# Chapter 5: Effectiveness of Best Management Practices

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## SUMMARY

Agricultural Best Management Practices (BMPs) in the Everglades Agricultural Area (EAA) consist of farming practices for managing water, nutrients and sediment. Basin-wide implementation of these BMPs is required by the Everglades Forever Act (Act) through the South Florida Water Management District's (District's) Everglades BMP Regulatory Program to achieve a minimum of 25 percent annual total phosphorus (TP) load reduction from the EAA. This chapter documents the effectiveness of BMPs at three spatial scales: basin level, farm level, and field level. The basin level assessment uses a statistical model to adjust for hydrologic variability and quantify the TP load and concentration reduction in relation to BMP implementation in the EAA. The results show that the TP load reduction in Water Year 2000 (May 1, 1999 through April 30, 2000) amounts to 55 percent compared with the predicted value assuming that BMPs were not in place. This represents the fifth year that the 25 percent TP load reduction goal has been exceeded. Between WY96 and WY00, the TP load reduction averaged 54 percent, and the TP concentration averaged 108 ppb, significantly lower than the 12-year average of 173 ppb during the pre-BMP period (from 1979 through 1991).

The farm level assessment uses farm monitoring data and BMP research results from the University of Florida Institute of Food and Agricultural Sciences (UF/IFAS). The results show that the TP load and concentration have been reduced at most farms with BMP implementation, following the general patterns observed at the basin level. However, the performance varies between farms within a year and between years within a farm. The success of a farm level BMP plan depends highly on the optimal integration of the three categories of BMPs fitted for site specific conditions and crop rotation patterns. Analyses of the event-based TP concentrations and loads indicate that large TP concentration and load spikes occur about three to ten times a year at all farms. UF/IFAS research found that particulate P (PP) accounts for over 50 percent of TP and is associated with large TP loading events. The farm level assessment indicates that additional TP load reductions can be achieved with basin-wide control of PP discharge.

The field level assessment uses available information and the Everglades Agricultural Area Model (EAAMOD) to evaluate the effectiveness of each BMP or categories of BMPs. The assessment indicates that most BMPs are effective, with each category having its unique mechanisms driving TP load reduction. Future research efforts should emphasize the development of alternative or enhanced sediment control BMPs to better control PP derived from aquatic weeds in farm ditches and canals. The chapter concludes

that BMPs implemented in the EAA are effective in reducing both TP load and concentration. Additional reduction is possible with effective BMP training, optimal integration of BMPs, and enhanced sediment control BMPs.

# INTRODUCTION

The Everglades Agricultural Area (EAA), situated south of Lake Okeechobee and north of the Everglades Protection Area (EPA), encompasses an area of approximately 700,000 acres of 2872 $km^2$ highly productive land (**Figure 5-1**) (Chapter 1). Agriculture within the EAA requires fertilization and extensive drainage of approximately 500,000 acres of organic soils; about 80 percent is planted with sugarcane, and the remainder in various vegetables, sod and rice. Drainage of the EAA is achieved with six main canals operated by the District that connect to secondary canals and pump structures operated by individual landowners (**Figure 5-1**). Drainage water from the EAA, containing dissolved nutrients and particulates derived from erosional sediment and decomposed aquatic macrophytes, is discharged into the District canals and subsequently into the EPA. The total phosphorus (TP) concentration of EAA drainage water averaged about 173 ppb from 1979 to 1991. A large body of scientific evidence indicates that the ecological integrity of the Everglades has been influenced by the introduction of the phosphorus rich drainage water (Chapter 3).

In 1991, the Florida legislature passed the Everglades Protection Act, requiring the District to initiate the Everglades BMP Regulatory Program (Chapter 40E-63, Florida Administrative Code [FAC]). Landowners in the EAA are required to implement on-farm BMPs in an effort to reduce TP load by 25 percent at the end of each 12-month water year (WY, May 1 through April 30). In 1994, the Everglades Protection Act was amended and became the Everglades Forever Act (Act). The Act mandated a comprehensive Everglades Restoration Program consisting primarily of onsite water quality control with BMPs and offsite water quality improvement with Stormwater Treatment Areas (STAs). The interim TP concentration goal after BMP implementation and STA treatment is 50 ppb. The Act requires that the effectiveness of BMPs for reducing TP load be assessed on an annual basis. This chapter in the Everglades Consolidated Report serves this purpose.

Last year's chapter was based on extensive literature research with the review of more than 30 references on BMP research, implementation and education projects specific to the EAA (Whalen et al., 2000). Multiple references from the same project were combined into a single "BMP initiative." **Table 5-1** lists selected information for these initiatives. Based on the analysis of these initiatives, last year's chapter concluded that:

- BMP implementation has resulted in loading reductions in full compliance with the 25 percent requirement mandated in the Act. The phosphorus load reduction represents a decrease of TP from the EAA farms, cities and industry. The most recent three-year trend (WY97-WY99) in cumulative TP reduction is 44 percent compared to that recorded from 1979 to 1988.
- The reduction in TP is attributable to landowners' implementing BMPs, as documented through the Everglades BMP Regulatory Program, as

well as research and educational programs conducted by at least 10 private and/or public entities.

- Initiatives between 1979 and 1999 provided information to support the EAA BMP program. Through continuing research, monitoring and refinement, further declines in TP load and concentration from the EAA are probable.

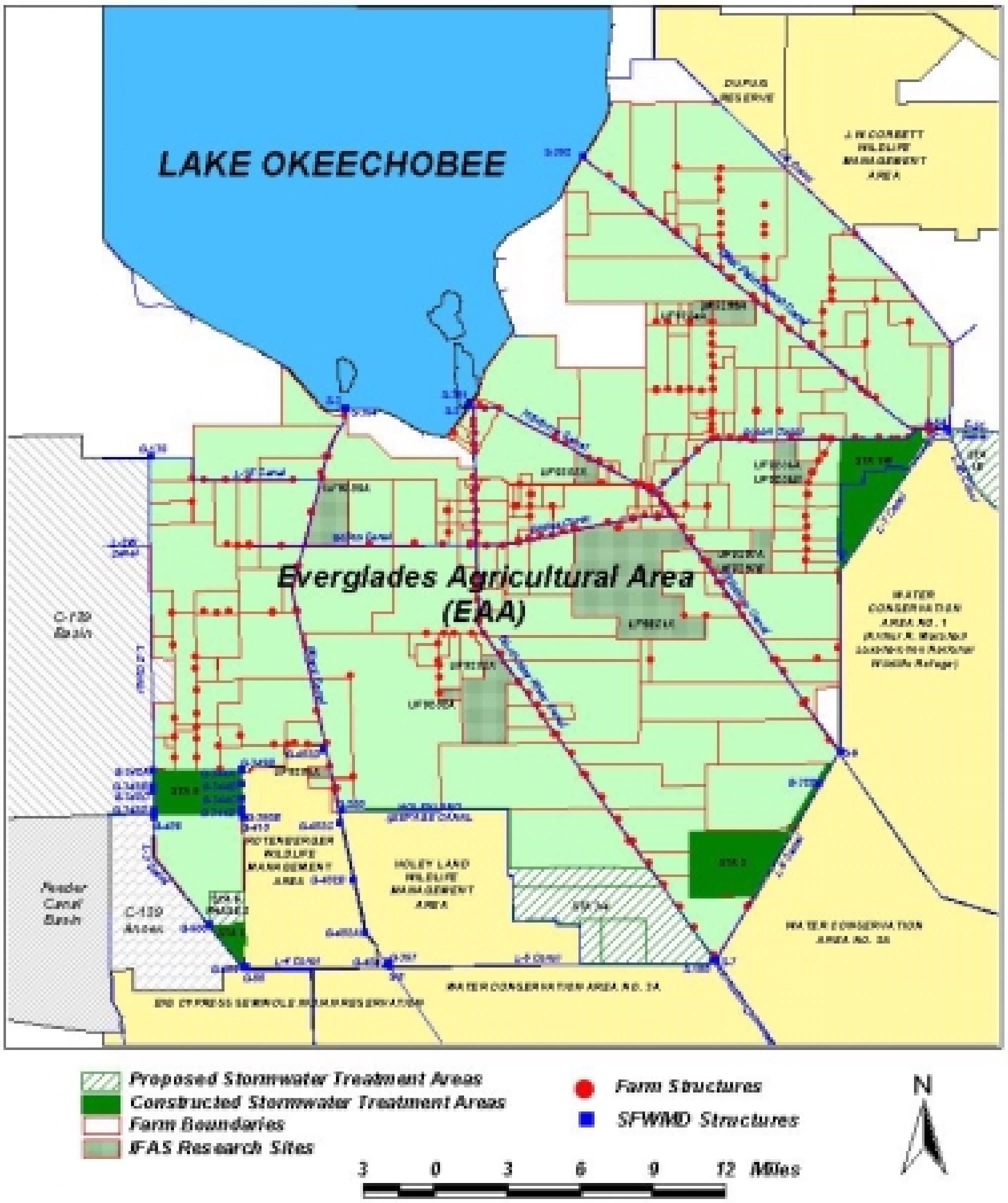


**Figure 5-1.** Geographic location of the EAA and internal features, including farm drainage basins, canals, pumping structures, and UF/IFAS research sites.

