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SOUTH FLORIDA WATER MANAGEMENT DISTRICT

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UPPER EAST COAST
WATER QUALITY STUDIES

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UPPER EAST COAST WATER QUALITY STUDIES

by

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INTRODUCTION

The Upper East Coast (UEC) planning area lies in Martin, St. Lucie and eastern Okeechobee counties. Drainage for Martin and St. Lucie Counties is provided primarily by three major canal systems: C-23, C-24, and C-25. These three canals total approximately 125 km in length and primarily drain improved pasture and citrus. Due to the lack of available data and the importance of this surface water resource to the region, the South Florida Water Management District (SFWMD) began, in 1974, studies of the water quality characteristics of these canals. Five studies were found to contain some water quality data on these canals (Price 1962, Bearden 1972, Frieberger 1972, Pitt 1972, and Miller 1975). Except for Frieberger (1972) and Miller (1975), these studies contained only a limited amount of water quality information. The purpose of this study was to establish a water quality data base for this system. This data base forms the basis for a characterization of the quality of water and an evaluation of the St. Lucie County Water Supply Plan for connecting C-23, C-24, and C-25 to Lake Okeechobee. This Plan would allow the lake to serve as both a receiving body for surplus water from the UEC area and as a source of irrigation water.

FORMAT OF REPORT

The results of this study will be presented in five parts. A summary of this report, along with major conclusions, will be presented in Part 1. Part 2 will describe the study area with emphasis on rainfall distributions during the study and the basic land cover in the area. Collection methodologies and analytical procedures will be addressed in Part 3. The water quality characteristics at structures S-97, S-49, and S-99, located on the primary canals, will be presented in Part 4. Included will be a discussion of relationships between the surface water and both the groundwater and the discharge pattern. Based upon the water quality at each control structure and daily discharge measurements, annual material loads exported from the three basins will be calculated and presented in Part 5. Part 5 will also discuss the effects of reduced sampling frequencies and a different collection methodology on the calculations of the annual material loads.

PART 1

SUMMARY AND CONCLUSIONS

Daily composite and weekly water chemistry grab samples were collected on
C-23 at S-97, C-24 at S-49, and C-25 at S-99 from November 1976 through
October 1977. The objectives of this sampling were to: (1) characterize the
quality of water at each structure, (2) identify seasonal and discharge
related water quality trends, (3) calculate material loads, basin-wide areal
export rates, and flow weighted concentrations, and (4) compare the effect of
varying sampling frequencies and collection methodologies on the calculation
of material loads.

General results of this study were:

(1) In all three canals the major cations and anions tended to increase
     through the dry season and decrease during the wet season. Daytime
     dissolved oxygen also tended to be higher during the dry season than
     during the wet season. Phosphorus displayed the opposite trend with
     higher concentrations occurring during the wet season. Nitrogen did
     not display any readily apparent trend.

(2) Nitrogen, phosphorus, and silica had higher concentrations during
     periods of wet season discharge resultant from rainfall. Chloride,
     sodium, potassium, calcium, magnesium, sulfate, hardness, and
     alkalinity had lower concentrations during wet season discharge as a
     result of rainfall dilution. During the dry season, major ion
     levels increased in the canals due to the influence of artesian
     groundwater irrigation and a lack of dilution by rainfall.

(3) The water quality between each structure during discharge was

variable. The following rankings were based upon flow-weighted concentrations (except conductivity):

Total Phosphorus (mg/L): S-49 (.260) > S-97 (.158) > S-99 (.113)

Total Nitrogen (mg/L): S-97 (1.58) > S-49 (1.54) > S-99 (1.38)

Major cations and anions (mg/L): S-49 > S-99 > S-97

Conductivity (micromhos/cm): S-49 (1605) > S-99 (1592) > S-97 (1039)

The phosphorus and nitrogen levels at the three structures were moderately low. The levels of major cations and anions were high.

(4) Turbidity levels were low at all the structures. Dissolved oxygen was highly variable with a typical range of less than 0.2 to over 8.0 mg/L. Mean concentrations ranged from 4.4 mg/L (S-99) to 5.5 mg/L (S-97).

(5) Based on this one year study the following material loads were calculated:

Flow (acre-ft): S-97 (48,116) > S-99 (38,766) > S-49 (27,097)

Total P (10^6g): S-97 (9.4) > S-49 (8.7) > S-99 (5.4)

Total N (10^6g): S-97 (93.9) > S-99 (66.2) > S-49 (51.4)

Chloride (10^6g): S-99 (12,946) > S-49 (11,281) > S-97 (9,575)

(6) The error in total phosphorus, total nitrogen, and chloride loading calculations, based upon subsurface samples, is approximately linear with respect to sampling frequency up to a period of at least two months. For each week's decrease in the sampling frequency, the error in calculated loads increased approximately 5 percent for total phosphorus, 4 percent for total nitrogen, and 1.5 percent for chloride. A biweekly sampling frequency appears to have errors of

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similar size to those of the analytical chemistry measurements and daily hydrology data.

(7) Sampling methodology can affect loading calculations more than sampling frequency. Chloride loads based upon weekly surface grab samples were the same as those based upon daily subsurface samples; however, total nitrogen loads based upon weekly surface samples ranged from 14 to 29 percent higher than those based upon daily subsurface samples. The discrepancy for phosphorus loads was even greater, with the loads based upon weekly samples ranging from 28 to 126 percent higher. The grab sampling technique which collects a surface film can result in substantially different phosphorus and nitrogen concentrations as compared to subsurface levels and may, therefore, greatly influence material loading calculations.

PART 2

DESCRIPTION OF THE STUDY AREA

A detailed description of the UEC planning area can be found in the "Summary Status Report, Upper East Coast Water Use and Supply Development Plan, October 1980". Most of which follows was extracted from this report.

The S-49, S-97, and S-99 structures and drainage basins are located in Martin and St. Lucie counties (Figure 1). These three structures drain 31 percent of the 4527 sq. km. contained within the two counties.

Agricultural activities account for 63 to 75 percent of the land cover in the S-49, S-97, and S-99 basins (Table 1). In general the land cover in the three basins is similar. Improved pasture dominates from 61 to 77 percent of the agricultural activities followed by citrus which accounts for 20 to 36 percent. Urban and built-up lands account for only 5 percent of the total S-49 basin and less than one percent of the total S-97 and S-99 basins.

Groundwater in this area is found in a shallow series of aquifers (the Shallow aquifer) and a deep series of aquifers (the Floridan aquifer). The Shallow aquifer is one of the major sources of potable water in Martin and St. Lucie counties and is located from 40 to more than 200 feet below National Geodetic Vertical Datum. The quality of water in the Shallow aquifer is generally good with less than 1000 ppm total dissolved solids. With the exception of the coastal area and local areas inland, the Shallow aquifer is predominantly a calcium-magnesium bicarbonate type.

The deeper Floridan aquifer has higher total dissolved solids than the Shallow aquifer and provides the only available water supply for agricultural activities during most of the dry season. Chloride is the dominant anion and sodium, calcium, and magnesium are the major cations. The high chloride levels are due to the presence of highly mineralized water trapped in

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TABLE 1. 1979 LAND COVER IN THE S-97, S-49, S-99 BASINS

	S-97		S-49		S-99	
Land Cover	km^2	%	km^2	%	km^2	%
Agriculture	302.1	64%	295.9	63%	337.9	75%
Dairy Farms	0.2	(<1%)			0.6	(<1%)
Fish Farms	0.03	(<1%)				
Truck Crops			0.4	(<1%)		
Citrus	107.5	(23%)	58.5	(12%)	102.4	(23%)
Improved Pasture	185.4	(39%)	228.8	(49%)	234.9	(52%)
Unimproved Pasture	9.0	(2%)	8.2	(2%)		
Barren Lands	1.0	1%	0.1	1%	0.4	1%
Forested Uplands	27.8	6%	42.3	9%	43.9	10%
Water	1.1	1%	3.4	1%	0.9	1%
Rangeland	1.5	1%	3.1	1%	6.5	1%
Urban & Build-up Lands	1.5	1%	25.8	5%	3.0	1%
Wetlands	135.0	29%	99.0	21%	55.3	12%
	470.0		469.5		447.8	
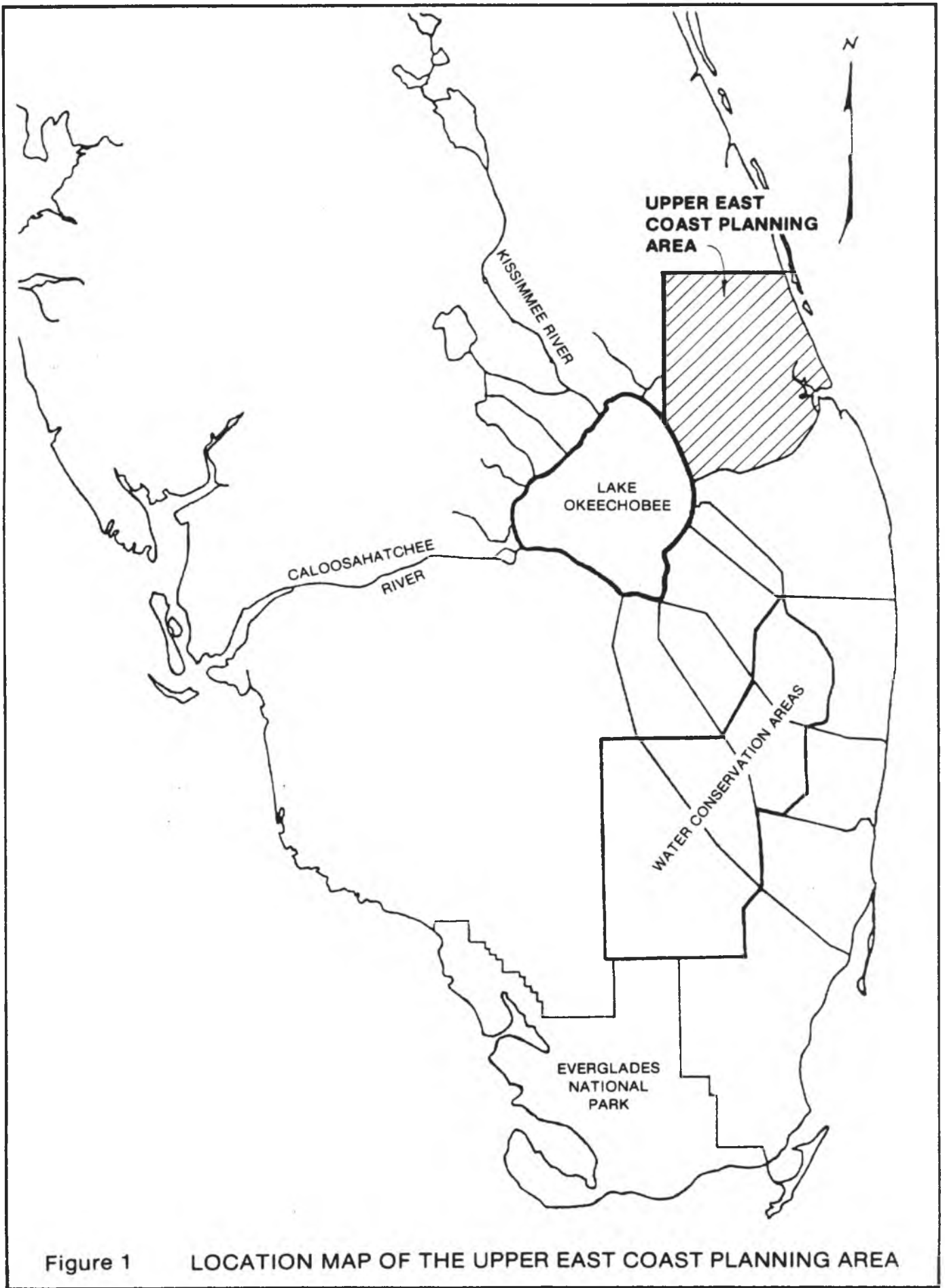
Figure 1   LOCATION MAP OF THE UPPER EAST COAST PLANNING AREA

The map includes the following labels:

- N (compass indicator, top right)
- UPPER EAST COAST PLANNING AREA
- KISSIMMEE RIVER
- LAKE OKEECHOBEE
- CALOOSAHATCHEE RIVER
- WATER CONSERVATION AREAS
- EVERGLADES NATIONAL PARK

sediments during an earlier geologic time and is not due to direct salt water intrusion from the Atlantic Ocean.

Rainfall

The climate in Martin and St. Lucie counties is controlled primarily by its flat terrain, southerly latitude and proximity to coastal waters. The strong offshore Gulfstream current is the most significant factor affecting the climate of the area. In general, local convection systems generate approximately 60 percent of the annual precipitation during the summer months. Average annual rainfall is approximately 50 inches (Table 2). During this one year study, rainfall was approximately 75 inches or 150 percent of normal. The seasonal rainfall pattern is displayed in Figure 2a-c.

TABLE 2. COMPARISON OF STUDY PERIOD RAINFALL TO PERIOD OF RECORD

Rainfall (inches)

	Period of Record 1960-1976	Study Period 1976-1977	% of Period of Record
November	2.44 1/	3.30 3/	135
December	1.85	3.15	170
January	2.23	2.50	112
February	3.18	2.15	68
March	2.58	0.50	19
April	1.84	2.20	120
May	5.09	5.90	116
June	7.14	6.10	85
July	7.38	15.75	213
August	6.27	12.95	207
September	6.57	14.50	221
October	5.82	6.30	108
	49.74 2/	75.30 4/	151

Rainfall quantities are for Station MRF 39 which is centrally located
in the UEC planning area

1/ Average monthly for period of record

2/ Average annual for period of record

3/ Total monthly for study period

4/ Total for study period

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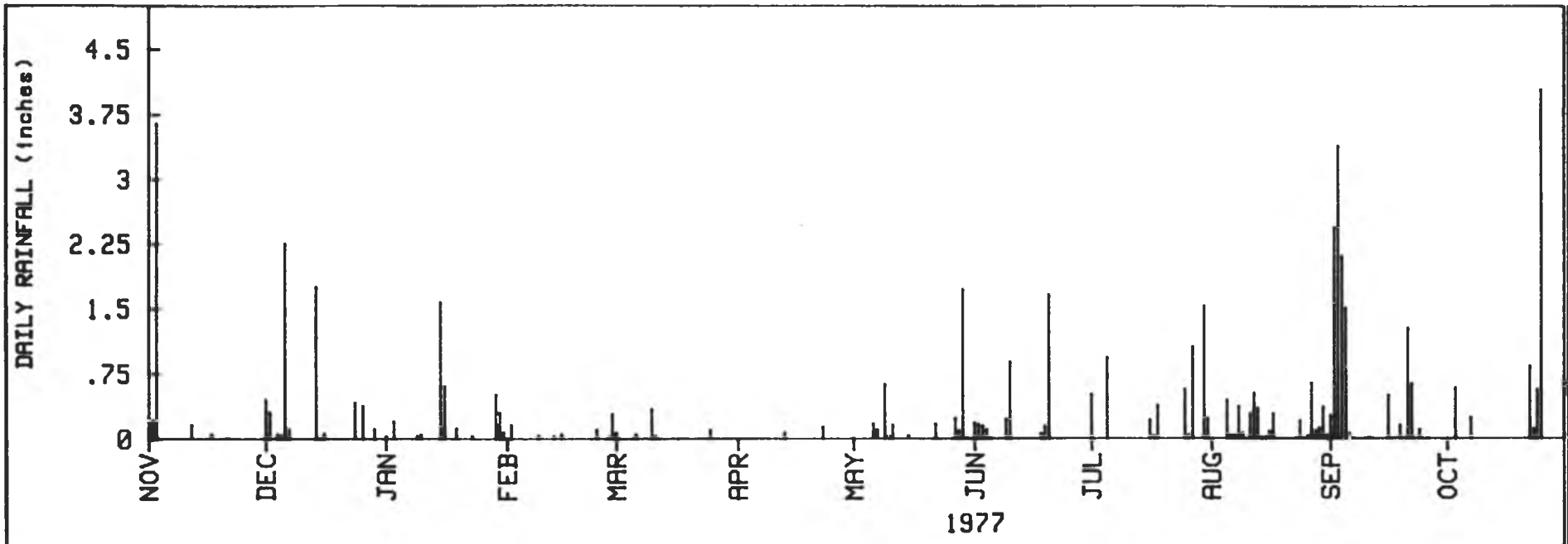
Figure 2a   DAILY RAINFALL NEAR C-23 (MRF60)
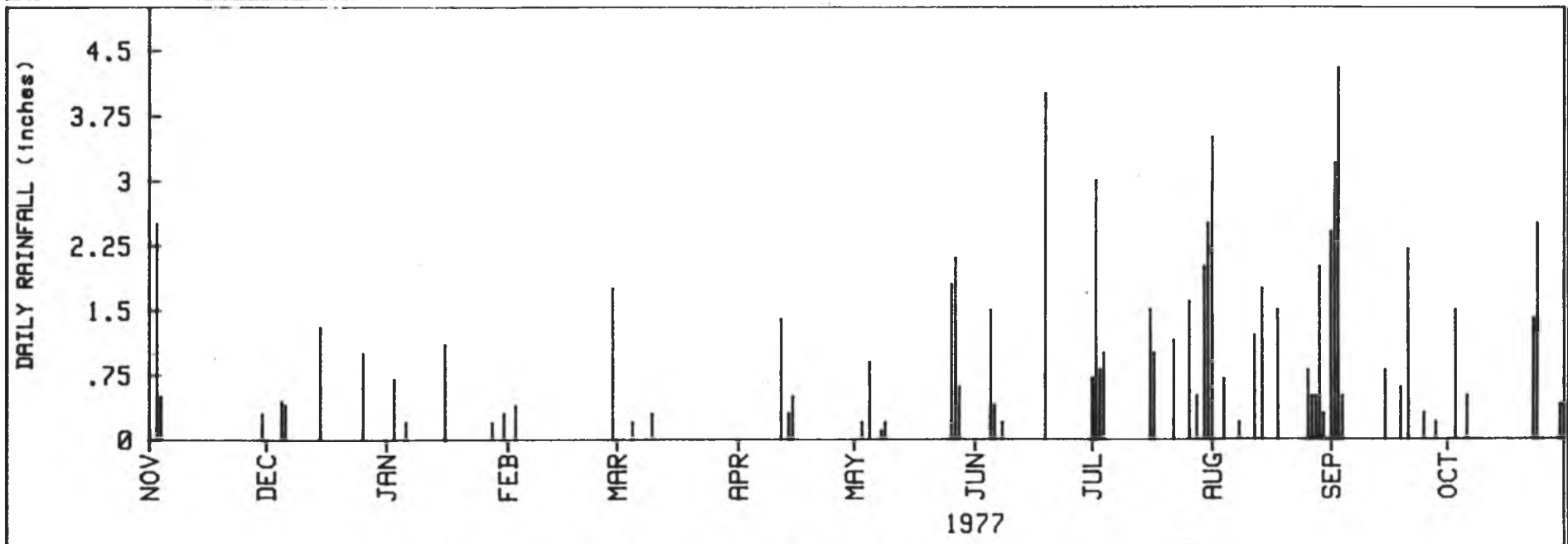
Figure 2b   DAILY RAINFALL NEAR C-24 (MRF39)
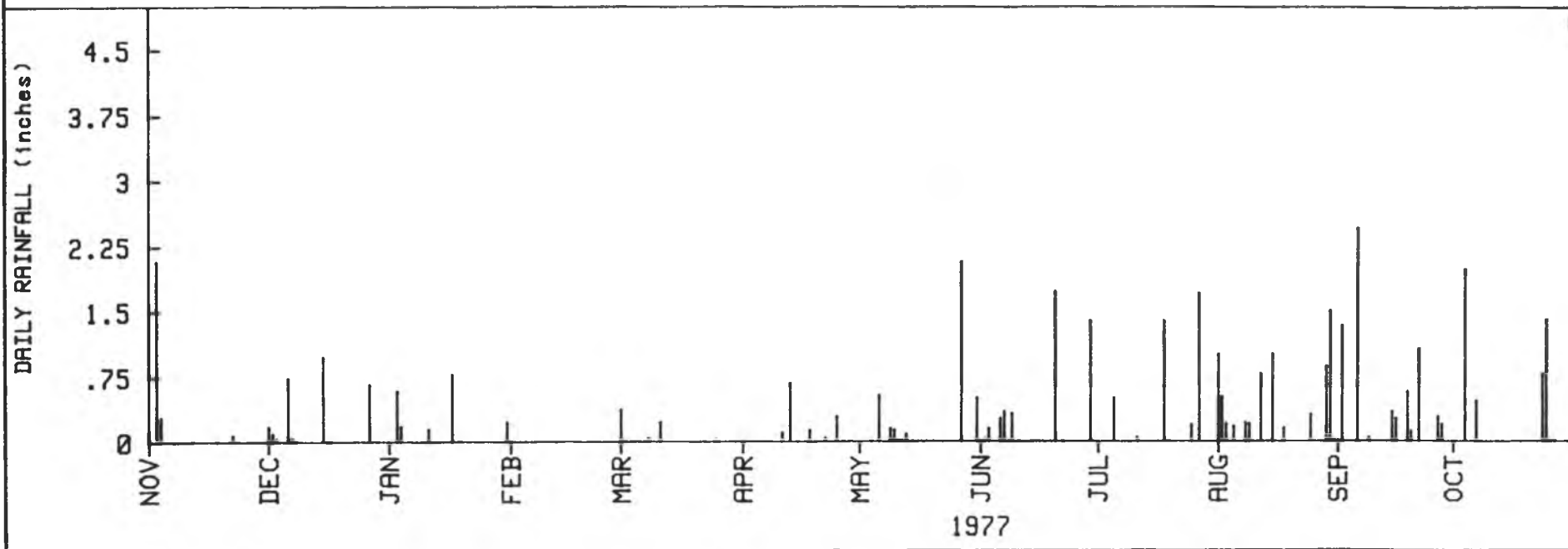
Figure 2c   DAILY RAINFALL NEAR C-25 (MRF37)

INDIAN RIVER COUNTY
ST. LUCIE COUNTY

ATLANTIC

OCEAN

C - 25
BASIN

S-99   C-25 CANAL

C - 24
BASIN

C-24 CANAL

S-49

S-97

ST. LUCIE COUNTY   C-23 CANAL
MARTIN COUNTY

C - 23
BASIN

O

LAKE

OKEECHOBEE COUNTY
MARTIN COUNTY

OKEECHOBEE

ST. LUCIE CANAL

MARTIN COUNTY
PALM BEACH COUNTY

C-18 CANAL

MILES

0   5

L-8 CANAL
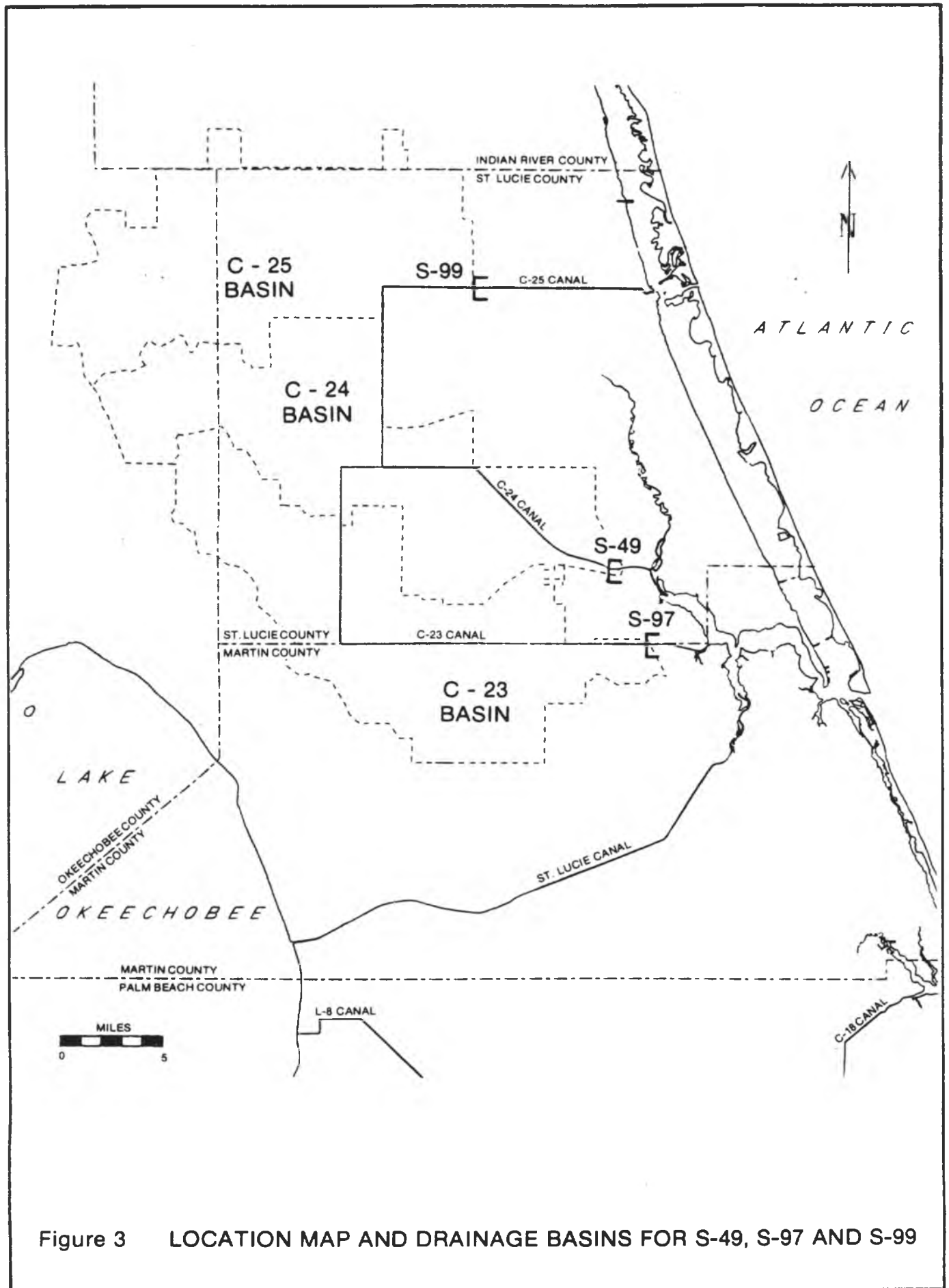
Figure 3   LOCATION MAP AND DRAINAGE BASINS FOR S-49, S-97 AND S-99

PART 3

PROGRAM DESIGN AND OBJECTIVES

PURPOSE AND SCOPE

This study was established as an intensive one year investigation of the water quality characteristics at S-49, S-97, and S-99. The sampling program was designed to collect daily water samples and weekly grab samples from each water control structure during the period November 1, 1976 to October 31, 1977. The purpose of this data collection was to:

(1) Characterize the quality of water at S-49, S-97, and S-99

(2) Identify seasonal water quality trends at each structure

(3) Identify relationships between water quality and discharge

(4) Calculate material loads, basin-wide areal export rates, and flow-weighted concentrations at each structure

(5) Examine the effect of sampling frequencies and collection methodologies on the calculation of material loads

(6) Establish a water quality data base for the evaluation of the "St. Lucie County Plan" (connecting C-23, C-24, and C-25 to Lake Okeechobee).

SAMPLING AND ANALYTICAL METHODS

Site Location

Displayed in Figure 3 are the locations of S-49, S-97, and S-99. All samples were collected 5 m upstream of the water control structures.

Sample Collection and Frequency

Two methods of sample collection were employed during this study. The first method involved the collection of daily subsurface water samples via an automatic sampler and the second method involved weekly surface grab samples.

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Daily Samples

Sample collection on a daily basis was accomplished through the use of three ISCO$^{(R)}$ Model 1391 automatic samplers. The samplers were adjusted to collect, on the average, a 125 ml aliquot every 1½ hours. This collection frequency filled a 500 ml polyethylene bottle every six hours. Thus, four 500 ml bottles represented a 24 hour period. The first and third bottles collected (1000 ml total volume) were preserved with 0.2% $HgCl_2$ on which all analyses, except for chloride, were performed. The second and fourth bottles (1000 ml) were not preserved in order to provide a sample for chloride analysis. The intake probe for each sampler was mounted on a float which maintained the intake a depth of 0.5 m. Copper tubing (¼" I.D.) was used as the supply line from the intake probe to the automatic sampler. Each sampler was serviced once a week, at which time the samples were returned to the laboratory for analysis.

Grab Sample

During the weekly servicing of the automatic samplers, grab samples and field data were collected. The grab samples were collected at the surface in a 2 L polyethylene bucket. This technique collected, in part, a surface film. The samples were also preserved with 0.2% $HgCl_2$ in the same manner as one-half of the daily samples. Field data (pH, temperature, dissolved oxygen, and specific conductance) were collected at 0.5 m intervals beginning at a depth of 0.5 m using a Hydrolab$^{(R)}$ Surveyor.

Sample Processing

All grab samples were returned to the laboratory once a week. Those samples collected for dissolved nutrient and major ion analysis were filtered in the laboratory through a 0.45 micron Nucleopore$^{(R)}$ membrane filter. The samples for major ion analysis were also acidified with concentrated nitric acid (2 drops/60 ml). Unfiltered aliquots were used for total nutrient

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analysis. All samples were stored in polyethylene bottles, at 4°C in the dark, prior to analysis. Analysis commenced within one week of sample collection.

Parameter Coverage

Laboratory analysis of samples included the following parameter groups:

1. Physical characteristics: turbidity
2. Nutrients - Dissolved: nitrite, nitrate, ammonia, ortho phosphorus, silica

   Total: Kjeldahl nitrogen and phosphorus
3. Major Ions: sodium, potassium, calcium, magnesium, sulfate, hardness, and alkalinity (primarily HCO_3^- and $CO_3^=$)

The analytical chemistry methods used in this study are described in Table 3 and were either recommended or approved by the Environmental Protection Agency or the American Public Health Association.

