DRAFT
TECHNCIAL DOCUMENT

IN SUPPORT OF CHAPTER 40E-63, F.A.C.

WORKS OF THE DISTRICT
WITHIN THE
EVERGLADES

(subject to review and modification)

March 3, 1992

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I. SUMMARY

A. AUTHORIZATION

The Majory Stoneman Douglas Everglades Protection Act (MSD Act) (373.4592, Florida Statutes) requires the SFWMD, as part of the SFWMD Structures Permit application, to include a regulatory program to reduce the phosphorus discharge from the EAA.

Each unit of land surface that discharges water to the Everglades Protection Area is a user of the system for its discharges. As such, it must be a part of the overall solution to the Everglades restoration and improvement. Since the end quality of water into the Everglades Protection Area must be permitted by the DER to the SFWMD or the US Army Corps of Engineers (USCOE), it is the responsibility of the District to establish an appropriate regulatory program, consistent with the MSD Act and the SFWMD permit.

B. HARM

The Florida Department of Environmental Regulation (DER) has determined that nutrient-induced impacts have been demonstrated in the Everglades Protection Area and have resulted in violations of the following water quality criteria:

17-302.510 (3) (q), F.A.C.	Nuisance Species
17-302.560 (7), F.A.C.	Biological Integrity
17-302.560 (13), F.A.C.	Dissolved Oxygen
17-302.560 (20), F.A.C.	Nutrients

A synopsis of DER's findings regarding nutrient-induced impacts to the Everglades and violations of Class III water quality standards resulting from these impacts is presented in Chapter 2, Nutrient-Induced Impacts and Water Quality Violations in the Florida Everglades.

C. GOAL OF RULE

This document is technical document in support of Chapter 40E-63, F.A.C, Part 1 Addition, Works of the District in the Everglades. This document provides the explanation of data and calculations used to derive the basin phosphorus allocations, monitoring requirements, compliance measurement, and other associated technical information.

The goal of the regulatory strategy is to reduce present total phosphorus loads from the EAA by 25%. The goal is to be accomplished by requiring discharges within the EAA to obtain Works of the District permit(s) in addition to any other required District permit. The permit will require the implementation of best management practices (BMPs) and compliance monitoring. Justification of the 25% reduction figure is discussed in further detail in Chapter 3, Best Management Practices (BMPs) for the EAA.

All the relevant measurements and other data are too extensive and bulky to publish in this document. They are available in hard copy for inspection at the

District Headquarters in West Palm Beach during regular working hours, and on floppy disc at cost. Arrangements for inspection and rates should be made through Sarah Nall, Office of Counsel, South Florida Water Management District (SFWMD).

D. BOUNDARY AREA

The area currently included in the scope of the Everglades SWIM Rule are presented in **Figure 1**.

Drainage areas within the EAA are defined by identifying those lands which drain to pump stations S-5A, S-6, S-7 (and gravity structure S-150), and S-8 through the base period of record (see below for "period of record" description).

The four primary drainage areas do not include the portions of the following special drainage districts which drain exclusively north to Lake Okeechobee:

- South Florida Conservancy Drainage District
- South Shore Drainage District
- Closter Farms Drainage District
- East Shore Drainage District
- East Beach Drainage District

E. PERIOD OF RECORD

Throughout this document there are several references to a *"Period of Record"* or a *"Historical"* record of water quality and hydrologic data. These references refer to the ten year period of October 1, 1978 through September 30, 1988 (Water Year 1979 - Water Year 1988). This period was selected because it represents a period of relatively uniform water management (i.e. post IAP), relatively constant land use practices, it traversed several "extreme" hydrologic conditions (wet and dry years), reliable water quality and hydrologic data is available, and it is the same period of record utilized within the Everglades and Lake Okeechobee SWIM Plans.

F. TOTAL PHOSPHORUS

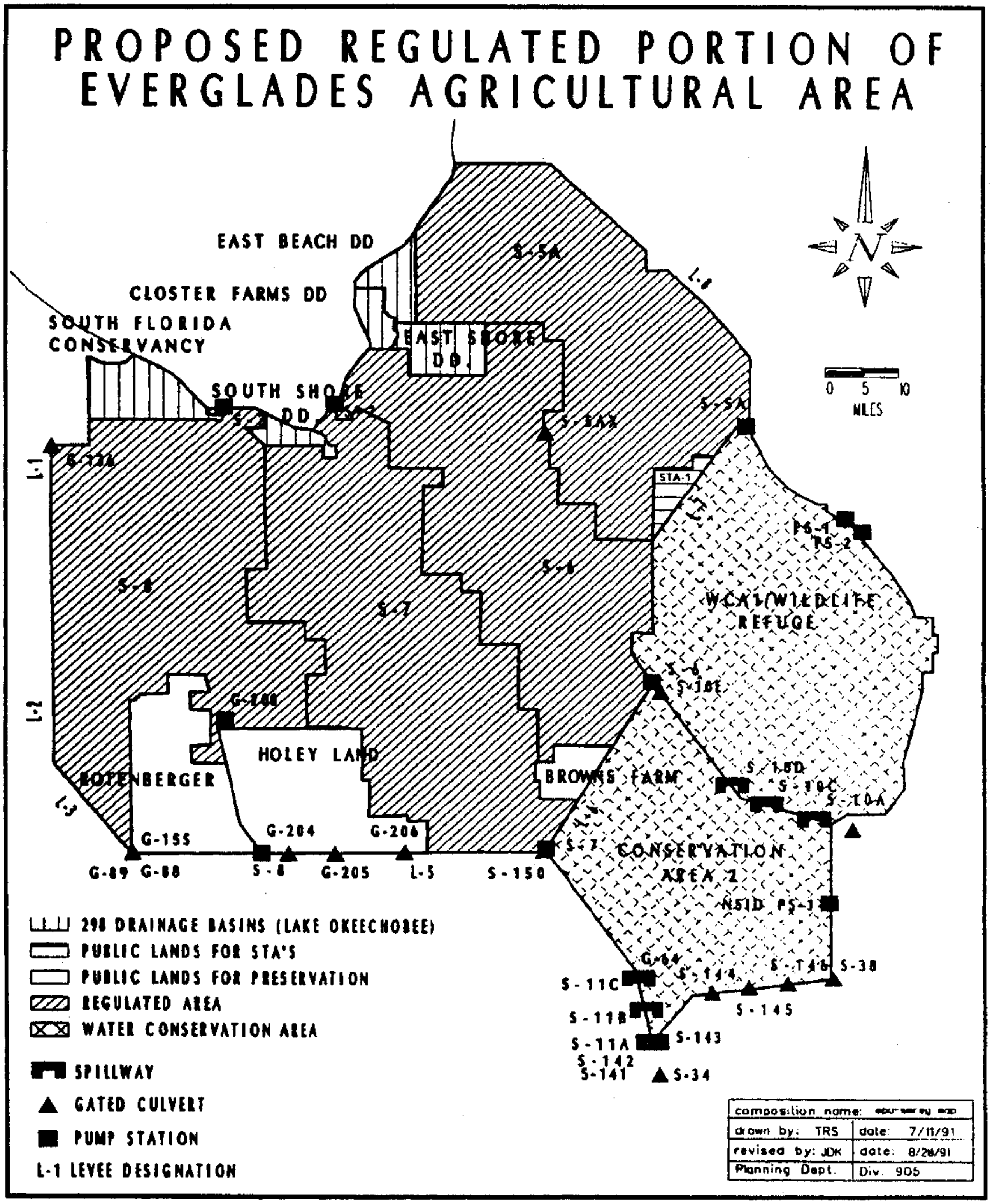
Total phosphorus (TP) described within this document is in terms of load over time (e.g. metric tons of TP per year). Total phosphorus load is defined as the total mass of phosphorus which passes a specific point of discharge or measurement during a specific period of time. Total phosphorus load is defined by the following general equation:

TP Load (mass/time) = TP concentration (mass/volume) × flow (volume/time)

Total phosphorus load calculations are discussed in further detail in Chapter 4, <u>EAA Period of Record Flow and Phosphorus Load Calculations</u>.

The average annual period of record TP loads will used as a baseline comparison measurement of compliance for future calculated TP loads from the EAA. Monitoring requirements for each permit are discussed in further detail in Chapter 5, <u>Monitoring Requirements</u>.

Figure 1. Major Drainage Basins of the EAA.*



* map is not drawn to scale

G. COMPLIANCE

A total phosphorus load allocation will be determined for the EAA on an annual basis. Compliance will be assessed at two levels: EAA Basin Level and Farm Level (only if EAA Basin is in violation).

The goal of this rule is to reduce the TP load from the EAA by 25%, therefore the annual TP allocation will be 75% of the load normally discharged from the EAA to the Everglades Protection Area, but **corrected for hydrologic variations**. The 75% allocation is computed from the average annual base line period of record with the actual present year's allocation adjusted for rainfall. This methodology is discussed in detail in Chapter 6, Determination of Phosphorus Load Allocations and Compliance.

In the event that the EAA basin has not met the required phosphorus reduction and is determined to be out of compliance, additional requirements will be required at the farm level. This methodology is discussed in detail in Chapter 6, Determination of Phosphorus Load Allocations and Compliance.

II. NUTRIENT-INDUCED IMPACTS AND WATER QUALITY VIOLATIONS IN THE FLORIDA EVERGLADES

The following is a draft report by the Florida Department of Environmental Regulation on nutrient related impacts to the Everglades Protection Area and related violations of Class III standards.

NUTRIENT-INDUCED IMPACTS AND WATER QUALITY VIOLATIONS IN THE FLORIDA EVERGLADES

Water Quality Technical Series
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1. INTRODUCTION

There are two principal questions related to nutrient enrichment in the Florida Everglades raised by the Settlement Agreement, Everglades SWIM Plan, and SFWMD Permit Applications: where have nutrient-induced impacts been demonstrated in the Everglades Protection Area and what violations of Class III standards are related to these impacts. The Department has conducted an extensive review of all available information pertaining to nutrient-induced impacts to the Everglades. The review included interviews with many of the scientists directly involved in Everglades research. In some cases the Department has also performed original analyses of previously unpublished data.

This paper is a synopsis of the Department's findings regarding nutrient-induced impacts to the Everglades and violations of Class III water quality standards resulting from these impacts. In addition, this paper presents evidence indicating what phosphorus concentrations can cause impacts in the Everglades. Analysis of scientific information on these issues is ongoing, so this review represents the Department's findings to date.

2. ECOSYSTEM OVERVIEW

The Everglades (Figure 1) are a unique national resource consisting of a vast, shallow sawgrass marsh, with wet prairies and aquatic sloughs interspersed with tree islands (Davis 1943). Construction of primary canals in the 1920s and the Central and Southern Florida Project for Flood Control and Other Purposes initiated in the late 1940s, has drained and converted large portions of the northern and eastern Everglades to agricultural or urban land uses. Only 50 percent of the original Everglades ecosystem remains today (Shortemeyer 1980). The remainder of the historic Everglades is the largest and most important freshwater sub-tropical peatland in North America. This unique ecosystem has a large diversity of wetland species and provides habitat for large populations of wading birds and numerous threatened and endangered species (Table 1), including wood storks, snail kites, bald eagles, Florida panthers, and American crocodiles.

The remaining components of the historic Everglades (Figure 1) are located in the Water Conservation Areas (WCAs) and Everglades National Park (ENP). The WCAs contain large tracts of land set aside in public ownership to provide multiple benefits, including flood protection, water supply storage, and environmental resource protection. WCA-1 is the Arthur R. Marshall Loxahatchee National Wildlife Refuge, administered by the U.S. Fish and Wildlife Service as a migratory bird refuge since 1951. The southern end of the Project discharges into Everglades National Park, which was authorized by Congress in the 1930s with a mandate to preserve the unique flora and fauna of the region. Both the Loxahatchee National Wildlife Refuge and Everglades National Park are Outstanding Florida Waters, a designation requiring special protection for the resource.

A nutrient gradient exists in the Everglades with the highest concentrations near Lake Okeechobee and the lowest concentrations in Florida Bay. Large portions of this ecosystem have evolved in response to low ambient concentrations of nutrients and seasonal fluctuations of water levels. Prior to the creation of the Everglades Agricultural Area (EAA) (Figure 1), nitrogen and phosphorus were mainly supplied to large areas only in rainfall (Parker 1974; McPherson et al. 1976; Swift 1984; Swift and Nicholas 1987). The low nutrient content, particularly phosphorus, in Everglades peats supports that the ecosystem was generally oligotrophic (nutrient-poor) (Freiberger 1972; Steward and Ornes 1975a,b; Parsons 1977; Koch and Reddy 1991; Jones in prep.). Disturbances, including fire, drought, and infrequent frosts, are additional factors shaping the ecosystem structure (SFWMD 1992). A large body of evidence (Steward and Ornes 1975a,b; Swift 1981; Lutz 1977; Steward 1974; Reeder and Davis 1983) indicates that phosphorus is the primary limiting nutrient throughout the remaining Everglades. Sawgrass (Cladium jamaicense) has lower phosphorus requirements than other species of Everglades vegetation, a characteristic which allows sawgrass to maintain its dominance in the oligotrophic marsh community (Steward and Ornes 1975a,b). Around 70 percent of the remaining Everglades consists of sawgrass marsh (McPherson et al. 1976), which exists in communities ranging from almost pure stands to mixed vegetation (SFWMD 1992).

Creation of the EAA has altered the nutrient regime of the area in three ways: (1) nutrient storage potential in accumulating peat is removed by conversion of marsh land to agricultural lands; (2) nutrients are imported to the area by fertilization; and (3) nutrients are released from agricultural peat due to soil oxidation within the EAA. Substantial portions of EAA nutrients are transported to the remaining Everglades either in dissolved or particulate form in surface waters or as atmospheric deposition from burning of cane fields or processing plant emissions (Richardson et al. 1990).

The introduction of phosphorus from EAA drainage water has resulted in ecological changes over large areas of Everglades marsh. These changes can generally be described as cultural eutrophication, or an increase in the supply of nutrients available in the marsh. The increased supply of phosphorus in Everglades marshes has resulted in documented impacts in several trophic levels, including microbial (Reeder and Davis 1983), periphyton (Swift and Nicholas 1987), macrophyte (Davis 1991), invertebrate (Terczak 1980), and vertebrate (Hoffman et al., 1990) communities. More than 20,000 acres of Everglades habitat has been modified by EAA discharges and the areal extent of these impacts is increasing (Swift and Nicholas 1987). Nutrient induced impacts have been well documented in SFWMD Technical Publications, journal articles, and unpublished data. These impacts have been substantiated by LOTAC II (1990).

3. RELATIONSHIP OF IMPACTS TO CLASS III STANDARDS

Evaluation of nutrient-induced impacts to wetland ecosystems is a complex process, since impacts occur in different parts of the ecosystem at different rates and to varying extents. For this reason, nutrient-induced impacts to a wetland ecosystem such as the Everglades must be evaluated by evidence from individual species, assemblages of species, and system-level changes in the chemical, physical and biological characteristics of the ecosystem. The Department's criterion regarding nutrient-induced imbalances of flora or fauna was written as a narrative rather than numeric criterion with the focus of maintaining the assemblage of flora and fauna characteristic of the ecosystem in question. The Department takes into account not only quantifiable impacts resulting from nutrient addition, but also factors such as the areal extent of an impact, degree of trophic involvement, and possible synergistic effects with other physical and chemical characteristics of the ecosystem, its hydrology, and disturbances such as fire. Imbalance also includes situations when nutrient addition results in the dominance of nuisance species or violation of numeric standards.

Review of available data and literature indicates that phosphorus-enriched water discharged from the EAA to the Everglades Protection Area has caused or contributed to at least four major and widespread violations of Class III water quality criteria: imbalances of aquatic flora or fauna, dominance of nuisance species, biological integrity, and dissolved oxygen. The communities most directly affected are the microbial decomposers, periphyton, macrophytes, and macroinvertebrates. Through food-web perturbations and alteration of the physical and chemical characteristics of the habitat, fish, waterfowl, wading birds, and other higher organisms are also affected.

3.1 Imbalances of Aquatic Flora or Fauna

Criterion 17-302.560(19), F.A.C., states "Nutrients - in no case shall nutrient concentrations of a body of water be altered so as to cause an imbalance in natural populations of aquatic flora or fauna." The Department uses the best available information to determine the normal unaltered structure and function of a particular aquatic community. Data set measurements (metrics) such as taxa richness, diversity, Florida Index, percent composition of important taxa, functional feeding group indices, etc., are used in this determination. An ecosystem is determined to be "imbalanced" when significant departures from the expected biological operation of a system occur. This is determined by a combination of factors, including professional judgment and measured differences between suspected "imbalanced" and unimpacted or "control" sites. The components of the Department's "imbalance determination" are discussed in the following sections.

3.1.1 Flow Pattern Description

Phosphorus concentrations in the water column and soil are both important in their potential effects to the Everglades ecosystem. Phosphorus exchange between soil and the overlying water column is a function of the physical, chemical and biological characteristics of the soil and water and the relative proportions of the various phosphorus forms in the soil and water. Phosphorus is retained in wetland soils primarily by biological uptake at the soil water interface and by sorption and precipitation mechanisms. The mobility and reactivity of phosphorus in wetlands is controlled by the chemical species in the soil and water, soluble/solid phase interactions, and organic matter decomposition rates. These processes control the bioavailability of phosphorus for aquatic vegetation (Reddy et al. 1991).

The introduction of phosphorus-enriched EAA drainage water has significantly affected a number of these processes, with resulting impacts to the indigenous flora and fauna of the Everglades ecosystem. Evidence of phosphorus enrichment in the Everglades is indicated in surface water and sediment data. Unenriched as well as enriched Everglades marshes generally act as a phosphorus sink (Reddy et al. 1991; Jones in prep.). At phosphorus-enriched sites, the soil can act as a source of phosphorus to the water column, at least for short periods of time. Soil phosphorus enrichment can not only influence growth rates of macrophytes such as sawgrass and cattail which derive their nutrients primarily from the soil (Davis 1991), but also influence growth rates of algae and floating aquatic plants which preferentially extract their nutrients from the water column.

Review of surface water phosphorus concentration data indicates significant temporal increases in concentration at most inflow structures to the Everglades Protection Area (Figure 6). No structures have significant temporal decreases in phosphorus concentration (Walker 1990; Walker, 1992). Data also indicate a general north to south gradient (Figure 7) in interior marsh phosphorus concentrations both between and within the Water Conservation Areas (Millar 1981).

In WCA-1 an increasing temporal trend in surface water phosphorus concentrations was seen for 14 interior marsh sampling stations over the period of record from 1978 to 1983 (SFWMD unpublished data). Phosphorus concentrations are elevated along the periphery in association with the canals, especially along the western periphery which is influenced by inflows from the S-5A and S-6 pump stations (Richardson et al. 1990). This influence can be seen in data as early as 1974 (McPherson et al. 1976). Richardson et al. (1990) and Doren et al. (in prep.) found that soil phosphorus concentrations (Figure 8) were also elevated along the periphery of WCA-1 in association with inflows from the S-5A and S-6 pump stations.

WCA-2A surface water phosphorus data also indicate increased phosphorus concentrations at interior marsh stations in

The WCAs and ENP each have characteristic flow patterns which are dependent on inflow and outflow volumes, rainfall, topography and stage. Patterns of distribution for relatively conservative substances such as phosphorus will follow the patterns of flow through the system, therefore it is important to understand the characteristic flow patterns for the WCAs and ENP.

WCA-1 (Figure 2) is a relatively shallow marsh encircled by a 3 to 4 meter deep canal. Surface inflows are predominantly from the S-5A and S-6 pump stations while surface outflows are primarily from the S-10 and S-39 structures. When stage levels are low, S-5A and S-6 inflows will generally flow south along the perimeter canal rather than penetrating the higher elevations of the interior marsh. As stage levels increase, perimeter canal waters increasingly penetrate the interior marsh (Millar 1981). As a result, the central area of WCA-1 is generally a rainfall-driven system while perimeter water quality is significantly influenced by pump station inflows. This pattern is evidenced in the distribution of essentially all conservative constituents in WCA-1 surface waters (Richardson et al. 1990).

In WCA-2A (Figure 3), surface inflows are predominantly from the S-10 structures on the northeast perimeter and the S-7 pump station on the western perimeter. Surface inflows from the S-10 structures traverse the marsh by sheet flow, while S-7 inflows flow by a combination of sheet and canal flow. Surface outflows are predominantly through the S-11 structures on the southwestern levee (SFWMD 1992).

Predominant flow patterns for WCA-3A (Figure 4) are less well documented. Penetration of inflows from the S-11 structures and the S-8 and S-9 pump stations into interior WCA-3A marshes have not been well quantified. Most inflow from the S-9 pump station is probably contained within the Miami Canal, which flows diagonally through WCA-3A. The S-339 and S-340 gated plugs force water from the Miami Canal into the marsh, but the relative extent of marsh penetration and re-entry into the Miami Canal has not been quantified (Davis in press).

Everglades National Park (Figure 5) receives surface water inflows primarily from the WCA-3A marsh and canal L-67A through the S-12 structures and L-67 extension, respectively. Canal L-67A receives inflows from the Miami, North New River, and South New River Canals and WCA-2A through the S-8, S-150 and S-9 pump stations and S-11 structures, respectively (Davis in press).

3.1.2 Evidence of Phosphorus Enrichment in Soil and Water Chemistry

Phosphorus concentrations measured in canals are often significantly higher than concentrations measured at interior marsh sites in the WCAs (Millar 1981). Therefore, elevated interior marsh phosphorus concentrations are closely associated with water flow patterns from the canals through the marsh.

association with the inflows from the S-10 structures and the S-7 pump station. This pattern can be seen in phosphorus data (Figure 9) for linear transects south of the S-10C structure (Reddy et al. 1991). Although the physical characteristics for WCA-2A soils are relatively homogeneous throughout the area, soil phosphorus concentrations (Figures 10 and 11) are also elevated in areas influenced by phosphorus-enriched inflows (Koch and Reddy 1991; Richardson et al. 1991; Doren et al. in prep.). The spatial distribution of the phosphorus-enriched soils is strongly correlated with the phosphorus-enriched surface waters. Phosphorus enrichment is found primarily in the top 10 centimeters of soil (Figure 12), however the enriched zone penetrates deeper near the S-10 structures (Reddy et al. 1991). Koch and Reddy (1991) have also found some differences in the forms of phosphorus storage in phosphorus-enriched areas when compared to unenriched sites. The distance elevated phosphorus concentrations have penetrated from the S-10 structures into interior marsh waters has increased from ~ 1.6 km in the 1970s to ~ 6.4 km in the 1980s (Davis in press) (Figure 13).

Historical surface water phosphorus concentration data are insufficient to characterize the extent of impact to WCA-3A at this time. Soil phosphorus samples have been obtained for WCA-3A but results were not available at the time of this writing. Steward and Ornes (1975a,b) performed a dosing study in WCA-3B. The results indicated that soil phosphorus concentrations in the dosed area increased significantly when compared with background soil phosphorus concentrations. Soil phosphorus remained elevated for several months after dosing ceased.

ENP data for interior marsh sites (Figure 14) indicate elevated soil phosphorus concentrations south of the S-12 structures extending roughly 1 km into the park (Doren et al. in prep.).

3.1.3 Microbial Community Impacts

Although the effects of nutrient enrichment on the macrophyte and periphyton communities are often the first effects to be observed visually, nutrient-induced changes in the microbial communities of both the water and soil can usually be detected earlier. Microbial community changes can significantly impact the overall water quality and productivity of the ecosystem, especially in a detrital-based system such as the Everglades (Jones 1992a).

Microbial processes are responsible for most of the cycling of phosphorus, therefore, their role in maintaining a stable ecosystem is critical (Jones 1992a). Nutrient-induced changes in soil microbial community composition can significantly affect detritus characteristics, food web structure, and nutrient uptake pathways. Increased phosphorus loading in WCA-2A from the S-10 structures is thought to have resulted in a shift in microbial populations (bacteria and fungi) responsible for sawgrass and cattail leaf litter decomposition (Reeder and Davis 1983). The microbial population shift at nutrient-enriched sites was associated with prolonged low dissolved oxygen concentrations or anoxic conditions. The authors concluded that microbial populations had changed from aerobic and facultative anaerobes to obligate anaerobes at nutrient-enriched sites. This change has impacts on many fundamental system characteristics. Water column microbial populations were also higher at nutrient-enriched sites.

Nutrient enrichment also influences detritus accumulation rates and physical characteristics of sediment. Davis (1990) (Figure 15) found that phosphorus-enriched sites dominated by cattail deposited 1160 g/m2/year of fine, flocculent sediment while unenriched sites dominated by sawgrass deposited 492 g/m2/year of intact and compact detritus. Amador and Jones (1992) added phosphate to Everglades peat soils of low (0.231 mg P/g soil), intermediate (0.386 mg P/g soil) and high (1.473 mg P/g soil) phosphorus content. Soil samples were obtained from sites downstream of the S-12 structures. Phosphate addition stimulated the microbial respiration rate of the low and intermediate phosphorus soil, but did not effect the microbial respiration rate of the high phosphorus soil. These results correspond with those of Maltby (1985), who found that the introduction of phosphorus in an ENP dosing study accelerated the microbial decomposition of cellulose. Phosphorus-induced increases in soil decomposition rates could result in lowered dissolved oxygen concentrations and decreased soil accretion rates (Amador and Jones 1992; Maltby 1985; Richardson et al. 1991).

Because phosphorus cycling is primarily achieved through microbial processes, bacteria are the first organisms to exhibit a change due to increased phosphorus loading. This change is reflected in decreased production of the enzyme, alkaline phosphatase (AP), which functions in the remineralization of dissolved and particulate phosphorus. All organisms possess AP but only bacteria and fungi exhibit extracellular excretion of the enzyme. Bacterial and fungal cells do not produce AP in the presence of either excess dissolved or particulate phosphorus. In addition, AP responds more rapidly to increased phosphorus concentrations than the processes by which phosphorus increases in the soil occur. Thus, AP is a sensitive indicator of excess phosphorus in the Everglades ecosystem (Jones, 1992a).

Research (Jones, 1992b) (Figure 16) showed that depressed AP activity in association with inflow structures was correlated to elevated phosphorus concentrations throughout the Everglades. Dr. Jones measured soil phosphorus and AP activity along transects in WCAs 1, 2A, 3A and ENP. The data indicated low AP activity in association with inflow structures for all transects. The data also indicated decreased AP activity at stations which had not yet exhibited increased soil phosphorus concentrations.

3.1.4 Periphyton Impacts

Periphyton are a community of microorganisms which live attached to the surface of aquatic plants and other submerged substrates.

Periphyton form submerged and floating mats which are abundant throughout the Everglades Protection Area (Swift 1981). Periphyton are significant primary producers, provide physical habitat for macroinvertebrates and small fish, and are an important part of the Everglades food chain (Wood and Maynard 1974). Periphyton also play an important role in the formation of the sediments underlying them (Gleason and Spackman 1974). The relative growth rates, algal species diversity and percentage of phosphorus in the periphyton community are influenced by changes in water quality, specifically phosphorus concentrations. Phosphorus concentration, major ion content and pH were all important water quality factors controlling periphyton species composition (Swift and Nicholas 1987).

In low-nutrient, alkaline Everglades waters throughout the marshes of WCAs 2A and 3A and ENP,a characteristic algal community, consisting of the calcareous filamentous blue-greens, Scytonema and Schizothrix and a group of hard water diatoms (e.g. Mastoglia) is spatially dominant (Gleason and Spackman 1974; Browder et al. 1981; Swift 1981; Swift 1984; Swift and Nicholas 1987). In the low-nutrient, acidic waters found in the interior of WCA-1, the algal community consists of the green filamentous species, Mougeotia and Spirogyra, as well as a rich desmid flora (Swift 1981; Swift 1984; Swift and Nicholas 1987).

Phosphorus enrichment has been significantly correlated with adverse changes in the taxonomic composition and community structure of Everglades periphyton communities in WCA-2A and WCA-3A (Swift 1981; Swift 1984; Swift and Nicholas 1987). Phosphorus-enrichment has dramatically altered species composition, reduced taxa richness, and stimulated the growth of pollution-tolerant species such as Microcoleus. Biostimulation (increased relative algal growth rates), increased periphyton community phosphorus content, and decreased algal N:P ratios have also been significantly correlated with increased water-column phosphorus concentrations.

Dosing studies in WCA-3A (Steward and Ornes 1975a,b) and ENP (Flora et al. 1987; Hall and Rice 1987) indicated that phosphorus enrichment results in elimination of calcareous periphyton in as little as 6 weeks. The calcareous periphyton were eliminated by other periphyton or phytoplankton species whose growth was stimulated by the phosphorus enrichment.

Raschke (1992) conducted studies on periphyton in Everglades National Park along a transect south of the S-12C inflow structure. Raschke's results indicated significant changes in periphyton community structure which were correlated with phosphorus enrichment from the structure.

3.1.5 Macrophyte Impacts

For thousands of years, sawgrass (Cladium jamaicense) marshes and aquatic sloughs have comprised a large percentage of the total vegetative cover of Everglades Protection Area marshes. Sawgrass grows either in pure or mixed stands. Sawgrass has lower phosphorus requirements than other marsh vegetation. It is this characteristic which gives sawgrass and indigenous Everglades slough vegetation a competitive advantage (Steward 1974). Phosphorus enrichment negates this competitive advantage and allows other macrophytes, such as cattail (Typha domingensis), to out compete and displace sawgrass marshes and slough communities.

