

Assessing Phosphorus Load Reductions Under Agricultural Best Management Practices¹

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Introduction

The Everglades Forever Act (1994) outlined a comprehensive restoration program designed to improve water quality and hydroperiod (water quantity and delivery timing) to the Everglades. Because the Everglades ecosystem evolved as a low-nutrient (oligotrophic) environment, increased deliveries of nutrient enriched waters from both agricultural and urban sources is an important water quality concern. The chemical element phosphorus (P) has attracted the most scrutiny since this nutrient is most likely to encourage undesirable ecosystem changes in aquatic and wetland ecosystems (Federico et al., 1981; Davis, 1994).

The Everglades Agricultural Area (EAA) is geographically located south of Lake Okeechobee and north of the Water Conservation Areas (WCAs). The EAA plays an important role in the Everglades water supply, either directly through agricultural drainage runoff, or indirectly by serving as a conduit for large water transfers from Lake Okeechobee to the WCAs. Drainage waters in the EAA can become

nutrient enriched through crop production inputs, natural mineralization (biological breakdown and nutrient release) of organic "muck" soils, and use of nutrient enriched irrigation waters from Lake Okeechobee. Because water storage options are limited by shallow soils with underlying limestone formations that resist percolation, excess water must typically be pumped off-farm into area drainage canals serving the EAA. This canal network drains a significant portion of EAA runoff into the WCAs through pump stations managed by the South Florida Water Management District (SFWMD).

Chapter 40E-63 of the Everglades Forever Act placed responsibility with the SFWMD to design the EAA Regulatory Program (SFWMD, 1992). This program requires that total P (TP) loads in EAA runoff entering the WCAs must be reduced by at least 25% relative to the 1979-1988 baseline period of record. This basin-level target is to be collectively achieved by all growers through the implementation of best management practices (BMPs) specifically designed to reduce TP discharge from their properties. Chapter 40E-63 also requires growers to

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1. This document is Research Technical Bulletin 905, Florida Agricultural Experiment Station, Institute of Food and Agricultural Sciences, University of Florida. First Published: August 1998; Revised October 2001. Please visit the EDIS Web site at <http://edis.ifas.ufl.edu>. Publications from the Florida Agricultural Experiment Station report results of original research. Results are not intended to make or imply recommendations by the Florida Agricultural Experiment Station, the Institute of Food and Agricultural Sciences, or the University of Florida.
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develop their own water quality monitoring plans consisting of drainage flow measurements and water sample collection at farm structures discharging into works of the SFWMD (Whalen and Whalen, 1996).

Basin-level TP drainage is continuously monitored at seven pump stations operated by the SFWMD. Recognizing that year-to-year differences in rainfall distributions will influence off-farm drainage requirements and overall basin runoff, the SFWMD developed a model which adjusts EAA basin TP discharge for annual rainfall distributions, based on comparisons to the 10-year period of record for similar data (SFWMD, 1992). For the first annual compliance determination (May 1995 through April 1996), the EAA basin recorded a 68% TP reduction (SFWMD, 1996).

The EAA Regulatory Program (SFWMD, 1992) is unique in that it assesses water quality improvements at the basin level rather than at the individual farm level. A farm-scale computer model (EAAMOD-FARM) currently under development will eventually provide growers with a sophisticated tool for designing effective P-reduction BMP systems for their farms (Pickering et al., 1997). At present, growers and water managers need timely feedback regarding the effectiveness of evolving farm BMP programs.

The objective of this publication is to present several methods that can be used to quantify TP reductions under BMP implementation at the farm level. Factors that can complicate or bias the interpretation of farm-level water quality monitoring data will be identified. The discussion will emphasize that meaningful water quality interpretations rely on an adequate assessment of rainfall that occurred during the collection of farm drainage water quality monitoring data.

Water Quality Monitoring Data

In order to monitor farm-level TP discharge, the farm discharge points should be instrumented to automatically collect water samples during drainage events. Some provision must also be made to track discharge flow (or volume) during the drainage event. Details regarding water sampling instrumentation and flow determinations, which

generally involve a pump calibration procedure and the automatic or manual monitoring of canal depth levels, are beyond the scope of this discussion. Suffice it to say that it is important to maintain accuracy and consistency across all monitoring and data collection protocols.

The EAA Regulatory Program (SFWMD, 1992) calls for the collection of composite water samples. Thus, over the course of a drainage event, the automatic water sampler is programmed to obtain an aliquot of water at pre-defined time intervals (say every two hours), with all aliquots combined within a single collection vessel. The TP concentration of this single composited water sample is considered representative of the drainage event (or events).

Raw Data

Included in Table 1 is a listing of raw water quality monitoring data collected over a 1-month period from a single farm discharge structure. Each data entry is representative of a 24-hr period. During the first four days, there was no pumping activity (drainage volume=0 gallons) and the TP concentration is simply left blank since no water sample was collected. The first pumping event, initiated sometime on day 5, produced a drainage volume of 5,119,240 gallons. Over the course of this event, the automated water sampling protocol used at this farm site collected a composite sample with a TP concentration of 0.0882 mg/L.

As shown, Table 1 deliberately contains "mixed" units (English and metric). Although monitoring data are generally collected in English units (gallons), water quality laboratories often report concentrations in metric units (mg/L). Subsequent use of these data to generate other calculated data values will invariably require some form of unit conversion. Details regarding units of measure for English and metric systems and nutrient load calculation protocols for various water sampling strategies are fully discussed in Rice and Izuno (2001).

Calculated Data: Load

A "load" is defined as a mass of a chemical or chemical compound that is moved from one location

to another. The P load for any given farm drainage event is simply the mass of P that is present in the given drainage volume, calculated by the product of the discharge volume with its associated TP concentration value (Equation 1):

$$\text{load} = \text{volume} \times \text{concentration} \times (\text{unit conversion factors}) \quad (1)$$

For the example data in Table 1, the total P load for day 5 is:

$$\begin{aligned} \text{load} &= (5,119,240 \text{ gal}) \times (0.0882 \text{ mg/L}) \times \{(3.785 \text{ L/gal}) \times (0.000001 \text{ kg/mg})\} \\ &= 1.709 \text{ kg}, \end{aligned}$$

which can be converted to English units:

$$\begin{aligned} \text{load} &= (1.709 \text{ kg}) \times (2.205 \text{ lbs/kg}) \\ &= 3.768 \text{ lbs}. \end{aligned}$$

Calculated Data: Unit Area Load (UAL)

