4	SS	11190	94.0	108	0.9	138	1.2	444	3.7	19	0.2
"	6	SS	18564	85.7	238	1.1	1914	8.8	922	4.3	20	0.1
"	6	SC	13806	94.8	38	0.3	410	2.8	300	2.1	8	0.1
"	6	FMC	27938	97.8	50	0.2	434	1.5	140	0.5	0	0.0
"	10	SS	16960	85.5	292	1.4	1278	6.3	1720	8.5	52	0.3
"	10	SC	18796	95.1	64	0.3	196	1.0	642	3.2	57	0.3
"	10	FMC	37828	99.2	76	0.2	132	0.3	90	0.2	8	<0.1
1975(34)	1	SS	5332	92.6	289	4.5	100	1.5	638	9.9	97	1.5
"	1	SC	3084	82.3	54	1.4	126	3.4	480	12.8	5	0.1
"	1	FMC	2294	89.7	26	1.0	26	1.0	210	8.2	0	0.0
"	4	SS	9122	82.5	472	4.3	282	2.6	1148	10.4	32	0.3
"	6	SS	12945	72.2	794	4.4	2736	15.2	1404	7.8	60	0.3
"	6	SC	9312	86.2	382	3.5	504	4.7	590	5.5	15	0.1
"	6	FMC	8142	90.6	40	0.4	68	0.8	710	7.9	22	0.2
"	10	SS	9172	66.4	208	1.5	1252	9.1	3158	22.8	33	0.2
"	10	SC	7822	91.2	96	1.1	254	3.0	364	4.2	43	0.5
"	10	FMC	6176	93.5	74	1.1	158	2.4	186	2.8	10	0.2
1976(26)	1	SS	3282	79.2	50	1.2	674	16.3	114	2.8	22	0.5
"	1	SC	4208	91.4	60	1.3	214	4.7	106	2.3	15	0.3
"	1	FMC	2054	92.4	38	1.7	24	1.1	108	4.9	0	0.0
"	4	SS	9208	82.6	134	1.2	1172	10.5	563	5.0	75	0.7
"	6	SS	20508	91.9	472	2.1	364	1.6	934	4.2	38	0.2
"	6	SC	13076	92.6	92	0.7	548	3.9	368	2.6	30	0.2
"	6	FMC	3584	93.9	18	0.5	20	0.5	168	4.4	26	0.7
"	8	SS	5330	89.0	190	3.2	298	5.0	123	2.1	51	0.9
"	8	SC	3406	92.3	50	1.8	146	4.0	66	1.8	4	0.1
"	8	FMC	1602	90.8	44	2.5	18	1.0	94	5.3	6	0.3
1977(22)	1	SS	5776	87.8	288	4.4	324	4.9	140	2.1	49	0.7
"	1	SC	3744	91.2	56	1.4	228	5.6	62	1.5	16	0.4
"	1	FMC	4508	94.5	92	1.9	62	1.3	98	2.1	8	0.2
"	4	SS	12552	86.4	102	0.7	1534	10.6	266	1.8	72	0.5

Table 10-6 (Continued)

Year	Location	Sublocation	TAXA									
			Clupeids		Lepomids		Pomoxids		Percids		Other	
			Total Number	%	Total Number	%	Total Number	%	Total Number	%	Total Number	%
1977(22)	4	SC	5730	93.0	40	0.6	272	4.4	110	1.8	8	0.1
"	4	FMC	4416	93.2	34	0.7	44	0.9	240	5.1	4	0.1
"	6	SS	26912	89.7	110	0.4	2152	2	802	2.7	37	0.1
"	6	SC	7114	93.0	8	0.1	422		102	1.3	7	0.1
"	6	FMC	7526	95.2	46	0.6	46		234	3.6	0	0.0
"	8	SS	7466	60.8	178	1.5	4092	33.3	428	3.5	109	0.9
"	8	SC	3362	82.5	38	0.9	500	12.3	166	4.1	10	0.2
"	8	FMC	2844	92.5	34	1.1	40	1.3	142	4.6	14	0.5
1978(22)	1	SS	6196	31.0	298	1.5	8262	41.3	5218	26.1	15	0.1
"	1	SC	3088	65.7	86	1.8	804	17.1	704	15.0	15	0.3
"	1	FMC	516	50.0	76	7.4	76	7.4	364	35.3	0	0.0
"	4	SS	4092	33.7	1864	15.4	5358	44.1	790	6.5	35	0.3
"	4	SC	2122	65.1	92	2.8	904	27.7	138	4.2	5	0.2
"	4	FMC	534	55.1	71	7.3	78	8.0	280	28.9	6	0.6
"	6	SS	9780	76.6	600	4.7	187	14.2	544	4.3	20	0.2
"	6	SC	7256	81.9	88	1.0	1268	14.3	240	2.7	3	<0.1
"	6	FMC	1186	76.8	12	0.8	30	1.9	304	19.7	12	0.8
"	8	SS	10462	66.6	1332	8.5	2488	15.8	1412	9.0	5	<0.1
"	8	SC	2612	56.6	164	3.6	1482	32.1	340	7.4	14	0.3
"	8	FMC	784	47.9	70	4.3	564	34.4	220	13.4	0	0.0
1979(24)	1	SS	752	85.8	50	5.7	30	3.4	40	4.6	4	0.5
"	1	SC	935	86.3	17	1.6	85	7.8	46	4.2	0	0.0
"	1	FMC	608	88.9	32	4.7	25	3.7	15	2.2	4	0.6
"	4	SS	6102	68.2	2204	24.6	236	2.6	394	4.4	14	0.2
"	4	SC	1036	86.1	42	3.5	50	4.2	75	6.2	0	0.0
"	4	FMC	776	89.0	50	5.7	14	1.6	32	3.7	0	0.0
"	6	SS	26007	93.2	1010	3.6	627	2.2	240	0.9	18	<0.1
"	6	SC	2642	85.7	93	3.0	278	9.0	71	2.3	0	0.0
"	6	FMC	1298	92.6	27	1.9	10	0.1	62	4.4	5	0.4
"	8	SS	8767	87.7	546	5.5	487	4.9	188	1.9	4	<0.1
"	8	SC	626	80.5	55	7.1	55	7.1	37	4.8	5	0.6
"	8	FMC	525	93.3	19	3.4	0	0.0	14	2.5	5	0.9

Table 10-7. Mean number of juvenile gizzard (GS) and threadfin (TS) shad/1000 m³ collected from Locations 1, 4, 6, and 9 on Lake Norman, North Carolina.

Year	Month	Day	Shoreline Areas		Channel Areas			
			GS	TS	Surface		5 m	
					GS	TS	GS	TS
1977	May	23	1.6	0.0	13.8	0.9	42.1	3.0
	June	3	4.0	9.7	1.7	58.9	132.5	34.5
	June	16	1.8	8.2	1.4	17.5	103.2	37.0
	June	30	0.0	1.2	1.8	12.3	22.4	35.1
	July	14	0.0	1.5	0.0	20.6	28.4	1002.7
	July	28	0.0	3.5	0.0	38.9	0.0	46.6
	August	11	0.0	2.3	0.0	20.7	0.0	305.3
	August	25	0.0	0.6	0.0	3.2	0.0	9.8
1978	May	25	3.0	0.0	0.6	0.6	0.6	0.0
	June	8	9.8	1.3	6.4	0.0	3.6	0.0
	June	22	10.4	0.6	12.7	1.2	65.0	0.0
	July	6	1.9	0.0	9.2	0.0	414.4	1.3
	July	20	2.5	3.0	5.1	0.7	13.5	1.3
	August	3	0.6	0.8	0.0	0.7	7.5	0.0
	August	17	0.0	0.0	2.0	0.6	2.6	0.0
	September	5	0.0	0.0	0.0	0.8	3.1	11.0
1979	June	7	0.0	0.0	0.0	0.5	0.0	0.0
	June	21	0.0	2.2	0.0	6.2	0.0	52.0
	July	5	0.0	4.7	0.0	76.5	0.0	23.0
	July	19	0.0	2.0	0.0	37.5	0.0	108.5
	August	12	0.0	6.7	0.0	12.5	0.0	250.2
	August	16	0.0	1.0	0.0	2.5	0.0	23.7
	August	30	0.0	1.2	0.0	2.7	0.0	21.2
	September	13	0.0	0.5	0.0	10.0	0.0	9.7

Table 10-8. Diel distribution of larval fish collected in Lake Norman, North Carolina, during 1975.