**Table 5-1.** Initiatives undertaken between 1985 and 1999 to address BMPs in the EAA (Modified from Whalen et al., 2000).

| Initiative No. | Program / Study | Period |
|---|---|---|
| 1 | Rule 40E-61, FAC. | 1989-present |
| | Rule 40E-63, FAC. (SFWMD, 1997a, b) | 1992-present |
| 2 | Plot-Scale BMPs Research (Izuno and Bottcher, 1991) | 1985-1991 |
| 3 | Water Management (Environmental Services and Permitting, 1991) | 1990-1991 |
| 4 | Plot-scale Sediment BMPs (Andreis, 1992; 1996) | 1992-1996 |
| 5 | Modified Pumping Practice (Hutcheon Engineers,1992;1994) | 1991-1994 |
| 6 | Sediment Control Demonstration (Hutcheon Engineers,1995) | 1993-1995 |
| 7 | Farm Scale BMP Research (Izuno and Rice, 2000) | 1992-present |
| 8 | Sediment Trapping in Rock Pit (Izuno and Rice, 1998) | 1997-1998 |
| 9 | BMP Procedure Guide (Bottcher et al., 1995) | 1993-1995 |
| 10 | BMP Workbook and Training (Hutcheon Engineers,1993) | 1993 |
| 11 | BMP Demonstration and Training (Palm Beach Soil and Water Conservation District, 1997) | 1996-1997 |
| 12 | Chemical Treatment (Anderson et al., 1992) | 1992 |
| 13 | Sugarcane Leaf Phosphorus and Genetics (Glaz et al., 1997) | 1999-present* |
| 14 | Chemical Dosing and Vegetative Treatment (e.g., Bion Technologies 1996) | 1992-1996 |
| 15 | Sugarcane Water Tolerance (Glaz, written communication) | 1996-present* |
| 16 | Wind Erosion BMPs (SFWMD, 1999) | 1997-1999 |
| 17 | Phosphorus Extraction/Calibrated Soil Test BMP (Rice, 1999) | 1999-present* |

* Ongoing research to refine BMPs. No substantial data allowing determination of BMP effectiveness were available at the time of report preparation.

This year's chapter is a continuation and update of the information contained in last year's chapter. The objectives are: (1) to update BMP efforts in the EAA; (2) to assess effectiveness of BMPs in terms of TP load reduction at basin, farm, and field scales; and (3) to provide future directions for Everglades BMP efforts.

# OVERVIEW OF PHOSPHORUS SOURCES AND BEST MANAGEMENT PRACTICES IN THE EAA

## PHOSPHORUS SOURCES

Phosphorus exists in the EAA drainage water in both dissolved and particulate phases. Particulate P originates primarily from fine soil particles eroded from the field and detritus materials of aquatic vegetation. Dissolved P in drainage water comes mainly from leaching of soil profiles. Fertilization and soil mineralization are the two major sources of P in soils. Recommended fertilization rates vary with crops and soil conditions. For example, a typical fertilization rate would be about 100 pounds P/ac/y for vegetables and 20 pounds P/ac/y for sugarcane (Coale, 1994; Schueneman and Sanchez, 1994). The difference explains why P concentrations in vegetable drainage water are much higher than from sugarcane fields (CH2M-Hill, 1979). Fertilization typically provides high concentrations of P in soil solution during a short period of time, which is more prone to leaching with rainfall and drainage.

Mineralization of organic matter in soils is a natural process, which is influenced by the water table (aerobic or anaerobic conditions), the soil temperature (the decomposition rate constant), and the quantity of substrate (soil depth and organic P content). Soil mineralization releases P year-round at a much slower rate than fertilization. Fertilization recommendations are based partly on the amount of P that soil mineralization can provide. The higher the soil mineralization rate, the less fertilizer is required. Given the complex soil environment in the EAA, the mineralization rate varies significantly from one farm to another. Reported soil mineralization rate ranges from about 20 to 150 pounds P/ac/y (Reddy, 1983; Reddy and Rao, 1983; Sanchez and Porter, 1994). Other sources of P entering the EAA include rainfall and irrigation water. The flux of these contributions (<2 pounds P/ac/y) is relatively small compared with that from soil fertilization and soil mineralization (Stuck, 1996).

Major P sinks in the EAA are biological uptake and transformation into inorganic forms in soils. The rate of biological uptake varies with crops, varieties, and the growth condition. A typical biological uptake rate on a growing season basis is about 35 pounds P/ac for sugarcane and 20 pounds P/ac for vegetables (Coale et al., 1993; Coale, 1994; Schueneman and Sanchez, 1994). Part of the P uptaken by plants is returned into the field, and the amount depends partly on practices, such as burning canes in the field and disposal of water and wastes from the sugar mill. Fertilization history also influences P concentration in soil solution. Given the same condition, drainage water from a site with a longer cultivation history tends to have higher P concentrations since soil P sorption sites are more saturated under a longer period of fertilization (CH2M-Hill, 1979).

## BEST MANAGEMENT PRACTICES

The Act defines agricultural BMPs as follows (Section 373. 4592(2)(a), Florida Statutes):

> "… a practice or combination of practices determined by the District, in cooperation with the Department [of Environmental Protection], based on research, field-testing, and expert review, to be the most effective and practicable, including economic and technological considerations, on-farm means of improving water quality in agricultural discharges to a level that balances water quality improvements and agricultural productivity."

**Table 5-2** lists agricultural BMPs grouped into three categories: water management, nutrient management and sediment control. Development of these BMPs is a collective effort of growers (Andreis, 1992), research institutions (Bottcher et al., 1995) and the District. As more information on the effectiveness of existing and new farming practices becomes available, additional BMPs will be reviewed and added in the list.

Each category of BMPs in **Table 5-2** has its unique mechanisms to control P sources and reduce TP loading from the EAA. Water management BMPs deal with both water quantity and quality issues with the aim to reduce off-farm discharge and TP concentration. For example, high P water from vegetable fields can be properly routed or recycled in sugarcane fields. Maintaining an appropriate water table in the field will reduce the mineralization process. Proper pumping to avoid over drainage of fields (drainage uniformity) will also minimize leaching of dissolved P out of soil profiles or reduce sediment transport. BMPs for nutrient management and sediment control address water quality for reducing TP concentration. More specifically, nutrient management BMPs are to control over or improper fertilization practices and reduce total dissolved phosphorus (TDP) concentration. Sediment control BMPs are mainly for particulate phosphorus (PP) reduction. To achieve maximum TP load reduction at any site within the EAA, a BMP plan should integrate all the three components. Any single category of BMPs may not be able to fully achieve the overall objective of TP load reduction.

**Table 5-2.** Agricultural BMPs in use or currently being studied for use in the EAA.

| ***Category*** | ***BMPs*** | ***Applicable Crops*** |
|---|---|---|
| Water management BMPs | Modified off-site pumping schedules based on rainfall and water table elevation or other criteria as appropriate | All |
| | Temporal water table control by optimizing drainage and irrigation schedules | All |
| | Spatial water table control with improved infrastructure and appropriate use of internal control structures (i.e., booster pumps, flash-board culverts, etc.) and laser leveling to obtain drainage and irrigation uniformity | All |
| | On farm storage or recycle of excess water or high phosphorus laden water in fields such as fallow/rice lands, canals and ditches, soil profiles, or on-farm storage reservoirs | All |
| Nutrient management BMPs | Fertilize according to expert recommendations based on calibrated soils test results as well as other factors as appropriate | All |
| | Fertilizer application control (i.e., banding, pneumatic, or other similar application) for more efficient use of fertilizer or for better placement of fertilizer at the root zone | All |
| | Split fertilizer application | Vegetable and sod |
| | Fertilizer spill prevention | All |
| Sediment control BMPs | Laser level field<br>Use of cover crop in field<br>Minimum tillage<br>Vegetated berms along ditch banks<br>Vegetated ditch bank<br>Sediment control devices (i.e., elevated culverts, risers, sumps) at ditch/canal connections<br>Sump upstream pump intake in canal<br>Sediment trap (or elevated barrier) upstream pump intake in canal<br>Canal cleaning<br>Weed boom or floating sediment barrier in canal<br>Mechanical weed harvesting in canal | All |
| Other BMPs | Urban BMPs including NPDES efforts, vegetative filters and Xeriscape | Urban |
| | Pasture management BMPs | Pasture |

# UPDATE ON EVERGLADES BMP EFFORTS

Efforts for BMP research, implementation and education to reduce TP discharge from the EAA have been underway since the plot-scale BMP screening study began in 1985. Last year's chapter provided an accounting of these activities (Whalen et al., 2000). Since then, UF/IFAS conducted a BMP training seminar in December 1999. The Everglades BMP Regulatory Program and the UF/IFAS farm scale BMP project are the most relevant ongoing efforts and are updated briefly below.