Nutrient load calculations are biased by farm size. Direct comparisons of P loads between farms can be misleading since discharge volume is a factor in the load calculation and big farms (with larger watersheds) will typically have greater volumes of water to drain than smaller farms. To avoid this issue, nutrient loads should be "normalized" for farm watershed area and re-expressed as "unit area loads" (UALs) (Equation 2):

$$\text{UAL} = \frac{\text{load}}{(\text{farm area})} \quad (2)$$

The calculation for day 5 UAL (in English units) is:

$$\begin{aligned} \text{UAL} &= (3.768 \text{ lbs}) / (2250 \text{ acres}) \\ &= 0.0017 \text{ lbs/acre}. \end{aligned}$$

Although Table 1 lists daily UAL values, it is more common to discuss UAL values representing longer time periods such as a month or year. Keep in mind that load calculations should be performed on daily data since the calculation (Equation 1) addresses specific discharge volumes and concentrations that occur on any given day. Once the daily load values are calculated, the easiest way to find the monthly UAL value is to calculate all daily

loads (Equation 1), total them to find the monthly load value (177.003 lbs; Table 1), and then divide this value by the farm area (Equation 2) to generate the UAL value for the month (0.0787 lbs/acre). This value can also be found by summing up all daily UALs over the month, but this option is more labor intensive.

Calculated Data: Cumulative UAL

The last two data columns in Table 1 present UAL and rainfall values as cumulative summaries. The cumulative UAL for any given day is simply the total UAL recorded from the first day of monitoring (i=day 1) through the given day of interest (i=day x) (Equation 3):

$$\begin{aligned} \text{cumulative UAL}_{(\text{for day } x)} \\ &= \sum (\text{UAL})_i, \text{ for } i = \text{day } 1 \text{ through } i = \text{day } x \quad (3) \end{aligned}$$

For the provided example (Table 1), cumulative UAL remains at zero over the first four days of monitoring when no pumping occurred. On day 5, cumulative UAL (0.0017 lbs/acre) is exactly equal to the UAL recorded for day 5. Additional pumping activity on day 6 produced a P load of 35.221 lbs (Equation 1) which equates to a UAL of 0.0156 lbs/acre (Equation 2). The cumulative UAL for day 6 is found by applying Equation 3 as follows:

$$\begin{aligned} \text{cumulative UAL}_{(\text{for day } 6)} \\ &= \text{UAL}_1 + \text{UAL}_2 + \text{UAL}_3 + \text{UAL}_4 + \text{UAL}_5 + \text{UAL}_6 \\ &= 0 + 0 + 0 + 0 + 0.0017 + 0.0156 \\ &= 0.0173 \text{ lbs/acre}. \end{aligned}$$

Note that the cumulative UAL value remains unchanged on days when no pumping has occurred. Thus, cumulative UALs remain at 0.0412 lbs/acre from day 10 through day 13 (when UAL=0 lbs/acre). A UAL of 0.0083 lbs/acre on day 14 results in the updated cumulative UAL value of 0.0495 lbs/acre (Table 1). On day 31, the last day of the monthly monitoring period, the cumulative UAL value (0.0787 lbs/acre) is exactly equal to the monthly UAL total recorded for the 31-day period.

Calculated Data: Cumulative Rainfall

Although rainfall is not a direct factor used in load and UAL calculations, an understanding of rainfall and its influence on farm discharge is critically important in the interpretation of water quality trends. The utility of a cumulative rainfall database will become apparent in subsequent discussions. For now, it is only necessary to note that the cumulative rainfall calculation is similar to the cumulative UAL calculation, except rainfall values from $i = \text{day } 1$ through $i = \text{day } x$ are used (Equation 4):

$$\begin{aligned} & \text{cumulative rainfall}_{(\text{for day } x)} \\ &= \sum (\text{rainfall})_i, \text{ for } i = \text{day } 1 \text{ through } i = \text{day } x \end{aligned} \quad (4)$$

Why Cumulative?

Once the cumulative UAL and rainfall databases have been calculated, there is no particular need to focus on any given value for any given day. The important aspect of this exercise is to generate the entire chronological listing of paired daily cumulative UAL and rainfall values. These paired data are useful for generating graphical descriptions of incremental UAL discharge over incremental rainfall. The utility of these graphs for interpreting water quality monitoring data will be discussed shortly.

Factors that Challenge the Interpretation of Monitoring Data

A number of factors can limit the options available for interpreting water quality monitoring data. It has already been mentioned that P load data should be adjusted for farm area since volume discharge requirements can be influenced by watershed size. For example, over similar 15-month BMP monitoring periods (Table 2), the total P load discharged from Farm C (768.2 lbs) was 60% smaller than for Farm B (1947.9 lbs). However, after normalizing for farm area, the total UAL discharged from Farm C (1.200 lbs/acre) was almost three times greater than for Farm B (0.423 lbs/acre).

Time is also a factor that can bias data interpretations. Calculating the total UAL discharge for baseline and BMP periods may serve as a convenient data summary, but these totals should not be compared to one another because the monitoring

time periods differ. For example, the total BMP period UAL (3.251 lbs/acre) for Farm A is 47% greater than for the baseline period (2.206 lbs/acre), largely because BMP data were acquired over an extra 294 days (Table 2).

Normalizing baseline and BMP total UALs by their respective time periods would minimize the effect of dissimilar monitoring time periods. However, subsequent comparisons of these UAL-to-time ratios are not instructive since these ratios fail to address differences in rainfall distributions (and the influence of rainfall on off-farm drainage requirements) that existed during baseline and BMP data collection.

An alternative to comparing UALs for entire monitoring periods is to assess UAL discharge trends over time. A natural inclination is to plot monthly UALs over time but these graphs generally fail to illustrate trend differences between baseline and BMP data. For example, some of the highest monthly UALs on record for a research farm site occurred after the implementation of P-reduction BMPs (Figure 1a). These observations highlight the fact that UALs are influenced by rainfall distributions which vary with season and year (Figure 1b). In the EAA, water removal through gravity and/or deep percolation/seepage is negligible due to flat basin topography, shallow soils, and a relatively impermeable bedrock. Given limited water storage options, farm (and basin) drainage requirements are closely tied to antecedent and current rainfall conditions.

In late-1994, Tropical Storm Gordon caused flooded conditions throughout the 16-county SFWMD regional drainage system which limited the efficient drainage of the EAA basin. During this time period, many farms were operating under BMP plans but, none-the-less, recorded elevated UAL discharges during a year that developed into the fifth wettest on record (SFWMD, 1995).

