Long-term Water Quality Trends after Implementing Best Management Practices in South Florida

Samira H. Daroub* and Timothy A. Lang University of Florida
Orlando A. Diaz South Florida Water Management District
Sabine Grunwald University of Florida

A mandatory best management practices (BMP) program was implemented in the Everglades Agricultural Area (EAA) farms basin-wide in 1995 as required by the Everglades Forever Act to reduce P loads in drainage water reaching the Everglades ecosystem. All farms in the EAA basin implement similar BMPs, and basin wide P load reductions have exceeded the 25% reduction required by law; however, differences remain in water quality between subbasins. Our objective was to determine long-term trends in P loads in discharge water in the EAA after implementing BMPs for 7 to10 yr and to explore reasons for differences in the performance of the subbasins. Two monitoring datasets were used, one from 10 research farms and the second from the EAA basin inflow and outflow locations. Mann-Kendall trend analysis was used to determine the degree of change in water quality trends. A decreasing trend in P loads was observed in general on sugarcane (*Saccharum officinarum* L.) farms, while mixed crop farms showed either decreasing or insignificant trends. The insignificant trends are probably related to management practices of mixed crop systems. Decreasing trends in P loads were observed in the outflow of the EAA basin, S5A, and S8 subbasins from 1992 to 2002. Inflow water from Lake Okeechobee had increasing P concentration from 1992 to 2006 with the highest trend in the east side of the lake. This analysis indicated there may be other factors impacting the success of BMPs in individual farms including cropping rotations and flooding of organic soils. Elevated P concentrations in Lake Okeechobee water used for irrigation may pose a future risk to degrade water quality on farms in the EAA, especially in the S5A subbasin.

Published in J. Environ. Qual. 38:1683–1693 (2009).
doi:10.2134/jeq2008.0462
Received 27 Oct. 2008.
*Corresponding author (sdaroub@ufl.edu).
© ASA, CSSA, SSSA
677 S. Segoe Rd., Madison, WI 53711 USA

Best management practices have been implemented in the United States and worldwide to reduce P pollution, eutrophication, algal blooms, fish kills, and improve water quality (Sharpley et al., 2000; D'Arcy and Frost, 2001; Sharpley et al., 2001a, 2001b; Wang et al., 2006; Zeimen et al., 2006, Way, 2007; Keipert et al., 2008). Best management practices for P include manure management (Penn et al., 2007; Sharpley et al., 2007; Garcia et al., 2008), soil testing, and use of P indices (Sims et al., 2000; Sharpley et al., 2003, 2008; DeLaune et al., 2004; Johnson et al., 2005). Other BMPs target P transport mechanisms in the watershed (McDowell et al., 2001; Hansen et al., 2002; Kleinman et al., 2006; Sharpley et al., 2008). A mandatory BMP program for reducing P loads from the EAA farms in south Florida was implemented basin-wide in 1995 as required by the Everglades Forever Act (EFA) passed by the Florida State Legislature in 1994. The EAA basin, located south and east of Lake Okeechobee and north and west of three water conservations areas (WCA) in Florida is unique as it is comprised of organic soils (Histosols) that have been artificially drained, totaling approximately 280,000 ha of flat landscape. Nearly 70% of the EAA is planted to sugarcane with lesser coverage of vegetables, sod, and rice (*Oryza sativa* L.) (Rice et al., 2002b).

To farm successfully, growers in the EAA must actively drain their fields via an extensive array of canals, ditches, and large volume, low lift, pumps. Excess water is pumped off farms into South Florida Water Management District (SFWMD) conveyance canals, from which it is pumped to stormwater treatment areas (STA). After treatment, water is sent southward to the WCAs and the Everglades National Park (ENP). Concerns about the quality of drainage water leaving the EAA basin and entering the ENP prompted the legislature to adopt the Everglades Regulatory program, part of the EFA. The main objective of the program is to reduce P loads from the EAA basin by 25% or greater compared to a 10-yr, pre-BMP baseline period which spans from 1978 to 1988. The program includes the establishment of STAs to further clean the water. The

S.H. Daroub and T.A. Lang, Everglades Research and Education Center, Univ. of Florida, Belle Glade, FL 33430; O.A. Diaz, South Florida Water Management District, West Palm Beach, FL 33411; S. Grunwald, Soil and Water Science Dep., Univ. of Florida, Gainesville, FL 32611.

Abbreviations: BMP, best management practices; EAA, Everglades Agricultural Area; EFA, Everglades Forever Act; ENP, Everglades National Park; FWTP, flow-weighted total phosphorus concentration; SFWMD, South Florida Water Management District; STA, storm water treatment area; UAV, unit area drainage volume; UAL, unit area phosphorus load; WCA, Water Conservation Area; WY, water year.

regulatory program also mandates a research program to be conducted in cooperation with the EAA landowners for evaluation and implementation of P BMPs. The EAA basin, divided into four hydrologic subbasins, is monitored for runoff volume and P concentrations by the SFWMD to determine compliance by water year (WY) (1 May–30 April). Phosphorus load reductions are calculated annually using a model that compares the basin P load to a pre-BMP baseline load (Van Horn et al., 2008).

Growers in the EAA are required to implement a suite of BMPs and conduct monitoring of daily rainfall, drainage water volume, and drainage water P concentrations. This is done through a BMP permit issued by the SFWMD. A point system is used to rate the BMPs; the suite of BMPs implemented must total 25 points as a base level of effort (Sievers et al., 2003; Daroub et al., 2004). Growers choose BMPs from a list that has four main categories: (i) soil testing and application of P fertilizer according to calibrated soil test; (ii) controlled P fertilizer application methods; (iii) water management practices; and (iv) sediment source and transport controls. Two BMPs employed by most EAA growers are soil testing and banding of P fertilizer using specialized application equipment. Farm basins differ in their water management BMPs, for example, the amount of rainfall they detain before drainage pumping is initiated. Rainfall detention amounts are 12.7, 25.4 or 38.1 mm. In general, less drainage discharge is needed for a sugarcane crop compared to a mixed cropping system, as sugarcane can tolerate high water tables and occasional flooding (Glaz et al., 2004a). The organic soils of the EAA have undergone considerable subsidence due to oxidation of organic matter and shallower soils need more frequent drainage to farm successfully, especially for vegetable crops (Snyder et al., 1978). Shih et al. (1979) reported a subsidence rate of 2.54 cm per year across the EAA. More recent studies have remeasured surface elevation along base subsidence lines and concluded that the average subsidence rate has decreased to 1.4 cm during the 19 yr from initial measurements, probably due to the maintenance of a higher water table in recent years (Shih et al., 1998).

A second BMP that varies between farm basins is the number and type of sediment control practices. Farms that employ the 12.7 mm rainfall detention BMP usually adopt additional sediment controls to achieve a 25 point total of BMP points. The sediment control BMPs focus on both minimizing the transport of sediments off the farm and removing accumulated sediments from canals. Examples of sediment BMPs include laser leveling of fields, constructing ditch and canal sumps to trap sediments, low water drainage velocity in the canal, and a canal cleaning program (Daroub et al., 2004, Van Horn et al., 2008).

During the 12 yr since basin-wide implementation of BMPs, the EAA continues to meet the required performance levels of the EFA as evidenced by an average reduction in total phosphorus (TP) loads of a 3-yr rolling average of 46% (Van Horn et al., 2008). The growers in all four subbasins of the EAA implement similar BMPs; however, higher P concentrations and loads have been consistently measured in the S5A and S6 subbasins (located on the east side of Lake Okeechobee) compared to the S7 and S8 subbasins (south side of Lake Okeechobee) (Fig. 1). It is not clear if the P load reduction in discharge water is consistent in all the four subbasins of the EAA. Possible reasons for the differences in P loads between the four subbasins may include the quality of the irrigation water, water management systems, cropping systems, and different soil depths (Daroub et al., 2007). During the dry season (November through May), growers irrigate their crops using irrigation water sourced from Lake Okeechobee which is recharged via rainfall and runoff from watersheds north of the lake. Water quality in Lake Okeechobee has degraded over the past several decades, mainly due to elevated P concentrations resulting from man-induced hydrologic and land-use modifications (Aumen, 1995) and active hurricane seasons in 2004 and 2005 (James et al., 2006). The increased P levels caused by sediment resuspension in the lake (James et al., 2006) and the elevated P concentrations of irrigation water from Lake Okeechobee has lead to concerns about the impact of the irrigation water quality on BMP performance in the EAA.

