TECHNICAL PUBLICATION 81-2

May, 1981

DRE-128

LAKE OKEECHOBEE WATER QUALITY STUDIES AND EUTROPHICATION ASSESSMENT

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LAKE OKEECHOBEE WATER QUALITY STUDIES AND EUTROPHICATION ASSESSMENT

by

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PREFACE

The objective of this report is to assemble and summarize seven years of water quality data collected on Lake Okeechobee. The format provided should be useful in promoting more intensive future analyses of the data.

The initial design and field efforts for this program belong to Messrs. Fred Davis and Michael Marshall. Collection of the quantity and quality of data presented herein would not have been possible without the technical support of numerous field and laboratory technicians.

The authors are indebted to Drs. Earl E. Shannon and Jay J. Messer for their helpful criticism and review of the draft report.

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CHAPTER I

INTRODUCTION

Lake Okeechobee is an important body of water from the perspective of limnology, water resource management, economics, recreation, and wildlife habitats. The lake has the second largest surface area of any freshwater lake wholly contained within the United States. It is the focal point of a complex water management system which provides flood protection and water supply to over 3 million people. The lake supplies essential irrigation water to an agricultural industry with a value of farm production in the range of $500 million to 1 billion dollars a year while directly supporting a large commercial fishing industry. The lake is also a world renowned recreational fishing and hunting area.

In attempts to increase the ability of Lake Okeechobee to meet these varied uses, the lake and its tributaries/distributaries have been considerably altered. Modifications were begun in 1881 by Hamilton Disston and continue to the present. The lake is now completely regulated with all inflows and outflows, except for Fisheating Creek, being controlled by some type of water control structure. The lake itself is completely surrounded by a 25 foot dike which is built on the 15 foot MSL contour. This dike was designed to prevent flooding which historically accompanied tropical storms, and to increase the storage capacity of the lake.

Due to the critical, and at times conflicting, nature of the uses to which the lake is put, and due to man's recent concern about the environment, Lake Okeechobee has been the subject of many diverse scientific studies. Table 1-1 provides a concise bibliographical summary of recent investigations on Lake Okeechobee. Data collection on the lake was begun in

TABLE 1-1. A BIBLIOGRAPHIC SUMMARY OF RECENT INVESTIGATIONS ON LAKE OKEECHOBEE AND ITS WATERSHED

History and Geology	Water Quality Surveys and Pollution Loading	Biological and Paleolimnological Studies	General Reports (Summaries)
Parker and Cooke 1944	Parker et al. 1955	Gleason and Stone 1975	Gleason 1974
Will 1964	Florida Game and Fresh Water Fish Commission (1966, 1967, 1969, 1971)	Marshall 1975	McCaffrey et al. 1976
Tebeau 1974	Joyner 1971, 1974	Dye et al. 1975	MacGill et al. 1976
Brooks 1974	EPA Working Paper #259 1973	Gayle 1975	Browder 1977
	Brooks 1974	Waller and Earle 1975	Gleason 1974
	Brezonik and Federico 1975	Ager et al. 1975	
	Federico and Brezonik 1975	Waller 1976	
	Davis and Marshall 1975	Pesnell and Brown 1977	
	Lamonds 1975	Brezonik et al. 1979	
	McPherson, Waller and Mattraw 1976		
	Lutz 1977		
	Black, Crow and Eidsness 1977		
	Messer and Brezonik 1977, 1978		
	Miller 1978		
	Maddy 1978		
	Dickson et al. 1978		
	CH_2M Hill 1978, 1979		
	Brezonik et al. 1979		
	Messer et al. 1979		
	Kratzer and Brezonik 1981		

1940 by the United States Geological Survey (U.S.G.S.) as part of their survey of surface water quality in the Southeastern United States (Parker et al. 1955). In 1969 the U.S.G.S., in cooperation with the Central and Southern Florida Flood Control District (now the South Florida Water Management District), initiated a three year project designed to document the limnological characteristics of Lake Okeechobee (Joyner 1971, 1974). This study represented the first major attempt at assessing the trophic state of the lake. Joyner concluded that the chemical and biological characteristics of Lake Okeechobee were indicative of an early eutrophic condition. In January 1973 the South Florida Water Management District (S.F.W.M.D.) began a limnological study of the lake which was designed to continue the baseline water chemistry data base begun by Joyner; develop material budgets; determine systematic relationships among chemical, biological, and physical factors; and assess the trophic state of the lake. The first 18 months of this study were reported by Davis and Marshall (1975). The S.F.W.M.D. has continued this major study to the present, the results of which are the subject of this report. The S.F.W.M.D. has also conducted several other studies designed to evaluate phytoplankton dynamics and primary productivity (Marshall 1977); identify the major aquatic plant communities in the lake's extensive littoral zone (Pesnell and Brown 1977); and assess the impact of agricultural drainage waters on the lake (Dickson et al. 1978). In 1976 the S.F.W.M.D. and the Florida Sugar Cane League (F.S.C.L.) initiated a joint program to gather water quality management data for the Everglades Agricultural Area. The results of this program are contained in two CH_2M Hill (1978, 1979) reports to the F.S.C.L. and in Dickson et al. (1978).

Other State agencies and universities also have been actively involved in scientific investigations of Lake Okeechobee. Most notably, the State of Florida, through the Department of Administration (DOA), Department of Natural Resources (DNR), and the Department of Environmental Regulation (DER), (formerly the Department of Pollution Control), funded the Special Project to Prevent the Eutrophication of Lake Okeechobee. This project, in turn, funded numerous studies of Lake Okeechobee and its major tributaries. Summaries of the overall project can be found in McCaffrey et al. (1976). Studies specific to the lake included an assesment of agricultural drainage on the lake (Brezonik and Federico 1975); an assessment of limiting nutrients (Dye et al. 1975); studies of geochemical sediment-water exchanges (Burton et al. 1975); and identificaton of aquatic vertebrate fauna (Yerger 1974).

The University of Florida has also been active in Lake Okeechobee research. Two University research grants have been funded by the S.F.W.M.D. The first grant evaluated the role of denitrification (Messer et al. 1979) while the second, still in progress, is designed to develop an in depth understanding of nutrient cycles in the lake. The Florida Sugar Cane League, a private organization, supported an intensive one year university study of factors affecting primary productivity in Lake Okeechobee (Brezonik et al. 1979).

FORMAT OF REPORT

This report presents the results of four distinct but related studies: (1) trend detection; (2) spatial analysis; (3) material budget and tributary analysis; and (4) trophic state assessment. These studies along with methodologies and a description of the study area will be presented in eight chapters following this introductory chapter. A summary of this report along with the major conclusions will be presented in Chapter 2. Chapter 3 will describe the study area with emphasis on the morphometric characteristics, hydroperiod of the lake, and basic land use in the tributary basins. Collection methodologies and analytical techniques common to each study will be addressed in Chapter 4. Methodologies specific to each study, along with sample site locations, parametric coverage, and frequency of sampling will be presented in each appropriate chapter prior to a discussion of the results. The quality of water in the tributaries along with a discussion of quality/discharge relationships will be addressed in Chapter 5. Discussion will focus on major inflows and also on smaller inflows draining representative land uses. Based upon the tributary quality data and daily discharge measurements, annual material budgets for this seven year study period will be calculated and discussed in Chapter 6. Presented in Chapter 7 will be the results and discussion of the routine water quality monitoring of eight limnetic zone stations. These data will be the basis of the discussion of annual and seasonal trends in the limnetic water quality. Analysis of the spatial distribution of selected inlake water quality parameters collected at 40 stations will be covered in Chapter 8. Chapter 9 will synthesize the information presented in the earlier chapters in an assessment of the lake's trophic state. This assessment will develop along several approaches, including an evaluation of classical trophic state indicators, trophic state indices, and input/output mass balance type trophic state models. Several mass balance nutrient prediction models will also be evaluated.

CHAPTER II

EXECUTIVE SUMMARY AND CONCLUSION

SCOPE AND OBJECTIVES

This report represents the culmination of an intensive seven year (1973-1979) water quality study of Lake Okeechobee. The study was designed specifically to address the chemical limnology of the lake. Various water quality parameters were measured in the lake and at the inflow and outflow points in order to identify water quality trends and assess the lake's trophic state. The trophic state of a lake is a hybrid concept involving a variety of biological and chemical conditions. Qualitative designations of trophic state have traditionally been assigned to the lake with certain biological and chemical characteristics. Oligotrophic is a term associated with lakes which usually have low nutrient concentrations; low chlorophyll a concentrations; low primary productivities, high transparencies; high algal, benthic, and fish species diversities; and low algal, benthic, and fish biomass. Eutrophic is a term associated with lakes which usually have high nutrient concentrations; high chlorophyll a concentrations; high primary productivities; increased algal bloom frequencies; high algal, benthic and fish biomass; and low algal, benthic and fish species diversity. It is the biological conditions, and not usually the chemical characteristics, which most notably impact a lake and influence its usability to man.

Since this study assessed only the chemical characteristics of Lake Okeechobee, well established and documented relationships between water quality and trophic state were employed in order to determine the lake's trophic state. It should be emphasized, however, that no direct assessment was made as to the biological condition of Lake Okeechobee. The general objectives addressed in this study were:

(1) Identify annual and seasonal limnetic water quality trends.

(2) Examine areal distribution of limnetic water quality and its relationship to tributary inflows.

(3) Identify annual water quality trends and quality/discharge relationships at each tributary.

(4) Calculate annual lake material budget for each of the seven years.

(5) Assess the trophic state of the lake using trophic state indicators and indices, mass balance models, and empirical models.

(6) Assess mass balance type trophic state nutrient predictive equations and

(7) Recommend mass balance model as criterion for eutrophic control.

STUDY INTRODUCTION

Methodology

Lake Okeechobee and its tributaries were monitored extensively for seven years from April 1973 through March 1980. The open waters of the lake were sampled on a biweekly to monthly frequency using either an eight or forty station network. The lake's twelve major inflow and outflow points were sampled biweekly throughout the study period. An additional five minor inflows were sampled during two years (1973 and 1979). In total, over 5,500 water samples were collected. Parametric coverage generally included nitrogen species, phosphorus species, sodium, potassium, calcium, magnesium, chloride, alkalinity, color, turbidity, temperature, dissolved oxygen and specific conductivity. In addition, chlorophyll *a* analyses were performed on samples collected in the lake's limnetic zones from 1947 to 1977. These parameters resulted in the generation of over 115,000 data points.

Major Events

Several major events occurred during this study which affected the study area. Since 1973, three regulation schedules have been in effect for Lake Okeechobee. Regulation schedules provide operational guidelines for the maintenance of maximum stage levels during the year. Attainment of these maximum levels depends upon antecedent conditions in the lake and its basins and upon sufficient rainfall. When the lake is below the regulation schedule, the actual stage is a function of the inflows, evaporation, and withdrawal demands. At the initiation of this study in 1973, the lake's regulation schedule was 14.0 to 15.5 feet. In August

1974 the schedule was raised to the 14.5 to 16.0 foot level. The regulation schedule was further increased to a 15.5 to 17.5 foot level in May 1978 after completion of the Port Mayaca structure (S-308). The implementation of the 17.5 foot maximum regulation schedule resulted in most of Kreamer, Torry, and Ritta Islands being inundated at times during 1978 and 1979. These islands were previously used for crop farming over the past 40 to 60 years. A drought in 1973-74 and implementation of the higher regulation schedule in 1978 resulted in a wide variation in the lake stage This study encompassed the fourth lowest (10.95' MSL in May/June 1974) and fourth highest (17.65' MSL in October/November 1979) lake stage since 1911 (Figure 2-1).

Other significant events included: (1) permitting of commercial fishing via trawling and seining in 1976 for the first time since 1955; (2) implementation of the Lake Okeechobee Temporary Operating Permit Interim Action Plan in July 1979 resulting in a decrease in the inflows into the south end of the lake from pump stations S-2 and S-3; and (3) Hurricane David on September 3, 1979, the first hurricane to strike the east coast of Florida since 1965.

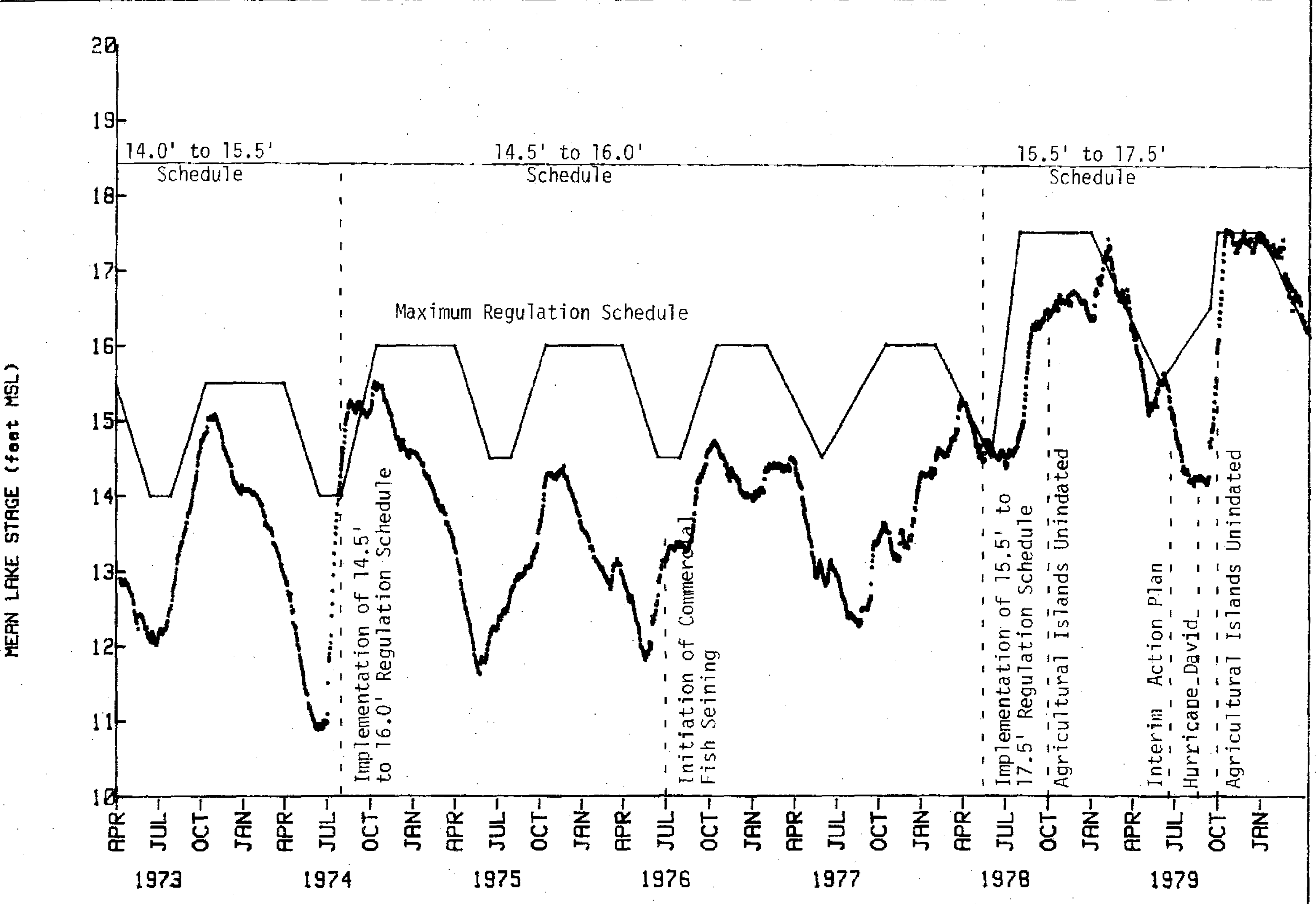


FIGURE 2-1. MEAN DAILY STAGE IN LAKE OKEECHOBEE

SUMMARY OF MAJOR FINDINGS

Lake Okeechobee contains highly mineralized water for an eastern lake (mean specific conductance of 589 μmhos/cm) which is dominated by calcium, sodium, chloride and bicarbonate ions. The lake also has moderately high and variable color levels (43 Pt units), high daytime dissolved oxygen concentrations (>6 mg/L), relative to FAC Chapter 17-3 Water Quality Standards, and an average percent O_2 saturation of 100 percent. The major ions, conductivity, and color did not display any readily apparent seasonal variations. Dissolved oxygen concentrations were usually lowest in the summer and highest in winter. Lakewide mean annual turbidity averaged 18.0 JTU, with the highest values occurring in the winter, probably as a result of wind-driven wave resuspension of bottom sediment. Significant mean annual variations were noted for all the above parameters, although steadily increasing or decreasing patterns from 1973 to 1979 were not identified. The mean annual alkalinity, however, was higher from 1973 (2.58 meq/L) to 1977 (2.55 meq/L) than in more recent years (2.29 and 1.95 meq/L in 1978 and 1979, respectively). Conductivity was significantly lower in 1979 than in the previous years. This was attributed to reduced pumpage into the lake from S-2 and S-3 as a result of implementation of the Interim Action Plan and higher rainfall and hydraulic loading rates.

Phosphorus and nitrogen concentrations in the lake's limnetic zone varied seasonally and displayed significant annual trends. The inorganic phosphorus and nitrogen concentrations demonstrated the most pronounced seasonal fluctuations with the highest levels primarily occurring in the winter and the lowest levels occurring primarily at the beginning of summer. The fall represented a period of increasing levels while the spring represented a period of declining levels. It was hypothesized that higher fall/wintertime lake stages provided a mechanism for nutrient transport from the littoral zone to the limnetic zone. In addition, increased wave resuspension of bottom sediments may have caused temporary increases in inorganic nutrient levels, especially nitrogen in the winter. This was supported by a moderately high correlation between turbidity and inorganic nitrogen levels (r = 0.61). The spring and summer decline in concentration was hypothesized to be a result of general increased biological activity.

Significant changes were noted in the mean annual inorganic and total fractions of both phosphorus and nitrogen. Annual ortho phosphorus concentrations increased significantly from 1973 (0.005 mg/L) to 1974 (0.014 mg/L)and more recently from1978 (0.018 mg/L) to 1979 (0.045 mg/l). The average concentration during the intervening years (1974 to 1978) remained relatively constant (Figure 2-2). The relatively large recent increases in limnetic phosphorus concentrations were hypothesized to be a function of above average phosphorus loadings and increased internal phosphorus cycling. Prolonged flooding of the littoral zone and the inundation of Torry and Ritta Islands,as a result of high lake stages in 1978 and 1979, were proposed as possible mechanisms for the increased internal phosphorus cycling.

The increases in the ortho phosphorus concentrations resulted in significant changes in total phosphorus. The proportional increases in the annual total phosphorus concentrations from 1973 (0.048 mg/L) were

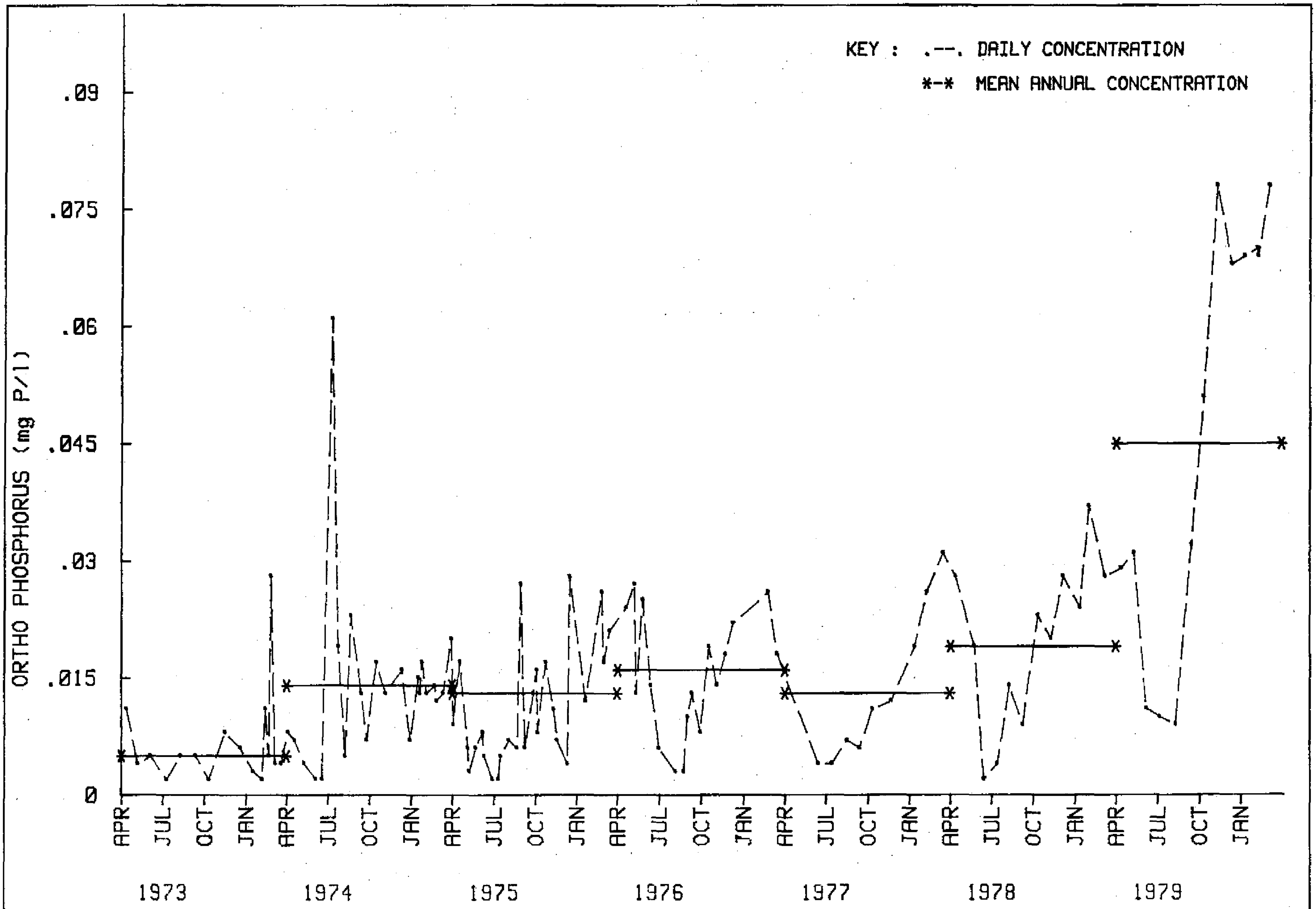


FIGURE 2-2. DAILY AND MEAN ANNUAL ORTHO PHOSPHORUS CONCENTRATIONS IN LAKE OKEECHOBEE

more gradual than the increase in ortho phosphorus, although the most significant increases again occurred recently, from 1978 (0.65 mg/L) to 1979 (0.097 mg/L) (Figure 2-3). There have been no significant decreases in the mean annual total and ortho phosphorus concentrations from 1973 to 1979. Concurrent with the increase in phosphorus concentrations was an overall increase in the proportion of ortho to total phosphorus from 19 percent in 1973 to 46 percent in 1979. Changes in the mean annual inorganic, organic, and total nitrogen concentrations did not parallel the phosphorus trend since both significant increases and decreases occurred from 1973 to 1979 (Figures 2-4 and 2-5).

There has been a significant decreasing trend in the nitrogen to phosphorus (N:P) ratios from 1973 to 1979. The mean annual inorganic nitrogen to inorganic phosphorus ratio decreased from 22.5 in 1973 to 6.1 in 1979. Gradual decreases were evident from 1973 (22.5) to 1976 (19.4) with the significant decreases occurring more recently in 1978 and 1979 (8.6 and 6.1, respectively) (Figure 2-6). This decline in the annual N:P ratio was a function of the disproportionate increase in phosphorus concentrations relative to nitrogen concentrations and also possibly a result of the lake adjusting to low N:P ratios in the inflows.

On a seasonal basis, the lower inorganic N:P ratios have occurred in the summer and the higher ratios in the winter. Summer nitrogen limitations may cause a seasonal shift from diatoms to nitrogen fixing blue-green algae late in the summer, a succession described by Marshall (1977). Inorganic phosphorus and nitrogen concentrations were sufficiently high in the winter so that neither nutrient was probably limiting. Other factors (i.e., temperature, light, micronutrients) may limit algal growth during the winter. The decrease in the annual ratios in 1978 and 1979 was primarily the result of a decrease in the peak wintertime ratios. The decreases in the mean annual

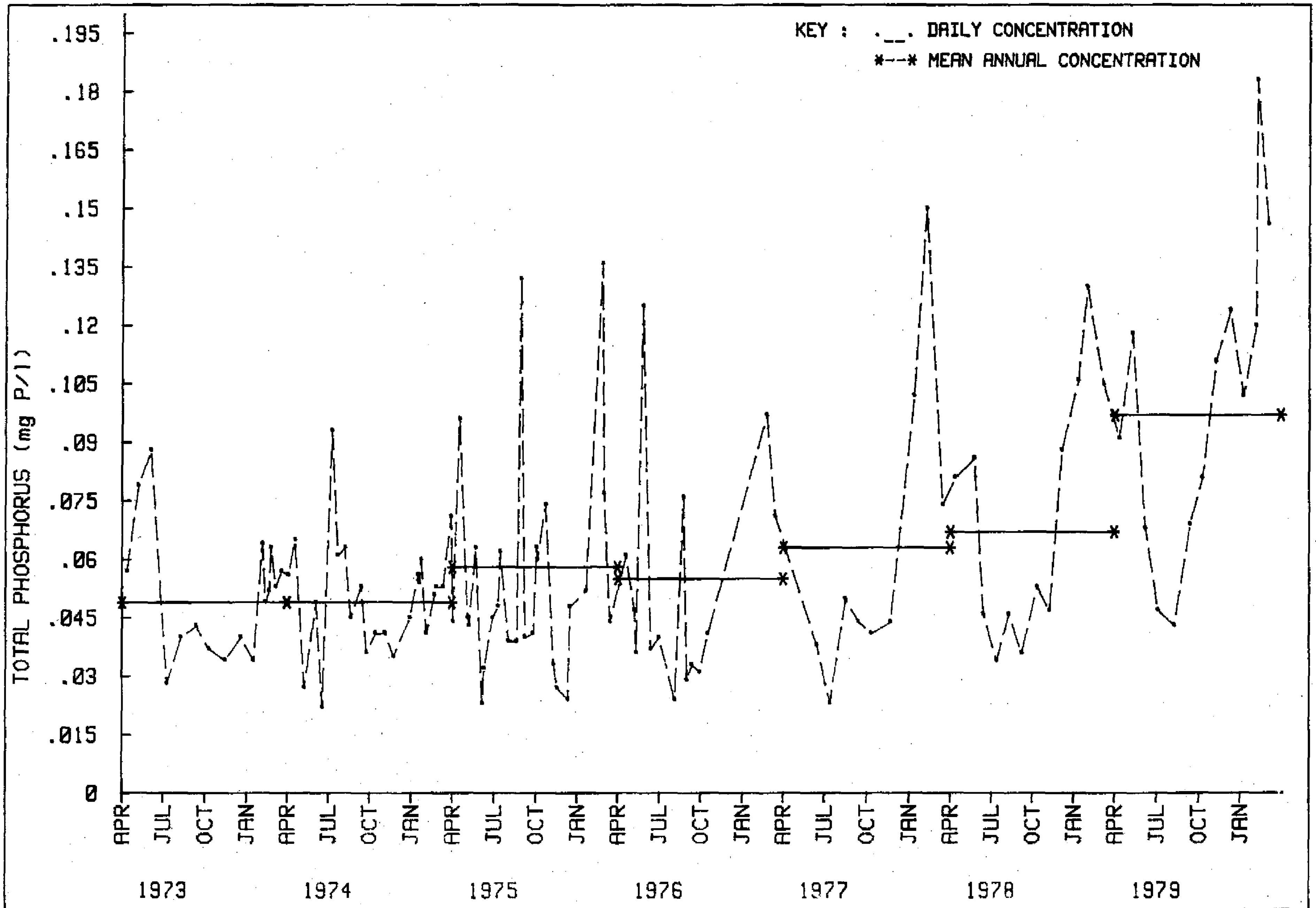


FIGURE 2-3. DAILY AND MEAN ANNUAL TOTAL PHOSPHORUS CONCENTRATIONS IN LAKE OKEECHOBEE

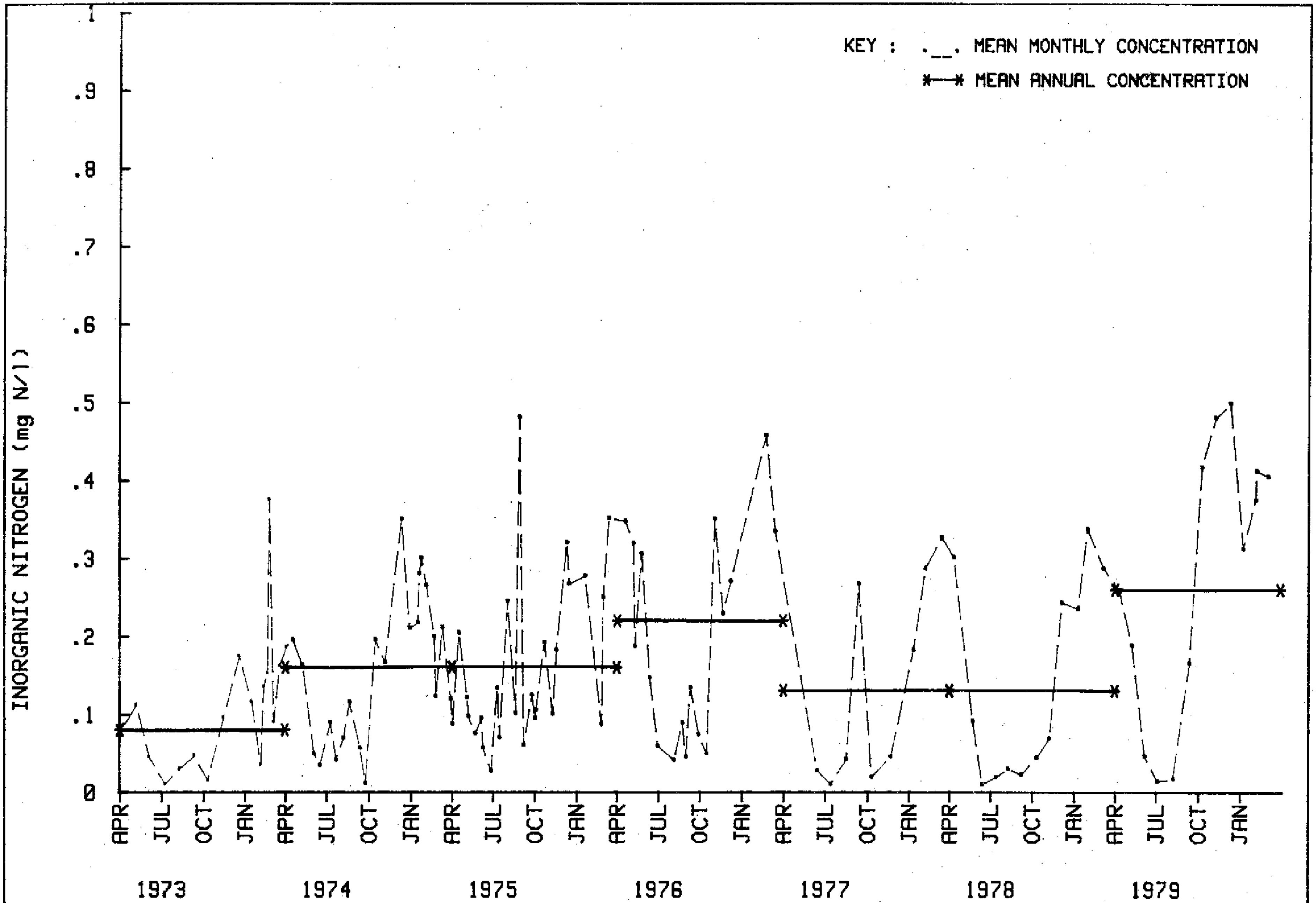


FIGURE 2-4. MEAN MONTHLY AND MEAN ANNUAL INORGANIC NITROGEN CONCENTRATIONS LAKE OKEECHOBEE

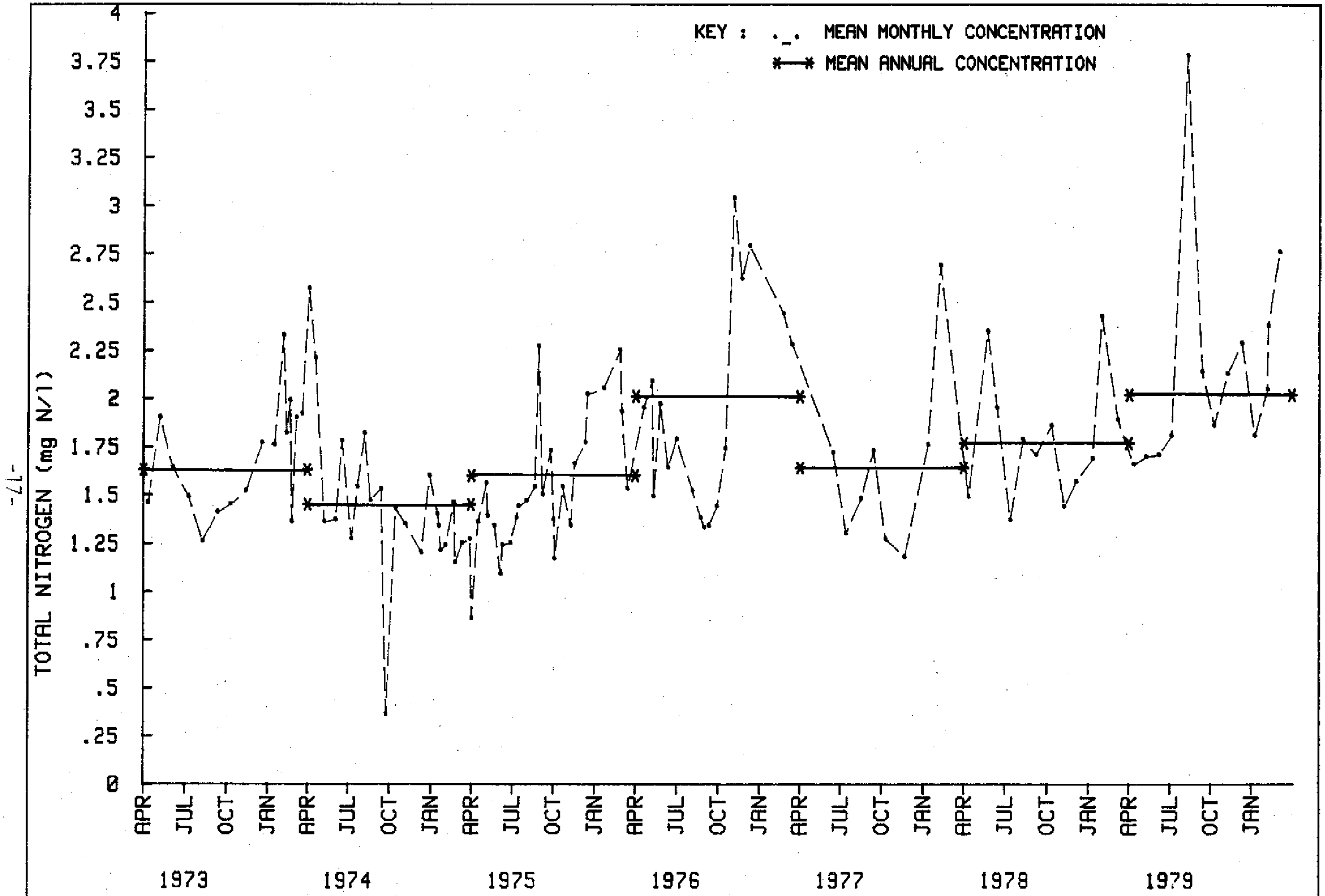


FIGURE 2-5. MEAN MONTHLY AND MEAN ANNUAL TOTAL NITROGEN CONCENTRATIONS IN LAKE OKEECHOBEE

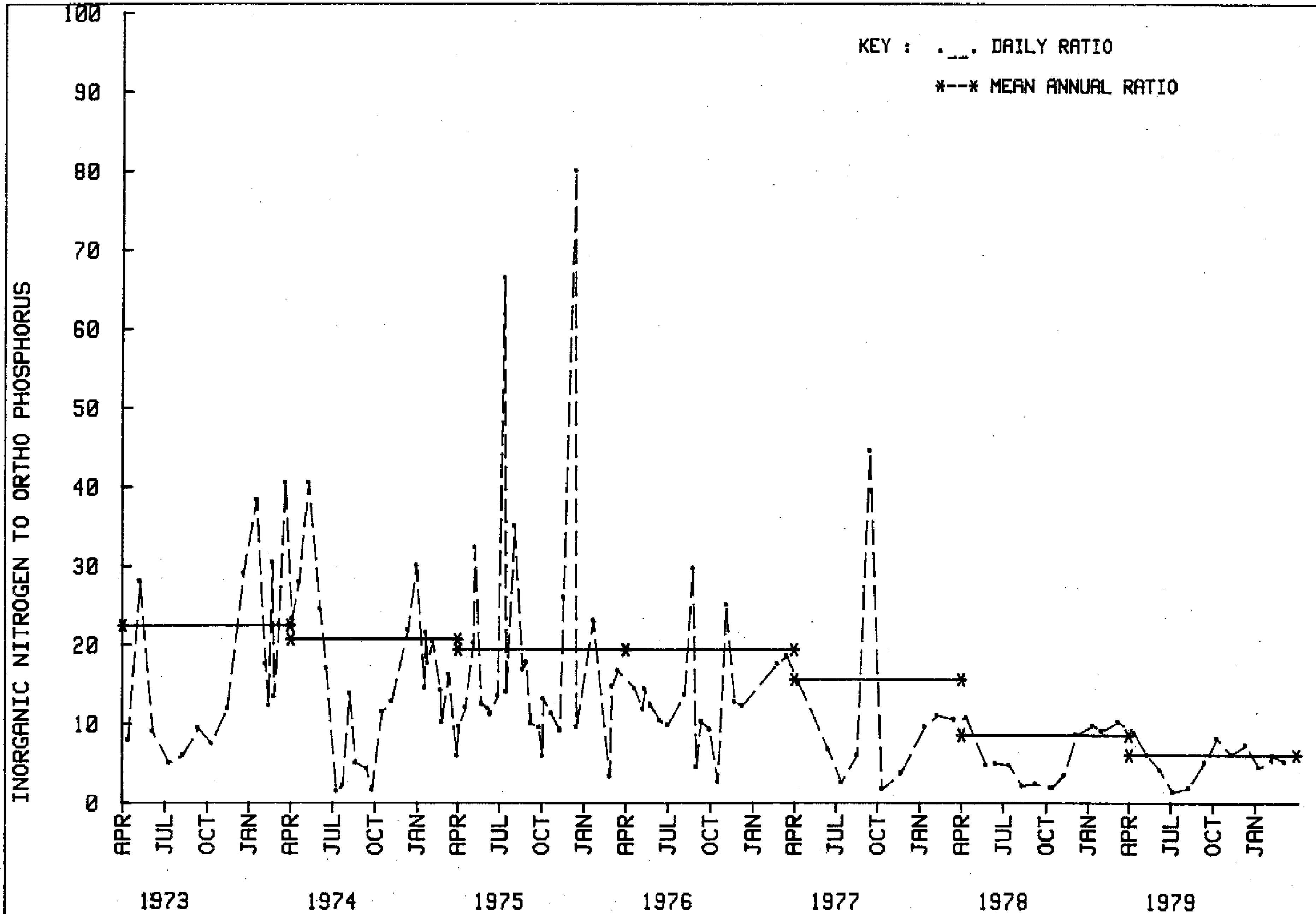


FIGURE 2-6. DAILY INORGANIC N TO ORTHO P RATIOS IN LAKE OKEECHOBEE

total nitrogen to total phosphorus ratios were not as consistent as with the inorganic ratios, although the 1979 ratio (23.6) as significantly lower than the 1973 ratio (43.9). The decreases in these ratios indicate at least a temporary shift from maximum biomass yield being potentially limited by phosphorus to being potentially limited by nitrogen, assuming all other algal growth requirements are met. The ambient concentrations of nitrogen and phosphorus in the lake, however, were sufficiently high so that neither nutrient probably limited the growth rate of phytoplankton.

Significant areal differences in the limnetic waters were noted for all major parameters except dissolved oxygen and organic nitrogen. Turbidity was generally higher over soft mud sediments than over hard sand sediments, supporting the wind-driven wave resuspension phenomenon. The sampling station closest to the Kissimmee River (C-38) had significantly lower major ion levels while the most westward station had the lowest mean nutrient levels. The highest average inorganic nitrogen and inorganic phosphorus levels occurred at the most southern stations closest to pump stations S-2 and S-3.

Specific studies from May 1978 through September 1979 were conducted to document, in greater detail, the distribution pattern of selected water quality variables in the lake. The distribution patterns which displayed large variations in conductivity, phosphorus, and nitrogen were selected as case studies designed to associate the areal patterns observed in the lake to the quality and quantity of tributary discharges. Since these case studies represent the extreme events in terms of high areal variability, they would tend to identify the maximum areas of tributary influence as defined by rapid changes in ambient lake levels. A large variation and high mean level in specific conductivity was measured from August 6 to 10, 1978. The northern region of the lake showed a large area of reduced conductivity levels. Approximately 25 sq. mi. of the northern region (4.2%) had conductivity levels which were two-thirds below the majority or background level of the lake. An additional 25 sq. mi. (4.2%) in the same region had conductivity levels one-half that of the rest of the lake. The lower conductivity levels in this total 50 sq. mi. area (8.4% of the lake) was directly attributed to large releases from C-38. During these same dates, conductivity levels were elevated in a 28.5 sq. mi. area in the south end of the lake. This increase in conductivity over 5 percent of the total lake surface was attributed to pumpage from the Everglades Agricultural Area primarily through S-2 and S-3. Pumpage from S-4 increased conductivity levels over an additional 41 sq. miles (7% of the lake).

The largest degree of areal variation in total phosphorus was measured during the September 8 to 13, 1979 sampling trip. In total, 23 percent (144 sq. mi.) of the lake's surface area had total phosphorus concentrations elevated above the background levels for this date. Nine percent (58 sq. mi.) of the increase was attributed to discharge from Taylor Creek/Nubbin Slough through S-191. The remaining 14 percent (86 sq. mi.) area of elevated phosphorus levels was the result of discharge from Fisheating Creek. Releases from C-38 appeared to have virtually no effect on ambient lake phosphorus concentrations.

The September 6 to 8, 1978 sampling trip displayed the largest areal variation in total nitrogen concentrations. During these dates, 4.4 percent (27 sq. mi.) of the lake's surface area was elevated above ambient levels. This area of elevated total nitrogen concentrations occurred in the southern end of the lake and was attributed to pumpage from S-2 and S-3.

There was a wide divergence of nutrient concentrations entering the lake from the various inflows. The highest mean annual flow-weighted total phosphorus concentration (0.906 mg/L) was measured at Taylor Creek/ Nubbin Slough at S-191. Consequently, S-191 has the lowest total nitrogen to total phosphorus (TN/TP) ratio (2.5) indicating a large excess of phosphorus relative to plant requirements. The North New River and Hillsboro Canals at S-2 and the Miami Canal at S-3 had the highest mean annual flow weighted total nitrogen concentration (5.82 mg/L and 4.92 mg/L, respectively). These high nitrogen concentrations resulted in the highest total nitrogen to total phosphorus (TN/TP) ratios of any inflow (44.1 at S-2 and 51.8 at S-3) indicating a large excess of nitrogen relative to plant needs. The Kissimmee River at S-65E had the lowest mean annual flow-weighted phosphorus concentration (0.092 mg/L) of any inflow to the lake excluding rainfall. S-65E also had the second lowest flow weighted total nitrogen concentration (1.39 mg/L) next to C-41A at S-84 (1.35 mg/L). Variations in nutrient concentrations at most of the tributary discharge points showed positive correlations to the amount of discharge.

The majority of the tributaries did not demonstrate any substantial increase or decrease in nutrient levels from 1973 to 1979. The tributaries which did show an increasing trend in mean annual phosphorus levels were S-4 (0.211 to 0.427 mg/L), the Kissimmee River (0.081 to 0.115 mg/L) and S-191 (0.737 to 1.013 mg/L). S-2 and S-3 exhibited decreasing mean annual total nitrogen concentrations from 1973 to 1974 while S-4 exhibited an increasing trend.

The annual flow weighted total nitrogen concentrations from all sources remained relatively constant over the study period, ranging from 1.66 mg/L in 1979 to 1.98 mg/L in 1977. The degree of annual fluctuations was greater for total phosphorus than for total nitrogen, although the fluctuations did not follow any secular trend. The lowest annual flow-weighted total phosphorus concentration was in 1975 (0.107 mg/L) while the highest concentration was in 1979 (0.163 mg/L). Based on comparisons of mean annual limnetic and flow weighted inflow concentrations, the ambient phosphorus levels in the lake did not always respond proportionally to the changes in the annual flow weighted phosphorus inflow concentrations.

Annual material budgets for water, phosphorus, nitrogen, and chloride were calculated for each of the seven years of this study. Over the study period, the water budgets had excellent accountability, coming within 4.0 percent of the storage reported by the Army Corps of Engineers. The average water residence time (excluding evaporation) and hydraulic loading rate (excluding rainfall) from 1973 to 1979 was 3.47 years and 1.57 m/yr, respectively. Based upon the average material budgets, direct rainfall and the Kissimmee River accounted for 70 percent of the water inflow to the lake. Evaporation was responsible for almost 66 percent of the water leaving the lake. The Nubbin Slough/Taylor Creek Basin (S-191 and S-133) was the largest contributor of phosphorus, 29.6 percent, although the basin supplied only 4.9 percent of the water. The next two largest sources of phosphorus, the Kissimmee River and rainfall, contributed proportionally less phosphorus (20.2% and 16.7%, respectively) with respect to the amount of water supplied (30.9% and 38.8%, respectively). Similar disproportionalities existed for nitrogen with the EAA (S-2, S-3, and S-4) contributing 25.0 percent of the total nitrogen load but only 8.2 percent of the water. Again, the Kissimmee River and rainfall supplied proportionally less nitrogen (24.6 and 24.3%, respectively) than water. On a lake-wide basis the areal phosphorus and nitrogen loading rate averaged 0.347 and 4.32 g/m^2 - yr, respectively. On the average, the lake retained approximately 84 percent of the phosphorus input and 64 percent of the nitrogen input. Annual phosphorus and nitrogen retention was highly correlated to the water residence time.

A comparison of Lake Okeechobee with literature critical values for six common trophic state indicators (Secchi disk, chlorophyll a, total phosphorus, ortho phosphate, total nitrogen, and inorganic nitrogen) indicated that the lake was eutrophic. The same classification was determined using a quantitative trophic state index based upon four indicators (Secchi disk, chlorophyll a, total phosphorus, and total nitrogen). There was no change in trophic state throughout the study period.