For the purposes of this report, inorganic nitrogen was calculated from the sum of NO_2^-, NO_3^-, and NH_4^+. Organic nitrogen was calculated from the difference of TKN and NH_4. The values for nitrogen and phosphorus are reported as mg N/L and mg P/L, respectively.

MATERIAL LOADING METHODOLOGY

Material loadings were calculated by combining daily flow rates at a particular site with the corresponding chemical data. If chemistry data on a particular day was missing, or if loads were calculated using weekly data, two chronologically successive chemistry data points were averaged to give an estimated value for the time period between the two points. This average was then used in conjunction with daily flow data within the time period to compute daily loadings. This was one of the preferred techniques described by Schneider et al. (1978). The material loads are reported in 10^6 grams

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TABLE 3.   ANALYTICAL METHODS

AutoAnalyzer II Method

Determination	Method	Range	Sensitivity	Detection Limits
Alkalinity	Colorimetric Automated Methyl Orange, Technicon AA II Method #111-71W, modified EPA Method #310.2	0-5.0 meq/L	0.1 meq/L	0.1 meq/L
Ammonia	Colorimetric Automated Phenate, Technicon AA II method #154-71W, modified EPA Method #350.1	0.0-50 mg/L	0.01 mg/L	0.01 mg/L
Chloride	Colorimetric Automated Ferricyanide, Technicon AA II Method #99-70W, modified EPA Method #325.2	0-200.0 mg/L	2.0 mg/L	4.0 mg/L
Nitrite	Colorimetric Automated Diazotization with Sulfanilamide and coupling with N-(1 naphthyl) ethylenediamine Dihydrochloride, Technicon colorimetric, automated AA II Method #120-70W, modified EPA Method #353.2	0-0.200 mg/L	0.002 mg/L	0.004 mg/L
Nitrate	Same as nitrite with Cadmium Reduction Column. Technicon AA II Method #100-70W, modified EPA Method #353.2	0.0.200 mg/L	0.002 mg/L	0.004 mg/L
Total Kjeldahl Nitrogen	Colorimetric, Semi-automated Block Digestor, Technicon AA II Method #376-75W, 334-74A, modified EPA Method #351.2	0-0.10 mg/L	0.001 mg/L	0.002 mg/L
Ortho Phosphate	Colorimetric, Automated, Phosphomolybdenum Blue Complex with Ascorbic Acid Reduction, Technicon AA II Method #155-71W, modified EPA Method #365.1	0-0.10 mg/L	0.001 mg/L	0.002 mg/L
Total Phosphate	Colorimetric, Semi-automated Persulfate Digestion followed by same method as Ortho Phosphate Technicon AA II Method #155-71W, modified EPA Method #365.1.	0-0.10 mg/L	0.001 mg/L	0.002 mg/L

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TABLE 3. (Continued)

AutoAnalyzer II Method (Cont.)

Determination	Method	Range	Sensitivity	Detection Limit
Silicates	Colorimetric, Automated Ascorbic Acid Reduction of Silicomolybdate Complex, Technicon AA II Method #105-71W	0-20.0 mg/L	0.20 mg/L	0.40 mg/L
Sulfate	Colorimetric, Automated Methylthymol Blue, Technicon AA II Method #118-71W, modified EPA Method #375.2	0-250.0 mg/L	5.0 mg/L	5.0 mg/L

Physical Parameters

Determination	Method	Range	Detection Range
Sodium	Atomic Absorption Direct Aspiration with Dual Capillary System (DCS), EPA Method #273.1	0-150 mg/L	As calculated from absorbance
Potassium	Atomic Absorption Direct Aspiration with Dual Capillary System (DCS), EPA Method #258.1	0-10 mg/L	As calculated from absorbance
Calcium	Atomic Absorption Direct Aspiration with Dual Capillary System (DCS), Samples are treated with La_2O_3/HCl with DCS, EPA Method #215.1	0-150 mg/L	As calculated from absorbance
Magnesium	Atomic Absorption Direct Aspiration with Dual Capillary System (DCS), Same treatment as calcium, EPA Method #242.1	0-40 mg/L	As calculated from absorbance

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(=1 metric tonne). Flow weighted concentrations were calculated by dividing the total annual mass by the total annual flow.

PART 4

WATER QUALITY CHARACTERISTICS

RESULTS

C-24 AT S-49

Major Ions

During the annual period of this study, the water quality at S-49 was
characterized as being highly mineralized, including high hardness and
alkalinity levels (Table 4). The graphical representation of the composition
of the major ions (Figure 4) indicates that the cations were dominated by high
levels of Na (7.07 meq/L or 47% of total) and Ca (5.19 meq/L or 35% of total).
Chloride dominated the anion composition (10.52 meq/L or 69% of total) with
bicarbonate and sulfate ions present in lesser, though substantial,
concentrations of 2.58 meq/L (17% of total) and 2.23 meq/L (15% of total),
respectively. These high mineral levels resulted in an average specific
conductance of 1605 micromhos/cm.

The high mineral content of S-49 appears to be primarily a result of
groundwater influences. Figure 5 provides a graphical pattern analysis of the
major ion composition of the surface waters at S-49 and of the groundwater in
the S-49 basin. The groundwater quality data are summarized in Appendix A.
The similarity of the S-49 and groundwater ion patterns suggests the influence
of groundwater on the surface waters in C-24. Both the groundwater and
surface waters were dominated by NaCl although the surface water levels were
less than half that of the groundwater. Calcium bicarbonate levels were very
similar while surface concentrations of sulfate and magnesium were
approximately half that of the groundwater.

The flow weighted concentrations of all the major ions was less than the
time-weighted average (Table 4) indicating that the mineral composition of the

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TABLE 4. SUMMARY OF MAJOR ION CONCENTRATIONS AT S-49, S-97, AND S-99*

Parameter (mg/L)	C-24 at S-49				C-23 at S-97				C-25 at S-99			
	Time Av.	Min.	Max.	Flow Wt. Av.	Time Av.	Min.	Max.	Flow Wt. Av.	Time Av.	Min.	Max.	Flow Wt. Av.
Cl	373.0	152.2	534.2	337.5	194.20	62.9	349.60	161.3	369.20	114.50	675.0	270.6
Na	162.6	59.98	293.26	150.1	96.70	33.5	293.00	78.2	156.41	30.93	304.97	98.1
K	8.89	3.71	14.43	8.2	5.75	1.75	10.77	5.0	8.29	3.63	17.31	5.9
Ca	103.96	53.38	145.04	93.3	93.21	40.15	125.14	76.1	104.54	60.32	144.88	89.9
Mg	30.90	13.18	46.10	28.0	18.96	8.42	31.80	15.8	33.35	14.35	63.86	21.7
SiO_2	7.7	.9	13.4	9.5	7.80	2.40	12.50	9.5	9.7	3.4	14.6	11.6
SO_4	107.3	29.9	221.2	90.2	68.40	17.20	150.80	57.2	124.0	45.8	243.2	101.1
Hardness ($CaCO_3$)	386.7	202.5	503.0	346.4	310.20	116.70	405.10	255.3	397.8	222.5	537.6	313.2
Alk ($CaCO_3$)	157.2	44.0	603.5	141.1	179.10	65.50	324.50	140.1	173.9	53.5	810.0	127.8

* Based on daily composite samples collected from Nov. 1, 1976 to Oct. 31, 1977

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S-49

CATIONS
- Ca $^{+2}$ — 35% (519)*
- K $^+$ (0.23)* — 2%
- Mg $^{+2}$ — 16% (2.54)*
- Na $^+$ — 47% (7.07)*

ANIONS
- Cl $^-$ — 69% (10.52)*
- SO4 $^{-2}$ — 15% (2.23)*
- HCO3 $^-$ — 16% (2.58)*

S-97

CATIONS
- Ca $^{+2}$ — 44% (4.65)*
- K $^+$ — 1% (0.15)*
- Mg $^{+2}$ — 15% (1.56)*
- Na $^+$ — 40% (4.21)*

ANIONS
- Cl — 56% (5.48)*
- SO4 $^{-2}$ — 14% (1.42)*
- HCO3 $^-$ — 30% (2.94)*

S-99

CATIONS
- Ca $^{+2}$ — 35% (5.22)*
- K $^+$ — 1% (0.21)*
- Mg $^{+2}$ — 18% (2.74)*
- Na $^+$ — 45% (6.80)*

ANIONS
- Cl $^-$ — 66% (10.42)*
- SO4 $^{-2}$ — 16% (2.58)*
- HCO3 $^-$ — 18% (2.85)*
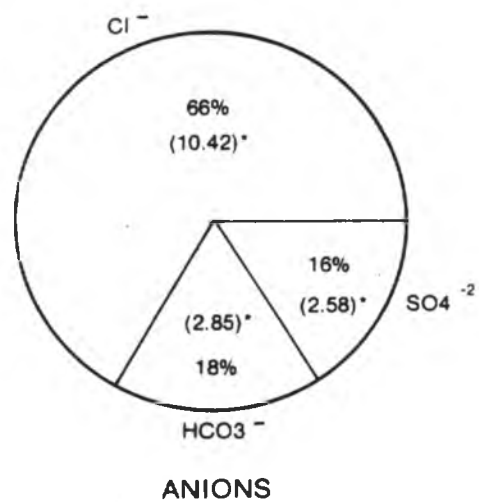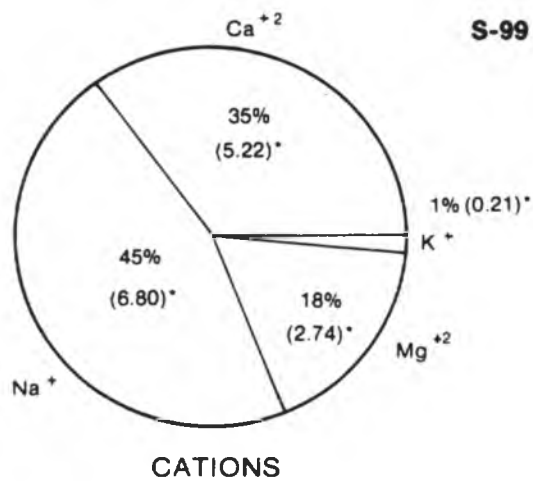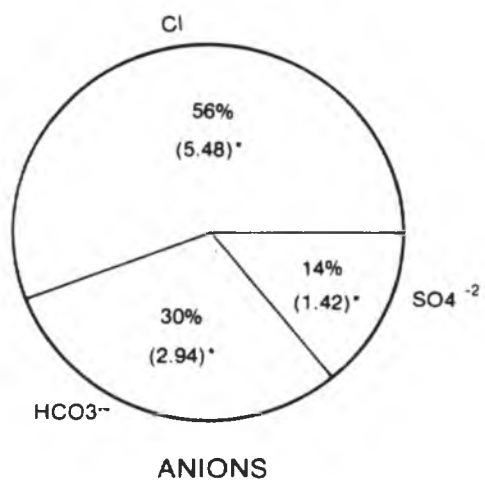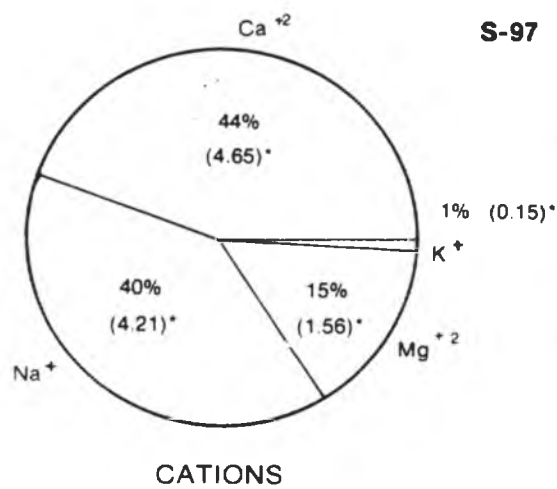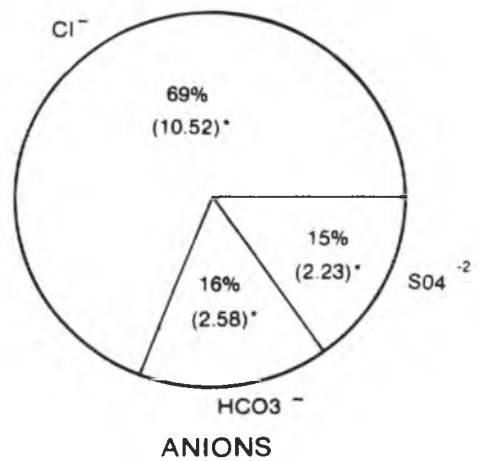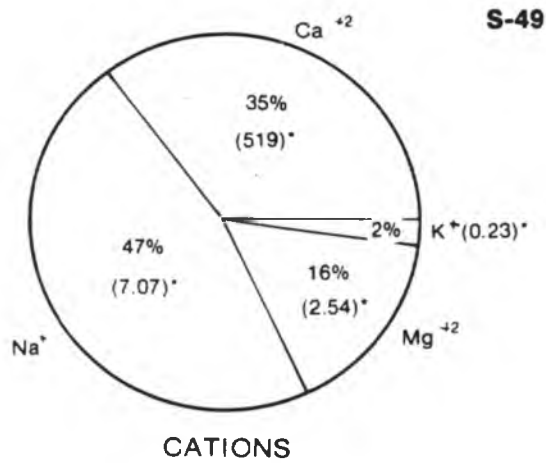
* UNITS: (meq/L)

Figure 4   ANION AND CATION COMPOSITION

30 25 20 15 10 5   5 10 15 20 25 30

Na + K ├─────────────────────────────────┤ Cl

Ca ├─────────────────────────────────┤ HCO₃

Mg ├─────────────────────────────────┤ SO₄

C-24
BASIN

S-49

GROUNDWATER

C-23
BASIN

S-97

GROUNDWATER

C-25
BASIN

S-99

GROUNDWATER

30 25 20 15 10 5 0 5 10 15 20 25 30

CATIONS, IN MILLIEQUIVELENTS
PER LITER

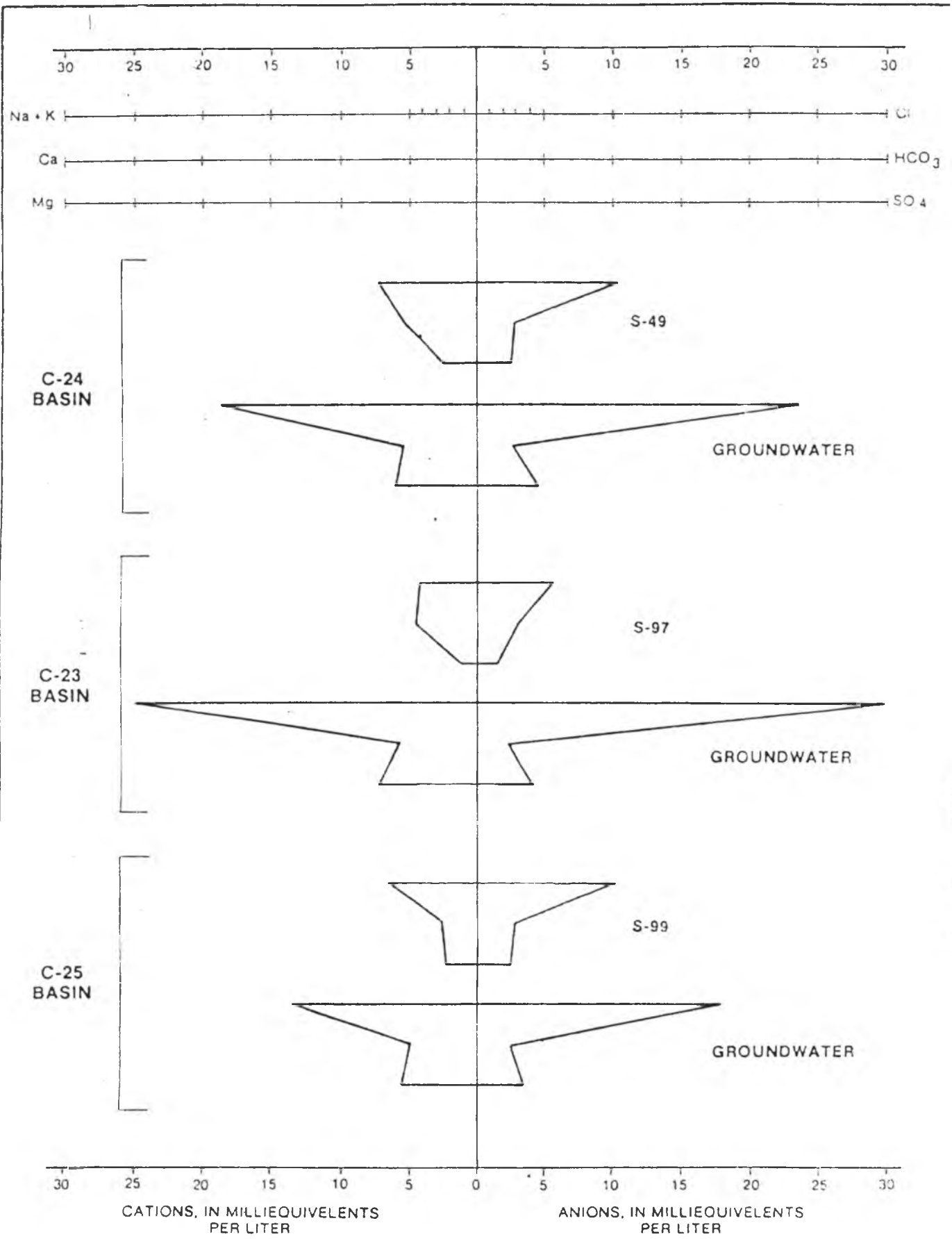ANIONS, IN MILLIEQUIVELENTS
PER LITER

Figure 5. SURFACE AND GROUNDWATER MAJOR ION PATTERN
COMPARISONS

surface water at S-49 was inversely related to discharge. This inverse relationship is shown in Figures 6 through 8. Throughout the dry season (November to May) the levels of the major ions increased steadily. Discharge during this period was in response to higher canal stages which probably resulted from artesian groundwater irrigation since rainfall was minimal (Figure 2b). This relationship could account for the similarity in the major ion composition of the surface water and groundwater.

At the initiation of the wet season in June, the major ion levels began to level off and subsequently declined during the latter part of the summer (August). In response to a dilution effect of 9.5 inches of rainfall in the first week of September, there was a very sharp decline in the level of all the major ions. Subsequent to this rainfall event, the ion levels at S-49 again displayed an increasing trend with the concentrations in November 1977 reaching the same level as those measured in the beginning of the study in November 1976. The cycle in the major ion levels appears to be a steadily increasing trend as a result of groundwater irrigation influences until major rainfall events cause a dilution of the ion levels in the canal. After the decline in ion concentrations the increasing trend is resumed.

Silica, an uncharged ion, displayed a trend opposite to that of the major charged ions (Figure 7). Silica levels decreased subsequently during the dry season months of November to mid-March then increased steadily until the end of August. The large rainfall that occurred in the beginning of September caused a sharp decline in the silica levels after which the levels began to rapidly increase.

Nitrogen and Phosphorus

The mean annual total nitrogen and phosphorus concentrations at S-49 were moderately low (1.44 and 0.192 mg/L, respectively) (Table 5). However, peak concentrations of total nitrogen were 2.8 times greater (4.04 mg/L) than the
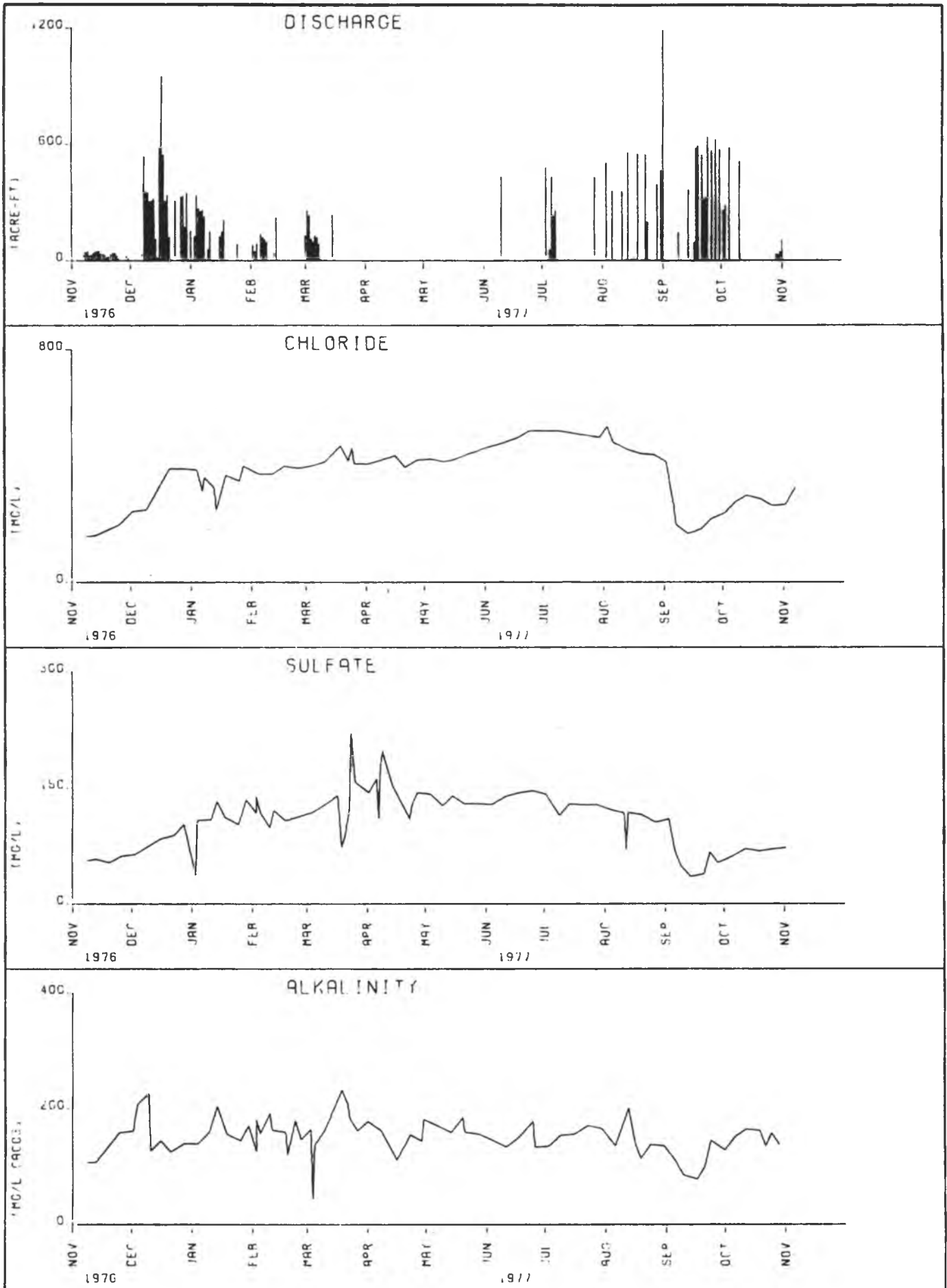
24

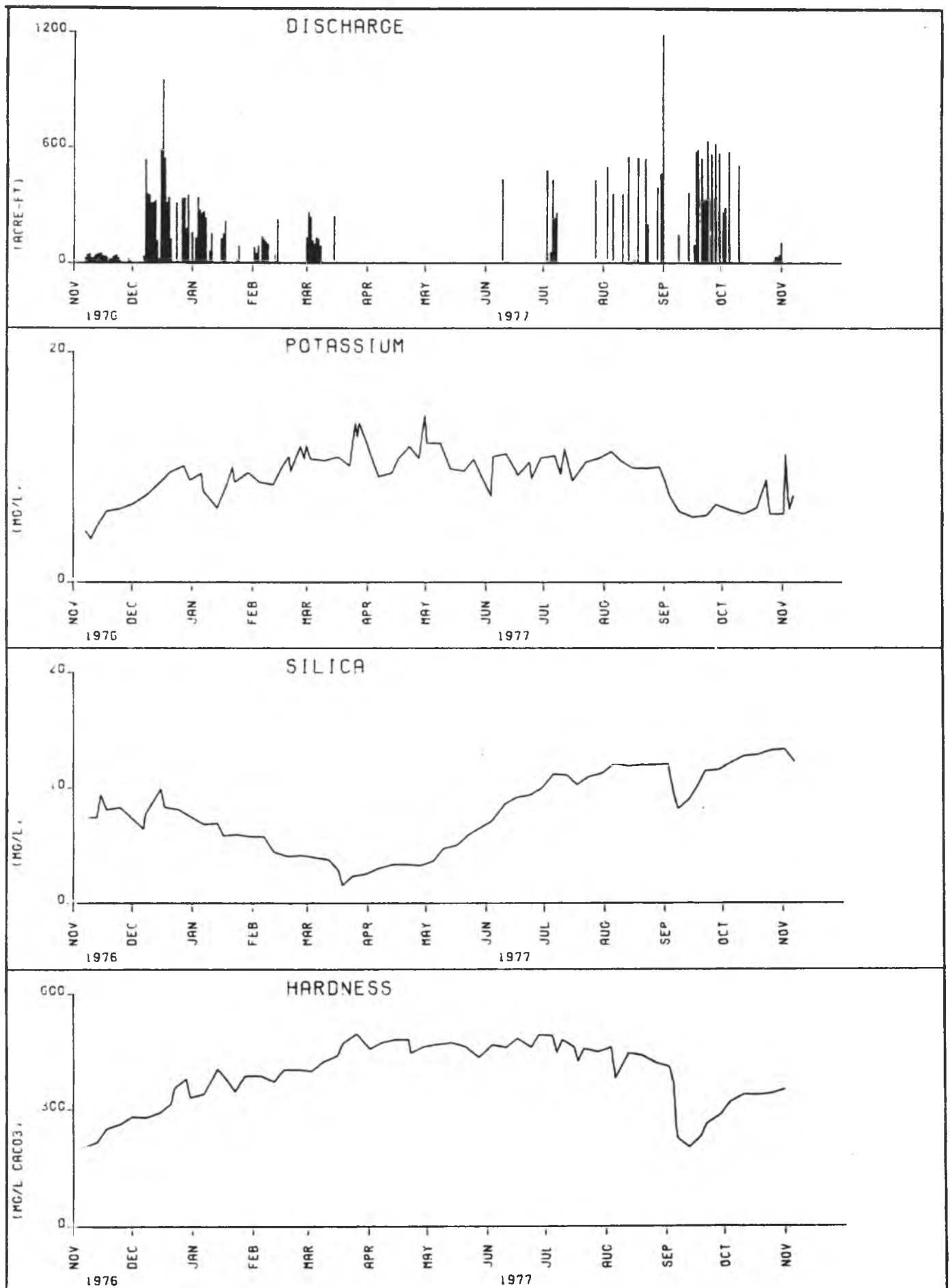Figure 6   CHLORIDE, SULFATE, ALKALINITY AND DISCHARGE FOR C-24 AT S-49

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Figure 7   POTASSIUM, SILICA, HARDNESS AND DISCHARGE FOR C-24 AT S-49
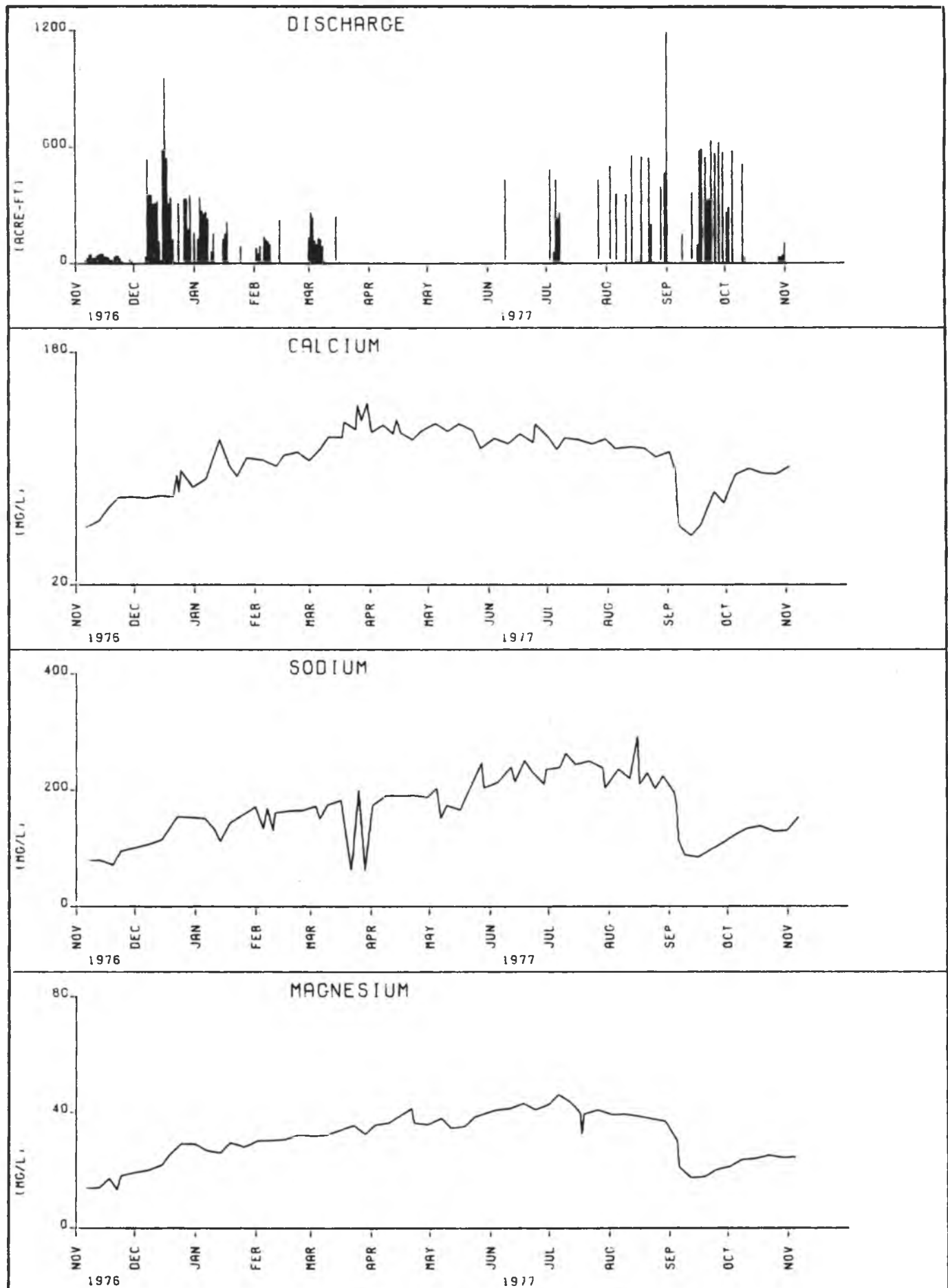
Figure 8   CALCIUM, SODIUM, MAGNESIUM AND DISCHARGE FOR C-24 AT S-49

mean annual concentration while peak total phosphorus levels were 3.5 times greater (0.673 mg/L) than the annual average. Organic nitrogen was the dominant nitrogen species (93%), while inorganic ortho phosphorus was the dominant phosphorus species (73% of the total).