Although cattail is widely distributed in small stands in oligotrophic Everglades areas (Davis in press), extensive cattail stands are not found in historical accounts or early maps of native Everglades environments and cattail is currently difficult to find in unenriched areas (Richardson et al. 1990; Kushlan 1990; Moore et al., 1989). Peat classifications for the Everglades have not included cattail peat (Davis 1946; Gleason et al. 1974; Cohen and Spachman 1974; Wieland 1981). In fact, soil studies indicate that sawgrass detritus has been the major component of Everglades histosols for 4000 years (McDowell et al. 1969). The primary occurrence of cattail in unenriched areas is in localized "nutrient rich" areas such as alligator holes and previous bird rookeries (Freiberg 1972; Richardson et al. 1990). All of these facts indicate that cattail extent was historically minimal and thus is not an important vegetative community in native Everglades environments.

Sawgrass longevity is five times that of cattail and the ability of sawgrass to take up and store phosphorus is one third that of cattail. Biomass and production responses of cattail enable it to be successful in environments prone to surges of phosphorus-enriched water. These characteristics have allowed cattail to out-compete sawgrass in phosphorus-enriched areas of the Everglades (Davis 1989,1991). Richardson et al. (1991) found that the phosphorus content of cattail shoots and roots (Figure 17) was much higher than sawgrass at all locations. Richardson et al. (1991) also found that cattail tissue exhibited a gradient of decreasing phosphorus from nutrient enriched to unenriched sites. A community shift to cattail under phosphorus-enriched conditions has been demonstrated by other investigators in a Michigan peat wetland (Kadlec 1987).

Numerous studies have documented cattail expansion in the Everglades in phosphorus-enriched areas. Richardson et al. (1990) found that cattail has recently dominated former sawgrass communities in aquatic sloughs and wet prairies in WCA-1. These conclusions were based on a series of photoplots and historic vegetative transects (Figure 18; Tables 2 and 3). Significant cattail occurrence was noted in 1987 photoplots but was not present in 1960s photoplots. Vegetative transect plot data substantiated these conclusions. Most (~90%) cattail are found within 1000 meters of the perimeter canal and virtually all cattail are less than 2000 meters from the canal. Richardson et al. (1990) estimated that 5,726 acres, or 4% of WCA-1, have been impacted by conversion to cattail. In a separate vegetative transect study in WCA-1, Doren et al. (1992) found a significant negative correlation between cattail and distance from the perimeter canal and positively correlated with soil phosphorus concentrations. Sawgrass, beakrush (Rhynchospora) and spikerush (Eleocharis) communities were positively correlated with distance from the canal and negatively correlated with soil phosphorus concentrations.

Cattail has become established in WCA-2A downstream of the S-10 structures and the S-7 pump station (Davis 1992; Koch and Reddy 1992; Doren et al. 1992). Davis (1992) noted that a monospecific cattail stand of ~6000 acres now exists below the S-10 structures and cattail has invaded an additional ~14,000 acres to produce a mixed cattail/sawgrass community in an area formerly composed primarily of sawgrass and slough communities. Occurrence of cattail stands (Figure 19) is significantly correlated to both surface water and soil phosphorus concentrations (Davis in press; Koch and Reddy 1991; Doren et al. in prep.).

Cattail has become established in WCA-3A along the western border and adjacent to structures S-339 and S-340. An extensive cattail stand now dominates the marsh near the confluence of the Miami Canal and L-67A and downstream of the S-339 and S-340 structures. This band of cattail continues southwest along the L-67A canal and has invaded gaps in the spoil bank to penetrate the WCA-3A marsh.

Steward and Ornes (1975a,b), in a dosing experiment in WCA-3B, found that phosphorus enrichment resulted in the elimination of bladderwort (Utricularia) and the macroscopic green alga, Chara, within a few weeks after the start of dosing. These species were eliminated by dense algal blooms which occurred as a result of the dosing.

In ENP, a band of cattail has been observed along the western border of the L-67 extension and south of the S-12 structures (Davis in press; Doren et al. in prep.; Gunderson 1992). Doren et al. (1992) found significant correlations between the occurrence of cattails and soil phosphorus concentrations. Phosphorus enrichment in a dosing study in ENP (Flora et al. 1987; Walker et al. 1987) resulted in a wet prairie/slough community shift from a spikerush/bladderwort assemblage to an assemblage dominated by maidencane (Panicum hemitomon), pickerelweed (Pondeteria lanceolata) and arrowhead (Sagittaria). Cattail have recently colonized the phosphorus-enriched channels of this study, and wet prairie/slough community recovery has not as yet occurred, even though the dosing was of limited duration (~ 2 years) and was discontinued more than six years ago (Urban et al. in review).

Some researchers have concluded that hydroperiod is a more important factor in determining Everglades vegetative patterns than phosphorus concentrations (Richardson et al. 1991). As stated in the introduction, nutrient concentrations, hydroperiod, and disturbances such as fire and frosts are all important factors in determining the innate heterogeneity of the Everglades. These factors all play a role in competition for community dominance between sawgrass, slough communities and cattail. Research indicates that Everglades sawgrass and slough communities prefer low nutrient levels, prolonged hydroperiods, shallow water depths, and 3 to 10 year burn intervals during the dry season, followed by gradual reflooding. Although less is known about cattails in the Everglades, its life history characteristics should give it a competitive advantage over sawgrass under deep water, high nutrient conditions (Urban et al. in review). However, without nutrient enrichment, cattails were never able to dominate deep-slough or other long-hydroperiod areas of the Everglades. The highly significant correlation between cattail distribution and soil phosphorus concentrations throughout the Everglades Protection Area (Urban et al. in review; Reddy et al. 1991) is convincing evidence that phosphorus availability significantly influences Everglades macrophyte community composition. Transects with uniform hydroperiod in WCA-1 and WCA-2A have significant correlations between cattail occurrence and phosphorus concentrations, indicating that phosphorus has a more significant influence than hydroperiod on macrophyte community composition. Urban et al. (in review) found that cattail displaced sawgrass during high water level years, however, nutrient enrichment accelerated this process by nearly an order of magnitude. Drought years reversed this process but the high resiliency and rapid biomass recovery characteristics of cattail allow it to make further inroads on the sawgrass community when favorable water levels return. Interspecific competition related to fire disturbances followed a similar pattern. They concluded that "Nutrient enrichment appears to support an expanding distribution and increasing density of cattail in sawgrass stands, during wet years and after fires, that is only temporarily set back by droughts."

Swift (1981) investigated correlations between periphyton communities and environmental factors such as phosphorus and major ion concentrations, pH, alkalinity, depth, and hydroperiod. He found that water column total phosphorus concentrations were the major factor controlling periphyton growth rates and phosphorus content, while phosphorus and major ion concentrations were the major factors controlling periphyton species composition. Depth and hydroperiod were not significantly correlated with periphyton growth rates, phosphorus content, or species composition in this study.

Finally, the ENP dosing study, which had the same hydroperiod in experimental and control channels, also experienced changes in community composition in phosphorus-enriched channels. The phosphorus-enriched channel eventually progressed to a cattail community (Flora et al. 1987; Walker et al. 1987; Hall and Rice 1987).

These factors all indicate that introduction of phosphorus from EAA drainage water are a primary cause of ecological changes which have occurred throughout substantial areas of Everglades marsh.

3.1.6 Macroinvertebrate Impacts

In WCA-1, the number of benthic macroinvertebrates collected by tub and stove pipe samplers was 46 percent higher while the total taxa collected was 32 percent lower between control and phosphorus-enriched stations (Terczak 1980). High individual numbers were accompanied by low species numbers, which generally corresponds to low diversity, a measure of ecosystem stability and maturity (Smith 1977). Other imbalances in macroinvertebrate fauna attributable to phosphorus enrichment were: 90 percent higher numbers of Dasyhelea sp. (which is tolerant of low dissolved oxygen concentrations), 65 percent lower numbers of freshwater shrimp Paleomonetes paludosa (an important food source), and the complete elimination of Asheum beckae, a saproxenous organism (i.e. moderately intolerant of organic enrichment). Hester-Dendy sampler data indicated 57 and 65 percent lower numbers of gastropods and ephemeropterans, respectively, at phosphorus-enriched sites.

In WCA-2A, the benthic macroinvertebrates population collected by tub and stove pipe samplers appeared severely stressed at a phosphorus-enriched site. Average taxa and total taxa collected at the phosphorus-enriched site were 50 and 73 percent less, respectively, than at the unenriched site (Terczak 1980). Other benthic macrofaunal imbalances attributable to phosphorus enrichment in WCA-2A included: a 76 percent decrease in Hyalella azteca (an important food source for fish), a 79 and 35 percent increase in Chironomus sp. and Tubifex tubifex, respectively (organisms considered tolerant of organically-enriched conditions), a 70 percent decrease in Ablabesmyia cinctipes, and complete elimination of Paleomonetes paludosa and Asheum backae. Hester-Dendy sampler data indicated an 83 percent decrease in gastropods and total elimination of ephemeropterans, odonates, trichopterans and decapods at phosphorus-enriched sites.

3.1.7 Fish & Wildlife Impacts

A major factor contributing to the value of the Everglades as wildlife habitat is its spatial complexity and diversity (LOTAC II 1990). A reduction in community heterogeneity due to phosphorus enrichment adversely impacts fish and wildlife. Although cattail stands may increase diversity initially, dense homogeneous stands of this species is detrimental to native Everglades fauna by replacing favorable habitat and food sources. Zaafke (1984) and Hoffman et al. (1990) reported that wading birds avoided dense stands of cattail. Federally endangered Everglades kites (Rostrhamus sociabilis) require sparse emergent vegetation with considerable open water for locating apple snails, their preferred food, and are unable to successfully forage in dense vegetation (Sykes 1987). Although kites may attempt to build nests in cattail, survival of these nests is rare (United States Fish and Wildlife Service 1983). In WCA-3, the least bittern (Ixobrychus exilis), a wading bird which prefers dense vegetation, was observed much more frequently in pure sawgrass and mixed sawgrass/cattail stands than in dense cattail (Frederick et al. 1990). Steiglitz (1965) indicated that approximately 80 percent of the diet of ducks utilizing WCA-1 consisted of beaked-rush, sawgrass seeds and smartweed (Polygonum spp). In general, homogeneous cattail stands are impenetrable, and provide poor quality wildlife habitat (Gilbert 1987; Sincock 1957).

3.1.8 Imbalance Summary

Phosphorus enrichment has resulted in changes in the soil and water column microbial communities, with associated impacts on detritus characteristics, which would impact food web structures and nutrient uptake pathways (Reeder and Davis 1983). Phosphorus-enrichment has dramatically altered periphyton species composition, reduced taxa richness, and stimulated the growth of pollution-tolerant species such as Microcoleus. Increased algal growth rates and algal phosphorus content, and decreased algal N:P ratios have also been significantly correlated with increased water-column phosphorus concentrations (Swift and Nicholas 1987). Cattail invasion, some existing in dense monocultures, is extensive throughout the Everglades Protection Area (Davis in press) and its occurrence is correlated with soil and water column phosphorus concentrations (Koch and Reddy 1991). Cattail monocultures have been associated with reduced diversity of bird and fish species (Gilbert 1987). Benthic macroinvertebrate data indicate reduced diversity, proliferation of pollution-tolerant species, and reduction or elimination of pollution-sensitive species in phoshorus-enriched areas.

Documented impacts at virtually all trophic levels in wide spread areas of the Everglades is conclusive evidence of violations of the Class III "imbalance" criterion. Concern over these violations is heightened by the Everglades' status as an important international resource which is habitat for a unique and characteristic assemblage of flora and fauna, many of which are threatened or endangered.

3.2 Nuisance Species

Criterion 17-302.510(3)(q), F.A.C., states "Substances in concentrations which result in the dominance of nuisance species - none shall be present." Nuisance species is defined in Rule 17-302.200(14), F.A.C. as "species of flora or fauna whose noxious characteristics or presence in sufficient numbers, biomass, or areal extent may reasonably be expected to prevent, or unreasonably interfere with, a designated use of those waters." The designated use for Class III waters is defined in Rule 17-302.400(1) as "Recreation, Propagation and Maintenance of a Healthy, Well-Balanced Population of Fish and Wildlife."

Elevated phosphorus concentrations have caused the elimination of native mixed autotrophic (oxygen producing) periphyton communities and their replacement by flora dominated by pollution indicator species such as the filamentous blue green alga, Microcoleus (Belanger and Platko 1986). Elevated phosphorus concentrations have also caused a shift from aerobic and facultative microbial communities to obligate anaerobes as the primary mode of leaf decomposition (Reeder and Davis 1983). Cattail invasion, some existing in dense monocultures, is extensive throughout the Everglades Protection Area (Davis 1991) and its occurrence is significantly correlated with soil and water column phosphorus concentrations (Koch and Reddy 1991; Reddy et al 1992; Doren et al. in prep.). Nutrient induced dominance of microbial, algal and macrophyte species which would not normally be expected to be present in the Everglades in large numbers or areal extent would have a strong potential to interfere with the maintenance of indigenous Everglades fish and wildlife populations, therefore these documented impacts represent violations of the nuisance species criterion.

3.3 Biological Integrity

Criterion 17-302.560(7), F.A.C., states "Biological Integrity - the Shannon-Weaver diversity index of benthic macroinvertebrates shall not be reduced to less than 75% of established background levels as measured using organisms retained by a U.S. Standard No. 30 sieve and, in predominantly fresh waters, collected and composited from a minimum of three Hester-Dendy type artificial substrate samplers of 0.10 to 0.15 m2 area each, incubated for a period of four weeks..."

In WCA-1 and WCA-2A, macroinvertebrates were collected (Terczak, 1980) on two separate sampling dates by methods compatible with the Class III biological integrity criterion. In each WCA, two stations were established to assess background conditions while one station was located in an area of phosphorus enrichment. Shannon-Weaver diversity was calculated for all stations and sampling dates. Background stations were averaged for each sampling date in each WCA. Based on this analysis, the WCA-1 phosphorus-enriched site was in violation of the biological integrity criterion (29 percent reduction) on one of two samplings.

The WCA-2A phosphorus-enriched site was in violation of the biological integrity criterion (31 and 100 percent reductions) on both sample dates.

3.4 Dissolved Oxygen

Criterion 17-302.560(13), F.A.C., states "Dissolved Oxygen - in predominantly fresh waters, the concentration shall not be less than 5 milligrams per liter. ... Normal daily and seasonal fluctuations above these levels shall be maintained in ... predominantly fresh waters ..." Dissolved oxygen concentrations in macrophyte dominated environments such as the Everglades routinely fall below the Class III standard of 5 mg/l on a diel basis due to plant respiration. These variations represent the normal diurnal variability typical for this type of ecosystem, therefore the Department does not consider these variations violations of the Class III dissolved oxygen standard. Review of interior marsh data indicates that this phenomenon occurs throughout the Everglades marshes.

However, comparison of paired dissolved oxygen and total phosphorus data (Figures 20, 21) indicates that phosphorus-enriched areas of marsh have dissolved oxygen concentrations which are significantly depressed when compared with unenriched areas. Normal daily and seasonal dissolved oxygen fluctuations were also depressed (Figure 22), in fact, nutrient-enriched sites barely exhibit any diurnal dissolved oxygen fluctuations (Belanger et al, 1989). Significant depression of dissolved oxygen concentrations and suppression of the normal daily and seasonal variability at nutrient-enriched sites do constitute violations of the Class III dissolved oxygen criterion. Data indicate that such violations are occurring at sites throughout the Everglades Protection Area.

4. PHOSPHORUS CONCENTRATIONS NECESSARY TO ACHIEVE COMPLIANCE WITH APPLICABLE CLASS III CRITERIA

The SFWMD, in the draft Everglades SWIM Plan and their application for structures discharging into or within the Everglades Protection Area, has proposed 50 ppb as a technically-based interim concentration limit for total phosphorus. This total phosphorus interim concentration limit of 50 ppb is necessary to initiate achieving and maintaining compliance with applicable state water quality standards to the maximum extent practicable. However, the 50 ppb may not be sufficient to meet the ultimate total phosphorus threshold levels to be determined by research. The weight of evidence (field observations, measurements and experiments) indicates that the total phosphorus concentrations ultimately necessary to fully achieve and maintain compliance with applicable Class III criteria are well below 50 ppb. Research data, evaluation, interpretation, and expert scientific and engineering opinion indicates that this concentration is technically achievable through a combination of Best Management Practices (BMPs) and Stormwater Treatment Areas (STAs).

Phosphorus data for inflow structures to ENP indicate that long-term median total phosphorus concentrations range from 7 to 14 ppb (Walker 1991). Data for interior marsh sites within Everglades National Park indicate elevated soil phosphorus concentrations south of the S-12 structures extending roughly 1 km into the park (Doren et al. in prep.). A band of cattail has become established along the western border of the L-67 extension and south of the S-12 structures (Davis in press; Doren et al. in prep.; Gunderson 1992). Doren et al. (in prep.) found significant correlations between the occurrence of cattails and soil phosphorus concentrations. Jones (1992a,b) has found an inverse correlation between alkaline phosphatase activity and soil phosphorus concentrations. The fact that cattail have become established and the microbial community has been impacted in areas of Everglades marsh which have historically received phosphorus concentrations well below the proposed 50 ppb level is strong evidence that 50 ppb is a higher concentrations than what will ultimately be necessary to fully achieve and maintain compliance with applicable Class III criteria.

In an ENP dosing study (Flora et al. 1987; Walker et al. 1987; Hall and Rice 1987) orthophosphate concentrations averaged 33 and 34 ppb. In this study, phosphorus enrichment, even at concentrations below 50 ppb, resulted in elimination of calcareous periphyton in as little as 6 weeks. A wet prairie/slough community shift from a spikerush/bladderwort assemblage to an assemblage dominated by maidencane (*Panicum hemitomon*), pickerelweed (*Pondeteria lanceolata*) and arrowhead (*Sagittaria*) also occurred as a result of the phosphorus enrichment. Cattail have recently colonized the phosphorus-enriched channels of this study, and wet prairie/slough community recovery has not as yet occurred, even though the dosing was of limited duration (~ 2 years) and was discontinued more than six years ago (Urban et al. in review).

Data for WCA-2A also indicate that extensive cattail expansion and relative dominance has occurred at locations with surface water total phosphorus concentrations of well below 50 ppb (Davis et al. in review; Koch and Reddy 1991)

Finally, comparison of paired dissolved oxygen and total phosphorus data from interior marsh stations throughout the Everglades Protection Area (SFWMD unpublished data) indicates that phosphorus-enriched areas of marsh have dissolved oxygen concentrations which are significantly depressed when compared with unenriched areas. Regression analysis of these data also indicate that the total phosphorus concentration below which normal daily and seasonal dissolved oxygen fluctuations are depressed and violations of the Class III dissolved oxygen criterion occur lies well below the 50 ppb level.

5. CONCLUSIONS

The Everglades are a unique national resource which provides habitat for large populations of wading birds and numerous threatened and endangered species. Around 50 percent of the original Everglades ecosystem has been drained and converted to agricultural and urban land uses. Introduction of phosphorus from EAA drainage water has resulted in ecological changes over large areas of Everglades marsh.

Review of available data and literature indicates that phosphorus-enriched water discharged from the EAA to the Everglades Protection Area has caused or contributed to at least four major and widespread violations of Class III water quality criteria: imbalances of aquatic flora or fauna, dominance of nuisance species, biological integrity, and dissolved oxygen. The communities most directly affected are the microbial decomposers, periphyton, macrophytes, and macroinvertebrates. Through food-web perturbations and alteration of the physical and chemical characteristics of the habitat, fish, waterfowl, wading birds, and other higher organisms are also affected.

Field observations, measurements and experiments indicate that that the total phosphorus concentrations necessary to fully achieve and maintain compliance with applicable Class III water quality standards are well below 50 ppb.

These findings are the result of an extensive review of available information pertaining to nutrient-induced impacts to the Everglades. Analysis of scientific information on these issues is ongoing, so this review represents the Department's findings to date.

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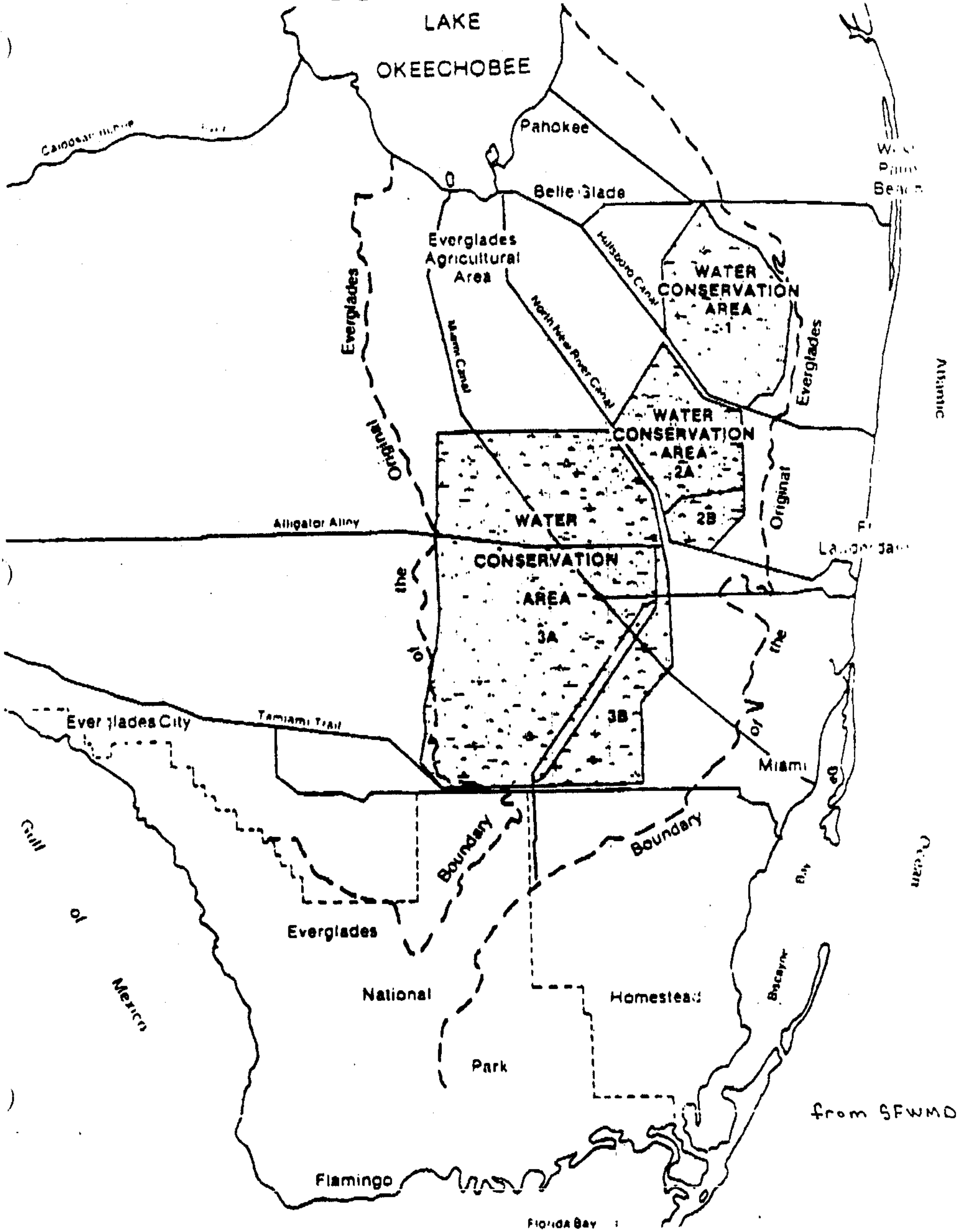
FIGURE 2



LAKE
OKEECHOBEE
Pahokee
Belle Glade
Everglades
Agricultural
Area
Hillsboro Canal
North New River Canal
Miami Canal
WATER
CONSERVATION
AREA
1
WATER
CONSERVATION
AREA
2A
2B
WATER
CONSERVATION
AREA
3A
3B
Alligator Alley
Tamiami Trail
Original
Everglades
the
of
Boundary
Miami
Atlantic
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National
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Flamingo
Florida Bay
Gulf
of
Mexico
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FIGURE 3