## EVERGLADES BMP REGULATORY PROGRAM

The Everglades BMP Regulatory Program was initiated in 1992. The District manages the Program through permitting and post-permit compliance task. As of WY99, there were approximately 35 active permits covering about 500,000 acres of land with 215 permit drainage basins and 305 drainage structures within the EAA (**Figure 5-1**). Detailed program activities and compliance status can be found in the Everglades BMP Program Annual Report (SFWMD, 2000).

Basin-wide BMP implementation was mandated to begin in 1994 and to be completed by January 1995. To ensure that a base level of BMPs for each landowner was established, the District developed a BMP "equivalents" system. The system assigns points to BMPs within the three basic categories for water management, nutrient management, and sediment control. Twenty-five BMP points were set as the minimum target BMP level. This approach allowed flexibility for each landowner to develop an integrated BMP scheme that was best suited for the site specific conditions.

To verify BMP implementation by landowners, onsite BMP field visits are conducted on an 18-to-24 month rotation schedule by District staff. The BMP verifications indicate that the permittees have implemented their respective BMP plans and are taking a proactive approach to reviewing and improving their plans, where possible. Since WY96, BMPs for nutrient management, water management and sediment control have been implemented across the entire EAA.

## FARM SCALE BMP RESEARCH AND DEVELOPMENT

The research conducted by UF/IFAS represents the most comprehensive, ongoing research program regarding the effectiveness of BMPs in the EAA. A ten-farm project was initiated in 1992 and funded primarily by the EAA Environmental Protection District (EAA-EPD) with supplemental monetary contributions from the Florida Department of Environmental Protection (Department) and the District. Ten farms, ranging in size from 320 to 4,600 acres, have been studied in an attempt to develop and verify the effectiveness of BMPs for reducing TP loading in the EAA. The ten farms are representative of the EAA, with respect to soils, crops, water and fertilizer management practices, and geographic locations (**Figure 5-1**). Land use on the selected farms varies from monocultures of sugarcane and vegetables to multicultures of vegetables, rice, sod and sugarcane. BMPs implemented on the ten farms are described in **Table 5-3**.

**Table 5-3.** Summary of BMPs implemented on the ten UF/IFAS experimental farm sites (Izuno and Rice, 2000).

| Site | Farm size (acres) | Cropping system | Major BMPs |
|---|---|---|---|
| UF9200A | 1280 | Sugarcane monoculture | Reduced frequency of irrigation/drainage events, attenuated water table micro- management, cleaned ditches, removed sedimentary material from ditch ways, installed weed-boom in main farm canals (98), calibrated soil test |
| UF9201A | 1280 | Vegetable monoculture | Routed water internally from field block to field block during planting season, allowed summer fallow flood waters to recede naturally through ET/percolation, water storage, calibrated soil test |
| UF9202A | 320 | Sugarcane monoculture | Improved drainage uniformity by installing internal booster pump, reduced off- farm discharge, minimum-tillage sugarcane planting practices, calibrated soil test |
| UF9203A | 4608 | Sugarcane/rice rotation | Installed control structures to allow for improved farm drainage and hydraulic control between internal blocks, increased farm drainage capacity, calibrated soil test |
| UF9204A | 640 | Sugarcane monoculture to sugarcane/rice rotation to sugarcane monoculture | Implemented new off-farm pumping protocol (1/95), rotated half of farm sugarcane acreage into rice (4/95) in absence of concurrent hydraulic BMP implementation, rotated melons back to fallow (10/95), calibrated soil test |
| UF9205A | 320 | Sugarcane monoculture to sugarcane/vegetable mix to sugarcane monoculture | Rotated almost half of farm sugarcane acreage into corn (3/94) followed by fallow and melons (5/95) in the absence of concurrent hydraulic BMP implementation, rotated melons back to fallow (10/95) and then sugarcane (2/ 96), calibrated soil test |
| UF9206A&B | 1754 | Sugarcane/sod mix with vegetable/rice rotation | Installed control structures, blocked farm into six hydraulically isolated units, routed vegetable/rice drainage water to other areas of farm for storage and/or removal through ET/percolation, installed weed-boom in main farm canals (98), calibrated soil test |
| UF9207A&B | 2500 | Sugarcane/vegetable mix | Reduced drainage pumping chemical injection and diversion of water around farm, sediment trap/pit in main farm canal, calibrated soil test |
| UF9208A | 262 | Sugarcane monoculture | Increased on-farm retention in soil profile and open waterways, reduced drainage pumping, implemented various ditch and canal sediment control strategies, calibrated soil test |
| UF9209A | 3072 | Sugarcane monoculture | Reduced drainage pumping using strict protocols for triggering off-farm discharge, installed internal booster pump for improved drainage, calibrated soil test |

Water Management BMPs to achieve drainage/irrigation uniformity are implemented at all ten farms

To monitor BMP efficacy, all sites have been instrumented with electronic flow, water sampling and data storage instruments. Flow and TP concentrations were monitored for the baseline period from 1992 to 1994, and for the BMP period from 1995 to present. Work has progressed in annual phases. One of the outcomes of the project is the development of the EAAMOD model. The model can simulate the water, TDP and PP discharges from various farming systems in the EAA, as affected by different management strategies, including BMPs at both field and farm scales (Bottcher et al., 1998). In recent phases of the project, water quality monitoring has been expanded to include the evaluation of PP transport and the characterization of other water quality parameters, including specific conductance, atrazine and ametryn. Eight annual reports and numerous publications from this project have been produced, and the results have been selectively used to assess BMP effectiveness for this chapter.

# ASSESSING BMP EFFECTIVENESS

Assessment of BMP effectiveness is conducted at three spatial scales or levels: basin, farm and field. The basin level assessment uses compliance data from the Everglades BMP Regulatory Program to quantify the relationship between BMP implementation and TP load and concentration reduction, as specified in the Act. The farm level assessment analyzes UF/IFAS research results, as well as flow and water quality monitoring data from each landowner, to determine the variability of BMP performance at the farm level and to provide direction for future BMP efforts. The field level assessment addresses the effectiveness of each BMP or group of BMPs and identifies future research needs for BMP development. Although assessments at these three levels are complementary, the TP load reduction obtained from each level of assessment should not be equated to the reductions at other levels.

## BASIN LEVEL ASSESSMENT

### Water quality and hydrologic monitoring

The basin level TP concentration and flow monitoring for the EAA is conducted at large pump stations and water control complexes operated by the District (**Figure 5-1**). This effort is an essential component of the District water quality and hydrologic monitoring network over the entire south Florida region. Composite and grab samples are taken for analyses of TP and other water quality parameters during a flow event. Appropriate Quality Assurance and Quality Control (QA/QC) procedures for water quality and hydrologic monitoring were followed. Because water leaving the EAA is a combination of EAA farm and urban runoff and water passing through the EAA canals from external basins (i.e., Lake Okeechobee), TP concentration and load are carefully separated to draw accurate conclusions on the TP load originating from the EAA agricultural and urban activities.

### Model for basin level assessment

The method used to evaluate the compliance for the minimum 25 percent TP load reduction is a statistical model that adjusts measured annual TP load from the EAA for hydrologic variability. The model compares the current year's measured TP load with a statistical prediction of what the TP load would have been without BMP implementation. The annual percent reduction of TP is calculated as the relative difference between the actual measured TP load and the predicted pre-BMP TP load. Monthly rainfalls during the water year are the basic input data for calculating the statistical and adjustment parameters. The predicted target load (in metric tons) in compliance of the 25 percent reduction goal of a given water year, assuming BMPs were not implemented, is estimated as follows:

$$\text{Target} = \exp\left[ -7.998 + 2.868X + 3.020\,C - 0.3355\,S \right] \qquad [5.1]$$

Where $X$ = natural logarithm of 12-month total rainfall inches during a water year
$C$ = coefficient of variation of monthly rainfall during a water year
$S$ = skewness coefficient of monthly rainfall during a water year

The first predictor (X) indicates that load increases approximately with the cube of total annual rainfall. The second and third predictors (C and S) indicate that the load resulting from a given annual rainfall is higher when the distribution of monthly rainfall has higher variance or lower skewness. Development of the model was conducted with the 10-year base period data (1979 to 1988) and the model accounts for about 91 percent of the variability. During the base period, there were about seven hurricanes and three tropical storms that directly or indirectly affected pumping or drainage in the EAA. The hurricane effects were implicitly contained in the three rainfall parameters. Validation of the model, using data from Water Year 89 to 92, indicated that the predicted TP load during that period matched the measured TP load reasonably well.

Considering the uncertainty involved, the basin is deemed to be out of compliance if it does not achieve the target 25 percent for three consecutive water years, or its load exceeds the upper 90 percent confidence limit for any single year. A detailed description of the model is documented in the Everglades BMP Program Report for WY99 (SFWMD, 2000).