A comparison of the flow-weighted nitrogen and phosphorus concentration with the time-weighted concentration indicates that the higher nutrient levels occurred during discharge events (Table 5). This relationship is evident in Figures 9 and 10, especially for the inorganic nutrient species. Inorganic nitrogen appears to follow a seasonal pattern of declining levels during the dry season months, with minimal levels occurring at the end of the dry season (May/June). This decline occurred even though there was substantial discharge through S-49. It appears that runoff which results from groundwater irrigation practices does not result in increased inorganic nitrogen concentrations. During the summer months inorganic nitrogen concentrations increased, with the sharpest increase occurring as a result of runoff and subsequent discharge generated from a major 9.5 inch cumulative 4-day rainfall event in early September. Inorganic nitrogen concentration approached 1.0 mg/L during this rainfall event. After a temporary decline the inorganic nitrogen concentration again increased sharply for the remainder of September. The inorganic nitrogen levels at the end of the study in October 1977 were the same as those at the beginning of the study in November 1976, suggesting a complete annual/seasonal cycle.

There was no obvious seasonal pattern in the organic nitrogen fluctuations and, consequently, there was little evidence of a seasonal pattern in total nitrogen concentrations (Figure 9). A slight increase in total nitrogen levels was detectable as a result of the peak September inorganic nitrogen levels.

TABLE 5. SUMMARY OF NUTRIENT PARAMETERS AT S-49, S-97, and S-99*

Parameter (mg/L)	C-24 at S-49				C-23 at S-97				C-25 at S-99			
	Time Av.	Min.	Max.	Flow Wt. Conc.	Time Av.	Min.	Max.	Flow Wt. Conc.	Time Av.	Min.	Max.	Flow Wt. Conc.
Total P	.192	.014	.673	.260	.106	.020	.451	.158	.064	.014	.342	.113
Ortho P	.140	.005	.484	.201	.070	.005	.279	.110	.032	.002	.247	.062
Total N	1.44	.42	4.04	1.54	1.30	.31	3.25	1.58	1.19	.44	3.76	1.38
NO_3-N	.096	.004	.656	.130	.097	.004	.480	.143	.049	.004	.760	.051
NO_2-N	.009	.004	.060	.011	.009	.004	.048	.017	.005	.004	.023	.010
NH_4-N	.08	.01	.67	.146	.05	.01	.41	.093	.07	.01	.44	.108
Org.-N	1.26	.34	3.96	1.25	1.15	.21	3.11	1.33	1.06	.33	3.71	1.22

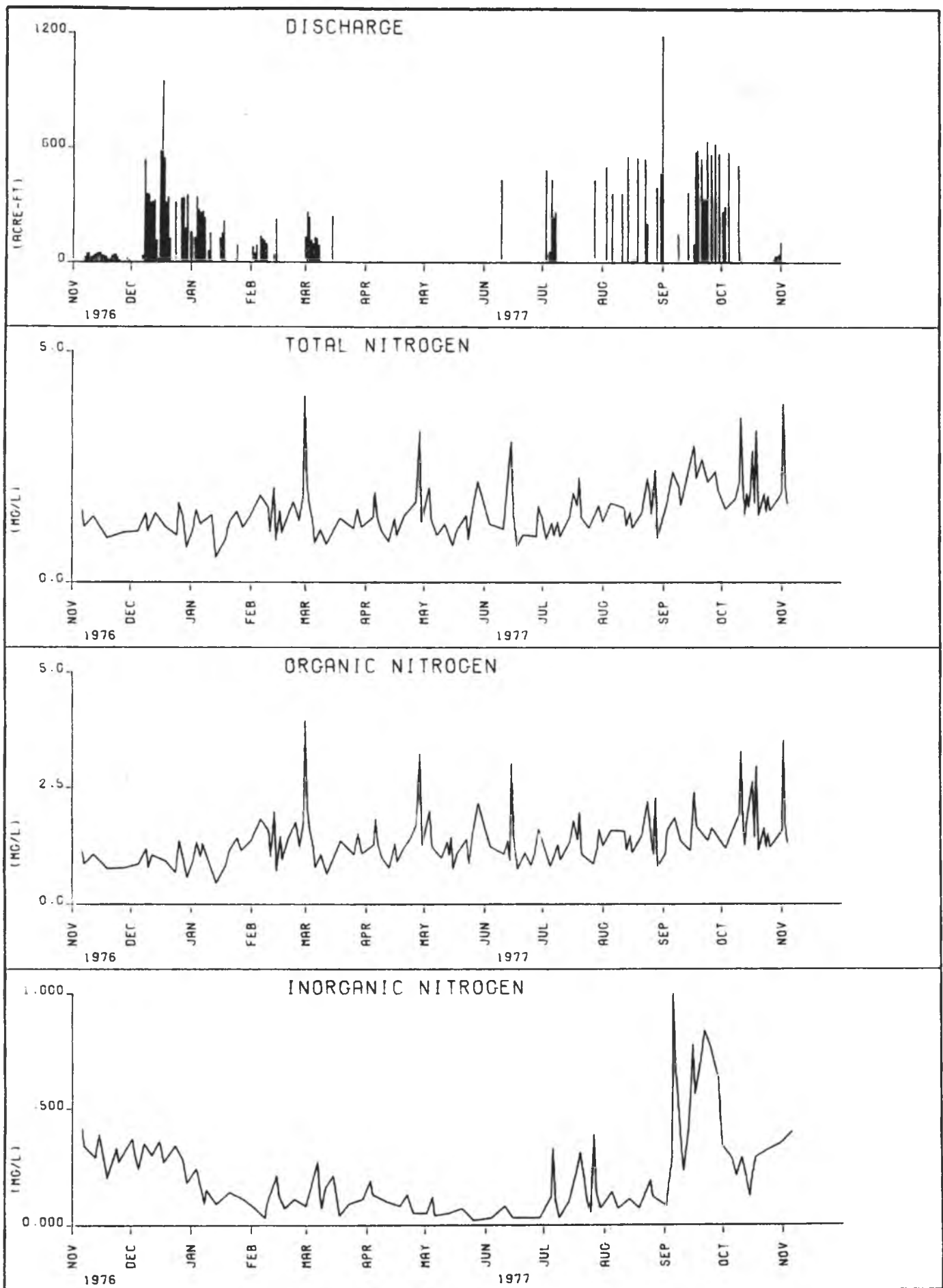* Based on daily composite samples collected from Nov. 1, 1976 to Oct. 31, 1977

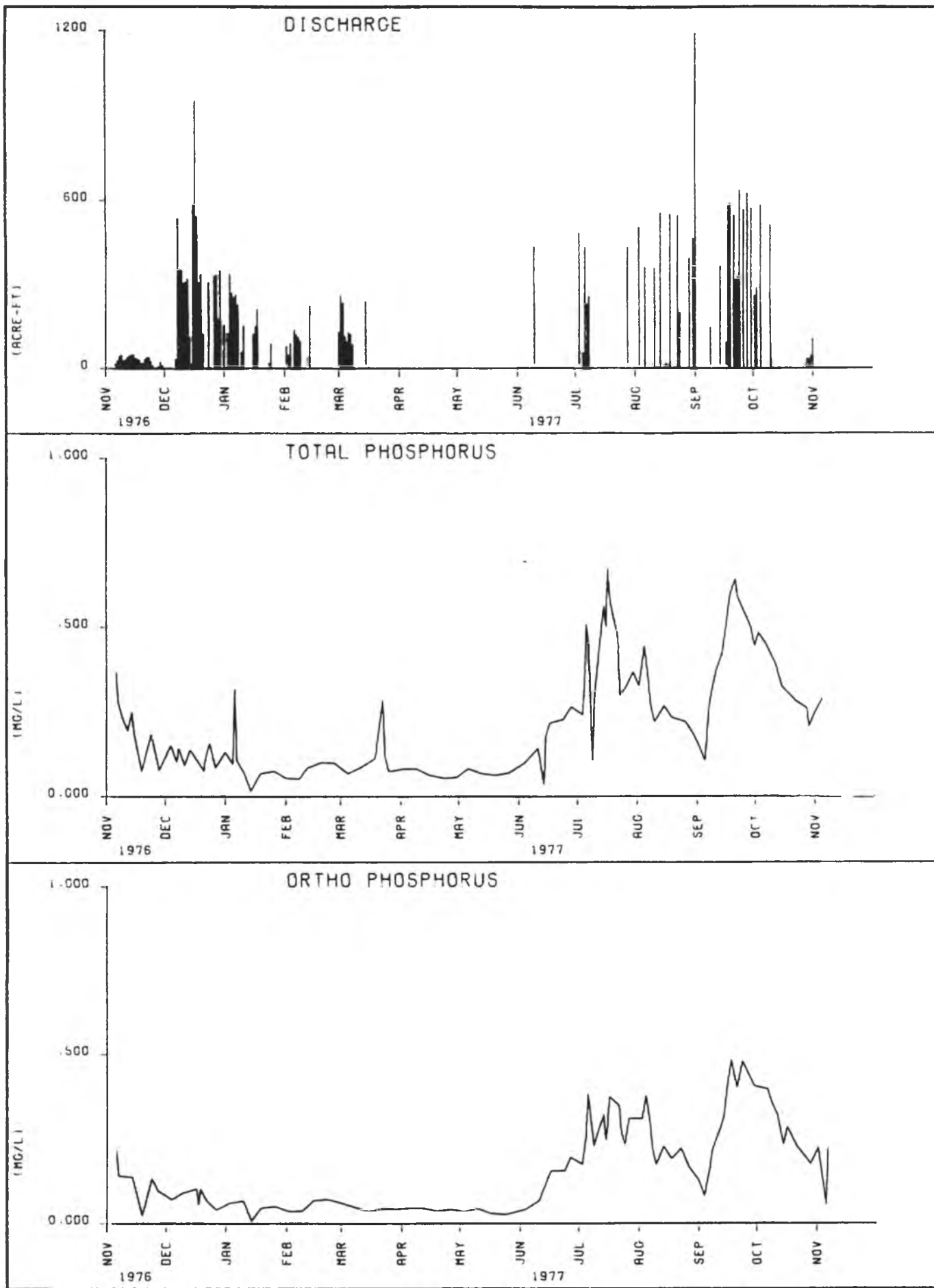Figure 9   NITROGEN AND DISCHARGE VS TIME AT S-49

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Figure 10   PHOSPHORUS AND DISCHARGE VS TIME AT S-49

Ortho phosphorus displayed a distinct seasonal pattern which was similar to the inorganic nitrogen pattern. Ortho phosphorus concentration declined during the dry season months of November to May, even though there were discharges, and subsequently increased rapidly in June (Figure 10). After a decline toward the end of August there was a sharp increase at the beginning of September, following an intense rainfall event, with the peak ortho phosphorus concentrations occurring in mid-September. Ortho phosphorus levels began to decline in October to the levels measured at the beginning of the study. It also appears that, as was the case with inorganic nitrogen, the high ortho phosphorus levels are not directly a function of discharge but are a result of rainfall generated runoff.

Since the ortho phosphorus fraction comprised 73 percent of the total, the seasonal pattern for total phosphorus was very similar to the ortho phosphorus pattern (Figure 10).

Field and Physical Parameters

There was a wide variation in dissolved oxygen concentrations measured at S-49, ranging from 0.1 to 10.4 mg/L (Table 6). The mean annual dissolved oxygen concentration was 5.1 mg/L, but values above this level were characteristic of dry season concentrations while values below 5 mg/L were characteristic of wet season concentrations (Figure 11). The percent saturation of dissolved oxygen followed a similar pattern with the dry season levels being above 60 percent saturation while the wet season values were below 60 percent saturation.

The mean annual specific conductance at S-49 was high at 1605 micromhos/cm. Extreme values ranged 17 fold from 150 to 2600 micromhos/cm. Since specific conductance represents an integration of the mineral content, the seasonal conductivity pattern paralleled the seasonal patterns of the

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TABLE 6 . SUMMARY OF FIELD AND PHYSICAL PARAMETERS AT S-49, S-97, AND S-99[1]

Parameter	S-49			S-97			S-99		
	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
Diss. Oxygen (mg/L)	5.1	0.1	10.4	5.5	0.1	8.3	4.4	0.2	9.1
Temp. (^{0}C)	24.0	13.6	30.7	24.0	13.5	31.2	23.9	13.3	30.6
Conductivity (micromhos/cm)	1605	150	2600	1039	115	2200	1592	140	2800
pH	7.33	6.60	8.00	7.43	6.40	8.00	7.17	6.50	7.90
Turbidity (NTU)	3.0	0.6	14.0	3.6	1.0	16.0	2.7	0.5	13.0

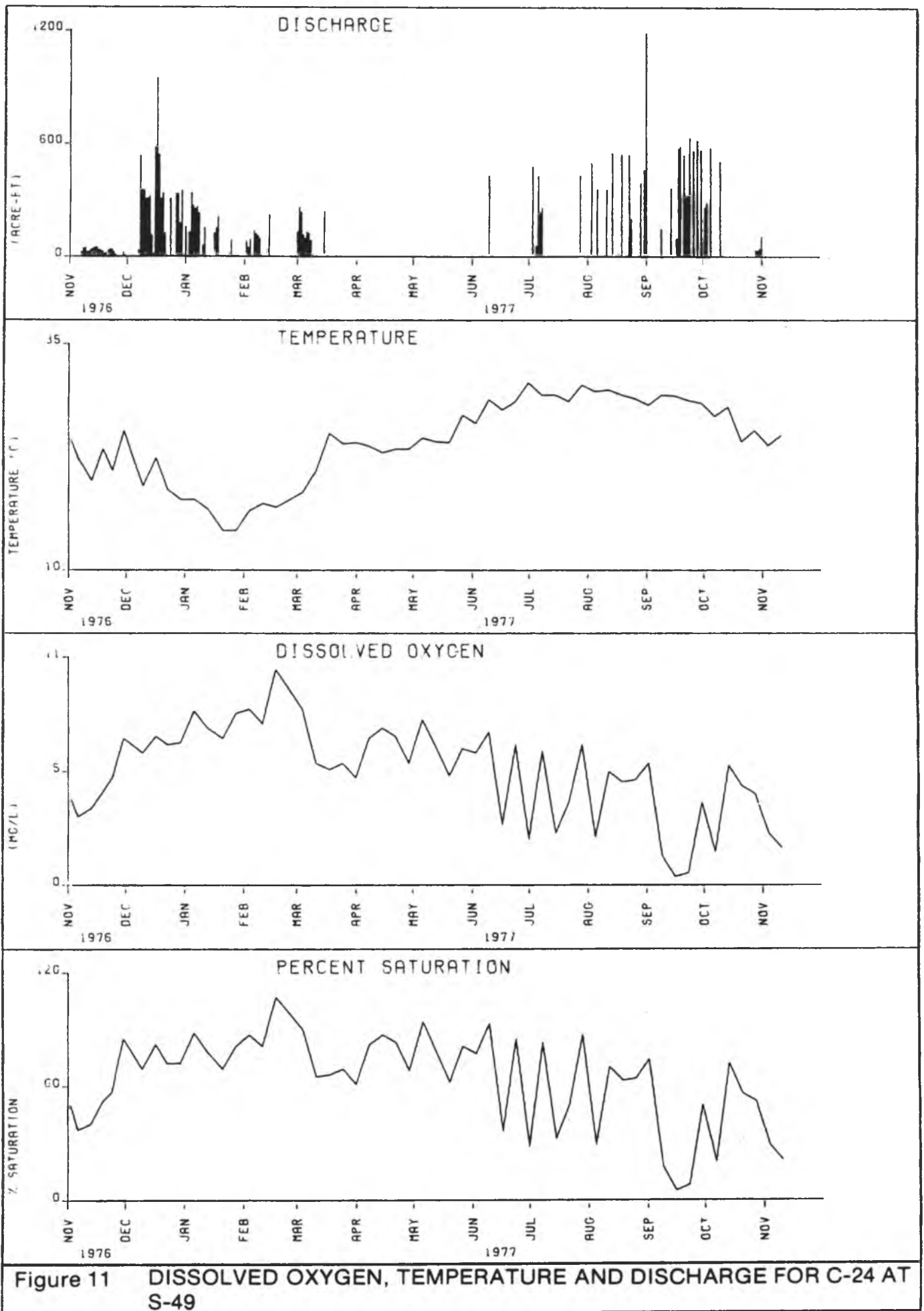[1] Based upon weekly measurements from Nov. 1, 1976 to Oct. 13, 1977

Figure 11   DISSOLVED OXYGEN, TEMPERATURE AND DISCHARGE FOR C-24 AT S-49

inorganic ions. The specific conductance increased during the dry season and subsequently decreased during the wet season.

Figure 12 displays the limited variation in the pH. The mean value of 7.3 and the narrow range of 6.6 to 8.0 (Table 6) is typical of surface waters with high alkalinity levels in south Florida. The mean surface pH is also very similar to the pH of the groundwater which ranged from 7.3 to 7.5 (Reese et al. 1980).

Turbidity levels at S-49 were very low, ranging from 0.6 to 14.0 NTU's with an average value of 3.0 NTU (Table 6). As displayed in Figure 12 the higher turbidities typically occurred during discharge events, although this relationship was not consistent for all discharge events.

C-23 AT S-97

Major Ions

The major ion concentrations at S-97 were substantially less than the concentrations measured at S-49 (Table 4). Chloride and sulfate concentrations at S-97 were about half that those at S-49 while bicarbonate levels were approximately equal (Figure 4). Calcium concentrations were 10 percent less at S-97 than at S-49 while sodium, magnesium, and potassium concentrations were 35 to 40 percent less. These relatively lower ion concentrations, however, were still indicative of highly mineralized water. The relative composition of the major ions at S-97 was somewhat different than that of S-49. At S-97 the relative cation composition was Ca^{+2} (44%) > Na^+ > (40%) > Mg^2 (15%) > K^+ (1%). This differed from the relative composition at S-49 where sodium was the dominant cation: Na^+ (47%) > Ca^{+2} (35%) > Mg^{+2} (17%) > K^+ (2%). The relative anion composition was similar between S-97 and S-49 with Cl^- > HCO_3^- > SO_4^{-2}.
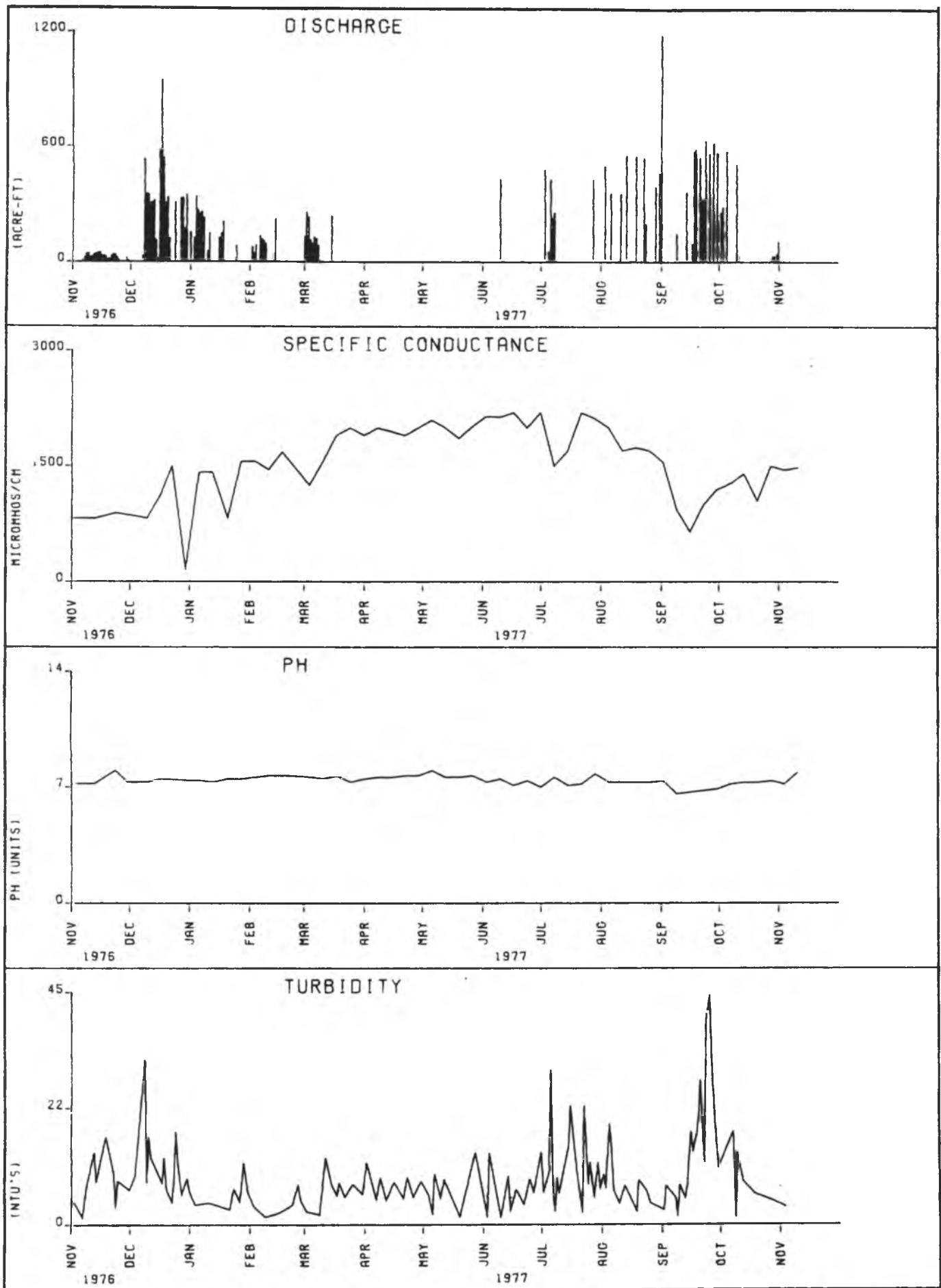
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Figure 12   CONDUCTIVITY, PH, TURBIDITY AND DISCHARGE FOR C-24 AT S-49

The similarity between the groundwater and surface water ion patterns at S-97 was less defined than was the similarity between the groundwater and surface water ion patterns found at S-49 (Figure 5). This suggests a lesser degree of influence of the groundwater in the S-97 than was apparent at S-49.

The lower ion concentrations generally occurred during discharge, as evidenced by the flow-weighted ion concentrations being less than the time-weighted concentrations. This inverse quality/discharge relationship was also previously described for S-49. The seasonal pattern of the major ions was similar to, although less pronounced, than the seasonal pattern at S-49. There was a slight increase in the dry season concentration of major ions at S-97 during discharge of surplus groundwater irrigation water. A subsequent sharp decline occurred in early September as a result of a rainfall event (Figures 13 to 15). The major ion levels then slowly increased in October back to the previous early dry season (November) levels.

The same seasonal silica pattern measured at S-49 (Figure 7) was also measured at S-97 (Figure 15). Silica concentrations decreased during the dry season from November to March with a minimum in mid-March. Beginning in April, and continuing through August, the level of silica at S-97 steadily increased. There was a sharp decline during the first week of September as a result of a large rainfall event, and a subsequent increase to the levels measured during the previous November.

Nitrogen and Phosphorus

Nitrogen and phosphorus concentrations at S-97 were generally lower than at S-49 with the exception of inorganic nitrogen levels. The annual total nitrogen concentrations at S-97 averaged 1.30 mg/L as compared to 1.44 mg/L at S-49. The average organic nitrogen concentration was also slightly lower at S-97 than at S-49 (1.20 vs 1.34 mg/L). Mean annual inorganic nitrogen concentrations were very similar between the two locations (Table 5). Average
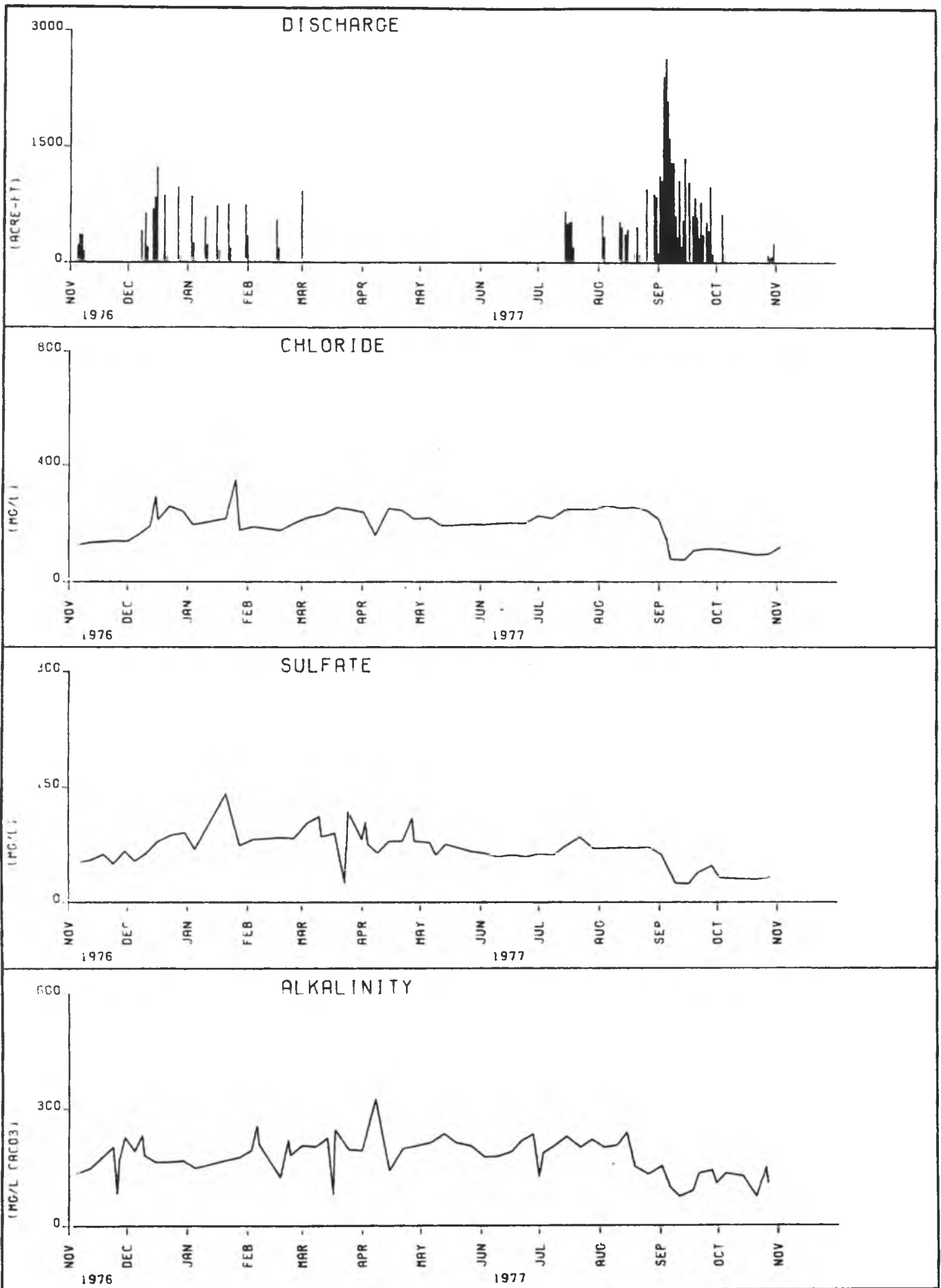
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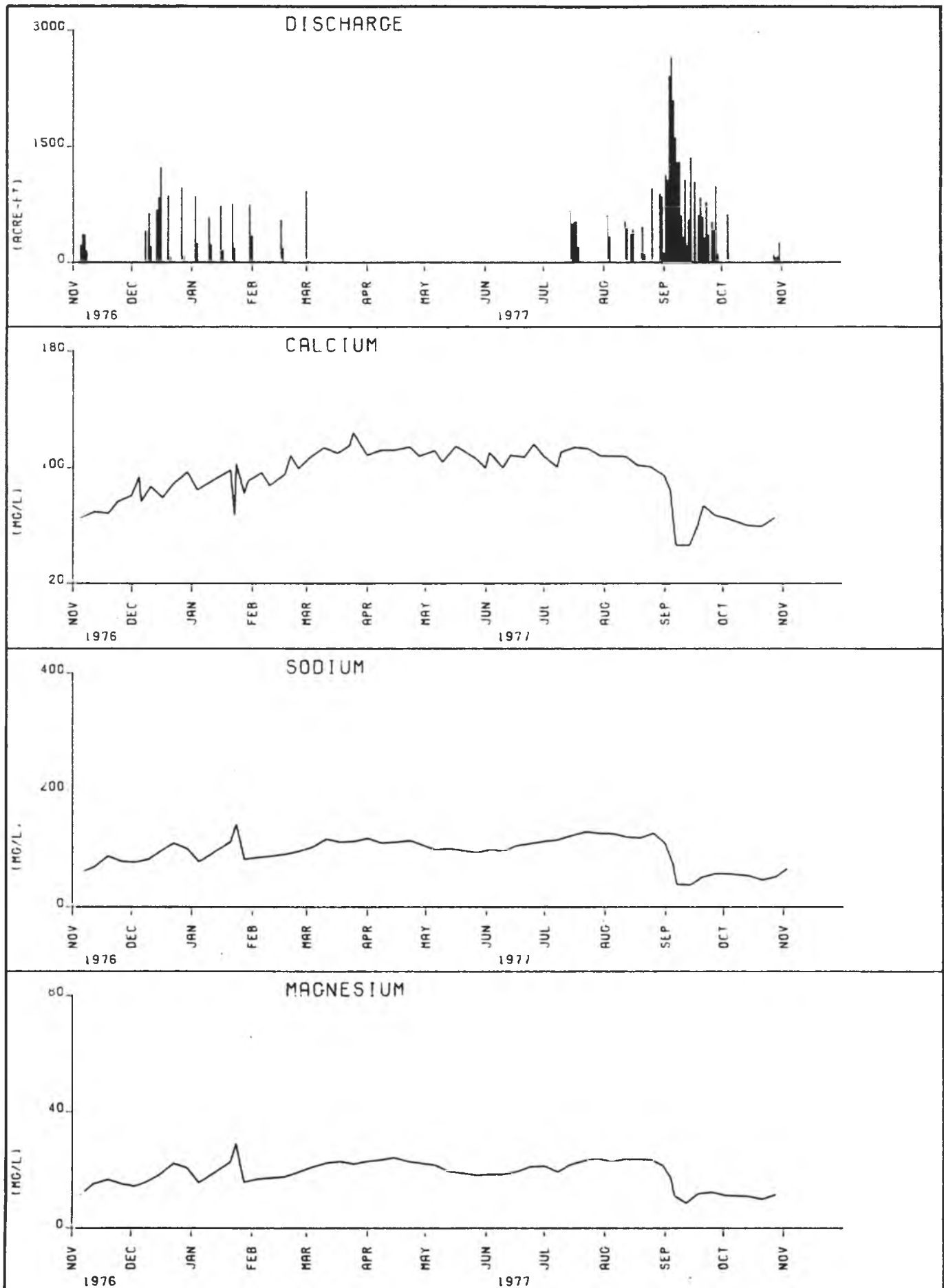Figure 13   CHLORIDE, SULFATE, ALKALINITY AND DISCHARGE FOR C-23 AT S-97