Clearly, UAL data comparisons between monitoring periods must employ methods that address rainfall profiles that existed during baseline and BMP data collection. The first inclination is to normalize UAL data for rainfall. Attempts to achieve a high degree of resolution by normalizing daily (or

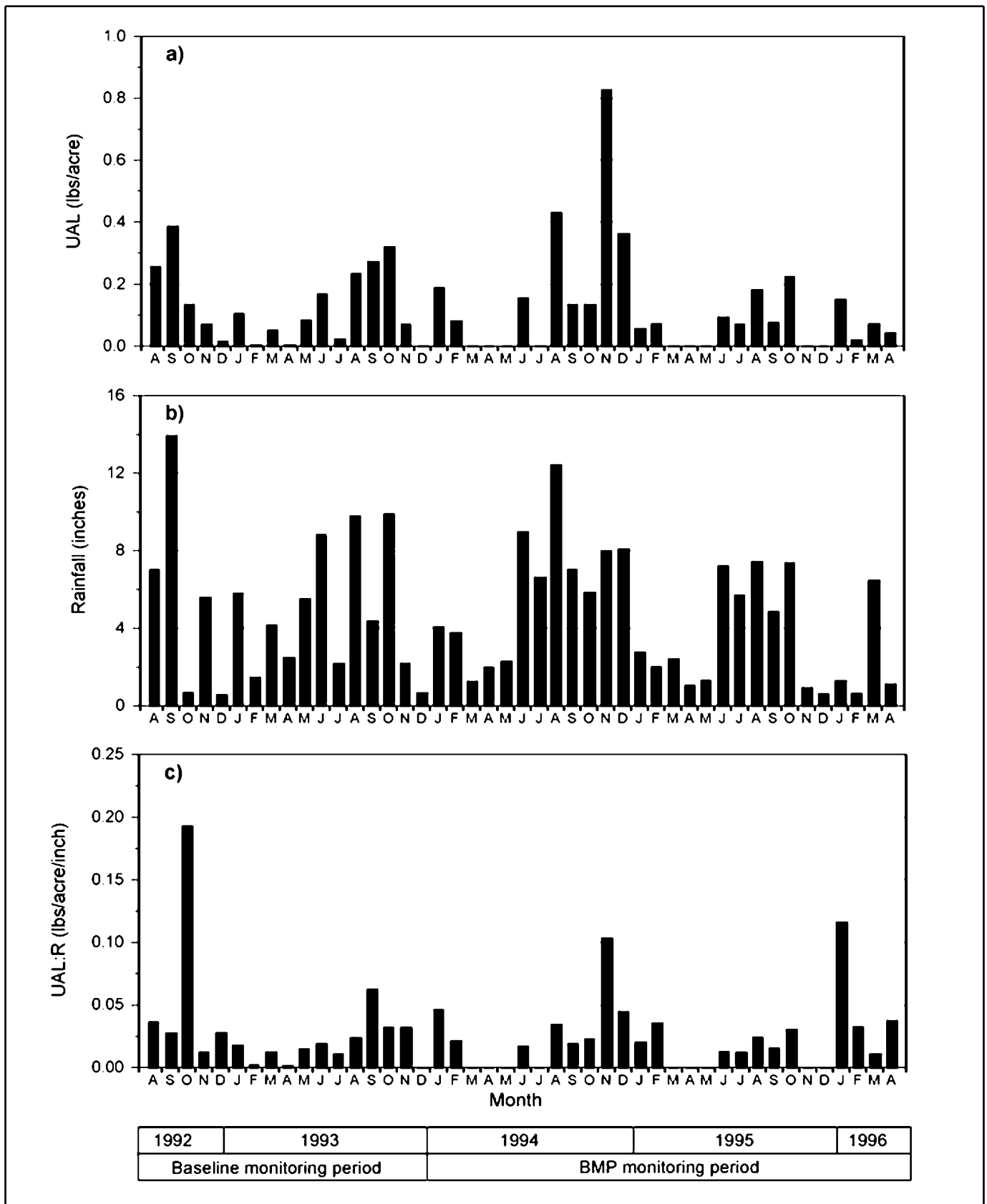


Fig. 1a-c. Example of monthly a) unit area load (UAL), b) rainfall, and c) UAL to rainfall (UAL:R) ratio data for baseline and BMP monitoring periods.

weekly) UAL data by daily (or weekly) rainfall totals are not instructive. A problem arises when there is no rainfall during these short time periods since the UAL-to-rainfall ratio goes to infinity (i.e. dividing by zero) which is not interpretable. Ironically, normalizing by longer monthly increments (Figure 1c) fails to illustrate clear trends over time because resolution is lost regarding daily rainfall distributions and their effect on off-farm pumping requirements.

This point is illustrated herein using data from a research farm site. Note that 1994 rainfall totals were similar in November (8.0 inches) and December (8.1 inches) (Figure 1b), but monthly UALs (0.83 and 0.36 lbs/acre, respectively) were strikingly different (Figure 1a). No additional information is gained by reviewing normalized monthly UAL-to-rainfall ratios (Figure 1c). Inconsistent trends across monthly data values will arise due to the effects of dissimilar daily rainfall distributions on pumping activities. In this example, November rainfall was delivered as a single 3-day tropical storm event and resulting flooded field conditions demanded unusually high discharges. In December, rainfall was distributed over three separate events throughout the course of the month. Under these less extreme rainfall conditions, the grower was able to moderate off-farm discharge activity.

In summary, a number of constraints limit the options available for interpreting south Florida water quality monitoring data. The following section highlights water management trends that have evolved under BMP implementation. Recognizing these trends is useful in the interpretation of water quality data. This section is followed by a presentation of three analytical methods that can provide useful assessments of water quality trends under P-reduction BMP technologies.

Water Management Trends Under BMPs

Many growers have improved on-farm water use efficiency in their efforts to reduce P (i.e. UAL) discharges. In general, crop production operations under BMP implementation will allow a more conservative water management response to rainfall. Popular BMP strategies include redesigning water conveyance networks to enhance farm drainage

uniformity and capacity, hydraulically isolating different crop commodities within contiguous areas to improve water table management, preferentially retaining high-nutrient draindown waters on-farm, using field rather than canal water levels to schedule irrigation and drainage events, maximizing water removal through evapotranspiration losses, extending fallow flooded field storage periods when appropriate, and conducting agriculture under higher than traditional water table levels (Izuno et al., 1995; Bottcher et al., 1995).

Over time, the comprehensive implementation of these strategies (either singly or in combination) gives growers additional flexibility with respect to water management decisions. Thus, under BMP operations, improved control over water within the confines of the farm should lead to reduced off-farm discharge pumping requirements, particularly in response to minor rainfall events.