Our overall objective was to determine the long-term trends in P concentrations and loads in discharge water in the EAA after implementing BMPs and to explore possible reasons for differences in the performance of the subbasins, including cropping system and irrigation water quality. Our specific objectives were to assess: (i) water quality at drainage outlets of 10 farms with different cropping systems within EAA after 7 to 10 yr of implementing BMPs (using BMP research database); (ii) water quality at the drainage outlet of EAA basin and associated four subbasins (using DBHYDRO database of SFWMD); and (iii) irrigation water quality used from Lake Okeechobee on farms in EAA (using DBHYDRO database of SFWMD) for its potential impact on P load reductions in the future.

Materials and Methods

Study Area

The EAA basin is divided hydrologically into four subbasins, S5A, S6, S7, and S8 (Fig. 1). The Histosols (suborder: saprist) of the EAA have a high soil organic matter content (>80%) that is highly decomposed (Snyder and Davidson, 1994). The organic soils of the EAA differ mainly in the depth of the O horizon to the limestone bedrock (Rice et al., 2002a). Soils located close to the east and south shores of Lake Okeechobee (S5A and S6 subbasins) are deeper, with depths >1 m, while soils further south and east of the lake (S7 and S8) are shallower, that is, <1 m (McCollum et al., 1978; Cox et al., 1988; Snyder, 2004). The EAA is located in a subtropical environment and has an average rainfall of 1.27 m per year. The distribution of the rainfall is, however, uneven with 66% occurring during the months of June through October (Ali et al., 2000).

On-farm Best Management Practice Research Program

A comprehensive research and monitoring program to measure the efficacy of BMPs on water quality was initiated on 10 farms in 1992 for a period ranging from 7 to 10 yr (Daroub et al., 2004). The goal of the long-term field research was to test the effectiveness of BMPs on representative farms in the EAA to assess impact on water quality and to optimize BMPs to reduce P loads further. The farm basins were selected to represent a typical

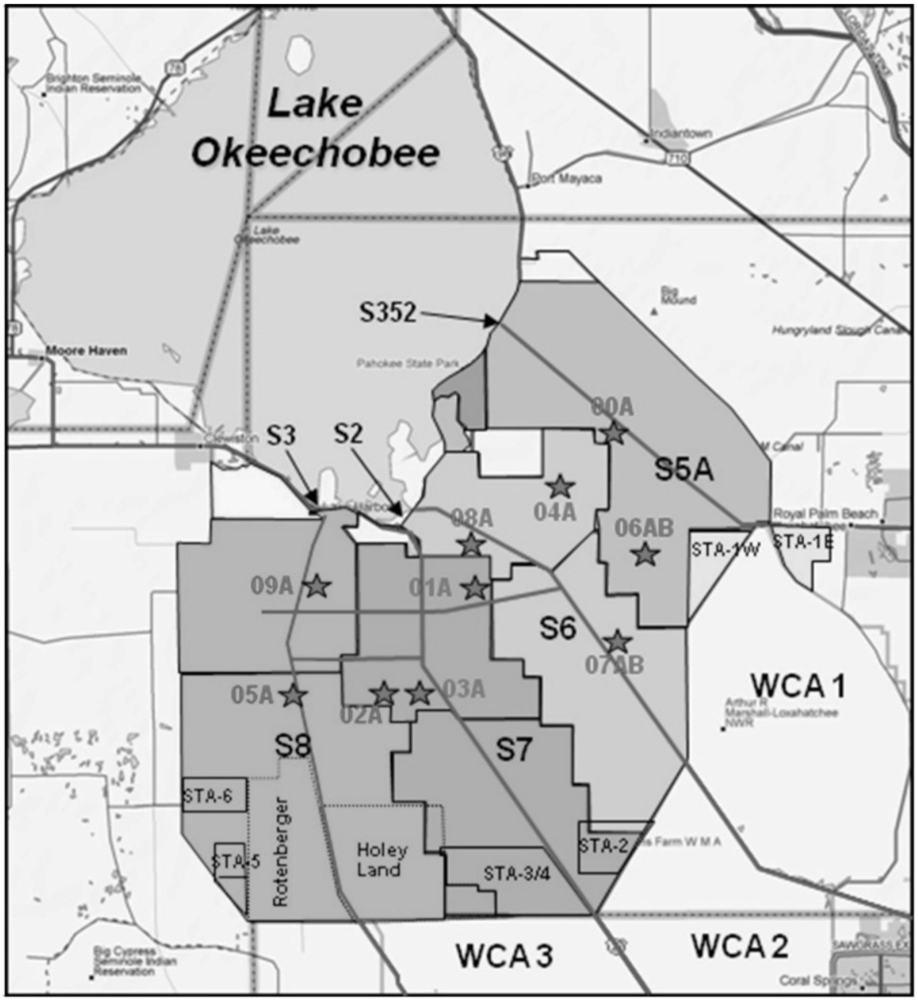

Fig. 1. Location of the ten research farms (indicated by star), sub- basins (S5A, S6, S7, and S8), and irrigation structures from Lake Okeechobee (S352, S2, S3) in the Everglades Agricultural Area in south Florida. Water conservation areas (WCA) and storm water treatment areas (STA) are also indicated on the map.

range of farm sizes, soil types, crop rotations, water management, and geographical distribution across the EAA (Table 1). Six of the farms (00A, 02A, 03A, 04A, 08A, and 09A) had sugarcane as the major crop planted, that is, more than 85% of the farm acreage planted to sugarcane in most years. One exception was farm 08A which switched from being predominantly sugarcane monoculture from 1992 to 1999 to 55% and 29% of the acreage planted to vegetables in 2000 and 2001, respectively. The remaining four farms had mixed-cropping systems: farm 01A was strictly vegetable monoculture; farm 05A was planted to sugarcane, sod, and melons; farm 06A/B was planted to sugarcane, vegetables, rice, sod and trees; and farm 07A/B grew sugarcane, vegetables, rice, and sod.

Monitoring of farm drainage volumes and P concentrations began in July 1992. Best management practices were similar for the 10 farms; differences were noted for rainfall detention amount and are presented in Table 1. Each site's drainage flow was determined using a data logger (Campbell Scientific CR-10, Campbell Scientific, Logan, UT) that was programmed with the site's calibrated pump flow equations and was wired to upstream and downstream pressure transducers and to drainage pump RPM sensors (shaft encoders). The data logger was also connected to a tipping bucket rain gauge (Texas Electronics TE525-WSL, Texas Electronics, Dallas) to measure rainfall and a water sampler (ISCO 3700, ISCO, Lincoln, NE) that was triggered by the data logger to collect a water sample once the requisite amount of drainage flow had been pumped. The water samplers collected 100 mL volume for each sampling and composited the samples into a 4 L pre-acidified bottle. Sample bottles were collected after drainage pumping cessation or once the bottles became full. Water samples were transported, stored, and analyzed following strict Quality Assurance/Quality Control (QA/QC) procedures (Chen, 2001; Chen et al., 2006). The QA/QC procedures included use of spikes, duplicate samples, laboratory and field blanks (Chen et al., 2006). All drainage water samples were analyzed for TP. Samples were digested using the mercury oxide digestion with a block digester AS-4020 (Scientific Instruments Services, Inc., Ringoes, NC) (Method 365.4, USEPA, 1983). After digestion, solutions were analyzed using a Flow IV segmented flow analyzer (OI Analytical, College Station, TX) using the ascorbic acid method (Murphy and Riley, 1962).

Table 1. List of the 10 research farms in the Everglades Agricultural Area, subbasin location, irrigation water source, crops, farm size, average soil depth, and rainfall detention best management practices.