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Figure 14   CALCIUM, SODIUM, MAGNESIUM AND DISCHARGE FOR C-23 AT S-97
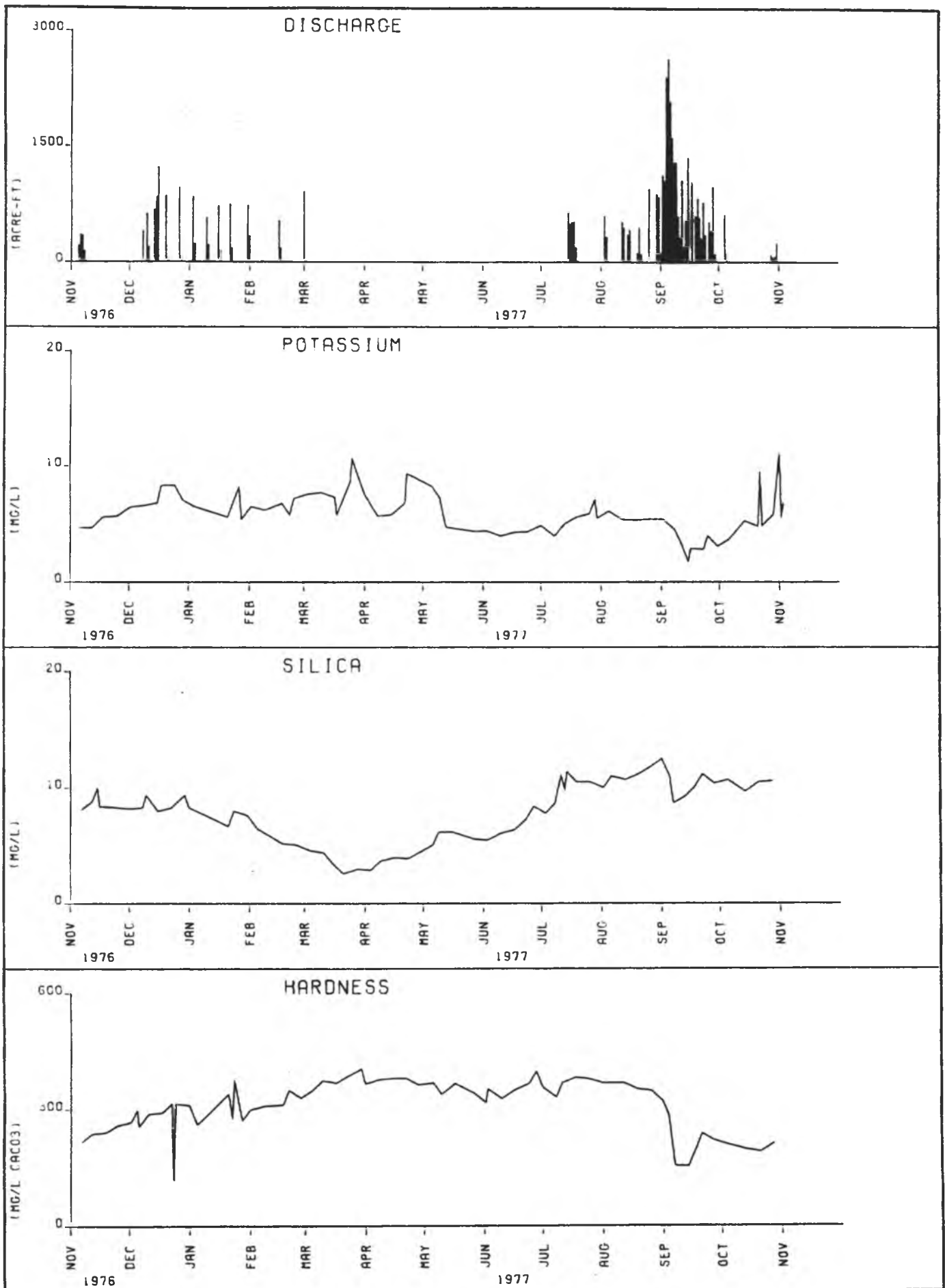
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Figure 15   POTASSIUM, SILICA, HARDNESS AND DISCHARGE FOR C-23 AT S-97

annual ortho phosphorus concentrations at S-97 were half that those at S-49 while annual total phosphorus concentrations were 45 percent lower. The proportion of ortho to total phosphorus was also less at S-97 (0.66) than at S-49 (0.73). Lower maximum nitrogen and phosphorus concentrations at S-97, as compared to S-49, provides a further distinction between the nutrient levels at the two structures.

The same basic seasonal nitrogen and phosphorus patterns evident at S-49 were also evident at S-97. Inorganic nitrogen declined during the dry season, even though there was discharge through the structure, reaching minimum values in late May. The level of inorganic nitrogen remained low throughout most of the summer. In early September when there was a sharp increase in concentration (Figure 16). This increase corresponded to high discharge levels which appeared to be a result of rainfall generated runoff. This seasonal pulse was not as large as the increase at S-49.

Ortho and total phosphorus at S-97 displayed seasonal patterns (Figure 17) very similar to S-49 except that the minimas and maximas were lower at S-97, and the late summer seasonal pulse began about one month later in July. At S-49 the seasonal increase occurred in June.

These late summer increases occurred during the period of heaviest discharge, resulting in the flow weighted nitrogen and phosphorus concentrations being greater than the time weighted average. As in the case of S-49, the highest nutrient concentration occurred during the highest flow periods.

Field and Physical Parameters

Dissolved oxygen concentrations at S-97 were not as variable as the concentrations at S-49 (Table 6). The lower maximum dissolved oxygen concentrations of 8.3 mg/L at S-97, as compared to 10.4 mg/L at S-49, coupled with a higher mean concentration (5.5 mg/L at S-97 vs 5.1 mg/L at S-49) is
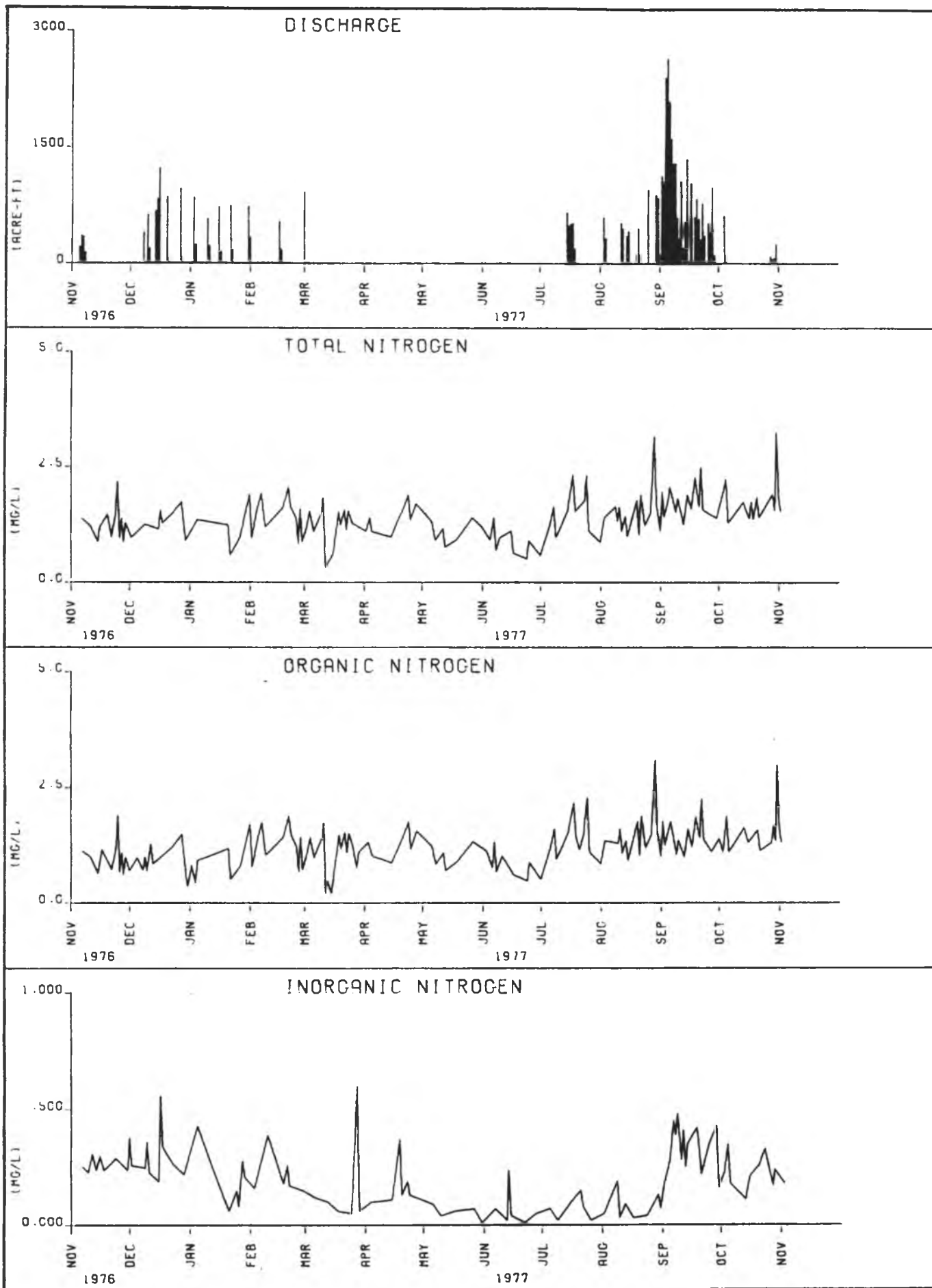
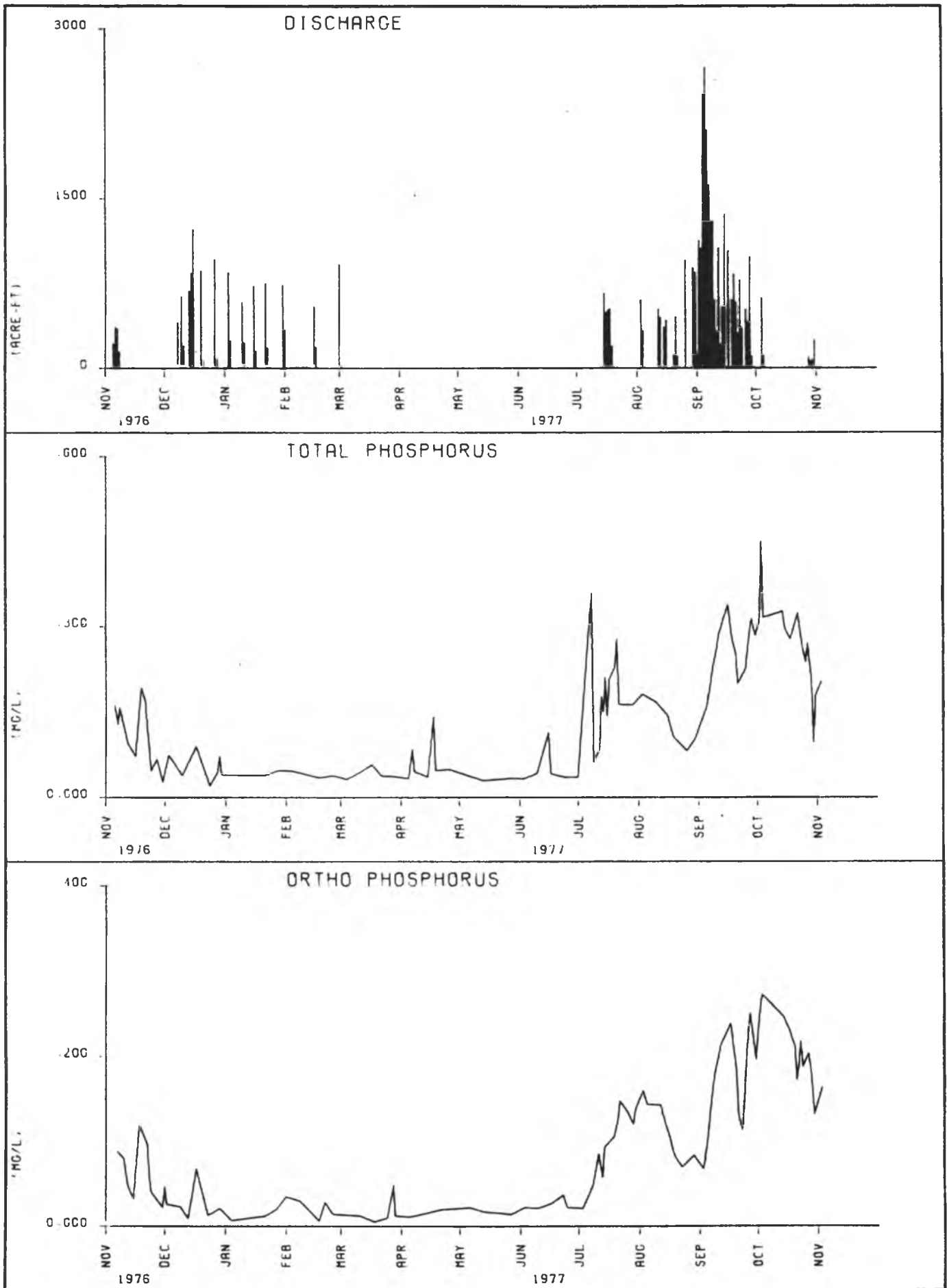Figure 16   NITROGEN AND DISCHARGE VS TIME AT S-97

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Figure 17   PHOSPHORUS AND DISCHARGE VS TIME AT S-97

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indicative of a more stable dissolved oxygen regime at S-97. Comparison of Figure 18 for S-97 to Figure 11 for S-49 typifies the lower dissolved oxygen variability at S-97. At S-97 the dissolved oxygen levels remained fairly constant, ranging between 5 and 8 mg/L, from November to July. This was a period of minimal rainfall and discharge activity. As a comparison, there was a seasonal wintertime peak in dissolved oxygen levels at S-49. The seasonal minimum in daytime dissolved oxygen occurred in September at S-97 during peak discharge conditions. This was similar to the September minimum at S-49.

Percent saturation of dissolved oxygen paralleled the variation in the concentrations (Figure 18). Values below 50 percent saturation occurred only 5 times (out of 52 measurements) during the 12 month study as compared to 13 times at S-49.

The specific conductance at S-97 ranged from 115 to 2200 micromhos/cm with an average value of 1039 micromhos/cm. These conductivity values were less than the corresponding values at S-49 and reflect the lower mineral content of the waters at S-97 as compared to S-49. The seasonal conductivity pattern at S-97 was similar, although less distinct, than the pattern at S-49 (Figure 19). The specific conductance of the water at S-97 increased gradually during the dry season and subsequently declined sharply in August and early September during a period of heavy rainfall and discharge activity.

The pH in the surface water at S-97 was very stable, averaging 7.4, and ranging between 6.4 and 8.0 (Table 6). The pH at S-97 was the same as the mean pH of the groundwater in the C-23 basin (7.4) and was very similar to that measured at S-49.

Turbidity levels at S-97 were low, ranging from 1.0 to 16.0 NTU's, with an annual average of 3.6 NTU's. These turbidity values were slightly greater than those measured at S-49 (Table 6). A greater distinction between the turbidity levels at the two structures was that there was no consistent
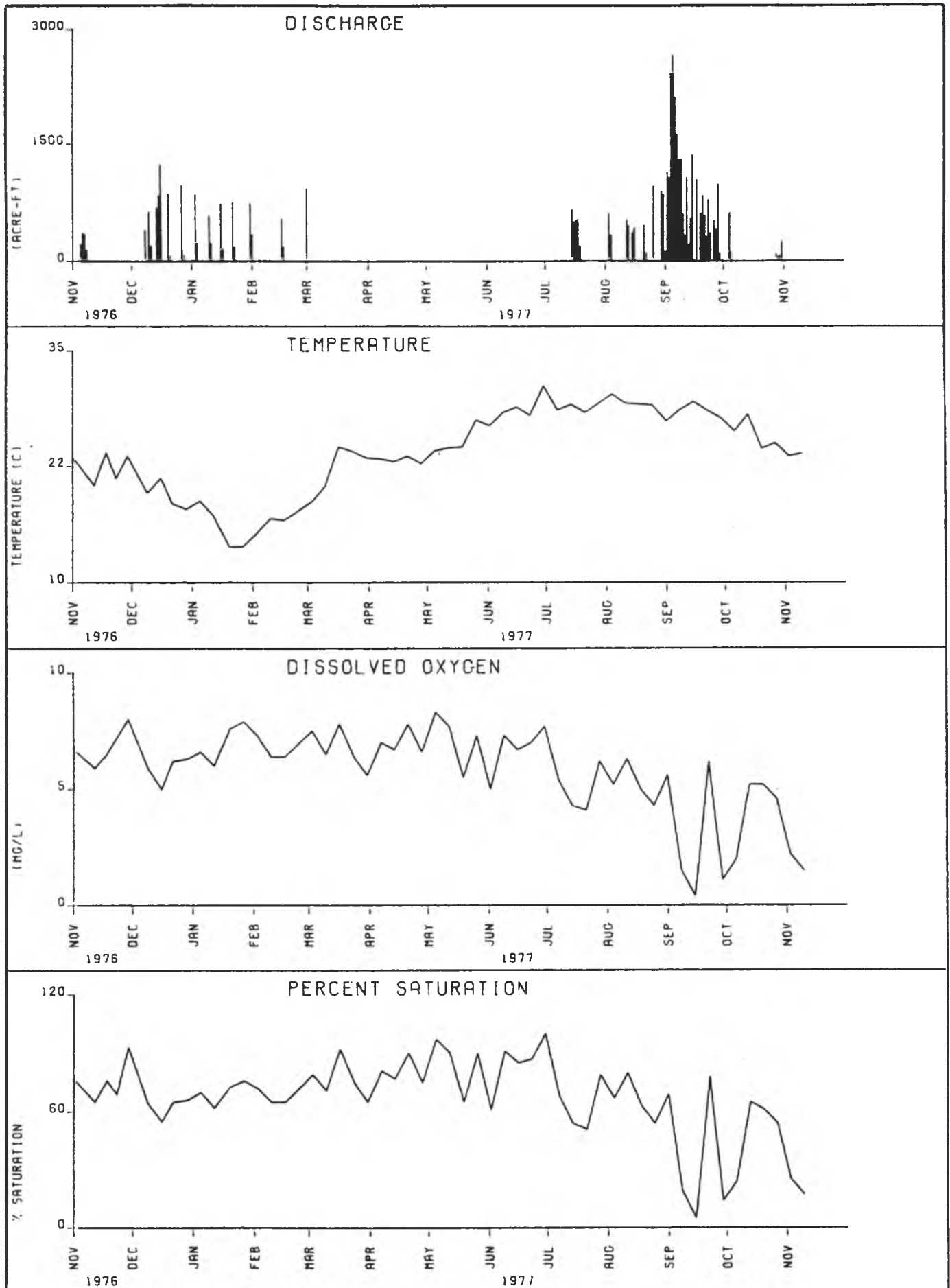
44

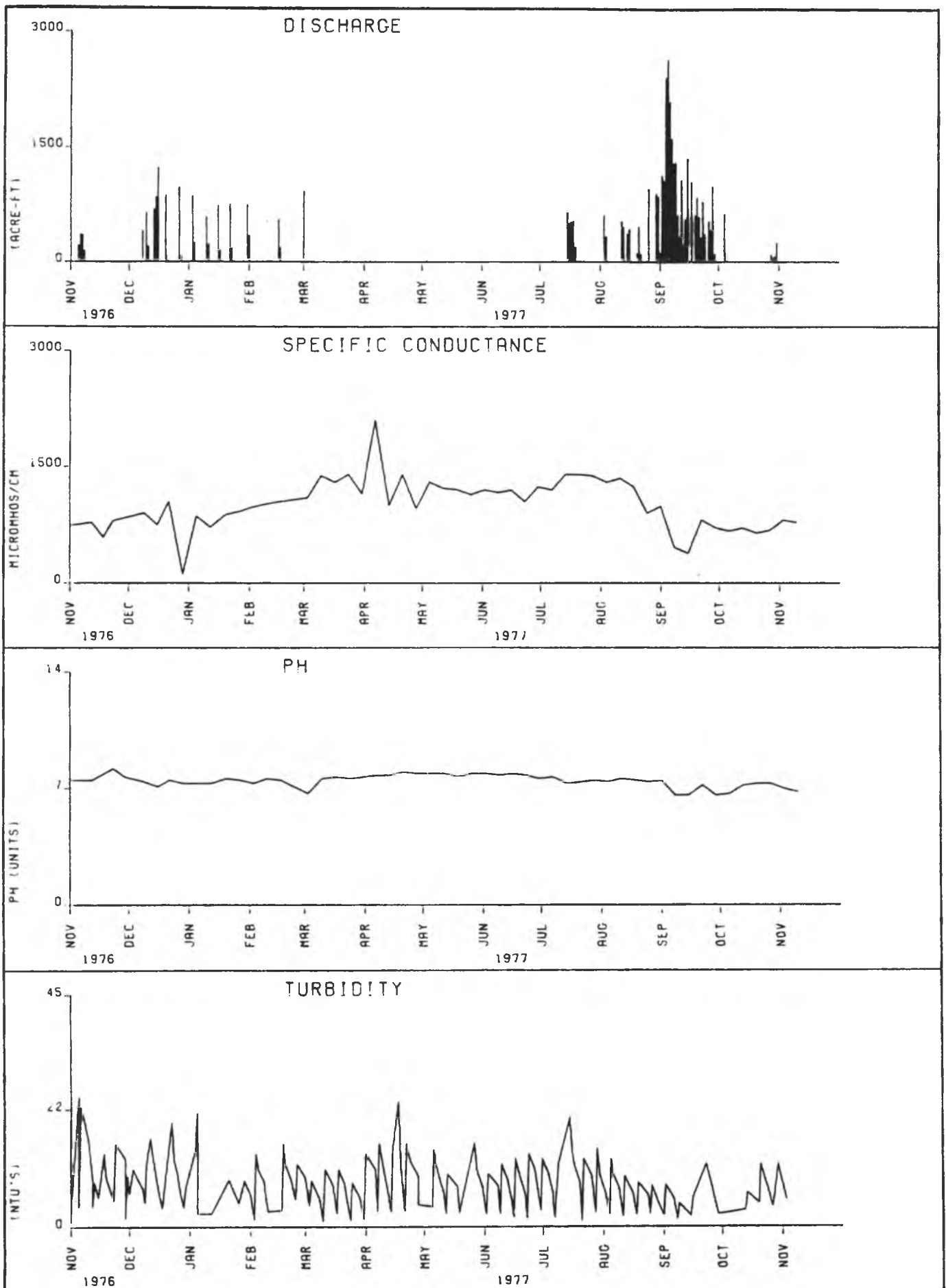Figure 18   DISSOLVED OXYGEN, TEMPERATURE AND DISCHARGE FOR C-23 AT S-97

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Figure 19   CONDUCTIVITY, PH, TURBIDITY AND DISCHARGE FOR C-23 AT S-97

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pattern of higher turbidity levels during discharge at S-97 (Figure 19) as there was at S-49 (Figure 12).

<div align="center">C-25 AT S-99</div>

Major Ions

The major cation and anion composition of the surface water at S-99 was very similar to S-49 which were both greater than S-97 (Table 4). The order of abundance of the major ions were: Na^+ (6.8 meq/L) > Ca^{+2} (5.2 meq/L) > Mg^{+2} (2.74 meq/L) > K^+ (0.21 meq/L) > Cl^- (10.4 meq/L) > HCO_3^- (2.9 meq/L) > SO_4^{-2} (2.6 meq/L) (Figure 4). The major ion pattern of the surface water at S-99 (Figure 5) and the groundwater in the C-25 basin were very similar in shape, with the surface water being of lower concentration for the major cations and chloride. This similarity is supportive of a stronger groundwater/surface water relationship than was observed at either S-49 or S-97.

The seasonal changes in the major ions followed the basic trends of increasing dry season concentrations and decreasing wet season concentrations previously described for S-49 and S-97 (Figures 20 to 22). However, for several ions, especially chloride, sodium, magnesium, and potassium, the summertime decline in concentrations occurred in early summer rather than in late summer. As was previously discussed for S-49 and S-97, the lower mineral levels also occurred during discharge events at S-99.

The seasonal pattern for silica provides another distinction in the seasonal behavior of the mineral content at S-99, as compared to S-49 and S-97. At S-49 and S-97, the minimum in the seasonal silica cycle occurred in mid-March, followed by a steadily increasing trend throughout the summer (Figure 21). At S-99, the silica minimum also occurred in mid-March, however, the levels increased rapidly, reaching peak concentrations by mid-April.