Assessing P Reductions Under BMP Implementation

Method 1: Comparing Baseline and BMP UAL-to-Rainfall Ratios

Calculating Meaningful Index Ratios

Given the above trends, an overall summary of water management response (discharge pumping) to rainfall can be estimated by normalizing monitoring period UAL totals by their respective rainfall totals (UAL:R). These calculations are performed with Equation 5 and Equation 6, where i =first day through i =last day of the baseline monitoring period and j =first day through j =last day of the BMP monitoring period (Equation 5) :

$$\begin{aligned} & \text{baseline UAL : R ratio} \\ &= \frac{(\text{total baseline period UAL})}{(\text{total baseline period rainfall})} \\ & \text{or,} \\ &= \frac{\left[\sum (\text{daily load})_i / (\text{farm area}) \right]}{\sum (\text{daily rainfall})_i} \end{aligned} \tag{5}$$

and (Equation 6),

$$\begin{aligned}
 & \text{baseline UAL : R ratio} \\
 &= \frac{(\text{total BMP period UAL})}{(\text{total BMP period rainfall})} \\
 & \text{or,} \\
 &= \frac{\left[\sum (\text{daily load})_i / (\text{farm area}) \right]}{\sum (\text{daily rainfall})_i}
 \end{aligned} \tag{6}$$

Using data for Farm B provided in Table 2 (monitoring period total loads and UALs are given), these equations produce the following UAL:R values:

$$\begin{aligned}
 & \text{baseline UAL:R ratio} \\
 &= (1.152 \text{ lbs/acre}) / (131.0 \text{ inches}) \\
 &= 0.00879 \text{ lbs/acre/inch, and} \\
 & \text{BMP UAL:R ratio} \\
 &= (0.423 \text{ lbs/acre}) / (58.5 \text{ inches}) \\
 &= 0.00723 \text{ lbs/acre/inch.}
 \end{aligned}$$

Assessing Ratio Differences

Over time, UAL:R ratios should decline as BMP strategies are phased into crop production operations. Evidence of a reduction in P discharge can be found when the UAL:R value for the BMP monitoring period is smaller than for the baseline period. This comparison can be quantified by finding the relative UAL:R difference, basically assessing to what extent (as a percentage) the BMP value differs from the baseline value (Equation 7):

$$\begin{aligned}
 & \text{relative UAL : R difference} \\
 &= \frac{(\text{BMP UAL : R} - \text{baseline UAL : R})}{(\text{baseline UAL : R})}
 \end{aligned} \tag{7}$$

Using the previously calculated UAL:R values for Farm B, this relative UAL:R difference is calculated as follows:

$$\begin{aligned}
 & \text{relative UAL:R difference} \\
 &= [(0.00723 - 0.00879) / 0.00879] * 100 \\
 &= -17.7\%.
 \end{aligned}$$

Thus, with respect to overall baseline and BMP rainfall, the total UAL discharge during BMP operations at Farm B was roughly 17.7% less than

during baseline operations. A negative value indicates that BMPs are effecting UAL reductions. Similar calculations for Farm A indicate a slight (+2.7%), but likely negligible, increase in UALs under BMPs. The +80.1% relative UAL:R difference for Farm C strongly suggests that BMP strategies are either inadequate or are improperly managed. This methodology provides rapid feedback regarding progress under BMPs, and allows the timely revision to the BMP program.

Method 2: Comparing Baseline and BMP Cumulative Data Distributions

Comparisons between monitoring period UAL:R ratios (discussed above) provide supporting evidence that P reductions are occurring under BMP implementation. However, these ratios fail to address the influence of daily rainfall distributions on UAL discharges. Daily resolution can be achieved by re-expressing UAL and rainfall data as cumulative data (Table 1, Equation 3 and Equation 4). The purpose is to generate a listing of paired data that reflect UAL and rainfall totals chronologically over time. Descriptions of farm P discharge profiles are achieved by plotting cumulative UAL as the dependent variable (Y-axis) and cumulative rainfall as the independent variable (X-axis). This description is distinctly advantageous because it assesses water quality trends relative to rainfall volume rather than calendar time.

Using Regression to Compare Cumulative Data Distributions

For comparative purposes, the cumulative values are first compiled separately for baseline and BMP data and then plotted together. The comparison is quantified with linear regression applied separately to the baseline and BMP cumulative databases. For this analysis, regression is intended to serve a descriptive purpose rather than a predictive function. Differences between baseline and BMP regression slopes can be quantified by finding the relative slope difference, which assesses to what extent (as a percentage) the BMP slope value differs from the baseline value (Equation 8):

$$\begin{aligned} & \text{relative slope difference} \\ & = \frac{(BMP \text{ slope} - \text{baseline slope})}{(\text{baseline slope})} \times 100 \end{aligned} \quad (8)$$

For illustrative purposes, Figure 2 presents schematic diagrams of various outcomes that can be expected with the linear regression exercise (actual cumulative data scatter plots are not shown). Evidence of consistent P reductions under BMP operations is found when the BMP slope is of lower magnitude than the baseline slope. This regression result indicates that the overall BMP data distribution (cumulative UAL vs. cumulative rainfall) resides below the baseline distribution, which in turn reflects a consistent decline in UAL discharge in response to rainfall during BMP operations. Given this situation, the relative slope difference (Equation 8) will produce a negative value. Although this scenario is depicted in Figure 2a, the relative slope difference (Equation 8) is minimal:

$$\begin{aligned} & \text{relative slope difference} \\ & = [(0.0291 - 0.0300)/0.0300] * 100 \\ & = -3.0\% . \end{aligned}$$

The reverse scenario (declining water quality trends under BMPs, albeit minor) is presented in Figure 2b, whereby the BMP slope is +3.1% larger than the baseline slope. Differences between baseline and BMP UAL discharge trends are more obvious in Figure 2c, with a relative slope difference (-30.0%) supporting the conclusion that water quality trends have improved markedly under BMP operations. The reverse scenario (Figure 2d) portrays a BMP slope value 42.9% greater than the baseline distribution slope. This relationship strongly suggests that the BMP program is either not working, is inadequate in scope, or is improperly implemented.