Farm site	Monitoring duration	Subbasin	Irrigation water structure/Canal†	Crops	Farm size	Avg. soil depth	Rainfall detention
	mo				ha	m	mm
00A	118‡	S5A	S352 WPB	Sugarcane	518	1.16	25.4
01A	90§	S6	S2 HB	Mixed	518	0.61	12.7
02A	118	S7	S2 NNR	Sugarcane	130	0.46	25.4
03A	118	S7	S2 NNR	Sugarcane	1865	0.43	12.7
04A	118	S6	S2 HB	Sugarcane	259	1.62	25.4
05A	90	S8	S3 Miami	Mixed	130	0.55	25.4
06AB	118	S5A	S352 WPB	Mixed	710	0.88	12.7
07AB	118	S6	S2 HB	Mixed	1012	0.98	25.4
08A	110¶	S6	S2 HB	Sugarcane	106	0.73	25.4
09A	118	S8	S3 Miami	Sugarcane	1243	0.98	25.4

† Canals being serviced by each irrigation structure: WPB = West Palm Beach canal; HB = Hillsboro canal; NNR = North New River canal.

‡ July 1992 to April 2002.

§ July 1992 to December 1999.

¶ July 1992 to August 2001.

Everglades Agricultural Area Basin Monitoring Program

The second database used was for the EAA basin inflow and outflow drainage flow, TP concentrations and loads obtained for the period of 1992 to 2002 from the SFWMD DBHYDRO database (http://my.sfwmd.gov/dbhydroplsql/show_dbkey_info.main_menu). The SFWMD monitors current inflow and outflow points defining the boundary of the EAA. Thirty water control structures defined this boundary for the EAA, and discharge TP samples were collected at 27 locations as of WY 2003. All monitoring locations in the EAA are equipped with automatic samplers. During discharge events, TP samples are collected primarily by automatic samplers that are programmed to collect samples on a flow proportional basis. Samples are composited at the end of the collection period (normally every 7 d). The data were aggregated into the S5A, S6/S7, and S8 subbasins. The S6 and S7 subbasins have the same inflow structure (S2), although they are monitored separately for outflow (Van Horn et al., 2008)

Using the DBHYDRO database, monthly means of inflow water TP concentrations were analyzed from 1992 through 2006 for the three inflow structures into the EAA (S352, S2, and S3) to determine the impact of the 2004 and 2005 hurricane seasons on irrigation water TP concentration trends. The EAA inflow TP concentrations represent irrigation water TP concentrations. Structure S352 provides irrigation water to the West Palm Beach Canal, which services farms in the S5A subbasin. Structure S2 provides irrigation water to the North New River and Hillsboro canals. The North New River Canal services farms in the S7 subbasin; the Hillsboro Canal services farms in the S6 subbasin. Structure S3 provides irrigation water to the Miami Canal which is the source of irrigation water for farms in the S8 subbasin (Fig. 1).

Statistical Data Analysis

Histograms of the 10 on-farm BMP research project were constructed to observe the data distributions of the variables using data summarized by WY (1 May through 30 April). Summary statistics of major variables are presented in notched box plots. Notched box plots provide a schematic graphical summary of important features of a distribution that includes the minimum and maximum range values, upper and lower quartiles, mean and median.

Trend analysis was conducted on the monthly on-farm research project data, on the monthly EAA basin monitoring data and on monthly means of irrigation water data to determine trends over time in each farm location, EAA basin, and from each inflow structure using Mann-Kendall analysis (Gilbert, 1987; McBride, 2005). The SAS program used for Mann-Kendall trend analysis was adapted from Winkler (Winkler, 2004) and includes Sen's Slope analysis, which determines the degree of change in trend. The program uses monthly data to determine if seasonality is present in the data, and if it is, then a seasonal Kendall test is conducted. If seasonality is not found in the monthly data, then the nonseasonal Mann-Kendall test is run. The Seasonal Kendall test (Hirsch et al., 1982) has been recommended for water quality time series (Gilbert, 1987). The nonparametric test is applicable to time series containing values which are missing, below detection limits, and/or influenced by seasonal factors (Walker, 1991). For the trend analysis, season was delineated into two categories: wet and dry, two distinct seasons in south Florida (Ali et al., 2000). Wet season was defined as the months of June to October and dry season as the months of November to May. The test first ranks all observations by date order, then the difference between each successive value is calculated, and the sum of the signs of those differences is evaluated as the Kendall sum statistic, or K value (Winkler, 2004). Kendall K is compared to a critical value for the significance of trend depending on the number of observations (Hollander and Wolfe, 1999). The seasonal Kendall test works on the same principal as the Mann-Kendall test, the main difference being that the Kendall K is calculated for each season and then summed (Winkler, 2004). The seasonal test accounts for the fact that there may be significant differences between data obtained in one season vs. another. Spearman correlation, a nonparametric test, was conducted to test correlation between variables (McBride, 2005).

Results and Discussion

Summary Statistics of On-farm Data

Mean yearly rainfall was somewhat uniform across all farms, ranging from a low of 1146 mm at 07AB to 1308 mm at 06AB; however, rainfall amounts varied by year as illustrated by the distribution lines which indicate the minimum and maximum rainfall values (Fig. 2a). There are major differences in unit area drainage volume (UAV) between farms (Fig. 2b). Four farms (02A, 03A, 04A, and 08A), all of which are sugarcane farms had a mean drainage volume of 400 mm or less and a SD of <150 mm. Three additional farms (00A, 07AB, and 09A) had a mean drainage volume above 400 but <600 mm. Farms 00A and 09A are also sugarcane farms, but 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 millimeters of 750 for 01A (SD of 410 mm), 959 for 06A/B (SD of 227 mm), and 1465 for 05A (SD of 663 mm). 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 is a small farm (130 ha) and the yearly unit area drainage volume varied considerably ranging from a minimum of 478 mm to a maximum of 2420 mm (Fig. 2b) indicating a seepage problem from the Miami canal. These findings indicate that in general farms with a sugarcane crop have less drainage volume.

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 small sugarcane farm (106 ha) located in the S6 subbasin with an average soil depth of 0.73 m. Excluding farm 05A, which had seepage problems and very 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, respectively. Farm 01A is strictly a vegetable farm in the S6 subbasin with an average soil depth of 0.6 m and farm 06A/B is a mixed crop farm located in the S5A subbasin with an average soil depth of 0.88 m. Both of these farms claim 12.7 mm rainfall detention mandated by shallow soils and crops that are water sensitive. Research has shown that sugarcane maintains optimum yields through a wide range of water tables (Glaz et al., 2004b) and cultivars with constitutive aerenchyma should be able to tolerate flooded conditions of at least 1 wk (Glaz et al., 2004a). Vegetables are water sensitive and cannot tolerate flooding or high water tables (Snyder et al., 1978).

Out of the 10 farms, four (02A, 05A, 08A, and 09A), had a mean yearly mean flow-weighted total phosphorus concentrations (FWTP) of <0.10 mg L^{-1} (Fig. 3a). All of these farms are sugarcane farms except for 05A. Four farms (00A, 03A, 04A, and 07A/B) had mean yearly FWTP ranging from 0.10 to 0.30 mg L^{-1}. One farm (06A/B) was at 0.33 mg L^{-1} and one farm (01A) at 0.77 mg L^{-1}. The higher concentrations in 06A/B and 01A most probably reflect the higher P fertilizer rates applied for vegetables and other crops compared to sugarcane. By comparison, TP 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