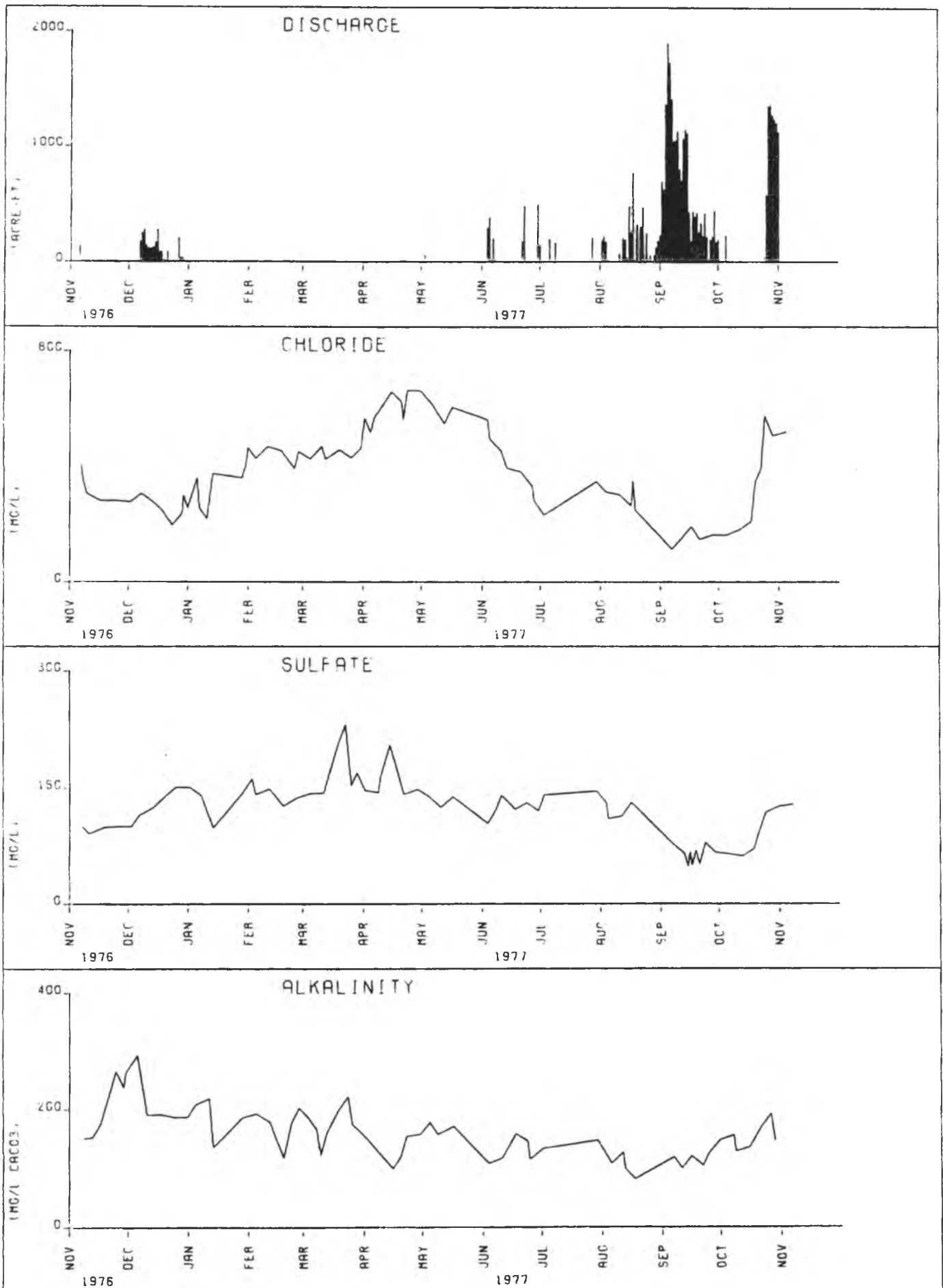<div align="center">47</div>

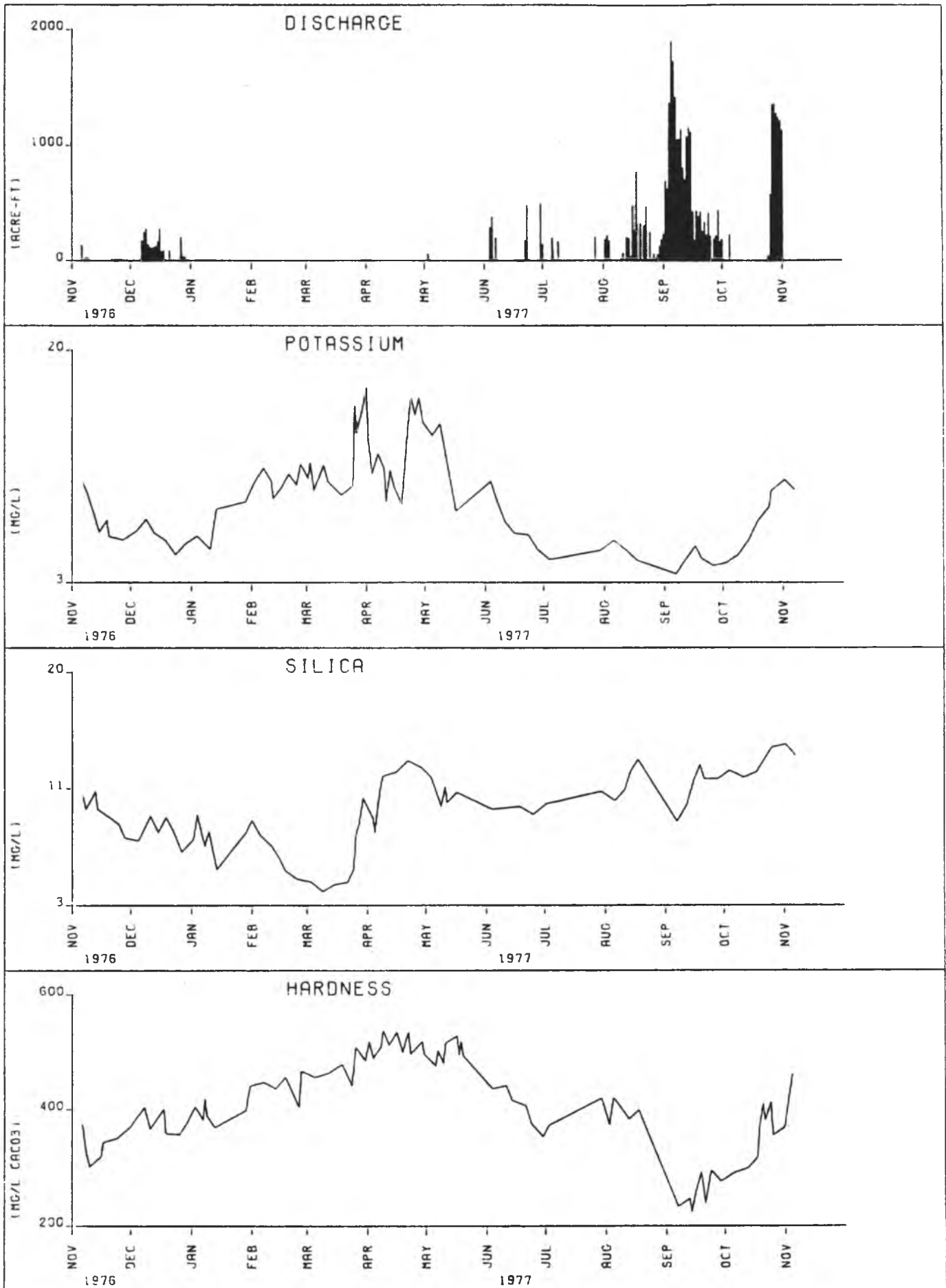Figure 20   CHLORIDE, SULFATE, ALKALINTY AND DISCHARGE FOR C-25 AT S-99

Figure 21   POTASSIUM, SILICA, HARDNESS AND DISCHARGE FOR C-25 AT S-99
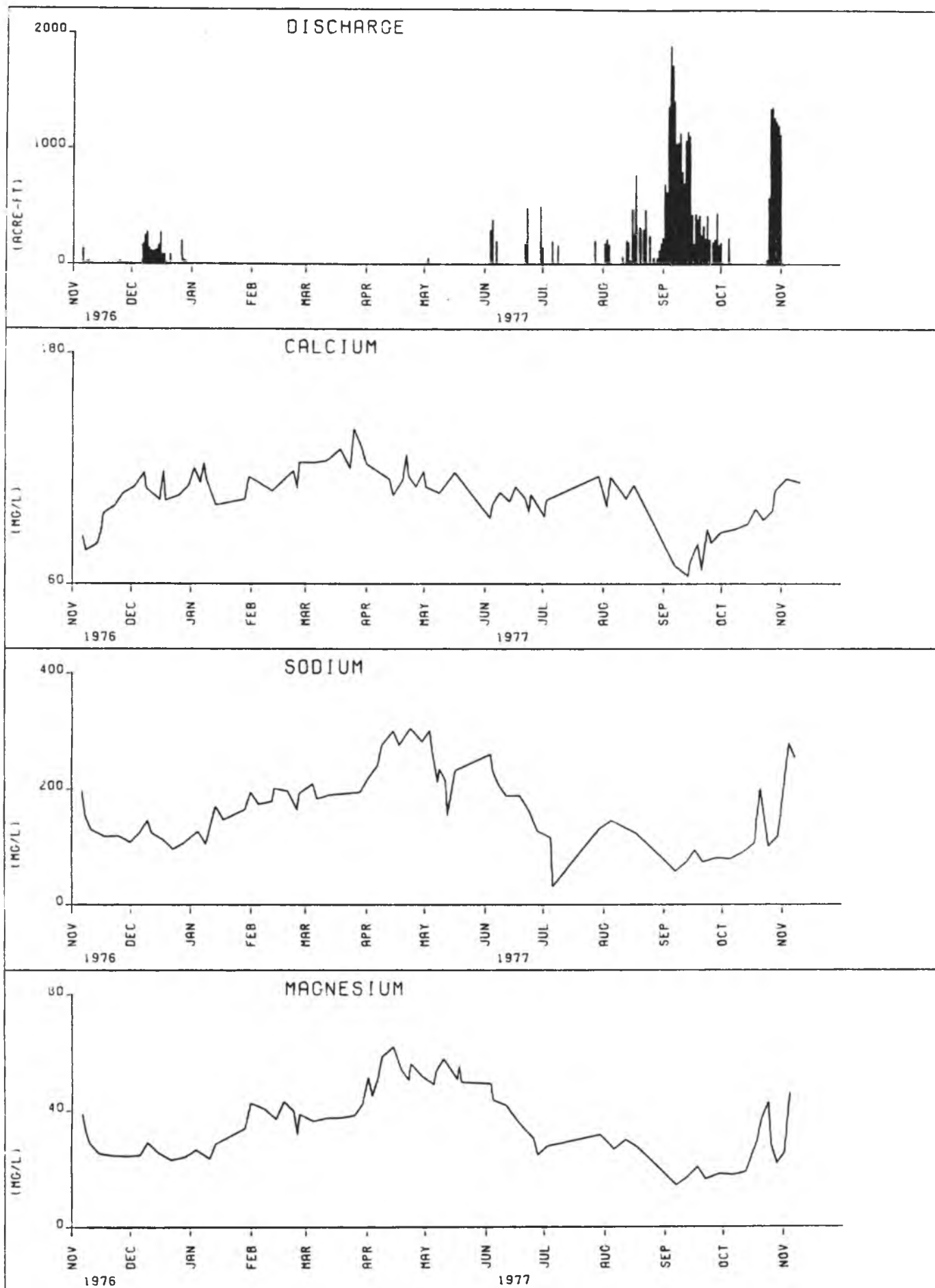
Figure 22   CALCIUM, SODIUM, MAGNESIUM AND DISCHARGE FOR C-25 AT S-99

Nitrogen and Phosphorus

The average nitrogen and phosphorus concentrations at S-99 were less than S-49 and S-97 (Table 5). The mean annual total nitrogen concentration at S-99 was 1.19 mg/L compared to 1.44 mg/L at S-49 and 1.30 mg/L at S-97. The average concentration of the various nitrogen species was also lower at S-99 than at S-49 or S-97. The most distinguishable difference in a comparison of nitrogen concentrations occurred in the nitrate levels, which at S-99 were half those of S-49 and S-97. Average ortho phosphorus levels at S-99 were also half those of S-97 and less than one-fourth those of S-49. In addition, ortho phosphorus averaged only 50 percent of the total phosphorus concentration compared to 66 percent at S-97 and 73 percent at S-49. Mean annual total phosphorus concentrations were also substantially less at S-99 (0.064 mg/L) than at S-49 (0.192 mg/L) and S-97 (0.106 mg/L).

Another distinguishing characteristic between the nutrient levels at S-99 and those at S-49 and S-97 relate to the maximum concentrations. Although the average nitrogen and phosphorus concentrations were lowest at S-99, the lowest peak concentrations did not consistently occur at this location. The peak total nitrogen, nitrite, ammonia, and organic nitrogen levels at S-99 were intermediate between S-49 and S-97.

Although the lowest maximum ortho and total phosphorus concentration occurred at S-99, the same basic seasonal patterns observed at S-49 and S-97 were also evident at S-99. Phosphorus concentrations were very low from December to August (Figure 23). In September there was a seasonal peak in phosphorus concentration which corresponded to the period of heaviest rainfall and discharge activity. However, while a late summer seasonal increase in inorganic nitrogen was recorded at S-49 and S-97 there was no similar peak measured at S-99 (Figure 24).
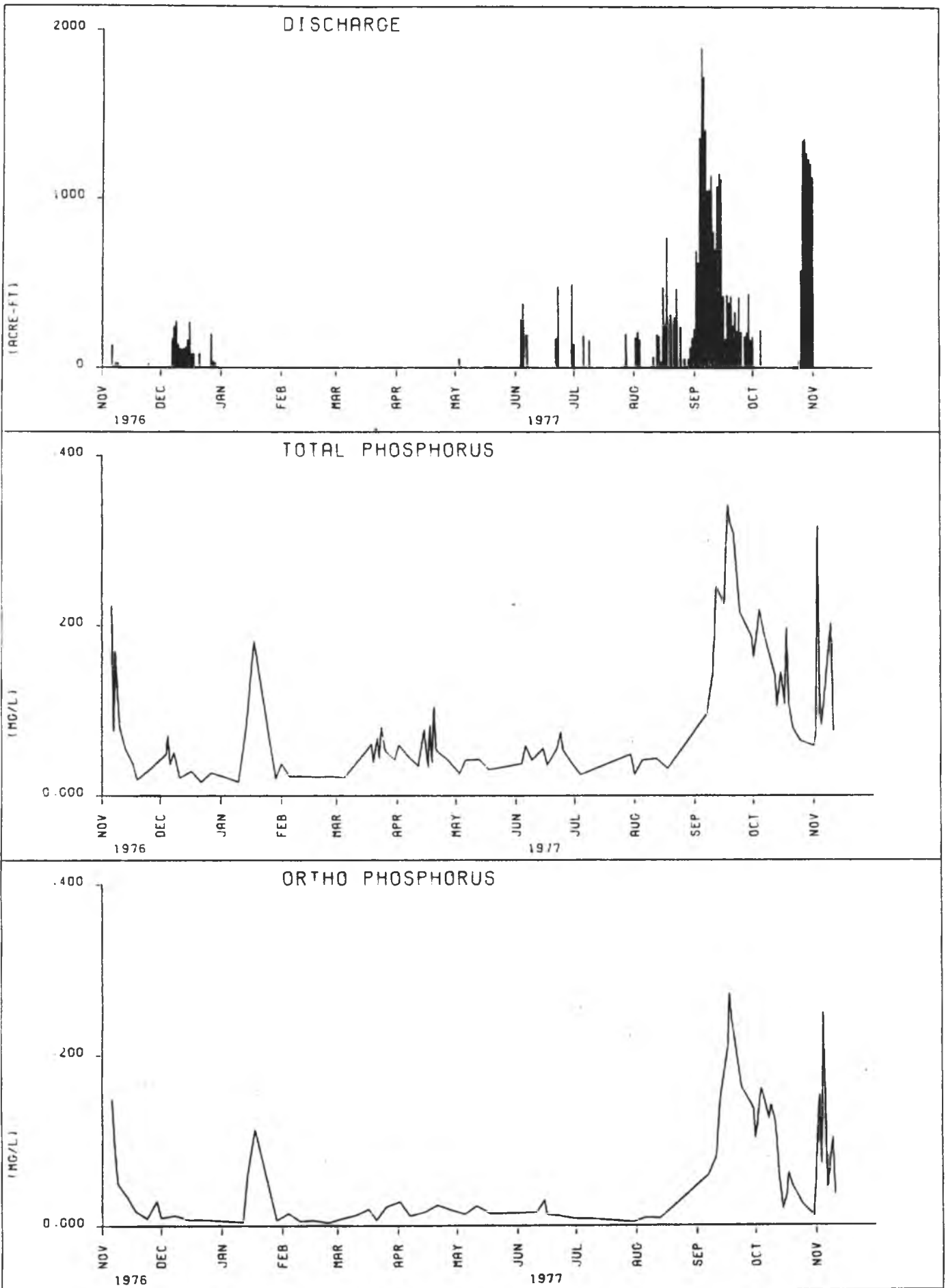
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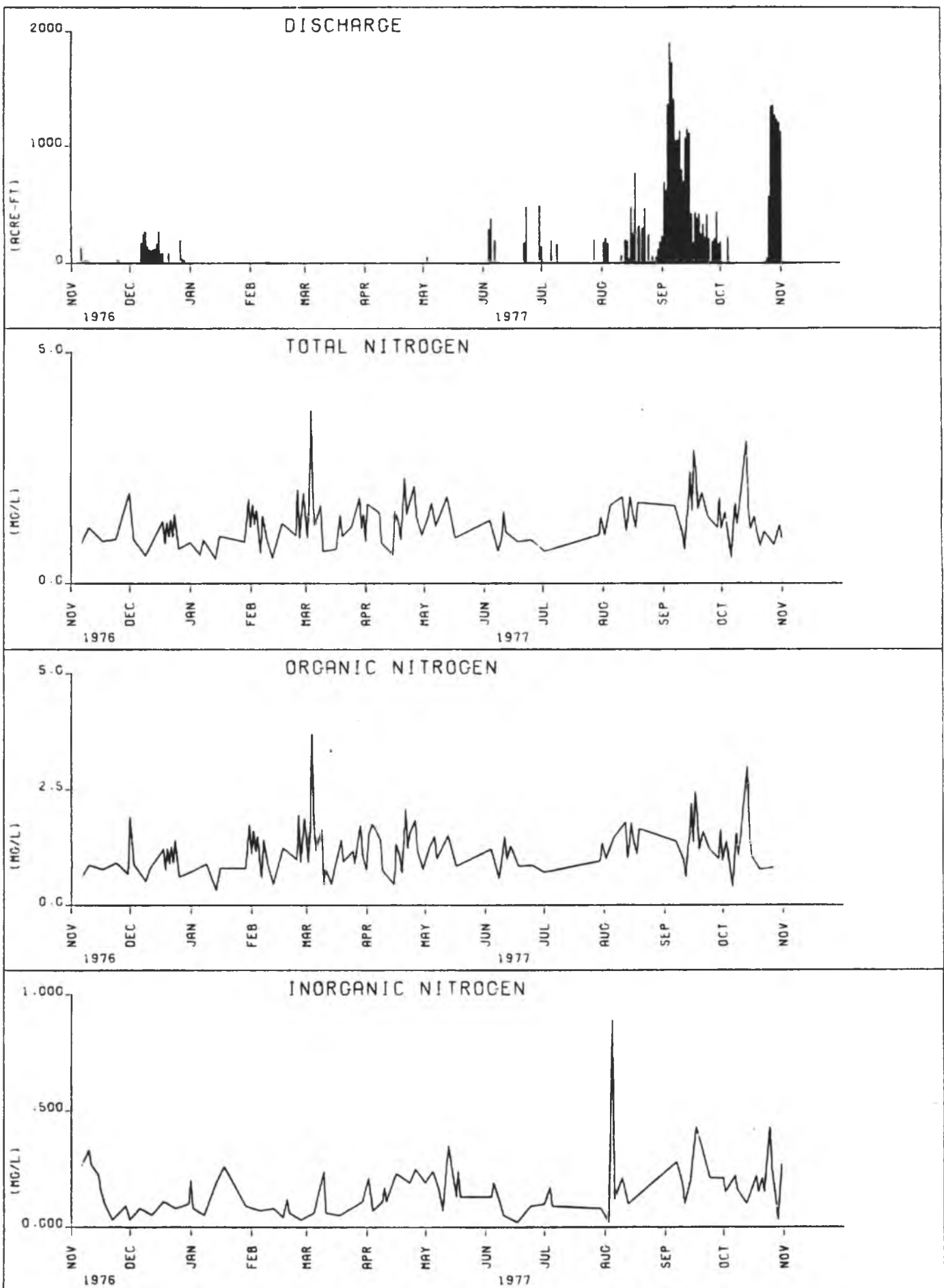Figure 23   PHOSPHORUS AND DISCHARGE FOR C-25 AT S-99

Figure 24 NITROGEN AND DISCHARGE FOR C-25 AT S-99

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Field and Physical Parameters

The average dissolved oxygen concentration at S-99 (4.4 mg/L) was lower than at either S-49 (5.1 mg/L) or S-97 (5.5 mg/L); however, the range of values (0.2 to 9.1 mg/L) were similar to the ranges reported for S-49 and S-97. The seasonal dissolved oxygen pattern at S-99 was also similar to S-49 and S-97 with the highest concentrations occurring during the winter (3 to 9 mg/l) and the lower concentrations occurring during the summer (0.2 to 8 mg/l). The lower dissolved oxygen concentrations also tended to occur during discharge (Figure 25). Percent saturation again paralleled the dissolved oxygen concentration. Percent saturations of less than 40 were common during the late summer months (Figure 25).

The specific conductance at S-99 was very similar to S-49 (Table 6) since there was a close similarity in the mineral composition. The average specific conductance of 1592 micromhos/cm and range of 140 to 2800 micromhos/cm is indicative of the high dissolved soids content at S-99. The seasonal conductivity pattern at S-99 was also very similar to S-49 and S-97 with an increasing trend during the dry season and a decreasing trend during the wet season. The lower conductivity values were usually measured during periods of discharge.

The pH at S-99 was also very similar to S-49 and S-97 (Table 6). The narrow range of pH values (6.5 to 7.9) (Figure 26) at S-99 is indicative of the highly alkaline waters in C-25 and is similar to the pH range of the groundwater (7.2 to 7.7).

The range (0.5 to 13.0 NTU) and average (2.7 NTU) turbidity levels at S-99 were lower than at either S-49 or S-97 (Table 6). The higher turbidity values were usually measured during periods of discharge (Figure 26).
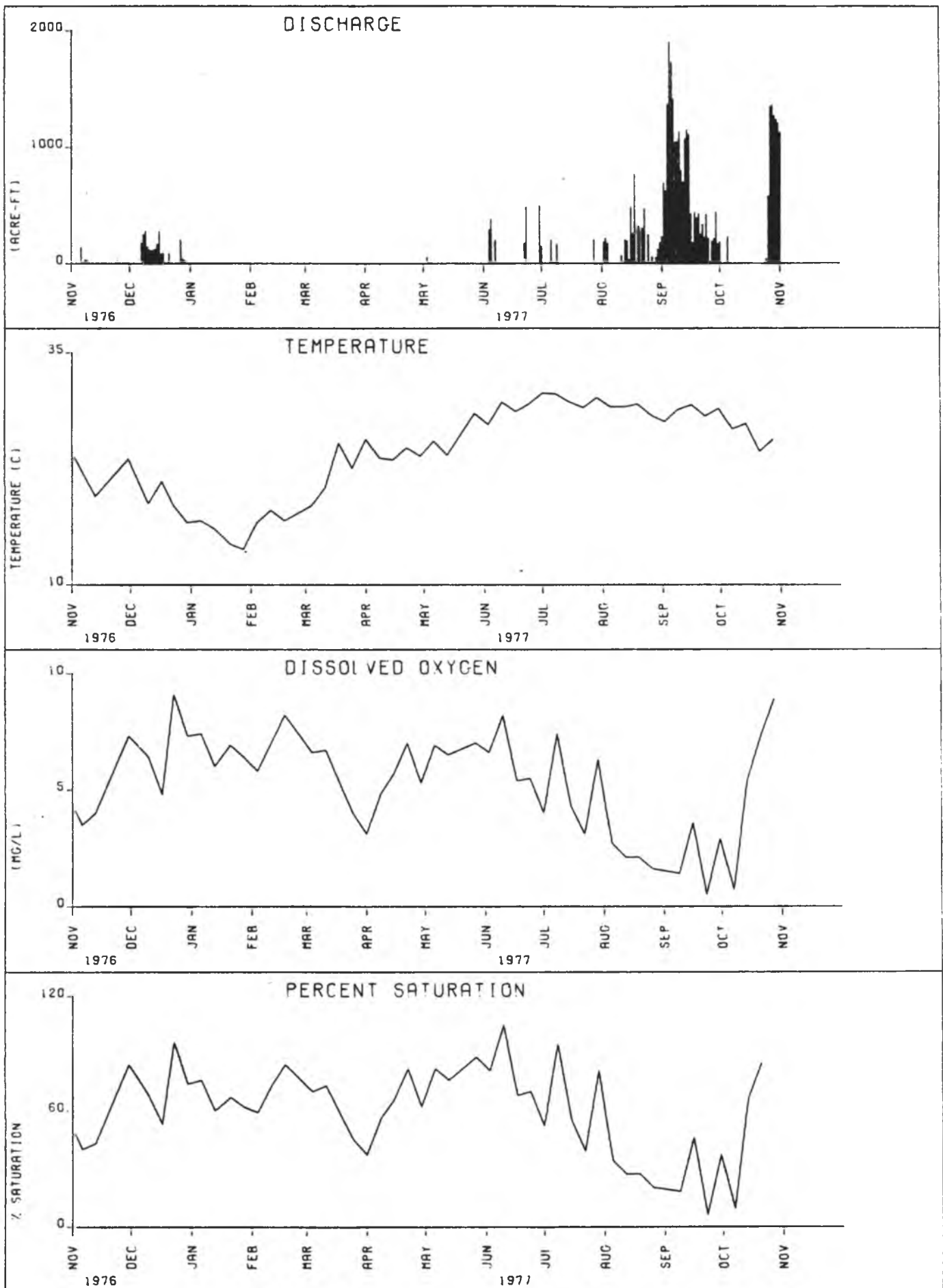
Figure 25   DISSOLVED OXYGEN, TEMPERATURE AND DISCHARGE FOR C-25 AT
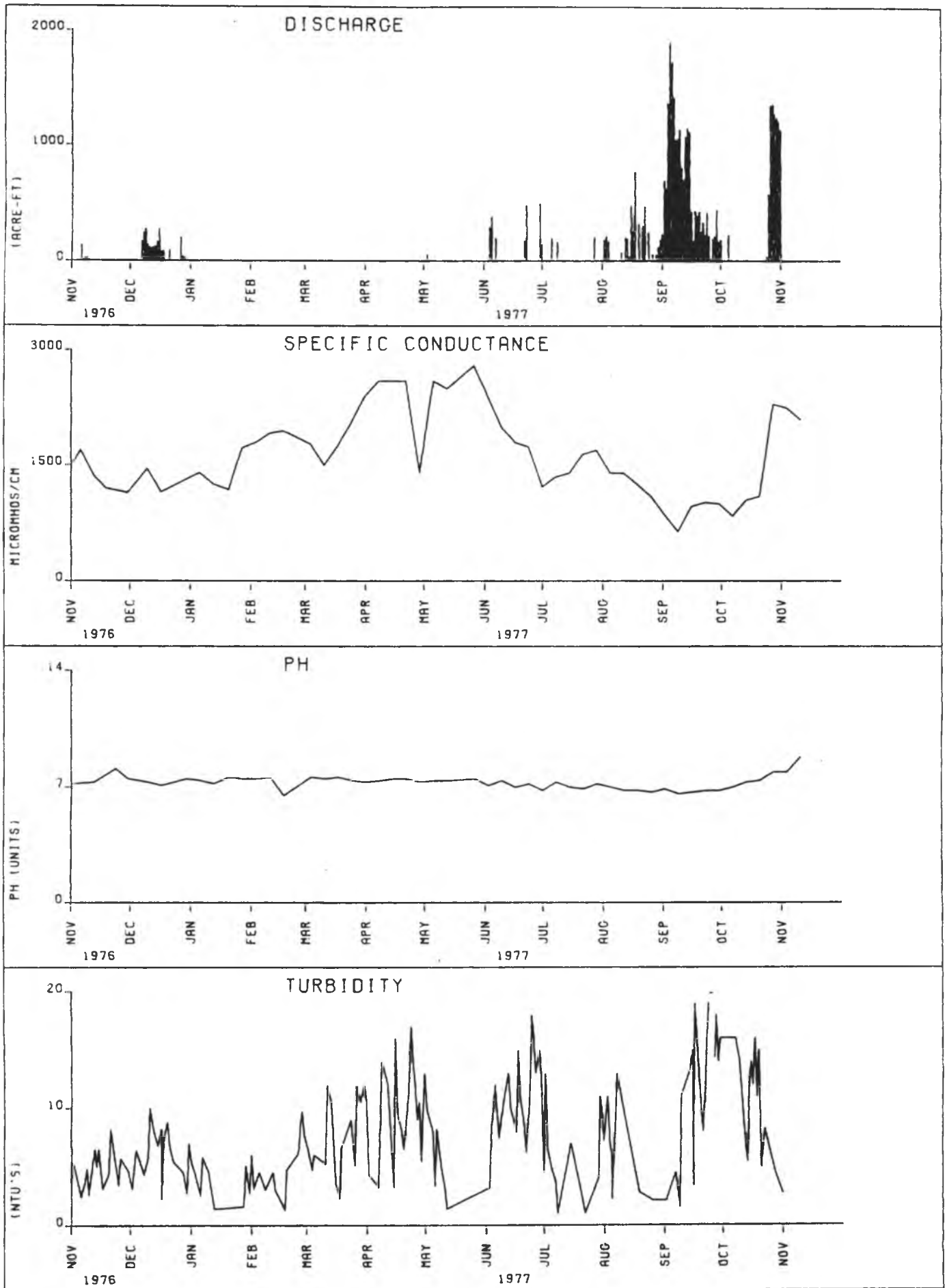S-99

Figure 26   CONDUCTIVITY, PH, TURBIDITY AND DISCHARGE FOR C-25 AT S-99

DISCUSSION

The most distinguishing water quality characteristics at S-49, S-97, and S-99 were the high dissolved solids levels. Mean annual specific conductance ranging between 1039 and 1605 micromhos/cm for the three structures were indicative of the high dissolved solids levels at these locations. Surface waters at the three structures could, however, be differentiated based upon relative differences in the major ion levels. The generalized ranking of the structures based upon flow-weighted major ion concentrations was: S-49 > S-99 > S-97 (Table 7). Reversals in the rankings occurred between S-49 and S-99 for sulfate and between S-99 and S-97 for alkalinity.

The relative abundance of the major ions in the surface water at S-49, S-97, and S-99 were similar to the relative abundance in the groundwater in each basin, indicating an influence of groundwater irrigation practices in these basins on the surface water in the primary canal system. This similarity was greatest at S-99 and smallest at S-97.