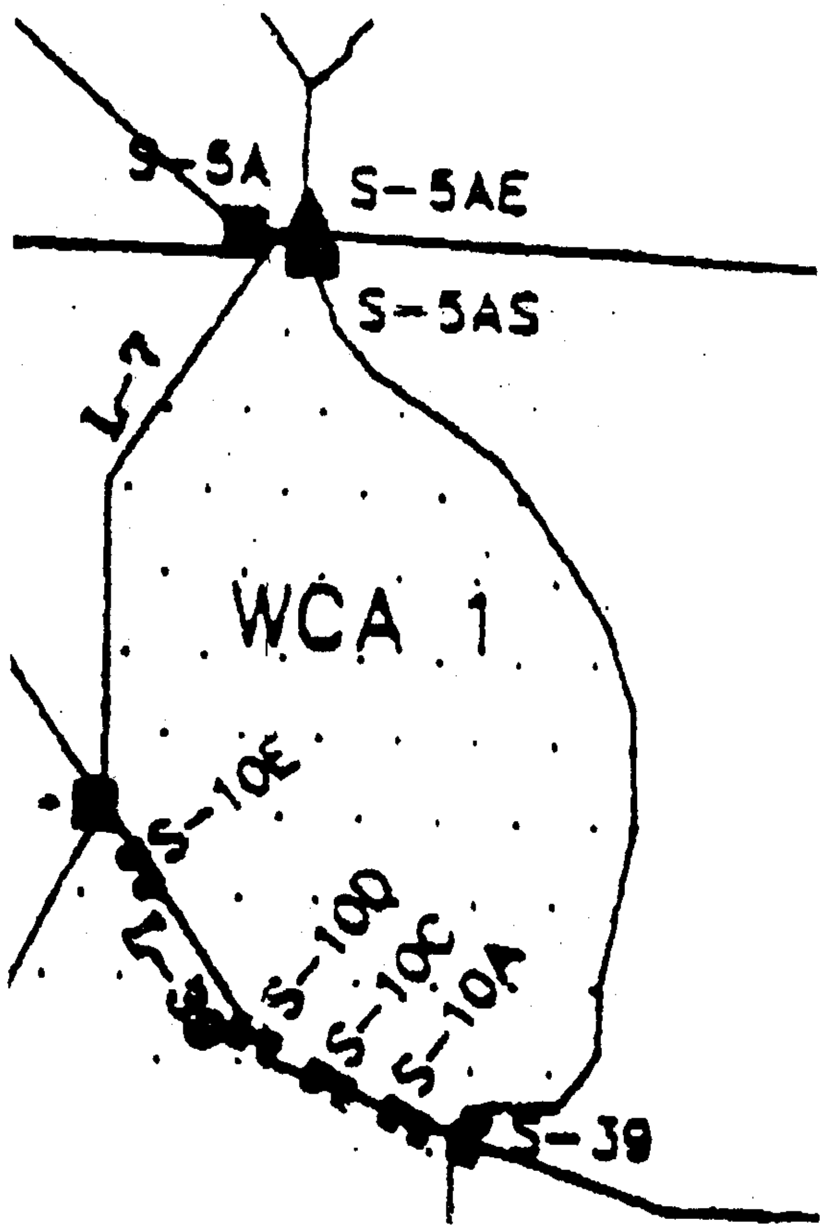

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FIGURE 4

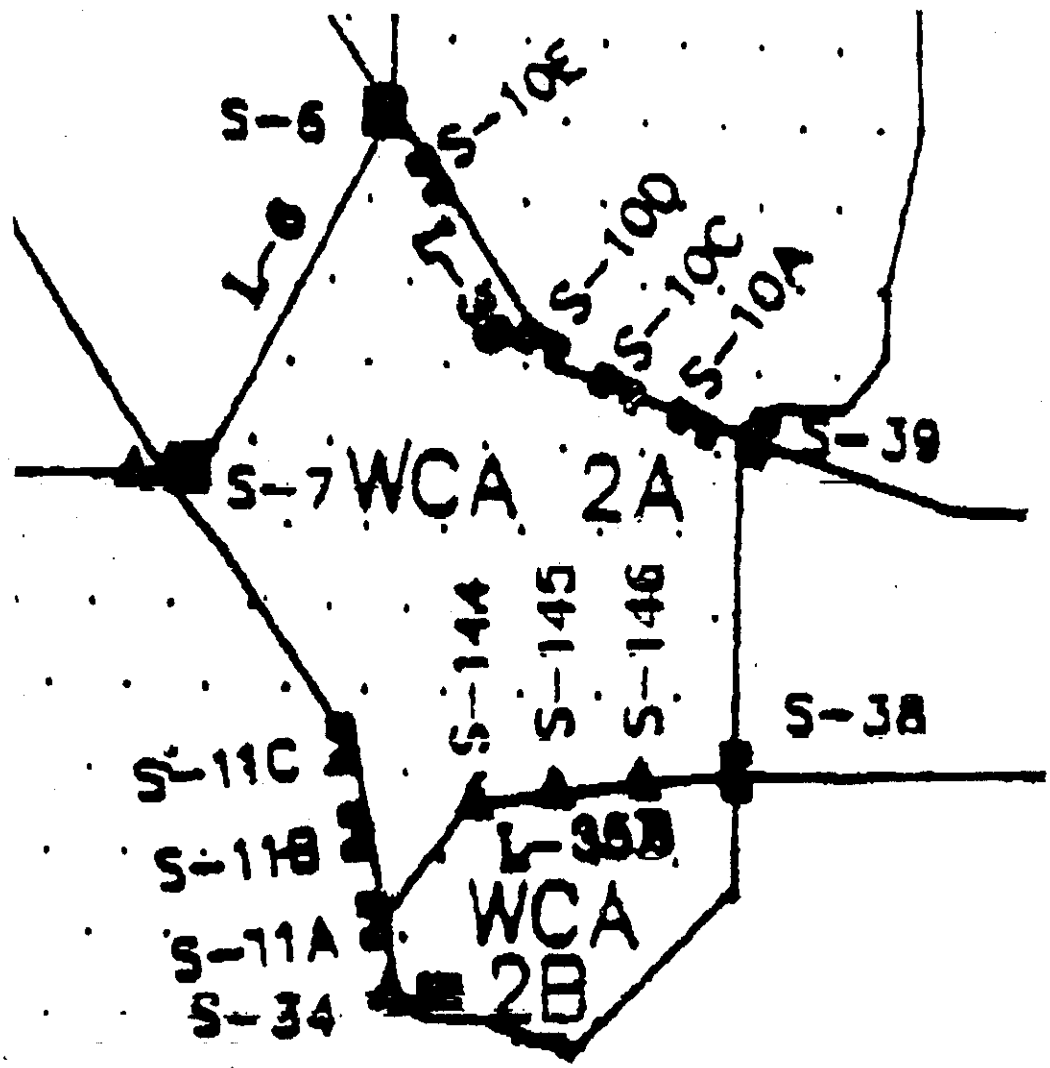

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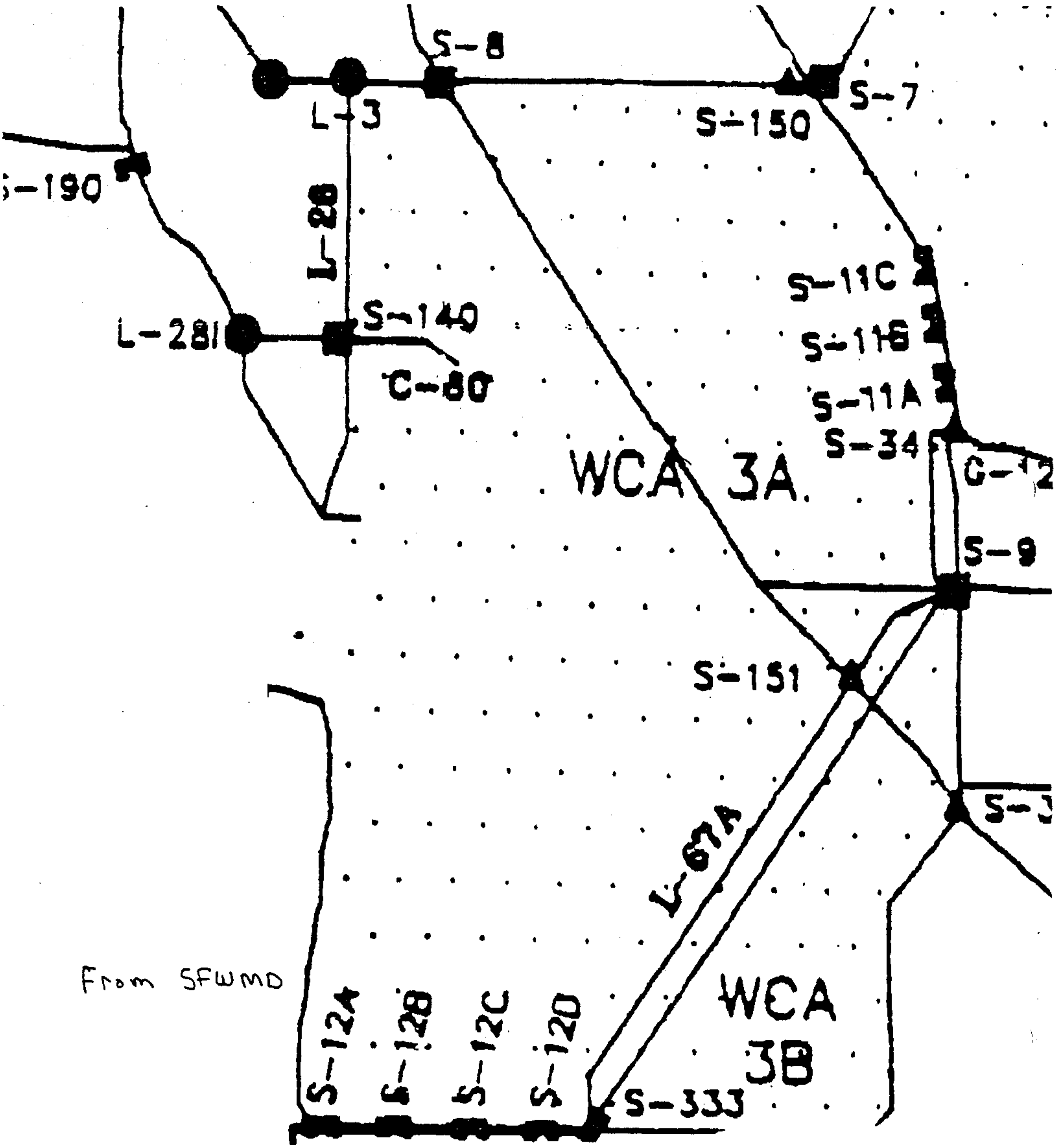
FIGURE 5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S-7
L-3
S-150
S-190
L-28
S-11C
S-140
S-11B
L-28I
C-60
S-11A
S-34
WCA 3A
S-9
S-151
L-67A
From SFWMD
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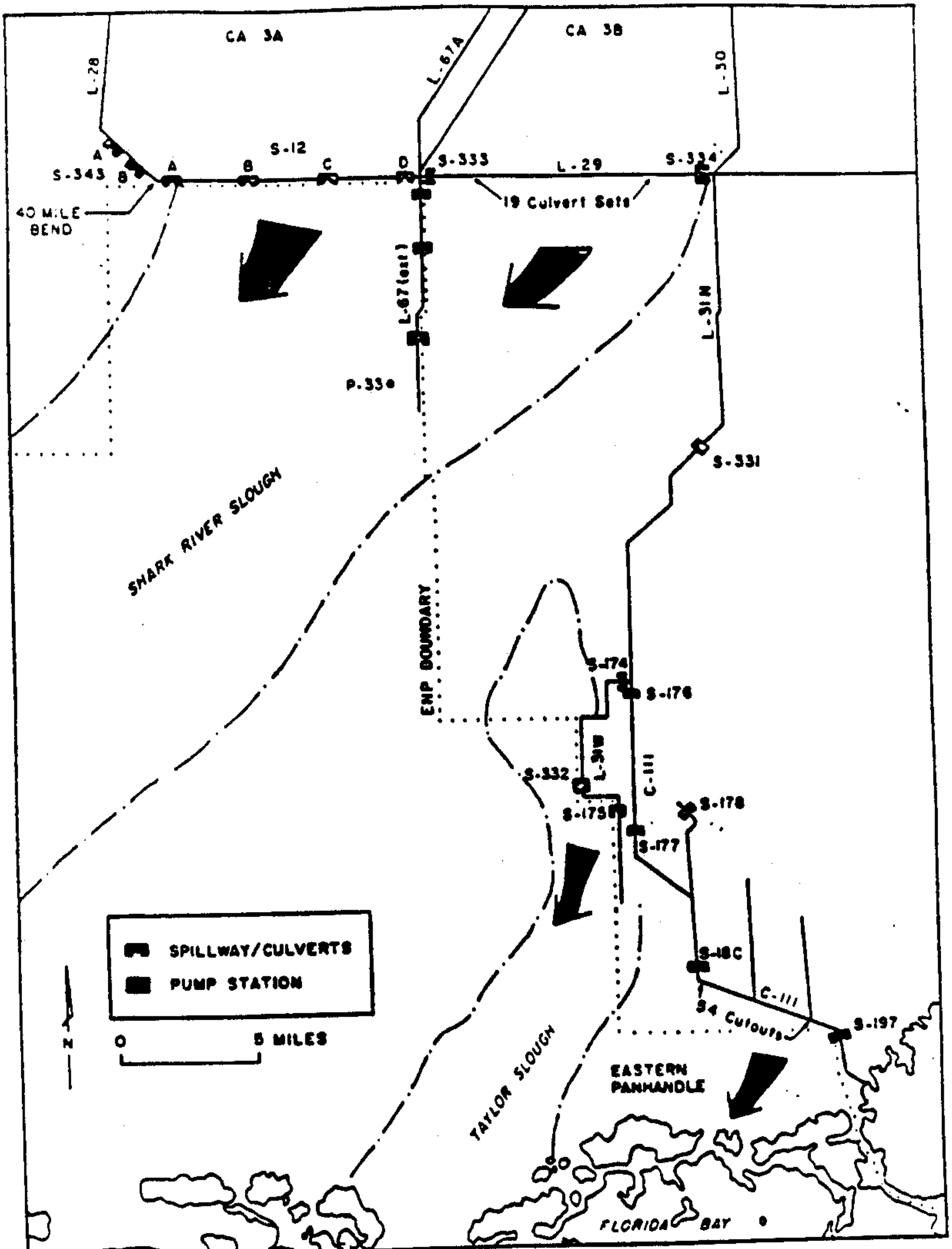
3B
S-12A
S-12B
S-12C
S-12D
S-333

FIGURE 6

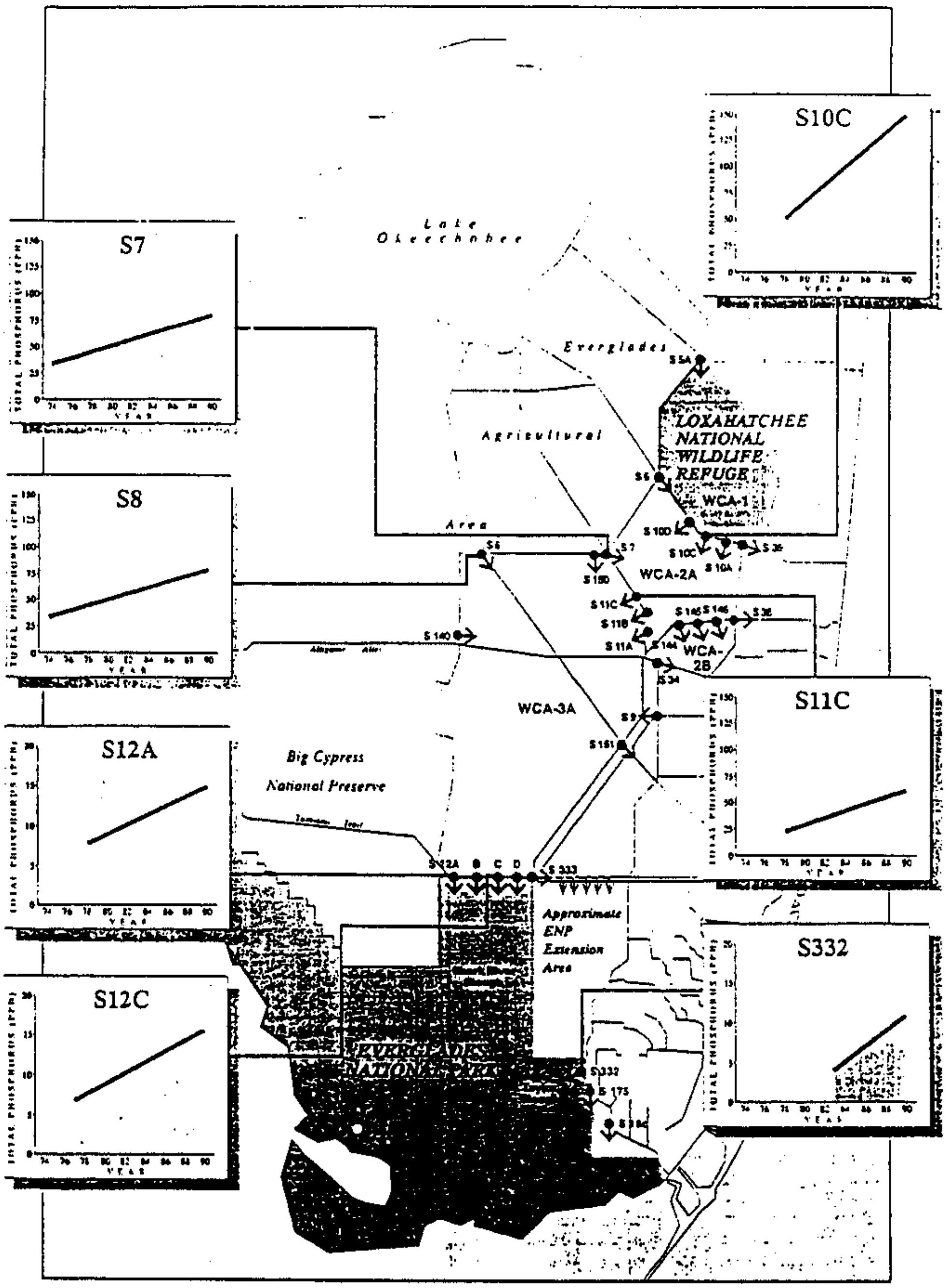


WATER DELIVERY SYSTEMS TO SHARK SLOUGH, TAYLOR SLOUGH, AND THE EASTERN PANHANDLE BASINS OF EVERGLADES NATIONAL PARK.

Increasing Trends in Phosphorus Concentrations

Note: No Stations Have Significant Decreasing Trend

FIGURE 7



Water Management Structure (arrows indicate direction of flow)

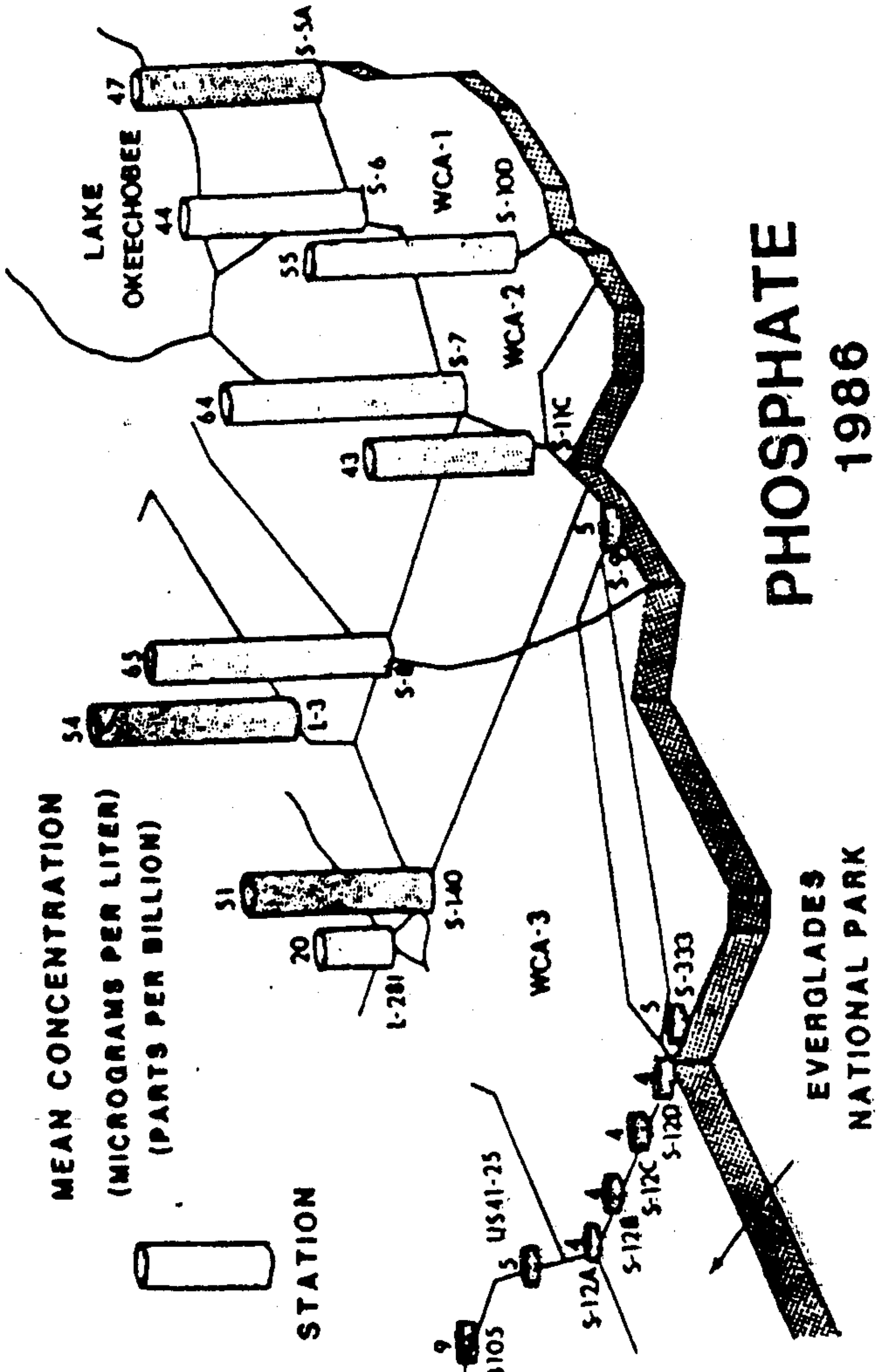
Monitoring Station at Water Management Structure with Significant Increasing Trend

Long Term Trend Line

Phosphorus Measured as ppb (parts per billion)
S7,S8,S10C,S11C: Ordinate Scale 0-150 ppb
S12A,S12C,S332: Ordinate Scale 0-20 ppb

Source: SFWMD WCA Inflow/Outflow Monitoring Data

FIGURE 8



PHOSPHATE
1986
MEAN CONCENTRATION
(MICROGRAMS PER LITER)
(PARTS PER BILLION)
STATION
LAKE
OKEECHOBEE
WCA-1
WCA-2
WCA-3
EVERGLADES
NATIONAL PARK
S-5A
S-6
S-7
S-8
S-9
S-10D
S-11C
S-140
L-3
L-28I
S-333
S-12A
S-12B
S-12C
S-12D
US41-25
BIOS
47
44
55
64
43
65
54
51
20
5
4
9

FIGURE 9

(Doren et al. in prep)

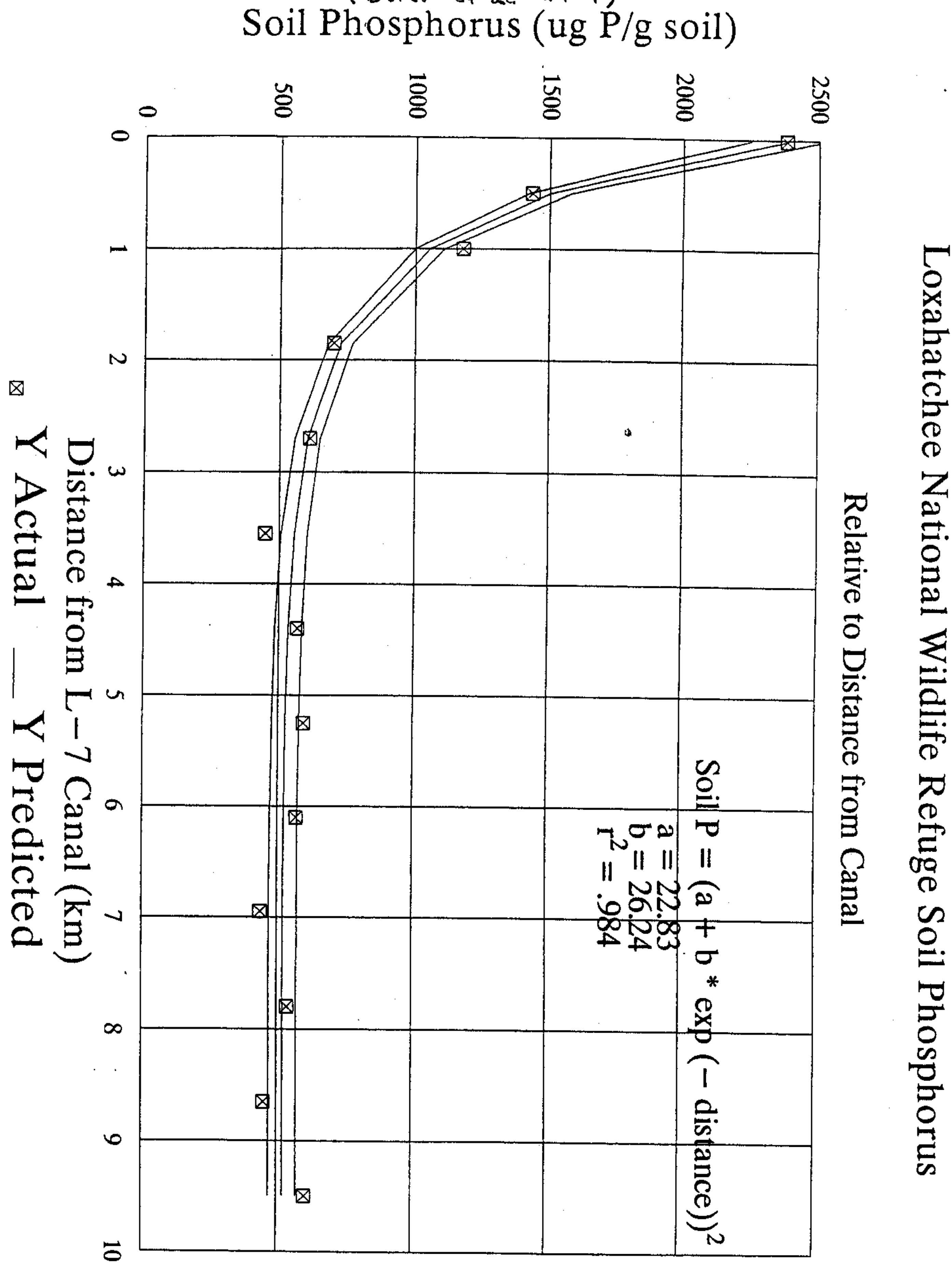
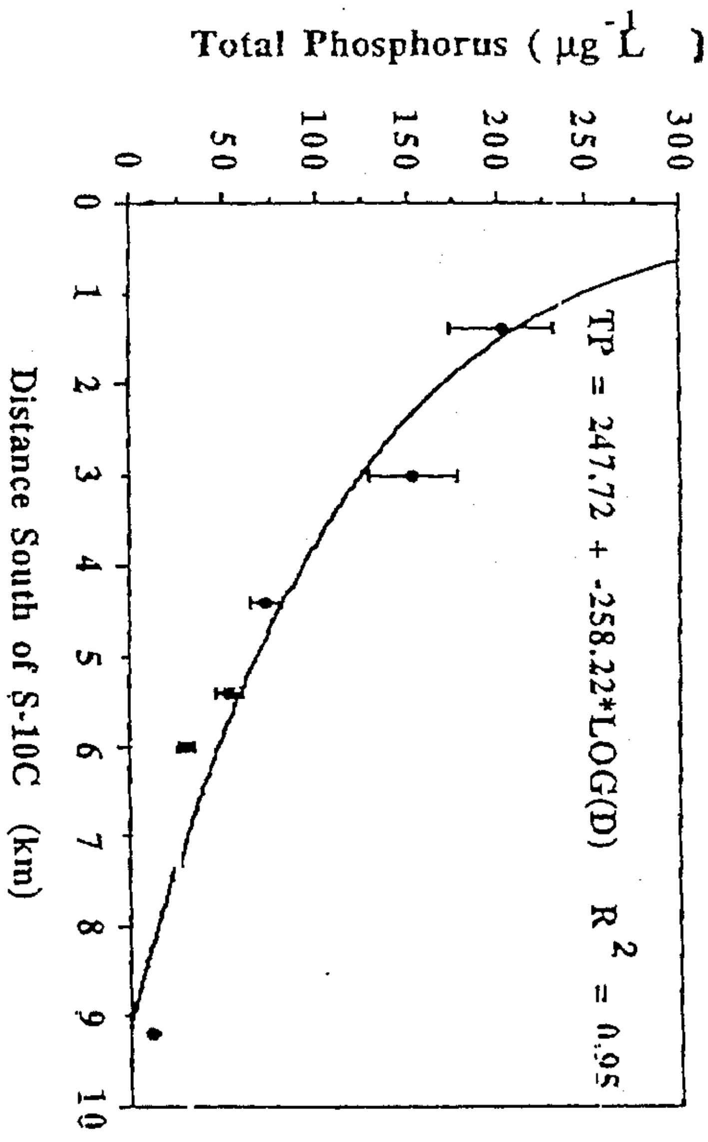
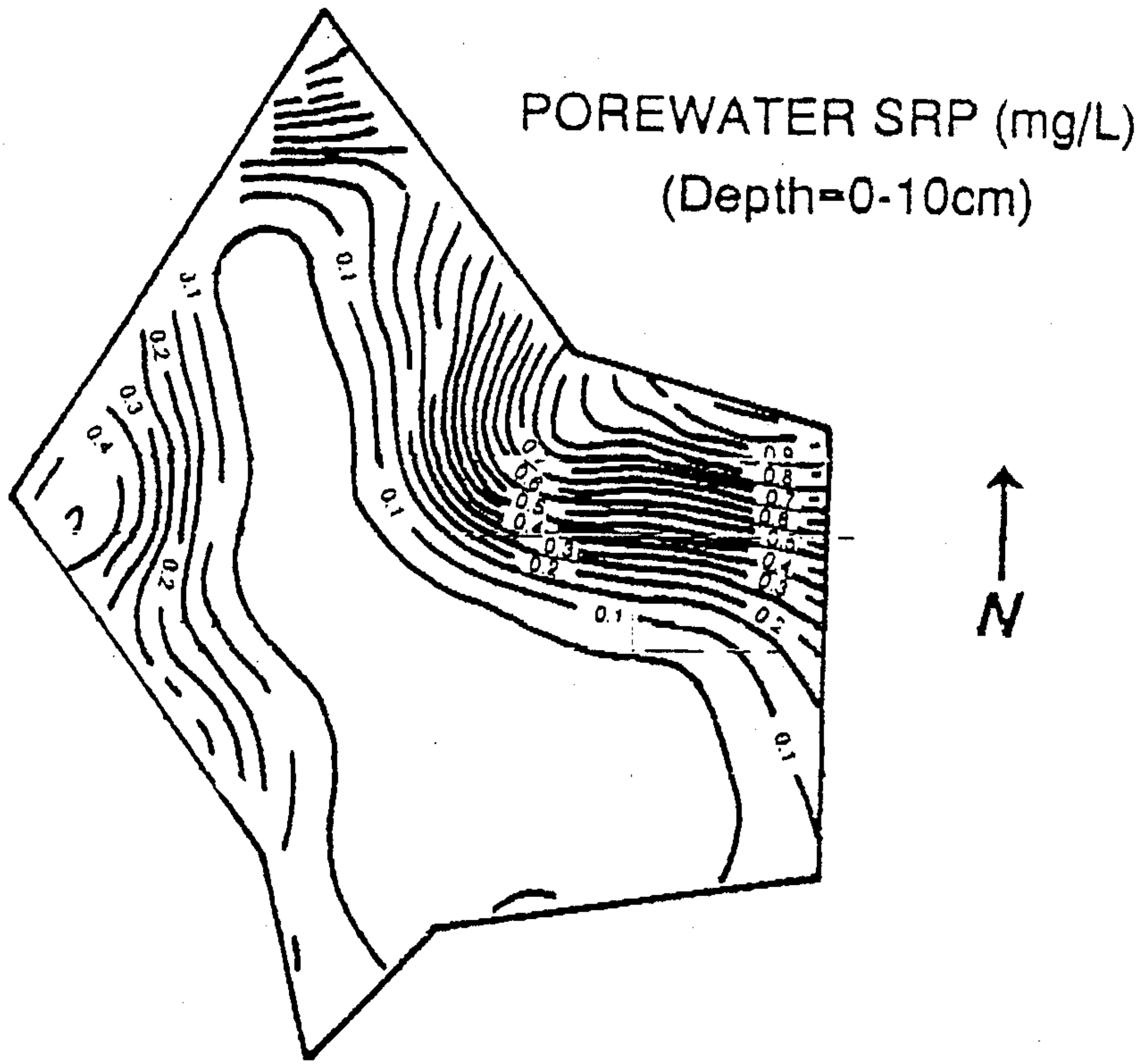


FIGURE 10



From Koch and Reddy 1992

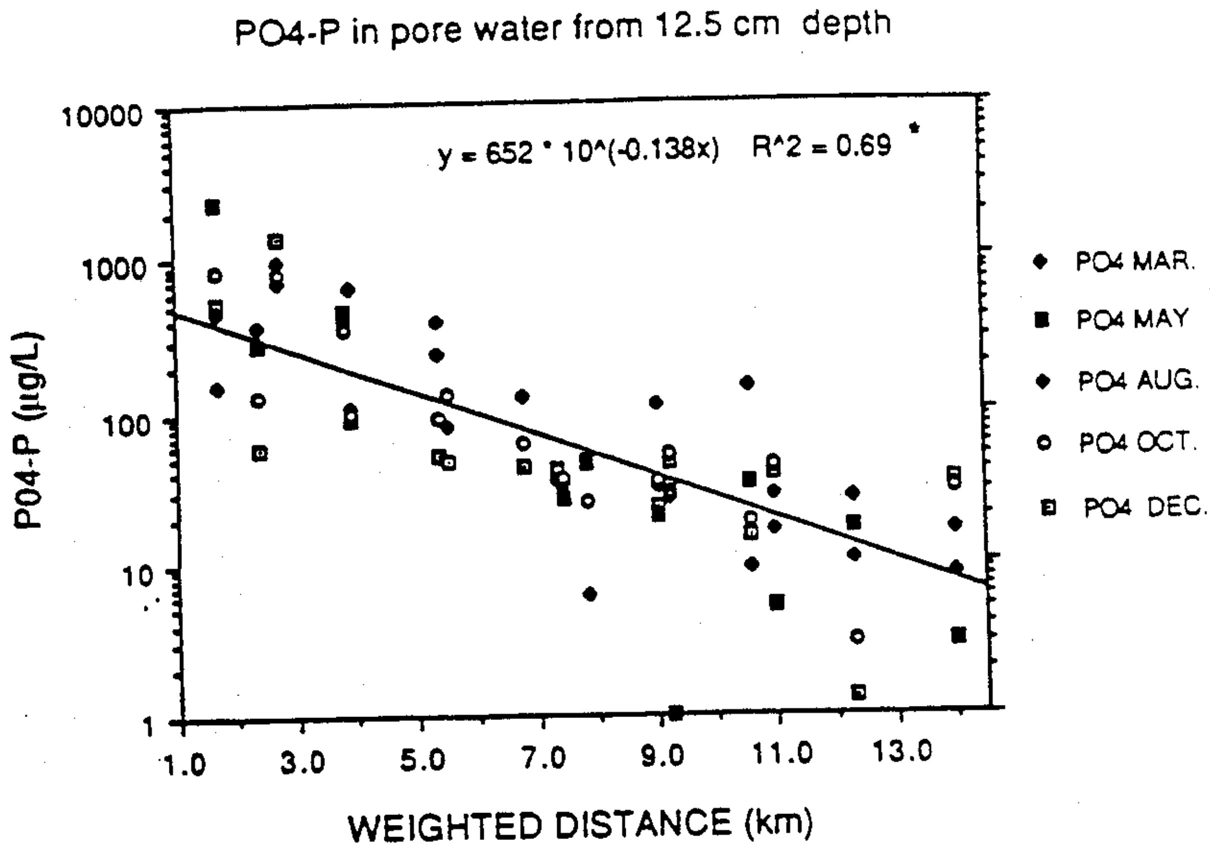
FIGURE 11



From

Koch & Reddy, 1991

FIGURE 12



PO4-P in pore water from the 12.5 cm depth vs. weighted distance along nutrient gradient in WCA-2A. The y-axis is logarithmic. Data for various months are indicated but do not indicate consistent seasonal differences.

