EVERGLADES AGRICULTURAL AREA BMPs FOR REDUCING PARTICULATE PHOSPHORUS TRANSPORT

FINAL REPORT

SUBMITTED TO THE
FLORIDA DEPARTMENT OF ENVIRONMENTAL PROTECTION

By
Samira H. Daroub, Timothy A. Lang. Orlando A. Diaz, Ming Chen, and James D. Stuck

Everglades Research and Education Center
Institute of Food and Agricultural Sciences
University Of Florida

June 2005

Executive Summary

Agricultural Best Management Practices (BMPs) have reduced phosphorus (P) loading from the Everglades Agricultural Area (EAA) by over 50% since 1995 as reported by the South Florida Water Management District (SFWMD) data and evidenced by the University of Florida/Institute of Food and Agricultural Sciences (UF/IFAS) research. A definition of a BMP pertinent to the EAA was defined as: *An alternative management practice that is technically feasible, economically viable, socially acceptable, and scientifically sound, that when implemented, will lead to reduced P concentrations and loads leaving farms in the EAA, while not threatening the viability of the agricultural industry.*

Initial studies by UF/IFAS that started in 1986 lead to the development of BMPs for reducing P concentrations and loads in the EAA. It was determined that fertilizer practices and a combination of improved drainage uniformity and a reduction in drainage pumping could yield significant reductions in P concentrations and loads for all crops. Using the results of these studies, and best professional judgment, expected reductions in P loading were attached to each BMP. It was hypothesized that P load reductions ranging from 20 to 60% could be realized for farms in the EAA and for the basin as a whole. The BMPs suggested by the UF/IFAS research, and others proposed by industry and the SFWMD, were selected by the SFWMD for inclusion in the table of BMP options used in compliance of Rule 40E-63. Mandatory BMP implementation in the EAA started in January 1995.

In 1992, the UF/IFAS started a wide-scale implementation and BMP efficacy verification project aimed at quantifying the load reductions that could be achieved. Ten farms located through out the EAA were selected as being representative of soils, geographic location, crop rotations, and water management philosophies. 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. Results of the BMP implementation and efficacy in the EAA study are reported in Chapter 1.

Specific conductance monitoring was started on two farms in 1997 and eight farms in 1998 with a main goal of determining if specific conductance in EAA farm canals is man induced and if it can be abated by additional BMPs. Related results on specific conductance in EAA canals are reported in Chapter 2.

Particulate P source, transport and control demonstration started in 2000 on three farms with the objective of determining conditions and farm operations that resulted in high loads of particulate P. Another objective was to recommend management practices to reduce particulate P and therefore total P loads. Due to the importance of aquatic weeds in the particulate P loads, aerial surveys and surveys of aquatic weed coverage in two farm canals were also conducted over a two year period. In addition, demonstration plots were established at the EREC farm to demonstrate optimized BMP practices to growers. These optimized BMPs include aquatic weed control as well as velocity control in the canals. Results of particulate P source, transport and control demonstration are presented in Chapter 3 and results of Aquatic weed and BMP demonstration are presented in Chapter 4.

The sugarcane lysimeter study was designed to demonstrate the effects of higher than traditional water table levels (that will occur naturally under BMP implementation) on 3 popular sugarcane cultivars as well as the effect of delivering nutrient-rich drainage waters (P-fertigation) to sugarcane. The vegetable/rice lysimeter study was designed to demonstrate short- and long-term soil fertility and crop nutrient uptake trends for different vegetable/rice/flooded fallow crop rotations. Drainage waters from the vegetable/rice lysimeters served as the P-fertigation source into select sugarcane lysimeters. The lysimeter study is presented in chapter 5.

Numerous BMP training seminars and workshops were conducted. A listing of these workshops is presented at the end of the report. Research and extension publications are also listed at the end of the report.

