Implementation and Verification of BMPs for Reducing P Loading from the Everglades Agricultural Area

2008 Annual Report

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Everglades Agricultural Area Environmental Protection District
And
The South Florida Water Management District
By

Samira H. Daroub, Timothy A. Lang, Orlando A. Diaz, and
Manohardeep S. Josan

University of Florida, Institute of Food and Agricultural Sciences
Everglades Research and Education Center, Belle Glade, FL 33430

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EXECUTIVE SUMMARY

The Everglades Agricultural Area (EAA) basin, located south of Lake Okeechobee and north of the Water Conservations Areas (WCAs), is comprised of organic soils (order: Histosols) totaling approximately 280,000 ha. The EAA, once part of the vast Everglades, was drained in the early 1900's for agricultural and urban purposes and currently is mainly farmed to sugarcane, vegetables, rice and sod. On-farm water management in the EAA is achieved by groundwater flow through the organic soils and by surface flow in open field ditches and canals to raise or lower the field water tables. Rainfall is highly seasonal and frequently intense, requiring growers in the EAA to actively drain excess water from their fields. Drainage is accomplished through an extensive array of canals and pumps both on- and off-farm. Concerns about the quality of the drainage water, specifically elevated Phosphorus (P) content water, leaving the EAA and entering the WCAs prompted the legislature to adopt the Everglades Regulatory program, part of the Everglades Forever Act, with a goal to reduce EAA basin P loads by 25% compared to a pre-BMP baseline period. Growers are required to implement a suite of BMPs and conduct monitoring of daily rainfall, drainage volume, and P concentration. This is done through a BMP permit issued by the South Florida Water Management District (SFWMD). A point system is used to rate the BMPs and the suite of BMPs implemented must total 25 points as a base level effort. The list of approved BMPs for the EAA basin includes nutrient control practices, water management practices, and particulate matter and sediment controls. Other BMPs can be implemented and claimed on the BMP permit if shown to be effective and are approved by the SFWMD. The BMPs were in place on the EAA farms by February 1, 1995 with 100% participation.

The Everglades Regulatory Program, Chapter 40E-63, F.A.C. ("Rule 40E-63") also mandates landowners in the EAA to sponsor a program for BMP research, testing and implementation. The University of Florida's Institute of Food and Agricultural Sciences (UF/IFAS) has conducted a comprehensive research program regarding BMP effectiveness, testing, and implementation since 1992 under the Everglades Agricultural Area-Environmental Protection District (EAA-EPD) BMP Master Permit Scope of Work. In March 2005, the SFWMD approved a modification of the EAA-EPD scope of work (SOP) required for the BMP research portion of the Master Permit for the EAA. The first task in the 2005 SOW included the statistical evaluation of BMP monitoring and research data of the EAA. The objective of the task was to assess parameters that affect farm P discharge providing information to improve the selection and application of existing BMPs. The report on statistical analysis was issued in August 2007, revised in November 2007 and accepted by the SFWMD in January 2008 (Daroub et al., 2007). The second task focused on extension activities including BMP workshops and one-on-one farm BMP consultations. This annual report documents the progress and achievements of the period of July 1, 2007 through June 30th, 2008. The report includes a summary of the statistical analysis report, and documents the extension activities conducted during the same time period. The proposed new Master Permit SOW is also presented.

Management and Environmental Factors that Impact Phosphorus Loading from EAA farms: Statistical Analysis

The objectives of this research were to conduct detailed data analysis to assess parameters that affect farm P load in drainage water, and to provide growers with comprehensible results and recommendations to improve the selection and application of existing BMPs. Various statistical analyses were employed to answer the question: "What are the factors impacting farm phosphorus loads in the EAA?". The BMP program has been very successful with the SFWMD reporting an average of 50% reduction over the 12 years since the implementation of the program. Despite the great success and having all farms in the EAA implementing similar BMPs, differences in P loads among sub-basins and among similar farms in the same sub-basin exist.

The main data set used for the analyses was from a long term (7-10 year), ten-farm BMP monitoring and research project conducted by the UF/IFAS from 1992-2002. The selected farms were chosen to give a representative sample of EAA farms in terms of crops, soils, rainfall, irrigation, management practices and location among the four sub-basins of the EAA. The UF/IFAS monitoring data base included information on rainfall, soil depth, monthly crop maps, BMPs implemented, canal elevations, drainage flow, and four-day composite flow P concentrations during drainage events. Data related to irrigation water was obtained from the SFWMD DBHYDRO data base.

Factors affecting P loads were grouped into four categories:

Water level management: on- and off-farm canal levels and pump to rainfall ratio

Cropping practices: percent sugarcane, percent flooded and fallow fields

Rainfall and irrigation: rainfall, irrigation demand and irrigation P concentration and load

Farm-specific constants: farm size, soil series, soil depth, and sub-basin.

The following complimentary statistical methods were used: Spearman correlation analysis, multivariate regression analysis on Box-Cox transformed data, Principal Component Analysis (PCA), and Classification and Regression Tree Analysis (CART). Other tests were used including the mixed model procedure and Wilcoxon Rank Sum test. The data was analyzed on a monthly basis and also on a Water Year basis. In addition, the data was aggregated into sugarcane and mixed crop farms to investigate the effect of farm type on P loads.

Results from the multivariate regression, Spearman correlation, and CART analysis were confirmatory and indicated that water management and cropping practices are important in predicting farm P loads in the EAA. The analysis also showed that irrigation water quality from Lake Okeechobee is deteriorating and may be impacting on P loads from sugarcane farms. A potential impact of soil depth on P loads was also revealed by the analysis. Water management practices as indicated by pump to rainfall ratio and canal elevations were important in predicting P loads. Higher P loads are expected with higher pump to rainfall ratios and higher canal head differences. High canal head difference indicates lower inside canal elevation (farm main canal), higher outside canal elevation (SFWMD canal), or both, and may result from farm drainage pumping due to rainfall and/or seepage.

The statistical analysis also indicated that lower P loads were associated with sugarcane as the main crop in the farm cropping rotation. Unit area P loads were negatively associated with sugarcane percentage in the crop rotation. This is not surprising due to the fact that sugarcane P fertilization rates are much lower than fertilizer rates of other crops. In addition, sugarcane can tolerate higher water tables and occasional flooding which reduces the total farm drainage volume on a per acre basis. The analysis showed that higher P loads were observed in farms that have a high acreage of flooded fallow in the summer. This conclusion is based on limited data and needs to be investigated further. One of the complicating factors is that farms that regularly flood their fields in the summer were also mixed-crop farms, which normally have higher P loads. But it has been observed in earlier research that flooded rice pre-harvest drainage water has high P concentrations due to the mobilization of

P from organic soils during flooding. Flooding fallow fields in the summer is a common cultural practice in the EAA which is quite beneficial for a number of reasons, among which are disease and insect control, nematode control, and reduction of soil loss from biological oxidation and is a practice that we fully recommend. Investigation of management practices to reduce the impact of flooding on P loads is recommended.

Seasonal Mann-Kendall trend analysis conducted on irrigation water discharged from three locations adjacent to Lake Okeechobee showed in general, increasing trends in P concentrations. The irrigation water P concentrations were highest from canals serving the S-5A and S-6 sub-basins and lowest for the S-7 and S-8 sub-basins. Limited analysis indicated that some of the farms in our projects were sinks for P with irrigation P loads higher than drainage P loads. The regression analysis also showed higher P loads in sugarcane monoculture farms with higher irrigation P concentrations when the data was analyzed on a monthly basis. These trends need to be confirmed possibly using the larger SFWMD BMP-permit database.

Another factor shown by the regression analysis affecting farm P load is soil depth. In general, deeper soil farms had higher P loads than shallower soil farms. Deepest soils were measured in the in the S-5A sub-basin, with depths decreasing towards the west and south and the shallowest soils measured in the S-7 and S-8 sub-basins. Land use and soil depth factors were difficult to separate, as three out of the four deeper soil UF/IFAS farms were also mixed-crop farms. One probable reason for the lower farm P loads from shallow soil farms is that as drainage water passes through the limestone bedrock, soluble P may be adsorbed or precipitated as a calcium-phosphate fraction. The relationship between soil depth and unit area load needs to be researched further to confirm the results. Field research and/or additional statistical analyses may confirm the relationship between soil depth and farm P load.

Recommendations to Improve BPM Effectiveness

1. Water Management: The first recommendation related to canal elevation is one that we emphasize in all our BMP training workshops and extension publications. Each farm needs to determine an optimum canal elevation that permits adequate drainage without transporting sediments out of the farm. Optimum canal elevations are specific for each farm and depend on canal configurations and pump capacities. It is

also important to emphasize the importance of a sound canal cleaning program that minimizes the potential for sediment transport off the farm.

2. Flooded Field Management: Flooding fallow fields in the summer is a practice we fully recommend taking into account the proper way of discharging the water from these fields. The benefits of flooding and the protection of the organic soils cannot be over-emphasized. We recommend that flooded water be routed throughout the farm to allow the soluble P in the water to adsorb and precipitate in the soil and canal sediments. It is also recommended if possible to allow water to evaporate and percolate down through the soil and substrata to drain the rice and flooded fields.
3. The impact of irrigation water quality on EAA farm P load requires further investigation.
4. The effect of soil depth on farm P load may explain partially the differences in farm P load between the sub-basins, and may indicate that obtaining further reductions from a certain sub-basin may not be possible.

Farm BMP Consultation Program

The consultation program consists of individual farm visits by UF/IFAS personnel to each farm basin in the EAA and discussions of BMP implementation with farm personnel with an objective of enhancing the performance and implementation of BMPs by all growers in the EAA basin. During the third year of the farm BMP consultation program, the efforts have concentrated on farms in the S-6 and S-7 sub-basins. This year we continued to conduct on-farm BMP training (in English and Spanish) in conjunction with the consultation program. These changes have resulted in better interaction between UF/IFAS personnel and farm personnel. Most common suggestions given to growers include sediment removal in farm canals, floating aquatic weed control, pumping practices and proper BMP documentation. We continued to elicit responses to a post BMP consultation survey to assess the benefits of the program and obtain grower recommendations for future BMP research topics. Some preliminary encouraging results are presented in the report.

The BMP consultation program has been very successful in reaching out to the growers in the EAA. Growers consulted to date have been willing to participate, listen, and consider making changes to their practices. Growers have also voiced their concerns about the impact of Lake Okeechobee irrigation water quality in the last few years on their farm P loads and the floating aquatic plant control of some secondary SFWMD canals. Farm BMP consultation program checklist and survey form are included in **Appendix A**.

BMP Training Workshops

Best Management Practices (BMP) workshops have been designed by UF/IFAS faculty to cover all major areas of the BMP program to insure uniform and successful implementation by EAA growers. The topics covered includes a review of Rule 40E-63, BMPs for Atrazine and Ametryn, floating aquatic weed control, BMP table overview, soil testing and plant tissue analysis, fertilizer application BMPs, rainfall detention, sediment control, and latest research findings. Six BMP training workshops were conducted from the period of July 1, 2007 – June 30th, 2008 with a total of 132 participants from all major companies in the EAA as well as different agencies including DOACS, USDA-NRCS, PBSWCD, USDA-ARS, and SFWMD. All presentation materials presented during the BMP workshops are now available in Spanish and are used in on-farm BMP training. A copy of BMP trainings presentations in English and Spanish are included in **Appendix B**.

BMP Extension Materials

Extension publications covering all aspects of BMPs in the EAA are published on line at the University of Florida extension website (EDIS) at: http://edis.ifas.ufl.edu. These publications are available in English and Spanish. A listing of all BMP extension publications are available in this section and the latest extension publication translated to Spanish in 2007 is included in **Appendix C.**

Proposed BMP Master Permit Scope of Work for 2008-2013

The proposed new SOW for the period of 2008- 2013 has two components, research and extension. The proposed SOW is presented here, but may be revised and changed before the final SOW is agreed upon and implemented. The research component focuses on the management of floating aquatic plants in farm canals. The research goal is to identify if farm canals that are maintained free of floating aquatic plants (FAP) will produce less transportable, less labile sediment than farm canals covered by floating aquatic plants. It is our hypothesis that FAP-free canals will be found to produce more cohesive, less reactive, P sediments due to a change in aquatic plant communities, increased light penetration, and increased aerobic conditions throughout the canal water column. These changes in the farm canal environment should result in increased retention of sediments on-farm in canal bottoms. The accumulated sediments can then be readily recycled back onto farm fields during normal canal cleaning operations.

Four pairs of sugarcane farms for a total of eight farms will be selected for the study, i.e., one pair of sugarcane farms for each major conveyance canal/sub-basin. Each sugarcane farm will be an experimental unit. Treatments imposed on a farm will involve one of two treatments, either complete/vigorous control of FAP in main and secondary canals via mechanical control followed by recommended herbicide spray program, or no-control of FAP in main and secondary canals. Farms will be paired to achieve similar characteristics of farm size, soil depth, cropping history, P load history, pump-to-rain ratio, drainage flow velocity, and canal system dimensions.

Prior to initiating the aquatic weed management study a survey of a representative number of EAA farm canals will be conducted to determine the range and distribution of EAA farm canal characteristics: depth, width, sedimentation, and current status and composition of floating aquatic plants. The survey information will be used to assist researchers and grower representatives to select the eight farms.

Some of the factors that will determine which farms are chosen for the study encompass willingness of the grower to cooperate, physical dimensions of main canals, geographic location of the farm, soil depth, and cropping and farm P load histories. Canal depth and the ratio between depth and width are key factors that affect light penetration and the composition and growth of the emergent/submerged plant communities in the canal. A target canal range will be determined which best represents the majority of EAA farm canals. Duration of field data collection will be a three to five years depending upon initial results. The primary data collected from the study will be measurements and analyses of aquatic plants, canal sediments, and canal waters. Plant population and plant biomass composition will be estimated once every two months. Farm canal sediments will be sampled annually to obtain mass estimates and to analyze sediment physical and chemical properties. Drainage water will be sampled flow-proportionally via auto-sampler; samples will be retrieved within 24 hours of compositing. During inter-event periods (ambient canal conditions), canal water will be sampled on a bi-monthly basis via grab sample. Both drainage and inter-event water samples will be analyzed for total P, particulate P, total dissolved P, soluble reactive P, and dissolved organic P. The expected outcome from this research is the development of an optional BMP for managing farm canal aquatic vegetation to provide growers an additional tool in their efforts to reduce off-farm P loading.

The second component of this SOW is the extension services provided to EAA growers. Researchers will continue to provide BMP training to growers in the EAA through workshops and individual BMP consultations. On average, two workshops are conducted for each company per year to ensure maximum participation. In addition, a general workshop is held once per year to include growers not associated with a major company. The previous BMP consultation service program will be scaled back to provide BMP consultations to growers on an 'as requested' basis.

INTRODUCTION

The EAA basin contains highly productive agricultural lands comprised of rich organic peat and muck soils located south of Lake Okeechobee and north of the Water Conservation Areas (WCAs). The EAA plays an important role in the Everglades water supply, either directly through agricultural drainage runoff or indirectly by serving as a conduit for large water transfer from Lake Okeechobee to the WCAs. The primary mode of drainage in the EAA is by groundwater flow, which may be by capillary action through the organic soils, or through fractures in the marl-soil interface. On-farm water management is achieved by using this groundwater flow and the level in open field ditches to raise or lower the field water tables. Rainfall is highly seasonal and frequently intense. Nearly all drainage discharge is achieved by pumping through high volume, low head axial flow pumps. Drainage water from the EAA, after treatment in Storm Treatment Areas, is ultimately discharged to the downstream WCAs, Everglades National Park (ENP), or the South Florida coastal estuaries. Agricultural drainage waters discharged from the EAA are nutrient-enriched compared to the original flow under which the Everglades evolved. This nutrient enrichment, specifically phosphorus (P), has been cited as one of the possible causes of changes in the ecosystems of the WCAs and the ENP (Whalen et al., 1992; Sievers et al., 2003). Concerns regarding the impact of the nutrient laden rich waters from the EAA on the fragile ecosystems of the Everglades Protected Areas prompted the state of Florida to enact the Everglades Forever Act (EFA) in 1994. The EFA mandated the South Florida Water Management District (SFWMD) to create and administer the Everglades Regulatory Program, Chapter 40E-63, F.A.C., which oversees and monitors the implementation of BMPs to reduce P loads from farms in the EAA basin.

The EAA basin is required by the EFA to achieve a P load reduction of 25 percent or greater relative to a rainfall adjusted baseline P load average (October 1978 - September 1988). Since January 1, 1995, BMP implementation has been mandatory for all farms that discharge water into SFWMD canals. The SFWMD monitors EAA basin P loads via a network of monitoring stations that border the EAA. The EAA continues to meet the required performance levels of the EFA as evidenced by an average reduction in TP loads of 46 percent over the past three years. However, water year (WY) 2007 was the first compliance year since WY1996 that the EAA did not achieve a minimum goal of 25 percent for total P (TP) load reduction for an individual year (Van Horn et al., 2008). Despite not achieving the desired 25 percent minimum level during WY2007, the basin remains in compliance. Load reduction since BMP implementation is equivalent to 1,767 mt of TP prevented from leaving the EAA basin as a runoff (Van Horn et al., 2008). In addition to the implementation of a suite of BMPs specifically designed for this area, each farm monitors daily rainfall, flow, and total P concentration at all discharge points, which is submitted to the SFWMD as required by each farm's BMP program.

The Everglades Regulatory Program, Chapter 40E-63, F.A.C. ("Rule 40E-63") also mandates landowners in the EAA to sponsor a program for BMP research, testing and implementation. The University of Florida's Institute of Food and Agricultural Sciences (UF/IFAS) has conducted a comprehensive research program regarding BMP effectiveness, testing, and implementation since 1992 under the Everglades Agricultural Area-Environmental Protection District (EAA-EPD) BMP Master Permit Scope of Work (SOW). In March 2005, the SFWMD approved a modification of the EAA-EPD Master Permit SOW required for the BMP research portion of the Master Permit for the EAA.

The tasks in the 2005 SOW for the master BMP permit include:

1. <u>Statistical Evaluation of BMP Monitoring and Research Data of the EAA</u>: The objective of the task was to assess parameters that affect farm P discharge providing information to improve the selection and application of existing BMPs. The statistical analysis report (management and environmental factors that impact phosphorus loading from Everglades Agricultural Area farms) was issued in August 2007, revised in November 2007 and accepted by the SFWMD in January 2008 (Daroub et al., 2007). We will present a summary and the major findings in this report.
2. <u>Extension Activities</u>: The success of the BMP program in the EAA is in part due to a continuous effort to update and refresh grower knowledge of effective BMP implementation, new methods that target improving BMP implementation and performance warrant evaluation. The educational efforts include providing direct, on-farm BMP consultation services to all interested growers and by annual grower participation in BMP training workshops conducted by UF/IFAS researchers.
    a. <u>BMP Consultation Program:</u> A one on one BMP consultation program that an objective of enhancing the dissemination and implementation of BMPs to all growers in the EAA basin. This outreach program targets all sub-basins and

farms and has a goal of appraising and consulting cooperatively with each farm basin of the EAA within a five year period. The BMP program is evaluated via grower feedback through a BMP farm consultation survey and by tracking the progress of recommendations.

b. Conduct BMP training workshops: Continue to provide BMP training seminars and workshops to all growers in the EAA as part of the requirements in their individual BMP permits to train farm personnel on BMP practices. Simultaneous with the BMP consultation program and workshops is an effort by UF/IFAS researchers to update and complete an online set of publications that explain to growers the rationale and techniques of each BMP recommended by the SFWMD for the EAA.

c. Extension publications: Targeting the all the BMPs in the EAA are published on line both in English and Spanish. These publications are founds at http://edis.ifas.ufl.edu/.

This annual report documents the progress and achievements of the period from July 1, 2007 through June 30th, 2008. It includes summary of the statistical analysis report and documents the extension activities conducted during this year. Consultations and preparation for the new 5-yr EAA Master Permit SOW started in February 2009 between UF/IFAS, EAA-EPD and SFWMD and continue to date. The proposed new Master Permit BMP research SOW is presented in this report, but may undergo additional changes and revisions before being accepted and implemented.

OBJECTIVES

Task 1: Management and Environmental Factors that Impact Phosphorus Loading from EAA farms: Conduct a comprehensive statistical analysis on research and monitoring data on water quality in the EAA.

> *Objective*: Assess parameters that affect farm P load in drainage water, and to provide growers with comprehensible results and recommendations to improve the selection and application of existing BMPs.

Task 2: Farm BMP Consultation Program: An intensive one-on-one consultation Program that consists of individual farm visits by UF/IFAS personnel to each farm basin in the EAA and discussions of BMP implementation with farm personnel.