From Richardson et al. 1991

FIGURE 13

(From Koch and Reddy 1992)

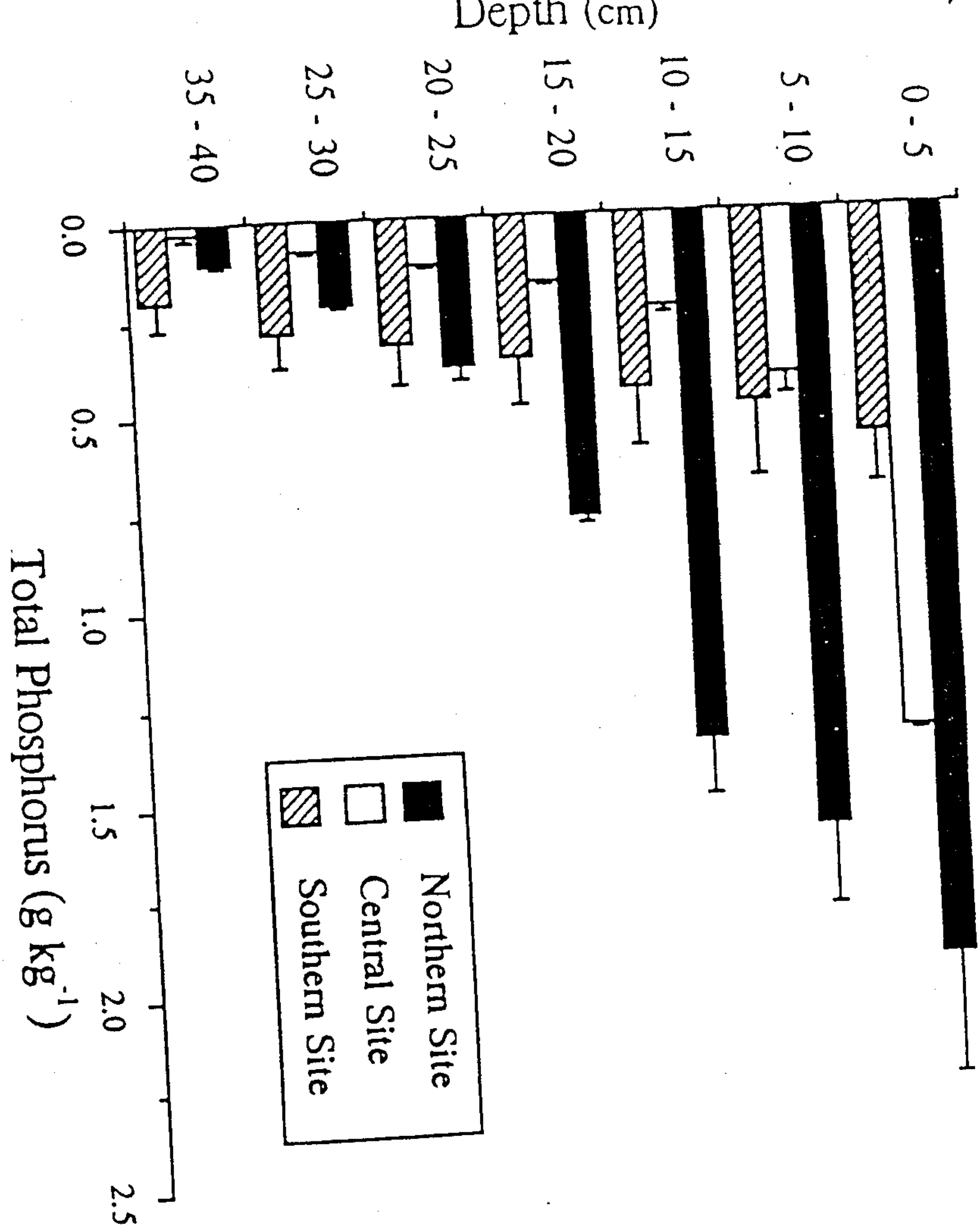
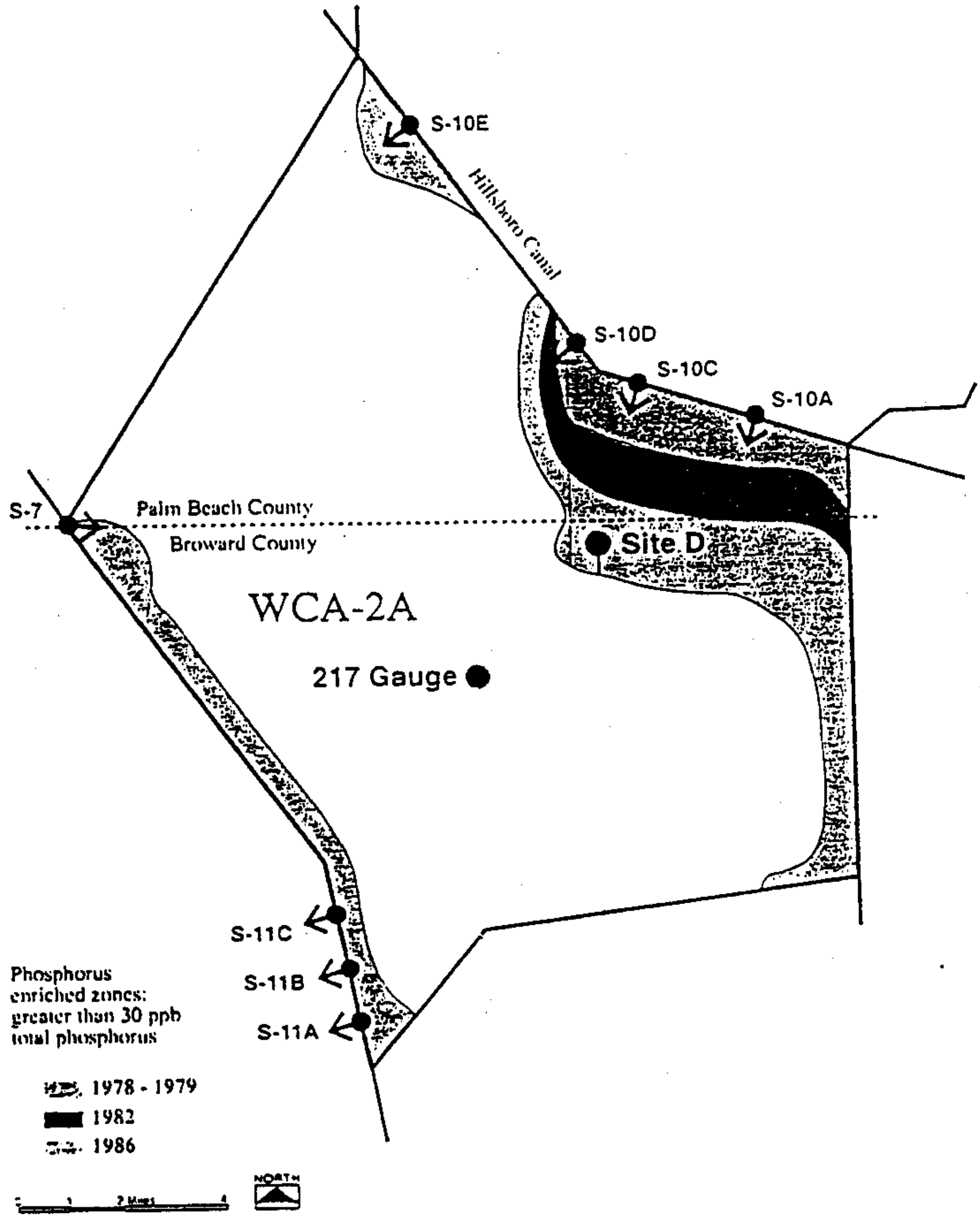


FIGURE 14

Progression of Nutrient Front: 1978-1986



Data: SFWMD

FIGURE 15

(From Doren et al in Pre

Everglades National Park Soil Total Phosphorus

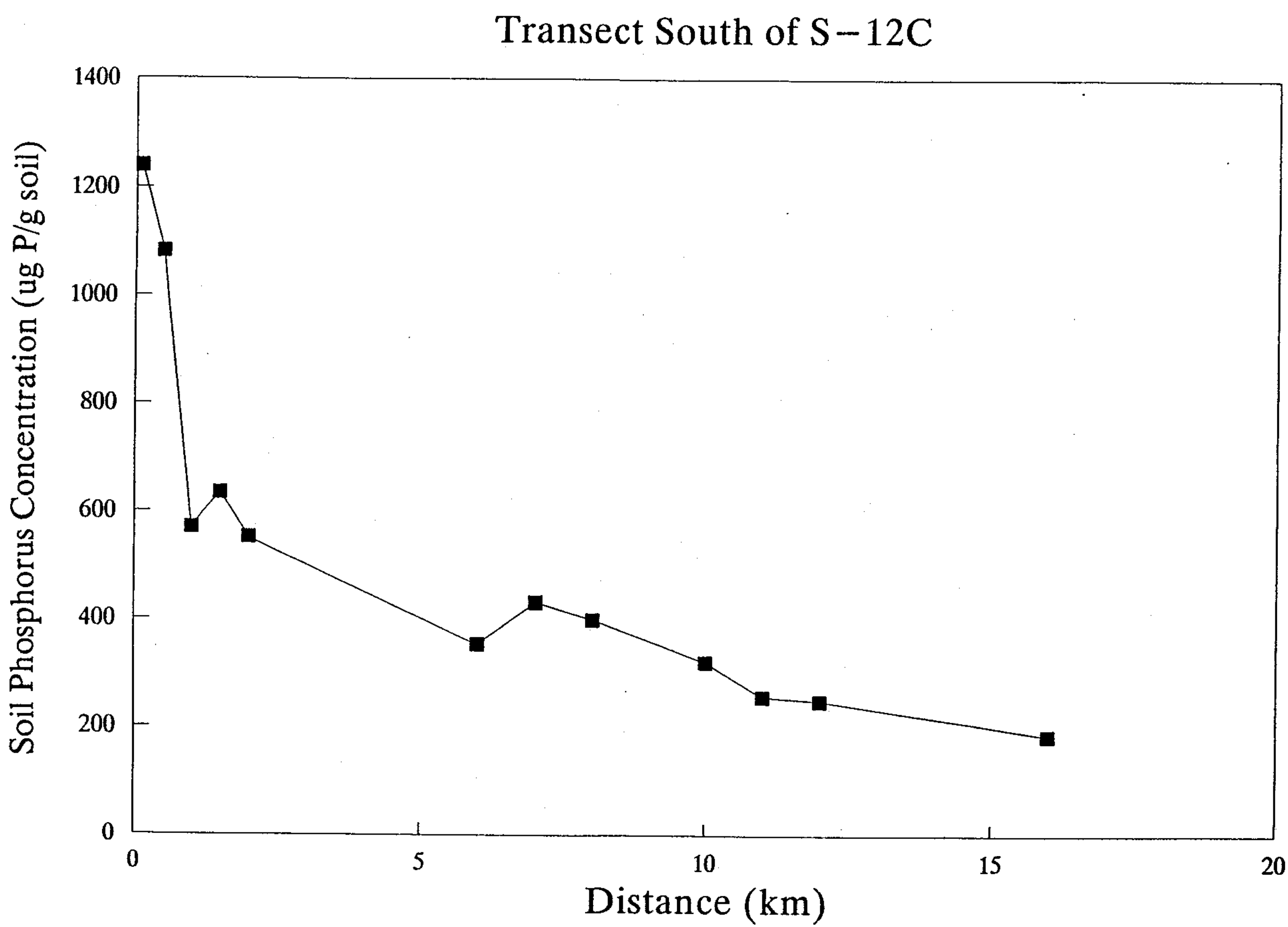
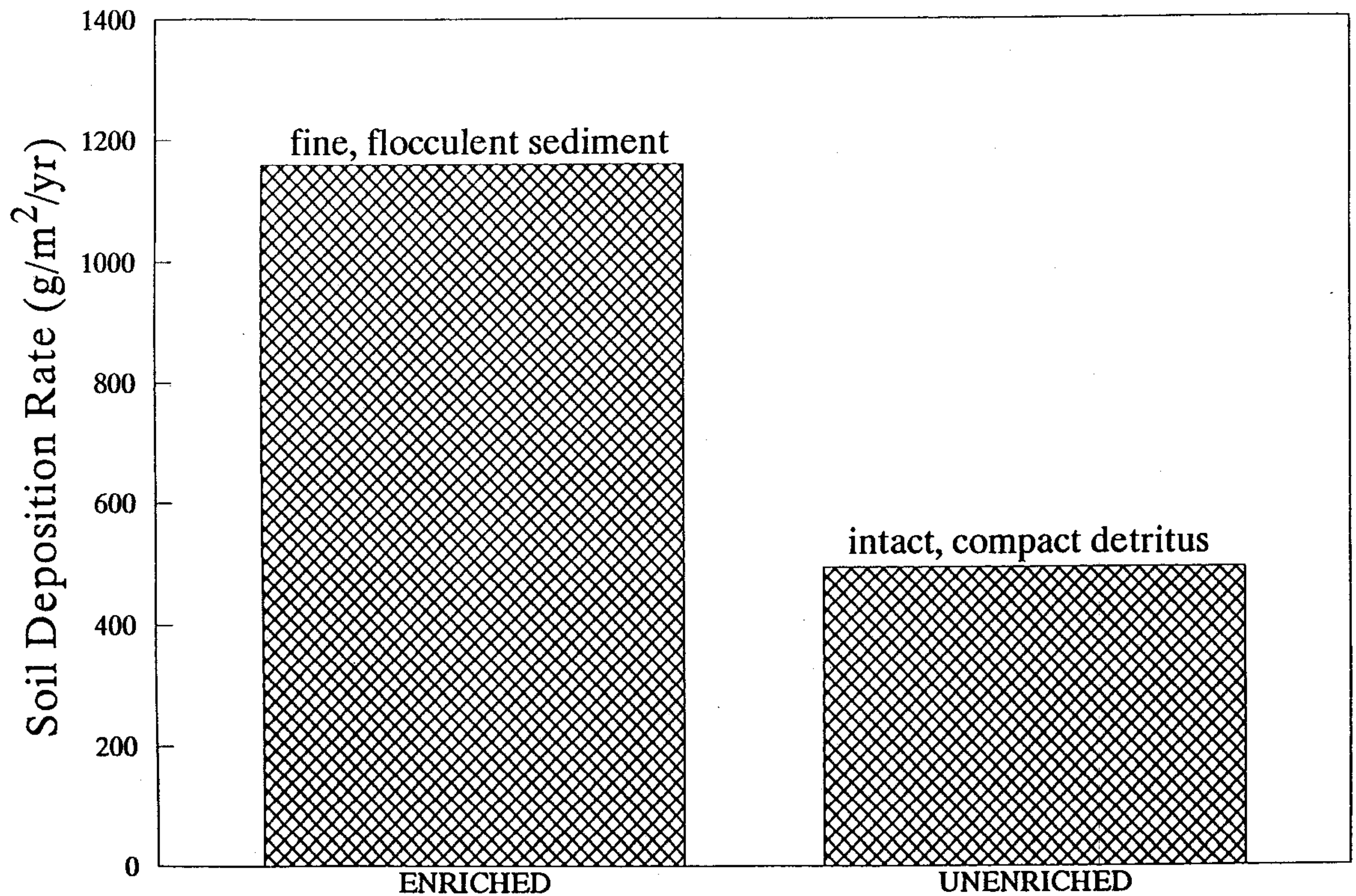


FIGURE 16
WCA – 2A Sediment Characteristics

Enriched versus Unenriched Sites



Everglades Alkaline Phosphatase vs Soil Total Phosphorus

Combined Data – WCA–1, WCA–2A, WCA–3A, ENP

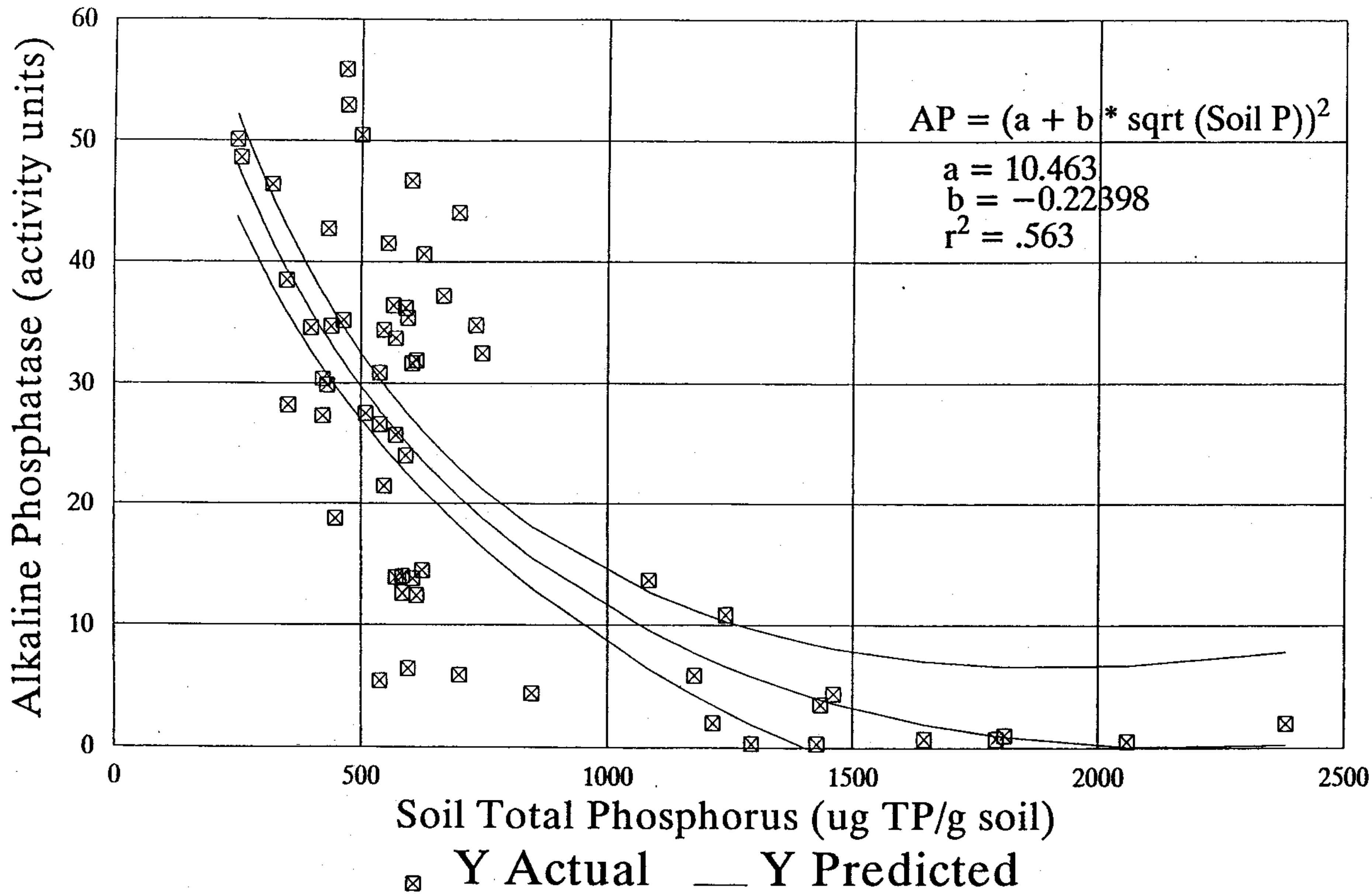
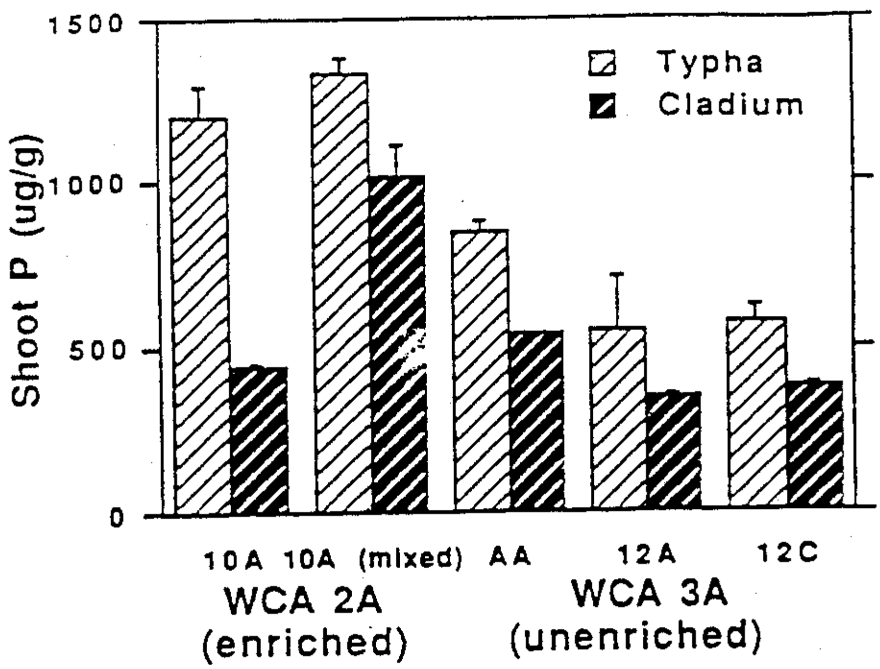
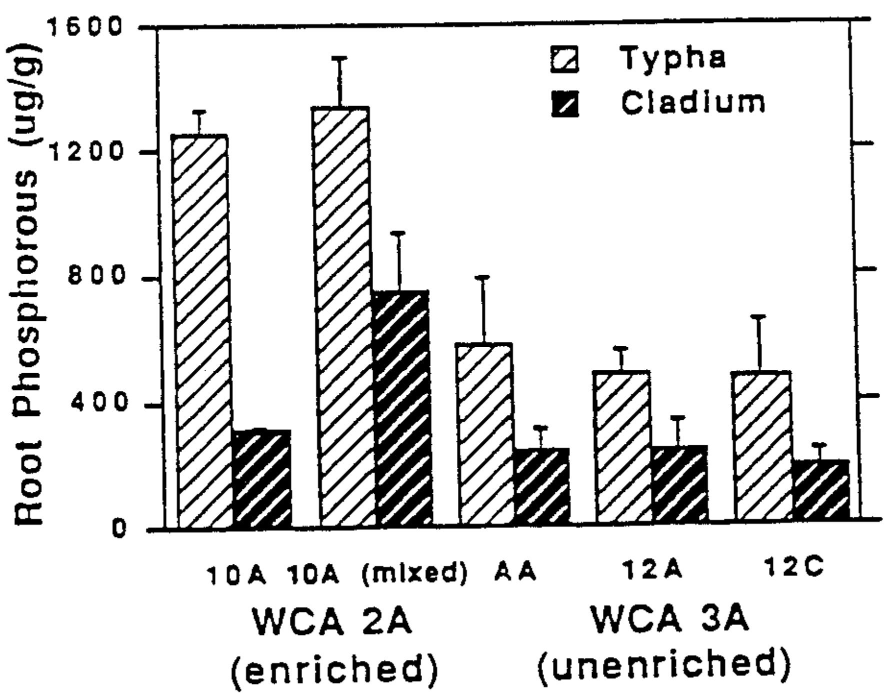


FIGURE 18

(From Richardson et al. 1991)

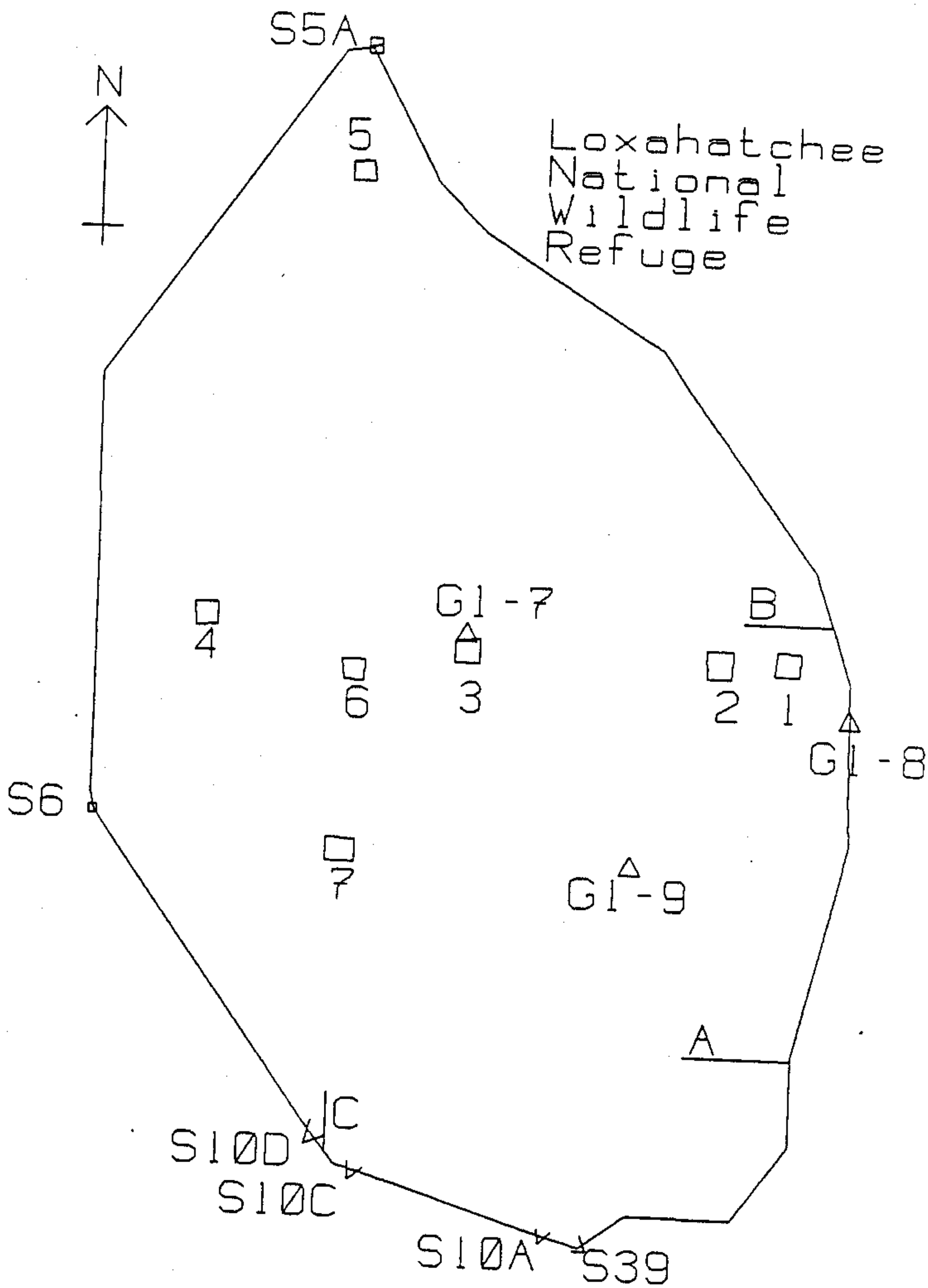


Phosphorus content of cattail (*Typha*) and sawgrass (*Cladium*) shoots collected from WCA-2A and WCA-3A.