During this study there were two distinct discharge periods at each structure, one during the dry season and one during the wet season. The dry season discharges were in response to higher canal stages which resulted from artesian groundwater irrigation (Figure 26). The wet season discharges were in response to intense rainfall activity and subsequent runoff. The sources of the discharge water appear to play a major role in determining the temporal quality characteristics of the water in the canals.

Temporal variations in the major ions followed a generalized seasonal pattern at all three structures. Typically, the ion levels were highest during the dry season (November to June) as a result of irrigation practices utilizing artesian groundwater, since the dry season rainfall was minimal. This pattern was previously identified by Bearden (1972) who reported that the increase in the ion levels in the canals was due to the continued use of

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TABLE 7. RELATIVE RANKING OF C-24, C-23, AND C-25

Parameter (mg/L)[1]	Ranking
Major Ions (flow weighted)	
Cl⁻	S-49 (337.5) > S-99 (270.6) > S-97 (161.3)
Alkalinity(HCO_3) (as $CaCO_3$)	S-49 (141.1) > S-97 (140.1) > S-99 (127.8)
SO_4^{-2}	S-99 (101.1) > S-49 (90.2) > S-97 (57.2)
Na^+	S-49 (150.1) > S-99 (98.1) > S-97 (78.3)
K^+	S-49 (8.2) > S-99 (5.9) > S-97 (5.1)
Ca^{+2}	S-49 (93.3) > S-99 (89.9) > S-97 (76.2)
Mg^{+2}	S-49 (28.0) > S-99 (21.7) > S-97 (15.8)
Hardness (as $CaCO_3$)	S-49 (346.4) > S-99 (312.6) > S-97 (255.3)
Nutrients (flow weighted)	
Total P	S-49 (.260) > S-97 (.158) > S-99 (.113)
Ortho P	S-49 (.201) > S-97 (.110) > S-99 (.062)
Total N	S-97 (1.58) > S-49 (1.54) > S-99 (1.38)
NO_3	S-97 (.143) > S-49 (.130) > S-99 (.051)
NO_2	S-97 (.017) > S-49 (.011) > S-99 (.010)
NH_4	S-49 (.146) > S-99 (.108) > S-97 (.093)
Inorganic N	S-49 (.297) > S-97 (.253) > S-99 (.153)
Organic N	S-97 (1.33) > S-49 (1.25) > S-99 (1.22)
Field & Physical Parameters (time weighted)	
Dissolved Oxygen	S-97 (5.5) > S-49 (5.1) > S-99 (4.4)
Sp. Conductance (micromhos/cm)	S-49 (1605) > S-99 (1592) > S-97 (1039)
pH	S-97 (7.4) > S-49 (7.3) > S-99 (7.2)
Turbidity (NTU)	S-97 (3.6) > S-49 (3.0) > S-99 (2.7)

[1] unless otherwise noted

mineralized artesian water, some concentration of fertilizers from the recirculation of irrigation water, and the decrease in the amount of fresh water available to the canals for diluting and flushing. The lack of rainfall and subsequent dilution was the dominant factor. The lowest ion concentrations occurred during the wet season in response to the dilution effect of rainfall. This response was clearly evident in September.

Silica was present in the surface water at S-49, S-97 and S-99 at high levels ranging from 9.5 to 14.6 mg/L. A distinct seasonal pattern was evident in the temporal variations of the silica levels which was opposite to that of the major ions. Silica concentrations decreased during the dry season months of November to mid-March and then increased steadily through the summer. Large rainfall events near S-49 and S-97 caused dramatic declines in silica levels in early September.

A comparison of the flow-weighted nitrogen and phosphorus concentrations with the time-weighted concentrations indicate that, in general, the higher nutrient levels occurred during discharge events. However peak inorganic nutrient (especially phosphorus) concentrations occurred during wet season discharges which resulted from rainfall. During dry season season discharge the nutrient levels tended to decline. It appears that dry season runoff, resulting from artesian groundwater irrigation, does not result in elevated nutrient levels in the canals, while rainfall derived runoff does cause higher nutrient levels. The phenomenon may be the result of both the irrigation and fertilization practices employed in the area. During this study, flood irrigation was the primary irrigation technique employed in the basins. In more recent years there has been a dramatic shift to more efficient irrigation systems such as drip and microjet for citrus. For citrus the crown flood irrigation method consists of three phases: In the first phase, water is pumped onto an isolated block of citrus until it floods to the crown of the

bed or at least near the base of the established trees. In the second phase, the pumping operation ceases and a brief "soak" time is permitted. In the third phase, water is drained from the block as fast as practical and returned to the project system for further use. The entire cycle usually takes place within three days. It is estimated that slow drainage from the saturated root zone takes place for two more days after the end of phase III. The root zone is assumed to be at field capacity after the free water has drained from the beds. The irrigation frequency is a function of the water holding capacity of the root zone and the consumptive use of the growing plants. For improved pasture the water table is raised in the secondary canal systems and allowed to seep into the adjoining land. These flood irrigation techniques do not provide an opportunity for prolonged contact between the subsurface water and the fertilizer applications which are applied to the surface in fall/winter. As a result there is little leeching of fertilizers during the dry season. This provides an explanation for the lack of an increase in phosphorus levels in the primary canals even though there was discharge.

In the summer, however, the discharge was the result of rainfall which percolates through the soil surface and, therefore, can leach out the late spring fertilizer application which is also applied on the surface. This mechanism can explain the sharply increased inorganic phosphorus levels, and to a lesser degree increased inorganic nitrogen levels, which were discharged during the summer months.

The absolute nitrogen and phosphorus concentrations measured at S-49, S-97, and S-99 were not unusual or distinctive for surface waters in south Florida. However, the variability in the nutrient levels between the three structures was greater than the comparative variability between major ion levels. There was almost a three-fold range in the total phosphorus flow-weighted concentration and a four-fold range in the ortho phosphorus

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concentration. The highest flow-weighted ortho and total phosphorus concentrations occurred at S-49 (0.201 and 0.260 mg/L, respectively) while the lowest concentrations were at S-99 (0.050 and 0.097 mg/L, respectively).

The variability in nitrogen concentrations were less than the variability in the phosphorus concentrations. There was little variation in total nitrogen and organic nitrogen or in the combined inorganic nitrogen species. The most variable individual nitrogen species was nitrate (0.053 to 0.143 mg/L) and ammonia (0.093 to 0.146 mg/L). S-97 had the highest nitrogen concentrations except for ammonia. The highest flow-weighted ammonia concentration was calculated at S-49.

Daytime dissolved oxygen concentrations displayed a similar wide variation in values at all three structures. Minimum values were 0.2 mg/L or less while maximum values were greater than 8 mg/L. There was little difference in the average oxygen concentrations between the three structures, ranging from 4.4 mg/L at S-97 to 5.5 mg/L at S-97.

The same seasonal pattern in dissolved oxygen was apparent at each structure. The highest concentration occurred during the dry season in the late winter while the lowest concentration occurred during the wet season in the late summer.

Variations in percent saturation of dissolved oxygen paralleled the actual concentrations. Saturations ranged from less than 10 percent to over 100 percent.

The pH levels at S-49, S-97, and S-99 were stable, ranging between 6.4 to 8.0. The average pH ranged between 7.2 and 7.4 which was similar to the pH of the groundwater (7.2 to 7.8). The high alkalinity levels in both the surface water and groundwater contribute to the stability of the pH.

Turbidity levels at all three structures were very low, with a range of 0.5 to 16 NTU. The higher turbidity levels tended to occur during discharge.

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PART 5

MATERIAL LOADING ANALYSIS

Basin Export Rates

One objective of this study was to calculate the material loads which
were exported from the C-23, C-24, and C-25 basins. These loads can be used
in the evaluation of the impact of runoff from the three major UEC Canals on
receiving waters and to generalize land use/water quality relationships.

Table 8 presents the annual material loads calculated from daily
discharge and daily water chemistry data. These material loads were converted
to an areal basis in order to adjust for the differing sizes of the drainage
basins (Table 9). The annual export rates were similar among the three basins
for virtually all the parameters reflecting the close similarity in the land
cover (Table 1).

Effect of Sampling Frequency on Material Load Calculations

The availability of daily discharge and daily water chemistry data
provides an opportunity to examine the effect on material loading calculations
of varying sample collection frequencies. This exercise attempted to evaluate
the effect of varying water quality collection frequencies without varying the
daily frequency of the discharge data. The procedure involved calculating the
material load based upon a daily collection frequency (as previously
described), then recalculating the load assuming samples were collected every
2nd day, then every 3rd day, etc., up to a collection frequency of once every
60 days. This procedure holds all variables fixed except for the periodicity
of the water quality data. The results of applying the technique for the
calculation of orthophosphorus, total phosphorus, inorganic nitrogen, organic
nitrogen, total nitrogen, and chloride loads are presented in Figures 27 to
32. By definition, the "best" frequency was based upon a daily collection

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TABLE 8. ANNUAL MATERIAL LOADINGS AT S-49, S-97, AND S-99

Annual Material Loads [1]

Parameter [2]	S-49 (C-24)	S-97 (C-23)	S-99 (C-25)
Discharge	27,097	48,116	38,766
Cl^-	11,281	9,575	12,946
SO_4^{-2}	3,015	3,395	4,834
Na^+	5,016	4,646	4,691
K^+	273	302	284
Ca^2	3,117	4,527	4,293
Mg^2	937	940	1,036
SiO_2	318	565	554
Total P	8.7	9.4	5.4
Ortho P	6.7	6.5	3.0
Total N	51.4	93.9	66.2
Inorganic N	9.6	15.0	8.0
Organic N	41.8	78.9	58.2

[1] Based upon daily samples (November 1, 1976 to October 31, 1977)

[2] Material loads in 10^6 g except discharge which is in acre-feet

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TABLE 9. ANNUAL EXPORT RATES AT S-49, S-97, AND S-99

Annual Export Rate (g/m^2)

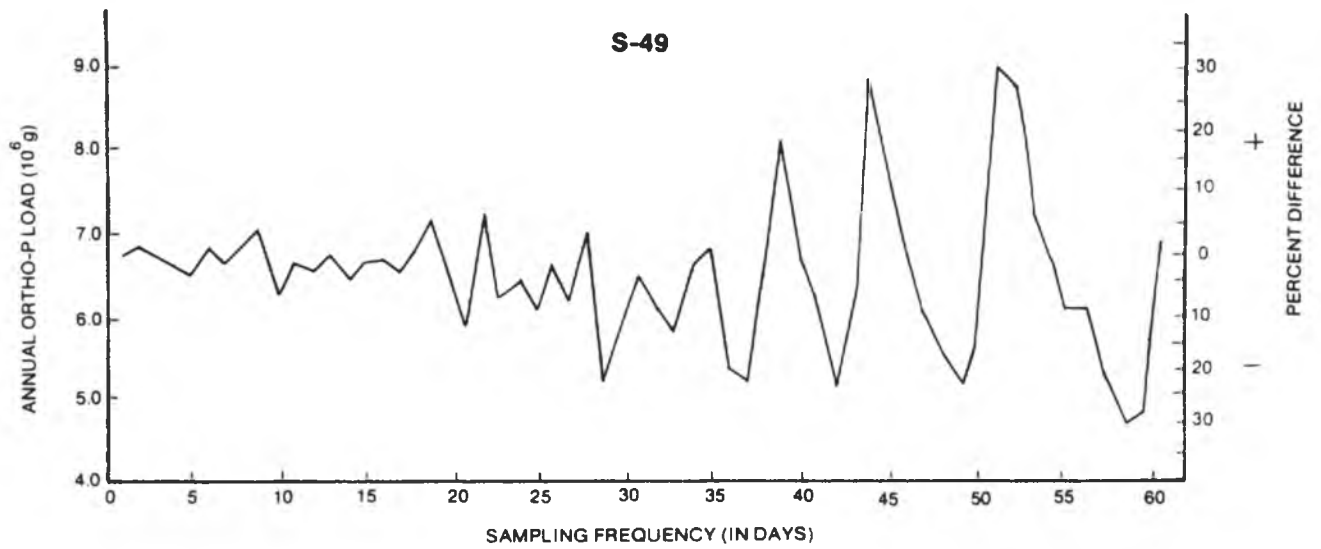| Parameter	S-49 (C-24)	S-97 (C-23)	S-99 (C-25)
Runoff rate (ft/yr)	0.25	0.45	0.38
Cl^-	24.0	20.4	28.9
SO_4^{-2}	6.4	7.2	10.8
Na^+	10.7	9.9	10.5
K^+	0.58	0.64	0.63
Ca^{+2}	6.6	9.6	9.6
Mg^{+2}	2.0	2.0	2.3
SiO_2	0.68	1.2	1.2
Total P	0.02	0.02	0.01
Ortho P	0.01	0.01	0.01
Total N	0.11	0.20	0.15
Inorganic N	0.02	0.03	0.02
Organic N	0.09	0.17	0.13
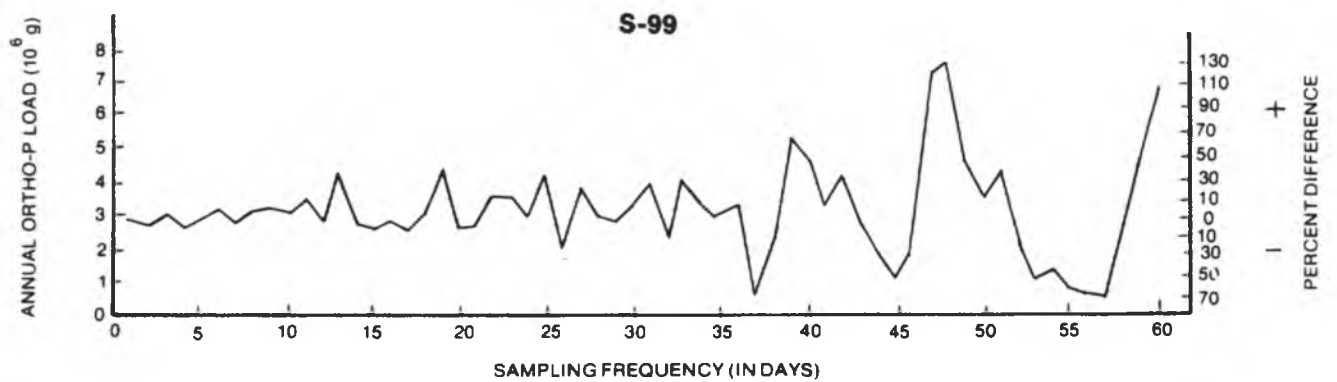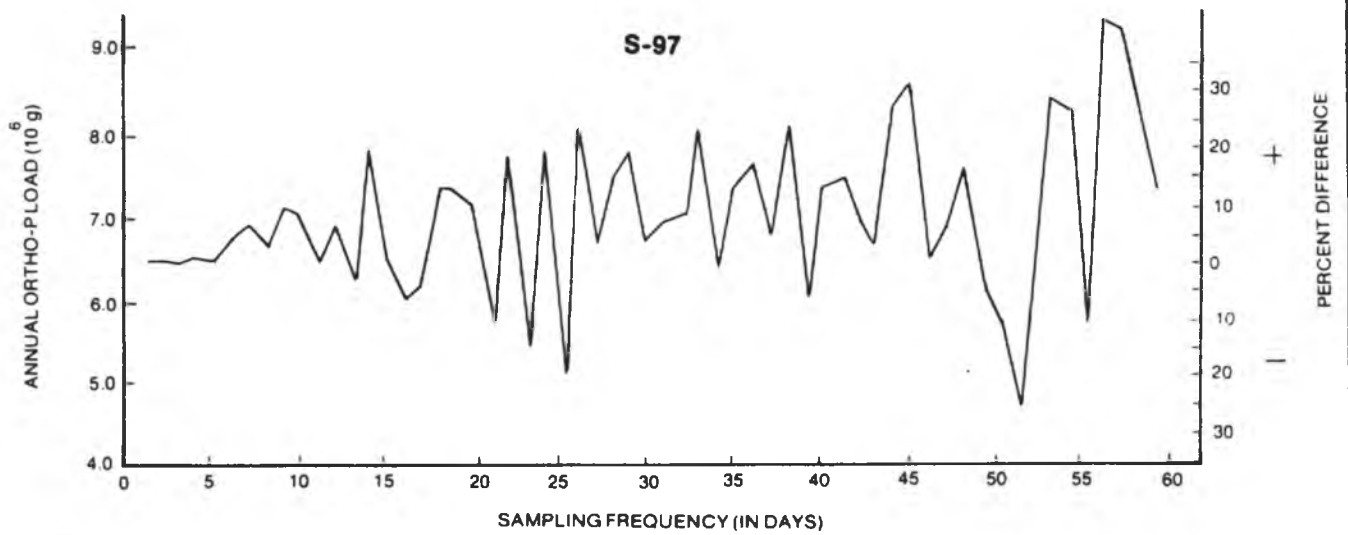
Figure 27   EFFECT OF SAMPLING FREQUENCY ON ANNUAL ORTHO-P LOADS
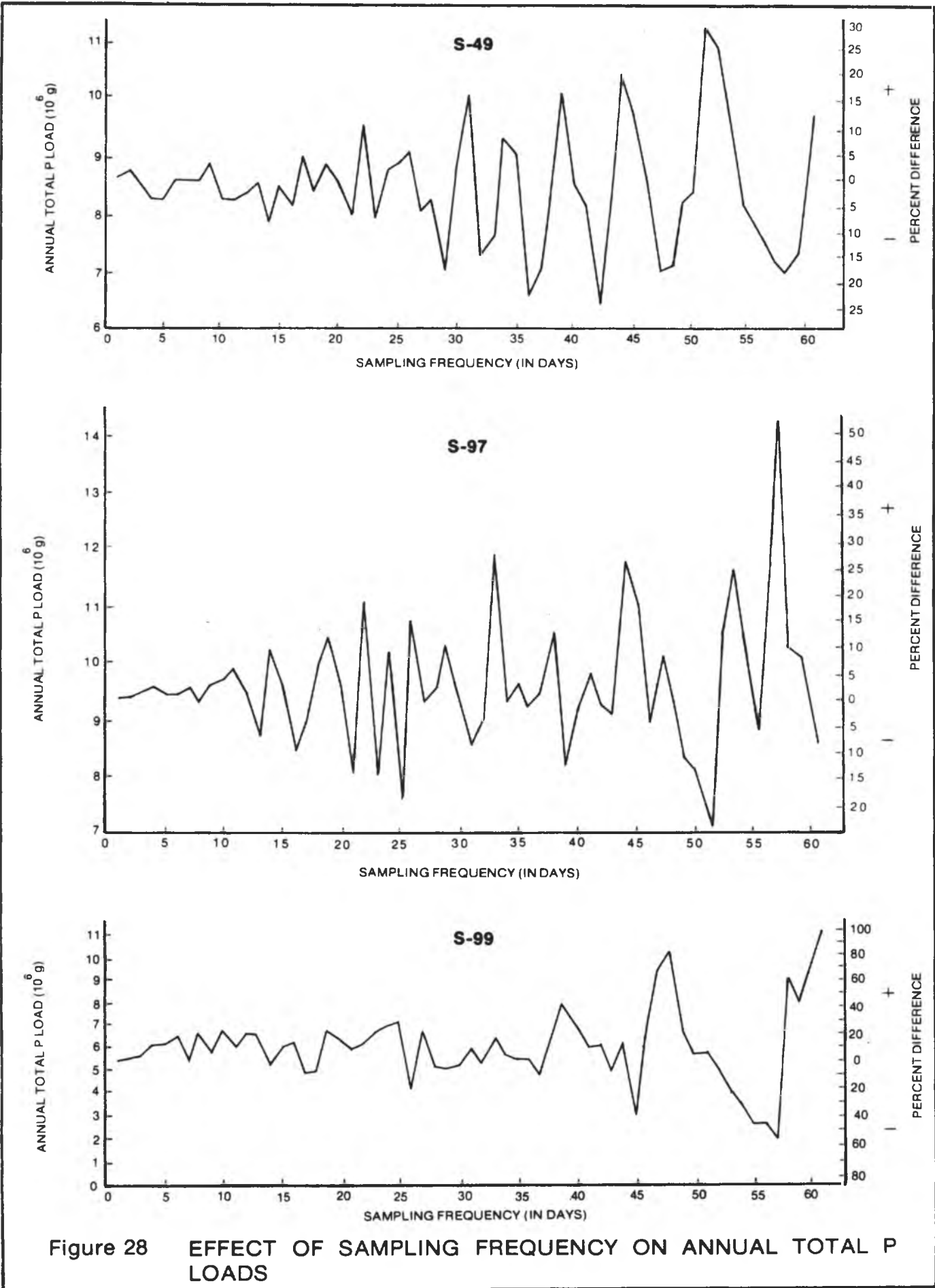
Figure 28   EFFECT OF SAMPLING FREQUENCY ON ANNUAL TOTAL P LOADS
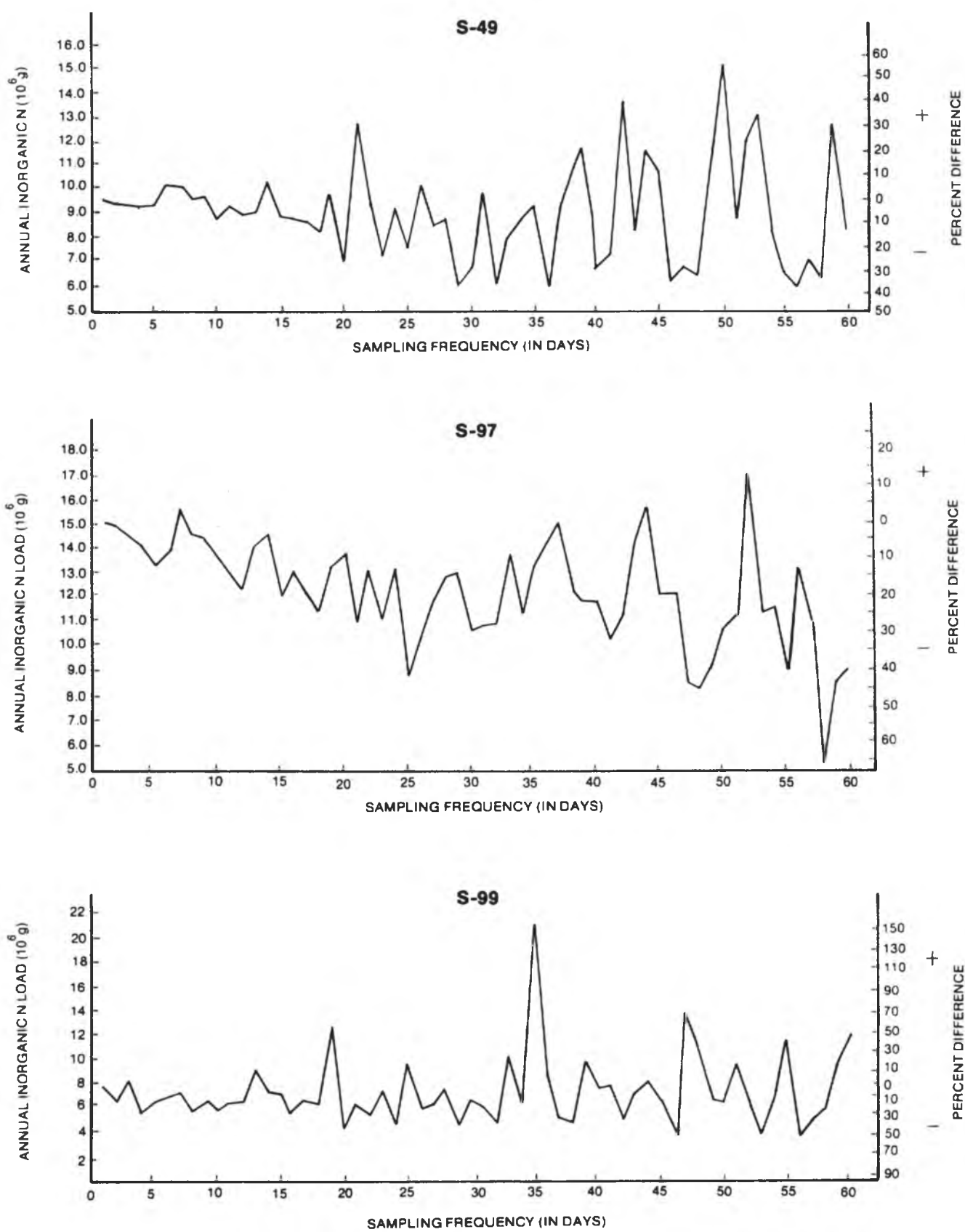
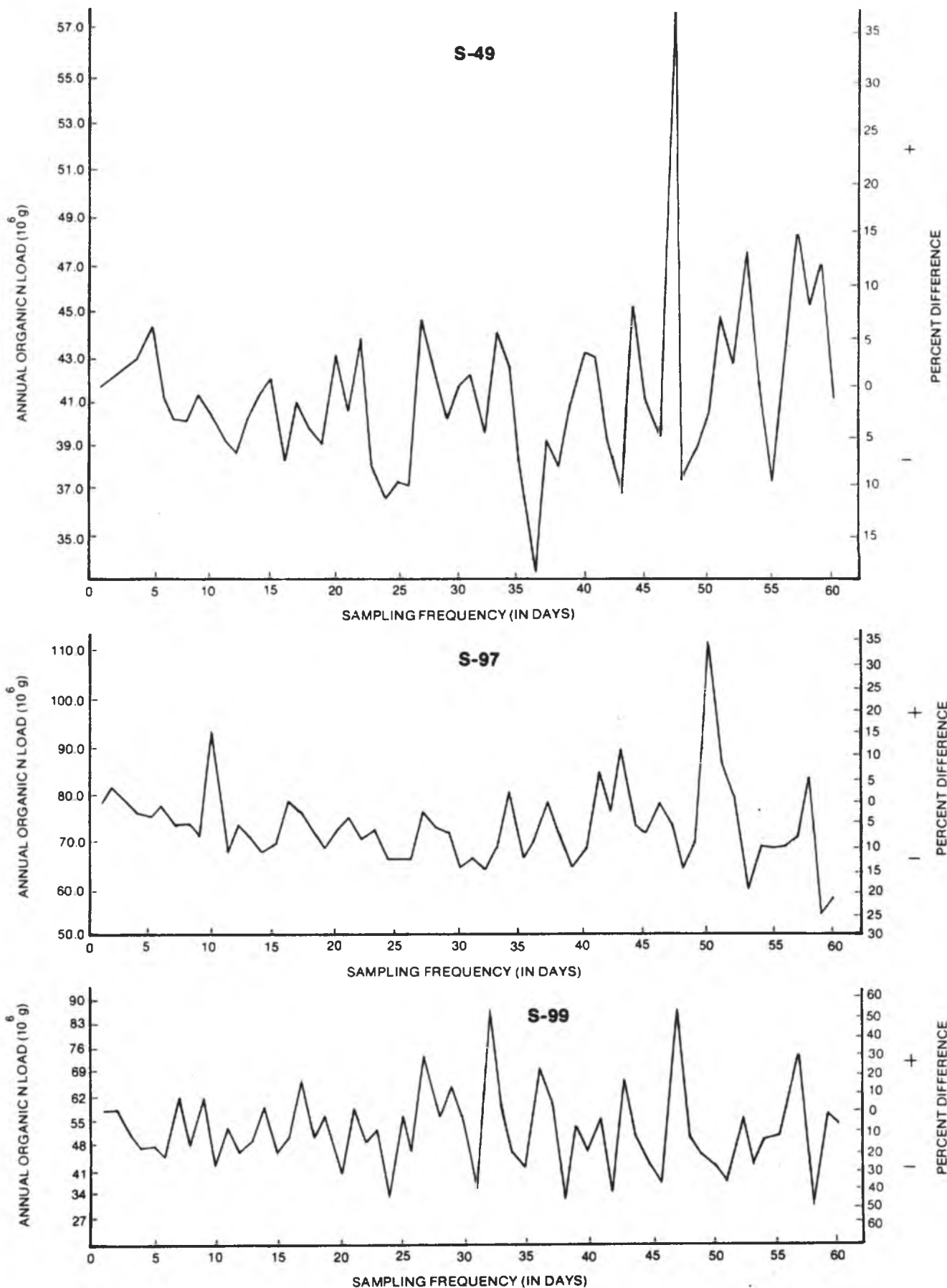Figure 29   EFFECT OF SAMPLING FREQUENCY ON ANNUAL INORGANIC N
             LOADS