> *Objective:* Enhance the performance and implementation of BMPs by all growers in the EAA basin. This outreach program targets all farmers in the EAA beginning with farms in the S-5A sub-basin and extending westward to the other sub-basins in the EAA.

Task 3: Conduct BMP Training Workshops: This task includes tailored BMPs training seminars and workshops for growers groups. A Spanish version has been incorporated to better train the Spanish speaking work force of the EAA in addition to on-farm BMP training sessions.

> *Objective:* Provide concise and updated BMP implementation information via training seminars to the EAA grower community. The information provided explains in layman's term the rationale and techniques of individual BMPs and the more recent research results on other water quality issues.

Task 4: Development of BMP Extension Materials: This task includes the development and publication of extension material on BMP implementation in the EAA.

> *Objective:* Provide extension material on the most commonly used BMPs in the EAA to the grower community.

Additional Task: Develop New Scope of Work for five year BMP Research: The proposed five-year research and extension program for the EAA-EPD Master Permit is presented.

Task I: Management and Environmental Factors that Impact Phosphorus Loading from EAA farms: Statistical analysis

Although the implemented BMP point system has been very effective in reducing P loads, there is still uncertainty concerning the efficacy of BMPs as evidenced by the load reduction variability in the different sub-basins in the EAA. The EAA has historically been delineated into six sub-basins according to the pump station system that drained the EAA basin. The original six sub-basins can be reduced to four, since the pump stations along Lake Okeechobee serve now primarily as irrigation inflow structures to the EAA. The four sub-basins, S-5A, S-6, S-7, and S-8 correspond to outflow structures that line the south and east periphery of the EAA basin. Each sub-basin is also associated with the main conveyance canal that transects each sub-basin, i.e., S-5A sub-basin contains the West Palm Beach Canal, the S-6 sub-basin contains the Hillsboro canal, the S-7 sub-basin contains the North New River Canal and the S-8 sub-basin contains the Miami Canal. Each sub-basin P load can be calculated separately; however BMP load reduction compliance is based on the EAA basin as a whole. These sub-basins vary greatly with regard to their respective P load exports (Adorisio et al., 2006). Since participation and implementation of BMPs by farms in the EAA since 1995 can be considered 100%, it would appear that there are other factors that may be affecting EAA farm P loads besides BMP implementation. Proper and conscientious implementation of BMPs may be an issue, but other environmental and geological factors may be impacting farm P loads. Some of these factors may include rainfall distribution and amount, soil depth, land use, farm location within the EAA, irrigation water quality, farm size, and rainfall detention amount. The increase in P concentration of irrigation water from Lake Okeechobee since the 2004 Hurricane season and the reduction of sugarcane acres in the EAA are two factors that may have future impact on farm P loads.

This statistical analysis investigates the causes of farm P load variability and thereby attempts to provide researchers, water managers, and EAA growers with a better understanding of some of the factors affecting farm P loading in the EAA basin. A number of hypotheses and questions were developed with the overall goal of understanding the factors affecting farm P loading in the EAA. Several factors were identified that may impact farm P loading in the EAA. The factors can be grouped into four categories: water management (canal elevations –inside, outside, and head difference, and pump to rainfall ratio), cropping practices (percent sugarcane, percent flood, percent fallow+flood), rainfall and irrigation (rainfall, irrigation demand, irrigation P concentration and irrigation P load) and farm-specific constants (farm size, soil series, soil depth, and location).

Methods

The main data set used to answer these questions was developed from a long-term BMP project that monitored ten EAA farms for various P load related parameters. The University of Florida's Institute of Food and Agricultural Sciences (UF/IFAS) has conducted a BMP research project on ten farms in the EAA that monitored BMP implementation and related P load parameters since 1992 (Daroub et al., 2003). The BMP project database contains detailed farm data, e.g. canal levels, flows, discharge water P concentrations, and land use maps. The monitoring lasted between 90 to 118 months. These farms had been chosen to represent a sample of the population of EAA farms (Table 1). Two time intervals, monthly and annual were selected for the analysis of factors that affect farm P loading. The same statistical methodologies were conducted for both time intervals. The annual time interval corresponds to the SFWMD Water Year (May 1 to April 30th). The monthly time interval provided analytical resolution to shorter-term response of farm P loading to variable changes. Unless noted otherwise, statistical significance was set at $p < 0.05$ for all analyses in the study.

Irrigation water P concentration data was obtained from SFWMD-DBHYDRO for the three main irrigation water inflow structures for the EAA (S-352, S-2, and S-3). Structure S-352 provides irrigation water to the West Palm Beach Canal which services farms in the S-5A sub-basin. Structure S-2 provides irrigation water to the North New River and Hillsboro canals. The Hillsboro Canal services farms in the S-6 sub-basin and the North New River Canal services farms in the S-7 sub-basin. Structure S-3 provides irrigation water to the Miami Canal which is the source of irrigation water for farms in the S-8 sub-basin. The irrigation water sampling record for the period of study was infrequent and inadequate for most of the duration of the study period. Missing monthly data from inflow structures were substituted with values generated from the annual geometric mean for that structure for that year. Irrigation demand was calculated by farm on a monthly basis from the difference of monthly pan evaporation measured at the EREC weather station in Belle Glade and farm monthly rainfall.

The statistical analyses and steps employed included:

1- Summary statistics: for different parameters on all farms were presented using notched box plots. Box plots provide a schematic graphical summary of important features of a distribution that include the minimum and maximum range values, upper and lower quartiles, mean and median. This collection of values is a quick way to summarize the distribution of a dataset. Box plots partition a data distribution into quartiles, that is, four subsets with equal size. A box is used to indicate the position of the upper and lower quartiles; the interior of the box indicates the inter-quartile range, which is the area between the upper and lower quartiles and consists of 50% of the distribution. Lines (sometimes referred to as whiskers) are extended to the minimum or maximum values in the dataset. Outliers are represented individually by symbols. The box is intersected by a crossbar drawn at the median of the data set. The mean is represented by a + sign.
2- Normality testing: histograms and quantile/quantile plots were constructed to test for the normal distribution of the data. Results presented in the full report (Daroub et al., 2007) showed a non-normal distribution of the data as most environmental data and transformation of the data was done for use in regression analysis.
3- Data transformation: was done using Box-Cox transformation use in the multivariate regression analysis. The Box-Cox transformation is heralded to best linearize the model, stabilize the variance, and make the residuals Gaussian distributed. The class of Box-Cox transformation is heralded to accomplish these multiple goals but is not without controversy (Schabenberger and Pierce, 2002).
4- Trend analysis: was conducted on the monthly ten UF/IFAS BMP farm data and on monthly means of irrigation water data from the SFWMD-DBHYDRO database to determine water quality and quantity trends over time in each farm location and in waters received from the three main irrigation structures that supply irrigation water to EAA farms. The trend analysis SAS program utilized was developed by Steve Winkler of the St. John's River Water Management District (Winkler, 2004). The statistical tests conducted by the program were the non-seasonal Mann-Kendall and the seasonal Mann-Kendall. Water quality trend analysis has increasingly been based on non-parametric methods, particularly those based on Kendall's tau and the Mann-Kendall test (McBride, 2005). Seasonal Kendall test is an extension of the Mann-Kendall test that removes seasonal cycles (Gilbert, 1987, McBride, 2005). The Winkler program uses monthly data, determines if seasonality is present in the data, and if it is, then the

Season Mann-Kendall test is conducted. If seasonality is not found in the monthly data, then the non-Seasonal Mann-Kendall test is run.

5- Spearman correlation analysis: correlation is usually defined as a measure of the linear association between random variables. Correlations that are based on the ranks of data rather than the actual values are not influenced by the underlying distribution. Spearman correlation is non-parametric and can be used to test the correlation in non-normal data (McBride, 2005).

6- Multivariate regression analysis: multiple linear regression models for both yearly and monthly time scales were tested using the ten farm data set. Transformed data were used for this analysis. The dependent variables were the Box-Cox transformed monthly farm P loading (boxcoxlbsual) and Box-Cox transformed yearly farm P loading (boxcoxyearlylbsual). Two variables, drainage volume and drainage water P concentration, are the two constituents comprising farm P loading and are predictor variables. Therefore the regression modeling did not include these two predictor variables. Their inclusion in the regression model would have overshadowed the contribution from truly independent variables. The monthly data set contains a total of 809 observations developed from the monthly data set for all farms combined and by farm type.

7- Classification and regression tree analysis (CART): is a non-parametric test with the advantage that the variables of importance to predict specific target variables of interest can be identified and ranked based on their importance (Breiman et al., 1984). The CART methodology was used to develop models to predict phosphorus loads (both monthly P loads and monthly unit area P loads). CART -based modeling has the following benefits: (1) non-parametric method ("distribution-free method"); (2) variables of importance to predict specific target variables of interest can be identified and ranked based on their importance; (3) high-order interactions between variables can be modeled explicitly using surrogates; (4) CART can handle large data sets which show complex and non-linear structures; (5) CART is robust to the effects of outliers, and (6) can handle categorical and continuous variables. Three different CART models were tested: (1) single tree regression trees, (2) committee trees (Bagging mode), and (3) committee trees (ARCing mode). The CART analysis adds additional non-parametric dimension to the study and improves the robustness of the results and conclusions.

Table 1. List of the 10 UF/IFAS farms, sub-basin location, crops, farm size, soil depth, and rainfall detention.

UF Farm	Monitoring duration (months)	Sub-Basin	Irrigation water source∗	Crops	Farm size (ha)	Average soil depth (m)	Rainfall detention (mm)
00A	118†	S-5A	S352 WPB	Sugarcane	518	1.16	25.4
01A	90‡	S-6	S2 HB	Mixed	518	0.61	12.7
02A	118	S-7	S2 NNR	Sugarcane	130	0.46	25.4
03A	118	S-7	S2 NNR	Sugarcane	1865	0.43	12.7
04A	118	S-6	S2 HB	Sugarcane	259	1.62	25.4
05A	90	S-8	S3 Miami	Mixed	130	0.55	25.4
06AB	118	S-5A	S352 WPB	Mixed	710	0.88	12.7
07AB	118	S-6	S2 HB	Mixed	1012	0.98	25.4
08A	110∞	S-6	S2 HB	Sugarcane	106	0.73	25.4
09A	118	S-8	S3 Miami	Sugarcane	1243	0.98	25.4

† July 1992 to April 2002
‡ July 1992 to December 1999
∞ July 1992 to August 2001
∗WPB = West Palm Beach canal; HB= Hillsboro canal; NNR= North New River canal.

Results

The following is a summary of the major results and discussion of the detailed statistical analysis conducted on UF/IFAS project research and monitoring data. The complete report was published in 2007 (Daroub et al., 2007) and can be found on-line at http://erec.ifas.ufl.edu/WQ/STAT%20REPORT%20FINAL.pdf.

Summary statistics

Summary statistics in notched box plots of yearly rainfall average (mm) and unit area drainage volume (UAV) in m^3 ha^{-1} from all the study farms during the study period are shown in Figure 1. Mean rainfall was uniform across all farms, ranging from a low of 1146 mm at 07A/B to 1308 mm at 06A/B, however rainfall amounts varied by year as illustrated by the distribution lines which indicate the minimum and maximum (Fig. 1a). Unit Farm drainage volume (UAV) is presented as per ha basis to compare farms since farms are of varying sizes (Fig. 1b). There are major differences in UAV between farms. Four farms (02A, 03A, 04A, and 08A) had a mean drainage volume of 4000 m^3 ha^{-1} or less. All of these farms are sugarcane farms. Three additional farms (00A, 07A/B, and 09A) had a mean drainage volume less than 6000 m^3 ha^{-1}. Farm 07A is a mixed crop farm with a relatively deep soil and a 25.4 mm rainfall detention. The remaining three farms had mean drainage volume in m^3 ha^{-1} of 7500 for 01A, 9590 for 06A/B, and 14645 for 05A. All of these three farms have mixed-cropping systems and claim 12.7 mm rainfall detention except for 05A which claims 25.4 mm rainfall detention. Farm 05A has significant seepage from the Miami canal that partially explains the high unit drainage volume from that farm. Farm 05A is a small farm (130 ha) and the yearly unit area drainage volume varied considerably ranging from a minimum of 4776 to a maximum of 24197 m^3 ha^{-1} indicating a seepage problem (Fig. 1b). In general, farms with shallow soils and mixed cropping systems have to pump more drainage water compared to farms with deeper soils and sugarcane crop.

Rainfall to pumping ratio was calculated from yearly rainfall and UAV for each farm. The lowest rainfall to pumping ratio was 0.22 at farm 08A, a sugarcane farm located in the S6 sub basin with an average soil depth of 0.73 m. Excluding Farm 05A, which had seepage problems and high rainfall to pumping ratio of 1.13, two farms had the highest rainfall to pump ratio, 0.68 for farm 01A and 0.73 for farm 06A/B. Farm 01A is a mixed crop farm in the S6 sub basin with an average soil depth of 0.6 m and farm 06A/B is also a mixed crop farm located in the S5A sub basin with an average soil depth of 0.88 m. Both of these farms claim 12.7 mm rainfall detention mandated by shallow soils and vegetable production. Vegetables are water sensitive and cannot tolerate flooding or high water tables.

Yearly mean flow-weighted total phosphorus concentrations (FWTP) and unit area loads are presented in Figure 2. Flow-weighted total phosphorus concentrations ranged from a low of 0.082 mg L^{-1} in 09A to a high of 0.768 mg L^{-1} in 01A. Out of the 10 farms, four (02A, 05A, 08A, and 09A) had a mean FWTP of less than 0.100 mg L^{-1}. All of these farms are sugarcane farms except for 05A. Four farms (00A, 03A, 04A and 07A/B) had FWTP concentrations ranging from 0.1 to 0.3 mg L^{-1}; one farm (06A/B) was at 0.329 mg L^{-1} and one farm (01A) at 0.768 mg L^{-1}. Both 06A/B and 01A are mixed crop farms. By comparison, total P annual average concentration from the EAA basin between WY 1994 and WY 2005 ranged from a high of 0.130 mg L^{-1} in WY 1995 to a low of 0.069 mg L^{-1} in WY 2003 (Adorisio et al., 2006).

Farm 01A showed the highest P loads (Water Year UAL) and wide variability ranging from 1.03 to 11.6 kg ha^{-1} (Fig 2b). The mean UAL at 01A was at 6.2 followed by 06A/B at 3.2 kg ha^{-1}. High drainage volume and high FWTP translated into the highest P loads out of these mixed crop farms compared to the rest of the research farms. Four farms (02A, 03A, 04A, 08A, and 09A) had an average UAL less than 0.55 kg ha^{-1} (Fig. 2b). All of these 5 farms are sugarcane farms. Although farm 05A had a higher volume pumped during the years, the mean FWTP was 0.084 mg l^{-1} and this translated into a load of 1.22 kg ha^{-1}. Farm 07A/B had an annual UAL of 1.4 kg ha^{-1}, while 00A had a UAL of 1.43 kg ha^{-1}. It is important to note that these UALs are not adjusted for rainfall. To compare with the EAA basin as a whole, about 72% of the farm basins in the EAA basin have UALs < 1.12 kg ha^{-1}; 20 % of the farms have UALs > 1.12 and < 2.24 kg ha^{-1}; 4 % of the farms have a UALs > 2.24 and < 3.36 kg ha^{-1}, while the remaining 4% of the farms UALs > 3.36 kg ha^{-1} (Adorisio et al., 2006).

<u>Water quality trends of UF/IFAS farms</u>

A decreasing trend was observed for monthly P UAL for seven of the ten farms and an insignificant trend was observed for the remaining three farms, with no farm showing increasing trends. For monthly, flow-weighted, drainage water P concentration, a decreasing trend was observed for six farms and no trend was observed for the remaining four farms.

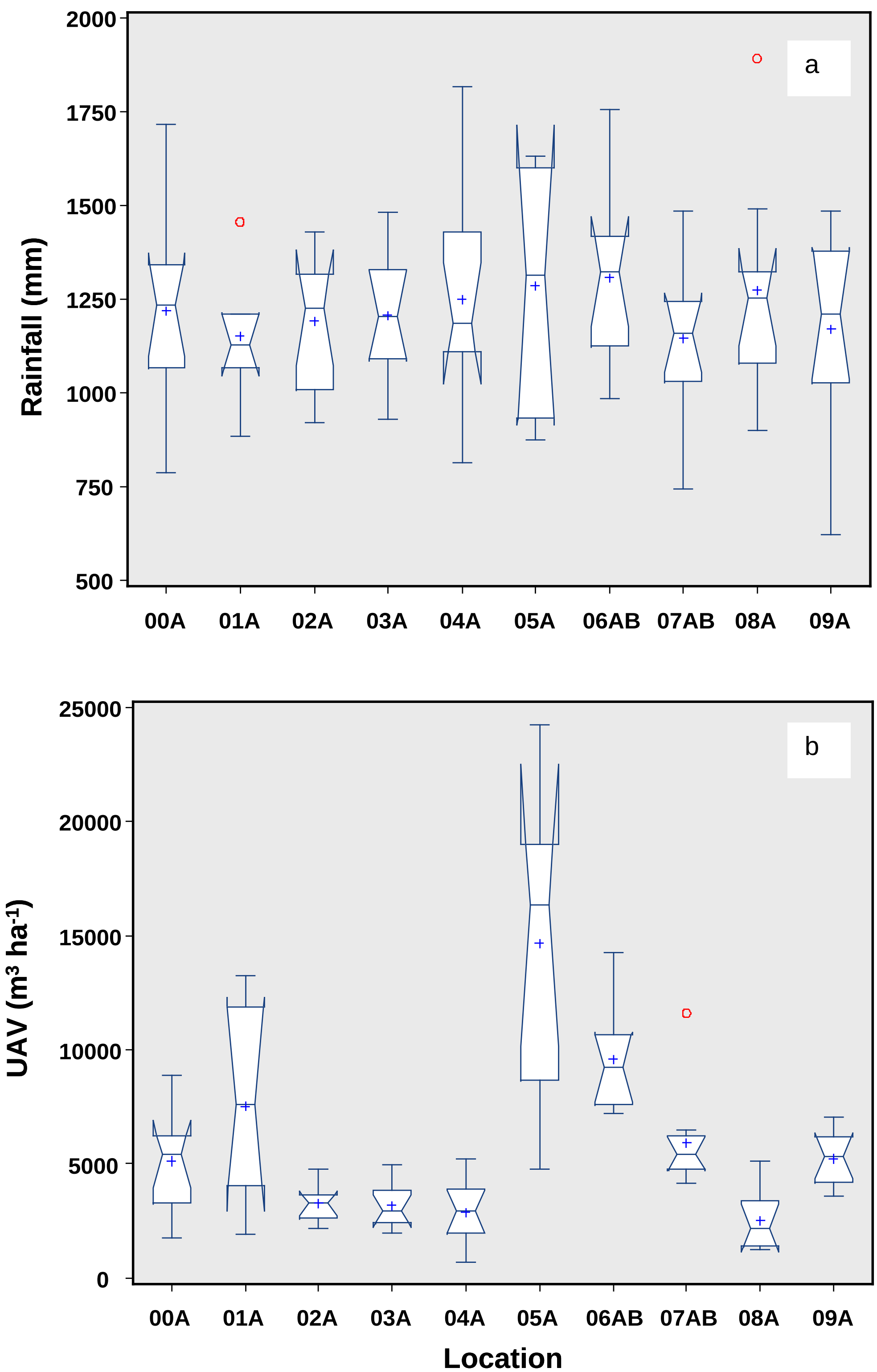

Figure 1. Plots of Water Year rainfall and unit area volume (drainage) for the ten UF/IFAS study farms in the EAA during the study period.

