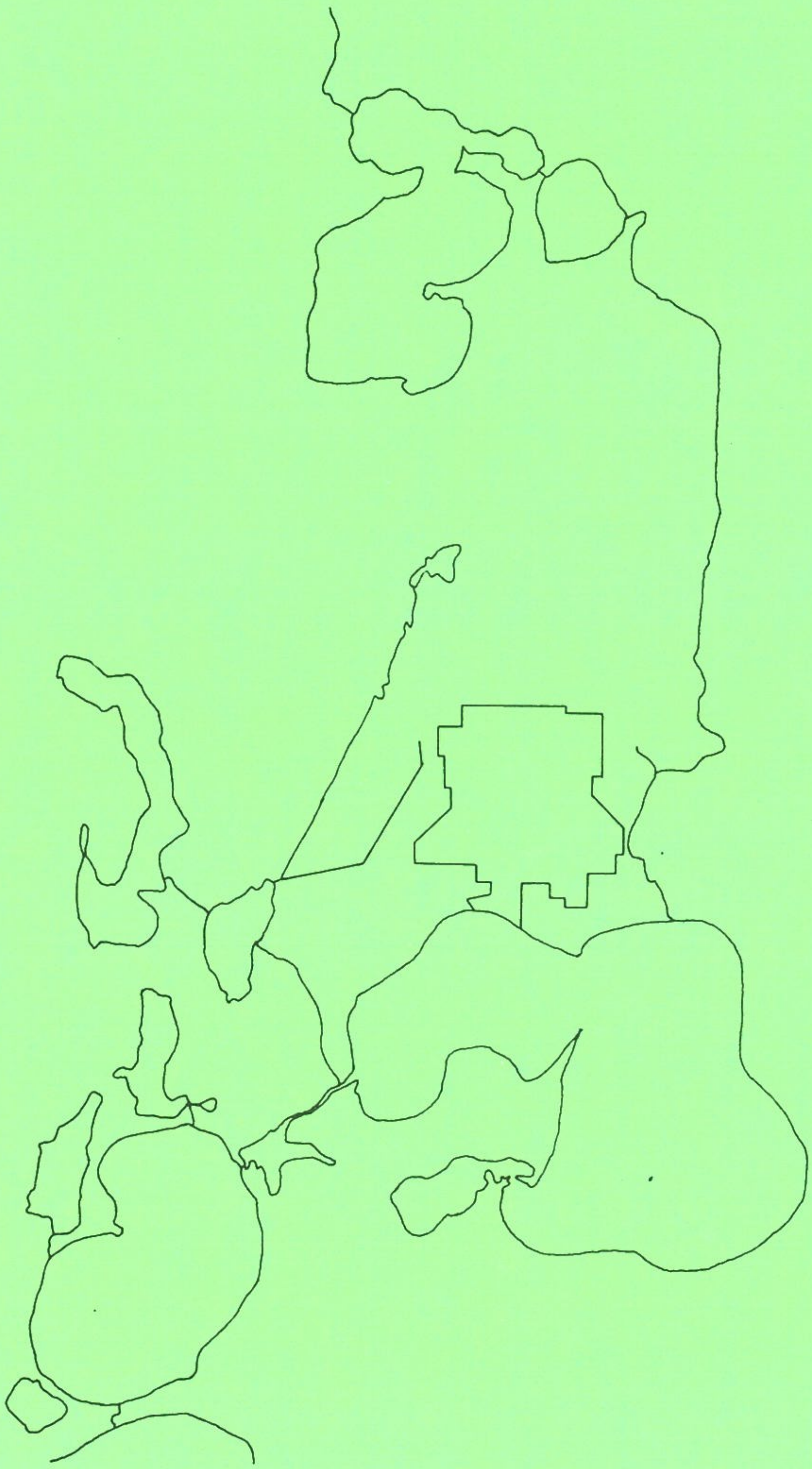
r Pelican River Watershed
Becker County, Minnesota
Impact of Special Phosphorus Removal Procedures



June 1981

Impact of Special Phosphorus Removal Procedures in the Upper Pelican River Watershed, Becker County, Minnesota, 1977-80

Joe K. Neel
Professor Emeritus of Biology
University of North Dakota
Grand Forks, North Dakota

June 1981

ABSTRACT

Stabilization pond effluent that had been previously subjected to sludge removal, biofiltration, and aeration, was treated in summer by land application (spray irrigation and intermittent discharge to grassed adsorption galleries or infiltration basins) and in winter by chemical (lime) precipitation for additional phosphorus removal. In 1977-78 P reduction ranged from 76-81%, being greatest with spray irrigation and lowest with infiltration basins; in 1978-79 it varied only from 74-76% among the three methods; but in 1979-80 spray irrigation showed almost 96%, infiltration basins 84%, and chemical precipitation only 63% phosphorus removal. The precipitation plant had no practical effect upon nitrogen; effects by infiltration basins ranged from 11% increase to 53% reduction, and by spray irrigation from 86% increase to 77% reduction. Increases were during the first two years. Nitrogen and phosphorus had ground water sources other than the wastewater influent.

Despite reduction achieved by the above methods, P concentration in Lake Sallie, downstream from the treatment area, increased in 1977-78 and 1978-79 with contributions from the east side of the upper watershed through Detroit Lake. These P elevations were accompanied by reduced blue-green plankton growth, which apparently resulted from removal of some other, to date unknown, wastewater nutrient elements. In 1980 zero inflows over a large part of the growing season greatly lowered the phosphorus and presumably the unknown nutrient elements, and phytoplankton growth was the lowest observed. No nuisance conditions developed in Lake Sallie over 1977-80, but drifts approaching critical stages occurred over limited areas of the lake in 1979 and 1980. Thick, extensive blue-green drifts that characterized the early and mid-1970's seemed a part of the past. Ground water effects of land application of wastewater influent varied from year to year.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

Financial support for this study was provided by the Pelican River Watershed District and the Minnesota State Planning Commission. Lakeside (Lake Sallie) laboratory and storage facilities were made available by the Minnesota Department of Natural Resources, with local cooperation by M. Branby, J. Hunnel, C. Nordhausen, and D. Olson. The Pelican River Watershed District and the City of Detroit Lakes continued the fine cooperation they first offered in 1968 when study of this eutrophication problem began. Local interest and help by T.A. Rogstad, W.C. Larson, A. Jahnke, and others aided progress considerably. Project personnel who assisted with data collection were: R. McVoy, J. Meany, A. Ungerecht, D. Klomstad, and R. Jacobsen. C.M. Roy assisted with data analysis and report preparation. Essential contributions by each of the above persons are gratefully acknowledged.

INTRODUCTION

This report details the third of three studies made of cultural eutrophication of lakes in the upper Pelican River watershed, especially Lake Sallie. The first study (1, 1968-71) evaluated the possibility of critical nutrient reduction through harvest of water weeds and associated organisms and led to the belief that removal of all organisms from the lake under consideration (Lake Sallie) would decrease annual nutrient increments insignificantly and contribute little or nothing toward the lake's recovery. Harvest, however, did markedly reduce the growth of aquatic weeds in later years.

The second study (1972-75) was initiated after conferees at a planning conference attended by Pelican River project personnel and representatives of the U.S. Environmental Protection Agency, U.S. Geological Survey, Minnesota Department of Natural Resources, and consultants, decided that a more profitable approach toward solution of eutrophication problems in this lake chain was reduction or removal of nutrients from influent waters. It was recommended that what then appeared the main nutrient inflow into Lake Sallie, wastewater influent from the City of Detroit Lakes, Minnesota, be subjected to additional treatment procedures to reduce nutrients, especially phosphorus. The consensus was that methods applied should include chemical precipitation, intermittent application to grassed adsorption galleries, and spray irrigation. The second study (2), proceeding while these facilities were under construction, provided background data on ground and surface waters, the varying importance of different nutrient sources, precipitation and seepage, a suggested trophic state index, etc. The third study, started after the above treatment facilities were completed, was mainly concerned with the impact of these nutrient removal procedures on the phytoplankton and water chemistry of Lake Sallie and the efficiency of each of the three methods.

This study began June 22, 1977, after the stabilization pond effluent had been applied to infiltration galleries and spray irrigation areas for a few weeks. It continued uninterrupted through May 31, 1979, but was limited by personnel shortages to phytoplankton sampling through the summer and fall of 1979. Chemical sampling began again in late 1979 and continued through October, 1980. Ground water elevations were not recorded prior to November, 1978.

29 | .45

SUMMARY OF MAJOR FINDINGS

The most significant occurrence during this three-plus year study was alleviation of objectionable conditions that had plagued Lake Sallie for a number of years. This situation had been largely promoted by blue-green algae, and their reduction by operation of special wastewater phosphorus removal facilities resulted in improvement of the lake. Recovery, however, did not appear to involve decrease of phosphorus, which over the period 1977-78 was more concentrated than previously in Lake Sallie, but rather from decline of other, to date unknown, nutrient elements or compounds that had formerly reached the lake from the wastewater.

Reduction of critical elements other than phosphorus is also indicated by decline of phosphorus consumption in Lake Sallie. Mean depletion of the influent P load over 1973-75 was 10,082 pounds, whereas it was 2,574 and 951 pounds, respectively, in 1978-79 and 1979-80.

Cessation of surface water inflow into Lake Sallie over a large part of the 1980 growing season lowered the influent phosphorus load and that of other algal nutrient substances. Which of these reductions was instrumental in bringing about lowered blue-green phytoplankton growth that year is not known from these records, but decline in phosphorus consumed in Lake Sallie strongly suggests that it was the latter.

Phosphorus loads that have reached Lake Sallie from the eastern part of the upper watershed through Detroit Lake have been adequate in years with the usual inflow to assure that element's remaining non-limiting to algal growth, and blue-green algal density observed in 1980 may be near the minimum that may be anticipated in this lake until phosphorus and possibly other nutreint levels are lower over the general watershed. Blooms may be expected at intervals, but low severity appears probable.

Plants use more nitrogen than phosphorus, but since determination of amounts fixed by blue-green algae in these lakes has been beyond the resources of this project, the extent of its limitation of algal and other plant growth has not been ascertained. The major nitrogen load to Lake Sallie has been supplied by St. Clair Lake, and its sources therein could include effluent from the chemical precipitation plant, algal N fixation, County Ditch 14, and possibly seepage to the ground from the stabilization pond. Surface inflow from Long Lake would be at most a minor contributor.

Operation of the three types (chemical precipitation, spray irrigation, and infiltration basins) of special phosphorus removal procedures gave near the same percentage reduction by each in 1977-78 and 1978-79. Efficiency of chemical precipitation fell considerably in 1979-80, while that of spray irrigation increased markedly above its previous levels. Reduction in infiltration basins in 1979-80 was 8-10% above levels of the preceding two years.

Chemical precipitation had very little or no effect upon nitrogen concentration of the wastewater influent, and reduction by spray irrigation exceeded that of the infiltration basins markedly in 1977-78 and 1979-80 and slightly (8%) in 1978-79.

Effects of land application of the wastewater influent often differed in ground water at individual sites over the affected area and from year to year. Variation, described in the body of this report, was related to differences in soil permeability, surface and subsurface flow patterns, and height of water table (there are probably other factors), and an adequate working knowledge of general effects on ground water would seem to require several years' water table elevation and analysis records. Land application of the influent initially increased the mineralization of ground water, sometimes at some distance from the recipient area, apparently by further leaching of calcium, magnesium, and other metal compounds from the soil, and introduction of chloride in the influent. It also at first leached significant quantities of nitrogen from upper soils, but such pick-up did not occur during 1980, when mineralization gained from the ground by applied influent was less noticeable than in former years. Ground application of wastewater has had no discernible effects upon surface waters to date.

RECOMMENDATIONS

1. Spray irrigation proved the most effective of the three special procedures applied to remove nutrients from the wastewater influent over this three-plus year period, and it appears desirable, both from the standpoints of waste reduction and economic advantage, to utilize this method to the greatest extent possible. It is not feasible during winter months, and provision of storage facilities to hold the stabilization pond effluent (wastewater influent) over this period may prove more advantageous, economically and technologically, than operation of the chemical precipitation plant. It is recommended that this matter be given serious consideration.

2. Growth of noxious blue-green and other algae in Lake Sallie has declined in response to special wastewater treatment procedures and meterological conditions that reduced influent surface water flows. Developments in Lake Sallie should be followed for a few more years with a minimum program that involves weekly examination of plankton in influent (Station 1) and effluent (Station 8) and near lake center (Station 4-1). This sampling should be accompanied by observations to detect plankton drifts, odors, and development of attached filamentous algae.

3. Ground water response patterns to land application of wastewater influent are incompletely known from three years' records representing only five of 33 sampling and observation sites in the general treatment area. Facilities available here offer an unique opportunity for study of wastewater effects on ground water and it is recommended that they be maintained and made available for any state, federal, or university subsidized study of this aspect.

4. The upper Pelican River watershed offers exceptionally good opportunities for more detailed disclosure of human influences on water quality and other aspects of a lake-river system; it has three studies that will furnish background and baseline information, and a Watershed District Board that is vitally interested in preservation of this aquatic resource. Its availability for study by governmental agencies and/or universities should be kept in mind and made generally known. Determination of phosphorus sources now affecting discharge from Detroit Lake appears especially relevant.

5. Alleviation of the Lake Sallie problem to the extent now accomplished will probably result in diversion of some attention of the Pelican River Watershed District Board to matters considered more pressing, but it is hoped that the eutrophication potential will be kept in mind and provision made to allow investigation of problems that may arise in the future.

STUDY AREA

The studied upper Pelican River watershed (Figure 1) extends from the head of Campbell Creek to the Pelican River exit from Lake Sallie. It incorporates nine lakes, the City of Detroit Lakes, Minnesota, and its waste treatment facilities, which are diagrammed in Figure 2. The waste treatment plant provides primary treatment by sludge settling and digestion and secondary treatment by biofiltration. The plant effluent is sent to an aerated pond where additional oxygen is supplied by a tethered aerator. The stabilization pond, next stop of the effluent, formerly discharged south toward St. Clair Lake, but now provides influent to the chemical precipitation plant in winter and the infiltration basins (adsorption galleries) and spray irrigation plots during open water seasons. Influent is pumped to the galleries and irrigation plots from the chemical precipitation building.

Thirty-three ground water sampling and observation wells were established in 1973 at the sites shown in Figure 1 and seven observations wells (not shown) were drilled near Long Lake. Ground water sampling site locations are shown in Figure 2 and surface water sampling stations (E, F, M, N, 1, 4 and 8) may be located in Figure 1. Manhole (MH) 18, near the chemical precipitation plant, was used, when flowing, as a diagnostic site for the entire infiltration basin area. It lacked discharge most of the summer of 1980. The area represented by PC16 (sampled only in 1980) did not receive surface application of wastewater influent, but evidently received some stabilization pond seepage. Other details of the studied area may be gained from (2).

Treatment Facility Operation Periods

	Spray Irrigation	Infiltration Basins	Chemical Precipitation
1977	May 5 - Oct. 24	April 7 - Nov. 21	Nov. 21 - April 18, 1978
1978	May 19 - Oct. 23	April 18 - Dec. 1	Dec. 4 - April 18, 1979
1979	May 14 - Oct. 16	May 11 - Dec. 10	Dec. 10 - April 10, 1980
1980	April 15 - Oct. 22	April 10 - Dec. 15	Dec. 15 - April 3, 1981

METHODS

Collection and analysis methods for water chemistry and phytoplankton were those listed in Standard Methods, 13th edition (3). Measurement of discharge (1978-80) depended upon daily stage records and weekly discharge determination by the U.S.G.S. center section method.

RESULTS OF STUDIES

Ground Water

Elevation

Height of water table at each of the five sampling wells, November, 1978 - May, 1979, indicated that ground water movement was toward the spray irrigation and infiltration basin areas from the upper airport region (Figure 3). The general ground water decline beginning in early winter was rather abruptly reversed in most areas by snow melt in April, but relative elevations exhibited earlier were maintained. Variation in ground water over the last seven months of 1979 appears in Figures 4 and 5. At three sites (PC12, 13 and 18) elevation rose in late June or early July, remained high until late September, and then declined to its early June level by the end of December. At PC3 it remained almost uniform over the seven months, rose and declined slightly at PC19, and varied up and down at PC10 and 11, dropping steadily at each during the last months of the year.

1980 ground water level increased rather steadily from April 26 (Record 8) to October 11 (Record 19) at PC12, 13 and 18 (Figure 6). At PC10 and 11, in irrigated plots, it rose from early April until late June (Records 7-13) and then varied until late October, remaining two to three feet higher than in winter or early spring. At PC19, except for a dip in late September, it was rather uniform after it rose slighly in early April (Figure 7).

Dilution and Replacement by Wastewater Influent

In 1977 chloride concentration in the wastewater influent ranged from 225 to 400 mgl, and that in native ground water from 18 to 30 mgl. This difference permitted recognition of influent dilution or replacement of ground water, and ground residence time of influent at each ground water sampling site. At PC3, in the infiltration basin area, and at PC10, in Irrigation Area 3, Cl concentration indicated that the influent had completely replaced native ground water in July, 1977, (Figure 8 and Table 1). It remained near the influent level at these two sites until land application of wastewater ceased, and then the influent was rather quickly replaced by native ground water. Chloride increased sharply at PC3 when influent application to infiltration basins was resumed, but no increase was evident at PC10 by June, 1978. Irrigation was delayed until May 19.

Ground water evidently receives an exceptional share of surface runoff at PC11, in Irrigation Area 4, since total hardness shows (Figure 22) it had been diluted ten or more times as much as other sites during snow melt. Influent did not completely replace native ground water there, but chloride peaked at 60% of the mean influent level in December, 1978, and declined rapidly after January, dropping to the ambient level in April, 1979.

PC19, 750 feet WNW of Irrigation Area 1, where mean water level over 1973-75 was 1.39 feet higher than at PC20 within this influent application area, did not show meaningful chloride increase until November, 1977, and reached a maximum concentration (37% of the influent level) in January, 1978. It then declined, but did not drop to the ambient level until May, 1978.

At PC32, 200 feet SE of the infiltration basins, near influent chloride levels were maintained over the period July, 1977, to January, 1978, when sampling at that site was discontinued and PC13 substituted (Table 1).

The above account considers only upper layers of phreatic water, since this zone was too shallow for deeper sampling at PC10 and 19. Deeper layers at PC3 showed complete displacement by the influent in July, 1977 (Table 1) and a loss in Cl concentration in January, as in the upper layers, but they were much more influenced by snow melt than their counterparts at PC3. At PC32 upper and lower ground waters were quite similar in chloride content.

In 1978-79 wastewater evidently replaced native ground water in infiltration and spray irrigation areas shortly after land application began in 1978 (Figure 9). Replacement was earlier in the infiltration basin area (PC3) which went into operation 15 days before spray irrigation plots (PC10 and 11). PC11 again showed the effects of greater natural inflow, seldom achieving chloride levels comparable to those at PC10. PC19, which appeared from chloride data to receive water from Irrigation Area 1 that remained from November, 1977, through January, 1978, was less affected in 1978-79, although a slight chloride elevation occurred there in December, 1978. Elevation at PC20 in Area 1 exceeded that at PC19 several times during summer of 1979. PC13 was unaffected by wastewater chloride in 1978-79.

Chloride in ground water at varied sites in 1980 is compared with that of the influent in Figures 10 through 14. Ground water at PC3B and PC16B exceeded the influent in this respect in March and April, but fell below it for the remainder of the sampling period. The initial high concentrations for bottom water at these sites may have represented stagnant water that was moved out when land application began. PC10 had greater chloride concentration than the influent in August and September, but fell below it in October. At PC11 chloride remained below the influent concentration all year, but showed an increase with passage of time, as did PC10, 16 and 13. At PC3B it showed a decrease after May and at PC3T leveled off after an increase in May. Ground water at PC13 showed a notable increase in chloride, suggesting penetration of influent to that site for the first time. Water level at PC13 has been exceeded only by that at PC18, which, when sampled in May and June, 1980, also showed a chloride increase above ambient, although below that at PC13. These events indicated the presence of ground water levels higher than any measured in Irrigation Plot 2, which may initiate flow of influent toward the north and west when natural ground water levels decline. PC19 showed uniform ambient chloride levels over the 1980 sampling period.

Temperature

In general, ground water temperature was below that of the influent in summer and above it in winter. In 1977-78 (Figures 15 and 16) PC11T equalled the influent temperature in September and was warmer than other sites in summer. In 1978-79 ground water (Figure 17) had its greatest temperature range at PC3, was seemingly affected by snow melt only at PC11, and was most uniform at PC13 and 19. In 1979-80 influent temperature ranged (monthly means) from 1.5° C in February to 24.2° C in July (Figure 18). Ground water temperature showed the greatest range at PC11T, from a monthly mean of 5.3° C in April to one of 17.3° C in August (Figure 19). Minimum temperatures were recorded in March and April, following snow melt, and maximums in late summer, but this was not always characteristic of all sites, as reference to Figure 19 and 20 will show.

Alkalinity and Hardness

In 1977-78 ground water under irrigation areas and infiltration basins showed increases over 1973-75 levels in the above two respects. Hardness concentrations of the wastewater influent (mean, 298 mgl) increased with flow through the earth, up to a mean of 506 mgl at PC10, 315 at PC3, 303 at PC11, and 372 at PC32. Alkalinity (mean, 329 mgl in the influent) increased less spectacularly at PC3, 10 and 32, and decreased at PC11 where dilution by surface runoff was considerably greater than at other sites. Gain in these two parameters represented pick-up from soil strata penetrated plus some concentration by evaporation. The influent is compared to ground water at four sites in Figures 21 and 22.

In 1978-79 ground water was more mineralized under areas receiving wastewater influent than at higher elevations. This phenomenon was demonstrated by alkalinity (Figure 23), calcium (Figure 24), magnesium (Figure 25), and especially by conductivity (Figure 49), which is influenced by a larger number of mineral compounds, e.g., sodium chloride. The wastewater influent had greater concentrations of alkalinity, chloride, and sulfate (not depicted) than native ground water, but this was not true for calcium and magnesium, and increases in these two elements are assumed due to additional leaching from soils.

Alkalinity of ground water was generally lower in 1979-80 than in preceding years, frequently below the level of the wastewater influent (Figure 26). PC10 rose above the influent level in August and remained there through October. PC3 stayed below the influent concentration all through the 1979-80 sampling period, and PC11B exceeded it from April through July and in October (Figure 27). PC19 had a pattern that seemed to have no relation to the waste influent and PC13 had a low concentration most of the summer that quickly grew to exceed that of the influent in October (Figure 28). Alkalinity demonstrated much less increase than in preceding years.

Calcium concentrations were considerably greater in ground water at PC3, 10, 11 and 32 in 1977-78 than in 1973-75, but they were in the same range at PC19 (Figures 29 and 30). Higher levels were present at the four sites first listed during periods with and without wastewater application, although they fell at PC3T and PC11T and B at spring snow melt. During summer of 1978, concentration at PC10 was lower than in 1977. The mean for PC19 was slightly lower for this period than in 1973-75, and noticeably so at PC13 for the shorter period covered. Higher concentrations at PC3, 10 and 11 continued through May, 1978, while those at PC13 and 19 remained below their pre-land wastewater application levels. In 1979-80 Ca at PC13 rose (annual mean) 142 mgl above its 1978-79 value, while that at PC19 returned to its 1977-78 level (Figure 31). Concentrations at PC3, 10 and 11T stayed far above their 1973-75 values (Figure 32). Calcium and magnesium content of wastewater influent in 1979-80 are shown in Figure 26.

In 1977-78 magnesium attained its highest maximum and mean in ground water at PC10. PC3T had a higher maximum and mean than PC11T or PC32T; PC3B and PC11B showed practically identical maxima and means, but PC32B was higher. Wastewater influent seemed to again influence highest magnesium concentrations in 1978-79 (Figure 25); its influence along this line in 1979-80 was most evident at PC11 and 13 (Figures 33 and 34). It is assumed that the wastewater influent caused the high levels at PC13 most of the year since ground water displayed a much higher than ambient chloride content there. PC11 had one of the higher Mg concentrations in 1978-79.

pH

Ground water pH (Figures 35-40) was clearly affected by the wastewater influent at times. It was observed below 7.0 only once (PC13, December, 1978) where and when it was not influenced by the wastewater. It declined to nearly 7.0 at PC19 in November, 1978, which also appeared unaffected by the influent. The wastewater influent had high pH values (at times above 9.0 and often above 8.0) during the growing season and at times in late fall and early spring or late winter when the stabilization pond evidently supported photosynthesis. During the 1980 period of operation influent pH fell below 8.0 only four times (individual readings) and at times exceeded 9.0 (Figure 41). Ground water had a 1980 range from slightly above 7.2 to 7.8, with higher values at PC16.

Oxygen

Oxygen was low to quite low in the wastewater influent many times when high pH values and the presence of CO_3 alkalinity indicated a photosynthetic activity that would usually be expected to produce high oxygen levels. Time and personnel limitations prevented any special investigation of this discrepancy, but it is suspected that it arose through the activities of heterocystous blue-green algae in the stabilization pond.

Ground water oxygen concentration varied considerably, both among stations and over the seasons, approaching but never observed to decline to 0.0 (Figures 42-47). Its concentration was frequently above that of the influent below infiltration basins and irrigation plots, especially the latter, and it was quite high at PC13 and 19 in 1980.

Conductivity

As would be anticipated from mineral pick-up mentioned previously, conductivity at PC3 and 10 generally exceeded that of the influent during 1977-78 (Figure 48). At PC19, where influent replaced less than 50% of the ground water, conductivity ranged far below that of the influent, and at PC11, with a high natural recharge rate, conductivity exceeded that of the influent only once.

From June 1 to December 14, 1978, ground water exceeded the wastewater influent in conductivity only three times at PC3T, once at PC3B and PC11T, six times at PC10, and never at PC11B, 13 and 19. PC11 had higher values than PC13 and 19, but with few exceptions was noticeably lower than PC3 and 10 (Figure 49 and Table 2).

In 1980 conductivity at PC10 was greater than that in the influent from July through October, but below it in April, May and June. PC3B was higher than the influent until September, but PC3T was below it throughout the land application period, as were PC11T and B. PC13 and 19 fell below the influent at all times and PC16 exceeded it after May. Relative values in ground water at the above sampling sites may be gained from Figures 50, 51 and 52.

Phosphorus

Mean phosphorus concentrations, mgl, in upper levels of the water table and in ground applied wastewater influent were as follows:

	Influent	PC3	PC10	PC11	PC13	PC19
1973-74	-	0.53	0.54	0.76	1.25	1.17
1974-75	-	0.40	0.53	0.56	0.33	0.33
1977, July-Dec.	3.66	0.77	0.61	0.64	-	0.58
1978, June-Dec.	5.07	1.33	0.74	0.95	0.42	0.62
*1979, Jan.-May	4.97	0.60	0.28	0.35	0.26	0.26
1980, Apr.-Oct.	4.56	0.71	0.17	0.21	0.19	0.16

*wastewater influent applied to ground only in May

Since chloride records indicate that the influent replaced native ground water in the infiltration basin area at PC3 and in Irrigation Plot 3 at PC10, and largely in Irrigation Plot 4 at PC11, it is assumed that phosphorus applied in the influent was solely or largely responsible for ground water concentrations at those sites during growing seasons. PC13 and 19 seemed above wastewater influences in 1978-79 and their P concentrations then are assumed native. In 1977, PC19 was influenced by wastewater late in the year, and PC13 from March to October, 1980, but phosphorus showed no appreciable change at either site during those periods.

Phosphorus concentration fluctuated up and down in ground water most years and it is difficult to ascribe reasons for all variation, as it occurred at all times (Figures 53-56). More uniformity was apparent in 1980 than during any previous year, but changes were quite evident then. Discussion of phosphorus removal from the wastewater influent by land application is reserved for a later section.

Nitrogen

From September to December, 1977, nitrogen content of the influent, with one exception, exceeded that of ground water, but in July and August it was considerably lower. It is assumed that N utilization by aquatic plants in the stabilization pond declined after August and again in December to give greater influent values. Some ground water nitrogen originated in sources other than the wastewater influent as is shown by increases at PC3, 10 and 11 between December and April, when no influent was applied to the ground (Figure 57). PC19 also acquired N from other places as shown by high concentrations prior to arrival of the influent at that site. During 1973-74, N was more than twice as concentrated at PC3 than in 1977-78, but was less abundant in upper ground water there in 1974-75, although 1 mgl+ more concentrated in deeper water; PC10 had more N in 1977-78 than from 1973-75; PC11 and 19 exhibited higher mean levels in 1973-75, which was contrary to events at PC32. Table 3 shows ground water nitrogen levels in 1977-78.

Total nitrogen was considerably less concentrated in the wastewater influent during the 1978 growing season (May - November) than from December, 1978 - April, 1979 (Table 2). Growth and proliferation of plants in the stabilization pond are assumed mainly responsible for the lower values. In ground waters (Figure 58) nitrogen was more concentrated at PC13 and 19 than under irrigated areas and infiltration basins. Nitrogen was largely in the nitrate form.

In 1979-80 total nitrogen in the wastewater influent (monthly means) varied from 3.294 mgl in July to 20.149 mgl in February (Figure 59). As in previous years, its lowest concentrations occurred during the most intensive photosynthetic periods in the stabilization pond. Its variation in ground water (Figures 60 and 61) seemed unrelated to events in the stabilization pond at PC3 and 19, but some relationship to lower quantities in the wastewater influent was evident at PC10, 11, 13 and 16.

Surface Waters

Discharge

The greatest water flow of 1978-79 was in spring of the latter year (Figure 62). It was initiated by snow melt and augmented and sustained by later precipitation. Backflow or minus discharge endured at Station N from early September until mid-December, 1978. All stop logs were then in place in the control structures at Station 1 and some channel obstruction by dead and dying vegetation affected the river just below the mouth of the ditch near Station N. Downstream discharge was renewed with removal of the top spillway log at Station 1 on December 18. Zero discharges occurred as follows: Station 1 Spillway, July 30 to August 23 and November 3-5; Station 1 Lock, August 13-23 and September 7 to December 17; Station F, December 5-11 and January 6-29; Station 8, October 6 to January 6. Eighteen days were required for renewal of discharge at Station 8 following removal of the top spillway log at Station 1.

Discharge in 1979-80 (Figure 63) was lacking over the following periods: Station N, May 7 to October 31 (reverse flow began October 18); Station F, May 22 to October 18; Station 1, June 15 to October 21; and Station 8, June 18 to October 28. Flow at none of the four Stations attained the peaks it reached in spring of 1979.

Discharge records were not maintained in 1977-78.

Chloride

This ion was monitored in surface waters from March through October, 1980. At the center of Lake Sallie (Station 4) variation over the above period was quite similar from surface down to 9 m (Figure 64). Water entering and leaving Lake Sallie had noticeably less chloride than that leaving St. Clair Lake (Station F) at all times (Figure 65); that entering and leaving Detroit Lake (Stations M and N) and the surface discharge from Long Lake (Station E) also had much less chloride than Station F (Figure 66). A comparison of Stations 1, 4-1 and 8 (Figure 67) indicates that surface inflow into Lake Sallie is the major source of this ion in the lake.

Temperature

Surface water temperatures peaked in July and then declined to annual lows that were usually reached in December (Figures 68 through 73). Warming was generally evident in April, but sometimes occurred in winter, e.g., Station 8 in 1979 (Figure 70).

Alkalinity

In 1977-78 total alkalinity was highest at Stations F and M and declined with distance down the lake system, showing lowest levels in Lake Sallie and its outlet (Figures 74 and 75). This general picture reflected photosynthetic activity which removed calcium carbonate. Station F was affected in this manner at times during the growing season, but such a reaction was not as evident as farther down the drainage system.

Variation in total alkalinity during 1978-79 (Figure 76) resembled that of 1977-78 and calcium (Figure 84) in being higher at M and F and generally lower during photosynthetic periods. However, it had a more definite winter increase at all sites that began later at M and F than that of calcium. This increase occurred on February 9, 1979, was not accompanied by any growth in calcium, and by one in magnesium only at Station N. In the winter of 1977-78 alkalinity increase was concurrent with one in calcium, which is the expected relationship since both respond similarly to photosynthetic variation. The simultaneous February, 1979, increase in alkalinity at all stations suggests a procedural artifact, reagent change unreported or unnoticed by the analyst. Alkalinity was greater in deeper water than nearer the surface at Station 4 (Figure 77).

In 1979-80 CO_3 and HCO_3 alkalinity (Figures 78 through 81) showed the normal relationship, with the former increasing and the latter decreasing during the most active photosynthetic period. Station M showed a rise in HCO_3 that lasted through May and June. Lack of flow at Stations F, N, 1 and 8 did not seem to affect greatly alkalinity relationships in water immobilized there in summer and early autumn.

Calcium

Calcium variation among sampling sites and over the seasons indicated the spread of photosynthetic influences over the upper watershed. Actively photosynthesizing plants soon exhaust free carbon dioxide, and calcium bicarbonate ($Ca(HCO_3)_2$) then serves as a source of supply, producing weakly soluble calcium carbonate ($CaCO_3$), much of which precipitates. Stations F and M, nearer wastewater and ground water sources of flow, had the highest Ca concentrations each year (Figures 82 through 86), with those at F being generally more eroded by photosynthesis during the growing season. Stations farther down the watershed had markedly lower concentrations each year.

Lower calcium levels were also brough about by inflow of snow melt in spring. This was most marked at F and M, but occurred at other sites, most noticeably in 1979.

Maintenance of lower calcium concentrations over winter in the three lower lakes (Detroit, Muskrat and Sallie) was referable to larger volumes which diluted inflows (Muskrat Lake was diluted by Detroit Lake discharge), some photosynthesis under ice cover, and isolation of surface waters from regions of most active carbon dioxide production (aerobic decomposition). There was a gradual calcium build-up from early December, 1978, to late March, 1979, in Muskrat Lake, despite detectable photosynthetic activity on January 25 and February 9. In surface waters of Lake Sallie (two exceptions at Station 8) $CaCO_3$ was present from June 1, 1978, to April 20, 1979, and after May 17, 1979. It was missing at nine meters depth (30 feet) from early February until May 17, 1979. Some photosynthesis occurred under ice cover in Sallie and calcium decline in April, 1979, resulted from dilution by melting snow. Vertical variation in Sallie (Figure 87) indicates a greater winter increase with depth, peaking at the lowest level, and generally higher concentration with depth at all seasons. Surface waters were more affected by photosynthesis and were the only level appreciably influenced by melt of snow cover (Figure 87, April 20, 1979).

Except at Station M, where an increase in calcium accompanied one in HCO_3 alkalinity in May and June, and at Station N, where an increase in Ca occurred in July, calcium generally responded to photosynthetic activity in 1979-80 as it had in previous years when there was general summer flow from Detroit, Muskrat and St. Clair Lakes (Figures 85 and 86).

Magnesium

Since magnesium bicarbonate ($Mg(HCO_3)_2$) appears less liable to photosynthetic breakdown than $Ca(HCO_3)_2$, and since magnesium carbonate ($MgCO_3$) is more soluble than $CaCO_3$, magnesium usually exhibits much less change than calcium in passage through a lake-river system. Variations that do occur are more apt to indicate a different basic water quality rather than conditions imposed by biological activities. 1978-79 profiles for individual sites (Figure 88) show greater uniformity than calcium (Figure 84) over the sampled area, and profiles for various depths in Lake Sallie (Figure 89) show less winter build-up in deeper waters. Magnesium was subject, as was calcium, to great dilution by snow melt at the surface of Lake Sallie and in the Pelican River above Detroit Lake (Station M). Extremes at M and F were ironed out to some extent in the larger lakes, but to a lesser degree than calcium, since magnesium suffered little if any biotic reduction. An illustration of the differing fates of calcium and magnesium is offered by mean values of each (1978-79) in Lake Sallie influent and effluent: magnesium was 142 mgl in the former and 143 in the latter, whereas corresponding values for calcium were 96 and 76 mgl.

Magnesium patterns in 1979-80 (Figures 90 and 91) resembled those of calcium, suggesting that it too was reduced by photosynthesis, which has not occurred before, but concentrations were greater than those of calcium and reduction with flow through Lake Sallie was not evident. Lack of flow from lakes in summer could have altered the general pattern.

pH

Surface water pH in 1977-78, like that of later years, was largely controlled by photosynthetic intensity during open water seasons and occasionally under the ice (Figures 92 and 93). Stations E, F, 1 and 8 lost ground in pH level (E had some resurgence in December, January and February) from the end of the 1977 open water season until photosynthesis became reestablished in April, 1978. Photosynthetic intensity was quite low at Station M over this period.

Maximum pH values for 1978-79 occurred in water discharged from St. Clair Lake followed by that from Lake Sallie, Muskrat and Detroit Lakes in that order (Figure 94). The river site M had a pH in excess of 8.0 only on September 15, 1978. Height of pH above 8.0 has appeared to be a more reliable measure of photosynthetic effects than oxygen concentration in these waters, since the latter has been depressed by photosynthesizing, nitrogen-fixing blue-green algae. Maximum intensity during the growing season was in St. Clair discharge, but Lake Sallie showed more uniformity and longer persistence of photosynthetic influence. St. Clair discharge preceded other sites in renewal of photosynthesis in May, 1979, but it was generally in full swing except at M on May 25 (Figure 94). Longer persistence of high values in Lake Sallie, especially under ice, is believed aided by isolation of surface water from areas of most active organic decomposition, but photosynthetic elevations have been noted under ice and snow. Upper waters had a generally higher pH level than those near the bottom in the deepest region of Lake Sallie (Figure 95).

In 1979-80 pH fell below 8.0 only at Stations F, M and 1. Its recovery at Station 1 occurred soon after ice melt and at F and M about one month later. The highest level was observed above Station 8 in August and September, but high values also occurred at 1, F and 4 (Figures 96 and 97). As in previous years, pH elevations were in response to photosynthetic activity.

Oxygen

Oxygen relationships in 1977-78 (Figures 98 and 99) were much as those described for 1978-79 below and are not detailed here.

Greatest 1978-79 oxygen concentrations occurred during periods of high photosynthetic activity, but blue-green algae had depressing effects, giving lows that were unaccompanied by pH decline on several dates (Figures 94 and 100). Oxygen was not reduced as much under ice in Detroit and Sallie as in St. Clair and Muskrat Lakes. Increases in spring, 1979, were initiated by snow melt and entrance of new water and then augmented by photosynthesis. These events were most striking in St. Clair Lake, where oxygen level increased from 0 to 20+ mgl. Oxygen showed its usual decline with depth in Lake Sallie (Figure 101), particularly in early spring, but very high values occurred at all depths coincident with temperature decline in fall of 1978.

In 1979-80 the oxygen picture was modified by the long period of zero flow from Detroit, Muskrat, Sallie and St. Clair Lakes, but a general relationship to photosynthesis was evident when discharge was reestablished, even the negative flow at Station N (Figures 102 and 103).

Conductivity

Conductivity of surface waters in 1977-78 (Figures 104 and 105) had much the same patterns as those described below for 1978-79, with highest values at Stations F and M.

Conductivity of surface water feed into this studied area, as exemplified by the Pelican River just above Detroit Lake (Station M) in 1978-79 was rather uniform (near 600 μmhos/cm) when not diluted by surface runoff, concentrated by evaporation, or reduced by photosynthesis of aquatic plants (Figure 106).

Dilution was largely restricted to spring, 1979, concentration to late summer, 1978, and photosynthetic reduction was noted on September 15, 1978, when calcium also declined. In St. Clair Lake conductivity reached considerably higher levels in winter, was decreased by spring runoff, and reduced by green plant life over much of the 1978 growing season. Winter conductivity levels have increased progressively in this lake since special phosphorus removal procedures went into effect; mean December - March values were: 1975-76, 709; 1977-78, 740; and 1978-79, 880 µmhos/cm. Causes of this increase are obscure at present and the role of the precipitation plant effluent somewhat contradictory. During the 1975-76 winter, wastewater influent went directly from the stabilization pond toward St. Clair Lake and in 1978-79 passed through the chemical precipitation plant, which effected a 10% conductivity reduction, enroute to St. Clair. Ground water conductivity at PC3 and 10 averaged 115 µmhos/cm greater than that of the precipitation plant effluent, and this water's movement may have possibly carried it into St. Clair Lake. It averaged 11 µmhos/cm greater than the stabilization pond in 1978-79, but this amount of gain is insufficient to account for the 1975-1979 increase in St. Clair.

Discharges from the other three lakes (Detroit, Station N; Muskrat, Station 1; and Sallie, Station 8) had noticeably lower conductivity than St. Clair Lake or Station M, and Detroit and Sallie showed less variation than Muskrat over the 1978-79 study period (Figure 106). Allowing for demineralizing effects of photosynthesis in each water body, the greater uniformity of the two larger lakes reflects the higher resistance their greater volumes afford against change by influent waters of differing quality and varying photosynthetic rate. This resistance is augmented by larger quantities of direct precipitation that their greater areas provide. In Muskrat conductivity was held to a lower level in winter than in St. Clair by dilution of St. Clair discharge with that from Detroit Lake. Very slight conductivity changes at

Station M from late September until early April (Figure 106) indicate a consistent quality of water passing that point which, although diluted, made some contribution toward uniformity in Detroit Lake. Vertical measurements in Lake Sallie (Figure 107) showed a higher range near the bottom (Station 4-4).

During the last year of study, instrument failure prevented recording of conductivity in August, which excluded patterns during the height of the photosynthetic season. Lower levels in September and October suggest that there was a reduction in August. Conductivity at Station F was above that at the Muskrat Lake outlet or in Lake Sallie, as usual (Figures 108 and 109).

Phosphorus

Lake St. Clair 1977-78 discharges contained more phosphorus in the soluble reactive state than any other surface water sampling site (Figure 110, Table 4). Dilution by the Pelican River and use by aquatic plants reduced the annual mean concentration by 36% when it reached Lake Sallie (Station 1). It was fairly well consumed in this body, showing an annual mean at Station 8 that was 18% of that at Station F. Seasonal low points in soluble reactive phosphorus curves (Figure 110) are assumed to reflect utilization by phytoplankton and other aquatic plants.

Total phosphorus was also generally most concentrated at Stations F and 1, but very high levels occurred at Station 8 in late summer 1977 (Figure 111, Table 5). This analysis includes P in the bodies of plankton organisms, and Station 8 exhibited high plankton densities at this time (Figure 133). At Station 4, near the center of the lake, highs in plankton and total P were concurrent with those at Station 8 (Figures 111 and 132), but P concentration was lower, whereas plankton concentration was about 40% higher. Stations 1 and F are recipient of comparatively large quantities of wastewater influent and they showed high total phosphorus concentrations when their plankton densities were low (Figures 111, 129 and 130), although their total P appeared affected by plankton in late summer, 1977.

Mean total phosphorus was higher in 1977-78 than in either 1973-74 or 1974-75, with two exceptions as shown below:

	Mean Total P, mgl					
	E	F	M	N	I	8
1973-74	0.27	1.62	-	0.28	0.47	0.19
1974-75	0.30	1.48	0.44	0.46	0.47	0.24
1977-78	0.49	0.81	0.51	0.37	0.59	0.47

At Station 4-1 mean total P was 0.40 mgl in 1975 and 0.44 mgl in 1977, but mean soluble reactive P was generally higher in 1975.

With the exceptions of St. Clair and Muskrat Lakes (Stations F and 1), total phosphorus reached greater concentrations during the 1978 growing season than in that of 1977, and 1977-78 levels were generally higher than those of 1975-76 (Figures 112, 113 and 114). This may represent a general watershed trend since inflow and outflow of both Detroit Lake and Lake Sallie were involved. Phosphorus loads contributed from the east side of the upper watershed (Station N) exceeded those from the wastewater recipient west side (Station F) in 1978-79 despite the long period of minus flows at Station N (Figure 115). A similar relationship characterized the first six months of 1975 when 13,139 pounds of P from Station F joined 22,002 pounds from Station N. In 1973 and '74 quantities from F markedly exceeded those from N (23,060 to 14,109 pounds in 1973; 12,963 to 7,760 pounds in 1974). Lower contributions from F in 1978-79 accompanied higher concentrations in Lake Sallie and its discharge. Heavier phosphorus loads occurred in summer of 1978 as discharge was declining, and in late winter and spring as discharge increased. The heaviest loads were in April, whereas discharge peaked in May. Phosphorus variation at different depths near the center of Lake Sallie in 1978-79 is shown in Figure 116.

Maximum and mean total phosphorus concentrations found in Lake Sallie during 1979-80 (Figure 117) were considerably below those noted from 1978-79.

This occurrence is attributed to the lower load (Figure 118) coming in during this sampling period (5,602 pounds at Station 1 vs. 20,672 pounds there in 1978-79). This is the lowest incoming load measured at Station 1 since the watershed studies began in 1972. For every other year during which discharge has been recorded, inflow at Station 1 has borne at least 20,000 pounds of phosphorus. Except for 1975 and 1978-79, when greatest quantities came from Detroit Lake (Station N), most P has been contributed by the Detroit Lakes wastewater influent. Total P loads (1973-1980) for Stations N, F, 1 and 8, in pounds, were as follows:

	PR6	PR30	PR7	PR8
	N	F	1	8
1973	14,109	23,060	27,998	13,448
1974	7,760	12,963	21,252	10,979
1975	22,002	13,139	20,988	15,564
1978-79	11,544	8,921	20,672	18,098
1979-80	2,580	3,612	5,602	4.651

Discharges from St. Clair, Long and Detroit Lakes (Stations F, E and N) in 1980 were below those of 1978-79 and 1977-78 in maximum and mean phosphorus concentrations (Figure 119). Although Stations F, N, 1 and 8 were without discharge from four to over five months in summer and fall, 1980, phosphorus records were maintained at all surface water stations during that time, and periods lacking discharge (see page 20) show phosphorus levels in Figures 117 and 119 that are meaningless with respect to phosphorus moved past those sites.

Nitrogen

During 1977-78 this element was most concentrated near the wastewater source (Station F) and declined down basin from this point, dropping to a minimum in Lake Sallie (Figure 120). It was most abundant during winter, and its marked decline in spring is believed referable to its utilization by aquatic plants in areas above and below Station F down to Station 1.

Total N concentration was generally less in 1977-78 than in either 1973-74 or 1974-75, with some exceptions that appear below:

Mean Total Nitrogen, mgl

	E	F	M	N	1	8
1973-74	-	1.540	-	0.137	0.290	0.330
1974-75	0.305	1.260	0.560	0.275	0.474	0.270
1977-78	0.136	1.080	0.230	0.187	0.346	0.064

In 1978-79 St. Clair Lake was again the major contributor of nitrogen to Lake Sallie. Over the past five years N concentration there has greatly exceeded that at more downstream locations (Stations 1 and 8) and on the east side of the upper watershed (Stations M and N), as shown in Figures 121, 122 and 123. St. Clair Lake from January - May, 1979, supplied 18,279 of the 30,882 pounds entering Lake Sallie at Station 1 (Figure 124). Detroit Lake contributed 8,137 pounds, and the remaining 4,466 pounds originated in Muskrat Lake, in the river below Station N, and in the ditch from St. Clair Lake. Greatest loads and concentrations occurred from mid-winter to early spring. Load was related to discharge, but not entirely, as the latter peaked after the maximum loads had passed (Figure 62). Unlike phosphorus (Figure 115), nitrogen had low or near annual low loads in early summer. Variation in total nitrogen at four depths near the center of Lake Sallie appears in Figure 125.

As in previous years, St. Clair Lake was the principal supplier of nitrogen to Lake Sallie in 1979-80 (Figures 126 and 127). Neither concentrations nor loads were as great as in 1978-79. Loads at least (Figure 128) were affected by the long periods without discharge at key sites. Values appearing for these periods in Figures 126 and 127 are of no significance to loads. The relationship of nitrogen fixation by blue-green algae to loads leaving varied lakes has not been evaluated.

Phytoplankton

Growths of blue-green phytoplankton that have annually produced odors and other conditions considered objectionable by most persons have been salient features of Lake Sallie and Muskrat Lake in recent years. Comparison of annual mean blue-green phytoplankton concentrations in 1975 and 1977, as μ^3 per ml, shows a noteworthy decline in 1977 in Muskrat Lake (75%) and a slight decrease (14%) in Lake Sallie. However, in Muskrat Lake lower concentrations occurred, with two exceptions, throughout the growing season, whereas 1977 Lake Sallie concentrations, with one exception, were greater in summer and less in fall than those of 1974 (Table 6).

Total phytoplankton production for the period 1975 to '78 is shown in Figures 129 to 133. At Station F (Figure 129) institution of the special phosphorus removal procedures had no noteworthy effects on total plankton production that were apparent in 1977 and '78, but there was considerable reduction in heterocystous blue-green algae. The limited sampling period in 1976 may have missed peaks attained that year.

At Station 1, 1977-78 total plankton densities were considerably below those of 1976, and slightly lower than 1975 levels (Figure 130). At N (Figure 131) 1977 levels were greater than those of 1975 or 1978, and the 1977 peak occurred when there was backflow into Detroit Lake from the ditch from Lake St. Clair. At Station 4, near the center of Lake Sallie, total plankton had made no response to the special treatment procedures (Figure 132), but at the Sallie outlet (Station 8) a decline could be claimed for 1977 (Figure 133).

1978-79 plankton densities of Stations 1, 4-1 and 8 are contrasted with those at the same sites in 1977-78 in Figures 134, 135 and 136. In Muskrat Lake (Station 1) heterocystous blue-green algae attained greater numbers in 1978-79 (Figure 134), whereas at Stations 4-1 and 8 (Lake Sallie) all figured groups reached higher peaks in 1977-78 (Figures 135 and 136), as did non-heterocystous blue-greens at Station 1. Since the heterocystous blue-green algae are usually involved in development of conditions offensive to most people, Muskrat Lake may have suffered some regression, but a trend toward lower density of this and other phytoplankton groups continued in Lake Sallie. Phytoplankton densities are broken down into major groups in Figures 137, 138 and 139. Diatoms and blue-green algae formed the bulk of the population at all three sites.

Blue-green algae densities in summer of 1979 (when no chemical records were kept) at Stations F, 1, 8 and N are compared with those of 1975, '77 and '78 (1978 lacking for Stations F and N) in Figures 140 through 147. At Station F heterocystous blue-greens were considerably denser in 1975 than in 1977 or '79, and 1979 concentrations reached lower peaks than those of 1977. Non-heterocystous blue-greens were much more concentrated in 1977 than in either 1975 or '79.

At Station 1 heterocystous forms were most numerous in 1975, but were considerably lower in density in 1977 than in '78 or '79; 1979 was below 1978. Non-heterocystous forms were least numerous in 1975, reached their highest peak in 1979 and reached zero in September of that year. They were more persistent in 1977 and '78, and higher levels were more common than in 1979.

At Station 8 heterocystous blue-greens were much less numerous in 1978 and '79 than in 1975 or '77. In 1975 higher numbers endured over long periods of time, whereas only one high peak occurred in 1977. Non-heterocystous forms were much more concentrated in 1977 than in any of the other three years, although one high peak was attained in 1975.

At Station N blue-green algae of both types reached greater densities in 1977 than in 1975 or 1979, but since 1977 maxima were reached at times when levels at Station 1 were below their annual peak, it appears unlikely that densities at Station N had any influence in Lake Sallie.

In 1979-80 plankton analyses were discontinued at Stations N, F and 8 when flow ceased at each in May and June, 1980, but analyses covered the entire period at Stations 1 and 4. Numbers were lower during this period than during any preceding year of record and periods of higher density reached at each site were of short duration. At Station N (Figures 148 and 149) the only group achieving any noteworthy density was diatoms in April, 1980; at Station F (Figures 150 and 151) maximum density, due to green algae, occurred the same month; and, at Station 8, (Figures 152 and 153) concentrations were about equal in April and May, the first involving green algae and the second Cryptophyceae. Heterocystous blue-green algae reached no significant densities at any of these three sites.

At Station 1, which did not contribute to Lake Sallie when discharge stopped, heterocystous blue-green algae reached near critical levels in June and July (Figure 154), but did not approach the levels reached by diatoms in May and September (Figure 155). In surface water near the center of Lake Sallie (Station 4-1) heterocystous blue-greens reached near troublesome densities only in July and September, which were the highest concentrations achieved by any group there (Figures 156 and 157).

General Lake Conditions

Lakeshore residents of Lake Sallie and persons freuqenting the general area have reported improving conditions therein since 1977. Appearance of the lake in 1979 and '80 supports this impression. In 1979 weekly observations showed potentially troublesome blue-green drifts along the east shore and at the northern public access boat landing on August 17, but they disappeared before August 24. Blue-green drifts of less density appeared again at these localities on August 31, and a thin drift of surface phytoplankton was present along the east shore on September 7. The east shoreline had cleared on September 14, but an onshore wind was accumulating blue-green algae in the public access area. On September 21 a light blue-green drift lay along the east shore and a heavy one at the boat landing. Both areas had cleared by September 28 and remained that way until the end of the sampling period. Prior to August 17 no surface algal accumulations were noted in the lake. Drifts noted in August and September did not produce malodorous conditions.

A dense blue-green drift that had accumulated across the north shore extending from the public access area to the lock area on August 22, 1980, affected no other part of the lake and apparently had been moved from there to the east shore by August 29 where a slight "blue-green" odor was detectable. The north shore was then clear of algae, as was the east shore by September 5. No other blue-green drifts were observed that year, but some temporary unsightly conditions were produced by green filamentous algae that had been displaced from their normal habitats and were decomposing near shore.

Plankton drifts observed during 1979 and '80 were of short duration and affected much smaller areas of the lake than those of the early and mid-1970's that covered 1/2 to 3/4 of the lake surface with a 6-8" thick layer of mixed blue-green algae (*Anabaena*, *Microcystis*, *Aphanizomenon*, *Coelosphaerium* and *Gloeotrichia*). A sample of such a drift collected in 1974 and preserved with formalin still gives off a strong "blue-green" odor seven years later.

Performance of Special Wastewater Treatment Facilities

Effects on nitrogen and phosphorus of the wastewater influent applied to spray irrigation plots, infiltration basins, and the chemical precipitation plant, 1977-1980, may be noted in Tables 7 and 8.

In 1977-78 ground water nitrogen content was very high during early months of land application, but marked decreases occurred later. In 1978-79 land application resulted in a decrease in N concentration at all ground water sites for the record period, although individual sites showed increases some months. In 1979-80 decreases occurred everywhere each month, and the period of record indicated greater efficiency for spray irrigation than for infiltration basins, which was also true of 1978-79.

The chemical precipitation plant had little effect on nitrogen contained in the wastewater influent, showing a net increase in 1977-78 and 1979-80 and a small percent reduction in 1978-79.

Phosphorus reduction was effected by both chemical precipitation and land application during all months chemical records were maintained. Spray irrigation was a few percentage points more efficient than either chemical precipitation or infiltration basins in 1977-78 and 1978-79 and markedly more effective in 1979-80 when chemical precipitation showed a decided drop in phosphorus removal and infiltration basins a mean increase of 10%.

GLOSSARY

acre foot - a volume of water one acre in area and one foot deep; 43,560 cubic feet or 325,829 gallons

adsorption gallery (or infiltration basin) - shallow grassed pond providing plant and soil adsorption or removal of phosphorus and nitrogen from wastewater applied intermittently

algae - simple plants, usually microscopic, that usually contain chlorophyll and other pigments

alkalinity - property usually imparted to water by salts of strong bases and weak acids; measured with a standard acid

ambient - as used in this report, not affected by special treatment facilities; also referred to as native; e.g., ambient temperature, ambient calcium concentration, native ground water

blue-green algae - organisms now considered to be bacteria by most investigators; nucleus and chloroplast both lacking, but chlorophyll present and most are active photosynthesizers; name describes the color of many

chemical precipitation - in this instance, removing phosphorus from wastewater by applying hydrated lime ($Ca(OH)_2$) to react with $Ca(HCO_3)_2$ and precipitate $CaCO_3$; pH is then adjusted downward by sulfuric acid (H_2SO_4) dosage

chlorophyll - green substance in plants and bacteria that is basic for photosynthesis

chromatophore - colored body, usually green (chloroplast), bearing chlorophyll in plant cells

Chrysophyceae - yellow-brown algae without glass cases; food stored as oil and leucosin, a white substance

Cryptophyceae - single celled algae with chloroplasts and nuclei; dominant pigment usually brown; two anterior flagella

cubic feet per second (cfs) - measure of water volume passing a point; sometimes listed as second feet

diatoms - algae with nuclei and brown colored chromatophores whose cells are enclosed in glass cases; chlorophyll present but usually obscured by other pigments

Dinophyceae - close relatives of Cryptophyceae, but with one anterior and one trailing flagellum; naked or with firm or hard covering

discharge - volume of water passing a point; listed as cubic feet or acre feet per time period; often called Q from formula used to determine it

effluent - water flowing from a water body or treatment process

Euglenophyta - single celled algae, usually green with chlorophyll in chloroplasts; one anterior flagellum

flagellum (pl. flagella) - a whip-like motile organ used by some small organisms for locomotion

green algae - algae usually grassy green in color with chloroplast and nucleus; active photosynthesizers and food usually stored as starch

hardness - property given to water by certain metals in solution (calcium, magnesium) that replace sodium in soap; total hardness usually equals calcium plus magnesium

heterocystous blue-green algae - blue-green algae with a structure called a heterocyst that aids in the fixation of free nitrogen; most of these algae promote malodorous and unsightly conditions when present in large numbers

infiltration basin - See: adsorption gallery influent - water flowing into or toward a water body or treatment process; see also: wastewater influent

mgl - milligrams per liter, equivalent to parts per million (ppm)

non-heterocystous blue-green algae - blue-green algae lacking heterocysts; usually not considered nitrogen fixers; some produce odors and other objectionable conditions

nucleus (pl. nuclei) - body in a cell directing its activities and bearing genetic or herditary material

photosynthesis - process by which plants, using chlorophyll, capture energy from the sun, combine carbon dioxide with hydrogen from water to manufacture food and liberate oxygen

spray irrigation - irrigation accomplished by spraying water or wastewater on the surface of the soil

wastewater influent (or influent) - water pumped from the stabilization pond to chemical precipitation plant, spray irrigation plots, and infiltration basins; samples taken as influent passed into or through the chemical precipitation plant

REFERENCES

1. Neel, J.K., S.A. Peterson, and W.L. Smith. 1973. Weed harvest and lake nutrient dynamics. U.S. Environmental Protection Agency, Report No. EPA-660/3-73-001, 91 pp.