### Basin level TP load and concentration reduction

The TP load and concentration, along with hydrologic data in the EAA, are summarized in **Table 5-4**. In WY00, the predicted TP load, assuming that BMPs were not implemented in the EAA, was 425 metric tons. The measured TP load was 193 metric tons, resulting in a 55-percent reduction. This is the fifth consecutive year that the 25-percent reduction goal has been exceeded. During WY96 to WY00, TP concentration varied from about 98 to 124 ppb, with a cumulative average of 108 ppb, significantly lower than the 12-year average of 173 ppb during the pre-BMP period (1979-1991). The 5-year cumulative TP load reduction averaged 54 percent.

Long-term trends in TP concentration and load reduction are shown in **Figure 5-2**. The load presented in the figure is a normalized view of the data to assist with the recognition of trends. The average annual TP load during the pre-BMP period is about 207 metric tons and the normalized load is obtained from “normalized annual load = 207 x [1 – annual percent reduction].” The three-year moving average clearly shows that both TP load and concentration decline significantly with the onset of BMP implementation, indicating that BMPs are effective in reducing TP load and concentration at the basin level.

**Table 5-4.** TP load and concentration reduction in the EAA

| Water Years | % area BMPs Implemented in EAA | Annual rainfall (in) | Annual flow (Kac-ft) | TP concentration (ppb) | Measured TP load (metric tons) | TP load reduction with 80% confidence interval (%) |
|---|---|---|---|---|---|---|
| 80 – 91 | 0 | 35.05-64.35 | 550-1965 | 173 (mean) | 85-473 | N/A |
| 92-93 | 0 | 47.61-61.69 | 908-1639 | 166 (mean) | 106-318 | N/A |
| 94 | 15 | 50.54 | 952 | 112 | 132 | 17 (-26-46) |
| 95 | 63 | 67.01 | 1878 | 116 | 268 | 31 (-4-54) |
| 96 | 100 | 56.86 | 1336 | 98 | 162 | 68 (54-78) |
| 97 | 100 | 52.02 | 996 | 100 | 122 | 49 (32-62) |
| 98 | 100 | 56.12 | 1276 | 102 | 161 | 34 (6-54) |
| 99 | 100 | 43.42 | 833 | 124 | 128 | 49 (29-64) |
| 00 | 100 | 57.51 | 1311 | 119 | 193 | 55 (38-68) |

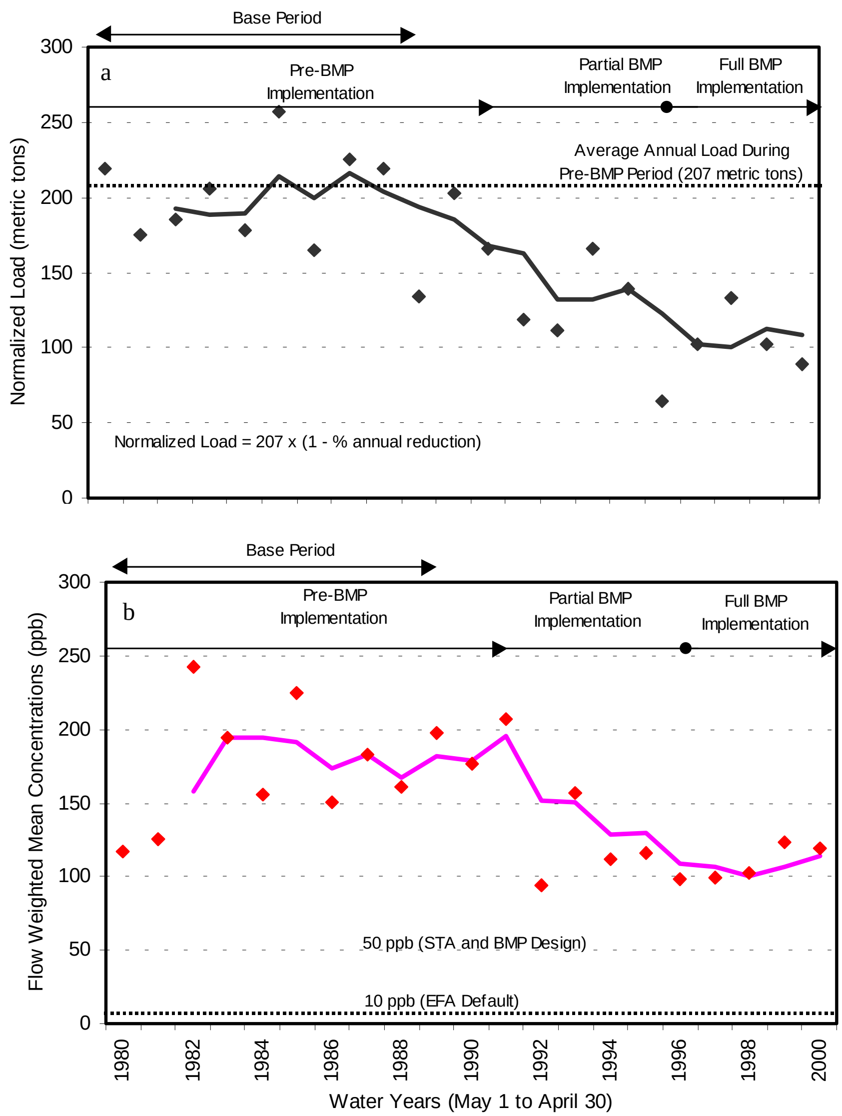


**Figure 5-2.** Long-term trends of (a) normalized TP load and (b) TP concentration of drainage water from the EAA in relation to BMP implementation. Lines are the 3-year moving average of annual data.

The TP load reduction calculated refers only to the EAA water. For example, the sum total of TP entering the EPA through the District operated pumps and gates during WY99 also includes 38 metric tons from Lake Okeechobee environmental and urban water supply releases, 34 metric tons from C-139 Basin, and 20 metric tons from other tributary basins and STA discharges (SFWMD, 2000).

# FARM LEVEL ASSESSMENT

## Farm flow and water quality monitoring

The UF/IFAS farm scale BMP project has conducted over eight years of flow and water quality monitoring. Selected data that were reported in the most recent annual report (Izuno and Rice, 2000) have been reviewed and are used for the farm level assessment in this chapter.

In addition to the ten farms monitored by UF/IFAS, all other farms have been monitoring the flow and TP concentration, as required by the Everglades BMP Regulatory Program. Most farms in the EAA started monitoring during WY94. Most flow measurements are calculated from individual pump calibrations, conducted in accordance with guidelines developed by the District, with assistance from a Flow Calibration Work Group, consisting of pump professionals and EAA landowners or their representatives. Water quality samples are typically collected with auto-samplers at the farm discharge structures (**Figure 5-1**). Samples are composited for a sampling period of up to 21 days before being collected and transported to a certified laboratory for TP analysis. Daily TP load is calculated by multiplying the TP concentration for the sampling period by each daily flow.

## Model for rainfall adjusting farm TP load

A hydrologic adjustment model was derived from the one used in the basin level assessment to obtain the adjusted unit area load (AUAL) of all farms in the EAA. The model adjusts the measured unit area load (UAL) based on a comparison of current water year rainfall (amount and distribution) with that during the base period. The equation is expressed as:

$$AUAL = UAL * (Rb/R)^{2.868} \qquad [5.2]$$

Where:

Rb = Rainfall characteristics specific to the farm's sub-basin during the base period
R = Rainfall characteristics specific to the sub-basin for the current water year

Both parameters are calculated with the nature log of total annual rainfall (X), coefficient of variation (C) and skewness coefficient (S) of monthly rainfall to do the rainfall adjustment. For the current water year:

$$R = \exp(X + 1.053\,C - 0.1170\,S) \qquad [5.3]$$

Rb is calculated similarly with known parameters for each sub-basin (X, C, and S) during the base period.

## Farm average TP concentration and load

To determine BMP effectiveness at the farm level, AUAL and TP concentration are respectively averaged according to farm area and flow for all EAA farms (with acceptable water quality monitoring data) and nine farms of the UF/IFAS project. Site UF9201A is not included since it does not discharge directly into a District canal. The results are shown in **Figure 5-3**. Between WY94 and WY99, using WY94 as the baseline year, the area-weighted AUAL reduction ranged from approximately 10 to 60 percent for an average of about 40 percent per year. Flow weighted TP concentration reductions, ranged from approximately 20 to –10 percent for an average of 5 percent per year. The general trend is close to that occurring in the basin (**Figure 5-2**). In general, the farm average TP concentration and load data support the basin level reduction, indicating that BMPs are effective at the farm level.