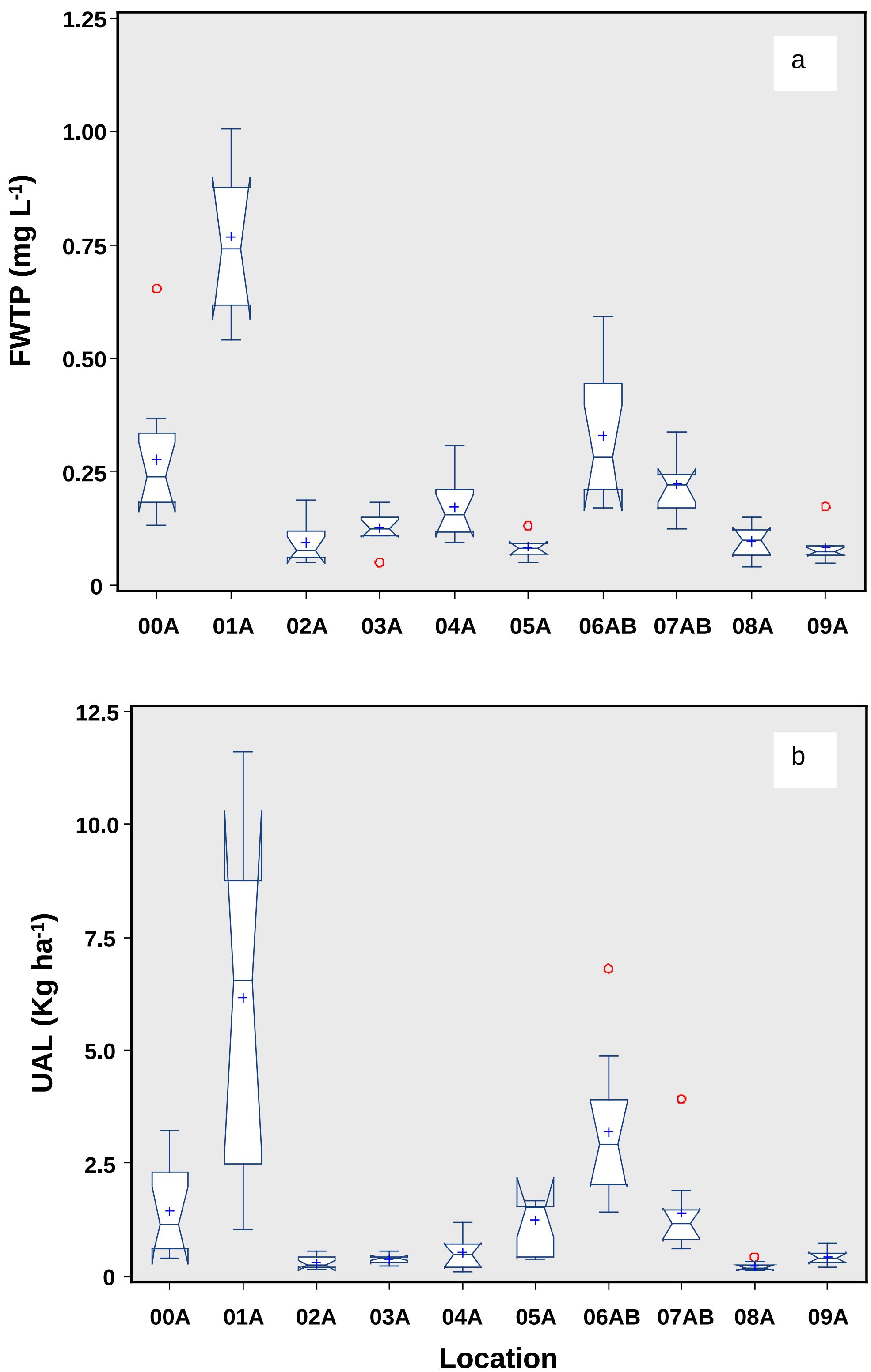

Figure 2. Plots of Water Year flow weighted total P concentration (FWTP) and unit area load (UAL) for the ten UF/IFAS study farms in the EAA during the study period.

What are the factors that affect farm P loads in the EAA?

To answer this question, multiple statistical analyses were conducted, including Spearman correlation analysis, multivariate regression analysis (on Box-Cox transformed data), and Classification and Regression Tree Analysis (CART). Analyses were conducted on a monthly and Water Year basis except for the CART that was conducted on the monthly data only. The multivariate regression and CART analyses were also conducted for all ten farms combined, the six sugarcane farms, and the four mixed-crop farms.

Spearman correlation analysis between Unit Area Loads (UAL) and other parameters using the monthly data are shown in Table 2. The relatively high correlation coefficients ($p < 0.001$) between farm P loading (UAL) and drainage water P concentration (FWTP) and drainage volume (UAV) are not surprising since farm P loading is a result of the product of drainage volume and drainage water P concentration. The variable with the highest correlation with farm P loading was drainage water volume (0.855). Unit Area Loads were correlated with pump to rainfall ratio (0.667; $p < 0.001$), rain (0.542, $p < 0.001$), canal head difference (0.243; $p < 0.001$), irrigation P concentration (0.259; $p < 0.001$), % fallow flood (0.179; $p < 0.001$) and soil depth (0.104; $p < 0.01$).

Unit area load had a negative correlation with % sugarcane (-0.142; $p < 0.001$) and with inside canal elevation (-0.167; $p < 0.001$). Correlation analysis does not indicate cause and effect but merely indicates that a relationship exists. The correlation analysis pointed to water management factors (pumping practices as indicated by pump to rainfall ratio, canal levels, summer flooding and irrigation water quality) and cropping systems as having an a relationship with farm P loads.

Table 2. Spearman correlation coefficients of monthly farm P loading parameters for the ten UF/IFAS farms.

Variable†	Unit Area Load (UAL)	Monthly FWTP	Unit monthly Drainage (UAV)	MIH	MOH (	MHD	Pump to Rain Ratio	Percent cane §	Percent Fall+ Flood §	Monthly Rain	Irrigation Demand Pan	IPC	Soil Depth	Farm Size (acres)
	Lbs ac^{-1}	mg L^{-1}		ft	Ft	ft	In:in	%	%	in	in	mg L^{-1}	ft.	acres
UAL	1.000	***	***	***	NS	***	***	***	***	***	***	***	**	NS
FWTP	0.511	1.000	NS	***	**	***	**	***	**	NS	NS	***	***	**
UAV	0.855	0.047	1.000	**	NS	**	***	***	**	***	***	***	NS	NS
MIH	-0.167	-0.153	-0.129	1.000	***	***	***	***	**	NS	NS	NS	***	***
MOH	0.022	0.101	-0.036	0.494	1.000	***	NS	NS	NS	NS	NS	NS	***	**
MHD	0.243	0.351	0.102	-0.581	0.289	1.000	***	***	**	***	**	**	**	***
Pump:Rain	0.667	0.093	0.730	-0.192	-0.015	0.241	1.000	***	***	NS	***	**	NS	NS
% Sugarcane	-0.412	-0.426	-0.224	0.229	-0.004	-0.375	-0.358	1.000	***	NS	*	NS	***	**
% Fall Flood	0.179	0.122	0.131	-0.096	-0.055	0.095	0.169	-0.524	1.000	NS	NS	***	***	**
Rain	0.542	-0.014	0.672	0.043	-0.036	-0.138	0.052	0.061	0.014	1.000	***	***	NS	**
Irr. Dem. Pan	-0.534	0.028	-0.672	-0.019	0.001	0.093	-0.151	-0.083	-0.018	-0.899	1.000	***	NS	**
IPC	0.259	0.237	0.190	-0.032	0.053	0.103	0.095	-0.057	-0.138	0.201	-0.205	1.000	**	NS
Soil Depth	0.104	0.244	0.007	-0.258	-0.205	0.115	0.003	0.248	-0.198	0.016	-0.030	0.099	1.000	NS
Farm Size	-0.032	0.107	-0.080	-0.399	0.131	0.611	-0.037	-0.083	0.094	-0.098	0.102	-0.050	-0.032	1.000

*Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
NS = non-significant at the 0.05 probability level.
† FWTP = Flow weighted total P concentration; MIH = Monthly Inside Head; MOH = Monthly Outside Head; MHD = Monthly Head Difference; Irr. Dem. Pan = Irrigation Demand Pan; IPC = Irrigation P concentration
§ = % of farm)

Table 3 summarizes the multivariate regression analysis done on Box-Cox transformed data by Water Year and monthly for all ten farms, the six sugarcane farms, and the four mixed-crop UF/IFAS farms. The pump to rainfall ratio appears as a significant variable in all the regression equations (Table 3). Another variable that is significant in all prediction equations (except in the annual prediction equation for sugarcane farm) is canal head difference. Canal head difference is the difference in canal elevation between the exterior SFWMD main canal and farm interior main drainage canal. The relationship between canal head difference and UAL indicates that greater canal head difference was associated with higher UAL. Both of these variables (pump to rainfall ratio and canal head difference) are water management variables and point to the importance of water management for farm UAL in the EAA.

The farm-specific variable, soil depth, was significant in three farm UAL prediction equations (all ten farms and six sugarcane farms for Water Year, and all ten farms at the monthly time scale) and indicates that deeper farm soils may have the potential to produce higher farm UAL. However, confounding the effect of soil depth on farm UAL is the effect of location (UF/IFAS farms in the S-5A sub-basin generally had the deepest soils but also receive the highest P concentration in irrigation water).

Irrigation variables (irrigation water P concentration, irrigation demand pan) were important in the monthly farm UAL regression equations. Irrigation water P concentration appears to play a role in increased P loads for the sugarcane farms. Irrigation demand pan had a negative relationship with farm UAL; high monthly irrigation demand indicated low monthly rainfall and thus little or no need for drainage pumping. Conclusions from the irrigation analysis should be judged as preliminary at best. Further research on this topic, including a judicious analysis of selected farm basins of the SFWMD BMP permit farm data set may reveal a clearer understanding of the relationship between irrigation water quality and farm P loading.

Land use and crop rotation also have an impact on farm UAL. It is evident from the regression equations that UAL has an inverse relationship with percent sugarcane acreage in rotation which was also revealed by the correlation analysis. The higher the percent acreage of sugarcane, the lower is the UAL. This finding is not surprising given the higher P fertilizer requirement and more intensive water management that crops besides sugarcane generally need. The percent fallow+flood acreage had a positive association with farm UAL on mixed-crop farms on a yearly basis. The relationship between summer flooding and UAL is not entirely clear and worthy of further investigation. It may be an indication that changes in land use (less sugarcane acres and increases in other crop acres) might be impacting farm P loads in the EAA.

In summary, results from the correlation and multiple regression analyses were confirmatory and indicated that P UAL are positively associated mostly with water management (pump to rainfall ratio and canal elevations) and negatively associated with percent sugarcane in the cropping systems. For sugarcane farms, irrigation P concentration appears to have an influence on UAL. For mixed-crop farms, percent fallow+flood acreage in the summer appears to play a role in predicting UAL on these farms.

Table 3. Summary results of the multivariate regression analysis to predict Box-Cox transformed unit area load on a water year and monthly basis for all ten farms, six sugarcane farms and four mixed-crop farms.

Analysis	Adj R^2	RMSE	N	Variables in regression equation†
Water Year – All farms	0.678	0.673	93	Pump to rainfall ratio Canal head difference Soil depth Percent cane acreage
Water Year – Sugarcane	0.423	0.689	59	Pump to rainfall ratio Soil depth
Water Year – Mixed farms	0.600	0.475	34	Pump to rainfall ratio Canal head difference Percent fallow and flood acreage
Monthly – All farms	0.630	0.696	809	Pump to rainfall ratio Monthly canal head difference Irrigation P concentration Soil depth Irrigation demand pan Percent cane acreage
Monthly – Sugarcane	0.506	0.671	475	Pump to rainfall ratio Monthly canal head difference Irrigation P concentration Irrigation demand pan Inside canal head
Monthly – Mixed farms	0.625	0.705	334	Pump to rainfall ratio Monthly canal head difference Irrigation demand pan Percent cane acreage

† Variables in blue text are positively related to UAL; variables in red text are negatively related to UAL.

The Classification and Regression Tree Analysis (CART) methodology was used to develop models to predict phosphorus loads (both monthly P loads and monthly unit area P loads). CART -based modeling has the following benefits: (1) non-parametric method ("distribution-free method"); (2) variables of importance to predict specific target variables of interest can be identified and ranked based on their importance; (3) high-order interactions between variables can be modeled explicitly using surrogates; (4) CART can handle large data sets which show complex and non-linear structures; (5) CART is robust to the effects of outliers, and (6) can handle categorical and continuous variables. Three different CART models were tested: (1) single tree regression trees, (2) committee trees (Bagging mode), and (3) committee trees (ARCing mode).

The predictions for monthly UAL in ARCing mode were excellent indicated by a high R^2 of 0.95 for all ten farms in the EAA. This best model identified the variables pump to rainfall ratio, percent flood, irrigation demand, and percent fallow-flood as most important to predict UAL across all ten farms (Table 4). The same variables had predictive power in Bagging and single tree modes confirming their importance to infer on UAL. However, these prime split variables were complemented by other environmental predictor variables in single tree mode (percent sugarcane, location) and Bagging mode (monthly outside head, monthly rain, and monthly inside head).

To assess if differences exist in prediction of UAL on sugarcane and mixed farms a separate set of trees were run. Excellent trees were generated in ARCing mode to predict UAL with R^2 of 0.99, RRE of 0.01 and cross-validated relative error of only 0.04 for sugarcane farms (Table 4). Among all three tree modes pump to rainfall ratio, irrigation demand and monthly rain ranked highest to predict UAL on sugarcane farms. Interestingly, percent fallow-flood and percent flood were less important to predict UAL on sugarcane farms.

The best tree in ARCing mode to predict UAL on mixed farms showed a R^2 of 0.98 with the most important variables monthly rain, pump to rainfall ratio, percent sugarcane, irrigation P concentration, irrigation demand and location (Table 4). Percent fallow-flood was important in Bagging and single tree modes to predict UAL on mixed farms.

Overall, CART was very successful in identifying relationships between phosphorus loads and environmental variables on ten farms in the EAA as indicated by high R^2 and low prediction errors. Committee trees in ARCing mode generated the best performing trees to predict monthly P load as well as P UAL. Hydrologic environmental variables showed the strongest relationships to monthly P load and UAL. However, variable importance differed among trees modes and subsets (ten farms, sugarcane and mixed-crop farms).

In addition to investigating the main first question, what are the factors that impact farm P loads in the EAA, we determined that five additional specific factors required further examination: influence of farm location, irrigation water quality, farm size, soil depth, land use and crop rotation, and rainfall detention amount.

Table 4. Summary results for committee tree model (ARCing) to predict monthly UAL of phosphorus for all ten farms, six sugarcane, and four mixed-crop farms.

Target Variable	Terminal Nodes	Cross-validated Relative Error	Resubstitution Relative Error	R^2	Variable Importance† (only the most important are listed)
10 farms (EAA)					
Committee tree (ARCing)	29** 10*	0.08 0.26	0.05 0.22	0.95 0.78	pumptorain (100) percentflood (72.5) irrdemand (70.0) percentfallflood (60.9) irrpconc (57.5) monthlyrain (54.5) monthlyoutsidehead (54.0) mojnthlyinsidehead (43.4) location (18.6) percentcane (14.2) soildepth (13.0) subbasin (11.6) ....
Sugarcane farms (mean UAL: 0.06 lbs P/acre)					
Committee tree ARCing)	73** 10*	0.04 0.09	0.01 0.05	0.99 0.94	pumptorain (100) irrdemand (67.9) monthlyrain (42.5) monthlyoutsidehead (36.3) percentflood (26.8) percentfallflood (20.2) location (19.5) irrpconc (19.4) soils (14.6) monthlyinsidehead (13.3) percentcane (11.0) farmsize (8.1) ....
Mixed farms (mean UAL: 0.27 lbs P/acre)					
Committee tree (ARCing)	41** 14*	0.09 0.14	0.02 0.06	0.98 0.95	monthlyrain (100) pumptorain (97.7) percentcane (64.2) irrpconc (56.2) irrdemand (54.3) location (45.8) monthlyinsidehead (40.7) soildepth farmsize (32.1) subbasin (30.1) percentfallflood (26.2) monthlyoutsidehead (20.8) percentflood (14.2)

Location and quality of irrigation water impact on farm P loads

The ten UF/IFAS farms BMP data summarized into annual and monthly intervals, was categorized into sub-basins, and analyzed using the Wilcoxon Rank Sum test to evaluate differences of farm P loading due to geographic location within the EAA (Daroub et al., 2007). Two farms (00A and 06A/B) are located in the S-5A sub-basin; four farms are located in the S-6 sub-basin (01A, 04A, 07A/B, and 08A); two farms in the S-7 sub-basin (02A, and 03A), and two farms in the S-8 sub-basin (05A, and 09A).

There were significant differences in UAL between UF/IFAS farms in the different sub-basins. Overall total P concentration in the UF/IFAS farms in EAA sub-basins tended to be grouped in two distinctive areas. Drainage water P concentrations from the UF/IFAS farms in S-5A and S-6 sub-basins were significantly higher than drainage water P concentrations from the S-7 and S-8 sub-basins. Six UF/IFAS farms were located in the S-5A and S-6 basins (three sugarcane and three mixed-crop farms). So out of the four mixed-crop UF/IFAS farms in this project, three were located in S-5A and S-6 sub-basins which may had a direct impact on P loads. In addition, the three main inflow structures supplying irrigation water to the EAA differed in the quality of the irrigation water they supplied. Of the three structures, the S-352, which supplies water to farms in the S-5A sub-basin via the West Palm Beach Canal, delivered the highest P concentration irrigation water during the period from 1992 through 2002.

Unit Area Drainage Volume (UAV) from the UF/IFAS farms in the S-5A sub-basin was significantly higher than those observed in the S-6 and S-7 sub-basins, and not significantly different from the S-8 sub-basin. High drainage of one farm (05A) located in the S-8 sub basin is most likely not typical of farms in that sub-basin. That small farm had seepage problems due to its location adjacent to the Miami canal and had high drainage volumes as a consequence.

At the monthly time interval, UAL was negatively correlated with irrigation P demand but positively correlated with irrigation P concentration. With high irrigation demand, there is generally little rainfall and subsequent need for drainage pumping. Therefore, the resultant negative correlation between irrigation demand at the monthly scale was observed.

Lake Okeechobee irrigation water trend analysis

The effect of poor quality irrigation water has probably become more pronounced in the last few years. The quality of the irrigation water from Lake Okeechobee has degraded after two years with multiple hurricanes impacting the lake (2004 and 2005). Trend analysis was conducted on the EAA inflow water quality data collected from DBHYDRO for the structures S2, S3, and S352 from July 1992 through September 2006 to determine potential future impact on farm P loads (Table 5). Trend analysis results for flow conditions revealed significant increasing trends for irrigation water P concentrations for S3 and S352. Results of the trend analysis for all samples collected (under flow and ambient conditions) showed an increasing trend for all three structures. Confirmation or repudiation of these qualified findings could be obtained from field investigations and from a targeted analysis of selected farm data from the EAA BMP permit database. We recommend the discerning use of the SFWMD BMP farm data set to analyze the impact of irrigation water on farm P loads.

Table 5. Trend analysis of phosphorus concentrations of irrigation water supplied by the three main inflow structures to the EAA from 1992 to 2006.

Structure†	N	Kendall K	Z Score	Z Probability	Trend	Season	Durbin-Watson‡
			Samples collected during flow conditions only				
S-2	165	132	0.185	0.854	insignificant	non-seasonal	1.8230
S-3	169	2635	3.581	0.001	increasing	non-seasonal	1.6396*
S-352	289	7224	6.513	0.001	increasing	seasonal	1.7033*
			Samples collected during flow and ambient conditions				
S-2	268	1508	2.017	0.044	Increasing	seasonal	1.8101
S-3	239	5946	4.813	0.001	Increasing	non-seasonal	1.0875*
S-352	537	20033	8.938	0.001	Increasing	seasonal	1.4055*

† Structure S-2 supplies water to the North New River and Hillsboro canals, Structure S-3 supplies irrigation water to the Miami canal, and Structure S-352 supplies irrigation water to the West Palm Beach canal.
‡ Durbin-Watson values with an asterisk * are significant for positive serial correlation.

What is the effect of farm P size on P loading?

We tested the hypothesis that Unit Area Drainage (UAV) and Unit Area Load (UAL) are affected by farm size. Field water tables in small farms would appear to be more susceptible to seepage from surrounding farms and adjoining water conveyance canals. Depending upon the small farm's relative elevation to the surrounding topography, this could lead to high drainage UAV and high UAL from small farms. In addition, small farms may not have the flexibility of storing the water on farm and may have less capacity to adjust water tables across the farm. The ten UF/IFAS BMP project farms were classified by size as follows: small - farms <1000 acres, medium - farms 1000-2000 acres, and large - farms >2000 acres. We used the Wilcoxon Rank Sum test to test differences between means of each group. A mixed linear model was tested on the transformed data with time as repeated measure to test the significance of farm size on UAL.

Phosphorus UAL at the ten UF/IFAS farms was affected by farm size, but the exact impact of farm size was not clear. The small size farms had a slightly (but significantly) higher yearly drainage UAV compared to the large farms, but much lower drainage UAV compared to the medium-size farms in this study. Small farms had the lowest UAL compared to the large and medium size UF/IFAS BMP farms, but the medium size farms had higher drainage UAV and UAL compared to large size farms.

The effect of farm size could not be separated from land use. Two of the medium sized farms were mixed-crop farms, which confounded the results and conclusions regarding drainage water P concentration, UAV, and UAL.

What is the effect of soil depth on P loading?