2. Neel, J.K. 1979. Watershed and point source enrichment and lake trophic state index. U.S. Environmental Protection Agency, Report No. EPA-600/3-79-046, 102 pp.

3. American Public Health Association. 1971. Standard Methods for the Examination of Water and Wastewater - 13th edition, Washington, D.C.

4. Peterson, S.A. 1971. Nutrient dynamics, nutrient budgets, and weed harvest as related to the limnology of an artificially enriched lake. Ph.D. Dissertation, University of North Dakota, Grand Forks, North Dakota, 210 + xvii pp.

5. Smith, W.L. 1972. Plankton, weed growth, primary productivity, and their relation to weed harvest in an artificially enriched lake. Ph.D. Dissertation, University of North Dakota, Grand Forks, North Dakota, 222 + xv pp.

6. Lee, D.R. 1972. Septic tank nutrients in groundwater entering Lake Sallie, Minnesota. M.S. Thesis, University of North Dakota, Grand Forks, North Dakota, 96 + x pp.

7. ________. 1977. A device for measuring seepage flux in lakes and estuaries. Limnology and Oceanography, 22:155-162.

8. Miekicki, S.J. 1973. Pattern of watershed enrichment and its effects on nutrient budgets and weed growth in a culturally eutrophied lake. M.S. Thesis, University of North Dakota, Grand Forks, North Dakota, 122 + xii pp.

9. Brakke, D.F. 1974. Weed harvest effects on algal nutrients and primary production in a culturally enriched lake. M.S. Thesis, University of North Dakota, Grand Forks, North Dakota, 83 + x pp.

10. Mann, W.B., IV, and M.S. McBride. 1972. The hydrological balance of Lake Sallie, Becker County, Minnesota. U.S. Geological Survey Professional Paper 800-D, pp. 189-191.

11. Stambaugh, J.W., Jr. 1977. Phytoplankton variation over the upper Pelican River watershed, Becker County, Minnesota. M.S. Thesis, University of North Dakota, Grand Forks, North Dakota, 114 + x pp.

12. West, W.M. 1977. Chlorophyll densities and plankton counts as measurements of phytoplankton biomass. M.S. Thesis, University of North Dakota, Grand Forks, North Dakota, 55 + viii pp.

13. McVoy, R.S. 1978. Immediate effects of expanded nutrient removal on a Minnesota watershed. Ph.D. Dissertation, University of North Dakota, Grand Forks, North Dakota, 216 + xiv pp.

14. U.S. Environmental Protection Agency. 1975. A compendium of lake and reservoir data collected by the National Eutrophication Survey in the Northeast and Northcentral U.S. Working Paper No. 474, 210 pp.

15. Allison, I.S. 1932. The geology and water resources of northwestern Minnesota. Minnesota Geological Survey Bulletin No. 22, 245 pp.

16. Moyle, J.B. 1945. Some chemical factors influencing the distribution of aquatic plants in Minnesota. American Midland Naturalist, 34:402-420.

17. Reedstrom, D.C. and R.A. Carlson. 1969. A biological survey of the Pelican River watershed, Becker, Clay, and Ottertail Counties. Minnesota Department of Conservation Special Publication No. 65, 117 pp.

FIGURES

KEY TO ABBREVIATIONS USED IN FIGURES

B - near the bottom of the phreatic zone, in reference to ground water wells, as in PC3B or 11B

CA - calcium

CO3 - CO_3 (carbonate) alkalinity

CRYP. - Cryptophyceae

DIA. - diatoms

HCO3 - HCO_3 (bicarbonate) alkalinity

HET.B-G - heterocystous blue-green algae

MG - magnesium

MGL - milligrams per liter

ML - milliliter

MSL - mean sea level

NON-HET.B-G (or NON-HET.) - non-heterocystous blue-green algae

T - near the top of the phreatic zone, in reference to ground water wells, as in PC11T or 3T

4-1 - refers to samples taken at the surface of Lake Sallie at Station 4

Note: space limitations precluded using dates in Figures 4 through 7 and the numbers used refer to bi-weekly sampling dates

Figure 1. Upper Pelican River Watershed

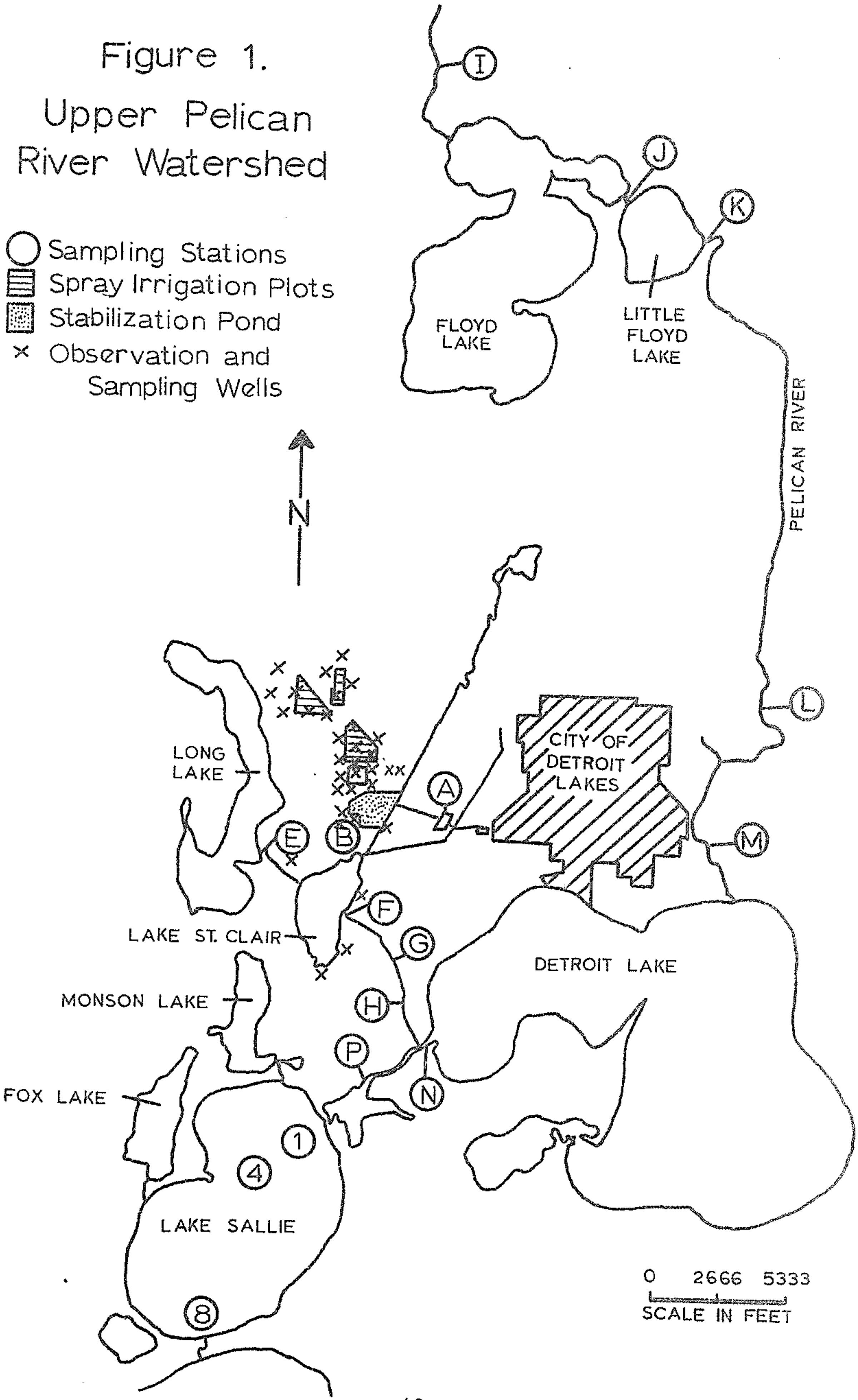
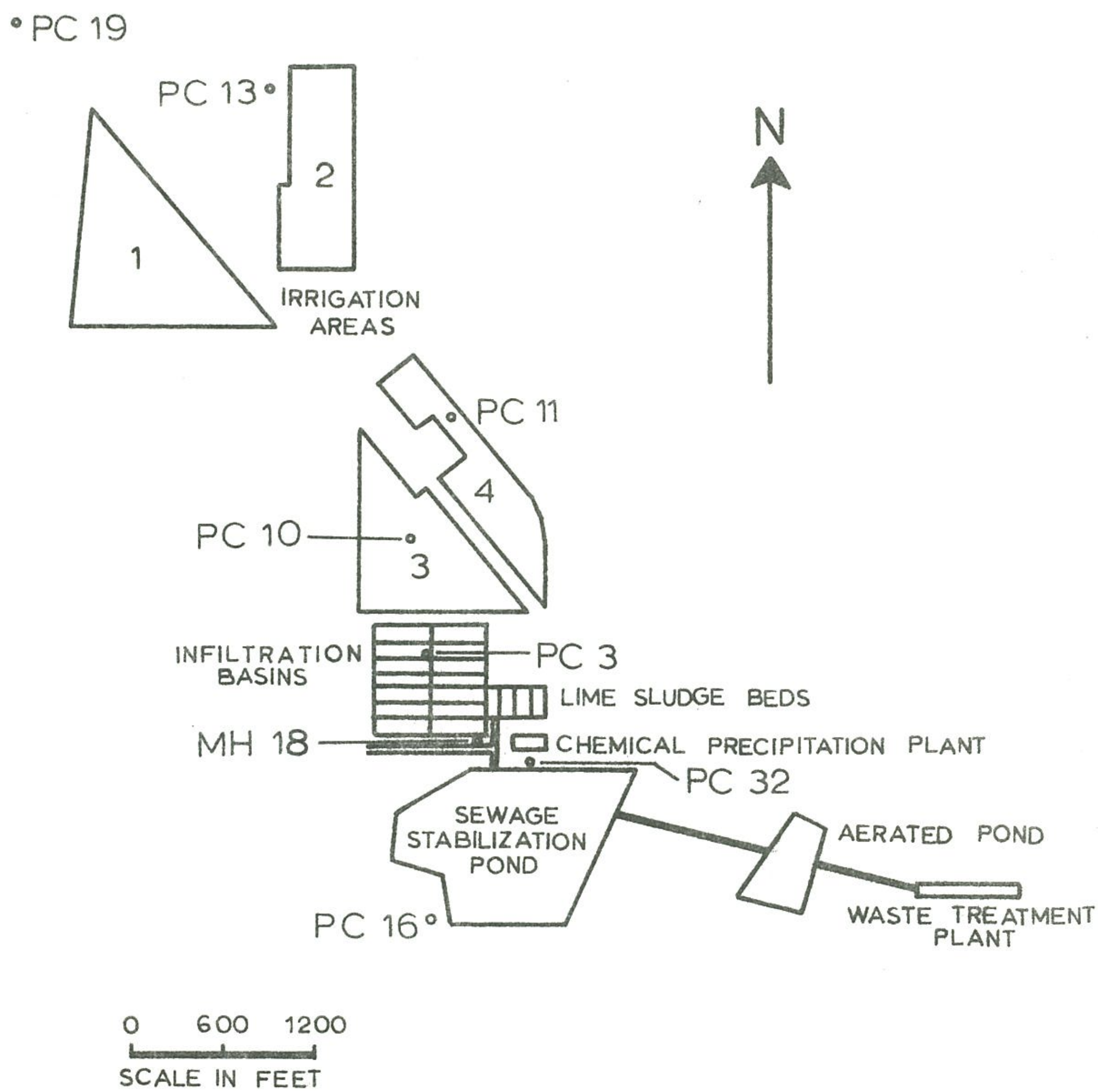


Figure 2. Details of Treatment Area



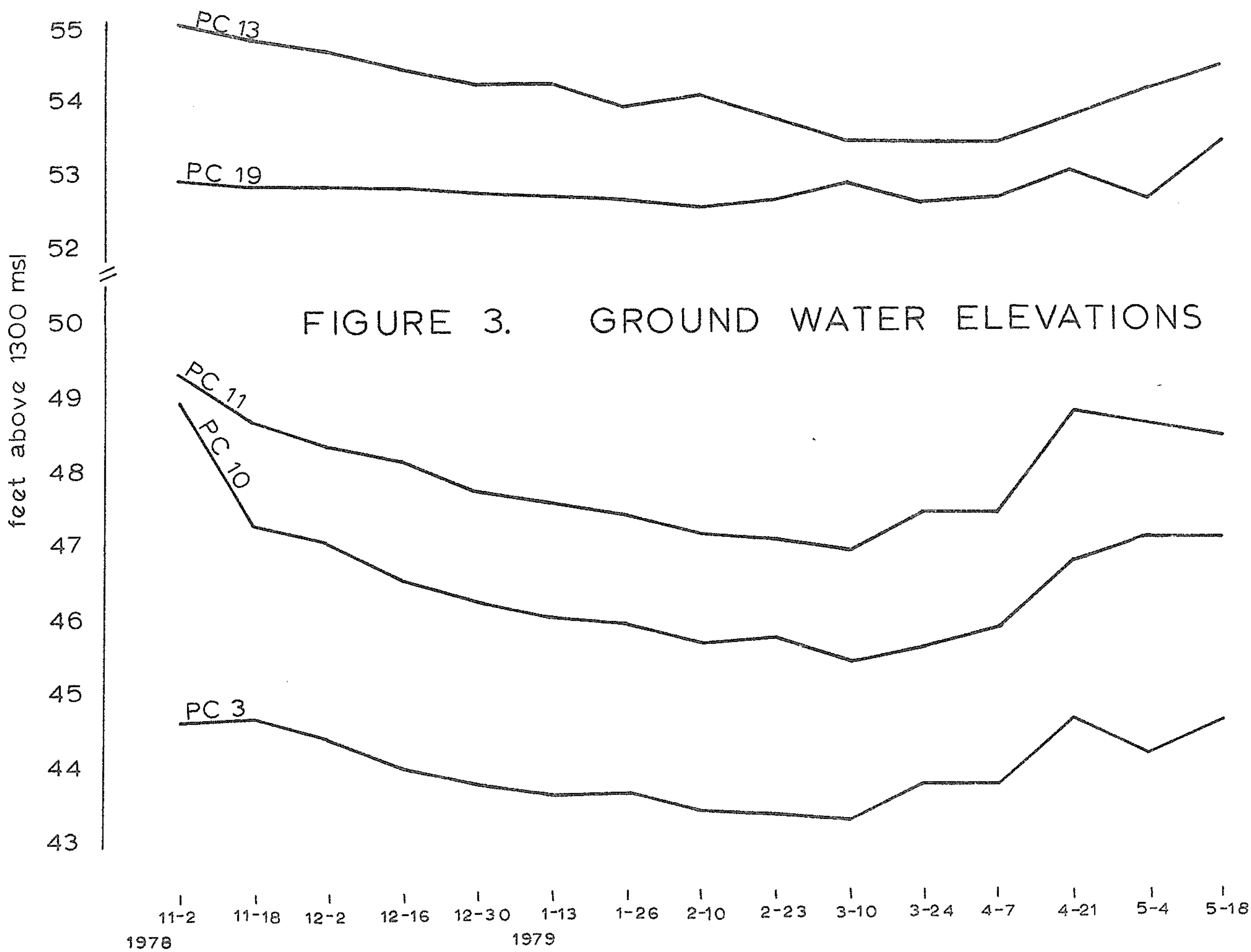


FIGURE 3. GROUND WATER ELEVATIONS

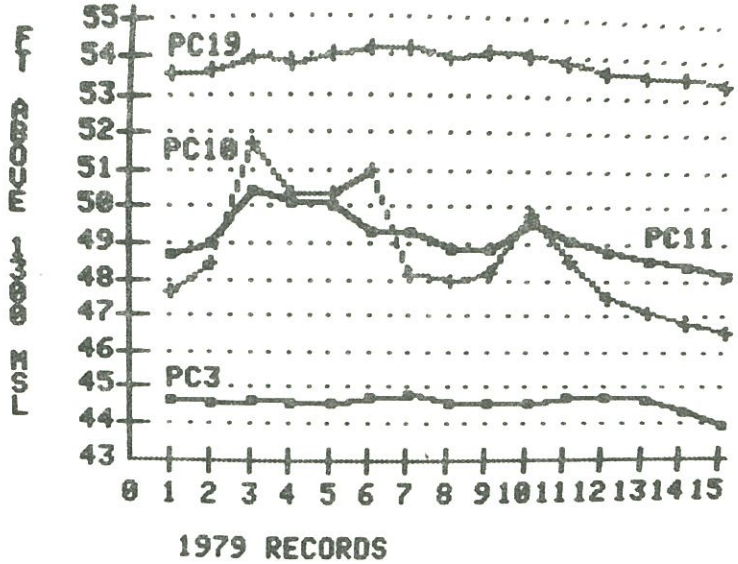


FIGURE 4. Ground water levels at PC3, 10, 11 and 19, June through December, 1979.

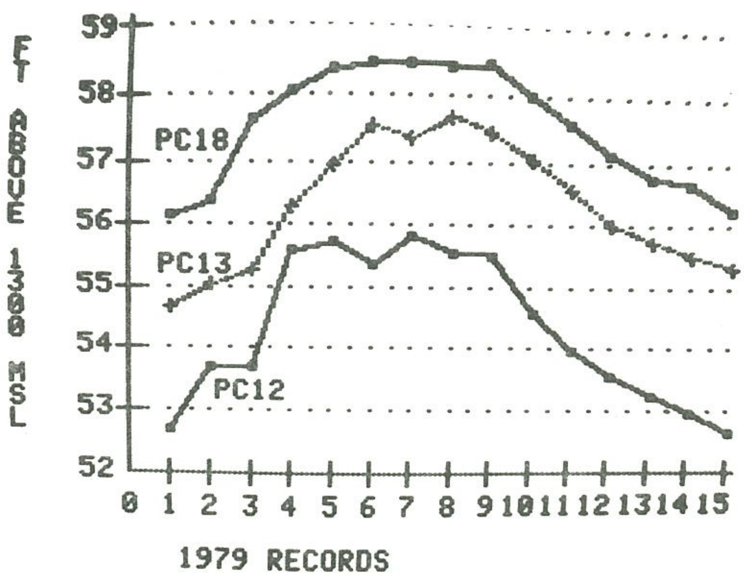


FIGURE 5. Ground water levels at PC12, 13 and 18, June through December, 1979.

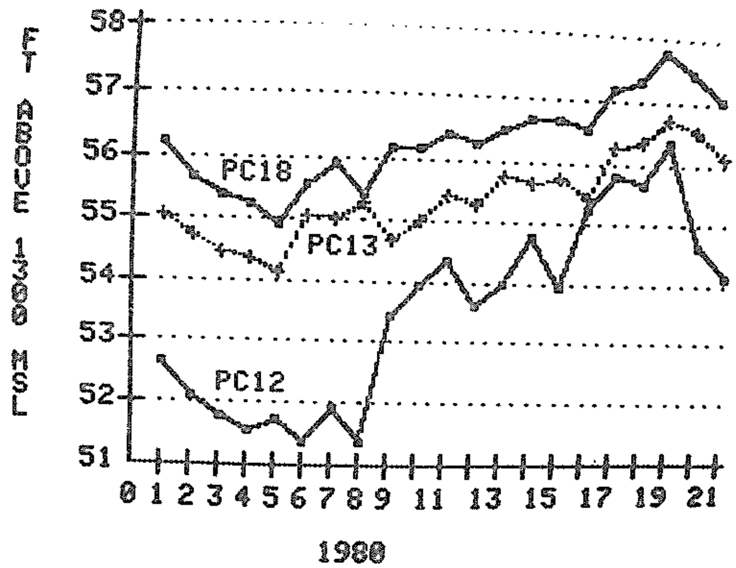


FIGURE 6. Ground water levels at PC12, 13 and 18, January through November, 1980.

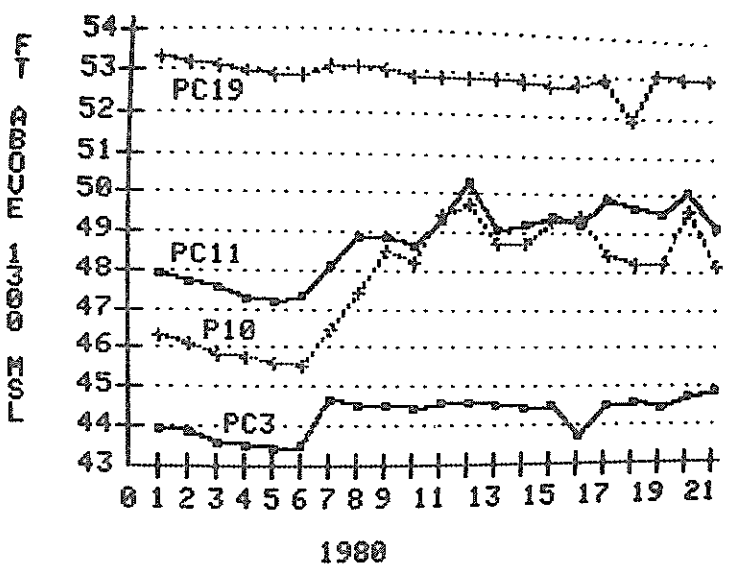


FIGURE 7. Ground water levels at PC3, 10, 11 and 19, January through November, 1980.

FIGURE 8.
Chloride in
Wastewater Influent and
Ground Waters

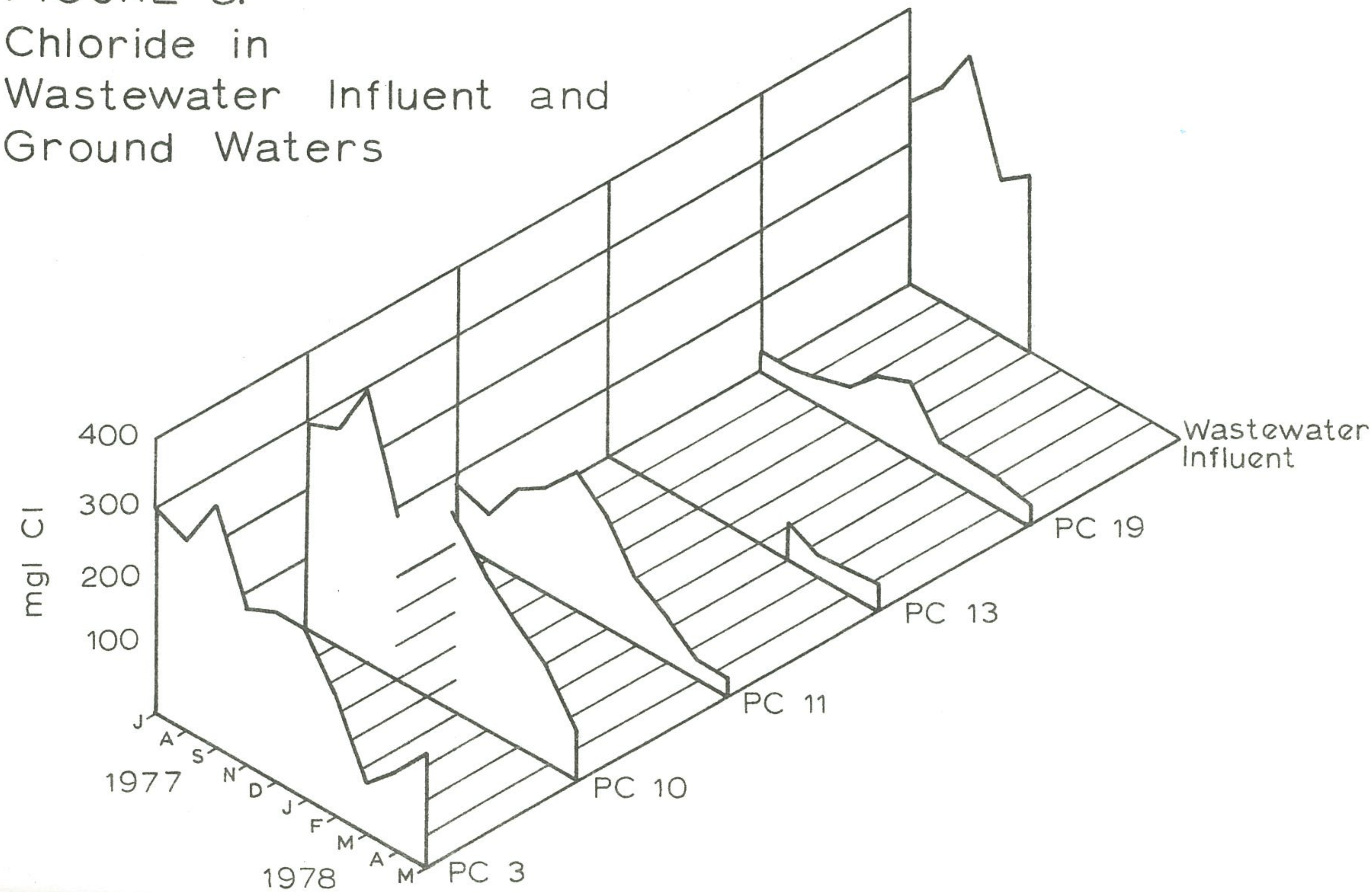
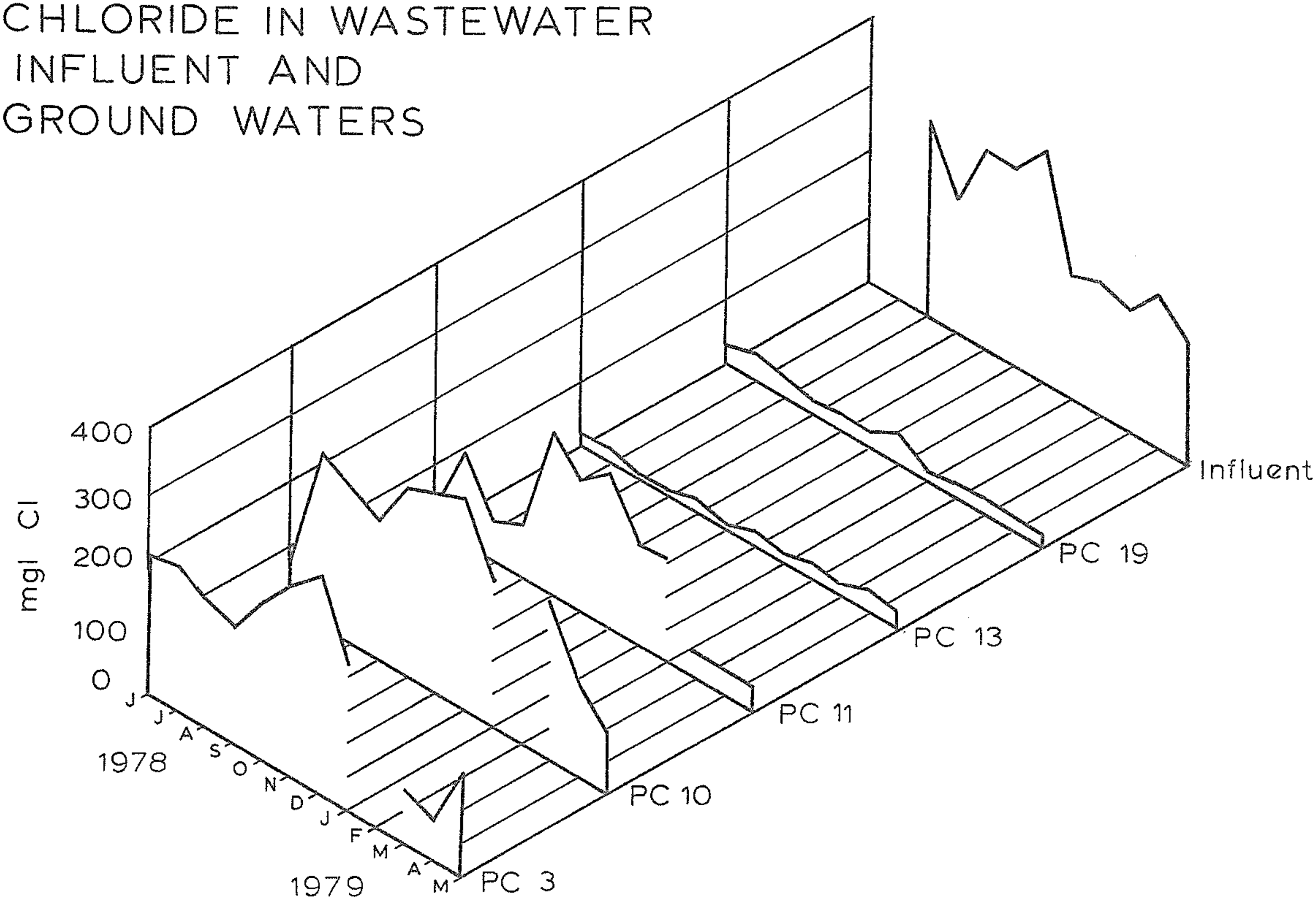


FIGURE 9.
CHLORIDE IN WASTEWATER
INFLUENT AND
GROUND WATERS



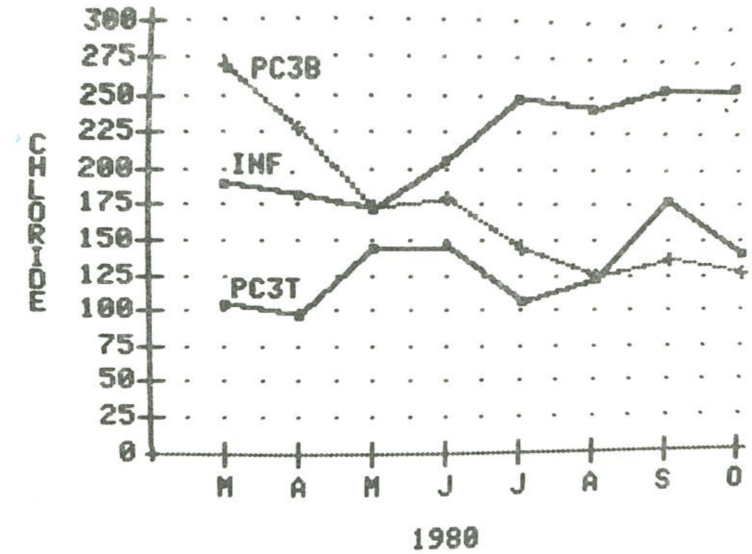


FIGURE 10. Comparison of monthly mean chloride concentrations (mgl) at PC3 and influent, 1980.

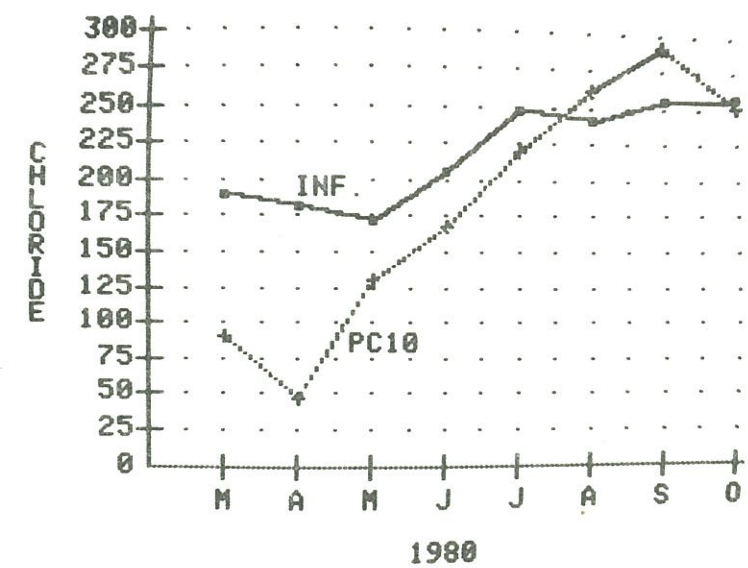


FIGURE 11. Comparison of monthly mean chloride concentrations (mgl) at PC10 and influent, 1980.

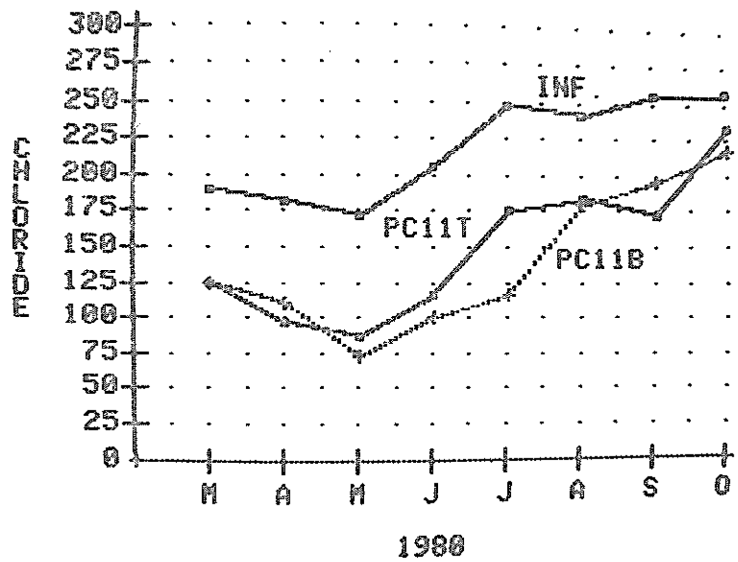


FIGURE 12. Comparison of monthly mean chloride concentrations (mgl) at PC11 and influent, 1980.

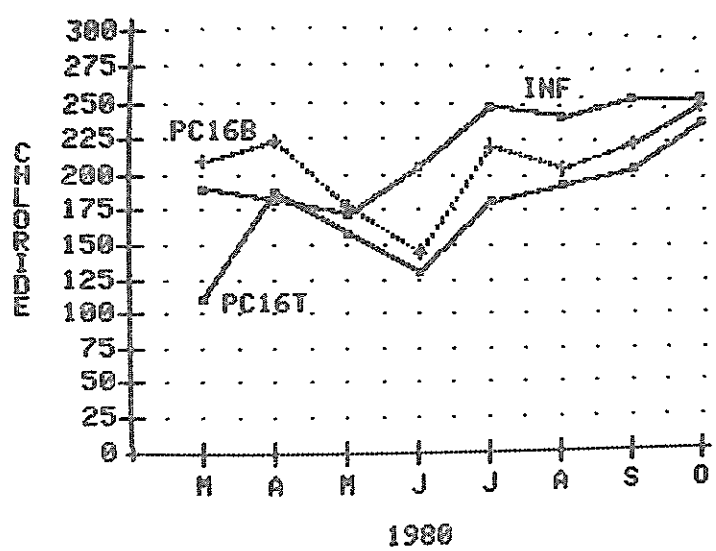


FIGURE 13. Comparison of monthly mean chloride concentrations (mgl) at PC16 and influent, 1980.

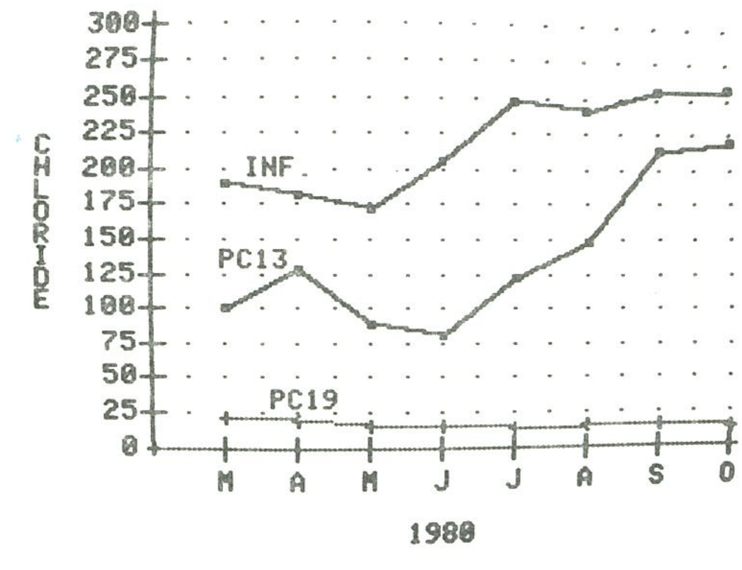


FIGURE 14. Comparison of monthly mean chloride concentrations (mgl) at PC13, 19 and influent, 1980.

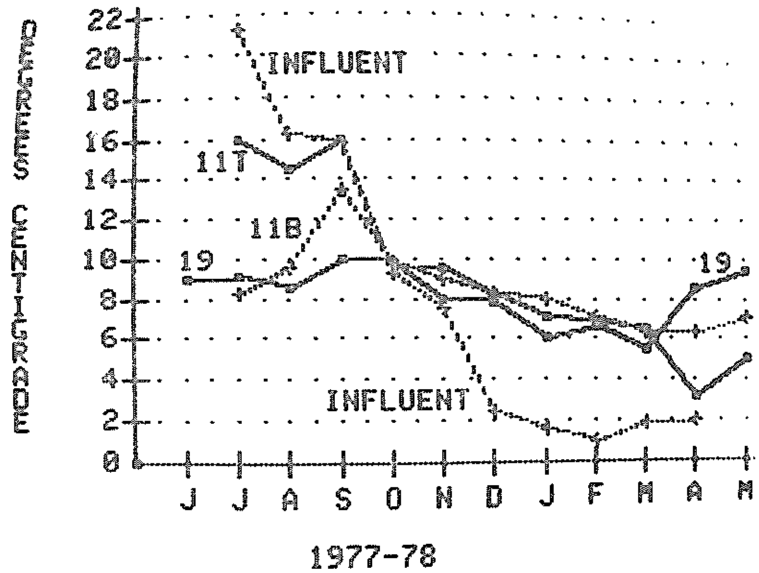


FIGURE 15. Monthly mean ground water temperature at PC11, 19 and influent, 1977-78.

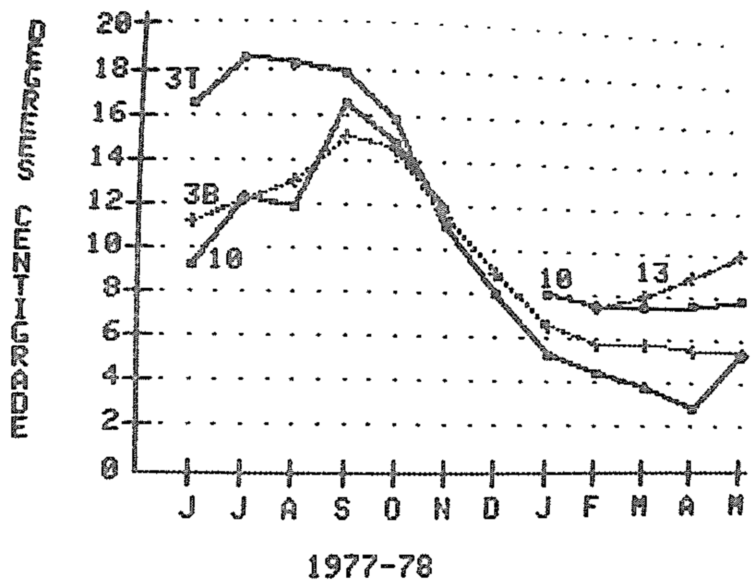
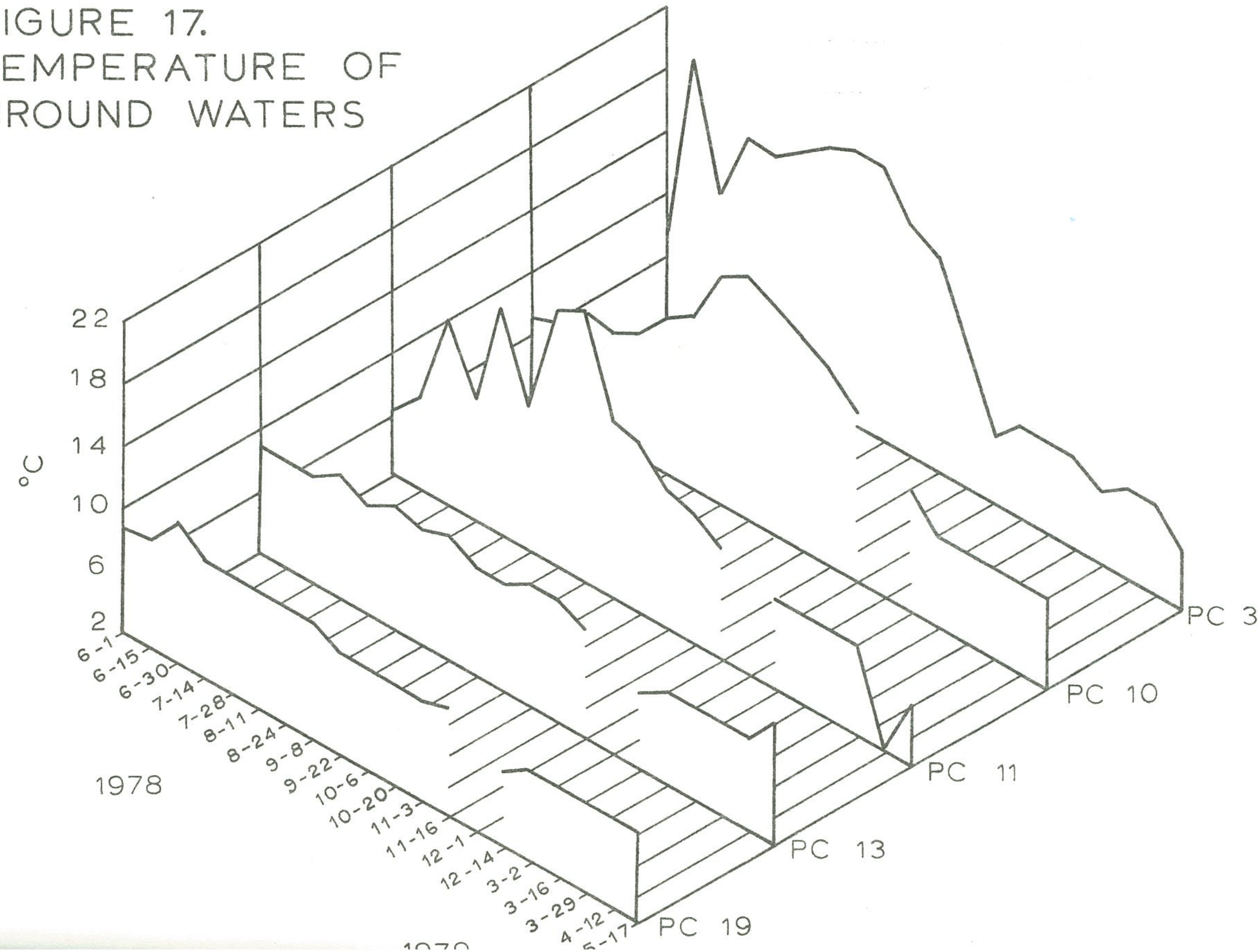


FIGURE 16. Monthly mean ground water temperature at PC3, 10 and 13, 1977-78.

FIGURE 17.
TEMPERATURE OF
GROUND WATERS



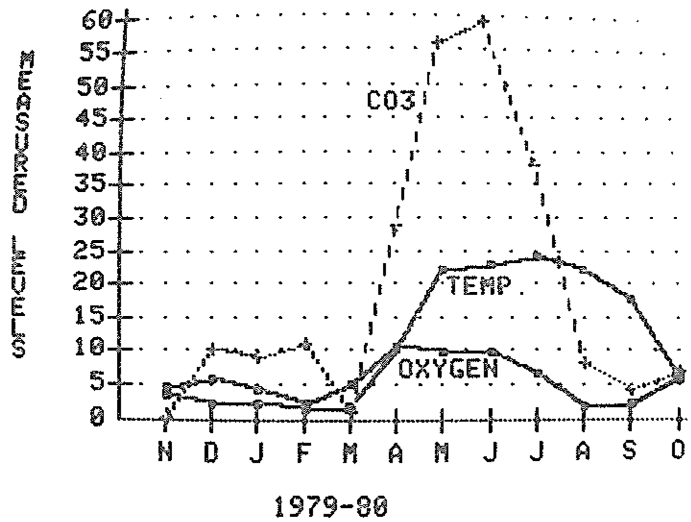


FIGURE 18. Monthly mean temperature (°C), CO_3 alkalinity (mgl CO_3), and oxygen concentrations (mgl) in the wastewater influent, 1979-80.

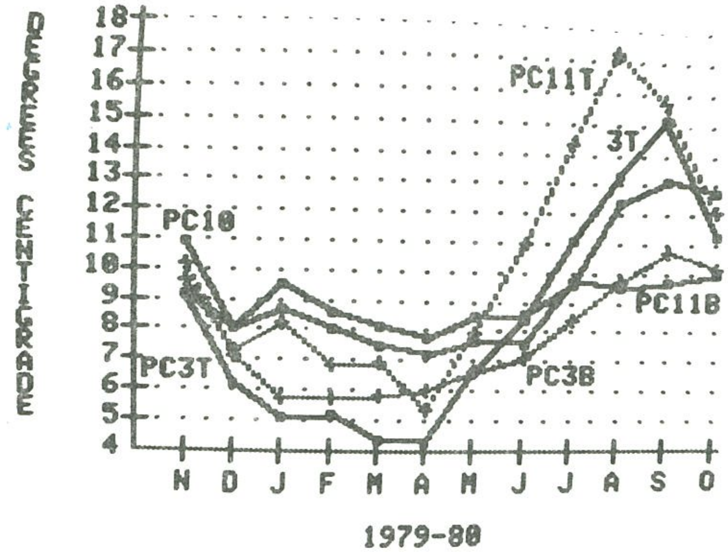


FIGURE 19. Monthly mean ground water temperature at PC3, 10 and 11, 1979-80.

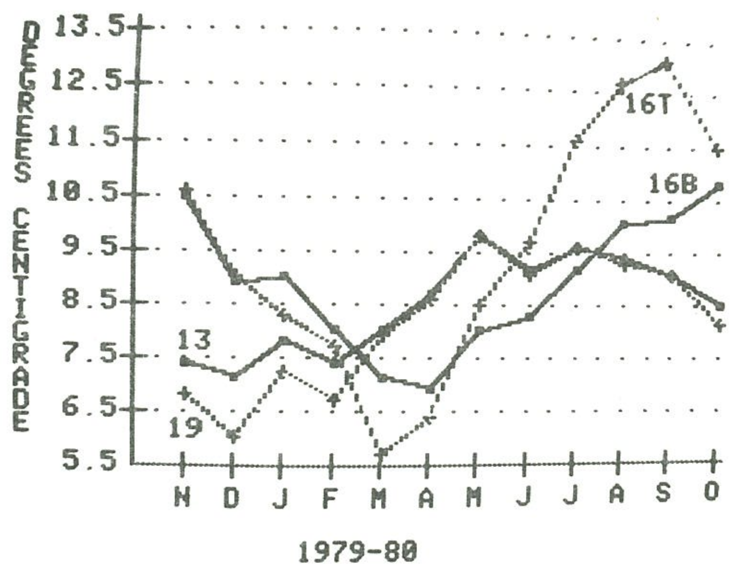


FIGURE 20. Monthly mean ground water temperature at PC13, 16 and 19, 1979-80.