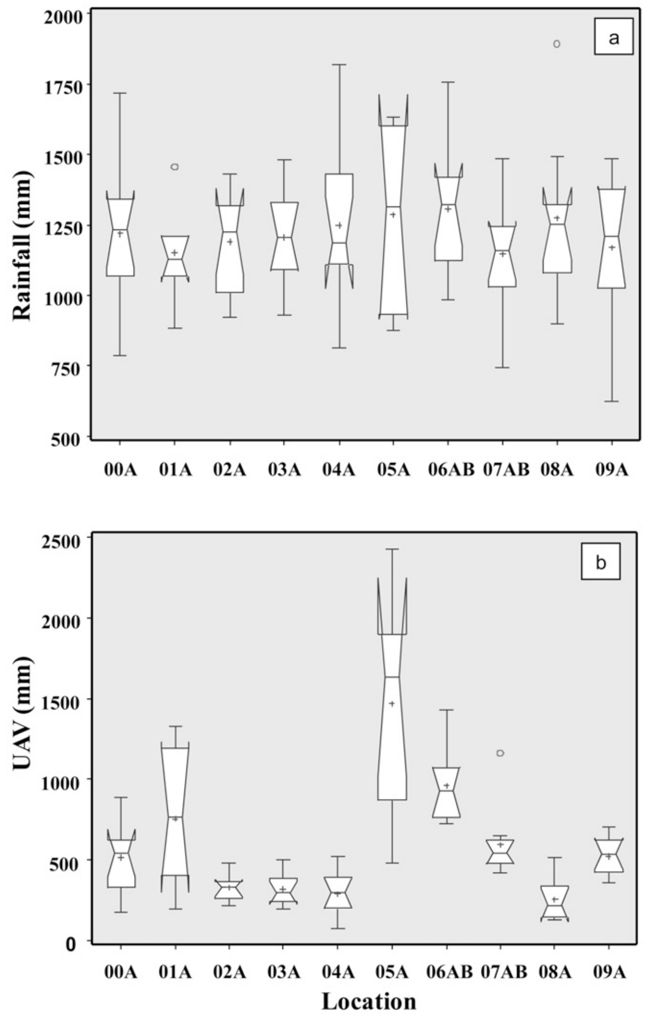

Fig. 2. Box Plot of (a) water year rainfall and (b) water year unit area drainage (UAV) volume for 10 research farms in the Everglades Agricultural Area during the study period. The mean is represented by a + sign, crossbar in box is the median, whiskers extend to the minimum and maximum values, interior of the box is the interquartile region (25th to 75th percentile). Outliers are presented by circles.

2003 (Adorisio et al., 2006). The frequency distribution of TP concentration in the EAA basin calculated from permit data in WY 2005 show that 12% of the farms have a TP concentration <0.05 mg L^{-1}; 24% have a P concentration of 0.05 to 0.10 mg L^{-1}; 23% have a concentration of 0.10 to 0.15 mg L^{-1}, 16% have a concentration of 0.15 to 0.20 mg L^{-1}; and 8% have a TP concentration of 0.20 to 0.25 mg L^{-1}. The rest of the farms (17%) have TP concentration of 0.25 mg L^{-1} or greater (Adorisio et al., 2006).

Farm 01A showed the highest P loads and wide variability of WY unit area phosphorus load (UAL) ranging from 1.03 to 11.6 kg ha^{-1} (Fig. 3b). The mean UAL at 01A was at 6.2 kg ha^{-1} 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. Five farms (02A, 03A, 04A, 08A, and 09A) had an average UAL <0.55 kg ha^{-1} (Fig. 3b). All of these five farms

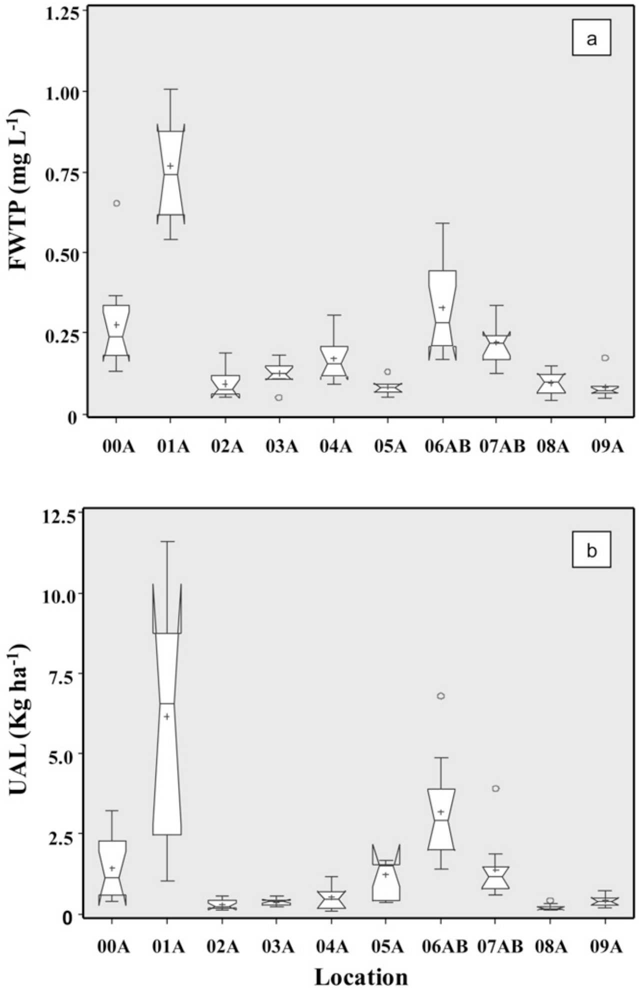

Fig. 3. Box Plot of (a) water year flow-weighted total phosphorus concentration (FWTP) and (b) water year unit area load (UAL) for 10 research farms in the Everglades Agricultural Area during the study period. Symbols are same as Fig. 2.

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 1.40 kg ha^{-1}, while 00A had an 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 in WY 2005 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).

On-farm Water Quality Trends

Trend analysis conducted for the monthly pump to rainfall ratio shows a decreasing trend in three farms (00A, 02A, and 09A) and an increasing trend in one farm (08A) (Table 2). The remaining farms showed an insignificant trend which indicated little change in drainage volume as a result of BMPs on these farms.

Monthly FWTP in farm drainage water showed a decreasing trend for 5 of the 10 farms, with four of these farms being a sugarcane monoculture. No trend was observed for the remaining five farms (Table 3). Of the five farms with no trend, three are mixed crop farms. A decreasing trend was observed in monthly UAL for 7of the 10 farms but the trend was not significant for the remaining three farms (01A, 05A, and 08A) (Table 4). The decrease in P loads reflected reduction in FWTP concentrations coming out of these farms. The farm with the highest decreasing UAL trend is 09A (highest negative Kendall K and Z-Score) and reflects the decrease in both UAV and FWTP trends on this farm. The K value for UAL at 09A was –710, which means there were 710 more negative differences than positive differences. A Z-Score of –3.174 was calculated, and the probability of getting such a score, if in fact there was no trend, was 0.002 (Table 4). In other words, there is 0.2% chance that there is really no decreasing trend of UAL on this farm. It is interesting to note that none of the 10 farms showed increasing FWTP or UAL trends.

Out of the three farms that had insignificant trends in UAL, two had mixed cropping systems (01A and 05A). As mentioned earlier, farm 05A has low FWTP, but has a high volume of drainage water due to seepage problems, thus further reductions of P loads on this farm may not be attainable. Farm 01A, on the other hand, is strictly for winter vegetable production, has relatively shallow soil depth, and claims 12.7 mm rainfall. Vegetable production requires higher fertilizer rates and lower water tables compared to sugarcane production. In addition, farm 01A practices summer flooding of fallow fields which releases P from soils (Reddy, 1983; Newman and Pietro, 2001). Vegetables are grown in the winter in south Florida and fields are normally kept fallow and flooded in the summer or used for rice production. The third farm that had insignificant farm P loading trend was the small sugarcane farm, 08A, which underwent several farm management changes and incorporated sweet corn (*Zea mays* L.) as a rotational crop.

Spearman correlation analysis was used to explore the impact of cropping systems and flooding on farm P loads. The parameters used to ascertain the impact of cropping systems were % sugarcane, % flood, and % fallow+flood. The crop mapping personnel often had difficulty making definitive determinations on flooding or fallow condition for fields that were often intermittently flooded so the two were combined in one variable. Before 1995, land use was checked on a quarterly basis. Starting in 1995, land use maps were updated monthly (Daroub et al., 2007). Spearman correlation analyses on the monthly data indicated that UAL is positively correlated ($P < 0.001$) with UAV (0.85), FWTP (0.51), and % fallow and flood (0.18) (Table 5). Phosphorus UAL was significantly correlated at $P < 0.01$ level with % flood (0.13). It is noted that the correlation coefficients for % flood and % fallow+flood with UAL are small though significant. Unit area loads and FWTP were highly and negatively correlated with % sugarcane in the farm ($P < 0.001$) indicating a positive impact of increased % sugarcane in the cropping rotation on water quality.