To illustrate the variability and the influence of land use on TP load and concentration at the farm level, AUAL and TP concentration of 115 farms, a selected subset of the EAA Regulatory Program farm-level data, are averaged from WY94 to WY99 according to land use patterns (**Figure 5-4**). These farms were selected based on several factors, including consistent land use over the review period, similar BMP implementation for each land use, and District verification of monitoring data. The selected farms are grouped according to sugarcane monoculture (19 farms), sugarcane with vegetables (6 farms), sugarcane with corn and rice rotation (56 farms), sugarcane with corn rotation (28 farms), and sugarcane with sod rotation (6 farms). The general trend shown in **Figure 5-4** follows that of **Figure 5-3**. The difference between land use patterns shows that, in general, sugarcane monoculture or with rice rotation has less TP loading than in rotation with vegetables and sod, supporting the results obtained by Izuno and Bottcher (1991). This further illustrates the importance of on-farm recycling of high phosphorus-laden water from vegetable or sod fields. The variability between farms within a year is demonstrated by the standard deviations shown in the figure. The variability is partly due to the change in locations within the EAA.

### Individual farm annual TP concentration and load

The TP concentration and AUAL over the past six consecutive years of the UF/IFAS ten farms are presented in **Table 5-5**. The data indicate that for most of the farms (7 of 10), the AUAL was about 20 to 80 percent lower than that recorded for WY94. This demonstrates that BMPs implemented are highly effective in reducing TP loading at the farm level. However, reduction in TP concentration is not as significant for most of the sites, partly because nutrient management BMPs were partially implemented during 1994 and 1995 in the EAA (**Table 5-5**). Similar conclusions are obtained by the project team with other assessment methods (Izuno and Rice, 2000).

**Table 5-5** also indicates that there are significant variations of TP concentration and AUAL between farm locations and years. The variations reflect differences in farm management practices and natural hydrologic conditions. The increase in AUAL and concentration in WY99 is a direct result of Hurricane Georges that was predicted to hit South Florida in September 1998, resulting in significant pumping in anticipation of the event. This drainage resulted in leaching of soluble phosphorus contained in the soil profile and accelerated transport of sediment. The increases in AUAL at sites UF9204A and UF9205A in 1995 reflect water management difficulties due to large-scale cropping system changes in the absence of water management BMPs implemented (**Table 5-3**). Site UF9204A has maintained its sugarcane monoculture since 1995 and showed continued AUAL reduction in WY97, 98 and 99. Site UF9205A opted to rotate back to melons in a block adjacent to the discharge structure and continues to have water management problems. Site UF9206 is also a mixed crop site. However, TP load reduction has been realized in the site with the adoption of comprehensive water management practices coupled with other BMPs. The increase in WY97 directly reflected the rotation of vegetable and rice production in blocks immediately adjacent to discharge structures. This again shows that coordinating farm cropping patterns is critical to the success of implemented BMPs.

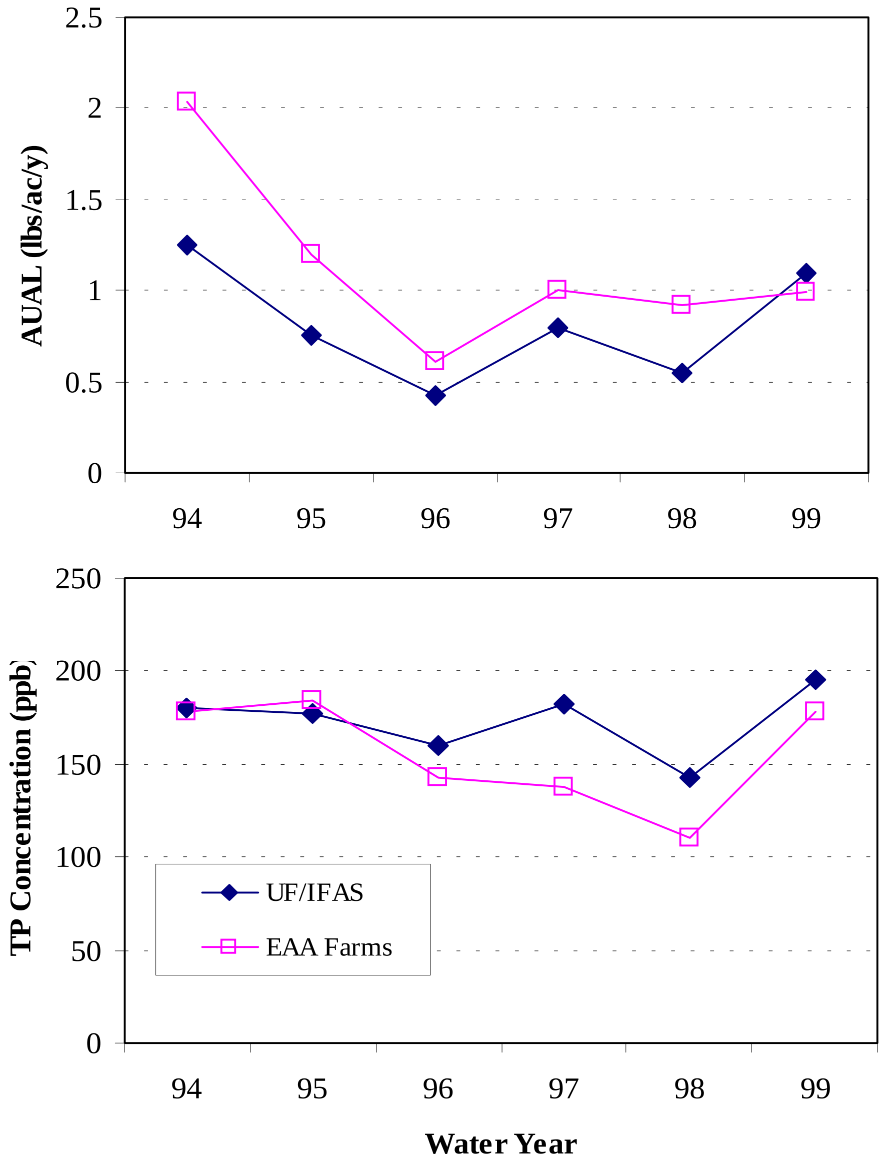


**Figure 5-3.** Area-weighted AUAL (a) and flow-weighted TP concentration (b) of farms in the EAA (EAA Farms) and those studied by UF/IFAS.

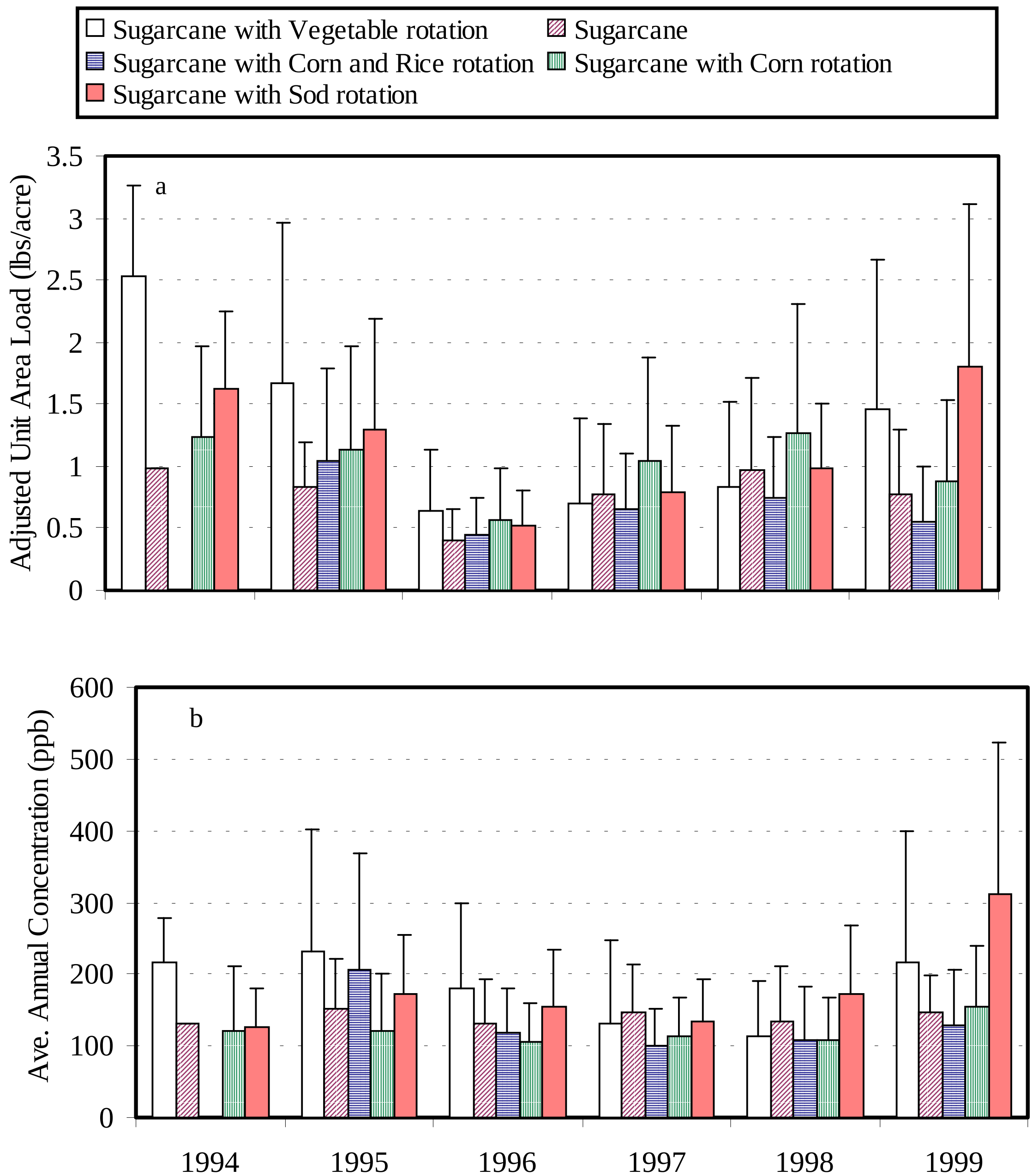


**Figure 5-4.** Average AUAL (a) and TP concentration (b) of selected farms in the EAA between WY94 and WY99. Error bars are one standard deviation.