Soil depth varies considerably across the EAA, with soil depth generally decreasing with distance from Lake Okeechobee. According to the last comprehensive soil survey of the organic soils of Palm Beach County conducted in 1988, soils in the S-5A sub-basin have the deepest soils, while the S-7 and S-8 sub-basins have the shallowest soils. Farms with deeper soils are able to hold more water on farm, reducing the need to drain more often, which can result in lower drainage volume and lower P loadings leaving the farms. Farms with shallow soils have less capacity to hold water, which makes them more susceptible to drain more often. However, the greater interaction of drainage water with the limestone

($CaCO_3$) shell rock on shallow soils may increase the probability that soluble P may be removed from the water column through sorption/precipitation processes, offsetting increases in P loading due to increased drainage volumes. Farms with soil depths < 2 ft (0.61 m) were classified as shallow (01A, 02A, 03A, and 05A), 2.01 to 3.5 ft (0.62 to 1.07 m) as medium (06AB, 07AB, 08A, and 09A), and > 3.5 ft (1.07 m) as deep (00A and 04A). The data was analyzed using the Wilcoxon Rank Sum test to assess statistical differences of P loading and other parameters due to different soils depths.

Shallow soil UF/IFAS farms had slightly higher yet significant ($p < 0.05$) yearly unit area drainage volume (UAV) compared to medium soil depth farms. There were no statistical differences in yearly UAV between shallow soil and deep soil UF/IFAS farms.

Flow-weighted total P (FWTP) concentrations were different among UF/IFAS farms with the three different soil depths ($p < 0.001$). Farms with deeper soils had a total yearly mean FWTP concentration of 0.365 mg L^{-1} compared to 0.185 mg L^{-1} in farms with medium soil depths and 0.103 mg L^{-1} in farms with shallow soil depths. Shallow soil UF/IFAS farms had a higher drainage UAV, but a low P concentration and therefore the lowest UAL. Farms with medium and deep soils had similar UAL loads.

These findings related to soil depth are based on the ten farms UF/IFAS BMP data set which may not necessarily hold true for the larger EAA farm basin population. This analysis gives us an initial reference on the effect that soil depth has on P load and other important farm parameters in EAA farms. This question may be answered more thoroughly by analyzing selected farm data from the SFWMD BMP farm database.

What is the impact of land use and crop rotation on P loads?

Over 80 percent of farm land in the EAA is planted to sugarcane. Other crops planted include sweet corn, green beans, various leafy vegetables, and sod. Also flooded rice is planted in the summer as a rotational cover crop. Flooding fallow fields and growing cover crops, such as rice, in the summer have been shown to be very effective in reducing soil losses due to wind and water runoff and potentially slowing down organic matter oxidation of the organic soils in the EAA. Spearman correlation analysis and a mixed linear model were used to investigate the impact of land use and flooding on farm P loading. The data set was comprised of six sugarcane farms and four mixed-crop farms with variable percentages of sugarcane and other crops. The test variables were percent sugarcane, percent flood, and percent fallow+flood in the crop rotation.

On an annual and monthly basis, UAL was positively correlated with fallow+flood acreage. The correlation coefficients were low, but significant (0.20 and 0.17 between UAL and flood-fallow acreage on an annual and monthly basis, respectively). Conversely, correlation analysis indicated that as percent sugarcane acreage in the crop rotation increased, lower drainage UAV and lower UAL were observed.

Results from the mixed linear model of Box-Cox transformed monthly data, showed a highly significant effect of percent sugarcane acreage on UAL, which confirms the correlation analysis results. The percent fallow+flood acreage and the percent flood acreage were also significant implying a possible impact of these practices on UAL. The analysis in this section agrees with the multivariate regression and CART analyses as they both indicated that the percent fallow+flood acreage was an important variable in predicting farm P loads of mixed-crop farms.

The results of this section should not be interpreted that flooding increases farm UAL in the EAA, given the limited data set used in this analysis. However, it is worthwhile to explore the practice of flooding farm fields, especially in mixed-crop farms, and develop practices to minimize the impact on UAL.

What is the effect of rainfall detention amount on farm P loading?

The rainfall detention BMP has a primary objective to temporary hold water until conditions for drainage release is met (half or one-inch rainfall detention). A primary benefit of this practice is the reduction in drainage volume that has a direct effect on farm UAL. Other benefits include the reduction of soil oxidation by keeping the farm water table higher and consequently reducing the potential amount of soil P released into soil solution. However, higher field water tables may harm water-sensitive crops such as leafy vegetables, sweet corn, and green beans.

To test the hypothesis that rainfall detention affects farm P loading, UF/IFAS study farms were grouped into two groups: farms claiming half-inch rainfall detention and farms claiming one-inch rainfall detention. For the IFAS BMP data set, three farms had implemented half-inch rainfall detention (01A, 03A, and 06AB) and seven farms (00A, 02A, 04A, 05A, 07AB, 08A, and 09A) implemented one-inch rainfall detention during the 10 year monitoring period.

The Wilcoxon Rank Sum test on a monthly and yearly basis showed that all tested parameters (FWTP, drainage UAV, Pump to rainfall, and UAL) from farms implementing the half-inch rainfall detention were significantly higher than the parameters from the farms practicing the one-inch rainfall detention, except for monthly drainage UAV for which there was no difference between rainfall detention amounts.

The higher drainage water year UAV in the half-inch detention farms was expected. However, the higher FWTP in farms with half-inch detention might be related to the fact that two out of the three farms from this group were mixed-crop farms, which generally require more intensive water management and higher P fertilization compared to sugarcane monoculture farms. Consequently, the results from this section most likely do not reflect the larger EAA farm population.

In summary, the detailed statistical analysis of the long term UF/IFAS study on selected EAA farms revealed some insight on some of the environmental and management factors that may be affecting P loading. Although some conclusions can be easily generalized to the other farms in EAA, other conclusions may be specific to these UF/IFAS research farms and further studies or analyses of a larger population of farms is needed to confirm these conclusions. The following general recommendations are given to improve BPM effectiveness:

1. Water Management: The first recommendation related to canal elevation is one that we emphasize in all our BMP training workshops and extension publications. Each farm needs to determine an optimum canal elevation that permits adequate drainage without transporting sediments out of the farm. Optimum canal elevations are specific for each farm and depend on canal configurations and pump capacities. It is also important to emphasize the importance of a sound canal cleaning program that minimizes the potential for sediment transport off the farm.
2. Flooded Field Management: Flooding fallow fields in the summer is a practice we fully recommend taking into account the proper way of discharging the water from these fields. The benefits of flooding and the protection of the organic soils cannot be over-emphasized. We recommend that flooded water be routed throughout the farm

to allow the soluble P in the water to adsorb and precipitate in the soil and canal sediments. It is also recommended if possible to allow water to evaporate and percolate down through the soil and substrata to drain the rice and flooded fields.

3. The impact of irrigation water quality on EAA farm P load requires further investigation.
4. The effect of soil depth on farm P load may explain partially the differences in farm P load between the sub-basins, and may indicate that obtaining further reductions from a certain sub-basin may not be possible.

Task II: Farm BMP Consultation Program

The continued success of the BMP program in the EAA depends upon the steadfast efforts of all involved in implementation of the program. This essential and diverse group includes supervisors, farm managers, drainage pump operators, fertilizer applicators, land owners, UF/IFAS personnel, and SFWMD EAA-BMP regulatory personnel. Basin P load reductions in the next several years will depend upon the ability of the group involved to adapt to the significant changes that the EAA is currently experiencing and those monumental changes that are expected with the proposed buyout of US Sugar by the State of Florida. In the recent past several changes in the EAA have likely impacted farm P load reduction levels. They include increased P concentration of the irrigation water from Lake Okeechobee, declines in sugarcane acreage, increases in acreage planted to less water tolerant and/or higher P demanding crops, and the unknown impact of shallower soils due to soil subsidence on farm P load. With the landscape-changing uncertainties that the EAA basin is facing the proper and adaptive implementation of BMPs across the entire basin will become even more critical, if the historical P load reduction levels of nearly 50% are to be achieved.

Methods

The BMP consultation program was developed and based upon the following premises:

1. There are benefits yet to be realized by improving the basin-wide implementation of existing BMP's.
2. The interests of the EAA agricultural community are best served by a proactive program on the part of the growers themselves to participate in a collaborative effort with IFAS researchers to informally assess BMP implementation on their respective farm basins and modify their implementation practices, assuming that modifications suggested by the collaboration team are feasible, economical, and known to reduce farm P loads.
3. A cooperative effort on the part of all growers to participate in the BMP consultation program provides a high benefit-to-cost ratio for overall basin compliance.
4. The BMP consultation program should be run under confidentiality, and should have the freedom to operate for the public good without the interference of governmental agencies.

The BMP consultation program began consulting with growers in the S-5A sub-basin in 2005. At that time SFWMD personnel suggested that the program begin with farm basins of the S-5A sub-basin, since the sub-basin often had the highest P load on a per acre basis compared to the other three hydrologic sub-basins (S-6, S-7, and S-8). It was thought that the best potential for near-term impact would be realized and observed upon completion of consultations with farm basins located in the S-5A sub-basin. The program completed most of the S-5A acreage by the end of that fiscal year and began to conduct BMP consultations with farm basins in the S-6 basin in FY2006. In FY2007 consultations with farm sub-basins in the S-7 sub-basin began, but consultation program was paused due to increased efforts that were required to complete the BMP statistical analysis and the new five-year BMP research SOW. Tables 6, 7, and 8 present farm basins acreages consulted by farm basin.

A BMP consultation begins with a review of the selected farm basin's P load history for the past twelve years. Annual drainage flow, drainage P concentration, farm P load, and rainfall are plotted using data retrieved from the EAA-BMP permit database. Load and flow are calculated on a per acre basis. Drainage pumping to rainfall ratios are also calculated. Once a farm basin's P load historical log has been developed and reviewed, initial contact with the farm manager occurs and a visit is scheduled. During the initial farm basin visit the BMP program is explained in detail. UF/IFAS researchers refer to the BMP appraisal checklist to ensure that the many factors that affect BMP performance are evaluated and investigated during the farm BMP consultation visits and discussions with the growers. The BMP appraisal checklist can be found in Appendix A. The BMP appraisal checklist is comprised of six main topics: BMP implementation methods, farm physical layout, farming operations, farm drainage volume and flow, farm drainage water P concentration, and farm characteristics and management. Topics are discussed informally with farm personnel to provide researchers with a general understanding of farm operations and water management and to provide farm personnel with researcher insight into processes influencing BMP efficacy. As discussions progress selected topics may be discussed in greater detail, if the related farming practices are not clearly understood by researchers and/or they are perceived by researchers to potentially have an impact on BMP performance. During the farm consultation visit, if BMP training is needed, the grower is able to schedule on-farm training which is conducted by IFAS researchers for farm personnel. The on-farm BMP training presentations are condensed versions of the BMP trainings conducted at the Everglades Research and Education Center. We have translated all BMP presentations into Spanish to serve the many Spanish speaking personnel who work on EAA farms. Copies of BMP presentations in English and Spanish are included in Appendix B. Extension publications addressing the more commonly used BMPs in the EAA have also been translated into Spanish, and are distributed to participants during the on-farm BMP presentations.

After the BMP consultation farm visit and BMP implementation discussions, a follow-up farm visit is generally scheduled. During the second farm visit, the managers and/or other farm personnel are accompanied by IFAS staff to observe fields and canals of the farm basins. The group visits the main water control structures and drainage water sampling installations of the farm. Other points observed and discussed are the farm basin's main canal system and the management of cropped and fallow fields. During the site visit farm personnel have the opportunity to question IFAS staff about any issues or problems with BMP implementation. Also, IFAS personnel are shown any farmer-devised, alternative BMP practices or modifications of conventional BMPs. Concerns of the farm personnel about the overall BMP program or other factors that may affect the quality/quantity of drainage water leaving their farms are also discussed. IFAS personnel encourage informal dialogue concerning potential BMP research topics that may be of interest to the farmer to further improve the water quality of the farm and other water quality topics that are of importance to the EAA community.

After completing a BMP consultation, IFAS staff request farm personnel to complete a short survey which asks the farm personnel to assess the BMP consultation program and provide suggestions for improvement. Results of completed surveys are included in this report in Table 9. The objective of this survey is to obtain input of the overall BMP program in the EAA from the grower's perspective. Copies of the cover letter and the BMP survey given to farm managers are included in Appendix A. The BMP survey is comprised of three main parts: comments about BMP trainings offered at the EREC auditorium, comments on the farm BMP consultation program, and comments of the overall BMP program in the EAA and research needed to improve BMP performance at the farm level in the EAA.

Results

BMP consultation program

Generally during farm visits short discussions are first conducted about the objectives of the BMP Consultation Program with the farm managers at the main offices of the farms. At this time, copies of the BMP Consultation Survey are now handed out to the managers and personnel that had previously attended the on-farm BMP presentations. Afterward, the farm manager and assistants accompany IFAS personnel to the different properties of the farm. The topics discussed during these visits ranged from main crops grown on the farm to the different BMPs that are being implemented throughout the farm. The farms visited were either sugarcane farms or mixed crop farms with sugarcane, sod, sweet corn, green beans, and rice. Some of these farms have properties at different locations throughout the S-6 and S-7 sub-basins, however, they try to implement the same suite of BMPs at all locations. Some of the BMPs discussed during the farm visits included water detention, improved infrastructure, soil testing, fertilizer application control and sediment control BMPs. Most of the main farm canals were clean with little aquatic vegetation; however, water lettuce is a problem at some pump-houses. Spot spraying (Rodeo or 2, 4 D depending on the weed) is frequently used to control small infestations and keep the aquatic vegetation growth at minimum. A regular canal cleaning program is one of the most commonly used sediment control BMP in the EAA basin. The farm managers explained that all main farm canals are cleaned once a year. However, some years the equipment used to clean canals is not available and only canal reaches upstream of the pump-houses are cleaned. To avoid being out of compliance, some farmers implement one or two extra sediment control BMPs that can be claimed in those years when one of their regular BMPs is not implemented for any reason.

Some farmers are being creative in the implementation of some sediment control BMPs. A farm manager from one of the visited farms showed us some sod fields that have been replaced with sugarcane. During land preparation, a strip of sod is left around field ditches and canal banks to stabilize the soil and control sediment runoff into canals. All sod and sugarcane fields are laser leveled before planting, facilitating a more uniform drainage and irrigation across the fields. Many farms have improved their water management infrastructure. Some of the improvements observed during the farm visits were the installation of new culverts and widening of farm canals, which will allow for more effective water management throughout the farm. Another BMP discussed during the farm visits was collection of soil samples and soil analyses. Soil samples are collected for every field that is planted with any crop. Depending on the grower, soil samples are sent to the EREC Soil Testing Laboratory or a private laboratory for analysis. Growers are careful to maintain records of all soil analyses and fertilizer applications in their farms. They are aware that either farm personnel or outside contractors must keep proper documentation of all farm activities. Farmers generally store this information in a data base on the fertility status of most of their fields, which allows them to make adjustment on their fertilizer management throughout the crop growing season.

Flooding is a common cultural practice in the EAA. Growers flood fallow fields for a number of reasons, among which are disease and insect control, nematode control, improvement of soil tilth and reduction of soil loss from biological oxidation. Some of the farms visited had some of their field flooded, however, the acreage flooded during this year have decreased due to low water levels in Lake Okeechobee. Use of rice as a cover crop is also a common BMP practice in the EAA that in addition of the rice production provides protection to fallow fields reducing soil losses due to wind and water erosion. Rice is the only crop for which flooding is maintained during the crop production period, reducing soil losses due to microbial oxidation.

At the request of one grower, IFAS personnel installed extra auto-samplers at two of the grower's farm basins to compare drainage water P concentrations at the farms' drainage pumps during the dry season. It was thought that more frequent sampling of short duration drainage events (less than 24 hours) would provide a more accurate sample for analysis. The standard auto-sampling frequency of the grower was every two hours. The comparison sampler was programmed to take samples every half hour. For the few events that occurred during the dry season, only one event of short duration (24 hours) was able to be sampled. The half hour sampling frequency resulted in P concentration of 0.194 mg L^{-1} and the 2 hour sampling frequency drainage water had a P concentration of 0.514 mg L^{-1}. Even though only one event was captured for a short duration pumping event during the dry season, more frequent sampling intervals during the dry season may provide a more accurate sample for drainage water P determination, due to the disproportionate weight of the first flush effect upon the composited drainage water samples with small sample numbers.

On-Farm BMP training

The process of the farm BMP consultation program includes on-farm BMP training and a BMP consultation survey. These two additional components provide better feedback and interaction between IFAS personnel and farm managers and other personnel involved at the farm level. The on-farm BMP training presentations are shorter versions on the regular BMP training presentations offered at the EREC. The advantage of this on-farm BMP training are the improved focus and attention that both researchers and farm personnel are able to give to a specific farm BMP program. In addition the trainings are able to emphasize and tailor the trainings to address topics that are of most concern to that particular farm.

Key issues requested for discussion during the on-farm presentations varied from farm to farm. One farmer requested a BMP training presentation with more emphasis on sediment control BMPs and field documentation. Another farm was more interested in sediment control BMPs, pump log documentation, and rainfall detention. Other topics of interest were soil testing and fertilizer recommendations for specialty crops, canal cleaning frequency, and effective control practices for surface aquatic vegetation. They may also request advice on how to address BMP Verification and Assessment letter received from SFWMD. Something worth noting during these presentations is the interaction of the audience. It appears that smaller groups stimulate more active participation between the growers and IFAS personnel during the presentation.

The on-farm training presentations have also been expanded to trainings in Spanish to better serve the Spanish speaking force of the different farms in the EAA. In addition, all EDIS publications as well as BMP presentations have been translated into Spanish to better serve those farms with a large Spanish speaking work force.

BMP consultation program survey

The BMP consultation survey results are presented in Table 9. The table has results from the surveys that were collected from farm managers during farm visits in the S-6 and S-7 sub-basins. These results provide an indication of how farm managers evaluate the role of IFAS personnel on the BMP consultation program and the efforts toward the BMP education program in the EAA. The farm managers also indicated future research topics to improve the overall quality of drainage waters leaving EAA farms. These surveys revealed that in general, farm mangers have been satisfied with the consultation program format and the information provided during the BMP training workshops at the EREC. They also believe that IFAS personnel provide critical support to the BMP program in the EAA.

Results from surveys evaluating the BMP consultation program are positive and indicate that farm managers believe that on-farm BMP training and discussions during follow-up farm visits are important and can make a difference in their BMP program. The surveys assess which part of the BMP consultation program was more beneficial to the growers and which practices will benefit the most with this program. The BMP consultation program is also a great opportunity to discuss and learn what type of future research farmers believe is important to maintain the level of success the BMP program has enjoyed since its inception and to further decrease P loads of drainage water leaving EAA farms. Several farm managers suggested that all farm personnel involved with pump operations should be trained annually either at EREC or on-farm. The focus of the training would be the operation of drainage pumps and the relationships between pump operation, field drainage rates, fuel consumption, and water quality.

Summary of BMP consultation program recommendations

The suggestions provided to farmers in the S-5A, S-6, and S-7 sub-basins were similar and are provided below.

Canal cleaning – Sediments and any other organic material in farm canals are a major part of the total P load leaving the EAA basin, therefore, any cultural practice that can regularly decrease the total amounts of sediments accumulated in drainage canals and field ditches will have a considerably impact on total P loads leaving the farm (Diaz et al., 2005). Canal cleaning is recommended to be implemented during quiescent farm periods and if possible in combination with irrigation to relocate re-suspended sediments to the back of the farm. Economics or lack of equipment prevents some farms to regularly clean the entire hydraulic system of the farm. Thus, it is recommended to concentrate the efforts and clean regularly the canal sections directly upstream of main drainage pumps. In addition it is recommended to avoid any drainage pumping activity during or immediately after cleaning operations to prevent the release of drainage water with high sediment concentration. A regular canal cleaning program is an important sediment control BMP that in addition of reducing the amount of sediments that can be transported out of the farm; also improve the storage and hydraulic capacity of the farm canals.

Floating aquatic vegetation control – In-stream biological growth in main farm canals is one of the major contributors of particulate P in drainage waters leaving EAA farms (Daroub et al., 2002a). Thus, limiting the growth of floating aquatic vegetation in main canals, especially upstream of major drainage structures is an important sediment control practice that is always recommended to all farm managers. An aggressive aquatic weed control is the most effective approach to reduce the main source of high P content particulate material. It is recommended to use weed-retention booms and trash racks well upstream of main drainage structures to reduce the likelihood of exporting particulate matter off the farm during drainage events. Use of herbicides to control heavy infestations is not recommended, because dead plant tissue becomes an easily transported floc material source high in P content. Mechanical harvesting of heavy infestations of floating aquatic vegetation is recommended, followed by spot-spraying of labeled herbicides for target species.