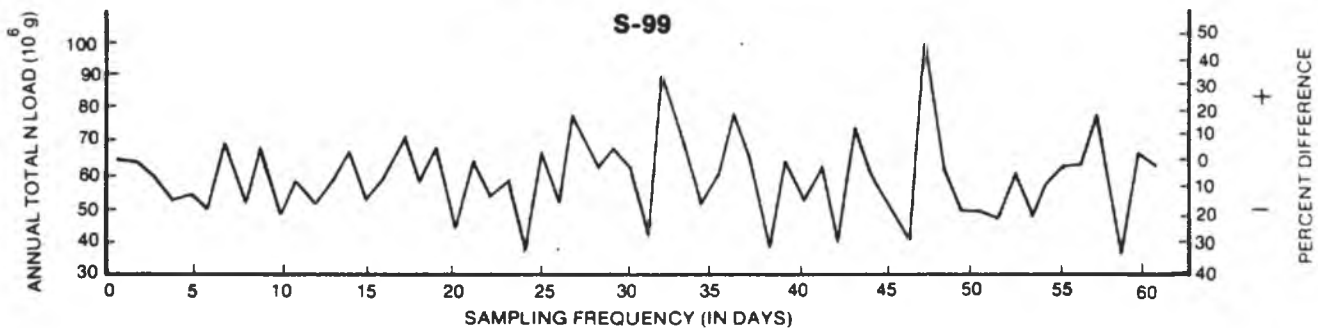Figure 30   EFFECTS OF SAMPLING FREQUENCY ON ORGANIC N LOADS
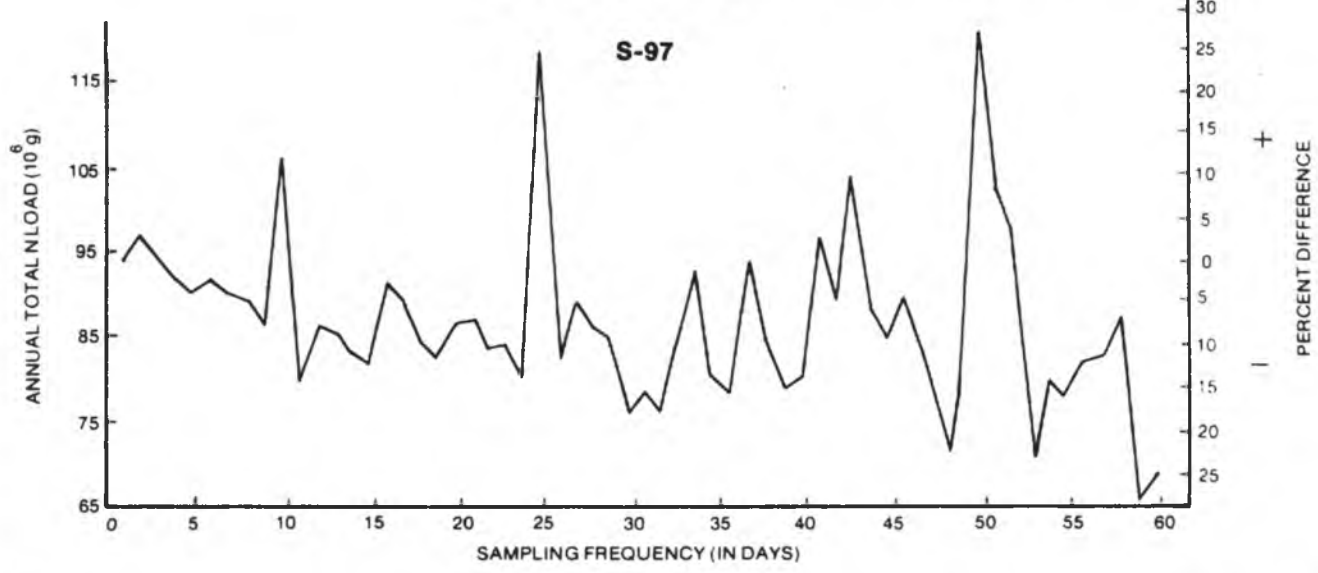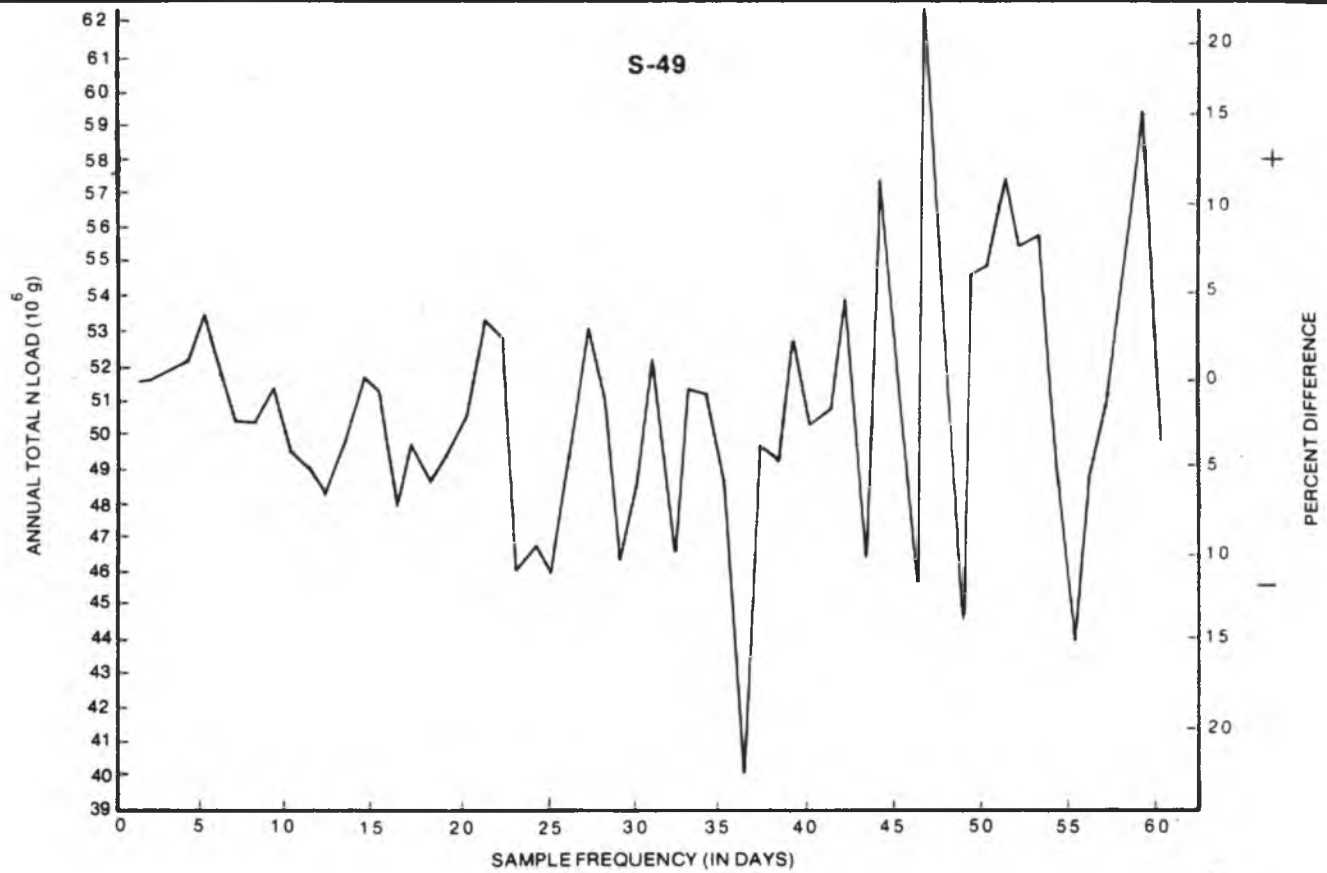
Figure 31   EFFECT OF SAMPLING FREQUENCY ON ANNUAL TOTAL N
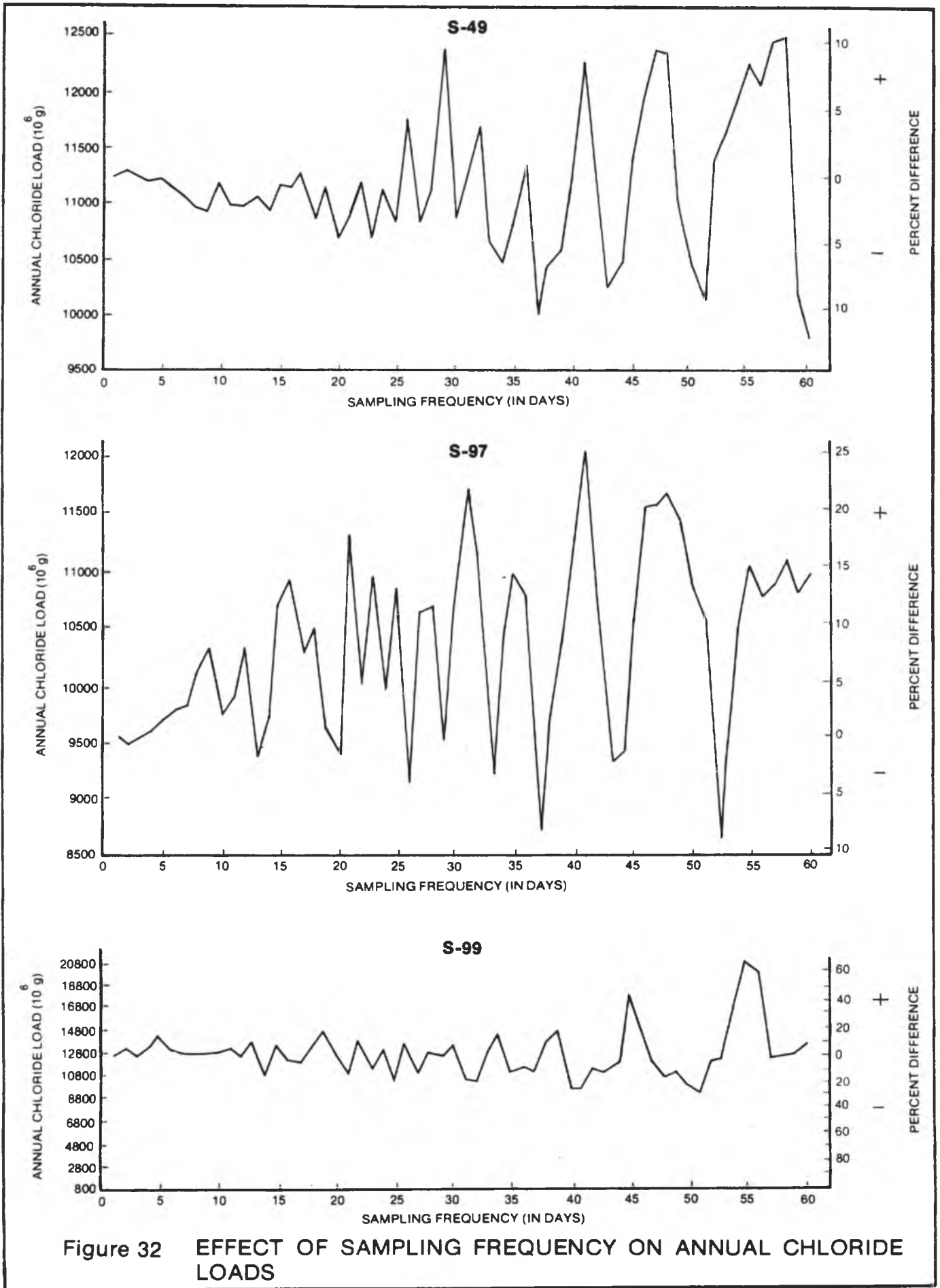LOADS

Figure 32   EFFECT OF SAMPLING FREQUENCY ON ANNUAL CHLORIDE LOADS

frequency. The results of the other sampling frequencies are presented as both the actual load and as a percentage of the best frequency. In general, the variation in the material loads increases as the sampling frequency decreases. The calculation of inorganic nitrogen loads appears to be the most sensitive to changes in sampling frequencies while the chloride loads appear to be the least sensitive.

A summary of the average and ranges in the absolute percent differences for the three structures at weekly intervals are presented in Table 10. These averages and ranges were based on the largest percent difference calculated up to the given weekly interval. There appears to be an approximate linear relationship between the average absolute error and the sampling frequency, although the slope of the relationship varied among the parameters. The variability in the calculated chloride load over all sampling frequencies ranged from 3 to 27 percent. The nitrogen and phosphorus species displayed substantially greater variations. Generally, the inorganic nutrient loads were more sensitive to lower sampling frequencies than were the total nutrient loads. Typically the calculation of total nutrient loads are more important than inorganic nutrient loads. Average errors for calculated total phosphorus and nitrogen loads were approximately 10 percent up to a biweekly sampling frequency. A doubling of the frequency to monthly resulted in an approximate doubling of the average error to 20 percent for total phosphorus and 19 percent for total nitrogen. Another doubling of the sampling frequency to bimonthly resulted in a less than two-fold increase in the total nitrogen error (32%) while the error in the calculated total phosphorus load more than doubled to 47 percent.

A multitude of factors including study objectives, manpower availability, logistics, travel expenses, and analytical costs enter into the decision making process in determining a sampling frequency for a particular study. If

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TABLE 10. SUMMARY OF PERCENT DIFFERENCES IN MATERIAL LOAD CALCULATIONS UNDER VARYING SAMPLING FREQUENCIES

Absolute Percent Difference

Sampling Frequency	Ortho-P	Total-P	Inorg N	Org N	Total N	Chloride
Daily	0 1/	0	0	0	0	0
	0	0	0	0	0	0
Weekly	5 2/	5	11	9	7	3
	3-10 3/	1-11	5-18	5-18	3-14	3-6
Biweekly	13	10	15	14	11	7
	6-20	6-16	9-21	6-23	5-14	2-15
Every 3 weeks	17	12	32	15	15	10
	16-30	6-15	16-52	8-24	12-19	3-19
Monthly	23	20	37	21	19	12
	16-30	15-26	25-52	9-39	8-30	7-20
Every 5 weeks	23	23	53	26	21	14
	16-30	17-26	23-104	9-53	14-34	8-20
Every 6 weeks	39	26	55	27	23	17
	23-70	21-33	39-104	13-53	14-34	10-23
Every 7 weeks	51	36	56	32	23	21
	27-99	23-61	39-106	15-53	20-25	10-36
Bimonthly	55	47	64	37	32	27
	31-100	24-77	41-106	28-54	25-43	12-52

1/ By definition

2/ Average of the three structures largest absolute percent difference up to the given sampling frequency

3/ Range among the three structures of the largest absolute percent difference

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the calculations of material loads is an important study objective, then the foregoing analysis may provide useful input in determining a sampling frequency. It appears that the error in nutrient loading calculations is approximately linear with respect to sampling frequency, at least up to a frequency of two months (Figure 33). Assuming adequate transferability of information, a biweekly sampling frequency appears to produce nutrient loads with an error of about 10 percent. This error is similar to the errors associated with the analytical chemistry process and may be less than the error associated with all but daily measured discharge data. A more frequent weekly sampling program doubles the logistical and manpower costs with only a relatively minimal 5 percent improvement in the material load error. Such a frequency probably would not be justifiable unless the analytical and hydrological errors are also on the order of 5 percent. In instances where daily measured hydrology data is available, a monthly or greater sampling frequency would probably introduce errors which were greater than those associated with the analytical process and the hydrological data collection.

Comparison of Material Loads Calculated from Daily Surface and Weekly Subsurface Samples

The foregoing analysis compared material loads calculated under varying collection frequencies, given the water samples were collected in the same manner (i.e. automatic sampler). This section will compare material loads based on weekly grab samples to the "best" method of daily composite samples (Table 11). In addition to comparing differing collection frequencies, this evaluation more importantly compares differing collection methodologies. The weekly grab samples were collected at the surface and included a surface film, while the daily samples were collected below the surface (0.5 m) by an automatic sampler.
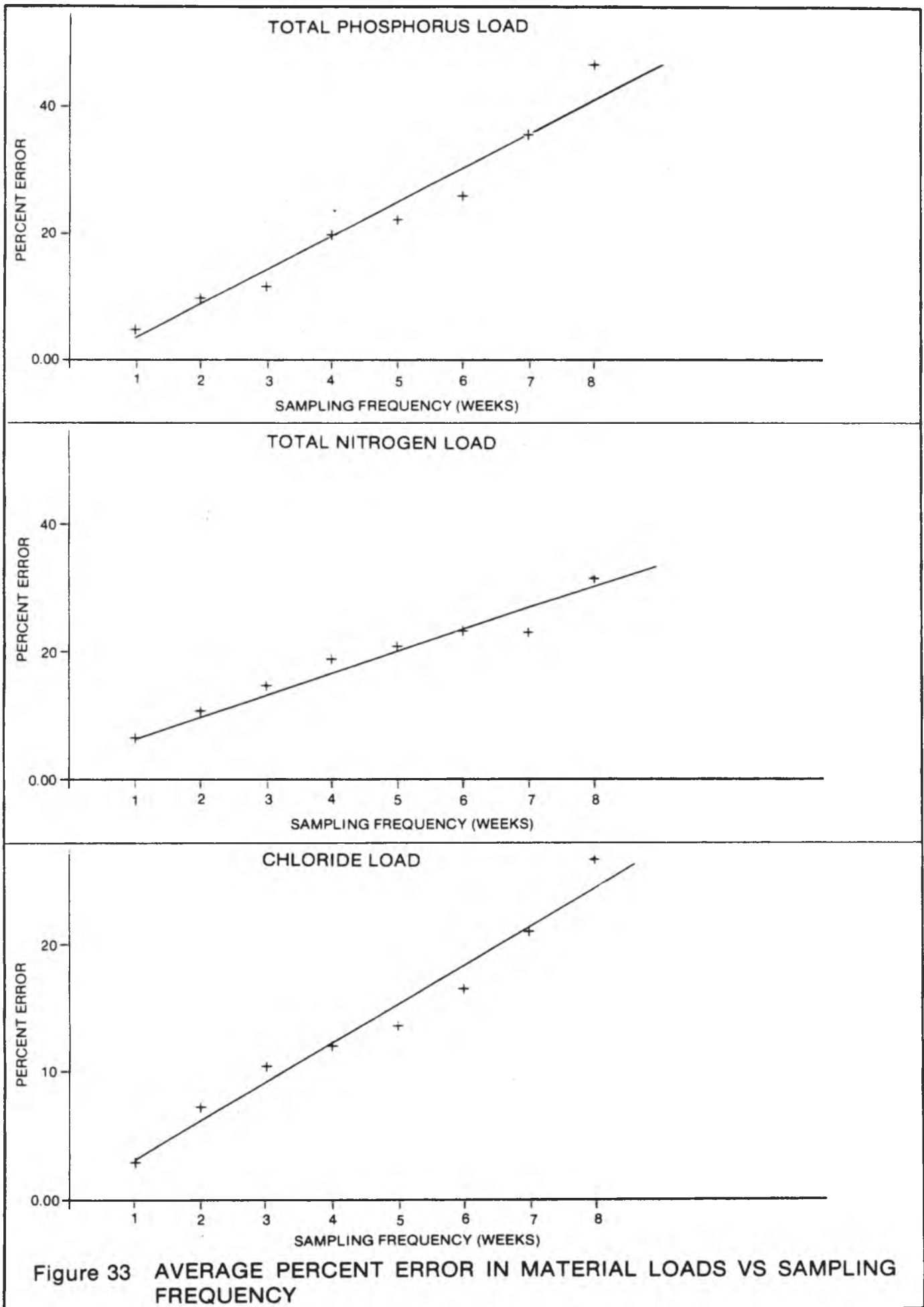
73

Figure 33 AVERAGE PERCENT ERROR IN MATERIAL LOADS VS SAMPLING FREQUENCY

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TABLE 11. COMPARISON OF ANNUAL DISCHARGE AND MATERIAL LOADS FROM UPPER EAST COAST CANALS CALCULATED
FROM DAILY AND WEEKLY SAMPLES [1]

Annual Load (10^6 g)

	Flow (acre-feet)	Total P			Total N			Cl		
		Daily Sub-Surface [2]	Weekly Surface [3]	% Diff.	Daily Sub-Surface	Weekly Surface	% Diff.	Daily Sub-Surface	Weekly Surface	% Diff.
S49	27,097	8.7	11.1	28	51.4	58.5	14	11,281	11,269	1
S97	48,116	9.4	13.9	48	93.9	108.6	16	9,575	9,679	1
S99	38,766	5.4	122.2	126	66.2	85.5	29	12,946	12,689	2
	113,979	23.5	37.2	58	211.5	252.6	19	33,802	33,637	1

[1] November 1, 1976 - October 31, 1977

[2] Daily: based on daily subsurface ISCO samples

[3] Weekly: based on weekly surface grab samples

The calculation of total phosphorus loads appears to be the most sensitive of the differing collection methodologies. The percent difference was always larger using weekly surface grab samples as compared to daily subsurface samples, averaging 58 percent, and ranging between 28 percent at S-49 to 126 percent at S-99. These large percent differences greatly exceeded the average 5 percent difference that was calculated based on a weekly collection frequency using an automatic sampler. Therefore, it appears that the method of collection (a surface grab sampling technique which collects a surface film) introduced a far greater degree of variation into the calculation of material loads than can be accounted for by the decreased collection frequency alone. The average degree of variation in the total phosphorus loads using weekly surface samples (55%) exceeded the percent difference of even a bimonthly sampling program using the automatic samplers at a subsurface collection depth.

Since the flow data used in calculating the material loads was the same regardless of the sampling technique, it is evident the disparity in the total phosphorus loads resides in the quality data. It appears that the technique of using a bucket collection device which samples the surface film, used in collecting the weekly grab samples, introduces a substantial degree of variation in total phosphorus concentrations and thus the material load calculations. Figures 34 to 36 display the total phosphorus concentration measured on the daily subsurface samples and the weekly surface grab samples. It is apparent from these figures that the total phosphorus concentrations, measured on samples collected using both techniques, was very similar from November to June. The dissimilarity occurred from June to November when the total phosphorus concentrations measured on the weekly surface grab samples were almost always greater than the daily subsurface samples. Since
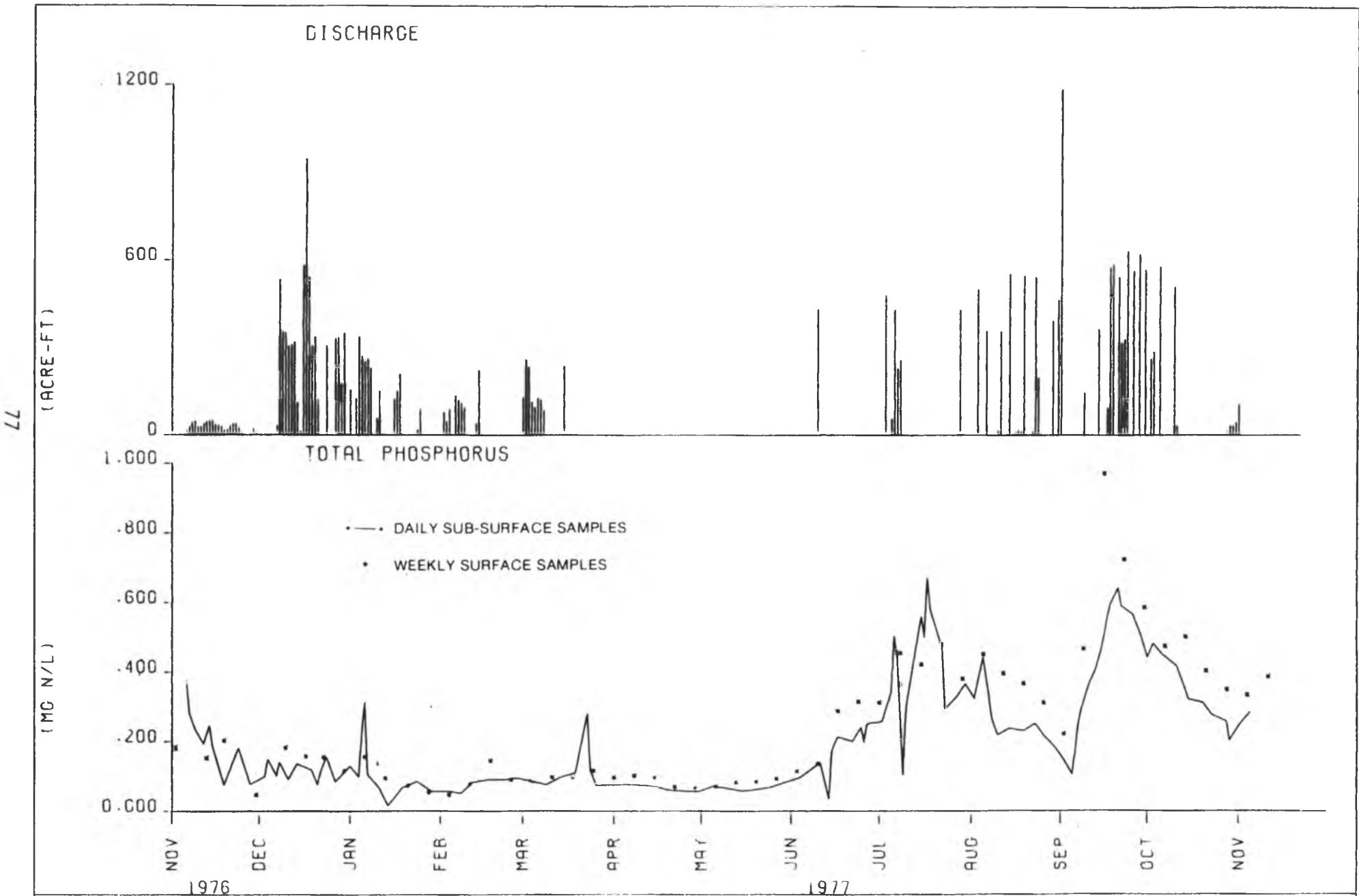
76

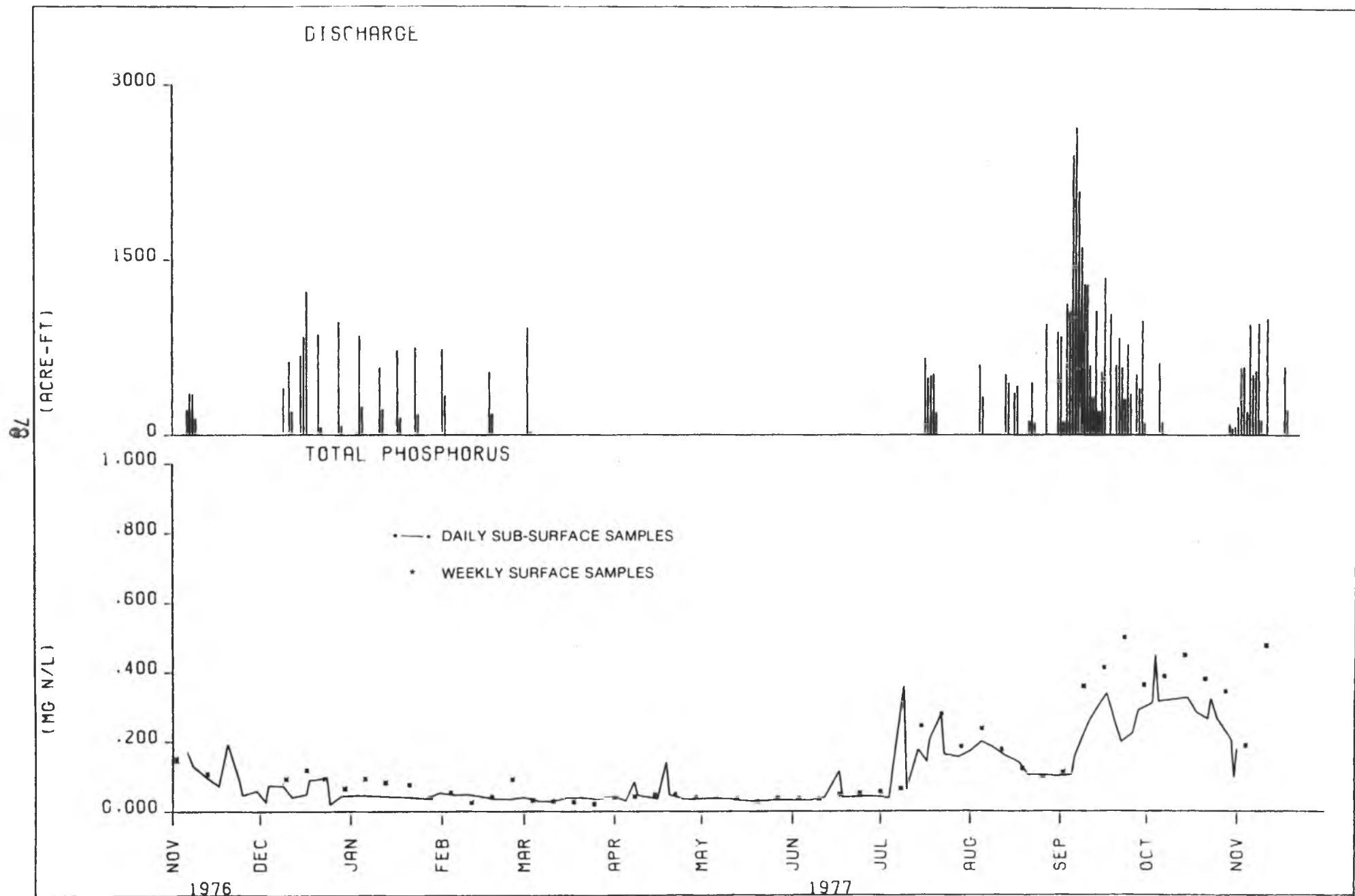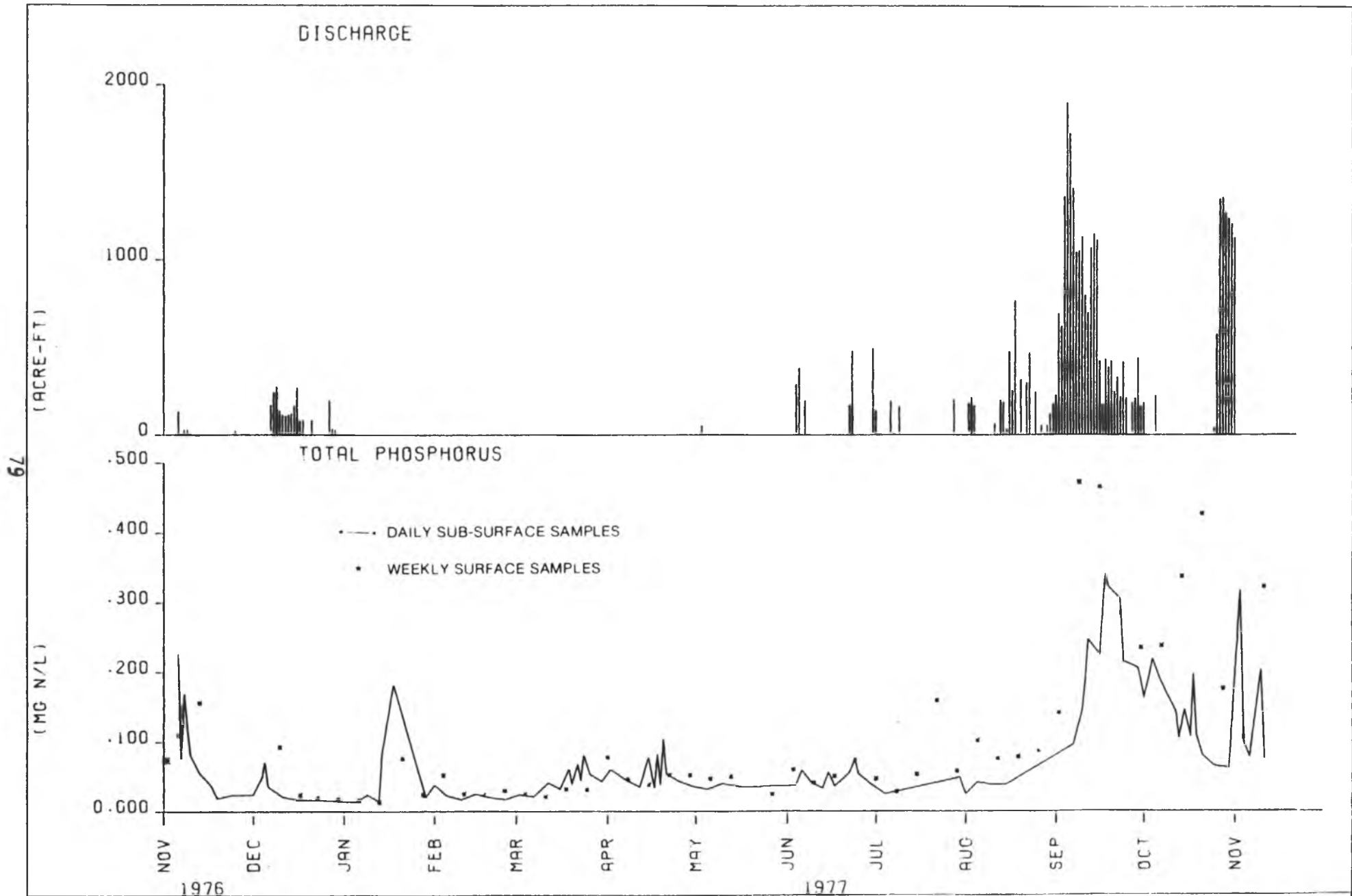Figure 34   DAILY SUBSURFACE AND WEEKLY SURFACE TOTAL PHOSPHORUS CONCENTRATIONS AT S-49

Figure 35   DAILY SUBSURFACE AND WEEKLY SURFACE TOTAL PHOSPHORUS CONCENTRATIONS AT S-97

Figure 36   DAILY SUBSURFACE AND WEEKLY SURFACE TOTAL PHOSPHORUS CONCENTRATIONS AT S-99

substantially similar flows occurred during the two periods, the difference in the concentration appears to be a seasonal phenomenon unrelated to flow.