FIGURE 21.
Mean Monthly Alkalinity - Ground Waters

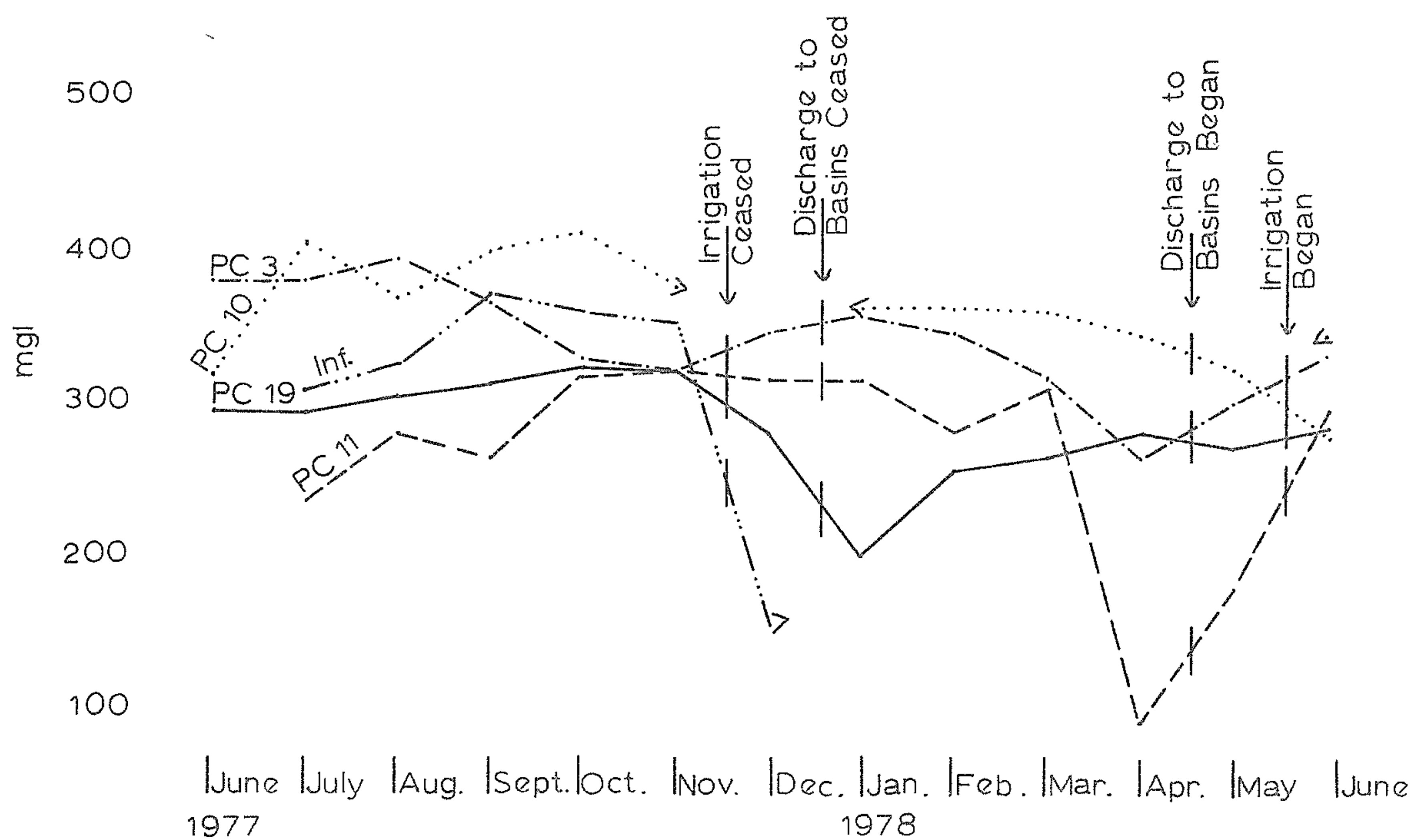


FIGURE 22. Mean Monthly Hardness - Ground Waters

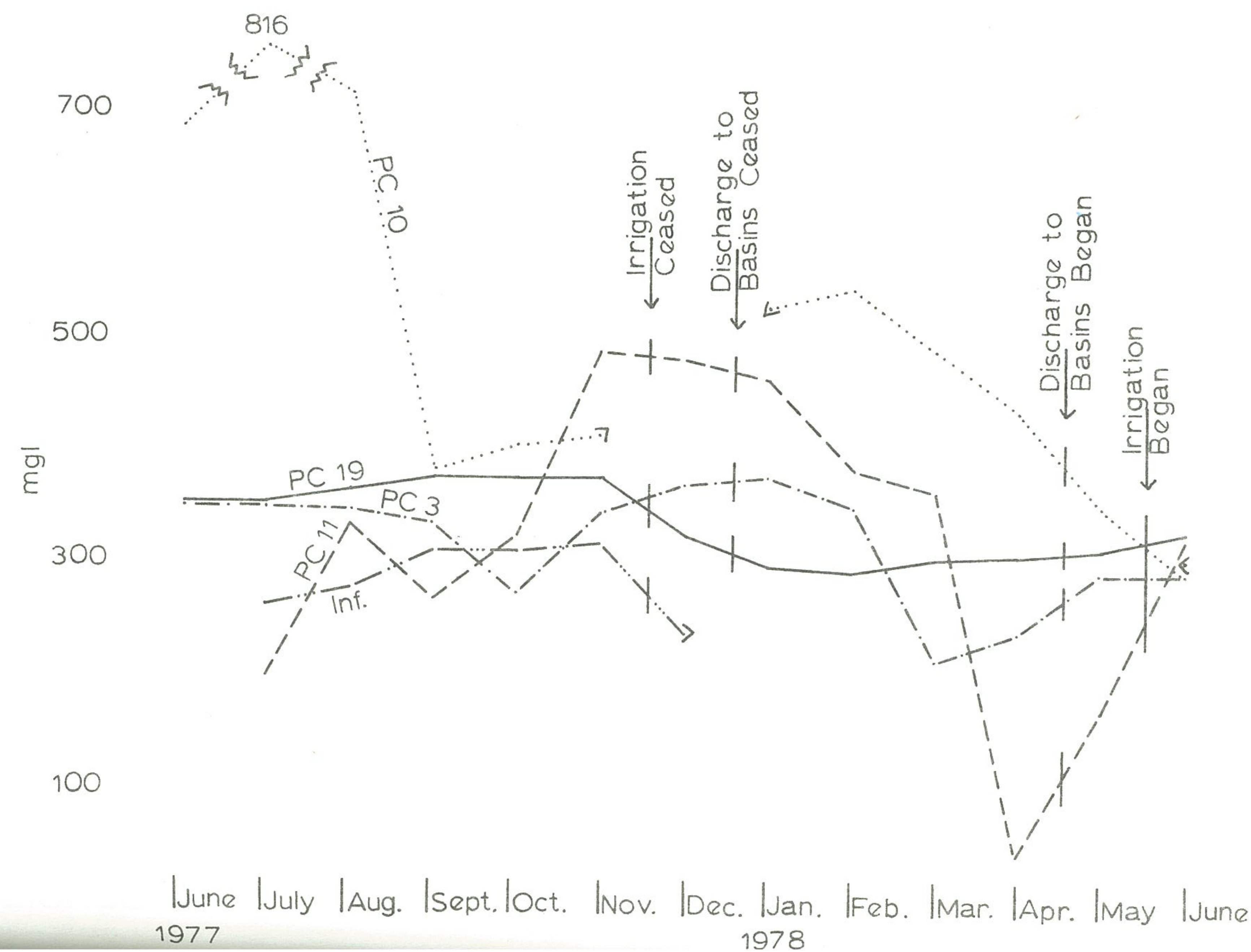


FIGURE 23.
TOTAL ALKALINITY
OF GROUND WATERS

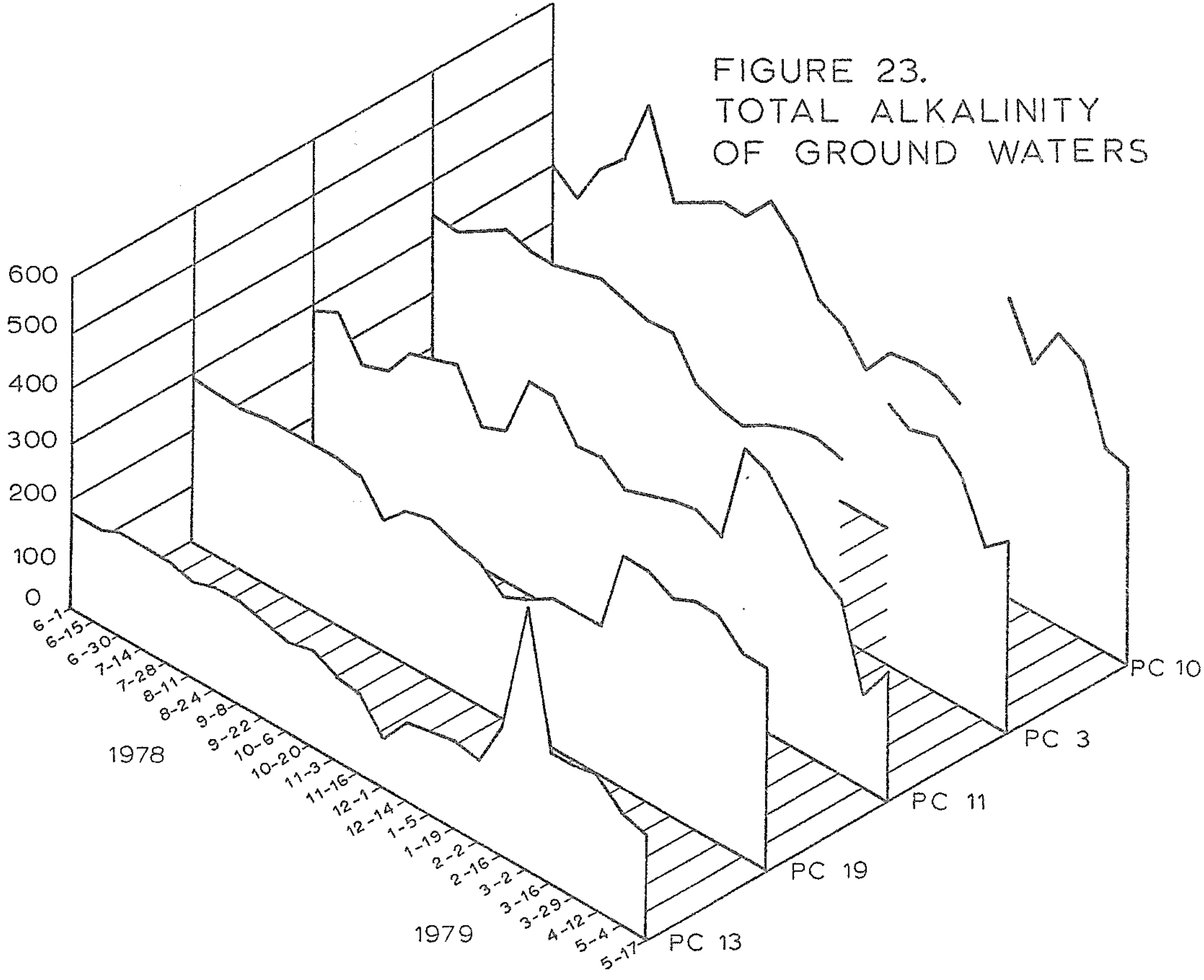


FIGURE 24.
CALCIUM IN
GROUND WATERS

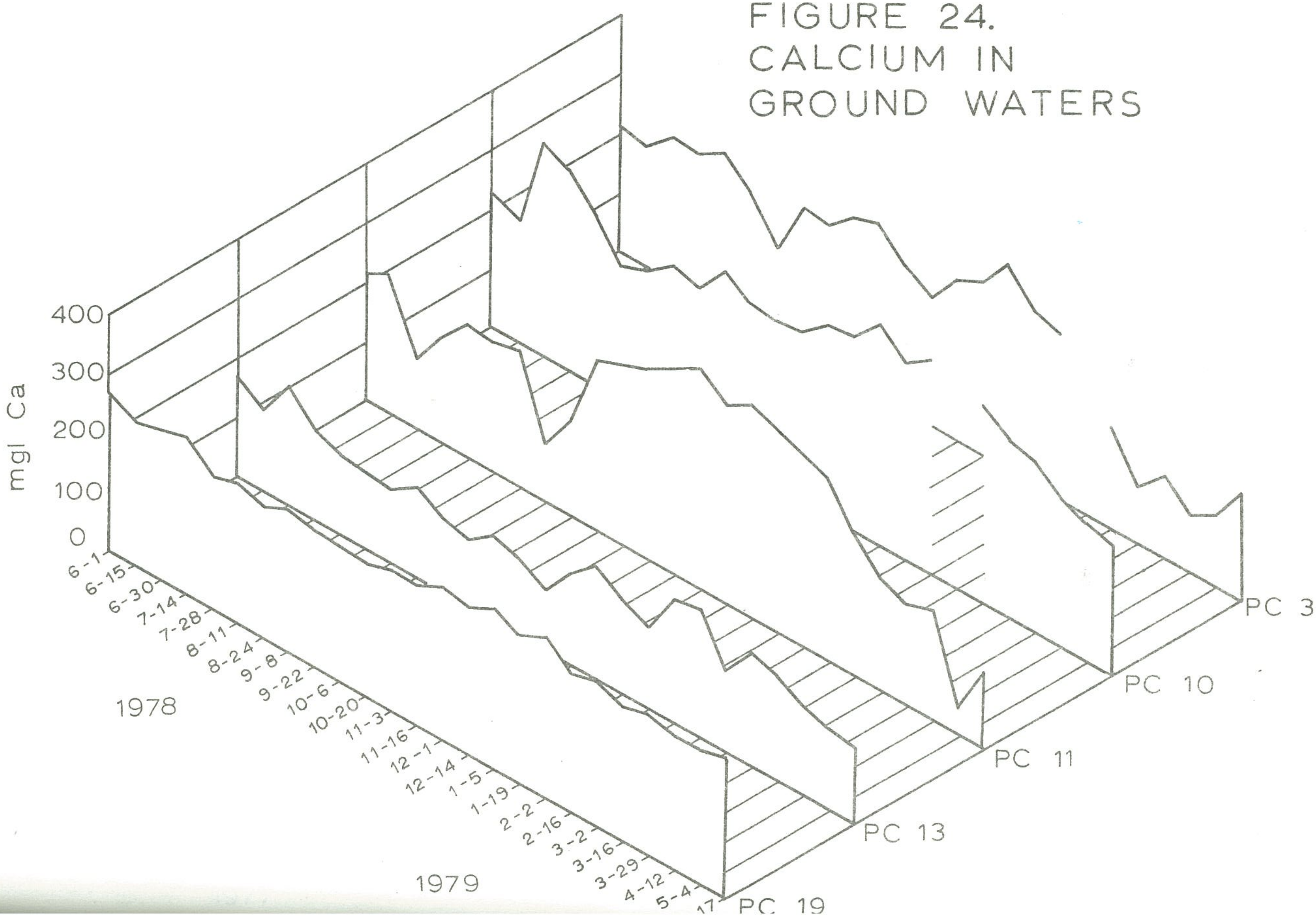
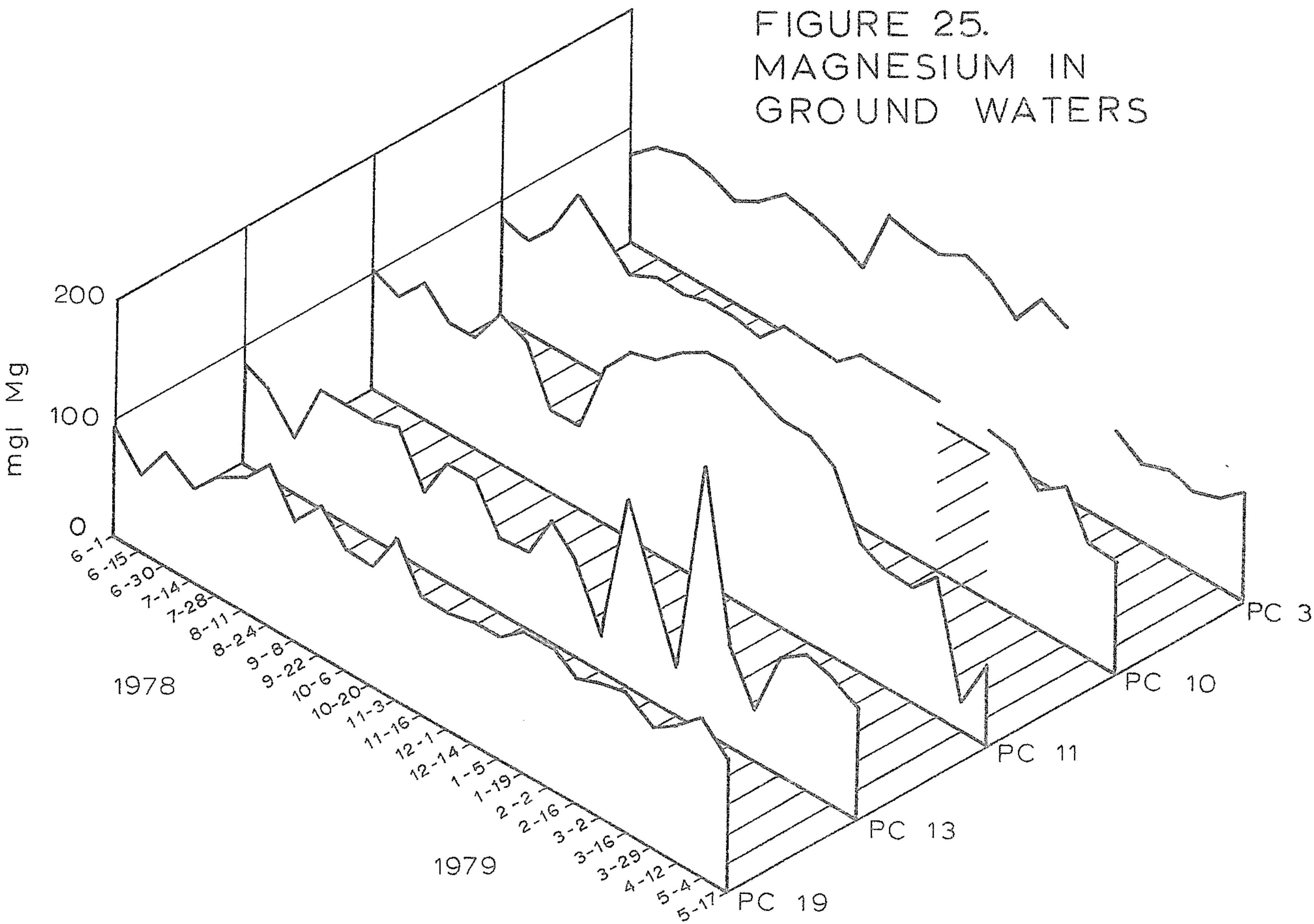


FIGURE 25.
MAGNESIUM IN
GROUND WATERS



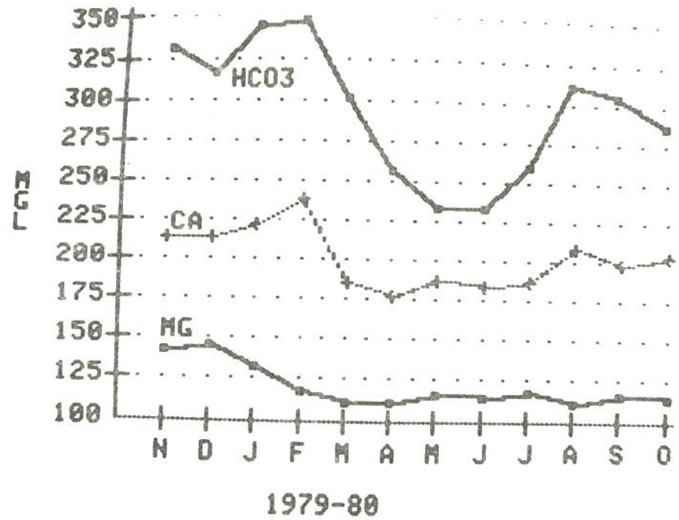


FIGURE 26. Monthly mean calcium and magnesium concentrations and HCO_3 alkalinity in the wastewater influent, 1979-80.

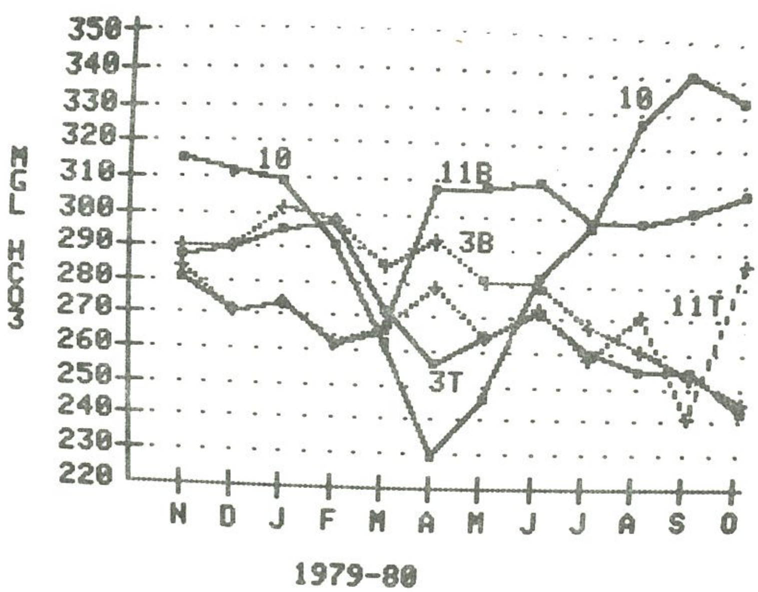


FIGURE 27. Monthly mean HCO_3 alkalinity at PC3, 10 and 11, 1979-80.

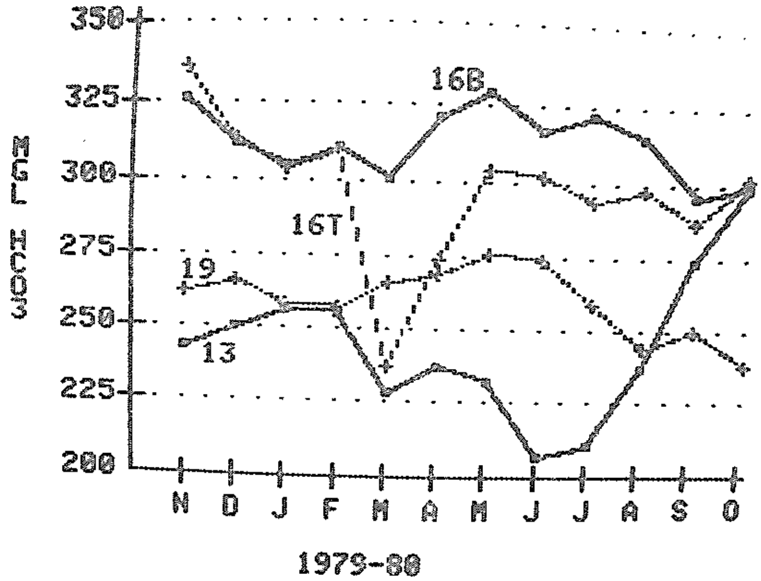


FIGURE 28. Monthly mean HCO_3 alkalinity at PC13, 16 and 19, 1979-80.

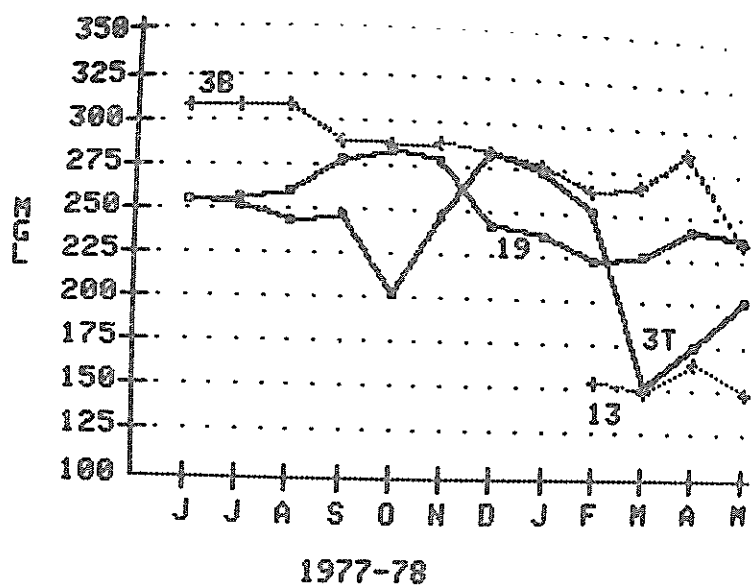


FIGURE 29. Monthly mean calcium concentrations at PC3, 13 and 19, 1977-78.

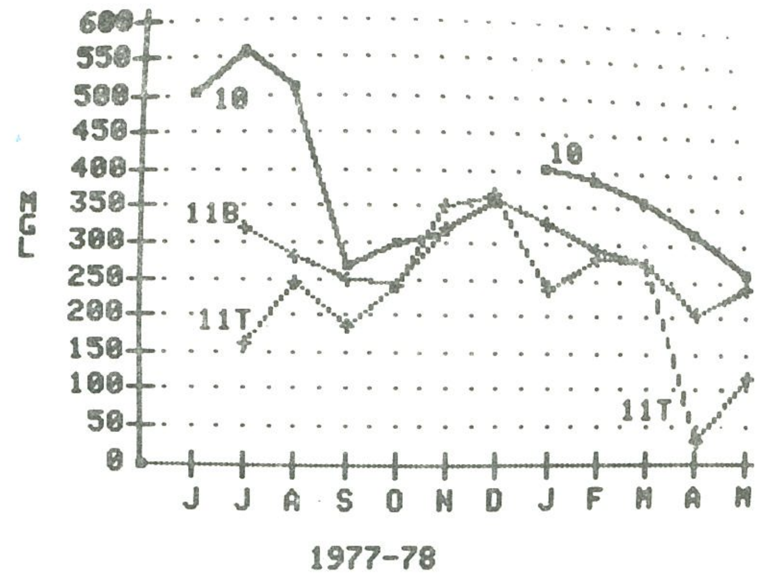


FIGURE 30. Monthly mean calcium concentrations at PC10 and 11, 1977-78.

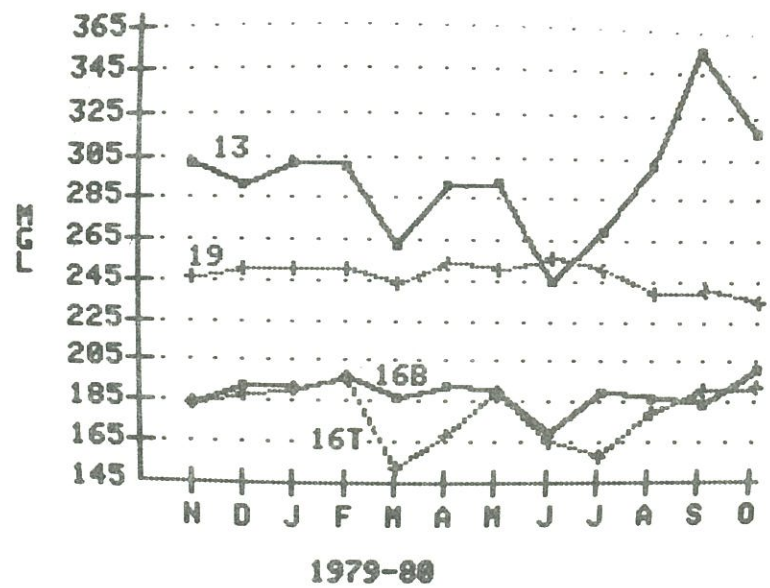


FIGURE 31. Monthly mean calcium concentrations at PC13, 16 and 19, 1979-80.

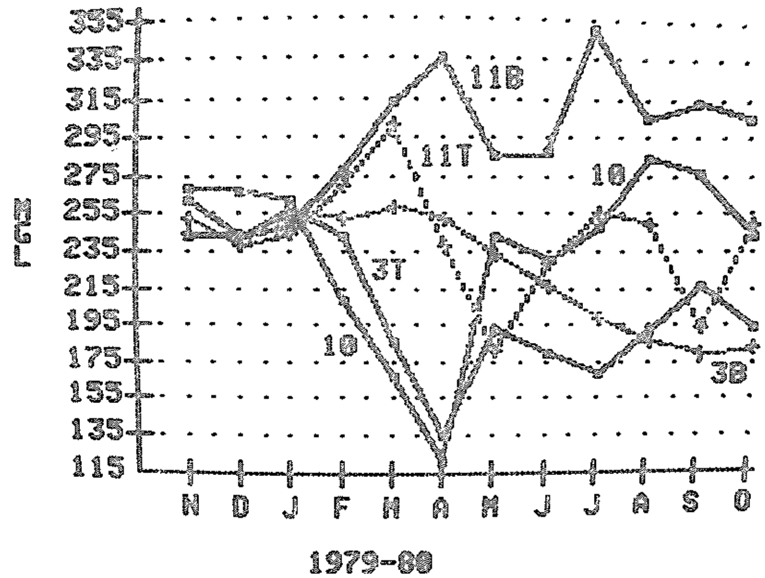


FIGURE 32. Monthly mean calcium concentrations at PC3, 10 and 11, 1979-80.

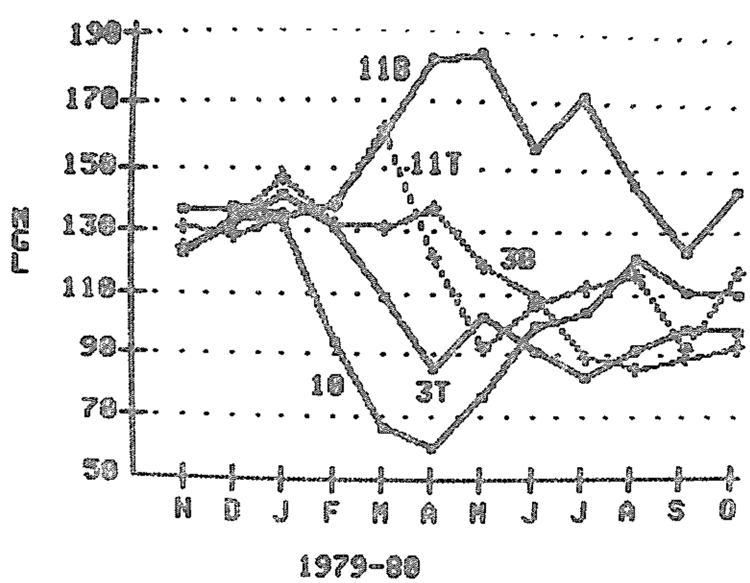


FIGURE 33. Monthly mean magnesium concentrations at PC3, 10 and 11, 1979-80.

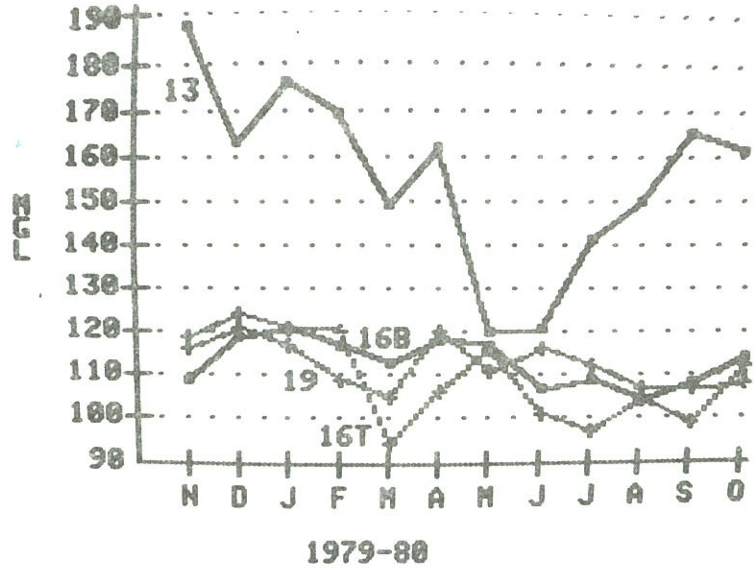


FIGURE 34. Monthly mean magnesium concentrations at PC13, 16 and 19, 1979-80.

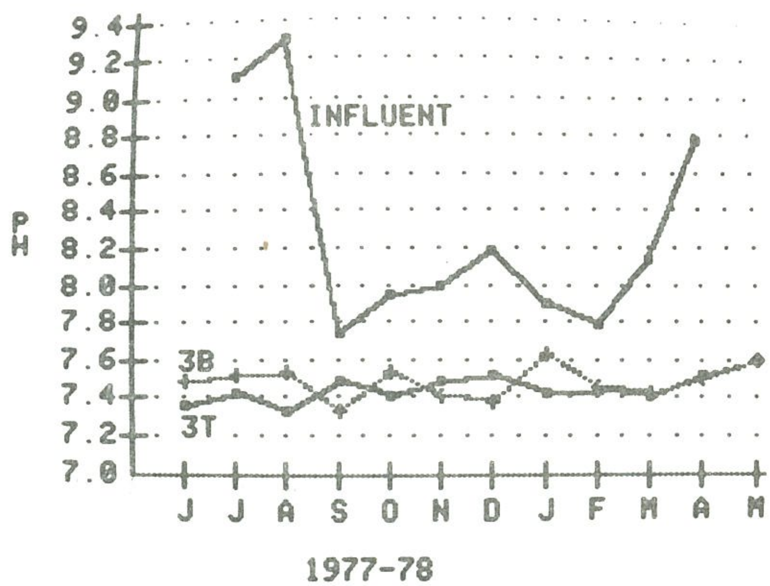


FIGURE 35. Comparison of monthly mean influent pH with pH at PC3, 1977-78.

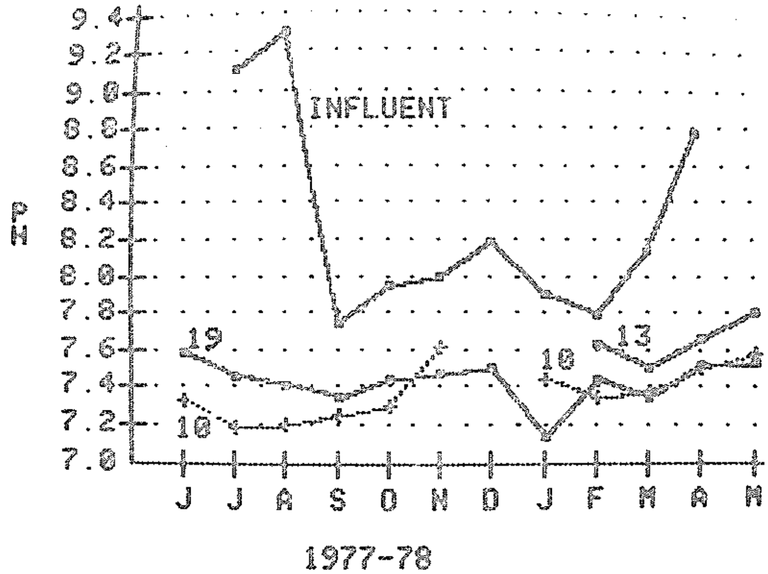


FIGURE 36. Comparison of monthly mean influent pH with pH at PC10, 13 and 19, 1977-78.

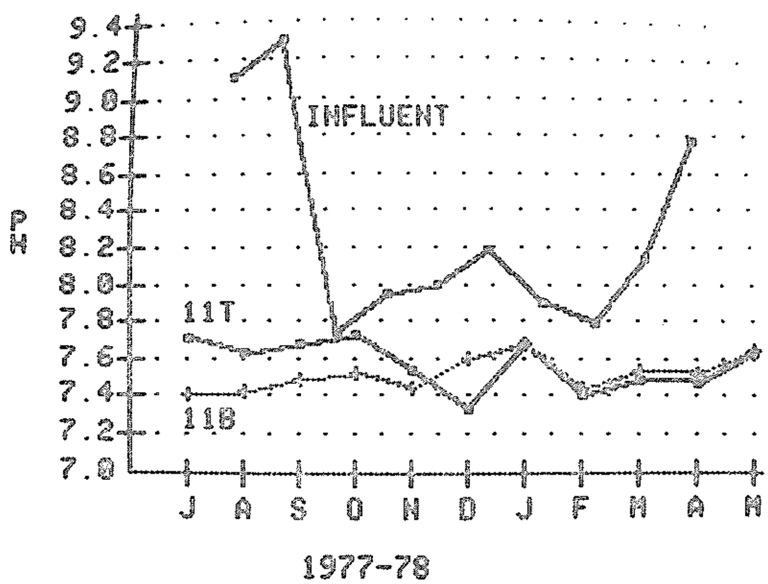


FIGURE 37. Comparison of monthly mean influent pH with pH at PC11, 1977-78.

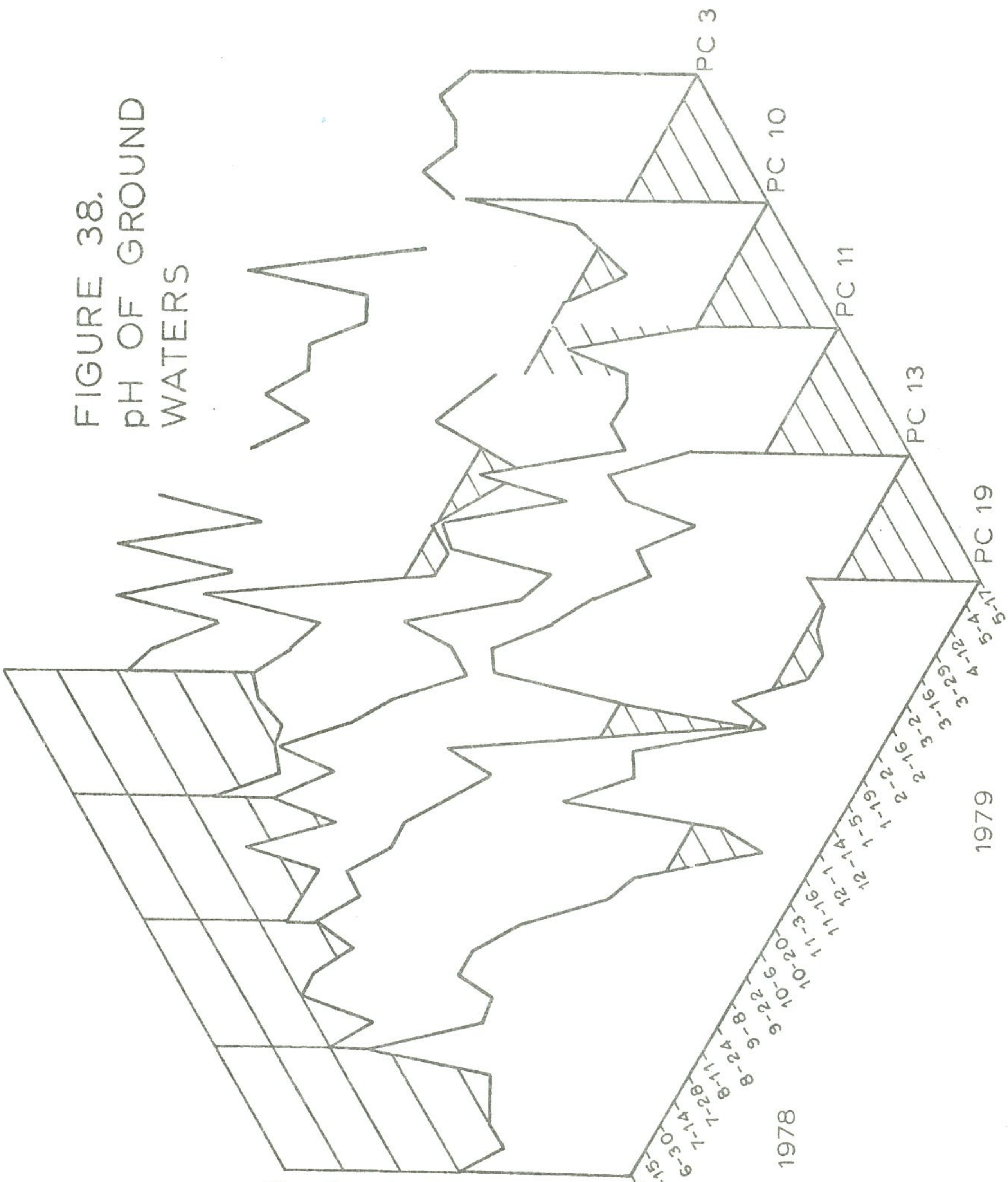


FIGURE 38. pH OF GROUND WATERS

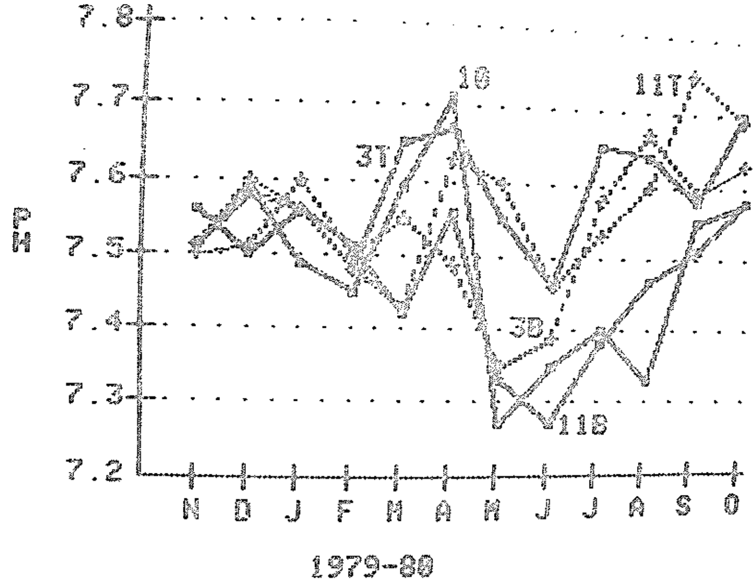


FIGURE 39. Monthly mean pH at PC3, 10 and 11, 1979-80.

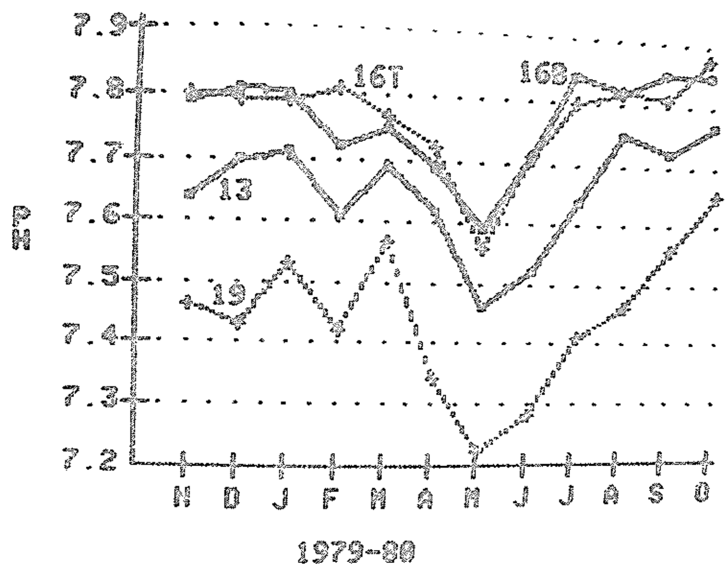


FIGURE 40. Monthly mean pH at PC13, 16 and 19, 1979-80.

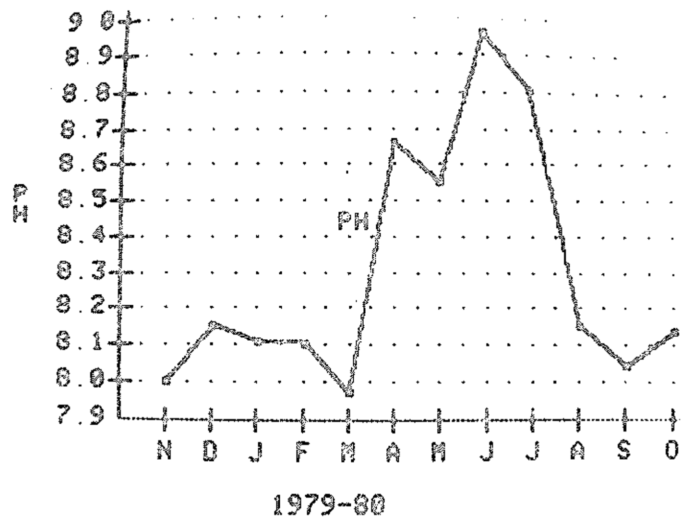


FIGURE 41. Monthly mean pH of wastewater influent, 1979-80.

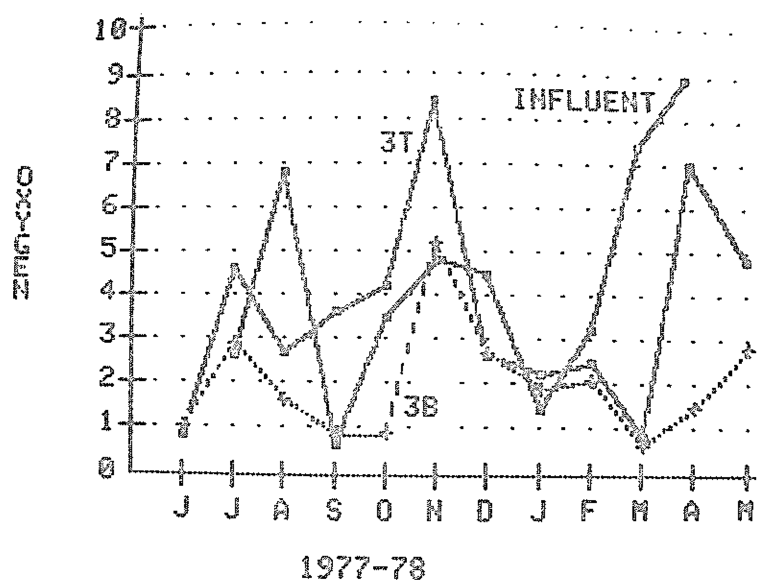


FIGURE 42. Comparison of monthly mean oxygen concentrations (mgl) in the influent with those at PC3, 1977-78.

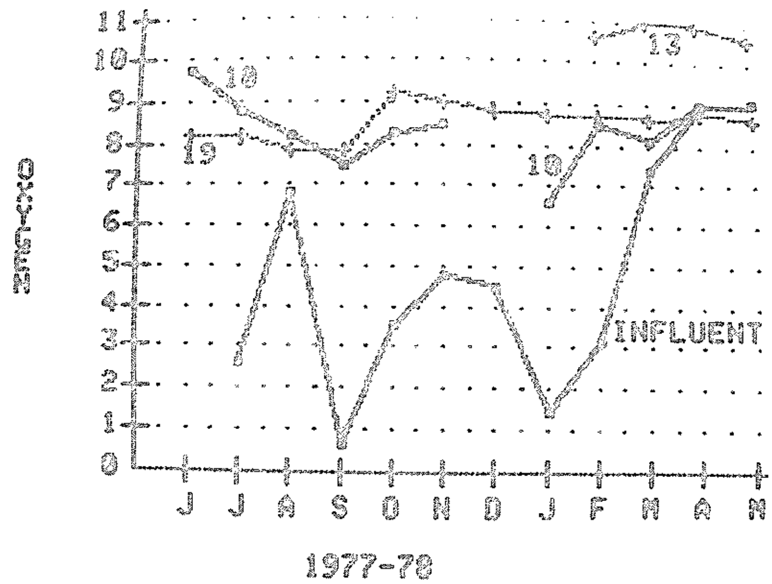


FIGURE 43. Comparison of monthly mean oxygen concentrations (mgl) in the influent with those at PC10, 13 and 19, 1977-78.

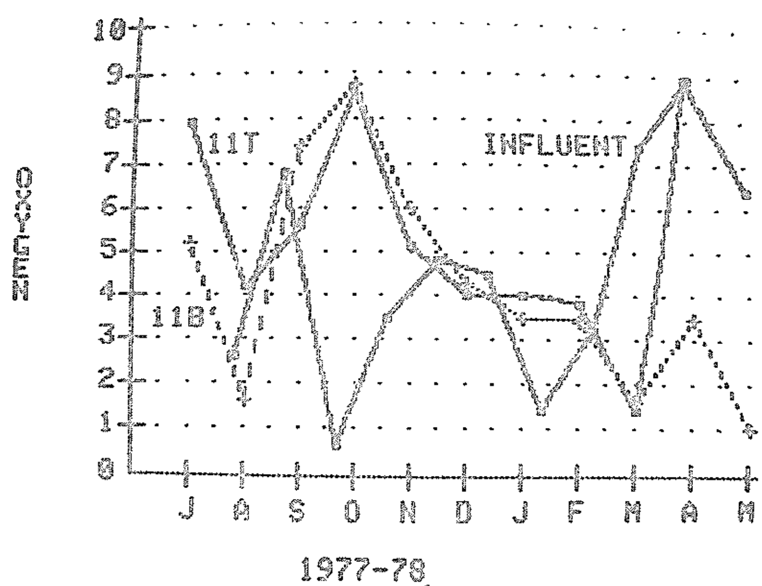


FIGURE 44. Comparison of monthly mean oxygen concentrations (mgl) in the influent with those at PC11, 1977-78.

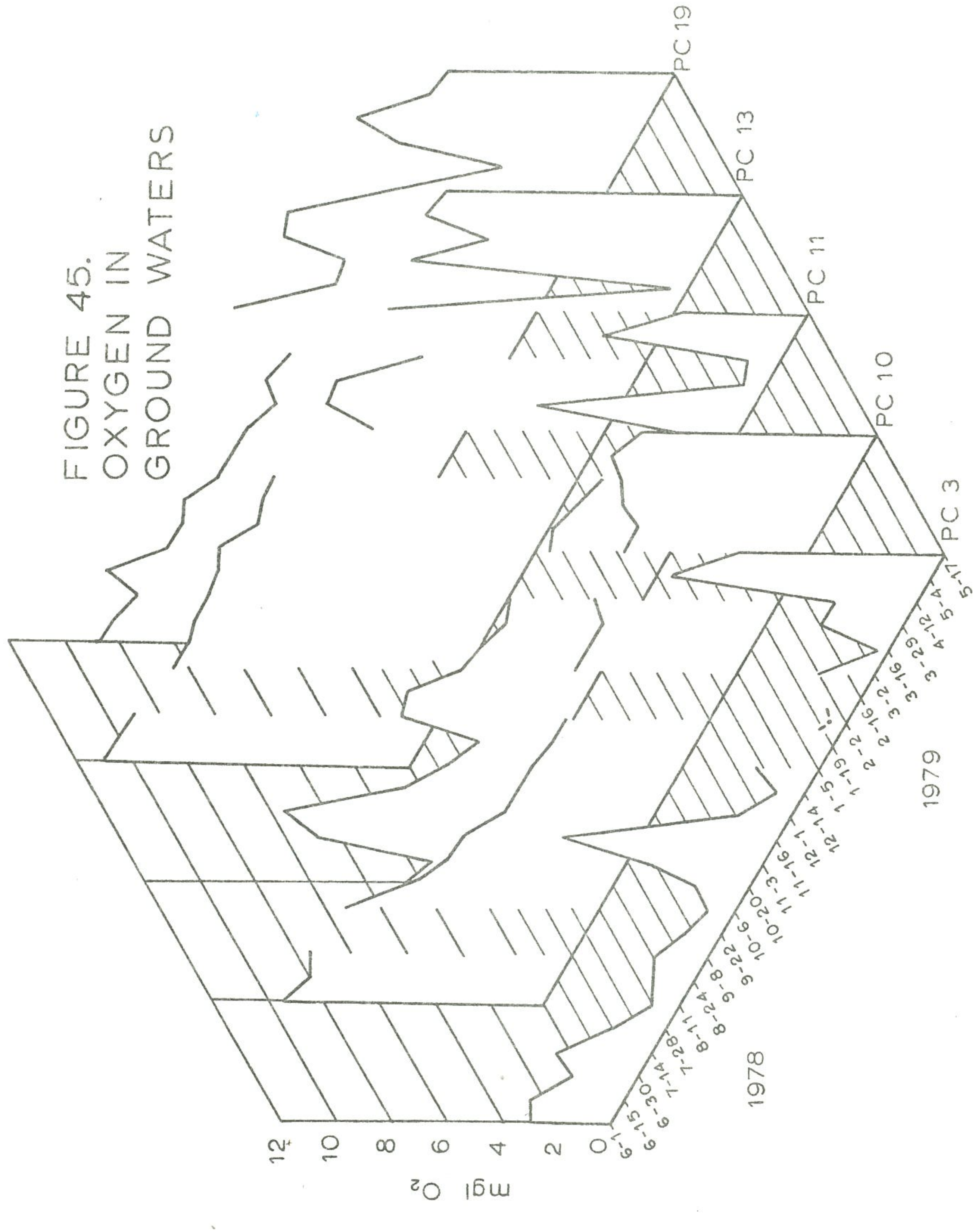


FIGURE 45.
OXYGEN IN
GROUND WATERS

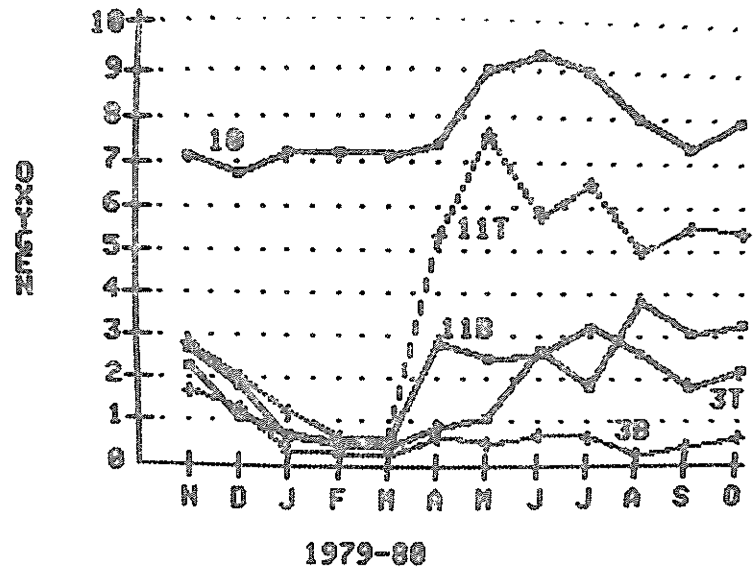


FIGURE 46. Monthly mean oxygen concentrations (mgl) at PC3, 10 and 11, 1979-80.

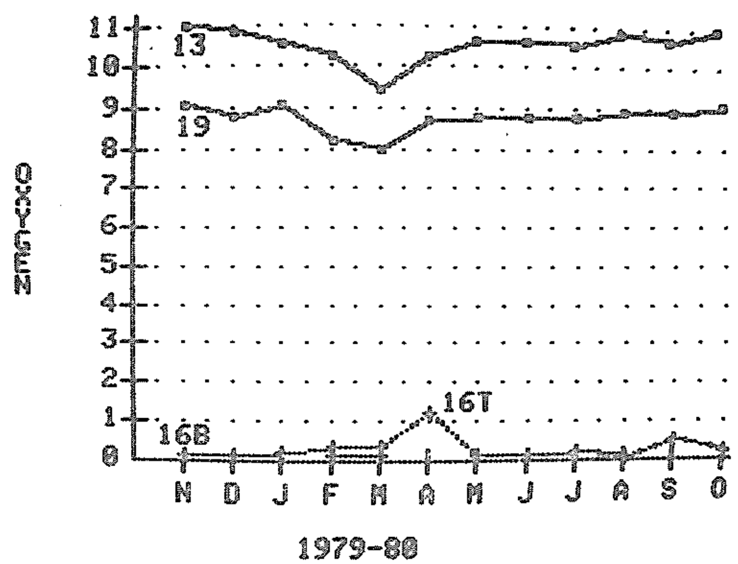
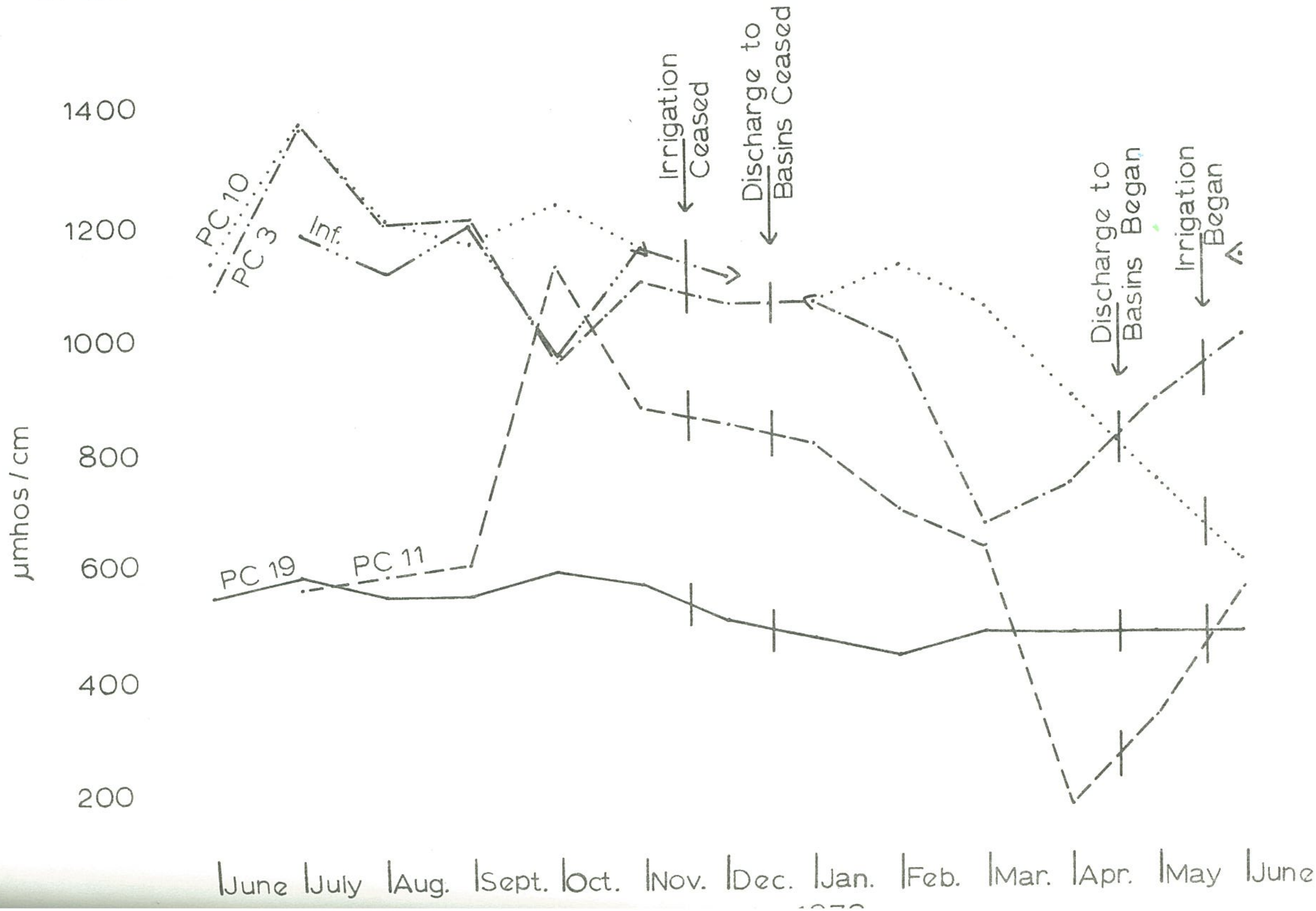


FIGURE 47. Monthly mean oxygen concentrations (mgl) at PC13, 16 and 19, 1979-80.

FIGURE 48.
Mean Monthly Conductivity -
Ground Waters



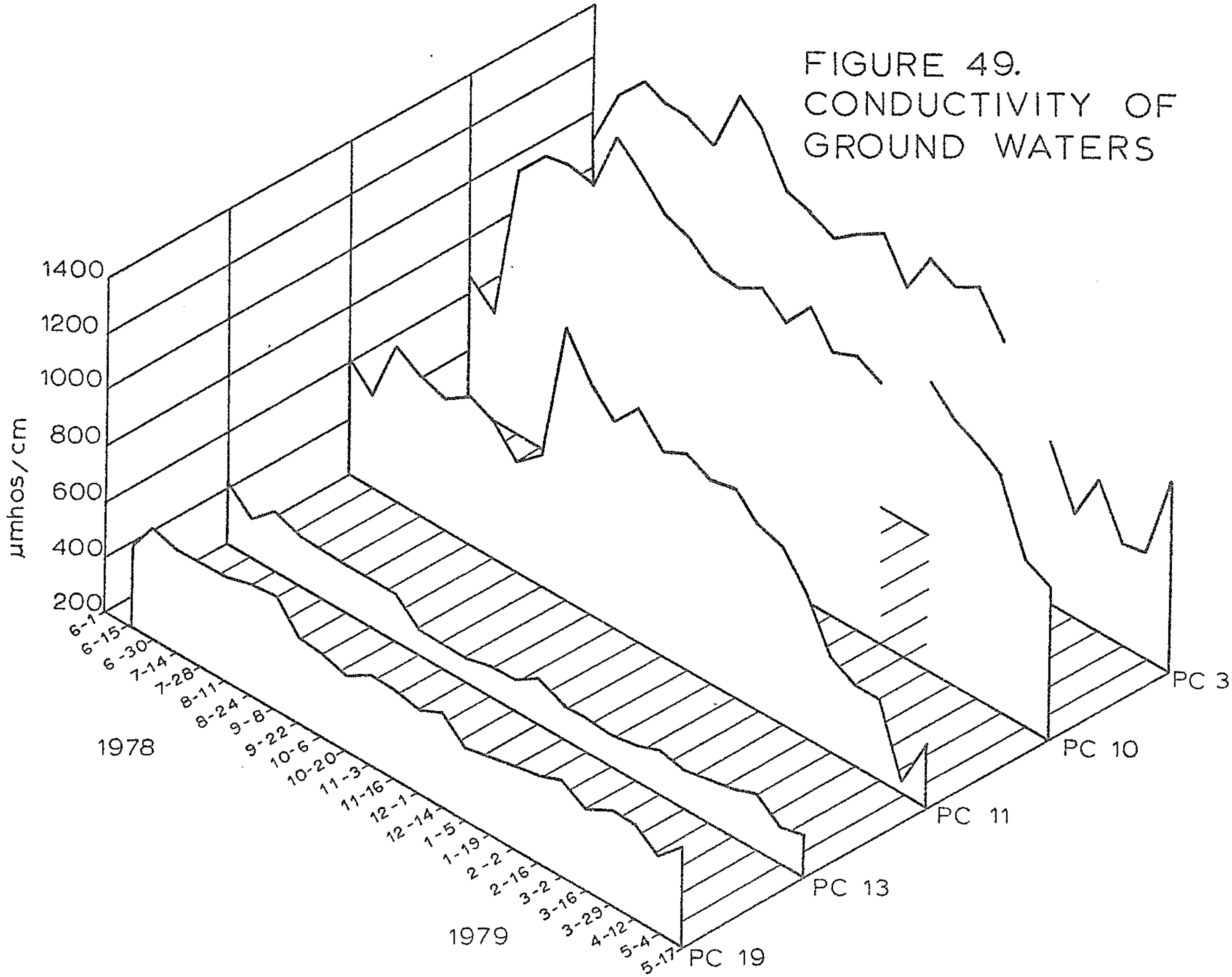


FIGURE 49.
CONDUCTIVITY OF
GROUND WATERS

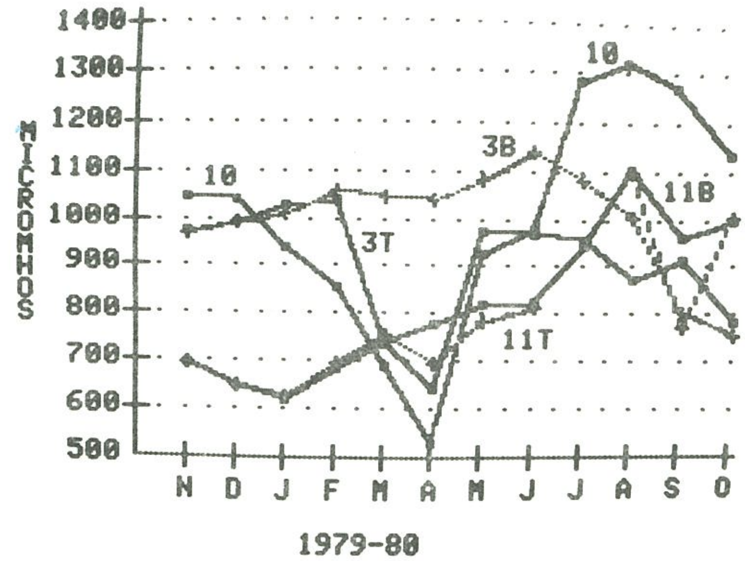


FIGURE 50. Monthly mean conductivity (µmhos/cm) at PC3, 10 and 11, 1979-80.

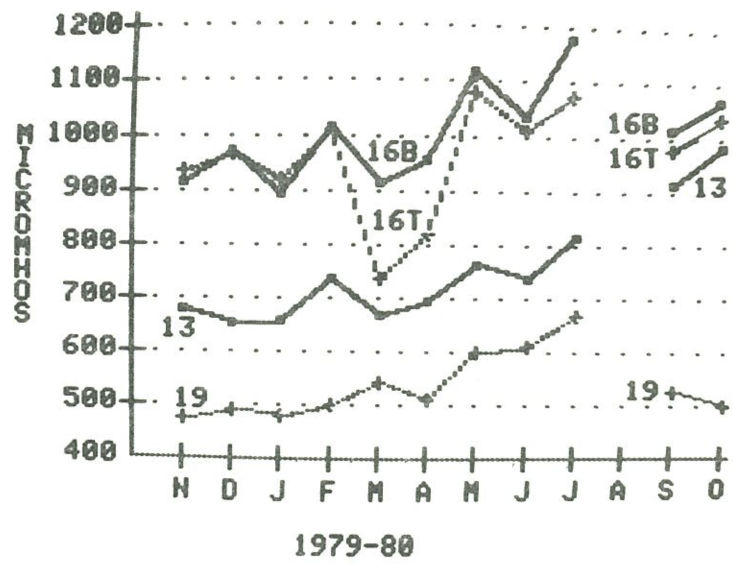


FIGURE 51. Monthly mean conductivity (µmhos/cm) at PC13, 16 and 19, 1979-80.