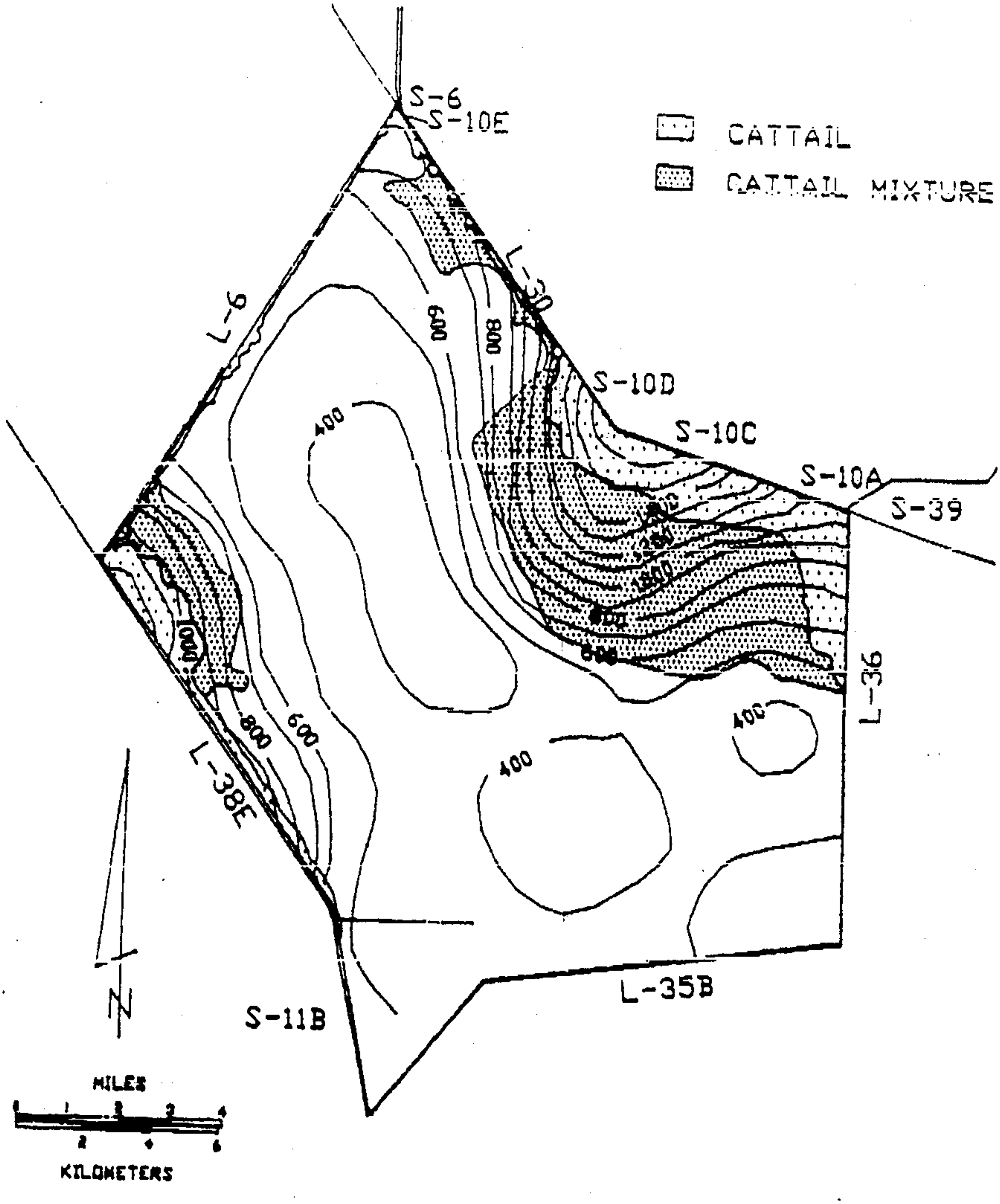
Phosphorus content of cattail (*Typha*) and sawgrass (*Cladium*) roots collected from WCA-2A and WCA-3A.

FIGURE 19



Map showing location of vegetation photoplots (1-7), vegetation transects (A-C), and gaging stations.

FIGURE 20



Cattail distribution and sediment total P isopleths (mg P kg^{-1} dry soil) in Water Conservation Area 2A. Phosphorus data from Reddy (1991).

FIGURE 21

Everglades Interior Marsh DO & TP Relationship

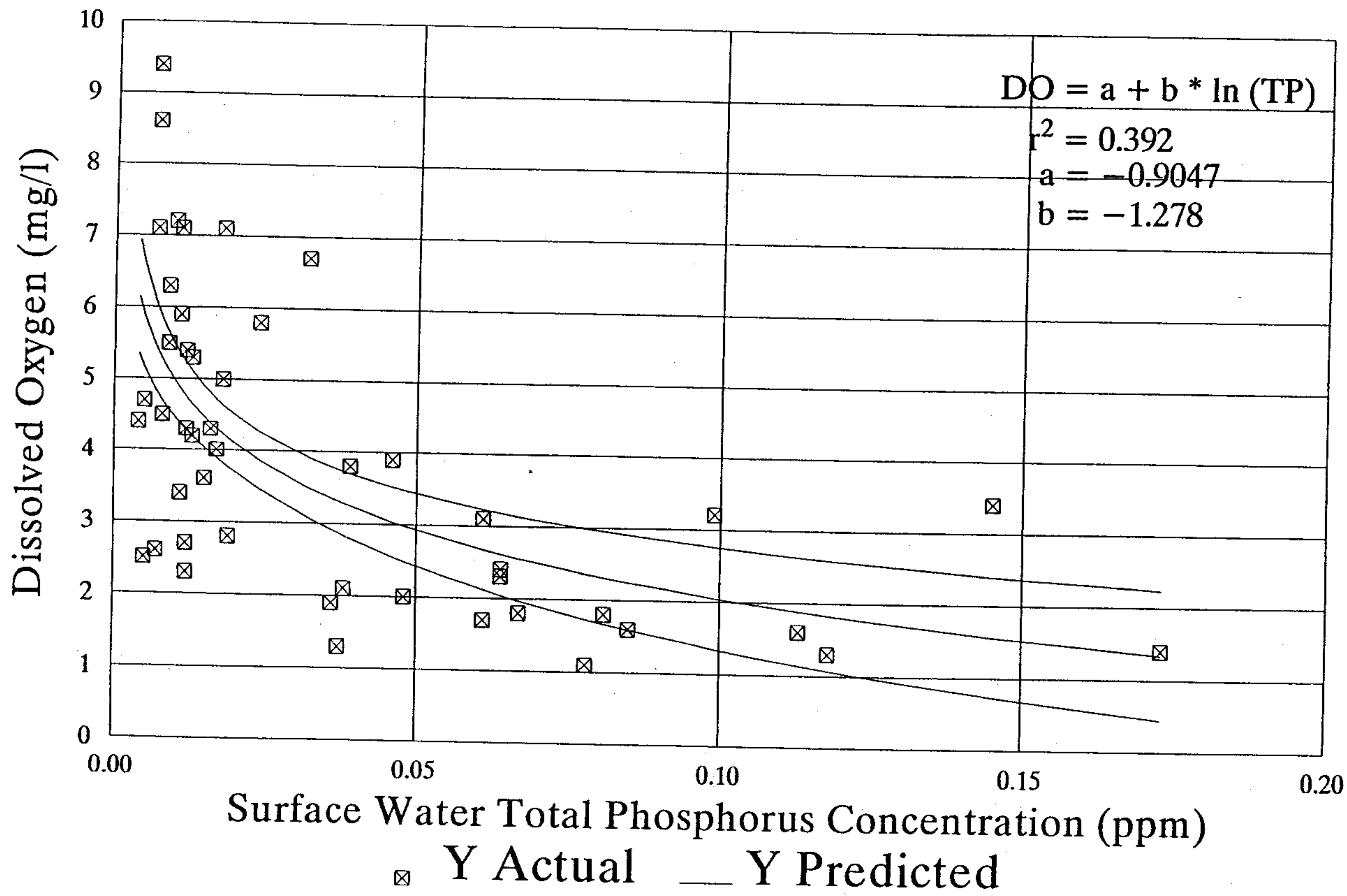


FIGURE 22

WCA–2A Interior Marsh DO/TP Relationship

S–10C Transect Data

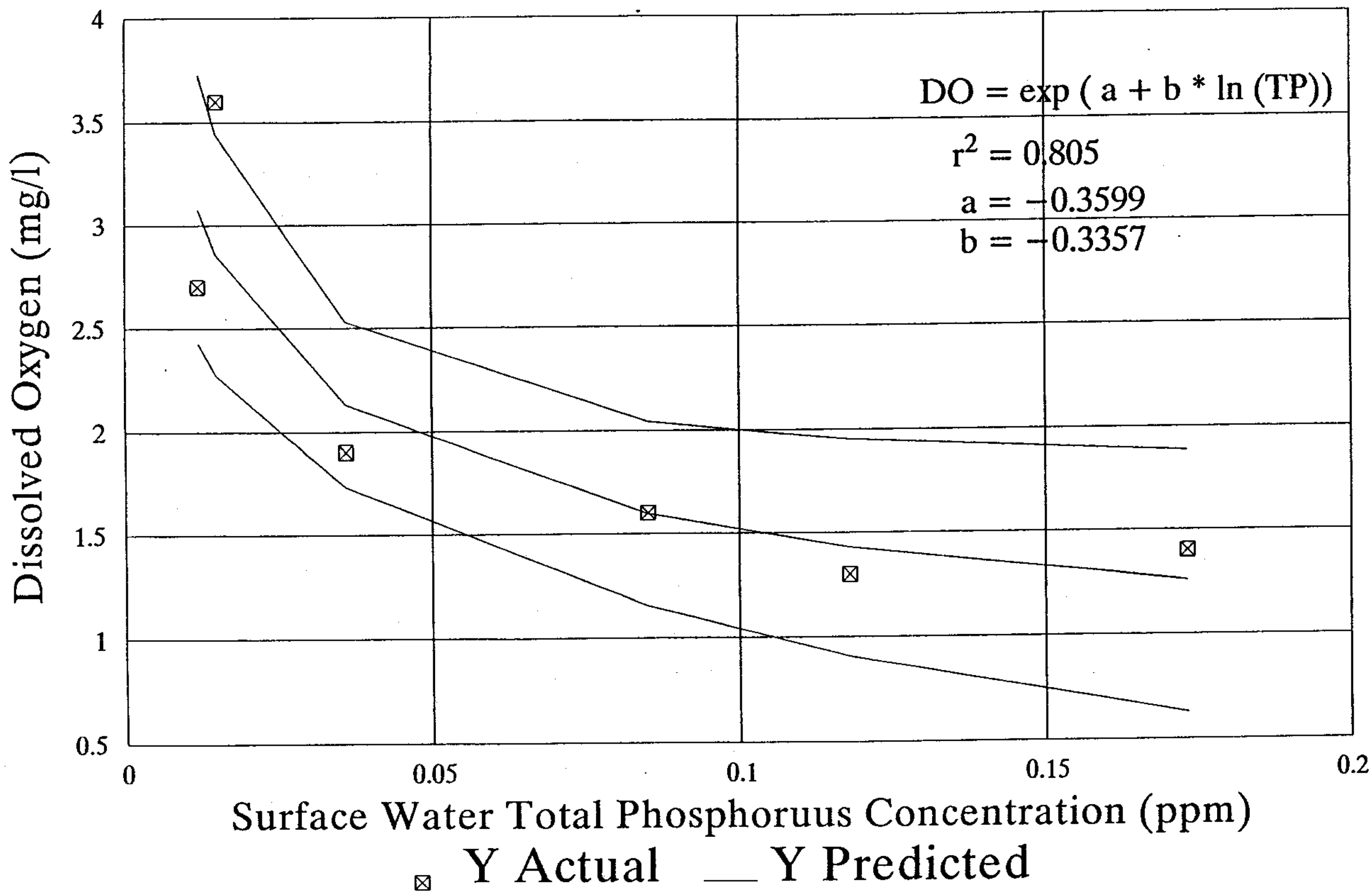
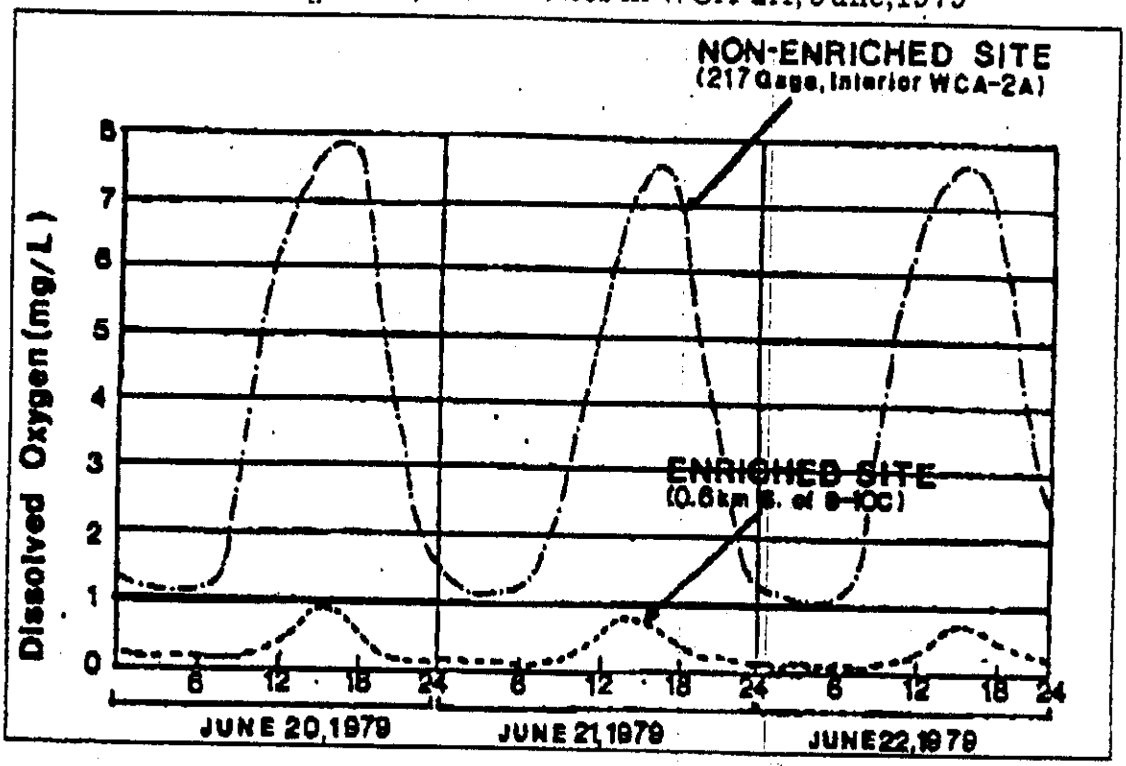


FIGURE 23

Diurnal Dissolved Oxygen Curves at Nutrient Enriched and Non-Enriched (Background) Marsh Sites in WCA-2A, June,1979



Source:SFWMD Unpublished Data

TABLE 1

Endangered, Threatened, and Species of Special Concern in the Everglades Planning Area.*

	Species		State Design.	Federal Design.
Amphibians and Reptiles	American alligator	*Alligator mississippiensis*	SSC	T
	Loggerhead sea turtle	*Caretta caretta*	T	T
	Atlantic green turtle	*Chelonia mydas mydas*	E	E
	American crocodile	*Crocodylus acutus*	E	E
	Leatherback turtle	*Dermochelys coriacea*	E	E
	Indigo snake	*Drymarchon corais*	T	T
	Atlantic hawksbill turtle	*Eretmochelys imbricata imbricata*	E	E
	Gopher tortoise	*Gopherus polyphemus*	SSC	UR
	Atlantic ridley turtle	*Lepidochelys kempii*	E	E
	Florida pine snake	*Pituophis melanoleucus megitus*	SSC	UR
	Gopher frog	*Rana areolata*	SSC	UR
Birds	Roseate spoonbill	*Ajaia ajaja*	SSC	
	Limpkin	*Aramus guarauna*	SSC	
	Burrowing owl	*Athene cunicularia*	SSC	
	Piping plover	*Charadrius melodus*	T	T
	White-crowned pigeon	*Columba leucocephala*	T	UR
	Kirtland's warbler	*Dendroica kirtlandii*	E	E
	Little blue heron	*Egretta caerulea*	SSC	
	Snowy egret	*Egretta thula*	SSC	
	Reddish egret	*Egretta rufescens*	SSC	UR
	Tricolored heron	*Egretta tricolor*	SSC	
	Swallow-tailed kite	*Elanoides forficatus*		UR
	White ibis	*Eudocimus albus*	SSC	
	Peregrine falcon	*Falco peregrinus*	E	T
	Southeastern kestrel	*Falco sparverius paulus*	T	UR
	Florida sandhill crane	*Grus canadensis pratensis*	T	
	American oystercatcher	*Haematopus palliatus*	SSC	
	Bald eagle	*Haliaeetus leucocephalus*	T	E
	Wood stork	*Mycteria americana*	E	E
	Osprey	*Pandion haliaetus*	SSC	
	Brown pelican	*Pelecanus occidentalis*	SSC	
	Red-cockaded woodpecker	*Picoides borealis*	T	E
	Crested caracara	*Polyborus plancus*	T	T
	Snail kite	*Rostrhamus sociabilis plumbeus*	E	E
	Least tern	*Sterna albifrons*	T	
	Bachman's warbler	*Vermivora bachmanii*	E	E
Mammals	Florida panther	*Felis concolor*	E	E
	Everglades mink	*Mustela vison evergladensis*	T	UR
	Florida mouse	*Peromyscus floridans*	SSC	UR
	Mangrove fox squirrel	*Sciurus niger avicennia*	T	UR
	West Indian manatee	*Trichechus manatus latirostris*	E	E
	Florida black bear	*Ursus americanus floridanus*	T	UR
Invertebrates	Florida tree snail	*Liguus fasciatus*	SSC	
	Bartram's hairstreak butterfly	*Strymon acis bartrami*		UR

E = endangered, T = threatened, SSC = species of special concern, UR = species presently under review.

* = FGFWFC, 1989 (List updated by M. Robson, FGFWFC, 1989)

from "Management Plan for Everglades Nutrient Removal Project" SFWMD 9/91

TABLE 2

Summary of historic vegetation transect data with comparisons to 1 classified vegetation map data.

VEGETATION MAP

1987	TRAN_A	TRAN_B	TRAN_C
AQUATIC	0.00	0.00	1.79
WP	54.64	6.24	22.29
SAW	20.39	20.64	11.05
BRUSH	12.73	37.08	11.44
TREE	9.85	22.80	11.74
CATTAIL	2.39	13.24	41.69
TOTAL	100.00	100.00	100.00

HISTORIC TRANSECTS

1966	TRAN_A	TRAN_B	TRAN_C
AQUATIC	14.30	1.40	12.80
WP	81.80	92.60	67.10
SAW	3.10	5.80	9.40
BRUSH	0.60	0.10	0.80
TREE	0.20	0.00	1.30
CATTAIL	0.00	0.00	8.50
TOTAL	100.00	99.90	99.90

63-64	TRAN_A	TRAN_B	TRAN_C
AQUATIC	14.00	3.40	21.60
WP	74.50	84.20	34.80
SAW	9.10	10.70	32.20
BRUSH	1.90	1.40	6.00
TREE	0.00	0.00	0.40
CATTAIL	0.00	0.00	5.00
TOTAL	99.50	99.70	100.00

TABLE 3

Summary of historic vegetation photoplot data with 1987 classified vegetation map data.

HISTORIC PLOTS

1962	PLOT1	PLOT2	PLOT3	PLOT4	PLOT5	PLOT6	PLOT7
AQUATIC	0.00	7.00	7.00	0.00	0.00	7.00	8.00
WP	35.00	64.00	56.00	21.00	13.00	60.00	64.00
SAW	43.00	4.00	23.00	67.00	15.00	19.00	14.00
BRUSH	20.00	3.00	6.00	7.00	58.00	5.00	9.00
TREE	2.00	23.00	7.00	4.00	14.00	8.00	5.00
TOTAL	100.00	101.00	99.00	99.00	100.00	99.00	100.00

1968	PLOT1	PLOT2	PLOT3	PLOT4	PLOT5	PLOT6	PLOT7
AQUATIC	1.00	9.00	8.00	0.00	0.00	9.00	7.00
WP	39.00	59.00	58.00	47.00	21.00	60.00	66.00
SAW	33.00	6.00	21.00	42.00	15.00	17.00	10.00
BRUSH	25.00	4.00	6.00	7.00	51.00	7.00	15.00
TREE	2.00	21.00	7.00	4.00	13.00	7.00	3.00
TOTAL	100.00	99.00	100.00	100.00	100.00	100.00	101.00

VEGETATION MAP

1987	PLOT1	PLOT2	PLOT3	PLOT4	PLOT5	PLOT6	PLOT7
AQUATIC	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WP	30.96	76.77	69.77	17.28	6.07	66.79	60.17
SAW	45.02	0.37	5.67	68.40	22.48	16.04	19.99
BRUSH	13.14	12.26	11.16	11.73	48.68	10.68	11.91
TREE	4.87	10.60	13.41	1.49	22.76	6.50	7.93
CATTAIL	6.01	0.00	0.00	1.11	0.00	0.00	0.00
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00

CHANGE

87 - 62	PLOT1	PLOT2	PLOT3	PLOT4	PLOT5	PLOT6	PLOT7
AQUATIC	0.00	-7.00	-7.00	0.00	0.00	-7.00	-8.00
WP	-4.04	12.77	13.77	-3.72	-6.93	6.79	-3.84
SAW	2.02	-3.64	-17.33	1.39	7.48	-2.96	5.99
BRUSH	-6.86	9.26	5.16	4.73	-9.32	5.68	2.91
TREE	2.87	-12.40	6.41	-2.51	8.76	-1.51	2.93

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III. BEST MANAGEMENT PRACTICES (BMPs) FOR THE EAA

A. INTRODUCTION

Holding and recycling water on farms or between farms in the EAA could potentially reduce phosphorus outputs by 20% to 60%. However the impacts on yields and management costs from systems which will reduce phosphorus by the maximum of 60% are simply not known.

B. DETERMINATION OF 25% REDUCTION FIGURE

A five year research project by Izuno and Bottcher (1991), which was funded by the SFWMD and participated on by members of the EAA, was completed earlier this year. This project reviewed all of the previous work relating to water quality research and other related finding in the EAA (Izuno and Bottcher, 1987) and evaluated four proposed BMPs in four separate replicated field experiments. The results provided estimates of the potential phosphorus transport model which will serve to evaluate BMPs (Izuno and Bottcher, 1991).

Based on the results of the project, previous findings, and experiences of the authors, estimates of P reductions for the BMPs were developed and are listed below. However, it is important to understand what the numbers being represented mean before proceeding. First, the indicated P reduction ranges are for individual fields and do not reflect basin-wide reduction potential for a particular BMP. The range reflects the variability caused by the diversity of existing management practices, cropping systems, and soil types and our limited state-of-knowledge. The low and high ends of the range represent the ideal (BMPs already applied) and worst-case (very poor existing conditions) scenarios, respectively. This is the same as to say the most poorly managed fields have the highest potential for improvement. The P reduction values presented are the long-term average annual reduction which could be expected from an individual field. Seasonal and annual variations could be much greater than those indicated. The basin-wide ranges will be discussed later.

BMPs and associated P reduction ranges are:

1. Calibrated soil test recommendations could reduce P losses from 0-25 and 0-10 percent for vegetables and sugar cane, respectively. This procedure reduces the potential of over fertilizing the soil from inadequate testing and recommendations practices.
2. Banding fertilizer for vegetable production instead of broadcasting it could reduce P losses from 10-40 percent and application rates of 50 percent.
3. Prevention fertilizer spills and the direct spreading of fertilizer into drainage ditches could reduce P losses by 0-15 percent.
4. Minimizing water table fluctuations in vegetable and sugar cane fields could reduce P losses from 0-50 percent. This BMP relates primarily to not over draining by keeping the water tables from going below an optimal level. This limits the amount of P mineralization in the organic soils. Some temporary upward fluctuation can be tolerated after small rain events to prevent pumping.
5. Retention of on-farm drainage could reduce P losses from 15-60 percent. This BMP requires the ability of farm drainage systems to keep water continuously

moving from field to field and to use some limited ditch or canal storage. This BMP could only be used for sugar cane production.

6. Retention of vegetables field drainage water in sugar cane or fallow lands could reduce P losses from 20-90 percent from any particular farm. The 90 percent reduction would reflect a situation where significant amount of sugar cane land was available to receive the drainage water. The use of vegetable drainage in sugar cane fields can also offset some of the fertilizer requirements in the receiving fields.
7. Aquatic cover crop for off-season vegetable production and fallow rotation of sugar cane could reduce P losses from 5-20 percent. The aquatic cover crop such as rice will uptake a significant portion of excess P that becomes readily available during any fallow flooding operation.
8. On-farm retention ponds utilized to store excess rainfall for later use as irrigation water could reduce P losses from 10-60 percent. Such ponds would require that about 5-10 percent of an individual farm's land to be removed from production. The sizing of the ponds would be based on the water retention and water level control requirements of the individual farm. For example, a sugar cane farm may require smaller ponds on a per acre basis than a vegetable farm.
9. Coordinated farm cropping patterns will be a necessary part of BMPs 4-7. This BMP refers to changing the cropping pattern of vegetables, sugar cane, fallow flooding, et. on a farm so that the optimum use of the above BMPs can be accomplished. For example BMP 6 could not be done if available sugar cane fields are not conveniently located near the vegetable fields. Any specific reductions of P due to coordinated cropping patterns would be reflected in the above individual BMPs.

Please also note that the above reductions are not accumulative in that the effectiveness of one BMP may be significantly reduced by the implementation of another BMP or the second BMP may not even be possible. Also it is important to note that the one indicated impact of a BMP on either vegetables or sugar cane must be corrected for the percentage of land that each represent within a basin in order to determine basin-wide effects.

Based on the above individual BMP effectiveness ranges Izuno and Bottcher (1991) estimated that the overall range of P reduction that could be accomplished for the EAA basin was between 20-60 percent. This range reflects Izuno and Bottcher's opinion of what could be accomplished at a reasonable cost (20 percent reduction figure) and what might be accomplished at a very high unknown cost (60 percent reduction figure). Though Izuno and Bottcher believe 40 percent or even higher P reductions might be reasonable accomplished by BMPs, the assurances based on currently available information that these levels could be accomplished at a marginal cost less that those for STAs could not be provided. The final 25 percent figure for P reduction from BMPs was, based upon the research conducted by Izuno and Bottcher, reasonable and achievable.

C. REDUCED DRAINAGE VERSUS P REDUCTION

The proposed BMPs can reduce the P loads to the STAs by either reducing the volume of water or by reducing the concentrations of P in the water or both. BMPs 1, 2, 3, and 7 are designed to reduce P concentrations where as BMPs 4-6 primarily reduce net water discharge from the farm through some P concentration reduction may be realized. Since the concentration reducing BMPs will be most effective for vegetable production (about 20 percent for the EAA) the net basin reduction would be lower than the ranges given above. Therefore, it was estimated that about 5-15 percent of the proposed 25 percent reduction would be accomplished by P concentrations reduction and the remaining 10-20 percent would come from drainage volume reductions. The actual percent attributed to concentration versus volume reductions will depend on the relative acceptance of the various BMPs by the farmers.

D. CONCLUSION

Currently available information clearly indicates that 25 percent P reduction from BMPs is a reasonable and obtainable goal. Current information also indicated that even higher reductions are possible but the cost-effectiveness of the BMPs versus the STAs is not known at this time.

E. REFERENCES

Izuno, F.T. and A.B. Bottcher. November 1987. Phase II Final Report: The Effects of On-Farm Agricultural Practices in the Organic Soils of the EAA on Phosphorus and Nitrogen Transport - Part II Components of the EAA Agricultural System that Relate to Water Quality in South Florida.

Izuno, F.T. and A.B. Bottcher. August 30, 1991. Final Report: The Effects of On-Farm Agricultural Practices in the Organic Soils of the EAA on Phosphorus and Nitrogen Transport - Screening BMPs for Phosphorus Loadings and Concentrations Reductions.

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IV. EAA PERIOD OF RECORD FLOW AND PHOSPHORUS LOAD CALCULATIONS

A. INTRODUCTION

This chapter presents and discusses the data, assumptions, and equations used to calculate the EAA flows and phosphorus loads.

B. DETERMINATION OF HYDROLOGY COMPONENTS OF THE EAA WATER BUDGET

1. Location of Discharges Monitoring Sites

These basins and associated Works of the District were previously described by R. M. Cooper in An Atlas of the Everglades Agricultural Area Surface Water Management Basins, SFWMD Technical Memorandum, September 1989.