Eight nutrient loading models were evaluated for their applicability to Lake Okeechobee. The evaluation criteria included the ability of the model to assess the trophic state of the lake as compared to the above subjective indicators and quantitative indices, the ability of the model to predict inlake nutrient concentrations, the model development data base and the model parameters. The model which best fit these criteria for both phosphorus and nitrogen was a modified Vollenweider (1976) model. This model predicted the average limnetic total phosphorus concentration from 1973 to 1979 within 2 percent and the total nitrogen concentration within 26 percent. Individual annual predictions ranged from 4 to 53 percent of the actual phosphorus and nitrogen concentrations. In addition, the model was developed from a Florida data base with measured nutrient budgets and considered the effect of the water residence time on the lake's response to nutrient loadings.

The modified Vollenweider (1976) model predicts a eutrophic state for Lake Okeechobee based upon both phosphorus and nitrogen loadings. Probability analysis of the modified Vollenweider (1976) model indicates that Lake Okeechobee had a 78 percent probability of being eutrophic using phosphorus loadings and a 79 percent probability using nitrogen loadings. This is consistent with the trophic state assessment involving qualitative subjective indicators and quantitative indices.

The application of the modified Vollenweider (1976) model to Lake Okeechobee indicated that, on the average, the phosphorus and nitrogen loads to the lake were 40 and 34 percent, respectively, above the excessive loading rate, the level which the lake can be expected to remain eutrophic. Since the lake is neither conclusively phosphorus or nitrogen limited and since the modified Vollenweider (1976) model predicts the same trophic state based upon either nutrient, both the phosphorus and nitrogen based models should be used to manage the lake at this time.

CHAPTER III

DESCRIPTION OF LAKE OKEECHOBEE

Lake Okeechobee ranks as the second largest freshwater lake in the United States after Lake Michigan. The lake is centrally located in south Florida between latitudes 27°12'N and 26°40'N and longitudes 80°37'W and 81°08'W. Brezonik et al. (1979) described the origin and early history of Lake Okeechobee. The lake originated by gentle epeirogenetic uplift of an irregular marine surface (Hutchinson 1957). Uneven sedimentation by currents formed the original submarine depression during the Pliocene (Parker and Cooke 1944). Recession of the sea during the Pleistocene probably formed the lake itself. The original lake was increased greatly by organic peat accumulation along the southern rim of the lake about 6,300 years ago (Brooks 1974). This natural dam reached its maximum elevation ($\sim$20 ft. mean sea level, MSL) less than 2,000 years ago. In its natural state Lake Okeechobee had no channelized outflows. The normal lake stage was a function of tributary inflows, direct rainfall, and evaporation. Surface outflow from the lake occurred only during periods of high lake stage ($>\sim$20 ft MSL). This surface release of water manifested itself as sheet flow over the southern and southwestern shores through the shallow sawgrass Everglades and eventually goes to Florida Bay and the Gulf of Mexico.

Prior to man-made alterations of the drainage basin, Lake Okeechobee received surface inflow from approximately 4,000 sq. miles. Since the early 1900's channel improvements and new canal systems have added approximately 600 sq. mi. of land to the lake's watershed. Figure 3-1 delineates drainage areas and differentiates between the natural drainage area and those that have been added by man. Historically the Kissimmee River, Fisheating Creek, and Taylor Creek were the primary tributaries to the lake. Additional smaller inflows occurred via Nubbin Slough (northeastern shore), Nicodemus Slough (western shore), Lettuce Creek (eastern shore), and Hendry Creek (eastern shore). Non-point sheet flow also occurred from areas along the northwest and northeastern shores, including Lake Istokpoga.

Improvements in the drainage patterns to the lake were begun in 1881 by Hamilton Disston. According to Brezonik et al. (1979) (from Will 1956) the Disston canals were dredged from old channels that had been previously dug by the Caloosa Indians or their predecessors. Since the early 1900's major channel improvements and canal systems have been introduced. Figure 3-2 displays the chronological succession of major drainage improvements in the Lake Okeechobee basin. Most of the present drainage and water supply system was designed and constructed by the U. S. Army Corps of Engineers and is maintained and operated by the SFWMD.

Erection of low muck levees along the south and southwest shores eliminated sheet flow into the Everglades in the early 1920's. These original levees were breached by the 1926 and 1928 hurricanes with the resultant loss of over 2,100 lives (Douglas 1947). This catastrophe resulted in the Corps of Engineers building a larger levee around the southern end of the lake. Construction of this section of levee was completed in 1937. Later, between 1960 and 1964, the levee was raised several additional feet and extended around the entire lake. Today the lake is

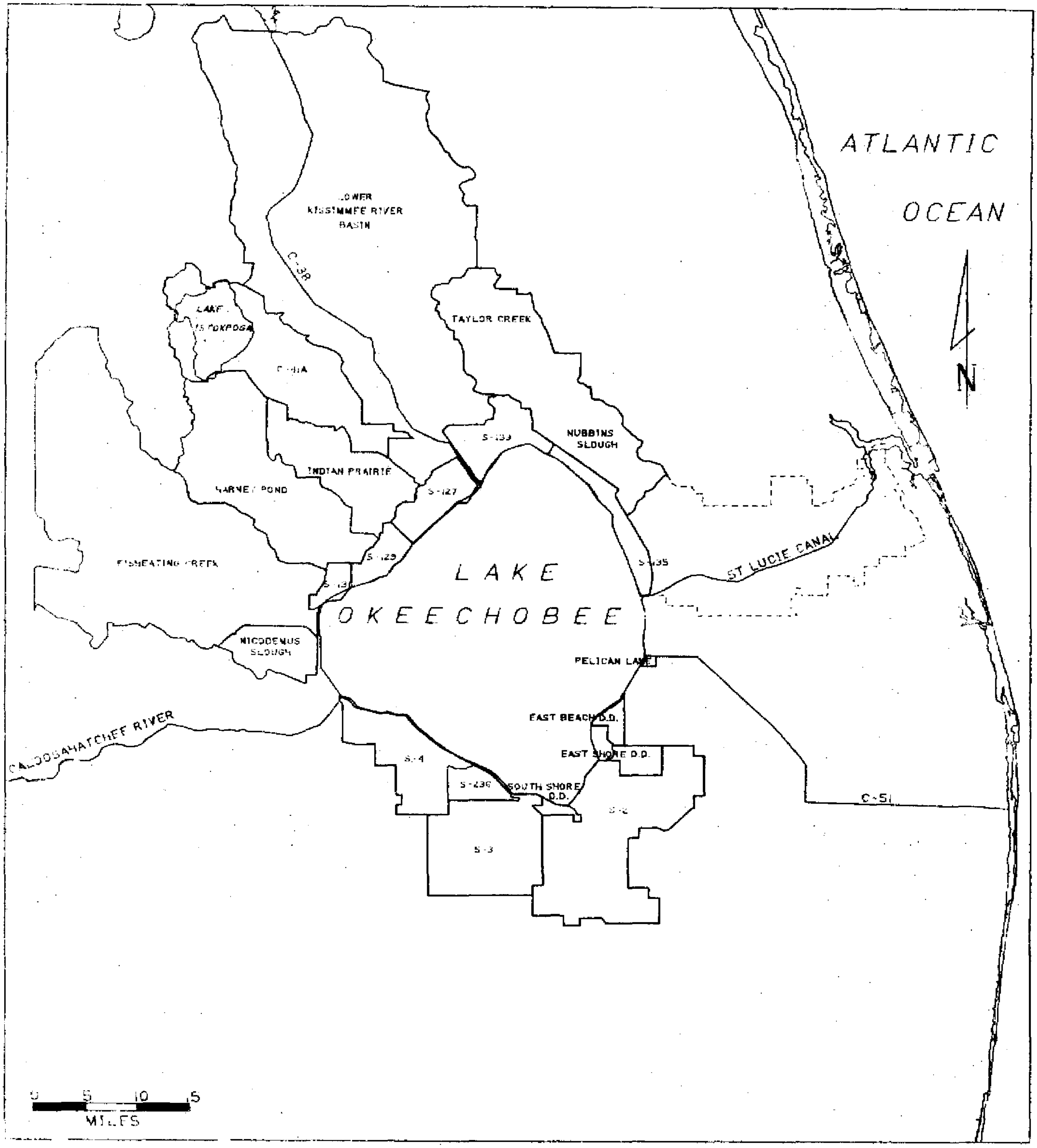


FIGURE 3-1. LAKE OKEECHOBEE SURFACE WATER DRAINAGE BASINS

NOTE: Areas designated by dashed lines contribute only small amounts of water at irregular intervals. Drainage basins south of the lake have been added by man.

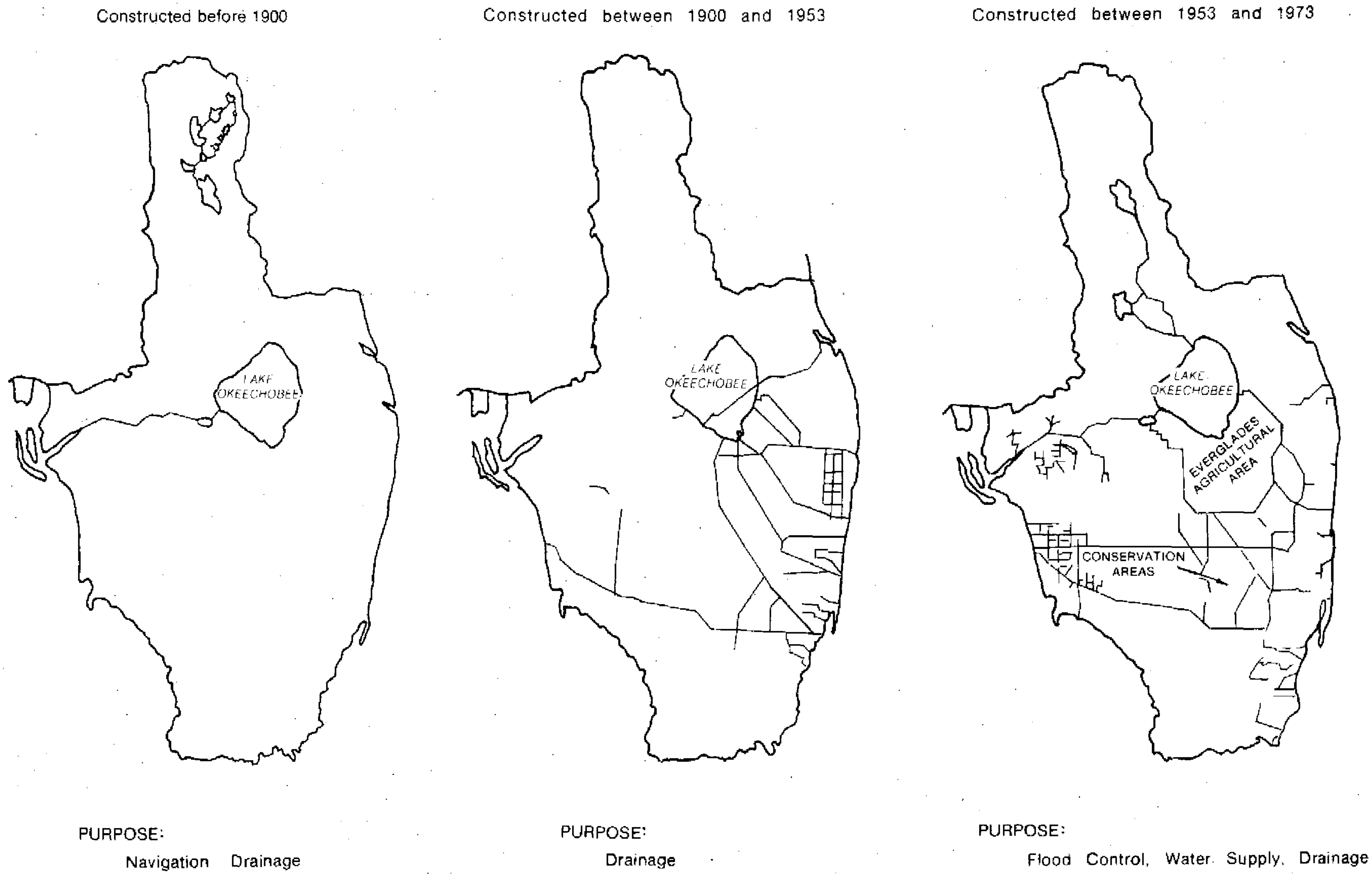


Figure 3-2. HISTORY OF THE CONSTRUCTION OF DRAINAGE CANALS AND FLOOD CONTROL STRUCTURES FROM 1900 THROUGH 1973. (Source: Brezonik et al. 1979 after Browder et al. 1973)

completely surrounded by a large levee, the Hoover Dike, which extends to a height of 40 ft. MSL and encompasses approximately 750 sq. miles. Due to construction of the Hoover Dike, Lake Okeechobee does not receive any direct sheet flow runoff. With the exception of Fisheating Creek, all the inflows to the lake pass through some type of water control structure. Since the natural slope of the land south of the lake is away from the lake, several large pump stations and canals are required to provide drainage into the lake from this area; however, these same canals can also be used as a gravity irrigation system. Figure 3-3 shows the major inflows and outflows to the lake and the direction in which water travels. Table 3-1 describes the function of each water control structure along the Hoover Dike.

Due to its shallow depth, Lake Okeechobee has an extensive littoral zone encompassing approximately 150 sq. miles. According to Pesnell and Brown (1977) the present littoral zone is a product of recent lake stages. Emergent vegetation occupies about 95,482 acres, which is a band 1/2 to 9 miles wide extending primarily from Clewiston on the southwest to the Kissimmee River on the north shore (Figure 3-4). The vegetation present in this emergent zone is listed in Table 3-2.

Tables 3-3 to 3-8 present the 1970-73 land use characteristics of each major drainage basin to Lake Okeechobee. In general, the entire Lake Okeechobee watershed is dominated by some type of agricultural activity. Cattle and dairy pasturelands are the primary land use activities north and northwest of the lake while cropland (sugarcane, vegetables, etc.) dominate the drainage basins south and east of the lake. There has not been any major shift in land use activities from 1970 to the present.

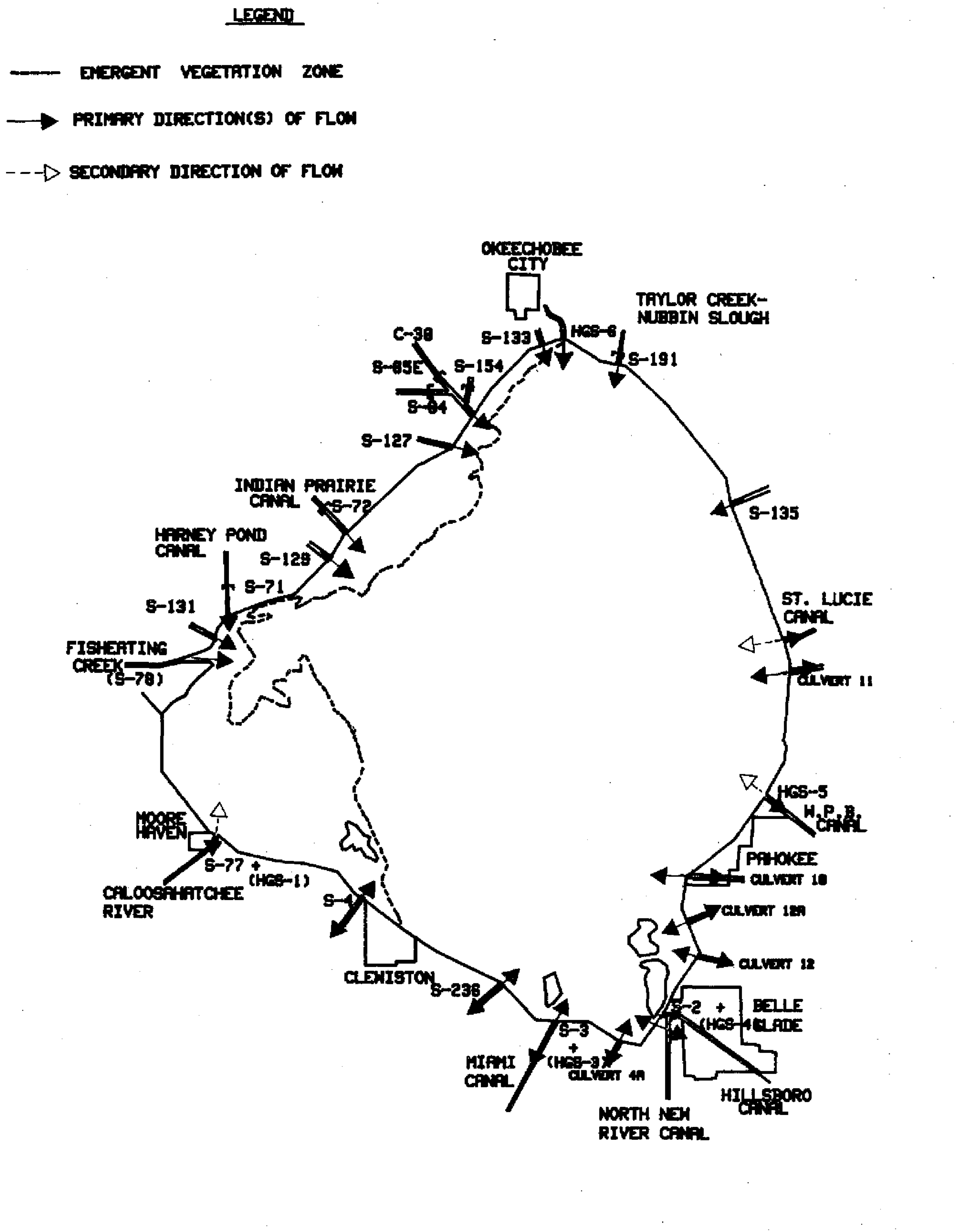


Figure 3-3 INFLOWS AND OUTFLOWS TO LAKE OKEECHOBEE

TABLE 3-1. DESCRIPTION OF LAKE OKEECHOBEE INFLOW AND OUTFLOW STRUCTURES

Pump Station	Location	Specifications
S-2	North New River Canal at Lake Okeechobee. 4 miles west of the City of Belle Glade	4-diesel powered pumps to drain 3/4 of an inch of water from a 180 sq. mile portion of the Everglades Agricultural Area in 24 hours into Lake Okeechobee. The maximum discharge is 3,600 CFS. Date of Acceptance - February 1, 1957.
S-3	Miami Canal at Lake Okeechobee in the Town of Lake Harbor	3-diesel powered pumps to drain 3/4 of an inch of water from a 129 sq. mile portion of the Everglades Agricultural Area in 24 hours into Lake Okeechobee. The maximum discharge capacity is 2,580 cfs. Date of Acceptance April 7, 1958.
S-4	C-20 Canal at Lake Okeechobee 3 miles N. W. of Clewiston	3-diesel powered pumps to drain 4 inches of water from a 4.3 sq. mile urban area and 3/4 of an inch from a 111.7 sq.mile portion of the Everglades AGricultural Area in 24 hours (via Canals C-20, C-21). The maximum discharge capacity is 2,805 cfs. Date of Acceptance July 11, 1975.
S-127	L-48 Canal 12 miles S.W. of the Town of Okeechobee	5-diesel powered pumps to drain 3/4 of an inch of water from a 31.2 sq. mile tributary drainage basin into Lake Okeechobee in 24 hours. The maximum discharge capacity is 625 cfs. 15' x 50' navigation lock adjacent to structure. Date of Acceptance December 14, 1965.
S-129	L-49 Canal 20 miles S.W. of the Town of Okeechobee	3-diesel powered pumps to drain 3/4 of an inch of water from an 18 sq. mile tributary drainage basin into Lake Okeechobee in 24 hours. The maximum discharge capacity is 375 cfs. Date of Acceptance December 14, 1965.
S-131	L-50 Canal 27 miles S.W. of the Town of Okeechobee	2-diesel powered pumps to drain 3/4 of an inch of water from an 11.7 sq. mile tributary drainage basin into Lake Okeechobee in 24 hours. The maximum discharge capacity is 230 cfs. 15' x 50' navigation lock adjacent to structure Date of Acceptance November 29, 1963.

TABLE 3-1 (Continued)

Pump Station	Location	Specifications
S-133	L-D4 Canal at Taylor Creek	5-diesel powered pumps to drain 3/4 inch of water from a 31 sq. mile tributary drainage basin into Lake Okeechobee in 24 hours. The maximum discharge capacity is 625 cfs. Date of Acceptance September 9, 1969.
S-135	L-47 Canal 15 mi. S.E. of the Town of Okeechobee	4-diesel powered pumps to drain 3/4 inch of water from a 25.4 sq. mile tributary drainage basin into Lake Okeechobee in 24 hours. The maximum discharge capacity is 500 cfs. 15' x 50' navigation lock adjacent to structure. Date of Acceptance March 6, 1970.

Inflow Structure	Location	Specifications
S-71	C-41 Canal (Harney Pond Canal) 22 miles S.W. of the Town of Okeechobee	3-Automatic vertical lift gates 25' wide by 12' high each: 196.4 sq. mile drainage basin south of Lake Istokpoga. The maximum discharge capacity is 6,800 cfs. Date of Acceptance October 1962.
S-72	C-40 Canal (Indian Prairie Canal) 15 miles S.W. of the Town of Okeechobee	2-Automatic vertical lift gates 27' wide by 12.5' high each: 100.6 sq. mi. drainage basin south of Lake Istokpoga. The maximum discharge capacity is 3,800 cfs. Date of Acceptance October 1962.
S-84	C-41A Canal (Brighton Canal) 8 miles west of the Town of Okeechobee	2-Automatic vertical lift gates 21' wide by 11.8' high each. Drains 70.4 sq. mile basin and directly drains from Istokpoga into the C-38 below S-65E. The max. discharge capacity is 9,000 cfs. Date of Acceptance November 1963.
S-65E	C-38 Canal (Kissimmee River) 8 miles west of the Town of Okeechobee	6-Vertical lift gates 27' wide by 13.7' high each. Drains entire 2,260 sq. mi. Kissimmee Basin. The maximum discharge capacity is 24,000 cfs. 30'x 90' navigation lock adjacent to structure. Date of Acceptance October 1964.
S-154	L-62 Canal (Popash Slough) 5 miles west of the Town of Okeechobee	2-Concrete box culverts 8' x 10' with automatic gates. 32.4 sq. mile drainage basin west of Okeechobee City. The maximum discharge capacity is 1,000 cfs. Date of Acceptance June 1978.

TABLE 3-1 (Continued)

Inflow Structure	Location	Specifications
S191	C-59 Canal (Nubbin Slough) at Lake Okeechobee 5 miles S.E. of the Town of Okeechobee	3-Automatic vertical liftgates 27' wide x 12.6' high each. 188 sq. mile drainage basin N.E. of the town of Okeechobee via canals L-63S, L63N, The maximum discharge capacity is 7,440 cfs. Date of Acceptance January 26, 1972.

Outflow Structure	Location	Specifications
HGS-3	Miami Canal at Lake Okeechobee adjacent to S-3	2-Horizontal swing gates each 25' wide. Drainage directly from Lake Okeechobee into the Miami Canal. *The maximum discharge capacity is 4,300 cfs. Date of Acceptance April 7, 1958.
HGS-4	N. New River Canal at Lake Okeechobee adjacent to S-2	2-Horizontal swing gates each 25' wide. Drains directly from Lake Okeechobee into the N. New River Canal. *The maximum discharge capacity is 4,300 cfs. Date of Acceptance February 11, 1957.
HGS-5	C-51 Canal (WPB Canal) at Lake Okeechobee in Canal Point	2-Horizontal swing gates each 25' wide. Drains directly from Lake Okeechobee into the West Palm Beach Canal. *The maximum discharge capacity is 4,300 cfs. Date of Acceptance February 1955.
S-77	C-43 Canal (Caloosahatchee River) S.W. shore of Lake Okeechobee at Moore Haven	4-vertical lift gates 20' wide by 11.9' high each. Drains directly from Lake Okeechobee into the Caloosahatchee River. The maximum discharge capacity is 9,300 cfs.

* Computed from average lake stage level from April 1973 - March 1980.

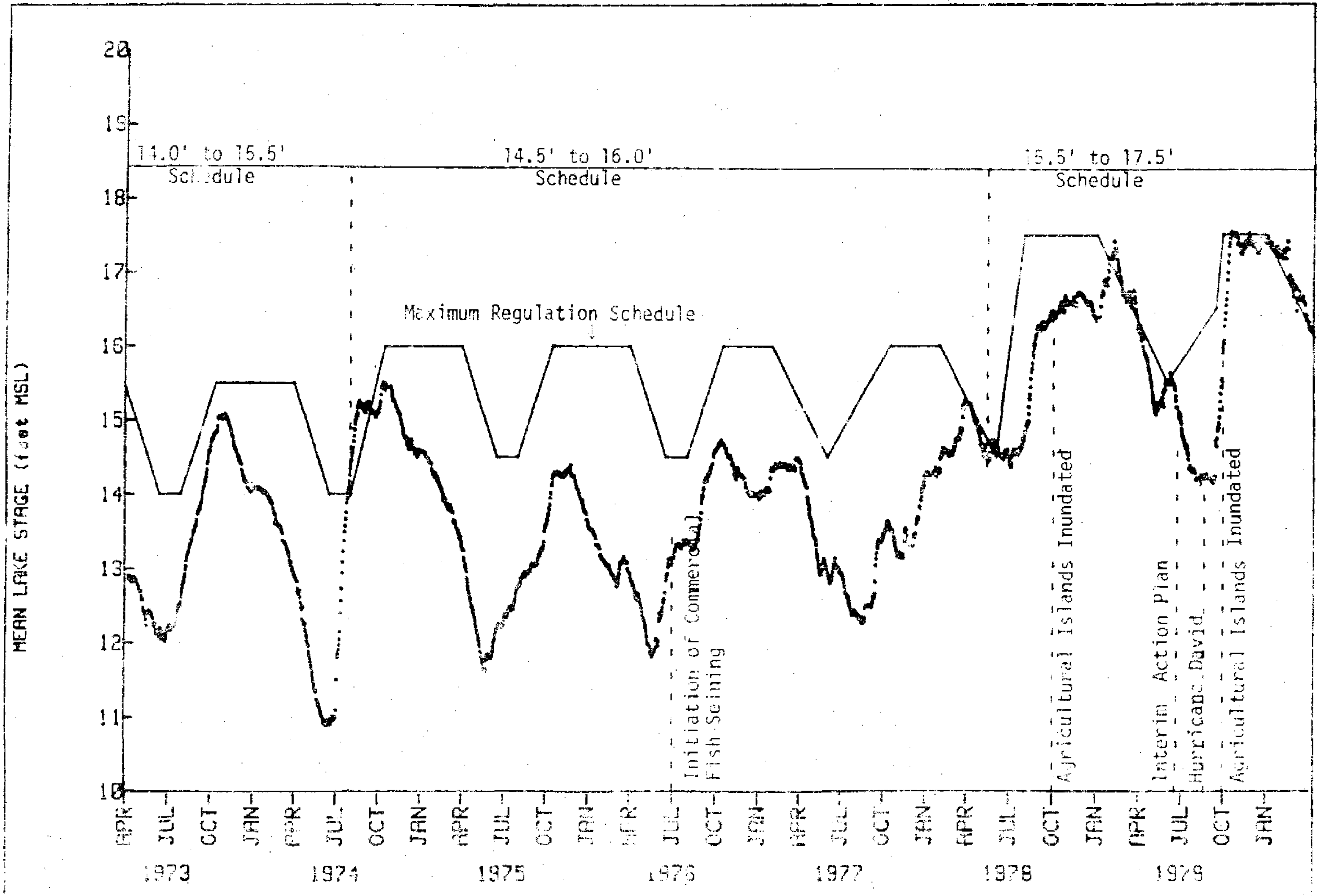


FIGURE 3-4 MEAN DAILY STAGE IN LAKE OKEECHOBEE

TABLE 3-2. THE VEGETATION OF LAKE OKEECHOBEE, FLORIDA

Plant Community	Acres
Bulrush	2,427
Spike-rush	17,609
Cattail	24,128
Willow	10,419
Beak-rush	15,120
Wire Cordgrass	6,907
Sawgrass	4,041
Buttonbush	1,426
Mixed Forest	1,642
Melaleuca	972
Mixed Grasses	9,552
Bog	582
Water Hyacinth	202
Water-Lily	401
Guava	34
TOTAL ACRES	95,482 (149.2 sq. mi.)

(Source: Supplement to Pesnell and Brown, 1977)

TABLE 3-3 LAND USE IN THE KISSIMMEE RIVER BASIN[1]

Lower Kissimmee Basin (below Lake Kissimmee)

Huber and Heaney (1974) [2]	Acres	%	Baldwin (1975)	Acres	%
Urban	1,300	.3%	Cropland	700	.2%
Cropland	1,600	.3%	Citrus	1,600	.4%
Improved Pasture	223,200	49.4%	Pasture	128,600	28.9%
Unimproved Pasture	133,200	29.5%	Range	233,400	52.4%
Citrus	1,000	.2%	Native	80,600	18.1%
Forest	7,500	1.7%			
Swamp	789,000	17.5%		444,900	
Marsh	2,200	.5%			
Barren	3,100	.6%			
Total	452,000				

Upper Kissimmee Basin [2]

Huber and Heaney (1974)	Acres	%	Baldwin (1975)	Acres	%
Urban	91,700	9.2%	Cropland	1,200	.1%
Cropland	1,200	.1%	Citrus	107,700	13.4%
Improved Pasture	234,600	23.6%	Pasture	88,190	11.0%
Unimproved Pasture	236,000	23.7%	Range	376,350	46.9%
Citrus	107,100	10.8%	Native	229,300	28.6%
Forest	38,200	3.8%			
Swamp	61,100	6.1%		802,740	
Marsh	130,300	13.1%			
Barren	0	0 %			
Surface Water	94,800	9.6%			
	996,000				

Entire Kissimmee Basin [2]

Huber and Heaney (1974)	Acres	%	Baldwin (1975)	Acres	%
Urban	93,000	6.4%	Cropland	1,900	.2%
Cropland	2,800	.2%	Citrus	109,300	8.8%
Improved Pasture	457,800	31.6%	Pasture	216,790	17.4%
Unimproved Pasture	369,200	25.4%	Range	609,750	48.9%
Citrus	108,100	7.5%	Native	309,900	24.8%
Forest	45,700	3.2%			
Swamp	140,000	9.7%		1,247,640	
Marsh	132,500	9.2%			
Barren	3,100	.2%			
Surface Water	95,800	6.6%			
	1,448,000				

[1] Source: McCaffrey et al. 1976
[2] 1970 Land Use

TABLE 3-4 LAND USE IN THE TAYLOR CREEK/NUBBIN SLOUGH BASIN[1/]

Florida Dept. of Pollution Control (1974)[2/]

	Acres	%
Agricultural	102,572	67.1%
Idle	0	0%
Forest	22,216	14.5%
Wetlands	22,111	14.5%
Urban/Built Up	5,916	3.9%
	152,815	

Soil Conservation Service (1973)

Citrus	2,700	1.6%
Cropland	500	.3%
Improved Pasture	64,500	39.3%
Unimproved Pasture	51,400	31.3%
Forest	40,000	24.4%
Non-Agricultural	5,000	3.1%
	164,100	

1/ Source: McCaffrey et al. 1976

2/ 1970 Land Use

TABLE 3-5 LAND USE IN THE FISHEATING CREEK BASIN

Florida Dept. of Pollution Control (1974)[2/]

	Acres	%
Agricultural	85,640	29.6%
Idle	48,835	16.9%
Forest	31,450	10.9%
Wetlands	120,897	41.8%
Urban/Built Up	2,568	0.8%
	289,390	

Soil Conservation Service (1973)

	Acres	%
Citrus	4,500	1.5%
Cropland	3,400	1.2%
Improved Pasture	43,800	14.6%
Unimproved Pasture	120,300	40.9%
Forest	118,500	40.3%
Non-Agricultural	4,300	1.6%
	293,800	

[1/] Source: McCaffrey et al. 1976

[2/] 1970 Land Use

TABLE 3-6 LAND USE IN THE EVERGLADES AGRICULTURAL AREA[1/]

Florida Dept. of Pollution Control (1974)[2/]

	Acres	%
Agricultural	478,300	68.4%
Idle	22,790	3.3%
Forest	20	0%
Wetlands	179,925	24.7%
Urban/Built Up	25,250	3.6%
	699,285	

Soil Conservation Service (1975)

	Acres	%
Citrus	0	0%
Cropland	255,700	38.5%
Improved Pasture	150,900	21.8%
Unimproved Pasture	47,300	6.8%
Forest	0	0%
Non-Agricultural	227,800	32.9%
	692,700	

1/ Source: McCaffrey et al. 1976

2/ 1970 Land Use

TABLE 3-7 LAND USE IN THE LAKE ISTOKPOGA AND HARNEY POND/INDIAN PRAIRIE BASINS 1/

Lake Istokpoga Basin

Florida Dept. of Pollution Control (1974) 2/	Acres	%	Soil Conservation Service (1973)	Acres	%
Agricultural	144,795	43.3%	Citrus	56,600	15.6%
Idle	6,560	2.0%	Cropland	800	.2%
Forest	146,942	44.0%	Improved Pasture	52,100	14.4%
Wetlands	12,405	3.7%	Unimproved Pasture	46,900	13.0%
Urban/Built up	23,470	7.0%	Forest	149,500	41.3%
	334,172		Non-Agricultural	55,900	15.5%
				361,800	

Harney Pond/Indian Prairie Basin 2/

Florida Dept. of Pollution Control (1974)	Acres	%	Soil Conservation Service (1973)	Acres	%
Agricultural	96,160	42.1%	Citrus	7,300	3.2%
Idle	29,140	12.8%	Cropland	1,600	.7%
Forest	19,285	8.5%	Improved Pasture	53,300	23.2%
Wetlands	81,055	35.5%	Unimproved Pasture	119,900	52.1%
Urban/Built up	2,590	1.1%	Wetlands	45,200	19.6%
	228,230		Non-Agricultural	2,900	1.2%
				230,200	

Entire Lake Istokpoga and Harney Pond/Indian Prairie Basin 2/

Florida Dept. of Pollution Control (1974)	Acres	%	Soil Conservation Service (1973)	Acres	%
Agricultural	240,955	42.8%	Citrus	63,900	11.7%
Idle	35,700	6.4%	Cropland	2,400	.4%
Forest	166,227	29.6%	Improved Pasture	57,430	10.6%
Wetlands	93,460	16.6%	Unimproved Pasture	166,800	30.7%
Urban/Built up	26,060	4.6%	Wetlands	45,200	8.3%
	562,402		Non-Agricultural	58,800	10.8%
			Forest	149,500	27.5%
				544,030	

[1] Source: McCaffrey et al. 1976

[2] 1970 Land Use

TABLE 3-8

1980 LAND COVER DATA FOR SMALL PUMP STATIONS*

S-131 BASIN

	Acre	%
Fish Farms	5	.07
Improved Pasture	6375	88.9
Levees	90	1.3
Extractive	57	.79
Cabbage Palms/Oaks	77	1.07
Water	13	.18
Rivers, Streams, Canals	174	2.4
Open and Undeveloped	14	.19
Mobile Homes	14	.19
Single Family Low Density	334	4.6
Willow	2	.027
Cattail	11	.15
	7172	

S-127 BASIN

	Acre	%
Dairy Farms	20	.096
Improved Pasture	17575	84.6
Spoil Areas	265	1.2
Cabbage Palms/Oaks	5	.024
Water	7	.033
Rivers, Streams, Canals	187	.9
Grassland	56	.26
Palmetto Prairies	82	.39
Open Under Development	99	.47
Open and Undeveloped	90	.43
Mobile Homes	350	1.7
Single Family Low Density	27	.13
Non-Forested Fresh	1997	9.6
	20766	

S-129 BASIN

	Acre	%
Improved Pasture	11333	93.6
Levees	208	1.7
Cabbage Palms/Oaks	50	.41
Rivers, Streams, Canals	180	1.4
Single Family High Density	334	2.7
	12106	

* Source: SFWMD files

TABLE 3-8 (continued)

1980 LAND COVER DATA FOR SMALL PUMP STATIONS*

S-133 BASIN

	Acre	%
Citrus	161	.6
Ornamentals	4	.015
Improved Pasture	15599	60.7
Unimproved Pasture	328	1.2
Levees	406	1.5
Extractive	502	1.9
Pine Flatwoods	257	1.0
Cabbage Palms/Oaks	911	3.5
Pine/Cabbage Palm	319	1.2
Oak	188	.7
Water	160	.6
Rivers, Streams, Canals	217	.8
Cultural & Entertainment	34	.1
Marinas & Boatyards	16	.06
Shopping Center	40	.1
Sales & Services	274	1.
Industrial	39	.1
Parks	16	.06
Recreational Facility	13	.05
Open Under Development	394	1.5
Open and Undeveloped	341	1.3
Multi-Family	234	.9
Mobile Homes	978	3.8
Single Family High Density	50	.1
Single Family Low Density	938	3.6
Single Family Medium Density	1564	6.0
Educational Facility	161	.6
Other Governmental	22	.08
Medical Facility	23	.08
Airports	525	2.0
Electrical Power Facility	13	.05
Broadcasting or Receiving Towers	17	.06
Water Supply Facility	4	.01
Cypress	767	2.9
Mixed Forested	31	.1
Cattail	23	.08
Non-Forested Fresh	86	.3
	25674	

TABLE 3-8 (continued)

1980 LAND COVER DATA FOR SMALL PUMP STATIONS*

S-135 BASIN

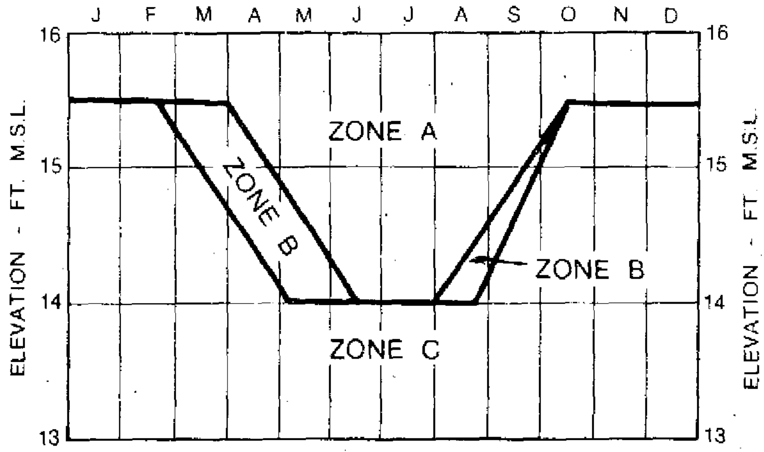
	Acre	%
Sugar Cane	4506	24.9
Dairy Farms	14	.08
Citrus	61	.33
Improved Pasture	9167	50.6
Levees	745	4.1
Pine Flatwoods	509	2.8
Cabbage Palms/Oaks	1024	5.6
Pine/Cabbage Palm	123	.6
Pine/Oak	124	.6
Water	687	3.7
Rivers, Streams, Canals	35	.19
Sales & Services	7	.038
Open and Undeveloped	25	.13
Mobile Homes	196	1.0
Single Family Low Density	111	.6
Cypress	154	.8
Non-Forested Fresh	23	.1
Pine & Wet Prairies	575	3.1
	18095	

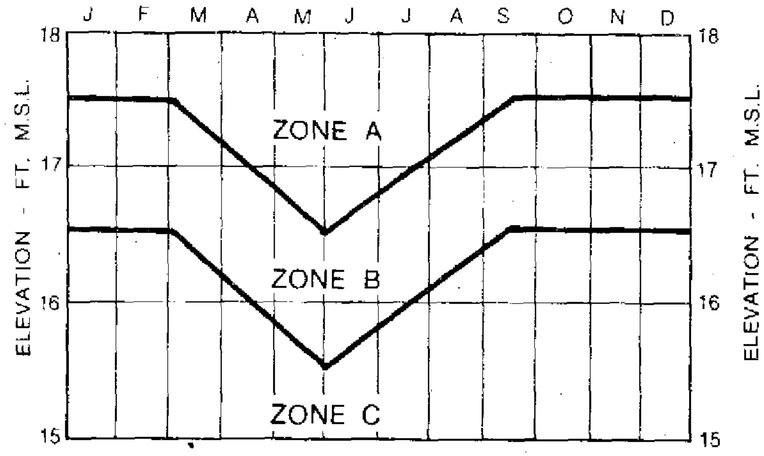
NICODEMUS SLOUGH BASIN

Improved Pasture	7552	30.
Unimproved Pasture	5618	22.3
Spoil Areas	17	.07
Commercial Forest (Pine)	219	.9
Cabbage Palms/Oaks	2424	9.6
Old Fields Forested	58	.2
Oak	735	2.9
Water	6	.02
Rivers, Streams, Canals	268	1.0
Palmetto Prairies	4710	18.7
Cypress	285	1.1
Mixed Forested	310	1.2
Sloughs	1357	5.4
Cypress & Wet Prairies	1638	6.5
	25197	

LAKE STAGE REGULATION

The U. S. Corps of Engineers regulates the water stage in Lake Okeechobee for water supply, flood protection, and navigation. From 1970 to August 1974 the maximum lake stage was limited to 14.0 ft. MSL at the beginning of the wet season (May) and 15.5 ft. MSL at the beginning of the dry season (October). In August 1974 an interim regulation schedule of 14.5 to 16.0 ft. MSL was implemented. In order to provide greater flood protection and water supply, modifications were made to the water control structures around the lake which, in May 1978, permitted the implementation of the present lake regulation schedule. The present regulation schedule varies between 15.5 ft. MSL (wet season) and 17.5 ft. MSL (dry season) (Figure 3-4). Figure 3-5 displays two of the regulation schedules and describes how regulatory releases are made and what other types of releases are permitted at stages below regulation levels. When the lake stage exceeds the maximum regulation schedule at any time, regulatory releases are made in order to bring the lake stage down to the maximum level. The order of priority for releases are first through the Agricultural Area (North New River, Hillsboro, and Miami Canals). These releases are made to the Conservation Areas which permit storage of the water and minimize the net loss of water from the system. If additional releases are still needed to bring the lake stage below regulation, then releases are next made through the Caloosahatchee River and finally through the St. Lucie Canal. Releases through Caloosahatchee River and St. Lucie Canal represent losses of the surface water resource to tidewater. More specifically, when the lake stage is in Zone C no regulatory releases are made. Lake levels in Zone B are lowered by discharges at the three major outflows. Zone B





RELEASE THROUGH OUTLETS AS INDICATED			
ZONE	AGRICULTURAL CANALS	CALOOSAHATCHEE RIVER	ST. LUCIE CANAL
A	PUMP MAXIMUM PRACTICABLE TO CONSERVATION AREAS FOR REGULATION AFTER REMOVAL OF LOCAL RUNOFF	UP TO MAXIMUM CAPACITY WITHOUT LOCAL FLOODING	UP TOO MAXIMUM DISCHARGE
B			UP TO MAXIMUM DISCHARGE WITH AVERAGE VELOCITY LIMITED TO 2.5 FT. / SEC
C	NO REGULATORY DISCHARGE	NO REGULATORY DISCHARGE	NO REGULATORY DISCHARGE
	FIRST PRIORITY	SECOND PRIORITY	THIRD PRIORITY

SCHEDULE OF REGULATION			
ZONE	ST. LUCIE CANAL	CALOOSAHATCHEE RIVER	AGRICULTURAL CANALS
A	MAXIMUM DISCHARGE THIRD PRIORITY	MAXIMUM DISCHARGE (9,300 C.F.S.) SECOND PRIORITY	MAXIMUM DISCHARGE AFTER REMOVAL FIRST PRIORITY
B*	DEC.-JAN.-FEB.-MAR. NO DISCHARGE APR.-MAY-SEPT.-OCT.-NOV. UP TO 3,500 C.F.S. JUN.-JUL.-AUG. UP TO 1,500 C.F.S.	UP TO 4,500 C.F.S.	MAXIMUM GRAVITY DISCHARGE AFTER REMOVAL OF LOCAL INFLOW
C	NO DISCHARGE	NO DISCHARGE	FOR ALL TYPE DEMANDS

* RELEASES THROUGH VARIOUS OUTLETS MAY BE MODIFIED TO MINIMIZE DAMAGES OR OBTAIN ADDITIONAL BENEFITS

LAKE OKEECHOBEE
1970 - 1974 REGULATION SCHEDULE

LAKE OKEECHOBEE
CURRENT REGULATION SCHEDULE
(1978 TO PRESENT)

NOTE: This page adapted from MacGill et al., 1976

Figure 3-5. LAKE OKEECHOBEE REGULATION SCHEDULES releases are below the maximum possible in consideration of local environmental and flooding concerns in the St. Lucie and Caloosahatchee estuaries. When the lake stage reaches Zone A, maximum discharges are made from the three outflows in the order previously described.

In addition to regulatory releases, releases are made from the lake to provide water for agricultural demands, for public water supplies, for well field recharge, and for maintenance of ecological habitats. These releases are made on an "as needed" basis.

MAJOR EVENTS

Several major events occurred during this study which affected the study area. Since 1973 there has been three regulation schedules in effect for Lake Okeechobee, as previously described. The implementation of the 17.5 foot maximum regualtion schedule in 1978 resulted in most of Kreamer, Torry, and Ritta islands being inundated at times during 1978 and 1979. These islands were previously used for crop farming over the past 40 to 60 years. A drought in 1973-74, and implementation of the higher regulation schedule in 1978, resulted in a wide variation in the lake stages. This study encompassed the fourth lowest (10.95' MSL) in May/June 1974) and fourth highest (17.65' MSL in October/November 1979 lake stage since 1912.

Other significant events included: (1) permitting of fishing via trawling and seining in 1976 for the first time since 1955; (2) implementation of the Lake Okeechobee Temporary Operating Permit Interim Action Plan in July 1979 resulting in a decrease in pumpage at S-2 and S-3; and (3) Hurricane David on September 3, 1979, the first hurricane to strike the east coast of Florida since 1965.

CHAPTER IV

MATERIALS AND METHODS

Three major data collection efforts were conducted during this study involving an eight station limnetic sampling program, a 40 station lake-wide sampling program and an inflow/outflow sampling program. The details specific to these three sampling programs (i.e., parametric coverage, station location, and sampling frequency) will be presented separately in their respective chapters prior to the discussion of results. This chapter will address the sampling and analytical techniques common to the several data collection efforts. All raw data is available upon request.

SAMPLING AND ANALYTICAL METHODS

Water samples were collected at 0.5 meters using a 2.2 liter PVC Niskin sampler. Those samples collected for dissolved nutrients and anion analysis, (ortho-$PO_4^=$, NO_x^-, NH_4^+, and NO_2^-, $SO_4^=$, Cl^-, alkalinity and color) were filtered immediately upon collection through a 0.45 micron Nucleopore(R) membrane filter. Aliquots for cation analysis (Ca^{++}, Mg^{++}, K^+, Na^+)were also filtered and acidified with concentrated nitric acid (2 drops/60 ml). Unfiltered aliquots were collected for TKN, total $PO_4^=$, total Fe, TOC, total suspended solids, and turbidity. All samples were stored in polyethylene bottles, on ice in the dark, until they were transported back to the laboratory. In the laboratory the samples were kept at four degrees Centigrade in the dark. Analyses were commenced within one week of sample collection.

The analytical methods used in this study are described in Table 4-1 and were either recommended or approved by the Environmental Protection Agency or the American Public Health Association.