BMP Implementation and Verification

All indicators of BMP efficacy have shown that consistent and sustained reductions in total P concentrations and loads have occurred due to the implementation of BMPs in the EAA. Basin-level numbers presented annually by the SFWMD reinforce the effectiveness of the BMP program, showing a sustained 50% reduction in total P loading from the EAA. In WY 2004, the TP load reduction from the EAA was 64% compared to the pre-BMP baseline period. The three year average load reduction is 55%. Phosphorus concentrations are also reduced. In WY 2004, P concentrations from the EAA averaged 69 ppb compared to the pre-BMP base period P concentration of 173 ppb. This major and sustainable reduction is 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 represents a project average reduction in adjusted unit area loads of approximately 44% which is close to the EAA basin load reduction. The UF/IFAS project baseline WY94 total P concentration was 0.198 mg/L. Phosphorus concentrations in WY02 from project sites was 0.10 mg/L which was very similar to the basin level P concentration of 0.092 mg/L. On the project sites, however, average concentrations are variable with years and reach 0.2 mg/L in certain years.

In addition to the above, a simpler method of normalizing data was used. Volumes of drainage and P UALs were indexed to the rainfall amounts received during the year. This yielded figures for how much drainage occurred for each inch of rainfall as well as how much P left the farms on a per inch of rain basis. The Volume: Rainfall (V:R) ratio for the pre-BMP period was 0.45 inches of drainage for each inch of rain received. After BMP implementation, the ratio fell 13% to an average of 0.39 inches per inch of rain. This is indicative of the reduction in farm drainage that occurred due to BMP implementation. The P UAL to rainfall ratio dropped from 0.0199 lbs of P discharged per acre per inch of rain to 0.0186, a reduction of approximately 6.5%.

The Everglades Forever Act of 1994 mandated a research and monitoring program on the evaluation of water quality standards in the EAA (Chapter 40E-63). The goal of this research was to evaluate the constituents that have been previously identified as elements of water quality concern that will likely not be significantly improved by the Stormwater Treatment Areas and current Best Management Practices being widely implemented throughout the EAA; and to identify strategies needed to address such parameters (40E-63.301(2)). These parameters were identified by the Florida Department of Environmental Protection (FDEP) as specific conductance, particulate P, and the pesticides Atrazine and Ametryn. The Everglades Agricultural Area-Environmental Protection District (EAA-EPD) and the SFWMD are responsible for the monitoring of Atrazine and Ametryn from the EAA basin. The UF/IFAS implemented a research project to investigate the specific conductance and particulate P issues in the EAA.

Specific Conductance in EAA Farm Canals:

The objectives of the specific conductance monitoring and research program as stated by Chapter 40E-63, Part III: "the farm-scale research shall be expanded to include monitoring for specific conductance at all points where total phosphorus is currently being monitored. The expanded research program shall include the development, testing, and implementation of BMPs to address reduction of specific conductance".

Specific conductance was monitored at ten EAA farms (12 pump structures). All data were collected using Hydrolab DataSonde (series 3, 4, and 4a) multi-parameter water quality data loggers. In order to identify the specific ions and ion ratios that comprise specific conductance, weekly grab samples were taken in 2001 and 2002 from eight farms (10 pump structures) and analyzed for ionic composition.

Summary statistics showed that mean specific conductance above 1.275 mS/cm occurred at only two out of the ten farms monitored. The farms with conductance above 1.275 mS/cm were UF9206A&B and UF9208A. Higher concentrations of sodium (Na^+) and chloride (Cl^-) were also observed at these two farms. Of the two farms, UF9208A, also showed high levels of sulfate (SO_4^{2-}). Determination of ion compositions in grab samples at the ten pump structures indicated that the major anions are bicarbonate (HCO_3^-), Cl^- and SO_4^{2-} and the major cations are Na^+ and calcium (Ca^{2+}) in farm canal water of the EAA farms.

Potential sources of specific conductance were evaluated. These included geological influences, drainage pumping, irrigation water and fertilizer application. Comparing average specific conductance data points of the study sites to historical Cl^- concentration maps of shallow groundwater revealed that the current elevated farm conductance readings of UF9208A coincided with historically high Cl^- concentrations in 20-50 ft ground water wells. UF9206A&B also is located in an area that has wells of high Cl^- concentration. The Na/Cl ratio in the farm canals ranged from 0.57 to 0.78. The Na/Cl ratio in seawater is 0.55. It has been reported that connate seawater underlies the area and exchanges with the surface water where canals are cut into the limestone. Shallow ground water hydrology and quality has a major impact on specific conductance in the EAA.