DATE	DEPTH	Mean Density (number/1000 m ³)					
		Clupeids		Pomoxids		Percids	
		Day	Night	Day	Night	Day	Night
April 23	Surface						
	Shoreline	0.0	0.0	0.0	0.0	13.3	124.5
"	Surface						
	Channel	0.0	0.0	0.0	0.0	15.5	26.7
"	5 m	0.0	0.0	0.0	0.0	17.0	7.3
"	10 m	0.0	0.0	0.0	0.0	3.3	5.5
"	15 m	0.0	0.0	0.0	0.0	0.3	1.5
May 20	Surface						
	Shoreline	124.7	2901.5	0.3	06.5	2.0	13.5
"	Surface						
	Channel	63.7	1636.0	0.0	37.5	2.3	3.5
"	5 m	15.7	120.0	17.3	4.0	0.3	26.0
"	10 m	16.7	14.0	3.0	1.5	1.7	8.5
"	15 m	0.7	11.0	0.7	0.5	0.3	3.5
July 21	Surface						
	Shoreline	0.0	32.5	0.0	0.0	0.0	0.0
"	Surface						
	Channel	0.0	96.0	0.0	0.0	0.0	0.0
"	5 m	3.0	62.5	0.0	0.0	0.0	0.0
"	10 m	2.3	8.0	0.0	0.0	0.0	0.0
"	15 m	0.3	6.5	0.0	0.0	0.0	0.0

Table 10.9. Water temperatures, dissolving oxygen concentrations, photoperiods, lake levels, and estimated spawning periods of larval fish collected from 1974 through 1979 in Lake Norman, North Carolina.

Species	Year	Estimated Spawning Period	Temperature(°C)	Dissolved Oxygen Concentration(mg/l)	Variable ranges	
					Photoperiod (hours)	Lake Level (m. m.s.l.)
Clupeids*						
1974	11 Apr - 25 Jul	14-28	6-10	13.1-14.5	230.3-231.5	
1975	23 Apr - 25 Jul	13-31	5-12	13.1-14.5	231.1-231.6	
1976	25 Mar - 18 Aug	13-31	6-10	13.0-14.5	230.3-231.3	
1977	14 Apr - 16 Aug	12-31	6-10	13.1-14.5	229.7-231.2	
1978	20 Apr - 23 Jul	13-31	7-11	13.1-14.5	230.5-231.6	
1979	19 Apr - 9 Aug	14-29	7-11	13.1-14.5	230.5-231.6	
Lepomis*						
1974	10 May - 25 Jul	18-28	6-9	13.9-14.5	230.7-231.8	
1975	6 May - 26 Aug	19-30	6-9	13.0-14.5	230.7-231.6	
1976	19 May - 18 Aug	19-31	6-10	13.0-14.5	230.2-231.3	
1977	29 Apr - 4 Aug	20-31	7-10	13.6-14.5	230.0-231.1	
1978	1 Jun - 30 Aug	19-31	7-10	13.9-14.4	230.8-231.2	
1979	17 May - 9 Aug	20-29	7-11	13.9-14.5	230.5-231.5	
Pomoxis*						
1974	17 Apr - 16 May	14-21	8-10	13.1-14.0	230.6-231.5	
1975	14 Apr - 28 May	13-27	7-11	13.1-14.4	231.1-231.6	
1976	7 Apr - 11 May	13-21	9-11	12.6-14.0	230.0-231.9	
1977	14 Apr - 28 May	12-24	7-10	13.1-14.4	231.1-231.2	
1978	20 Apr - 1 Jun	13-25	9-11	13.1-14.4	230.8-231.3	
1979	5 Apr - 3 May	12-24	8-11	12.6-13.6	231.2-231.6	
Percids**						
1974	28 Mar - 23 May & 6 Jun	13-24	8-10	12.5-14.4	230.4-231.5	
1975	5 Mar - 17 Jun	8-28	6-11	11.4-14.5	231.1-231.6	
1976	10 Mar - 16 Jun	9-25	8-11	11.4-14.5	230.0-231.6	
1977	17 Mar - 9 Jun & 18 Aug	5-27	6-10	11.9-14.5	230.8-231.4	
1978	22 Mar - 30 Jun	5-28	9-13	11.9-14.5	230.8-231.6	
1979	21 Mar - 29 Jun & 23 Aug	7-26	8-11	11.9-14.2	231.2-231.7	

* Estimated spawning period based on the occurrence of larval fish of 5 to 8 mm total length. A one week incubation and development period was assumed.

** Estimated spawning period based on occurrence of larval percids of 5 to 8 mm total length. A three week incubation and development period for first occurrence and a one week period for last occurrence of 5 to 8 mm larval percids was assumed.

Table 10-10. Number of young-of-year Ictaluridae (total length <80 mm) and Micropterus salmoides (total length <100 mm) per ha collected on Lake Norman, North Carolina, using rotenone.

Taxa	Year	Locations			
		4.0	6.0	8.5*	10.0*
Ictaluridae	1973	122.2	323.3		656.5
	1974	157.1	35.9		134.9
	1975	221.2	180.0		291.4
	1976	197.8	458.8	200.0	
	1977	426.3	1547.8	300.0	
	1978	128.9	367.5	148.9	
	1979	116.3	128.2	152.1	
	1980	124.4	292.1	167.4	
<u>Micropterus salmoides</u>	1973	116.7	225.6		391.3
	1974	102.0	153.8		162.8
	1975	59.6	90.0		80.0
	1976	134.8	88.2	112.5	
	1977	65.8	91.3	132.1	
	1978	48.1	147.5	97.8	
	1979	151.0	79.5	89.6	
	1980	128.9	234.2	119.6	

*Location 8.5 replaced 10.0 beginning in 1976.