In Situ dissolved oxygen, temperature, specific conductivity, and pH measurements were made using a Hydrolab Surveyor II(R) or a Hydrolab Series 8000(R). Secchi disc readings were measured in centimeters using a standard 8" disc.

For purposes of this report, inorganic nitrogen was calculated from the sum of NO_2, NO_3, and NH_4. Inorganic phosphorus is synonymous with ortho phosphorus. The values for nitrogen and phosphorus analyses are reported as mg/L N and mg/P, respectively.

CHLOROPHYLL ANALYSIS

Chlorophyll a samples were collected for 3 years, from April 1974 to March 1977. Unfiltered samples for chlorophyll analysis were placed in 1000 ml polyethylene bottles and stored in the dark, on ice, until transported back to the laboratory (maximum time 24 hours). Immediately upon return to the laboratory, the samples were filtered through Gelman glass fiber filters (0.45 micron pore size) and neutralized with $MgCO_3$. If necessary, the samples were frozen for not more than one week before continuing the analysis. The filters were ground for one to two minutes with a plastic pestle and extracted with 90% acetone for approximately 18 hours. The extracted samples were then analyzed on a Coleman double beam spectrophotometer using the trichromatic method of Strickland and Parsons (1972).

RAINWATER QUALITY COLLECTION METHODOLOGY

The quality of rainfall in the vicinity of Lake Okeechobee was measured by using three bulk precipitation collectors located near the City of Okeechobee, at the S-2 pump station, and at S-131 (Figure 4-1). The rainwater collection apparatus consisted of a 20 cm funnel covered by a screen (1 mm mesh). The collection vessel was a 1 liter bottle. A crown was placed around the edge of the screen in order to reduce perching

TABLE 4-1. ANALYTICAL METHODOLOGIES

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

TABLE 4-1 (Continued)

AutoAnalyzer II Method (Continued)

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, Technican AA II Method #118-71W, modified EPA Method #375.2	0-250.0 mg/L	5.0 mg/L	5.0 mg/L
Total Dissolved Iron	Colorimetric, Automated TPTZ Complex with thioglycolic acid pretreatment, Technicon AA II Method #109-71W	0-1.0 mg/L	0.02 mg/L	0.02 mg/L
Total Iron	Colorimetric, Semi-automated, Hydrochloric Acid Digestion modified Standard Methods 13th Ed., pp 192, 1971, followed by Total Dissolved Iron Determination	0-1.0 mg/L	0.02 mg/L	0.02 mg/L

Physical Parameters

Determination	Method	Range	Detection Range
Suspended Solids	Gravimetric Standard Methods Procedure #208D, 14th Ed., pp 94, 1975, EPA Methods #160.1 to 160.4	20-20,000 mg/L	1.0 mg/L or 5% whichever is greater
pH	Electrometric, EPA Method #150.1	0-14 pH	(sensitivity 0.01 pH)
Turbidity	Nephelometric Standard Methods #214A, 14th Ed., pp 132, 1975, EPA Method #180.1	0-1,000 N.T.U.	2% of scale used
Color	Colorimetric, modified Standard Method #204A, 14th Ed., pp 64, 1975 (modified as per N.C.A.S.I. Technical Bulletin #243) modified EPA Method #110.2	0-500 mg/L as platinum in platinum-cobalt solution	1.0 mg/L

TABLE 4-1. (Continued)

Atomic Absorption

Metals - Major Cation

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

and subsequent contamination by bird droppings. All the collection equipment was constructed of a plastic, except for the housing, which was constructed of wood. The collector was mounted 1 m above ground level, in the open, in order to prevent ground splash and drip contamination. The rainwater collector was serviced daily during week days. Daily samples (if any) were frozen into biweekly composites.

MATERIAL LOADING METHODOLOGY

Material loadings were calculated by combining daily flow rates at a particular site and time period, with the corresponding chemical data. Since chemistry data was not collected daily, two chronologically successive chemistry data points were averaged to give an estimated value for the time period between these two points. This average was then used in conjunction with daily flow data within the time period to compute the daily loadings. The material loads are reported in 10^6 grams (= metric tonne). This was one of the preferred techniques described by Scheider, et al. (1978). Flow weighted concentrations were calculated by dividing the mass by the flow for a given time period (i.e., annually or monthly).

ANNUAL PERIODS

Throughout this report year designations will represent the 12 month period from April 1st of the year indicated through March 31st of the following year (i.e., 1973 corresponds to the period April 1, 1973 to March 31, 1974).

CHAPTER V

TRIBUTARY WATER QUALITY

INTRODUCTION

This chapter will deal primarily with nitrogen and phosphorus levels entering Lake Okeechobee from the major surface inflows. The three major outflows from the lake have, on rare occasions, served as minor inflows. Under conditions of high canal stages and low lake stages, the Caloosahatchee River (S-77) discharged into the lake for one month in June 1974, the St. Lucie Canal for three days in 1979, and the West Palm Beach Canal (HGS-5) for five weeks in 1974, and for one week in 1975 and 1976. Since these were minor events, the quality of the discharge water will not be discussed.

Specific areas of discussion will focus upon: (1) the diversity of the general water quality characteristics of the tributaries; (2) relative ranking of the tributaries based upon nitrogen and phosphorus; (3) average nutrient levels over the study period; (4) changes in the mean annual phosphorus and nitrogen concentrations; (5) nutrient/discharge relationships; and (6) nitrogen to phosphorus ratios.

The location of the inflows are indicated in Figure 5-1. These tributaries were sampled approximately biweekly from April 1973 through March 1980 (Table 5-1). Sampling methodologies were previously described in Chapter IV. Parameters covered included NO_3, NO_2, TKN, NH_4, O-PO_4, Total PO_4, SO_4, Cl, alkalinity, total Fe, TOC, total suspended solids, turbidity, color, dissolved oxygen, temperature, pH and conductivity. Flow-weighted concentrations presented herein were calculated by dividing the total annual material mass by the total annual flow.

TABLE 5-1

SAMPLING FREQUENCIES FOR TRIBUTARIES

Station	Dates	Sampling Frequency
N.N.R. & Hills. C. (S-2) Miami C. (S-3) Harney Pond C. (S-71) Indian Prairie C. (S-72) Fisheating Creek Nubbin Slough (S-191) WPB Canal (HGS-5) Caloosahatchee R. (S-77)	4/73-10/73 11/73-5/75 6/75-10/75 11/75-3/80	weekly biweekly weekly biweekly
S-4	3/76-3/80	biweekly
Kissimmee R. (S-65E)	4/73-10/73 11/73-11/74 12/74-11/78 12/78-3/80	weekly biweekly monthly biweekly
S-84	4/73-10/73 11/73-11/74 12/74-9/78 10/78-3/80	weekly biweekly monthly biweekly
S-127 S-129 S-131 Taylor Creek (S-133) S-135	4/73-10/73 11/73-4/74 5/79-3/80	weekly biweekly biweekly
Rainfall stations: Okeechobee F.S. S-2 S-131	11/74-3/80	approx. biweekly
St. Lucie Canal (S-308)) (L004)	4/73-1/74 2/74-12/76 1/77-3/80	monthly biweekly monthly

RESULTS AND DISCUSSION

General Tributary Water Quality

Table 5-2 presents the mean and range of values for all water quality parameters (except nitrogen and phosphorus) measured at the inflows to Lake Okeechobee. Nitrogen and phosphorus will be discussed in more depth following this section. The 15 major inflow points to Lake Okeechobee exhibited a wide range of water quality characteristics. Mean cation and anion levels exhibited a 4 to 15 fold range among the tributaries. This is typified by specific conductance which ranged from an average of 1025 and 847 μmhos/cm at S-2 and S-3, respectively, to 167 and 168 μmhos/cm at S-84 and S-65E, respectively. One of the minor inflows (S-135) also had a high average specific conductance (920 μmhos/cm). The largest variation in a single parameter occurred in alkalinity which ranged from 0.33 meq/L at S-84 to 5.04 meq/L at S-2. Total iron displayed a different pattern with the lowest average concentrations occurring at S-2, S-3, and S-4 (0.17, 0.16 and 0.16 mg/L, respectively) and the highest concentration at S-72 (0.78 mg/L).

In response to the low geographic relief of south Florida, total suspended solids and turbidity levels entering Lake Okeechobee were very low. Total suspended solids ranged from an average of 5.4 mg/L at S-154 to 12.7 mg/L at S-3. Similarly, turbidity ranged from an average of 1.1 JTU at S-131 and Fisheating Creek to only 4.9 JTU at S-3.

Mean total organic carbon levels were relatively low at all the tributaries ranging from 16.1 mg/L at S-84 to 28.8 mg/L at S-2; however, the tributaries had high maximum total organic carbon concentrations from 29.8 to 93.9 mg/L.

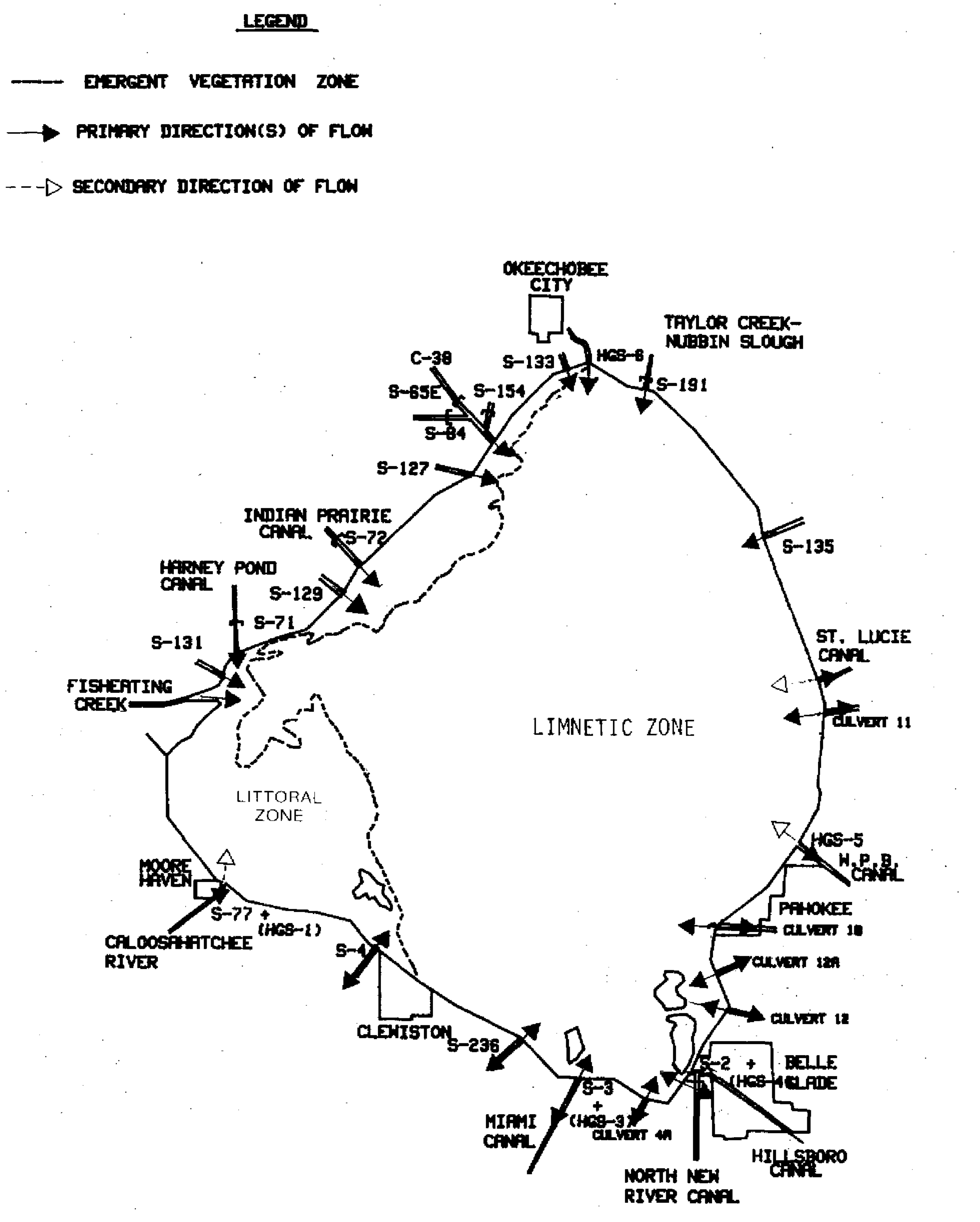


Figure 5-1 INFLOWS AND OUTFLOWS TO LAKE OKEECHOBEE

TABLE 5-2. SELECTED WATER CHEMISTRY PARAMETERS FOR LAKE OKEECHOBEE INFLOWS

Inflow	SO_4 mg/L	Cl mg/L	Alkalinity meq/L	Total Fe mg/L	TOC mg/L	Total Sus. Solid mg/L
S-2	101.3 [1] 46.1-251.9 [2]	136.1 15.7-403.6	5.04 .24-10.0	0.17 .02-.80	28.8 7.8-55.9	11.4 .7-56.
S-3	77.5 190.0-129.1	113.4 62.8-277.2	4.05 .4-8.4	0.16 .02-.78	23.0 11.4-44.8	12.7 .7-95.1
S-4	67.7 23.4-131.5	114.6 53.0-196.7	4.02 1.82-6.96	0.16 .02-.55	24.5 6.9-40.9	8.3 .8-35.7
Fisheating Ck	15.0 4.4-56.6	47.9 9.6-155.1	0.65 .07-4.22	0.41 .08-1.21	21.7 12.3-39.6	6.4 .3-66.0
S-127	65.6 35.2-109.6	88.0 28.7-207.9	2.70 .60-4.22	0.31 .02-1.07	24.4 14.8-31.4	6.4 1.0-16.0
S-129	7.13 53.1-80.2	72.1 17.6-109.1	2.44 1.39-4.22	0.27 .04-.96	24.3 16.1-47.6	6.3 1.0-14.0
S-131	34.0 13.5-54.0	80.2 34.7-116.6	2.35 .30-4.22	0.26 .02-.90	19.4 12.4-35.1	5.8 1.0-24.0
S-133	55.8 43.0-69.1	75.2 18.4-123.6	2.09 .87-4.22	0.31 .02-1.35	19.2 10.6-29.8	5.9 1.0-17.0
S-135	52.9 46.7-62.1	111.5 82.9-170.7	3.45 1.78-5.44	0.18 .02-.66	21.8 12.0-38.6	5.6 1.0-11.0
S-71	36.9 9.3-75.0	30.9 7.9-102.3	0.87 .10-4.22	0.50 .03-1.40	19.8 6.0-37.8	7.0 .2-37.9
S-72	58.9 20.4-125.2	33.4 1.8-113.7	0.99 .10-4.22	0.78 .10-2.60	24.5 7.0-39.5	6.4 .4-37.5
S-154	47.4 40.9-53.8	69.1 22.3-147.7	0.77 .43-1.12	0.70 .13-2.09	22.2 8.9-65.8	5.4 1.0-17.0
S-65E	21.1 8.5-40.0	19.7 4.0-67.0	0.60 .10-4.93	0.40 .18-.83	17.6 3.5-93.9	6.2 1.0-21.0
S-84	26.8 18.4-30.8	16.8 6.5-31.0	0.33 .08-4.22	0.72 .09-3.04	16.1 6.3-32.8	5.9 1.0-18.0
S-191	38.4 9.5-75.5	111.1 15.6-355.8	1.38 .34-4.22	0.48 .02-1.37	20.5 8.9-35.9	9.6 1.0-136.4

1/ Mean value April 1973 - March 1980

2/ Range

TABLE 5-2 (Continued)

Inflow	Turbidity JTU	Color Units	Temp °C	D.O mg/L	Sp. Cond. μmhos/cm	pH
S-2	4.6 .9-25.	92 13-215	24.1 13.2-32.3	5.0 .3-9.8	1025 297-1990	7.67 6.60-10.20
S-3	4.9 .7-23.	68 6-161	24.3 10.8-32.2	6.1 2.1-10.3	847 320-1500	7.84 6.40-9.80
S-4	2.2 .6-11.0	98 10-320	24.9 13.2-33.1	6.0 .4-13.8	839 360-1400	7.51 6.80-8.50
Fisheat-ing Ck	1.1 .4-3.5	211 28-344	24.6 11.1-34.0	5.5 .1-10.8	251 22-1250	6.67 5.10-9.40
S-127	1.5 .05-3.6	172 85-320	24.8 14.1-32.0	5.3 .3-9.6	787 470-1310	7.68 6.75-8.84
S-129	1.4 .5-3.7	136 70-250	24.7 14.3-31.9	5.8 .3-9.8	677 430-845	7.88 6.78-9.38
S-131	1.1 .4-3.0	122 70-255	25.1 16.1-34.0	6.8 .4-11.0	654 220-820	7.68 6.08-8.40
S-133	2.6 .6-17.0	111 60-220	23.4 13.5-29.9	5.4 1.7-9.6	664 480-860	7.64 6.91-8.40
S-135	2.4 .7-8.7	80 35-170	24.1 14.0-32.0	5.8 1.6-9.8	920 698-1100	7.97 7.15-8.45
S-71	1.6 .4-5.0	181 24-410	24.7 13.6-32.5	5.5 .3-9.6	330 75-2360	6.91 5.60-10.30
S-72	1.7 .06-9.4	228 25-700	24.9 13.0-32.5	5.3 .3-10.0	349 97-1130	6.99 5.50-9.87
S-154	1.3 .6-2.5	187 80-390	22.9 13.6-31.5	5.5 .8-9.0	364 162-734	6.60 6.10-7.30
S-65E	1.8 .8-4.4	107 50-240	23.6 15.1-31.1	6.5 2.0-9.1	168 96-265	7.05 6.00-8.40
S-84	2.4 0.8-20.0	146 80-318	23.1 15.4-29.4	6.4 2.3-9.1	167 70-246	6.69 5.70-8.40
S-191	3.7 .5-49.0	204 26-400	24.2 13.3-31.9	4.7 .1-10.2	603 130-1300	7.06 5.70-8.51

Table 5-2 (continued)

Inflow	SiO_2	Na	K	Ca	Mg	Hard
S-2	14.8 4.3/34.8	94.82 48.00/209.72	6.91 3.90/21.99	85.42 10.54/154.48	33.30 6.70/82.67	350.3 91.6/628.1
S-3	12.4 3.7/24.9	75.00 33.90/130.00	5.78 4.00/12.19	75.10 22.31/143.92	25.41 6.50/47.50	292.1 100.8/504.9
S-4	7.4 7.4/7.4	71.64 29.43/114.91	8.88 4.04/27.29	81.21 36.40/139.64	21.11 9.18/29.81	289.5 152.2/470.0
Fisheating Ck	3.6 0.1/14.1	26.98 4.31/99.00	2.75 0.20/9.80	14.58 3.09/51.00	6.20 1.15/22.40	61.8 13.1/219.5
S-127	6.7 1.9/11.4	47.21 33.00/93.15	4.39 1.65/6.55	52.93 33.80/100.17	10.88 6.30/22.40	176.8 122.3/326.4
S-129	6.8 1.6/10.8	40.42 20.00/64.02	4.57 2.40/6.33	56.04 17.00/80.69	10.10 7.60/17.40	181.9 87.7/263.7
S-131	4.1 .7/9.7	44.21 21.70/78.59	3.56 1.11/6.64	37.47 13.80/61.52	9.63 4.20/18.30	133.2 51.7/208.3
S-133	5.9 1.5/18.4	39.83 20.80/64.93	3.96 2.45/7.20	36.71 17.60/59.44	10.13 4.80/16.80	133.2 70.7/214.0
S-135	5.7 0.4/9.7	59.13 13.70/98.61	4.20 2.83/5.50	60.45 37.40/96.98	14.66 8.80/18.00	211.3 136.2/311.9
S-71	6.2 .5/14.1	20.18 3.08/99.00	3.16 1.52/8.80	29.46 7.80/62.83	7.88 2.40/22.40	106.0 33.5/219.5
S-72	7.5 1.7/22.3	20.77 1.30/99.00	3.03 1.17/9.68	30.44 4.40/222.00	8.03 1.80/22.40	109.1 18.4/579.9
S-154	0	74.94	6.19 One Value	28.61	15.15	133.8
S-65E	4.4 1.0/26.0	14.80 6.0/99.00	1.95 .90/8.80	15.34 5.40/108.00	4.44 2.20/22.40	56.6 22.5/283.7
S-84	3.7 0.4/14.1	12.62 6.00/99.00	1.99 1.20/8.80	13.29 4.50/51.20	4.86 2.50/22.40	53.2 24.2/219.5
S-191	6.5 0.5/48.0	61.94 7.00/151.20	7.66 2.17/13.46	35.56 7.00/74.47	11.72 2.80/25.00	137.0 29.0/276.1

As a group, the tributaries discharged water with high concentrations of color. The extremes in the averages ranged from 68 at S-3 to 228 at S-72. These high color levels result from natural tannins and ligands which are common in south Florida and correspond to the moderately high total organic carbon levels.

The average pH of the tributary waters varied approximately 1.4 units from a low of 6.6 at S-154 to a high of 7.97 at S-135. Several tributaries demonstrated substantial variations in pH levels, with the extreme case occurring at S-71 (range of 5.6 to 10.3).

Daytime dissolved oxygen concentrations were moderate ranging from an average of 4.7 mg/L at S-191 to 6.8 mg/L at S-131. Individual values typically ranged from less than 2 mg/L to over 9 mg/L.

NITROGEN AND PHOSPHORUS

North New River and Hillsboro Canals at S-2

The S-2 pump station provides drainage for the North New River and Hillsboro Canals, two of the four major EAA drainage canals. The average flow weighted total and ortho phosphorus concentrations at S-2 were 0.132 and 0.077 mg/L, respectively, which was lower than 12 of the 17 surface inflows to the lake (Tables 5-3 and 5-4). S-2, however, had the highest total nitrogen concentration (5.82 mg/L) and inorganic nitrogen concentration (2.24 mg/L) of any tributary (Tables 5-5 and 5-6). These high nitrogen concentrations are the result of mineralization of nitrification of soil organic matter (muck), natural processes which are enhanced through present drainage practices (Messer and Brezonik 1977, Messer 1978). No major changes in the annual phosphorus levels were observed during this study, with the highest concentrations occurring in 1973 and the lowest occurring in 1976 (Tables 5-3 and 5-4). The highest mean total nitrogen concentration (7.31 mg/L in 1973) was substantially higher than the next six years which ranged between 5.12 and 6.01 mg/L. Inorganic nitrogen concentrations were more uniform, ranging between 1.99 and 3.50 mg/L.

Based upon the dissimilarity of the flow weighted and time weighted concentrations for the seven year period, there was a significant quality/ discharge relationship for nitrogen (Table 5-7). Since the flow weighted nitrogen concentration was greater than the time weighted average concentration for both total nitrogen (5.82 vs. 4.01 mg/L, respectively) and inorganic nitrogen (2.24 vs. 1.28 mg/L, respectively), the higher nitrogen concentrations tended to occur during higher discharges. This relationship can be identified graphically in Figure 5-2. A similar relationship was observed for ortho phosphorus but not for total phosphorus (Table 5-8).

TABLE 5-3. FLOW WEIGHTED TOTAL PHOSPHORUS CONCENTRATIONS FOR TRIBUTARY INFLOWS

Inflows	1973 Conc. 1/	1974 Conc.	1975 Conc.	1976 Conc.	1977 Conc.	1978 Conc.	1979 Conc.	Avg. 1973-79 Conc.
N.N.R. & Hills C. (S-2)	0.177	0.125	0.171	0.099	0.112	0.107	0.123	0.132
Miami C. (S-3)	0.173	0.140	0.094	0.059	0.108	0.056	0.082	0.095
S-4	-	0.211	0.210	0.227	0.370	0.336	0.427	0.314
Harney Pond C. (S-71)	0.346	0.263	0.241	0.154	0.212	0.226	0.322	0.260
Indian Prairie C. (S-72)	0.319	0.219	0.335	0.146	0.203	0.166	0.252	0.217
Kissimmee R. (S-65E)	0.081	0.088	0.073	0.083	0.084	0.107	0.115	0.092
S-84	0.070	0.067	0.069	0.055	0.074	0.057	0.073	0.066
Fisheating Creek	0.126	0.498	0.205	0.190	0.138	0.142	0.203	0.235
S-127 2/	0.384	0.459	0.459	0.459	0.459	0.459	0.533	0.484
S-129 2/	0.161	0.184	0.184	0.184	0.184	0.184	0.206	0.189
S-131 2/	0.150	0.139	0.139	0.139	0.139	0.139	0.153	0.138
Taylor Creek (S-133) 2/	0.281	0.329	0.329	0.329	0.329	0.329	0.377	0.341
S-135 2/	0.136	0.169	0.169	0.169	0.169	0.169	0.204	0.181
Nubbin Slough (S-191)	0.737	0.739	0.957	0.950	1.106	0.939	1.013	0.906
Rainfall 3/	0.057	0.058	0.049	0.063	0.093	0.052	0.053	0.061
Flow Weighted Average	0.138	0.144	0.107	0.131	0.161	0.134	0.163	0.140

1/ Year represents period April 1st to March 31st.
2/ Concentrations from 1974 to 1978 were computed using average of flow weighted concentrations for 1973 and 1979.
3/ Time weighted.

TABLE 5-4 FLOW WEIGHTED ORTHO PHOSPHORUS

Inflows	1973 Conc.	1974 Conc.	1975 Conc.
N.N.R. & Hills C. (S-2)	0.130	0.082	0.080
Miami C. (S-3)	0.103	0.118	0.058
S-4	-	0.162	0.162
Harney Pond C. (S-71)	0.273	0.179	0.185
Indian Prairie C. (S-72)	0.211	0.131	0.284
Kissimmee R. (S-65E)	0.038	0.090	0.042
S-84	0.028	0.025	0.021
Fisheating Creek	0.086	0.359	0.148
S-127 1/	0.267	0.299	0.299
S-129 1/	0.109	0.140	0.140
S-131 1/	0.060	0.108	0.108
Taylor Creek (S-133) 1/	0.255	0.258	0.258
S-135 1/	0.085	0.143	0.143
Nubbin Slough (S-191)	0.577	0.630	0.861
Rainfall 2/	0.036	0.039	0.041
Flow Weighted Average	0.093	0.113	0.074

1/ Concentrations from 1974 to 1978 were based on actual measured in 1973 and 1979

2/ Time weighted

CONCENTRATIONS FOR TRIBUTARY INFLOWS

1976 Conc.	1977 Conc.	1978 Conc.	1979 Conc.	Avg. 1973-79 Conc.
0.059	0.067	0.058	0.066	0.077
0.033	0.054	0.014	0.048	0.054
0.175	0.293	0.264	0.391	0.254
0.107	0.152	0.157	0.215	0.185
0.099	0.147	0.109	0.143	0.139
0.033	0.048	0.057	0.076	0.058
0.019	0.043	0.022	0.046	0.028
0.127	0.029	0.087	0.151	0.161
0.299	0.299	0.299	0.304	0.299
0.140	0.140	0.140	0.147	0.140
0.108	0.107	0.108	0.118	0.108
0.258	0.258	0.258	0.259	0.258
0.143	0.143	0.143	0.152	0.143
0.790	0.992	0.854	0.692	0.749
0.038	0.056	0.035	0.043	0.041
0.086	0.113	0.093	0.113	0.100

flow and flow weighted concentrations

TABLE 5-5 FLOW WEIGHTED TOTAL NITROGEN CONCENTRATIONS FOR TRIBUTARY INFLOWS

Inflows	1973 Conc.[1/]	1974 Conc.	1975 Conc.	1976 Conc.	1977 Conc.	1978 Conc.	1979 Conc.	Avg. 1973-79 Conc.
N.N.R. & Hills C. (S-2)	7.31	5.63	5.50	5.12	6.01	5.80	5.91	5.82
Miami C. (S-3)	6.59	4.69	5.04	4.96	5.36	4.56	3.90	4.92
S-4	-	2.42	2.42	2.52	3.19	3.43	3.29	2.56
Harney Pond C. (S-71)	2.37	2.10	2.24	2.26	1.90	2.21	2.59	2.26
Indian Prairie C. (S-72)	2.42	2.67	1.82	1.79	2.45	2.46	2.36	2.59
Kissimmee R. (S-65E)	1.50	1.26	1.24	1.36	1.80	2.01	1.35	1.39
S-84	1.25	1.05	1.37	1.50	1.67	1.49	1.39	1.35
Fisheating Creek	1.54	2.89	1.77	1.54	1.75	1.73	2.41	2.08
S-127 [2/]	1.72	2.15	2.15	2.15	2.15	2.15	2.58	2.31
S-129 [2/]	1.86	2.11	2.11	2.11	2.11	2.11	2.37	2.17
S-131 [2/]	1.55	1.83	1.83	1.83	1.83	1.83	2.10	1.87
Taylor Creek (S-133) [2/]	1.61	1.84	1.84	1.84	1.84	1.84	2.07	1.90
S-135 [2/]	1.58	1.98	1.98	1.98	1.98	1.98	2.37	2.14
Nubbin Slough (S-191)	1.95	2.08	2.16	2.09	2.35	2.69	2.74	2.29
Rainfall [3/]	1.06	1.06	1.06	1.10	1.12	1.18	1.05	1.09
Flow Weighted Average	1.71	1.67	1.84	1.64	1.98	1.79	1.66	1.74

1/ Year represents period April 1st to March 31st.

2/ Concentrations from 1974 to 1978 were computed using average of flow weighted concentrations for 1973 and 1979.

3/ Time weighted.

TABLE 5-6 FLOW WEIGHTED INORGANIC NITROGEN CONCENTRATIONS FOR TRIBUTARY INFLOWS

Inflows	1973 Conc.	1974 Conc.	1975 Conc.	1976 Conc.	1977 Conc.	1978 Conc.	1979 Conc.	Avg. 1973-79 Conc.
N.N.R. & Hills C. (S-2)	1.99	1.39	2.03	2.04	3.50	2.55	2.09	2.24
Miami C. (S-3)	3.51	1.04	2.37	2.27	2.44	1.69	1.21	2.02
S-4	-	0.423	0.443	0.445	0.953	0.903	0.940	0.740
Harney Pond C. (S-71)	0.529	0.418	0.415	0.605	0.400	0.467	0.385	0.451
Indian Prairie C. (S-72)	0.452	0.413	0.307	0.315	0.529	0.423	0.280	0.393
Kissimmee R. (S-65E)	0.142	0.141	0.202	0.145	0.232	0.084	0.148	0.197
S-84	0.095	0.92	0.255	0.271	0.333	0.162	0.132	0.143
Fisheating Creek	0.045	0.313	0.087	0.074	0.034	0.024	0.189	0.139
S-127 1/	0.191	0.406	0.407	0.406	0.406	0.406	0.439	0.406
S-129 1/	0.076	0.223	0.223	0.223	0.223	0.223	0.258	0.223
S-131 1/	0.122	0.203	0.203	0.203	0.203	0.203	0.220	0.203
Taylor Creek (S-133) 1/	0.339	0.388	0.388	0.389	0.389	0.388	0.405	0.389
S-135 1/	0.202	0.253	0.253	0.253	0.253	0.253	0.260	0.253
Nubbin Slough (S-191)	0.450	0.492	0.735	0.633	0.682	0.747	0.595	0.601
Rainfall 2/	0.619	0.604	0.812	0.579	0.536	0.377	0.429	0.565
Flow Weighted Average	0.465	0.417	0.747	0.510	0.753	0.411	0.349	0.499

1/ Concentrations from 1974 to 1978 were based on actual flow and flow weighted concentrations measured in 1973 and 1979

2/ Time weighted

TABLE 5-7. SUMMARY OF NITROGEN CONCENTRATIONS FOR LAKE OKEECHOBEE TRIBUTARIES (4/1/73-3/31/80)

mg/l

Tributary	Mean		Max.		Min.		Std. Dev.		Flow Weighted	
	Inorg.	Tot.	Inorg.	Tot.	Inorg.	Tot.	Inorg.	Tot.	Inorg.	Tot.
N.N.R. & Hills C. (S-2)	1.28	4.01	12.43	18.20	0.01	1.03	1.73	2.71	2.24	5.82
Miami C. (S-3)	1.01	3.33	7.60	13.07	0.01	0.81	1.41	2.21	2.02	4.92
S-4	0.57	2.78	2.95	5.58	0.01	0.65	0.58	0.98	0.74	2.56
Harney Pond C. (S-71)	0.43	2.04	3.74	5.20	0.01	0.35	0.42	0.87	0.45	2.26
Indian Prairie C. (S-72)	0.32	2.02	2.57	7.40	0.01	0.59	0.28	0.79	0.39	2.59
Kissimmee R. (S-65E)	0.18	1.43	0.49	4.41	0.01	0.27	0.12	0.53	0.20	1.39
S-84	0.20	1.39	0.74	2.99	0.01	0.18	0.14	0.49	0.14	1.35
Fisheating Creek	0.09	1.76	0.95	6.36	0.01	0.23	0.11	0.68	0.14	2.08
S-127	0.27	2.25	3.56	6.92	0.01	0.81	0.49	1.03	0.41	2.31
S-129	0.12	1.99	0.78	3.67	0.01	0.21	0.13	0.60	0.22	2.17
S-131	0.14	1.77	0.92	4.10	0.01	0.22	0.14	0.56	0.20	1.87
Taylor Creek (S-133)	0.28	1.86	1.35	3.54	0.01	0.99	0.23	0.52	0.39	1.90
S-135	0.17	1.72	0.69	3.17	0.01	0.10	0.16	0.56	0.25	2.14
Nubbin Slough (S-191)	0.69	2.27	2.21	5.52	0.01	0.77	0.41	0.75	0.60	2.29

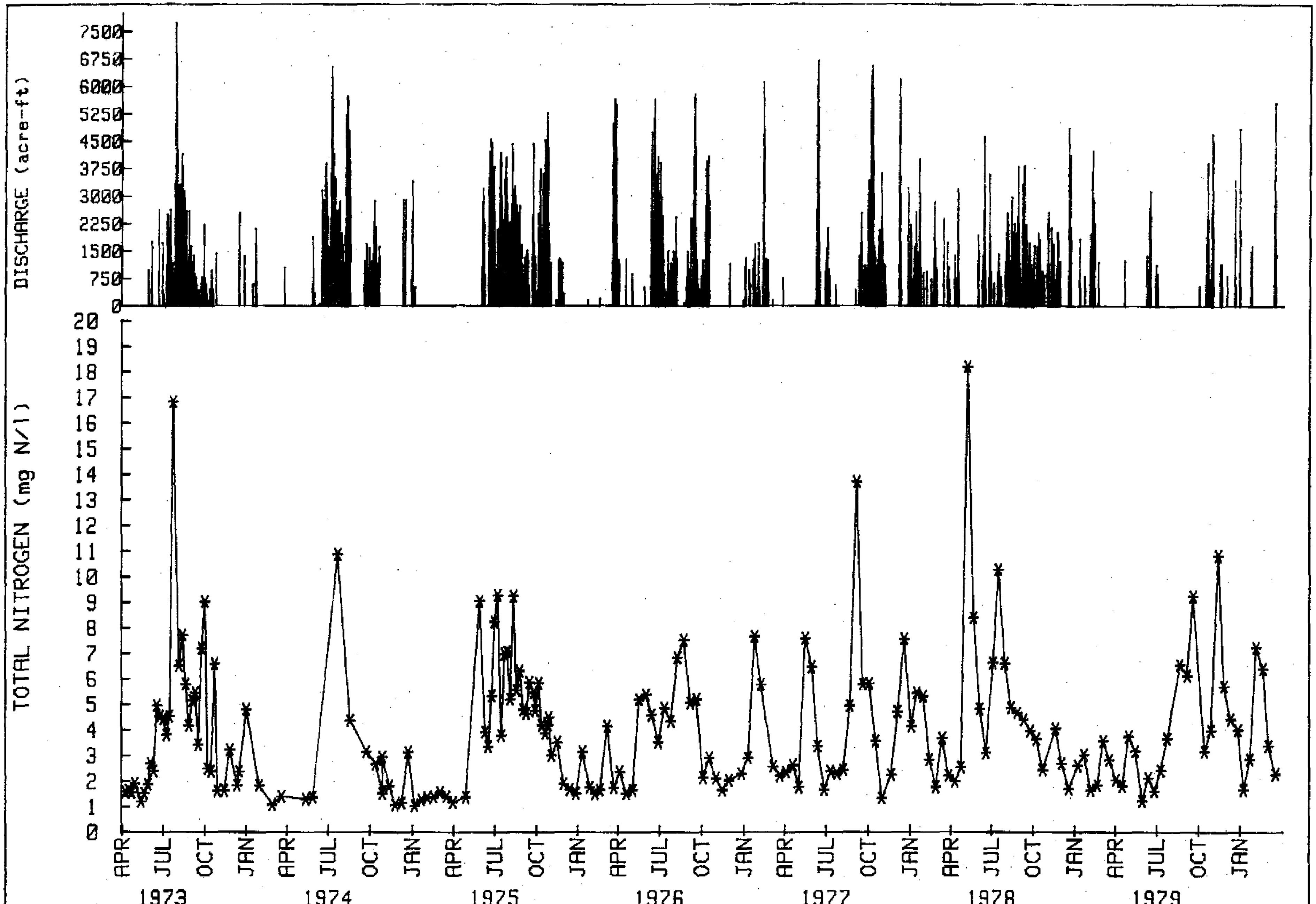


FIGURE 5-2, NITROGEN AND DISCHARGE VS TIME FOR NORTH NEW RIVER AND HILLSBORO CANALS AT S-2

TABLE 5-8 SUMMARY OF PHOSPHORUS CONCENTRATIONS FOR LAKE

mg/l

Tributary	Mean OPO_4	Mean TPO_4	Max. OPO_4	Max. TPO_4
N.N.R. & Hills. C. (S-2)	0.059	0.149	0.396	0.832
Miami C. (S-3)	0.032	0.070	0.880	1.120
S-4	0.149	0.210	1.247	1.412
Harney Pond C. (S-71)	0.127	0.186	0.618	0.772
Indian Prairie C. (S-72)	0.108	0.168	0.580	0.688
Kissimmee R. (S-65E)	0.050	0.086	0.267	0.490
S-84	0.027	0.064	0.188	0.910
Fisheating Creek	0.089	0.141	1.079	1.280
S-127	0.205	0.298	0.518	0.762
S-129	0.091	0.155	0.268	0.338
S-131	0.056	0.106	0.176	1.000
Taylor Creek (S-133)	0.233	0.306	0.780	0.880
S-135	0.073	0.134	0.304	1.105
Nubbin Slough (S-191)	0.756	0.905	1.513	2.108

OKEECHOBEE TRIBUTARIES (4/1/73 - 3/31/80)

Min.		Std. Dev.		Flow weighted	
OPO_4	TPO_4	OPO_4	TPO_4	OPO_4	TPO_4
0.002	0.021	0.068	0.091	0.077	0.132
0.001	0.005	0.076	0.095	0.054	0.095
0.002	0.019	0.228	0.259	0.254	0.314
0.002	0.045	0.109	0.132	0.185	0.260
0.002	0.018	0.098	0.118	0.139	0.217
0.002	0.025	0.052	0.062	0.058	0.092
0.002	0.005	0.028	0.076	0.028	0.066
0.002	0.026	0.101	0.139	0.161	0.235
0.003	0.067	0.131	0.169	0.299	0.484
0.002	0.048	0.061	0.073	0.140	0.189
0.002	0.022	0.045	0.127	0.108	0.138
0.012	0.006	0.165	0.177	0.258	0.341
0.002	0.002	0.066	0.161	0.143	0.181
0.002	0.010	0.303	0.300	0.749	0.906

Miami Canal at S-3

The S-3 pump station drains a major portion of the EAA through the Miami Canal. Total and inorganic nitrogen concentrations at S-3 were the second highest of any tributary, averaging 4.92 and 2.02 mg/L, respectively, while phosphorus concentrations were among the lowest. Mineralization of muck soils and nitrification were the primary sources of these high nitrogen levels (CH_2M Hill 1978, 1979). Annual trends in the nutrient levels at S-3 followed a pattern similar to those discussed for S-2. The highest average total nitrogen, inorganic nitrogen and total phosphorus concentrations were recorded in 1973 with lower levels occurring during the following six years (Tables 53, 5-5, and 5-6).

Also, in a pattern similar to S-2, the higher nitrogen concentrations occurred during the higher discharges. This is evidenced by flow weighted concentration and time weighted concentrations of 4.92 vs. 3.33 mg/L for total nitrogen and 2.02 vs 1.01 mg/L for inorganic nitrogen (Table 5-7). A graphical presentation of those relationships is presented in Figure 5-3. Phosphorus did not show as strong a discharge related pattern as did nitrogen (Table 5-8).

Canal 20 at S-4

The nutrient levels at S-4 were uncharacteristic of those found elsewhere in the EAA at S-2 and S-3. This is primarily due to differing soil types, with land in the S-2 and S-3 basin being primarily muck while the S-4 basin contains more sand (CH_2M Hill 1978). The inorganic and total nitrogen concentrations at S-4 were lower than at S-2 and S-3, averaging 0.74 and 2.56 mg/L, respectively. These are the third and fourth highest average concentrations of any tributary. Also, unlike S-2 and S-3, total

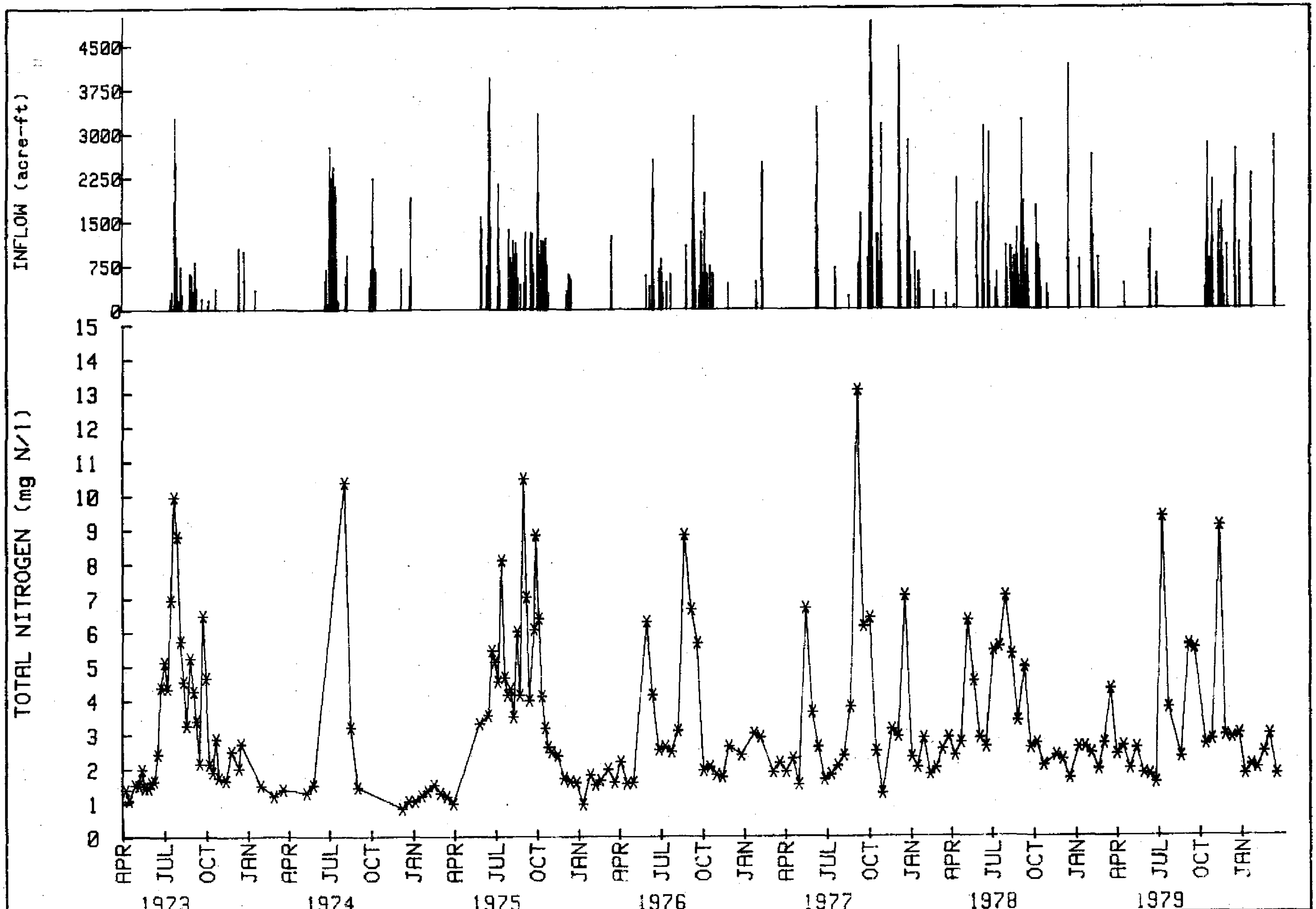


FIGURE 5-3 TOTAL NITROGEN AND DISCHARGE VERSUS TIME FOR THE MIAMI CANAL AT S-3

nitrogen levels demonstrated a general increase over the past six years. From 1974 to 1976 mean total nitrogen levels ranged from 2.42 to 2.52 mg/L. This increased to a range of 3.19 to 3.43 mg/L during the more recent period of 1977 to 1979 (Table 5-5). Total phosphorus levels were the fourth highest of the tributaries, averaging 0.314 mg/L while ortho phosphorus concentrations were the fifth highest (0.254 mg/L). This average concentration is 2 to 3 times higher than the average at S-2 or S-3. Annual changes in the mean total phosphorus concentrations paralleled the changes in nitrogen. Average phosphorus concentrations during the first three years of pump station operation (1974 to 1976) ranged from 0.210 to 0.227 mg/L. During the latter three years (1977 to 1979) the average concentrations increased to a range of 0.336 to 0.423 mg/L. Discharge related patterns at S-4 were also opposite to those at S-2 and S-3. The higher phosphorus levels occurred during higher discharges (Table 5-8 and Figure 5-4) while nitrogen levels appear relatively unresponsive to varying discharges (Table 5-7).