The effect of drainage pumping on specific conductance was variable and site specific. There was a low correlation between drainage pumping and conductance when all the sites were combined. Irrigation had a low negative correlation with specific conductance. Statistical analysis of the daily average specific conductance at three intensively monitored farms indicated that drainage pumping increased specific conductance at UF9200A and UF9209A, but not at UF9206A&B. Irrigation decreased specific conductance at all three farms, UF9200A, UF9206A&B and UF9209A. Drainage event analysis on the two elevated specific conductance farms (UF9206A&B and UF9208A) also demonstrated the variable effect of pumping. For example, out of six selected drainage events on UF9206A, three were observed to have increased conductance with volume pumped. Specific conductance had no relationship with drainage pumping to rainfall ratio. One farm that had the lowest drainage pumping to rainfall ratio, showed the highest specific conductance. This strengthened the conclusion that farm conductance is strongly influenced by underlying ground water composition.

Irrigation had a weak negative correlation with specific conductance. On the three intensely monitored farms, UF9200A, UF9206A&B, and UF9209A, irrigation had the effect of decreasing specific conductance. The irrigation water utilized by the farms with the highest specific conductance (UF9206A&B and UF9208A) was also characterized by higher specific conductance. Farm UF9208A received irrigation water via a secondary canal that connects to the Hillsboro canal. Farm UF9206A&B received irrigation water from a secondary canal that connects to the Ocean canal. The Ocean canal may source its water from either the West Palm Beach Canal to the east, or the Hillsboro Canal to the west. Both the Ocean and the Hillsboro Canals have historically had relatively high specific conductance compared to other major district canals in the EAA.

Previous research in the EAA indicated that potassium chloride (KCl) fertilizer application contributed less than 3% to the total dissolved solids (TDS) concentrations in canal waters. It is also reported that a sugarcane crop at harvest takes up more P and K from the soil than that applied by fertilizers. Our results show KCl fertilizer application in one of the high conductance farms with mixed cropping systems contributed less than 6.5% of the TDS in drainage water. This was calculated assuming that all the KCl fertilizer ended up in the drainage water which is highly unlikely as crops take up K^+ and Cl^- in large quantities.

To assess the impact of current P load reduction BMPs on specific conductance, non-parametric Mann-Kendall trend analyses and Sen's slope analysis of specific conductance at different pump structures in the EAA were conducted. Both of these analyses indicated that downward trends were statistically significant at structures UF9202A, UF9205A and UF9207B during the study period. One farm UF9208A showed an upward trend using the Mann-Kendall trend analysis, however there was no significant trend using the Sen's slope analysis.

In conclusion, specific conductance in the EAA canals is strongly influenced by the composition of the shallow ground water, historically reported to be high in Na^+ and Cl^- due to connate seawater entrapment and the mixing of surface and ground water. The effect of drainage pumping was variable and site specific. Irrigation, in general, decreased specific conductance. Canal specific conductance is governed mainly by the quality and the hydrology of the underlying shallow ground water, which is farm specific. Fertilizers contributed a very small percentage to the total dissolved solids in the drainage water therefore had no substantial contribution to specific conductance in the EAA. Current P load reduction BMPs have reduced specific conductance in some locations in the EAA. It is the conclusion of this study that no further BMPs can be identified by additional research that would provide abatement of specific conductance in the discharge in the EAA. The issue of specific conductance in the EAA is a geological one, and shallow ground water is the major factor controlling the level of specific conductance in the EAA farm canals.