Application of Statistics to Regression Data

If desired, one can take the regression exercise one step further by assessing whether or not the difference in baseline and BMP slopes are statistically significant. The slopes can be compared with a *t*-test that addresses the entire paired cumulative data set for both monitoring periods, using the test statistic (Equation 9):

$$t_c = \frac{(BMP \text{ slope} - \text{baseline slope})}{\left[(s.e._{BMP})^2 + (s.e._{BL})^2 \right]^{0.5}} \quad (9)$$

where $s.e._{BMP}$ and $s.e._{BL}$ are the standard errors associated with the regression slope estimates for the BMP and baseline cumulative distributions, respectively. Given a "sufficiently large" database, the slopes are significantly different if (Equation 10 and Equation 11):

$$|t_c| \geq 1.97 \dots \text{significant at the 5\% level, and} \quad (10)$$

$$|t_c| \geq 2.60 \dots \text{highly significant at the 1\% level} \quad (11)$$

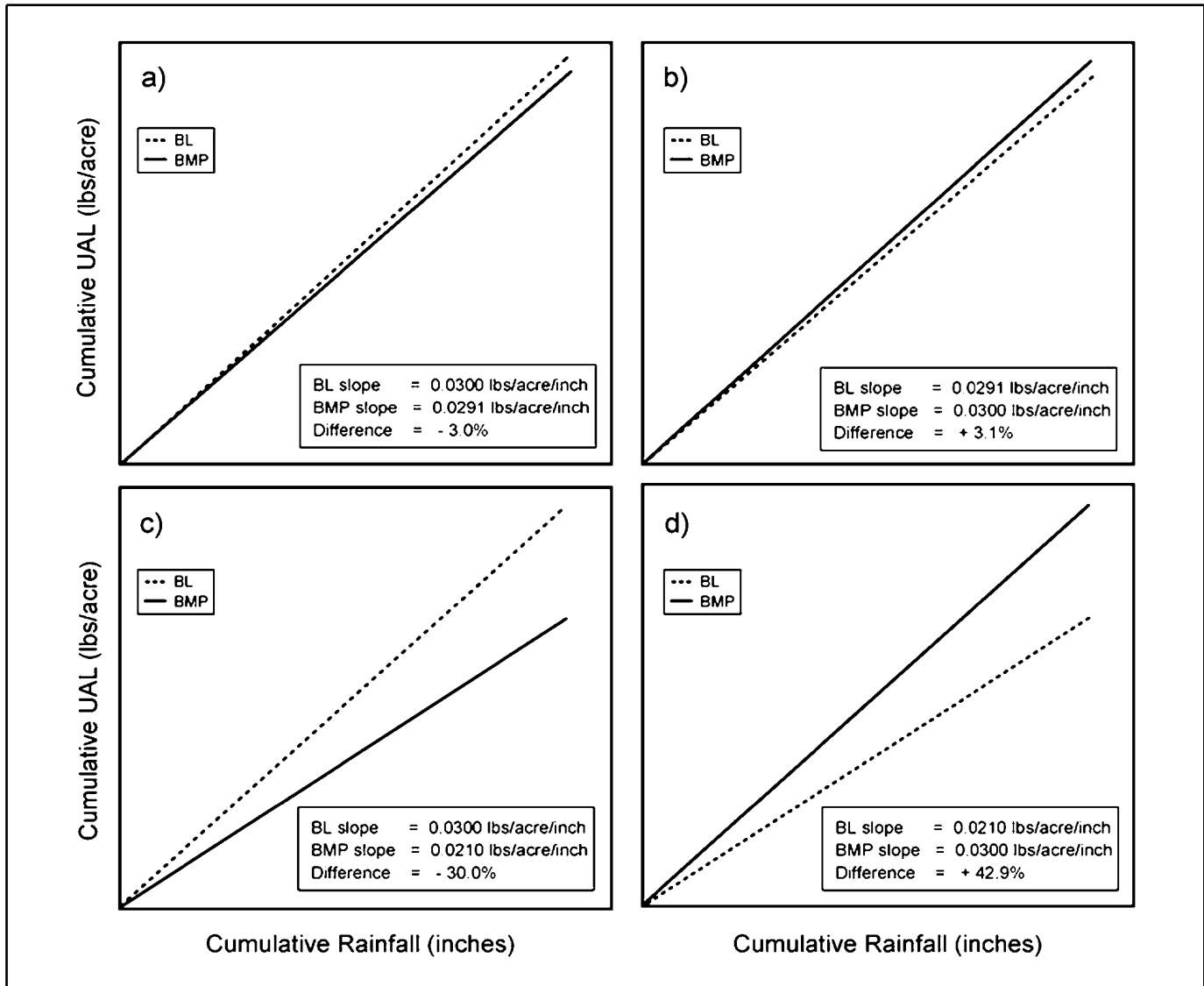
where $|t_c|$ refers to the absolute value of t_c . From a statistical standpoint, "sufficiently large" refers to a combined cumulative baseline and BMP water quality database exceeding 242 days (this equates to 240 degrees of freedom for the *t*-test which, relative to standard statistical tables for the *t* distribution, minimizes the critical *t*-values to either 1.97 or 2.60, depending on the choice of significance level). In reality, any meaningful interpretations of water quality data would require monitoring efforts that greatly exceed 242 days, thus the critical *t*-values listed in Equation 10 and Equation 11 are appropriate.

Examples From Farm Research Sites

The interpretative value of cumulative UAL and rainfall distributions will be highlighted below for four research farm sites that collectively represent a wide range of cropping systems and BMP implementation strategies.

In Figure 3a there is depicted the baseline and BMP cumulative data distributions for Site UF9206A&B, a mixed-crop (sugarcane, vegetables, rice, and sod) operation. To facilitate comparisons, linear regression lines for the baseline and BMP data are also provided. Based solely on linear regression results, one would conclude that BMPs have failed to improve UAL discharge trends since the BMP slope value is larger than the baseline slope value. This difference is quantified with Equation 8, using slope values provided in Table 3:

$$\begin{aligned} & \text{relative slope difference} \\ & = [(0.04608 - 0.04302)/0.04302] * 100 \end{aligned}$$



= +7.1%.

A review of the data scatter plots reveals that new water management practices during early BMP operations actually supported reduced UAL discharges over the first 46 inches of cumulative rainfall (Figure 3a). The abrupt UAL increase from 1.21 to 3.68 lbs/acre occurred during a 2-week pumping period in response to an 8-inch rainfall event (Tropical Storm Gordon). Placed in perspective, this 3-day storm incurred a discharge load that exceeded the sum total load incurred over the first 197 days of the BMP period. As a result, the BMP distribution is displaced above the baseline distribution (Figure 3a), masking attempts to reasonably quantify P-reduction trends under BMP operations.