Harney Pond Canal at S-71

The Harney Pond Canal is one of three major canals which drain the Istokpoga Basin. Total and ortho phosphorus levels were moderately high, averaging 0.260 and 0.185 mg/L, respectively. These were the fifth and sixth highest concentrations entering the lake. Total nitrogen concentrations were moderate, averaging 2.26 mg/L and ranking eighth out of 17 tributaries. Inorganic nitrogen concentrations were also moderate, averaging 0.45 mg/L. Annual phosphorus levels varied approximately twofold over the seven year period although there was no consistent

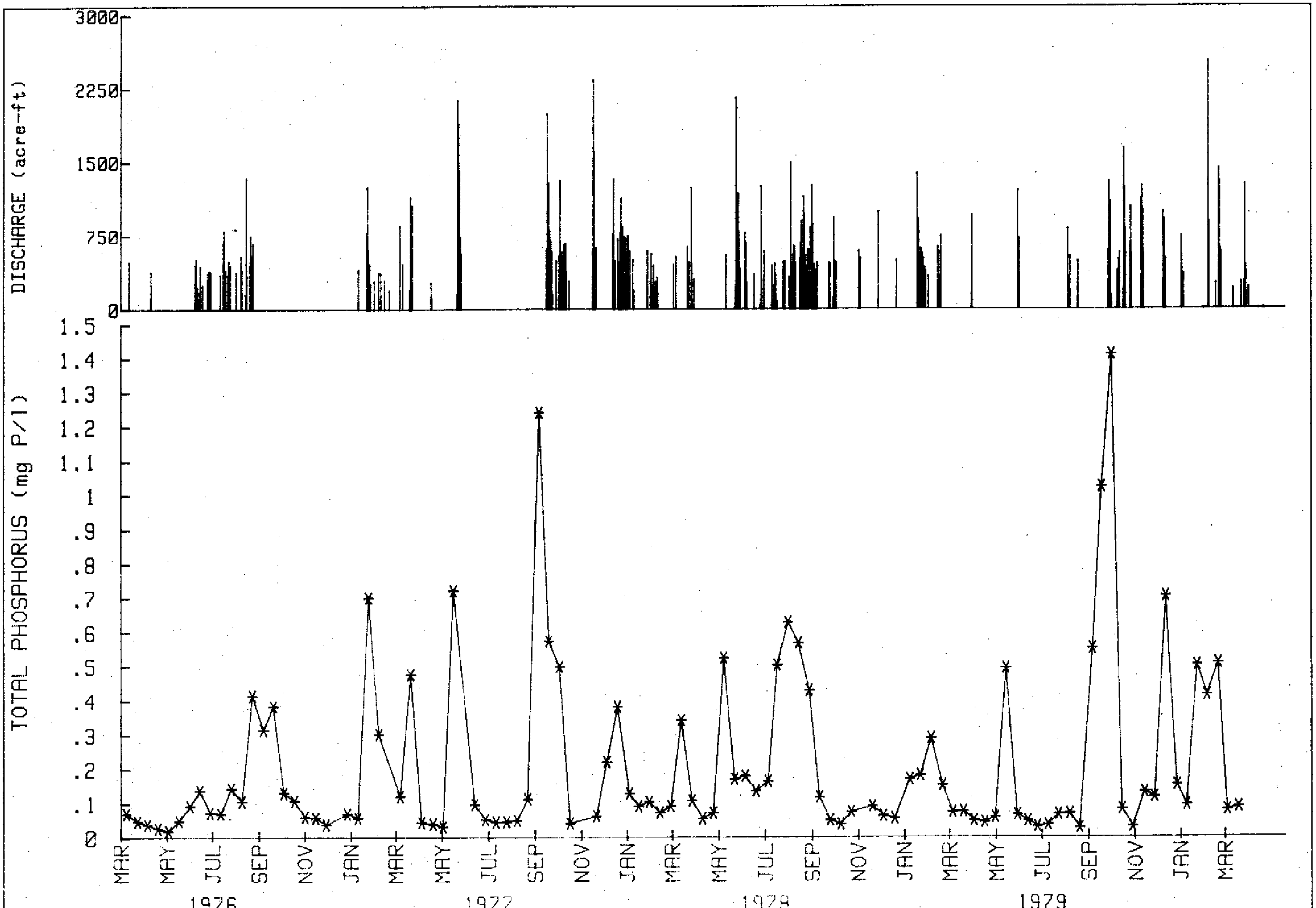


FIGURE 5-4. TOTAL PHOSPHORUS AND DISCHARGE VERSUS TIME FOR C-20 AT S-4

increasing or decreasing trend. Annual total nitrogen concentrations were fairly uniform ranging from 1.90 mg/L (1977) to 2.59 mg/L (1979). A comparison of flow weighted to time weighted concentrations (Table 5-7) indicated that nitrogen concentrations were not affected by varying discharge rates. Phosphorus, however, did demonstrate a small degree of discharge related activity (Table 5-8).

Indian Prairie Canal at S-72

The Indian Priarie Canal is the second major canal which drains the Istokpoga Basin. The average total phosphorus and total nitrogen concentrations were moderately high (0.217 and 2.59 mg/L, respectively) as were the nitrogen levels (0.39 and 0.14 mg/L, respectively). These levels were similar to those found at S-71 on the Harney Pond Canal. There have been no consistent changes in annual concentration of either phosphorus or nitrogen since 1973. The phosphorus and nitrogen levels appear to be somewhat higher during periods of discharge (Tables 5-6 and 5-7).

C-41A at S-84

Canal 41 is the third canal system which drains the Istokpoga Basin. The average total phosphorus and nitrogen concentrations were the lowest of any tributary (0.066 and 1.35 mg/L, respectively), and more virtually the same as rainfall (Tables 5-3 and 5-5). Both total nutrient concentrations have remained low and relatively unchanged since 1973. Inorganic nutrient concentrations were also very low, but have been more variable (Tables 5-4 and 5-6). Based on comparisons in Tables 5-7 and 5-8, there appear to be no discharge related patterns to the nutrient levels.

Kissimmee River (C-38) at S-65E

The Kissimmee River (C-38) is the largest inflow to Lake Okeechobee, both in terms of volume of discharge and size of the drainage basin. Ortho and total phosphorus concentrations were among the lowest of any inflow to the lake, averaging 0.058 and 0.092 mg/L, respectively, (Tables 5-3 and 5-4). Mean annual total phosphorus levels were relatively constant from 1973 to 1977 ranging from 0.073 to 0.088 mg/L. During the latter years, 1978 and 1979, the mean phosphorus concentrations increased to 0.108 and 0.115 mg/L, respectively. Mean annual ortho phosphorus concentrations, however, did not show an increasing trend. Somewhat higher phosphorus concentrations occurred during discharge as evidenced by the flow weighted concentration being slightly greater than the time weighted concentration, and by the graphical relationship displayed in Figure 5-5. This relationship, however, is fairly weak.

The mean total nitrogen concentration (1.39 mg/L) was the second lowest of any tributary, being only slightly higher than the lowest average concentration of 1.35 mg/L which occurred at S-84. Mean annual total nitrogen levels remained fairly constant during the study period, ranging from 1.24 mg/L (1975) to 2.01 mg/L (1978) (Table 5-5). Inorganic nitrogen levels were also fairly low. No discharge related patterns in nitrogen concentrations were indicated (see also Messer 1978).

Fisheating Creek at S.R. 78

Fisheating Creek is the only surface inflow to Lake Okeechobee which does not pass through some type of water control structure. Total and inorganic phosphorus levels in Fisheating Creek were moderately high,

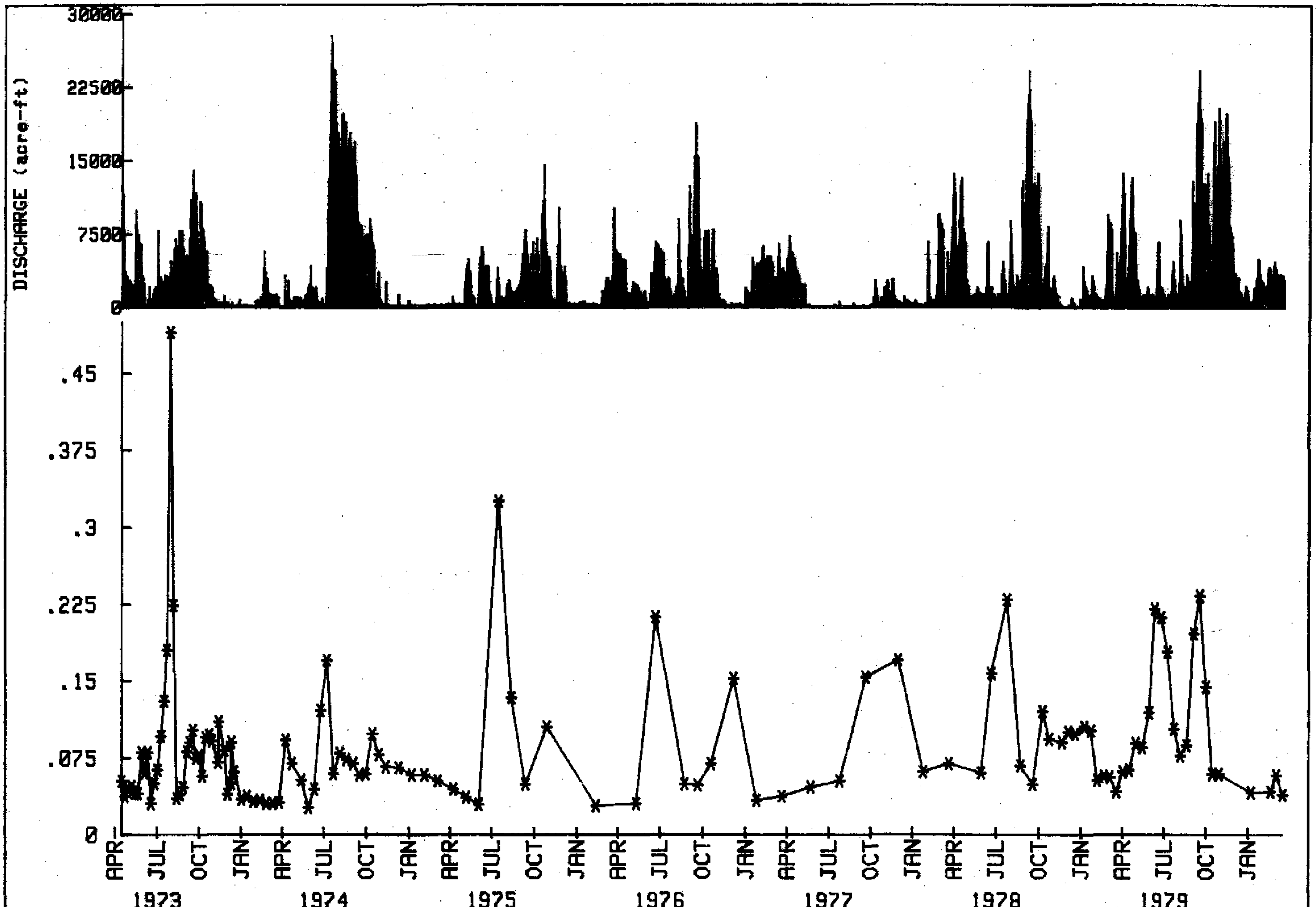


FIGURE 5-5. TOTAL PHOSPHORUS AND DISCHARGE VS TIME FOR C-38 AT S-65E

averaging 0.235 and 0.161 mg/L, respectively. On an annual basis the total phosphorus concentrations have fluctuated over a four-fold range from 0.126 mg/L in 1973 to 0.498 mg/L in 1974. Ortho phosphorus concentrations fluctuated over a 12 fold range (Table 5-4); however, there has been no consistently increasing or decreasing pattern in the annual phosphorus levels. Since the flow weighted total phosphorus concentration (0.235 mg/L) is substantially higher than the time weighted concentration (0.141 mg/L), a strong discharge related pattern is indicated. A similar discharge related pattern was evident for ortho phosphorus. This relationship of higher phosphorus concentrations occurring during higher flows is displayed in Figure 5-6.

Inorganic and total nitrogen concentrations in Fisheating Creek were moderate, averaging 0.139 and 2.08 mg/L, respectively. Variations in the mean annual total nitrogen concentrations were less than those of phosphorus, ranging from 1.54 mg/L (1973 and 1976) to 2.89 mg/L (1974). Nitrogen showed a lesser degree of correlation to discharge than did phosphorus (Table 5-7).

Nubbin Slough at S-191

Nubbin Slough and Taylor Creek (S-191) account for the highest total phosphorus levels entering the lake, averaging 0.906 mg/L from 1973 to 1979. This is almost twice the level of the next most concentrated source (0.484 mg/L at S-127). Over 80 percent of the total phosphorus is in the form of inorganic ortho phosphorus. Animal waste from dairy farms and beef cattle pasture are the primary source of these high phosphorus levels (Allen et al. 1975, Federico 1977, Stewart et al. 1977, Goldstein

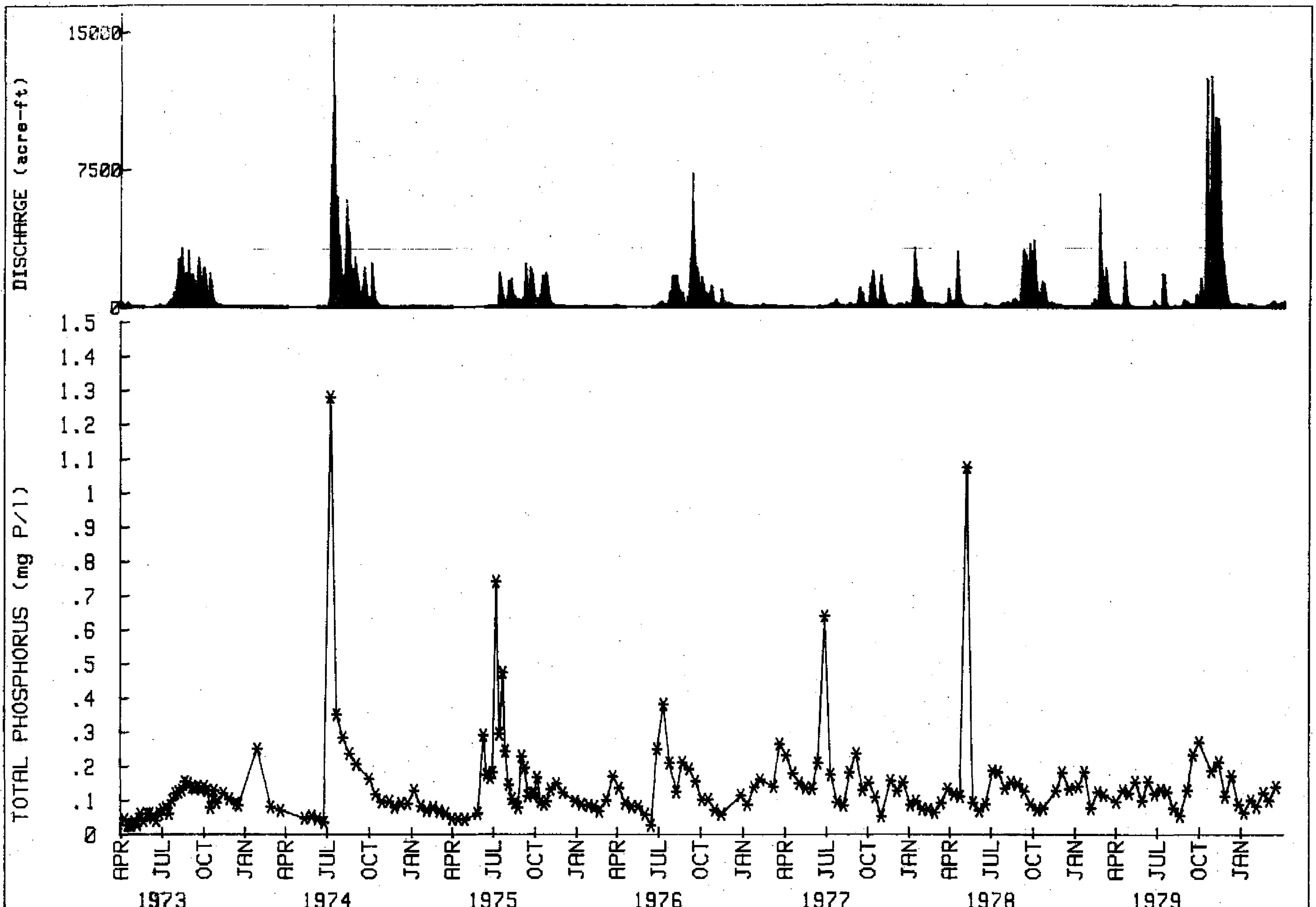


FIGURE 5-6. TOTAL PHOSPHORUS AND DISCHARGE VS TIME FOR FISHEATING CREEK AT S.R. 78

et al. 1980). The mean annual total phosphorus concentrations have increased fairly consistently since 1973. In 1973 and 1974 the average total phosphorus concentration was 0.74 mg/L. This increased to 0.957 mg/L in 1975 and has since ranged from 0.950 to 1.106 mg/L (Table 5-3). Ortho phosphorus was highly variable but did not follow the same pattern (Table 5-4). There does not appear to be a discharge related pattern to the phosphorus concentrations based on either a comparison of flow weighted means to time weighted means (Table 5-8) or a graphical comparison (Figure 5-7).

Total and inorganic nitrogen concentrations at S-191 were moderate, averaging 2.29 and 0.51 mg/L, respectively. Total nitrogen levels also increased during the study from 1.95 mg/L in 1973 to 2.74 mg/L in 1979 (Table 5-5). Inorganic nitrogen levels did not parallel this increase (Table 5-6). As was the case with phosphorus, nitrogen levels were not correlated to discharge (Table 5-6).

Minor Pump Stations (S-127, S-129, S-131, S-133, S-135)

Pump stations S-127, S-129, and S-131 drain small areas of land along the northwest shore of Lake Okeechobee. Land use in the S-129 and S-131 basins is primarily devoted to cattle grazing on improved pasture. Land in the S-127 basin is becoming developed with finger canals and housing. Pump station S-133 drains the lower 5 miles of Taylor Creek which passes through the City of Okeechobee and receives secondary effluent from the city's 1 mgd sewage treatment plant. The remaining small pump station, S-135, is positioned along the northeast shore of the lake and drains primarily unimproved cattle pasturelands. These 5 pump stations

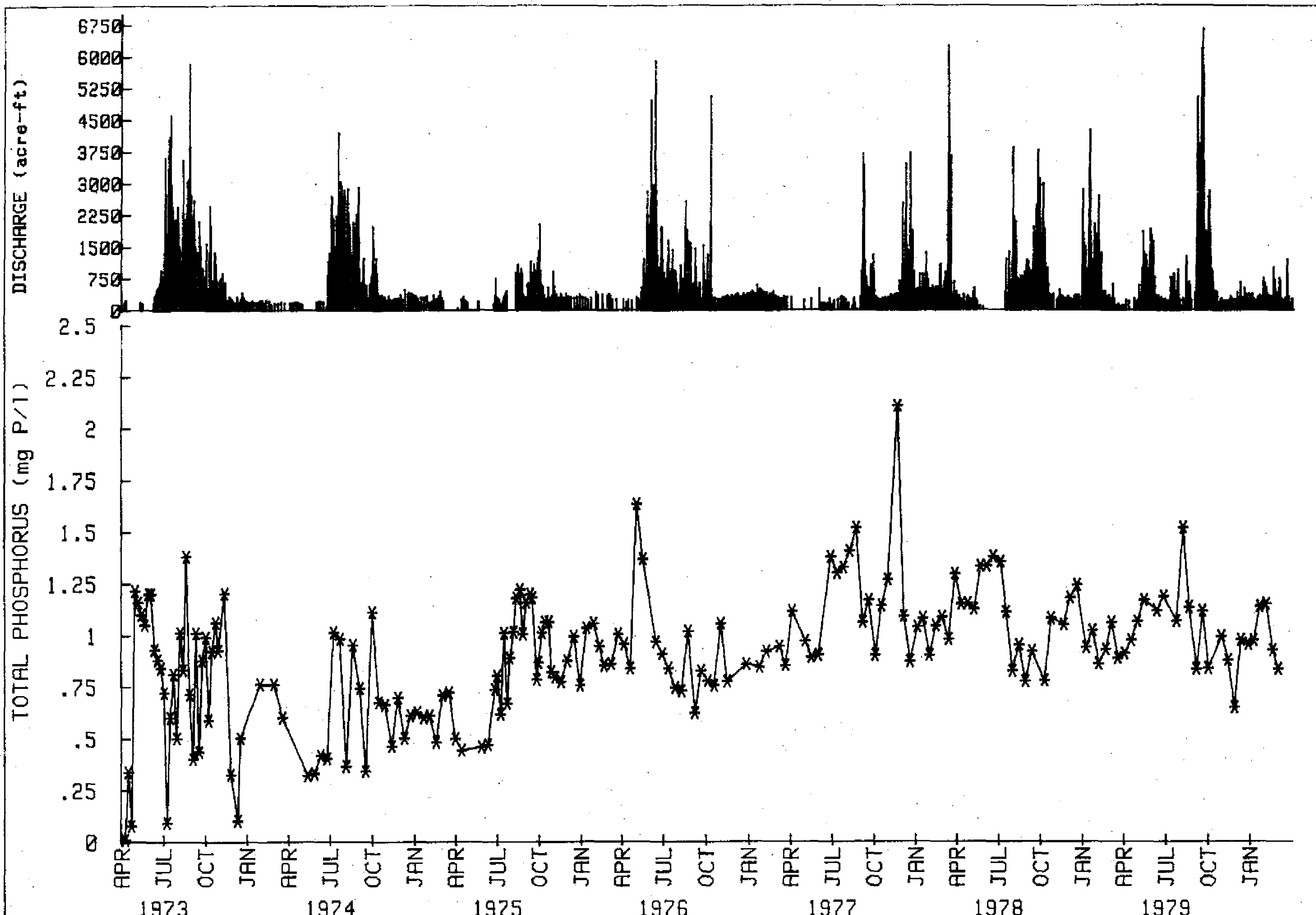


FIGURE 5-7, TOTAL PHOSPHORUS AND DISCHARGE VERSUS TIME FOR NUBBIN SLOUGH AT S-191 contribute less than 2 percent of the total surface water inflows to Lake Okeechobee.

The mean concentrations of total phosphorus varied widely between these pump stations with S-127 (0.484 mg/L) > S-133 (0.341 mg/L) > S-129 (0.189 mg/L > S-135 (0.181 mg/L) > S-131 (0.138 mg/L). The concentrations of total phosphorus at S-127 and S-133 were the second and third highest, respectively, of any tributary to the lake. The mean annual total and ortho phosphorus concentrations at each pump station were greater in 1979 than in 1973 (Table 5-3),although no data was collected in the intervening years to document a consistent trend. For all five pump stations, the levels of total and ortho phosphorus appear to be positively correlated to discharge since the flow weighted concentrations were greater than the time weighted concentrations (Table 5-8).

Total nitrogen concentrations were fairly uniform along the pump stations, ranging from an average of 1.87 mg/L at S-131 to 2.17 mg/L at S-137 (Table 5-5). As was the case for phosphorus, the total and inorganic nitrogen concentrations were all greater in 1979 than in 1973, but again no data in the intervening years was collected (Tables 5-5 and 5-6). Nitrogen levels were also correlated to discharge, although the degree of association does not appear to be as prominent as compared to phosphorus (Table 5-7).

Rainfall

Rainfall represented the lowest concentrations of both total phosphorus and total nitrogen entering the lake, with an average of 0.061 and 1.09 mg/L, respectively; however, rainfall had the fourth highest inorganic nitrogen concentration (0.57 mg/L). Since 1973, the mean annual concentrations have remained relatively constant, ranging between 0.049 mg/L

(1975) and 0.093 mg/L (1977) for total phosphorus and between 1.05 mg/L (1979) and 1.12 mg/L (1977) for total nitrogen (Tables 5-3 and 5-5)

All Sources

The average flow-weighted total phosphorus and nitrogen concentrations entering the lake from all sources from 1973 to 1979 was 0.140 and 1.74 mg/L, respectively. Since 1973 the mean annual inflow concentrations of both nutrients have remained relatively constant. Total phosphorus varied between only 0.131 mg/L (1976) and 0.163 mg/L (1979), while total nitrogen varied between 1.64 mg/L (1976) and 1.98 mg/L (1977) (Tables 5-3 and 5-5). The inorganic phosphorus and nitrogen inflow concentrations averaged 0.100 and 0.50 mg/L, respectively. The variation among the mean annual inorganic nutrient concentrations was greater than the annual variations among the total nutrients, 60 vs 20 percent, respectively. Overall, although annual differences in the nutrient content from all sources was moderately variable, no consistently increasing or decreasing trends were identified.

Nutrient Ratios

Presented in Tables 5-9 and 5-10 are the total nitrogen to total phosphorus (TN/TP) and inorganic nitrogen to inorganic phosphorus (IN/IP) ratios for the major inflows to Lake Okeechobee. These ratios were based upon the flow weighted concentrations presented in Tables 5-2 and 5-5. Based on the average ratio from 1973 to 1979, only S-3, S-2 and HGS-5 had IN/IP ratios greater than 10 (37.4, 29.1 and 13.4, respectively). These tributaries had disproportionately high nitrogen concentrations and can be considered to be potentially phosphorus limited. All of the remaining tributaries can be considered to be potentially nitrogen limited with IN/IP ratios of 5 or less.

Eleven of the 17 surface inflows had TN/TP ratios greater than 10. In decreasing order, these inflows were: S-3 (51.8) > S-2 (44.1) > HGS-5 (24.2) > S-84 (20.5) > S-77 (16.6) > S65E (15.1) > S-131 (13.6) > S-308 (12.3) > S-72 (11.9) > S-135 (11.8) > S-129 (11.5). Six of the inflows had ratios which were less than 10. Specifically, these inflows were: Fisheating Creek (8.9) > S-71 (8.7) > S-4 (8.2) > S-133 (5.6) > S-127 (4.8) > S-191 (2.5). The average IN/IP and TN/TP ratios in rainfall were 13.8 and 17.7 while the combined ratios from all inflows were 5.0 and 13.0, respectively.

No consistent changes in the nutrient ratios from 1973 to 1979 were noted for any of the inflows, although annual variations were noted. There were also no consistent changes in the combined IN/IP and TN/TP ratios from all the inflows. There was, however, a 36 percent variation in the combined TN/TP ratios and a 69 percent variation in the combined IN/IP ratios during the study period.

TABLE 5-9 INORGANIC-NITROGEN TO ORTHO-PHOSPHORUS RATIOS FOR TRIBUTARY INFLOWS

Inflows	1973 Conc.	1974 Conc.	1975 Conc.	1976 Conc.	1977 Conc.	1978 Conc.	1979 Conc.	Avg. 1973-79 Conc.
N.N.R. & Hills C. (S-2)	15.3	17.0	25.4	34.6	52.2	44.0	31.7	29.1
Miami C. (S-3)	34.1	8.8	40.9	68.8	45.2	120.7	25.2	37.4
S-4	-	2.6	2.7	2.5	3.3	3.4	2.4	2.9
Harney Pond C. (S-71)	1.9	2.3	2.2	5.7	2.6	3.0	1.8	2.4
Indian Prairie C. (S-72)	2.1	3.2	1.1	3.2	3.6	3.9	2.0	2.8
Kissimme R. (S-65E)	3.7	1.6	4.8	4.4	4.8	1.5	2.0	3.4
S-84	3.4	3.7	12.1	14.3	7.7	7.4	2.9	5.1
Fisheating Creek	0.5	0.9	0.6	0.6	1.2	0.2	1.3	0.9
S-127	0.7	1.4	1.4	1.4	1.4	1.4	1.4	1.4
S-129	0.7	1.6	1.6	1.6	1.6	1.6	1.8	1.6
S-131	2.0	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Taylor Creek (S-133)	1.3	1.5	1.5	1.5	1.5	1.6	1.6	1.5
S-135	2.48	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Nubbin Slough (S-191)	0.8	0.8	0.9	0.8	0.7	0.9	0.9	0.8
Rainfall	17.2	15.3	19.8	15.2	9.6	10.8	10.0	13.8
Flow Weighted Average	5.0	3.7	10.1	5.9	6.7	4.4	3.1	5.0

TABLE 5-10 RATIO OF TOTAL NITROGEN TO TOTAL PHOSPHORUS FOR LAKE OKEECHOBEE INFLOWS

Inflows	1973 [1/]	1974	1975	1976	1977	1978	1979	Avg. 1973-79
N.N.R. & Hills C. (S-2)	41.3	45.0	32.2	51.7	53.7	54.2	48.1	44.1
Miami C. (S-3)	38.1	33.1	53.6	84.1	49.6	81.4	47.6	51.8
S-4		11.5	11.5	11.1	8.6	10.2	7.7	8.2
Harney Pond C. (S-71)	6.9	8.0	9.2	14.7	9.0	9.8	8.0	8.7
Indian Prairie C. (S-72)	7.6	12.2	5.4	12.3	12.5	14.8	9.4	11.9
Kissimmee R. (S-65E)	18.5	14.3	17.0	16.4	21.4	18.8	11.7	15.1
S-84	17.9	15.7	19.9	27.3	22.6	26.1	19.0	20.5
Fisheating Creek	12.2	5.8	8.6	8.1	11.4	12.2	11.9	8.9
S-127	4.5	4.7	4.7	4.7	4.7	4.7	4.8	4.8
S-129	11.6	11.5	11.5	11.5	11.5	11.5	11.5	11.5
S-131	10.3	13.2	13.2	13.2	13.2	13.2	13.7	13.6
Taylor Creek (S-133)	5.7	5.6	5.6	5.6	5.6	5.6	5.5	5.6
S-135	11.6	11.7	11.7	11.7	11.7	11.7	11.6	11.8
Nubbin Slough (S-191)	2.7	2.8	2.3	2.2	2.1	2.9	2.7	2.5
Rainfall	18.6	18.3	21.6	17.5	12.0	22.7	19.8	17.7
Average	12.4	11.6	17.2	12.5	12.3	16.1	11.0	13.0

[1/] Year represents period April 1st to March 31st

SUMMARY

The quality of water entering Lake Okeechobee from the 15 primary tributaries displayed diverse water quality characteristics. Water entering the south end of the lake from S-2 and S-3 was typically very high in dissolved solids (average specific conductance of 1025 and 847 μmhos/cm, respectively. This is in contrast to the water entering the north end of the lake via S-65E and S-84 which was relatively low in dissolved solids (average specific conductance of 168 and 167 μmhos/cm, respectively). Turbidity and total suspended solids were very low while total organic carbon and color were typically high at all the inflows. Mean daytime dissolved oxygen concentrations were moderate at the inflow points (ranging between 4.7 and 6.8 mg/L) to the lake although the individual daytime values at each tributary displayed wide variations (less than 2 mg/L to over 9 mg/L).

The highest mean annual ortho and total phosphorus concentrations were measured in Taylor Creek/Nubbin Slough at S-191 (0.906 and 0.749 mg/L, respectively). These high phosphorus levels in the Taylor Creek/Nubbin Slough basin originated from a large number of intensive dairy operations. As a result of the high phosphorus concentrations, Taylor Creek/Nubbin Slough had the lowest TN/TP ratio (2.5) and the lowest IN/IP ratio (0.7). The North New River and Hillsboro Canals at S-2 had the highest mean annual total nitrogen and inorganic nitrogen concentrations (5.82 and 2.24 mg/L, respectively). This was followed closely by the Miami Canal at S-3 with average total nitrogen and inorganic nitrogen concentrations of 4.92 and 2.02 mg/L, respectively. The high nitrogen concentrations at S-2 and S-3 were a result of mineralization of muck soils and nitrification in the EAA basin. These high nitrogen concentrations resulted in the highest TN/TP

ratios of any inflow (44.1 at S-2 and 51.8 at S-3).

The lowest total phosphorus and nitrogen concentrations were measured at S-84 (0.066 and 1.35 mg/L, respectively). The Kissimmee River at S-65E had the second lowest mean annual total phosphorus concentration (0.092 mg/L) and total nitrogen concentration (1.39 mg/L) of any inflow to the lake, except rainfall. Most of the tributaries displayed at least some degree of positive correlation between nutrient concentrations and discharge. The two notable exceptions were Taylor Creek/Nubbin Slough at S-191, and C-41A at S-84.

The majority of the tributaries did not demonstrate any substantial increase or decrease in nutrient levels since 1973. The tributaries which did show increasing total phosphorus levels were S-4 (0.211 to 0.427 mg/L), the Kissimmee River (0.081 to 0.115 mg/L), and S-191 (0.737 to 1.013 mg/L). S-2 and S-3 exhibited decreasing mean annual total nitrogen concentrations from 1973 to 1979, while S-4 showed an increasing trend. Mean annual inorganic nutrient concentrations were usually more variable than total nutrient concentrations, resulting in a lack of consistent discernable trends.

The combined annual flow weighted total nitrogen and inorganic nitrogen concentrations from all sources to the lake varied approximately 16 and 57 percent, respectively, from 1973 to 1979. The combined annual total phosphorus and ortho phosphorus concentrations varied approximately 25 and 18 percent, respectively; however, there were no consistently increasing or decreasing annual trends in either nutrient from 1973 to 1979. The annual IN/IP and TN/TP ratios in the combined inflows also showed variability and lack of consistent change, ranging from a high in 1975 (10.1 and 17.2, respectively) to a low in 1979 (2.9 and 11.0, respectively).

CHAPTER VI

MATERIAL BUDGET ANALYSIS

INTRODUCTION

One of the primary purposes of this study was to develop a comprehensive materials budget for Lake Okeechobee. This chapter describes the methodology used in calculating water, phosphorus, nitrogen, and chloride budgets and will present and discuss the annual budgets from 1973 to 1979. Lake Okeechobee has nine major inflows and five major outflows (Figure 6-1). Sample collection locations, sampling frequency, and parametric coverage were presented in the previous chapter (V). In addition, quality data for St. Lucie Canal (S-308) was collected at the limnetic station L004 (see Figure 5-1). Rainfall quality samples were generally collected every two weeks from November 1974 to March 1980.

Sources for the hydrologic data are summarized in Table 6-1. The three organizations supplying data for the water budgets were the U.S. Geological Survey (U.S.G.S.), the Army Corps of Engineers (C.O.E.), and the South Florida Water Management District. Seepage through the Hoover Dike was estimated from a District Technical Memorandum (Shaw 1980). Flows at the St. Lucie Canal (S-308) tributary were calculated because direct measurements were not available. The C.O.E. monthly water budget for the lake were used for the rainfall, evaporation, storage, and surface area. Much of the published data for February and March of 1980 was not available at the time of budget calculation, thus, the values were calculated from the available preliminary data.

The material loads for Lake Okeechobee were calculated by combining the water and material data bases. The average concentration between

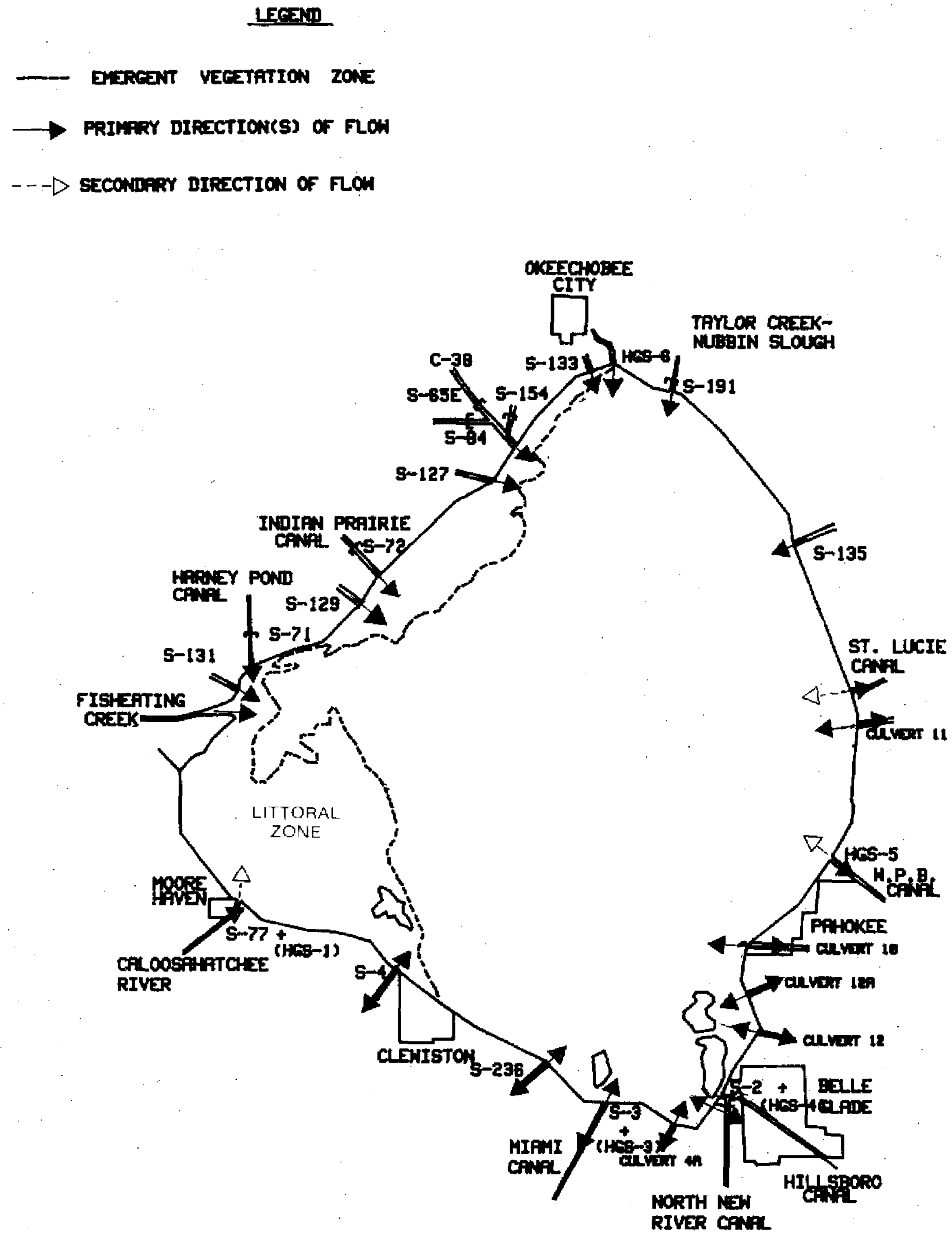


Figure 6-1 INFLOWS AND OUTFLOWS TO LAKE OKEECHOBEE

TABLE 6-1. DATA SOURCES FOR WATER BUDGET[1/]

Station	Inflow/Outflow	Period of Record	Source of Data
N.N.R. & Hills.C. (S-2)	inflow/outflow	4/73-1/80	USGS
		2/80-3/80	SFWMD[3/]
Miami C. (S-3)	inflow/outflow	4/73-1/80	USGS
		2/80-3/80	SFWMD[3/]
S-4	inflow/outflow[3/]	6/74-3/80	SFWMD
Harney Pond C. (S-71)	inflow	4/73-1/80	USGS
		2/80-3/80	SFWMD (calc)[4/]
Indian Prairie C. (S-72)	inflow	4/73-1/80	USGS
		2/80-3/80	SFWMD (calc)[4/]
Kissimmee R. (S-65E)	inflow	4/73-3/80	USGS
S-84	inflow	4/73-1/80	USGS
		2/80-3/80	SFWMD (calc)[4/]
Fisheating Creek	inflow	4/73-3/80	USGS
S-127	inflow	4/73-3/80	SFWMD
S-129	inflow	4/73-3/80	SFWMD
S-131	inflow	4/73-3/80	SFWMD
Taylor Creek (S-133)	inflow	4/73-3/80	SFWMD
S-135	inflow	4/73-3/80	SFWMD
Nubbin Slough (S-191)	inflow	4/73-3/80	SFWMD
WPB Canal (HGS-5)	inflow/outflow	4/73-1/80	SFWMD
		2/80-3/80	SFWMD (calc)[4/]
St. Lucie Canal (S-308)	inflow/outflow	4/73-7/78	SFWMD (calc)[6/]
		8/78-3/80	SFWMD (calc)[5/]
Caloosahatchee R. (S-77)	inflow/outflow	4/73-1/80	USGS
		2/80-3/80	SFWMD[5/]
Seepage	outflow	4/73-3/80	Shaw, SFWMD[7/]
Rainfall	inflow	4/73-1/80	COE
		2/80-3/80	SFWMD (calc)[8/]
Evaporation	outflow	4/73-1/80	COE
		2/80-3/80	SFWMD (calc)[9/]

TABLE 6-1 (CONT.)
DATA SOURCES FOR WATER BUDGET

Station	Inflow/Outflow	Period of Record	Source of Data
Storage		4/73-1/80	COE
		2/80-3/80	SFWMD (calc)10/
Surface Area		4/73-1/80	COE
		2/80-3/80	SFWMD (calc)10/

1/ Stored on SFWMD tape #7083

2/ Preliminary SFWMD pumping records, including siphoning from Lake Okeechobee at S-2 and S-4 for 1/80-3/80

3/ Only outflow is siphoning from lake for 1/80-3/80

4/ Calculated from SFWMD operational logs and structure rating curves

5/ Preliminary COE data from SFWMD Field Services daily logs

6/ Calculated from a rainfall-runoff relationship for the St. Lucie Canal Basin by SFWMD Water Resources Division

7/ From: Shaw, J. E. 1980. Hydrogeologic investigations along eastern portions of Lake Okeechobee. SFWMD Tech. Memorandum

8/ Calculated from preliminary COE data for seven rainfall stations using polygon method to weight stations, and using a 20% reduction for the lake as proposed by Riebsame, Woodley, and Davis:

Average L.O rainfall = 0.8 (0.12 (HGS-6) + 0.19 (Indian Prairie) + 0.12 (HGS-1) + 0.21 (HGS-2) + 0.08 (HGS-4) + 0.11 (HGS-5) + 0.17 (Port Mayaca))

9/ Calculated from preliminary COE data using the COE weighing system:

Average L.O. evaporation = 0.434 ((HGS-6) + (HGS-2))

10/ Stage is calculated from preliminary COE data using a simple average:

Average L.O. stage = 1/3 ((HGS-6) + (HGS-2) + (Port Mayaca))

Storage and surface area are found from the stage-storage and stage-surface area relationships used by the COE.

sampling dates was multiplied by the daily flows to produce daily material loads. For S-4 and the small pump stations (S-127, S-129, S-131, S-133, S-135), material loads for unsampled periods were calculated by applying flow weighted concentrations from the sampled periods to the discharges during the unsampled periods. Seepage outputs were calculated by multiplying the average annual lake concentration by the annual seepage.

Additional terms based on the data in the water and material budgets will be discussed in this chapter and in Chapter IX. These terms include flow weighted concentration, water residence time, hydraulic loading rate, nutrient retention coefficient, and areal loading rate. The flow weighted concentration is equal to the material load divided by the flow. It is often considered in place of mean time weighted concentrations because it accounts for the effects, if any, of flow on concentrations. The water residence time (τ_{ω}) is equal to the lake water volume divided by the surface outflows (excluding evaporation). The water residence time represents the period of time that water is present in a lake with respect to nutrients, since nutrients are not lost via evaporation. This is an extremely important hydrologic parameter in nutrient loading models (Chapter IX), as in the hydraulic loading rate (q_s). The hydraulic loading rate is calculated by dividing the surface water inflows (excluding rainfall) by the surface area of the lake. It represents the height (m/yr) that the surface inflows would raise the lake level during a year, assuming no loss of water through evaporation or outflow. The proportions of phosphorus and nitrogen which are trapped in a lake during a year are called the nutrient retention coefficients (R_{exp}, R_{exn}), respectively. The areal loading rate for phosphorus (L_p) or nitrogen (L_n) is simply the annual material load divided by the surface area of the lake.

WATER BUDGET

The annual (April through March) water budgets for 1973 to 1979 are tabulated in Table 6-2. The last column presents the average budget for the seven year period. The ability of these water budgets to account for the net change in the lake's annual storage is shown in Table 6-3 as percent errors. For the entire seven year period the water budgets came within 4.0 percent of the lake storage reported by the COE. With the exception of 1977 all the budgets had positive errors, i.e., in flows overestimated and/or outflows underestimated. This was most significant for 1973 (12.6%). Over the entire study period, however, the water budgets were in very good agreement with the published storage.

Chloride was considered in the material budgets as an accuracy check. Since chloride is a conservative element, the budget could account for all additions and losses of chloride over time. Thus, chloride can be considered as an indicator of material budget accountability. The percentage error in the chloride budgets is shown in Table 6-3 along with the water budget errors. For the seven year period the average chloride budget came within 5.9 percent of the computed storage; however, unlike the water budgets, the overall chloride budgets had apparent overestimates of outflows and/or underestimates of inflows (i.e., negative error). Nevertheless, the overall accuracy of the materials budget was very good.

Rainfall directly on the surface of the lake was the largest source of water to the lake, accounting for almost 39 percent of the 3,546,427 acre feet of water supplied annually to the lake over the seven year period. The Kissimmee River represents the second largest source (31%) and the single largest surface inflow. Twenty-five (25) of the remaining 30 percent of the water inputs were distributed about equally between S-2 (5.6%), S-7 (4.9%), S-84 (4.0%), Fisheating Creek (5.8%), and S-191 (4.4%). The remaining five

TABLE 6-2. ANNUAL WATER BUDGETS

	1973 2/	1974	1975
Inflows:			
N.N.R. & Hills.C (S-2)	154,092	207,708	318,447
Miami C. (S-3)	21,567	42,812	76,545
S-4 1/	-	29,249	26,575
Harney Pond C. (S-71)	154,893	171,079	82,170
Indian Prairie C(S-72)	24,367	43,304	7,504
Kissimmee R (S-65E)	1,028,913	1,442,038	838,503
S-84	232,553	211,044	87,290
Fisheating Creek	151,627	288,417	105,736
S-127	4,850	12,950	466
S-129	6,032	12,500	944
S-131	1,624	9,035	674
Taylor Creek (S-133)	14,442	14,170	2,065
S-135	8,347	12,601	369
Nubbin Slough (S-191)	210,695	155,419	63,178
WPB Canal (HGS-5) 3/	0	41,211	6,918
St. Lucie C (S-308) 3/	0	0	0
Caloosahatchee R(S-77) 3/	0	11,177	0
Rainfall	1,206,250	1,472,190	1,207,499
Total inflow	3,220,252	4,176,904	2,824,883
Outflows:			
N.N.R. & Hills. C (HGS-4)	276,173	322,241	220,498
Miami C (HGS-3)	161,255	275,431	158,424
S-4 1/	-	0	0
WPB Canal (HGS-5)	151,230	231,443	114,843
St. Lucie C (S-308)	10,632	245,351	10,893
Caloosahatchee R(S-77)	74,863	766,522	115,910
Seepage	52,000	52,000	52,000
Evaporation	2,120,264	2,082,860	2,183,982
Total outflow	2,846,417	3,975,848	2,856,550
Total inflow	3,220,252	4,176,904	2,824,883
Total outflow	2,846,417	3,975,848	2,856,550
Change in storage	-51,900	105,000	-98,400
Other sinks	425,235	96,056	66,733

1/ 6 yr average only (thus, total input and total output ≠ Σ

2/ Annual 12 month period April 1st to March 31st

3/ Occasional inflows

FOR LAKE OKEECHOBEE (ACRE-FEET)

1976	1977	1978	1979	Avg. 1973-79
205,499	213,347	200,173	71,892	195,880
46,582	83,934	69,512	49,181	55,733
23,558	44,645	50,956	34,338	34,887
99,935	140,083	295,688	245,018	169,838
20,484	34,753	72,116	59,445	37,425
1,157,951	520,423	1,297,681	1,231,434	1,073.849
57,644	11,974	207,740	176,167	140,630
147,977	126,448	197,368	379,569	203,449
3,061	7,968	13,438	33,468	10,886
10,602	8,190	14,773	25,135	11,168
6,044	4,443	7,149	7,970	5,277
5,705	7,168	22,392	43,819	15,680
7,666	7,323	27,192	58,525	17,432
176,204	132,339	167,181	170,085	153,586
15,342	0	0	0	9,067
0	0	0	9,172	1,310
0	0	0	0	1,597
1,315,416	1,304,892	1,507,918	1,438,583	1,350,393
3,299,670	2,647,930	4,151,277	4,033,791	3,479,244
186,146	169,284	257,238	197,737	232,760
84,465	79,277	144,482	128,614	147,421
0	0	0	1,537	256
104,523	62,550	92,526	87,520	120,662
9,537	50,367	236,693	283,411	120,983
73,881	135,475	772,698	779,329	388,383
52,000	52,000	52,000	52,000	52,000
2,140,336	1,890,285	2,036,168	1,965,673	2,059,930
2,650,888	2,439,238	3,591,805	3,495,821	3,122,367
3,299,670	2,647,930	4,151,277	4,033,791	3,479,244
2,650,888	2,439,238	3,591,805	3,495,821	3,122,367
602,200	400,100	356,900	146,300	208,671
46,582	-191,408	202,572	391,670	148,206

inputs and outputs, respectively)

TABLE 6-3. PERCENTAGE ERROR IN WATER AND CHLORIDE BUDGETS

	Water			Chloride		
Year[1/]	Avg. Annual storage (acre-feet)	Other sinks (acre-feet)	% [2/] error	Avg. Annual storage (10^6 g)	Other sinks (10^6 g)	% [2/] error
1973	3,365,000	425,235	+12.6 [3/]	354,294	9,993	+ 2.8
1974	3,504,000	96,056	+ 2.7	340,915	-62,068	-18.2
1975	3,185,000	66,733	+ 2.1	342,394	57,535	+16.8
1976	3,462,000	46,582	+ 1.3	385,372	-14,856	- 3.9
1977	3,389,000	-191,408	- 5.6	408,510	-11,179	- 2.7
1978	4,429,000	202,572	+ 4.6	500,096	-73,142	-14.6
1979	4,495,000	391,670	+ 8.7	458,895	-69,631	-15.2
Avg. 1973-79	3,690,000	148,206	+ 4.0	396,682	-23,359	- 5.9

1/ Annual period is from April through March

2/ Percentage error = ((Other sinks) ÷ (Average annual storage)) X 100

3/ Positive error means that total inflows > total inflows percent of the inflow is attributable to the small pump stations (S-127, S-129, S-131, S-133, and S-135) and the large outflow structures which occasionally discharge into the lake at low lake stages (HGS-5, S-308, and S-77).