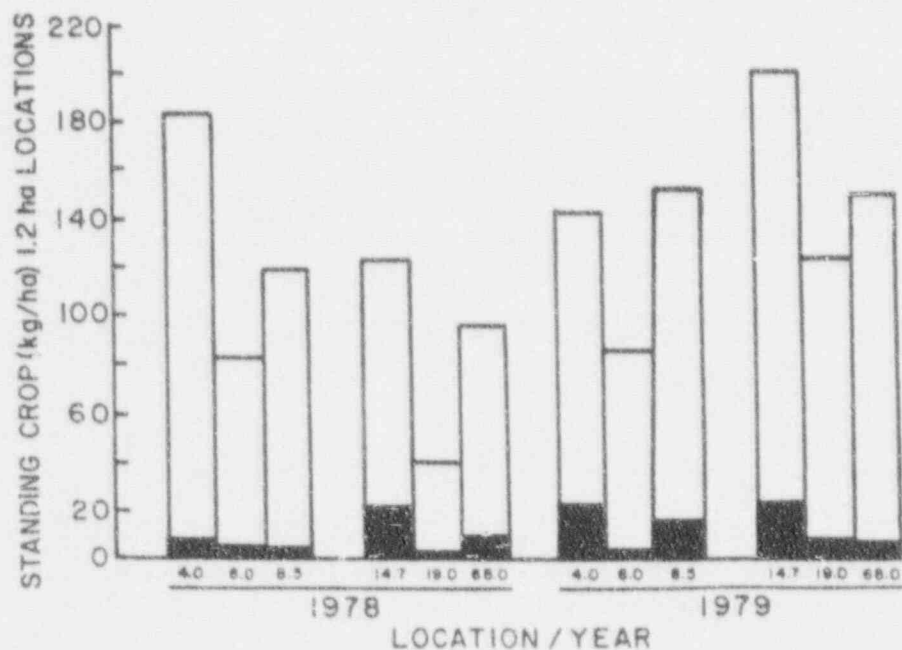
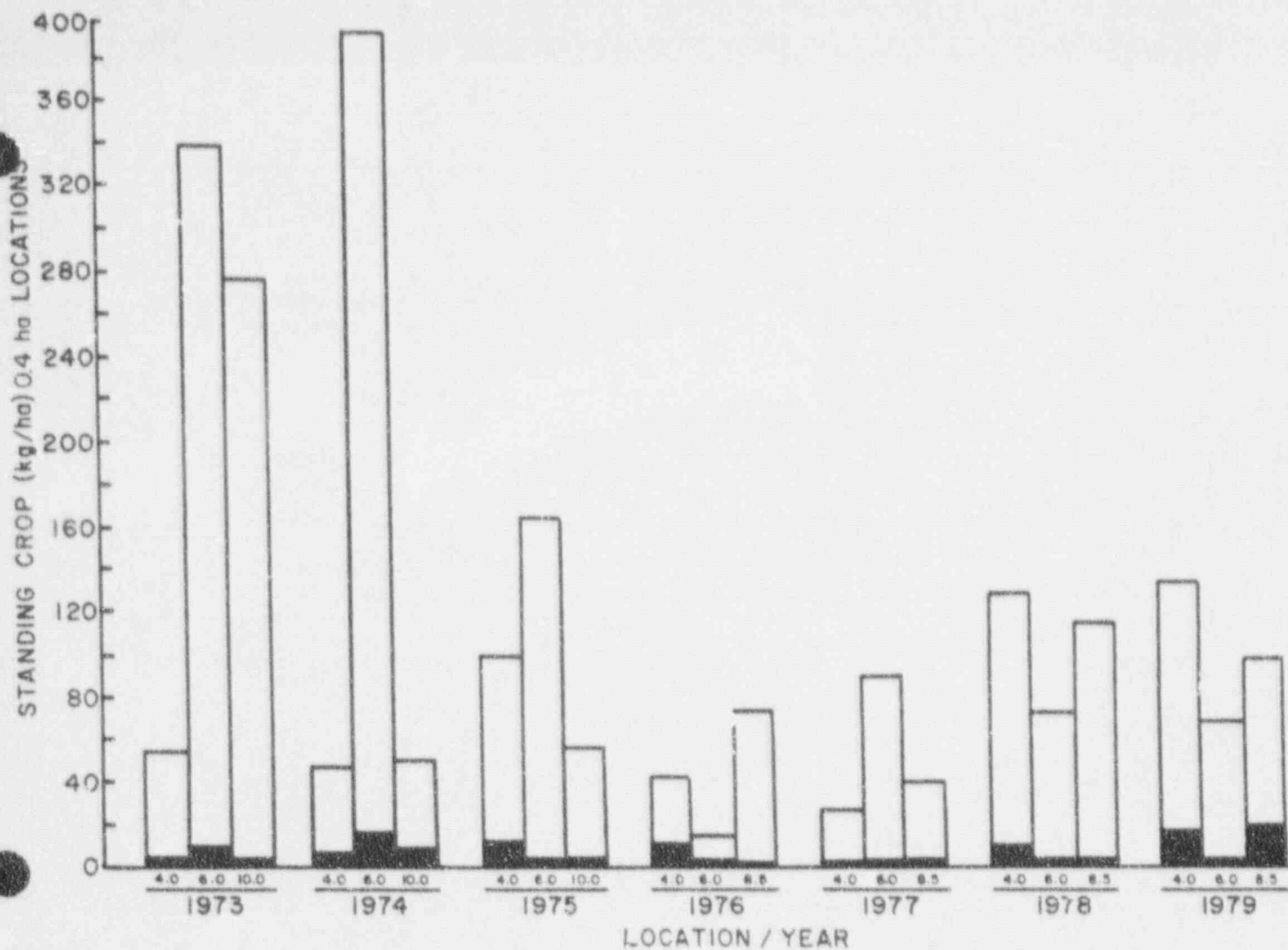


Figure 10-1. Total standing crop (□) and harvestable sport fish crop (■) from 0.4 ha sampling locations during 1973 through 1979 and 1.2 ha sampling locations during 1978 through 1979 on Lake Norman, NC. Harvestable crops are defined using the criteria of Hayne et al. (1967) with the restrictions of North Carolina creel limits and including only ictalurids, percichthyids, and centrarchids.