Particulate P Measurement and Control in the EAA

The objective of the particulate P research as stated by Chapter 40E-63, Part III: "In recognition that substantial particulate matter such as sediments are being discharged from farms, given that published University of Florida Institute of Food and Agricultural Sciences data has demonstrated that particulate phosphorus constitutes a significant portion of total phosphorus, the farm-scale research shall be expanded to include the development, testing, and implementation of BMPs for reducing discharge of particulate phosphorus (i.e. sedimentation basins)".

Phosphorus transport in runoff can occur in soluble and particulate forms. Particulate P consists of all solid phase forms including P sorbed by sediment particles and organic material transported during runoff. Particulate P accounts for 20% to 70% of the total P load exported from EAA farms and is frequently the cause of spikes in farms total P loads. The conclusion of our earlier studies suggests that a significant fraction of the particulate P in the EAA originates from in-stream biological growth rather than from field soil erosion. Recently deposited biological sediment material such as settled plankton, filamentous algae, and macrophyte detritus is the fraction that contributes the most to particulate P export. Exported solids may also be contributed directly from loosely bound material detached by turbulent shear forces of floating aquatic vegetation. Other contributions to particulate P loads come from submerged aquatic vegetation and planktonic growth. One of the primary goals of this study was to identify conditions that cause increased particulate P load rates, and analyze those conditions to determine operating procedures that may be optimized to reduce particulate P export, and therefore overall P export at the farm level. Load rate is the product of flow and concentration over a given unit time period.

The particulate P demonstration study was conducted on three farms in the EAA: a sugarcane farm in the northern EAA (UF9200A), a mixed-crop operation in the eastern EAA (UF9206A&B), and a sugarcane farm in the western EAA (UF9209A). Each pump station was fully instrumented, and data was continually recorded for key parameters such as rainfall, pump flow rates, and inlet and outlet water levels. All pump stations are equipped with ISCO®3700 portable automatic samplers that collect water samples every 15 or 30 minutes and composite them into one- or two-hour discrete samples for analysis. All collected samples are analyzed for total suspended solids (TSS), total P, and total dissolved P (TDP). Particulate P is calculated as the difference between total P and TDP. The complexity and the diversity of the systems included are considerable. The approach that has been adopted here was to conduct various forms of cluster analysis to attempt to identify primary parameters that have had the most impact on particulate P transport at the study farms.

Event analysis was conducted on the fraction of the total P load contributed by particulate P for each pump station over the four-year study period. The annual contributions from the particulate P loads to the total P loads have decreased in two of the three farms in 2003. Particulate P at UF9200A decreased from an average of 50%

over the last three years (2000-2002) to 28% in 2003. The particulate P load contributions of UF9206A increased from 26% in year 2000 to 36% in years 2001 and 2002, and decreased to 27% in 2003. Particulate P load contributions from farm UF9206B decreased from 40% in 2000 to an average contribution of 36% during the last three years. At UF9209A the contribution from particulate P to total P load was almost constant, around 67% in 2001 and 2002. In 2003, UF9209A pumped its canals lower and longer than previous years, causing more sediments to be dislodged from the bottom of the canal and transported out of the farm, resulting in a particulate P contribution of 80% to the total P load.

Load Distribution Analysis of the cumulative hydraulic and particulate P loads generated for each farm and year, showed that 50% of the annual particulate P loads was contributed by less than 25% of the hydraulic load. **Process Distribution Analysis** was conducted to determine the most probable mechanism for particulate P transport in the sub-events that contribute most to the annual loads, i.e. those in the top 50% of the load distribution. The objective of this analysis is to identify conditions that give rise to the increased particulate P transport events. The most distinctive pattern observed from this analysis is the number of farm-years that were dominated by few events. Data over the four-year study shows that six of the 15 farm-years sampled had a single event that contributed 30% or more to the top 50% particulate P load. Three farm-years had two events that contributed a total of 30% or more. Three farm-years had three events that contributed a total of 30% or more. Only two of the 15 farm-years had their load rates distributed such that it took more than three events to contribute a total of 30% or more to the top 50%.