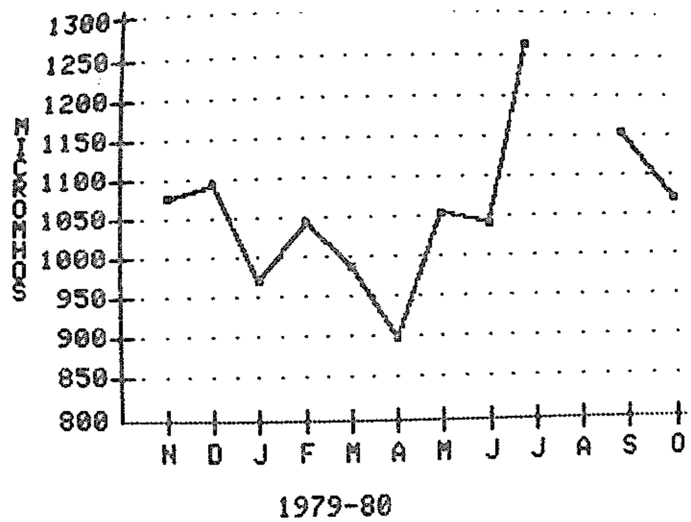
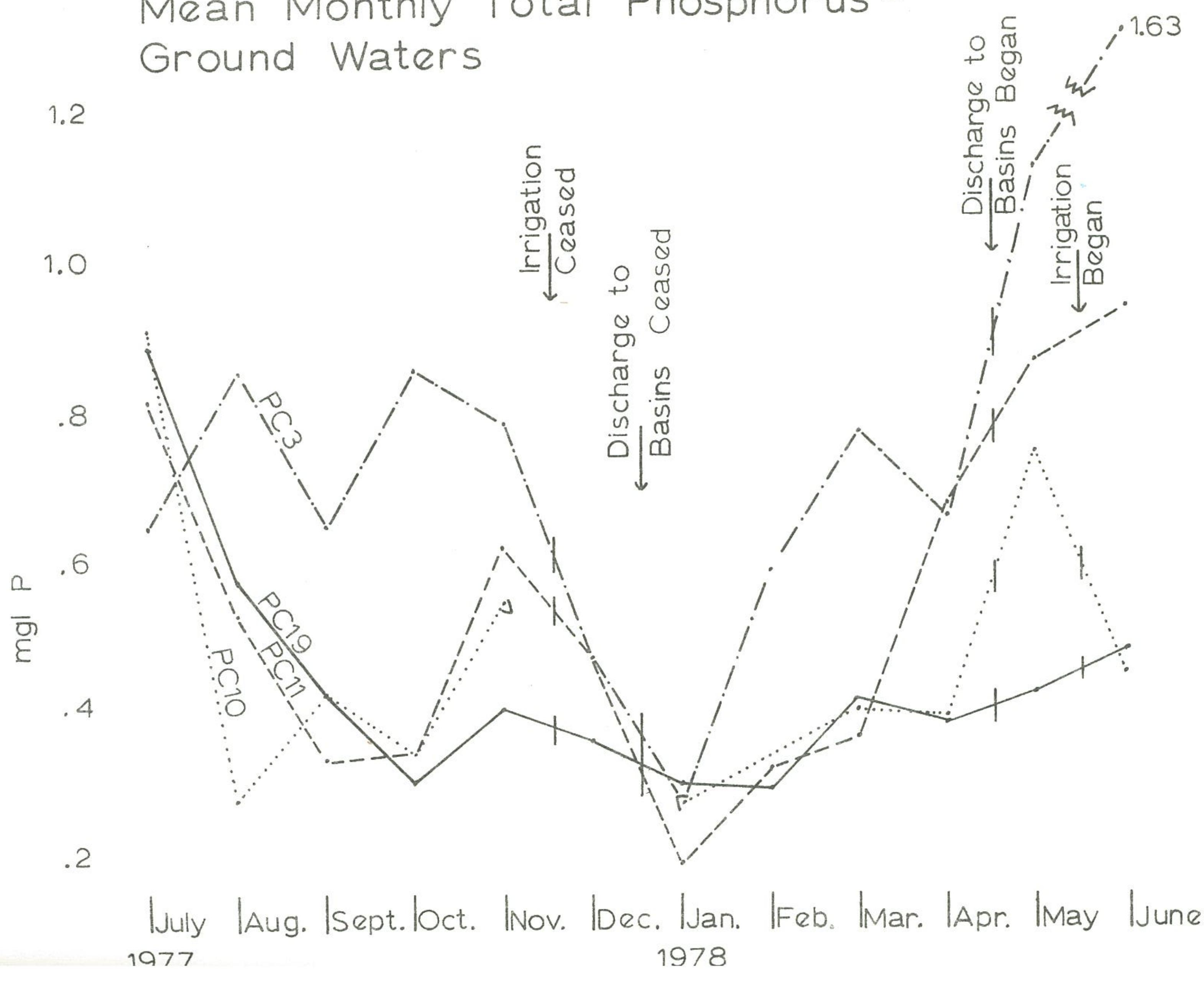


FIGURE 52. Monthly mean conductivity (μmhos/cm) of the wastewater influent, 1979-80.

FIGURE 53.
Mean Monthly Total Phosphorus - Ground Waters



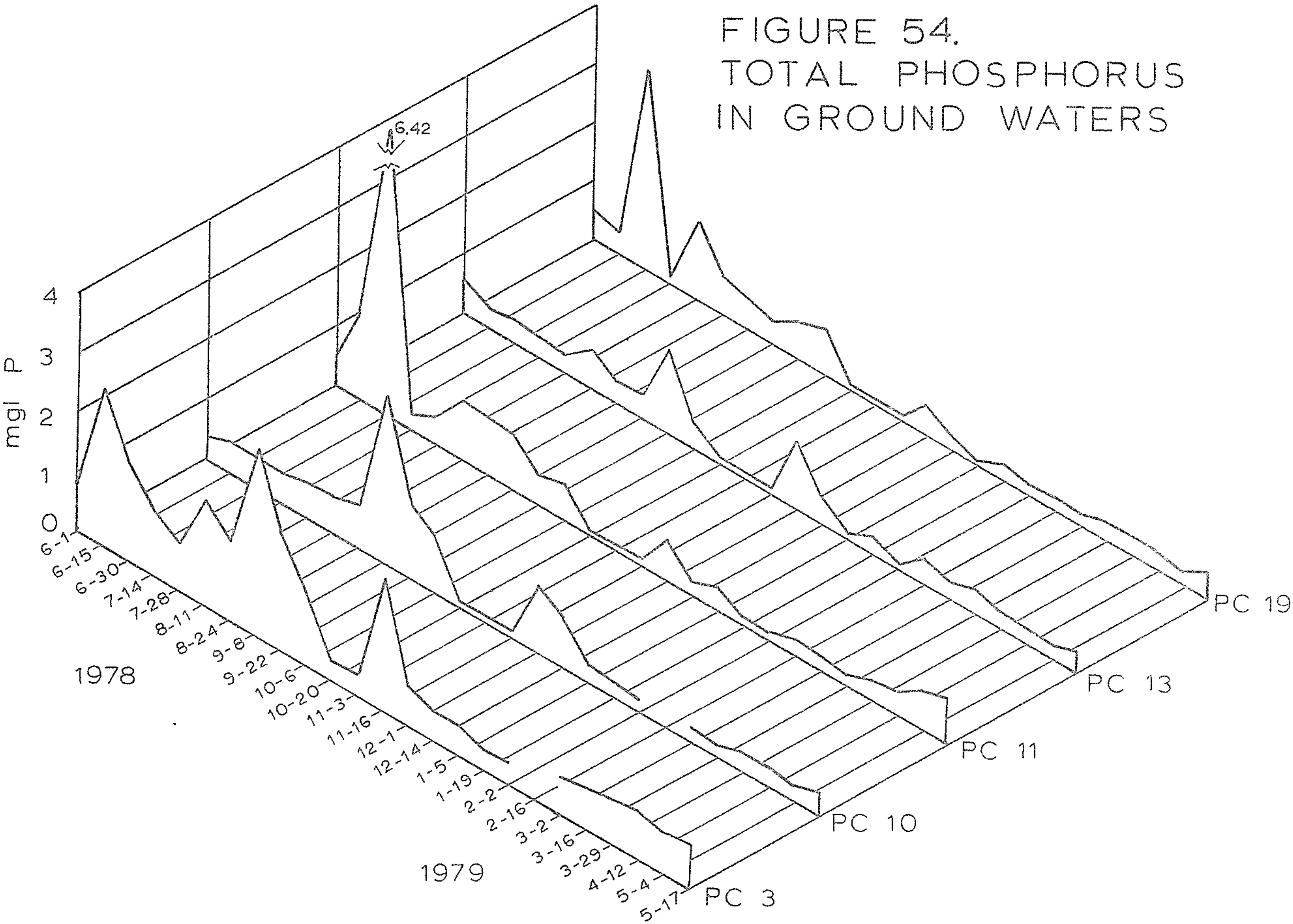


FIGURE 54.
TOTAL PHOSPHORUS
IN GROUND WATERS

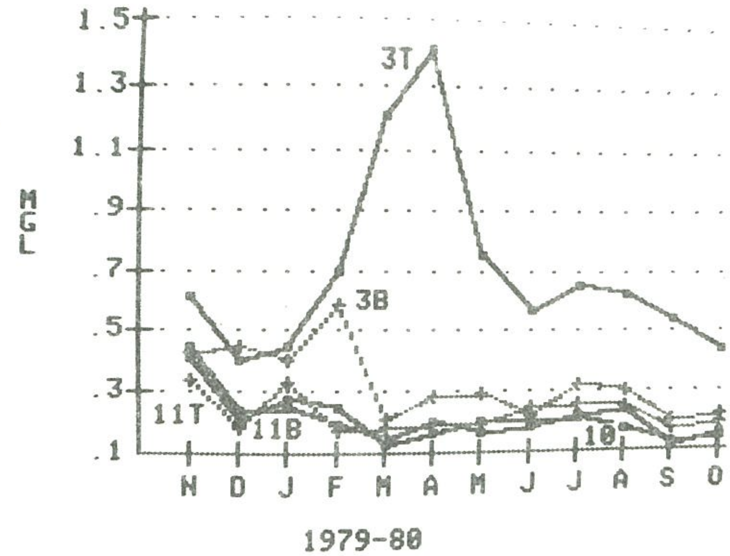


FIGURE 55. Monthly mean concentrations of total phosphorus at PC3, 10 and 11, 1979-80.

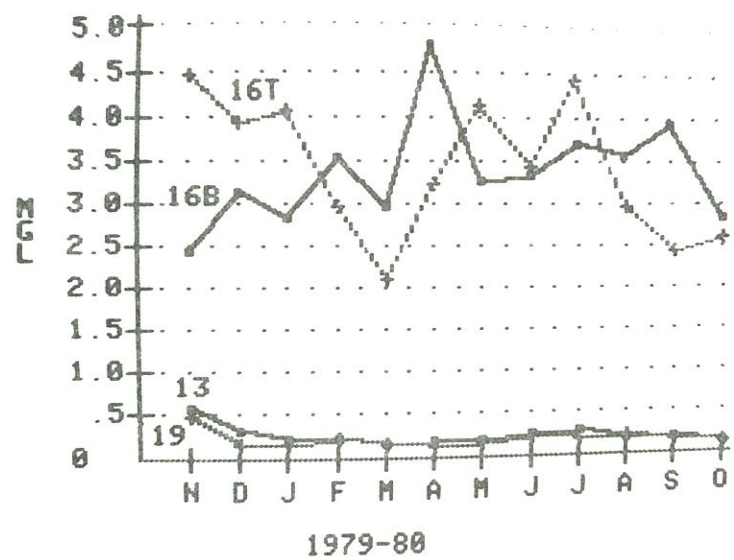
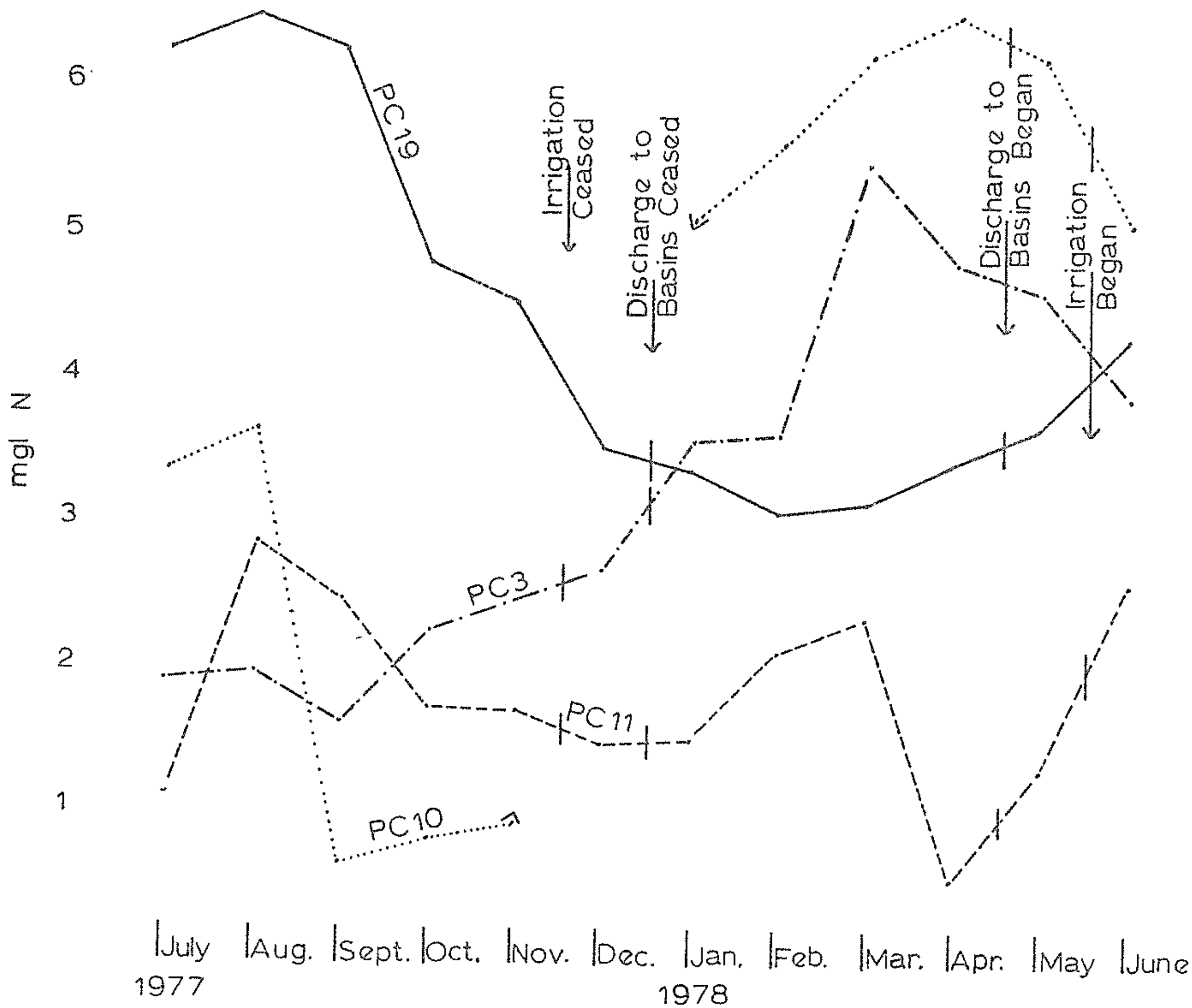


FIGURE 56. Monthly mean concentrations of total phosphorus at PC13, 16 and 19, 1979-80.

FIGURE 57.
Mean Monthly Total Nitrogen-
Ground Waters



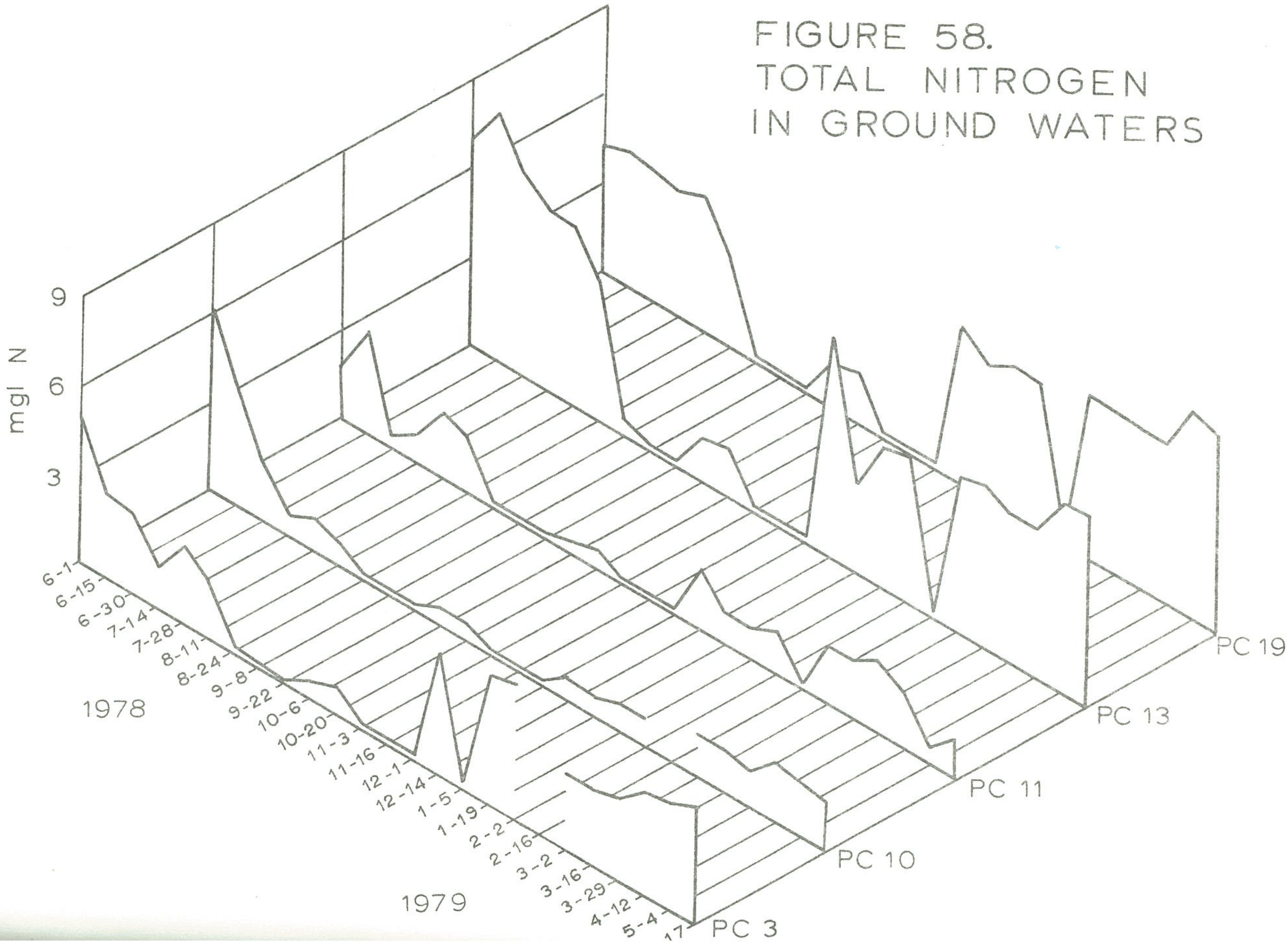


FIGURE 58.
TOTAL NITROGEN
IN GROUND WATERS

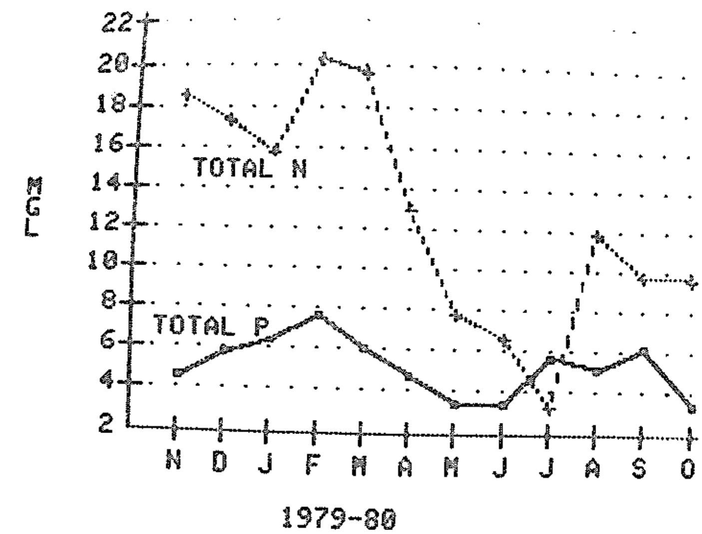


FIGURE 59. Monthly mean concentrations of total phosphorus and total nitrogen in the wastewater influent, 1979-80.

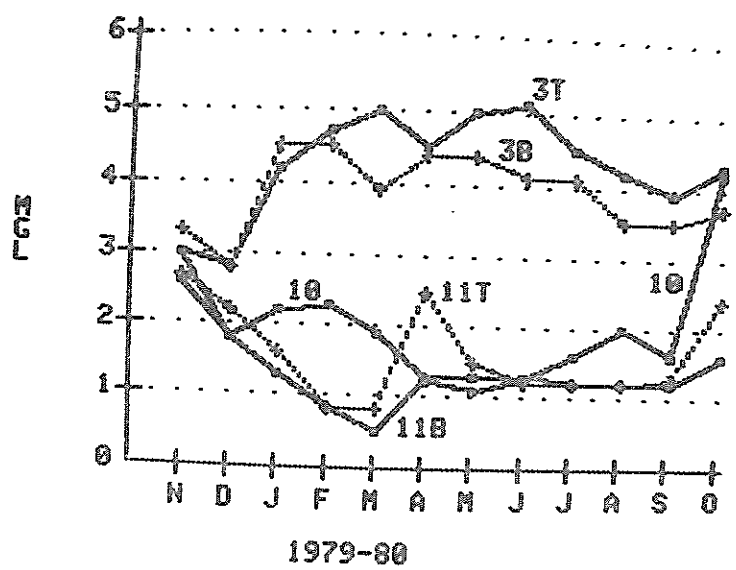


FIGURE 60. Monthly mean concentrations of total nitrogen at PC3, 10 and 11, 1979-80.

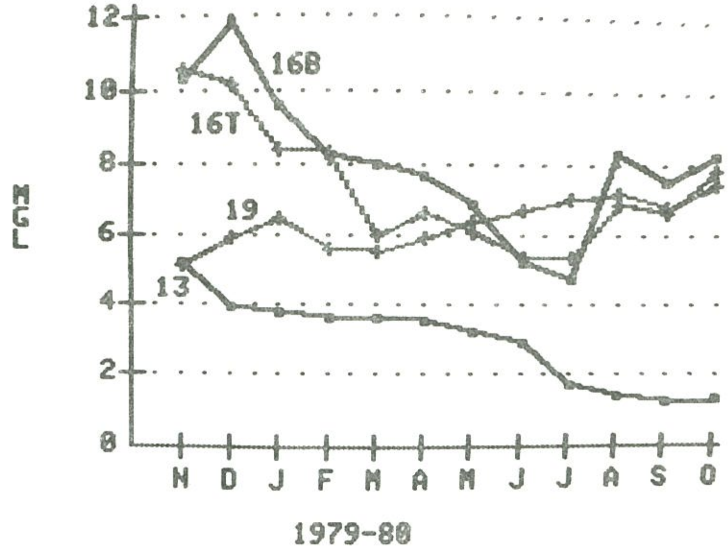
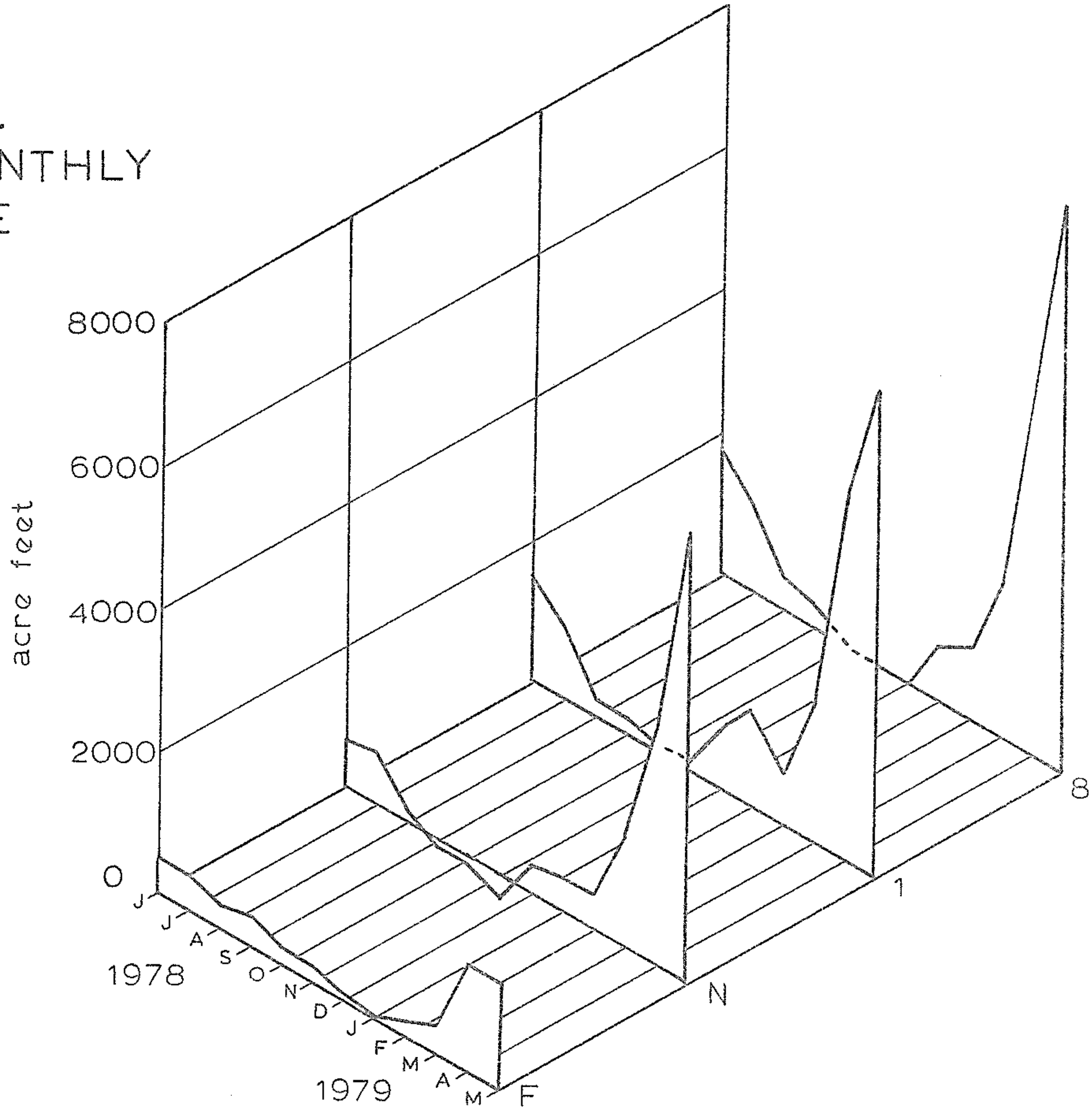


FIGURE 61. Monthly mean concentrations of total nitrogen at PC13, 16 and 19, 1979-80.

FIGURE 62.
TOTAL MONTHLY
DISCHARGE



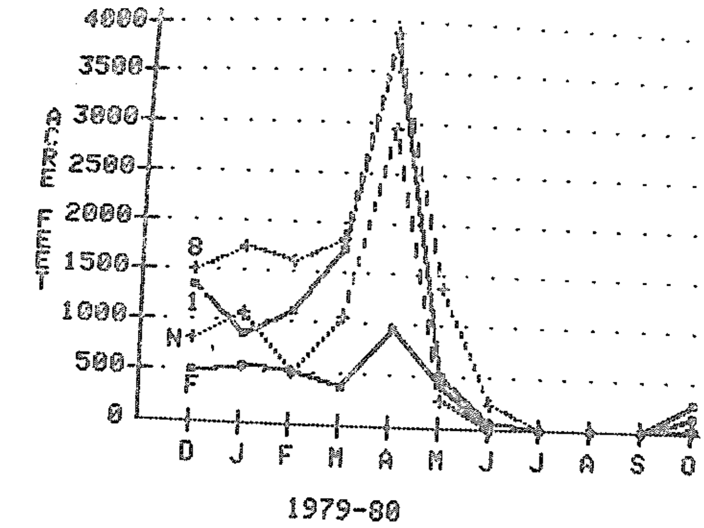


FIGURE 63. Total monthly discharge at Stations 1, 8, F and N, 1979-80.

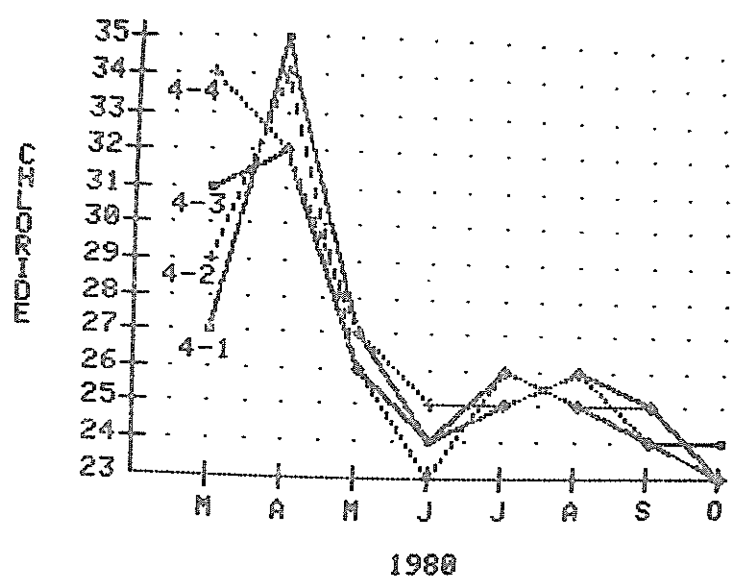


FIGURE 64. Variation of monthly mean chloride concentrations (mgl) with increasing depth in Lake Sallie, 1980.

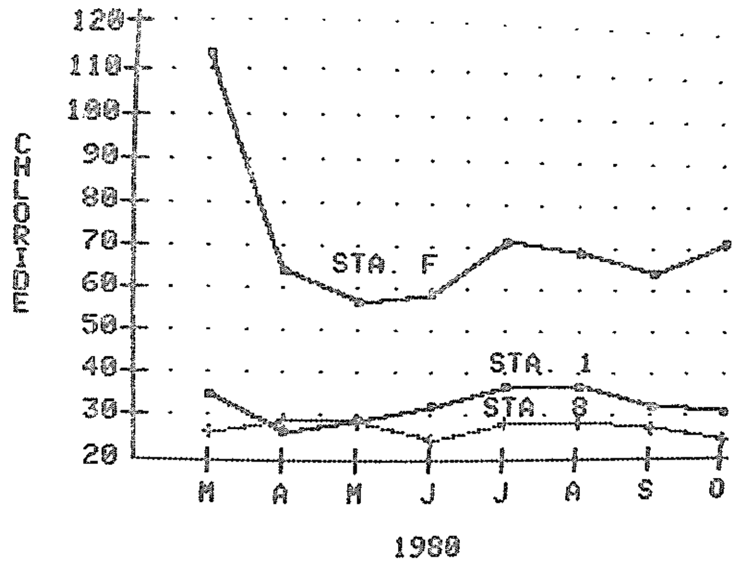


FIGURE 65. Monthly mean chloride concentrations (mgl) at Stations 1, 8 and F, 1980.

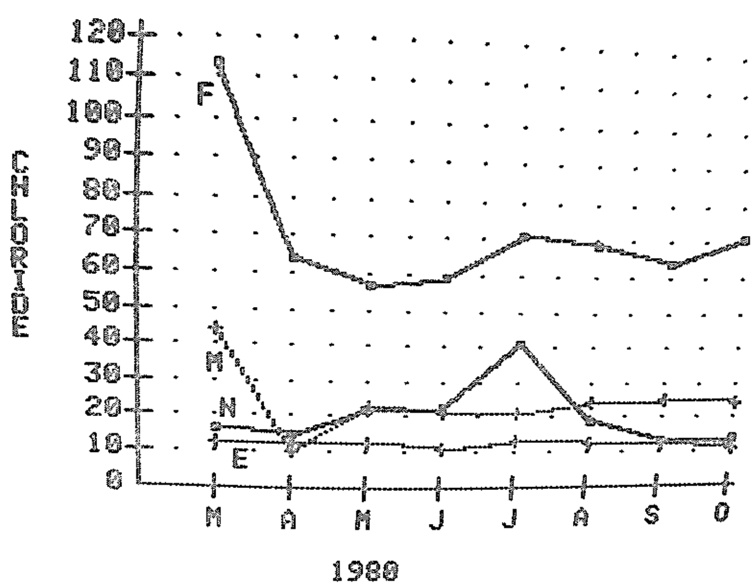


FIGURE 66. Monthly mean chloride concentrations (mgl) at Stations E, F, M and N, 1980.

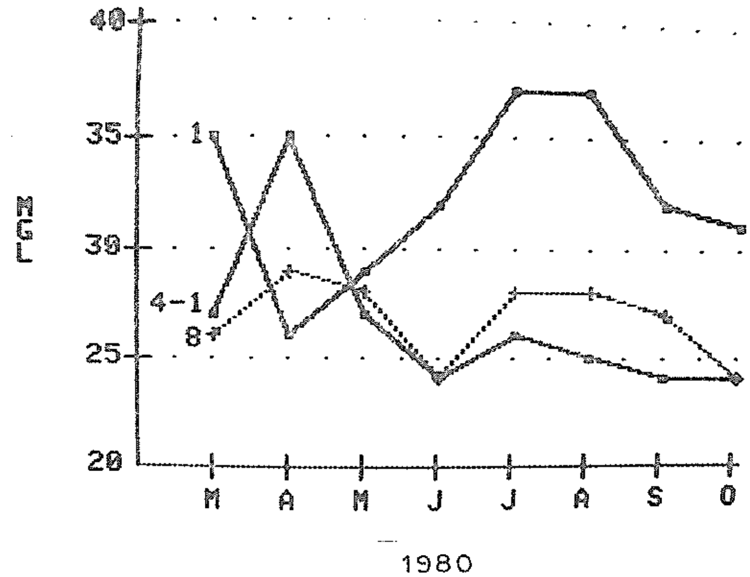


FIGURE 67. Monthly mean chloride concentrations (mgl) at Stations 1, 4 and 8, 1980.

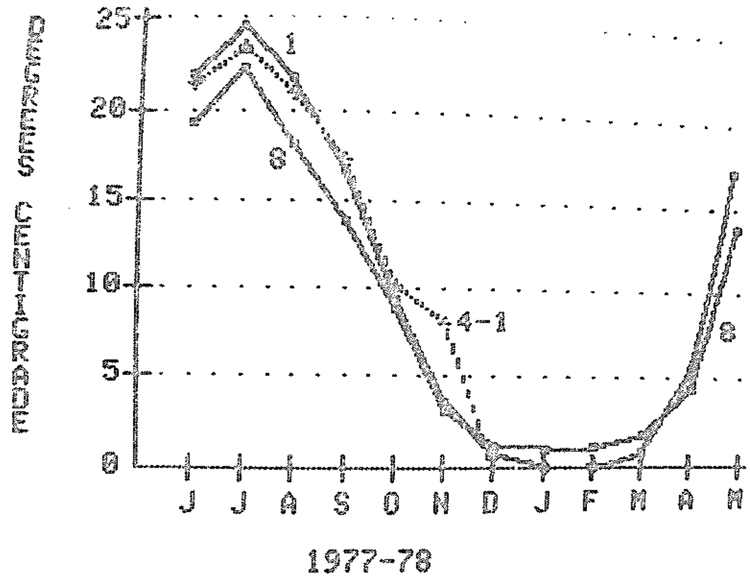


FIGURE 68. Monthly mean water temperature at Stations 1, 4 and 8, 1977-78.

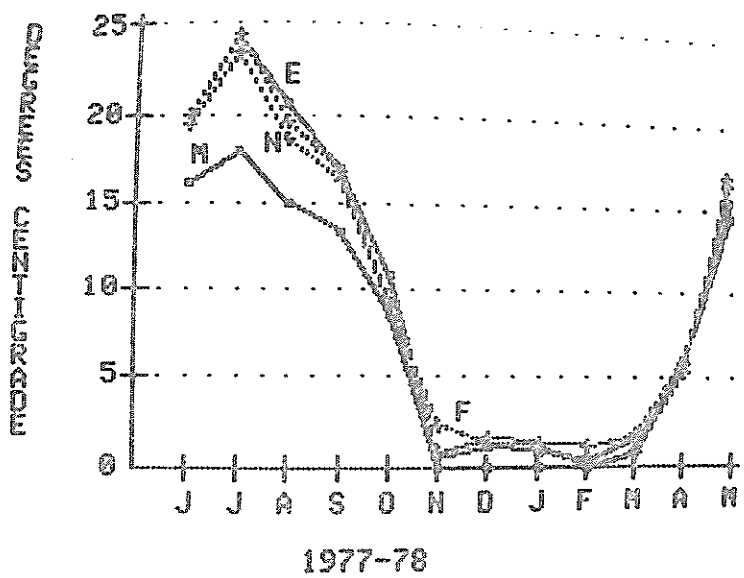
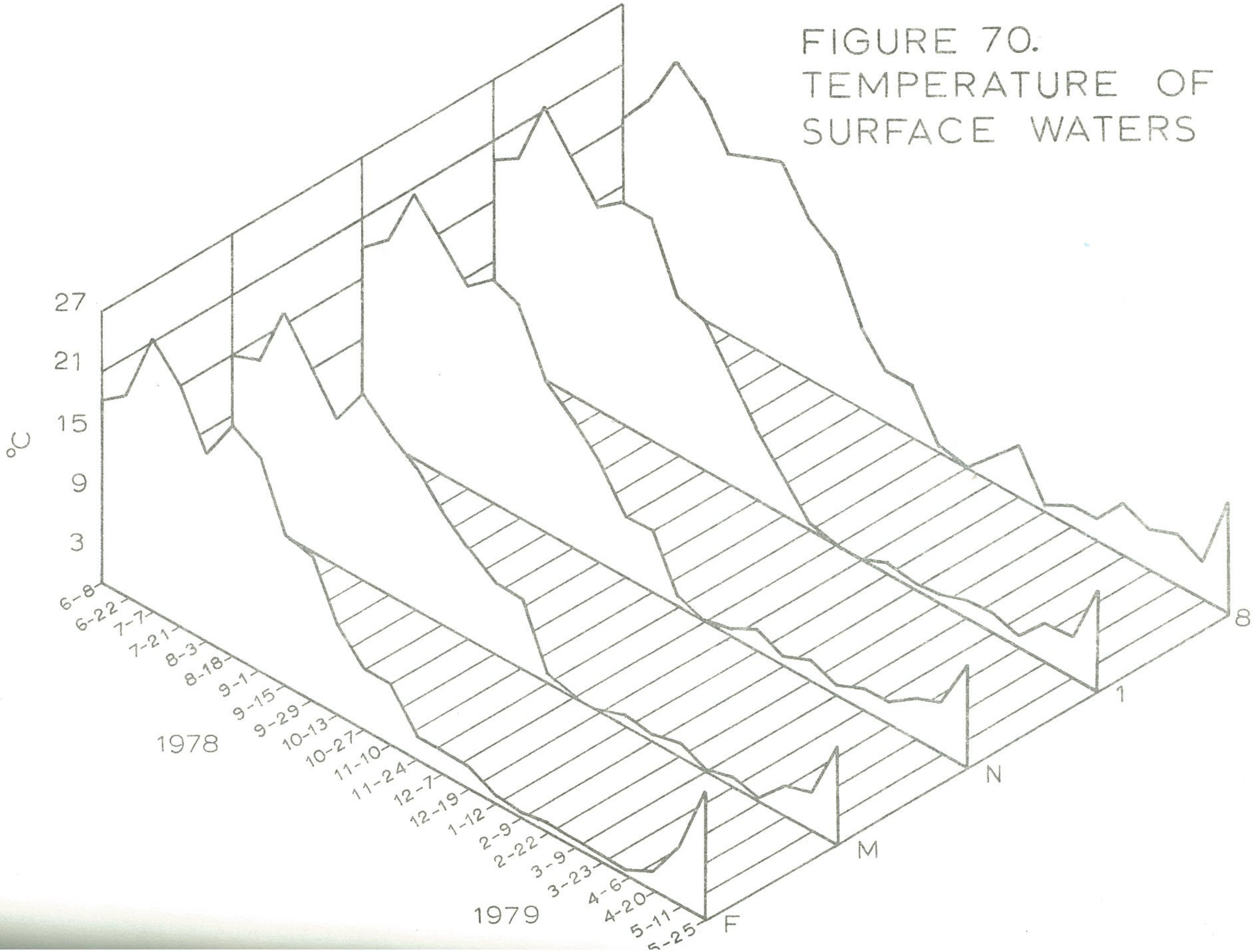


FIGURE 69. Monthly mean water temperature at Stations E, F, M and N, 1977-78.

FIGURE 70.
TEMPERATURE OF
SURFACE WATERS



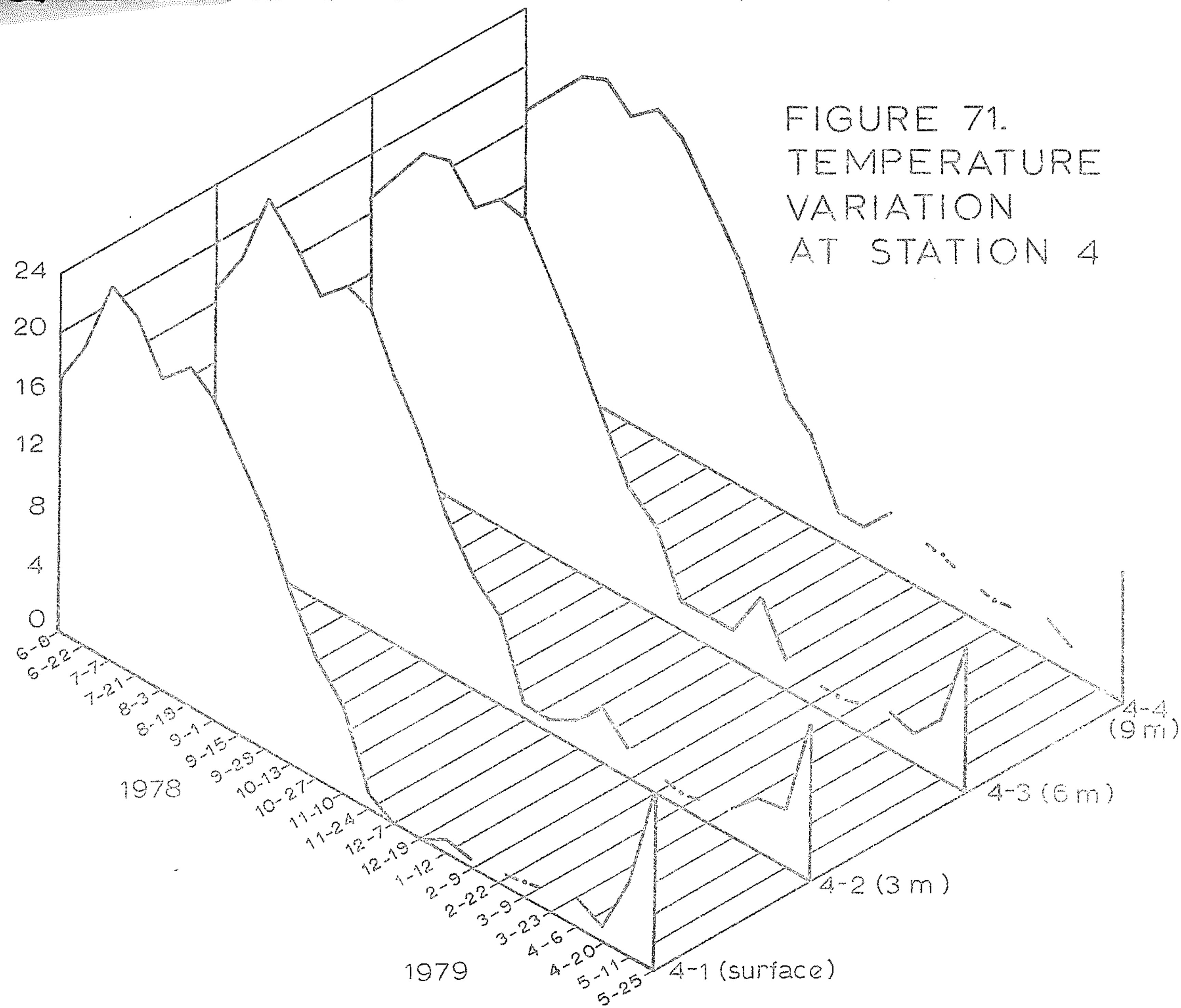


FIGURE 71.
TEMPERATURE
VARIATION
AT STATION 4

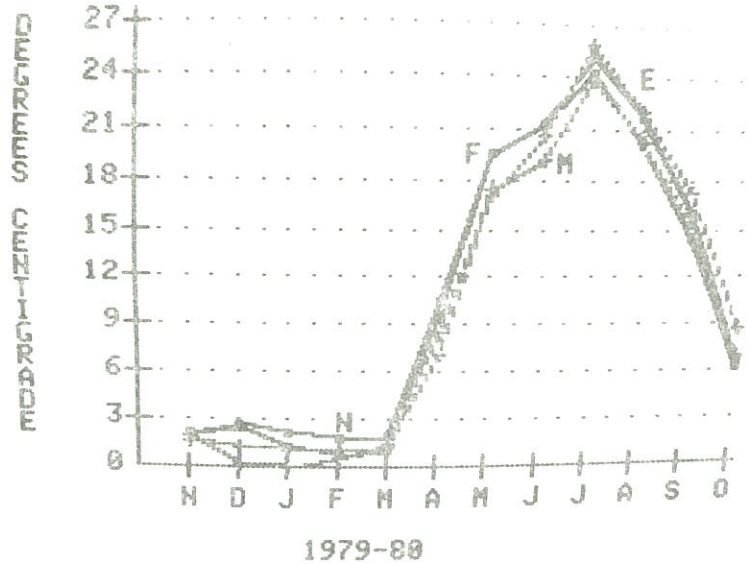


FIGURE 72. Monthly mean water temperature at Stations E, F, M and N, 1979-80.

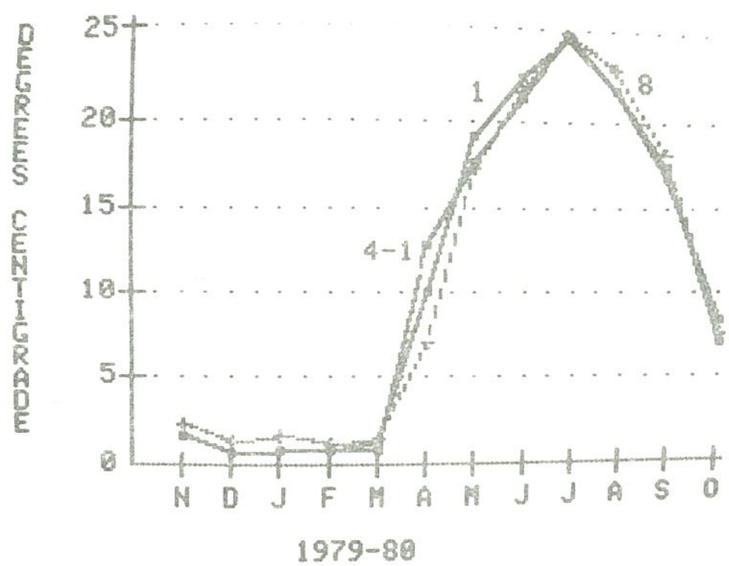


FIGURE 73. Monthly mean water temperature at Stations 1, 4 and 8, 1979-80.

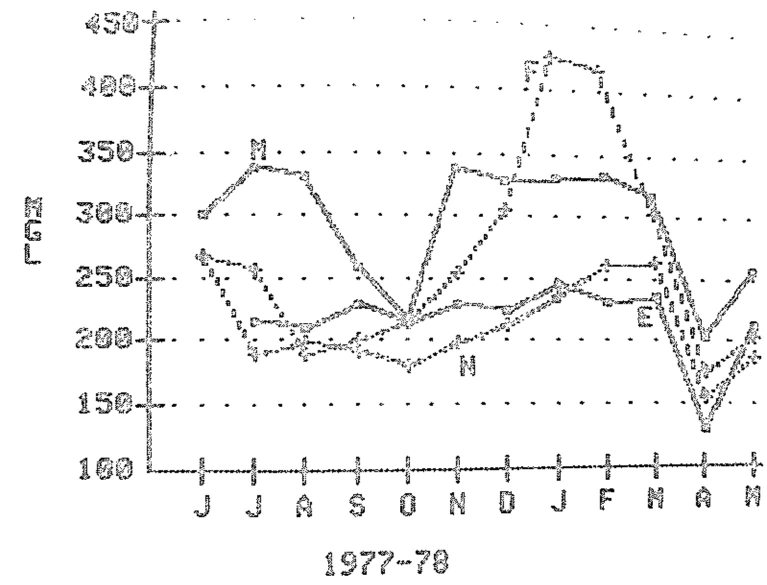


FIGURE 74. Monthly mean total alkalinity at Stations E, F, M and N, 1977-78.

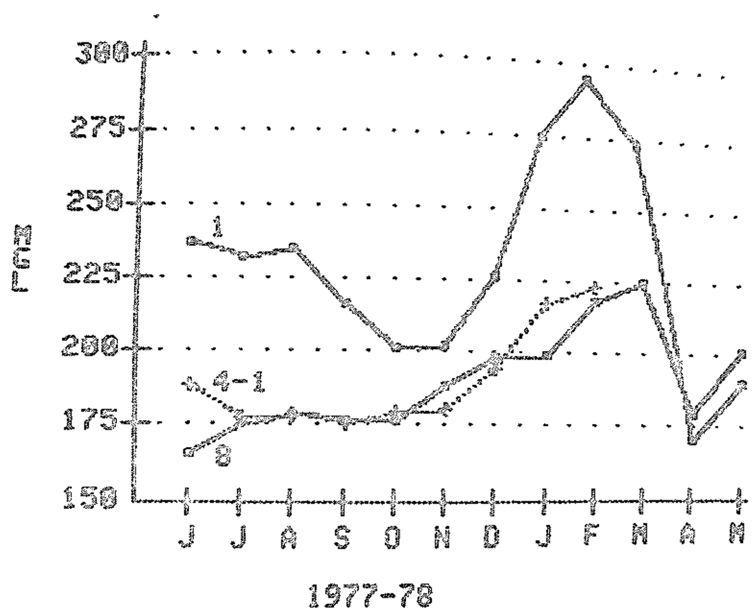


FIGURE 75. Monthly mean total alkalinity at Stations 1, 4 and 8, 1977-78.

FIGURE 76.
TOTAL ALKALINITY
IN SURFACE WATERS

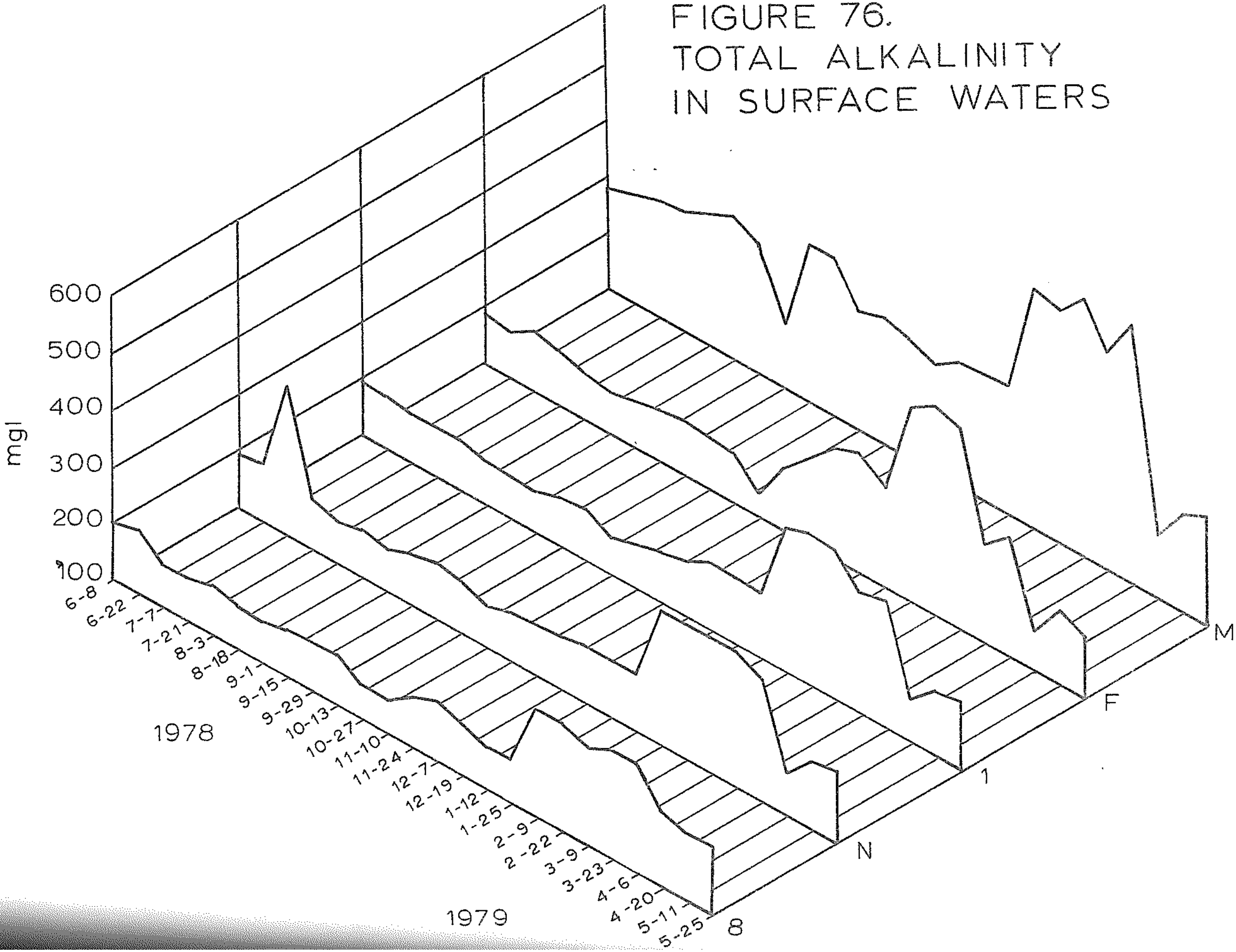
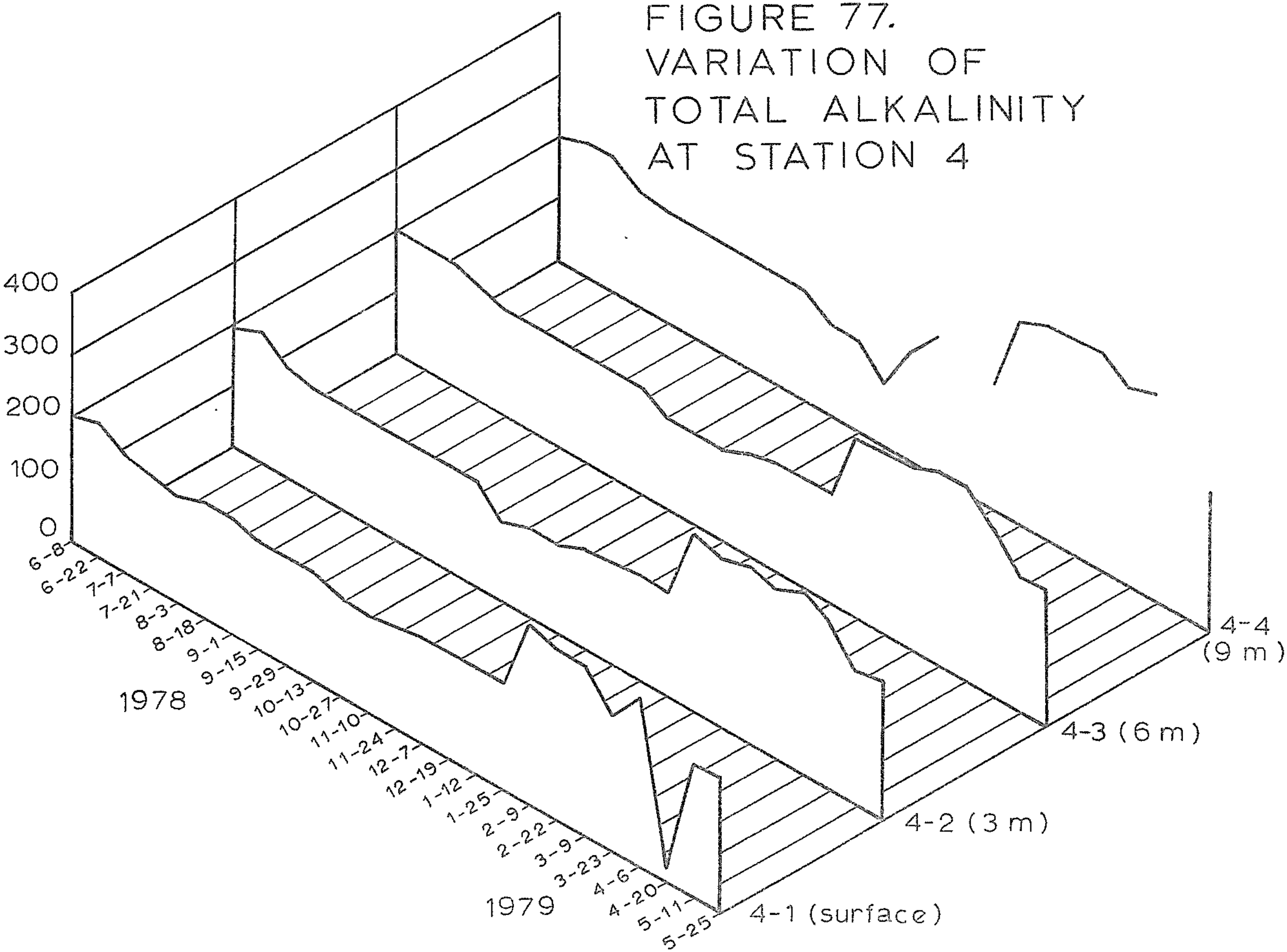


FIGURE 77.
VARIATION OF
TOTAL ALKALINITY
AT STATION 4



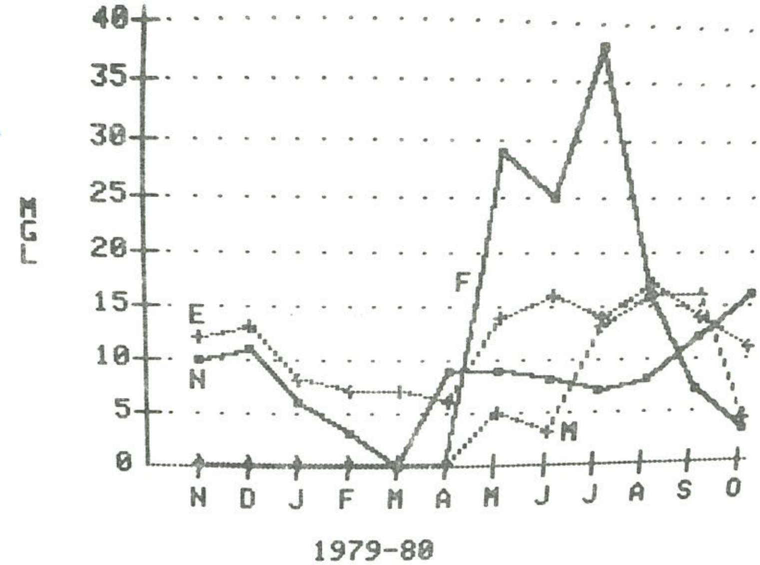


FIGURE 78. Monthly mean CO_3 alkalinity at Stations E, F, M and N, 1979-80.