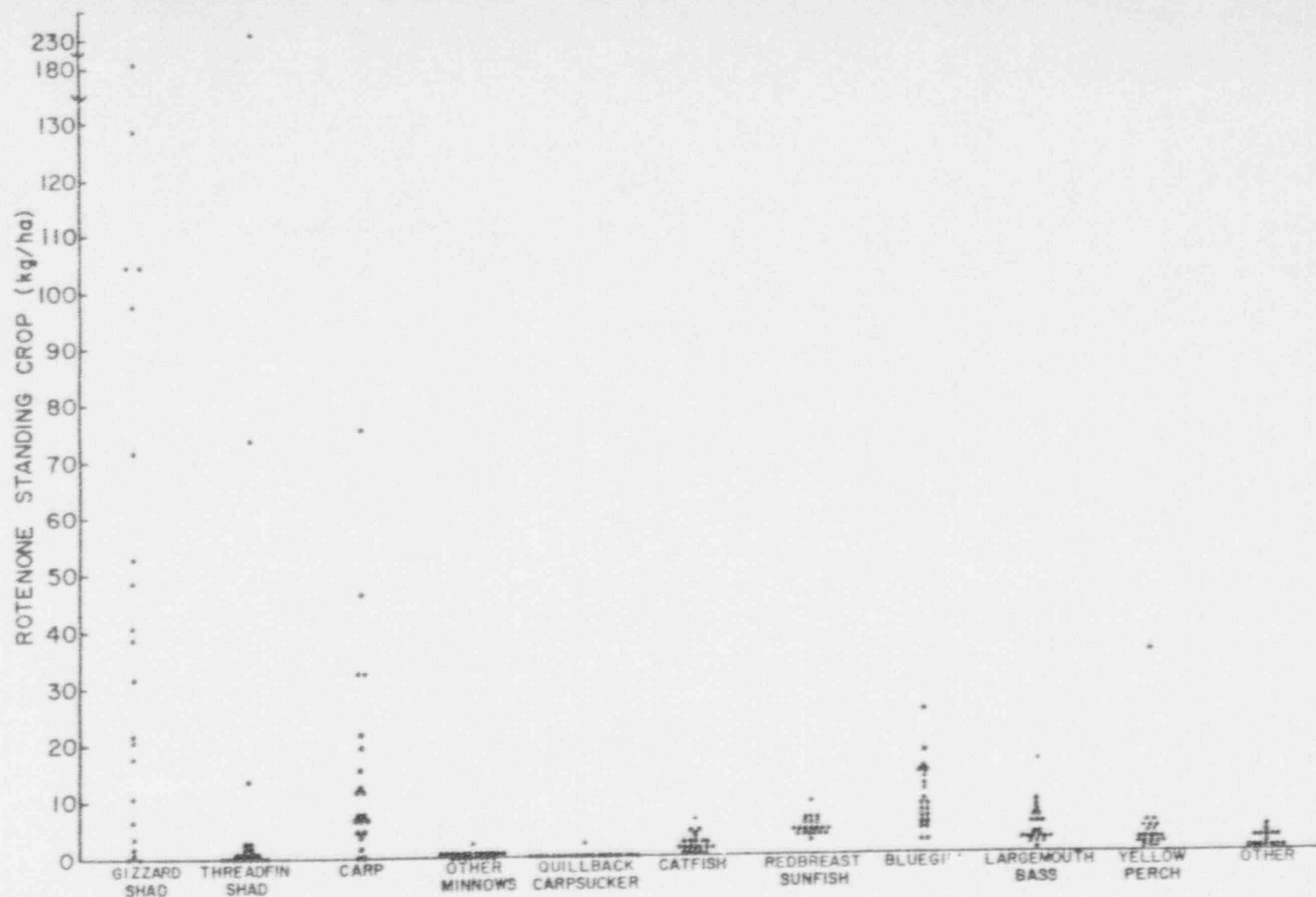


Figure 10-2. Distribution of annual catches by taxon for 0.4 ha rotenone samples. Data points represent catches from 1974 through 1979 at Locations 4.0, 6.5/6.0, and 10.0/8.5 on Lake Norman, NC.

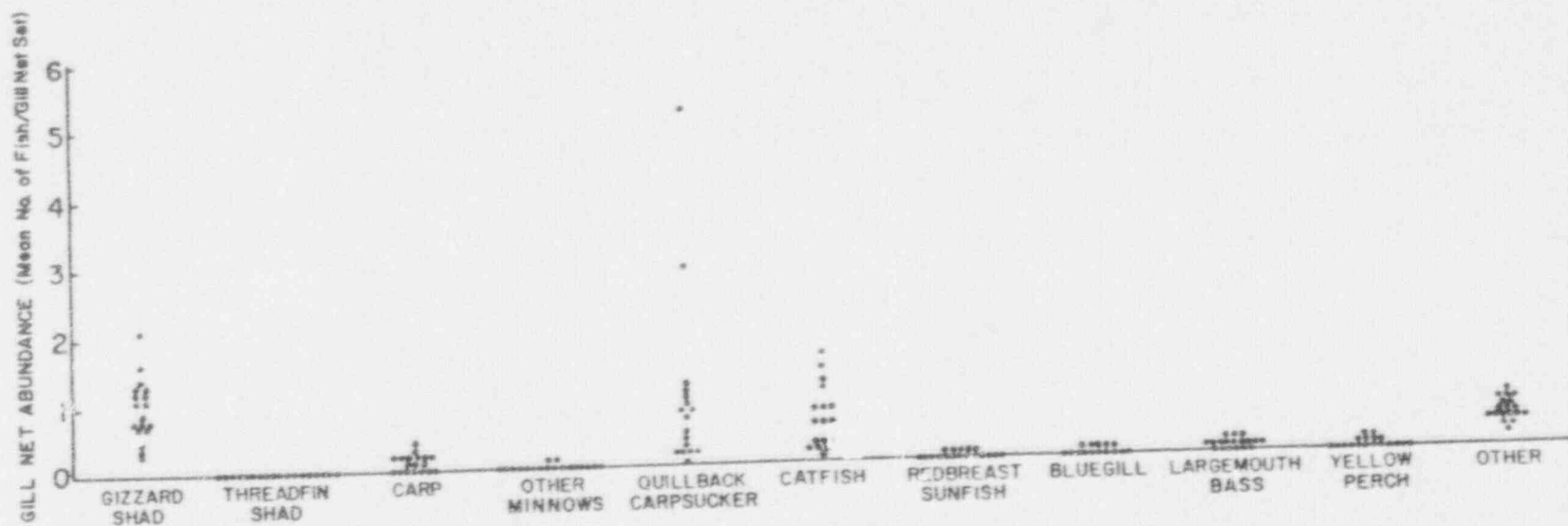


Figure 10-3. Distribution of average catches by taxon for gill net sets at Location 1, Lake Norman, NC. Data points represent catches from 1974 through 1979 at Location 1.

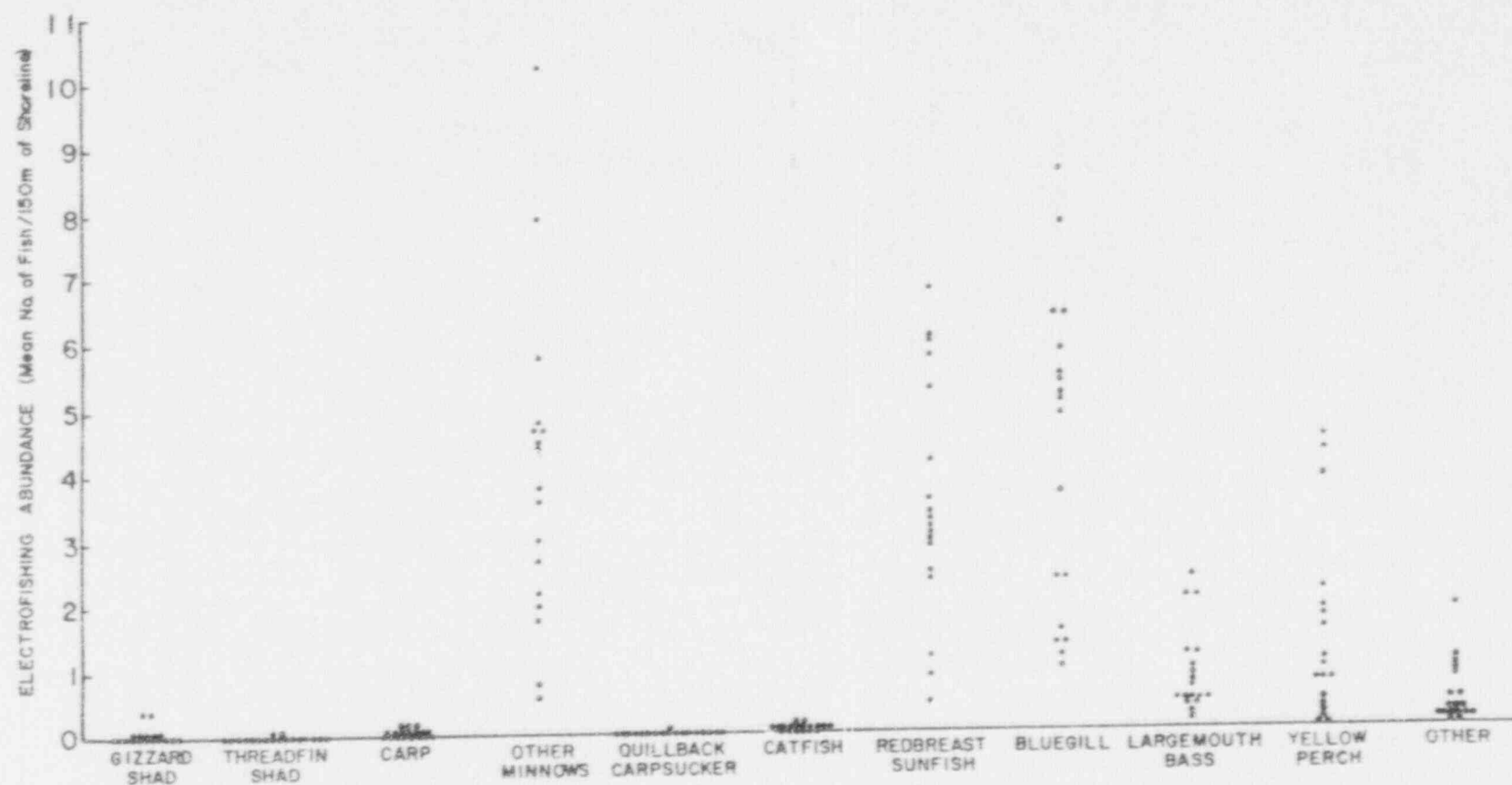


Figure 10.4. Distribution of average catches by taxon for quarterly electrofishing samples. Data points represent catches from 1974 through 1979 at Locations 4.0, 6.5/6.0, and 10.0/8.5 on Lake Norman, NC.