A visual evaluation of the BMP distribution suggests that, once the farm site recovered from this single aberrant weather event, BMP discharge trends returned to those existing prior to the storm. Recognizing that south Florida historically encounters such conditions, the EAA Regulatory Program (SFWMD, 1992) provides for the exclusion of extreme rainfall conditions from water quality monitoring databases. Basin-wide flooding during this November 1994 storm resulted in the temporary abandonment of water management BMPs in efforts to drain flooded fields during the sugarcane harvest and winter vegetable production season. In order to address the disproportionate effects of this single weather event, baseline and BMP distributions are presented for cumulative databases with November data omitted (Figure 3b). An evaluation of this data subset reveals a consistent P-reduction BMP effect of

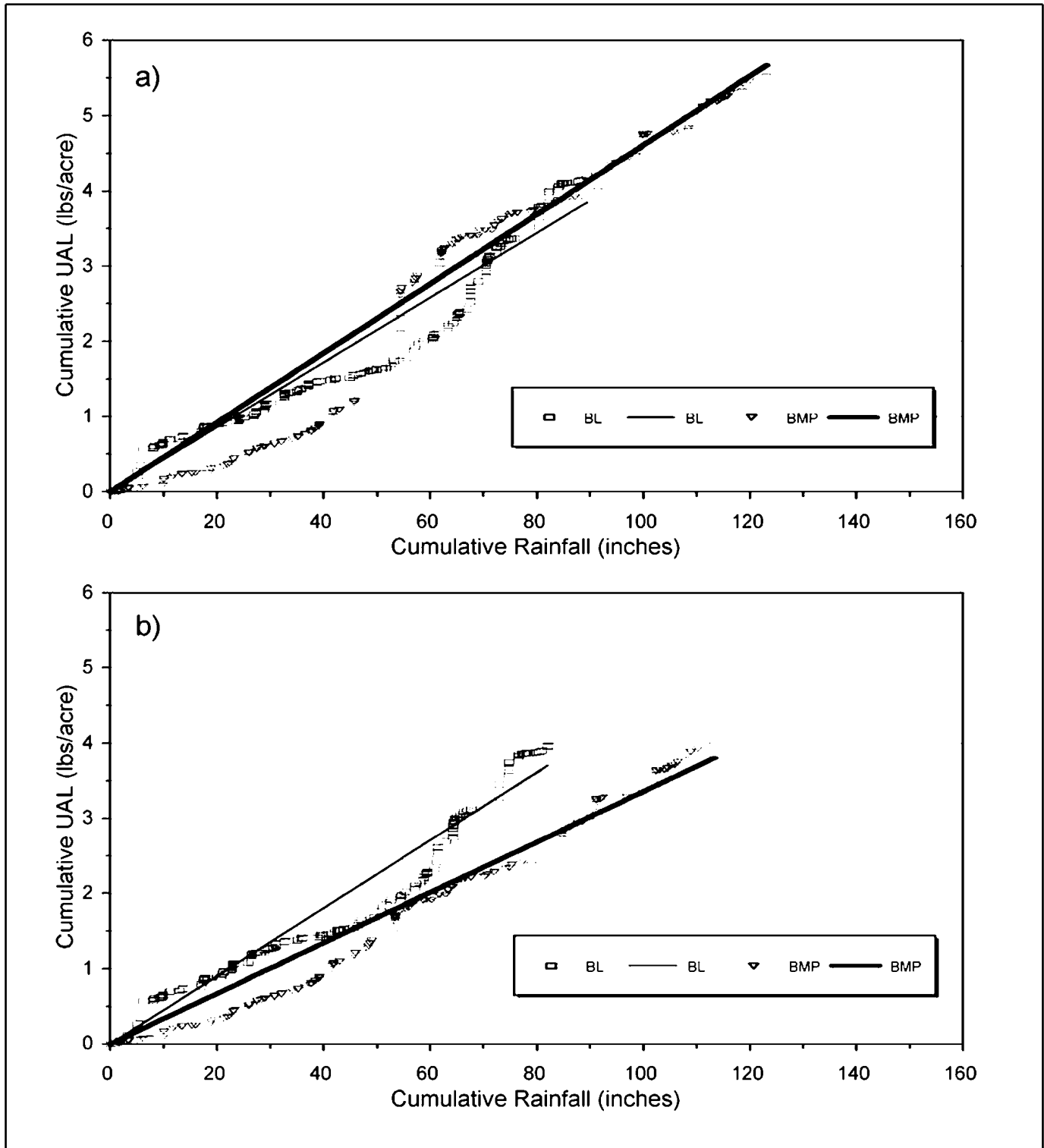


Fig 3a-b. Site UF9206A&B baseline (BL) and BMP monitoring period cumulative rainfall versus cumulative unit area P load (UAL) distributions for a) all monitoring data, and b) a data subset omitting the disproportionate impact of a single tropical storm event.

25.6% (Equation 8) relative to baseline operations. This UAL reduction under BMP operations is highly significant, confirmed by using regression data (Table 3) to calculate a t_c value of -46.1 (Equation 9), where $|t_c|=+46.1$ which is greater than 2.60 (Equation 11):

$$t_c = (0.03355 - 0.04512) / [(1.17 \times 10^{-4})^2 + (2.22 \times 10^{-4})^2]^{0.5}$$

$$\begin{aligned}
 &= (-0.01157)/(1.37 \times 10^{-8} + 4.93 \times 10^{-8})^{0.5} \\
 &= (-0.01157)/(6.30 \times 10^{-8})^{0.5} \\
 &= (-0.01157)/(2.51 \times 10^{-4}) \\
 &= -46.1.
 \end{aligned}$$

In contrast to mixed-cropping operations, sugarcane monocultures are less sensitive to immediate water table levels. The ability of sugarcane to withstand short-term flooding and periodic "wet feet" gives growers additional latitude with respect to discharge pumping. Although cumulative UALs doubled from 0.18 to 0.36 lb/acre (data not shown) during Tropical Storm Gordon, farm operations at Site UF9209A (sugarcane monoculture) quickly recovered and a return to BMP strategies ultimately supported a 20.2% UAL reduction (Equation 8; Table 3). A BMP effect is clearly evident for this site when data encompassing the Tropical Storm Gordon period are omitted from the analysis (Figure 4). The baseline and BMP cumulative distributions describe a consistent divergence and the 30.1% difference between slope magnitudes (Equation 8; Table 3) reflects a consistent attenuation in UAL discharge during BMP operations.

The linear regression exercise may not be universally appropriate to all cropping operations. Both the baseline and BMP cumulative distributions for Site UF9201A (Figure 5), a vegetable monoculture, describe non-linear UAL discharge profiles. Unlike other crop production enterprises, pumping activity for vegetable monocultures will periodically be driven by factors unrelated to rainfall. For example, successive cropping operations throughout the winter production season necessitate scheduled drainage events (regardless of rainfall) to accommodate field preparation and crop harvest machinery. In addition, there is no relationship between off-farm discharge and rainfall during the summer off-season when fields are deliberately maintained under fallow flooded conditions.