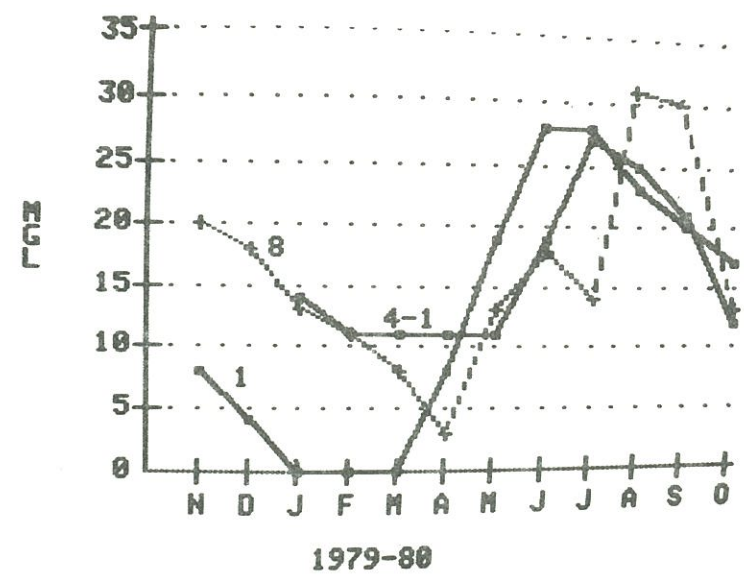


FIGURE 79. Monthly mean CO_3 alkalinity at Stations 1, 4 and 8, 1979-80.

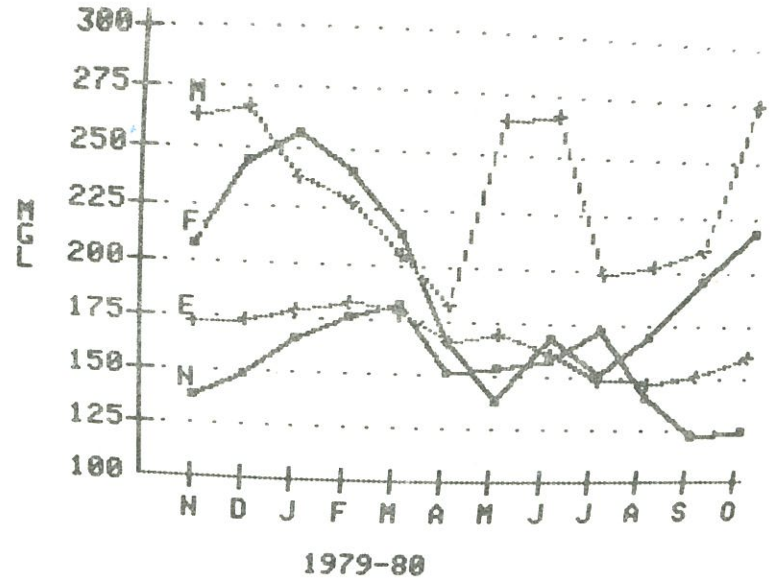


FIGURE 80. Monthly mean HCO_3 alkalinity at Stations E, F, M and N, 1979-80.

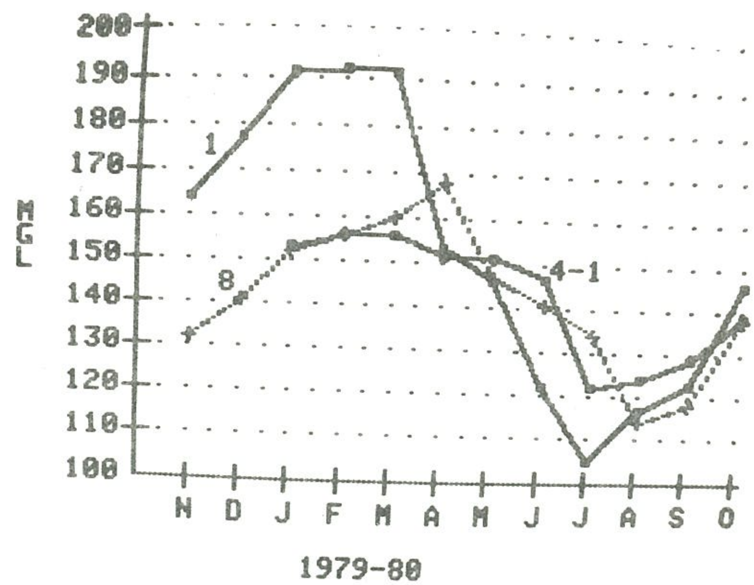


FIGURE 81. Monthly mean HCO_3 alkalinity at Stations 1, 4 and 8, 1979-80.

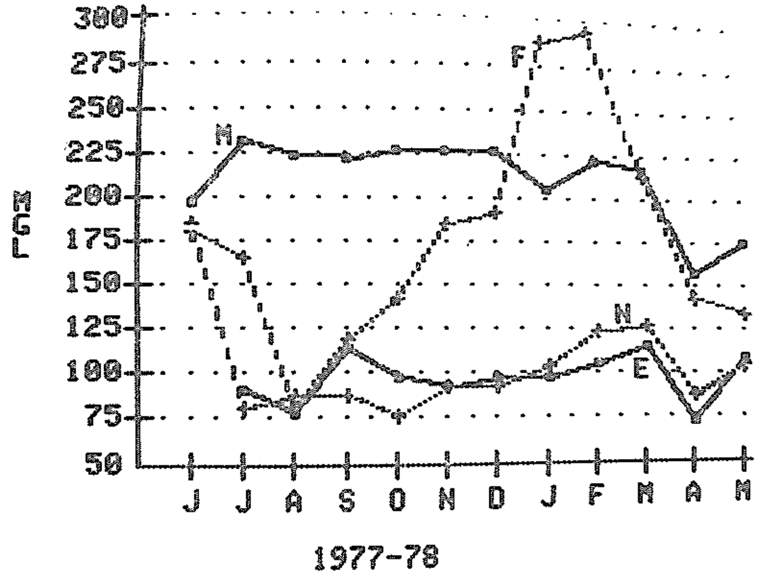


FIGURE 82. Monthly mean calcium concentrations at Stations E, F, M and N, 1977-78.

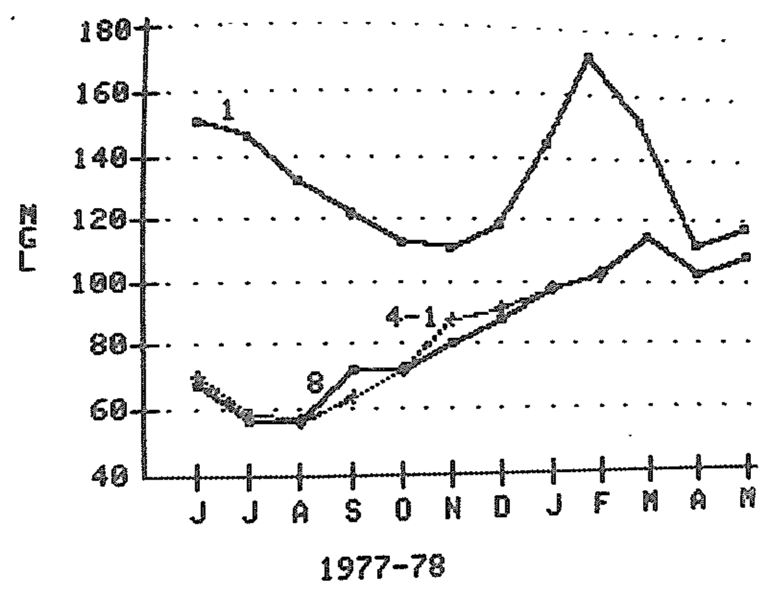
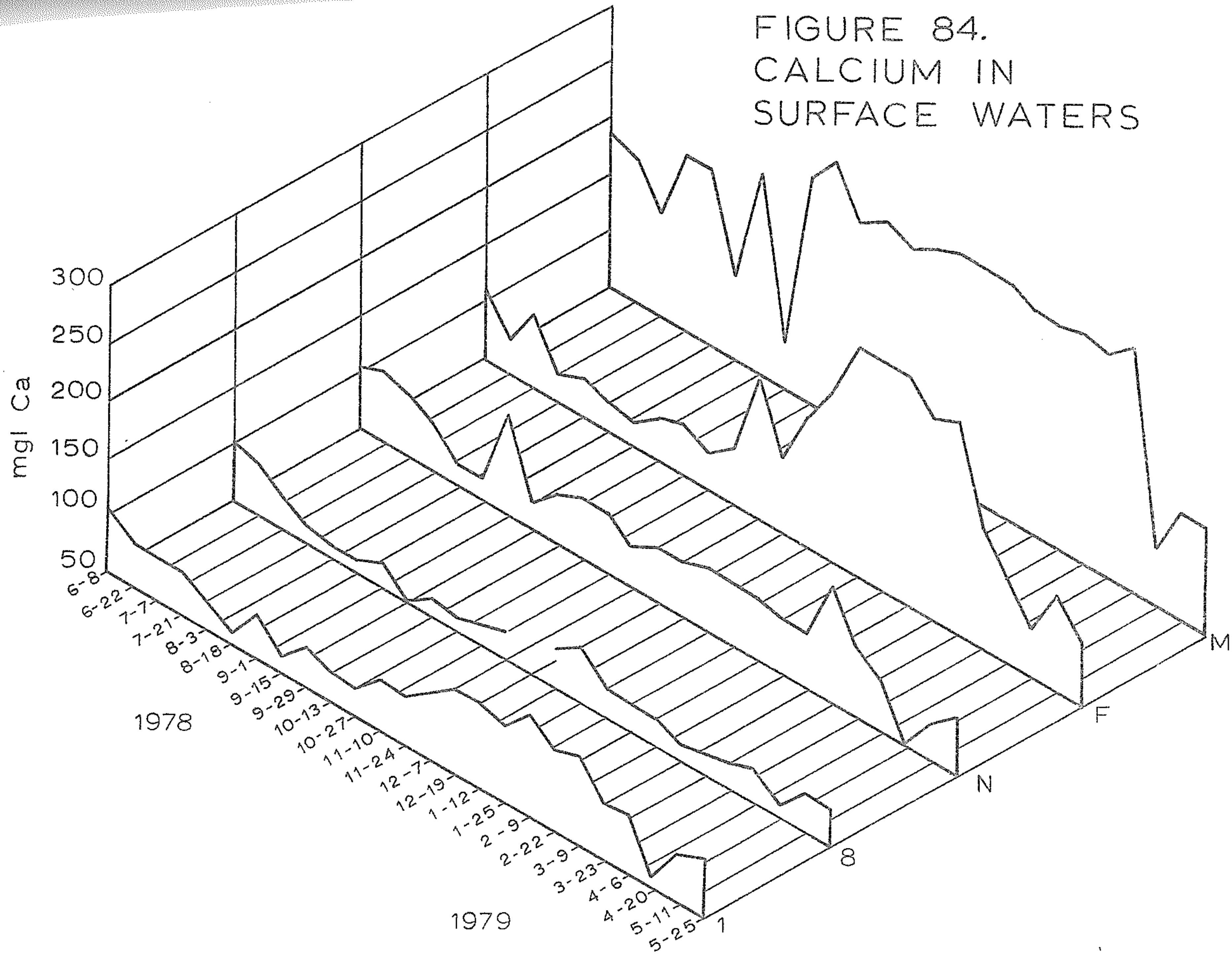


FIGURE 83. Monthly mean calcium concentrations at Stations 1, 4 and 8, 1977-78.

FIGURE 84.
CALCIUM IN
SURFACE WATERS



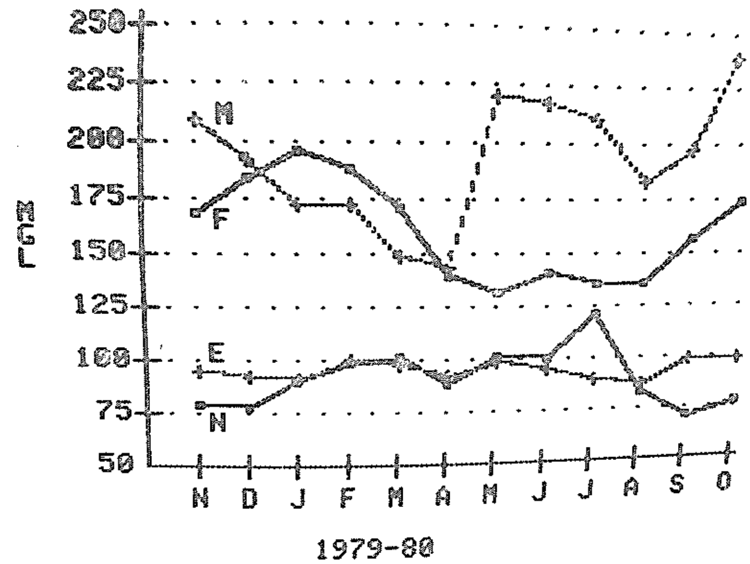


FIGURE 85. Monthly mean calcium concentrations at Stations E, F, M and N, 1979-80.

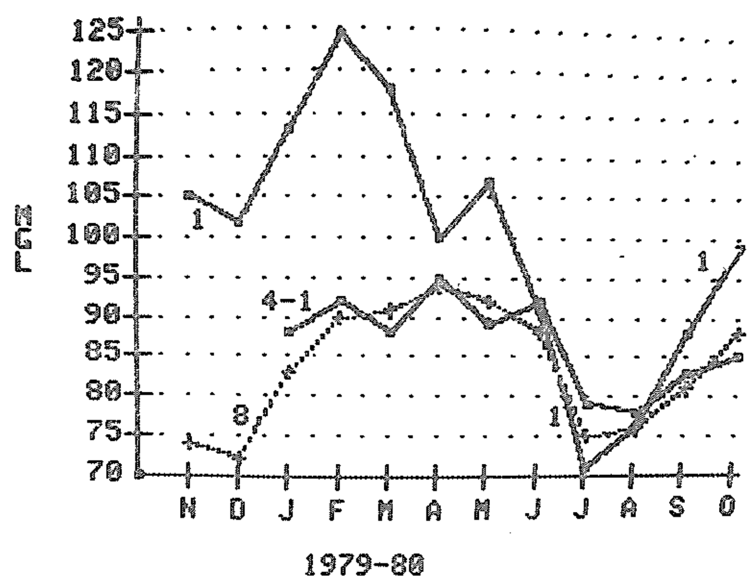
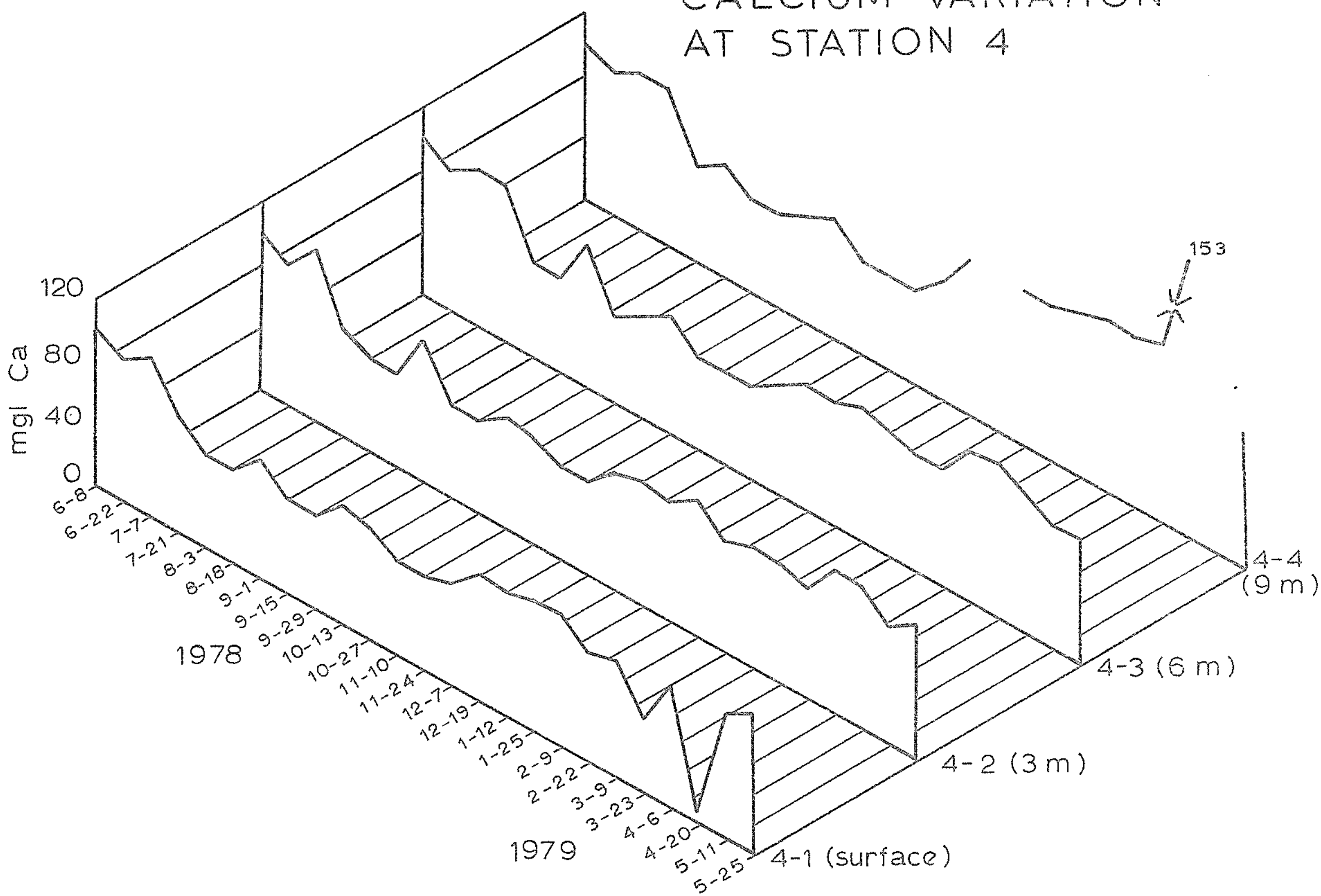


FIGURE 86. Monthly mean calcium concentrations at Stations 1, 4 and 8, 1979-80.

FIGURE 87.
CALCIUM VARIATION
AT STATION 4



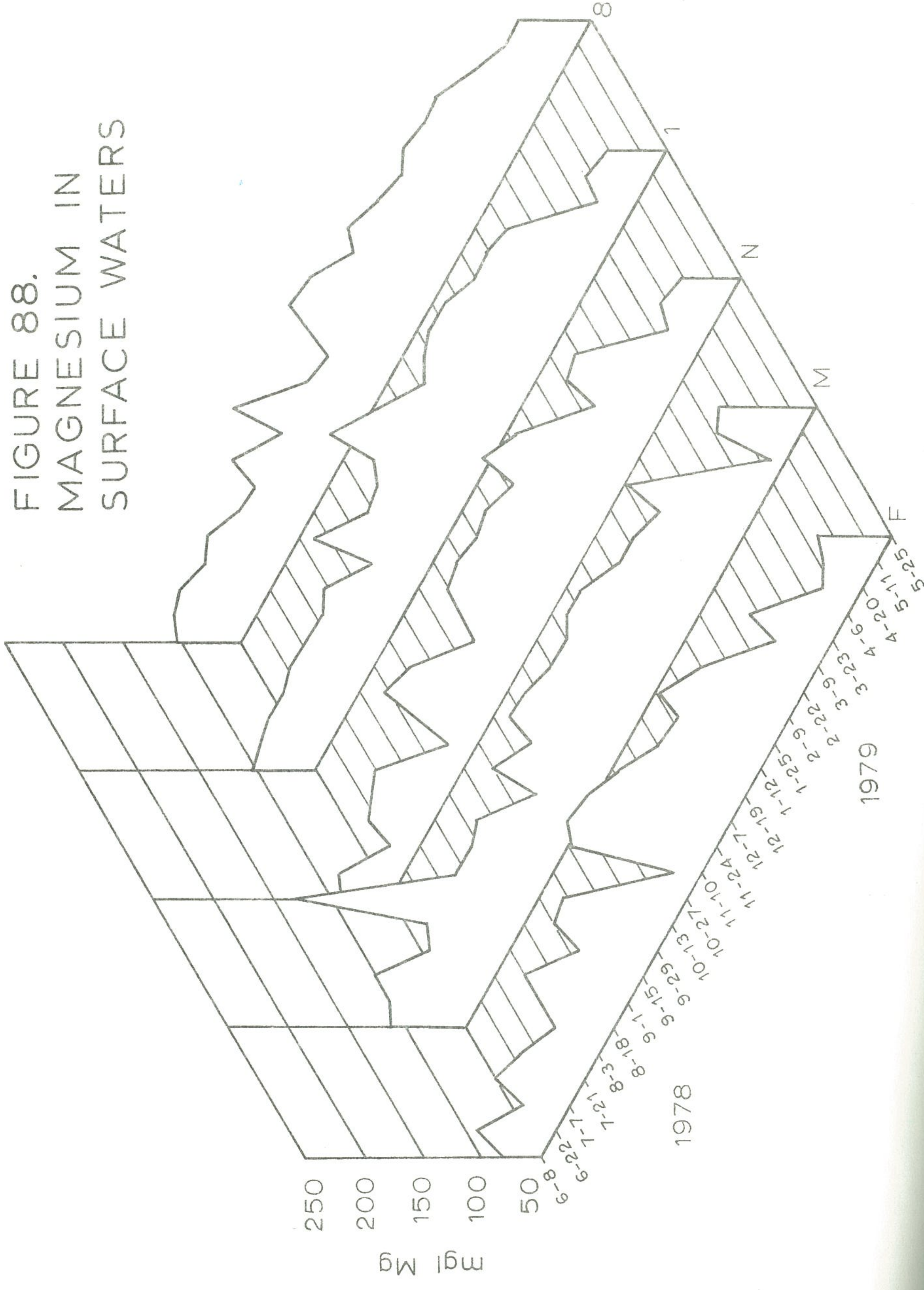
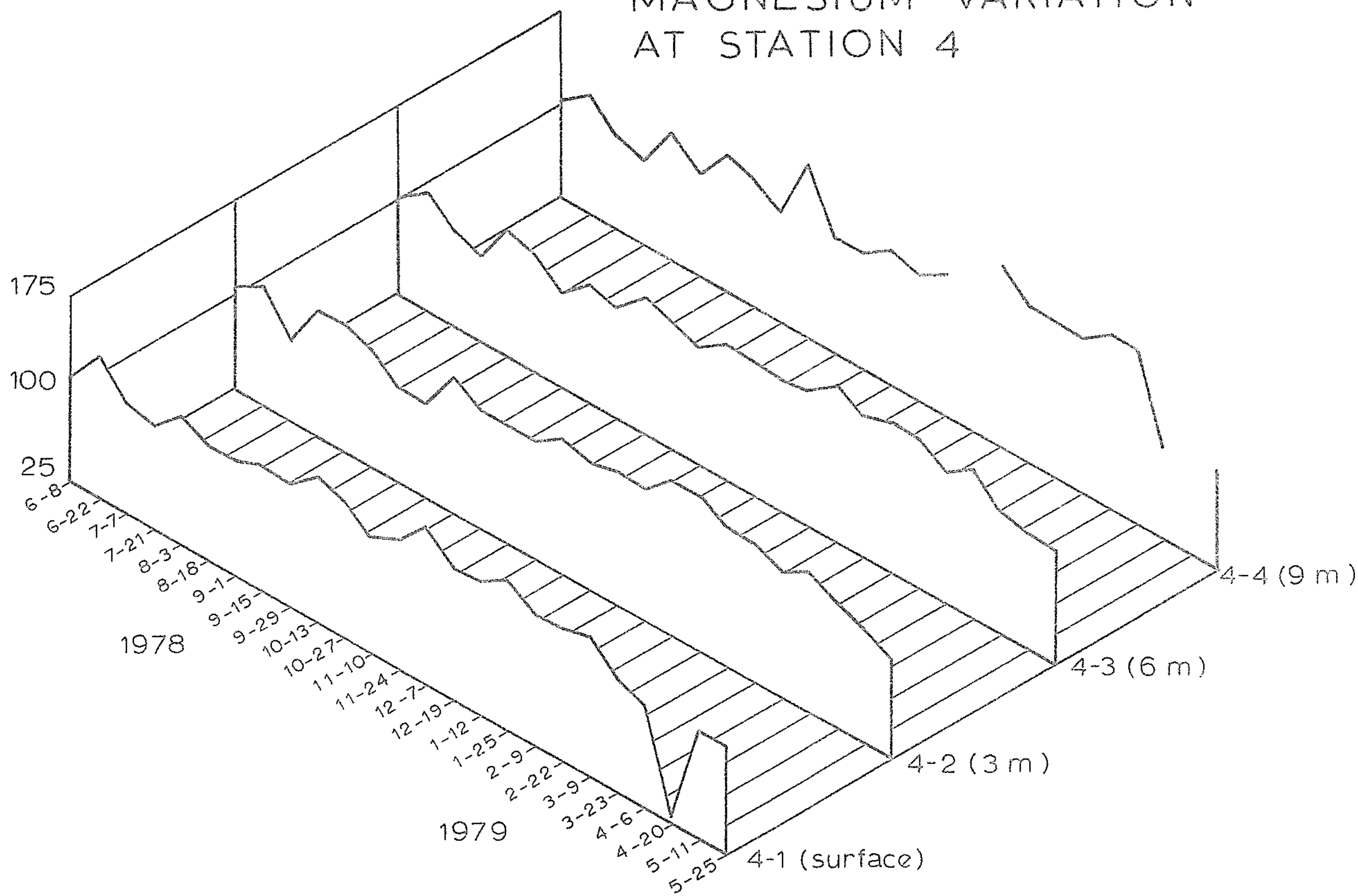


FIGURE 88.
MAGNESIUM IN
SURFACE WATERS

FIGURE 89.
MAGNESIUM VARIATION
AT STATION 4



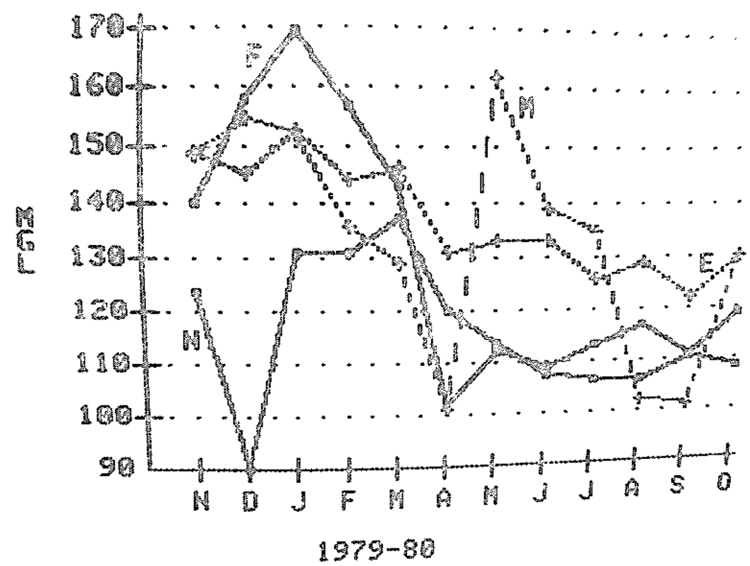


FIGURE 90. Monthly mean magnesium concentrations at Stations E, F, M and N, 1979-80.

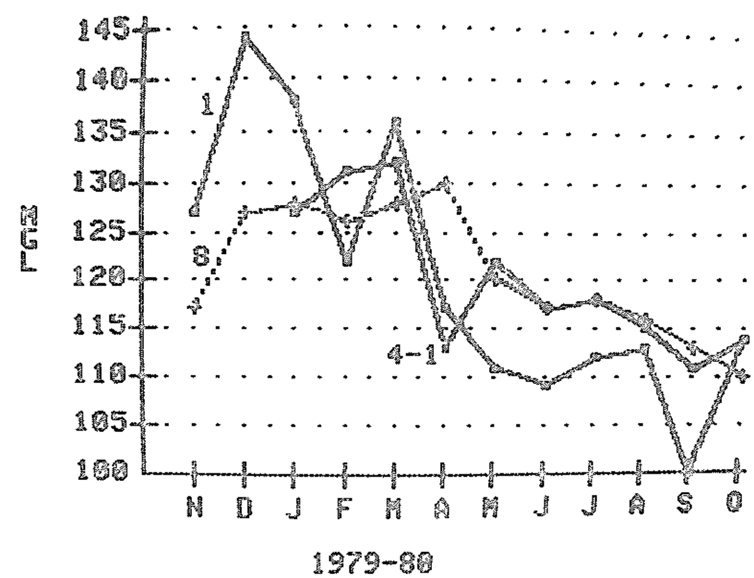


FIGURE 91. Monthly mean magnesium concentrations at Stations 1, 4 and 8, 1979-80.

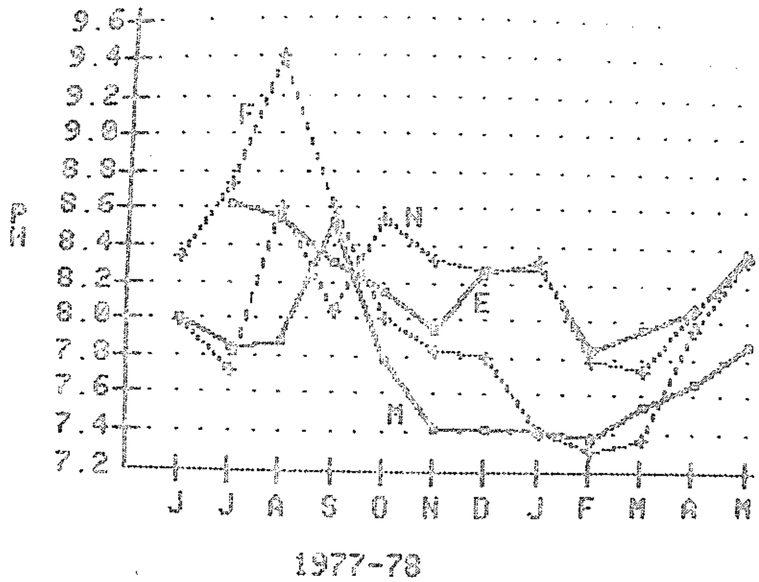


FIGURE 92. Monthly mean pH at Stations E, F, M and N, 1977-78.

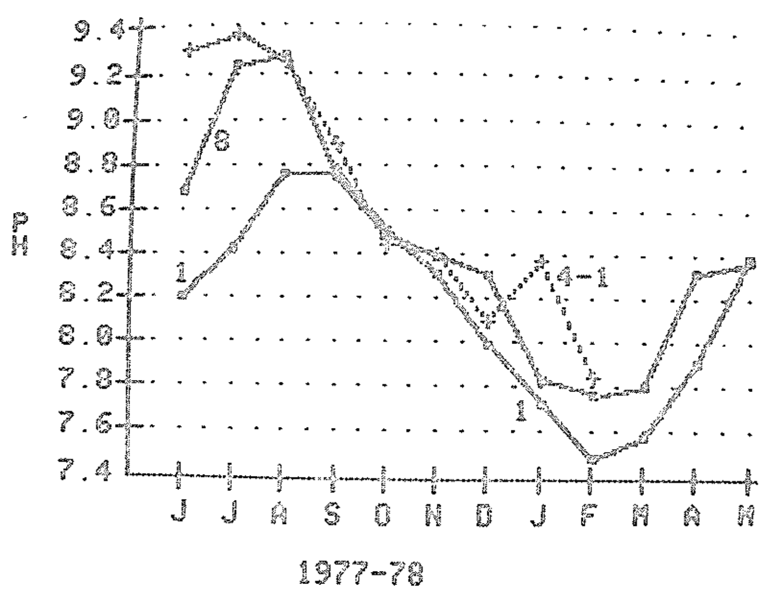
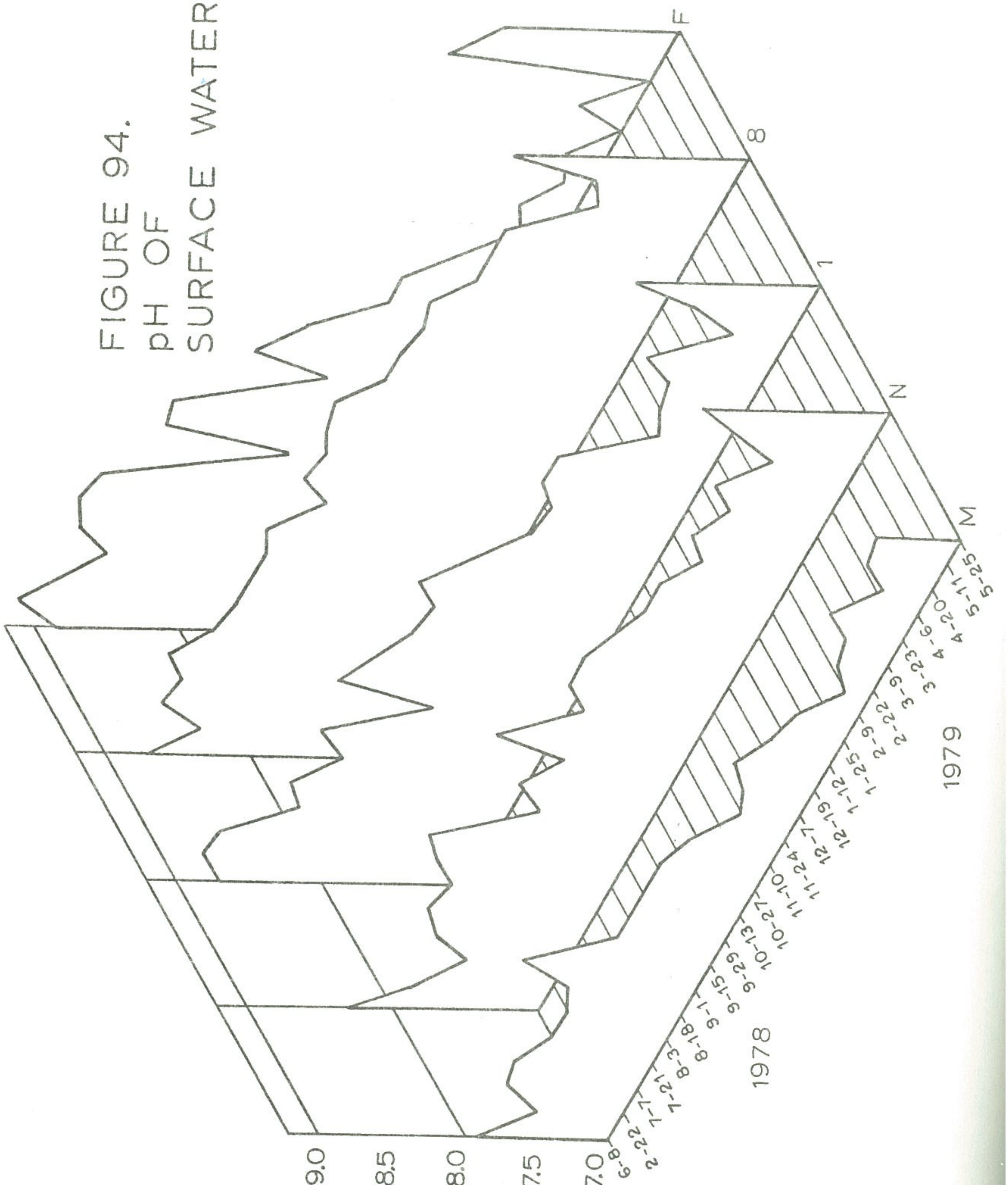


FIGURE 93. Monthly mean pH at Stations 1, 4 and 8, 1977-78.

FIGURE 94.
pH OF
SURFACE WATERS



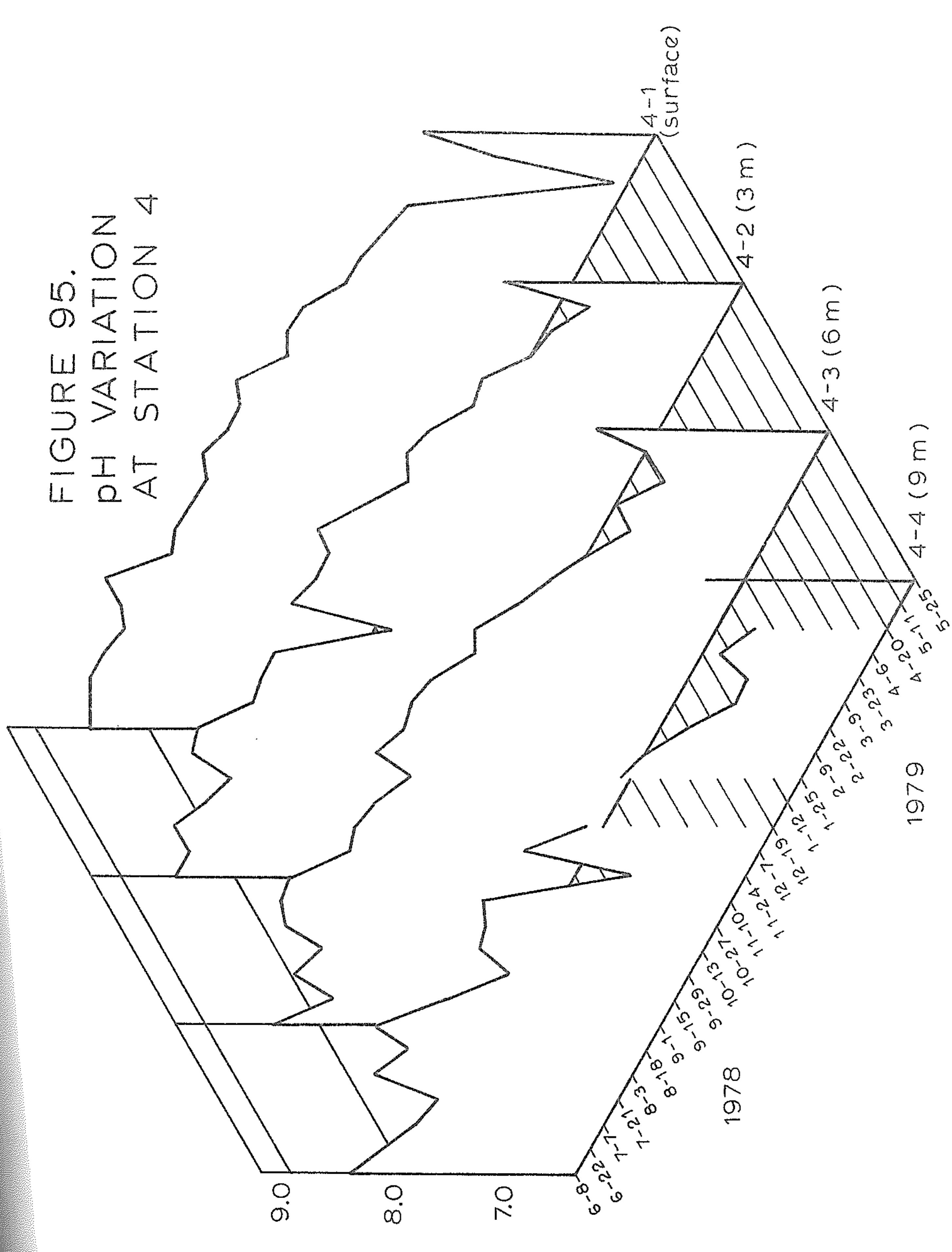


FIGURE 95. pH VARIATION AT STATION 4

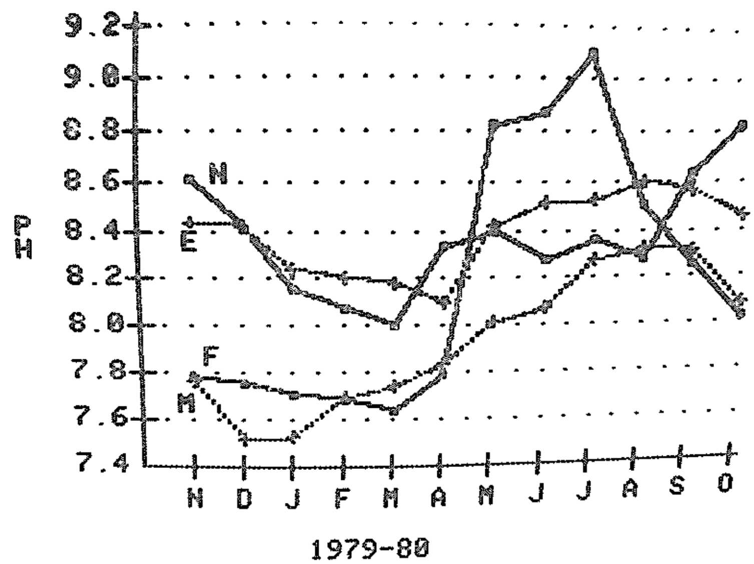


FIGURE 96. Monthly mean pH at Stations E, F, M and N, 1979-80.

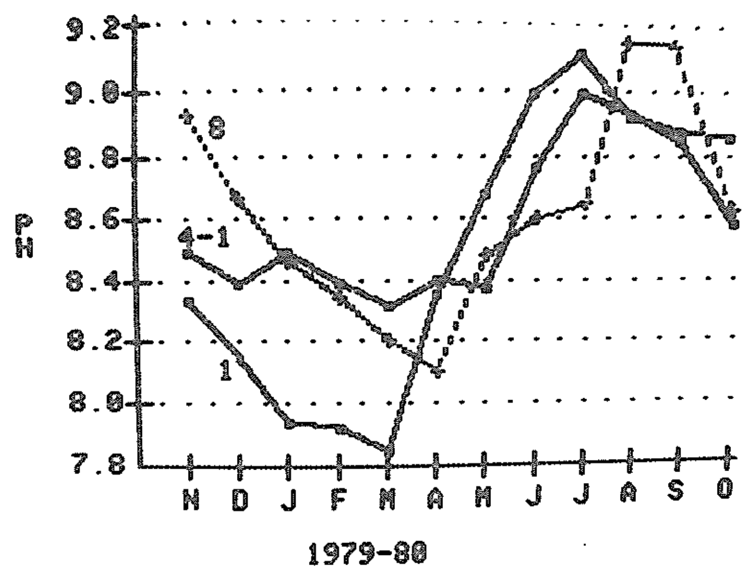


FIGURE 97. Monthly mean pH at Stations 1, 4 and 8, 1979-80.

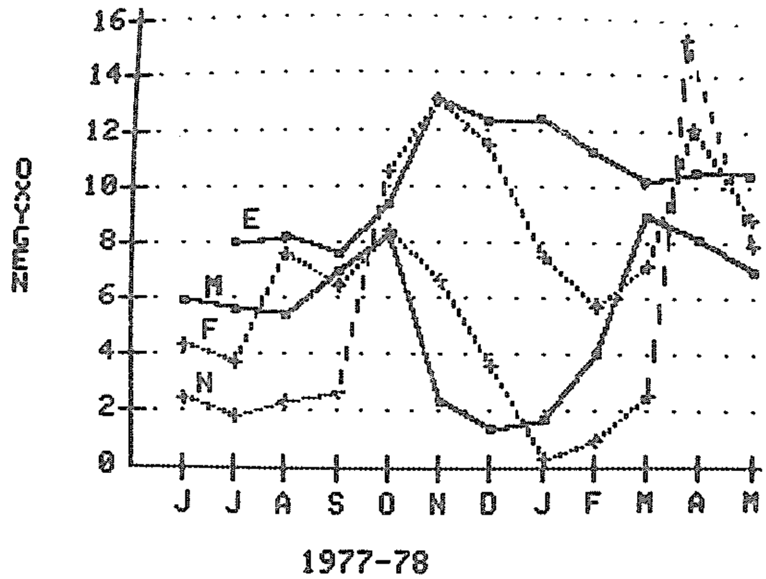


FIGURE 98. Monthly mean oxygen concentrations (mgl) at Stations E, F, M and N, 1977-78.

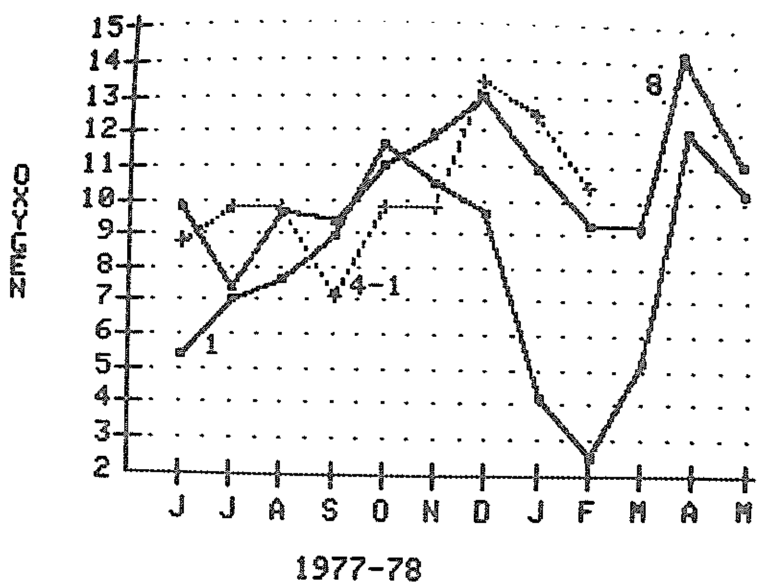


FIGURE 99. Monthly mean oxygen concentrations (mgl) at Stations 1, 4 and 8, 1977-78.

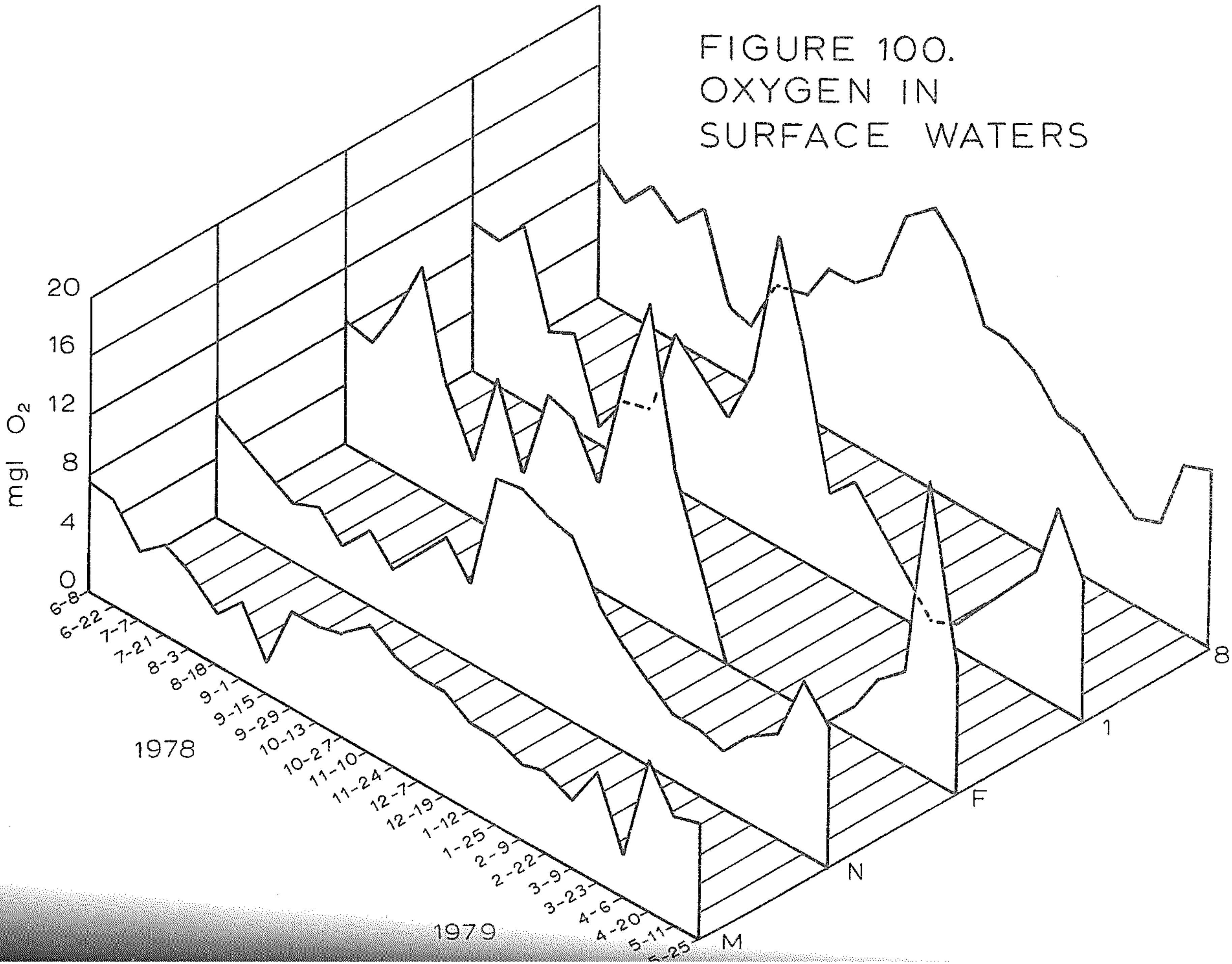
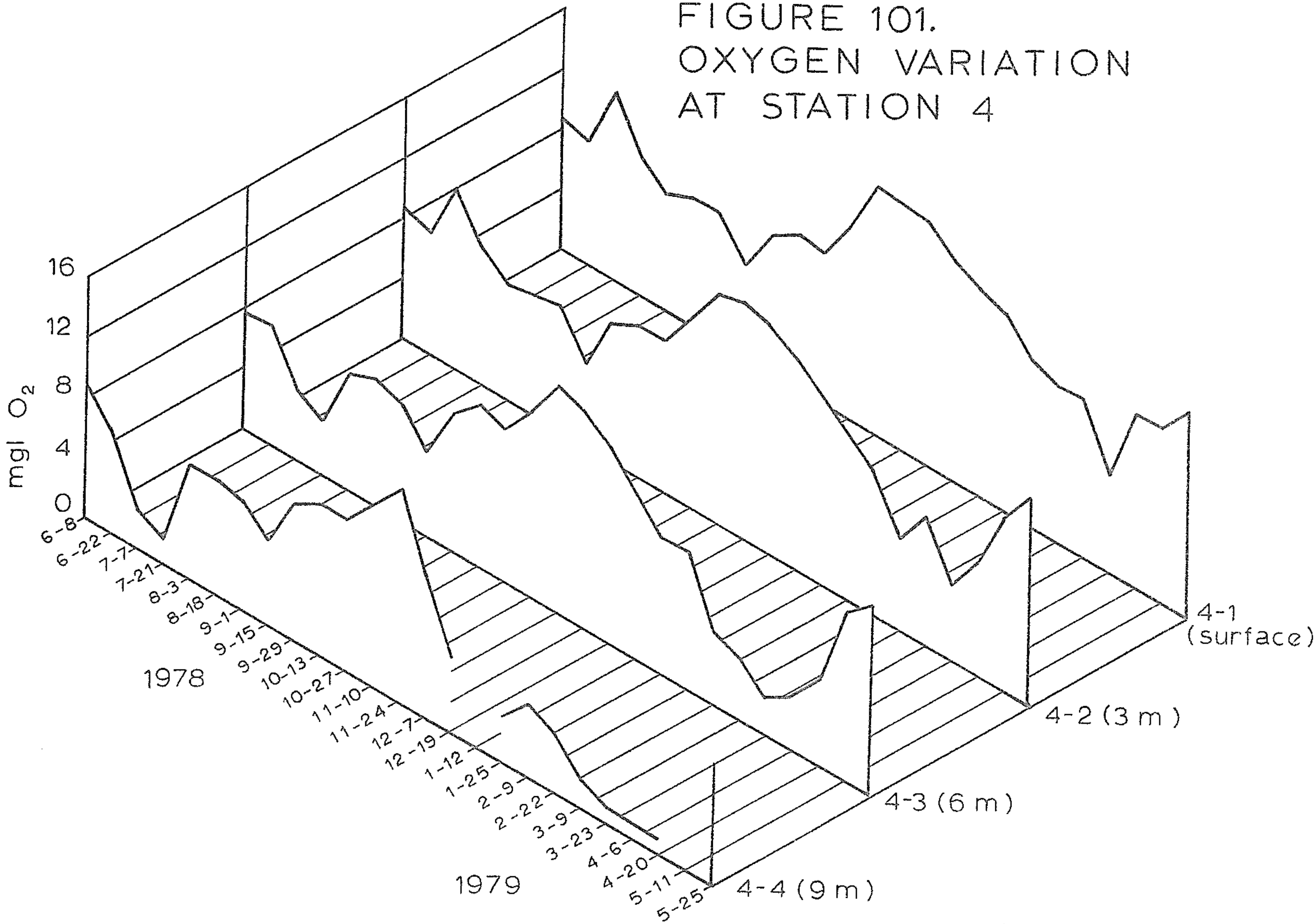


FIGURE 100. OXYGEN IN SURFACE WATERS

FIGURE 101.
OXYGEN VARIATION
AT STATION 4



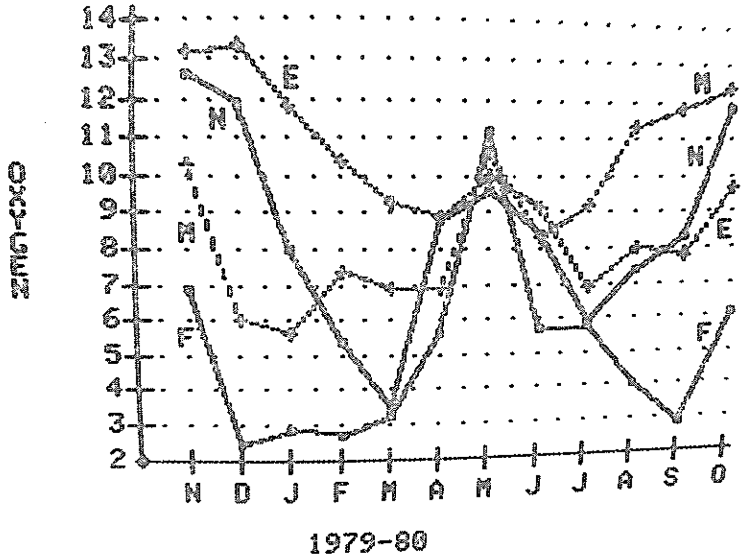


FIGURE 102. Monthly mean oxygen concentrations (mgl) at Stations E, F, M and N, 1979-80.

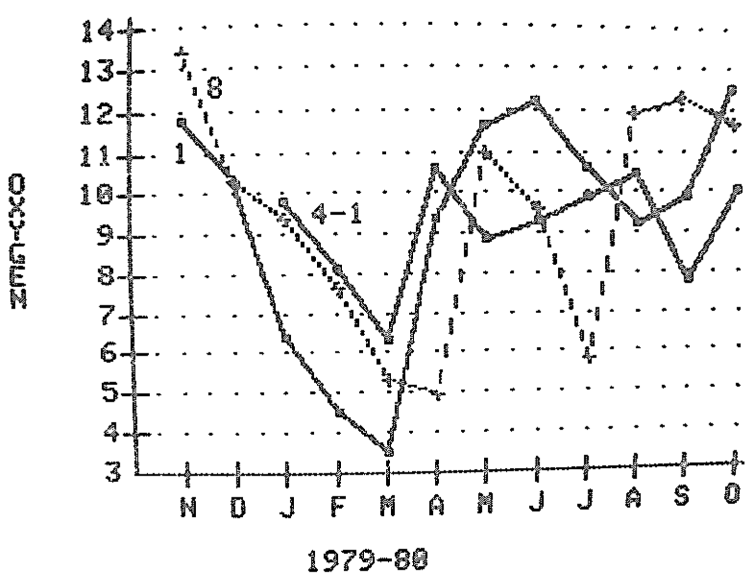


FIGURE 103. Monthly mean oxygen concentrations (mgl) at Stations 1, 4 and 8, 1979-80.