Evaporation accounted for an average of 66 percent of the water loss from the lake (2,059,930 acre-feet). The Caloosahatchee River was the single largest surface outflow (12.4%) followed by HGS-4 (7.5%). HGS-3, HGS-5, and S-308 released water amounting to 4.7, 3.9 and 3.9 percent of the total outflow, respectively. Seepage through the Hoover Dike was small (1.7%).

Hydrological and morphometric parameters for Lake Okeechobee are shown in Table 6-4. The mean depth, surface area, and volume of the lake remained fairly constant from 1973 to 1977, but increased sharply during 1978. The water residence time varied considerably from 1.85 years in 1974 to 6.78 years in 1976, primarily as a result of large variations in annual surface outflows. Although surface inflows were not as variable as outflows, they did create considerable variation in the hydraulic loading rate. These rates ranged from 0.98 m/yr in 1977 to 1.96 m/yr in 1974.

MATERIAL BUDGET

Annual Lake Okeechobee budgets for water, phosphorus, nitrogen and chloride are shown in Tables 6-5 to 6-11. Table 6-12 compares the annual variation in the material loads of the major inflows as a percent of their respective seven year average. Based on these percentages there was considerable variation in the annual flows, total phosphorus loads and total nitrogen loads from 1973 to 1979. The nitrogen loads to the lake do not consider atmospheric contributions through dry deposition of NO_2 and nitrogen fixation. Messer (1978) and Brezonik et al. (1979) estimated that nitrogen fixation may contribute an additional 15 to 20 percent to the nitrogen budget. The extreme years varied for each inflow with no

TABLE 6-4. HYDROLOGICAL AND MORPHOMETRIC PARAMETERS OF LAKE OKEECHOBEE

Year[1]	Mean Lake Stage (ft)	Mean[2] Depth $\bar{z}$, m	Surface Area A, km^2	Volume V, A-F	Water[3] Residence Time τ_ω, yrs	Hydraulic[4] Loading Rate qs, m/yr
1973	13.58	2.46	1685	3,365,000	4.63	1.47
1974	13.86	2.54	1703	3,504,000	1.85	1.96
1975	13.16	2.40	1637	3,185,000	4.74	1.22
1976	13.81	2.48	1719	3,462,000	6.78	1.42
1977	13.65	2.47	1690	3,389,000	6.17	0.98
1978	16.01	2.99	1828	4,429,000	2.85	1.78
1979	16.15	3.03	1828	4,495,000	2.95	1.75
Average						
1973-79	14.32	2.64	1727	3,690,000	3.47	1.52

1/ Annual period is from April through March

2/ Mean depth = volume/surface area

3/ Based on surface outflows (excluding evaporation)

4/ Based on surface inflows (excluding rainfall)

TABLE 6-5.

1973 WATER, P, N, AND CL BUDGET FOR LAKE OKEECHOBEE (4/1/73 - 3/31/74)

	Q (Acre-feet)	TPO_4 (10^6 grams)	Total N (10^6 grams)	Cl (10^6 grams)
Inputs:				
N.N.R. + Hills. C. (S-2)	154,092	33.6	1390.4	27,667
Miami C. (S-3)	21,567	4.6	175.2	3,044
S-4	-	-	-	-
Harney Pond C. (S-71)	154,893	66.1	451.9	3,248
Indian Prairie C. (S-72)	24,367	9.6	72.6	698
Kissimmee R. (S-65E)	1,028,913	103.3	1900.4	22,685
S-84	232,553	20.1	357.9	4,895
Fisheating Creek	151,627	23.6	288.7	6,176
S-127	4,850	2.3	10.3	411
S-129	6,032	1.2	13.8	474
S-131	1,624	0.3	3.1	142
Taylor Creek (S-133)	14,442	5.0	28.7	1,029
S-135	8,347	1.4	16.3	928
Nubbin Slough (S-191)	210,695	191.5	506.0	13,735
WPB Canal (HGS-5)	0	0.0	0.0	0
St. Lucie Canal (S-308)	0	0.0	0.0	0
Caloosahatchee R. (S-77)	0	0.0	0.0	0
Rainfall 1/	1,206,250	84.9	1577.3	6,399
Total input (M_{in})	3,220,252	547.5	6792.6	91,531
Outputs:				
N.N.R. + Hills. C. (S-2)	276,173	18.8	625.0	34,107
Miami C. (S-3)	161,255	14.4	333.8	19,370
S-4	-	-	-	-
WPB Canal (HGS-5)	151,230	15.0	396.4	19,114
St. Lucie Canal	10,632	0.8	21.4	1,153
Caloosahatchee R. (S-77)	74,863	5.0	138.6	7,730
Seepage 2/	52,000	3.1	108.4	5,485
Evaporation 3/	2,120,264	0.0	0.0	0
Total output (M_{out})	2,846,417	57.1	1623.6	86,959
Total input (M_{in})	3,220,252	547.5	6792.6	91,531
Total output (M_{out})	2,846,417	57.1	1623.6	86,959
Change in storage (ΔM) 4/	-51,400	-3.1	-107.2	-5,421
Other sinks 5/	425,235	493.5	5276.2	9,993
Areal loading rate (g/m^2-yr) 3/		0.325	4.03	54.3

1/ Using surface area = 500,000 acres

2/ Seepage = 0.72 cfs/mi x miles of dike (100 miles)

3/ Using COE surface area (avg. = 1685 km^2)

4/ ΔM = final storage - initial storage (using annual avg. concs. for P, N, and Cl)

5/ Other sinks = $M_{in} - M_{out} - \Delta M$

TABLE 6-6

1974 WATER, P, N, AND CL BUDGET FOR LAKE OKEECHOBEE (4/1/74 - 3/31/75)

Inputs	Q (Acre-Feet)	TPO4 (10^6 grams)	Total N (10^6 grams)	Cl (10^6 grams)
N.N.R. + Hills. C. (S-2)	207,708	32.0	1442.7	32,135
Miami C. (S-3)	42,812	7.4	247.5	5,017
S-4	29,249	7.6	87.4	4,047
Harney Pond C. (S-71)	171,079	55.5	442.9	3,882
Indian Prairie C. (S-72)	43,304	11.7	142.7	1,103
Kissimmee R. (S-65E)	1,442,038	157.0	2232.8	25,558
S-84	211,044	17.5	272.7	6,714
Fisheating Creek	288,417	177.1	1027.3	13,821
S-127	12,950	7.3	34.3	1,261
S-129	12,500	2.8	32.5	1,069
S-131	9,035	1.6	20.4	852
Taylor Creek (S-133)	14,170	5.8	32.2	1,222
S-135	12,601	2.6	30.8	1,679
Nubbin Slough (S-191)	155,419	141.7	397.9	11,511
WPB Canal (HGS-5)	41,211	9.1	212.8	4,951
St. Lucie Canal (S-308)	0	0.0	0.0	0
Caloosahatchee R. (S-77)	11,177	1.6	26.5	1,267
Rainfall 1/	1,472,190	105.2	1923.7	7,723
Total input (M_{in})	4,176,904	743.5	8607.1	123,812
Outputs:				
N.N.R. + Hills. C. (S-2)	322,241	25.6	897.4	37,854
Miami C. (S-3)	275,431	13.9	532.2	30,772
S-4	0	0.0	0.0	0
WPB Canal (HGS-5)	231,443	31.5	644.0	24,781
St. Lucie Canal	245,351	14.6	714.8	23,510
Caloosahatchee R. (S-77)	766,522	94.2	1723.5	53,643
Seepage 2/	52,000	3.3	93.0	5,074
Evaporation 3/	2,082,860	0.0	0.0	0
Total output (M_{out})	3,975,848	183.1	4604.9	175,634
Total input (M_{in})	4,176,904	743.5	8607.1	123,812
Total output (M_{out})	3,975,848	183.1	4604.9	175,634
Change in storage (ΔM) 4/	105,000	6.6	187.8	10,246
Other sinks 5/	96,056	553.8	3814.4	-62,068
Areal loading rate (g/m^2-yr) 3/		0.437	5.05	72.7

1/ Using surface area = 500,000 acres
2/ Seepage = 0.72 cfs/mi x miles of dike (100 miles)
3/ Using COE surface area (avg. = 1703 km^2)
4/ ΔM = final storage - initial storage (using annual avg. conc. for P, N, and Cl
5/ Other sinks = $M_{in} - M_{out} - \Delta M$

TABLE 6-7

1975 WATER, P, N, AND CL BUDGET FOR LAKE OKEECHOBEE (4/1/75 - 3/31/76)

Inputs	Q (Acre-Feet)	TPO4 (10^6 grams)	Total N (10^6 grams)	Cl (10^6 grams)
N.N.R. + Hills. C. (S-2)	318,447	67.0	2,160.1	66,434
Miami C. (S-3)	76,545	8.9	475.6	11,296
S-4	26,575	6.9	79.2	3,691
Harney Pond C. (S-71)	82,170	24.5	226.8	3,857
Indian Prairie C. (S-72)	7,504	3.1	16.8	286
Kissimmee R. (S-65E)	838,503	75.5	1,283.0	18,791
S-84	87,290	7.4	147.9	1,882
Fisheating Creek	105,736	26.8	231.2	4,456
S-127	466	0.3	1.2	45
S-129	944	0.2	2.5	81
S-131	674	0.1	1.5	64
Taylor Creek (S-133)	2,065	0.8	4.7	178
S-135	369	0.1	0.9	49
Nubbin Slough (S-191)	63,178	74.6	168.4	8,002
WPB Canal (HGS-5)	6,918	1.5	35.3	1,373
St. Lucie Canal (S-308)	0	0.0	0.0	0
Caloosahatchee R. (S-77)	0	0.0	0.0	0
Rainfall 1/	1,207,499	73.7	1,575.2	5,958
Total input (M_{in})	2,824,883	371.4	6,410.3	126,443
Outputs:				
N.N.R. + Hills. C. (S-2)	220,498	32.9	654.2	28,749
Miami C. (S-3)	158,424	5.6	444.5	17,647
S-4	0	0.0	0.0	0
WPB Canal (HGS-5)	114,843	10.2	307.4	13,542
St. Lucie Canal	10,893	1.0	22.1	1,134
Caloosahatchee R. (S-77)	115,910	4.6	235.2	12,758
Seepage 2/	52,000	3.5	98.1	5,517
Evaporation 3/	2,183,982	0.0	0.0	0
Total output (M_{out})	2,856,550	57.8	1761.5	79,347
Total input (M_{in})	2,824,883	371.4	6410.3	126,443
Total output (M_{out})	2,856,550	57.8	1761.5	79,347
Change in storage (ΔM) 4/	-98,400	-6.6	-185.7	-10,439
Other sinks 5/	66,733	320.2	4834.5	57,535
Areal loading rate (g/m^2-yr) 3/		0.227	3.92	77.2

1/ Using surface area = 500,000 acres
2/ Seepage = 0.72 cfs/mi x miles of dike (100 miles)
3/ Using COE surface area (avg. = 1637 km^2)
4/ ΔM = final storage - initial storage (using annual avg. conc. for P, N, and Cl)
5/ Other sinks = $M_{in} - M_{out} - \Delta M$

TABLE 6-8

1976 WATER, P, N, AND CL BUDGET FOR LAKE OKEECHOBEE (4/1/76 - 3/31/77)

Inputs	Q (Acre-Feet)	TPO4 (10^6 grams)	Total N (10^6 grams)	Cl (10^6 grams)
N.N.R. + Hills. C. (S-2)	205,499	24.8	1,297.3	42,651
Miami C. (S-3)	46,582	3.4	284.9	7,167
S-4	23,558	6.6	73.3	3,332
Harney Pond C. (S-71)	99,935	19.0	278.2	2,884
Indian Prairie C. (S-72)	20,484	3.7	45.1	655
Kissimmee R. (S-65E)	1,157,951	118.0	1,941.1	23,792
S-84	57,644	3.9	106.3	1,237
Fisheating Creek	147,977	34.6	280.8	6,561
S-127	3,061	1.7	8.1	298
S-129	10,602	2.4	27.6	906
S-131	6,044	1.0	13.6	570
Taylor Creek (S-133)	5,705	2.3	12.9	492
S-135	7,666	1.6	18.7	1,021
Nubbin Slough (S-191)	176,204	206.5	455.2	19,123
WPB Canal (HGS-5)	15,342	1.5	38.9	1,838
St. Lucie Canal (S-308)	0	0.0	0.0	0
Caloosahatchee R. (S-77)	0	0.0	0.0	0
Rainfall 1/	1,315,416	102.5	1,777.9	8,105
Total input (M_{in})	3,299,670	533.5	6,659.9	120,632
Outputs:				
N.N.R. + Hills. C. (S-2)	186,146	12.0	534.2	26,088
Miami C. (S-3)	84,465	3.7	216.1	11,265
S-4	0	0.0	0.0	0
WPB Canal (HGS-5)	104,523	13.0	290.1	12,518
St. Lucie Canal (S-308)	9,537	0.9	24.7	949
Caloosahatchee R. (S-77)	73,881	3.6	196.2	9,695
Seepage 2/	52,000	3.5	124.4	5,959
Evaporation 3/	2,140,336	0.0	0.0	0
Total output (M_{out})	2,650,888	36.7	1,385.7	66,474
Total input (M_{in})	3,299,670	533.5	6,659.9	120,632
Total output (M_{out})	2,650,888	36.7	1,385.7	66,474
Change in storage (ΔM) 4/	602,200	40.1	1,441.2	69,014
Other sinks 5/	46,582	456.7	3,833.0	-14,856
Areal loading rate (g/m^2-yr) 3/		0.310	3.87	70.2

1/ Using surface area = 500,000 acres
2/ Seepage = 0.72 cfs/mi x miles of dike (100 miles)
3/ Using COE surface area (avg. = 1719 km^2)
4/ ΔM = final storage - initial storage (using annual avg. conc. for P, N, and Cl)
5/ Other sinks = $M_{in} - M_{out} - \Delta M$

TABLE 6-9

1977 WATER, P, N, AND CL BUDGET FOR LAKE OKEECHOBEE (4/1/77 - 3/31/78)

Inputs	Q (Acre-Feet)	TPO4 (10^6 grams)	Total N (10^6 grams)	Cl (10^6 grams)
N.N.R. + Hills. C. (S-2)	213,347	29.4	1,580.7	37,309
Miami C. (S-3)	83,934	11.2	554.9	11,334
S-4	44,645	20.4	175.7	6,347
Harney Pond C. (S-71)	140,083	36.7	328.1	4,571
Indian Prairie C. (S-72)	34,753	8.7	105.1	1,553
Kissimmee R. (S-65E)	520,423	53.9	1,153.3	15,228
S-84	11,974	1.1	24.6	380
Fisheating Creek	126,448	21.6	273.3	6,183
S-127	7,968	4.5	21.1	776
S-129	8,190	1.9	21.3	700
S-131	4,443	0.8	10.0	419
Taylor Creek (S-133)	7,168	2.9	16.3	618
S-135	7,323	1.5	17.9	976
Nubbin Slough (S-191)	132,339	180.6	383.9	14,476
WPB Canal (HGS-5)	0	0.0	0.0	0
St. Lucie Canal (S-308)	0	0.0	0.0	0
Caloosahatchee R. (S-77)	0	0.0	0.0	0
Rainfall 1/	1,304,892	149.2	1,809.7	8,152
Total input (M_{in})	2,647,930	524.4	6,475.9	109,022
Outputs:				
N.N.R. + Hills. C. (S-2)	169,284	14.8	602.7	24,413
Miami C. (S-3)	79,227	5.3	245.6	10,771
S-4	0	0.0	0.0	0
WPB Canal (HGS-5)	62,550	10.3	193.8	8,405
St. Lucie Canal (S-308)	50,367	4.5	103.0	5,997
Caloosahatchee R. (S-77)	135,475	7.6	320.1	16,070
Seepage 2/	52,000	4.2	107.1	6,274
Evaporation 3/	1,890,285	0.0	0.0	0
Total output (M_{out})	2,439,238	46.7	1,572.3	71,930
Total input (M_{in})	2,647,930	524.4	6,475.9	109,022
Total output (M_{out})	2,439,238	46.7	1,572.3	71,930
Change in storage (ΔM) 4/	400,100	32.6	824.3	48,271
Other sinks 5/	- 191,408	445.1	4,079.3	-11,179
Areal loading rate (g/m^2-yr) 3/		0.310	3.83	64.5

1/ Using surface area = 500,000 acres
2/ Seepage = 0.72 cfs/mi x miles of dike (100 miles)
3/ Using COE surface area (avg. = 1690 km^2)
4/ ΔM = final storage - initial storage (using annual avg. conc. for P, N, and Cl)
5/ Other sinks = $M_{in} - M_{out} - \Delta M$

TABLE 6-10

1978 WATER, P, N, AND CL BUDGET FOR LAKE OKEECHOBEE (4/1/78 - 3/31/79)

Inputs	Q (Acre-Feet)	TPO4 (10^6 grams)	Total N (10^6 grams)	Cl (10^6 grams)
N.N.R. + Hills. C. (S-2)	200,173	26.5	1,433.2	37,031
Miami C. (S-3)	69,512	4.8	391.0	11,384
S-4	50,956	21.1	215.5	6,858
Harney Pond C. (S-71)	295,688	82.5	805.6	7,651
Indian Prairie C. (S-72)	72,116	14.8	218.5	2,410
Kissimmee R. (S-65E)	1,297,681	171.4	2314.6	27,438
S-84	207,740	14.7	382.8	4,164
Fisheating Creek	197,368	34.5	420.2	8,814
S-127	13,438	7.6	35.6	1,308
S-129	14,773	3.4	38.5	1,263
S-131	7,149	1.2	16.1	674
Taylor Creek (S-133)	22,392	9.1	50.8	1,931
S-135	27,192	5.7	66.4	3,623
Nubbin Slough (S-191)	167,181	193.7	554.4	14,281
WPB Canal (HGS-5)	0	0.0	0.0	0
St. Lucie Canal (S-308)	0	0.0	0.0	0
Caloosahatchee R. (S-77)	0	0.0	0.0	0
Rainfall 1/	1,507,918	96.1	2,198.8	8,537
Total input (M_{in})	4,151,277	687.1	9,142.0	137,367
Outputs:				
N.N.R. + Hills. C. (S-2)	257,238	26.6	1,036.5	34,808
Miami C. (S-3)	144,482	10.9	470.9	18,600
S-4	0	0.0	0.0	0
WPB Canal (HGS-5)	92,526	14.9	315.8	13,358
St. Lucie Canal (S-308)	236,693	41.1	561.8	25,943
Caloosahatchee R. (S-77)	772,698	60.4	2,070.2	71,544
Seepage 2/	52,000	4.4	114.2	5,882
Evaporation 3/	2,036,168	0.0	0.0	0
Total output (M_{out})	3,591,805	158.3	4,569.4	170,135
Total input (M_{in})	4,151,277	687.1	9,142.0	137,367
Total output (M_{out})	3,591,805	158.3	4,569.4	170,135
Change in storage (ΔM) 4/	356,900	30.4	783.7	40,374
Other sinks 5/	202,572	498.4	3,788.9	-73,142
Areal loading rate (g/m^2-yr) 3/		0.376	5.0	75.1

1/ Using surface area = 500,000 acres
2/ Seepage = 0.72 cfs/mi x miles of dike (100 miles)
3/ Using COE surface area (avg. = 1828 km^2)
4/ ΔM = final storage - initial storage (using annual avg. conc. for P, N, and Cl)
5/ Other sinks = $M_{in} - M_{out} - \Delta M$

TABLE 6-11

1979 WATER, P, N, AND CL BUDGET FOR LAKE OKEECHOBEE (4/1/79 - 3/31/80)

Inputs	Q (Acre-Feet)	TPO_4 (10^6 grams)	Total N (10^6 grams)	Cl (10^6 grams)
N.N.R. + Hills. C. (S-2)	71,892	10.9	524.5	12,557
Miami C. (S-3)	49,181	5.0	236.3	7,049
S-4	34,338	18.1	141.0	4,165
Harney Pond C. (S-71)	245,018	97.2	782.3	6,007
Indian Prairie C. (S-72)	59,545	18.5	173.2	2,133
Kissimmee R. (S-65E)	1,231.434	175.0	2,044.8	27,795
S-84	176,167	15.8	302.9	3,044
Fisheating Creek	379,569	95.2	1,127.8	10,263
S-127	33,468	22.0	106.5	3,662
S-129	25,135	6.4	73.4	2,318
S-131	7,970	1.5	20.6	802
Taylor Creek (S-133)	43,819	20.4	112.0	4,428
S-135	58,525	14.7	171.2	9,084
Nubbin Slough (S-191)	170,085	212.6	574.9	13,345
WPB Canal (HGS-5)	0	0.0	0.0	0
St. Lucie Canal (S-308)	9,172	2.2	25.7	1,438
Caloosahatchee R. (S-77)	0	0.0	0.0	0
Rainfall 1/	1,438,583	94.9	1,859.9	7,955
Total input (M_{in})	4,033,791	810.4	8,277.0	116,045
Outputs:				
N.N.R. + Hills. C. (S-2)	197,737	18.6	543.6	24,270
Miami C. (S-3)	128,614	10.4	380.5	15,010
S-4	1,537	0.2	6.4	171
WPB Canal (HGS-5)	87,520	13.1	240.6	12,797
St. Lucie Canal (S-308)	283,411	44.1	980.1	31,248
Caloosahatchee R. (S-77)	779,329	62.6	2,092.7	81,802
Seepage 2/	52,000	6.2	130.2	5,344
Evaporation 3/	1,965,673	0.0	0.0	0
Total output (M_{out})	3,495,821	155.2	4,374.1	170,642
Total input (M_{in})	4,033,791	810.4	8,277.0	116,045
Total output (M_{out})	3,495,821	155.2	4,374.1	170,642
Change in storage (ΔM) 4/	146,300	17.5	366.4	15,034
Other sinks 5/	391,670	637.7	3,536.5	-69,631
Areal loading rate (g/m^2-yr) 3/		0.443	4.53	63.5

1/ Using surface area = 500,000 acres
2/ Seepage = 0.72 cfs/mi x miles of dike (100 miles)
3/ Using COE surface area (avg. = 1828 km^2)
4/ ΔM = final storage - initial storage (using annual avg. conc. for P, N, and Cl)
5/ Other sinks = $M_{in} - M_{out} - \Delta M$

TABLE 6-12 ANNUAL VARIATIONS IN MATERIAL LOADS TO LAKE OKEECHOBEE

	Total Inflow		Total P load		Areal P loading rate		Total N load		Areal N loading rate	
Year	Acre-feet	%1/	10^6g	%	g/m^2-yr	%	10^6g	%	g/m^2-yr	%
1973	3,220,252	93	547.5	91	0.325	94	6792.6	91	4.03	93
1974	4,176,904	120	743.5	123	0.437	126	8607.1	115	5.05	117
1975	2,824,883	81	371.4	62	0.227	65	6410.3	86	3.92	91
1976	3,299,670	95	533.5	89	0.310	89	6659.9	89	3.87	90
1977	2,647,930	76	524.4	87	0.310	89	6475.9	87	3.82	89
1978	4,151,277	119	687.1	114	0.376	108	9142.0	122	5.00	116
1979	4,033,791	116	810.4	135	0.443	128	8277.0	111	4.53	105
	3,479,244		602.5		0.347		7480.7		4.32	

1/ percent of seven year average

consistent pattern. There were also no steadily increasing or decreasing trends among the major inflows although for most of the tributaries the highest relative loads occurred in 1978. Compared to the surface inflows, the annual variation in the material loads attributable to direct rainfall on the lake remained relatively constant. The effect of the Interim Action Plan (IAP) in reducing loadings at S-2 and S-3 was evident during its initial year of 1979. The largest relative reduction was accomplished at S-2 where the 1979 material loads were less than 40 percent of the seven year average. These were by far the lowest material loads measured at S-2 during the study. The material loads at S-3 in 1979 were 70 to 88 percent below the average although lower relative loadings occurred in 1973 and 1976.

An average material budget for the period 1973-79 is shown in Table 6-13. A summary of the relative contributions of each tributary are presented in Table 6-14, where the values are expressed as percentages of the total inflow or outflow. It is evident from these tables that the two largest sources of water to the lake contribute less nutrients in proportion to the amount of water. Rainfall, which on the average contributed 38 percent of the water, accounted for only 16.7% of the phosphorus, 23.3 percent of the nitrogen, and 6.3 percent of the chloride. Similarly, the Kissimmee River, which accounted for 32.2 percent of the water, contributed only between 20 and 27 percent of the phosphorus, nitrogen, and chloride. In contrast, Taylor Creek/Nubbin Slough (S-191) which supplied only 4.3 percent of the water, contributed over one-fourth of the total load of phosphorus to the lake (28.5%). A similar disparity

TABLE 6-13

AVERAGE WATER, P, N, AND CL BUDGET FOR LAKE OKEECHOBEE (4/1/73-3/31/80)

	Q (acre-feet)	TPO_4 (10^6 grams)	Total N (10^6 grams)	Cl (10^6 grams)
Inputs:				
N.N.R. & Hills. C. (S-2)	195,880	32.0	1404.1	36,541
Miami C. (S-3)	55,733	6.5	337.9	8,042
S-4 1/	34,887	13.5	128.7	4,740
Harney Pond C. (S-71)	169,838	54.5	474.2	4,605
Indian Prairie C. (S-72)	37,425	10.0	119.7	1,264
Kissimmee R. (S-65E)	1,073,849	122.0	1838.6	23,041
S-84	140,630	11.5	233.8	3,390
Fisheating Creek	203,449	59.1	521.3	8,039
S-127	10,886	6.5	31.0	1,108
S-129	11,168	2.6	29.9	973
S-131	5,277	0.9	12.2	503
Taylor Creek (S-133)	15,680	6.6	36.8	1,414
S-135	17,432	3.9	46.0	2,480
Nubbin Slough (S-191)	153,586	171.6	434.4	13,496
WPB Canal (HGS-5)	9,067	1.7	41.0	1,166
St. Lucie Canal (S-308)	1,310	0.3	3.7	205
Caloosahatchee R. (S-77)	1,597	0.2	3.8	181
Rainfall	1,350,393	100.9	1817.5	7,547
Total input (M_{in})	3,479,244	602.5	7480.7	117,846
Outputs:				
N.N.R. & Hills. C. (S-2)	232,760	21.3	699.1	30,041
Miami C. (S-3)	147,421	9.2	374.8	17,634
S-4 1/	256	0.0	1.1	28
WPB Canal (HGS-5)	120,662	15.4	341.2	14,939
St. Lucie Canal (S-308)	120,983	15.3	346.8	15,414
Caloosahatchee R. (S-77)	388,383	34.0	968.1	36,200
Seepage	52,000	4.0	110.8	5,648
Evaporation	2,059,930	0.0	0.0	0
Total output (M_{out})	3,122,367	99.2	2841.6	117,326
Total input (M_{in})	3,479,244	602.5	7480.7	117,836
Total output (M_{out})	3,122,367	99.2	2841.6	117,326
Change in storage (ΔM)	208,671	16.8	472.9	23,869
Other sinks	148,206	486.5	4166.2	-23,359
Areal loading rate (g/m^2-yr)		0.347	4.32	68.2

1/ 6-yr average only (thus, total input and total output ≠ Σ inputs and outputs, respectively).

TABLE 6-14

AVERAGE PERCENTAGE WATER, P, N, AND CL BUDGET FOR LAKE OKEECHOBEE (4/1/73-3/31/80)

	Q (Acre-Feet)	TPO_4 (10^6 grams)	Total N (10^6 grams)	Cl (10^6 grams)
Inputs:				
N.N.R. & Hills. C. (S-2)	5.6	5.3	18.8	31.0
Miami C. (S-3)	1.6	1.1	4.5	6.8
S-4	1.0	2.2	1.7	4.0
Harney Pond C. (S-71)	4.9	9.0	6.3	3.9
Indian Prairie C. (S-72)	1.1	1.7	1.6	1.1
Kissimmee R. (S-65E)	30.9	20.3	24.6	19.6
S-84	4.0	1.9	3.1	2.9
Fisheating Creek	5.8	9.8	7.0	6.8
S-127	0.3	1.1	0.4	0.9
S-129	0.3	0.4	0.4	0.8
S-131	0.2	0.1	0.2	0.4
Taylor Creek (S-133)	0.5	1.1	0.5	1.2
S-135	0.5	0.6	0.6	2.1
Nubbin Slough (S-191)	4.4	28.5	5.8	11.5
WPB Canal (HGS-5)	0.3	0.3	0.5	1.0
St. Lucie Canal (S-308)	0.0	0.0	0.0	0.2
Caloosahatchee R. (S-77)	0.0	0.0	0.0	0.2
Rainfall	38.8	16.7	24.3	6.4
Total input	99.5	100.1	100.3	100.8
Outputs:				
N.N.R. & Hills. C. (S-2)	7.5	21.5	24.6	25.6
Miami C. (S-3)	4.7	9.3	13.2	15.0
S-4	0.0	0.0	0.0	0.0
WPB Canal (HGS-5)	3.9	15.5	12.0	12.7
St. Lucie Canal (S-308)	3.9	15.4	12.2	13.1
Caloosahatchee R. (S-77)	12.4	34.3	34.1	30.9
Seepage	1.7	4.0	3.9	4.8
Evaporation	66.0	0.0	0.0	0.0
Total output	100.1	100.0	100.0	100.1

existed for the contribution of nitrogen and chloride relative to water. S-2 contributed 18 percent of the nitrogen and 30.5 percent of the chloride but supplied only 5.5 percent of the water.

Table 6-15 presents the mean annual material inputs for the lake by drainage basins. The same basic trends as discussed above are evident. Rainfall and the Kissimmee Basin (S-65) supplied 70 percent of the water (38.8 and 30.9%, respectively). The Taylor Creek/Nubbin Slough Basin (S-191 and S-133) was the largestcontributor of phosphorus (29.6%), followed by the Kissimmee Bsin (20.2%). The Istokpoga Basin represents the third largest surface input (12.6%), excluding rainfall. Seventy-five percent of the total nitrogen load to the lake was contributed equally from three sources - the Kissimmee Basin (24.6%), EAA (25.0%), and rainfall (24.3%). The high load from the Kissimmee Basin and rainfall was the result of large discharges and low concentrations while the high contribution from the EAA was the result of high concentrations and relatively low discharges. Atmospheric nitrogen loadings may be underestimated since the dry deposition of NO_2 on wet surfaces was not accounted for by the bulk rainwater precipitation collectors used in this study (Messer and Brezonik 1981).

The areal loading rates of phosphorus, nitrogen, and chloride are included at the bottom of each annual budget. The areal loading rates have varied over the seven year period, although there were no steadily increasing or decreasing trends which were consistent from 1973 to 1980. The phosphorus areal loading rates (L_p) ranged from 0.227 g/m^2-yr in 1975 to 0.443 g/m^2-yr in 1979. Nitrogen rates (L_n) ranged from 3.83 g/m^2-yr in 1977 to 5.05 m/g^2-yr in 1974. Annual variations in the loading rates from all sources, expressed as a percent of the seven year average, are listed in Table 6-16. Two years, 1973 and 1976, most closely matched the "average" year. Below average

TABLE 6-15 AVERAGE WATER, P, N, CL INPUTS BY

Inputs	Flow Acre-Feet	%
Rainfall	1,350,393	38.8%
Kissimmee Basin (S-65E)	1,073,849	30.9%
Istokpoga Basin, (S-71, S-72, S-84)	347,893	10.0%
EAA (S-2, S-3, S-4)	286,500	8.2%
Fisheating Creek	203,449	5.8%
Taylor Crk./Nubbin Slough (S-191, S-133)	169,266	4.9%
Minor Pump Sta. (S-127, S-129, S-131, S-135)	44,763	1.3%
Occasional Inflows: WPB Canal (HGS-5)	9,067	0.3%
Caloosahatchee R. (S-77)	1,597	0.05%
St. Lucie (S-308)	1,310	0.04%
Avg. Total Input	3,479,244	100.3%

BASIN FOR LAKE OKEECHOBEE (4/1/73-3/31/80)

Total P		Total N		Cl	
10^6 g	%	10^6 g	%	10^6 g	%
100.9	16.7%	1,817.5	24.3%	7,547	6.4%
122.0	20.2%	1,838.6	24.6	23,041	19.6%
76.0	12.6%	827.7	11.1%	9,259	7.9%
52.0	8.6%	1,870.7	25.0%	49,323	41.9%
59.1	9.8%	521.3	7.0%	8,039	6.8%
178.2	29.6%	471.2	6.3%	14,910	12.7%
13.9	2.3%	119.1	1.6%	5,064	4.3%
1.7	0.3%	41.0	0.5%	1,166	1.0%
0.2	0.03%	3.8	0.05%	181	0.2%
0.3	0.05%	3.7	0.05%	205	0.2%
602.5	100.2%	7,480.7	100.5%	117,836	101.0%

TABLE 6-16 ANNUAL VARIATION IN MATERIAL LOADS FOR THE MAJOR INFLOWS

		Percent of 7 Year Average						
		1973	1974	1975	1976	1977	1978	1979
N.N.R.- Hills. C. (S-2)	Flow	79	106	163	105	109	102	37
	TP 1/	105	100	209	78	92	83	34
	TN 2/	99	103	154	92	113	102	37
Miami C. (S-3)	Flow	39	77	137	84	151	125	88
	TP	71	114	137	52	172	74	77
	TN	52	73	141	84	164	116	70
S-4	Flow	-	84	76	68	128	146	98
	TP	-	56	51	49	151	156	134
	TN	-	68	62	57	137	167	110
Harney Pond C. (S-71	Flow	91	101	48	59	82	174	144
	TP	121	102	45	35	67	151	178
	TN	95	93	48	59	69	170	165
Kissimmee R. (S-65E)	Flow	96	134	78	108	48	121	115
	TP	85	129	62	97	44	140	143
	TN	103	121	70	106	63	126	111
S-84	Flow	165	150	62	41	9	148	125
	TP	175	152	64	34	10	128	137
	TN	153	117	63	45	11	164	130
Fisheating Ck	Flow	75	142	52	73	62	97	187
	TP	40	300	45	59	37	58	161
	TN	55	197	44	54	52	81	216
Nubbin Slough (S-191)	Flow	137	101	41	115	86	109	111
	TP	112	83	43	120	105	113	124
	TN	116	92	39	105	88	128	132
Direct Rainfall	Flow	89	109	88	97	97	112	107
	FP	84	104	73	102	148	95	94
	TN	87	106	87	98	100	121	102

1/ TP = total phosphorus load

2/ TN = total nitrogen load

loadings occurred in 1975 and 1977, while above average loadings occurred in 1974, 1978, and 1979. Although the Interim Action Plan for reducing loadings at S-2 and S-3 was in effect in 1979, increased loadings from the other inflows were sufficiently high so as to cause the 1978 and 1979 lake load to be well above average.

The nutrient retention coefficients displayed in Table 6-17 indicate that the percentage of phosphorus retained by the lake was greater than the percentage of nitrogen retained. Phosphorus retention by the lake ranged from 75.6 percent to 93.6 percent with a seven year average of 84.0 percent. The amount of nitrogen retained was somewhat lower ranging from 47.6 percent to 82.9 percent with an average retention of 64.3 percent. The year 1974 had the lowest phosphorus and nitrogen retention while 1976 had the highest. The amount of nutrient retention was directly proportional to the water residence time ($r = 0.96$ for phosphorus retentions and 0.95 for nitrogen retention). The differential in the phosphorus versus nitrogen retention is also reflected in the total nutrient ratio. The total N to total P ratio (TN/TP) in the outflow was more than twice that of the waters entering the lake. This relationship is a function of the greater relative retention of phosphorus as compared to nitrogen and nitrogen fixation within the lake. The TN/TP ratio in the outflow was also highly correlated to the water residence time ($r = 0.92$).

TABLE 6-17 FLOW WEIGHTED CONCENTRATIONS FOR LAKE OKEECHOBEE COMBINED INFLOWS (INCLUDING RAINFALL) AND OUTFLOWS

	TPO_4 (mg/l)		Total N (mg/l)		TN/TP Ratio		Nutrient Retention		
Year	C_{in}	C_{out}	C_{in}	C_{out}	in	out	R_{exp}	R_{exn}	τ_{ω}
1973	.138	0.064	1.71	1.81	12.4	28.3	0.895	0.757	4.6
1974	.133	0.078	1.67	1.97	11.6	25.3	0.756	0.476	1.9
1975	.107	0.070	1.84	2.12	17.2	30.3	0.842	0.717	4.7
1976	.131	0.058	1.64	2.20	12.5	37.9	0.936	0.829	6.8
1977	.161	0.069	1.98	2.32	12.3	33.6	0.916	0.785	6.2
1978	.134	0.082	1.79	2.38	13.4	29.0	0.779	0.540	2.9
1979	.163	0.082	1.66	2.32	10.2	28.3	0.813	0.494	3.0
Average 1973-79	.140	0.076	1.74	2.17	12.4	28.6	0.840	0.643	3.5

where,

$R_{exp} = ((P_{in} + \Delta P) - P_{out}) \div (P_{in} + \Delta P)$

$R_{exn} = ((N_{in} + \Delta N) - N_{out}) \div (N_{in} + \Delta N)$

$C_{in} = M_{in} \div Q_{in}$

$C_{out} = M_{out} \div (Q_{out} - \text{evaporation})$

SUMMARY

The Kissimmee River and direct rainfall account for 70 percent of the water entering Lake Okeechobee, while evaporation accounts for almost 66 percent of the water leaving the lake. Over the seven year study period the water budgets for the lake were within 4.0 percent of the published C.O.E. storage. The average water residence time and hydraulic loading rate for Lake Okeechobee from 1973 to 1979 was 3.47 years and 1.52 m/yr, respectively.

The Nubbin Slough/Taylor Creek basin (S-191 and S-133) was the largest contributor of phosphorus, 29.6 percent, although it accounted for only 4.9 percent of the water. The next two largest sources of phosphorus, the Kissimmee River and rainfall, contributed proportionally less phosphorus (20.2 and 16.7%, respectively) with respect to the amount of water (30.9% and 38.8%, respectively). Similar disparities existed for nitrogen. The EAA (S-2, S-3, and S-4) accounted for 25.0 percent of the total nitrogen load while contributing only 8.2 percent of the water. Again the Kissimmee River and rainfall supplied proportionally less nitrogen (24.6 and 24.3%, respectively) than water. No steadily increasing or decreasing changes in the material loads which were consistent from 1973 to 1979 were indicated.

The areal phosphorus and nitrogen loading rate averaged 0.347 and 4.32 g/m^2-yr, respectively, over the seven year study period. The nitrogen loading rate did not include nitrogen fixation nor dry deposition of NO_2. The lake, on the average, retained approximately 84 percent of the phosphorus load and 64 percent of the nitrogen load (excluding dry deposition of NO_2). Included in the nitrogen retention would be denitrification losses to the atmosphere.

CHAPTER VII

LIMNETIC WATER QUALITY - CHEMICAL CHARACTERISTICS AND WATER QUALITY TRENDS

INTRODUCTION

This chapter will address the chemical characteristics and water quality trends in the limentic area of Lake Okeechobee from April 1973 to March 1980. This evaluation will be based upon surface data collected at the eight baseline stations (Figure 7-1) since previous study by Davis and Marshall (1975) indicated that Lake Okeechobee was vertically well mixed at these locations. Year designations will represent the 12 months from April 1st of the year indicated through March 31st of the following year (i.e. 1973 will correspond to the period April 1, 1973 to March 31, 1974). Locations were selected so as to adequately account for major areal variations but not localized tributary influences. The primary objectives of the sampling program and of this chapter were:

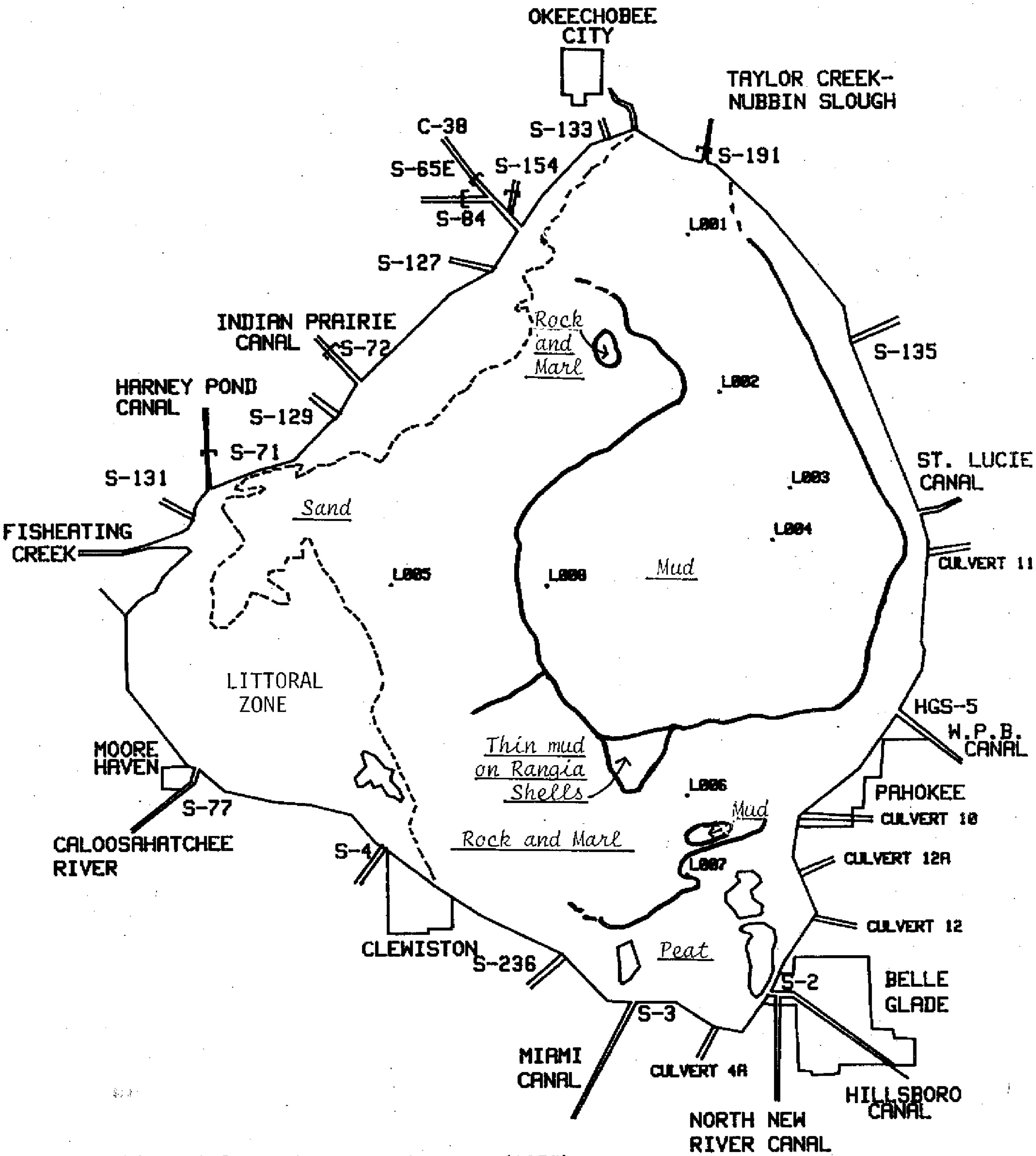
(1) Characterize the chemical quality of Lake Okeechobee

(2) Identify seasonal and annual water quality trends

(3) Assess the limiting nutrient conditions based upon nutrient ratios, and

(4) Identify spatial variation in the limnetic zone

Stations were sampled monthly from April 1973 to January 1977, bi-weekly from February 1974 to December 1976, and monthly from January 1977 to March 1980. Samples collected were analyzed for NO_x, NO_2^-, NH_4, TKN, ortho $PO_4^=$, total $PO_4^=$, Cl^-, Na^+, K^+, Ca^{++}, Mg^{++}, alkalinity (primarily $HCO_3^=$, and $CO_3^=$), color, and turbidity. In situ field data (temperature, pH, specific conductance, and dissolved oxygen) were also collected. The collection methodologies were described in Chapter IV.



Adapted from Gleason and Stone (1975)

FIGURE 7-1 LAKE OKEECHOBEE LIMNETIC WATER QUALITY STATIONS

The water quality characterization, identification of seasonal and annual trends, and assessment of limiting nutrients were based upon the eight baseline stations averaged lake-wide for each sampling trip. Spatial variations were evaluated using data collected at the individual stations over the course of the entire study period. Statistical summaries of the data collected at each station are in Appendix A. Seasonal patterns in the water quality data were evaluated from visual inspections of time series graphs. Patterns in annual concentrations were determined statistically by application of a 2-way ANOVA (station and year) followed by Duncan's multiple range test.

The theory of nutrient limitation is based upon the concept that of the many nutrients required for plant growth, the one present in the least amount relative to a plant's needs (assuming all other physical and biological requirements are satisfied) will limit the growth of that plant at that time and is, therefore, considered the "limiting nutrient". The assessment of the limiting nutrient for a given body of water can be complicated due to the large number of chemical, physical, and biological factors required for growth and due to the spatial and temporal variations in these requirements which can exist in a lake. Therefore, the limiting factor can vary in both time and space. Of the more than 15 elements required for algal growth, nitrogen or phosphorus is usually the limiting nutrient since the other elements are usually required in such small quantities that they are rarely in short supply. Also the supply of these other elements is usually correlated to the supply of nitrogen and phosphorus.