Correlation analysis does not identify a cause and effect but merely indicates that a linear relationship may exist. It is a common practice to flood fallow fields in the summer that were used for winter vegetable production and then let flood water evaporate and percolate slowly into the soil which would have no impact on water quality. The farm with the highest percent of flooded acres

Table 2. Trend analysis for monthly drainage volume to rainfall ratio (pump to rain ratio) by farm location for the 10 research farms in the Everglades Agricultural Area.

Site	Months	Kendall K	z-Score	z-Prob	Trend	Season	Sen slope
00A	118	−497	−2.288	0.022	Decreasing	Seasonal	−0.0014
01A	87	−5	−0.029	0.977	Insignificant	Seasonal	0.0000
02A	118	−467	−2.558	0.011	Decreasing	Seasonal	0.0000
03A	118	−86	−0.380	0.704	Insignificant	Seasonal	−0.0001
04A	118	−338	−1.585	0.113	Insignificant	Seasonal	0.0000
05A	90	−321	−1.117	0.264	Insignificant	Nonseasonal	−0.0249
06A/B	118	−399	−1.784	0.074	Insignificant	Seasonal	−0.0225
07A/B	118	−391	−1.770	0.077	Insignificant	Seasonal	−0.0087
08A	110	868	2.328	0.020	Increasing	Nonseasonal	0.0000
09A	118	−1686	−3.923	0.000	Decreasing	Nonseasonal	−0.0356

Table 3. Trend analysis for monthly flow-weighted total phosphorus (FWTP) (mg L^{-1}) in drainage water by farm location for the 10 research farms in the Everglades Agricultural Area.

Site	Months	Kendall K	z-Score	z-Prob	Trend	Season	Sen slope
00A	118	−381	−1.753	0.080	Insignificant	Seasonal	0.0000
01A	87	101	0.729	0.466	Insignificant	Seasonal	0.0000
02A	118	−477	−2.613	0.009	Decreasing	Seasonal	0.0000
03A	118	−1182	−2.753	0.006	Decreasing	Nonseasonal	−0.0056
04A	118	−706	−3.315	0.001	Decreasing	Seasonal	−0.0031
05A	90	−85	−0.293	0.769	Insignificant	Nonseasonal	−0.0001
06A/B	118	−471	−1.095	0.274	Insignificant	Nonseasonal	−0.0041
07A/B	118	−479	−2.169	0.030	Decreasing	Seasonal	−0.0069
08A	110	130	0.685	0.493	Insignificant	Seasonal	0.0000
09A	118	−1291	−3.003	0.003	Decreasing	Nonseasonal	−0.0036

Table 4. Trend analysis for monthly unit area P load (UAL) (kg P ha^{-1}) by farm location for the 10 research farms in the Everglades Agricultural Area.

Site	Months	Kendall K	z-Score	z-Prob	Trend	Season	Sen slope
00A	118	−587	−2.703	0.007	Decreasing	Seasonal	−0.0006
01A	87	−53	−0.192	0.848	Insignificant	Non-seasonal	0.0000
02A	118	−427	−2.339	0.019	Decreasing	Seasonal	0.0000
03A	118	−448	−2.001	0.045	Decreasing	Seasonal	−0.0007
04A	118	−560	−2.629	0.009	Decreasing	Seasonal	0.0000
05A	90	−47	−0.314	0.754	Insignificant	Seasonal	0.0000
06A/B	118	−447	−1.999	0.046	Decreasing	Seasonal	−0.0052
07A/B	118	−453	−2.051	0.040	Decreasing	Seasonal	−0.0016
08A	110	272	1.439	0.150	Insignificant	Seasonal	0.0000
09A	118	−710	−3.174	0.002	Decreasing	Seasonal	−0.0015

Table 5. Spearman correlation coefficients between monthly variables for the 10 research farms in the Everglades Agricultural Area.

Variable†	UAL	UAV	Sugarcane (percent of farm)	Flood (percent of farm)	Fallow and flood (percent of farm)	FWTP
	kg P ha^{-1}	m^3 ha^{-1}	%			mg L^{-1}
UAL, kg P ha^{-1}	1.00					
UAV, m^3 ha^{-1}	0.85***	1.00				
Sugarcane, percent of farm	−0.41***	−0.22***	1.00			
Flood, percent of farm	0.13**	0.05 ns‡	−0.18***	1.00		
Fallow and flood, percent of farm	0.18***	0.13**	−0.52***	0.34***	1.00	
FWTP, mg L^{-1}	0.51***	0.05 ns	−0.43***	0.16***	0.12**	1.00

** Significant at 0.01 level.

*** Significant <0.001 level.

† UAL, unit area phosphorus load; UAV, unit area drainage volume; FWTP, flow-weighted total phosphorus concentration.

‡ ns, not significant.

is 01A, which is a vegetable monoculture farm. The impact of vegetable production management practices, like higher fertilizer rates and lower water tables, could not be separated from impact of flooding in the summer. Flooding the fallow fields preserves the organic soils and controls nematodes and other pests (Hall and Cherry, 1993; Katan, 2000; Snyder, 1987). Flooding of vegetable farms during the summer impacted P concentration, UAL, and flooding increased P release into drainage effluent by about four to eight times in organic soils from south and central Florida (Reddy, 1983). Newman and Pietro (2001) found that immediately following flooding of re-established wetlands on land presently in agricultural production, these wetlands will act as a source rather than a sink of P. Innovative practices to manage the flood water before land preparation for the subsequent vegetable crop may have a positive impact on P concentrations and UAL. These practices include rerouting water around a farm before being discharged to allow for precipitation and adsorption reactions or allow flooded water to evaporate and percolate through soils.

Everglades Agricultural Area Basin and Subbasins Water Quality Trends

Seasonal Kendall analysis of aggregated monthly metrics of flow, concentration, and load by subbasin and the EAA basin from 1992 to 2002 using the SFWMD DBHYDRO database was conducted (Table 6). Inflow parameters indicate what is entering each subbasin and EAA from Lake Okeechobee. Outflow parameters indicate what is leaving each subbasin and EAA to downstream ecosystems. The trend analysis was conducted for the same period as that of the research farms (1992–2002). All the inflow parameters (flow, concentration, and load) had insignificant trends during that time period except for inflow P concentrations from the S5A subbasin (S352 structure) with an increasing trend (Kendall K of 1128 and Sen's slope 0.00964 mg L^{-1} yr^{-1}) (Table 6). This suggests that irrigation water P concentration into the S5A basin was increasing during the time period of 1992 to 2002. The outflow drainage and runoff from the different subbasins and the EAA basin had significant decreasing trends except for the S8 subbasin. This indicated lower drainage volumes from the subbasins with exception of S8. One logical explanation is the shallow soils in the S8 subbasin with less capacity to hold water.

The outflow P concentrations and loads had a decreasing trend in all subbasins except for the S6/7, which had insignificant trends in both concentrations and loads. The decreasing trend in the S5A subbasin is a combination of decreasing trends in P concentrations and drainage flow despite the increasing inflow trend in P concentrations. The pronounced decreasing trends in concentration and loads out of the EAA basin and subbasins despite the insignificant trends in the inflow parameters clearly indicate the success of the BMP program in the EAA. Phosphorus may have been used by the crops, retained in the soil due to adsorption (Porter and Sanchez, 1992) and precipitation reactions, or retained in canal sediments (Stuck et al., 2001). Farm canals accumulate organic sediments rich in P from biological growth in the canals (Stuck et al., 2001). Management practices to control floating aquatic vegetation growth, including mechanical harvesting and chemical spraying, are used at various levels. Dredging canal sediments is done on some farms once every few years with sediments returned to the field. These practices control the transport of sediments and particulate P and may reduce the loads coming out of EAA farm with canal sediments acting as sink for P (Stuck, 1996; Stuck et al., 2001).