Total nitrogen loads were much less sensitive to the combination of a reduced sampling frequency and a differing collection methodology. The total nitrogen loads based on the weekly surface grab samples were greater than the loads based upon the daily subsurface samples. The average percent difference was 19 percent with a range of 16 percent at S-97 to 29 percent at S-99. Based on Figures 37 to 39, which display the daily and weekly concentrations, there also appears to be a seasonal effect in the differences in total nitrogen concentrations. Although not as pronounced as was the case with total phosphrous, there was also a tendency for higher total nitrogen concentrations to be measured in the summer and fall (June to November) using the surface grab sampling technique as compared to the subsurface automatic sampler technique.

There was virtually no difference in either the chloride concentrations (Figures 40 to 42) or the chloride loads based on the daily or weekly grab sampling program.

It is apparent from the preceding discusion that the collection of surface and subsurface samples results in differing total phosphrous and total nitrogen concentrations and loads. The grab sampling technique, which collected at least a partial surface film, resulted in higher total phosphorus and total nitrogen concentrations and loads as compared to the technique which collected samples at a subsurface depth (i.e. 0.5 m). The difference between the weekly surface and daily subsurface collection techniques was not a result of differing holding times between the two methodologies. Comparisons between the weekly surface data and the corresponding daily subsurface data collected on the same day indicates that the surface data was always equal to or greater than the corresponding
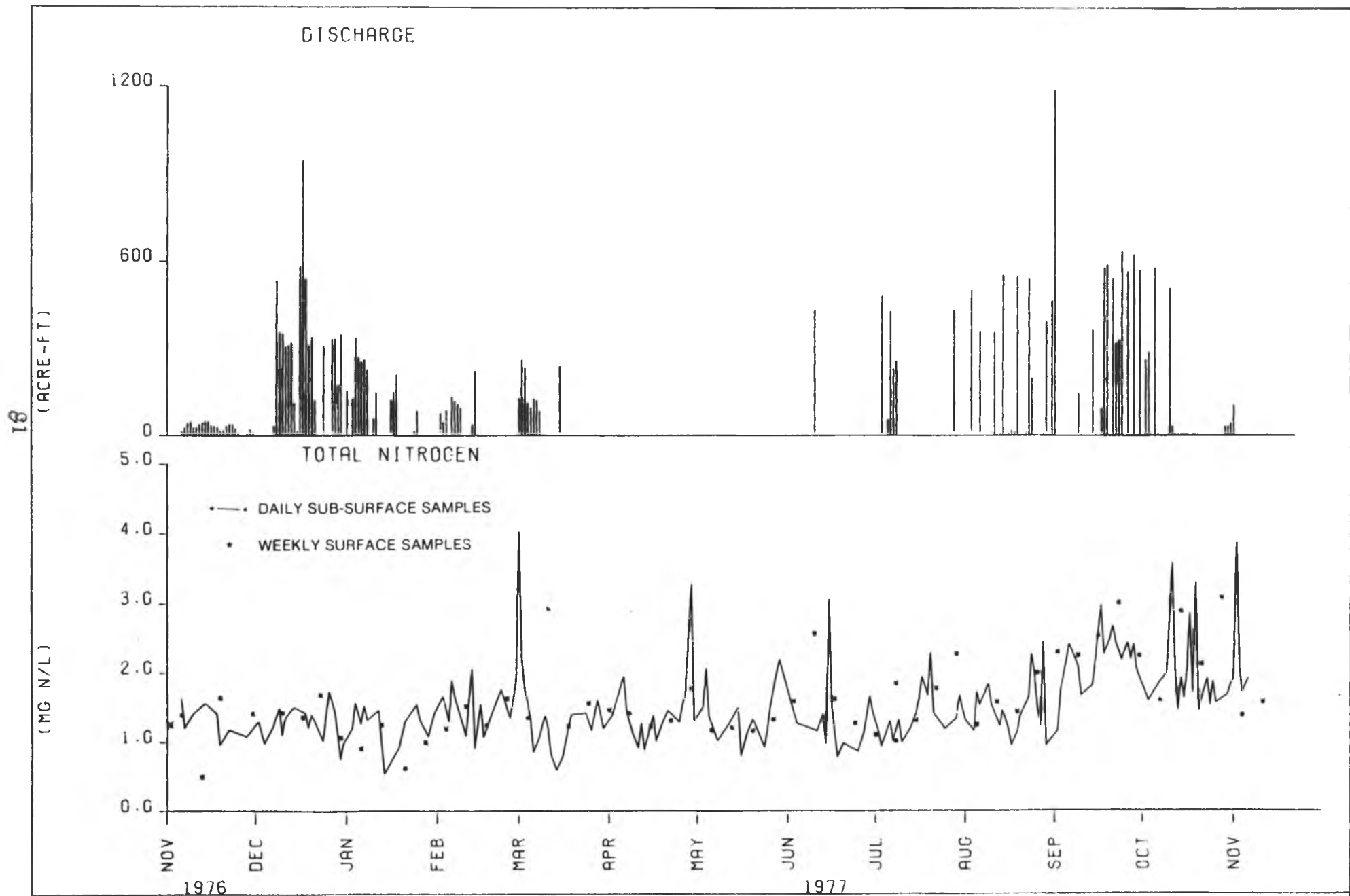
80

Figure 37   DAILY SUBSURFACE AND WEEKLY SURFACE TOTAL NITROGEN CONCENTRATIONS AT S-49
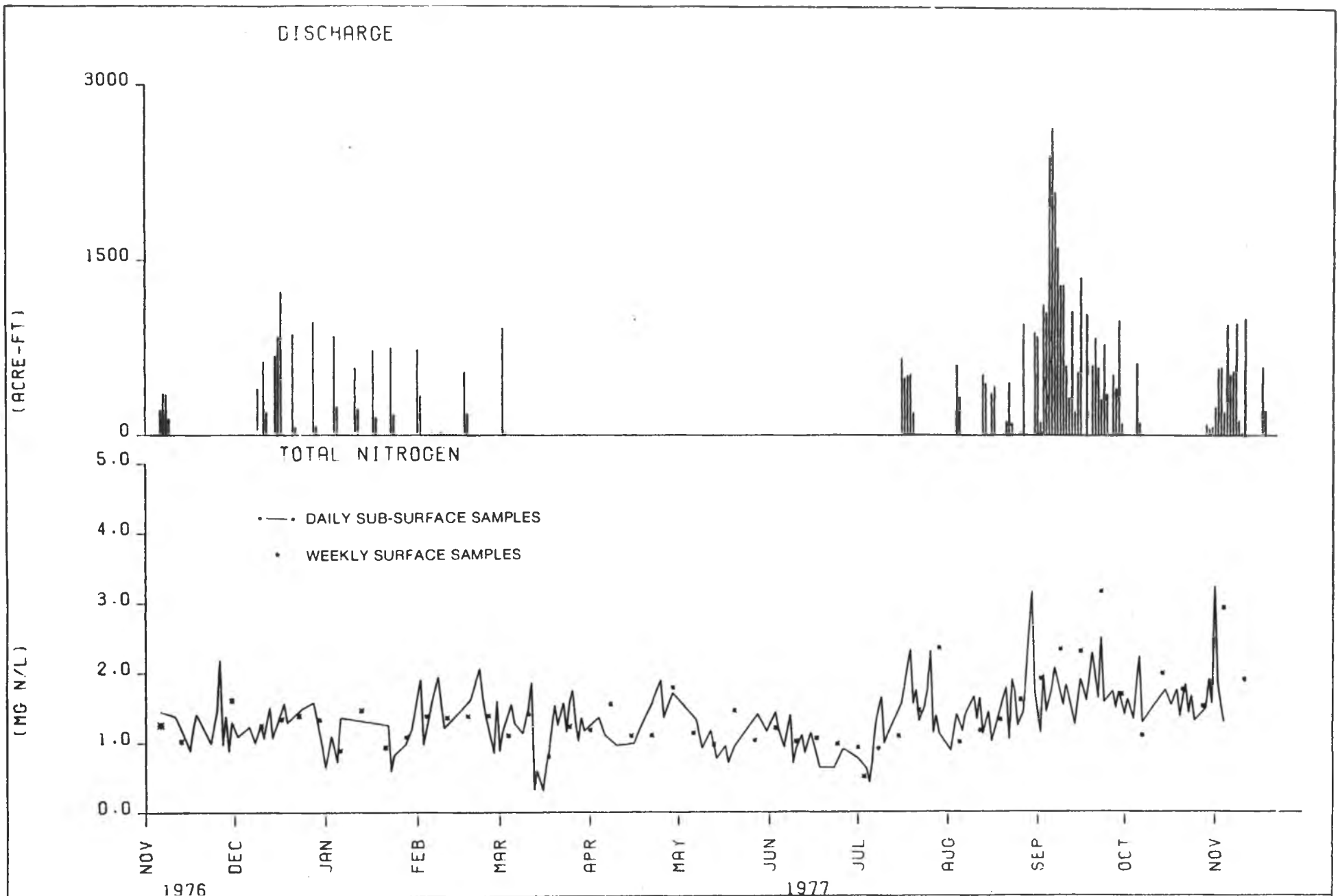
Figure 38   DAILY SUBSURFACE AND WEEKLY SURFACE TOTAL NITROGEN CONCENTRATIONS AT S-97
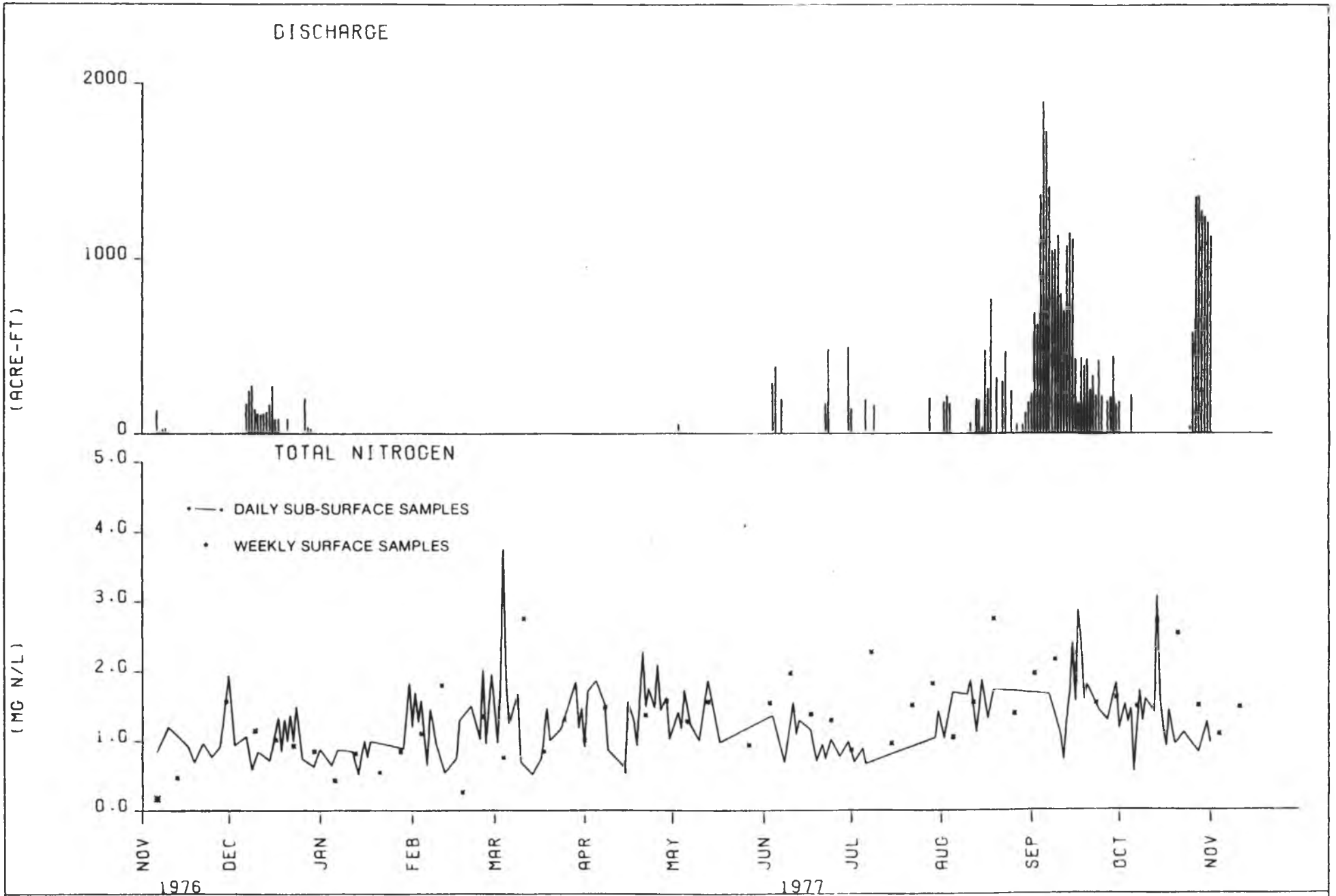
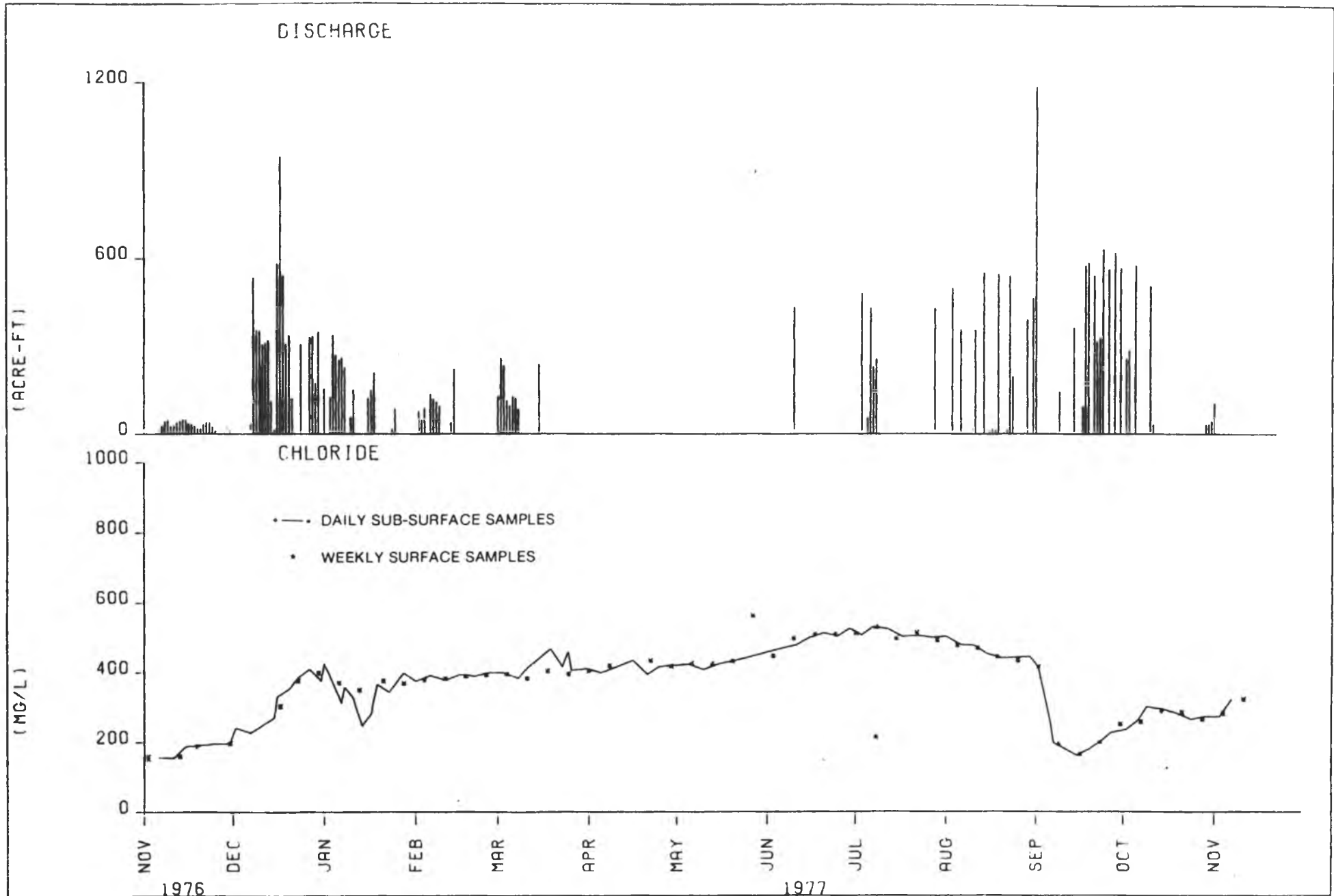Figure 39   DAILY SUBSURFACE AND WEEKLY SURFACE TOTAL NITROGEN CONCENTRATIONS AT S-99

Figure 40   DAILY SUBSURFACE AND WEEKLY SURFACE CHLORIDE CONCENTRATIONS AT S-49
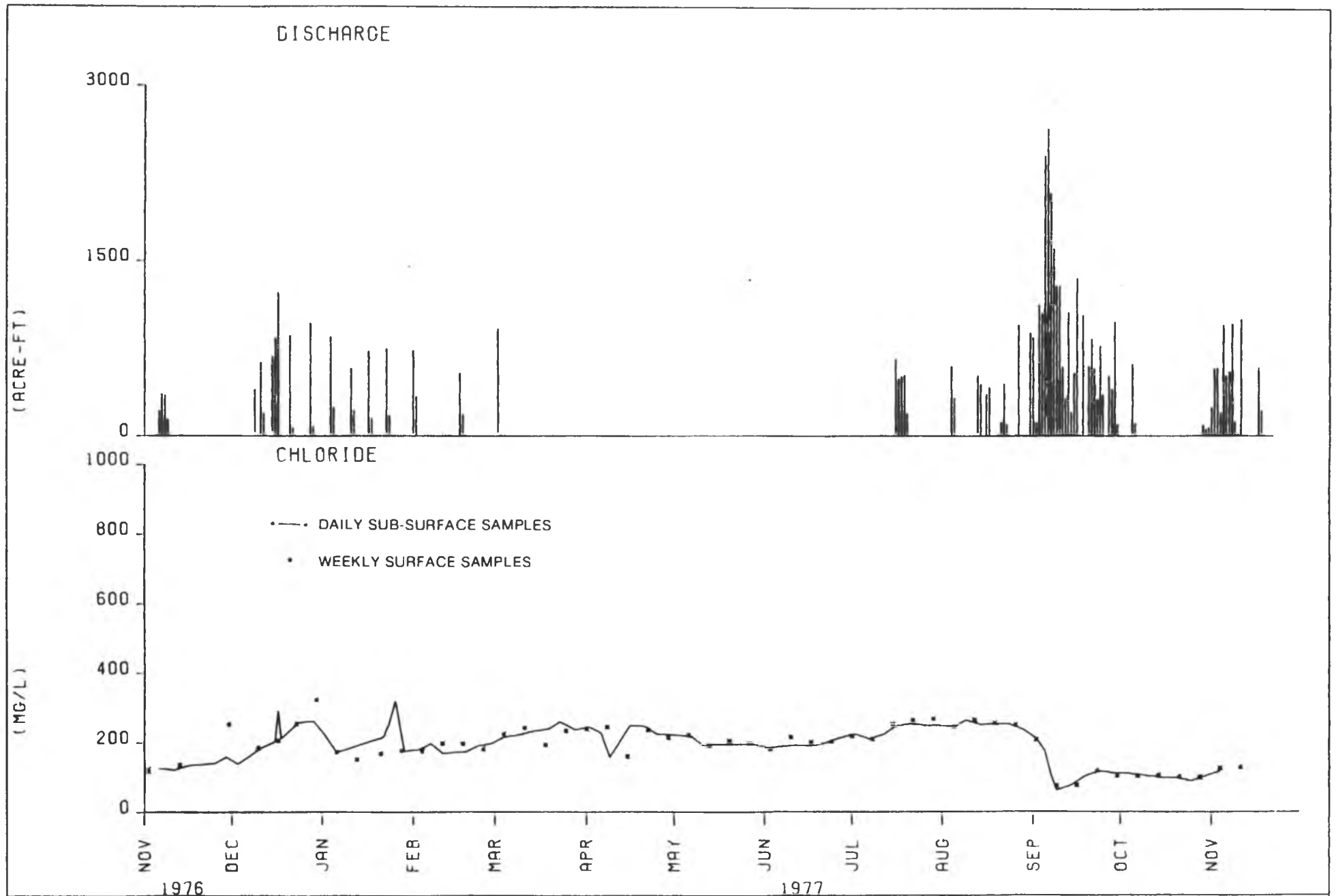
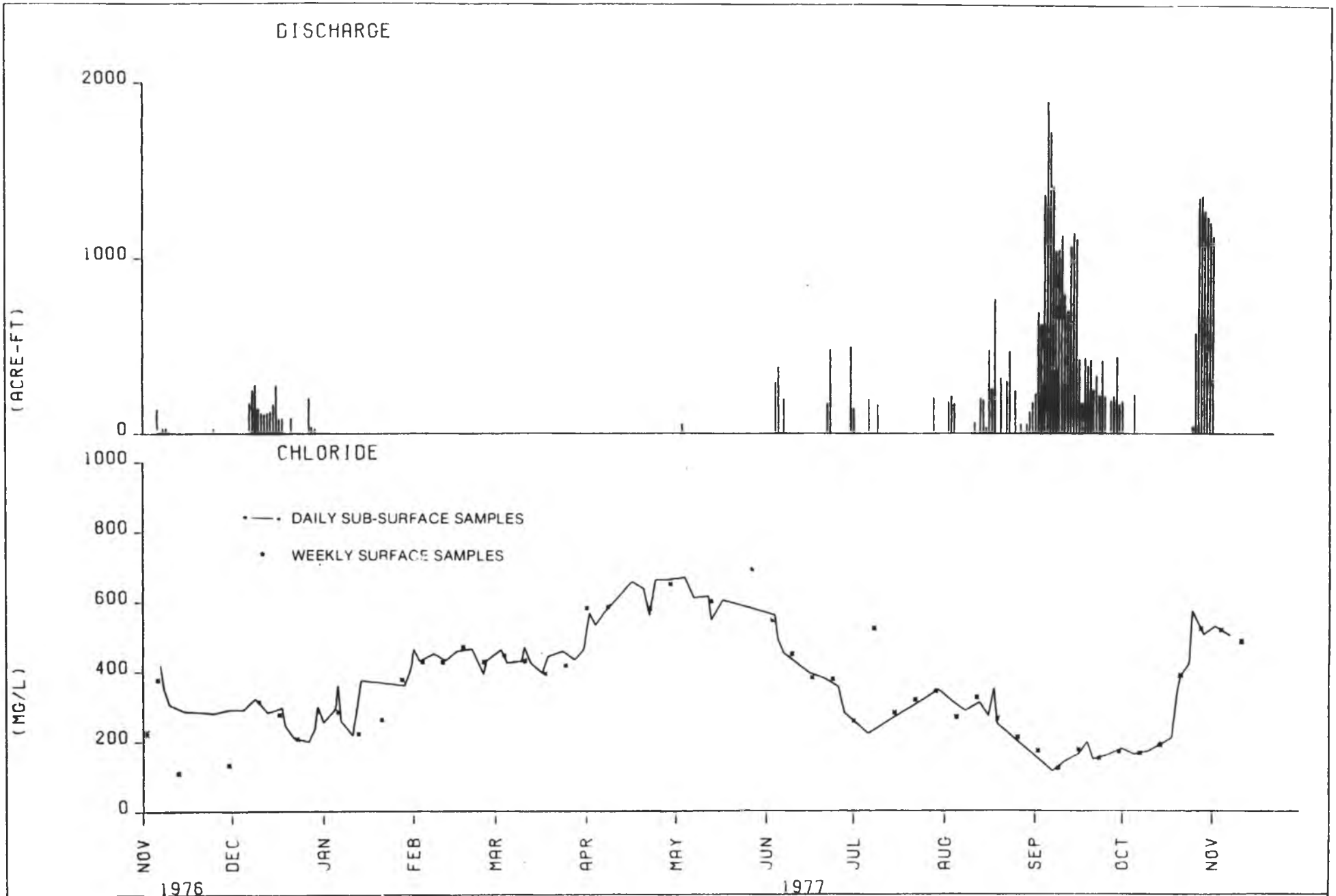Figure 41   DAILY SUBSURFACE AND WEEKLY SURFACE CHLORIDE CONCENTRATIONS AT S-97

Figure 42   DAILY SUBSURFACE AND WEEKLY SURFACE CHLORIDE CONCENTRATIONS AT S-99

subsurface data. Whether a surface or subsurface sample better represents the actual concentration, and results in a better estimate of the material load, depends in part on the flow patterns. A subsurface sample would probably result in a better material loading estimate if the flow were past a structure which employs lift gates and discharges bottom waters. Alternatively, a surface sample may be more representative where there is flow over the top of a structure as in the case of a weir. In any case, the actual sample collection technique may have more influence on the material loads than the sampling frequency.

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APPENDIX A

GROUNDWATER QUALITY IN THE

UPPER EAST COAST PLANNING AREA

TABLE A-1. GROUNDWATER QUALITY COLLECTION SITES

C-23	C-24	C-25
MF-1	SLF-14	SLF-1
SLF-23	SLF-17	SLF-2
SLF-32	SLF-31	SLF-4
MF-2		SLF-5
SLF-18		SLF-7
		SLF-11
		SLF-20

Source: Reece et al. 1980

TABLE A-2. GROUNDWATER QUALITY IN UPPER EAST COAST PLANNING AREA

Basin		Sp. Cond. (micromhos/ cm)	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	SO$_4$ mg/L)	Alk. (mg/L as CaCO$_3$)
S49 (C-24)	Avg.	2588	421.3	15.1	112.9	74.2	865.6	196.2	136.4
	Min.	1698	320.3	10.3	91.4	60.8	637.9	41.5	70.5
	Max.	3470	541.7	25.9	138.8	89.6	1035.8	253.7	164.5
S97 (C-23)	Avg.	3405	559.4	18.6	118.7	88.2	1059.6	188.9	139.4
	Min.	2052	382.4	10.4	98.6	73.8	786.7	38.8	114.0
	Max.	4480	793.1	32.7	154.9	107.1	1247.3	229.4	164.5
S99 (C-25)	Avg.	2021	310.7	11.4	99.5	67.0	631.5	157.0	146.1
	Min.	1082	197.3	7.1	73.6	46.3	122.4	24.6	110.5
	Max.	3606	474.5	21.6	141.2	94.8	100.7	280.6	188.5

Source: Reece et al. 1980