Drainage flow velocity control – Velocity is the key control parameter for reducing particulate P export. The various types of sediments accumulated in drainage farm canals respond different to changes in hydraulic conditions (Daroub et al, 2002b). At low velocity, only the light, flocculent easily transportable sediment material will be re-suspended and transported. As velocity in the canal increases, turbulence levels increases and the forces responsible to dislodge sediment material from the canal bottom increase, resulting in larger amounts of sediment material transported off the farm. In general, the light sediment material transported at the beginning of a drainage event is the freshest biological deposited material with the highest P content, while the heaviest sediment transported at higher velocities is the oldest most mineralized sediment material. Thus, controlling canal velocities during drainage events is an important practice to reduce the amount of sediment material exported off the farm. However, recommended velocities are relative, in that they must be within the operating framework of the configuration and size of the farm canals.

Two recommendations that are often suggested to reduce water velocity are: first, to maintain a minimum canal level during drainage events that is farm specific. Canals should not be pumped to a level less than recommended or specific in the BMP permit. Low canal levels may lead to high drainage velocity in the canal that will result in sediment erosion and subsequent transport with drainage water off the farm. The second recommendation is to achieve a desired canal level and then maintain that level by pumping at a lower flow rate for a longer period of time, rather than pumping faster for a shorter period of time. This can be accomplished by shifting to a lower capacity pump, reducing the number of pumps running, or reducing RPMs.

Proper BMP documentation – Most of the farmers visited in the S-6 sub-basin keep a detailed documentation of their BMP practices. However, this is an important topic that we keep reminding to all growers. Proper documentation of all BMPs being implemented in the farm is a requirement by the SFWMD. District personnel conduct routine BMP verification visits to make sure that the BMPs listed in the farm's BMP permit are being properly implemented.

Recommendations were provided for proper BMP documentation on topics such as soil testing, fertilizer spill prevention, canal cleaning, and aquatic weed control. However, the topics of more interest to the farmers were proper documentation on pump log operations, rainfall detention, and some of the sediment control BMPs. It was emphasized the importance of documenting every drainage event and the reasons for pumping. Examples were provided explaining the type of documentation required to justify drainage pumping that occurred before the rainfall detention for the farm has been achieved.

Rainfall detention is a topic that some farmers need more information for better implementation and proper documentation in the farm. Additional explanation on the topic was provided to several farmers that requested more information and guidance on proper documentation. However, this is a topic that needs more information that could be distributed to farmers to better explain this BMP practice and be used as a guide to growers for better implementation and proper documentation in the farm.

Sometimes there is a concern from the SFWMD that some of the sediment control-BMPs are not being properly implemented every year. Some farmers were proactive and were already implementing alternate sediment control practices that can be used in years that one of their regular BMPs is not implemented. This practice was explained and recommended to other farmers.

Growers' concerns

Quality of irrigation water from Lake Okeechobee – This is a concern that is being raised by the majority of the farmers, especially now with the drought and the low water levels in Lake Okeechobee. Data from the last five years (WY2002-WY2006) shows that the average total P load to the lake is 714 metric tons per year. This P load is over five times higher than the established TMDL of 140 metric tons, considered to be necessary to achieve the in-lake target P concentration of 40 ppb (Zhang et al., 2007). Total P loading to Lake Okeechobee for WY2006 was considerable high (795 metric ton), with an average total P concentration of 214 ppb. Growers are concerned that the deterioration in the quality of irrigation water coming from Lake Okeechobee during the last few years will have a negative impact on their BMP efforts to reduce farm P loads leaving their farms.

Cleaning and maintenance of secondary District and community canals – Some farmers have concerns that the quality of irrigation water is being compromised by the amount of sediment and lack of maintenance of some secondary canals. Some farmers from the S-6 sub-basin that have properties bordering the Bolles Canal in the S-7 sub-basin are very concerned about the lack of maintenance of this canal and the negative impact that irrigation water from this canal may be having on total P loads being imported into the farms. Large sections of this canal are completely infested with aquatic vegetation and full of organic sediments, which also reduces the capacity of this canal to transport water more efficiently.

Conclusions

Overall the third year of the farm BMP consultation program was positively accepted by the growers of the S-6 and S-7 sub-basins. All growers have been very cooperative and have taken time to fully participate and engage with IFAS personnel in discussions concerning their BMP programs and other water quality related issues in the area. In general, the following can be concluded:

a) All growers visited acknowledged the importance of the BMP Program in the EAA and are committed to continue implementing and modifying practices to ensure the success of the program is maintained across the entire basin.

b) Growers appeared open and comfortable discussing their farm BMP program with IFAS personnel. This level of trust is critical for conducting successful interactions that the BMP consultation program requires. These interactions allow for an open channel of communication with a two-way flow of suggestions and critical review of current BMPs and possible modifications. These interactions are a valuable resource that at times produces recommendations for future BMP research topics and designs and alternative implementation techniques.

c) The on-farm BMP training workshops have been very well received by the growers. The level of interaction between participants and IFAS personnel during trainings has been optimum. Since the training takes place at the grower's site, a greater number of farm personnel are able to participate in the training than if the training takes place at an off-farm location.

d) The translation to Spanish of all BMP training materials and subsequent trainings in Spanish have been well-received by the farming community of the EAA, especially those farms with a large percentage of workers whose first language is Spanish.

e) Growers are aware of the vital role that research has played in the BMP program in this area. Some farmers have suggested topics they would like to be researched in the near future. Many understand that additional research may be needed on BMP and other water quality issues to maintain the success of this program and are willing to contribute and collaborate any way they can with IFAS personnel on future projects.

In summary, it can be concluded that the year has been a success in terms of farmer's participation and willingness to listen and make changes to their BMP practices to further improve the water quality of drainage waters leaving their farms. The positive attitude observed during the on-farm BMP training workshops and the overall cooperation from farm managers during follow-up farm visits is a positive sign of the level of commitment that EAA farmers have toward the BMP program. Growers appear committed to continue doing their best to improve their individual BMP programs and to ensure that the basin continues to be successful in reducing the P loads leaving EAA farms.

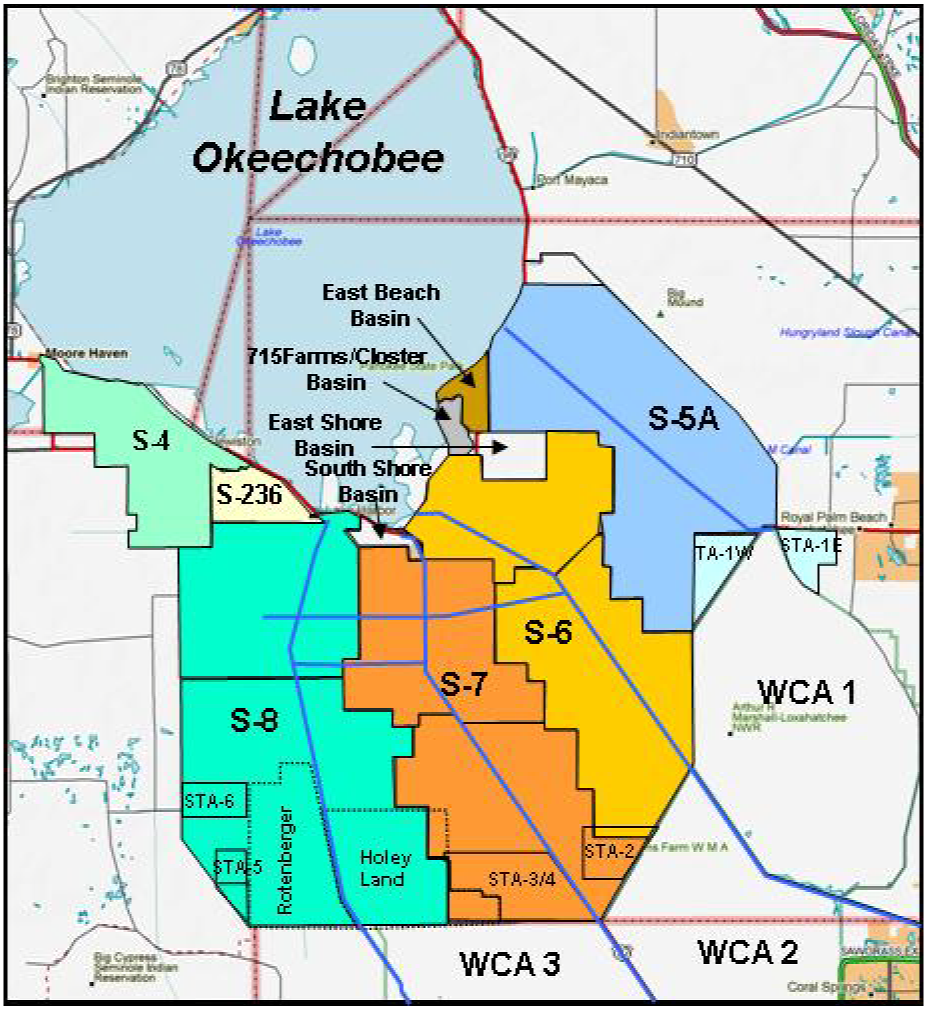

Figure 3. The EAA basin with boundaries of the hydrologic sub-basins.

Table 6. Farm basins and acreages located in the S-7 sub-basin.

Basin ID	2006 Acres	Basin ID	2006 Acres
50-003-01	242	50-034-04	4138
50-003-02	520	50-041-02	300
50-003-04	320	50-042-01	320
50-005-01	320	50-046-01	35
50-005-02	233	50-048-02	640
50-005-03	320	50-058-01	157
50-005-04	310	50-061-03	3434
50-005-06	502	50-061-05	314
50-009-02	4272	50-061-06	237
50-009-05	1479	50-061-07	318
50-014-01	1520	50-061-11	13235
50-017-01	895	50-061-12	730
50-018-14	570	50-061-13	1060
50-018-15	757	50-062-01	4626
50-018-16	240	50-062-02	10754
50-018-17	488	50-062-03	1188
50-018-18	358	50-062-04	901
50-018-19	314	50-062-05	5250
50-018-20	381	50-062-09	7659
50-018-25	3808	50-062-11	1277
50-019-01	568	50-063-01	9792
50-019-02	1210	50-069-01	317
50-019-03	1051	50-077-01	3168
50-022-01	320	50-078-01	72
50-024-01	574	50-080-01	8109
50-029-01	531	50-081-01	210
50-032-01	306	50-082-01	484
50-034-03	4612		
	Completed Acres	**64,455**	**61%**
	Remaining Acres	**41,291**	**39%**
	Total Acres	**105,746**	

Table 7. Farm basins and acreages located in the S-6 sub-basin.

Basin ID	2006 Acres	Basin ID	2006 Acres
50-006-02	359	50-039-02	143
50-006-03	640	50-041-01	109
50-007-01	6,473	50-045-01	282
50-009-04	317	50-045-02	161
50-010-01	784	50-047-01	630
50-010-02	5,327	50-047-02	640
50-010-04	7,159	50-047-03	1,832
50-011-01	1,748	50-047-04	198
50-011-03	14,338	50-047-05	314
50-011-04	4,066	50-047-08	1,558
50-012-01	1,022	50-048-01	1,185
50-018-10	8,254	50-051-01	811
50-018-11	1,871	50-053-01	149
50-020-01	320	50-055-01	393
50-021-01	2,558	50-055-02	810
50-023-01	278	50-055-03	2,871
50-027-01	2,772	50-056-01	850
50-027-02	799	50-060-01	8,137
50-027-03	1,353	50-060-02	7,614
50-027-04	2,520	50-061-01	639
50-028-01	220	50-061-18	1,555
50-030-01	446	50-061-20	156
50-031-01	1,609	50-062-10	8,772
50-031-02	1,387	50-065-02	938
50-031-03	602	50-065-07	513
50-034-01	7,897	50-065-10	792
50-034-02	601	50-070-01	245
50-035-01	478	50-070-02	244
50-039-01	63		
	Completed Acres	**70,620**	**59%**
	Remaining Acres	**48,184**	**41%**
	Total Acres	**118,803**	

Table 8. Farm basins and acreages located in the S-5A sub-basin.

Basin ID	2005 Acres	Basin ID	2005 Acres
50-002-01	5656	50-047-07	3494
50-002-02	9285	50-049-01	1909
50-004-01	909	50-054-01	7600
50-006-01	397	50-054-02	960
50-007-02	5717	50-054-03	1227
50-013-01	1363	50-054-04	3684
50-015-01	3276	50-059-01	9614
50-015-02	2554	50-059-02	1768
50-016-01	1497	50-059-03	710
50-018-01	5902	50-059-04	306
50-018-02	6594	50-061-08	375
50-018-03	9062	50-061-15	6760
50-018-12	1655	50-061-17	1598
50-018-13	594	50-064-01	899
50-025-01	824	50-064-03	145
50-033-02	1159	50-064-04	1150
50-035-02	1634	50-065-03	3752
50-035-03	205	50-065-05	930
50-037-01	1663	50-065-06	454
50-038-01	1285	50-065-08	628
50-040-01	216	50-068-01	2616
50-040-02	499	50-068-02	1998
50-044-01	2169	50-073-01*	68
	Completed Acres	**100,254**	**86%**
	Remaining Acres	**16,506**	**14%**
	Total Acres	**116,760**	

Table 9. BMP consultation survey results from participating EAA farm managers.

How often do you attend BMP training at EREC?	**Twice or more per Year** 4 (40%)	**Once a Year** 6 (60%)	**Once every Two Years** -	**Never** -	-	**Abstain** -
How beneficial is information from BMP training offered at the EREC?	**Always Beneficial** 5 (50%)	**Beneficial** 4 (40%)	**Neutral** 1 (10%)	**Sometime Beneficial** -	**Never Beneficial** -	**Abstain** -
What is the level of support of EREC personnel on BMP program in the EAA?	**Very Supportive** 9 (90%)	**Supportive** 1 (10%)	**Undecided** -	**Somewhat Supportive** -	**Not Very Supportive** -	**Abstain** -
What part of BMP consultation was most useful?	**On-farm Presentation** -	**BMP Discussion** 2 (20%)	**Farm Field Visit** 1 (10%)	**All Parts of program** 4 (40%)	**Other** -	**Abstain** 3 (30%)
Practices you are likely to change as a result of the BMP consultation program?	**Water Management** 4 (40%)	**Fertilizer Application BMPs** 1 (10%)	**Sediment Control** 3 (30%)	**Other** -		**Abstain** 2 (20%)
How do you rate the quality and usefulness of BMP consultation program?	**Excellent** 3 (30%)	**Very Good** 4 (40%)	**Good** -	**Average** -	**Poor** -	**Abstain** 3 (30%)
Research needed to improve BMP performance at the farm level	**Irrigation Water Quality** 2 (20%)	**Pump Operation** 1 (10%)	**-**	**-**	**-**	**Abstain** 7 (70%)
Overall BMP training ratings	**Excellent** 4 (40%)	**Very Good** 3 (30%)	**Good** -	**Average** -	**Poor** -	**Abstain** 3 (30%)
Question	**Strongly Agree**	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**	**Abstain**
The farm visit helped in the implementation of BMPs.	4 (40%)	3 (30%)	1 (10%)	-	-	2 (20%)
Help to better understand the effect of sediments.	4 (40%)	4 (40%)	-	-	-	2 (20%)
Information provided was easy to understand.	6 (60%)	2 (20%)	-	-	-	2 (20%)
Information provided was accurate and up-to-date.	4 (40%)	4 (40%)	-	-	-	2 (20%)
Information provided was useful.	2 (20%)	6 (60%)	-	-	-	2 (20%)
All questions were adequately answered.	4 (40%)	4 (40%)	-	-	-	2 (20%)
Increased the awareness of field documentation.	4 (40%)	3 (30%)	1 (10%)	-	-	2 (20%)
Program should be done more often.	3 (30%)	3 (30%)	2 (20%)	-	-	2 (20%)

Task III: BMP Training Workshops

Best Management Practices workshops have been designed by UF/IFAS faculty to cover all major topics of the BMP program to insure uniform and successful implementation by EAA growers. The topics covered includes a review of Rule 40E-63, BMPs for Atrazine and Ametryn, BMP table overview, soil testing and plant tissue analysis, fertilizer application BMPs, rainfall detention, sediment control, and update on current research. A copy of all the BMP presentations including revised presentations in Spanish is included in Appendix B.

Six BMP training workshops were conducted from the period of July 1, 2007 – June 30th, 2008 (Table 10). All BMP workshops were conducted in the Conference Center of EREC, and all workshops lasted for 4 hours. In addition to the BMP program, latest research findings on different environmental aspects were also shared with the participants. The presentations were given by S.H. Daroub, T.A. Lang, and O.A. Diaz. Important information covering the proper use of the pesticide Ametryn and Atrazine were presented by Dr. Curtis Rainbolt, weed scientist at the EREC. Other faculty members with different expertise on the different BMP topics of interest to the growers that had participated on these workshops include Dr. Mabry McCray, Agronomist, Dr. Alan Wright, Soil Scientist, and Barry Glaz, Research Agronomist, from USDA Sugarcane Field Station, Canal Point. Continuing education units (pesticide and certified crop advisor) were offered to all participants. Material covered as well as list of attendees from each workshop has already been sent to the SFWMD.

Table 10. List of BMP training workshops in 2007 conducted by UF/IFAS at EREC.

No.	Date	Company	No of attendees	Notes
1	9/25/2007	US Sugar	11	EREC Workshop
2	9/26/2007	Okeelanta & Roma	11	EREC Workshop (Morning session)
3	9/26/2007	Okeelanta & Roma	12	EREC Workshop (Afternoon session)
4	10/9/2007	General BMP Training	65	EREC Workshop. Attended by Sugar Cane growers COOP members, DOCAS, USDA-NRCS, PBSWCD, USSC, USDA-ARS, Florida Crystals, and SFWMD personals.
5	12/12/2007	Sugar Farms COOP	18	EREC Workshop
6	12/12/2007	Sugar Farms COOP	13	EREC Workshop (Spanish)

Summary results of BMP training evaluations

A total number of 132 participants were present in the 2007 BMP training workshops. A live picture of the one of the BMP training workshop is presented in Figure 4. During the previous year (July 1, 2006 – June 30th, 2007), six BMP trainings were held and a total of 94 participants were present (Figure 5). There is a 30% increase in the attendance over the previous year, thus showed that growers had shown a keen interest in the BMP training workshops conducted by the EREC staff. This also resulted in a more number of returned evaluations from the growers.

Figure 4. Pictures from two BMP training workshops offered to EAA growers.

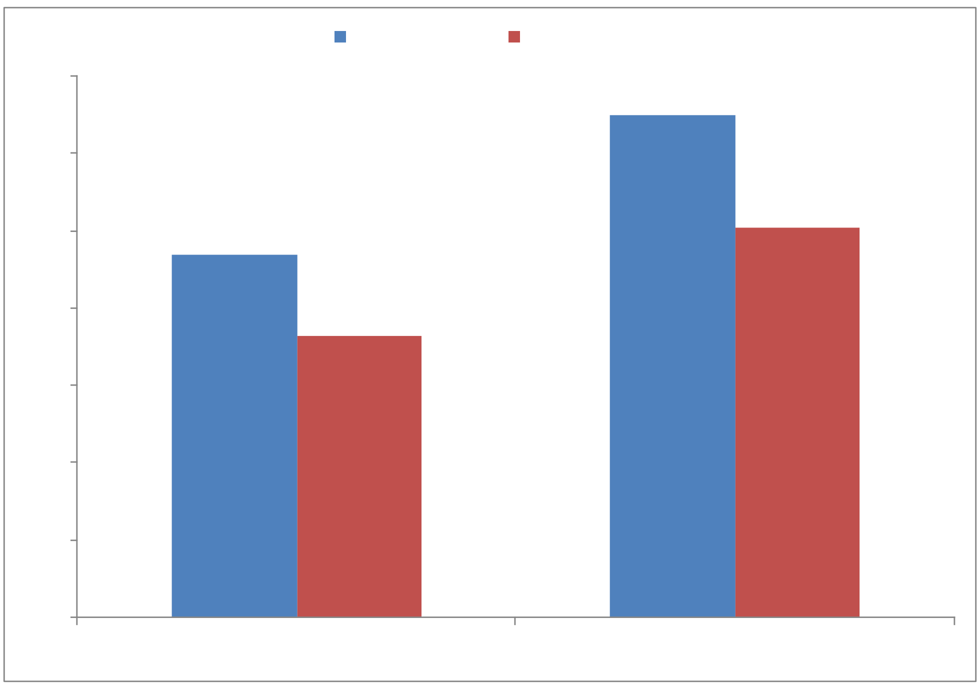

Figure 5. Comparison of total number of participants and returned evaluations between the year of 2006 and 2007.