Irrigation Water Quality Trend Analysis through 2006

The potential impact of irrigation water quality on BMP performance in the EAA was evaluated by trend analysis of irrigation TP concentrations (inflow concentrations) from 1992 to 2006 from the three inflow lake structures into the EAA. The analysis was done for the period of 1992 to 2006 to capture the impact of the two hurricane seasons of 2004 and 2005. One trend analysis was conducted on irrigation water P concentration data collected during flow conditions. A second analysis was conducted on data for all samples collected at the structure, which includes samples collected under both flow and nonflow (ambient) conditions. Trend analysis results of flow conditions revealed significant increasing trends for irrigation water P concentration for two of the three structures (Table 7). In addition a seasonal difference was observed at structure S-352, but not at S-2 and S-3 indicating a difference in irrigation water quality between the wet and dry season at S-352. Results of the trend analysis using all data collected under flow and ambient conditions showed an increasing trend for all three inflow structures (Table 7, Fig. 4). A seasonal effect was observed at two structures, S-2 and S-352 but not at S-3. Kendall K (7224) with a Z score of 6.513 and sen slope of 0.0075 mg L^{-1} yr^{-1} was observed at the S-352 structure during flow conditions indicating the greatest increase in P concentration out of the S-352 structure. The increase is equivalent to 0.105 mg L^{-1} over a 14 yr period. This analysis confirms that P concentration of irrigation water supplied to the EAA basin has been increasing due to the impact of 2004 and 2005 hurricane seasons and is greatest at the S-352 structure that supplies irrigation water to the S5A subbasin through the West Palm Beach Canal. Total P concentrations in the Lake had a mean of 0.10 mg L^{-1} until 1995 and increased in the following 5 yr to an average of 0.14 mg L^{-1} (James et al., 2006). Two active hurricane seasons in 2004 and 2005 resulted in much higher TP concentration in the Lake compared to the previous 10-yr average, for example, average P concentration for WY 2005 was 0.236 mg L^{-1} reflecting the impact of the two hurricane seasons.

Clearly, there are differences in irrigation water quality coming from the Lake from the different structures. Based on plant diversity and abundance, Lake Okeechobee has three distinct ecological regions that also have different water quality and physical characteristics (Havens, 2003). There is a littoral zone with shallow water depth along the west and south shore line with low TP concentrations (5–20 μg L^{-1}) (Havens et al., 2004); an adjacent near shore zone with moderate TP concentrations (30–60 μg L^{-1}) and a central pelagic zone that is deep, turbid, light limited, does not support any rooted plants or attached algae (Havens et al., 1995), and has high TP concentrations (>100 μg L^{-1}). These elevated TP values in Lake Okeechobee may pose future risk to degrade water quality on farms in the EAA due to use of irrigation water that is high in P. In particular, S5A subbasin is at risk to be impacted by increasing P levels.

Table 6. Seasonal Mann-Kendall trend analysis of aggregated monthly metrics by subbasin in the Everglades Agricultural Area from 1992 to 2002. Data are from the South Florida Water Management District DBHYDRO database.

Basin†	Months	Kendall K	z-Score	z-Prob	Trend	Seasonal	Sen slope‡
				Inflow flow			
S5A	117	−267	−1.198	0.231	insignificant	yes	−0.330
S6/7	117	−289	−1.299	0.194	insignificant	yes	−0.432
S8	117	−715	−1.682	0.093	insignificant	no	−0.910
EAA	117	−385	−1.728	0.084	insignificant	yes	−2.032
				Inflow concentration			
S5A	105	1128	5.898	0	increasing	yes	0.00964
S6/7	101	175	0.927	0.354	insignificant	yes	0.001638
S8	117	−175	−0.783	0.434	insignificant	yes	−0.00091
EAA	117	692	1.628	0.104	insignificant	no	0.002167
				Inflow load			
S5A	117	24	0.104	0.918	insignificant	yes	0.000
S6/7	117	−190	−0.853	0.394	insignificant	yes	−0.022
S8	117	−425	−1.908	0.056	insignificant	yes	−0.097
EAA	117	−192	−0.860	0.390	insignificant	yes	−0.136
				Outflow flow			
S5A	117	−772	−3.471	0.001	decreasing	yes	−1.293
S6/7	117	−545	−2.448	0.014	decreasing	yes	−1.495
S8	117	−330	−1.481	0.139	insignificant	yes	−0.651
EAA	117	−599	−2.691	0.007	decreasing	yes	−3.540
				Outflow concentration			
S5A	115	−1993	−4.815	0	decreasing	no	−0.00811
S6/7	115	388	0.935	0.35	insignificant	no	0.001103
S8	117	−541	−2.43	0.015	decreasing	yes	−0.00236
EAA	103	−745	−2.12	0.034	decreasing	no	−0.00283
				Outflow load			
S5A	117	−799	−3.592	0.001	decreasing	yes	−0.452
S6/7	117	−340	−1.526	0.127	insignificant	yes	−0.130
S8	117	−584	−2.624	0.009	decreasing	yes	−0.109
EAA basin	117	−662	−2.975	0.003	decreasing	yes	−0.714

† Basin or subbasin name.

‡ Sen slope provides an idea of relative slope of change, slope for concentration is in mg L^{-1} yr^{-1}.

Table 7. Trend analysis of phosphorus concentrations of irrigation water supplied by the three main inflow structures from Lake Okeechobee to the Everglades Agricultural Area subbasins from 1992 to 2006. Data are from the South Florida Water Management District DBHYDRO database.

Lake inflow structure†	Subbasin	N	Kendall K	Z Score	Z Probability	Trend	Season	Sen slope‡
				Samples collected during flow conditions				
S-352	S5A	289	7224	6.513	0.001	increasing	seasonal	0.0075
S-2	S6/7	165	132	0.185	0.854	insignificant	nonseasonal	0.0002
S-3	S8	169	2635	3.581	0.001	increasing	nonseasonal	0.0033
				Samples collected during flow and ambient conditions				
S-352	S5A	537	20,033	8.938	0.001	increasing	seasonal	0.0068
S-2	S6/7	268	1508	2.017	0.044	increasing	seasonal	0.0021
S-3	S8	239	5946	4.813	0.001	increasing	nonseasonal	0.0037

† 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.

‡ Sen slope provides an idea of relative slope of change; slope for concentration is in mg L^{-1} yr^{-1}.

Conclusions

Long-term water quality trends on ten research farms in the EAA showed in general a decreasing trend in P loads on sugarcane farms after 7 to 10 yr of implementing mandatory BMPs. Mixed crop farms, on the other hand, showed either decreasing or insignificant trends. The insignificant trends are probably related to management practices of mixed crop systems, including higher P fertilizer rates compared to sugarcane, and the need to maintain low water tables as indicated by higher pump to rainfall ratios. Correlation analysis showed a positive, but weak, relationship between UAL and flooding fallow fields in the summer after vegetable production. The results of correlation analysis should not be interpreted to mean that flooding increases UAL on all EAA farms. It is a common practice not to discharge flooded water directly, but rather to reroute throughout the farm or let the water seep slowly throughout the fields allowing for P sorption in the organic soils. Trend analysis on P concentrations and loads out of the EAA basin and subbasins showed a decreasing trend from 1992 to 2002. Irrigation water from Lake Okeechobee, on the other hand, was shown to have an increasing P concentration trend from 1992 to 2006, with the highest trend in the pelagic zone on the east side of the lake into the S5A subbasin.