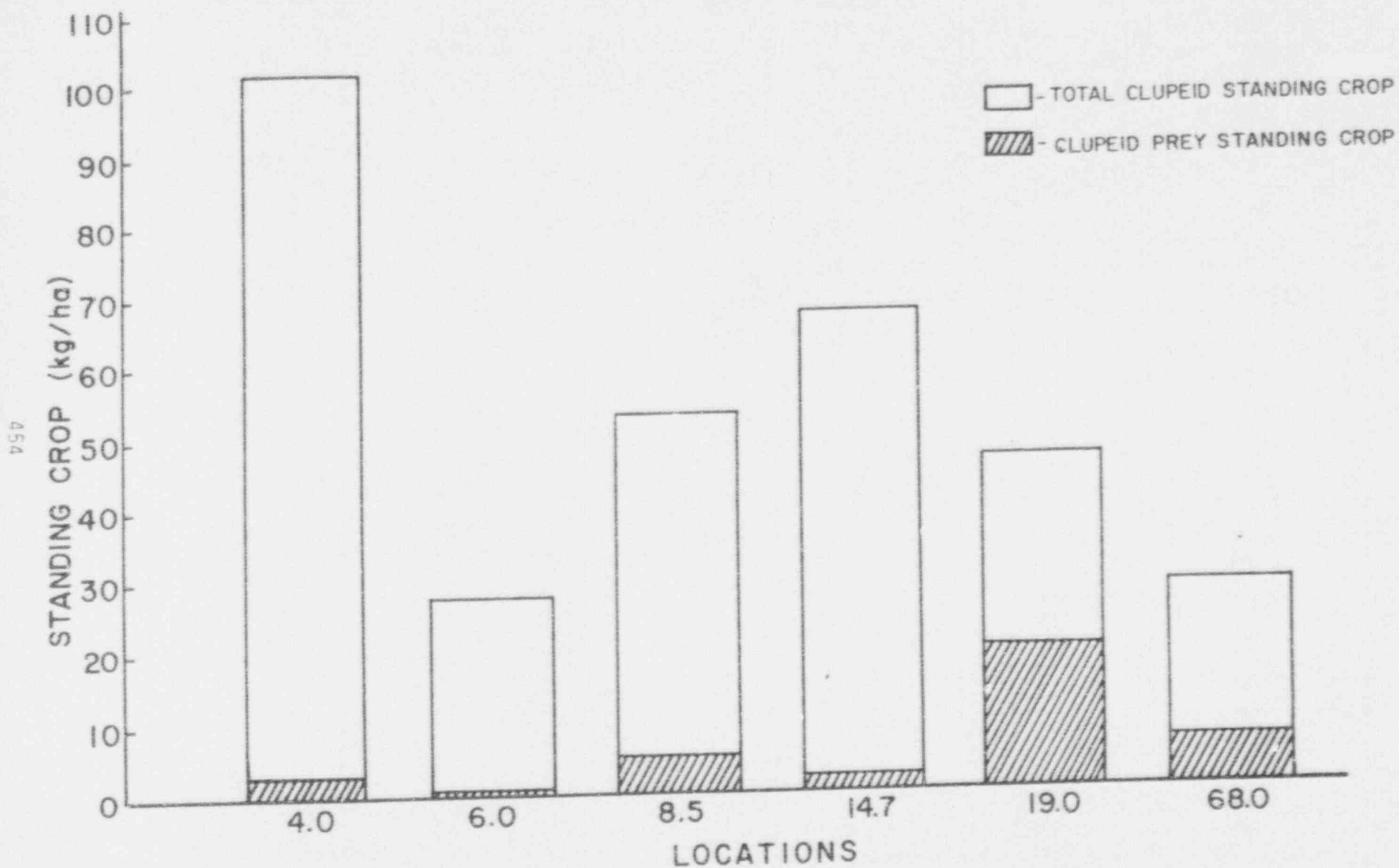


Figure 10-5. Total clupeid standing crop and clupeid prey crop (<140 mm) from six locations on Lake Norman, NC. Values represent means of 1978 and 1979, 1.2 ha rotenone samples.