There were two kinds of BMP workshop surveys used during this period to evaluate the effectiveness of BMP workshops. The surveys were modified in the middle of year in order to get more feedback from the participants. Another effort was to simplify the surveys so that more information can be collected from the participants. It was observed in the past that attendees were hesitant to express their opinion or concerns in writing. The detailed results of six BMP training Workshops are presented in Tables 11 through 16. The survey results are divided into three sections and will be referred as section 1, 2 and 3 in the following discussion.

Section 1: This section contained usefulness of BMP information, speakers' effectiveness and training material ratings. The results from this section were averaged from all the surveys and are presented in Figure 6.

Section 2: This section consist information about the most beneficial topic of training/s, reason for attending, and suggestions for improvement and new topics of interest to the growers.

Section 3: This section explains the importance of BMP program and growers willingness to continue the BMP trainings in near future.

Section 1: Results from the section 1 (Figure 6) show that 78 of the participants considered that the BMP training workshop met their objectives very effectively with excellent and very good ratings indicating the provided BMP information was very useful. The rest of the participants (22%) rated the provided information as useful. About 81% of the participants considered that the speakers were very effective in explaining the different BMP topics, and the material presented was appropriate for the trainings. Similar ratings about usefulness of the provided BMP information and quality of the training materials were recorded in the previous year. During this year, the general BMP training held on 10/09/2007 had almost 50% of the total attendees with the survey having wide range of responses about the BMP workshops.

Section 2: Results from the second section were more diverse by the virtue of two kinds of surveys and also a wide spread in the participants that were being evaluated. Hence the results are explained one by one case.

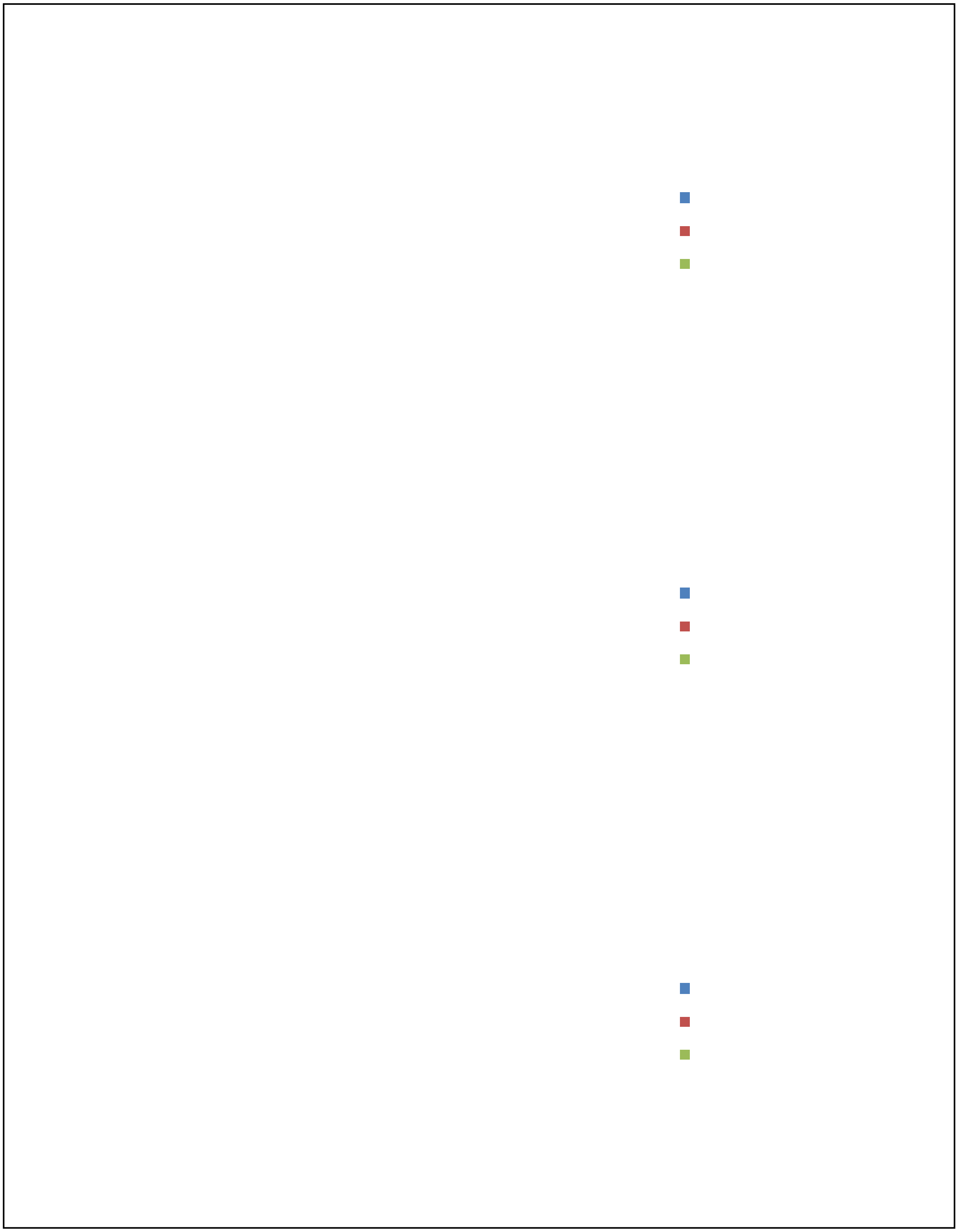

Figure 6. Mean percentages of responses (n=101) from section 1 of the BMP training surveys

BMP Training workshop for US Sugar: This training was held on 9/25/2007 at the EREC convention center and results are presented in Table 11. The P BMPs were amongst the top priority to the most of the US sugar participants (46%). Additionally, 36% of the participants attended to get educated about the BMP issues related to EAA. About 90% participants would recommend this training to others and the other 9% did not provide any opinion about it. The sediment control and particular P research was the most beneficial topic of study amongst the US sugar attendees (37%).

BMP Training workshop for Okeelanta and Roma (Both morning and afternoon session): There were total of 23 attendees, 11 in the morning session and 12 in the afternoon session (Tables 12, 13). Most of the participants expressed that they came to learn about P BMPs (50% for the morning and 27% for the afternoon session), and were also interested in learning about the compliance rules. Most of the participants (60-73%) had no suggestions; however 30% attendees in the morning session expressed to add new topics in the BMP training program. The most beneficial topic of the training was the sediment control and particular P research (30% for the morning session and 18% of the afternoon session), and 27-40% participants expressed that all of the topics were important to them.

General BMP training workshop: The training workshop was attended by a diverse group of sugar cane growers and the participants from DOACS, USDA-NRCS, PBSWCD, USSC, USDA-ARS, Florida Crystals and SFWMD. The survey results are presented in Table 14. The training workshop was held on 10/09/2007 at the convention center of EREC. There were 65 attendees and 51 participants (78%) returned their evaluations. Interestingly about 50% attendees did not comment on the suggestions section, whereas 33% participants had no suggestions for the BMP training. This showed that BMP training offered by the EREC staff was up to date and the information provided was sufficient to educate about the BMP issues in the EAA region. The information about the most beneficial topic, as expressed by attendees, is presented in Figure 7 to accommodate and reflect the wide spread of BMP topics that were considered most important. The information is presented as the % of individuals responses obtained in the surveys. About 22% of the attendees expressed that all the topics presented in this training were beneficial. The sediment control and particulate P issues were important and 20% attendees suggested addressing this issue as the top priority in the EAA region. Twelve percent of the participants showed that floating aquatic weed management was the most beneficial topic to them (Figure 7).

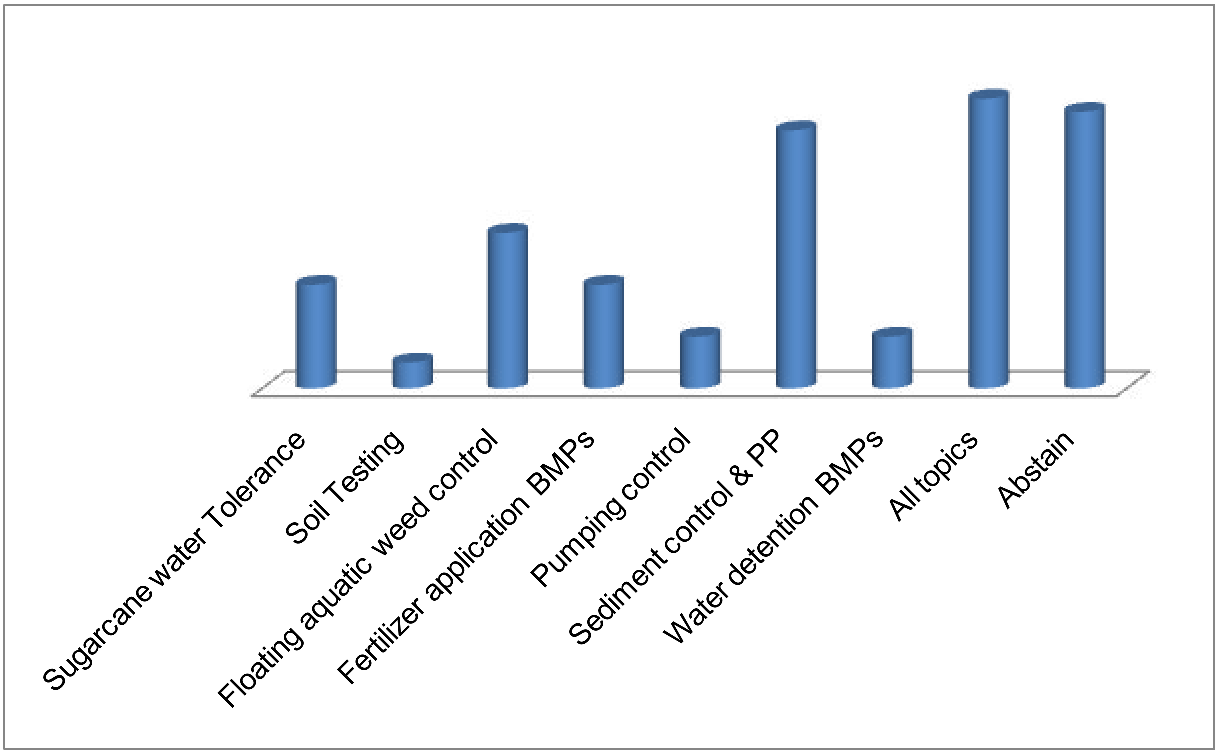

Figure 7. The percentage of responses about the most beneficial topic of the BMP training workshop held at the EREC on 10/09/2007. (Total number of participants = 65, total number of evaluations = 51.)

BMP Training workshop for Sugar Farms COOP: The training workshop was held on 12/12/2007 and attended by 18 growers. A total of 16 attendees responded to the evaluation surveys and the results are presented in Table 15. Twenty five percent of the attendees considered that all the topics were beneficial. Whereas 6% attendees considered the fertilizer application BPMs and water detention BMPs were the most beneficial topic of training to them.

Spanish BMP Training workshop for Sugar Farms COOP: The survey results for the workshop are presented in Table 16. It was held at the convention center of EREC and the main objective of this workshop to educate the Spanish speaking growers of the EAA region. There were 13 attendees and all of them participated in the survey. This training was provided mainly by Dr. Orlando Diaz, presently working as a senior scientist at the SFWMD. Twenty three percent of the attendees considered that all of the topics presented in the workshop were important to them. Sediment control and particulate P (15%), and water detention BMPs (8%) were amongst the other most beneficial topics of training to the participants.

Section 3. This section pertains to the information obtained from the three surveys (10/09/2007, 12/12/2007, and 12/13/2007) and is based on the improved evaluations reports. The combined average results are presented in Figure 8. The results showed that the majority of attendees either strongly agree or agree with the different parameters that were evaluated in the surveys. These results again demonstrate that the growers of the EAA region had shown a wide range of inertests and the BMP training program has been a learning ladder to these growers. Thus the continuation of this program in future will certainly help the EAA growers to better understand the different BMP requirements to further reduce P loads from the EAA.

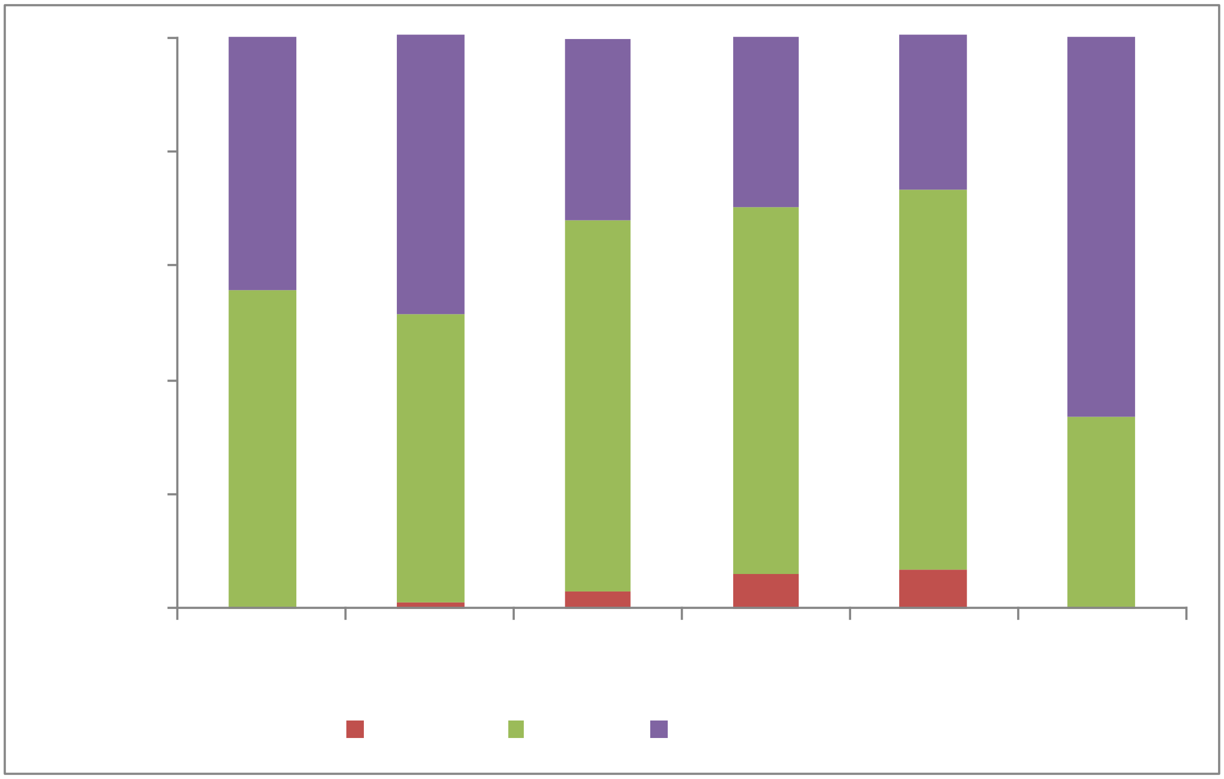

Figure 8. Average percentage responses of the section 3 of survey results. The values 1-6 on the horizontal axis are described below:

1. The information provided helped me to be aware of the importance of field BMP documentation
2. The information helped me to better understand the effect of sediments on water quality
3. The information provided during the BMP training was easy to understand
4. The information provided during the BMP training was accurate and up-to-date
5. All of my questions were adequately answered during the BMP training
6. Overall, the training is an important educational tool of the BMP program in the EAA and I would recommend it to others

Table 11. Survey results from a BMP training workshop for US Sugar (9/25/2007)

		Excellent	**Good**	**Average**	**Poor**	**Abstain**
The BMP workshop met your objectives.		2 (18%)	9 (82%)			
The speakers were effective during the training.		3 (27%)	8 (73%)			
Rating of the training material.		3 (27%)	8 (73%)			
Reason for attending training.		**Learn more P BMPs** 5 (46%)	**Learn rules to be in compliance** -	**Learn more Pumping BMPs** 1 (9%)	**Education** 4 (36%)	**Abstain** 1 (9%)
Suggestion for improvement.		**None** 7 (64%)	**Add New Topics** 1 (9%)	**Shorten Training**		**Abstain** 3 (27%)
Would you recommend this training to others?		**Yes** 10 (91%)	**No**			**Abstain** 1 (9%)
Most beneficial topic of training.	**Pesticide Application BPMs** 1(9%)	**Fertilizer Application BMPs** 2 (18%)	**Sediment Control and PP** 4 (37%)	**Water Detention BMPs** -	**All Topics** 1 (9%)	**Abstain** 3 (27%)
Least beneficial part of training.		**All** 1 (9%)	**Fertilizer Application BMPs**	**Soil Testing and Plant Tissue** 1(9%)	**None** 3 (27%)	**Abstain** 6 (55%)
New topics that you would like in the future.		**Explain More Point system**	**Information on Sulfur**	**Water Table Research**	**None** 8 (73%)	**Abstain** 3 (27%)

Notes: Total attendance = 11, Participants in the evaluation = 11

Table 12. Survey results from a BMP training workshop for Okeelanta & Roma (9/26/2007) (Morning Session)

	Excellent	**Good**	**Average**	**Poor**	**Abstain**
The BMP workshop met your objectives.	6 (60%)	4 (40%)			
The speakers were effective during the training.	9 (90%)	1 (10%)			
Rating of the training material.	8 (80%)	2 (20%)			
Reason for attending training.	**Learn more P BMPs** 5 (50%)	**Learn rules to be in compliance** 2 (20%)	**Learn more Pumping BMPs**		**Abstain** 3 (30%)
Suggestion for improvement.	**None** 6 (60%)	**Add New Topics** 3 (30%)	**Shorten Training**		**Abstain** 1 (10%)
Would you recommend this training to others?	**Yes** 9 (90%)	**No**			**Abstain** 1 (10%)
Most beneficial topic of training.	**Fertilizer Application BMPs**	**Sediment Control and PP** 3 (30%)	**Water Detention BMPs** 2 (20%)	**All Topics** 4 (40%)	**Abstain** 1 (10%)
Least beneficial part of training.	**All** 1 (10%)	**Fertilizer Application BMPs** 2 (20%)	**Soil Testing and Plant Tissue**	**None** 2 (20%)	**Abstain** 5 (50%)
New topics that you would like in the future.	**Explain More Point system**	**Information on Sulfur**	**Water Table Research**	**None** 5 (50%)	**Abstain** 5 (50%)

Notes: Total attendance = 11, Participants in the evaluation = 10

Table 13. Survey results from a BMP training workshop for Okeelanta & Roma (9/26/2007) (Afternoon Session)

	Excellent	**Good**	**Average**	**Poor**	**Abstain**
The BMP workshop met your objectives.	10 (91%)	1 (9%)			
The speakers were effective during the training.	10 (91%)	1 (9%)			
Rating of the training material.	10 (91%)	1 (9%)			
Reason for attending training.	**Learn more P BMPs** 3 (27%)	**Learn rules to be in compliance** 2 (18%)	**Learn more Pumping BMPs**	**Pesticide BMPs** 1 (9%)	**Abstain** 5 (46%)
Suggestion for improvement.	**None** 8 (73%)	**Add New Topics**	**Shorten Training**		**Abstain** 3 (27%)
Would you recommend this training to others?	**Yes** 10 (91%)	**No**			**Abstain** 1 (9%)
Most beneficial topic of training	**Fertilizer Application BMPs** 2 (18%)	**Sediment Control and PP** 2 (18%)	**Water Detention BMPs**	**All Topics** 3 (27%)	**Abstain** 4 (37%)
Least beneficial part of training.	**All** -	**Fertilizer Application BMPs**	**Soil Testing and Plant Tissue** 1 (9%)	**None** 3 (27%)	**Abstain** 7 (64%)
New topics that you would like in the future.	**Explain More Point system**	**Information on Sulfur**	**Water Table Research**	**None** 6 (55%)	**Abstain** 5 (45%)

Notes: Total attendance = 12, Participants in the evaluation = 11

Table 14. Survey results from a general BMP training workshop for sugar cane growers COOP members, and participants from: DOACS, USDA-NRCS, PBSWCD, USSC, USDA-ARS, Florida Crystals and SFWMD (10/09/2007)

				Excellent	**Very Good**	**Good**	**Average**	**Fair**	**Abstain**
Usefulness of the BMP information.				17 (33%)	26 (51%)	8 (16%)	-	-	-
The speakers were effective during the training.				11 (22%)	28 (55%)	12 (24%)	-	-	-
Rating of the training material.				16 (31%)	26 (51%)	9 (18%)	-	-	-
Suggestion for improvement.				**None** 17 (33%)	**More Training** 2(4%)	**Add New Topics** 4 (8%)	**Lunch & Quiz** 3 (6%)	**-**	**Abstain** 25 (49%)
Most beneficial topic of training	**Sugarcane Water Tolerance** 4 (8%)	**Soil Testing** 1 (2%)	**Floating Aquatic Weed Control** 6(12%)	**Fertilizer Application BMPs** 4 (8%)	**Pumping Control** 2 (4%)	**Sediment Control and PP** 10 (20%)	**Water Detention BMPs** 2 (4%)	**All Topics** 11 (21%)	**Abstain** 11 (21%)
New topics that you would like in the future.	**Record Keeping** 1 (2%)	**Mechanical weed control** 1 (2%)	**Fertilizer recomme-ndations** 1 (2%)	**BMP standards** 1 (2%)	**Economics weed control** 2 (4%)	**Economics BMPs** 1 (2%)	**Water table research** 1 (2%)	**None** 18 (35%)	**Abstain** 25 (49%)
				Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**	**-**
The information provided helped me to be aware of the importance of field BMP documentation							**24 (47%)**	**27 (53%)**	
The information helped me to better understand the effect of sediments on water quality						**1 (2%)**	**28 (55%)**	**22 (43%)**	
The information provided during the BMP training was easy to understand						**2 (4%)**	**28 (55%)**	**21 (41%)**	
The information provided during the BMP training was accurate and up-to-date						**9 (18%)**	**27 (53%)**	**55 (29%)**	
All of my questions were adequately answered during the BMP training						**7 (14%)**	**31 (61%)**	**12 (24%)**	
Overall, the training is an important educational tool of the BMP program in the EAA and I would recommend it to others							**19 (37%)**	**32 (63%)**	

Notes: Total attendance = 65, Participants in the evaluation = 51

Table 15. Survey results from a general BMP training workshop for Sugar Farms COOP (12/12/2007).