There are two types of limitation which can be identified: growth rate limitation and yield limitation. For growth rate limitation to exist the concentration of the limiting nutrient needs to be sufficiently low so that its uptake rate from solution is below optimum and, therefore, the growth rate of the plant is limited by the rate at which it can assimilate the nutrient from the water. In yield limitation, all the nutrients needed for growth are present at concentrations which permit maximum uptake rates, but one nutrient will be deficient relative to the stoichiometric needs of the plant. This type of limitation is considered potential rather than actual since other factors such as light, temperature, and predation may prevent the algae from reaching maximum biomass and depleting the supply of the yield-limiting nutrient. Yield limitation is more important than growth rate limitation since it is the maximum algal biomass, rather than the rate of algal growth, which most adversely affects the quality of the water.

The relative biological requirement of nutrients is based upon the presumption that as a result of photosynthesis, algae will assimilate nitrogen and phosphorus in a stoichiometric atomic ratio of approximately 16N:1P, which is equal to a mass ratio of 7.2N:1P. This rate of depletion continues until one of the two nutrients becomes depleted in the water body at which time the nutrient present in the water in the lowest concentration, relative to the stoichiometric demands of the algae, will limit subsequent growth. If the mass ratio at that time is greater than 7.2:1 then phosphorus is considered limiting. If the mass ratio is less than 7.2:1, then nitrogen is considered the limiting nutrient. When the ratio is around 7.2:1 then either nitrogen or phosphorus may be limiting. A critical N:P mass ratio of 7-8:1 was adopted by Rast et al. (1978)

for limiting nutrient assessment of the U. S. portion of the North American O.E.C.D. water bodies and was also used by Schindler (1977). Rast et al. (1978) also recommended that the inorganic forms of nitrogen and phosphorus be used in assessing nutrient limitation.

RESULTS AND DISCUSSION

Temporal Analysis

Figures 7-2 to 7-4 present a time series display of the average major ion levels for each sampling trip from 1973 to 1979. Inspection of these graphs indicate that monthly variations in sodium, potassium, calcium, magnesium, chloride, alkalinity and conductivity did not follow a seasonal pattern. There were also no consistent increasing or decreasing patterns in the mean annual major ion concentrations from 1973 to 1979 (Table 7-1) although significant variations in the annual means were indicated (Tables 7-2 to 7-3). A significant decrease in specific conductance occurred in 1979. This reduced level of conductivity may have been at least partially the result of implementation of the Interim Action Plan (IAP). The IAP, in 1977, drastically reduced the inflow of high conductivity water from S-2 and S-3 which averaged 1025 and 847 μmhos/cm, respectively. Although the largest total volume of water from all sources entered the lake in 1979 (4,495,000 acre-feet) a similar quantity entered in 1978 (4,429,000 acre-feet) without a corresponding reduction in conductivity. Therefore, the total volume of water entering the lake appears to not have been a direct factor affecting the decline in the lake's conductivity in 1979. The mean annual alkalinity was higher from 1973 (2.58 meq/L) to 1977 (2.55 meq/L) than in more recent years (2.29 and 1.95 meq/L in 1978 and 1979, respectively).

In general, however, the inorganic ionic composition of Lake Okeechobee can be adequately represented by the average from 1973 to 1979 (Table 7-1). The lake can thus be characterized as being composed of highly mineralized water for a lake in a humid climatic zone. Sodium and calcium levels

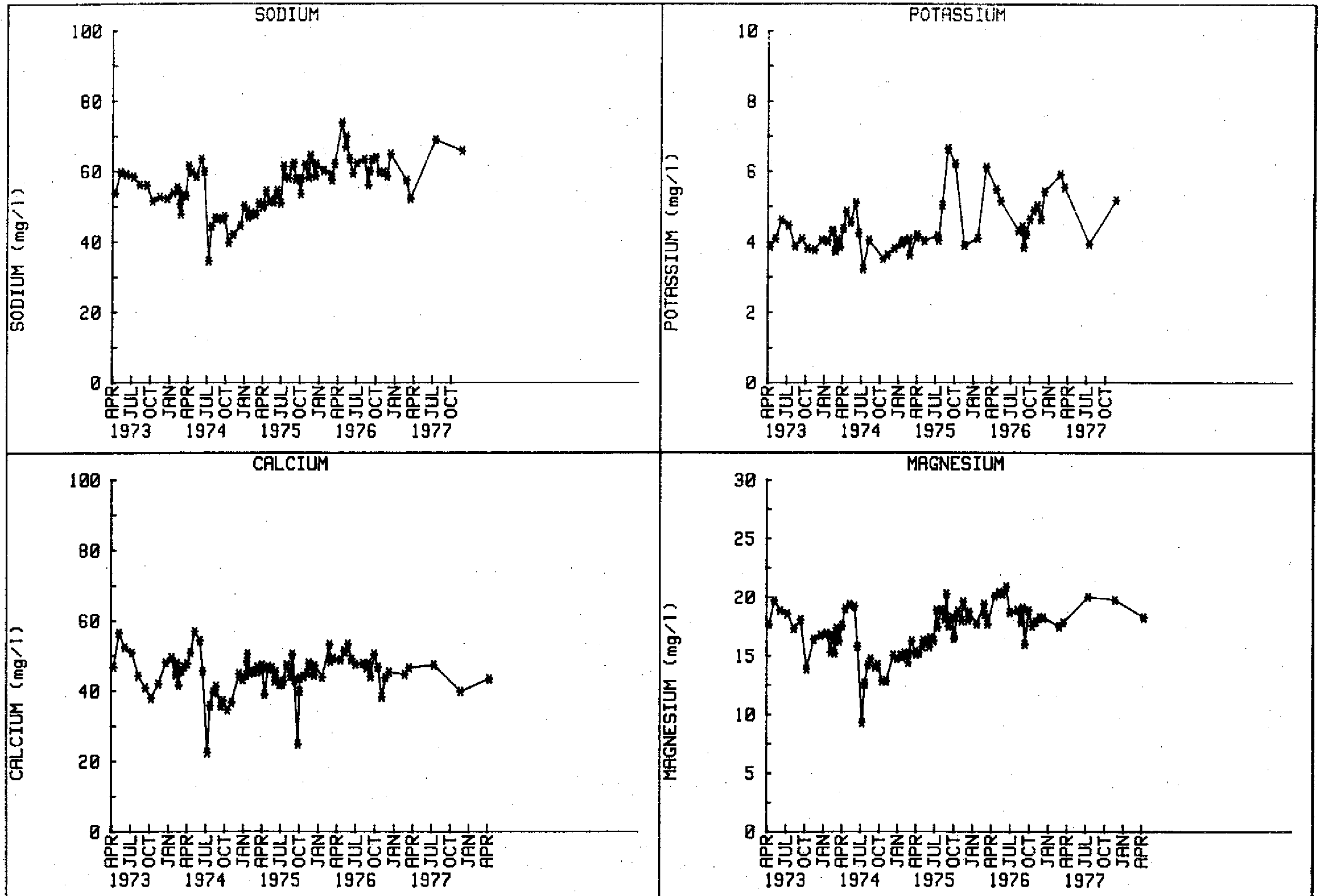


FIGURE 7-2. MEAN DAILY MAJOR CATION CONCENTRATIONS IN LAKE OKEECHOBEE

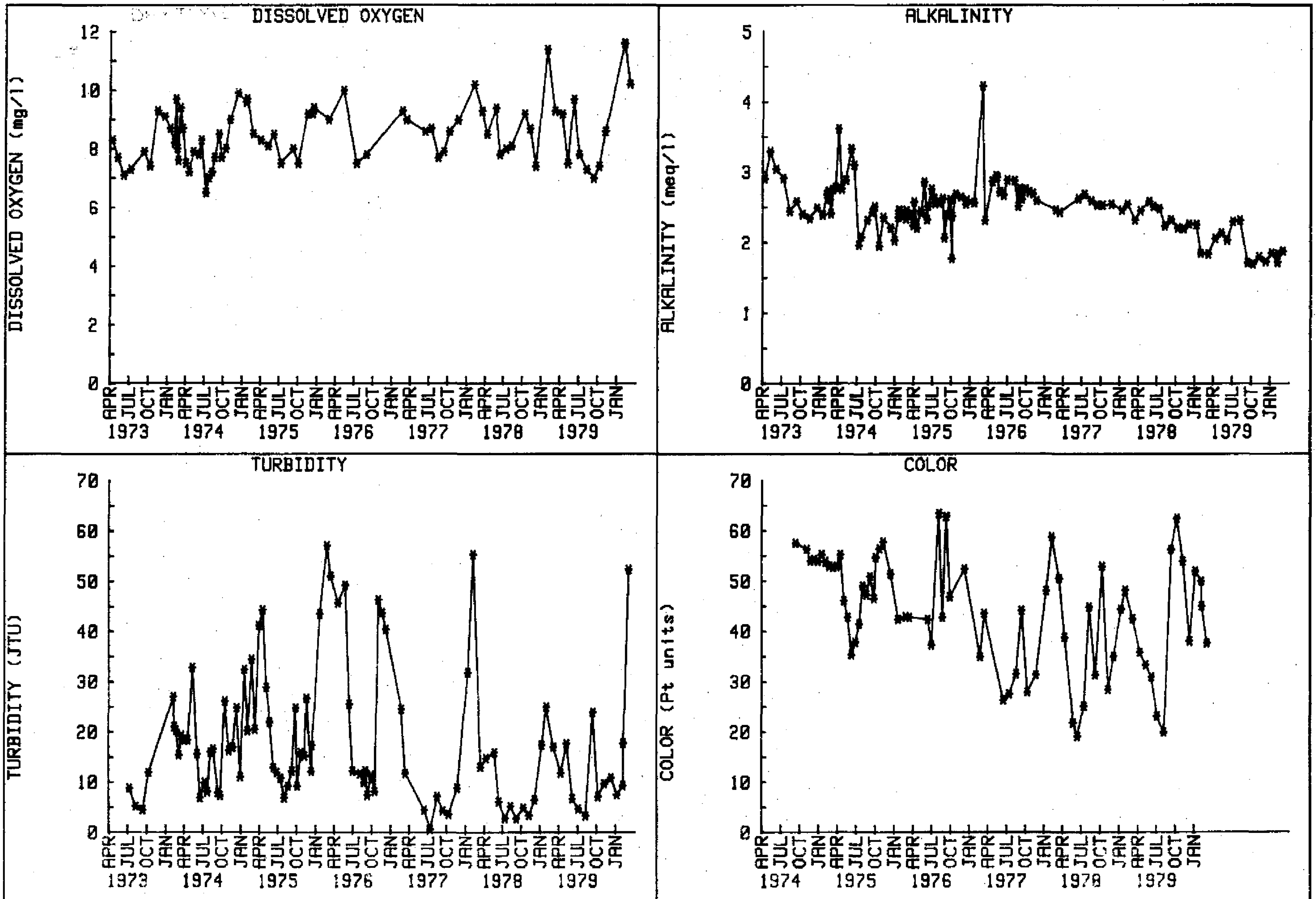


FIGURE 7-3 MEAN DAILY DISSOLVED OXYGEN, ALKALINITY, TURBIDITY, AND COLOR IN LAKE OKEECHOBEE

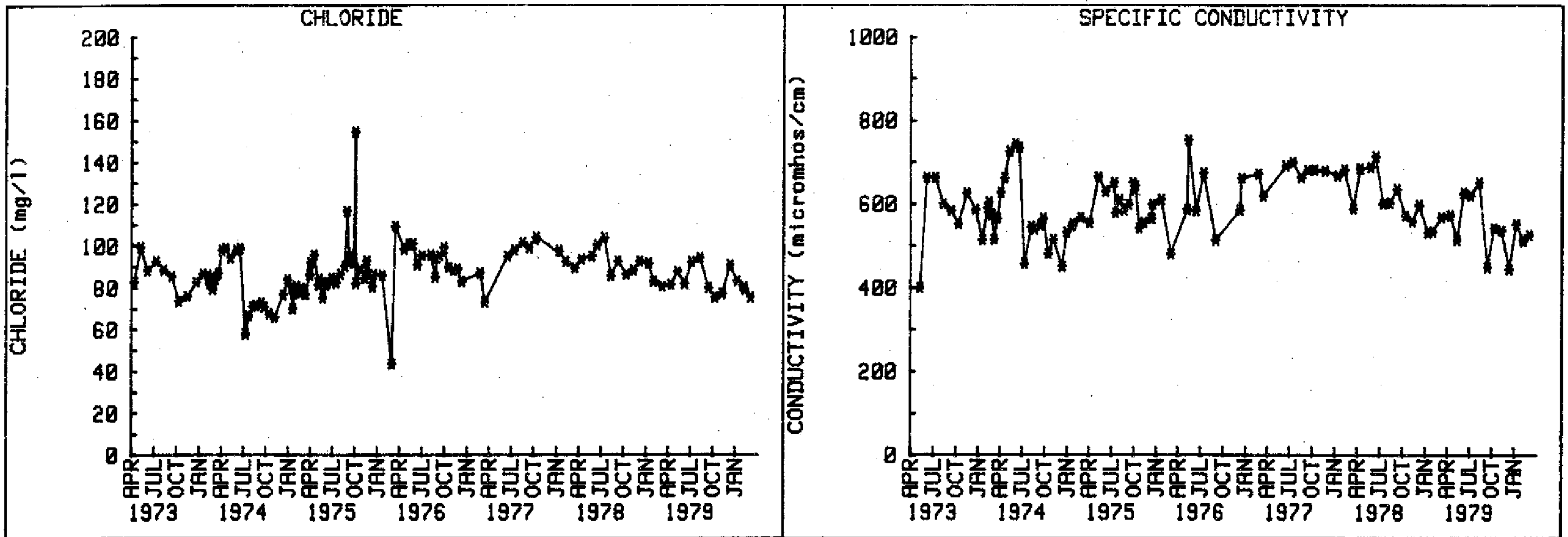


FIGURE 7-4. MEAN DAILY CHLORIDE AND CONDUCTIVITY IN LAKE OKEECHOBEE

TABLE 7-1. SUMMARY OF MEAN ANNUAL LIMNETIC WATER QUALITY

Mean Annual Concentration

Parameter[1/]	1973	1974	1975	1976	1977	1978	1979	Avg. 1973-79
Ortho-P	0.005	0.014	0.013	0.016	0.013	0.019	0.045	0.018
Total P	0.049	0.049	0.058	0.055	0.063	0.067	0.097	0.063
Inorganic N	0.08	0.16	0.16	0.22	0.13	0.13	0.26	0.16
Organic N	1.55	1.29	1.44	1.81	1.53	1.63	1.74	1.57
Total N	1.63	1.45	1.60	2.01	1.64	1.77	2.02	1.73
Cond. (μmhos/cm)	574	570	594	621	617	614	545	589
Cl	85.6	79.1	87.4	90.5	98.0	91.8	83.0	87.4
Na	55.0	49.2	57.8	61.7	67.4	-	-	56.3
K	4.1	4.0	4.8	5.1	4.6	-	-	4.4
Ca	46.6	43.0	44.6	46.9	43.5	-	-	45.1
Mg	17.3	15.1	17.6	18.6	19.9	-	-	17.3
Hardness ($CaCO_3$)	187	169	184	194	190	-	-	184
SO_4	50.2	52.3	54.9	58.4	60.1	-	-	54.6
SiO_2	4.8	5.5	6.6	8.4	12.0	-	-	6.5
Alkalinity (meq/l)	2.7	2.5	2.6	2.7	2.5	2.3	1.9	2.5
Total Fe	0.22	0.47	0.52	0.56	0.22	0.26	0.53	0.44
Dissolved oxygen	8.2	8.2	8.4	8.8	8.9	8.7	8.8	8.6
Turbidity (JTU)	11.7	19.8	26.6	25.7	15.5	9.1	13.9	18.0
Color (Pt units)	-	55	47	46	38	35	40	43
Secchi Disc (M)	0.6	0.6	0.5	0.6	0.7	-	-	0.6
Cholorophyll *a* (μg/L)	-	24.0	27.0	26.1	-	-	-	25.7

1/ Units in mg/L unless otherwise noted.

TABLE 7-2 DUNCAN'S MULTIPLE RANGE TEST FOR MEAN ANNUAL CHLORIDE, SODIUM, CALCIUM, AND ALKALINITY CONCENTRATIONS 1/

Chloride (mg/l)

1973 2/	1974	1975	1976	1977	1978	1979
85.6	79.0	87.2	90.6	98.2	91.6	83.3
	A					
B		B				B
		C	C		C	
			D		D	
				E		

Sodium (mg/l)

1973	1974	1975	1976	1977	1978	1979
55.0	49.4	57.9	61.6	66.9	ND 3/	ND 3/
	A					
B						
		C				
			D			
				E		

Calcium (mg/l)

1973	1974	1975	1976	1977	1978	1979
46.5	43.1	44.7	46.9	42.2	43.4	ND 3/
	A	A		A	A	
B		B			B	
C			C			

Alkalinity (meq/l)

1973	1974	1975	1976	1977	1978	1979
2.68	2.47	2.59	2.70	2.55	2.29	1.95
						A
					B	
	C	C		C		
D		D	D			

1/ Means with the same letter are not significantly different (α= .05)

2/ Annual means from April of the year indicated through March of the following year.

3/ ND = no data collected

TABLE 7-3 DUNCAN'S MULTIPLE RANGE TEST FOR MEAN ANNUAL DISSOLVED OXYGEN, TURBIDITY, AND SPECIFIC CONDUCTANCE LEVELS [1]

Dissolved Oxygen (mg/l)

1973[2]	1974	1975	1976	1977	1978	1979
8.2	8.2	8.4	9.2	9.0	8.8	8.8
A	A	A				
		B			B	B
			C	C	C	C

Turbidity (JTU)

1973	1974	1975	1976	1977	1978	1979
11.7	19.9	26.6	25.8	16.4	9.1	14.1
A					A	
B				B		B
	C			C		
		D	D			

Specific Conductance (μmhos/cm)

1973	1974	1975	1976	1977	1978	1979
589	570	595	621	615	615	545
	A					A
B	B	B				
C		C	C	C	C	

[1] Means with the same letter are not significantly different ($\alpha = .05$)

[2] Annual means from April of the year indicated through March of the following year

were high (averaging 56.3 and 45.1 mg/L, respectively) and equally dominated the cation composition (39.2 and 36.0%, respectively). The anion composition was dominated equally by chloride and alkalinity (40.3 and 40.2%, respectively, Table 7-4) which were also present in relatively high levels (mean Cl =87.4 mg/L and alkalinity = 2.5 meq/L). In addition, the high specific conductance measured in the lake (averaging 589 μmhos/cm) is indicative of high dissolved solids levels.

Color did not display any consistent seasonal pattern although the actual levels displayed a three-fold range between 20 and 60 Pt units. The mean color level of 42.6 Pt units is moderately high for a lake system. No consistent changes in the mean annual color levels were apparent from 1973 to 1979.

Turbidity was low but varied seasonally throughout the study period. Turbidity during the calmer summer months was very low, usually ranging from 1 to 5 JTU. The higher turbidities (20-60 JTU) were recorded during the winter. Davis and Marshall (1975) previously identified turbidity (as measured by Secchi disc) as a variable which was positively correlated with seasonal nutrient fluctuations. Turbidity, in turn, was stated to be primarily dependent upon wintertime wind stress which effectively mixes the entire water column and causes a resuspension of sediment material. The relationship between turbidity and nutrient levels was analyzed in this study by use of correlation analysis. There was a relatively high degree of association ($r = 0.61$) between the $\log_{10}$ transformation of turbidity and inorganic nitrogen. There were also significant, though much lower, correlations between turbidity and total phosphorus ($r = 0.38$), ortho phosphorus ($r = 0.26$) and total nitrogen ($r = 0.26$). Turbidity, therefore, appears to more selectively affect inorganic nitrogen levels rather than

TABLE 7-4 AVERAGE* ANION-CATION BALANCE FOR LIMNETIC ZONE OF LAKE OKEECHOBEE

Mean Concentration* (meq/L)

Anions			Cations		
Chloride	2.46	40.3%	Sodium	2.45	39.2%
Alkalinity	2.45	40.2%	Calcium	2.25	36.0%
Sulfate	1.14	18.7%	Magnesium	1.42	22.7%
	6.1		Potassium	0.11	1.8%
			Total Iron	0.02	0.3%
				6.25	

percent error: 1.2%

* Average of time period April 1973 through March 1980

phosphorus or total nitrogen. This supports Messer et al. (1979) and Brezonik et al. (1979) who reported that wind driven sediment resuspension in Lake Okeechobee resulted in greater releases of nitrate into the water column than phosphorus. Wind induced turbidity can thus affect the sediment/water nutrient exchange relationships and at least temporarily affect the ambient inorganic nitrogen levels.

There were no consistent increasing or decreasing trends in the mean annual turbidity levels from 1973 to 1979, although there were significant annual variations (Table 7-3). The highest mean annual turbidity levels occurred in 1975 and 1976 (26.6 and 25.8 JTU, respectively), while the lowest turbidity levels occurred in 1973 and 1978 (11.7 and 9.1 JTU, respectively).

Lakewide daytime limnetic dissolved oxygen concentrations were high, relative to the 5.0 mg/L minimum set forth in the Florida Administrative Code Chapter 17-3 Water Quality Standards, being consistently above 6 mg/L. Oxygen saturation varied widely, ranging from 30 to 200 percent. The lowest concentrations usually occurred in the summer (Figure 7-3). Several factors which could account for these summertime lows include temperature (decreased O_2 solubility at higher temperatures), lower photosynthetic activity due to intense light inhibition (Marshall, 1977) and increased sediment oxygen demand. Significant differences in annual concentrations were noted (Table 7-3) with the highest average concentrations occurring in 1976 (9.2 mg/L) and the lowest average concentration occurring in 1973 and 1974 (8.2 mg/L). The average dissolved oxygen concentration over the entire study period was 8.6 mg/L with an average saturation of 100 percent.

Inorganic phosphorus and nitrogen concentrations in the lake's limnetic zone varied seasonally and displayed significant annual trends. The typical seasonal inorganic nutrient cycle displayed minimum values in the summer, an increase in concentrations in the fall, maximum values in the winter,and a decrease in concentrations in the spring (Figure 7-5). This pattern has become better defined since 1976. The clarity of this pattern varied between the eight stations (Figure 7-6 and 7-7). Stations 4 and 8, the most centrally located stations furthest from tributary influences, displayed the most well defined seasonal pattern. Assuming this seasonal pattern continues, the high limnetic ortho phosphorus and inorganic nitrogen concentrations measured at the end of this study in March 1980 should decline during the spring of 1980. Seasonal variations in ortho phosphorus resulted in parallel, although less pronounced, variations in total phosphorus (Figure 7-5). The seasonal variations in inorganic nitrogen, however, did not consistently produce parallel variations in the total nitrogen (Figure 7-5).

Significant changes were detected in the mean annual phosphorus and nitrogen concentrations. Statistically significant increases were evident in the mean annual ortho phosphorus concentrations from 1973 to 1974 (0.005 to 0.014 mg/L) and more recently from 1978 to 1979 (0.018 to 0.045 mg/L) (Table 7-5). The average concentration during the intervening years (1974 to 1978) remained relatively constant. The recent increases in 1978 and 1979 were primarily the result of both higher seasonal maximums and minimums. The increases in the ortho phosphorus concentrations resulted in significant changes in total phosphorus. The increase in the annual total phosphorus concentrations from 1973 (0.048 mg/L) to 1978 (0.065 mg/L) was more gradual than the increase in ortho phosphorus, although the most significant increase

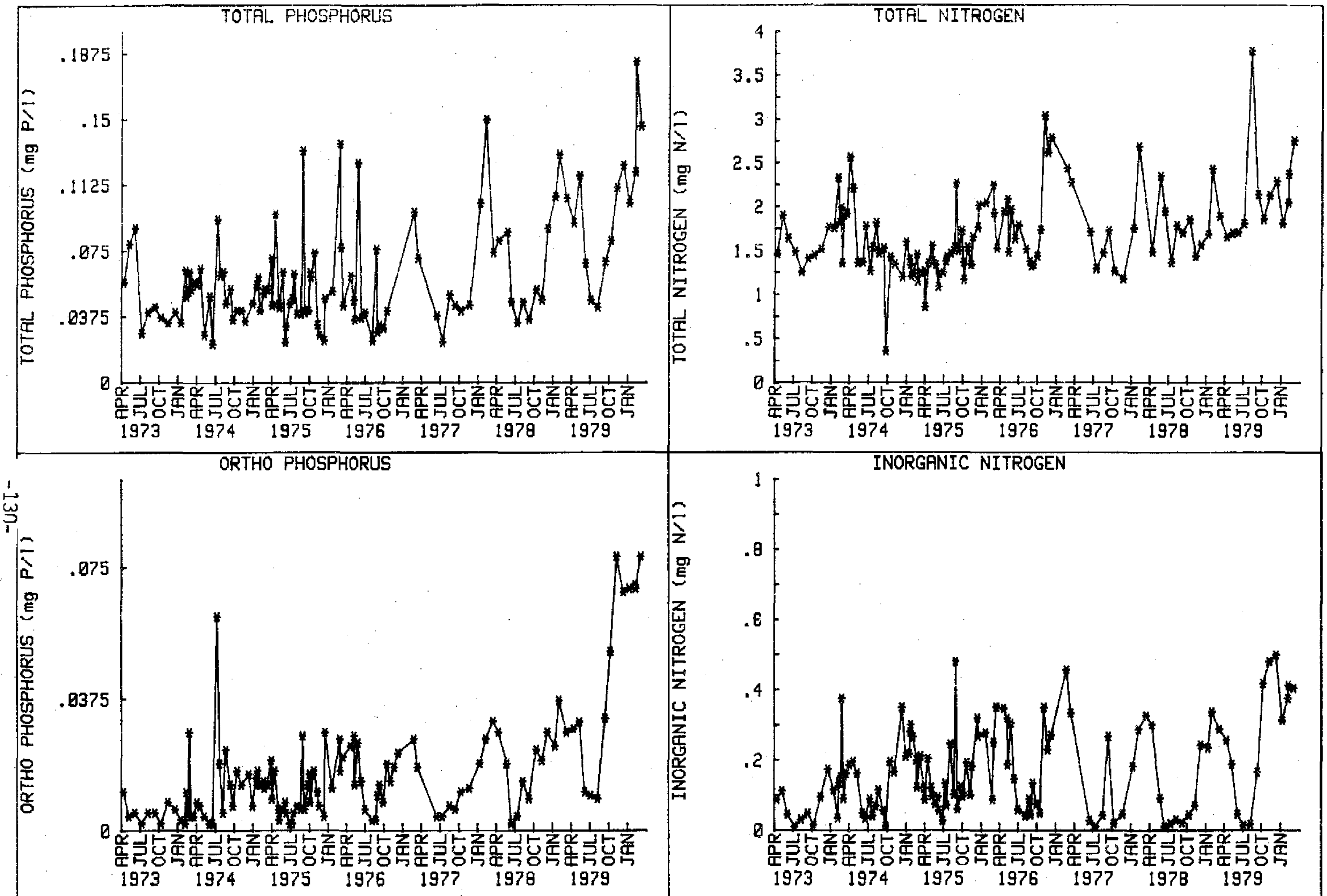


FIGURE 7-5. MEAN DAILY PHOSPHORUS AND NITROGEN CONCENTRATIONS IN LAKE OKEECHOBEE

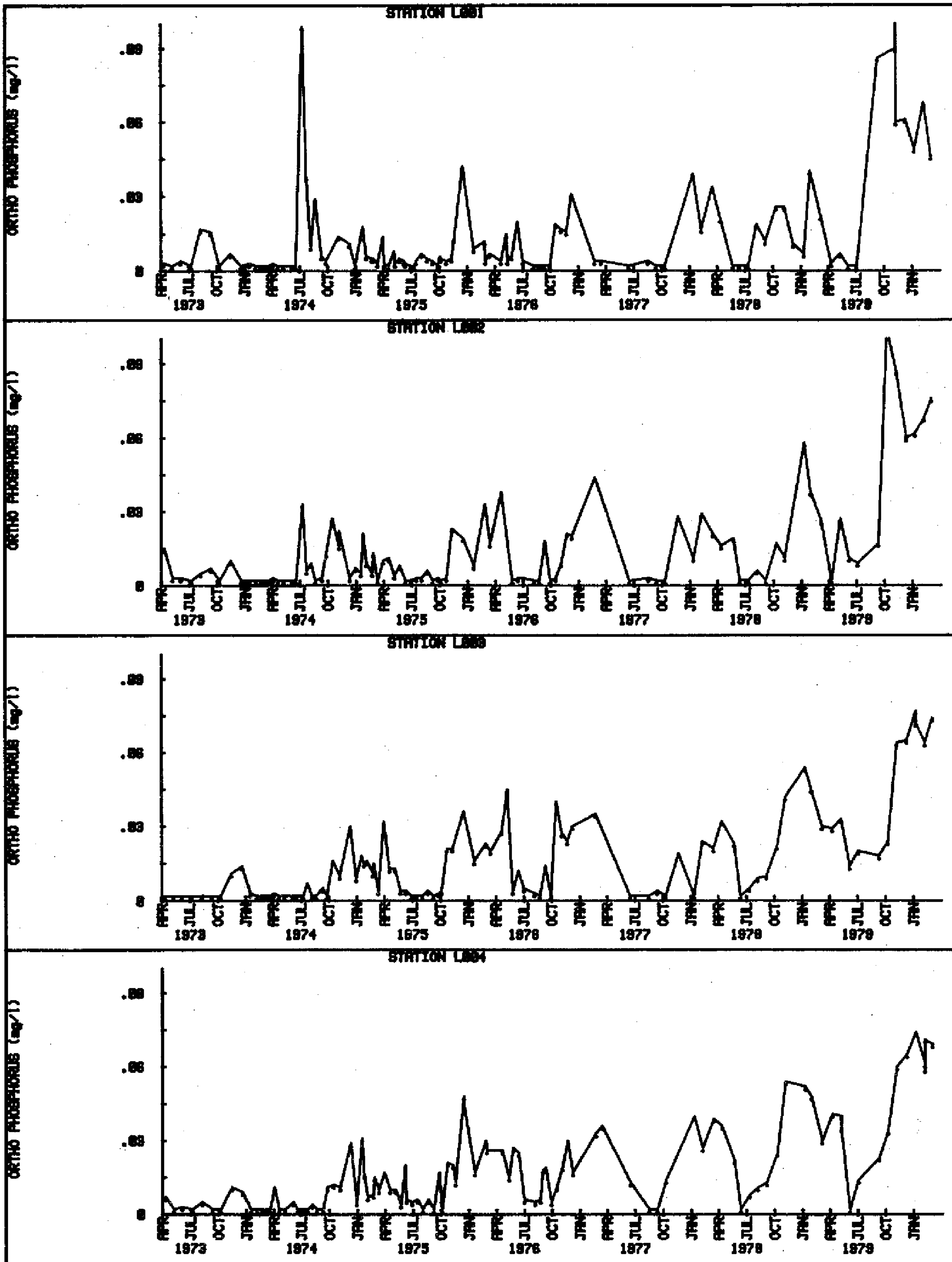


FIGURE 7-6. ORTHO PHOSPHORUS VS TIME AT THE 8 BASELINE STATIONS

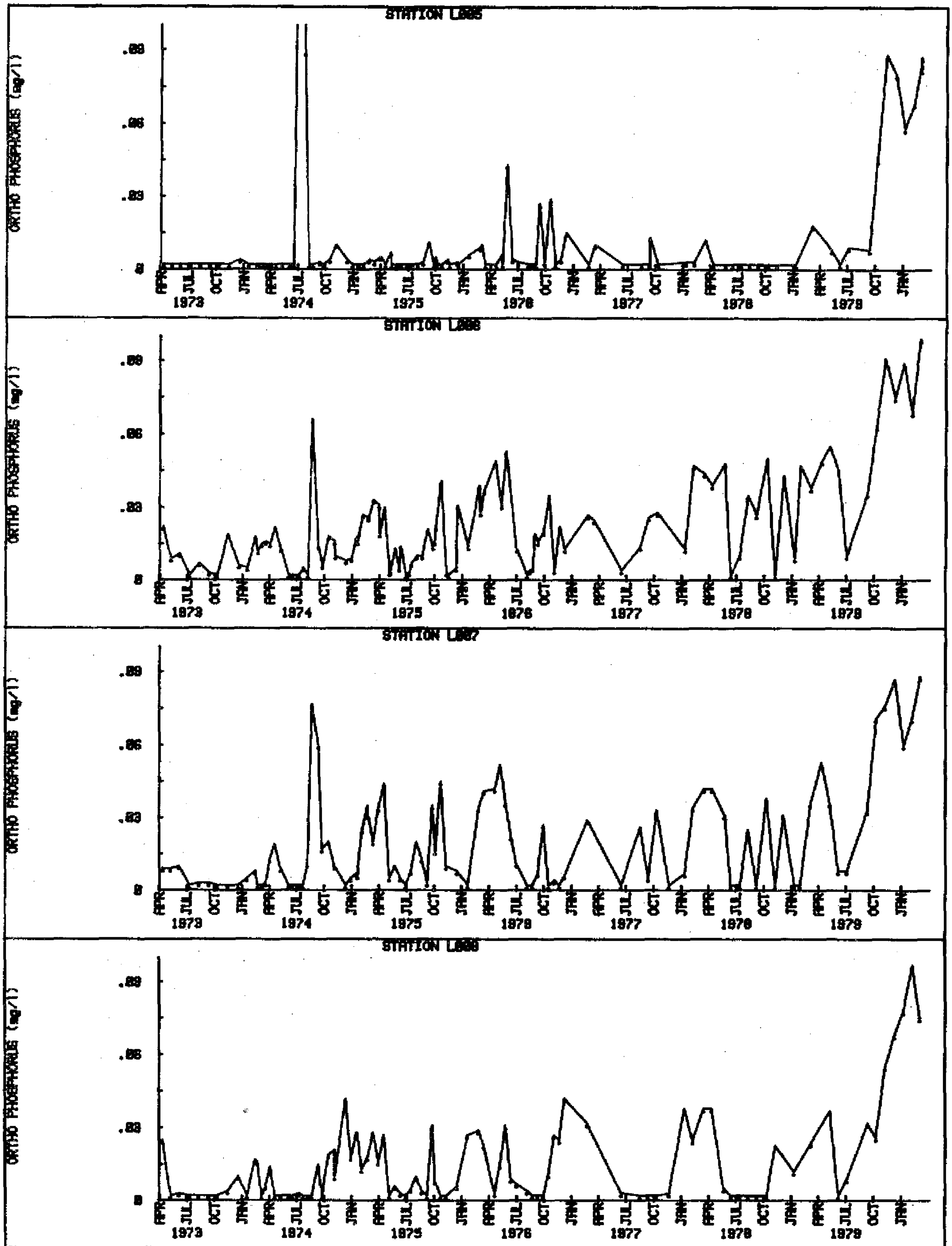


FIGURE 7-6. CONTINUED

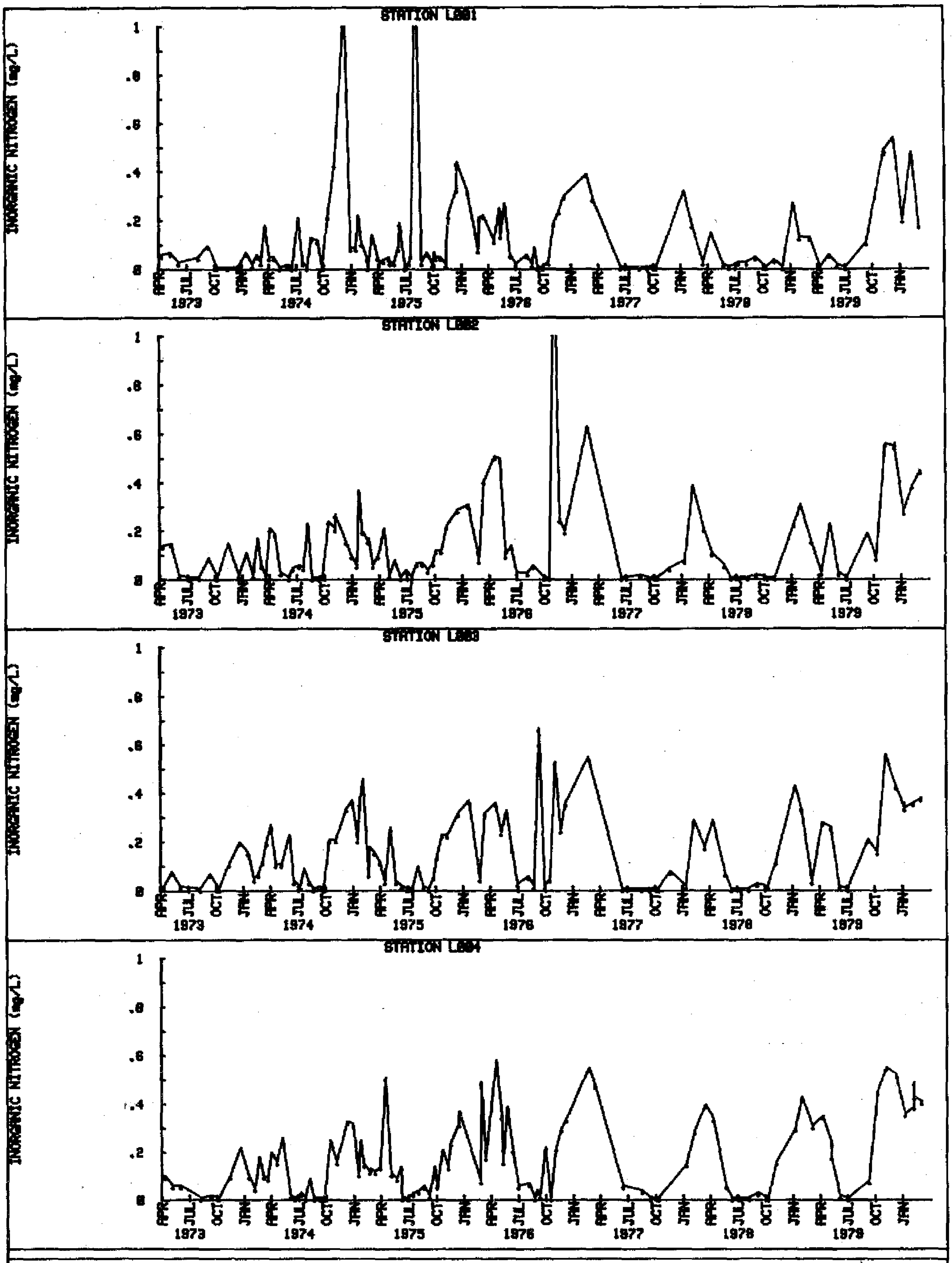


FIGURE 7-7. INORGANIC NITROGEN VS TIME AT THE 8 BASELINE STATIONS

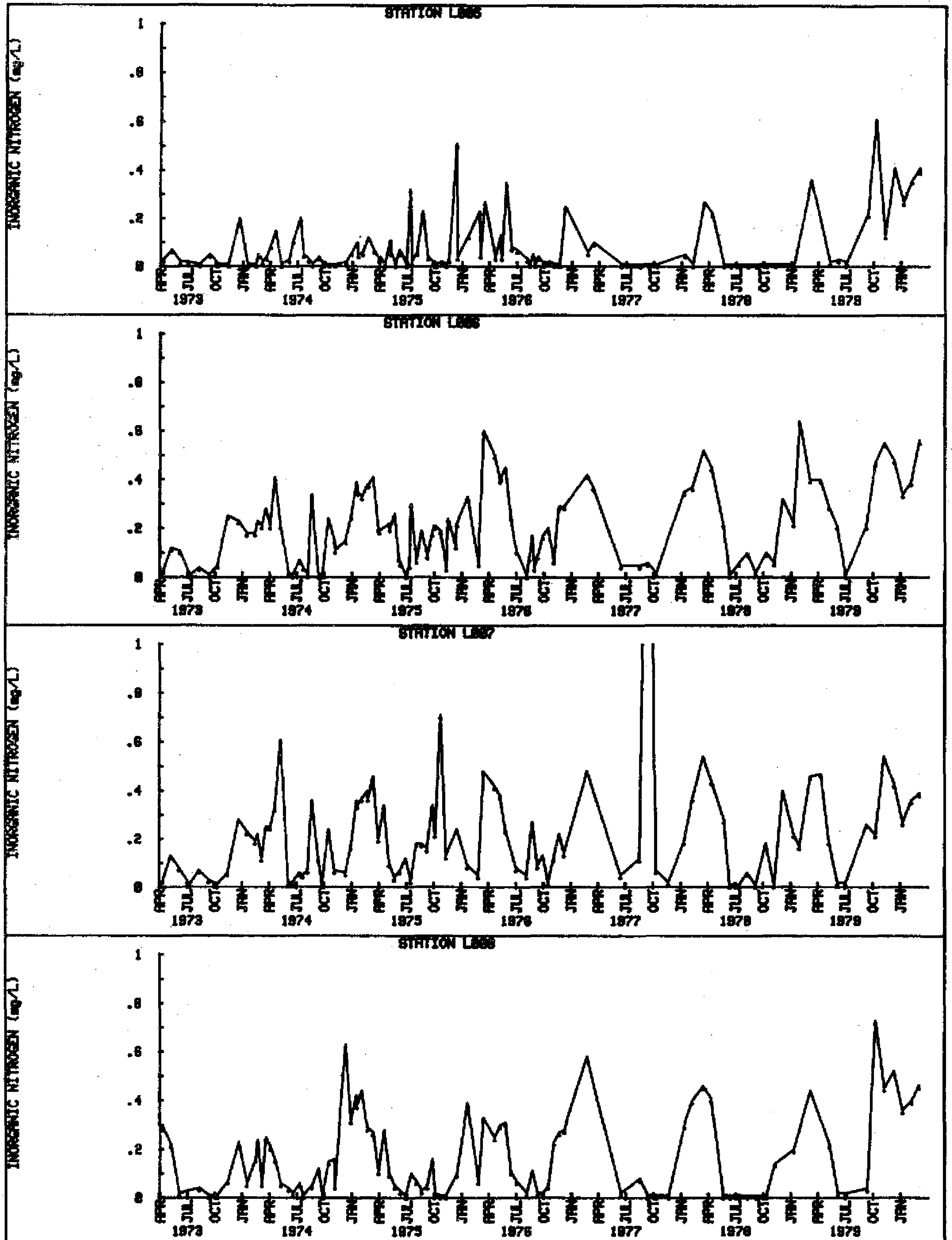


FIGURE 7-7. CONTINUED

TABLE 7-5. DUNCAN'S MULTIPLE RANGE TEST FOR MEAN ANNUAL PHOSPHORUS AND NITROGEN CONCENTRATIONS [1]

Ortho Phosphorus (mg P/l)

1973[2]	1974	1975	1976	1977	1978	1979
.005	.014	.013	.017	.014	.018	.045
A						
	B	B	B	B	B	
						C

Total Phosphorus (mg P/l)

1973	1974	1975	1976	1977	1978	1979
.048	.049	.059	.055	.066	.065	.097
A	A	A	A			
		B	B	B	B	
						C

Inorganic Nitrogen (mg N/l)

1973	1974	1975	1976	1977	1978	1979
.09	.16	.16	.22	.15	.12	.26
A					A	
	B	B		B	B	
			C			C

Organic Nitrogen (mg N/l)

1973	1974	1975	1976	1977	1978	1979
1.56	1.29	1.43	1.81	1.54	1.66	1.75
	A					
B		B		B		
C				C	C	
					D	D
			E			E

Total Nitrogen (mg N/l)

1973	1974	1975	1976	1977	1978	1979
1.63	1.45	1.59	2.02	1.67	1.76	2.03
	A	A				
B		B		B		
C				C	C	
			D			D

1/ Means with the same letter are not significantly different ($\alpha = .05$)

2/ Annual means from April of the year indicated through March of the following year.

again occurred recently from 1978 (0.065 mg/L) to 1979 (0.097 mg/L) (Table 7-5). There have been no significant decreases in the mean annual ortho and total phosphorus concentrations from 1973 to 1979. Concurrent with the increase in phosphorus concentrations was an overall increase in the proportion of ortho to total phosphorus from 19 percent in 1973 to 46 percent in 1979.

The trend in the mean annual inorganic, organic, and total nitrogen concentrations did not parallel the phosphorus trend since both significant increases and decreases occurred from 1973 to 1979 (Table 7-5). The highest average concentrations occurred in 1976 and 1979 for these nitrogen components. The lowest average concentrations occurred in 1973 and 1978 for inorganic nitrogen, in 1974 for organic nitrogen, and in 1974 and 1975 for total nitrogen. These mean annual nitrogen and phosphorus concentrations were sufficiently high so as to indicate that growth rate limitation due to a limitation in the rate of nitrogen and phosphorus assimilation by phytoplankton, was probably an infrequent event.

The causitive mechanism responsible for the seasonal variations and annual changes in the inorganic nutrient levels is probably a complex association between many factors, including phytoplankton dynamics, littoral zone dynamics, external nutrient inputs, internal nutrient cycling, and hydraulic loading characteristics. Although elucidation of this mechanism is beyond the scope of this study, seasonal and annual comparisons between the limnetic nutrient variations and the input characteristics can be useful in indicating the relative importance of some of the inflows and morphometric characteristics on limentic nutrient levels.

Specifically, monthly variations in limnetic ortho phosphorus and inorganic nitrogen concentrations were compared to monthly variations in the lake's morphometric characteristics (lake stage, mean depth, volume, and surface area) and inflow characteristics (total monthly inflow, total monthly inorganic nutrient loads, monthly flow weighted inorganic nutrient concentrations). Graphical comparisons between these characteristics and limnetic ortho phosphorus and inorganic nitrogen levels (Figures 7-8 - 7-11) suggest that the limnetic ortho phosphorus concentrations fluctuate in parallel with the lake stage, mean depth, volume, and prior to 1978, with the surface area. Variations in the inorganic nitrogen concentration did not appear to be closely related to variations in the monthly morphometric characteristics. These relationships were quantified using linear, logarithmic exponential, and 2° polynomial regression analysis. Since the 2° polynomial regressions produced the highest correlations. only the polynomial relationships are reported (Table 7-6). The highest correlation ($r = 0.75$) was between ortho phosphorus and mean depth. Additional significant correlations were also obtained between ortho phosphorus and lake stage, volume and surface area due to the mutual interdependency between the morphometric parameters.

The relationship between the monthly limnetic ortho phosphorus levels and the inflow characteristics were not as well defined. It appears from Figure 7-11 that there may be some degree of association between the input loads of ortho phosphorus and the ortho phosphorus levels in the limnetic zone if an approximate three month lag in the response time is assumed. This would be similar to the response time between the monthly inflow and the lake stage (compare Figure 7-10 and 7-11).