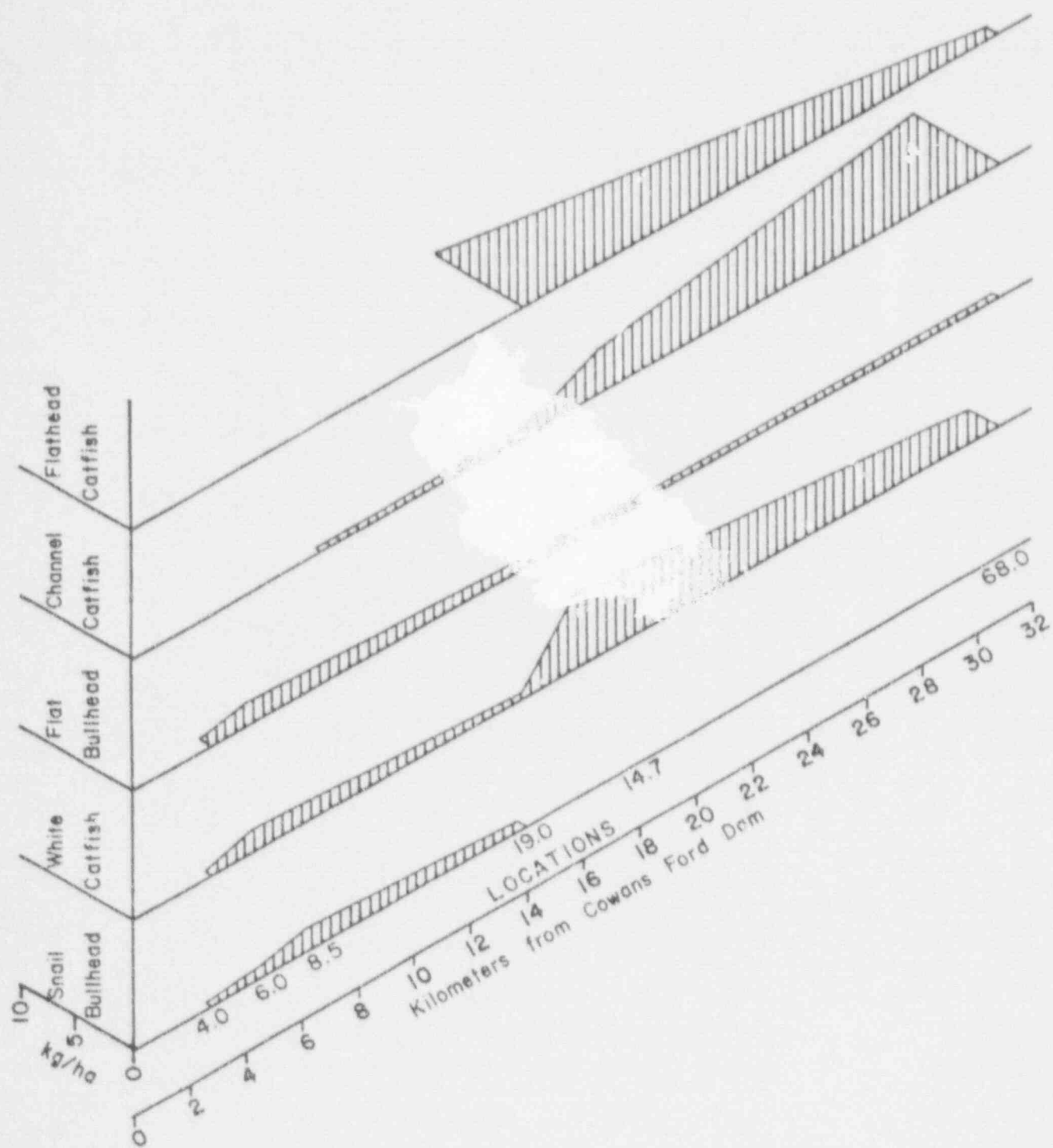


Figure 10-6. Standing crops of five species of ictalurids from six rotenone sampling locations on Lake Norman, NC. Values represent means of 1978 and 1979, 1.2 ha rotenone samples.

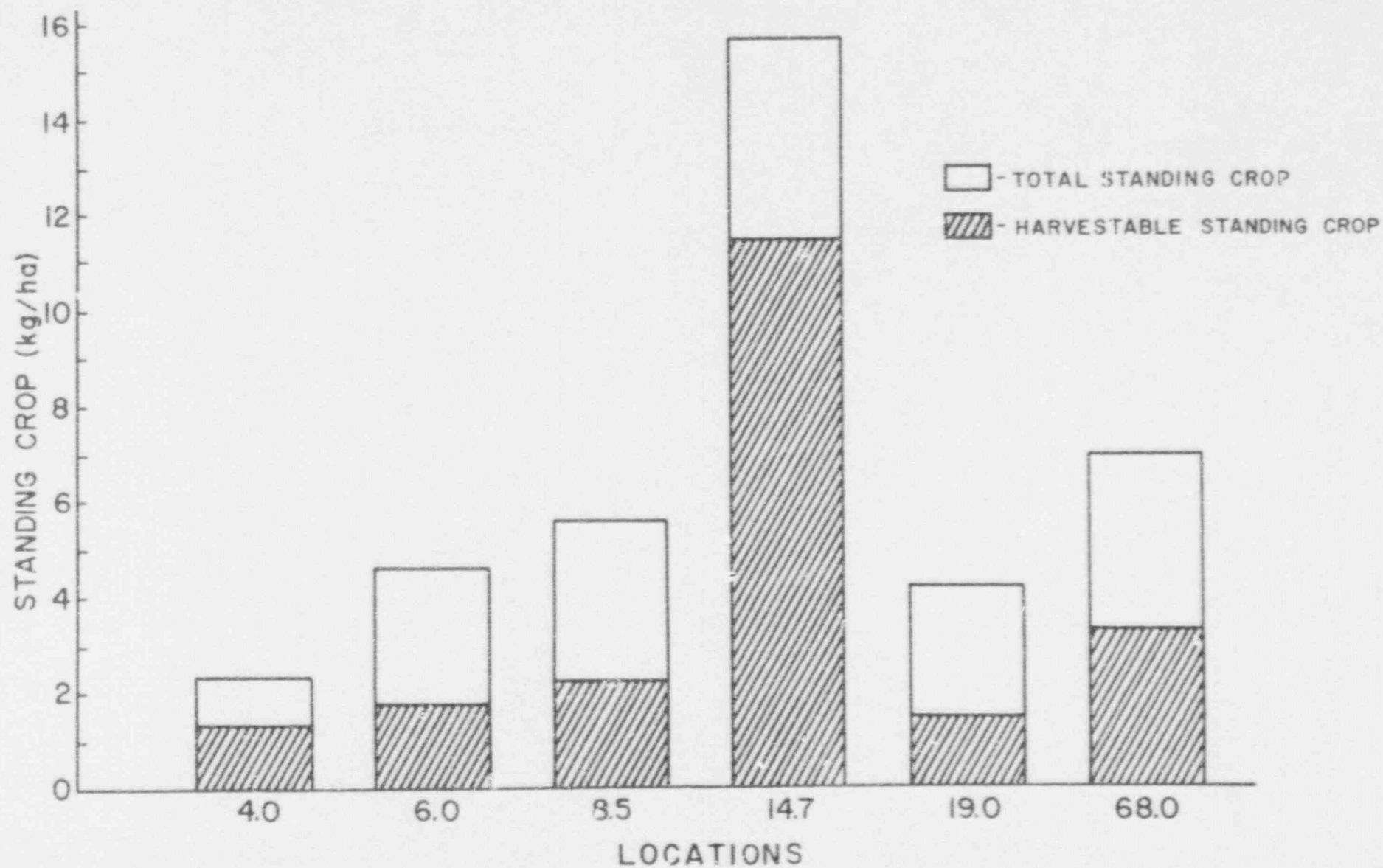


Figure 10-7. Total and harvestable (>305 mm) standing crops of largemouth bass from six locations on Lake Norrmann, NC. Values represent means of 1978 and 1979, 1.2 ha rotenone samples.