	Excellent	**Very Good**	**Good**	**Average**	**Fair**	**Abstain**
Usefulness of the BMP information.	10 (63%)	4 (25%)	2 (12%)	-	-	-
The speakers were effective during the training.	8 (50%)	7 (44%)	1 (6%)	-	-	-
Rating of the training material.	7 (44%)	7 (44%)	2 (12%)	-	-	-
Suggestion for improvement.	**None** 3 (19%)	**Add New Topics** -	**Shorten Training** -	-	**-**	**Abstain** 13 (81%)
Most beneficial topic of training.	**Fertilizer Application BMPs** 1 (6%)	**Sediment Control and PP** -	**Water Detention BMPs** 1 (6%)	**All Topics** 4 (25%)	-	**Abstain** 10 (63%)
New topics that you would like in the future.	**Explain More Point system** -	**Information on Sulfur** -	**Water Table Research** -	-	**None** 3 (19%)	**Abstain** 13 (81%)
	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**	**-**
The information provided helped me to be aware of the importance of field BMP documentation				13 (81%)	3 (19%)	
The information helped me to better understand the effect of sediments on water quality				13 (81%)	3 (19%)	
The information provided during the BMP training was easy to understand			1 (6%)	10 (63%)	5 (31%)	
The information provided during the BMP training was accurate and up-to-date				10 (63%)	6 (37%)	
All of my questions were adequately answered during the BMP training			1 (6%)	11 (69%)	4 (25%)	
Overall, the training is an important educational tool of the BMP program in the EAA and I would recommend it to others				9 (56%)	7 (44%)	

Notes: Total attendance = 18, Participants in the evaluation = 16

Table 16. Survey results from a general BMP training workshop for Sugar Farms COOP in Spanish (12/13/2007)

	Excellent	**Very Good**	**Good**	**Average**	**Fair**	**Abstain**
Usefulness of the BMP information.	12 (92%)	-	1 (8%)	-	-	-
The speakers were effective during the training.	6 (46%)	7 (54%)	-	-	-	-
Rating of the training material.	7 (54%)	4 (31%)	2 (15%)	-	-	-
Suggestion for improvement.	**None** 7 (54%)	**Add New Topics** 1 (8%)	**Shorten Training** -	-	-	**Abstain** 5 (38%)
Most beneficial topic of training.	**Fertilizer Application BMPs** -	**Sediment Control and PP** 2 (15%)	**Water Detention BMPs** 1 (8%)	**All Topics** 3 (23%)	-	**Abstain** 7 (54%)
New topics that you would like in the future.	**Explain More Point system** -	**Information on Sulfur** -	**Water Table Research** -	-	**None** 6 (46%)	**Abstain** 7 (54%)
	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**	-
The information provided helped me to be aware of the importance of field BMP documentation				5 (38%)	8 (62%)	
The information helped me to better understand the effect of sediments on water quality				2 (15%)	11 (85%)	
The information provided during the BMP training was easy to understand				10 (77%)	3 (23%)	
The information provided during the BMP training was accurate and up-to-date				10 (77%)	3 (23%)	
All of my questions were adequately answered during the BMP training				9 (69%)	4 (31%)	
Overall, the training is an important educational tool of the BMP program in the EAA and I would recommend it to others				1 (8%)	12 (92%)	

Notes:
Total attendance = 13, Participants in the evaluation = 13

Task IV. Development of BMP Extension Materials

A list of all extension publications on BMPs of the EAA are listed. These publications cover the most commonly used BMPs in the EAA. Copies of these publications are published online at the UF/IFAS EDIS extension web site http://edis.ifas.ufl.edu/. Four extension publications were translated to Spanish and published online at the UF/EDIS extension web site in 2007. The objective of these translations is to better inform the Spanish speaking participants, which is an important part of the working force in the different farms in the EAA. Copies of these extension materials are made available in BMP trainings and also during the Farm Consultation Visits.

English Publications

1. Lang, T.A., S.H. Daroub, O.A. Diaz, and M. Chen. 2006. Best Management Practices in the Everglades Agricultural Area: Fertilizer Application Control. EDIS SL232/SS451 **http://edis.ifas.ufl.edu/SS451**
2. Diaz, O.A., S.H. Daroub, R.W. Rice, T.A. Lang, and M. Chen. 2005. Best Management Practices in the Everglades Agricultural Area: Fertilizer Spill Prevention. EDIS SL231/SS450 **http://edis.ifas.ufl.edu/SS450**
3. Daroub S.H., O.A. Diaz, T.A. Lang, and M. Chen. 2005. Best Management Practices in the Everglades Agricultural Area: Soil Testing. EDIS SL225/SS 445 **http://edis.ifas.ufl.edu/SS445**.
4. Diaz, O.A., T.A. Lang, S.H. Daroub, and M. Chen. 2005. Best Management Practices for the Everglades Agricultural Area: Controlling Particulate Phosphorus and Canal Sediments. EDIS SL232/SS 448 **http://edis.ifas.ufl.edu/SS448**
5. Daroub S.H., J.D. Stuck, T.A. Lang, and O.A. Diaz. 2002. Particulate phosphorus in the Everglades Agricultural Area: II- Transport Mechanisms. EDIS Sl198/SS417 **http://edis.ifas.ufl.edu/SS417**
6. Daroub S.H., J.D. Stuck, T.A. Lang, and O.A. Diaz. 2002. Particulate phosphorus in the Everglades Agricultural Area: I- Introduction and Sources. EDIS SL197/SS410 **http://edis.ifas.ufl.edu/SS410**
7. R. W. Rice, R. A. Gilbert and S. H. Daroub. 2002. Application of the Soil Taxonomy Key to the Organic Soils of the Everglades Agricultural Area. EDIS SS-AGR-246. **http://edis.ifas.ufl.edu/AG151**
8. T. A. Lang, S. H. Daroub and R. S. Lentini. 2002. Water Management for Florida Sugarcane Production. EDIS SS-AGR-231. **http://edis.ifas.ufl.edu/SC031**

A. Spanish Publications

1. Daroub, S.H., O.A. Diaz, T.A. Lang, V.M. Nadal, and M. Chen. 2007. Mejores Prácticas de Manejo en el Area Agrícola de los Everglades: Pruebas de Suelos. EDIS SL225/SS472 **http://edis.ifas.ufl.edu/SS472**. Fecha de primera publicación Mayo 2007.
2. Lang, T.A., S.H. Daroub, O.A. Diaz, V.M. Nadal, and M. Chen. 2007. Mejores Prácticas de Manejo en el Area Agrícola de los Everglades: Control de la Aplicación de Fertilizantes. EDIS SL232/SS470 **http://edis.ifas.ufl.edu/SS470.** Fecha de primera publicación Mayo 2007.
3. Diaz, O.A., S.H. Daroub, R.W. Rice, T.A. Lang, V.M. Nadal, and M. Chen. 2007. Mejores Prácticas de Manejo en el Area Agrícola de los Everglades: Prevención de el Derramamiento de Fertilizantes. EDIS SL231/SS471 h**ttp://edis.ifas.ufl.edu/SS471**. Fecha de primera publicación Mayo 2007.
4. Diaz, O.A., T.A. Lang, S.H. Daroub, and V.M. Nadal. 2007. Mejores Prácticas de Manejo en el Area Agrícola de los Everglades: Controlando el Fósforo en Partícula y Sedimento en Canales UF/IFAS Extension Publicación (EDIS): SL228/SS476. **http://edis.ifas.ufl.edu/SS476** Fecha de primera publicación Agosto 2007.

Task V. Proposed BMP Research SOW for Master Permit

The proposed 5-yr SOW is presented here, but may be revised and changed before the final SOW is agreed upon and implemented

Introduction

The Everglades Agricultural Area (EAA) basin, comprising approximately 250,000 ha of farms and several small communities south and east of Lake Okeechobee, is located in the geographic center of the south Florida watershed. The EAA has highly productive agricultural land comprised of rich organic soils. Sugarcane, vegetables, sod, and rice are grown in the EAA and annually provide south Florida with jobs and over one billion dollars to Florida's economy (FDACS, 2004).

Waters from Lake Okeechobee to the north are released into the EAA basin for irrigation. Lake Okeechobee waters are also conveyed through the EAA basin to supply water to the Everglades Protection Area (Water Conservation Areas and Everglades National Park). Discharges from the EAA have been identified as contributors to the phosphorus (P) enrichment of the Everglades (Sievers et al., 2003). Concerns regarding the impact of elevated P concentration waters on the fauna and the flora of the Everglades Protection Area prompted the state of Florida to enact the Everglades Forever Act (EFA) in 1994.

The EFA mandated that the South Florida Water Management District (SFWMD) create and administer the Everglades Regulatory Program. This regulatory program enables the SFWMD to promulgate Chapter 40E-63, F.A.C., which details the scope of the Everglades Regulatory Program for the EAA basin. In this rule the SFWMD describes the procedures for the Best Management Practice (BMP) program which include, i) enforcing implementation of BMPs, ii) conducting a water quality monitoring program, iii) tracking area-wide P loads, and iv) developing a mandatory BMP research program for P and other water quality parameters of concern.

The EAA basin as a whole is required by the EFA to achieve P load reductions of 25 percent or greater relative to a baseline P load average (derived from 1979 to 1988 monitoring data). Since January 1, 1995, BMP implementation has been mandatory for all farms that discharge drainage water into SFWMD conveyance canals. The SFWMD monitors EAA basin P loads via a network of monitoring stations, i.e. pump stations and structures that border the EAA. During the twelve years since BMP program initiation, the EAA basin's annual P load reduction has averaged 50 percent.

EAA farmers employing BMPs incur additional costs. The costs are derived from increased water management, sediment control practices, farm drainage water monitoring, specialized nutrient application equipment, training of personnel, possible reductions in yields, etc. The on-farm BMP costs are recovered partially by a reduction in Agricultural Privilege taxes that result from exceeding the 25% basin-wide, P load reductions. Agricultural tax credits have accumulated from highly successful P load reductions, allowing for the minimum tax rate to be collected until the year 2013, unless the credits are utilized as a result of non-compliance (SFWMD, 2007).

A list of BMPs recommended by the SFWMD for implementation on EAA farms is presented in the SFER report (SFWMD, 2007). Each BMP is assigned a point value and each farm basin implements a suite of BMPs, which must sum to a total of 25 points or more. In addition to implementing a SFWMD approved suite of BMPs, each farm monitors its daily rainfall, drainage flow, and drainage water P concentration. Individual farm basin monitoring data is submitted regularly to the SFWMD as required by each farm's BMP permit.

As a direct result of state-mandated, basin-wide BMP implementation, significant reductions in P loads discharged from the EAA basin have been achieved. Further reductions in farm P loads arising from implementation of a floating aquatic plant management BMP may serve to improve the performance of STAs, especially those STAs performing at less than expected levels.

Justification

Previous research has shown that approximately half of the P exported from EAA farms is in the particulate form. Studies (Stuck, 1996; Izuno and Rice, 1999, and Daroub et al., 2005) concluded that a significant portion of the particulate P (PP) in EAA farm canals originates from in-stream biological growth rather than from soil erosion. Particulate P that contributes significantly to farm P export has been determined to be, for the most part, recently deposited biological material such as settled plankton, filamentous algae, and macrophyte detritus. There are several sediment control practices in the SFWMD-EAA BMP table from which EAA farmers are able to choose and employ on their farms. One of the sediment control practices is the control of aquatic plants in farm canals. In addition most growers control the growth of FAP in their canals to varying degrees. However, this practice is seldom claimed on BMP permits because there is inadequate scientific knowledge regarding its efficacy and method of implementation.

Limiting the growth of FAP in farm canals is a practice that has the known benefit of improvement in the conveyance of drainage and irrigation waters throughout the farm. In addition suppressing the growth of FAP will influence the plant community in the canal and likely result in increased predominance of algae, phytoplankton, and possibly submerged aquatic vegetation. This change in the canal aquatic plant community should increase the levels of dissolved oxygen in the canal water column, and possibly result in altered P species composition of the EAA farm drainage water.

It is hypothesized that with better light penetration into canal waters more P may be co-precipitated with Ca compounds and form cohesive sediments that are less likely to be re-suspended and transported off the farm during drainage events. Production of the less transportable and less labile sediments should result in decreased farm loads. Results from this study will quantify changes in sediment composition and drainage water P speciation in EAA sugarcane farms. It will determine any changes in the chemistry of the different P species in canal waters and overall total P loads as influenced by the total control or less stringent control of FAP in farm canals. This information will be valuable to improve the management of farm canals and will aid in efforts to further reduce EAA farm P loads.

Objectives

1. Evaluate two floating aquatic plant (FAP) management practices, complete control and no control, for impact on farm drainage water P load.
2. Evaluate the effects of the two FAP management practices on P speciation of farm drainage water.
3. Determine effective and economic methods to manage floating aquatic plants in farm drainage canals that will lead to reduced farm P loads.
4. Package the floating aquatic plant management methods into a viable and effective BMP for implementation by EAA growers.

Review of IFAS BMP Research

The University of Florida/Institute of Food and Agricultural Sciences (UF/IFAS) has been involved in a research and education program for implementation of BMPs to reduce P loading in the EAA since 1986. A landmark study concluded that a significant fraction of the particulate P in the EAA originates from in-canal biological growth rather than from field or canal bank soil erosion and that recently deposited biogenic sediments, such as settled plankton, filamentous algae, and macrophyte detritus were the fraction that contributed the most to particulate P export (Stuck et al., 1996). Several preceding and succeeding projects were conducted that studied BMP efficacy and implementation.

BMP Efficacy Study

In 1992, the UF/IFAS initiated a wide-scale BMP implementation and efficacy verification project aimed at quantifying achievable farm P load reductions. Ten farms located throughout the EAA were selected to represent the soils, sub-basins, crop rotations, and water management philosophies of the conditions in the EAA. Best management practice packages were developed for each farm and implemented. Monitoring of farm drainage volumes and total P concentrations began in Water Year 1993. The number of farms included in the project was reduced to seven in 2000 and to three in January 2002.

All indicators of BMP efficacy revealed consistent and sustained reductions in total P concentrations and loads occurred due to the implementation of BMPs in the EAA. Basin-level numbers presented annually by the SFWMD reinforced the effectiveness of the BMP program, and showed a sustained 50% reduction in total P loading from the EAA. This major and sustainable reduction was credited to the BMP program. Adjusted unit area loads on project farms averaged 0.73 lbs total P/acre after BMP implementation compared to 1.30 lbs total P/acre prior to WY95. This represented a project average reduction in adjusted unit area loads of approximately 44% which was similar to the EAA basin load reduction.

Particulate Phosphorus Study

A three-year study conducted on three EAA farms investigated conditions on-farm that result in large P load export (Daroub et al., 2005). The study revealed that approximately one-half of a farm’s particulate P load was comprised of recently deposited, less dense, organic matter of aquatic plant origin and one-half consisted of denser, higher mineral content, canal sediments. Aquatic plants and plant detritus were found to be key components in the development of an EAA farm's P load. They serve as sinks for soluble reactive P (SRP), as well as sources for P-laden detritus and soluble P (SRP and dissolved organic P) returning to the water column during decay. Results from the particulate P research indicated that there are certain operating procedures (e.g. reducing drainage flow velocity) when implemented could lead to reductions in the transport of particulate P and therefore overall P export. High particulate P loads, however, may occur from transport of moderate amounts of high P content readily transportable biological material close to the pump station. This light material can be transported at moderate flow rates, for example at pump start-up after long inter-event time periods. Limiting the growth of the predominant floating aquatic plants found in EAA farm canals was thought would result in a reduction of easily transportable particulate P floc and subsequent particulate P (and farm total P) loads.

BMP Demonstration Farm

In light of the previous studies' findings on particulate P sources and transport on EAA farms, the University of Florida's Everglades Research and Education Center created a BMP demonstration sugarcane farm at the research center (Daroub et al., 2005). The two-year demonstration study compared the effects of velocity control and floating aquatic weed management on particulate, dissolved, and total P loads. Two hydraulically isolated sugarcane blocks of 125 and 200 acres each were created and equipped with identical drainage pumps and monitoring instrumentation to record rainfall, flow, canal levels and to collect discrete hourly drainage water samples. The main objectives of the demonstration farm were to apply flow velocity and floating aquatic weed controls and effectively demonstrate the resultant P load reductions to growers in the EAA.

The influence of FAP on farm P loads was demonstrated. In theory the elimination of emergent aquatic weeds should provide conditions that optimize P co-precipitation with calcium carbonate from the canal water column, a process that occurs during active photosynthesis by submerged aquatic plants growing in waters saturated with calcium carbonate (Dierberg et al., 2002). Photosynthesis-induced calcium carbonate precipitate contains P that is of low bio-availability and relatively low transportability. Optimizing P co-precipitation in main farm canals was identified as a means to encourage the sequestering of P in less mobile canal sediments and to allow for eventual recycling of canal sediments back to farm fields.

Results confirmed the hypothesis that particulate P source control (elimination of FAP in farm canal) and application of critical velocity limits lead to measurable P load reductions. Drainage water concentrations of total P, total dissolved P, and particulate P for the BMP block were 54, 58 and 51 % lower than Control block concentrations. BMP block unit area loads for total P, total dissolved P, and particulate P were 28, 21, and 32 % lower than corresponding loads from the Control block. The observed P load reduction in the BMP block was reported to be the result of decreases in easily transportable particulate P as well as the absence of conditions that allow export of less transportable P sources (canal sediments). Under the study's design it was difficult to determine what fraction of the P load reduction was due to source control and what fraction was due to critical velocity control. The P content of TSS for the Control and BMP blocks were 1531 and 6108 mg kg^{-1}, respectively, indicating that the solids exported from the Control block had lower P content than the BMP block TSS. The higher P content indicates the source is from biological material rather than from soil erosion. The Control block average TSS concentration of 49.3 mg L^{-1} was eight times greater than the TSS concentration of the BMP block (6.2 mg L^{-1}).

Monitoring of FAP on Two EAA Farms

This two year study monitored the aquatic plant growth mass in the main canals and field ditches on two EAA farms from 2000 to 2002 (Daroub et al., 2005). Additionally, the P content of the aquatic plants was determined in order to calculate P removal or P re-introduction potentials. Aerial surveys of the farm main canals and ground surveys of the field ditches were conducted. The aerial reconnaissance cycle began in July 2000 and ended in June 2002. These surveys yielded the total area of surface waters covered by floating aquatic plants. The P mass estimate was determined through aerial surveys of the farm main canals coupled with ground surveys and physical sample collection. Aerial photographs of the main farm canals and field ditches were taken once per month from October through March and twice per month during April through September. It was demonstrated that FAP serve as substantial reservoirs for P. A process by which the FAP could be grown as a crop and incorporated into a management practice to mitigate total P loading was not recommended. It was apparent that controlling the growth of FAP by conscientious and consistent spraying, to minimize infestations of macrophytes in the canals, would reduce particulate production and subsequent particulate P loads. Equally apparent from this study was that floating aquatic plants can significantly affect the P cycle, and hence P loading, in EAA farm canals. The study concluded that there are many factors that contribute to a complicated phosphorus cycle in an EAA farm canal and ditch system, and that there were no clear indications that simple and sustainable management practices could be devised for incorporating the intentional growth and removal of FAP into a P load reduction BMP.