**Table 5-5.** Unit area load and adjusted unit area load for WY94 through WY99 in the ten UF/IFAS experimental sites (Izuno and Rice, 2000).

| Site | Water Year | Baseline TP (ppb) | BMP TP(ppb) | UAL (lbs/acre-y) | AUAL (lbs/acre-y) | % AUAL change from WY94 |
|---|---|---|---|---|---|---|
| UF9200A | 94 | 234 | - | 1.446 | 1.950 | - |
| | 95 | 275 | - | 2.173 | 0.973 | -50.1 |
| | 96 | - | 241 | 0.932 | 0.512 | -73.7 |
| | 97 | - | 153 | 0.451 | 0.550 | -71.8 |
| | 98 | - | 131 | 0.347 | 0.285 | -85.4 |
| | 99 | - | 654 | 2.869 | 3.740 | 91.8 |
| UF9201A | 94 | 743 | - | 3.547 | 6.133 | - |
| | 95 | 858 | - | 5.841 | 3.020 | -50.8 |
| | 96 | - | 616 | 2.223 | 1.014 | -83.5 |
| | 97 | - | 540 | 0.924 | 0.977 | -84.1 |
| | 98 | - | 903 | 10.359 | 10.048 | 63.8 |
| | 99 | - | 1006 | 7.754 | 14.514 | 136.7 |
| UF9202A | 94 | 71 | - | 0.136 | 0.141 | - |
| | 95 | 51 | - | 0.154 | 0.075 | -46.8 |
| | 96 | - | 90 | 0.385 | 0.120 | -14.9 |
| | 97 | - | 63 | 0.182 | 0.146 | 3.55 |
| | 98 | - | 57 | 0.187 | 0.132 | -6.40 |
| | 99 | - | 157 | 0.370 | 0.313 | 122.0 |
| UF9203A | 94 | 181 | - | 0.355 | 0.368 | - |
| | 95 | 108 | - | 0.365 | 0.178 | -51.6 |
| | 96 | - | 110 | 0.377 | 0.117 | -68.2 |
| | 97 | - | 174 | 0.392 | 0.313 | -14.9 |
| | 98 | - | 148 | 0.376 | 0.266 | -27.7 |
| | 99 | - | 112 | 0.195 | 0.165 | -55.2 |
| UF9204A | 94 | 152 | - | 0.281 | 0.486 | - |
| | 95 | 211 | - | 0.982 | 0.508 | 4.53 |
| | 96 | - | 302 | 1.063 | 0.485 | -0.21 |
| | 97 | - | 151 | 0.167 | 0.176 | -63.8 |
| | 98 | - | 151 | 0.385 | 0.373 | -23.3 |
| | 99 | - | 93 | 0.164 | 0.306 | -37.0 |
| UF9205A | 94 | 81 | - | 0.345 | 0.474 | - |
| | 95 | 91 | - | 1.328 | 0.987 | 108.2 |
| | 96 | - | 81 | 1.383 | 0.534 | 12.7 |
| | 97 | - | 87 | 1.356 | 0.818 | 72.6 |
| | 98 | - | 69 | 1.483 | 1.576 | 232.5 |
| | 99 | - | 131 | 1.387 | 0.632 | 33.3 |
| UF9206A&B | 94 | 288 | - | 2.745 | 3.702 | - |
| | 95 | 273 | - | 3.481 | 1.559 | -57.9 |
| | 96 | - | 363 | 2.459 | 1.352 | -63.5 |
| | 97 | - | 480 | 4.343 | 5.295 | 43.0 |
| | 98 | - | 211 | 2.007 | 1.652 | -55.4 |
| | 99 | - | 268 | 1.805 | 2.353 | -36.4 |
| UF9207A&B | 94 | 226 | - | 1.308 | 2.262 | - |
| | 95 | 338 | - | 3.500 | 1.809 | -20.0 |
| | 96 | - | 338 | 1.693 | 0.773 | -65.8 |
| | 97 | - | 244 | 1.025 | 1.084 | -52.1 |
| | 98 | - | 214 | 0.792 | 0.769 | -66.0 |
| | 99 | - | 189 | 1.058 | 1.980 | -12.5 |
| UF9208A | 94 | 150 | - | 0.166 | 0.286 | - |
| | 95 | 121 | - | 0.163 | 0.084 | -70.6 |
| | 96 | - | 124 | 0.154 | 0.070 | -75.5 |
| | 97 | - | 98 | 0.115 | 0.121 | -57.7 |
| | 98 | - | 59 | 0.118 | 0.114 | -60.1 |
| | 99 | - | 111 | 0.218 | 0.408 | 42.7 |
| UF9209A | 94 | 86 | - | 0.412 | 0.566 | - |
| | 95 | 85 | - | 0.534 | 0.397 | -29.9 |
| | 96 | - | 66 | 0.325 | 0.125 | -77.9 |
| | 97 | - | 78 | 0.432 | 0.260 | -54.1 |
| | 98 | - | 62 | 0.296 | 0.315 | -44.3 |
| | 99 | - | 173 | 0.658 | 0.300 | -47.0 |

The variability of TP load and concentration between all EAA farms is illustrated in **Figure 5-5**. The figure summarizes all the farms that provided data in WY99, and shows the number of farms with high TP load or concentrations. One potential reason to account for farms that did not achieve the desired TP load reduction is that water management, nutrient management, and sediment control BMPs are not optimally integrated according to land use and cropping rotation patterns.

### Event-based P concentration and load

Analyses of the event-based TP concentration and load during an annual cycle indicate that large TP concentration and load spikes occur about three to ten times a year at all of the UF/IFAS farms. These spikes are the major contributors of farm level TP loading. An example is given in **Figure 5-6** for Site UF9209A in 1998. Three such spikes occurred during September through November. Reducing TP concentration and drainage flows of these events may result in large reductions in farm load. **Figure 5-6** shows that the spikes in TP concentration and load are associated with dramatic increases in discharge of phosphorus in particulate forms (PP = TP – TDP). The TDP concentration stayed relatively stable during the entire year. This suggests that sediment control BMPs need to be developed or enhanced to control PP sources responsible for the spikes at the farm level. For a complete set of definitions of phosphorus forms, refer to the Glossary at the end of this Report.

## FIELD LEVEL ASSESSMENT

Field level assessment focuses on the review of available information of TP load reduction of each BMP or group of BMPs and identifies the need for future BMP research. Because experimental data on individual BMP effectiveness are limited, EAAMOD (version 3.5.1) was used as a tool to estimate the relative TP load reductions in the assessment. When estimating individual BMP effectiveness, one needs to assume that the tested BMP is the only variable in the system. Many variables, including rainfall, soil type, and crop type affect BMP effectiveness; the field level assessment is inevitably subject to uncertainty. The TP load reduction of a group of BMPs should not be obtained by the summation of individual BMP reductions.

### Water management BMPs

Water management BMPs consist of water table management BMPs and water retention/recycling BMPs to reduce TP load by minimizing temporal and spatial water table fluctuations and retaining phosphorus-laden water on farm. Drainage practices also influence soluble phosphorus release from soils and sediment transport in farm ditches and canals.

Water table management BMPs aim to control off-site discharges and irrigation according to the optimal water level required for crops. In general, vegetables have much lower water tolerance than sugarcane, and require frequent pumping. The modified pump schedule BMP was initially proposed for sugarcane by the Florida Sugar Cane League in 1992. Hydrologic modeling performed by Hutcheon Engineers (1992) and Brown and Caldwell Consultants (1993) indicated that this BMP may reduce the volume of farm discharge by about 20 percent for sugarcane. Temporal and spatial control of water table fluctuation proposed by UF/IFAS (Bottcher et al., 1995) is an advanced approach to water table management and may result in more reduction.