Periodically, large volume (500-1000 liter) composite samples were taken at each of the study farms. These samples were concentrated by sedimentation in the field. The sedimented solids were collected and further concentrated in the lab, after which they were analyzed for the same physical and chemical properties as the farm sediments, including bulk density, solids content, particle specific gravity, organic matter content, and P content. Selected samples were analyzed for particle size distribution and settling velocity distribution. The analysis from the concentrated suspended solids (bulk samples) showed that the exported suspended solids volume is relatively small when present in its settled state. However, the contribution to the total annual P load of the farm could be significant. Thus the importance of the suspended solids on the overall water quality of the farm must be considered when solids removal and control plans are being evaluated.

Farm Sediment Surveys were conducted with the objective of determining the P storage in the main canal sediments, to evaluate farm sediments properties, and to monitor changes in sediment character and inventory over time. Quarterly inventories were conducted of canal sediment volume, mass, and P content at each farm. A number of transect locations were set up at regular intervals upstream of the pump station at each farm. Canal sediment surface elevation and depth was determined at each location. Core samples of the sediment were taken at each transect, sectioned and analyzed for key physical and chemical parameters, including bulk density, solids content, particle specific gravity, organic matter content, and P content. The surveys reported cover the 22-month period from November 2000 through August 2002 for UF9200A, UF9206B, and UF9209A. It appears that there was a trend toward sediment accumulation over the study period at UF9206B and UF9209A, while at UF9200A sediment depth remained relatively constant. The P content (on a dry weight basis) typically decreases as depth increases, but the bulk density of the sediment increases as depth increases.

To understand the transport of particulate P in farm canals in the EAA it is necessary to identify and state the primary processes of movement. **Major processes identified** affecting particulate P movement were first flush, cumulative high velocity, restart flush, particulate phosphorus spike, and pump cycling. The **first flush** includes biological material accumulated during the quiescent period between pumping events. This highly mobile material causes an increase in the concentration of suspended solids during the first hours of pump events. **Cumulative high velocity** produces a steadily increasing discharge concentration of suspended solids as the water farther upstream has a longer time to accumulate eroded suspended solids as it moves downstream to the discharge pump station. **Restart flush** is similar to first flush. When pumping is terminated, suspended solids in the canal system settle out in place. If there has been a significant concentration of suspended solids in the downstream reaches of the canal system at shutdown, there will be a high initial concentration in the discharge when the pump is restarted. **Particulate P spikes** occur occasionally. A particulate P spike is defined when the particulate P concentration for a particular sample is more than twice that of either the preceding or succeeding samples. The spike is assumed to originate from a random release of particulate material from upstream sources, such as a collection of floating macrophytes or a removal of a flow obstruction. **Pump Cycling** differs from pump restart in that the pump cycles through on-off oscillations over relatively short time periods, e.g. 30 minutes to two hours. This condition occurs when a farm pump is on automatic on-off control that is tied to canal level.

The diversity of the farms has allowed a number of observations to be made regarding the importance of various operating parameters affecting particulate P loads. Dominant events started when pumping operations deviated from typical practices, but these deviations were specific to each particular farm. A detailed operational summary of study farms with specific recommendations to each farm is presented in Chapter 3. But following is a short description of recommendations to reduce particulate P loads.

Recommendations to Reduce Particulate P Loads:

Velocity in Canals – Velocity is a key control parameter for reducing particulate P export. Recommended velocities are relative, in that they must be within the operating framework of the configuration of the farm. Velocities should be as low as possible, and velocity excursions should be avoided, regardless of the average or typical velocity of the canal system. Velocities greater than 0.4 m/s (1.3 ft/sec) have been associated with greater transport rates at the study farms. Given the parabolic relationship between velocity and erosion, “slow and long periods” is preferred than “fast and short periods” for pumping a given volume of water.

Pump Cycling and Reduced Run Times – Long-run period cycling of about 8-16 hours, which reduces continuous pumping duration, has been shown to be beneficial in interrupting continued high velocity transport. This was evidenced on farms where the response time of the farm hydraulic system (i.e., the time required from pump start-up to the time when the equivalent of one volume of farm canal water is exported) is greater than the pump cycling period. Short period cycling of one hour or less is detrimental and should be avoided.