Intermittent plateaus (no change in cumulative UAL over increasing rainfall) reflect these deliberate fallow flooded field storage periods when rainfall events have no bearing on drainage requirements (Figure 5). However, the clear separation between baseline and BMP distributions support conclusions favoring P reductions under BMP operations. In particular, note that the BMP distribution begins to diverge rapidly from the baseline distribution at 15.7 inches of cumulative rainfall, when baseline UALs

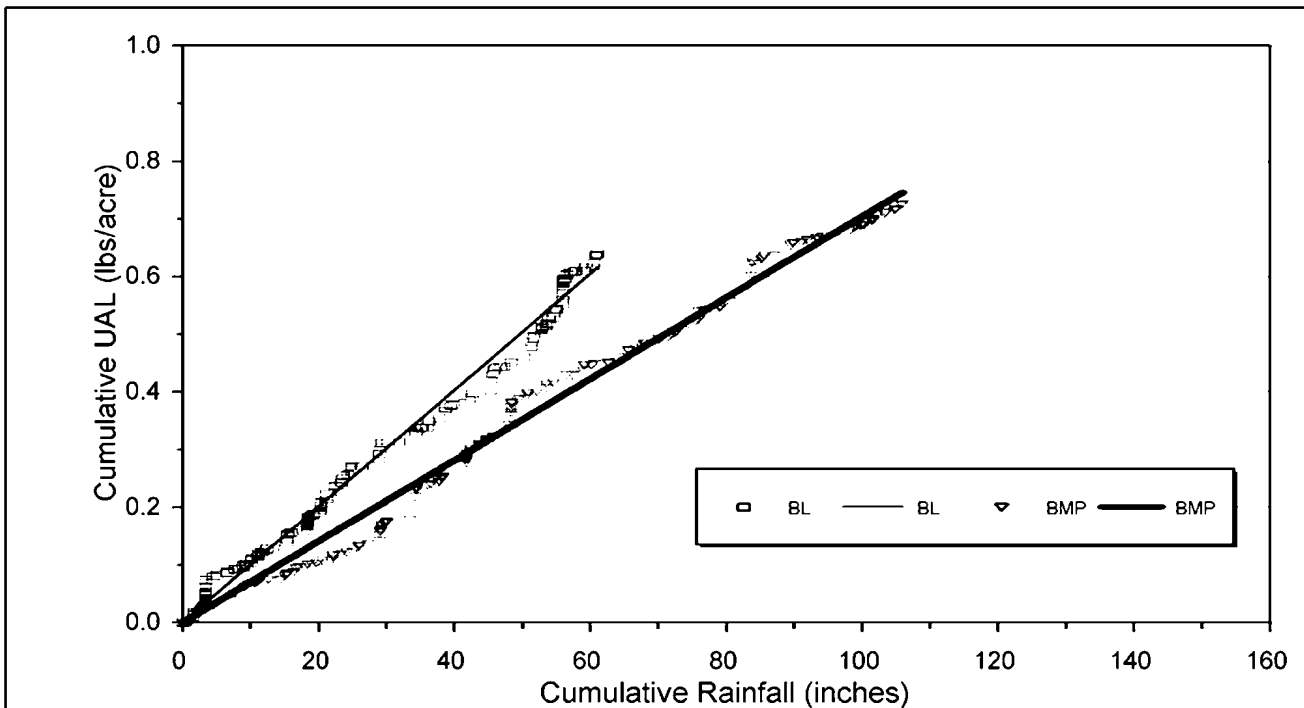


Fig 4. Site UF9209A baseline (BL) and BMP monitoring period cumulative rainfall versus cumulative unit area P load (UAL) distributions for a data subset omitting the disproportionate impact of a single tropical storm event.

shifted vertically from 4.36 to 5.87 lbs/acre. This UAL increase under zero rainfall conditions during baseline operations represents the deliberate discharge of summer fallow flood waters to accommodate September planting schedules. Under BMP operations, modified water management strategies and new drainage practices were implemented to address this traditional "September UAL spike" period. The diverging distributions (Figure 5) document declining UAL discharge trends under these BMP strategies.

also describe declining water quality trends. This scenario is illustrated for Site UF9204A (Figure 6) whereby the BMP cumulative distribution remains consistently above the baseline distribution. This site was under sugarcane production during baseline operations but five months into BMP operations, half the farm area was rotated into flooded rice. This major cropping modification occurred without the concurrent implementation of an adequate water management plan. The 130.6% UAL increase during the BMP period (Table 3) reflects the inability to