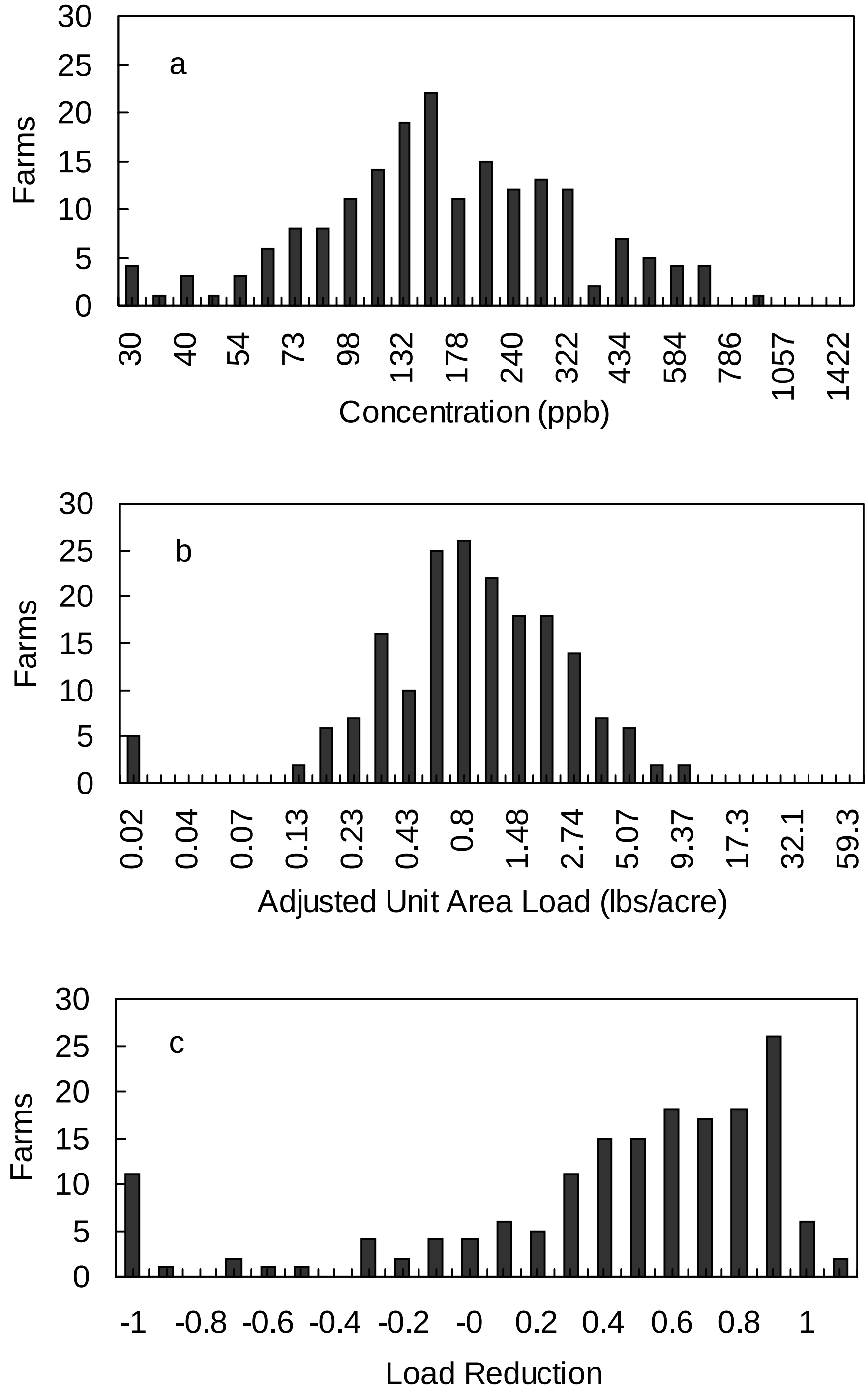


**Figure 5-5.** Histogram of WY99 farm monitoring data (all EAA farms): a. TP concentration; b. AUAL; c. AUAL reduction.

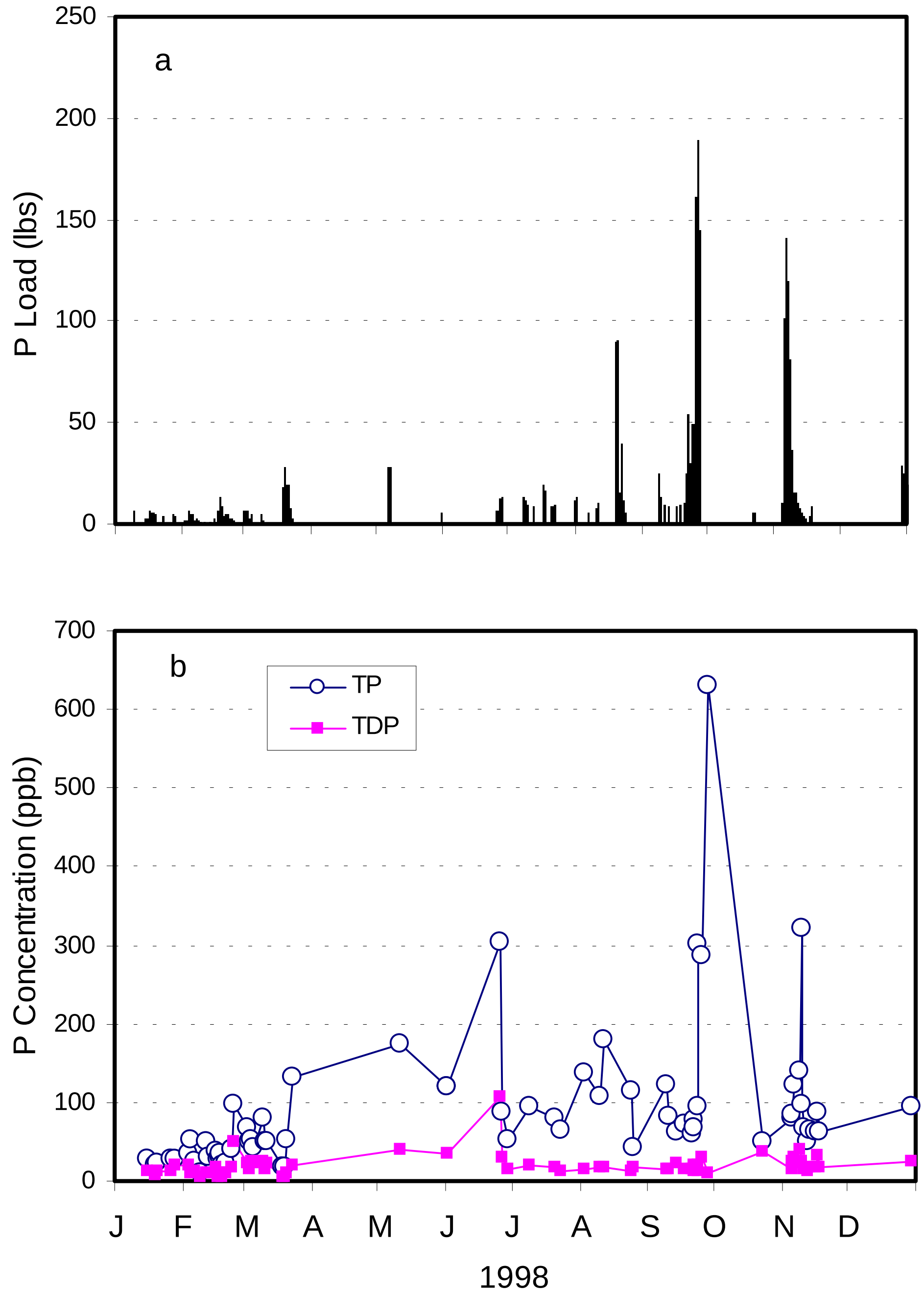


**Figure 5-6.** Event-based data of UF/IFAS Site UF9209A during 1998: (a) TP load; (b) TP and TDP concentrations (Data Source: Izuno and Rice, 2000)

Four water management practices were simulated with EAAMOD-Field for sugarcane. These water control practices include: (1) Typical historic pump control practices prior to 1988, which will slightly over-pump field ditches after rainfall events (approximately a 2 ft draw-down at pump) and will irrigate as needed when over-pumped; (2) Anticipatory water management, which will pump the field ditches nearly dry before turning off pumps prior to large rain events (approximately a 3 ft draw-down at pump) and will re-irrigate immediately to replenish water if over-drained; (3) Simple pump BMP with a float control on the farm pump to control pumping and irrigation; and (4) Water table control with observed field water table levels at the trigger well so that both irrigation and pumping are performed according to the water tables experienced by the crops. The modeling result showed that TP loading from a field may be reduced by about 15 percent with the simple pump BMP, 25 percent by the water table BMP, and increase by about 28 percent with anticipatory pumping.

Spatial control of the water table is particularly effective when a farm has significant hydraulic gradients with poor hydraulic capacity. Simulations with EAAMOD-Farm showed that TP load from a farm with only eight fields can be reduced by about 10 percent. It is expected that about 20 percent or more reduction can be achieved in a large farm. Bottcher et al. (1995) estimated that retaining phosphorus-laden water on farm by storage in isolated farm blocks, rice fields, on-farm reservoirs, or routing vegetable drainage into a sugarcane field could reduce phosphorus losses by 15 to 60 percent. Simulations with EAAMOD-Farm indicated that recycling high phosphorus drainage water with a ratio of one vegetable field to three sugarcane fields may reduce TP load by about 60 percent. **Table 5-6** summarizes TP load of each of the water management BMPs, based on the modeling results and those reported by Brown and Caldwell consultant (1993) and Bottcher et al. (1995).