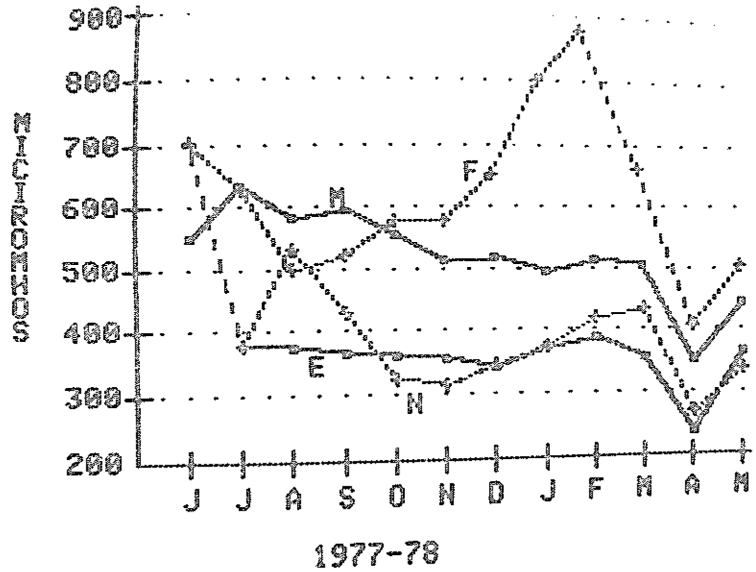


FIGURE 104. Monthly mean conductivity (μmhos/cm) at Stations E, F, M and N, 1977-78.

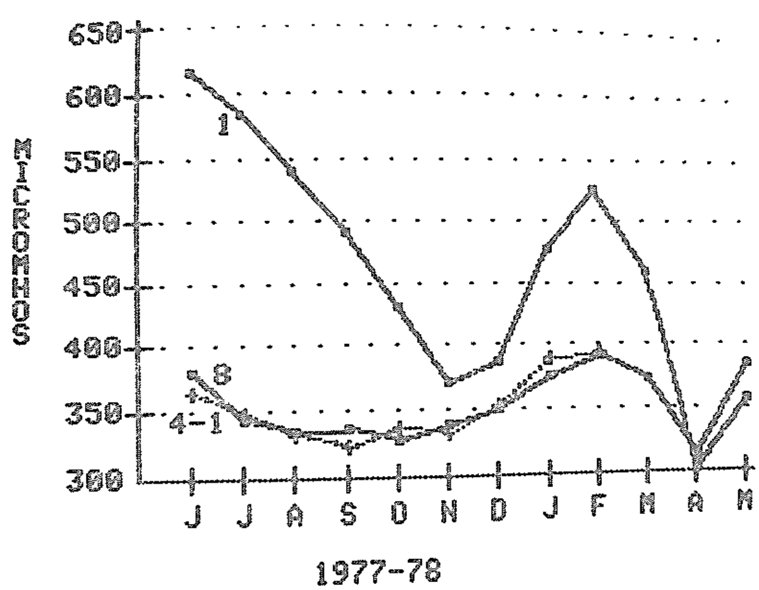


FIGURE 105. Monthly mean conductivity (μmhos/cm) at Stations 1, 4 and 8, 1977-78.

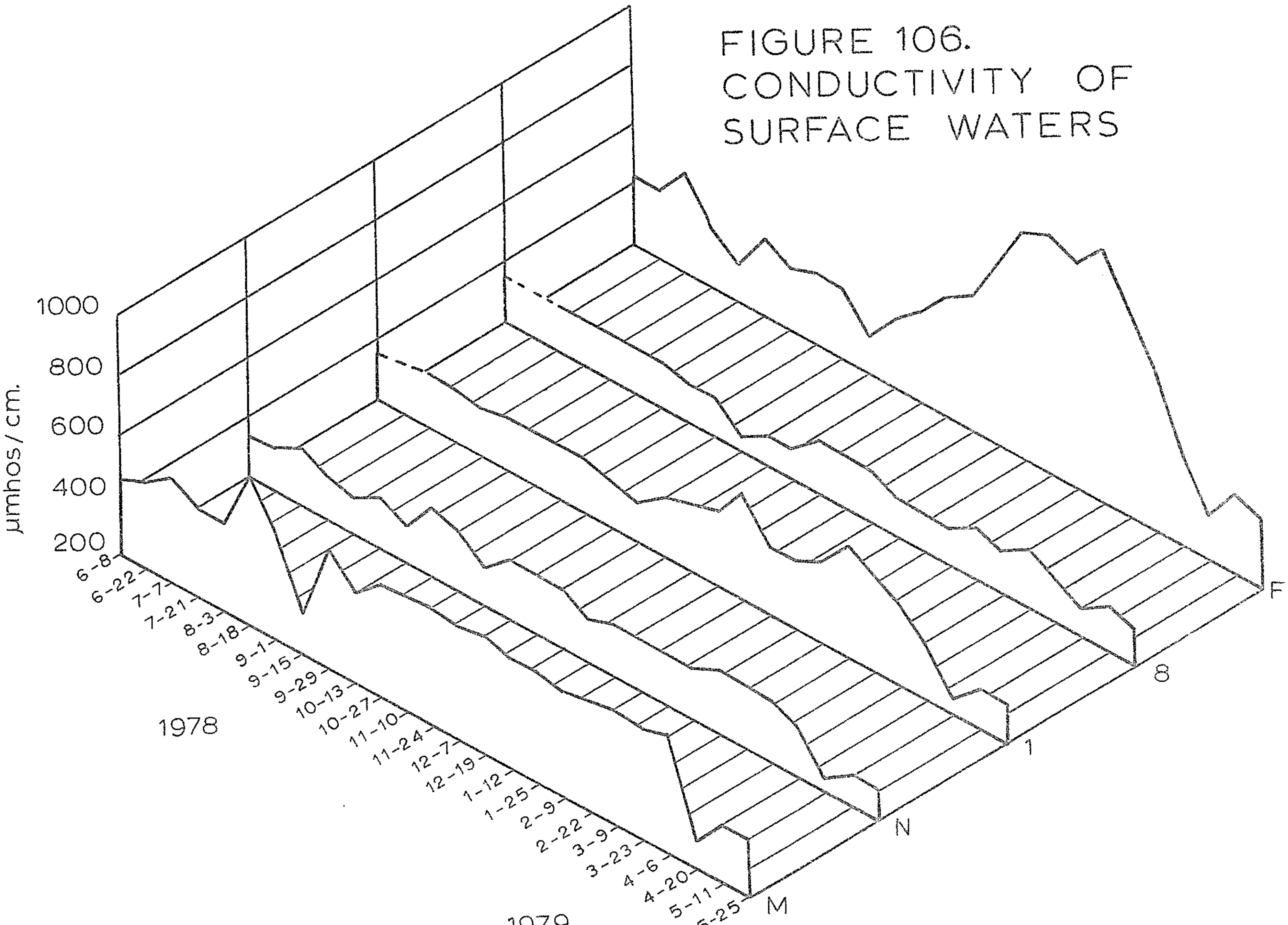


FIGURE 106.
CONDUCTIVITY OF
SURFACE WATERS

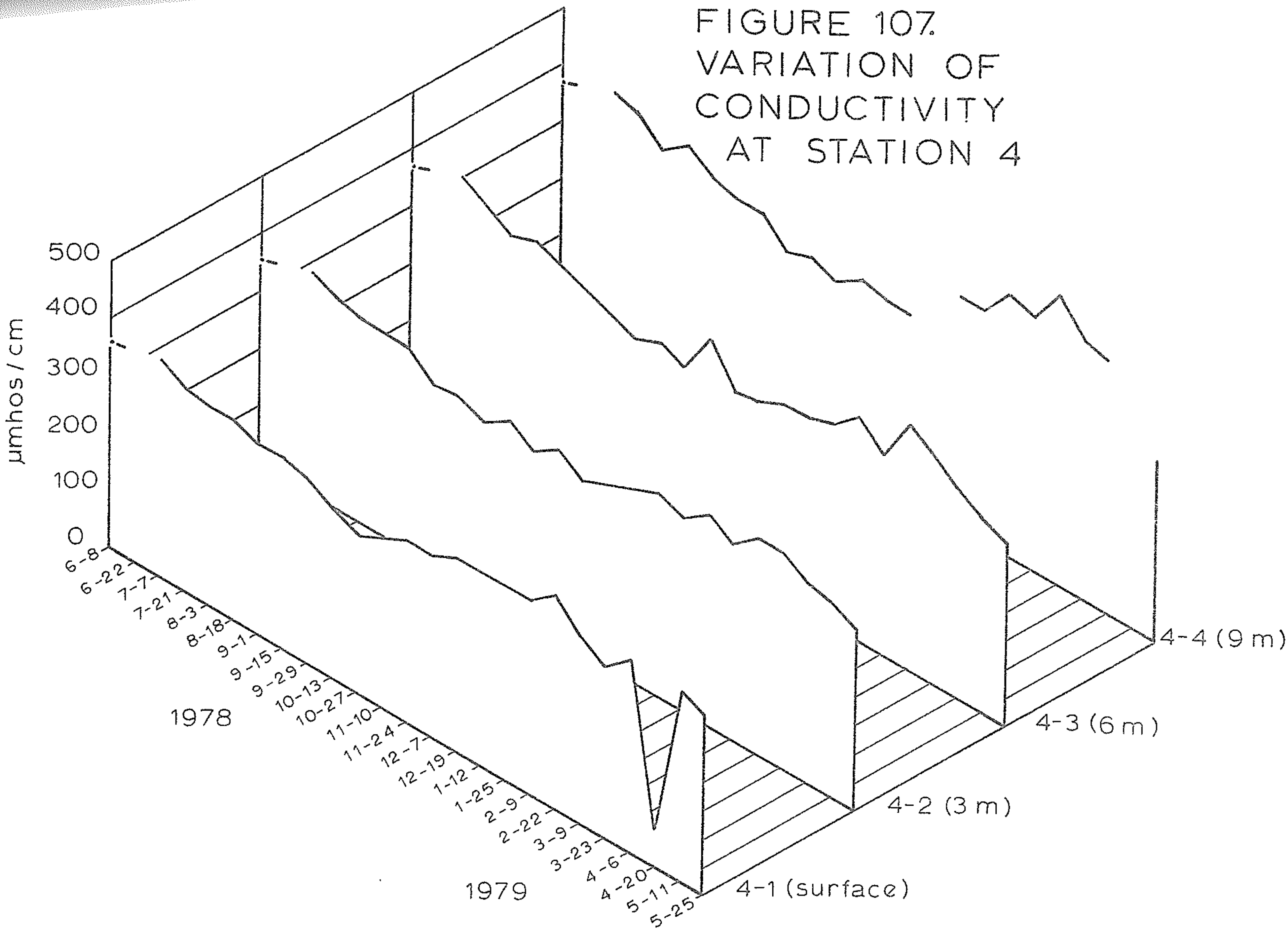


FIGURE 107.
VARIATION OF
CONDUCTIVITY
AT STATION 4

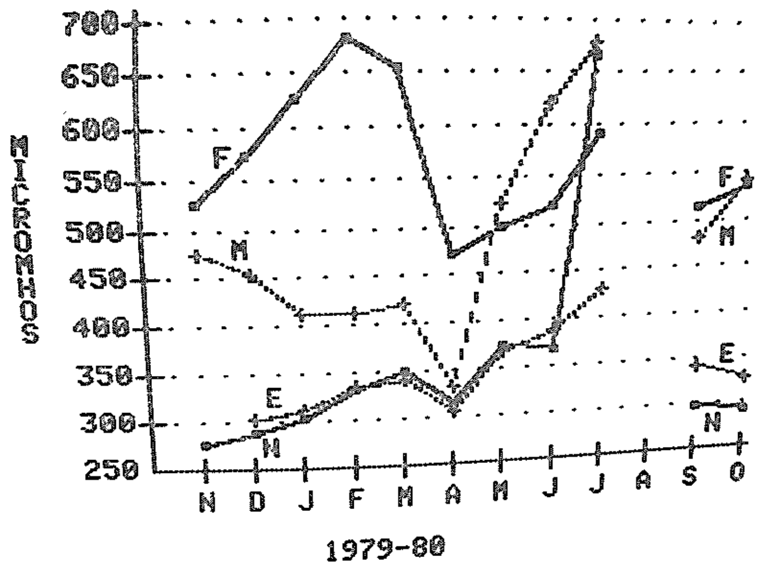


FIGURE 108. Monthly mean conductivity (μmhos/cm) at Stations E, F, M and N, 1979-80.

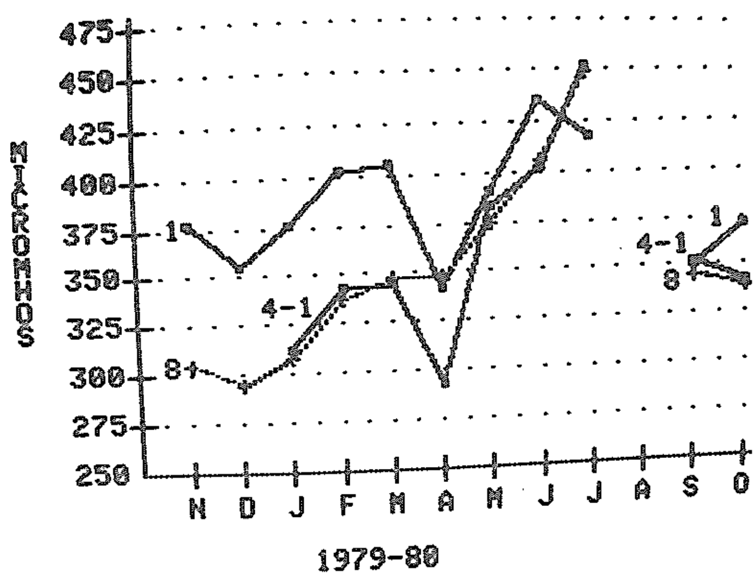


FIGURE 109. Monthly mean conductivity (μmhos/cm) at Stations 1, 4 and 8, 1979-80.

FIGURE 110.
Mean Monthly Soluble Reactive Phosphorus – Surface Waters

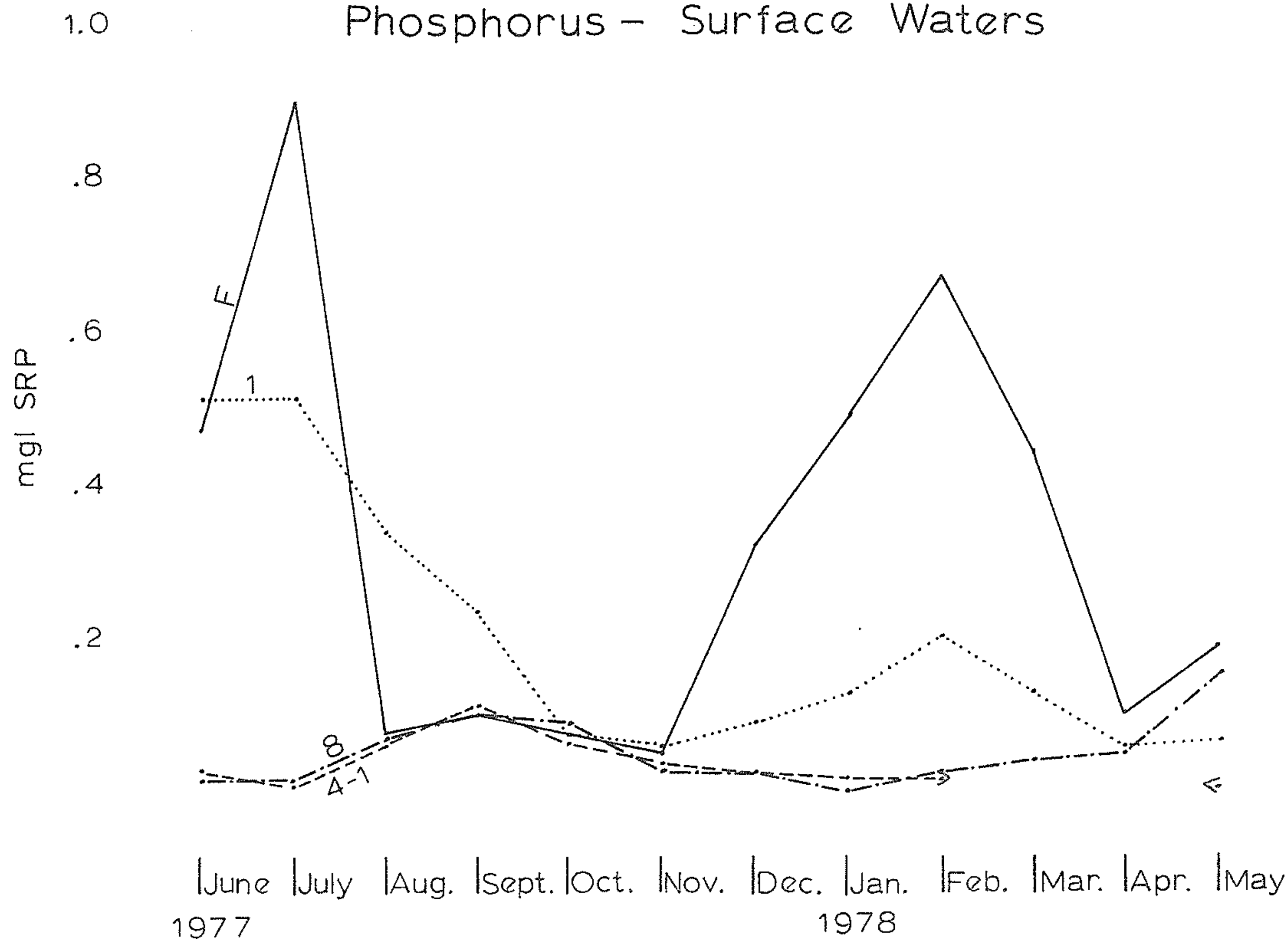
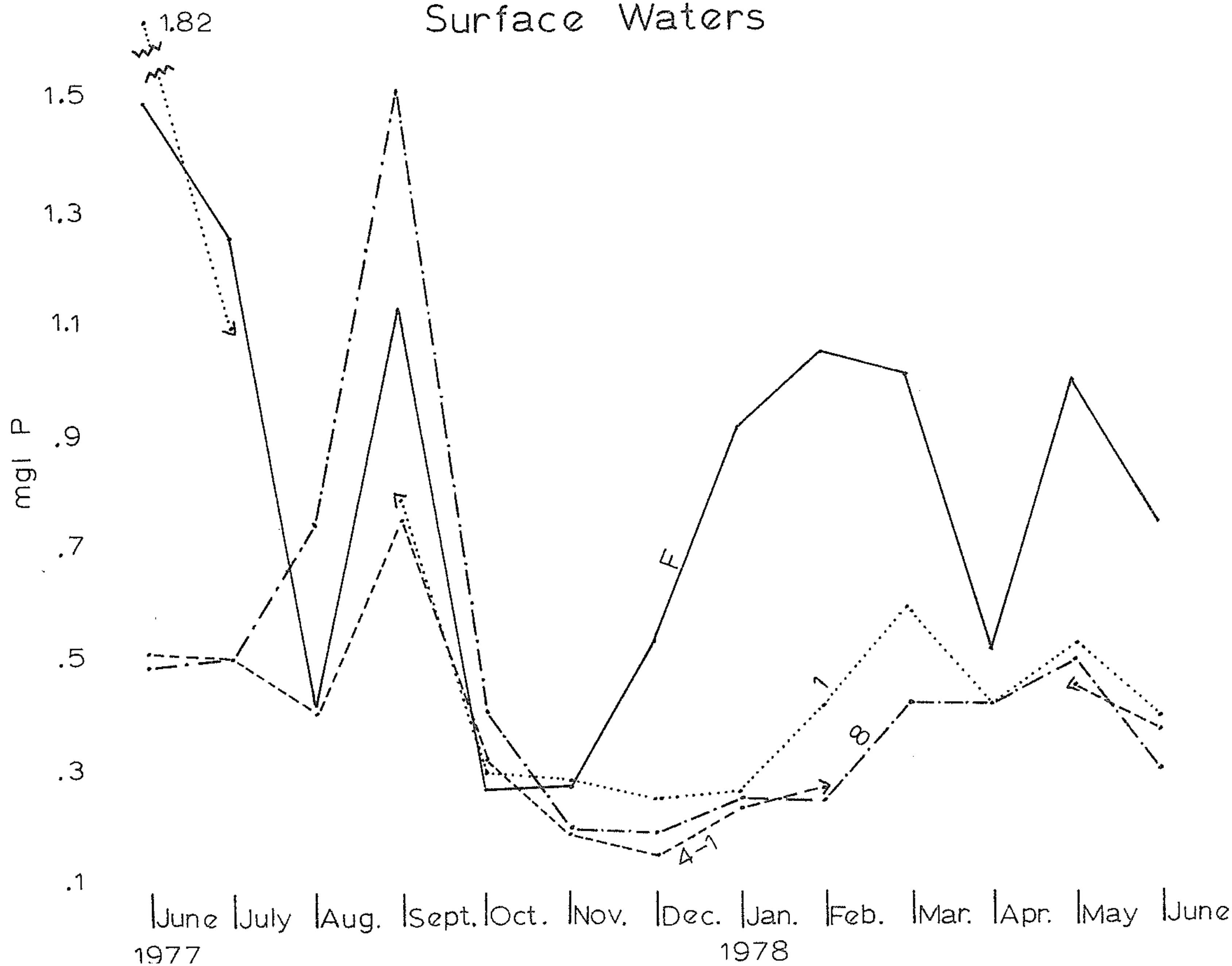


FIGURE 111.
Mean Monthly Total Phosphorus - Surface Waters



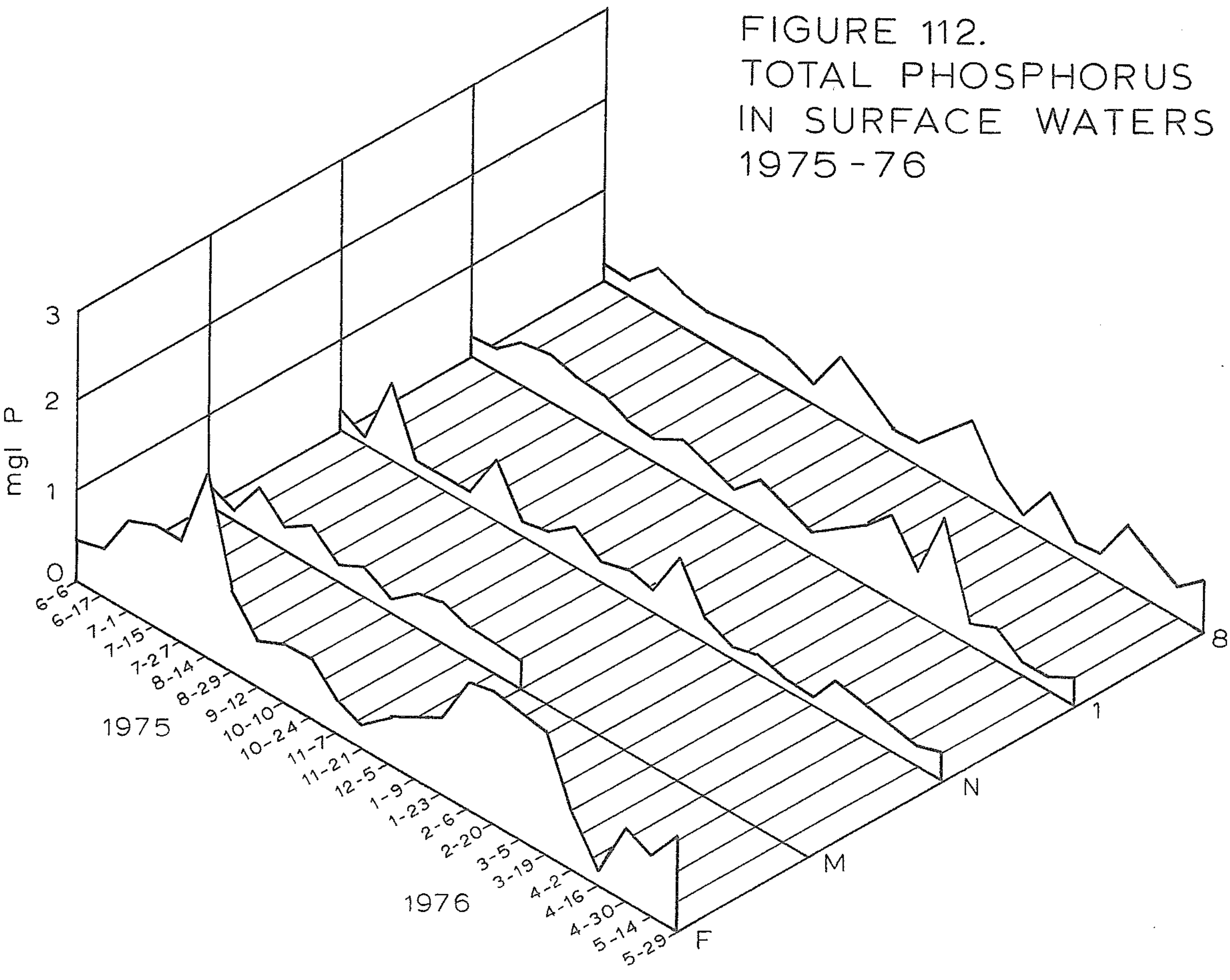
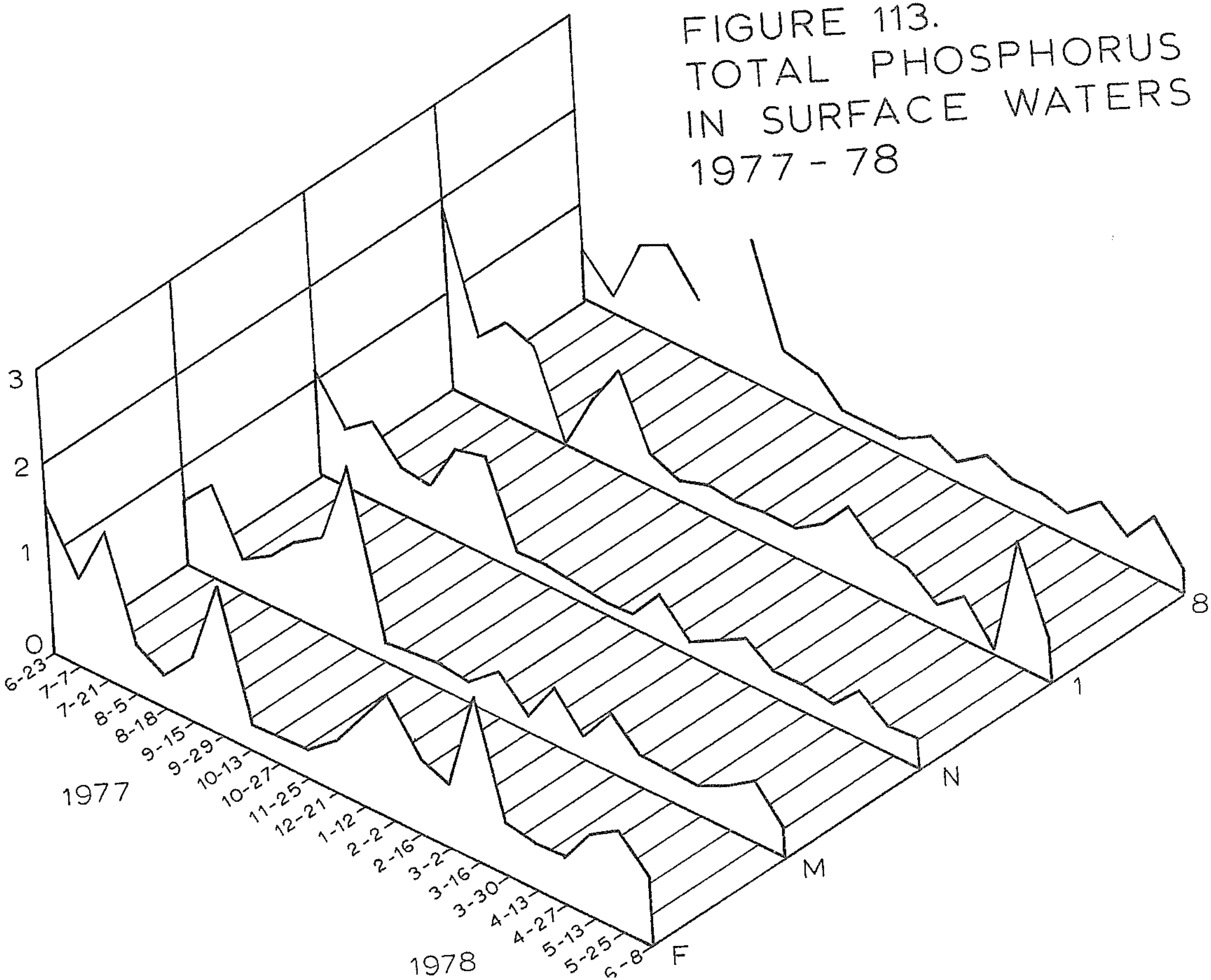


FIGURE 112.
TOTAL PHOSPHORUS
IN SURFACE WATERS -
1975 - 76

FIGURE 113.
TOTAL PHOSPHORUS
IN SURFACE WATERS –
1977 - 78



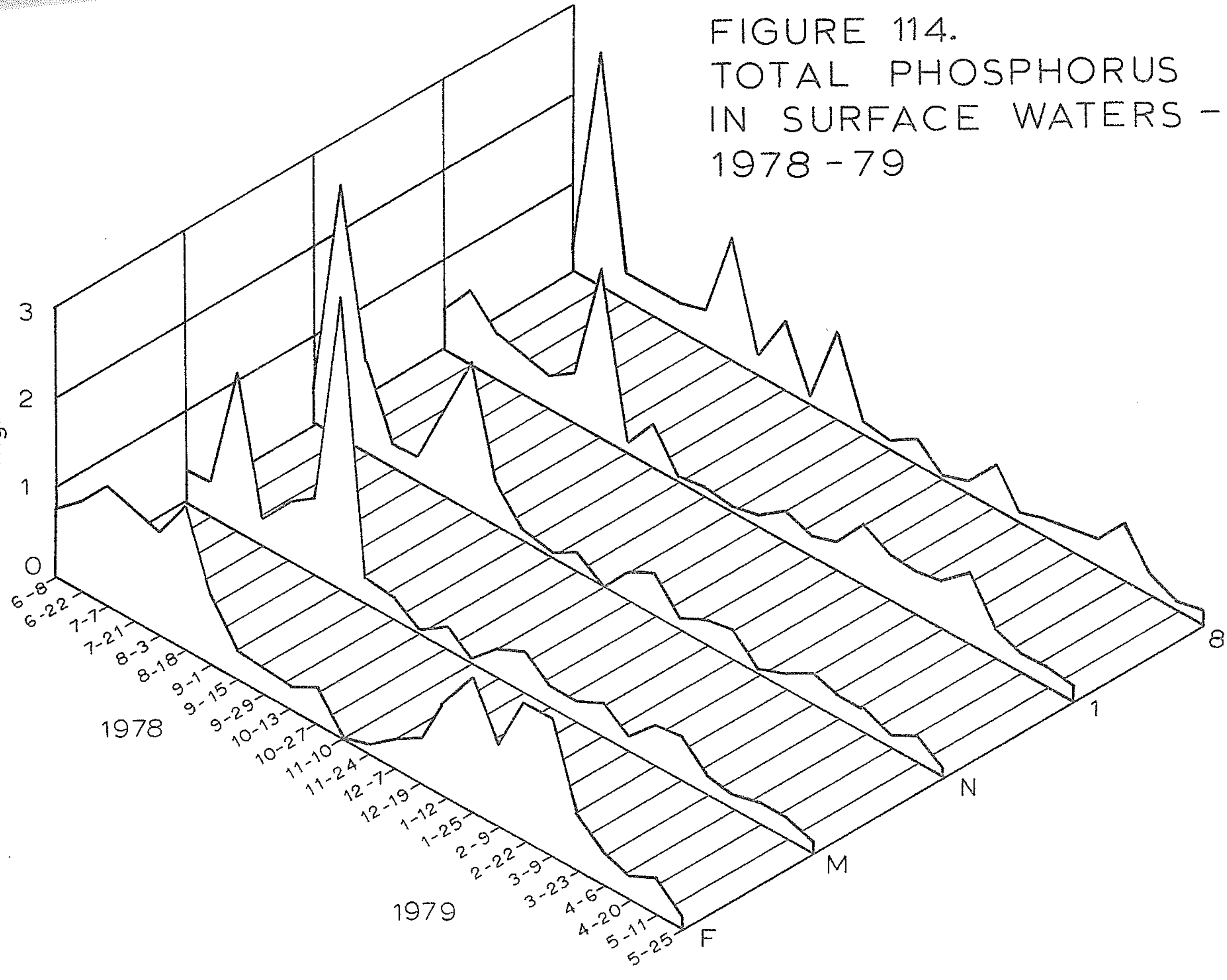


FIGURE 114.
TOTAL PHOSPHORUS
IN SURFACE WATERS -
1978 - 79

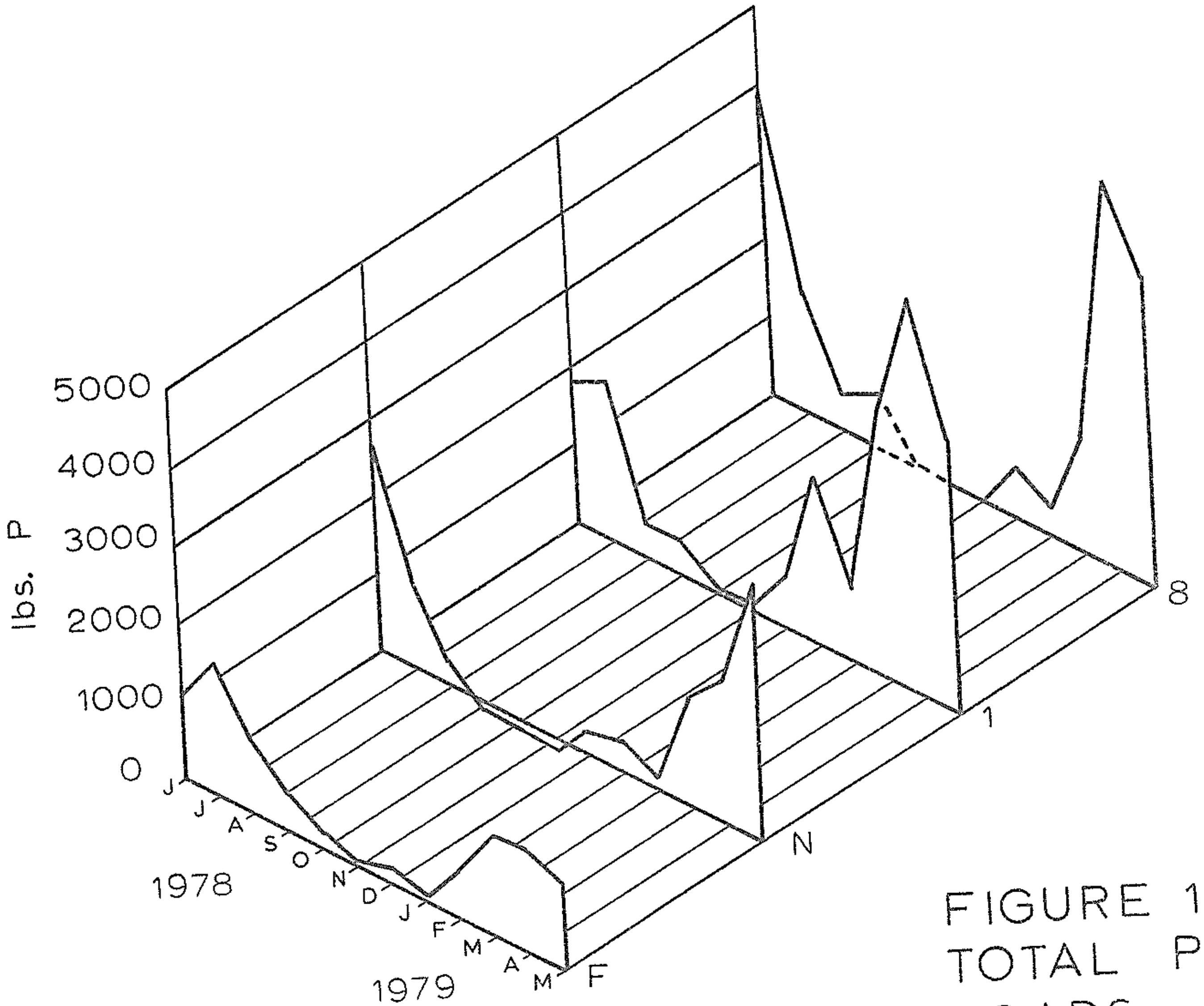
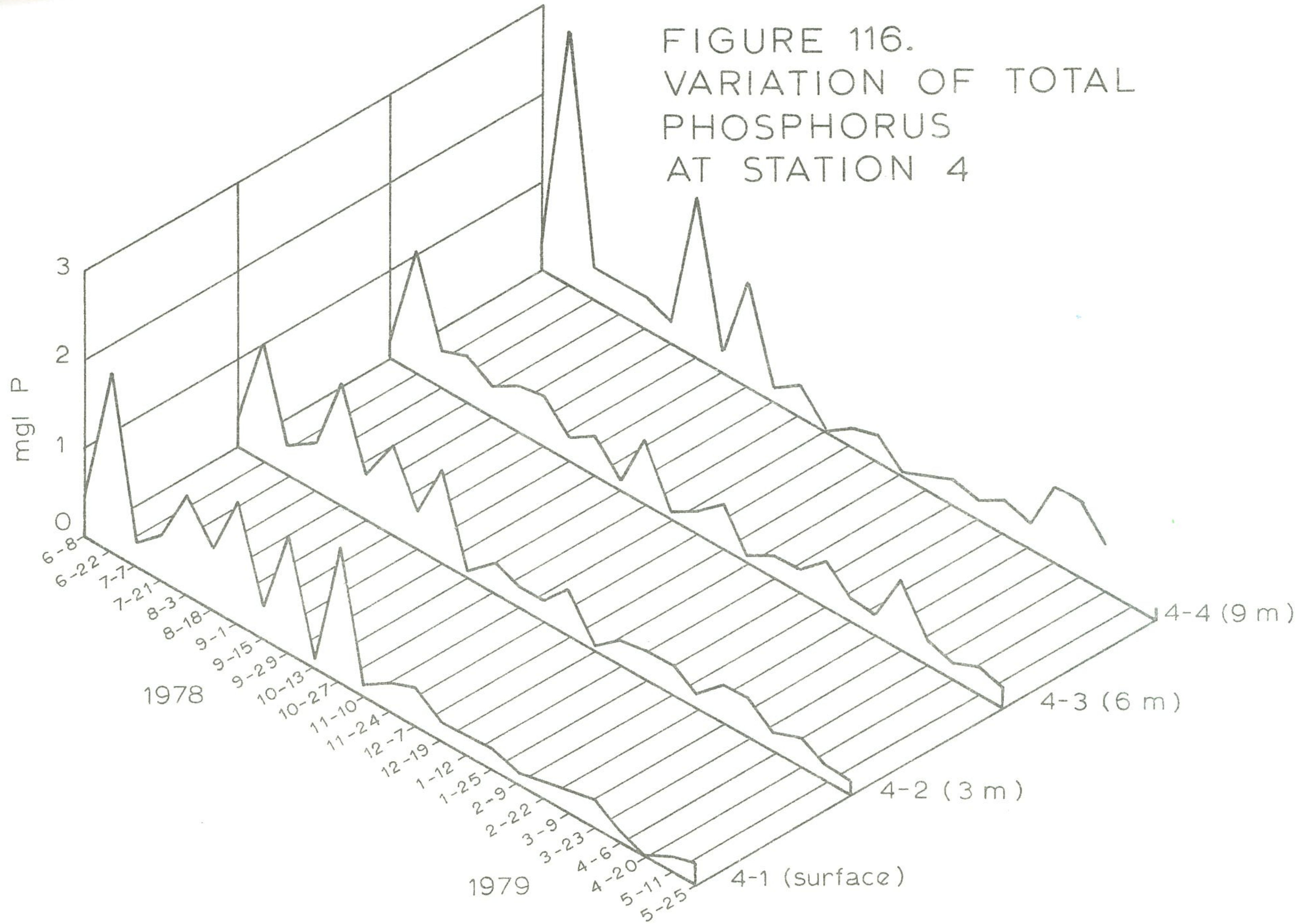


FIGURE 115.
TOTAL PHOSPHORUS LOADS

FIGURE 116.
VARIATION OF TOTAL
PHOSPHORUS
AT STATION 4



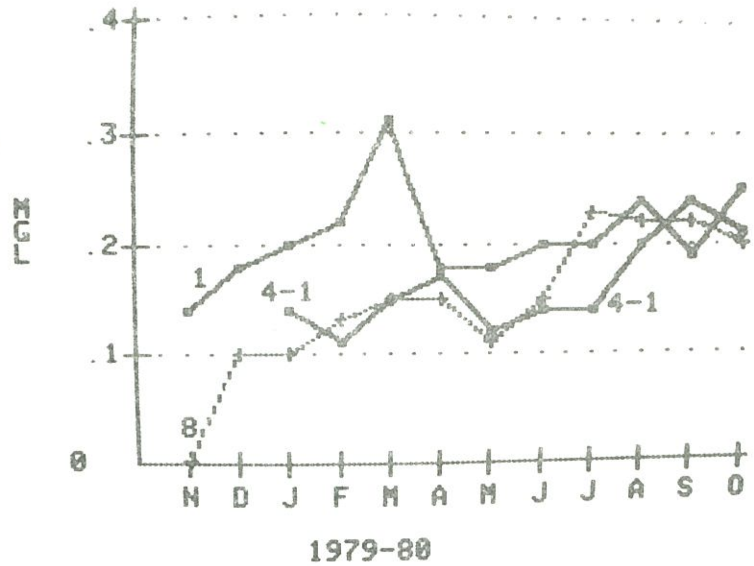


FIGURE 117. Monthly mean concentrations of total phosphorus at Stations 1, 4, and 8, 1979-80.

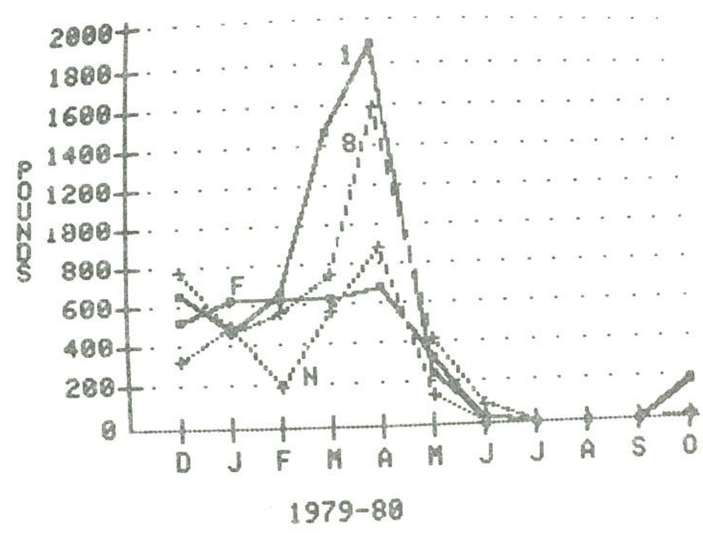


FIGURE 118. Monthly loads of total phosphorus at Stations 1, 8, F and N, 1979-80.

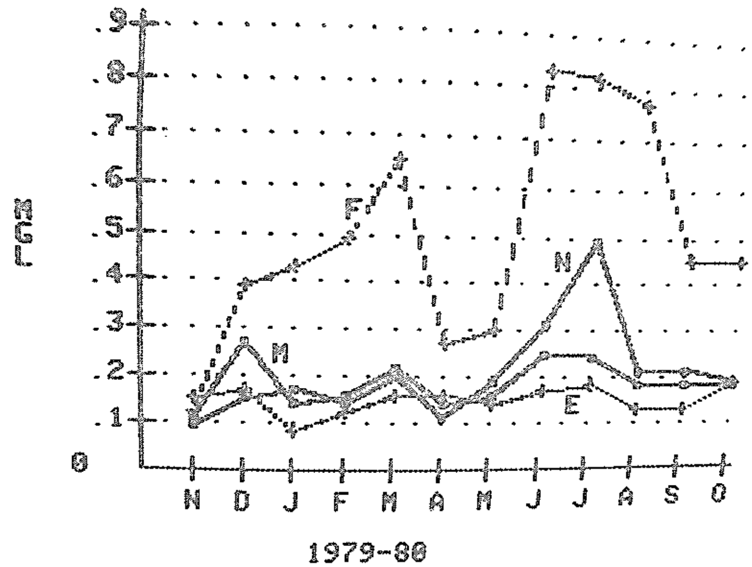


FIGURE 119. Monthly mean concentrations of total phosphorus at Stations E, F, M and N, 1979-80.

FIGURE 120.
Mean Monthly Total
Nitrogen - Surface Waters

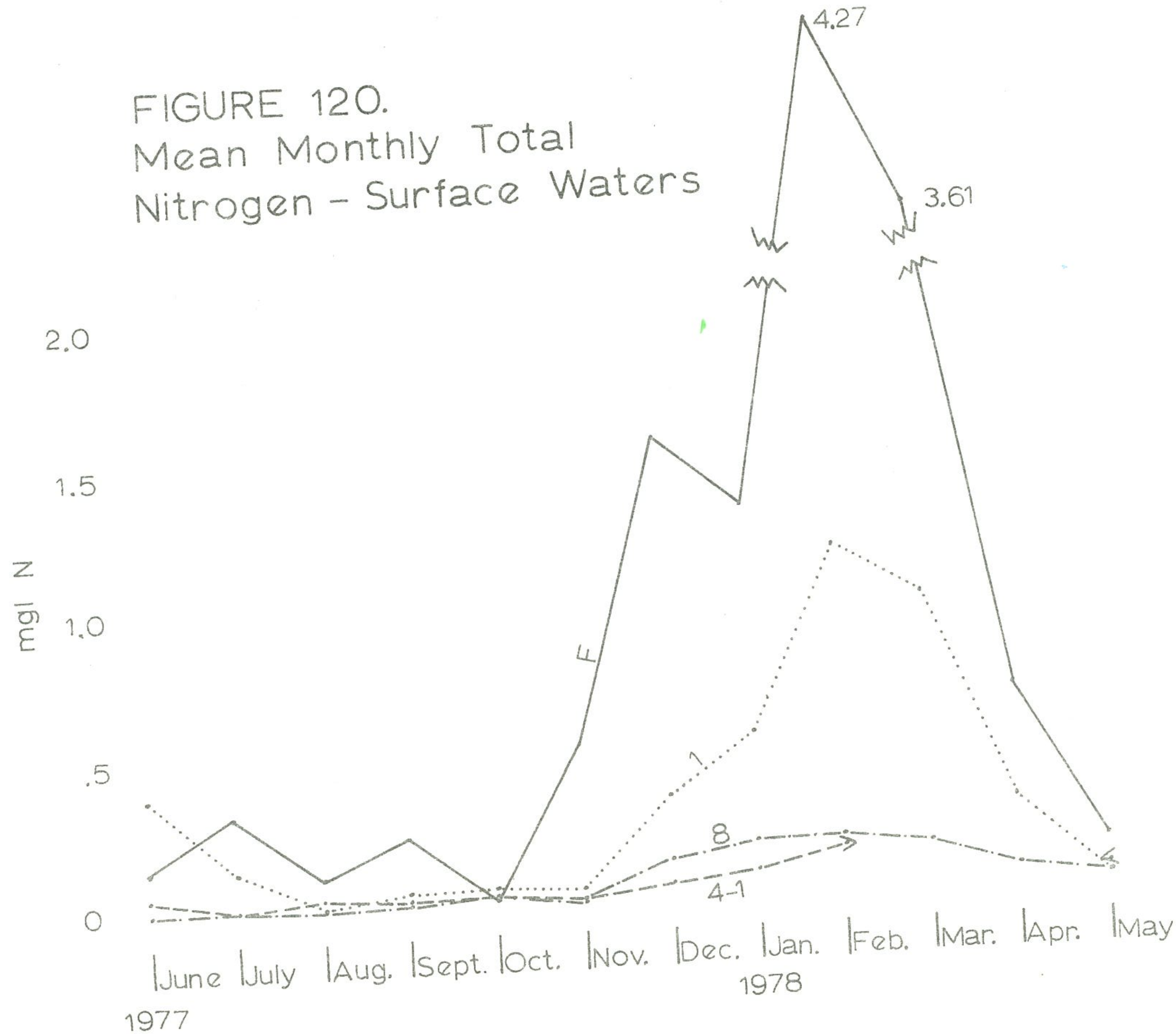


FIGURE 121.
TOTAL NITROGEN IN SURFACE WATERS - 1975-76

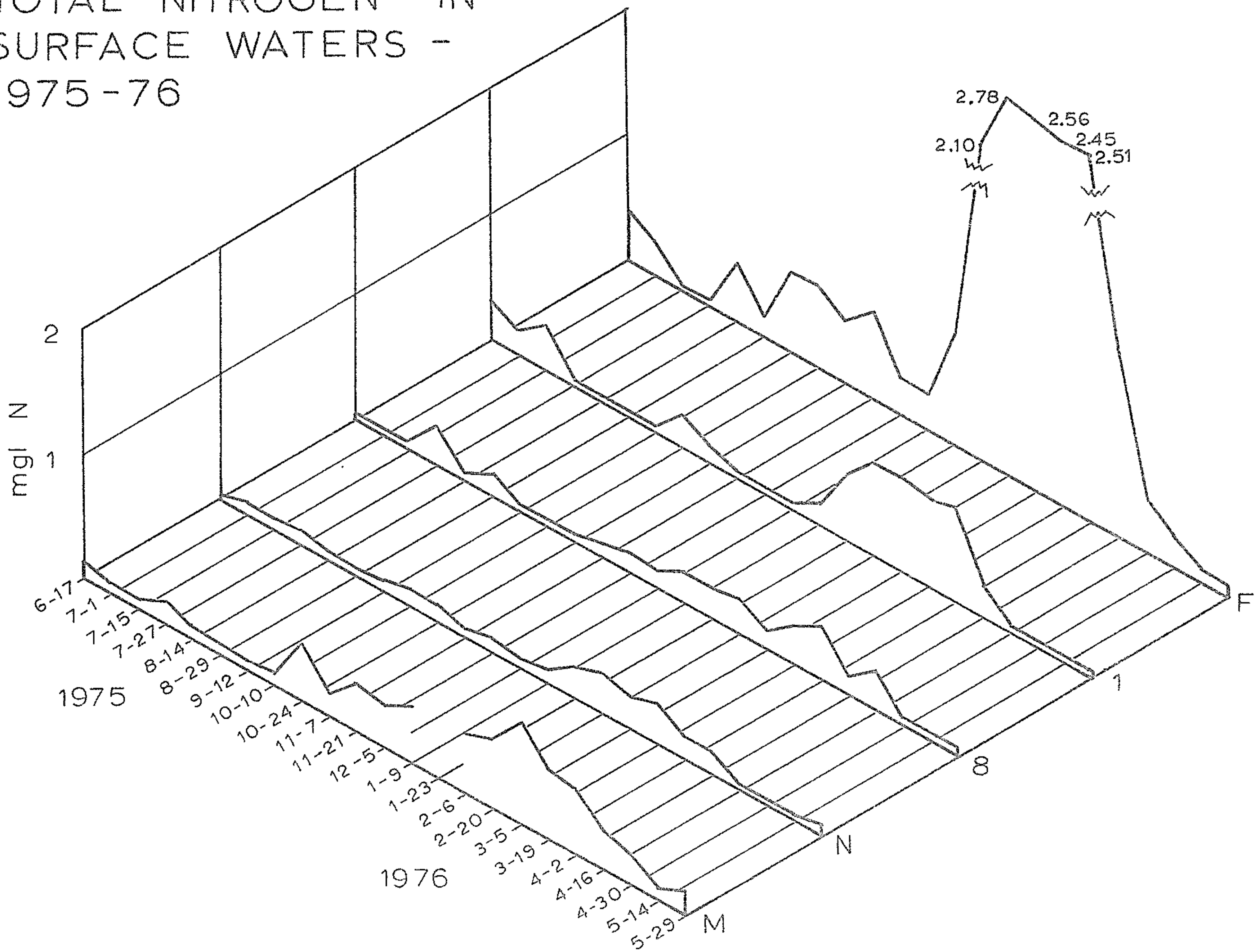
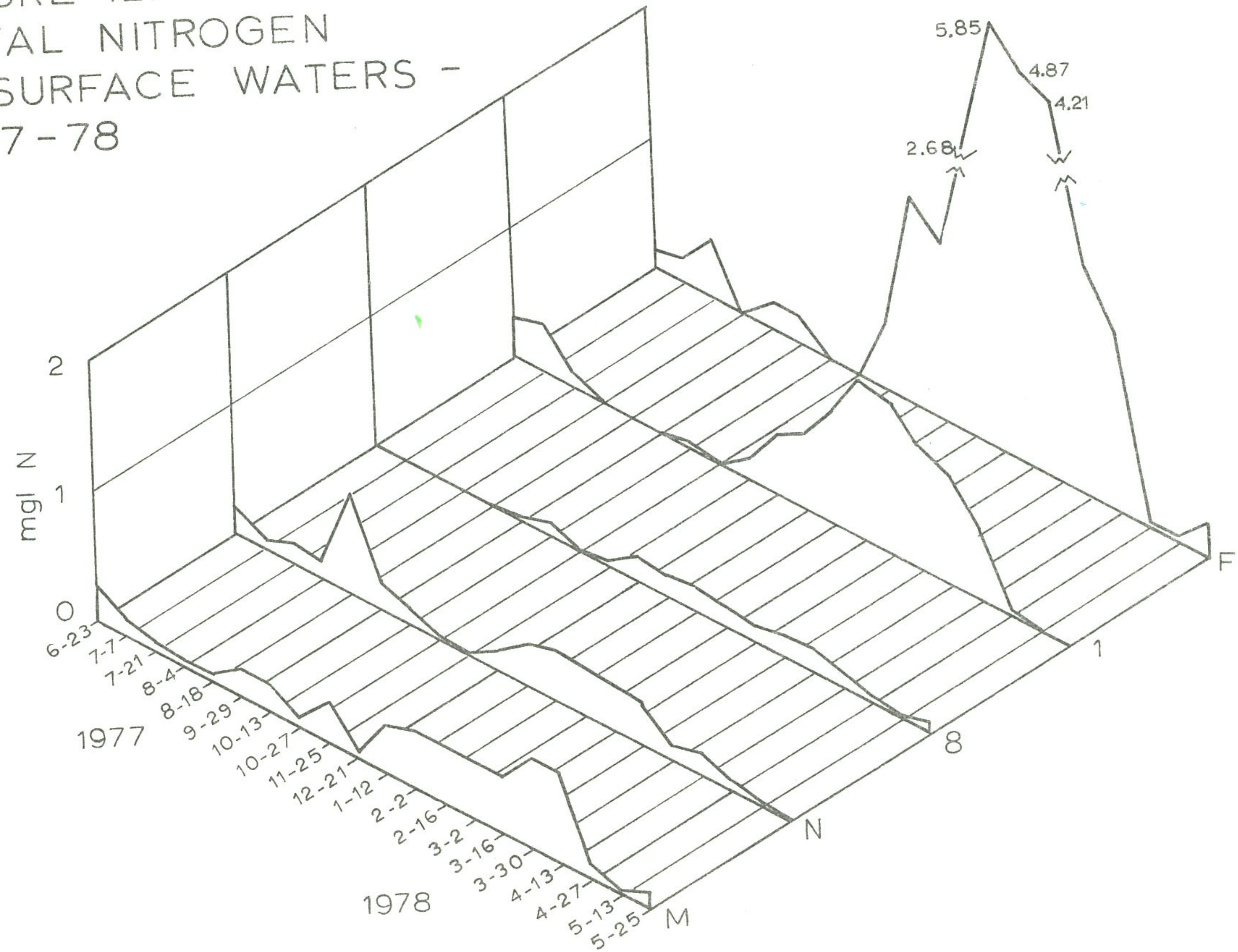