The SFWMD currently monitors discharges and water quality at the structures named above, as well as structures discharging water to/from Lake Okeechobee (S-2/S-351, S-352, and S-3/S-354). Besides the surface water discharges, hydrologic monitoring sites include rain gauges (**Figure 24**) and evaporation pans (**Figure 25**). The District also monitors atmospheric deposition at Clewiston, and cooperates with the Florida Sugar Cane League to monitor deposition quality at S-7 and the East Shore Drainage District.

The SFWMD processes and stores all hydrologic data on a computerized data base called DBHYDRO. The DBHYDRO Database information retrieval and processing procedure that was used to provide EAA flow data for the period of October 1, 1978 to September 30, 1988.

2. Components of the EAA Water Budget

The EAA was divided into three major basins so that the task of determining components of the EAA water budget could be completed. These basins are defined as the Miami, the North New River-Hillsboro and the West Palm Beach canal basins. Flows from, to, and through these basins are defined in terms of the flows at the major structures at the northern and southern ends of these basins. Computations must be completed on a daily basis since flows may reverse themselves within a single month. The following flows have been computed for the period of record:

a) inflows to the EAA

b) outflows from the EAA

c) backpumping and backflows to Lake Okeechobee

d) flows from Lake Okeechobee which pass-through the EAA to the WCAs and the C-51/L-8 basins

e) irrigation flows (supplemental water use) from Lake Okeechobee to the EAA

f) irrigation flows from the WCAs and the C-51/L-8 basins to the EAA

g) flows from the EAA to the WCAs and the C-51/L-8 basins

h) net outflows from the EAA

i) total net inflows to the EAA

Figure 24. Location and Identification of Rain Gages for Precipitation Monitoring within the EAA.

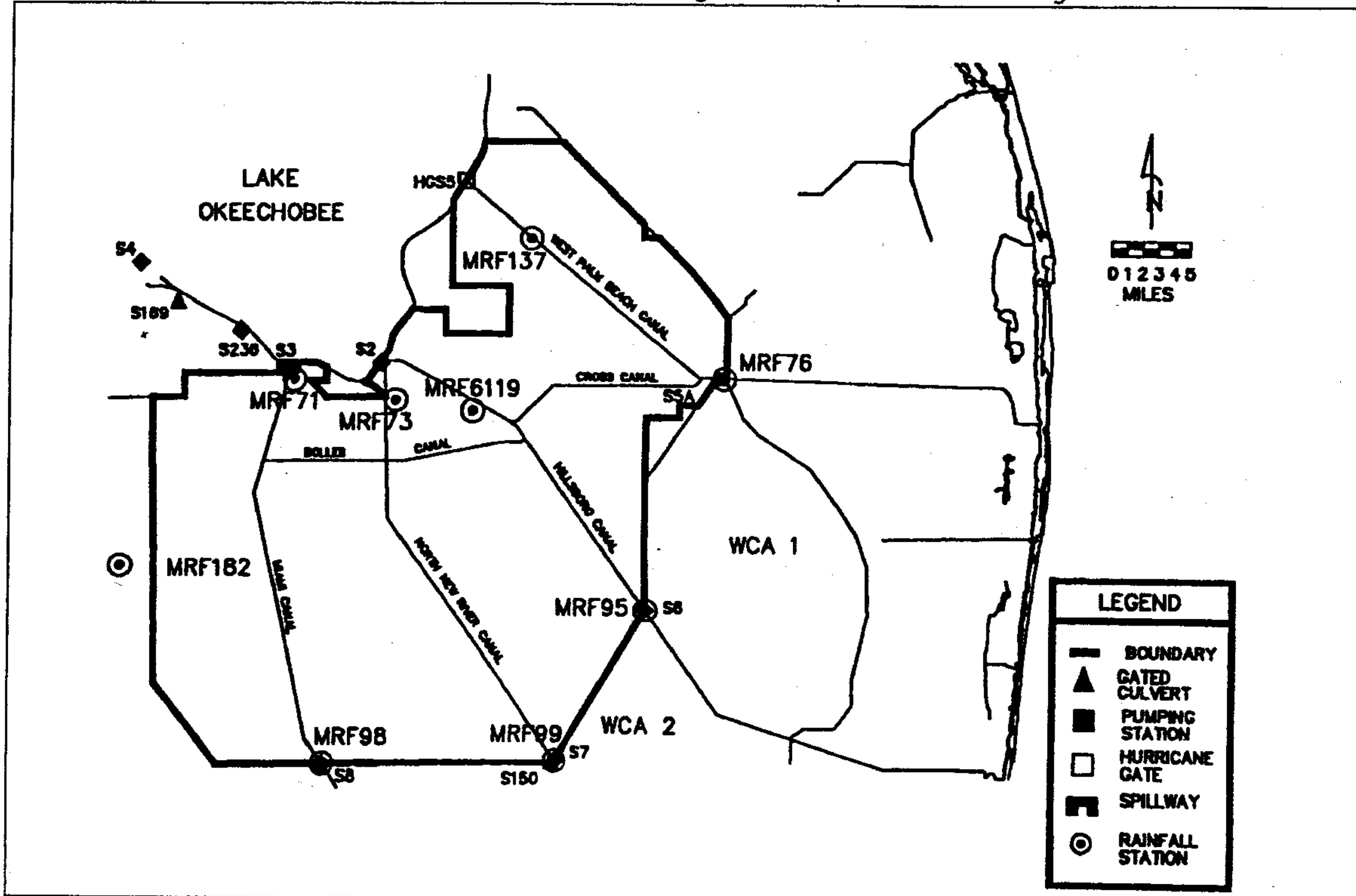
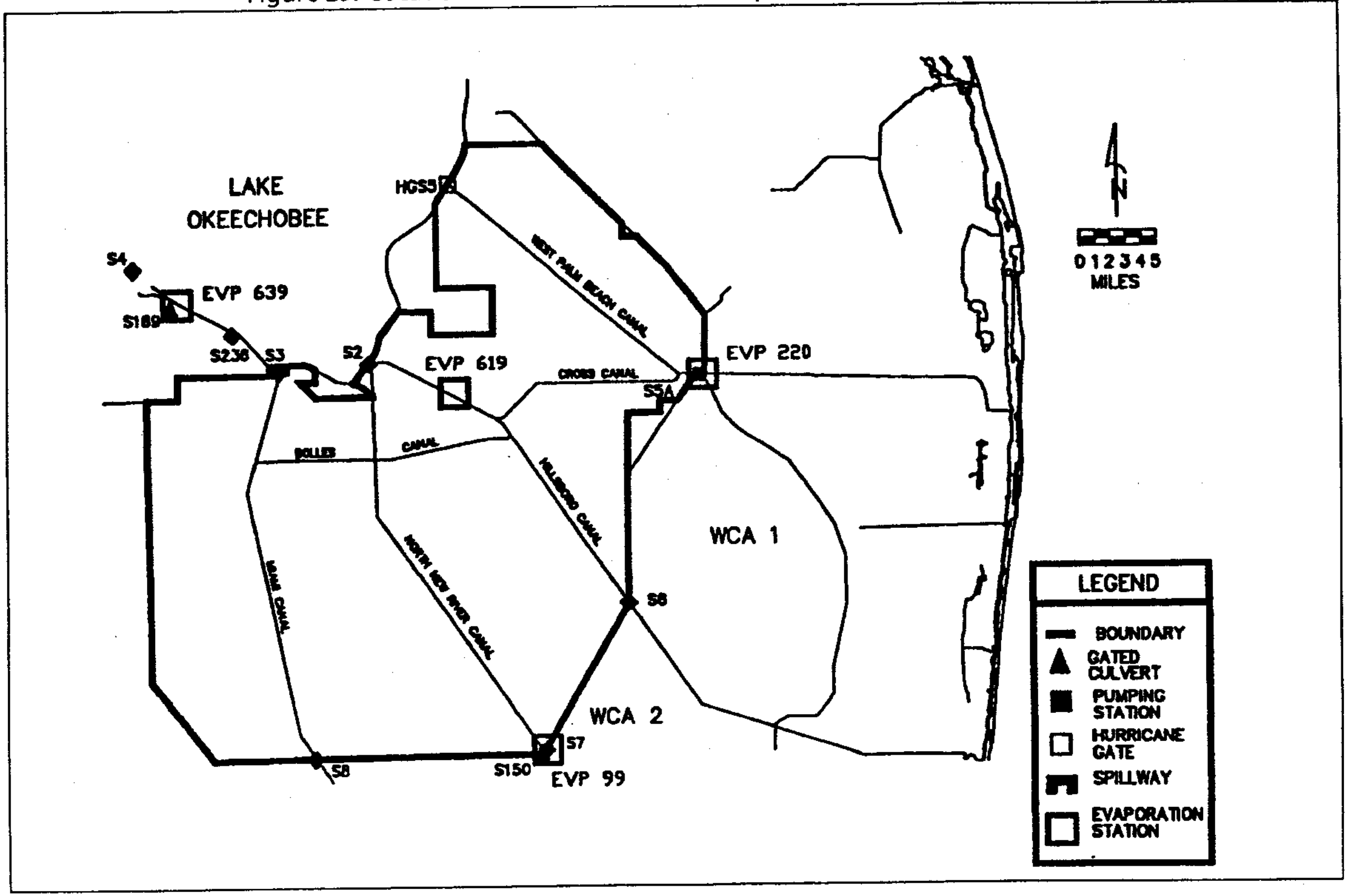


Figure 25. Location and Identification of Evaporation Pans within the EAA.



The methodology for computations of the components of the EAA water budget are based on flow comparisons at the north and south ends of each basin. The following is a narrative description of how the criteria listed above are applied.

- **Miami Canal.** Basin computations are based on the comparisons between the S-8 flow at the south end and the S-3 / HGS-3 flow at the north end.
- **North New River-Hillsboro Canal.** Combined basin computations are made by comparing the sum of the S-6, S-7 and S-150 flows at the south end to the S-2 / HGS-4 flow at the north end.
- **West Palm Beach Canal.** Basin computations are made by comparing the flows upstream of the S-5A pump in the West Palm Beach canal estimated by the U.S.G.S. at the south end, and the HGS-5 structure at the north end.
- **The S-5A Complex.** The S-5A complex as shown in **Figure 26** has six flow measurement or computation stations. Station #1 is located on West Palm Beach Canal above S-5A. The DBKEY for this station in the DBHYDRO Database is 00317. The daily flow values are the difference between the pumpage at S-5A and the gate discharge at S-5AW. Negative flows are flows to the EAA. Positive flows are flows to the east and/or to Water conservation Area 1 via S-5A pump.

  Station #2 is a six units pump station whose primary purpose is to pump surplus water from the EAA to Water Conservation Area 1. The DBKEY for this station in the DBHYDRO Database is 00319. Combined daily flows through station S-5AS and the pump station S-5A are recorded under this DBKEY.

  S-5AS is a gated spillway at the southern end of L-8 borrow canal. This structure functions with S-5AE, S-5AW, and pumping station S-5A to control flood runoff and to make irrigation releases from WCA-1 to L-10, L-12, L-8 and C-51 basins. The Dbkeys in the DBHYDRO Database for the S-5AS are 12899, 06758,04680, and 06757. Positive flows are flows into WCA-1 and negative flow is to L-8, C-51 or L-10 and L-12 or any combinations.

  S-5AW is a culvert located on C-51 at the point where L-8 meets C-51. This structure functions with S-5AE, S-5AS and S-5A to control irrigation releases in the L-10, L-12 basin and to pass flood runoff from L-8 and C-51 to WCA-1 via pumping station S-5A. negative flows are towards the EAA and positive flows are to the east. The Dbkey for this station in the DBHYDRO Database is 00322.

  Station #4 (S-5AE) is a culvert located on C-51 at the point where L-8 crosses that canal. This structure functions with S-5AW, S-5AS and S-5A to control irrigation releases in the area served by C-51 and to discharge flood runoff from L-8 via C-51 to the ocean and from C-51 to WCA-1 via pump station S-5A. The Dbkey in the DBHYDRO Database is 00328. Negative flows are flows to the west and positive flows are flows to the east.

  Station #3 is L-8 canal at WPB canal. Flow is regulated by operation of S-5AE, S-5AS, S-5AW just down stream and pumpage at S-5A. Discharge is summation of flows at S-5AE, S-5AS, and S-5AW (S-5AS + S-5AE/S-5AW). Positive flow is to the junction and negative flow is to L-8 to the north. The Dbkey in the DBHYDRO Database is 00325.

Figure 26. Structure 5-Complex.

WATER RESOURCES DATA FOR FLORIDA, 1990
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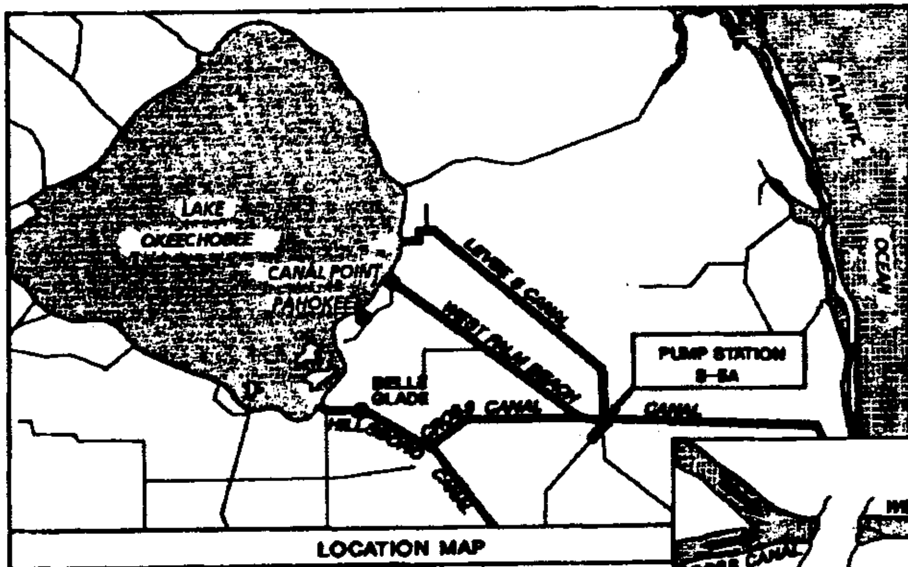


STREAMFLOW STATION

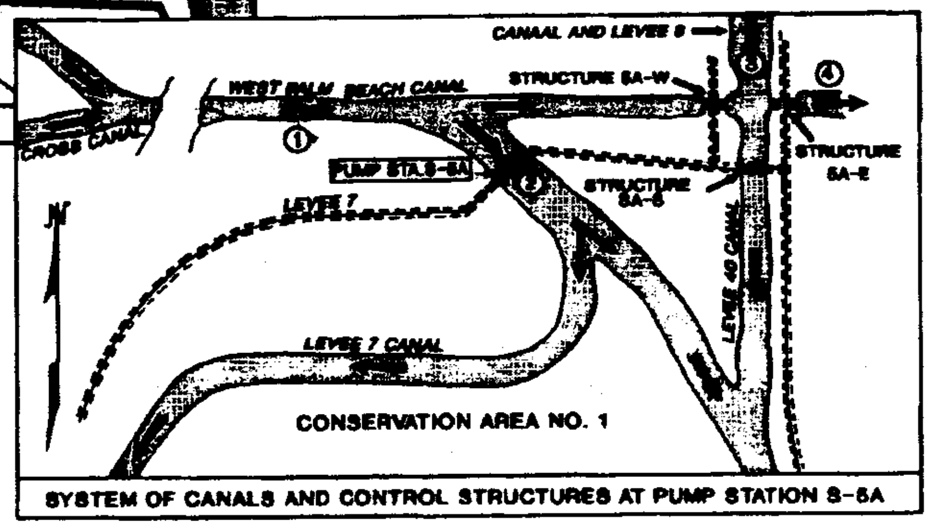
① Station 02278450, West Palm Beach Canal above S-5A, near Loxahatchee, Fla.

② Station 02278500, Diversions to Conservation Area No. 1 at S-5A and S-5A-S, near Loxahatchee, Fla.

③ Station 02278550, Levee 8 Canal at West Palm Beach Canal, near Loxahatchee, Fla.

④ Station 02278600, West Palm Beach Canal below S-5A-E, near Loxahatchee, Fla.

SOUTH FLORIDA
WATER MANAGEMENT DISTRICT
STRUCTURE 5 COMPLEX



3. Inflows to the EAA

The following are the initial examination criteria reviewed to begin the daily calculation of inflows to the EAA.

- **Inflow to the EAA.** The sources of inflow to the EAA basin are Lake Okeechobee, Water Conservation Areas, Hendry County, and L-8 / C-51 via S-5A complex.
- **Inflow to EAA from Lake Okeechobee.** In the DBHYDRO Database, positive flows through structures S-2 (S-351), S-3 (S-354), HGS-5 (S-352) are inflows to the EAA basin from Lake Okeechobee.
- **Irrigation Flows from Lake Okeechobee to the EAA.** This is computed by subtracting the flow leaving a basin at the south end of the EAA from that entering at the north end on the same day. If flows at the south end are negative, they are first set to equal zero. If the final computation for a particular basin is less than zero, then it is set equal to zero.
- **Irrigation flows from the WCAs and the C-51/L-8 basins to the EAA.** This is the sum of negative flows from S-5A1, S-6, S-7, S-150, and S-8.
- **Inflows from Hendry County.** These inflows are indicated with positive flows through G-88 and G-136.
- **Inflows to the EAA from the Water Conservation Areas.** These flows are identified in DBHYDRO as negative flows from Structures S-6, S-7, S-8, and S-150.
- **Inflow to the EAA through the S-5A complex.** These flows are identified in DBHYDRO as negative flows through S-5A/S-5AW. In this case the source of water could be either L-8, C-51 or WCA-1 or any combination.

  At the S-5A complex inflows from WCA-1 to the EAA could occur if S-5AW and S-5AS have both negative readings.
- **Total Net Inflow to the EAA.** This is the volume of flow at the north end minus the flow at the south end of each basin. If this difference is less than zero, it is set equal to zero.

4. Outflows from the EAA

The following are the initial examination criteria reviewed to begin the daily calculations of outflow from the EAA.

- **Outflows from the EAA.** The possible directions of Outflow from the EAA are to Lake Okeechobee, Water Conservation Areas, and L-8/C-51 Canals.
- **Outflows from the EAA to Lake Okeechobee.** These flows are indicated in the DBHYDRO database as negative flows through structures S-2, S-3, and HGS-5.
- **Outflows to Water Conservation Areas.** These flows are indicated in the DBHYDRO database as positive flows from structures S-6, S-7, S-8, and S-150.
- **Outflows from the EAA to WCA-1 and/or L-8/C-51 Canals.** These flows are indicated in the DBHYDRO database as positive flows through S-5A and S-5AW.

- **Backpumping and backflows To Lake Okeechobee From The EAA.** This is the sum of the daily negative flow values at HGS-5, S-2 / HGS-4, and S-3 / HGS-3.
- **Flows From Lake Okeechobee Through The EAA to the WCAs and to the C-51/L-8 Basins.** This is computed by taking the minimum of the daily flow entering the north end of the EAA and that leaving the south end of the EAA for each basin. If, on any day for a given basin, these minimums are less than zero, they are set equal to zero.
- **Flows from the EAA to the WCAs and C-51/L-8 Basin.** This is the sum of all positive flows leaving each basin to the Water Conservation Areas and the C-51/L-8 basins. This flow is determined by summing all positive flows at S-6, S-7, S-8, S-150, and upstream of the S-5A pump (designated as S-5A1 by the U.S.G.S.) in the West Palm Beach canal at the boundary of the EAA.
  a) To determine portion of flow from the EAA that enters the Water Conservation Areas, the contribution from the West Palm Beach canal is first determined by taking the minimum of the positive flow leaving the EAA at S-5A1 and the positive flow entering the Water Conservation Area 1 through the S-5A complex (designated as S-5A2 by the U.S.G.S). This flow value is then added to the sum of the positive flows at S-6, S-7, S-150 and S-8.
  b) The remainder of S-5A1 positive flows are assumed to flow to the C-51/L-8 canal basins and the flows computed by subtracting the positive flow at S-5A2 from the positive flow at S-5A1. If this difference is negative, it is set equal to zero.
- **Total Net Outflow From The EAA.** This is the flow at the south end of each basin minus the flow at the north end (positive or negative) of each basin. If this difference is less than zero for an individual basin, it is set equal to zero.

5. Supplemental Water Use in the EAA

Supplemental water use is defined as the quantity of water diverted from the major canals for satisfying water demand in the EAA basin. In the DBHYDRO Database, positive difference in daily flows between structures S-3/G-88/G-136 and S-8; S-2 and S-6/S-7/S-150; HGS-5 and S-5A/S-5AW is calculated as the supplemental water used in the EAA basin for any uses.

6. Runoff from the EAA Basin

In the DBHYDRO Database, negative difference in daily flows through structures S-3/G-88/G-136 and S-8; S-2 and S-6/S-7/S-150: HGS-5 and S-5A/S-5AW is calculated as the runoff from the Everglades Agricultural area.

7. Flow-Through the EAA Basin

Flow-through is defined to be that quantity of water that is released from Lake Okeechobee to the Water Conservation Areas, the Lower East Coast and the West Palm Beach canal. The release could be regulatory release for flood control, water supply or to maintain canal and WCA stages. The following are the equations that were used to calculate daily runoff, supplemental water use and flow-through from the inflow and outflow data.

CASE I

DAILY CANAL INFLOW - DAILY CANAL OUTFLOW = 0 (1)

DAILY SUPPLEMENT WATER USE = 0 AND RUNOFF = 0 (2)

DAILY FLOW-THROUGH = INFLOW = OUTFLOW (3)

or

DAILY SUPPLEMENTAL WATER USE = RUNOFF (4)

DAILY FLOW-THROUGH = INFLOW - SUPP. WATER USE (5)

DAILY FLOW-THROUGH = OUTFLOW - RUNOFF (6)

CASE II

DAILY CANAL INFLOW - DAILY CANAL OUTFLOW >0 (7)

DAILY SUPP. WATER USE>0 AND RUNOFF = 0 (8)

DAILY FLOW-THROUGH = INFLOW - SUPP. WATER USE (9)

CASE III

DAILY CANAL INFLOW - DAILY CANAL OUTFLOW < 0 (10)

DAILY SUPPLEMENTAL WATER USE = 0 and RUNOFF > 0 (11)

DAILY FLOW-THROUGH = OUTFLOW - RUNOFF (12)

where:

DAILY RUNOFF = water pumped out of the irrigated land in to the major canals for the day

DAILY SUPPLEMENTAL WATER USE = water diverted from the major canals for any purpose for the day

DAILY CANAL INFLOW = the sum of inflows into EAA through the canals for the day

DAILY CANAL OUTFLOW = the sum of outflows through the respective canals for the day

DAILY FLOW-THROUGH = water released from Lake Okeechobee to W.P.B. Canal, WCAs and Lower East Coast.

When calculating flow-through for Miami Canal Basin there are few exception cases for the above flow-through equation. In a case where there is inflow through G-88 and G-136 and outflow through S-3. Balance should be done between the four structures to calculate the flow-through value through S-8 or the back pumping through S-3.

Total daily inflow from Lake Okeechobee was proportioned to North New River and Hillsboro Canals using a linear regression coefficient between the outflows at S-6 (Hillsboro) and S-7 and S-150 (North New River) as requested. The regression equation ($R = 0.69$) that was used is presented as follows.

$$\text{Hillsboro outflow} = 0.534769 * \text{North New River outflow} \qquad (13)$$

8. Calculation of Daily and Monthly Flows

Flows are calculated from measurements taken on a daily basis. On the occasion of missing values for daily flows, data is interpolated. The following is a summary of basin-wide water budget parameters and equations used for computation and interpolation of missing values.

Missing flow values for stations S-5A, S-5AW, S-6, S-7, S-8, S-150, G-88, G-136, S-2, S-3, and HGS-5 were estimated using one or more of the following objective and subjective equations:

- If a value is missing, zero or non-zero status was determined by comparing with preceding and succeeding values, values of other relevant structures, month of year, and rainfall data.
- A non-zero value is estimated generally using linear interpolation between preceding and succeeding values. In cases where one station has more than one set of data, then missing data of one was filled from the other set.
- In cases where a reference was not available to estimate a missing data, subjective decision is made based on the District's knowledge of the system.

The monthly flows are computed by a simple summation of all daily calculated flows at a given structure.

C. DETERMINATION OF TOTAL PHOSPHORUS LOADS

1. Location of Water Quality Monitoring Sites.

The basins and associated Works of the District are described by R. M. Cooper in An Atlas of the Everglades Agricultural Area Surface Water Management Basins, SFWMD Technical Memorandum, September 1989. The District's hydrologic and water quality monitoring programs are described by G. J. Germain and J. E. Shaw in Surface Water Quality Monitoring Network, SFWMD Technical Publication 88-3.

The District currently monitors discharges and water quality at the structures named above, as well as structures discharging water to/from Lake Okeechobee (S-2/S-351, S-352, and S-3/S-354). In addition to the surface water discharges, hydrologic monitoring sites include rain gauges (**Figure 24**) and evaporation pans (**Figure 25**). The District also monitors atmospheric deposition at Clewiston, and cooperates with the Florida Sugar Cane League to monitor deposition quality at S-7 and the East Shore Drainage District.

2. Calculation of Phosphorus Loads Into and Out of the EAA.

Total Phosphorus Loading Calculations. Mass transport (load) is the amount of phosphorus carried past a monitoring point by the movement of water. It cannot be measured directly (except in very special circumstances), and so is calculated based on available measurements.

S-5A, S-6, S-7, and S-8. Total phosphorus loads were calculated based upon a hierarchy of available concentration data:

1) First Priority: Flow-proportional composite sample (automatic sampler).
2) Second Priority: Grab-sample (adjusted as automatic sampler equivalent).
3) Third Priority: Regression estimate based upon existing automatic sampler data and flow.

Flow-proportional composite sampler data was utilized as the primary source of data for computing loads at the S-5A, S-6, S-7, and S-8 structures. The method for calculating phosphorus loads from automatic sampler data is described below.

Grab-sample data was also simultaneously collected at the structures. When automatic sampler data was not available (e.g. mechanical service), grab sample data was used to calculate phosphorus loads. The grab-sample adjustment and load calculation methodology are described below.

Estimated loads were used in cases where automatic sampler and grab samples were not available for a discharge event at the structures. Phosphorus loads were estimated by a regression analysis of past automatic sampler phosphorus concentration relationships. The regression estimation methodology and equations are described below.

S-150, S-2, S-3, and HGS-5. Total phosphorus loads were calculated based upon a hierarchy of available concentration data:

1) First Priority: Grab-sample.
2) Second Priority: Regression estimate based upon existing grab-sample data and flow.

Automatic sampler data is not available at the S-150, S-2, S-3, and HGS-5 structures. Grab-sample data and the grab-sample method of load calculation were used as the primary method and are described below.

Estimated loads were used in the event that grab-sample data was not available for a discharge event at the structures. Phosphorus loads were estimated by a regression analysis of past grab-sample vs. phosphorus concentration relationships. The regression estimation methodology and equations are described below.

Data Processing. The actual calculation of loads and load estimates from flow and chemistry data stored in the SFWMD data bases is a multi-step process that is diagramed in **Figure 27**.

Automatic Sampler Loading Calculations. The standard procedure described below was used to calculate loads from flow-proportional composite (automatic sampler) concentrations and daily flows when both phosphorus concentration and daily flow measurements were available.