**Table 5-6.** Estimated TP load reduction (%) for water management BMPs

| Water management BMPs | | Sugarcane | Vegetable |
|---|---|---|---|
| 1. | Modified offsite pump schedule based on rainfall and water table elevation or other criteria | 20 | 6 |
| 2. | Temporal water table control by optimizing drainage and irrigation schedules | 25 | 7 |
| 3. | Spatial water table control with improved infrastructure and appropriate use of flashboard culverts and laser leveling to obtain drainage and irrigation uniformity | 15 | 6 |
| 4. | On farm storage or recycle of excess water or high phosphorus laden water in fields such as fallow/rice lands, canals and ditches, soil profiles, or on-farm storage reservoirs | 30 | 50 |

About 50% of variation from the estimates are possible due to the variability of the natural environment and farm management in the EAA.

Research is needed to define or improve the water tolerance of different crops. Experiments along this line are ongoing for sugarcane (**Table 5-1**). Because water management BMPs require the analysis of the hydrology and hydraulics of the farm water management system, a detailed BMP guidebook incorporating the knowledge gained over the years at the UF/IFAS ten research sites will be helpful to ensure proper implementation of these BMPs.

### Nutrient management BMPs

Nutrient management BMPs focus on preventing over or improper fertilization to reduce TDP concentration in drainage water. They are particularly effective for vegetables since they require much more phosphorus fertilization than sugarcane. Limited field data showed that banding instead of broadcasting reduced phosphorus application rate by 50 percent and total dissolved phosphorus load by 19 percent (Izuno and Bottcher, 1991). Simulations with EAAMOD-field showed that 10 percent decrease in annual fertilization rate might reduce TP load by about 6 percent for sugarcane and 12 percent for vegetables. The estimated TP load reductions shown in **Table 5-7** are based on the projected decrease in the quantity of fertilizer applied as well as the estimates reported by Brown and Caldwell Consultants (1993) and Bottcher et al. (1995).

**Table 5-7.** Estimated TP load reduction (%) for nutrient management BMPs

| Nutrient management BMPs | | Sugarcane | Vegetable |
|---|---|---|---|
| 1. | Fertilize according to expert recommendations based on calibrated soils test results as well as other factors as appropriate | 10 | 20 |
| 2. | Fertilizer application control (i.e., banding, pneumatic, or other similar application) for more efficient use of fertilizer or for better placement of fertilizer at the root zone | 4 | 15 |
| 3. | Split fertilizer application | - | 7 |
| 4. | Fertilizer spill prevention | 5 | 7 |

About 50% of variation from the estimates are possible due to the variability of the natural environment and farm management in the EAA.

Research is needed to improve the use of soil test results for ideal fertilizer application recommendations with improved application methods such as banding, pneumatic application, and split application. The District is currently funding a project to refine the current soil tests for sugarcane. This project addresses a need articulated by various growers to investigate different soil phosphorus extraction procedures to assess their utility within the context of phosphorus fertilizer management for sugarcane production on EAA organic soils.

### Sediment control BMPs

Sediment control BMPs were developed to reduce PP concentration in discharge water. Izuno and Bottcher (1991) are among the first to report that EAA drainage water contains over 50 percent of PP. Anderson (1992) also stated that PP accounted for an average of 81 percent of TP concentration in 19 pump stations within the EAA and 49 percent at the District discharge structures. The high PP concentration still remains in EAA drainage water, and the UF/IFAS farm research showed that PP accounts for about 46 to 76 percent of TP in farm discharge water (Izuno and Rice, 2000).

Most sediment control BMPs (listed in **Table 5-2**) were proposed by the United States Sugar Corporation (USSC) in 1992 with the aim to control PP derived from soil erosion in the field. The effectiveness of these BMPs were tested by USSC (Andreis, 1996), and the results are summarized in **Table 5-8**.

**Table 5-8.** Experimental verification of the effectiveness of sediment control BMPs by Andreis (1996).

| BMPs | Number of observations/samples | Parameter tested | Reduction (%) |
|---|---|---|---|
| Sump with pipe vs. no sump | 6 | Sediment concentration of water leaving field | 76-83 |
| Cover crop vs. fallow | 6 | Air-borne soils entering canal | 73 |
| Cover crop (ratoon cane) vs. fallow | 53 | Air-borne soils entering canal | 72 |
| Cover crop (ratoon cane) vs. fallow | 70 | Particulate P concentration in canal water | 29 |
| Minimum tillage vs. conventional tillage | Various samples collected over an 82-day period | Air-borne soils entering canal | 54 |
| Ditch bank berm vs. no ditch bank berm | 34 | Particulate P concentration in ditch water | 41 |
| Vegetated ditch bank (sod covered) vs. bare bank | 6 | Sediment concentration of drainage water | 94 |
| Vegetated ditch bank (grass covered) vs. disked bank | 30 | Particulate P concentration in ditch water | 23 |
| Sump upstream of culvert vs. no sump | 32 | Particulate P concentration in ditch water not drained to the bottom | 56 |
| Sump upstream pump vs. no sump | 32 | Particulate P concentration in canal water | 34NS |
| Sediment trap upstream pump house | 31 | Particulate P concentration in canal water up and down stream of the trap | 64 |
| Parallel canal water treatment | 23 | Particulate P concentration in inlet and out-let canal water | 48 |
| Canal cleaning vs. no cleaning | 72 | Particulate P concentration in canal water | 44 |

All reductions are significant at P=0.05 except indicated by NS

Although accumulation of erosional sediment in field ditches and canals is common (Hutcheon Engineers, 1995), the capacity of these BMPs in controlling PP discharge from EAA farms was seriously questioned by Stuck (1996) and Stuck et al. (2000a, b). Their data indicated that sediment discharged from two farms, West Palm Beach Canal and East Shore Sedimentation Basin contained significantly higher TP levels than EAA farm soils and bed sediment. They further concluded that the sediment is mostly derived from decomposed aquatic macrophytes, which grow abundantly in South Florida environments. This implies that practices to control macrophyte growth in main canals could potentially be effective in reducing PP output from EAA farms. Options to deal with floating macrophytes range from isolation away from pumping stations (using weed booms) to the actual physical cultivation and harvest of the plants to extract soluble phosphorus from the water. These practices are currently being studied by UF/IFAS (Izuno and Rice, 2000), and their effectiveness will be reported as such data are available. In addition, the Indian River Citrus League led the initiative to produce a Citrus BMP Manual for Indian River Area, which includes details on various aquatic weed control BMPs, some of which could potentially be transferred to the EAA (Boman et al., 2000).

# FINDINGS AND FUTURE DIRECTIONS

Evidence summarized in this chapter supports three general findings on agricultural BMPs in the EAA:

1. BMPs for managing water, nutrients, and sediment are effective with each category having its unique mechanisms driving TP load reduction. The success of a farm-level BMP plan depends highly on the optimal integration of the three categories of BMPs fitted for site specific conditions and crop rotation patterns.
2. Basin-wide TP load reduction continues to exceed the 25 percent reduction goal. Between WY96 and WY00, the TP load reduction averaged 54 percent, and the TP concentration averaged 108 ppb, significantly lower than the 12-year average of 173 ppb during the pre-BMP period (from 1979 through 1991).
3. Farm level TP load and concentration reduction follows the general patterns observed for the basin. However, the BMP performance varies between farms within a year and between years within a farm. Approximately three to ten spikes in TP load and concentration occur during a typical year at farms in the EAA, and these spikes are associated with elevated PP concentration in the drainage water.

Based on the analysis of BMP effectiveness, the following are proposed to direct future Everglades BMP efforts to achieve additional TP load reduction at the basin level:

1. *BMP Research:* Research should be conducted to develop effective and economical alternative or enhanced sediment control BMPs, including control of aquatic macrophyte growth in farm ditches and canals. Additional control of particulate matter using these new BMPs may substantially reduce TP loads from EAA farms.
2. *BMP Education:* Seminars and field demonstration activities should be conducted periodically to provide information on new and existing BMPs to all EAA landowners. An updated and detailed Everglades BMP manual, or a BMP expert system organizing and integrating all BMP information available, should be developed to achieve this goal.
3. *BMP Implementation:* The integration of BMPs for managing water, nutrients and sediment for each farm should be optimized, based on site specific conditions including crop rotation and drainage patterns to achieve uniform TP load reductions across the EAA. A comprehensive analysis of all data from EAA farms may provide additional information as to which individual BMP or combinations of BMPs are more effective in reducing TP loads.

With these future efforts, additional TP load reductions can be achieved at the basin level. Given the encouraging information on BMP effectiveness and the STA performance (Chapter 6) there is increased confidence that the Everglades Forever Act's interim goal of achieving 50 ppb TP concentration can be achieved and maintained.

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