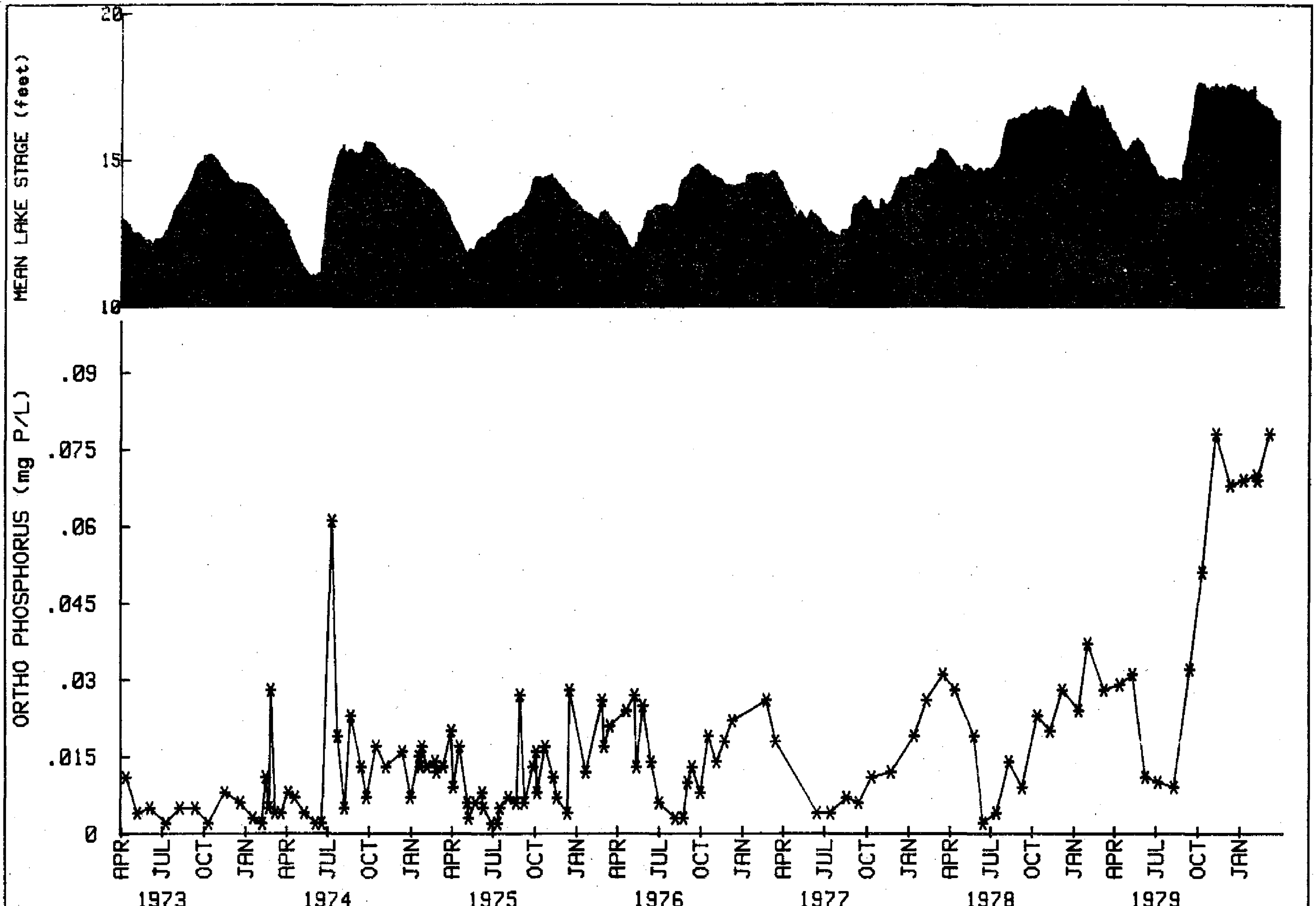


FIGURE 7-8. LIMNETIC ORTHO PHOSPHORUS CONCENTRATIONS AND DAILY STAGE IN LAKE OKEECHOBEE

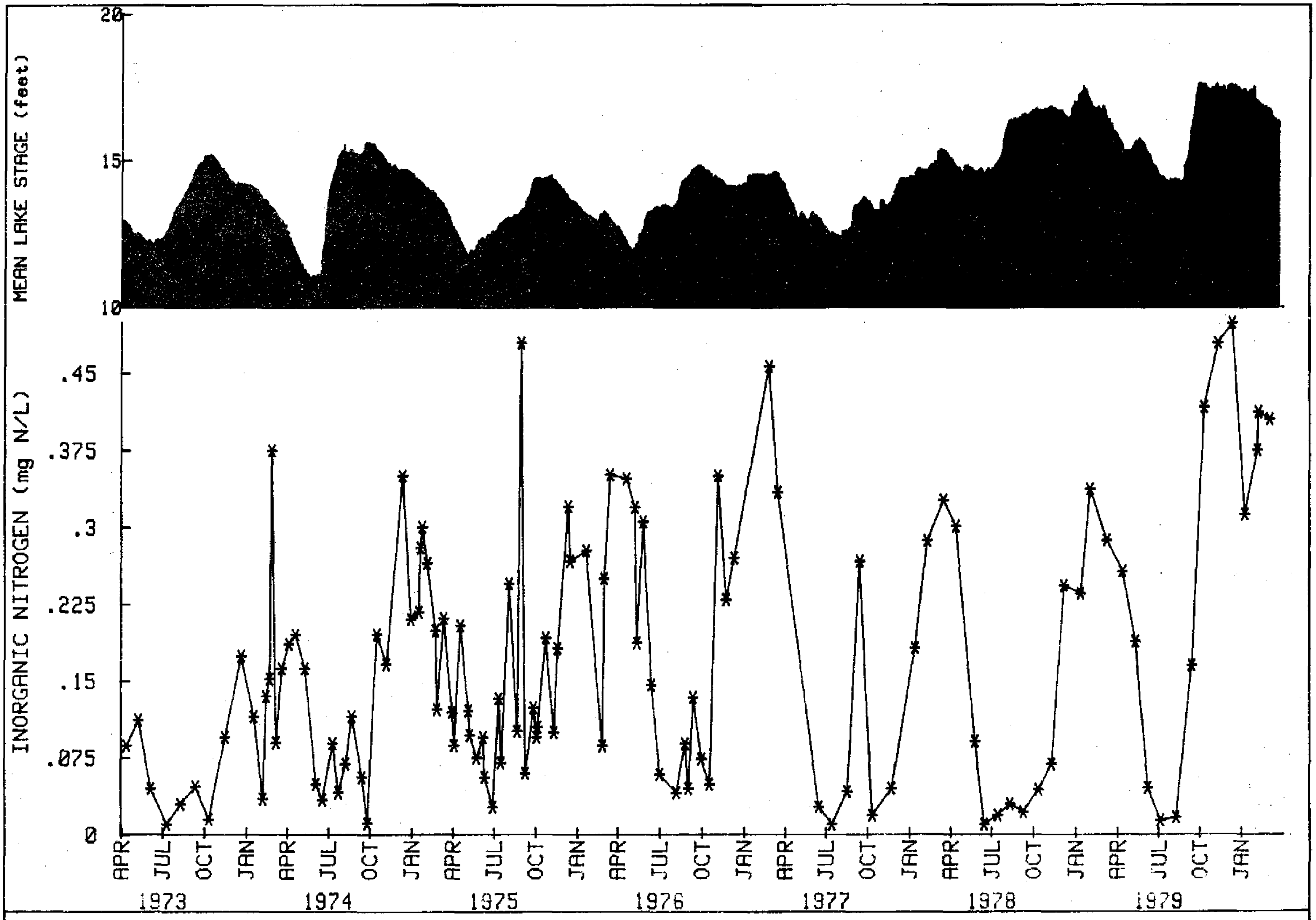


FIGURE 7-9. LIMNETIC INORGANIC NITROGEN CONCENTRATIONS AND DAILY STAGE IN LAKE OKEECHOBEE

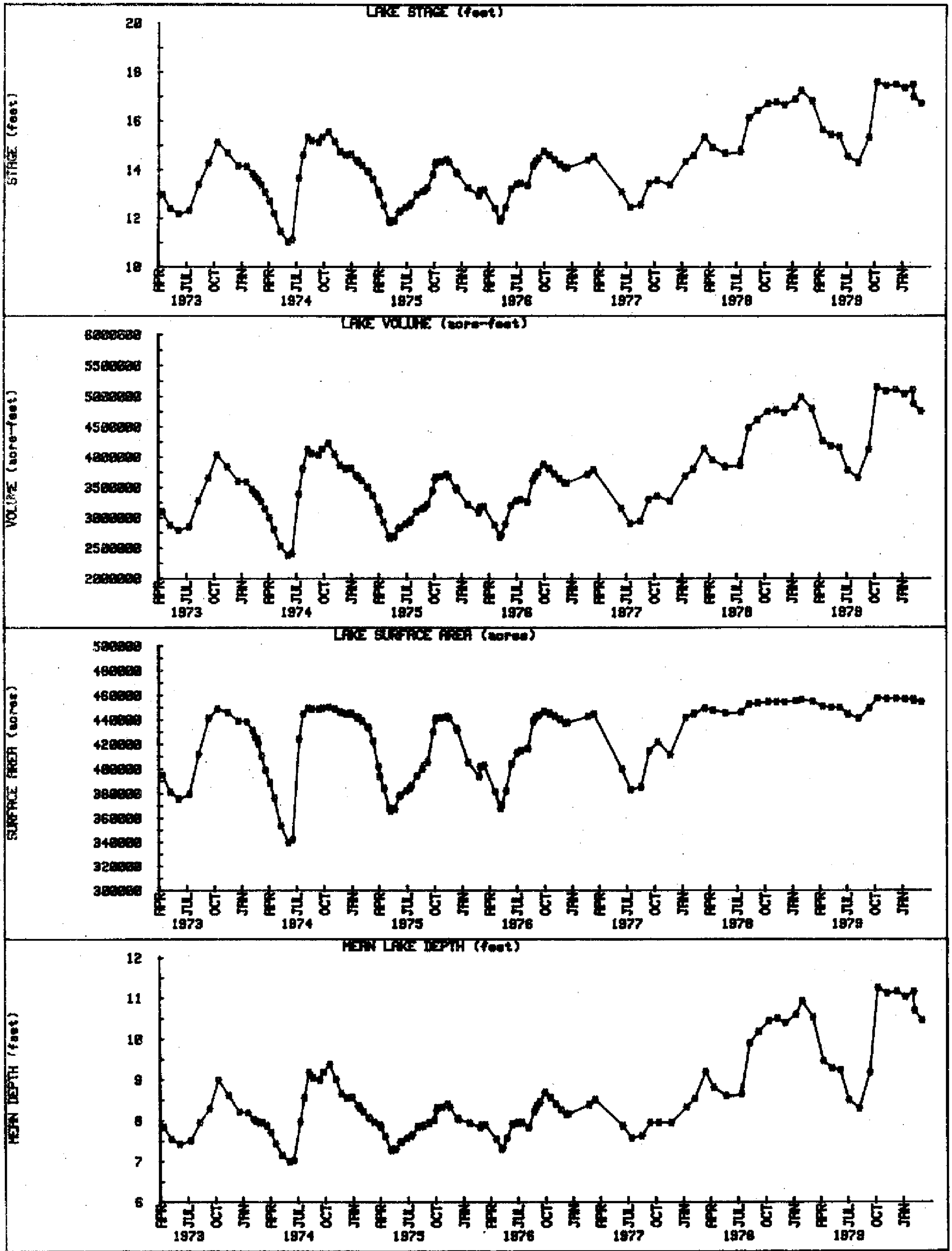


FIGURE 7-10 STAGE, VOLUME, MEAN DEPTH, AND AREA FOR LAKE OKEECHOBEE

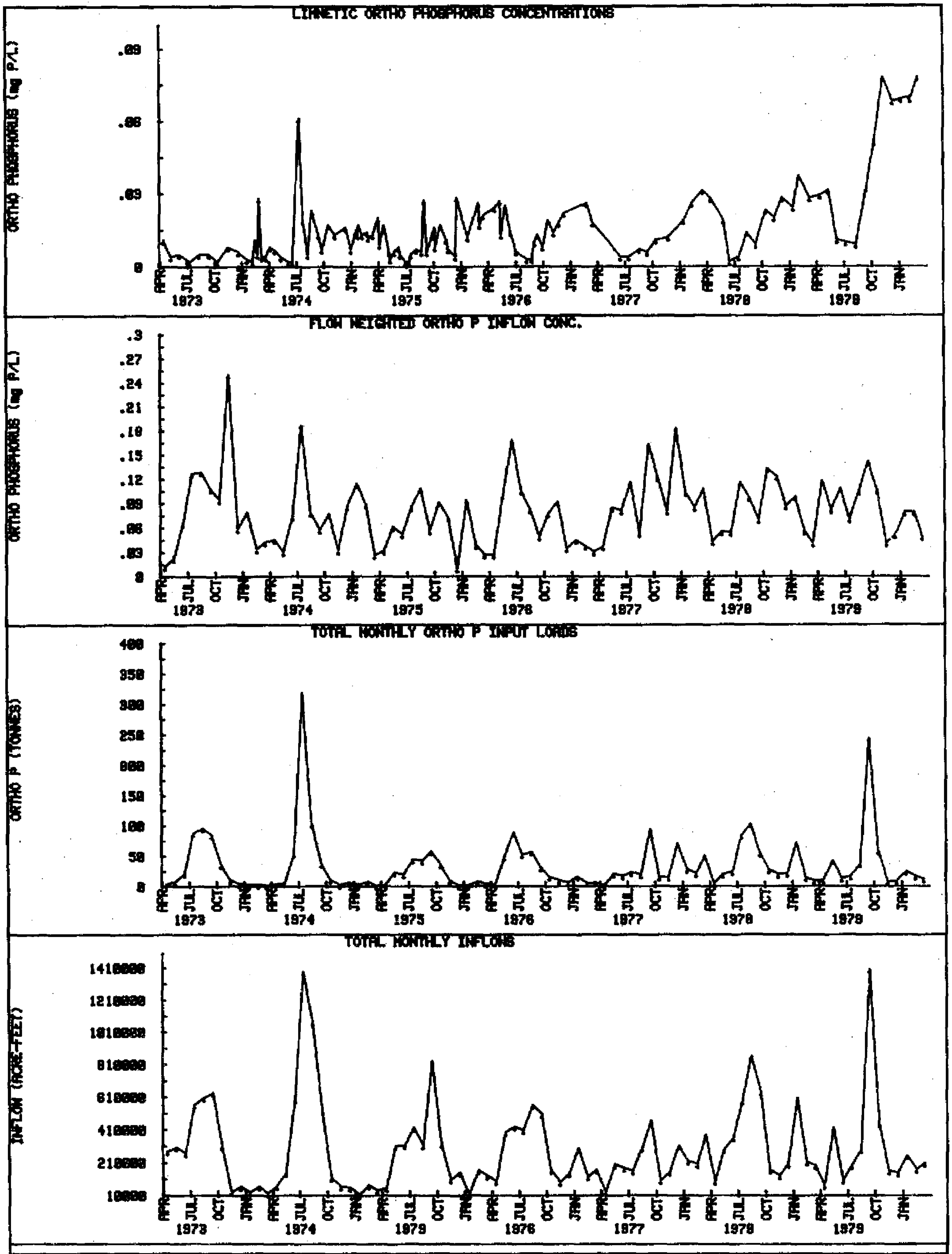


FIGURE 7-11. AMBIENT ORTHO P CONCENTRATIONS AND INFLOW PARAMETERS

TABLE 7-6. CORRELATIONS* BETWEEN LIMNETIC INORGANIC NUTRIENT CONCENTRATIONS AND LAKE MORPHOMETRIC AND INFLOW CHARACTERISTICS

	Ortho P		Inorganic N	
	r	r^2	r	r^2
Stage*	0.69	0.48	0.40	0.16
Mean depth	0.75	0.56	0.40	0.16
Volume	0.63	0.40	0.40	0.16
Surface area	0.53	0.28	0.33	0.11
Total monthly inflow	0	0	0.35	0.12
Total monthly inorganic nutrient load	0	0	0.32	0.10
Flow weighted inorganic nutrient conc.	0	0	0.048	0.23

* 2° polynomial

** monthly values

Factors which can affect the response time include withdrawal demands, evaporation, the operational regulation schedule, and the lake morphometry; however, since the limnetic ortho phosphorus concentrations appear to more closely parallel the mean depth, lake volume, and surface area than the inorganic phosphorus input loads, a seasonal internal nutrient cycling process is suggested. The seasonal increase in the lake stage (or mean depth) results in a seasonal flooding of the lake's large littoral zone along the western shoreline (125,000 acres or about 25% of the lake's surface area). In the fall, there is some dieback and subsequent decomposition of the littoral zone vegetation which releases nutrients (Brezonik et al. 1979). According to Brezonik et al. (1979), maximum macrophyte growth occurs in the summer (May to August). At the end of the growing season in the fall, most macrophytes senesce, collapse to the sediment and begin to decompose. This decomposition releases proportionally more phosphorus than nitrogen (Brezonik et al. 1979). It is hypothesized that the fall/winter flooding of the littoral zone (as evidenced by increased lake surface area (Figure 7-10) facilitates the transport of these nutrients into the lake's limnetic zone. This would correspond to the fall/winter peak in inorganic phosphorus and nitrogen levels.

Monthly limnetic inorganic nitrogen concentrations were not well correlated to either the lake stage, mean depth, lake volume or the surface area (Figure 7-12 and Table 7-6). There was some degree of association between the total monthly inorganic nitrogen load and the limnetic inorganic nitrogen concentration assuming a three month lag as was the case with phosphorus. Wintertime release of nitrogen from the sediments as a result of wind sediment resuspension was previously discussed

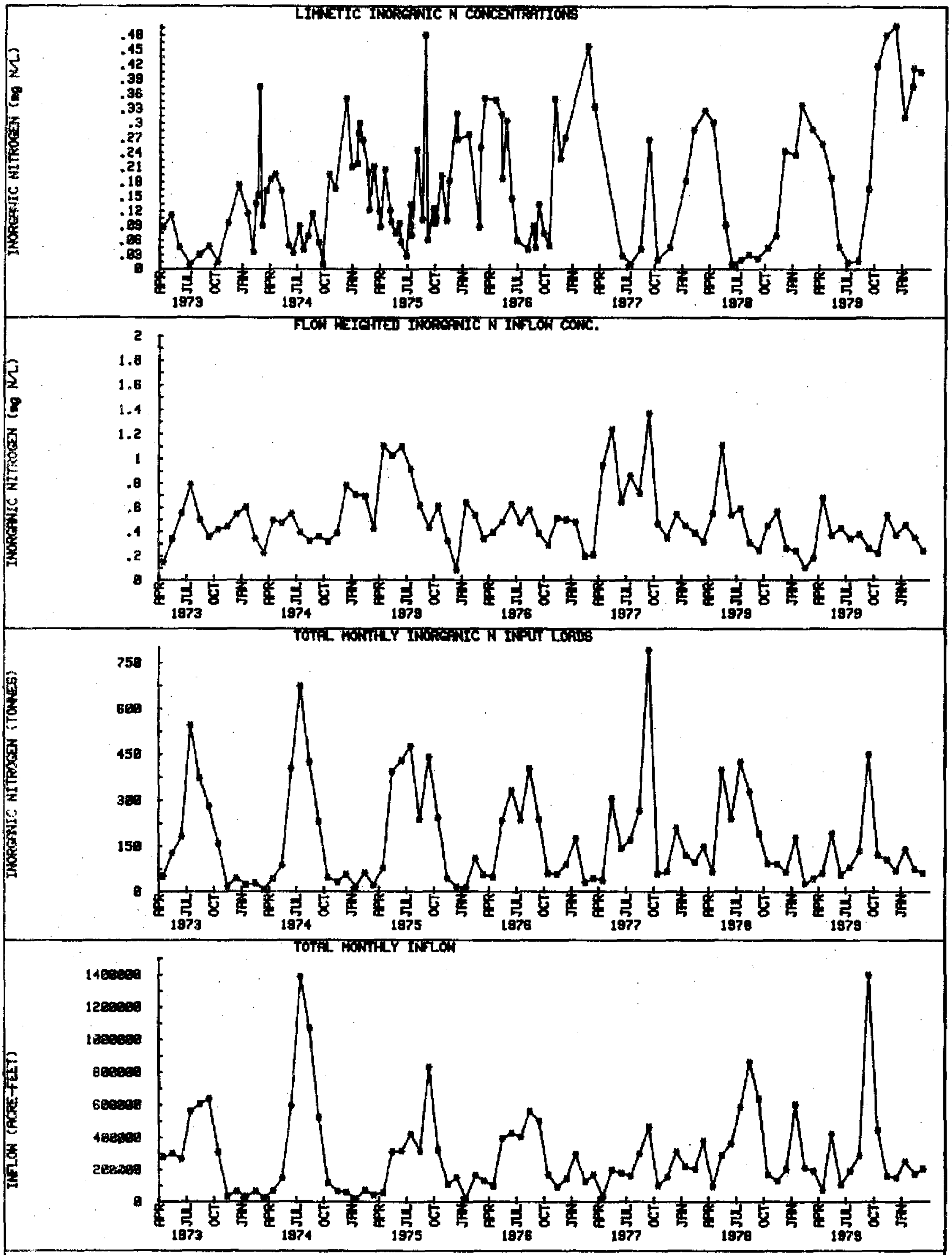


FIGURE 7-12. AMBIENT INORGANIC N AND INFLOW CHARACTERISTICS

as a mechanism which also may partially account for the winter increase in inorganic nitrogen.

Comparisons between annual limnetic ortho phosphorus and inorganic nitrogen concentrations and the annual morphometric and inflow characteristics are presented in Table 7-7. These comparisons support the association between limnetic ortho phosphorus levels and mean depth, lake stage, lake volume, and surface area. A sharp increase in these morphometric characteristics in 1978 and 1979 corresponded to a large increase in the limnetic ortho phosphorus concentrations. There also appears to be an association between the annual ortho phosphorus loads to the lake and the limnetic ortho phosphorus concentrations. Specifically, the three years which experienced an above average ortho phosphorus load (1974, 1978, and 1979) corresponded to the three largest increases in the annual limnetic ortho phosphorus concentrations.

There is, however, some lack of sensitivity in this relationship between ortho phosphorus loads and the limnetic concentrations. For example, a decrease in the limnetic concentration from 1976 to 1977 occurred when there was an increase in the annual load. In addition, although the highest annual ortho phosphorus load to the lake occurred in 1974 (580×10^6 g P), three other years (1976, 1978 and 1979) had higher limnetic ortho phosphorus concentrations and lower ortho phosphorus loads. Although the lake appears somewhat responsive to external nutrient inputs, these inputs cannot solely account for the recent increase (1978 and 1979) in the limnetic ortho phosphorus concentrations. Therefore, significant internal loads may have occurred in 1978 and 1979.

These recent increases may have been a result of the implementation of the 17.5' regulation schedule. Implementation of this higher schedule,

TABLE 7-7. COMPARISON OF LIMNETIC NUTRIENT CONCENTRATIONS AND HYDROLOGIC CHARACTERISTICS

	Mean Annual Limnetic Conc. mg/L		Flow-weighted Inflow Conc. mg/L		Total Annual Load 10^6g		Total Annual Inflow	Mean Annual Lk/Stg.	Annual Mean Depth	Ann. Mean Surf. Area	Annual Lake Vol.
	Ortho P	Inorg.N	Ortho P	Inorg.N	Ortho P	Inorg.N	A/Ft.	Ft/MSL	Ft.	Acres	A/Ft.
1973	.005	.08	.093	.47	369	1,848	3,220,252	13.6	8.07	416,364	3,365,000
1974	.014	.16	.113	.42	580	2,149	4,176,904	13.9	8.33	420,811	3,504,000
1975	.013	.16	.074	.75	259	2,604	2,824,883	13.2	7.87	404,503	3,185,000
1976	.016	.22	.086	.51	350	2,077	3,299,670	13.8	8.14	424,765	3,462,000
1977	.013	.13	.113	.75	378	2,461	2,647,930	13.7	8.10	417,599	3,389,000
1978	.019	.13	.093	.41	478	2,106	4,151,277	16.0	9.81	451,699	4,429,000
1979	.045	.26	.113	.35	562	1,734	4,033,791	16.5	9.94	451,699	4,495,000
Avg. 1973-79	.018	.16	.100	.50	425	2,140	3,479,244	14.4	8.66	426,742	3,690,000

coupled with sufficient rainfall in the lake's drainage basins, permitted the lake to exceed a stage of 16.5' MSL from October to April during both 1978 and 1979. These higher lake stages may have provided two possible pathways for increased internal phosphorus cycling. The first involves an extension of the mechanism proposed for the seasonal transport of nutrients from the littoral zone. The mean depth and surface area graphs displayed in Figure 7-8 indicates that there was a prolonged flooding of the littoral zone to a deeper depth in 1978 and 1979 than typically occurred prior to October 1978. This may have provided an opportunity for the transport of a larger quantity of nutrients from the littoral zone than would have normally occurred if the flooding cycle would have been of a shorter duration as was typical from 1973 to 1977. This mechanism would have had more impact in 1979 than in 1978 since the littoral zone was flooded to a deeper depth and for a longer period of time in 1979 than in 1978. If this mechanism is plausible, then it would be expected that the largest relative increase in ortho phosphorus concentration would have occurred at the station closest to the littoral zone. Ortho phosphorus data collected at station 5, located closest to the large western littoral zone tends to support this mechanism. Annual ortho phosphorus concentrations at station 5 increased ten-fold from 1978 to 1979 (0.004 to 0.041 mg/L), the largest increase for any of the limnetic stations (Table 7-8).

A second pathway for internal cycling involves the inundation of three of the agricultural islands located in the south end of the lake (Ritta, Kreamer, and Torry Islands). Ritta and Torry Islands have been intensively farmed for primarily sweet corn. Approximately 525 acres of Ritta Island have been farmed since the 1920's while 950 acres of Torry

TABLE 7-8. MEAN ANNUAL ORTHO PHOSPHORUS CONCENTRATIONS AT THE BASIC EIGHT STATIONS

	Mean Annual Ortho Phosphorus Conc. (mg/L)						
Station	1973	1974	1975	1976	1977	1978	1979
L001	0.005	0.014	0.008	0.009	0.013	0.016	0.038
L002	0.004	0.009	0.009	0.013	0.014	0.018	0.044
L003	0.004	0.009	0.011	0.019	0.011	0.025	0.041
L004	0.004	0.009	0.015	0.019	0.022	0.028	0.042
L005	0.002	0.023	0.004	0.009	0.005	0.004	0.041
L006	0.011	0.017	0.016	0.021	0.020	0.029	0.058
L007	0.004	0.019	0.018	0.017	0.018	0.018	0.050
L008	0.007	0.013	0.011	0.015	0.013	0.011	0.044

Island have been farmed since the 1940's. Since the topsoil of the islands is organic muck, the fertilizers applied during farming contained an abundance of phosphorus relative to nitrogen (4-20-20, Don Bottz, personal communication). After many years of fertilizer applications, muck soils lose their fixation capacity for phosphorus (CH_2M Hill, 1979) and, as a result, phosphorus in the soil profile becoms more mobile. When the lake exceeded 16.5' MSL in October 1978, farming was abandoned on the islands. With no active drainage facilities, these islands flooded from October to April in 1978 and 1979. This flooding could have extracted ortho phosphorus from the soil and subsequently transported it back into the limnetic zone. A similar increase in nitrogen would not be expected since fertilizer application of nitrogen was insignificant and since the mineralization of organic nitrogen in the muck soil would tend to decrease when the soil flooded. Saturated muck soils tend to become anaerobic which can slow the mineralization of soil nitrogen (Messer 1979).

This proposed mechanism for increased internal phosphorus cycling would also be expected to have been more effective in 1979 than in 1978 since both of the agricultural islands were flooded to a deeper depth for a longer period of time in 1979 than in 1978. Support for this mechanism is suggested by a comparison of the annual ortho phosphorus concentration at stations 6 and 7 located closest to the agricultural islands. These stations had the highest mean annual ortho phosphorus concentrations in 1979 relative to the other six limnetic stations. If flooding of the agricultural islands do provide a mechanism for increased ortho phosphorus concentrations, the increase may be transient. It would be expected that the quantity of phosphorus released from these agricultural islands would decrease during future flooding since the remaining quantity of extractable ortho phosphorus would decrease with each subsequent inundation.

There has been a significant decline (Table 7-9) in the annual inorganic nitrogen to inorganic phosphorus ratios (IN/IP). The mean annual IN/IP ratio decreased from 22.5 in 1973 to 6.1 in 1979. Gradual decreases were evident from 1973 (22.5) to 1976 (19.4) with significant decreases occurring more recently in 1978 and 1979 (8.6 and 6.1, respectively) (Table 7-9). The primary reason for the decline in the annual IN/IP ratio was an increase in ortho phosphorus concentrations, relative to inorganic nitrogen concentrations, from 1973 to 1979 (Table 5-5). Another factor may have involved implementation of the Interim Action Plan (IAP) for reduction of nutrient loads at S-2 and S-3 in May 1979. The IAP had the effect of reducing nitrogen loadings from the EAA, relative to the previous years (33% of seven year average) (Chapter V). These reduced nitrogen loadings (50% of which were in the inorganic form) would also tend to contribute to the lower IN/IP ratio in 1979.

An additional external factor which also needs to be considered in addressing the decline in the IN/IP ratio are the external nutrient loads. Figure 7-13 displays the IN/IP ratio in the combined inflows. The IN/IP ratios in the lake do not appear to be sensitive to relative short term annual changes in the IN/IP ratio in the inflows; however, the lake may be responding to a long term effect of receiving low IN/IP ratio inputs.

The decrease in the annual IN/IP ratio in Lake Okeechobee indicates at least a temporary shift from a system where maximum biomass yield is potentially limited by phosphorus to one which is potentially limited by nitrogen. This potential shift in limitation can become significant if

TABLE 7-9 DUNCAN'S MULTIPLE RANGE TEST FOR MEAN ANNUAL NITROGEN TO PHOSPHORUS RATIOS 1/

Inorganic Nitrogen to Ortho Phosphorus Ratio

1973 2/	1974	1975	1976	1977	1978	1979
22.5	20.7	19.4	19.4	15.6	8.6	6.1
					A	A
				B	B	
C	C	C	C	C		

Total Nitrogen to Total Phosphorus Ratio

1973	1974	1975	1976	1977	1978	1979
43.9	39.1	35.3	42.7	33.7	38.5	23.6
						A
	B	B		B	B	
C	C		C	C		

1/ Means with the same letter are not significantly different ($\alpha = .05$)

2/ Annual means from April of the year indicated through March of the following year

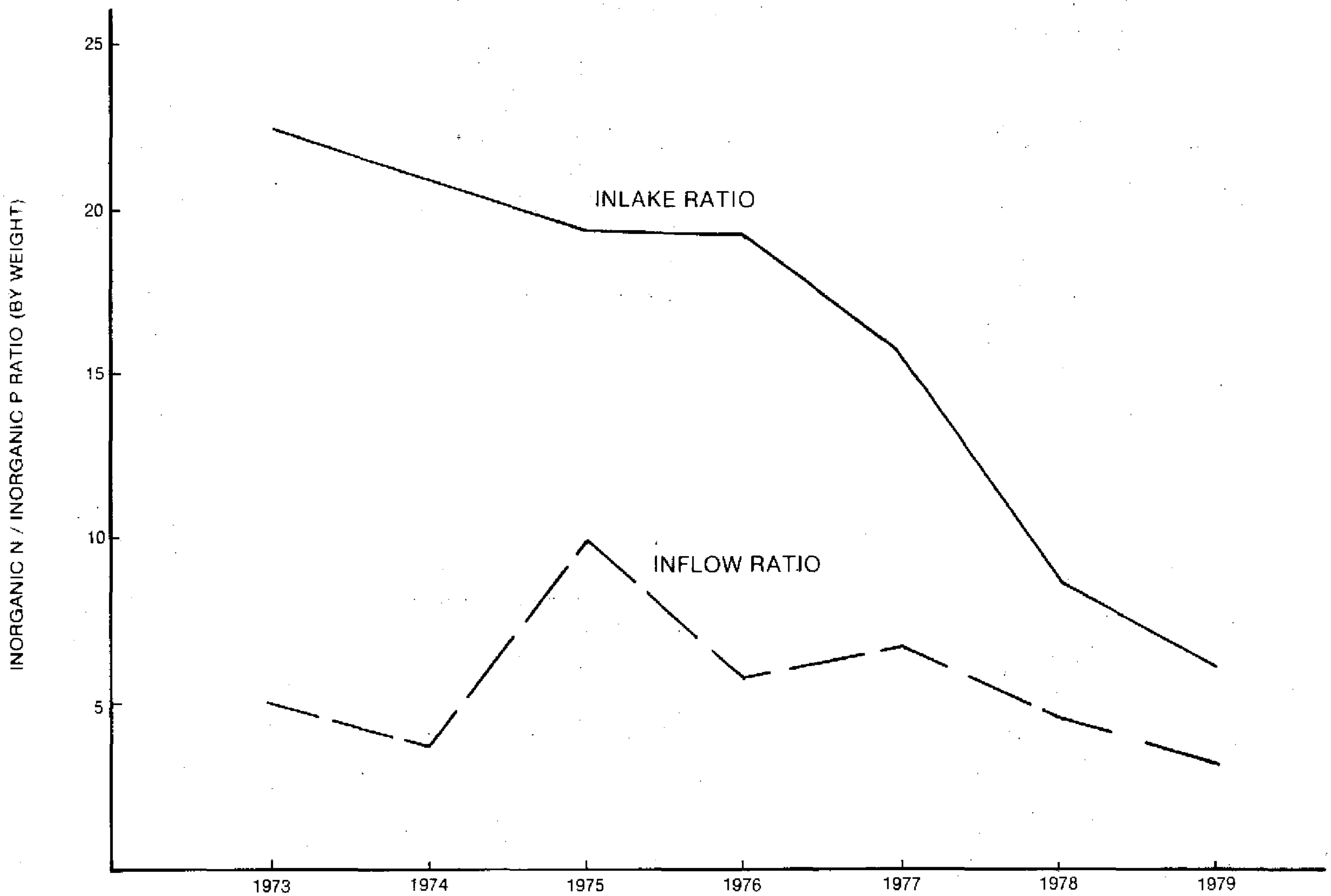


Figure 7-13 COMPARISON OF INFLOW AND INLAKE INORGANIC NITROGEN TO INORGANIC PHOSPHORUS RATIOS

the ambient levels of inorganic nutrients in the lake decline or if the other factors required for algal growth (i.e. macronutrients, light, temperature, etc.) are not limiting.

On a seasonal basis, the lower IN/IP ratios occurred in the summer while the higher IN/IP ratios occurred in the winter (Figure 7-14). The lower summertime IN/IP ratios (frequently below 7-8) corresponded to the period of lowest ambient inorganic nutrient levels (<0.01 mg/L ortho phosphorus, and <.05 mg/L inorganic nitrogen). The low IN/IP ratio in conjunction with the low inorganic nutrient concentrations suggests that there is nitrogen limitation of summer phytoplankton. This summer nitrogen limitation may trigger the seasonal shift from phytoplankton dominance by diatoms in the spring to late summer dominance by nitrogen fixing blue-green algae which Marshall (1977) documented had occurred in 1974. This late summer bloom represents the annual peak in phytoplankton biomass. Prior to 1978, there appeared to be a depletion of inorganic phosphorus from the water column during the late summer/early fall, resulting in an increase in the IN/IP ratio to a range of 10-80. This depletion of ortho phosphorus and increase in the IN/IP ratios was probably the result of phosphorus assimilation by the fall blue-green bloom assuming the data collected by Marshall (1977) is representative of other years. In 1978 and 1979, however, there appeared to be excess inorganic phosphorus remaining in the water column during the late summer bloom, as exemplified by maximum IN/IP ratios of about 11 and 10, respectively.

During the winter, inorganic phosphorus and nitrogen levels were sufficiently high so as to make neither phosphorus nor nitrogen a limiting factor. Some other factor (i.e. light, temperature, micronutrients) probably limits winter phytoplankton growth.

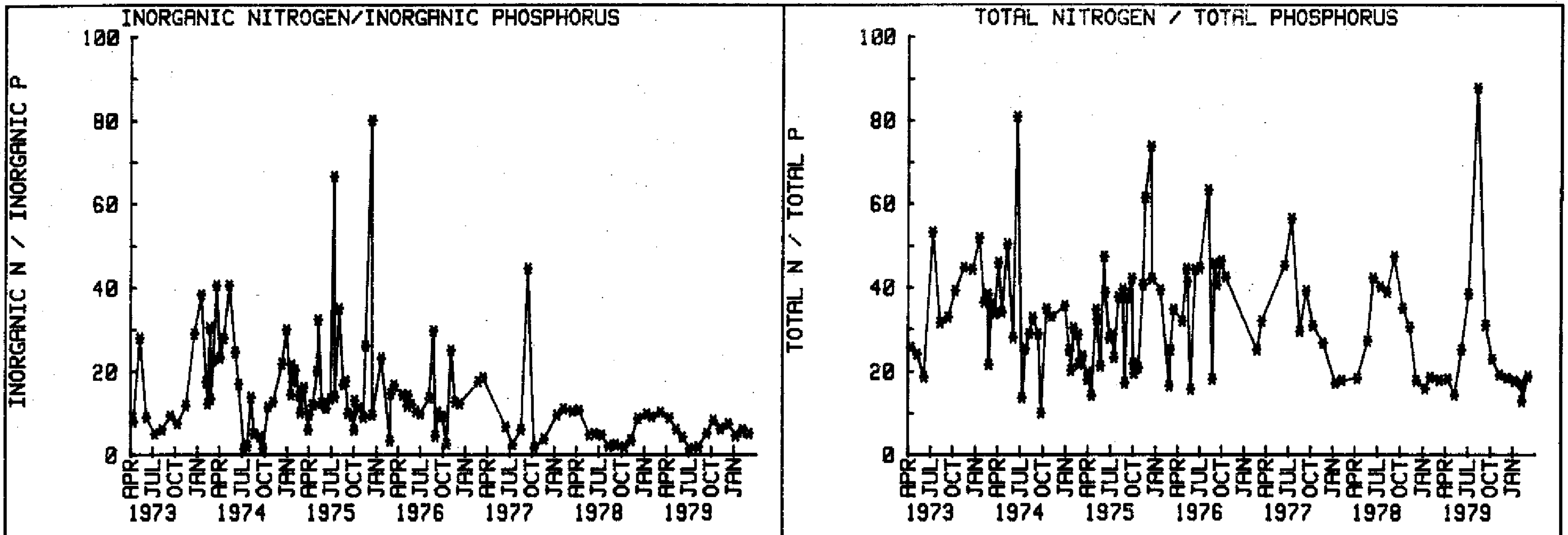


FIGURE 7-14. MEAN DAILY NITROGEN TO PHOSPHORUS MASS RATIOS IN LAKE OKEECHOBEE

Decreases in the mean annual total nitrogen in total phosphorus ratios (TN/TP) were not as consistent nor as large as the decreases in the inorganic ratios, although the 1979 TN/TP (23.6) was significantly lower than the 1973 ratio (43.9). On a seasonal basis the higher TN/TP ratios occurred in the summer while the lower ratios occurred in the winter. The seasonal pattern in the TN/TP ratios was opposite to the seasonal pattern of the IN/IP ratios.

Areal Analysis

There were significant areal variations in certain water quality parameters between the eight limnetic stations. The location of these stations allows an assessment of only large area differences in the limnetic zone. These data cannot be used to delineate areas of tributary influence. Such an evaluation will be addressed in the next chapter.

Dissolved oxygen was the only parameter which was uniform among the eight stations (Table 7-10 to 7-12). Mean turbidity levels at stations 3, 4, 6, and 8, which were located over soft mud sediments, were significantly greater than the levels at stations 1, 5, and 7 which were located over hard sand sediments (Figure 7-1). These associations were reported earlier by Davis and Marshall (1975). All the major cations and anions were significantly lower at station 1 than at the remaining stations. Station 1 is located closest to the mouth of the Kissimmee River (C-38) and reflects the low ion levels characteristic of C-38 waters (Federico, in preparation).

Nitrogen and phosphorus both displayed similar areal variations. Station 5, the most westward station, had the lowest average nitrogen

TABLE 7-10. DUNCAN'S MULTIPLE RANGE TEST FOR AVERAGE STATION DISSOLVED OXYGEN, TURBIDITY, AND SPECIFIC CONDUCTANCE [1/]

Dissolved Oxygen (mg/l)

Station	6	3	4	7	8	2	1	5
	8.4 [2/]	8.5	8.6	8.6	8.7	8.7	8.7	8.8
	———	———	———	———	———	———	———	———

Turbidity (JTU)

Station	5	1	7	2	3	6	4	8
	11.0	12.4	13.8	17.0	20.5	21.4	22.9	27.0
	———	———	———					
		———	———	———				
				———	———	———		
					———	———	———	
							———	———

Specific Conductance (μmhos/cm)

Station	1	5	2	3	6	8	4	7
	535	566	592	601	602	604	608	610
	———	———						
		———	———	———	———	———	———	———

1/ Means connected by the same line are not significantly different ($\alpha = .05$)

2/ Station means calculated from April 1973 through March 1980

TABLE 7-11. DUNCAN'S MULTIPLE RANGE TEST FOR AVERAGE STATION CHLORIDE, SODIUM, CALCIUM, AND ALKALINITY LEVELS [1]

Chloride (mg/l)

Station	1	5	2	6	8	4	3	7
	77.3 [2]	86.1	88.0	89.0	89.1	89.6	89.7	90.1
		—	—	—	—	—	—	—

Sodium (mg/l)

Station	1	5	2	8	7	6	4	3
	50.3	55.1	56.7	56.7	57.1	57.5	58.1	58.3
		—	—	—	—	—	—	—

Calcium (mg/l)

Station	1	5	2	8	3	7	6	4
	40.7	43.0	45.7	45.8	46.2	46.4	46.5	46.6
	—	—						
		—	—	—				
			—	—	—	—	—	—

Alkalinity (meq/l)

Station	1	2	5	6	3	4	8	7
	2.2	2.4	2.4	2.5	2.5	2.5	2.5	2.5
		—	—	—	—	—	—	—

[1] Means connected by the same line are not significantly different ($\alpha = .05$)

[2] Station means calculated from April 1973 through March 1980

TABLE 7-12. DUNCAN'S MULTIPLE RANGE TEST STATION NUTRIENT MEANS[1]

Total Phosphorus (mg/l)

Station	5	7	2	3	1	6	8	4
	.046[2]	.055	.063	.064	.067	.067	.068	.073

Ortho Phosphorus (mg/l)

Station	5	1	2	8	3	4	7	6
	.012	.015	.016	.016	.018	.020	.021	.025

Total Nitrogen (mg/l)

Station	5	6	1	2	3	8	4	7
	1.63	1.68	1.70	1.72	1.74	1.76	1.78	1.83

Inorganic Nitrogen (mg/l)

Station	5	1	2	3	8	4	6	7
	.08	.13	.15	.16	.17	.18	.21	.23

Organic Nitrogen (mg/l)

Station	6	5	2	3	8	1	7	4
	1.47	1.55	1.57	1.58	1.59	1.59	1.60	1.61

[1] Lines connected by the same line are not significantly different

[2] Mean of period April 1973 through March 1980

and phosphorus levels (Table 7-13). The highest total and inorganic nitrogen concentrations occurred at the most southerly stations (station 7). Mean organic nitrogen concentrations were uniform throughout the lake, ranging from 1.47 mg/L at station 6 to 1.61 mg/L at station 4. These means were calculated over the entire study period, thus are an average of the lower levels measured in 1973 and the highest levels measured in 1979. The ANOVA used to test for significant differences indicated no significant station-year interaction which implies that the decrease observed from 1973 to 1979 occurred uniformly at all the stations.

TABLE 7-13. DUNCAN'S MULTIPLE RANGE TEST FOR AVERAGE STATION NUTRIENT RATIOS[1/]

Inorganic Nitrogen to Ortho Phosphorus

Station	7	5	2	1	3	8	4	6
	25.4[2/]	17.2	15.3	15.1	14.8	14.7	14.2	12.4

Total Nitrogen to Total Phosphorus

Station	5	7	2	8	3	6	1	4
	56.9	44.8	35.6	33.5	32.6	31.6	30.9	29.6

1/ Means connected by the same line are not significantly different ($\alpha = .05$)

2/ Station means calculated from April 1973 through March 1980

SUMMARY

Eight limnetic stations were sampled on a minimum monthly frequency from April 1973 through March 1980. Routine parameters included nitrogen, phosphorus, major ions, turbidity, color, and in situ field parameters (dissolved oxygen, temperature, pH, and specific conductance). The specific objectives of this sampling were to: (1) characterize the chemical water quality of Lake Okeechobee; (2) identify season and long term temporal trends; (3) assess the limiting nutrient(s) of the lake based upon nutrient ratios; and (4) identify long term spacial variations. The following specific conclusions were supported by this data.

(1) There were no readily apparent seasonal variations or consistent increasing or decreasing changes in mean annual levels associated with the major ions (Na, K, Ca, Mg, Cl, alkalinity) or specific conductance. The lake is composed of highly mineralized water with the cations being dominated by calcium and sodium and the anions being dominated by chloride and alkalinity.

(2) Color levels were moderately high for a lake system, averaging 42.6 Pt units. No seasonal trends were noted although there was a wide range in individual values (19 to 59 Pt units).

(3) Turbidity levels varied seasonally with the highest values (20 to 60 JTU) occurring during the winter. Wind driven wave resuspension of sediments was attributed to the higher turbidity levels. On the average, however, turbidity remained low (18 JTU). No consistent increasing or decreasing trend was observed from 1973 to 1979.

(4) Lakewide daytime dissolved oxygen concentrations were high (relative to FAC Chapter 17-3 Water Quality Standards) being consistently above 6 mg/L and averaging 8.6 mg/L. Saturation ranged from 30 to 200 percent with an average of 100 percent.

(5) Inorganic phosphorus and nitrogen concentrations in the lake's limnetic zone displayed distinct seasonal patterns. Peak concentrations typically occurred in the winter while the lowest concentrations occurred in the summer. The fall represented a period of increasing levels while the spring represented a period of declining levels. It was hypothesized that higher fall/wintertime lake stages provided a mechanism for nutrient transport from the littoral zone to the limnetic zone. The spring and summer decline in concentration was probably a result of increased biological activity.

(6) Mean annual limnetic ortho phosphorus concentrations increased significantly from 1973 to 1979 (0.005 to 0.045 mg/L) with the largest increase occurring in 1978 and 1979. Three hypothesized mechanisms which may have contributed to these increased levels of ortho phosphorus were: (a) increased cycling of nutrients from the littoral zone as a result of the littoral zone being flooded for an extended period of time and to a deeper depth in 1978 and 1979; (b) extraction and transport of soluble ortho phosphorus from the two agricultural islands, following inundation at higher 1978 and 1979 lake stages; and (c) above average ortho phosphorus loads entering the lake in 1978 and 1979.

(7) The increases in the annual ambient ortho phosphorus concentrations in 1978 and 1979 resulted in significant increases in the ambient total phosphorus levels. In addition, the proportion of ortho to total phosphorus in the limnetic zone increased from 19 percent in 1973 to 46 percent in 1979.