In this procedure, the concentration measured in the composite sample is multiplied by the flow recorded on each day during the sample accumulation period. The sample accumulation period extends backward in time from the recorded sample date (the terminal date of the accumulation period) to the day following the previous sample date, or 30 days, whichever is less. This is illustrated by the following graph:

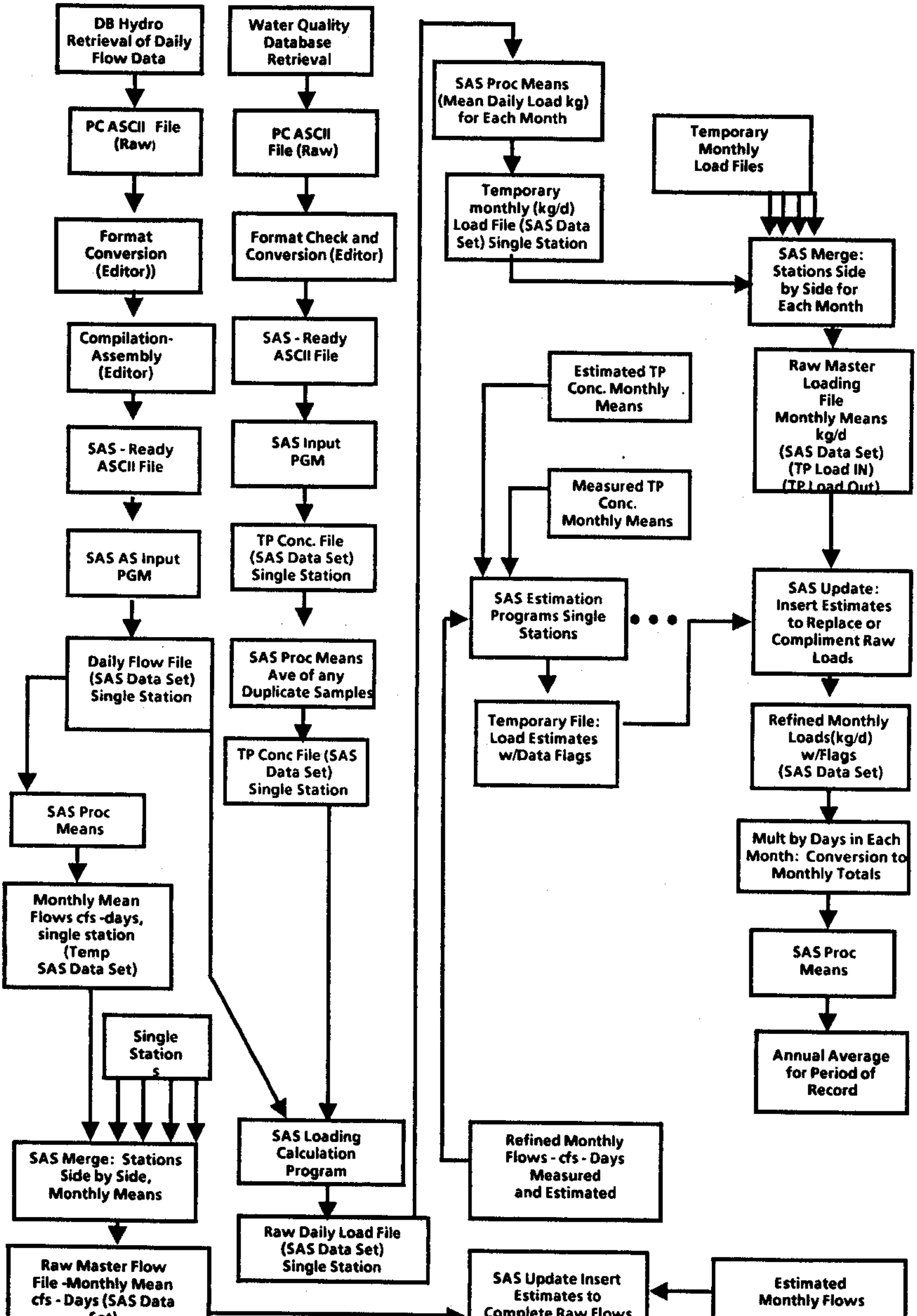
X<--------------X<---------X<--------------------X

WHERE:

X	=	End of automatic sampler accumulation period and recorded date of phosphorus measurement
------	=	Daily flow measurement
<--------X	=	Accumulation period to which composite sample concentration is applied

Grab-Sample Loading Calculations. Automatic sampler data and the automatic sampler method were used to calculate monthly loadings at S-5A, S-6, S-7, and S-8 structures. When automatic sampler measurements were unavailable, loading calculations based on grab-sample measurements (if available) were used.

Figure 27. Data Retrieval an Loa ing Calculation Process.



The standard procedure described below was used to calculate loads from grab-sample concentrations and daily flows when both phosphorus and daily flow measurements were available. This is the preferred method of Scheider, et al. (1978) and takes into account the fact that flow is routinely measured more frequently (daily) than phosphorus (bi-weekly).

In this procedure, daily flow measurements are multiplied by the concentration measurement nearest in time to the date of the measured flow. This is illustrated by the following graph:

<---------------I----------><---------I----><----I--><--I

WHERE:

I = Phosphorus measurement

------ = Daily flow measurement

<---I----> = Period to which grab-sample concentration is applied

An actual phosphorus measurement was assumed to be the best available approximation of in-stream concentration for a period extending up to 30 days on either side of the measurement. Note that only those grab-samples collected on days with net mean flow greater or equal to one cubic foot per second (cfs) are used in grab-sample loading calculations.

Conversion of Grab-Sample Loads to Automatic sampler Equivalents. Loadings based on grab-sample calculations are not interchangeable directly with those based on automatic sampler calculations, but at sites S-5A, S-6, S-7, and S-8, there is a strong linear relationship between grab-sample based monthly load and automatic sampler based monthly load at each site for the period of record.. The relationships described above are presented as a regression coefficient (conversion factor) in **Table 4**.

For sites S-5A, S-6, S-7, and S-8, linear regression was used to convert grab-sample-based loads to equivalent auto-sampler-based loads for months when automatic sampler data was unavailable. In developing these regression equations, paired grab- and automatic sampler loads for the period of record were used. Three grab-samples were excluded in the development of these regression equations (S-6, 8/19/81, TP = 0.872; S-7, 6/25/85, TP = 1.03; S-8, 6/11/86, TP = 0.067). These grab-samples were found to have undue influence on the regression analysis, and, with the exception of S- 8, were extreme outliers (> 4 standard deviations from the site mean) in the chemistry data set. Not only were these samples excluded from the development of the conversion equations, but they were also not used to calculate loadings for these sites because suitable automatic sampler data were available for the periods represented by these outliers.

These relationships allow the two types of loads to be interconverted with high reliability at these specific sites for this period of record.

Estimated Loading Calculations.

S-5A, S-6, S-7, and S-8. In cases where both automatic sampler and grab-sample data were not available for a given month at one of these four sites, then the load for that site was estimated from the relationship between monthly load calculated from existing automatic sampler data and monthly total flow at that

Table 4. Conversion of grab-sample loads to automatic sampler equivalents*.

Site	Conversion Factor	R^2	Std. Error	Total df	Months Estimated over POR
S-5A	0.85	0.94	0.04	32	22
S-6	0.80	0.86	0.05	41	26
S-7	0.81	0.91	0.04	36	37
S-8	1.17	0.96	0.04	33	21

* Monthly grab-sample loads are multiplied by the regression coefficient (conversion factor) to obtain the automatic sampler equivalent. No intercept was fitted in these regression models, as previous analyses had shown the intercepts to be not significantly different from zero.

site for the period of record. The relationships described above are presented as cubic polynomials in **Table 5**.

Regression equations are in the form: TP LOAD = B_1*flow + B_2*flow^2 + B_3*flow^3

where: flow is measured in CFS per month,
load is in kilograms per month

At these four sites, variations in flow, rather than changes in concentration, dominate the variation in monthly mean loads. Therefore, with a reasonably complete record of load and flow, it is possible to estimate monthly load from flow data alone with good accuracy.

Ta le 5. Summary o regression equations use to estimate TP loa s rom low when phosphorus measurements were unavailable for S-5A, S-6, S-7, and S-8.

Site	B_1 (Std. Error)	B_2 (Std. Error)	B_3 (Std. Error)	R^2	df	Months Estimated over POR
S-5A	0.35 (0.067)	9.6×10^{-6} (3.6×10^{-6})	-1.0×10^{-10} ($<10^{-10}$)	0.93	104	18
S-6	0.21 (0.068)	1.6×10^{-5} (7.7×10^{-6})	-4×10^{-10} ($<10^{-10}$)	0.90	101	23
S-7	0.31 (0.045)	-1.3×10^{-5} (3.6×10^{-6})	4×10^{-10} ($<10^{-10}$)	0.91	108	18
S-8	0.71 (0.13)	-3.9×10^{-5} (8.5×10^{-6})	8×10^{-10} ($<10^{-10}$)	0.85	112	41

S-150, S-2, S-3, and HGS-5. Grab-sample data is the primary phosphorus concentration collection methodology at S-150, S-2, S-3 and HGS-5, and thus the grab-sample calculation method was used. For any month in which a grab-sample concentration of total phosphorus was not obtained at these sites, the load was estimated from the relationship between grab-sample load and flow at that specific site for the period of record. The relationships described above are presented as a regression coefficient in **Table 6**.

Regression equations are in the form: TP LOAD = B_1*flow
where: flow is measured in CFS per month,
load is in kilograms per month

At these four sites, variations in flow, rather than changes in concentration, dominate the variation in monthly mean loads. Therefore, with a reasonably complete record of load and flow, it is possible to estimate monthly load from flow data alone with good accuracy.

Ta le 6. Summary o regression equations use to estimate TP loa s rom flow when phosphorus measurements were unavailable for S-150, S-2, S-3, and HGS-5.

Site	B_1	R2	Std. Error	df	Months Estimated over POR
S-150	0.18	0.79	0.012	58	5
S-2	0.19	0.65	0.016	74	25
S-3	0.16	0.79	0.009	83	19
HGS-5	0.26	0.70	0.021	70	28

* Flows are multiplied by the regression coefficient to obtain the grab sample equivalent. No intercept was fitted in these regression models, as previous analyses had shown the intercepts to be not significantly different from zero.

3. Calculated loadings.

A summary of calculated loadings for the structures discussed above is presented in **Table 7**.

EAA Inflow Loadings. The calculated monthly loads and flow volumes for S-2, S-3, and HGS-5 are presented in **Table 8**.

EAA Outflow Loadings. The number of grab samples taken during backpumping events were sparse (**Table 9**). The mean TP chemistry of grab samples taken during the backpumping events for S-2, S-3, and HGS-5 were multiplied by the monthly backpumping flows to obtain monthly backpumping loadings (**Table 8**). Yearly average loads for these structures were small (**Table 7**).

Table 7. Average annual TP load and flow volume for the period of record.

STATION	TP LOAD metric tons	FLOW Acre-Feet	PERCENT LOAD	PERCENT FLOW
G-88 (EAA Inflow)	5.2	12,992	31.3	7.9
G-136(EAA Inflow)	1.0	10,586	6.0	6.5
HGS-5 (EAA Inflow)	9.6	65,649	59.5	61.3
S-2 (EAA Inflow NNR)	12.8	131,298	98.1	97.8
S-2 (EAA Inflow Hills)	6.8	70,207	95.1	92.9
S-3 (EAA Inflow)	10.3	139,211	62.3	38.8
HGS-5 (EAA Outflow)	0.4	2.749	0.7	1.0
S-2 (EAA Outflow Hills)	6.7	32,387	19.3	17.1
S-2 (EAA Outflow NNR)	12.5	60,569	27.5	18.0
S-3 (EAA Outflow)	10.1	48,972	13.0	13.6
S-5A1(Flow-Through)	1.0	7,880	1.9	3.0
S-6 (Flow-Through)	0.2	2,826	0.8	1.8
S-7 + S-150 (Flow-Through)	5.6	50,731	16.9	18.3
S-8 (Flow-Through)	3.7	63,422	5.4	20.2
S-5A1 (Backflow)	6.5	41,455	40.5	38.7
S-6 (EAA Backflow)	0.4	5,325	1.8	2.5
S-7 (EAA Backflow)	0.1	2,001	1.0	1.5
S-150 (EAA Backflow)	0.1	921	0.9	0.7
S-8 (EAA Backflow)	0.1	832	0.4	0.5
S-5A2 (WCA inflow)	76.7	314,198	141.5	117.7
S-5A1 (EAA outflow)	54.2	266,949	99.3	99.3
S-6 (EAA Outflow)	27.9	157,471	80.7	82.9
S-7 (EAA Outflow)	27.7	218,717	61.1	65.1
S-150 (EAA Outflow)	5.2	56,640	11.4	16.9
S-8 (EAA Outflow)	67.2	311,996	99.5	99.5
S-5A (Runoff)	53.5	261,819	98.1	97.1
S-6 (Runoff)	27.6	154,645	99.4	98.2
S-7 (Runoff)	27.3	224,626	83.0	81.6
S-8 (Runoff)	63.5	248,573	94.5	79.8

Table 8. Average monthly total phosphorus loads for the period of record.

STATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
G-88 (EAA Inflow)	0.00	0.00	0.00	0.00	0.13	1.38	1.09	1.91	0.29	0.00	0.40	0.00
G-136(EAA Inflow)	0.00	0.00	0.02	0.01	0.00	0.17	0.22	0.28	0.12	0.11	0.06	0.02
HGS-5(EAA Inflow)	0.60	0.52	0.75	1.65	2.33	1.41	0.25	0.08	0.13	0.44	0.70	0.70
S-2 (EAA Inflow)	1.14	2.15	3.39	4.57	3.48	2.54	0.39	0.11	0.27	0.39	0.59	0.64
S-3 (EAA Inflow)	0.98	1.27	1.48	2.07	1.88	1.05	0.29	0.11	0.18	0.18	0.36	0.48
HGS-5 (EAA Outflow)	0.00	0.02	0.09	0.00	0.17	0.00	0.00	0.08	0.00	0.00	0.00	0.00
S-2 (EAA Outflow Hills)	0.25	0.24	0.48	0.11	0.42	0.66	0.75	1.25	1.62	0.22	0.50	0.18
S-2 (EAA Outflow NNR)	0.47	0.45	0.89	0.21	0.78	1.24	1.40	2.33	3.04	0.41	0.94	0.34
S-3 (EAA Outflow)	1.03	2.26	2.83	0.33	0.77	0.29	0.20	0.42	0.27	0.18	0.43	1.04
S-5A1(Flow-Through)	0.19	0.08	0.14	0.29	0.12	0.04	0.00	0.01	0.00	0.02	0.05	0.09
S-6 (Flow-Through)	0.14	0.01	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
S-7 + S-150 (Flow-Through)	0.44	1.12	1.81	1.47	0.31	0.07	0.01	0.00	0.05	0.10	0.14	0.12
S-8 (Flow-Through)	0.22	0.29	0.29	0.32	0.15	0.57	0.54	0.87	0.16	0.04	0.18	0.02
S-5A1 (Backflow)	0.47	0.37	0.24	0.65	0.94	0.79	0.21	0.39	0.28	0.79	0.67	0.72
S-6 (EAA Backflow	0.05	0.06	0.02	0.02	0.03	0.09	0.02	0.01	0.00	0.04	0.00	0.02
S-7 (EAA Backflow)	0.00	0.00	0.03	0.02	0.01	0.00	0.02	0.00	0.01	0.03	0.02	0.00
S-150 (EAA Backflow)	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.02	0.03	0.02	0.00
S-8 (EAA Backflow)	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.00
S-5A2 (WCA inflow)	4.38	4.81	5.95	3.11	4.87	7.66	8.32	9.81	15.09	6.17	4.62	1.93
S-5A1 (EAA outflow)	2.33	4.15	4.94	1.34	3.16	6.16	6.84	5.47	10.09	4.56	3.33	1.84
S-6 (EAA Outflow)	1.72	0.60	1.11	0.89	2.94	3.47	4.56	3.67	4.26	1.89	2.26	0.49
S-7 (EAA Outflow)	1.36	1.19	2.00	1.15	1.83	5.93	4.36	4.30	2.41	1.52	1.18	0.50
S-150 (EAA Outflow)	0.22	0.80	1.41	0.67	0.22	0.11	0.10	0.67	0.34	0.22	0.25	0.16
S-8 (EAA Outflow)	2.15	2.83	3.41	2.11	1.82	8.42	14.0	7.46	6.35	4.71	2.50	1.37

Table 9. Average total phosphorus concentrations used to calculate loadings for backflows, backpumping, and inflows from G-88 and G-136.

SITE	TP AVERAGE mg/l	STDERR	N	PERIOD OF RECORD
G-88	0.324	0.076	11	79 - 05/91
G-136	0.076	0.014	19	09/82 - 06/84
S-2 (Backpump)	0.167	0.006	208	04/79 - 01/91
S-3 (Backpump)	0.166	0.007	165	04/79 - 08/91
HGS-5 (Backpump)	0.107	0.022	2	05/81 - 03/82
S-5A1 (Backpump)	0.127	0.017	32	11/78 - 08/91
S-6 (Backflow)	0.054	0.018	7	05/80 - 03/81
S-7 (Backflow)	0.055	0.008	13	07/83 - 03/91
S-150(Backflow)	0.100	0.013	3	07/84 - 07/85
S-8 (Backflow)	0.064	0.009	3	01/84 - 03/91

EAA Inflow Loadings from G-88 G-136 Canals. These are small canals that periodically flow bringing water into the Miami Canal from Hillsboro County. Chemistry data during positive flows are sparse (**Table 9**). For G-88 canal a total of 11 samples were taken during positive flow. For G-136 canal only 4 samples were taken during positive flow which gave a TP value of 0.118. Because of this small number, all grab samples (n = 19) were used to define the average chemistry for G-136 because it increased the period of record (from 6/83-10/83 to 09/82-6/84). Because there is no backflow in this canal the additional samples were taken when there was zero flow. They represent a better estimate of the average chemistry for waters that have flowed into this canal from Hillsboro County. The mean of total phosphorus were multiplied by the flow in the respective canal to obtain the loads from these canals (**Table 8**). The yearly mean loads and flows for G-136 were small (**Table 7**).

Water Conservation Area Loadings. The calculated average annual loads and flow for S-5A2, S-6, S-7, S-150, and S-8 are presented in **Table 7** while average monthly loads and flow are presented in **Table 8**. S-5A2 consists only of the water being pumped into WCA -1. The values are greater than 100% of the load coming out of the EAA through S-5A1, because some of the water and phosphorus comes from the L-8 and C-51 canals to the north and east respectively.

Water Conservation Area Backflow Loadings to the EAA. The number of grab samples taken from S-5A, S-6, S-7, S-150, and S-8 during backflow events were rather small (**Table 9**). The mean TP chemistry of these samples taken during backflow events were multiplied by the sum of monthly backflows to obtain monthly backflow loads. Only the backflow from S-5A1 was a significant portion of the input to the EAA (**Table 7**).

Flow-through Loadings from Lake Okeechobee. Total phosphorus loadings associated with releases from Lake Okeechobee, which flow-through the EAA to the WCAs or lower East coast, were calculated in a two-step process:

1. Monthly flow-weighted TP concentrations for the three Lake Okeechobee outflows (HGS-5, S-2, and S-3) were obtained by calculation (dividing total monthly loading by total monthly flow volume at each structure).
2. A monthly flow-through load was then calculated by multiplying the monthly flow-weighted concentration obtained in step 1 by the estimated monthly flow-through volume for each site.

The contribution of Lake Okeechobee flows and loads was converted to a fraction of the total at S-5A, S-6, S-7, S-150, and S-8. For example the contribution of Lake Okeechobee flow-through releases to the S-5A load was 0.010 of the total (1/54 metric tons), and the Lake contribution to S-5A flow was 0.030 of the total (7,880/266,949) (**Table 7**).

Lake Okeechobee flow through from S-2 to S-6 (Hillsboro Canal) and S-7 + S-150 (North New River Canal) was proportioned according to the outflow from these stations(equation 13, under section B.7 of this report). The flow weighted concentration of TP at S-2 was multiplied by these proportioned flows to defined the Lake Okeechobee flow through load for each canal. Note that S-150 is lumped with S-7 due to the proximity of these two sites.

Flow through for the Miami Canal was multiplied by the flow weighted concentration of TP from S-3, G-88, and G-136 to define the flow-through load at S-8.

The monthly estimates of flow-through loads are presented in **Table 8**.

Runoff Loads to WCA from EAA. These loads were calculated as the WCA load from the S-5A1, S-6, S-7 + S-150, and S-8 minus the calculated flow through loads for those structures. These represent significant portions of the outflow from these structures (**Table 7**). Because loads are a combination of flow and concentration of TP, it is possible to have a positive flow of water to the EAA and a negative load of TP. This negative load is the amount of TP actually adsorbed by the soils of the EAA during that time period. It is also possible to have a zero net runoff flow (100% of the water flowing out in a given period is flow-through) and have a positive load (the EAA adds TP to the water flowing through it). These are rare instances over the period of record.

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V. MONITORING REQUIREMENTS

A. DATA AND REFERENCES ON MONITORING REQUIREMENTS AND PROTOCOLS.

Chapter 40E-63 is concerned with two monitoring programs within the EAA designed to assess phosphorus loadings. The first program will be conducted by the District and will document the phosphorus loads originating from the EAA basins and discharged from S-5A, S-6, S-7, S-8, and S-150. This program has been described in Germain and Shaw (SFWMD Technical Publication 88-3). The second program is a regulatory program to assess phosphorus loads discharged to District canals from lands within the EAA. This program is also described (partially) in the permit application document, but the permittees will have responsibility for carrying it out. Detailed scope and protocol for this regulatory program are given below.

1. Monitoring Requirement Objectives

The SWIM Rule requires that permit applicants supply a water quality monitoring plan designed to document compliance with annual phosphorus load allocation, high phosphorus events, and BMP effectiveness. The plan must monitor flow and total phosphorus concentration discharged from the permitted area on a continuing basis, or as otherwise required by the District. The Rule also outlines other requirements and conditions of this regulatory program.

The objectives of this regulatory program are to:

a) Identify sources of the water quality constituents that fail to meet targeted load reduction goals set for the EAA.

b) Provide adequate documentation of problem source areas to support corrective efforts.

c) Provide an on-going assessment of ambient water quality within the District's primary canal system to measure progress of BMP's toward achieving interim loads and applicable water quality standards.

2. Monitoring Requirement Scope

Samples for total phosphorus analysis will be collected over weekly periods at each structure discharging to a District canal. Samples will only be collected during periods of discharge. If there has been no discharge during the week, no samples need to be collected.

Samples will be collected at 0.5 meters below the water surface or at mid-depth, and will be collected by automatic sampler or, in a few exceptions, the grab method. The method of sample collection will be made part of the discharge permit and can only be changed with the agreement of the District.

Samples will be collected on the upstream side of the culvert discharging to the District canal (in tailwater of pump, if present).

Automatic samplers can be configured to collect flow-proportional or time-composite samples. By either method, samples will be composited into one large container. For sites with pumps run at variable speed, the flow-proportional method is required. In this method, tachometers on the pump(s) will determine how much water is collected by the automatic sampler per time interval. For sites with single or multiple pumps run at constant speed, the time- composite method may be used for each pump. Constant volumes of water are collected at set intervals by this method as long as the pump is operating. Samples will be preserved by acidification, but refrigeration during collection periods prior to pick-up will not be required.

For portable pumps or other sites where the permittee and District determines that automatic samplers are not feasible or cost- effective, grab samples may be collected instead. The grab sample must be collected not less than two hours after the onset of pumping. If the pump is run for less than two continuous hours, no sampling will be required. Samples must be collected each day that the pump is operating. Each sample will be analyzed separately.

Representative samples will be collected and analyzed for total phosphorus. Sampling must be conducted by qualified individuals and samples must be analyzed by a certified laboratory with a QA/QC plan approved by DER.

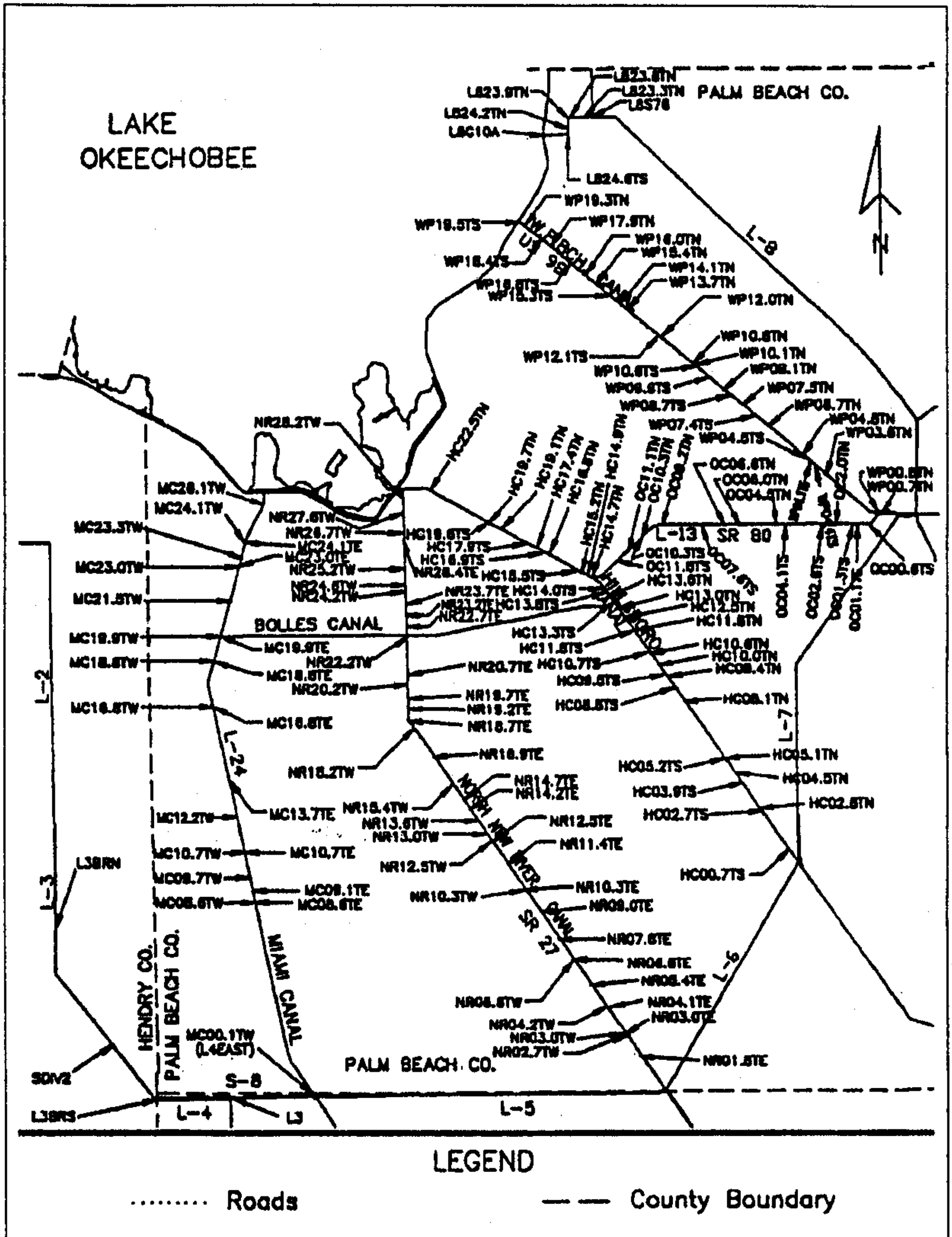
Discharges will be measured by flow meters or estimated from pump operation logs. If estimated by operation logs, the pumps must be calibrated.

Daily phosphorus loads will be calculated by multiplying the daily discharge by the concentration in the composite sample for the period (automatic samplers) or the concentration in the sample collected on that day (grab samples).

Total phosphorus concentrations, daily discharges, and daily loads will be reported to the SFWMD monthly. The report should note the times of sample collection and the times of discharge. These reports will be submitted in an electronic format to be specified by the District.

The District will conduct a scaled-down program similar to the one it is currently conducting (water quality grab samples only) at selected sites shown in **Figure 28** to verify the accuracy of the data submitted by the permittees.

Figure 28. SFWMD current Works of the District water quality monitoring Sites in the EAA



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VI. PHOSPHORUS LOAD ALLOCATIONS AND COMPLIANCE CALCULATIONS

A. INTRODUCTION

The purpose of this chapter is to establish a procedure for determining compliance with the proposed administrative rule that requires a 25 percent total phosphorus (TP) load reduction for the Everglades Agricultural Area (EAA) in the South Florida Water Management District (the District). This procedure is to apply to any set of hydrologic conditions that could arise in the period following the installation of farm-level best management practices (BMPs).

Under the Marjory Stoneman Douglas Act (MSD Act), the District is required to reduce the long-term average total phosphorus (TP) loads from the Everglades Agricultural Area (EAA) to the Water Conservation Areas (WCAs). There are four sub-basins in the EAA, identified by their outflow structures as the S-5A, S-6, S-7, and S-8 sub-basins. It has been surmised that reductions equivalent to 25 percent of TP loadings calculated for the 10-year period of October 1978 to September 1988 (the base-period) over the long term is technologically feasible and a necessary first step toward achieving the restoration and long-term maintenance of water quality in the Everglades.

Permits will be issued to the District by the Florida Department of Environmental Regulation (DER) for the Districts pump stations at S 5A, S-6, S-7, and S-8 whose canals generally convey water south from each of the EAA sub-basins. The District, in turn, will issue permits for agricultural stormwater runoff pumps that will convey BMP-treated water from each of the farms to the Districts canal system. As long as long-term average load reductions achieved in the EAA is 25 percent or better, TP load reduction requirements at the farm level will not be enforced. If the long-term average TP load reduction is not achieved, there will be a need to identify the farms whose BMPs are insufficient.