Statistical Analysis of Factors Affecting BMP Performance in EAA

The objectives of this research were to conduct detailed statistical analyses of a ten-farm BMP research data set to assess parameters that affect EAA farm P loads. Various statistical analyses were employed to answer the question: "What are the factors impacting farm phosphorus loads in the EAA?"The main data set analyzed was from the long term (7-10 year), ten-farm, BMP efficacy and implementation project conducted by the University of Florida / Institute of Food and Agricultural Sciences (UF/IFAS) from 1992-2002. The UF/IFAS monitoring data base included information on rainfall, soil depth, monthly crop maps, BMPs implemented, hourly canal elevations, five-minute drainage flows, and four-day flow-composited P concentration of drainage events.

The following statistical methods were utilized in the study: Spearman correlation analysis, multivariate regression analysis on Box-Cox transformed data, Principal Component Analysis (PCA), and Classification and Regression Tree Analysis (CART). The data was analyzed on both monthly and Water Year basis. In addition, the data was aggregated by sugarcane and mixed-crop farm types to investigate the effect of farm type on factors affecting farm P loads.

Results from the analyses indicated that water management and cropping practices were important predictors of farm P loads in the EAA. The analyses also showed that irrigation water quality from Lake Okeechobee was deteriorating and negatively impacting P loads from sugarcane farms. A potential impact of soil depth on P loads was also revealed by the analyses.

Water management practices as indicated by pump to rainfall ratio and farm canal level were important in predicting P loads. Higher P loads were expected with higher pump to rainfall ratios and higher canal head differences. High canal head difference indicated lower inside canal elevation, higher outside canal elevation, or both, and may result from farm drainage pumping due to rainfall and/or seepage.

The statistical analyses also indicated that lower P loads were associated with sugarcane as the main crop in the farm cropping rotation. This was not surprising due to the fact that sugarcane P fertilization rates are much lower than rates for other crops. In addition, sugarcane can tolerate higher water tables and occasional flooding which allows growers to reduce the total farm drainage volume (and drainage rate) per rainfall event.

The analyses showed that higher P loads were observed in farms that have a high acreage of flooded fallow in the summer. This conclusion was based on limited data and it was recommended to be investigated further. Flooding is a common cultural practice in the EAA which is quite beneficial for a number of reasons, among which are plant disease and insect control, nematode control, and reduction of soil loss from biological oxidation and is a practice that is recommended by water managers and researchers. Investigation of management practices to reduce the impact of flooding on P loads was recommended.

Trend analysis conducted on irrigation water discharged from three outflow structures adjacent to Lake Okeechobee showed in general, increasing trends in P concentrations. The irrigation water P concentrations were higher from canals serving the S-5A sub-basin and lower for the S-6, S-7, and S-8 sub-basins. Limited analysis indicated that some of the farms were sinks for P with irrigation P loads higher than drainage P loads. Regression analysis showed higher P loads from sugarcane farms with higher irrigation P concentrations when the data was analyzed on a monthly basis.

In general, farms with deeper soils had higher P loads than farms with shallow soils. Farms in the S-5A sub-basin had the deepest soils and the shallowest soils reported to be in the S-7 and S-8 sub-basins. The effects of land use and soil depth were difficult to separate, as three out of the four deeper soil UF/IFAS farms were mixed-crop farms also. One explanation for the lower P loads from shallow soil farms is that as drainage water passes through the limestone bedrock, soluble P may be adsorbed or precipitated as a calcium-phosphate fraction.

Review of Supporting Research

Phosphorus Co-precipitation with Calcium Carbonate

Studies have shown that an increase in photosynthetic activity of algae and other submerged aquatic vegetation in stream water lowers pCO_2, resulting in high pH levels (Reddy, 1981). These high pH values, if associated with high Ca levels, can potentially co-precipitate P with $CaCO_3$ (Otsuki and Wetzel, 1972; Murphy et al., 1983). Since photosynthesis-induced pH elevation is critical for reaching the supersaturated conditions necessary for $CaCO_3$ precipitation, all submerged photosynthetically active plant communities have the potential to co-precipitate P with $CaCO_3$ in hardwater environments. Co-precipitation of P with $CaCO_3$ is well documented in aquatic systems with high Ca and alkalinity levels, coupled with high pH caused by algal photosynthesis (Murphy et al., 1983; Reddy et al., 1987; Danen- Louwerse et al., 1995).

Calcareous deposits have been frequently observed in periphyton mats (Brouder et al., 1984) and on the stems and leaves of submerged aquatic vegetation (SAV) growing in hardwater environments, confirming that $CaCO_3$ precipitation does occur on plant surfaces (McConnaughey et al., 1994). Phosphorus co-precipitated by this mechanism is eventually assimilated by the above-ground parts of the plant or deposited in the sediment after plant senescence. However, documentation of this mechanism in SAV communities is more difficult to document than in phytoplankton and periphyton communities. Light limitation is more likely to have an effect on reducing diurnal pH levels within SAV communities than in phytoplankton communities because SAV does not have the ability to circulate to the euphotic zone as other plant communities. In addition, most SAV species are rooted and can obtain a considerable amount of their P needs from the interstitial water (Graneli and Solander, 1988). Finally, SAV communities often support significant quantities of periphyton, which can also contribute to P removal from the water column, either by direct uptake or co-precipitation.

Incubation vessels using city water form West Palm Beach with different Ca and alkalinity treatments were incubated with either P-enriched or P-deficient Southern naiad, *Najas guadalupensis*. Results showed that a rapid biogenic calcification occurred on the tissue surfaces of the *N. guadalupensis* in the high Ca/alkalinity medium (Dierberg et al., 2002). For *N. guadalupensis* cultured in P-deficient medium, soluble reactive P concentrations within the water column decreased to near detection limits (2 µg/L) within 5.5 h in both low and high calcium and alkalinity treatments. The authors concluded that SRP removal by *N. guadalupensis* depended on the nutritional status of the plant as well as on the degree of water hardness. Reddy et al., (1987) reported that P removal in experimental tanks containing nutrient enriched *Elodea densa* (American waterweed) without sediment exceeded the amount recovered in the plant tissue, indicating a major removal process other tan plant uptake. They hypothesized that high pH conditions in the water column probably resulted in the precipitation of soluble P with Ca, forming insoluble Ca-phosphates.

Another promising advanced treatment technology evaluated was a system using submerged aquatic vegetation and limerock (SAV/LR). Removal of P is accomplished by plant uptake as well as by co-precipitation with $CaCO_3$, which precipitates from the water column due to photosynthesis-induced pH elevations. DeBusk et al. (2001) designed an experiment to evaluate the P removal efficiency of a SAV/LR treatment system under various hydraulic retention times (HRT). Results indicated that most of the P removal was provided by the front-end SAV unit process. Outflow TP concentrations from the 1.5, 3.5 and 7.0 days HRT averaged 53, 28, and 23 µg L^{-1} during the experimental period. These concentrations were further reduced in the downstream limerock beds to 40, 19, and 15 µg L^{-1} respectively. Influent TP values to the SAV treatments during this period averaged 108 µg L^{-1}. This study showed that by increasing the HRT from 1.5 to 3.5 days there was a notable improvement in the P removal capacity of the system; however, doubling the HRT from 3.5 to 7.0 days had little additional effect on P removal. Direct plant uptake and co-precipitation of SRP with $CaCO_3$ are likely the major mechanisms for P removal in SAV systems.

Phosphorus Storage in Sediments

The largest P storage site in a wetland is typically associated with the wetland soils and new sediments. The original soil of newly established wetlands may undergo some modification due to subsequent operation of the system. Existing initial pools of available P in the soil may be reduced by a combination of leaching and plant uptake by the new aquatic vegetation (Reddy et al., 2003). If the original soils are P deficient, they may function as a temporary sorption sink for the above water column. However, most of the initial P in the soil column is recalcitrant, occurring as both organic and inorganic forms of biologically unavailable P (Kadlec, 2006). Sediments in new constructed wetlands are generally new deposits characterized by low bulk densities, which are commonly called floc. In wetland systems of south Florida, the rates of sediment accretion range from 0.1 to 2.0 cm/yr (Richardson and Craft, 1993). The ability of constructed wetlands to remove nutrients from surface waters has increased their popularity for water quality improvement (Kadlec and Knight, 1996). During the first few months of operation, depending on soil and macrophyte conditions, the wetland may function as a source instead of a sink for P. Concentrations of Fe and Al have been suggested to be important factors controlling P retention in acid soils while Ca and Mg are more important in alkaline soils (Syers et al., 1973). Phosphorus sorption studies in the EAA and WCAs have shown positive relationships between P sorption and Ca (Porter and Sanchez, 1992; Richardson and Vaithiyanathan, 1995). As the organic soils of the Everglades subside, more of the soil volume will be influenced by the bedrock, and the sorption or precipitation of P by exchangeable Ca or carbonate materials should increase. The Fe and Al oxide contents of histosols also tend to increase with ash content, which increases with age because of subsidence and mineralization (McCool, 1954). Cogger and Duxbury (1984) found they could explain differences in P sorption of soil by measuring total or extractable Fe and Al contents. Combined with correlations of Ca and P storage, this led Richardson and Vaithiyanathan (1995) to suggest that P sorption in Everglade soils is regulated by $CaCO_3$. A study of the flooded organic soils of the ENR Project in south Florida (Newman and Pietro, 2001) suggested that organic P was the primary means of P retention in those soils; however, Ca-phosphates also may play a significant role in P storage. Related studies have shown that high Ca concentrations in EAA canal water combined with pH values > 8.5 result in the formation of Ca-phosphate minerals (Diaz et al., 1994). Newman and Pietro (2001) suggested that high concentrations of Ca and Mg in ENR water column, combined with high temperatures and alkaline pH make ideal conditions for P co-precipitation with $CaCO_3$ and the formation of other stable Ca-phosphate minerals, which may have important implications for long- and short-term P storage within the STAs.

Total P concentrations in treatment wetlands soils display a 10-fold range, from less than 200 mg kg^{-1} to over 2000 mg kg^{-1} in the top-most sediment horizon. Vertical zonation of most wetland soils includes a typically top layer consisting of macrophyte litter and/or flocculant microdetritus. Under that surface layer there is usually a vertically decreasing concentration profile of the various P fractions (Kadlec, 2006). The removal of P in wetlands is usually the result of a combination of processes, including sorption on antecedent soils, uptake by biota, and accretion of new sediments and soils. There generally exist storage of available P in the form of detrital material, living biomass and labile P in sediments, soils and porewater. Detritus is composed of flocculant material that originates from algae and bacteria, together with fragments of dead macrophytes biomass (Kadlec, 2006). Kadlec (2006) describes an aggregated conceptual model for constructed wetlands comprised of three main compartments: the water column, available P and permanent P storage of accreted P. All these different P pools interact with each other, with P moving to the different pools through various processes. However, the majority of the P uptake is subsequently returned to the water column, as a result of decomposition and desorption processes. However, some small fraction of the available P is converted to forms that are biologically unavailable, including refractory organic P and some of the inorganic forms (Reddy et al., 2003).

Soluble reactive P is the P fraction most readily utilized and processed from the water column, presumably by bacteria and algae. Pietro et al. (2006) reported that SRP concentrations from the water column in cell 1 from the ENR Project considerable decreased in just a few hours, with the rapid uptake not explained by the SAV community of the study. Richardson (1985) estimated that micro-flora and micro-fauna from freshwater wetlands accounts for about 50% of the P uptake from the water column. However, the life cycle of these small organisms is short and it is likely that most of the P is returned to the water column as DOP and PP. All aquatic vegetation from freshwater wetlands is also known to incorporate and store P in their tissue for the duration of their life cycle. Studies have shown that aquatic plant growth varies considerably among species. Macrophyte turnover in south Florida is considered to be rapid compared to colder climates, with as many as five turnovers of the aboveground vegetation per year (Davis, 1994). In addition, some species such as *Typha spp*. and periphyton, which are native to the Everglades have shown the ability to uptake and store more P in their tissue with increasing P availability in their environment (Kadlec, 2006). However, overall P storage in wetland ecosystems attributed to macrophyte cycling is directly influenced by the rate at which decomposing plant residues return P to the water column as DOP and PP. Half-lives for various forms of litter have been shown to range from about 15 days for SAV to 200 days for EAV (Chimney and Pietro, 2006).

Proposed Work and Deliverables for 2008-2013

Several BMP research projects involving EAA farms have identified floating aquatic plants (FAP) as a source of readily transportable particulate P. No studies have been conducted to isolate and measure the effects of limiting FAP growth in farm canals on farm P load. The research component of this SOW attempts to quantify the effects of canal FAP management on farm P load, drainage water P speciation, and canal sediment composition. The research will focus on sugarcane farms since they comprise the majority of the acreage of the EAA and thus any benefits from the employing research recommendations will have greater potential for extension and impact. Four pairs of sugarcane farms, one pair in each sub-basin, will be monitored in the study. A complete control of FAP treatment will be imposed on one farm in each pair. The other farm in a pair will have no FAP controls imposed, i.e., FAP is expected to eventually cover nearly the entire surface of the farm's main canal.

Current BMP permit monitoring by the grower will continue to observe changes in P load by ongoing monitoring operations and to compare with the farm's P load history. Data loggers, canal level sensors, pump RPM sensors, auto-samplers, and tipping bucket rain gauges will be installed on each cooperator farm to monitor water management operations and treatment impacts in greater detail. Canal sediment depth and characterization and FAP coverage and composition will be monitored on all farms.

Task I: Aquatic Plant Management in EAA Farm Canals Study

The objectives of this component are to evaluate two FAP management practices, complete control and no control, for impact on farm drainage water P load, evaluate the effects of the two FAP management practices on P speciation of farm drainage water, and determine effective and economic methods to manage floating aquatic plants in farm drainage canals that will lead to reduced farm P loads.

The following activities are envisioned to be conducted for this study:

A. Before final cooperator farms can be selected, an initial survey of EAA sugarcane farms is proposed. The survey will provide researchers a representative range of farm canal characteristics and FAP characterization for farms within a sub-basin. Eight or more sugarcane farms in each sub-basin will be selected and visited to obtain information on canal dimensions and layout, estimated average and maximum flow velocities, prevalent FAP species and coverage, farm FAP management strategies, sediment depths, visual observations of sediments, canal cleaning schedules, average farm soil depth, and cropping history. Additional data for drainage water P concentration, drainage flow, and pumping to rainfall ratio will be obtained from SFWMD's BMP permit database. Data will be plotted to observe standard statistical characteristics.

B. Following survey completion an initial selection of four pairs of similar EAA sugarcane farms (cooperator farms) will be completed. The following will be considered in choosing the candidate farm pairs:

1. Farm size between 640 to 1280 acres with a single exit pump station
2. Similar dimensions of main farm canals
3. Sugarcane farm
4. One pair of farms per sub-basin: S5A, S-6, S-7, and S-8
5. Similar P load histories for the past five years
6. Similar P concentrations for the past five years
7. Similar drainage pumping to rainfall ratios for the past five years
8. Same irrigation source canal
9. Willingness of the grower to cooperate and incur extra cost for possibly need to remove canal sediments and mechanical harvesting of FAP at start of experiment.

After initial selection farm pairs will be checked to see if they are within the norms of the respective sub-basin surveyed sugarcane farm ranges. Tests for differences between pairs of farms using two-tailed, paired t-test will be conducted for P load related parameters. Farms will be reselected if farm pair characteristics are too dissimilar or are outliers of survey norms.

C. Once pairs of farm have been identified that reasonably represent the sugarcane farms in their sub-basin and are found to have similar histories for P load parameters, then a site survey of each of the eight selected cooperator farms will be conducted. Farm data will be collected pertaining to:

1. Canal system configuration
2. Cropping history
3. BMPs plan and implementation
4. Soil depth and variation
5. Sediment characterization, depth, and variation
6. Ambient canal water P speciation and spatial variation
7. Estimated canal velocities for recent water years
8. Pump calibration equations
9. Floating aquatic plant management practices

This farm level data will be compiled and checked for obvious major differences between paired farms. Treatments imposed on a farm will involve one of two treatments, either complete/vigorous control of FAP in main and secondary canals via mechanical control followed by recommended herbicide spray program, or no-control of FAP in main and secondary canals. Reselection, canal cleaning, and/or mechanical FAP removal may be required before finalizing the four pairings of farms. We may consider also seeding the no control farm with FAP.

D. The eight cooperator farms will be instrumented with data loggers that have been outfitted with radio telemetry and solar power. The data loggers will be programmed to calculate drainage flow using pump calibration equations, canal levels from sensors installed in the inflow and outflow canals of the farm and pump RPMs from sensors attached to drainage pumps. Rainfall will be measured by tipping bucket rain gauges connected to data loggers. Farm drainage flow samples will be collected by auto-samplers triggered to collect flow-proportional samples by the data loggers. Flow composite samples will be held in iced or refrigerated conditions on-site prior to sample collection.

E. Drainage water, ambient canal water, canal sediments, and FAP biomass will be sampled and analyzed. Drainage water samples will be collected over a maximum of 24 hours of drainage pumping. Attempts will be made to collect samples from every drainage event for each of the eight farms. Ambient canal water samples will be collected via grab sampling twice monthly, unless drainage pumping has occurred the week prior to collection. Floating biomass samples will be collected once every two months. Canal sediments will be sampled annually. Brief descriptions of the analyses to be conducted on each type of sample as follow:

a. Flow-composited drainage water and ambient canal water samples will be analyzed for total P (TP), total dissolved P (TDP), particulate P (PP), soluble reactive P (SRP), dissolved organic P (DOP), total suspended solids (TSS), pH, and total dissolved Ca. Additional canal water analyses, e.g., temperature, Redox potential, and dissolved organic carbon may be conducted if additional supporting data is required or indicated.
b. Farms' main canal sediments will be analyzed for TP, organic matter by loss on ignition, and physical characteristics. A subset of the samples may be analyzed further using solid state assessment techniques, e.g., x-ray diffraction.
c. Floating aquatic plants biomass sub-samples will be analyzed bi-monthly for total biomass, species composition, and TP. Secchi measurements will be conducted bi-monthly to measure water clarity.

F. A statistical program for analysis of the study data will be developed using SAS and/or similar widely-accepted statistical application. The main study is a randomized complete block design with repeated measures over time. There are two treatments: FAP completely controlled in main and lateral farm canals and FAP uncontrolled growth in farm canals. A block is one pair of farms; each block is located in a different sub-basin of the EAA basin. The analyses will compare P load parameter differences within a farm using pre- and post-treatment imposition data, as well as test for differences between the two farms of a pair for treatment effects.

Task II: BMP Education and Extension Services:

The objective of this activity is to enhance the dissemination of existing BMPs to all growers in the EAA. This objective will be met through two activities, the regular seminar and workshop program and a program that includes individual BMP consultations. The BMP workshops and seminars will be conducted for groups of growers. These venues emphasize the importance of correct BMP implementation and introduce new and effective implementation techniques as they become available. The BMP consultation service will be provided by UF/IFAS to all interested EAA growers. Following are the activities associated with this task:

a. BMP implementation workshops and seminars: we will continue to conduct P BMP workshops for groups of growers. The workshops also include the latest BMP research results. Three or more workshops will be held each year by grower group to ensure complete participation. In addition, a general workshop open to all will be held once per year to provide to all growers the opportunity to participate in BMP implementation training.

b. Pesticide training will be conducted through the IFAS extension office in Belle Glade. We will continue to educate growers on the judicial use of Ametryn and Atrazine during the P BMP workshops.

c. BMP extension publication(s): produce electronic presentations for BMP workshops, extension personnel, and others involved in sustaining improvements in EAA water quality. Also produce online extension web pages explaining effective BMP implementation in the EAA. The extension publications will describe and explain the SFWMD BMP table as well as current and past UF/IFAS research related to the control of farm P loading.

d. BMP consultation program: a BMP consultation typically consists of an initial contact, one or more field visits to assess BMP operating procedures and issues that confront the grower, an analysis of information provided by grower, and a follow up visit for conveying any recommendation. Extension materials developed by UF/IFAS that explain the SFWMD BMP table in detail are distributed to the grower as well. Farm basins in the S-5A and S-6 have been covered in 2006 and 2007. Future BMP consultations will be conducted on as requested or as needed basis. A summary of consultations will be compiled and included in the annual report.

This work plan will remain in effect for a period of five years, or until conclusions have been reached, submitted, and accepted by the SFWMD. Each year an annual report will be provided to EAA-EPD and SFWMD.

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Appendix A. Farm BMP Consultation Materials

Farm BMP Consultation Program Checklist

Farm BMP Consultation Survey Form

Appendix B. BMP Workshop Training Presentations

Appendix C. BMP Extension Publications

Samira Daroub
University of Florida/IFAS
Everglades Research and Education Center
Belle Glade, Fl, 33430| T: 561-993-1593| sdaroub@ufl.edu
http://erec.ifas.ufl.edu