(8) There were significant variations in the mean annual inorganic and total nitrogen concentration; however, there was no steadily increasing or decreasing trend from 1973 to 1979.

(9) The mean annual limnetic inorganic nitrogen to phosphorus (IN/IP) ratio decreased steadily from 25 in 1973 to 6.1 in 1979. Prior to 1978, the ratio was greater than 15, indicating potential phosphorus limitation of maximum biomass. In 1978 the ratio (9.8) was in a transition range. During the last year (1979) the ratio declined to 6.1, which is indicative of potential nitrogen limitation. The ratio for 1978 and 1979 were significantly lower than those calculated prior to 1977. It was suggested that the decline in the ratio was primarily a result of the disproportionate increase in ortho phosphorus relative to inorganic nitrogen. In addition, reduction of nitrogen loadings in 1979 through implementation of the Interim Action Plan may have also contributed to the lower IN/IP ratio in 1979.

(10) The mean annual total nitrogen to phosphorus varied between 34 and 44 from 1973 to 1977 with no consistent pattern. A significant decrease occurred in 1979 when the ratio declined to 24.

(11) Distinct seasonal trends occurred in the nutrient ratios. The IN/IP ratio was lowest during the summer, frequently below 7-8. These low summer IN/IP ratios, coupled with low inorganic nutrient levels, probably resulted in nitrogen limiting conditions in the summer. It was hypothesized that this seasonal shift to low summer IN/IP ratios triggers the late summer bloom of nitrogen fixing blue-green algae reported by Marshall (1977). During the fall/winter, the ratios were highest, ranging from 19 to 80. Since the winter inorganic nutrient concentrations were typically at their peak, it is unlikely that either phosphorus or nitroge was limiting in the spring.

(12) Significant areal differences were noted in all major parameters except for dissolved oxygen and organic nitrogen. Turbidity levels were higher over soft mud sediments than over hard sand sediments. Station 1, located closest to the Kissimmee River (C-38), had significantly lower major ion levels. Station 5, the most westward station, had the lowest mean nutrient levels. The highest average inorganic phosphorus and nitrogen concentrations occurred at stations 6 and 7, the most southerly stations.

CHAPTER VIII

SPATIAL DISTRIBUTION OF WATER QUALITY VARIABLES IN LAKE OKEECHOBEE - CASE STUDIES

INTRODUCTION

From May 1978 through September 1979, the S.F.W.M.D. operated an intensive (forty station) water quality monitoring network within the limnetic and littoral zones of Lake Okeechobee (Figure 8-1). This extensive network was established to assess the areal variation of several water quality variables. The approach taken in this assessment was to present cases which illustrated extreme distributional characteristics with regards to several water quality variables. These cases represent variable hydrologic conditions.

In the 40 station network, several stations were located immediately adjacent to inflow and outflow points around the perimeter of the lake. The majority of these perimeter stations were accompanied by another station which was located two miles offshore. Additional stations were situated near the public water supply (PWS) intake structures for Okeechobee City (LZ2), Belle Glade (LZ24), Clewiston (LZ30), Pahokee (LZ19) and South Bay (LZ26). The remaining stations were distributed uniformly over the rest of the lake. The eight baseline limnetic zone monitoring stations were included within the forty station network in order to maintain a continuous period of record for those stations during this intensive study. The latitude and longitude of all stations are given in Table 8-1.

Monthly sampling was conducted at all stations. The sampling dates and the routine variables which were monitored are given in Table 8-2. All samples were collected within one-half meter of the surface.

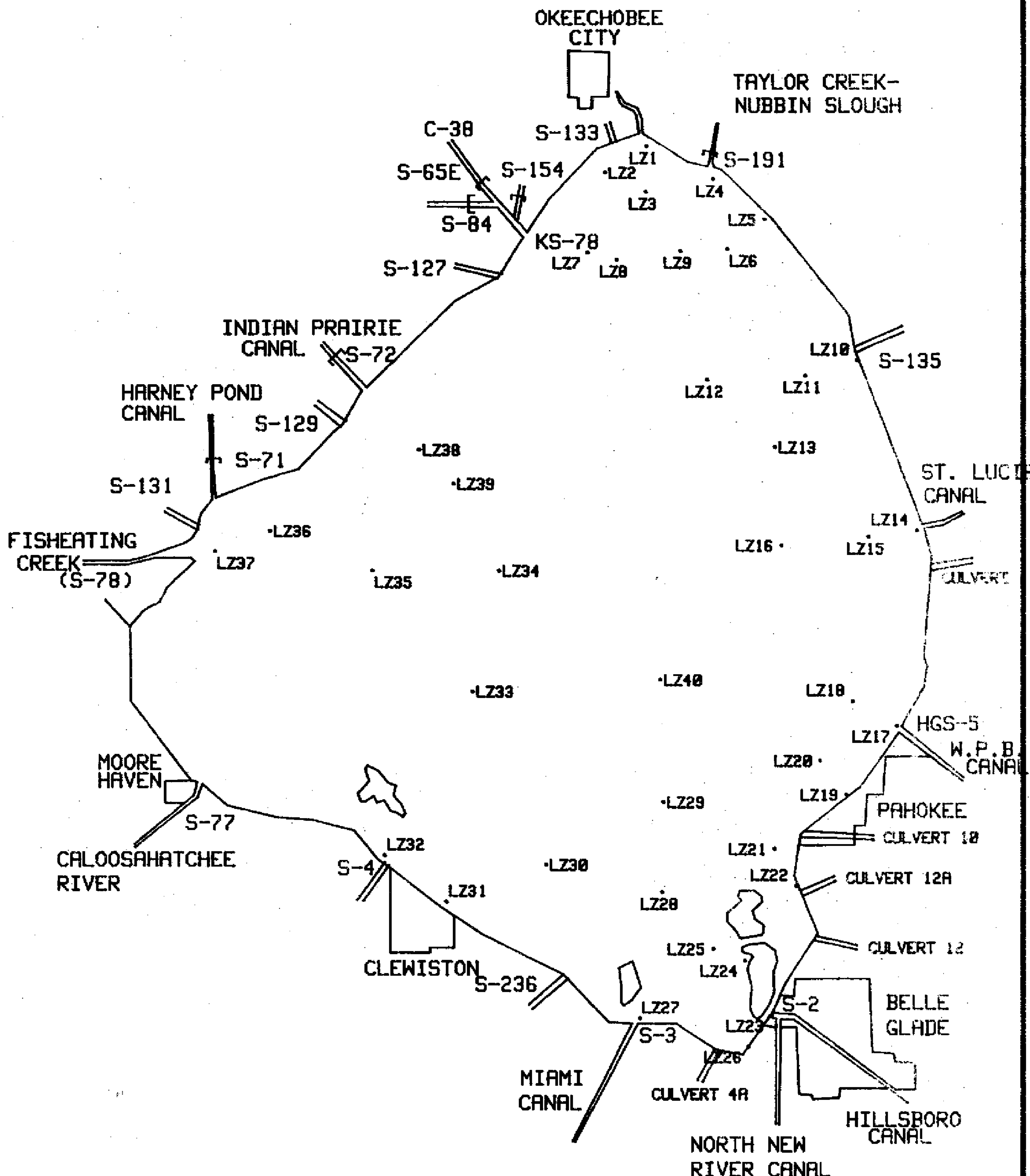


FIGURE 8-1 FORTY STATION LOCATION MAP

TABLE 8-1 COORDINATES OF THE FORTY MONITORING STATIONS WITHIN LAKE OKEECHOBEE

Station Code	Latitude	Longitude	Comments
LZ1	27 12 20 N	80 47 47 W	
LZ2	27 11 30 N	80 49 52 W	P.W.S.[1] intake for Okeechobee City
LZ3	27 10 37 N	80 47 24 W	
LZ4	27 11 27 N	80 45 50 W	
LZ5	27 09 32 N	80 43 14 W	
LZ6	27 08 24 N	80 44 41 W	
LZ7	27 08 31 N	80 50 57 W	
LZ8	27 08 23 N	80 49 06 W	
LZ9	27 08 38 N	80 47 07 W	Also = Station L001
LZ10	27 05 07 N	80 39 55 W	
LZ11	27 05 10 N	80 41 50 W	
LZ12	27 04 30 N	80 46 10 W	Also = Station L002
LZ13	27 02 55 N	80 43 47 W	Also = Station L003
LZ14	26 59 06 N	80 37 30 W	
LZ15	26 59 06 N	80 39 26 W	
LZ16	26 58 55 N	80 43 43 W	Also = Station L004
LZ17	26 51 52 N	80 38 02 W	
LZ18	26 52 53 N	80 39 36 W	
LZ19	26 49 37 N	80 40 07 W	P.W.S. intake for Pahokee
LZ20	26 50 48 N	80 41 18 W	
LZ21	26 48 05 N	80 43 07 W	
LZ22	26 46 54 N	80 41 53 W	
LZ23	26 42 07 N	80 42 58 W	
LZ24	26 44 04 N	80 43 59 W	P.W.S. intake for Belle Glade
LZ25	26 44 20 N	80 45 00 W	
LZ26	26 40 59 N	80 43 53 W	P.W.S. intake for South Bay
LZ27	26 41 54 N	80 48 23 W	
LZ28	26 46 30 N	80 47 33 W	Also = Station L007

TABLE 8-1 (CONTINUED)

Station Code	Latitude	Longitude	Comments
LZ29	26 49 24 N	80 47 16 W	Also = Station L006
LZ30	26 47 54 N	80 51 38 W	P.W.S. intake for Clewiston
LZ31	26 45 35 N	80 55 05 W	
LZ32	26 47 27 N	80 57 42 W	
LZ33	26 53 27 N	80 52 57 W	
LZ34	26 57 33 N	80 54 14 W	Also = Station L008
LZ35	26 57 33 N	80 58 40 W	Also = Station L005
LZ36	26 58 42 N	81 02 12 W	
LZ37	26 58 07 N	81 04 05 W	
LZ38	27 02 00 N	80 56 10 W	
LZ39	27 00 56 N	80 54 42 W	
LZ40	26 52 56 N	80 47 15 W	

[1] Public Water Supply

TABLE 8-2 FORTY STATION SAMPLING FREQUENCY AND ROUTINELY MONITORED VARIABLES

Sampling Dates

May 22 - 24, 1978	Nov. 7 - 9, 1978	May 8 - 10, 1979
June 12 - 14, 1978	*Dec. 5 - 6, 1978	June 5 - 7, 1979
July 12 - 14, 1978	Jan. 9 - 11, 1979	July 3 - 5, 1979
August 8 - 10, 1978	*Jan. 30 - 31, 1979	August 7 - 9, 1979
Sept. 6 - 8, 1978	March 6 - 8, 1979	Sept. 10 - 13, 1979
October 10 - 12, 1978	*April 10 - 12, 1979	

NOTE: "*" indicates that contour maps were not run on those dates.

Variables

Analytical		Field
NO_x	*Cl	*Dissolved Oxygen
NO_2	*Alkalinity	Specific Conductance
NO_3	*T-Fe	*Temperature
NH_4	*T-Org. C	*pH
TKN	*Turbidity	
$O\text{-}PO_4$	*Color	
$T\text{-}PO_4$		

NOTE: "*" indicates that contour maps were not run for these variables

DATA EVALUATION

The areal distribution of several water quality variables has been depicted via a series of contour maps. These maps were generated by utilizing "SYMAP" - a computer mapping program which was developed at Harvard University's Laboratory for Computer Graphics and Spatial Analysis. These contour maps display data by interpolating a continuous surface in the regions where there are no data points. These interpolated values are a function of the distance to, and the values of, the neighboring data points (Dougenik et al. 1975). Each smoothly interpolated value is modified by a weighting factor whose magnitude is inversely proportional to the square of the distance between the neighboring data points.

The contour maps contained within this report were assembled as objectively as possible, but several factors affect the graphic output of the SYMAP program. By changing the width of the contour intervals it is possible to change the area of influence which can be attributed to each point source discharge to the lake. Other factors which affect the graphic output of SYMAP are map dimension, map scale, data point distribution, and the search radius for neighboring data points involved in interpolation. In order to mitigate the effects which these factors have on the final output, and to allow for an objective comparison of output between sample dates, many of the above factors were standardized from map to map. Each class interval within the contour maps was represented by a unique character so as to aid in discerning one contour level from the next. These unique characters were chosen so that, ideally, the density of the print on the paper increased with each increase in contour levels (i.e. the higher the variable concentration, the darker the print).

The map legend gives the width of each class interval, the characters associated with each class interval, the data value extremes for each map and a histogram of actual data values. Various inflow and outflow conveyances were labeled around the perimeter of each map. Several prominent land masses within the lake itself were also identified. These land masses were treated by SYMAP as impermeable barriers.

The SYMAP evaluation was limited to three water quality variables (i.e. specific conductance, nitrogen, and phosphorus). The criterion used to determine which sampling dates would be discussed was based on the variability of the variable as measured by its standard deviation. The dates which were selected were generally the dates of highest and lowest variability, although other factors such as overall means and the rate of discharge for certain tributaries were also considered. Once the contour maps were generated, the lake area within each contour interval was calculated by using a Hewlett Packard 9815 calculator with a digitizing board. In order to analyze the potential effects that the inflows had on the SYMAP's of the lake, it was first necessary to determine:

(1) Which conveyances were discharging to the lake when the actual sampling took place.

(2) The relative significance of the volume of water discharged from one conveyance as compared to the next.

(3) The quality of water discharged at each conveyance.

(4) The ambient quality of the water in the lake.

In order to determine #1 and #2, tables were constructed which displayed the operational status of the inflows to the lake for the time period which involved each sample date. Since each sampling trip took three days to complete, three different time periods of discharge were recorded in these tables. The discharge values in these tables may be compared to the maximum discharges made during the seven year study period (Table 8-3). Each time period consists of the actual date samples were collected in the vicinity of an inflow plus two days prior to that date. In order to ascertain #3, a table was summarized from Chapter V (Table 8-4) which contains mean values of several water quality variables which are representative of the water discharged to the lake from the majority of the inflows surrounding the lake. Values contained in Table 8-4 are either flow proportional means or means of values collected only during discharge from April 1973 through March 1980. For the purpose of this analysis, the ambient water quality of the lake was defined as the water contained in the contour level which covered the largest surface area of the lake.

Specific Conductance

The contour maps which illustrate the areal distribution of the specific conductance in Lake Okeechobee are shown in Figures 8-2 and 8-3. The map of the August 1978 trip, which illustrates variable conductivity data, is representative of cases when several conveyances were discharging to the lake. The August 1979 map, which displays uniform conductivity data, represents a limited discharge case. Each class interval (i.e. contour level) used in the specific conductance maps was 200 μmhos/cm wide. There were nine intervals ranging from 0 to 1800 μmhos/cm. The area within each interval is displayed in Table 8-5. The total lake area of the conductivity maps was calculated to be approximately 619 square miles.

TABLE 8-3 MAXIMUM DAILY DISCHARGES TO LAKE OKEECHOBEE FROM 1973 THROUGH 1980

Structure	Peak Discharge (acre-feet)	Structure	Peak Discharge (acre-feet)
S-65E	27769	S-4	2531
S-84	7002	Fisheating Creek	15927
S-133	1478	S-131	399
S-191	6663	S-71	5831
S-135	1194	S-129	726
S-2	7755	S-72	3035
S-3	4919	S-127	1412

NOTE: Daily discharge records were not available for several of the structures which were listed in the "Operational Status" tables.

TABLE 8-4 MEAN VALUES REPRESENTATIVE OF DISCHARGE TO THE LAKE (4/1/73-3/31/80)

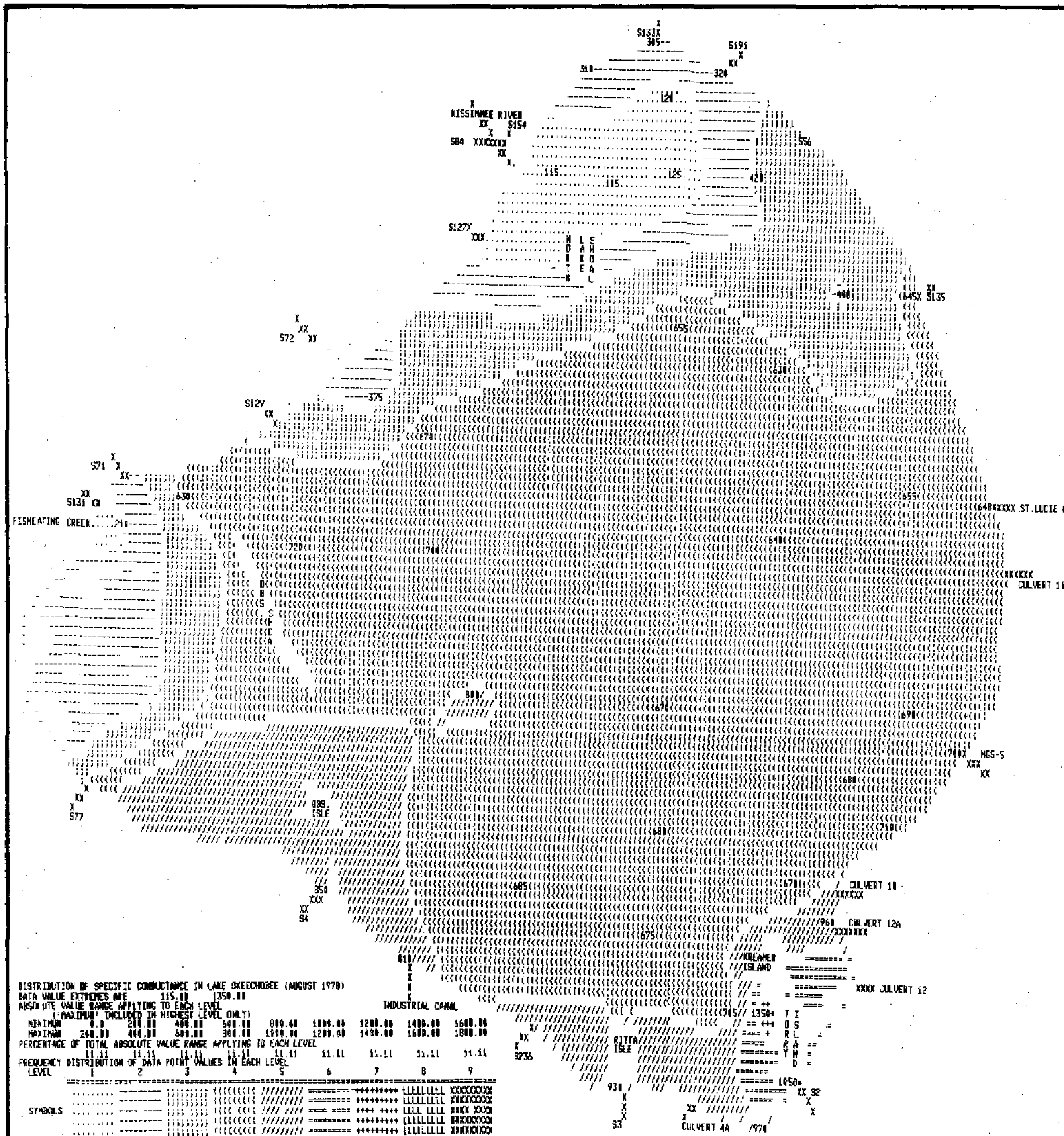
		Variable[1]			
Inflow	Sp. Cond.[3]	Total N	Inorg N	Total P	Ortho P
S-2[2]	1407	5.82	2.24	0.132	0.077
S-3[2]	1110	4.92	2.02	0.095	0.054
S-4[2]	875	2.56	0.74	0.314	0.254
S-71[2]	176	2.26	0.45	0.260	0.185
S-72[2]	191	2.59	0.39	0.217	0.139
S-65E[2]	152	1.39	0.20	0.092	0.058
S-84[2]	129	1.35	0.14	0.066	0.028
Fisheating Ck[2]	109	2.08	0.14	0.235	0.161
S-127[2]	675	2.31	0.41	0.484	0.299
S-129[2]	607	2.17	0.22	0.189	0.140
S-131[2]	605	1.87	0.20	0.138	0.108
S-133[2]	610	1.90	0.39	0.341	0.258
S-135[2]	857	2.14	0.25	0.181	0.143
S-191[2]	376	2.29	0.60	0.906	0.749
Culvert 10[4]	1581	7.39	3.64	0.265	0.169
Culvert 11[4]	1637	3.41	1.28	0.485	0.435
Culvert 12[4]	1642	13.43	7.14	0.129	0.083
Culvert 12A[4]	3206	7.40	2.75	0.305	0.248
Culvert 4A[4]	1638	5.14	2.77	0.080	0.039
S-236[4]	1565	5.07	2.32	0.086	0.022

(1) Units are Sp. Cond. (μmhos/cm), N or P (mg/L as N or P).

(2) Nutrient concentrations are flow weighted.

(3) Specific Conductance is time weighted for discharge cases only.

(4) Nutrient concentrations are time weighted for discharge cases only.

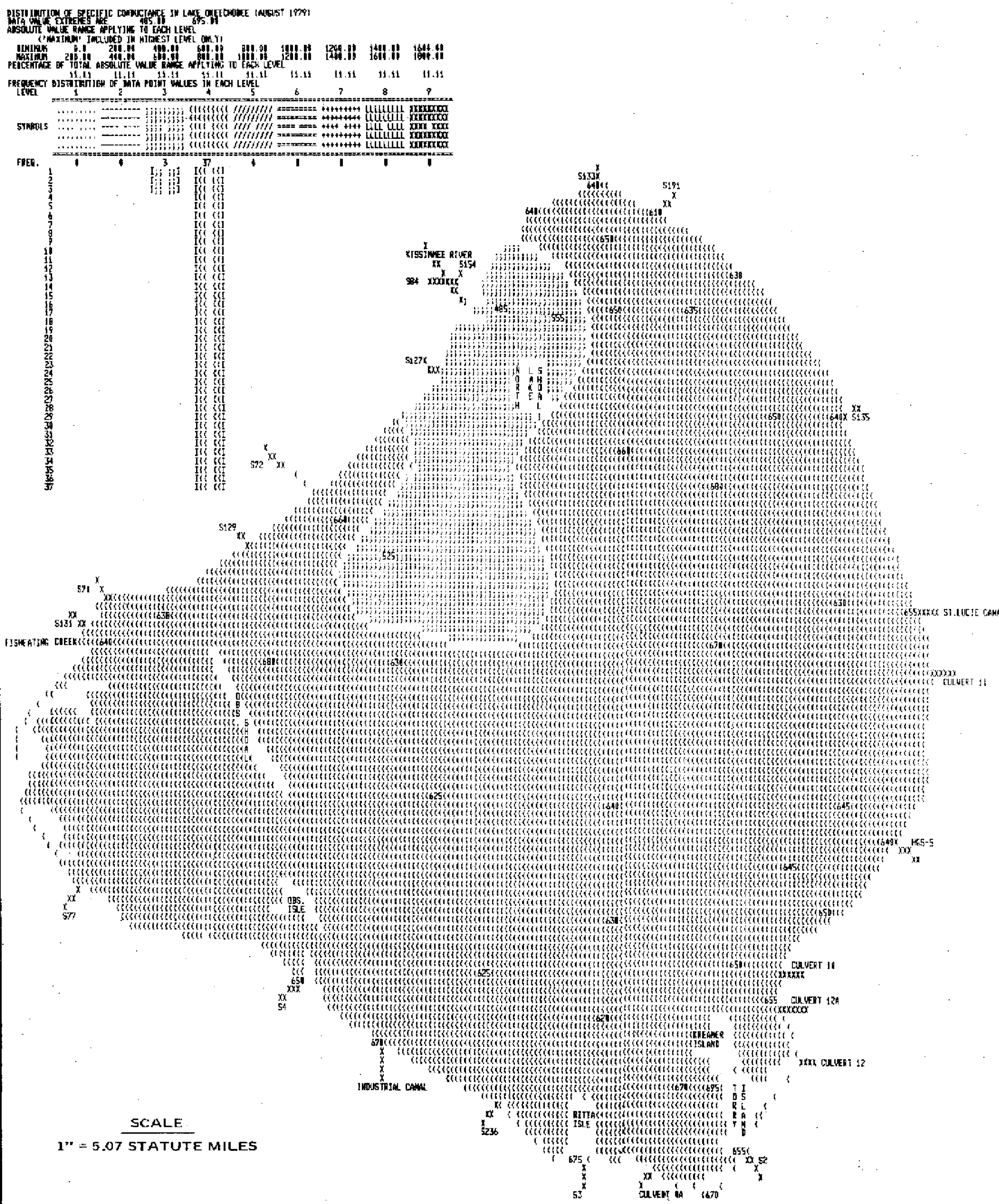


DISTRIBUTION OF SPECIFIC CONDUCTANCE IN LAKE OKEECHOBEE (AUGUST 1978)
DATA VALUE EXTREMES ARE 115.00 1350.00
ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

LEVEL	1	2	3	4	5	6	7	8	9
MINIMUM	0.0	200.00	400.00	600.00	800.00	1000.00	1200.00	1400.00	1600.00
MAXIMUM	200.00	400.00	600.00	800.00	1000.00	1200.00	1400.00	1600.00	1800.00
PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL	11.11	11.11	11.11	11.11	11.11	11.11	11.11	11.11	11.11
SYMBOLS	....	---------	;;;;;;;;;	(((((((((	/////////	=========	+++++++++	LLLLLLLLL	XXXXXXXXX
FREQ.	4	5	3	20	6	1	1	0	0

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

Figure 8-2 200 umho/cm. CONTOUR INTERVALS FOR SPECIFIC CONDUCTANCE (AUGUST 1978)



SCALE

1" = 5.07 STATUTE MILES

Figure 8-3 200 umho/cm. CONTOUR INTERVALS FOR SPECIFIC CONDUCTANCE (AUGUST 1979)

TABLE 8-5 LAKE AREA WITHIN SPECIFIC CONDUCTANCE CONTOUR INTERVALS

Contour interval μmhos/cm	August 1978 sq. mi.	%	August 1979 sq. mi.	%
< 200	25.7	4.2		
200 - 400	49.1	7.9		
400 - 600	79.4	12.8	61.1	9.9
600 - 800	394.0	63.6	563.2	91.0
800 - 1000	61.8	10.0		
1000 - 1200	7.2	1.2		
1200 - 1400	0.7	0.1		
1400 - 1600				
Mean	614		639	
Std. Dev.	267		39	

Note: Total lake area for specific conductance maps = 619 sq. mi.

The operational status of the inflows to Lake Okeechobee for August 1978 and 1979 are depicted in Tables 8-6 and 8-7, respectively. It is evident from Table 8-6, that water releases from the Kissimmee River Basin, during August 1978, should have the greatest impact on the ambient water quality in the north end of the lake since it is the single largest source of water. The large releases from S-65E and S-84 probably obscure the impact on the ambient water quality of the lake of discharge from S-127, S-133, S-191 and S-135. Besides the Kissimmee River (S-65E) and S-84, significant releases of water to the lake were also made by S-2, S-3, S-4, S-71, S-72, and Fisheating Creek.

It is evident from Table 8-4 that water which entered the northern region of the lake had a much lower conductivity than that which entered the southern region.

The contour map depicting the areal distribution of specific conductance data in Lake Okeechobee during the August 1978 sampling trip (Figure 8-2) has ambient level conductivity values in the range of 600 to 800 μmhos/cm (Level 4) as indicated in Table 8-5. Approximately 64% of the area of the lake (394 square miles) contained water defined as ambient. This means 36% of the lake was affected by the various inflows based on the criteria used to generate the contour map for this date. Relatively low conductivity water entering the north and west sides of the lake had a dilution effect on the ambient lake water. Approximately 116 square miles (18.7%) of the lake was affected by the various discharges from S-129 clockwise to S-135. Level 2 contour data (200 to 400 μmhos/cm) in the vicinity of the Indian Prairie Canal (S-72) illustrate the localized area of impact due to releases from this area. This dilution agrees favorably with the conductivity data for S-72 (Table 8-4). Although

TABLE 8-6. OPERATIONAL STATUS OF INFLOW CONVEYANCES TO LAKE OKEECHOBEE

Volume and Date of Discharge 1/

August 1978

Inflow	6th	7th	8th*	9th*	10th*	Total	Comments
S-65E	19379	18665	18903	2/		56947	A
S-84	3808	4185	3312			11305	A
S-154	- 2/	-	-				B
S-133	0	472	0			472	F
S-191	750	684	307			1741	A
S-135	0	365	0			365	F
Culvert 11	-	-	-				D
Culvert 10	-	-	-	-			D
Culvert 12A		-	-	-			D
Culvert 12		-	-	-			D
S-2		2222	1103	446		3771	A
Culvert 4A		-	-				D
S-3		510	500	0		1010	A
S-236		0	0	0			C
Industrial C.		-	-	-			E
S-4			607	325	595	1527	A
Fisheating Ck.			2598	2440	2301	7339	A
S-131			0	0	143	143	F
S-71			2420	2103	990	5513	A
S-129			0	0	0		F
S-72			1984	1718	107	3809	A
S-127	0	234	0			234	F

Total Inflow = 94176 acre-feet
Average Lake Stage on 8/6/78 = 15.90 ft. (MSL)

NOTE: 1/ Volumes are expressed in acre-feet. The time frame under consideration includes the date sampling occurred in the vicinity of the inflow conveyance plus two days prior to that date/

2/ - means flows not available
Blank means flows not applicable

COMMENTS:
(A) Fairly continuous discharge prior to these dates.
(B) Structure on automatic. Discharge occurred daily. Volume not calculated.
(C) Not in operation at this time.
(D) Operated by private drainage districts. No discharge data available, however, there probably was discharge at this time since S-2, S-3, and S-4 were pumping also.
(E) These waterways were not gauged at this time.
(F) Small releases are made every 3 to 4 days.

*indicates actual sample dates

TABLE 8-7. OPERATIONAL STATUS OF INFLOW CONVEYANCES TO LAKE OKEECHOBEE

Volume and Date of Discharge[1]

August 1979

Inflow	5th	6th	7th*	8th	9th*	Total	Comments
S-65E	[2]	1822	1469	2138		5429	A
S-84		0	0	0			
S-154		0	0	0			
S-133		0	0	0			
S-191		171	119	175		465	
S-135	- [2]	0	0	0			
Culvert 11	-	-	-				B
Culvert 10	-	-	-				B
Culvert 12A	-	-	-				B
Culvert 12	-	-	-				B
S-2	0	0	0				
Culvert 4A	-	-	-				B
S-3	0	0	0				
S-236	0	-	0				D
Industrial C.			-	-	-		C
S-4			0	0	0		
Fisheating Ck.			143	147	149	439	A
S-131			0	0	0		
S-71			0	0	0		
S-129			0	0	216	216	
S-72			0	0	0		
S-127		0	0	0			

Total Inflow = 6549 acre-feet

Average Lake Stage on 8/5/79 = 14.30 ft. (MSL)

NOTE: [1] Volumes are expressed in acre-feet. The time frame under consideration includes the date sampling occurred in the vicinity of the inflow conveyance plus 2 days prior to that date.

[2] - means flows not availalbe

Blank means flows not applicable

COMMENTS: (A) Fairly continuous discharge prior to these dates.

(B) Operated by private drainage districts. No discharge data available.

(C) This waterway not gauged at this time.

(D) Pumped for 8 hours on the 6th. Volume not calculated.

*indicates actual sample dates

water releases from S-65E, S-84 and S-191 were significant, it is difficult to determine the exact zone of influence of each source due to their close proximity to one another. Based on the conductivity data in Table 8-4, it's reasonable to assume that all Level 1 contour data (0 to 200 μmhos/cm) in that vicinity is directly attributable to discharge from C-38 (Kissimmee River) and S-84. This Level 1 contour accounts for 24.8 square miles or 4% of the total lake area. The Level 2 contour in the same vicinity reflects the combined influences of C-38, S-84 and S-191. This Level 2 contour represents 24.8 square miles or an additional 4% of the surface area of the lake. Level 3 data (400 to 600 μmhos/cm) reflects the additional influence of the Indian Prairie Canal combined with C-38, S-84 and, S-191 water releases. This Level 3 contour accounts for an additional 63.4 square miles (10%) of lake surface area affected by discharge into the north end of the lake.

On the west side of the lake from the Caloosahatchee River (S-77) clockwise to the Harney Pond Canal (S-71), 38 square miles or approximately 6% of the lake's surface displayed conductivity levels which were diluted below the ambient concentration. Conductivity values which are representative of discharge from this area (Table 8-4) indicate that a dilution effect should be evident. Fisheating Creek and S-71 both contributed significant amounts of water to that portion of the lake, while discharge from S-131 was negligible in comparison. The small display of Level 1 contour data (approximately 1 sq. mile) is probably directly attributable to Fisheating Creek, while Level 2 (21 square miles) and 3 contours (16 square miles) are the result of the combined influence of the water releases in that area. Since there is a large littoral zone in this region of the lake which was not penetrated by the sampling program, the true contour levels in this area may depart somewhat from the SYMAP representation. In addition, regulatory releases of water from the lake via the Caloosahatchee River (S-77) began on August 8th. These regulatory releases may have caused water in this region of the lake to flow toward S-77 rather than disperse in some other manner. No data currently exists to either prove or disprove this hypothesis, however.

Water quality in the vicinity of pump station 4 (S-4) and the Industrial Canal also was altered from the ambient level in the lake. Level 5 contours (800 to 1000 μmhos/cm) indicate that the specific conductance was raised in a 41 square mile area of the lake. This area in the Level 5 contour was equal to approximately 7% of the surface area and had conductivity values that resembled the mean value for S-4 (875 μmhos/cm). Since no quality or quantity data is available for the Industrial Canal, it is not possible to attribute the Level 5 contour data to either one source or another with a great deal of certainty. It does, however, appear that S-4 was responsible for the elevated conductivities in that area since ambient lake concentrations may be found immediately east of the Industrial Canal, whereas S-4 is more or less centered within the boundary of the Level 5 contour.

Another area of elevated conductivity data is the south end of the lake from culvert 10 clockwise to S-236. Approximately 28.5 square miles or 5% of the lake is affected by discharge from this area. The highest conductivity values (Level 7; 1200 to 1400 μmhos/cm) are found in a one square mile area in South Bay immediately adjacent to Kreamer and Torry Islands. This Level 7 contour is probably due to high chloride concentrations in the water being pumped off of Torry Island due to construction of the Belle Glade marina and recreation complex on the island. Level 5 (800 to 1000 μmhos/cm) and 6 (1000 to 1200 μmhos/cm) contours in that same area reflect the combined impact of backpumping from S-2 and S-3 as well as discharge from the privately owned and operated culverts. Although water discharged through the private culverts typically has higher conductivities than that which is backpumped from S-2 and S-3 (Table 8-4), a lack of hydrology data for these culverts makes an appraisal of their relative effect on the water in the lake impossible.

In contrast to the August 1978 map of the distribution of specific conductance values, the August 1979 distribution map (Figure 8-3) displays a much more homogeneous lake. Approximately 61 square miles (10%) of the lake were diluted from the ambient concentration (Level 4; 600 to 800 μmhos/cm) to a Level 3 contour (400 to 600 μmhos/cm). The reason for the lake being more homogeneous during the August 1979 trip than during the August 1978 trip was that 14 times more water entered the lake in August 1978 than did in August 1979.

Nitrogen

The total nitrogen and inorganic nitrogen data for the September 1978 sampling have been mapped (Figures 8-4 and 8-5, respectively) since both parameters had a high degree of variability. In contrast, the distribution of both parameters was very uniform during the January 1979 sampling and the maps of the distributions are shown in Figures 8-6 and 8-7.

As can be seen from the summaries of the discharges into the lake during the two sampling trips (Tables 8-8 and 8-9), there was

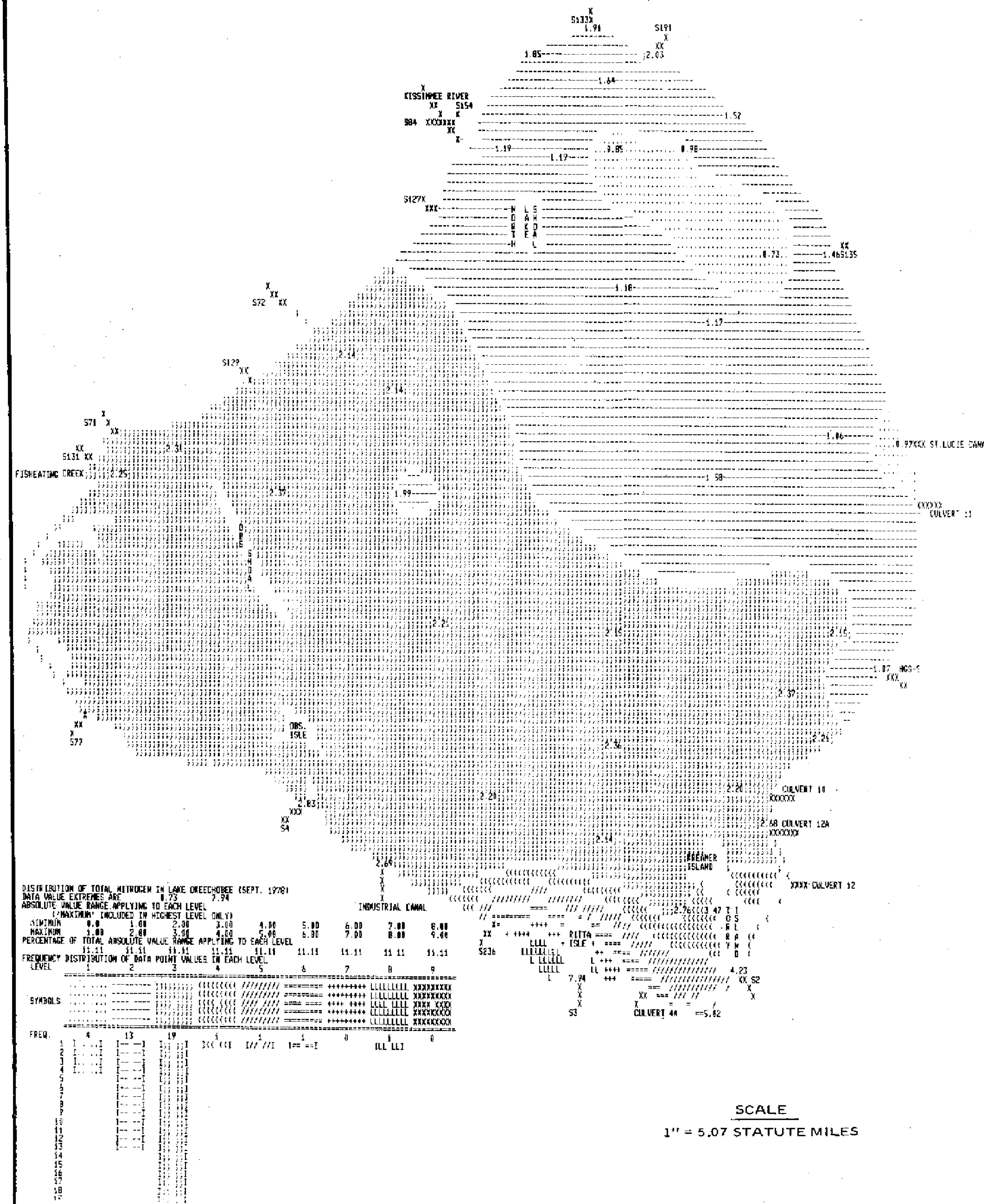


Figure 8-4 1.00 mg/L CONTOUR INTERVALS FOR TOTAL NITROGEN (SEPT. 1978)

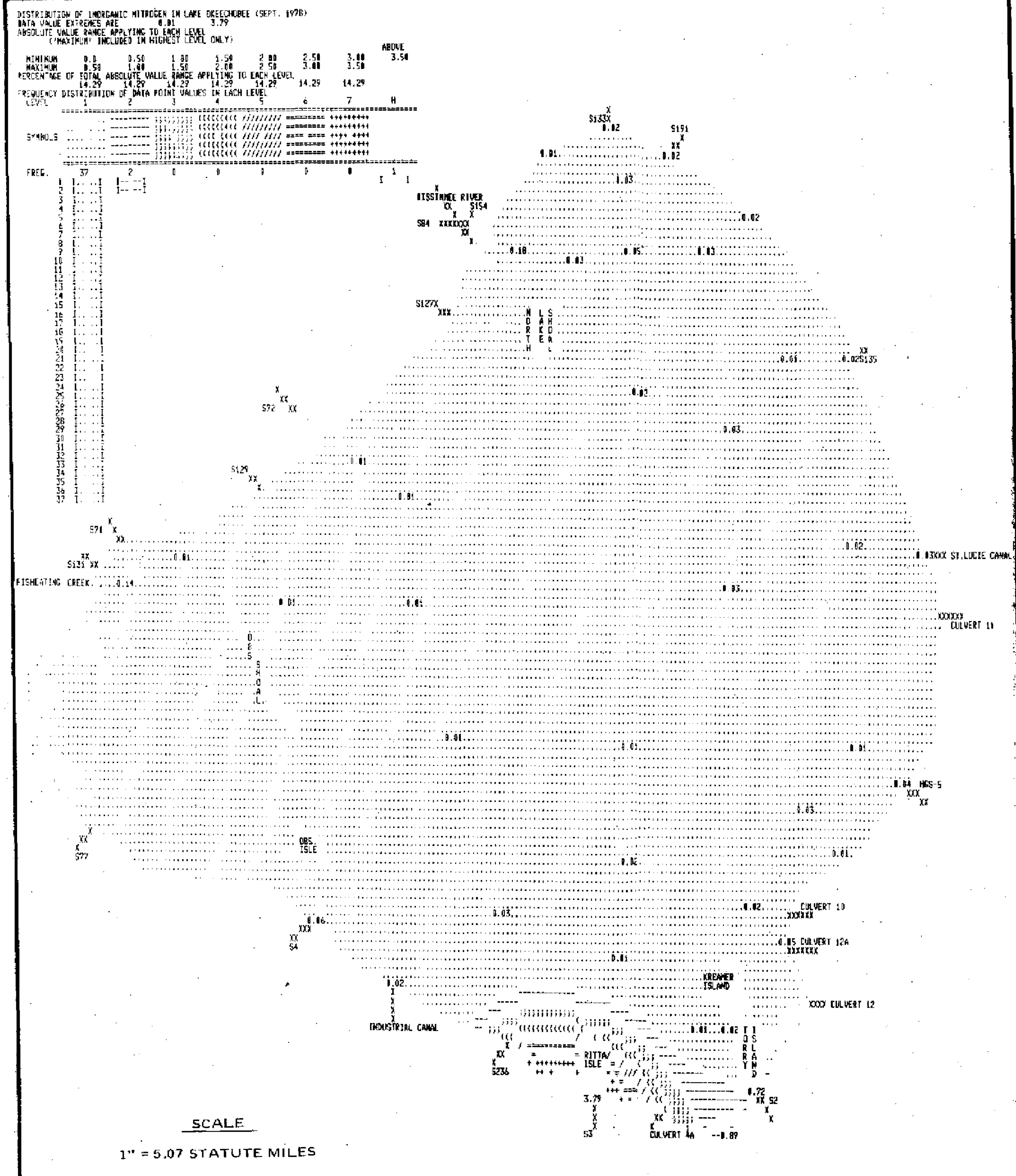


Figure 8-5 0.50 mg/L CONTOUR INTERVALS FOR INORGANIC NITROGEN (SEPT. 1978)

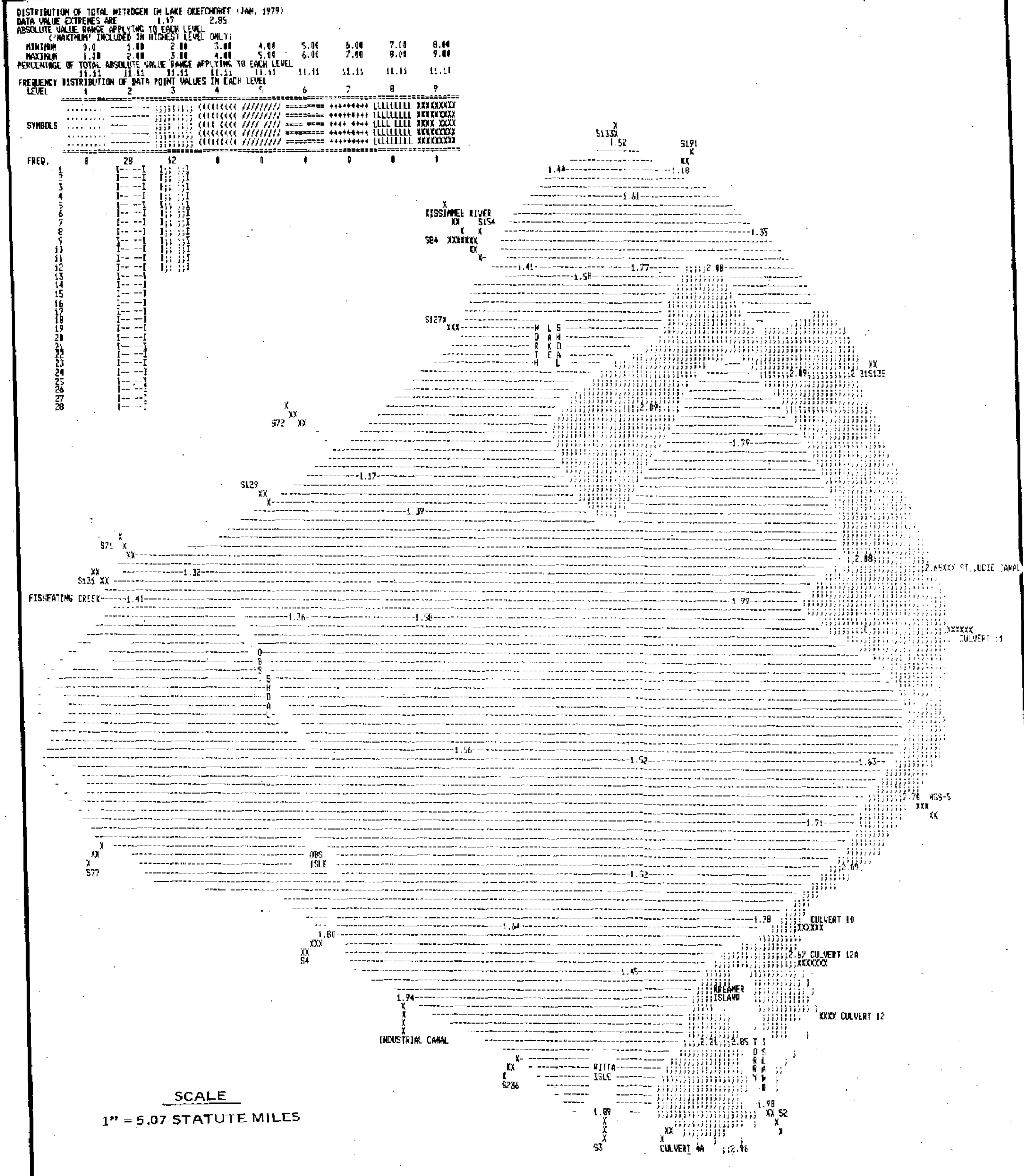


Figure 8-6 1.00 mg/L CONTOUR INTERVALS FOR TOTAL NITROGEN (JAN. 1979)