This analysis indicated there may be other factors impacting the success of BMPs in individual farms including cropping

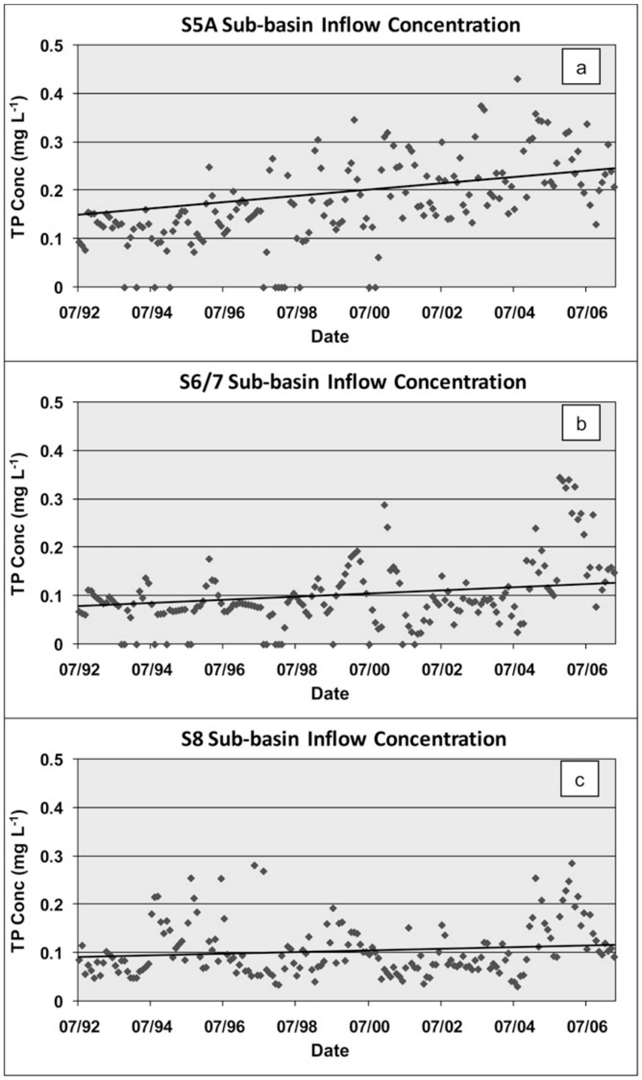

Fig. 4. Inflow P concentration from Lake Okeechobee into (a) S5A subbasin, (b) S6/S7 subbasin and (c) S8 subbasin in the Everglades Agricultural Area basin for the period of 1992 to 2006. Solid line indicates trend lines. Data are from the South Florida Water Management District DBHYDRO database.

rotations, flooding of organic soils, and irrigation water quality. Further analysis of the data to quantify the management and environmental factors that are affecting P loads in the EAA is needed. Use of advanced statistical techniques, for example, multivariate regression and classification and regression tree analysis, to determine the potential impact of irrigation water is critical.

Acknowledgments

This project was funded by the Everglades Agricultural Area-Environmental Protection District. The collaboration and cooperation of the growers in the Everglades Agricultural Area is tremendously appreciated. Support in the form of data, as noted from the South Florida Water Management District, is respectfully appreciated. This project was also supported by the Florida Agricultural Experiment Station.

References

Adorisio, C., C. Bedregal, S.H. Daroub, J. DeLeon, M. Edwards, C. Garvey, J. Madden, P. McGinnes, C. Miessau, D. Pescatore, P. Sievers, S. Van Horn, T. Van Veen, J. Vega, S.K. Xue, and H. Zhao. 2006. Chapter 3: Phosphorus controls for the basins tributary to the Everglades protection area. South Florida Environmental Report. South Florida Water Management District. West Palm Beach, FL. Available at https://my.sfwmd.gov/portal/page?_pageid = 2714,14424186&_dad = portal&_schema = PORTAL (verified 23 Apr. 2009).

Ali, A., W. Abtew, S. Van Horn, and N. Khanal. 2000. Temporal and spatial characterization of rainfall over central and south Florida. J. Am. Water Resour. Assoc. 36:833–848.

Aumen, N.G. 1995. The history of human impacts, lake management, and limnological research on Lake Okeechobee, Florida (USA). Arch. Hydrobiol. Spec. Issues Adv. Limnol. 45:1–16.

Chen, M. 2001. Everglades Research and Education Center quality manual. Everglades Res. and Educ. Center, Inst. Food and Agric. Sci., Univ. of Florida, Belle Glade.

Chen, M., S.H. Daroub, and V. Nadal. 2006. Comparison of two digestion methods for determining total phosphorus in farm canal water. Commun. Soil Sci. Plant Anal. 37:2351–2363.

Cox, S., D. Lewis, S. McCollum, M. Bledsoe, and R. Marrotte. 1988. Subsidence study of the Everglades agricultural area. USDA, Soil Conserv. Serv., Greenacres, FL.

D'Arcy, B., and A. Frost. 2001. The role of the best management practices in alleviating water quality problems associated with diffuse pollution. Sci. Total Environ. 265:359–367.

Daroub, S.H., T.A. Lang, O.A. Diaz, M. Chen, and J.D. Stuck. 2004. Annual report phase XII: Implementation and verification of BMPs for reducing P loading in the EAA and Everglades Agricultural Area BMPs for reducing particulate phosphorus transport. Submitted to the Everglades Agric. Area Environ. Protection District and The Florida Dep. of Environ. Protection. Univ. of Florida, Everglades Res. and Education Ctr., Belle Glade, FL. Available at http://erec.ifas.ufl.edu/WQ/WQ-ReportSum.htm (verified 23 Apr. 2009).

Daroub, S.H., T.A. Lang, O.A. Diaz, and M. Josan. 2007. Management and environmental factors that impact phosphorus loading from Everglades Agricultural Area farms. Final report submitted to the Everglades Agricultural Area Environmental Protection District and the South Florida Water Management District. Univ. of Florida, Everglades Res. and Education Ctr., Belle Glade, FL. Available at http://erec.ifas.ufl.edu/WQ/WQ-ReportSum.htm (verified 23 Apr. 2009).

DeLaune, P.B., P.A. Moore, Jr., D.K. Carman, A.N. Sharpley, B.E. Haggard, and T.C. Daniel. 2004. Development of a phosphorus index for pastures fertilized with poultry litter—Factors affecting phosphorus runoff. J. Environ. Qual. 33:2183–2191.

Garcia, A.M., T.L. Veith, P.J.A. Kleinman, C.A. Rotz, and S.S. Saporito. 2008. Assessing manure management strategies through small-plot research and whole farm modeling. J. Soil Water Conserv. 63:204–211.

Gilbert, R.O. 1987. Statistical methods for environmental monitoring. John Wiley & Sons, New York.

Glaz, B., D.R. Morris, and S.H. Daroub. 2004a. Periodic flooding and water table effects on two sugarcane genotypes. Agron. J. 96:832–838.

Glaz, B., D.R. Morris, and S.H. Daroub. 2004b. Sugarcane photosynthesis, transpiration, and stomatal conductance due to flooding and water table. Crop Sci. 44:1633–1641.

Hall, D.G., and R.H. Cherry. 1993. Effect of temperature in flooding to control the wireworm *Melanotus communis* (Coleoptera: Elateridae). Fla. Entomol. 76:155–160.

Hansen, N.C., T.C. Daniel, A.N. Sharpley, and J.L. Lemunyon. 2002. The fate and transport of phosphorus in agricultural systems. J. Soil Water Conserv. 57:408–417.

Havens, K.E. 2003. Submerged aquatic vegetation correlations with depth and light attenuating materials in a shallow subtropical lake. Hydrobiology 493:173–186.

Havens, K.E., V.J. Bierman, Jr., E.G. Flaig, C. Hanlon, R.T. James, B.L. Jones, and V.H. Smith. 1995. Historical trends in the Lake Okeechobee Ecosystem. VI. Synthesis. Arch. Hydrobiol. Monograph. Beitrage. 107:101–111.