FIGURE 122.
TOTAL NITROGEN
IN SURFACE WATERS -
1977-78



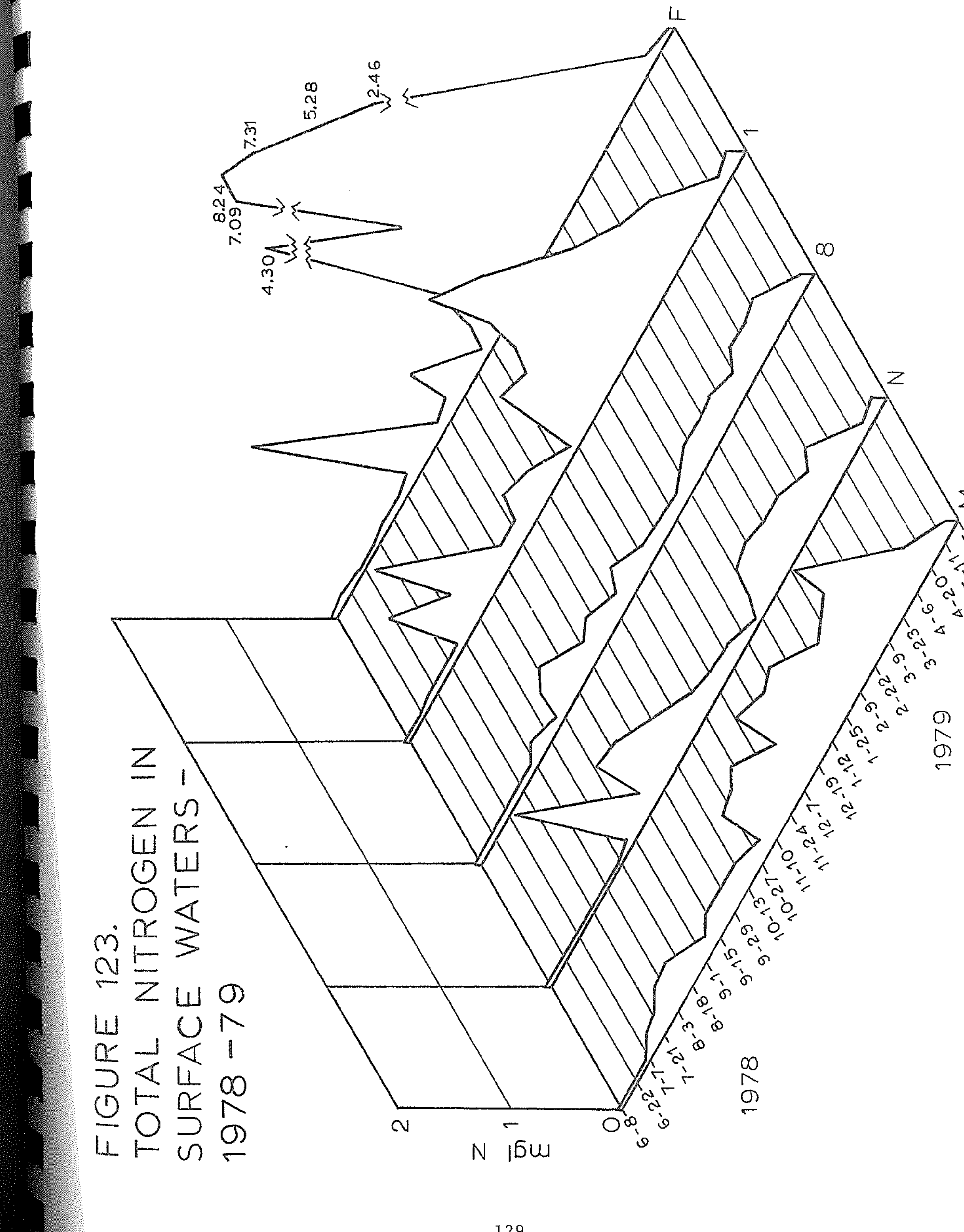


FIGURE 123.
TOTAL NITROGEN IN SURFACE WATERS – 1978 – 79

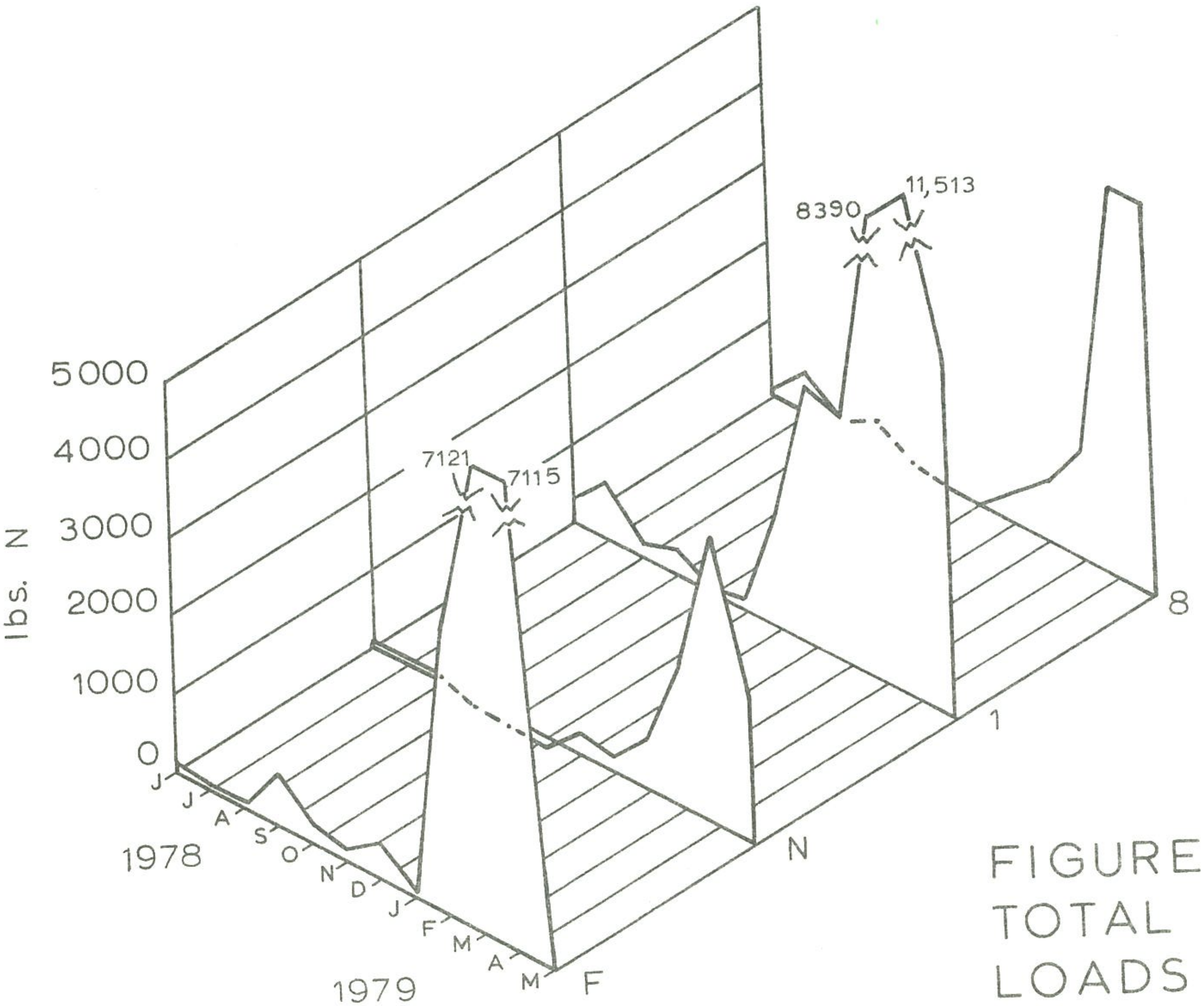


FIGURE 124.
TOTAL NITROGEN
LOADS

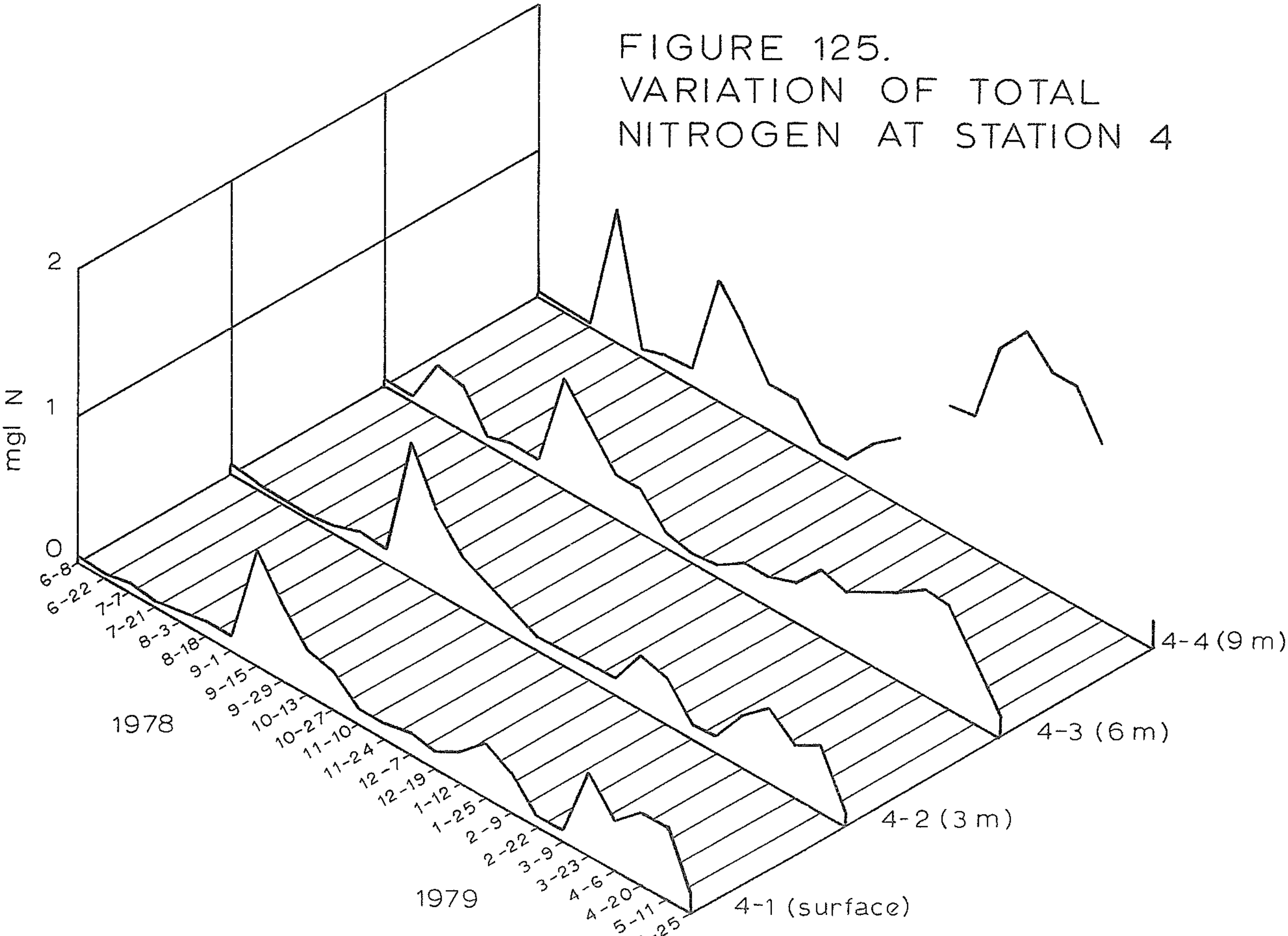


FIGURE 125.
VARIATION OF TOTAL
NITROGEN AT STATION 4

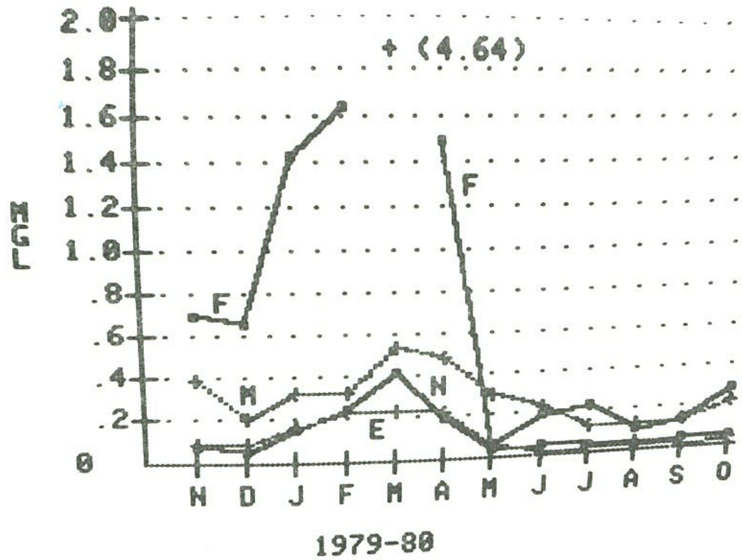


FIGURE 126. Monthly mean concentrations of total nitrogen at Stations E, F, M and N, 1979-80.

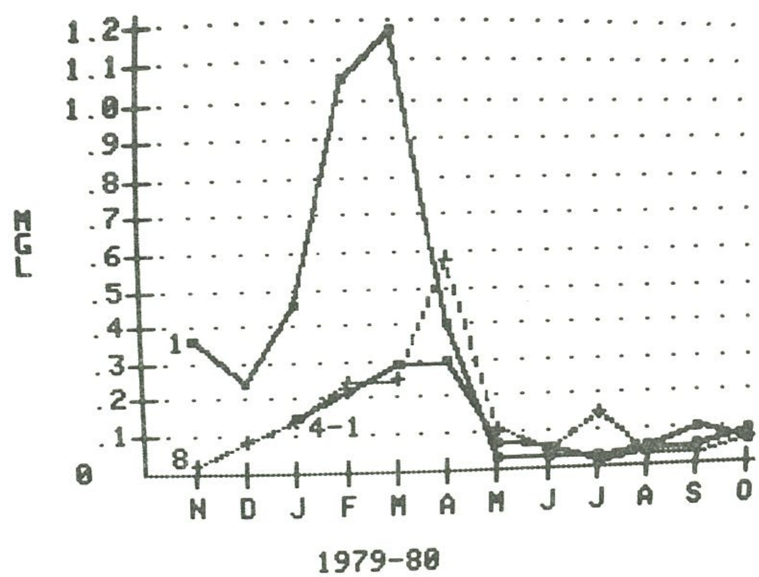


FIGURE 127. Monthly mean concentrations of total nitrogen at Stations 1, 4 and 8, 1979-80.

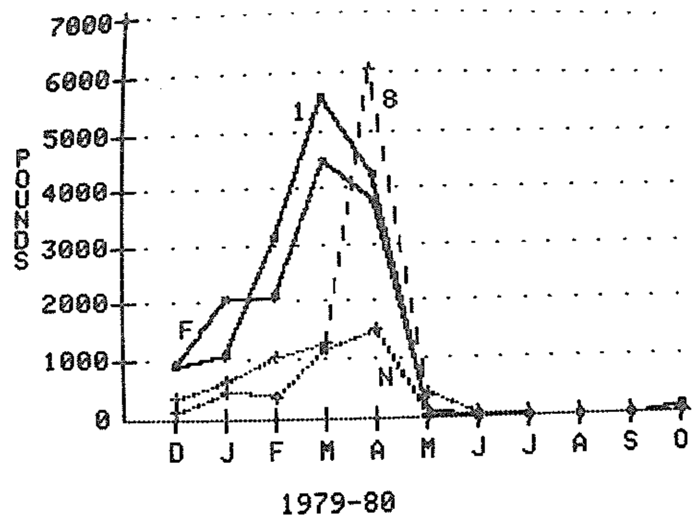


FIGURE 128. Monthly loads of total nitrogen at Stations 1, 8, F and N, 1979-80.

FIGURE 129.
Variation in Total Phytoplankton at Station F

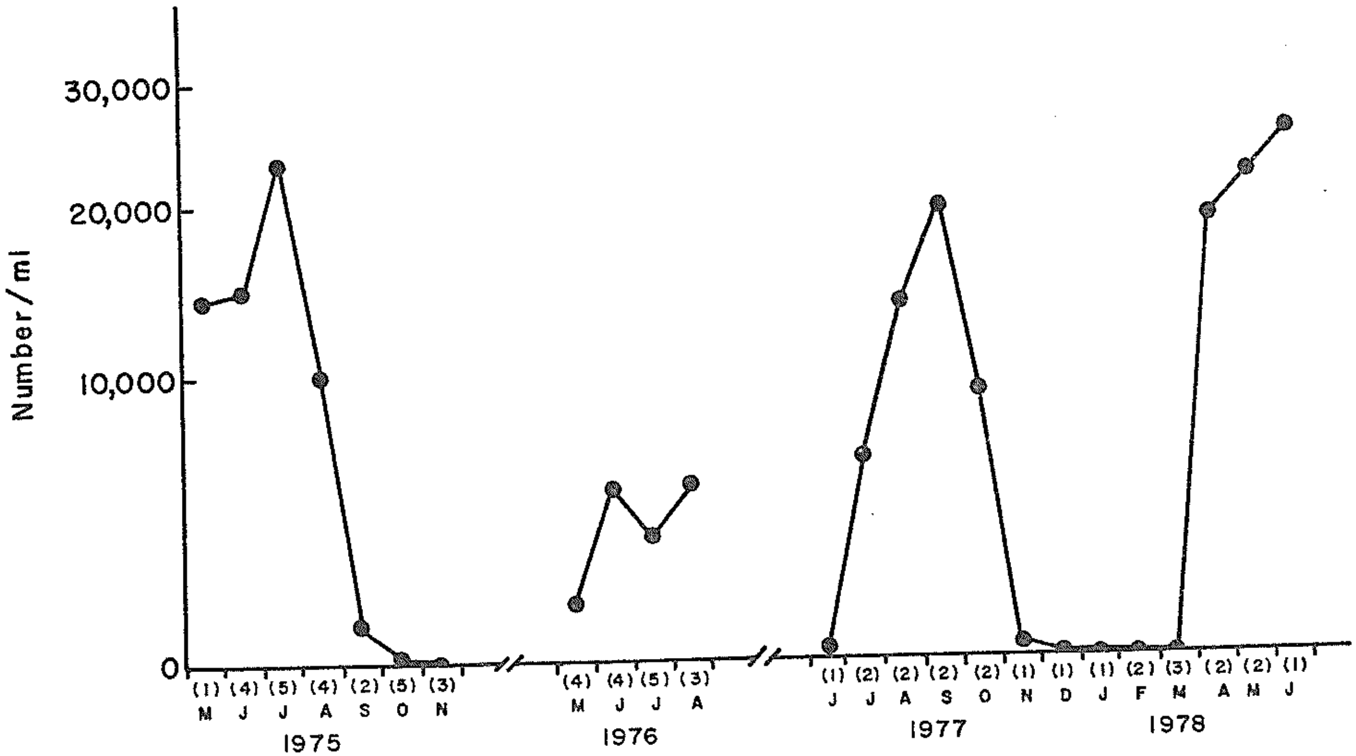


FIGURE 130.
Variation in Total Phytoplankton at Station 1

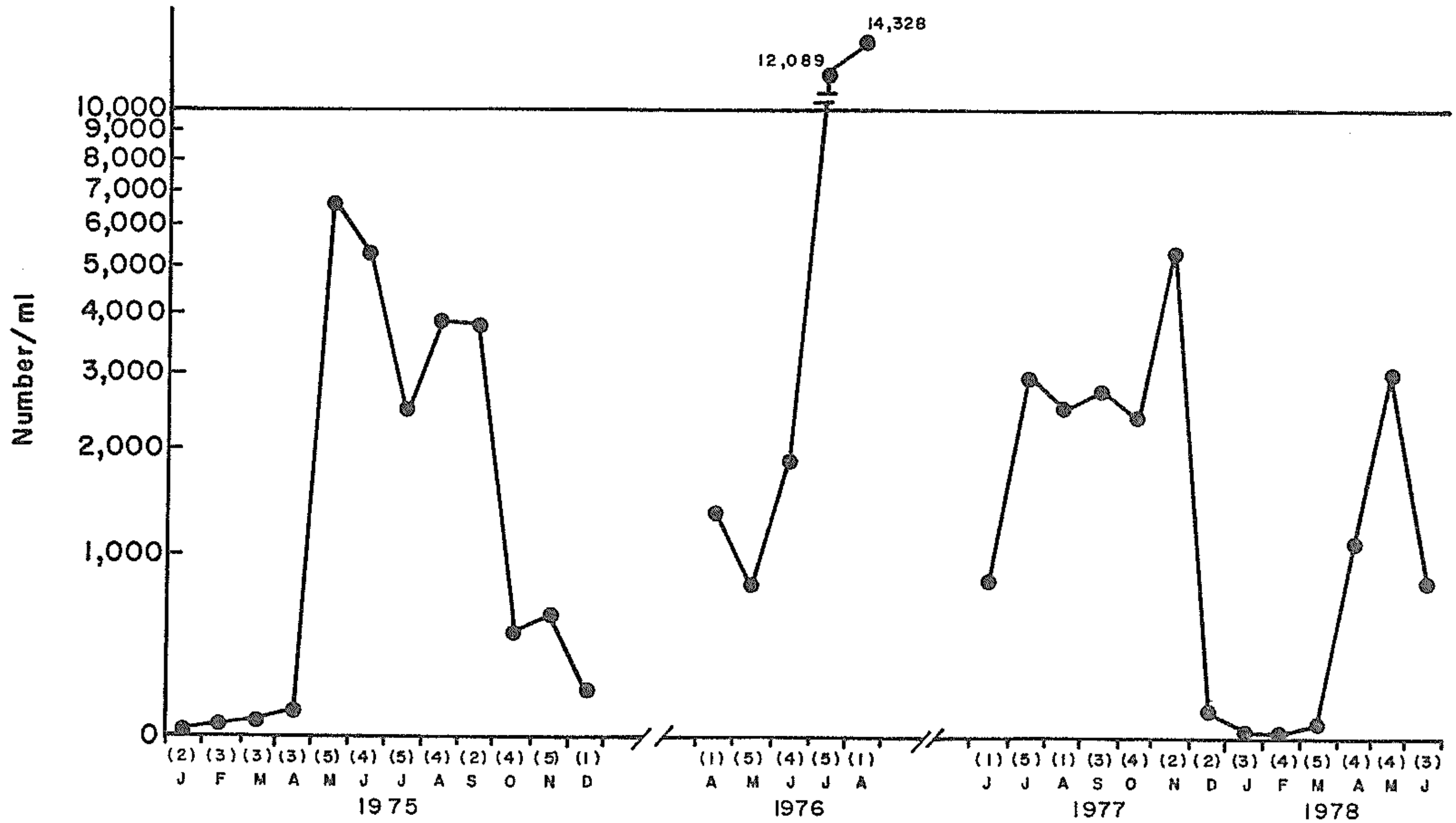


FIGURE 131.
Variation in Total Phytoplankton at Station N

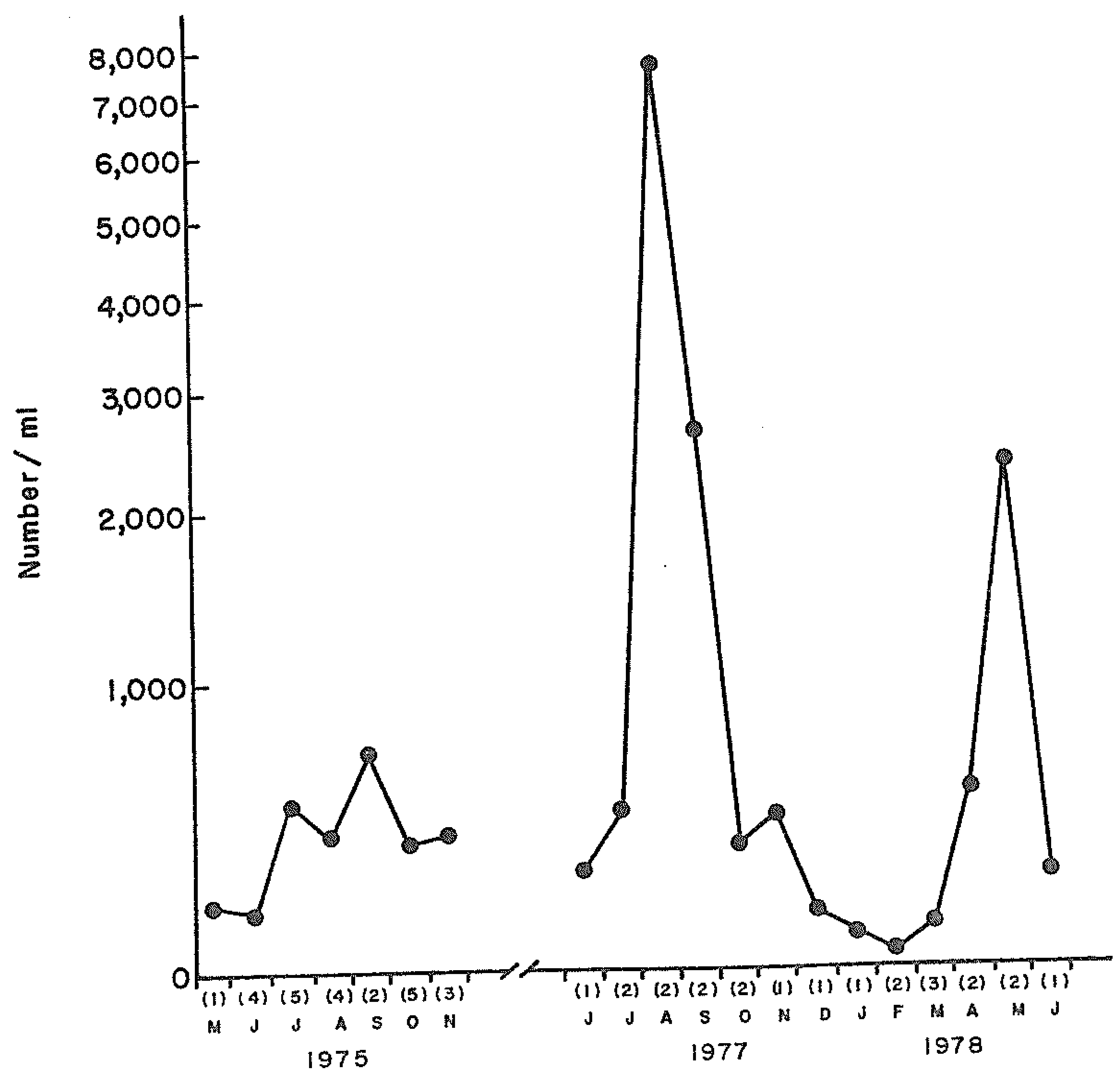


FIGURE 132.
Variation in Total Phytoplankton at Station 4-1

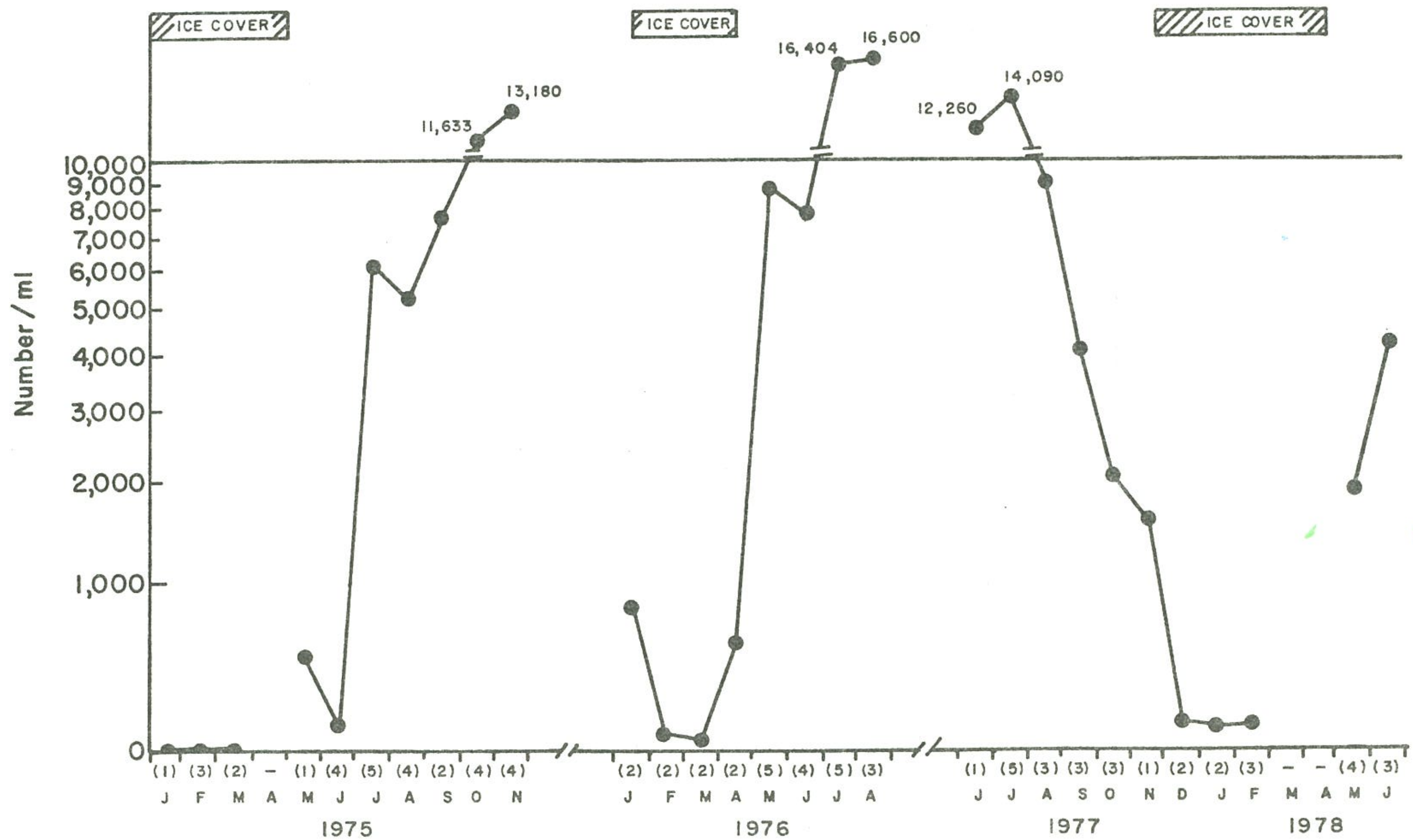


FIGURE 133.
Variation in Total Phytoplankton at Station 8

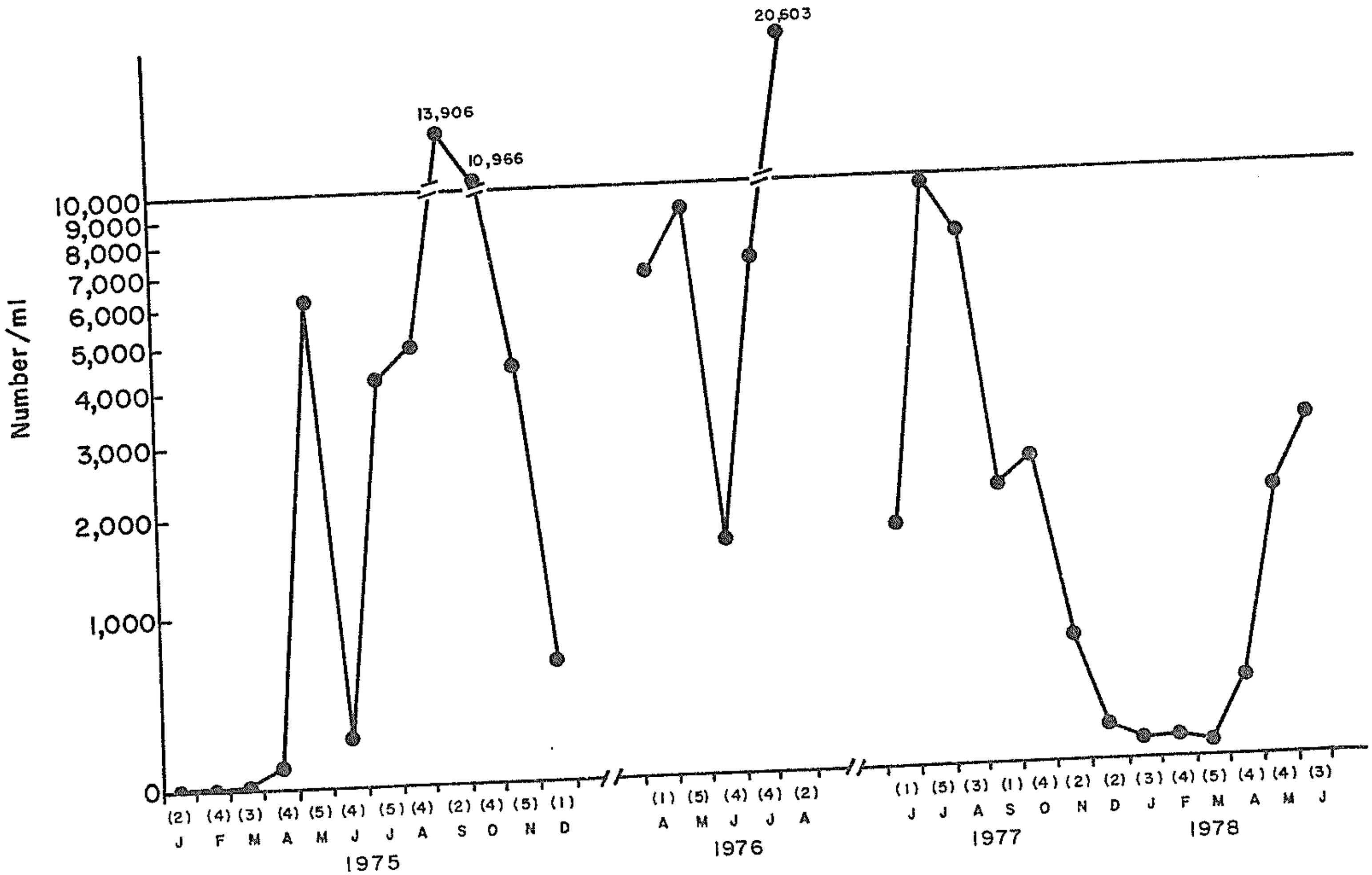


FIGURE 134.
HETEROCYSTOUS
BLUE - GREEN
ALGAE

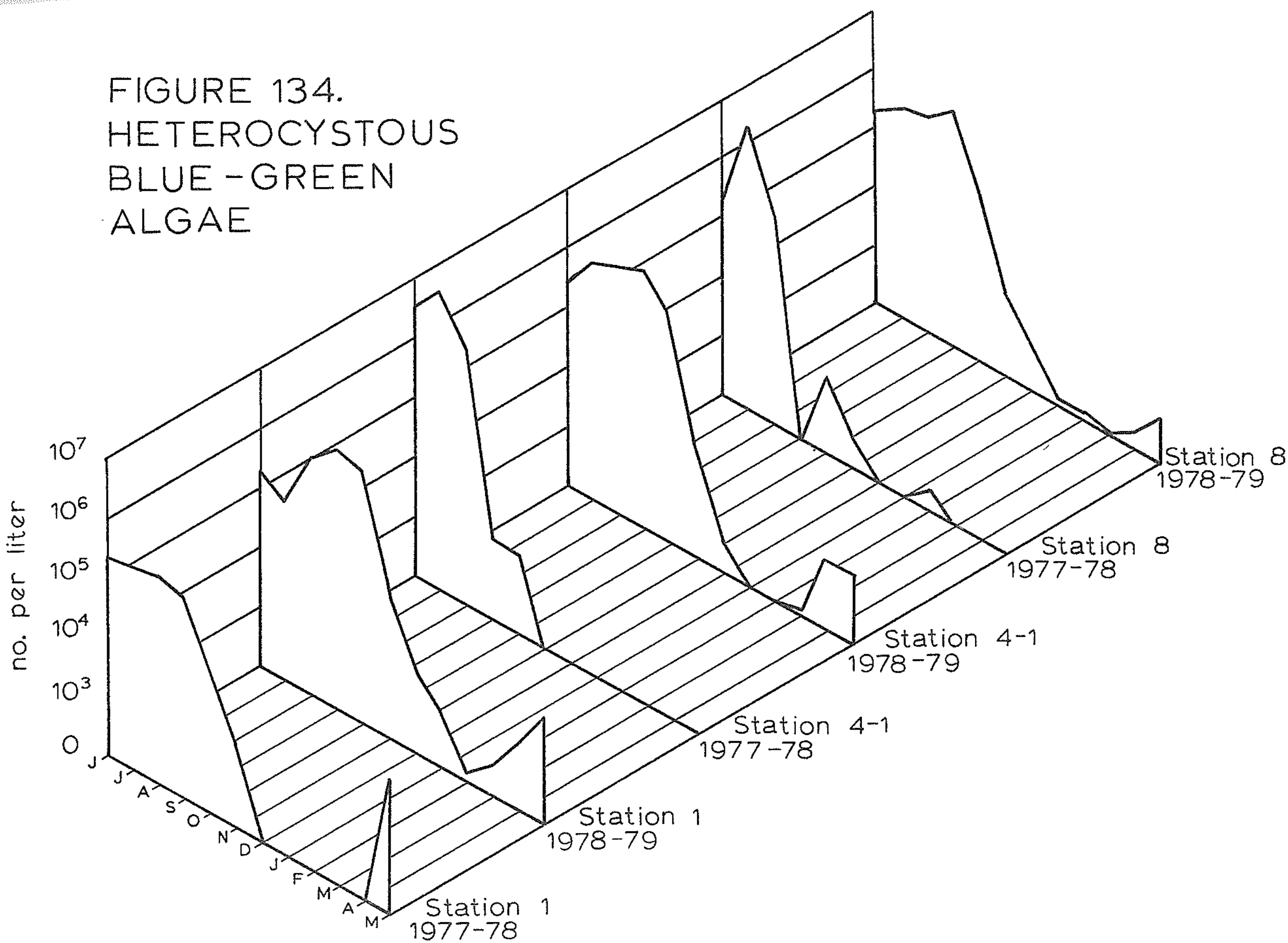


FIGURE 135.
NONHETEROCYSTOUS
BLUE - GREEN
ALGAE

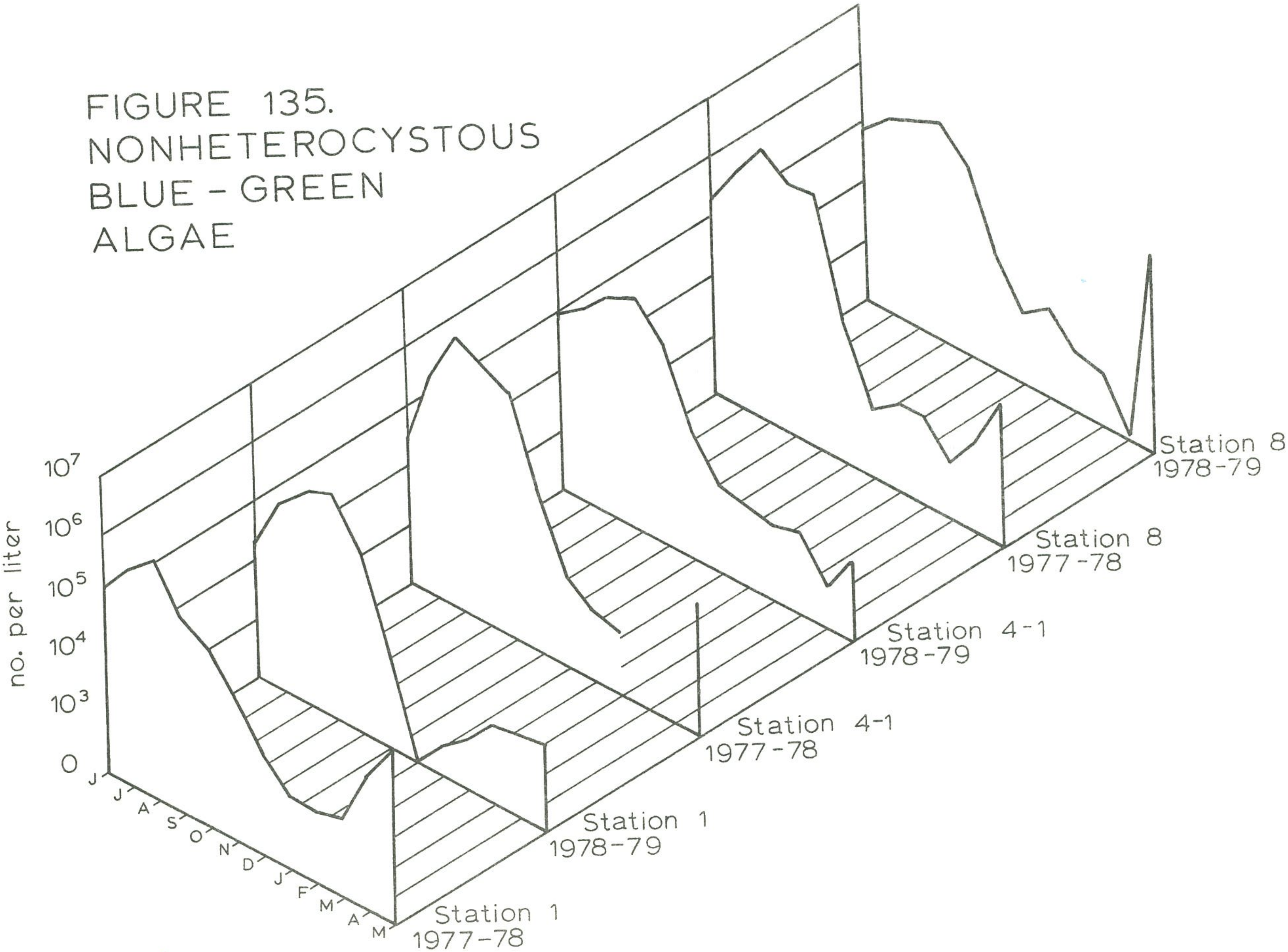


FIGURE 136.
DIATOMS

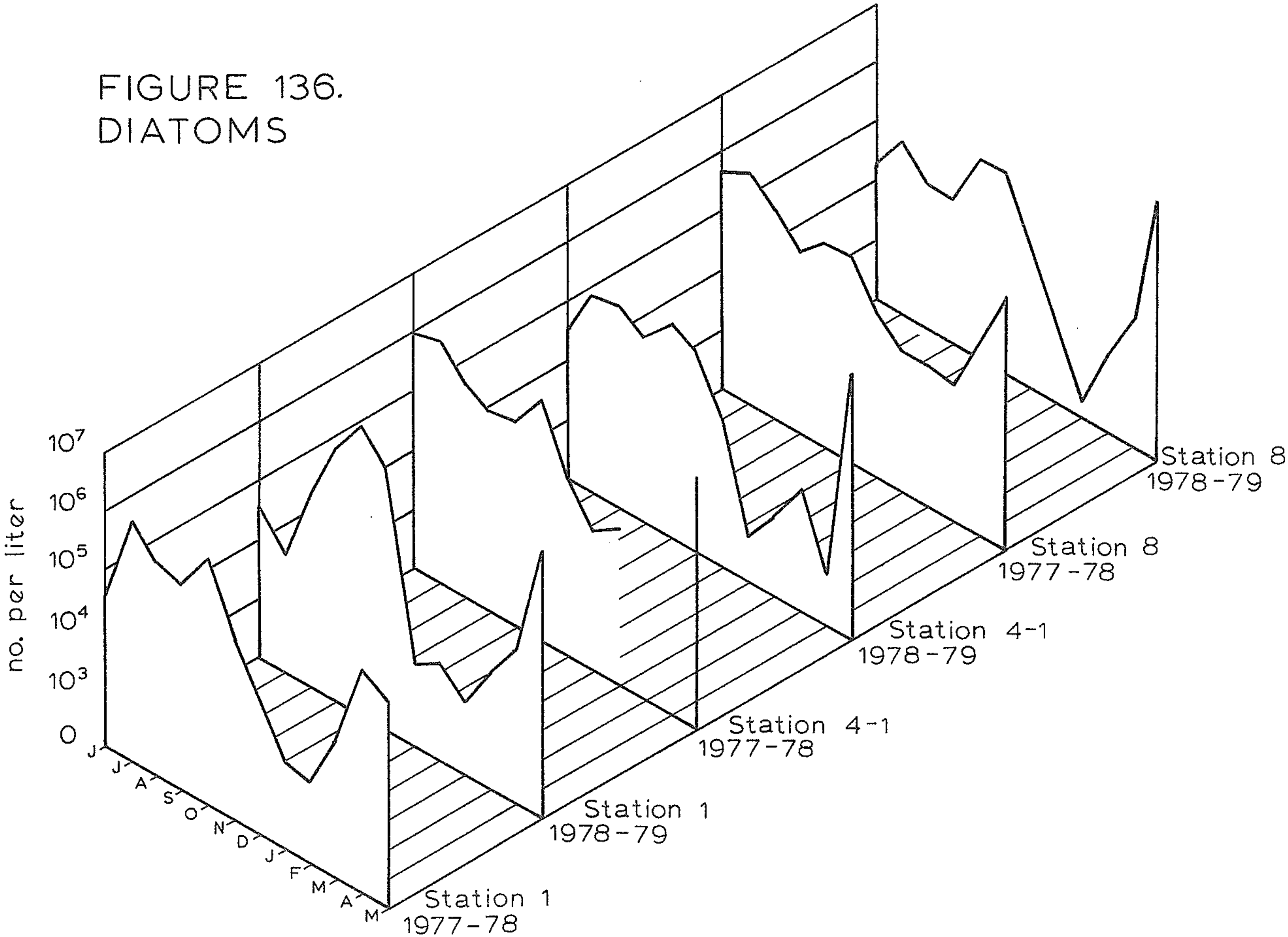


FIGURE 137.
PLANKTON DENSITY
AT STATION 1

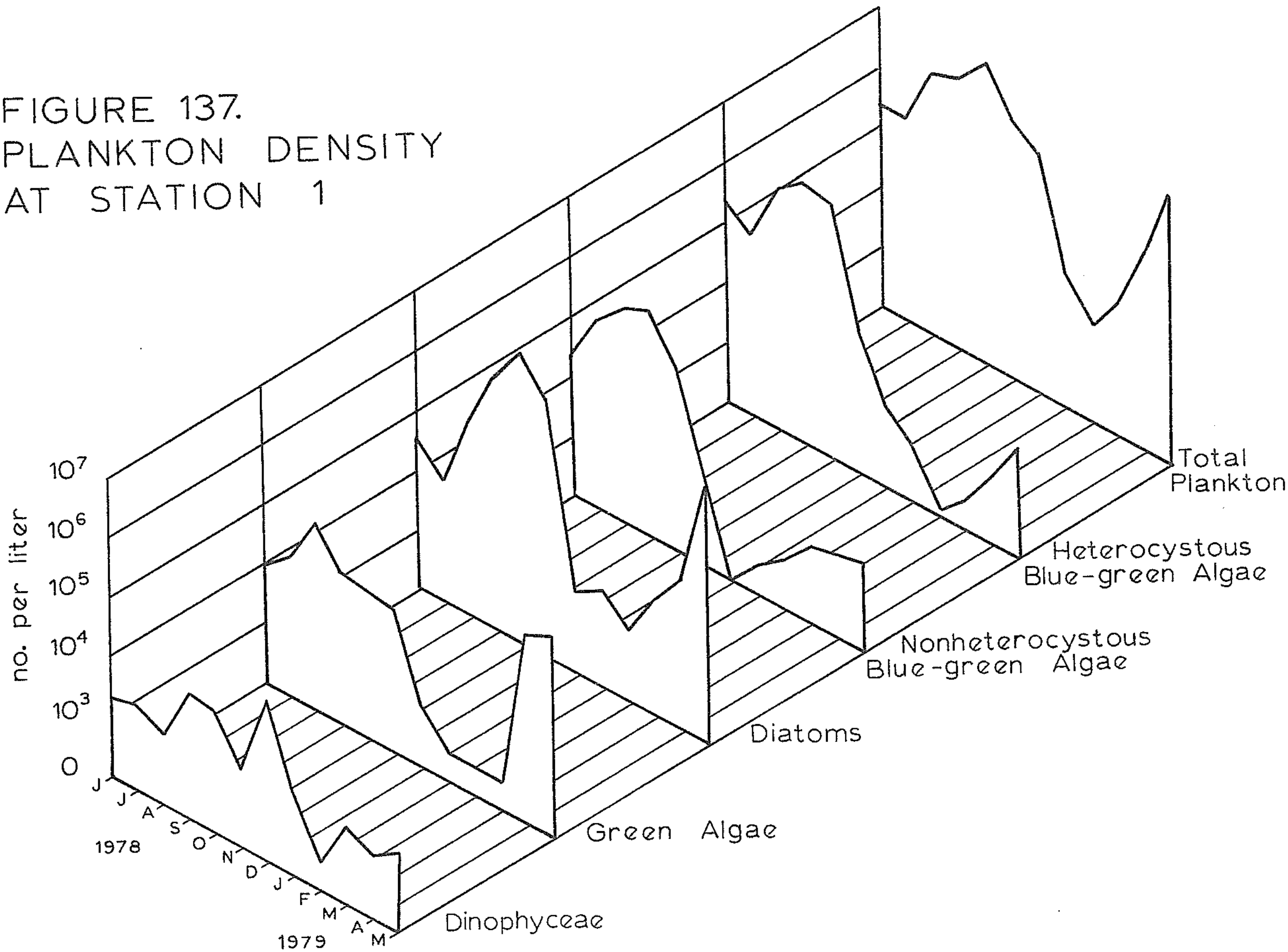


FIGURE 138.
PLANKTON DENSITY
AT STATION 4-1

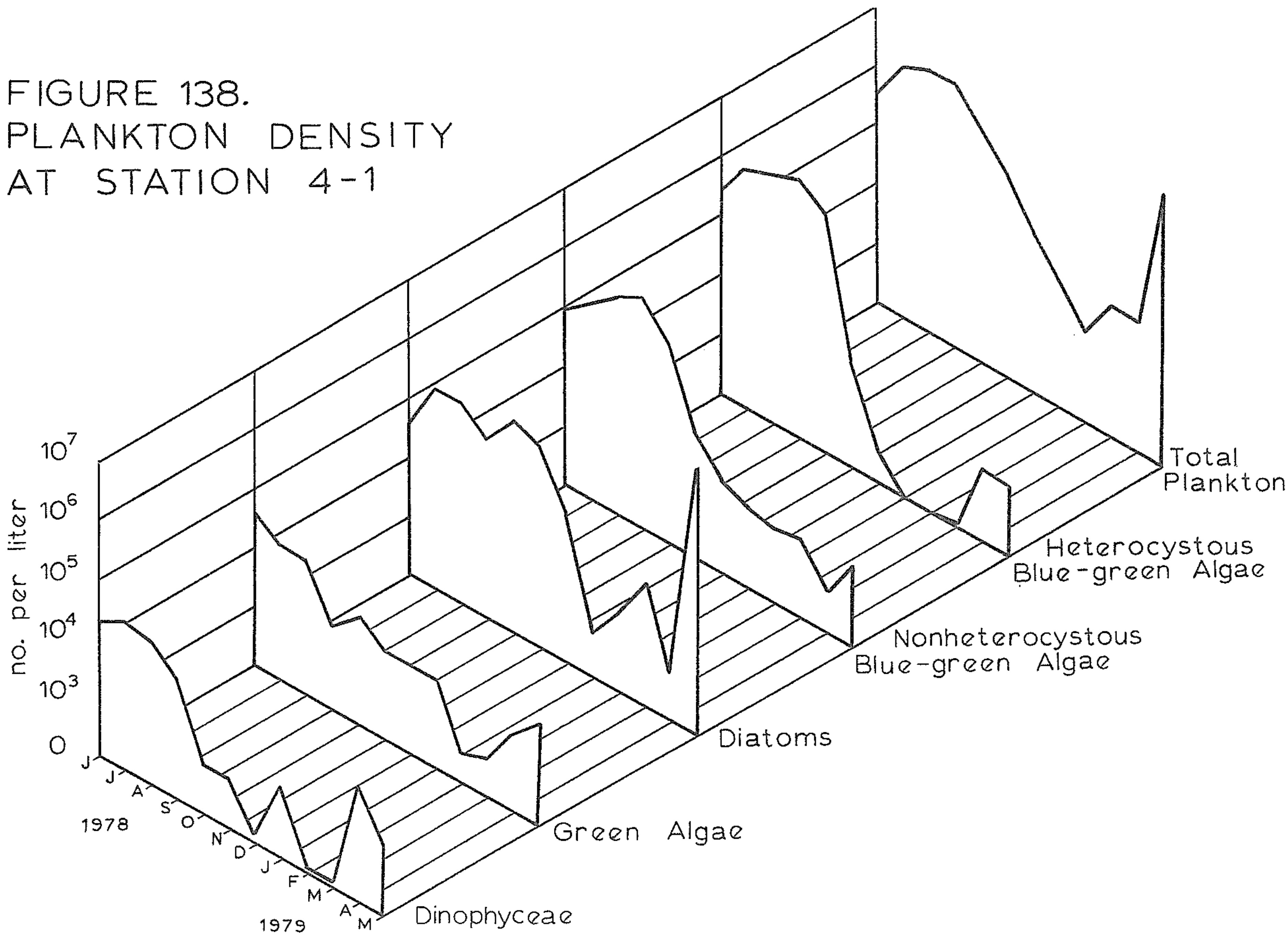
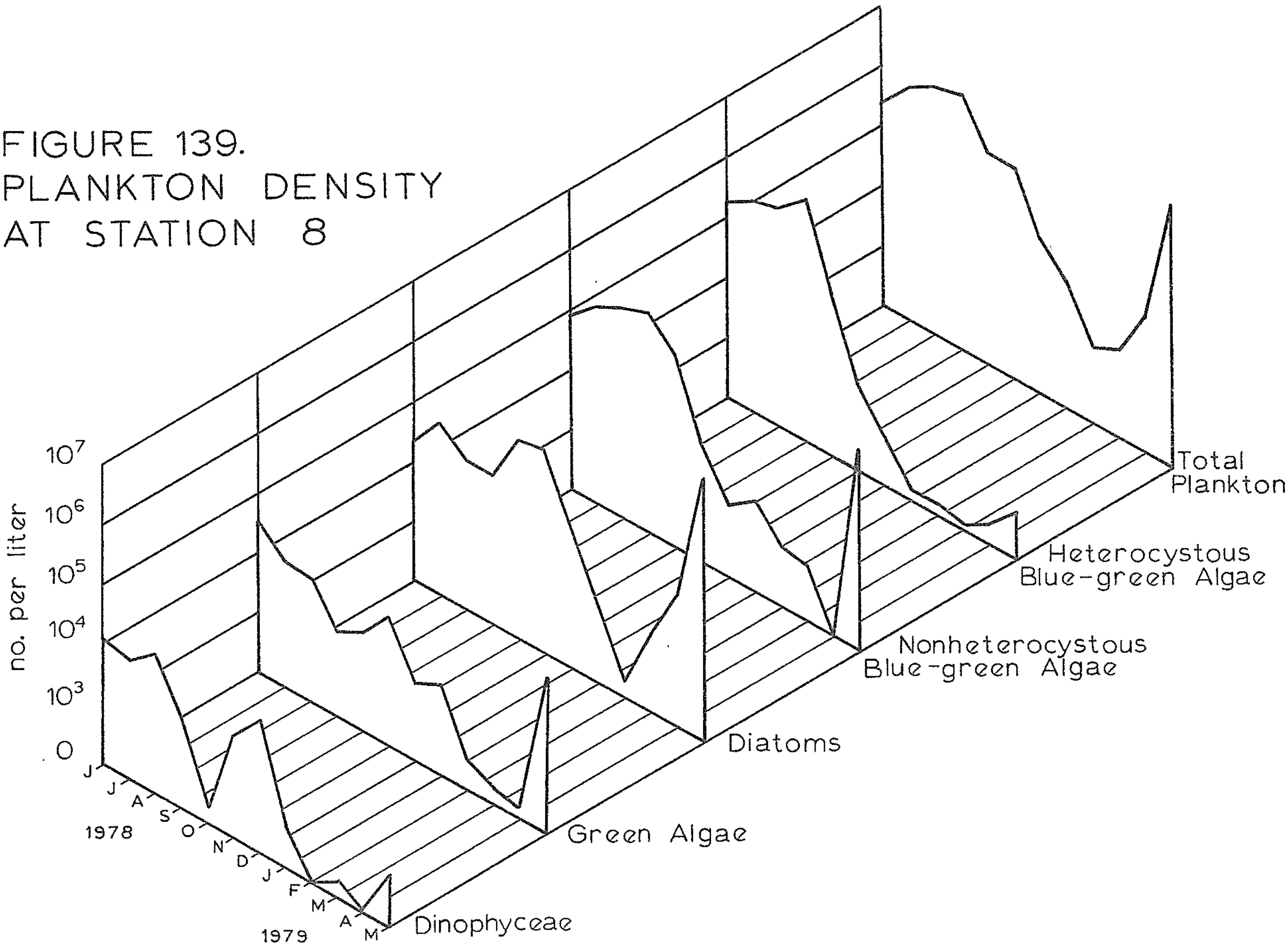


FIGURE 139.
PLANKTON DENSITY
AT STATION 8



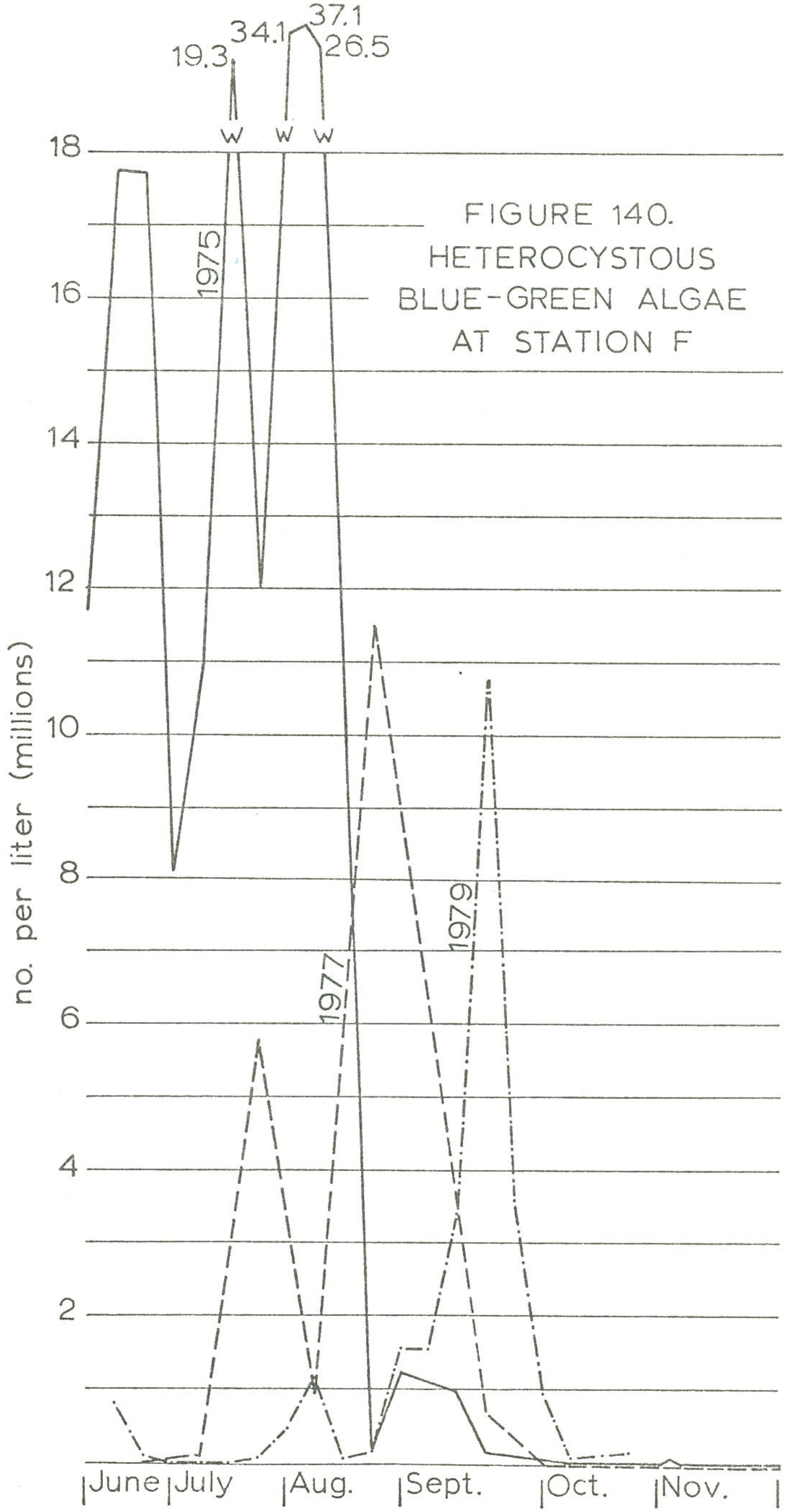


FIGURE 140.
HETEROCYSTOUS
BLUE-GREEN ALGAE
AT STATION F
no. per liter (millions)
18
16
14
12
10
8
6
4
2
19.3
34.1
37.1
26.5
W
W
W
1975
1977
1979
June
July
Aug.
Sept.
Oct.
Nov.