Level Control – Control of canal water levels is critical in avoiding major velocity excursions, and also to stay away from large deviations of the normal farm canal velocities. Lack of level control or major changes in minimum canal levels have resulted in dominant events at the two farms that did not practice strict canal water level control.

Canal levels should be controlled to give minimum canal depths that do not exceed the maximum velocity recommendation.

Aquatic Weed Control – Weed control programs in the main canals is one of the most productive techniques in reducing the supply of high P content biomass. Physical removal along the entire length of the main canals is expensive to implement and not practical. For that reason, installation of weed-retention booms is recommended to be located at a distance >300 m (984 ft) upstream the main pump station. Spot spraying of weeds closest to the pump station is also recommended. Chemical treatment of major weed infestations will lead to the accumulation of transportable material into the bottom of the canal and is not recommended.

Influence of Floating Aquatic Weeds on Everglades Agricultural Area Farm P Loads

To achieve additional reductions in the EAA farm P exports through improvements in BMP implementation, the processes of P cycling, especially particulate P production in farm canals require better elucidation. In EAA farm canals the predominant floating or emergent aquatic plant species are water lettuce (*Pistia stratiotes*), water hyacinth (*Eichhornia crassipes*), and water pennywort (*Hydrocotyle verticillata*). These three fast-growing aquatic plants are capable of quickly covering a farm's entire system of canals and ditches, effectively inhibiting drainage of farm fields and increasing canal drainage velocities.

To begin the process of garnering the necessary information to enable the determination of the feasibility of controlling the growth and senescence of aquatic weeds, monitoring of the weed growth mass in the main canals and field ditches over the course of two weed cycles was determined. Additionally, the P content of the weeds was determined in order to calculate P removal or P re-introduction potentials. Aerial surveys of the farm main canals, coupled with ground surveys of the field ditches, were undertaken for a two-year period. These surveys yielded the total area of surface waters covered by aquatic weeds. 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. The aerial reconnaissance cycle began in July 2000 and ended in June 2002.

As additional assessment of possible P load reductions from EAA farms, the influence of these floating aquatic weeds 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 (DeBusk and Dierberg, 2003). 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. The impacts of controlling emergent aquatic weed and drainage flow velocity were assessed and demonstrated at the Everglades Research and Education Center's BMP Demonstration Farm. The BMP demonstration sugarcane farm consists of two hydraulically isolated sugarcane blocks of 125 and 200 acres each. Each block is equipped with identical drainage pumps and monitoring instrumentation to record rainfall, flow, canal levels and to collect discrete hourly drainage water samples. The BMP farm was established to demonstrate to growers the operational differences between an optimized BMP sugarcane farm and a conventional BMP sugarcane farm. Demonstration farm data, i.e., drainage volume, P species concentrations, total suspended solids, canal levels, flow velocities, and rainfall were analyzed to assess the effectiveness of optimized BMPs. This study compared the effects of velocity control and floating aquatic weed management on particulate, dissolved, and total P farm loads.

It was demonstrated that an aquatic weed crop serves as a substantial reservoir for P during a season. A process by which the weeds could be grown as a crop and incorporated into a management practice to mitigate total P loading is not currently foreseeable. It is apparent that controlling the growth of weeds by conscientious and consistent spraying, to minimize huge infestations of macrophytes in the canals, will reduce particulate production and subsequent particulate P loads. Equally apparent from this study and past studies, is that aquatic plants and animals can significantly affect the P cycle, and hence P loading, in EAA farm canals. The physical removal of weeds from open channels should help limit the available P in the water column. However, a system must be devised that minimizes major dislodgment of detritus during weed removal. There are many factors that contribute to a very complicated phosphorus cycle in an EAA farm canal and ditch system. With that understanding, and beyond the obvious notion that the physical removal of aquatic weeds from the canal and ditch systems will remove a substantial amount of P from the water column, there is no clear indication that a simple and sustainable management practice can be devised for incorporating the intentional growth and removal of aquatic weeds into a total P load reduction BMP.