Havens, K.E., B. Sharfstein, T.L. East, and A.J. Rodusky. 2004. Phosphorus uptake in the littoral zone of a subtropical lake. Hydrobiology

517:15–24.
Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. Techniques for trend analysis for monthly water quality data. Water Resour. Res. 18:107–121.
Hollander, M., and D.W. Wolfe. 1999. Nonparametric statistical methods. John Wiley & Sons, New York.
James, R.T., J. Zhang, S. Gornak, S. Gray, G. Ritter, and B. Sharfstein. 2006. Lake Okeechobee protection program-State of the lake and watershed. South Florida Environ. Rep., South Florida Water Management District, West Palm Beach, FL. Available at https://my.sfwmd.gov/portal/page?_pageid = 2714,14424186&_dad = portal&_schema = PORTAL (verified 23 Apr. 2009).
Johnson, A., D. Osmond, and S. Hodges. 2005. Predicted impact and evaluation of North Carolina's phosphorus indexing tool. J. Environ. Qual. 34:1801–1810.
Katan, J. 2000. Physical and cultural methods for the management of soil-borne pathogens. Crop Prot. 19:725–731.
Keipert, N., D. Weaver, R. Summers, M. Clarke, and S. Neville. 2008. Guiding BMP adoption to improve water quality in various estuarine ecosystems in Western Australia. Water Sci. Technol. 57:1749–1756.
Kleinman, P.J.A., A.N. Sharpley, A.M. Wolf, D.B. Beegle, H.A. Elliott, J.L. Weld, and R. Brandt. 2006. Developing an environmental manure test for the phosphorus index. Commun. Soil Sci. Plant Anal. 37:2137–2155.
McBride, G.B. 2005. Using statistical methods for water quality management, issues, problems and solutions. John Wiley & Sons, New York.
McCollum, S.H., E. Cruz, L.T. Stem, W.H. Wittstruck, R.D. Ford, and F.C. Watts. 1978. Soil survey of Palm Beach County area, Florida. USDA/NRCS in cooperation with Univ. of Florida Agric. Exp. Stn., Gainesville.
McDowell, R.W., A.N. Sharpley, L.M. Condron, P.M. Haygarth, and P.C. Brookes. 2001. Processes controlling soil phosphorus release to runoff and implications for agricultural management. Nutr. Cycling Agroecosyst. 59:269–284.
Murphy, J., and J.P. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta 27:31–36.
Newman, S., and K. Pietro. 2001. Phosphorus storage and release in response to flooding: Implications for Everglades stormwater treatment areas. Ecol. Eng. 18:23–38.
Penn, C.J., R.B. Bryant, B. Needelman, and P. Kleinman. 2007. Spatial distribution of soil phosphorus across selected New York dairy farm pastures and hay fields. Soil Sci. 172:797–810.
Porter, P.S., and C.A. Sanchez. 1992. The effect of soil properties on phosphorus sorption by Everglades histosols. Soil Sci. 154:387–398.
Reddy, K.R. 1983. Soluble phosphorus release from organic soils. Agric. Ecosyst. Environ. 9:373–382.
Rice, R.W., R.A. Gilbert, and S.H. Daroub. 2002a. Application of the soil taxonomy key to the organic soils of the Everglades Agricultural Area. EDIS Doc. SS-AGR-246. Florida Coop. Ext. Serv., Inst. of Food and Agric. Sci., Univ. of Florida, Gainesville.
Rice, R.W., F.T. Izuno, and R.M. Garcia. 2002b. Phosphorus load reductions under best management practices for sugarcane cropping systems in the Everglades Agricultural Area. Agric. Water Manage. 56:17–39.
Sharpley, A.N., B. Foy, and P. Withers. 2000. Practical and innovative measures for the control of agricultural phosphorus losses to water: An overview. J. Environ. Qual. 29:1–9.
Sharpley, A.N., S. Herron, and T. Daniel. 2007. Overcoming the challenges of phosphorus-based management in poultry farming. J. Soil Water Conserv. 62:375–389.
Sharpley, A.N., P.J.A. Kleinman, A.L. Heathwaite, W.J. Gburek, G.J. Folmar, and J.P. Schmidt. 2008. Phosphorus loss from an agricultural watershed as a function of storm size. J. Environ. Qual. 37:362–368.
Sharpley, A.N., P.J.A. Kleinman, and R. McDowell. 2001a. Innovative management of agricultural phosphorus to protect soil and water resources. Commun. Soil Sci. Plant Anal. 32:1071–1100.
Sharpley, A.N., R.W. McDowell, and P.J.A. Kleinman. 2001b. Phosphorus loss from land to water: Integrating agricultural and environmental management. Plant Soil 237:287–307.
Sharpley, A.N., J.L. Weld, D.B. Beegle, P.J.A. Kleinman, W.J. Gburek, P.A. Moore, and G. Mullins. 2003. Development of phosphorus indices for nutrient management planning strategies in the United States. J. Soil Water Conserv. 58:137–152.
Shih, S.F., B. Glaz, and R.E. Barnes, Jr. 1998. Subsidence of organic soils in the Everglades Agricultural Area during the past 19 years. Proc. Soil Crop Sci. Soc. Fla. 57:20–29.
Shih, S.F., E.H. Stewart, L.H. Allen, Jr., and J.E. Hilliard. 1979. Variability of depth to bedrock in Everglades organic soil. Proc. Soil Crop Sci. Soc. Fla. 38:66–71.
Sievers, P., D. Pescatore, S. Daroub, J.D. Stuck, J. Vega, P. McGinnes, and S. Van Horn. 2003. Chapter 3. Performance and optimization of agricultural best management practices. Everglades Consolidated Report, Water Year 2002, South Florida Water Management District, West Palm Beach, FL. Available at https://my.sfwmd.gov/portal/page?_pageid = 2714,14424186&_dad = portal&_schema = PORTAL (verified 23 Apr. 2009)
Sims, J., A. Edwards, O. Schoumans, and R. Simard. 2000. Integrating soil phosphorus testing into environmentally based agricultural management practices. J. Environ. Qual. 29:60–71.
Snyder, G.H. 1987. Agricultural flooding of organic soils. Tech. Bull. 870. Agric. Exp. Stn., Inst. Food and Agric. Sci., Univ. of Florida, Gainesville.
Snyder, G.H. 2004. Everglades Agricultural Area soil subsidence and land use projections. 2004. Prepared for the South Florida Water Manage. Dist., West Palm Beach, FL. Available at http://www.evergladesplan.org/pm/projects/project_docs/pdp_08_eaa_store/pdp_08_sub_land_use_report.pdf (verified 23 Apr. 2009).
Snyder, G.H., H.W. Burdine, J.R. Crockett, G.J. Gascho, D.S. Harrison, G. Kidder, J.W. Mishoe, D.L. Myhre, F.M. Pate, and S.F. Shih. 1978. Water table management for organic soil conservation and crop production in the Florida Everglades. Bull. 801. Agric. Exp. Stn., Inst. of Food and Agric. Sci., Univ. of Florida, Gainesville.
Snyder, G.H., and J.M. Davidson. 1994. Everglades agriculture: Past, present, and future. p. 85–115. *In* S.M. Davis and J.C. Ogden (ed.) Everglades, the ecosystem and its restoration. St Lucie Press, Boca Raton, FL.
Stuck, J.D. 1996. Particulate phosphorus transport in the water conveyance systems of the Everglades agricultural area. Ph.D. diss., Univ. of Florida, Gainesville.
Stuck, J.D., F.T. Izuno, K.L. Campbell, A.B. Bottcher, and R.W. Rice. 2001. Farm-level studies of particulate phosphorus transport in the Everglades Agricultural Area. Trans. ASAE 44:1105–1116.
USEPA. 1983. Methods for chemical analysis of water and wastes. U.S. Environmental Protection Agency, Environ. Monitoring and Support Lab., Cincinnati, OH.
Van Horn, S., C. Adorisio, C. Bedregal, J. Gomez, and J. Madden. 2008. Phosphorus source controls for basin tributary to the Everglades Protection Area. South Florida Environ. Rep., South Florida Water Management District, West Palm Beach, FL. Available at https://my.sfwmd.gov/portal/page?_pageid = 2714,14424186&_dad = portal&_schema = PORTAL (verified 23 Aprc. 2009).
Walker, W.W. 1991. Water quality trends at inflows to Everglades National Park. Water Resour. Bull. 27:59–72.
Wang, L., J. Lyons, and P. Kanehl. 2006. Habitat and fish responses to multiple agricultural best management practices in a warm water stream. J. Am. Water Resour. Assoc. 42:1047–1060.
Way, P.L. 2007. Development of a functional, widely accepted and adopted BMP program in response to government regulation. J. Potato Res. 84:39–46.
Winkler, S. 2004. A user-written SAS program for estimating temporal trends and their magnitude. Technical Publ. SJ2004–4. St. Johns River Water Manage. Dist., Palatka, FL.
Zeimen, M.B., K.A. Janssen, D. Sweeney, G.M. Pierzynski, K.R. Mankin, D.L. Devlin, D.L. Regehr, M.R. Langemeier, and K.A. McVay. 2006. Combining management practices to reduce sediment, nutrients, and herbicides in runoff. J. Soil Water Conserv. 61:258–267.