FIGURE 141.
NONHETEROCYSTOUS BLUE-GREEN ALGAE AT STATION F

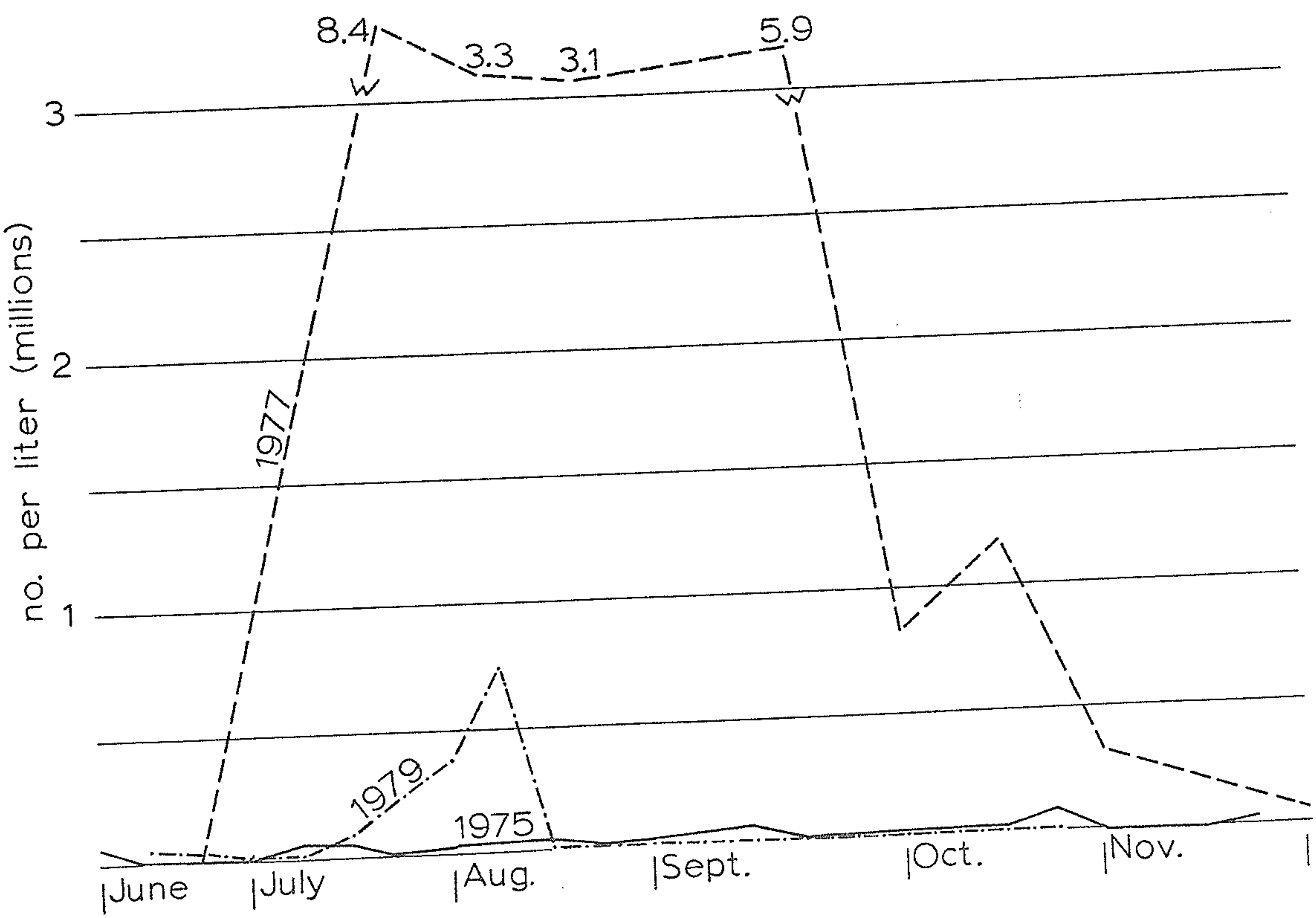


FIGURE 142.
HETEROCYSTOUS BLUE-GREEN ALGAE AT STATION 1

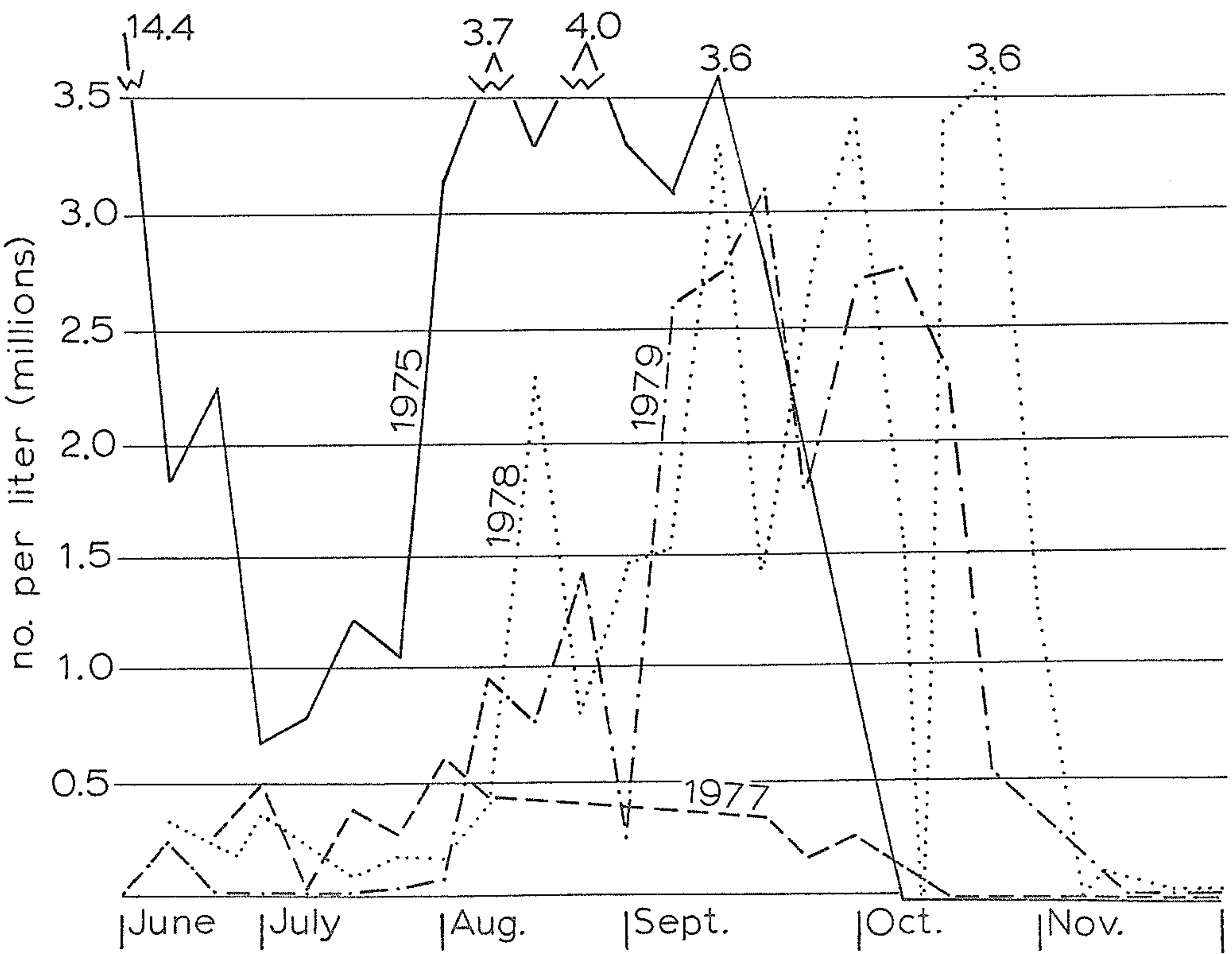


FIGURE 143.
NONHETEROCYSTOUS BLUE-GREEN ALGAE AT STATION 1

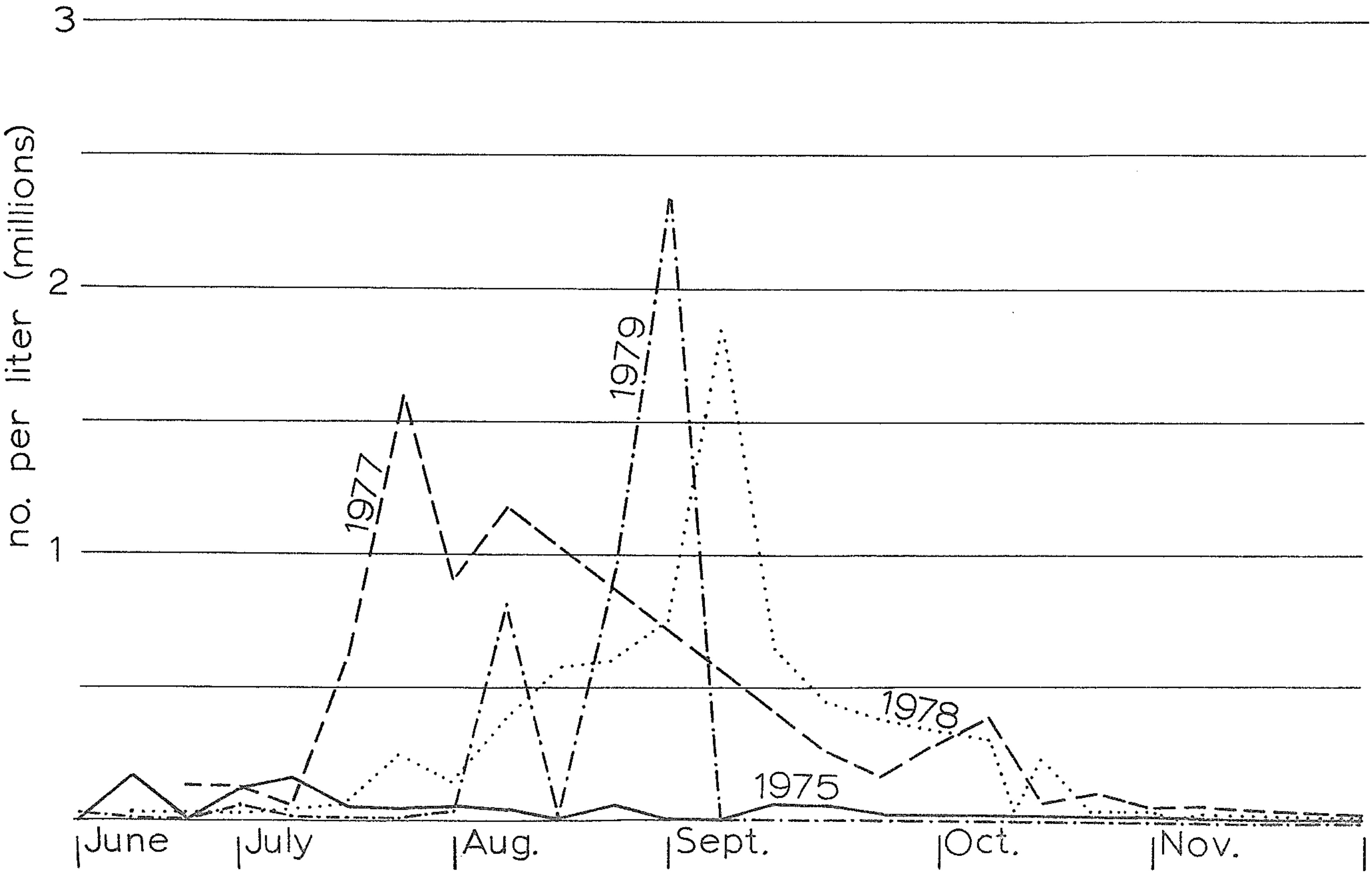


FIGURE 144.
HETEROCYSTOUS BLUE-GREEN ALGAE
AT STATION 8

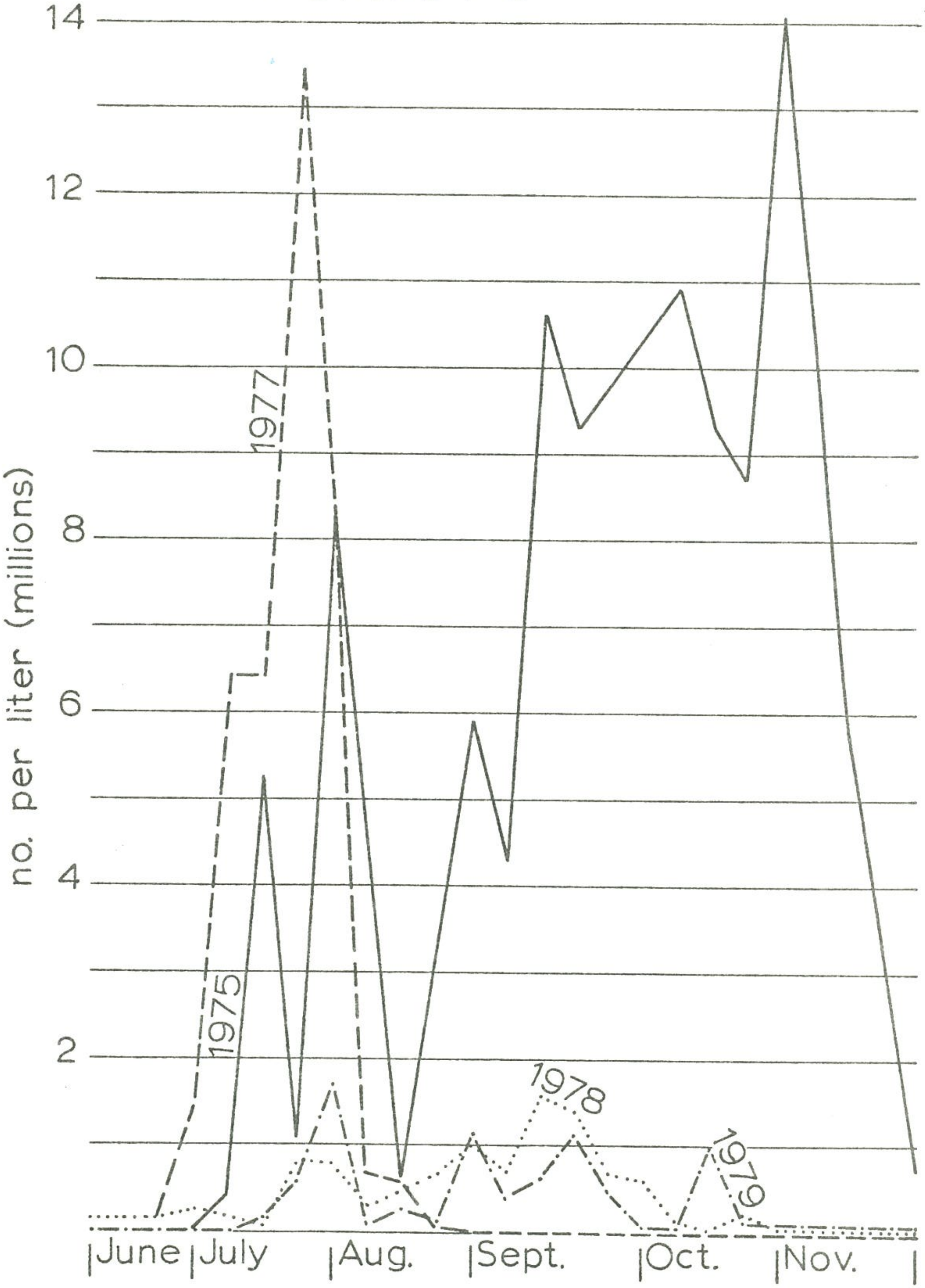


FIGURE 145.
NONHETEROCYSTOUS BLUE-GREEN ALGAE AT STATION 8

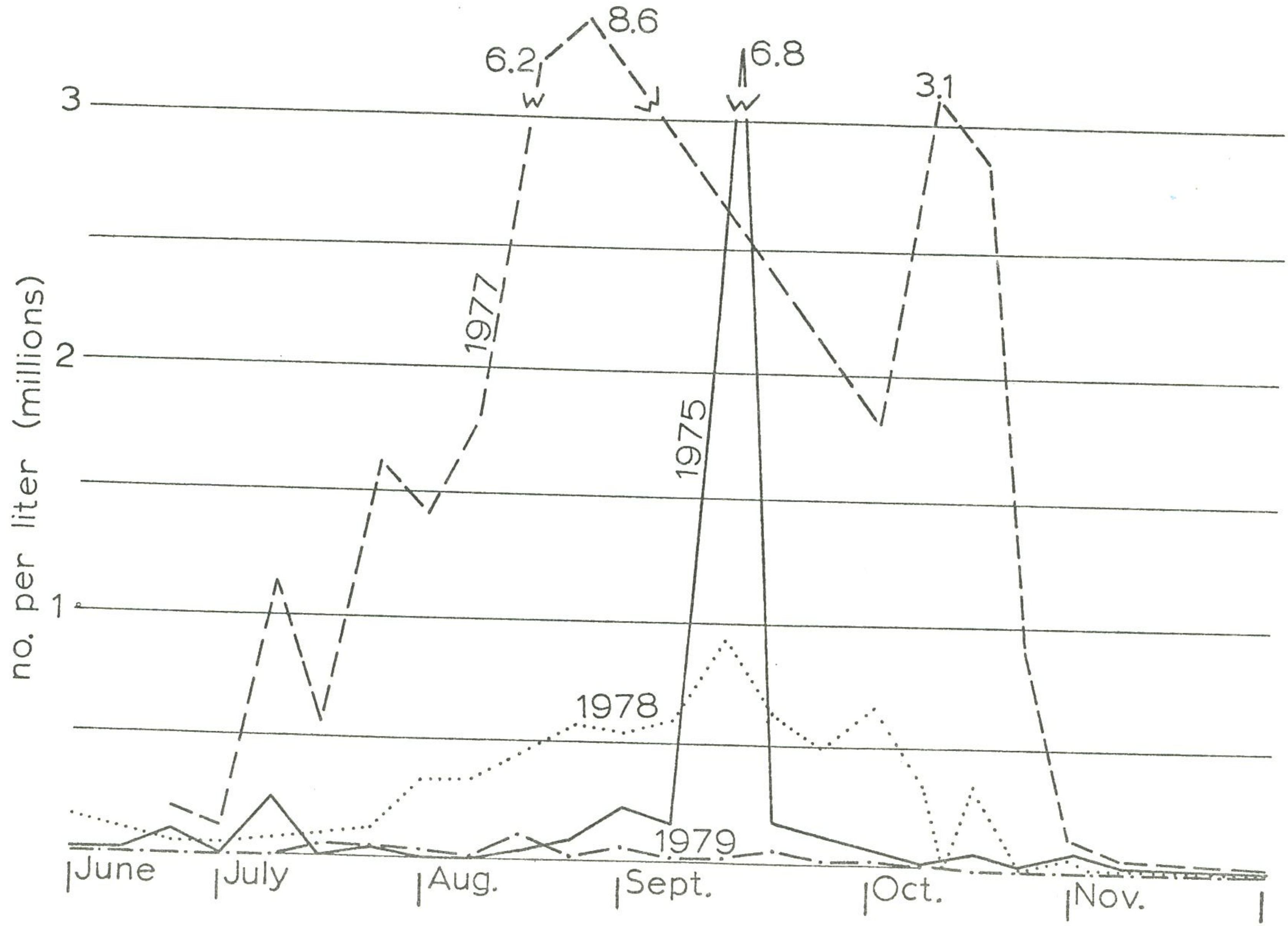


FIGURE 146.
HETEROCYSTOUS BLUE-GREEN ALGAE AT STATION N

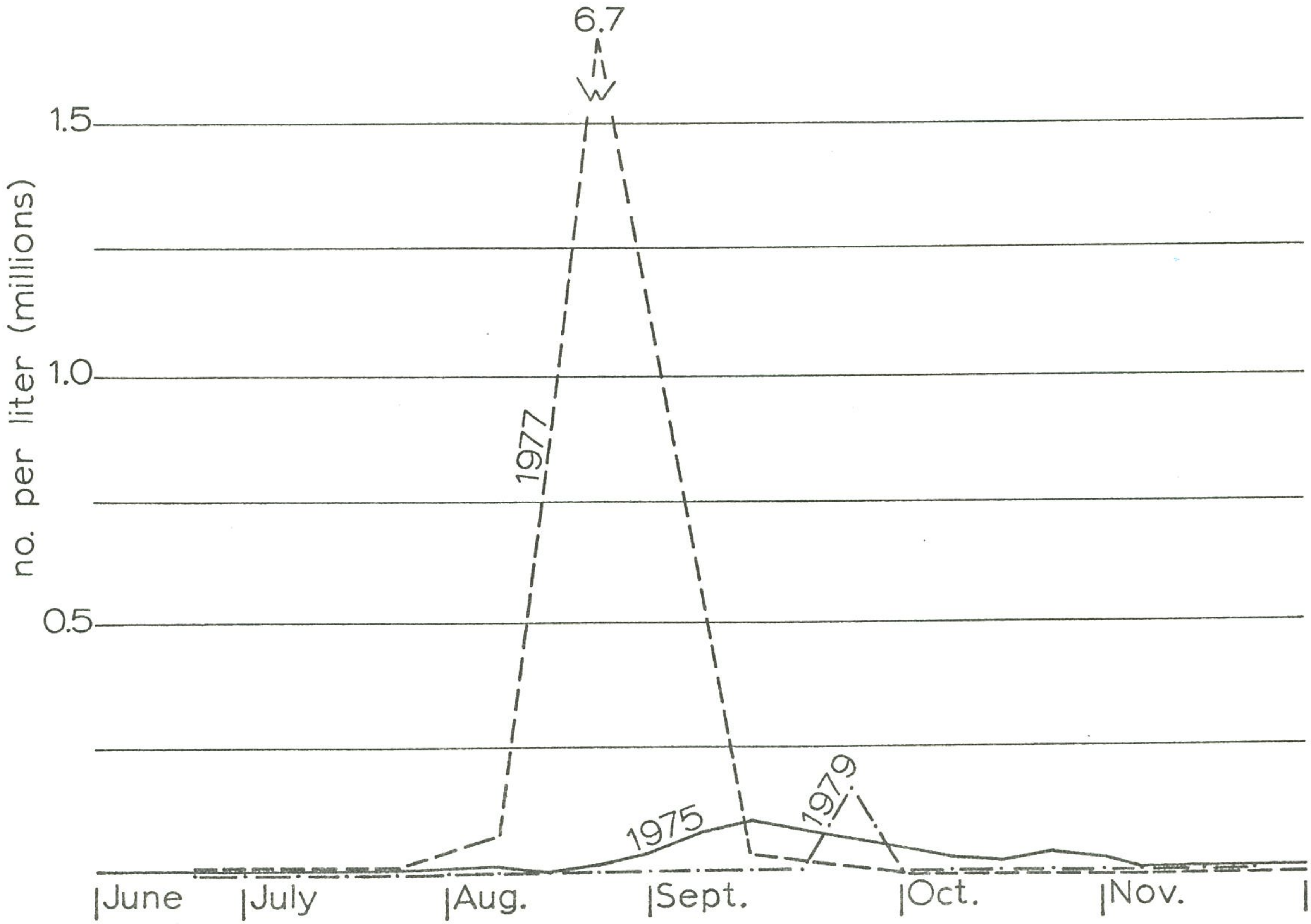


FIGURE 147.
NONHETEROCYSTOUS BLUE-GREEN ALGAE AT STATION N

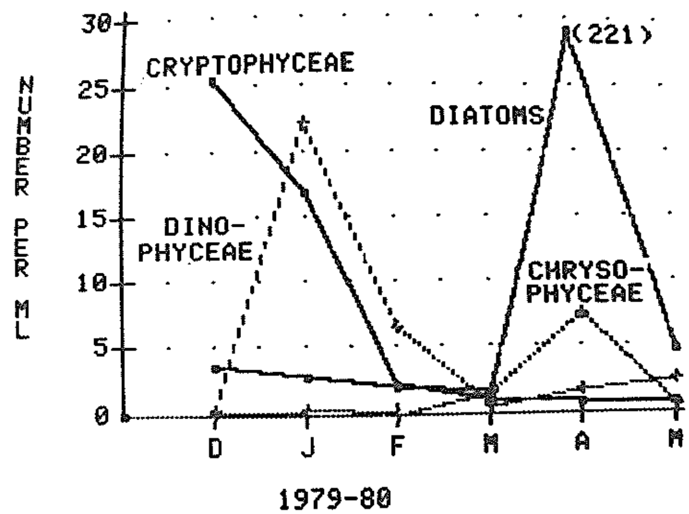


FIGURE 148. Monthly mean density of various plankton groups at Station N, 1979-80.

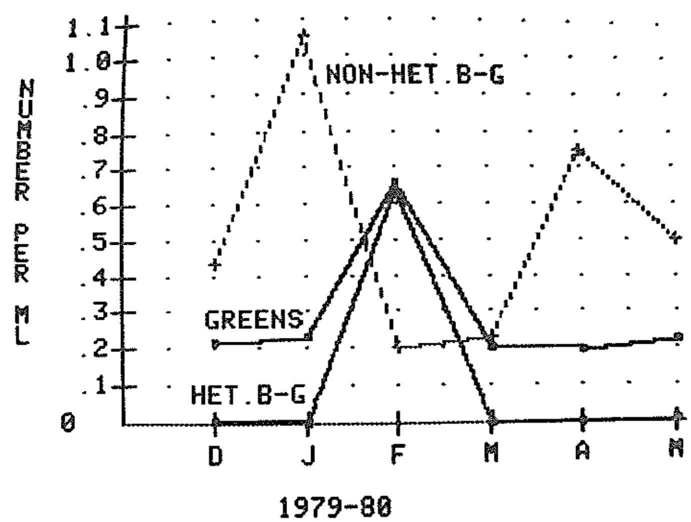


FIGURE 149. Monthly mean density of green and blue-green algae at Station N, 1979-80.

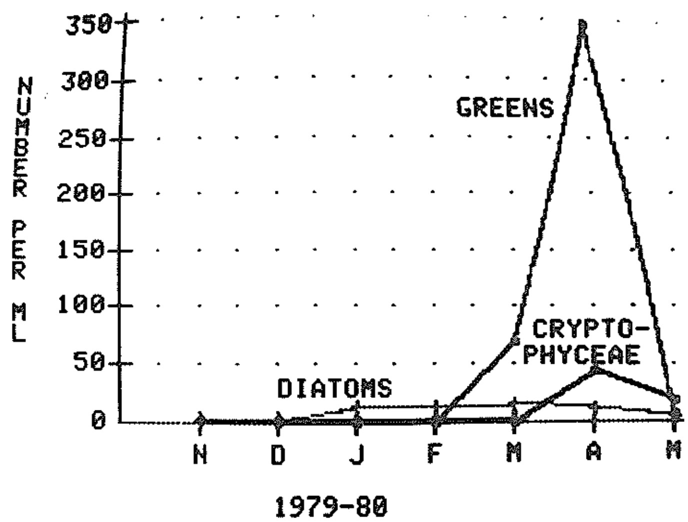


Figure 150. Monthly mean density of various plankton groups at Station F, 1979-80.

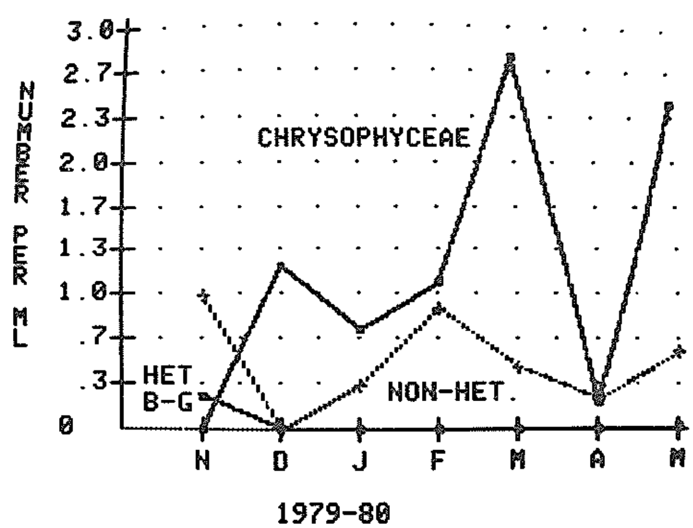


FIGURE 151. Monthly mean density of blue-green algae and Chrysophyceae at Station F, 1979-80.

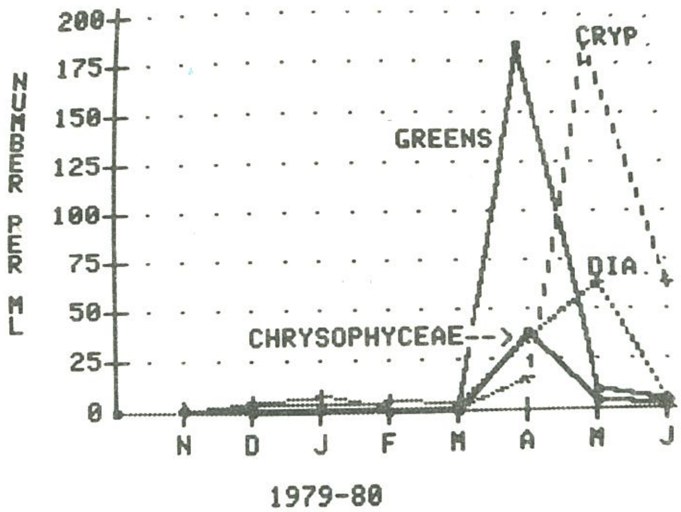


FIGURE 152. Monthly mean density of various plankton groups at Station 8, 1979-80.

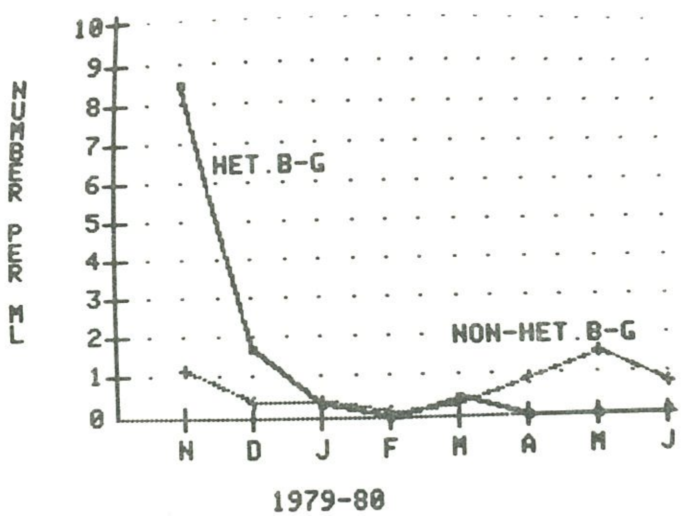


FIGURE 153. Monthly mean density of blue-green algae at Station 8, 1979-80.

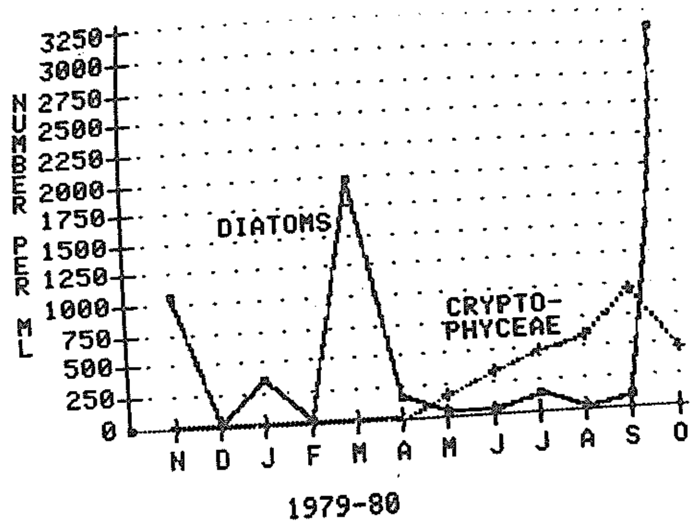


FIGURE 154. Monthly mean density of various plankton groups at Station 1, 1979-80.

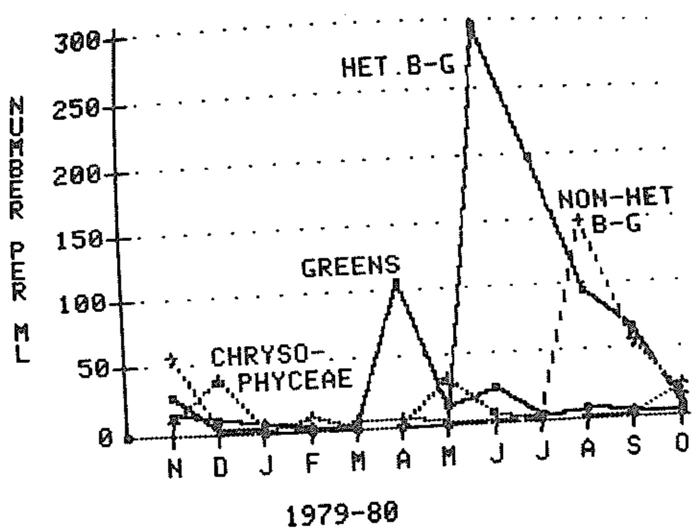


FIGURE 155. Monthly mean density of diatoms and Cryptophyceae at Station 1, 1979-80.

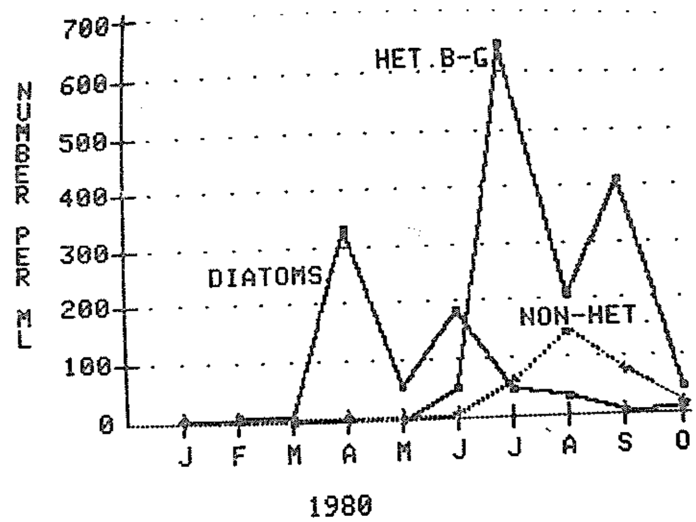


FIGURE 156. Monthly mean density of blue-green algae and diatoms at Station 4-1, 1979-80.

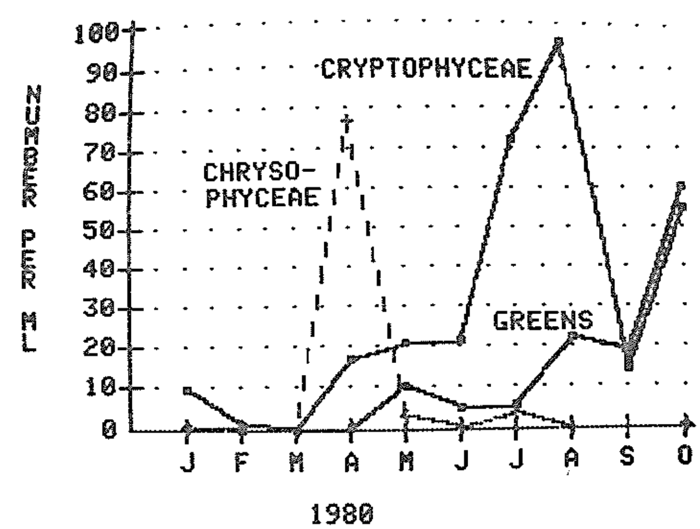


FIGURE 157. Monthly mean density of various plankton groups at Station 4-1, 1979-80.

TABLES

TABLE 1. Chloride concentration in wastewater influent and ground waters

	WELLS									
	PC3T*	PC3B	PC10	PC11T	PC11B	PC13	PC19	PC32T	PC32B	Waste-water Infl.
1977										
7/27	300	265	305	81	130	-	23	200	210	265
8/11	280	295	310	65	115	-	29	235	270	310
9/23	350	350	390	120	325	-	35	310	325	375
11/3	232	241	236	153	186	-	52	227	232	227
12/15	245	259	-	198	189	-	90	231	231	259
1978										
1/19	255	236	274	159	178	-	107	212	222	-
2/23	170	184	220	89	105	45	45	-	-	-
3/23	73	179	173	66	73	31	45	-	-	-
4/20	116	192	142	26	45	30	40	-	-	-
5/18	167	182	77	25	20	30	30	-	-	-

* T = near top of phreatic zone
B = near bottom of phreatic zone
No letter indicates near top of phreatic zone

Table 2. Temperature and Chemical Measurements of Wastewater Influent

	°C	pH	Total Alk.	Ca	Mg	µmhos	O_2	Total P	Total N
1978									
6/8	18.5	8.50	335	181	113	1080	5.4	3.42	3.409
6/22	–	7.70	358	286	36	1220	3.9	3.96	4.000
7/7	25.5	9.25	267	127	98	1165	4.1	3.00	0.393
7/21	21.0	8.50	326	153	128	1400	1.8	3.79	1.498
8/3	16.5	8.00	400	214	118	1240	0.7	5.56	12.300
8/18	20.5	8.50	347	153	133	1360	1.0	4.00	0.982
9/1	19.0	8.50	327	204	163	1160	2.1	3.30	1.960
9/15	15.0	7.81	388	296	41	1240	7.6	7.26	12.521
9/29	13.0	8.35	360	211	113	1160	3.0	3.21	1.870
10/13	18.0	7.80	352	268	93	1160	4.3	2.92	1.410
10/27	5.0	8.00	330	262	87	1130	6.5	6.02	2.540
11/10	6.5	8.00	330	205	149	1230	8.7	6.50	4.570
11/24	2.5	7.65	374	–	–	1400	6.9	5.81	2.490
12/7	2.0	8.05	376	286	133	1340	6.1	8.19	19.020
12/19	1.0	7.75	412	319	124	1440	3.9	8.37	15.420
1979									
1/12	1.0	7.65	350	330	31	1130	5.7	5.43	19.530
1/25	–	7.90	347	292	76	1100	9.1	6.13	15.539
2/9	1.2	7.90	560	204	122	975	3.6	6.10	15.804
2/22	1.6	7.65	575	245	92	1080	2.5	5.92	15.795
3/9	1.5	8.70	424	153	92	930	5.1	3.55	15.412
3/23	2.0	7.70	519	184	107	975	2.7	5.36	14.937
4/6	2.0	8.10	542	189	122	940	2.2	5.69	12.914
4/20	4.0	7.65	377	148	82	805	7.4	4.05	9.525
5/11	7.0	8.10	382	173	112	855	10.0	4.66	7.460
5/25	5.0	8.15	377	204	122	910	11.1	2.79	3.826

TABLE 3. Mean monthly total nitrogen concentrations, ground waters, mgl

	WELLS								
	PC3T	PC3B	PC10	PC11T	PC11B	PC13	PC19	PC32T	PC32B
1977									
June	2.01	4.94	2.27	–	–	–	5.66	7.15	5.69
July	1.87	4.19	3.40	1.18	3.17	–	6.32	5.60	6.35
Aug.	2.00	3.46	3.65	2.91	2.44	–	6.55	5.05	5.10
Sept.	1.62	3.04	.65	2.49	1.29	–	6.30	4.11	3.99
Oct.	2.29	2.58	.82	1.76	1.94	–	4.83	3.25	3.34
Nov.	2.50	2.57	.94	1.72	1.37	–	4.58	3.63	3.46
Dec.	2.72	2.93	–	1.50	1.23	–	3.58	4.10	3.43
1978									
Jan.	3.61	3.68	5.13	1.52	2.44	–	3.41	3.58	3.57
Feb.	3.66	3.73	5.64	2.16	1.85	6.70	3.13	–	–
Mar.	5.52	3.45	6.27	2.39	2.20	8.00	3.19	–	–
Apr.	4.83	3.69	6.56	.59	1.75	7.44	3.48	–	–
May	4.62	4.85	6.24	1.31	2.53	7.63	3.71	–	–

TABLE 4. Mean monthly soluble reactive phosphorus concentrations, surface waters, mgl

	STATIONS										
	E	F	M	N	R	1	4-1	4-2	4-3	4-4	8
1977											
June	-	.48*	.16*	.59*	-	.52	.033	.012	.033	.009*	.017
July	.27*	.91	.18	.25	.91*	.52	.007	.007	.006	.06	.019
Aug.	.21	.08	.16	.18	.40	.35*	.06	.06	.07	.06	.07
Sept.	.19	.11	.20	.18	.72*	.24	.12	.12	.10	.10	.11
Oct.	.15	.08	.20	.10	.36	.08	.07	.13	.16	.13	.10
Nov.	.08*	.05*	.08*	.06*	-	.06*	.04*	.08*	.04*	.04*	.03
Dec.	.08*	.33*	.11*	.06*	-	.10	.03	.04	.05	-	.03
1978											
Jan.	.10*	.50*	.24*	.07*	-	.14	.02	.02	.05	-	.003
Feb.	.09	.68	.14	.13	-	.21	.02	.05	.12	.12	.03
Mar.	.09	.45	.12	.14	-	.14	-	-	-	-	.05
Apr.	.07	.11	.08	.06	-	.07	-	-	-	-	.06
May	.20	.20	.17	.14	-	.08	.13	.11	.17	.11	.17

* 1 record only

TP

TABLE 5. Mean monthly total phosphorus concentrations, surface waters, mgl

	STATIONS									
	Long outlet	SC3	PR3	PR6	PR7	SALLIE				PR8
	E	F	M	N	1	4-1	4-2	4-3	4-4	8
1977										
June	-	1.50*	0.66*	1.06*#	1.82	0.52*	0.75*	0.69*	-	0.49*
July	1.07*	1.26	0.67	0.73#	1.10	0.51	0.47	0.33	0.51	0.51
Aug.	0.91	0.42	0.67	0.51	-**	0.41	0.79	0.92	0.65	0.74
Sept.	0.99	1.13	1.44	1.07	0.78	0.75	0.73	0.92	0.95	1.52*
Oct.	0.23	0.27	0.22	0.24	0.30	0.32	0.34	0.32	0.35	0.41
Nov.	0.25*	0.27*	0.27*	0.19*	0.28	0.18*	0.23*	0.22*	0.20*	0.20
Dec.	0.24*	0.53*	0.22*	0.18*	0.25	0.15	0.15	0.20	-	0.18
1978										
Jan.	0.27*	0.91*	0.43*	0.15*	0.26	0.23	0.24	0.33	-	0.25
Feb.	0.29	1.04	0.40	0.33	0.41	0.26	0.26	0.29	0.28	0.24
Mar.	0.36	1.00	0.42	0.37	0.58	-	-	-	-	0.42
Apr.	0.31	0.51	0.33	0.30	0.41	-	-	-	-	0.41
May	0.48	0.98	0.54	0.41	0.52	0.44	0.38	0.45	0.46	0.48

* 1 record only
\# reverse flow
** no flow

TABLE 6. Blue-green phytoplankton volume, 1,000 μ^3/ml

	Muskrat Lake		Lake Sallie	
	1975	1977	1975	1977
6/24	1,525	594	3,297	8,115
7/1	1,400	897	1,105	4,701
7/8	2,141	33	2,780	17,963
7/16	1,853	720	21,736	12,623
7/22	5,665	814	14,073	36,056
7/28	6,902	1,123	14,460	23,700
8/5	6,797	1,850	756	13,843
8/12			13,626	15,649
8/19			6,944	25,614
9/5			25,948	-
9/16	5,204	704	7,113	6,699
9/24			-	4,902
9/30	15	519	16,399	4,178
10/8	23	595		
10/14	4	7	20,524	5,523
10/21	35	12	19,017	1,918
10/28			25,869	567
11/4	1	4	17,167	217

TABLE 7. Nitrogen reduction, 1977-1980.

		Infiltration Basins					Spray Irrigation					Precipitation Plant	
	W.W. Infl.	PC3 mgl	PC3 % Reduc.	MH18 mgl	MH18 % Reduc.	Mean Reduc.	PC10 mgl	PC10 % Reduc.	PC11 mgl	PC11 % Reduc.	Mean Reduc.	Plant Eff.	% Reduc.
1977													
July	0.86	1.87	117.44*	3.10	260.47*	188.96*	3.40	295.35*	1.18	37.21*	166.28*	–	–
Aug.	0.56	2.00	257.14*	1.06	89.29*	173.22*	3.65	551.79*	2.91	419.64*	485.72*	–	–
Sept.	5.86	1.62	72.35	2.78	52.56	62.46	0.65	88.91	2.49	57.51	73.21	–	–
Oct.	5.31	2.29	56.87	2.26	57.44	57.16	0.82	84.56	1.76	66.86	75.71	–	–
Nov.	4.72	2.50	47.03	4.15	12.08	29.56	0.94	80.08	1.72	63.56	71.82	–	–
Dec.	16.02	2.72	83.02	–	–	83.02	–	–	–	–	–	15.89	0.81
1978													
Jan.	16.95	–	–	–	–	–	–	–	–	–	–	16.60	2.06
Feb.	21.45	–	–	–	–	–	–	–	–	–	–	21.79	1.59*
March	16.73	–	–	–	–	–	–	–	–	–	–	17.33	3.59*
April	9.86	4.83	51.01	4.81	51.22	51.12	–	–	–	–	–	10.26	4.06*
Mean for Period			9.19*		29.41*	11.27*		118.72*		53.78*	86.25*		1.27*

*Increase

TABLE 7. Continued

		Infiltration Basins						Spray Irrigation					Precipitation Plant	
	W.W. Infl.	PC3 mgl	PC3 % Reduc.	MH18 mgl	MH18 % Reduc.	Mean Reduc.	PC10 mgl	PC10 % Reduc.	PC11 mgl	PC11 % Reduc.	Mean Reduc.	Plant Eff.	% Reduc.
1978													
June	3.705	3.477	6.15	3.890	4.99*	0.58	4.021	8.53*	1.861	49.77	20.62	-	-
July	0.946	1.902	101.06*	1.447	52.96*	77.01*	0.851	10.04	1.592	68.29*	29.13*	-	-
Aug.	6.641	1.025	84.57	2.282	65.64	75.11	0.367	94.47	0.903	86.40	90.44	-	-
Sept.	5.450	0.123	97.74	0.942	82.72	90.23	0.121	97.78	0.073	98.66	98.22	-	-
Oct.	1.975	0.672	65.97	0.752	61.92	63.95	-	-	-	-	-	-	-
Nov.	3.530	0.145	95.89	0.885	74.93	85.41	-	-	-	-	-	-	-
Dec.	17.220	-	-	-	-	-	-	-	-	-	-	15.860	7.90
1979													
Jan.	17.535	-	-	-	-	-	-	-	-	-	-		
Feb.	15.800	-	-	-	-	-	-	-	-	-	-	16.557	5.58
Mar.	15.175	-	-	-	-	-	-	-	-	-	-	16.911	7.03*
Apr.	11.220	-	-	-	-	-	-	-	-	-	-	15.081	0.62
May	5.643	4.121	26.97	0.223	96.05	61.51	1.760	68.81	1.310	76.79	72.80	11.027	1.72
												-	-
Annual Mean			39.46		46.19	42.83		52.51		48.67	50.59		1.76

*Increase

TABLE 7. Continued

	W.W. Infl.	Infiltration Basins: PC3 mgl	PC3 % Reduc.	MH18 mgl	MH18 % Reduc.	Mean Reduc.	Spray Irrigation: PC10 mgl	PC10 % Reduc.	PC11 mgl	PC11 % Reduc.	Mean Reduc.	Precipitation Plant: Plant Eff.	% Reduc.
1979													
Nov.	18.53	3.02	83.70	-	-	83.70	-	-	-	-	-	-	-
Dec.	17.30	2.84	83.58	-	-	83.58	-	-	-	-	-	16.95	2.02
1980													
Jan.	15.66	-	-	-	-	-	-	-	-	-	-	15.20	2.94
Feb.	20.15	-	-	-	-	-	-	-	-	-	-	20.18	0.15*
March	19.50	-	-	-	-	-	-	-	-	-	-	20.44	4.82*
April	12.99	4.55	64.97	5.52	57.51	61.24	1.30	89.99	2.53	80.52	85.26	-	-
May	7.76	5.02	35.31	-	-	35.31	1.27	83.63	1.54	80.15	81.89	-	-
June	6.59	5.13	22.15	-	-	22.15	1.33	79.82	1.25	81.03	80.43	-	-
July	3.29	4.51	37.08	-	-	37.08	1.60	51.37	1.23	62.61	56.99	-	-
Aug.	11.93	4.24	64.46	-	-	64.46	1.98	83.40	1.22	89.77	86.59	-	-
Sept.	9.69	3.90	59.75	-	-	59.75	1.64	83.08	1.31	86.48	84.78	-	-
Oct.	9.56	4.29	55.13	8.48	11.30	33.22	4.18	56.28	2.38	75.10	65.69	-	-
Mean for Period			56.24		34.41	53.39		75.37		79.38	77.38		0.25*

*Increase

TABLE 8. Phosphorus reduction, 1977-1980.

		Infiltration Basins					Spray Irrigation					Precipitation Plant	
	W.W. Infl.	PC3 mgl	PC3 % Reduc.	MH18 mgl	MH18 % Reduc.	Mean Reduc.	PC10 mgl	PC10 % Reduc.	PC11 mgl	PC11 % Reduc.	Mean Reduc.	Plant Eff.	% Reduc.
1977													
July	1.89	0.65	65.61	0.90	52.38	59.00	0.92	51.32	0.82	56.61	53.97	-	-
Aug.	1.75	0.86	50.86	0.56	68.00	59.43	0.28	84.00	0.53	69.71	76.86	-	-
Sept.	5.35	0.65	87.85	0.89	83.36	85.61	0.42	92.15	0.31	94.21	93.18	-	-
Oct.	4.64	0.87	81.25	0.45	90.30	85.78	0.34	92.67	0.34	92.67	92.67	-	-
Nov.	5.01	0.79	84.23	1.16	76.85	80.54	0.55	89.09	0.62	87.62	88.36	-	-
Dec.	4.16	0.47	88.70	-	-	88.70	-	-	-	-	-	1.33	68.03
1978													
Jan.	6.54	-	-	-	-	-	-	-	-	-	-	1.20	81.65
Feb.	6.65	-	-	-	-	-	-	-	-	-	-	0.83	87.52
March	5.44	-	-	-	-	-	-	-	-	-	-	1.11	79.60
April	3.62	0.66	81.77	1.22	66.30	74.04	-	-	-	-	-	1.14	68.51
Mean for Period			77.18		72.87	76.16		81.85		80.16	81.01		77.06

TABLE 8. Continued

	W.W. Infl.	Infiltration Basins: PC3 mgl	PC3 % Reduc.	MH18 mgl	MH18 % Reduc.	Mean Reduc.	Spray Irrigation: PC10 mgl	PC10 % Reduc.	PC11 mgl	PC11 % Reduc.	Mean Reduc.	Precipitation Plant: Plant Eff.	% Reduc.
1978													
June	3.84	1.61	58.07	1.20	68.75	63.41	0.48	87.50	2.77	27.86	57.68	-	-
July	3.40	0.95	72.06	0.92	72.94	72.50	0.55	83.82	0.37	89.12	86.47	-	-
Aug.	4.78	1.54	67.78	0.72	84.94	76.36	0.64	86.61	0.99	79.29	82.95	-	-
Sept.	4.59	2.47	46.19	0.89	80.61	63.40	2.00	56.43	0.70	84.75	70.59	-	-
Oct.	4.47	0.77	82.77	0.46	89.71	86.24	-	-	-	-	-	-	-
Nov.	6.16	1.30	78.90	1.60	74.03	76.47	-	-	-	-	-	-	-
Dec.	8.28	-	-	-	-	-	-	-	-	-	-	1.60	80.68
1979													
Jan.	5.78	-	-	-	-	-	-	-	-	-	-		
Feb.	6.01	-	-	-	-	-	-	-	-	-	-	1.55	73.18
Mar.	4.46	-	-	-	-	-	-	-	-	-	-	1.03	82.86
Apr.	4.87	-	-	-	-	-	-	-	-	-	-	1.14	74.44
May	3.72	0.73	80.38	0.62	83.33	81.86	0.45	87.90	0.73	80.38	84.14	1.74	64.27
												-	-
Annual Mean			69.45		79.19	74.32		80.45		72.28	76.37		75.09

TABLE 8. Continued

		Infiltration Basins					Spray Irrigation					Precipitation Plant	
	W.W. Infl.	PC3 mgl	PC3 % Reduc.	MH18 mgl	MH18 % Reduc.	Mean Reduc.	PC10 mgl	PC10 % Reduc.	PC11 mgl	PC11 % Reduc.	Mean Reduc.	Plant Eff.	% Reduc.
1979													
Nov.	4.53	0.61	86.53	–	–	86.53	–	–	–	–	–	–	–
Dec.	5.79	0.40	93.09	–	–	93.09	–	–	–	–	–	3.23	44.21
1980													
Jan.	6.43	–	–	–	–	–	–	–	–	–	–	1.97	69.36
Feb.	7.60	–	–	–	–	–	–	–	–	–	–	2.27	70.13
March	6.03	–	–	–	–	–	–	–	–	–	–	1.86	69.15
April	4.71	1.41	70.06	1.40	70.28	70.17	0.16	96.60	0.19	95.97	96.29	–	–
May	3.39	0.75	77.88	–	–	77.88	0.20	94.10	0.19	94.40	94.25	–	–
June	3.41	0.57	83.28	–	–	83.28	0.20	94.13	0.24	92.96	93.55	–	–
July	5.63	0.65	88.45	–	–	88.45	0.21	96.27	0.25	95.56	95.92	–	–
Aug.	5.08	0.62	87.80	–	–	87.80	0.17	96.65	0.24	95.28	95.97	–	–
Sept.	6.22	0.54	91.32	–	–	91.32	0.12	98.07	0.17	97.27	97.67	–	–
Oct.	3.45	0.44	87.25	1.06	69.28	78.27	0.14	95.95	0.19	94.49	95.22	–	–
Mean for Period			85.07		69.78	84.09		95.97		95.13	95.55		63.21