A second goal of this task was to assess and demonstrate the combined effects of drainage flow velocity and floating aquatic weeds on the P loads exported in the drainage waters from sugarcane fields. Results confirm the hypothesis that particulate P source control (removal of floating aquatic weeds) 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 most likely is a 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 present arrangement it is difficult to determine what fraction of the P load reduction is due to source control and what fraction is due to critical velocity control. The efficacy of each practice may be determined separately. Blocks could be operated with identical velocity controls and differing levels of aquatic weed control. Contributions to P load from controlled aquatic weed growth vs. uncontrolled weed growth could then be compared. Conversely, both blocks could be operated with identical levels of control of floating aquatic weeds and different drainage velocities to compare the effect of velocity on P load.

Effects of BMPs on Crops and Soil

A large-scale lysimeter demonstration project was started in December 1997 to understand the efficacy of various proposed BMP strategies and potential impacts of BMP implementation on long-term soil fertility and crop production trends. The lysimeter site included 25 lysimeters: 11 smaller units dedicated to vegetable (crisphead lettuce) and rice cropping systems and 14 larger units planted to sugarcane. The sugarcane lysimeter assessment was designed to demonstrate the effects of higher than traditional water table (WT) levels (that occur under BMP implementation) on 3 popular sugarcane cultivars as well as the effects of delivering nutrient-rich drainage waters (P-fertigation) to sugarcane. The vegetable/rice lysimeter study was designed to demonstrate short- and long-term soil fertility and crop nutrient uptake trends for different vegetable/rice/flooded fallow crop rotations. Drainage waters from the vegetable/rice lysimeters served as the P-fertigation source into select sugarcane lysimeters.

Averaged across all lysimeter treatments for the entire duration of the 36-month study period the vegetable/rice P export (122 lbs P/ac) was almost eleven times greater than the P amount exported by sugarcane (11 lbs P/ac). This large difference arose from the great difference in fertilizer P input into the two systems. The vegetable/rice treatment received approximately 6.6 times greater fertilizer P input than the sugarcane treatments.

Water extractable P soil test values in the sugarcane lysimeters did not change appreciably over the course of the project and the treatment that included vegetable irrigation waters did not show any marked increase in soil test P. Water extractable soil test P levels for the vegetable/rice treatments increased while fertilizer P was being applied at high rates, but once water extractable soil P levels reached a plateau (~40 lbs P/ac), resultant fertilizer P additions were subsequently reduced, soil P levels decreased to approximately 30 lbs P/ac.

Depth of water table had no effect on P load exported from sugarcane grown under two water table regimes, 18 to 24 inch and 14 to 20 inch water tables. The sugarcane treatment that received vegetable drainage water exported 2.7 times more P in drainage waters than sugarcane that did not receive vegetable drainage water.

From this field lysimeter assessment it appears that routing vegetable and rice drainage waters through sugarcane fields is an effective practice to lower vegetable drainage water P loads, but is somewhat limited by the timing and intensity of the specific rainfall event and the stage of growth of the sugarcane receiving the drainage water.

Project Conclusions

- Results of over 10 year BMP research on EAA farms have shown the efficacy of implemented BMPs. Each farm in the EAA implements a suite of BMPs totaling 25 points. Success is observed on individual farms, and on the EAA basin as a whole. The Everglades Forever Act (EFA) mandates a 25% load reduction of P from the EAA basin. The average reduction is measured and calculated by the SFWMD after adjusting to rainfall. The total P load reduction in WY 2004 was 64% and the last three-year average total P reduction is 55%. Total P concentrations from the EAA have also decreased. The actual WY 2004 total P concentration from the EAA with BMPs implemented is 69 ppb. Prior to BMP implementation, the average EAA total P concentration was 173 ppb.