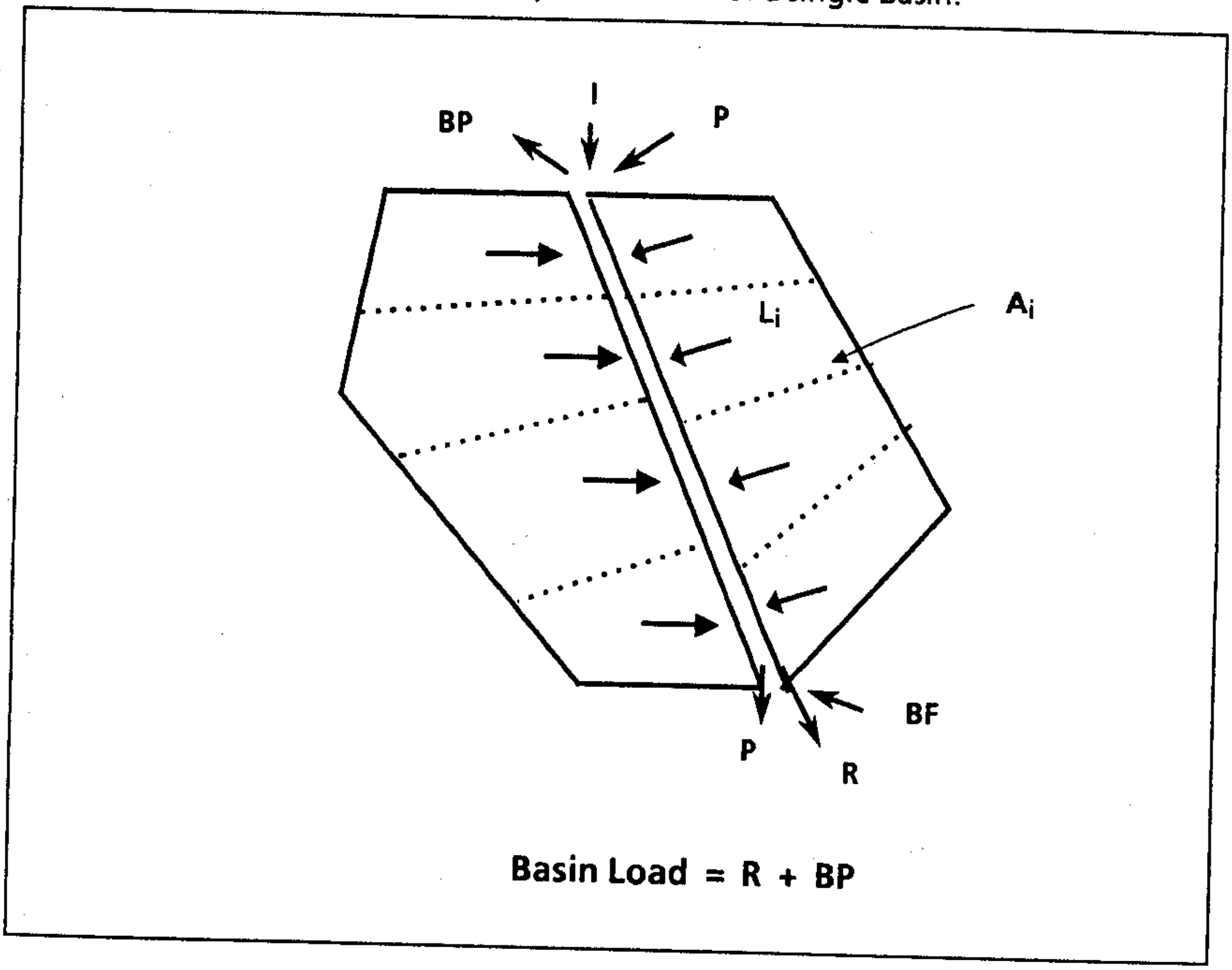
Monitoring at the Districts structures will be conducted to determine the likelihood of exceedance of EAA basin TP load limits with each successive month of monitoring data after BMP implementation. These data will be compared against the results of a model that predicts what EAA basin loads should be if the 25% reduction was achieved. When developing the model, the District sought to define an administratively simple, yet rigorous and defensible approach that would lead to TP load compliance. A consideration during the process of model development was that the approach selected would not overreact to months with highly improbable TP loads associated with extreme storm events that are unlikely to recur. It was determined that compliance will be assessed yearly at May 1, while reports will be issued monthly to judge progress towards the 25% reduction. The May 1 cutoff coincides with the break between dry and wet rainfall periods, thereby including a contiguous wet and dry cycle in each annual compliance period.

Even though the EAA basin is divided into four sub-basins, sub-basin boundaries are not definite because of flat topography. Interbasin transfer of water has occurred in all basins and in particular through the Cross Canal and the Bolles canal. Interbasin water transfer has been, and will continue to be, an important tool in both flood control and water supply. Considering this, compliance will be evaluated for the entire EAA, instead of each sub-basin.

B. DEFINITIONS

With reference to **Figure 29**, the following variables are defined to illustrate the existence of different types of discharge quantities that must be considered in computing loads associated with the EAA runoff.

Figure 29. Description sketch for a single basin.



BP = TP load associated with backpumping to Lake Okeechobee for the 12-month period ending on April 30.

BF = TP load associated with backflow from south and west into EAA for the 12-month period ending on April 30.

I = TP load of the supplemental irrigation water discharged to EAA for the 12-month period ending on April 30.

P = TP load associated with the pass-through flows for the 12-month period ending on April 30.

R = TP load associated with the runoff (excluding the runoff associated with backpumping) for the 12-month period ending on April 30.

B = TP load of total runoff (including backpumping) estimated at the basin outlets for the 12-month period ending on April 30.

A_i = Drainage area corresponding to the discharge location i.

L_i = Loading at the discharge point i for the 12-month period ending on April 30.

U_i = Unit Area Load (UAL) at discharge point i for the 12-month period ending on April 30.

Note that the following hold:

$$B = R + BP$$

$$L_i = U_i * A_i$$

Discussions that follow will focus on the TP load associated with the total runoff, denoted by B.

C. APPROACH TO EAA BASIN HYDROLOGIC VARIABILITY

The District approach will require that, prior to completion of required Stormwater Treatment Areas (STA), the EAA will be allowed a long-term average loading of 75 percent of the base period, but **corrected for hydrologic variations.** After completion of the STAs, the EAA will be allowed a long-term average loading of less than 75 percent of the base period, since land has been taken out of agricultural production. Note however, that the average unit area reduction required remains the same, pre- and post- STA. The actual percentage of the base period allowed after completion of the STAs depends on the final acreage of the STAs.

Correcting for hydrologic variability requires the completion of two tasks. The first task is to develop a model for estimating the long-term average TP loads of the EAA basin during base-period (1978-1988). From a statistical modeling viewpoint, this task can be accomplished by evaluating the relationships between the set of hydrologic conditions and TP loads observed over various lengths of time during the base-period. A statistical model could employ hydrologic factor(s) as independent variable(s) and should be capable of estimating long term base period TP loading target for a given set of base period hydrologic conditions. Having accomplished this, the model could then be used to estimate future TP loads, by substituting future hydrologic conditions into the model. If the measured TP loading from the EAA basin in that future period is less than 75 percent of the model estimate then, in general, the EAA basin would be in compliance and no further action would be imposed on farms within the basin.

However, models developed will likely have some statistical error, so the second task must be to determine the statistical likelihood that the EAA basin is out of compliance with its long-term average TP load limit. This can be accomplished by specifying a required level of statistical confidence in the prediction of the long-term average TP load. The 90th percentile confidence level was selected by the District as reasonable. Greater confidence intervals would lead to longer times required to judge compliance; lesser confidence intervals could lead to unwarranted compliance actions.

1. Data for Model Development

The EAA was divided into four sub-basins, identified as West Palm Beach Canal, Hillsboro Canal, North New River Canal and Miami Canal with primary downstream control structures at S-5A, S-6, S-7 and S-8, respectively. Hydrologic data, such as rainfall and streamflow, have been collected before, during and after the base period of 1978-88. These data are stored as daily records in the District's hydrology database. Data from nine (9) rainfall stations in the area (**Figure 24** in Chapter IV) were used to develop a Thiessen's network to compute mean areal rainfall for the entire basin and each sub-basin. Streamflow data were developed for relevant water control structures including three that discharge to the EAA from Lake Okeechobee (S-351, S-352, and S-354) and four that discharge from the EAA to the WCAs (S-5A structure complex, S-6, S-7, and S-8). Flows measured at S-150, G-88 and G-136 were also used in the computations.

TP concentration data at or near those water control structures are also available in the District's database. Detailed procedures to compute loads are in the Technical Document published in support of Chapter 40E-63, part 1, F.A.C.

The choice of 1978 through 1988 as the base-period of record for model development was based on the following:

a) No significant BMPs were implemented in any of the basins, hence TP outflow was that of 'natural' agricultural area.

b) There was a large range of hydrologic variations in the period, including a severe drought between 1980-81 when the average depth of Lake Okeechobee decreased significantly, drying up vast expanses of shoreline normally inundated.

c) There were no significant gaps in hydrologic and TP loading data.

Because future loadings are to be evaluated yearly, yearly discharge and TP loading data were compiled for the base period. Yearly discharge (in acre-feet) and TP loading (in Kg) were computed for the basin from daily data. Yearly rainfall and TP loads in the EAA are plotted in **Figure 30.**

2. Model Selection

Rainfall is the driving force of hydrology in south Florida. Obviously, discharge and/or rainfall are dominant factors when computing TP loads. However, rainfall and stream flow are subject to large temporal and spatial variation in this area. If not properly accounted for, the hydrologic variability could be large enough to obscure the true signal (i.e., effectiveness of BMP to reduce TP loadings) that the District wants to measure. Therefore, a method was devised to strengthen the ability to detect the effectiveness of BMP to reduce TP loadings.

Guidelines Adopted for Model Development. Models developed should be able to filter out the true signal (i.e., effectiveness of BMP to reduce TP loadings) while recognizing the following constraints, assumptions, and guidelines:

a) The base-period is given as the water years 1978 to 1988. The system is expected to be subject to changes in its event-responsiveness as a result of BMP implementations. Therefore, measurements of the dependent variable (TP loading) under the conditions of the base period will not be available in the future.

b) The Interim Action Plan (IAP) is anticipated to continue in the future with occasional temporary suspensions.

c) There will be a gap of about 4 years between the end of base period (1988) and the time of applying the model for compliance purposes (1992).

d) TP loading from the EAA basin outflow will be calculated monthly, so the model will be used each month to evaluate progress towards basin compliance. Actual regulatory compliance evaluations will occur on May 1 of each year. The period considered by the model for compliance evaluation purposes will ideally include at least one water year.

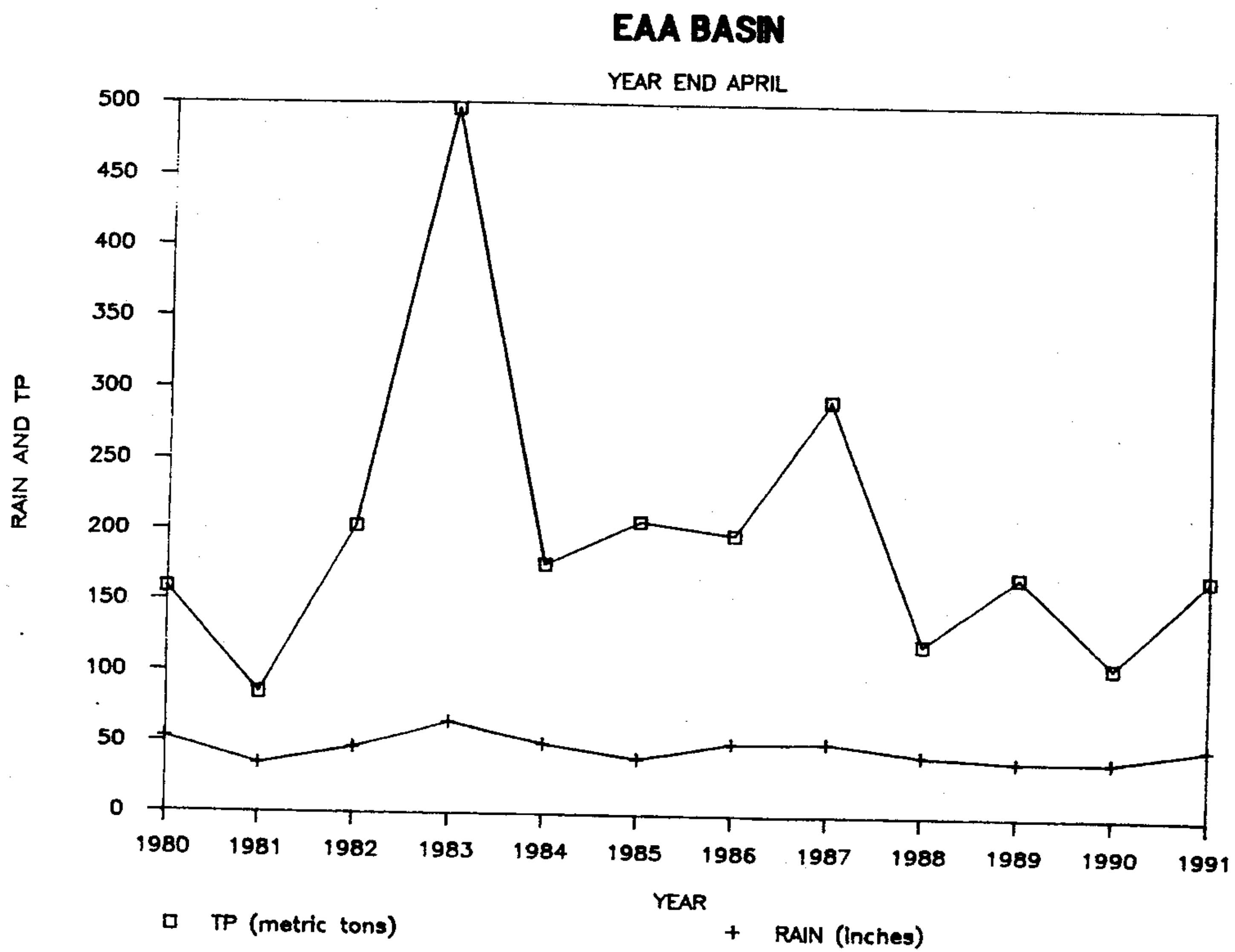
e) A simple, robust model is preferred over abstract and complicated ones for easy understanding and regulatory enforcement.

Selection of Model Variables and Appropriate Model. Both rainfall and discharge, and their derivatives (such as rainfall raised to a certain exponent or power, and differences in outflow and inflow, etc.) were examined initially as independent variables for predicting the dependent variable, TP loading. Rainfall was chosen as the only independent variable to define hydrologic conditions for both the base-period and the future for the following reasons:

a) It is a truly independent variable, not subject to direct control of human activities, such as through water retention by BMPs.

b) Sufficient and consistent local rainfall records are, and will be, available.

Figure 30. Yearly rainfall and TP loads in the EAA.



D. THE EAA BASIN MODEL

1. Qualitative Explanation of the Model

A regression model that relates TP loading to rainfall was selected by the District for judging basin compliance. For purposes of explanation, the simplest regression model would have one constant (intercept) and one slope. One could start the reasoning from a yearly model, as the model is required to generate yearly load estimates in actual application. The dependent variable (left-hand-side of equation) would be TP load, or a transformation of TP load. The independent variable could be rainfall, or a transformation of rainfall, measured in the same period as the dependent variable. The variability of rainfall within years was found to be important in predicting the TP load and therefore, the coefficient of variation and skewness of monthly rainfall were also included as independent variables.

2. Quantitative Description of the Regression Model

This methodology tests compliance with the required 25% reduction in phosphorus load from the EAA. It applies to the total load from S-2, S-3, S-5A, S-6, S-7 & S-150, and S-8 to the Water Conservation Areas and Lake Okeechobee. Load is calculated from concentration and flow data collected by SFWMD, USCOE, and USGS at structures bordering the EAA.

The compliance test is based upon a regression model relating annual load to rainfall distribution. The model has been calibrated to data collected in 9 consecutive 12-month periods starting May 1, 1979 and ending April 30, 1988. The model has been tested using data collected between May 1, 1988 and April 30, 1991 (**Table 10**, presented and discussed further in this chapter). To reflect the required 25% reduction, measured loads are multiplied by 0.75 before performing the following regression:

$$\ln(L) = -5.892 + 3.071X + 2.236\,C - 0.3572\,S$$

[Explained Variance = 92.9%, Standard Error of Estimate = 0.1687]

Predictors (X,C,S) are calculated from the first three moments (m_1,m_2,m_3) of the 12 monthly rainfall totals (r_i, i = 1...12, inches) for the current year:

$$m_1 = \text{Sum}[\, r_i\,] / 12$$

$$m_2 = \text{Sum}[\, r_i - m_1\,]^2 / 12$$

$$m_3 = \text{Sum}[\, r_i - m_1\,]^3 / 12$$

$$X = \ln(12\, m_1)$$

$$C = \ln(\, [(12/11)\, m_2]^{.5} / m_1)$$

$$S = (12/11)\, m_3 / m_2^{1.5}$$

where,

L = 12-month load attributed to EAA Runoff, reduced by 25% (metric tons)

X = natural logarithm of 12-month total rainfall (inches)

C = natural logarithm of coefficient of variation calculated from 12 monthly rainfall totals

S = skewness coefficient calculated from 12 monthly rainfall totals

The first predictor (X) indicates that load increases approximate with the cube of total annual rainfall. The second and third predictors (C & S) indicate that the load resulting from a given annual rainfall is higher when the distribution of monthly rainfall has higher coefficient of variation or lower skewness. For a given annual rainfall, the lowest load occurs when rainfall is evenly distributed across months and the highest load occurs when all of the rain falls in one month. Real cases fall in between.

Compliance will be tracked by comparing the measured EAA Load with:

$$\text{Target} = \exp[-5.892 + 3.071\,X + 2.236\,C - 0.3572\,S]$$

$$\text{Limit} = \text{Target}\ \exp(1.476\,SE\ F)$$

$$SE = 0.1687\,[1 + 1/9 + 5.122\,(X-X_m)^2 + 9.675\,(C-C_m)^2 + 0.4985\,(S-S_m)^2 + 6.245\,(X-X_m)(C-C_m) - 1.187\,(X-X_m)\,(S-S_m) - 1.971\,(C-C_m)(S-S_m)]^{.5}$$

where,

m = subscript denoting average value of predictor in base period ($X_m = 3.866$, $C_m = -.3361$, $S_m = 0.7339$)

Target = predicted load for current rainfall conditions (metric tons/yr)

Limit = upper 90% confidence limit for predicted load (metric tons/yr)

SE = standard error of predicted ln(L) for May-April interval

F = factor to reflect variations in model standard error as a function of month (last in 12-month interval), calculated from base period:

Month	F	Month	F
Jan	2.201	Jul	1.354
Feb	1.774	Aug	2.462
Mar	1.508	Sep	3.397
Apr	1.000	Oct	3.020
May	1.534	Nov	3.025
Jun	1.242	Dec	2.508

The Load, Target, and Limit will be tracked monthly using data from the most recent 12 months. Warnings will be issued if the Load exceeds the Limit in any 12-month interval or if the Load exceeds the Target in any 12-month interval ending April 30. Compliance will be determined based upon the Measured Load, Target, and Limit computed for the 12-month period ending April 30 of each year.

A violation will be declared in either of the following conditions:

a) The Measured Load exceeds the Limit in any May-April period.

or

b) The Measured Load exceeds the Target in 3 or more consecutive May-April periods.

E. IDENTIFICATION OF MAXIMUM UNIT AREA LOADS FOR SELECTED DISCHARGE SITES IN THE EAA

1. Qualitative Explanation of the Calculation

In order to determine the basin compliance, the measured EAA basin load computed from the data monitored at the basin outlets for the 12-month period ending April 30 every year will be compared with the EAA basin goal and the limit computed from the basin model. In case of noncompliance at the basin-level a determination of the farm-level compliance is required and the enforcement of corrective actions to improve the performance of BMP's may be necessary.

At each farm pump discharge point within a basin, both TP loads and discharge will be computed for every event during which discharge into primary canals occurs. These data and additional data that may be collected at selected locations in the primary canals within the basin will be used to determine performance standards and enforce farm-scale compliance. At the time of the evaluation of the basin, three types of load estimates will be available:

(a) TP loading goal and the associated 90 percent limit as computed from the basin model,

(b) Total TP load associated with the runoff (including backpumping) from the basin,and

(c) Sum of loads as reported for all discharge points within the basin.

Almost certainly, the actual basin runoff load and the sum of the loads within the basin will not match. When the entire EAA is not in compliance, the most likely scenario is that the sum of loads within the basin will exceed the actual basin load measured at the outlet. In this case, the approach outlined in this document can be used to identify a maximum allowable unit loading rate for each site and the corresponding sites which exceed this limit.

If a basin is not in compliance, and yet the sum of loads within the basin is less than the goal, then a thorough investigation will be necessary to identify the sources of excess TP load at the basin outlets. This investigation should focus on the following:

(a) The accuracy of the reported loads at the off-site discharge locations.

(b) The magnitude and the sources of the unknown loads contributing to the excess load at the basin outlets.

Both items (a) and (b) above can be addressed through (1) more intense monitoring of concentration and discharges within the basin primary canals; and (2) modeling of fate and transport of nutrients within the basin. It is our intent to monitor concentration and discharge at selected locations in every primary canal in the EAA during every major storm. This data will be used not only for verifying TP loads reported at each discharge point but also for identifying locations and sources of excess load over and above what is reported for the permitted off-site discharge locations. Deterministic simulation models can also be developed, calibrated and applied to predict the expected load at each discharge point during major storm events.

Once a basin-level noncompliance is inferred from data, the farm-level enforcement will be executed within the basin regardless of the magnitude of the sum of loads reported at the off-site discharge points. The enforcement action will be designed to reduce the sum of loads within the basin by the same percentage required to reduce the actual basin runoff load to the target basin load.

It is important to note that the unit area loading for a particular 12-month evaluation period corresponds to a particular rainfall pattern in that period. For a dry period, it is likely the UALs will be less than those corresponding to a more wetter period. This is illustrated in **Figure 31**. Because of the dependence of UAL on hydrologic variability, a Unit Area Loading limit determined from the current data cannot be used directly as a measure of average performance in the future. To be used as a performance standard the unit area loading should correspond to the average rainfall condition or to any other design rainfall scenario.

A simple approach to account for the farm-level hydrologic variability is to adjust all the unit area loading values corresponding to the current rainfall to reflect basin average rainfall. The general form of the hydrologic variability regression model developed for the entire basin is used to adjust the farm-level data.

For a given Target Load at the farm level, the method presented below will identify the Maximum Unit Area Loading (MUAL) for each farm such that if all larger unit area loadings are reduced to the corresponding MUALs, then the sum of loads at the farm level will reduce to its target value.

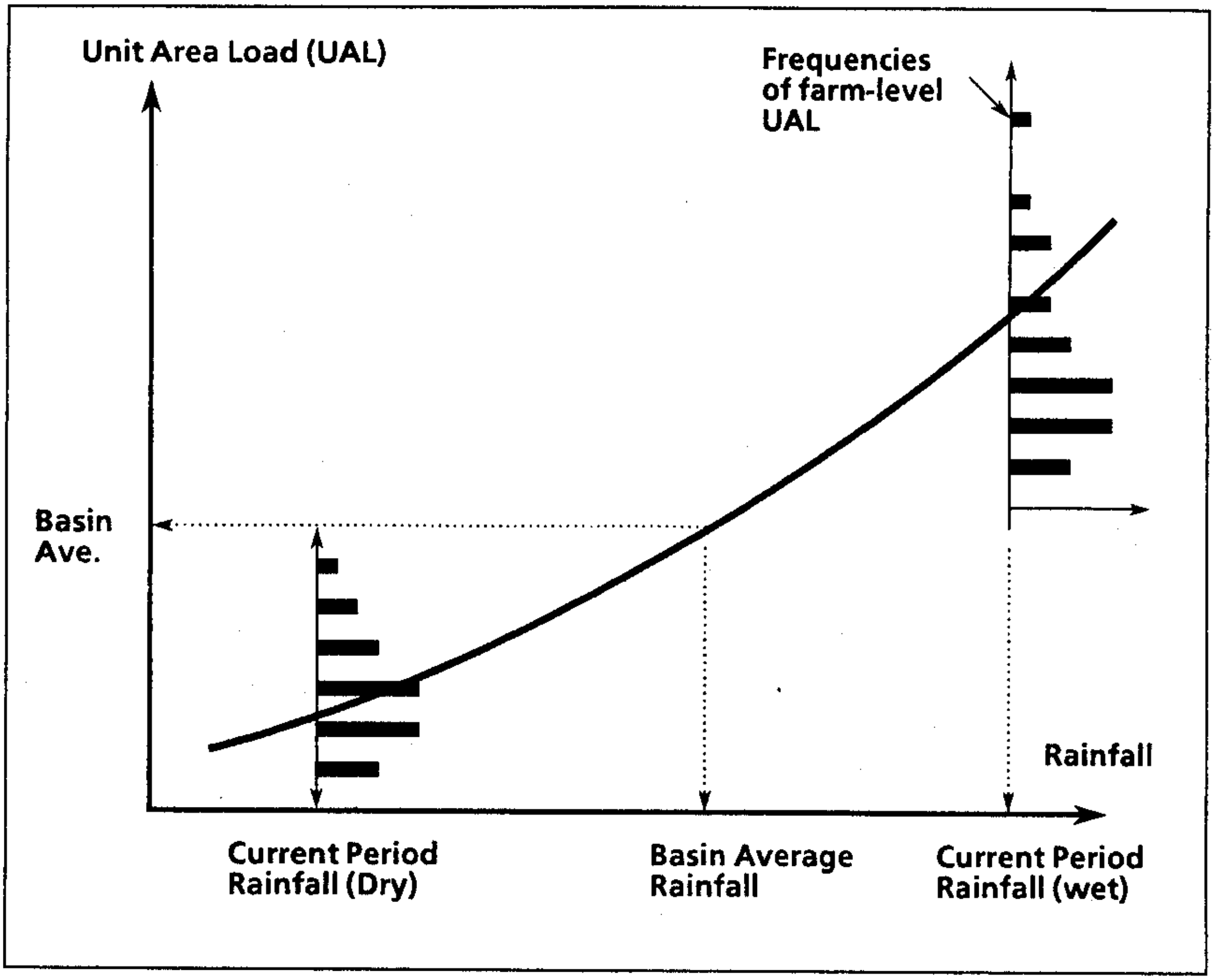
2. Quantitative Description of the Farm-level Calculation

This procedure will be used to regulate phosphorus loads from individual farms in a manner which is most likely to result in achieving the Basin Target Load. It will be applied only if the measured Basin Load is found to be out of compliance or in a "warning" status, based upon the criteria described above. Resulting farm-scale allocations will be enforced only if the Basin Load is found to be out of compliance.

- Compute the ratio of the Basin Target load to the Basin Measured load for the current year:

$$Y = \text{Target} / \text{Measured}$$

Figure 31. Illustration of the hydrologic variability of Unit Area Loadings at the Farm Level.



- Compute the Unit Area Loading (UAL) from each regulated Farm, based upon concentration and flow data reported for the most recent 12-month period:

$$UAL_i = L_i / A_i$$

where,

UAL_i =	Unit Area Load for Farm i (lbs/acre-year)
L_i =	Load calculated by SFWMD using flow and concentration data supplied by Farm i, plus other data obtained by SFWMD, as necessary (lbs/year)
A_i =	Area of Farm i (acres)

- Compute the Adjusted Unit Area Load ($AUAL_i$), considering observed rainfall in the corresponding EAA subasin (S-5A, S-6, S-7, or S-8) in the current year:

$$AUAL_i = UAL_i \, (R_{am} / R_a)^{3.071}$$

$$R_a = \exp[X + 0.7280\,(C - C_m) - 0.1163\,(S - S_m)]$$

where,

m =	subscript denoting average value of rainfall statistic in base period for EAA Subasin containing Farm i (**Table 10**)
R_{am} =	base period log-mean adjusted rainfall for EAA Subasin containing Farm i (inches, **Table 10**)
R_a =	adjusted subasin rainfall in current year (inches)

Table 10. Rainfall distribution coefficients by basin computed from monthly rainfall totals, May 1979 - April 1988

BASIN	X_m	C_m	S_m	R_{am}
EAA Total	3.866	-0.3361	0.7339	47.73
S-5A	3.918	-0.2826	0.9999	50.31
S-6	3.907	-0.3238	0.7476	49.77
S-7	3.835	-0.3429	0.6112	46.27
S-8	3.822	-0.2529	0.8409	45.68

This calculation adjusts the UAL to reflect average rainfall conditions observed in the 1979-1988 base period. It also adjusts for spatial variations in rainfall among EAA subasins in the current year.

- Compute the total adjusted TP load across all Farms (ALOAD, lbs/yr):

$$ALOAD = SUM[AUAL_i * A_i]$$

- Compute the Farm-Level Target load (TLOAD, lbs/yr), assuming that the percentage reduction in total load required at the Farm scale equals the percentage reduction required at the Basin scale:

$$TLOAD = ALOAD \; Y$$

Farm-scale allocations will be conducted for all farms whose $AUAL_i$ exceed $AUAL_0$, calculated from the following equation:

$$AUAL_0 = TLOAD / AREA / 3$$

$$AREA = \text{Total Farm Acreage}$$

This procedure distributes the responsibility of achieving further load reductions over all farms whose $AUAL_i$ exceed one third of the mean AUAL corresponding to the basin target load. Farms with $AUAL_i$ values greater than $AUAL_0$ will be required to develop new BMP plans. These plans will be designed to reduce $AUAL_i$ values to Maximum Unit Area Loads ($MUAL_i$) given by:

$$MUAL_i = AUAL_0 + (AUAL_i - AUAL_0)(1 - K)$$

The coefficient K applies to all farms with $AUAL_i$ above $AUAL_0$. It is calculated to achieve the basin target load (25% reduction) using the following equation:

$$TLOAD = SUM\,[\,MUAL_i \times A_i\,] + SUM\,[AUAL_j \times A_j]$$

The first summation (i) is over all Farms which have $AUAL_i$ greater than $AUAL_0$. The second summation (j) is over all other Farms which have $AUAL_j$ equal to or less than $AUAL_0$.

Enforcement actions will be taken at all Farms whose $AUAL_i$ exceeds $MUAL_i$ in subsequent years.

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