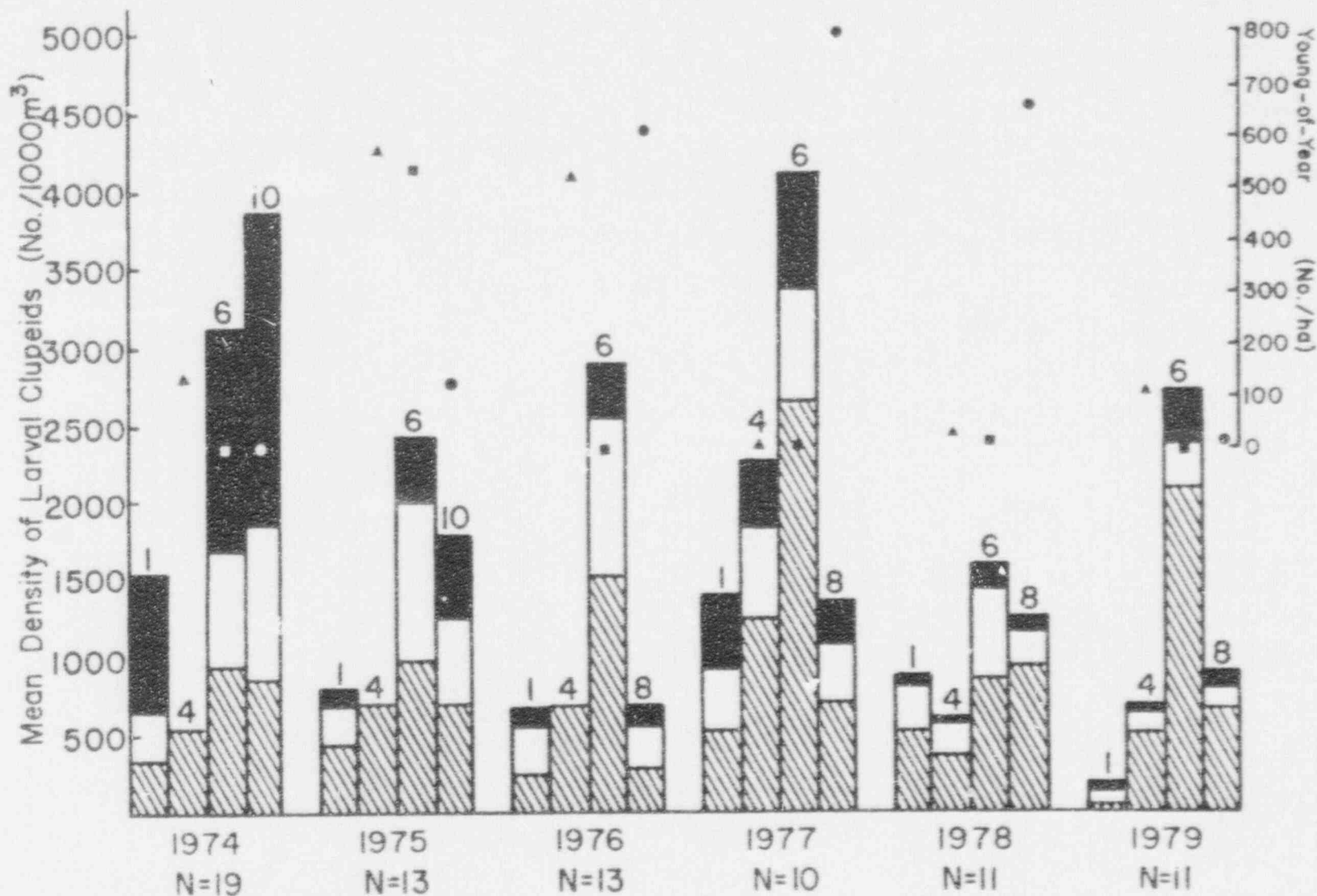


Figure 10-8. Yearly mean density of larval clupeids (number/1000 m³) having a total length <21 mm collected in Lake Horman, North Carolina. N = number of sampling dates larval clupeids were collected. The number above the bar represents the location. The slashed portion of the bar represents the mean density at shoreline areas, the blank portion the mean density of surface channel areas, and the solid portion the mean density at 5-m channel areas. The standing crop of young-of-year threadfin shad is indicated by a triangle for Location 4.0, a square for Location 6.0, and a circle for Location 10.0/8.0.

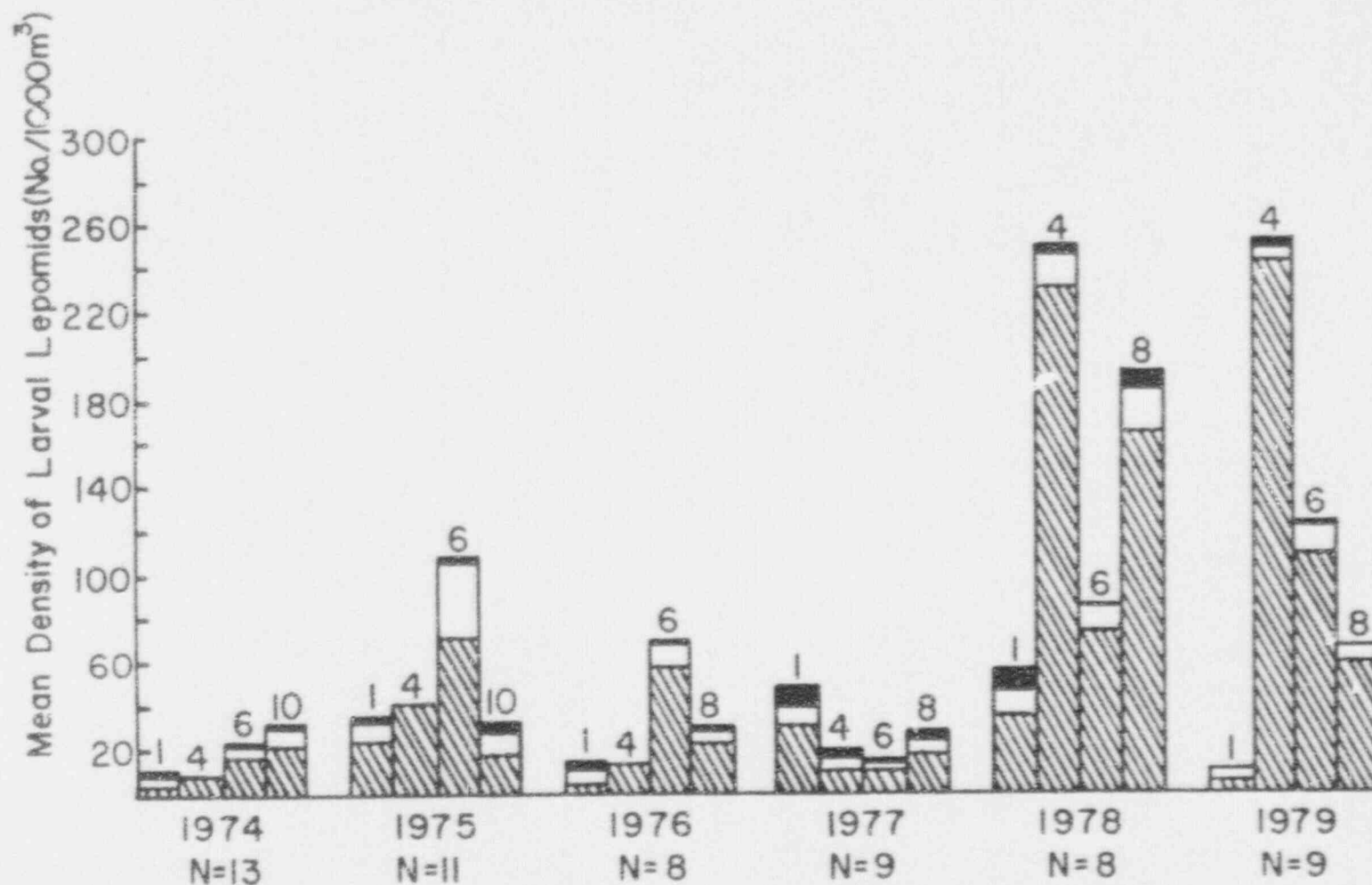


Figure 10-9. Yearly mean density of larval lepomis (number/1000 m³) having a total length of ≤ 21 mm collected in Lake Norman, North Carolina. N = number of sampling dates larval lepomis were collected. The number above the bar represents the location. The slashed portion of the bar represents the mean density at shoreline areas, the blank portion the mean density of surface channel areas, and the solid portion the mean density at 5-m channel