- Specific conductance was not an issue in the majority of the EAA farm canals monitored. Out of the ten farms that were monitored, only two had average specific conductance higher than 1.275 mS/cm. Specific conductance in the EAA canals is strongly influenced by the composition of the shallow ground water, historically reported to be high in Na^+ and Cl^- due to connate seawater entrapment and the mixing of surface and ground water. The effect of drainage pumping was variable and site specific. Canal specific conductance is governed mainly by the quality and the hydrology of the underlying shallow ground water, which is farm specific. Fertilizers contributed a very small percentage to the total dissolved solids in the drainage water therefore had no substantial contribution to specific conductance in the EAA. Current P load reduction BMPs have reduced specific conductance in some locations in the EAA. It is the conclusion of this study that no further BMPs can be identified by additional research that would provide abatement of specific conductance in the discharge in the EAA. The issue of specific conductance in the EAA is a geological one, and shallow ground water is the major factor controlling the level of specific conductance in the EAA farm canals.

- Results from the particulate P research, that included monitoring of three farm operations as well as aerial survey of two farms, indicate that there are certain operating procedures when implemented could lead to reductions in the transport of particulate P and therefore overall P export. This should help substantially with reducing P spikes that are occasionally observed in farms' concentrations and loads. Aquatic weeds in EAA farm canals are a major source of particulate P loads. Increased particulate P loads 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. Increased particulate P load rates may also occur from transport of large amounts of lower P content sediment material over a short period of time. This type of increased particulate P load rate could occur during high pumping rate events, that causes canal level to drop close to the bottom, increasing flow velocity, and resulting in the dislodging and transport of base sediment material in the canal.

- Recommendations to reduce particulate P loads and occasional spikes include reducing velocity in canals, maintaining a minimum canal level, and controlling the growth of macrophytes in farm main canals. Reducing velocity in the canals will reduce the loads of particulate P transported off the farm especially the lower P content sediment material. Reducing velocity in canals can be achieved by pumping at a slower rate for a longer period of time and practicing canal level control. In the EAA, pumping rates may be easily doubled or tripled by running multiple pumps or switching from small to large capacity pumps. Velocities may also change rapidly when canals are drawn down to low levels. Floating aquatic weeds contribute to the readily transportable biological materials close to the pump station, but the best approach for aquatic weed management may not be straight forward. Weed booms are recommended to keep the floating aquatic weeds away from the pump station. Spot chemical treatment is also recommended to control aquatic weeds and prevent major infestation. Chemical treatment of major aquatic weed infestations, however, will lead to the death and accumulation of highly transportable sediments.

- It was demonstrated that an aquatic weed crop serves as a substantial reservoir for P during a season. It is apparent that controlling the growth of weeds by physical removal and a conscientious and consistent spraying will reduce particulate production and subsequent particulate P loads. Spraying heavily infested canals with aquatic weeds will lead to the accumulation of highly transportable biological materials and is not recommended. A process by which the weeds could be grown as a crop and incorporated into a management practice to mitigate total P loading is not currently foreseeable. Data from the demonstration farm at the Everglades Research and Education Center confirm the hypothesis that particulate P source control (removal of floating aquatic weeds) and application of critical velocity limits lead to measurable P load reductions. The observed P load reduction in the BMP block most likely is a 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). Results from the lysimeter study show that the vegetable/rice P export was approximately 11 times greater than the P amount exported by sugarcane. This difference arose from the great difference in fertilizer P input into the two systems. The vegetable/rice treatment received approximately 6.6 times greater fertilizer P input than the sugarcane treatments. Water extractable P soil test values in the sugarcane lysimeters did not change appreciably and the treatment that included vegetable irrigation waters did not show any marked increase in soil test P. Water extractable soil test P levels for the vegetable/rice treatments increased while fertilizer P was being applied at high rates but decreased as fertilizer P additions decreased . Depth of water table had no effect on P load exported from sugarcane grown under two water table regimes, 18 to 24 inch and 14 to 20 inch water tables. The sugarcane treatment that received vegetable drainage water exported 2.7 times more P in drainage waters than sugarcane that did not receive vegetable drainage water. From this field lysimeter assessment it would appear that routing vegetable and rice drainage waters through sugarcane fields is an effective practice, but is limited by the timing and intensity of the specific rainfall event and the stage of growth of the sugarcane receiving the drainage water.