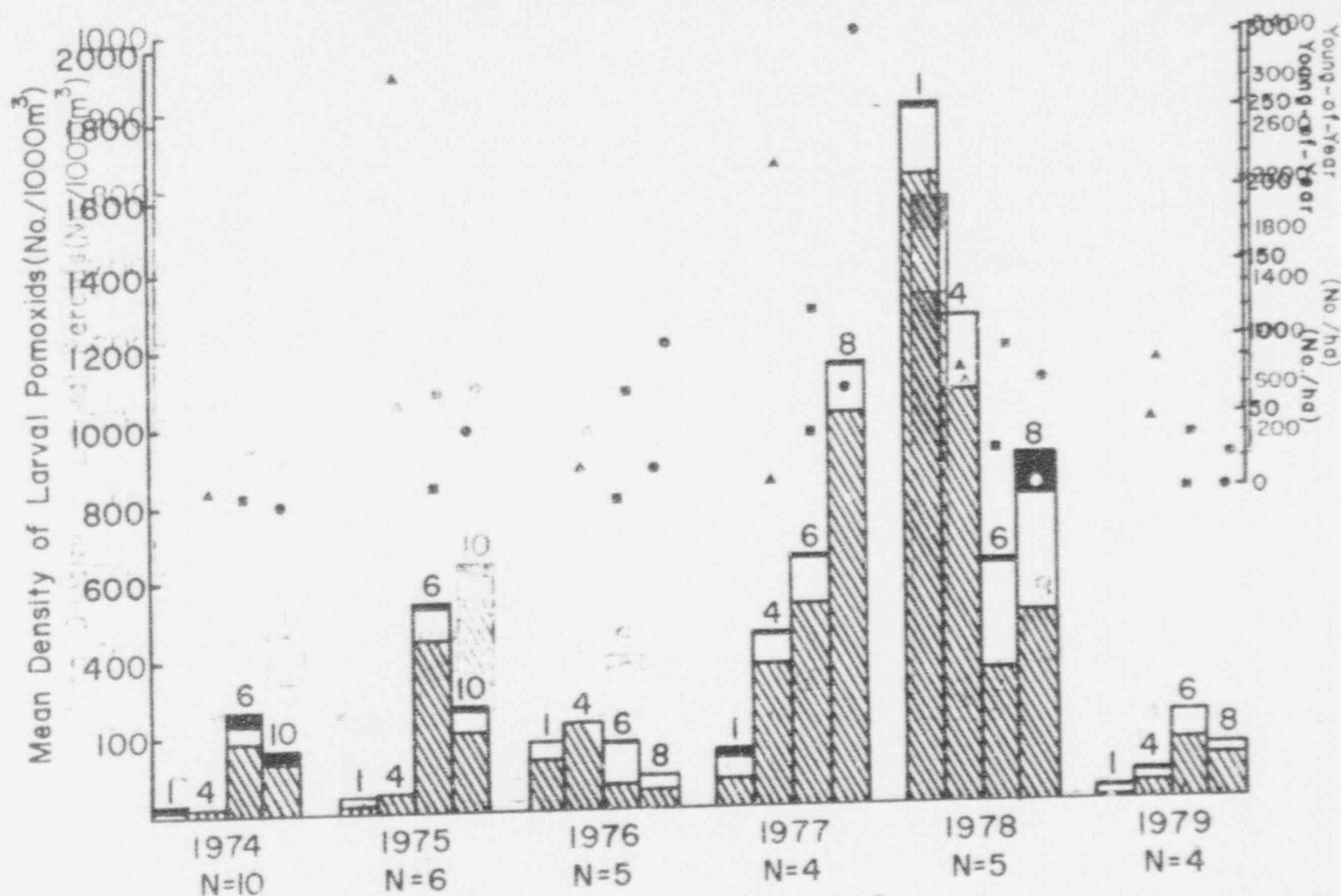


Figure 10-10. Yearly mean density of larval pomoxids (number/1000 m³) having a total length ≤ 15 mm collected in Lake Norman, North Carolina. N = number of sampling dates larval pomoxids were collected. The number above the bar represents the location. The slashed portion of the bar represents the mean density at shoreline areas, the blank portion the mean density at 5-m channel areas. The standing crop of young-of-year pomoxids is indicated by a triangle for Location 4.0, a square for Location 6.0, and a circle for Location 10.0/8.0.

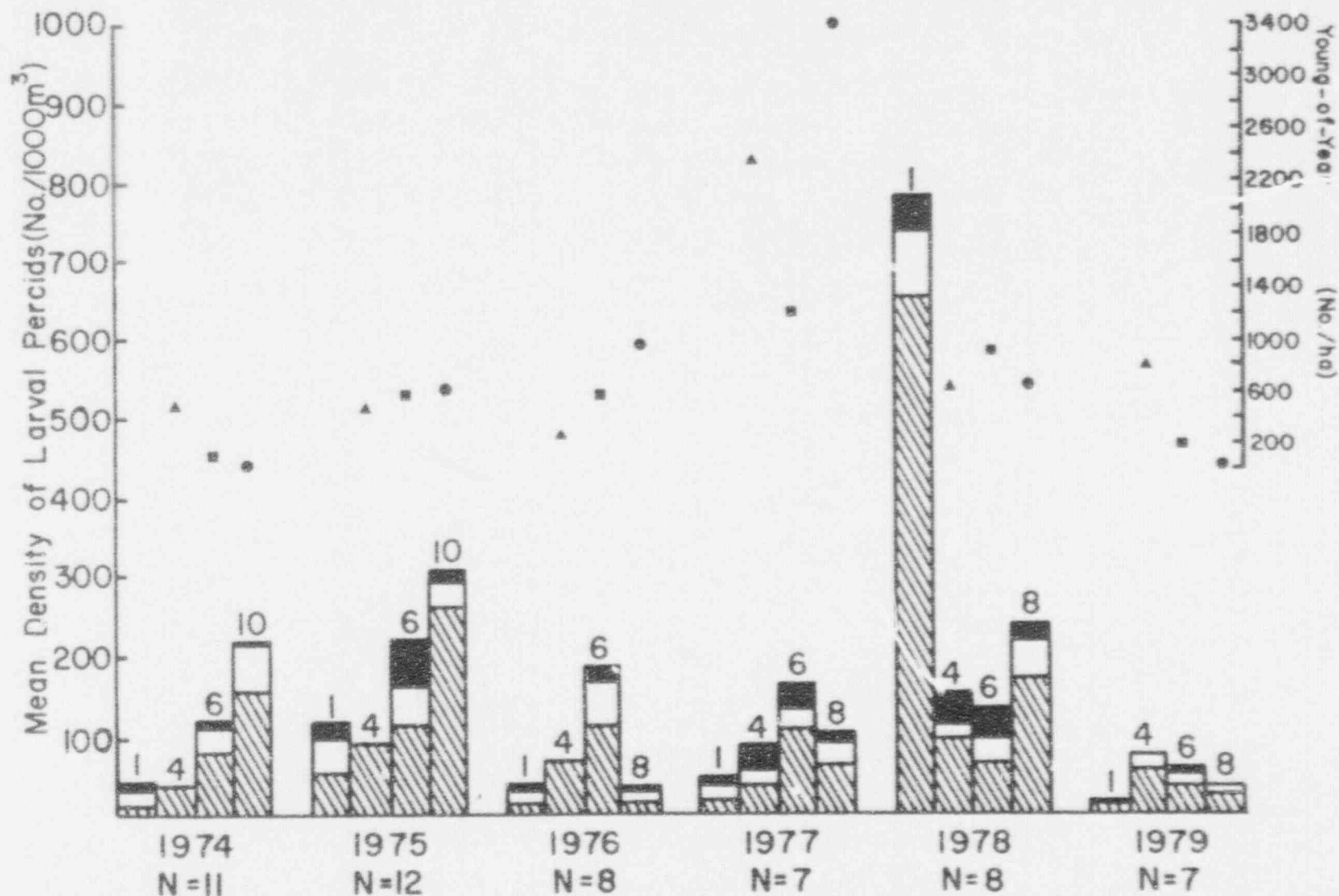


Figure 10-11. Yearly mean density of larval percids (number/1000 m³) having a total length <21 mm collected in Lake Norman, North Carolina. N = number of sampling dates larval percids were collected. The number above the bar represents the location. The slashed portion of the bar represents the mean density at shoreline areas, the blank portion the mean density of surface channel areas, and the solid portion the mean density at 5-m channel areas. The standing crop of young-of-year percids is indicated by a triangle for Location 4.0, a square for Location 6.0, and a circle for Location 10.0/8.0.