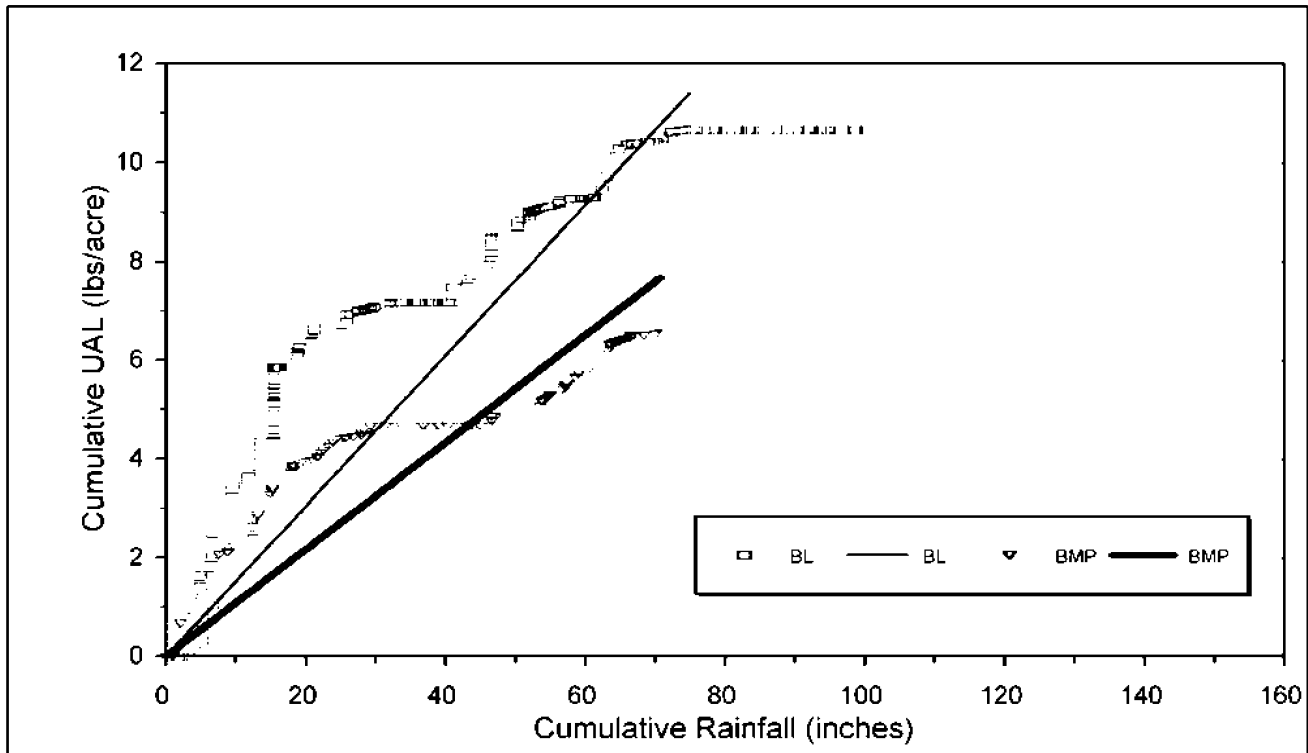


Fig 5. Site UF9201A baseline (BL) and BMP monitoring period cumulative rainfall versus cumulative unit area P load (UAL) distributions for a data subset omitting the disproportionate impact of a single top for these type of data, one can take the baseline and BMP cumulative UAL values recorded at (for this example) every 10-inch rainfall increment through 70 cumulative inches (the limit of the BMP distribution; Figure 5). Using these values, an average cumulative UAL can be calculated for the BMP (4.69 lbs/acre) and baseline periods (7.48 lbs/acre). These average values can subsequently be used in place of slopes (Equation 8) to calculate an overall 37.3% UAL reduction under BMP operations.

As schematically described in Figure 2d, comparisons of cumulative data distributions will

properly manage rice drainage waters at this site. It is important to emphasize that rice production is a perfectly feasible production practice, given the implementation of appropriately designed BMPs. The adoption of improved management strategies at a different sugarcane-rice farm (data not shown) supported a 25.7% UAL reduction during BMP operations.

Method 3: Comparing Rainfall-Adjusted UALs

The EAA Regulatory Program (SFWMD, 1992) requires the EAA basin to achieve a minimum 25% P load reduction. All growers in the EAA are

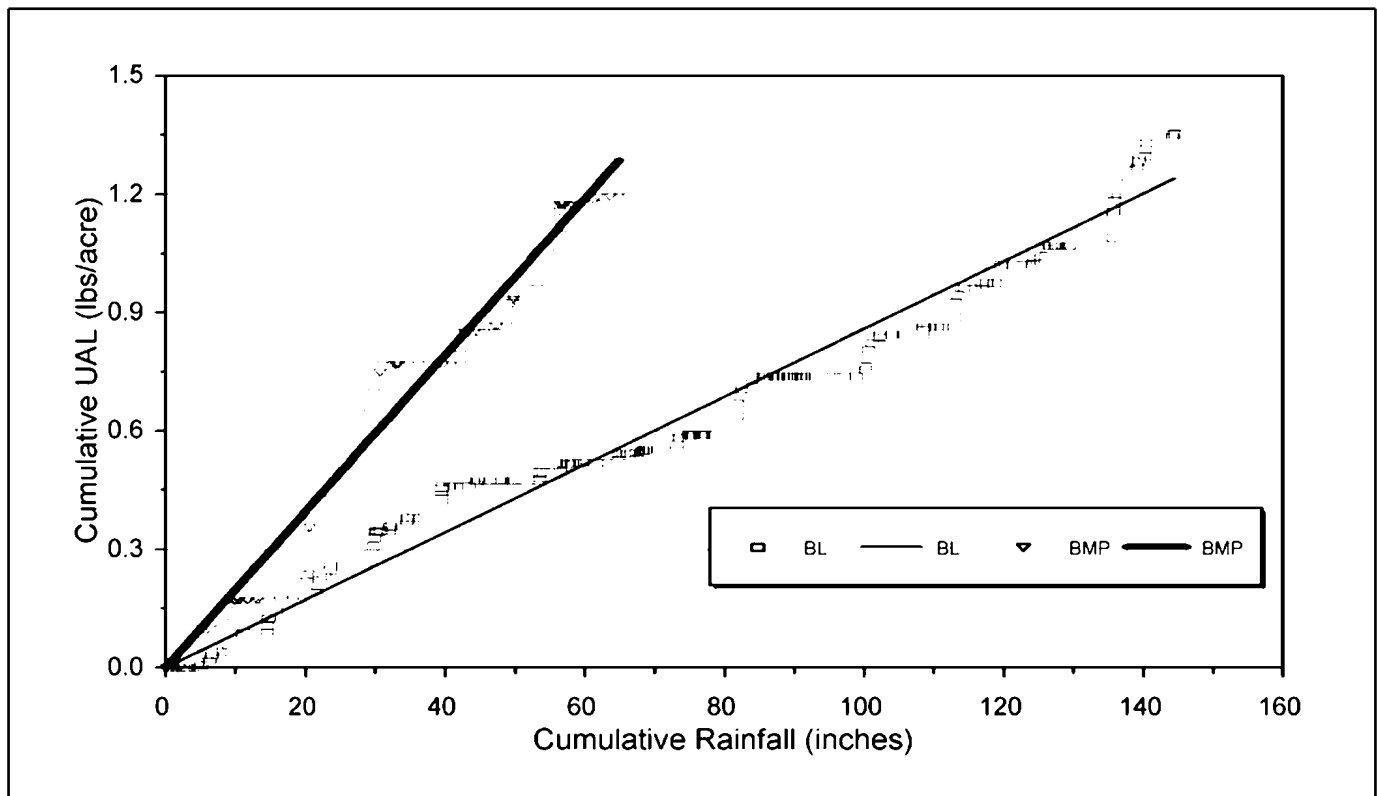


Fig 6. Site UF9204A baseline (BL) and BMP monitoring period cumulative rainfall versus cumulative unit area P load (UAL) distributions for a data subset omitting the disproportionate impact of a single tropical storm event.

collectively in compliance if the basin target is met. The annual compliance evaluation involves a model that adjusts annual EAA sub-basin P loads for hydrologic variability (SFWMD, 1992). The model also allows for the calculation of estimated farm-level rainfall-adjusted UALs (AUALs). The model calculates a rainfall-adjusted load based on the comparison of current "water year" load (and monthly rainfall distribution) to an earlier 10-year (1979-1988) period of record database. By definition, the 1994 water year (WY94) is the 12-month period beginning May 1, 1993 and ending April 30, 1994.

Required Data for AUAL Calculations

In order to calculate farm-level AUAL estimates for a given WY, the following information and data are required:

1. Identify the farm location with respect to EAA sub-basin (S5A, S6, S7, or S8),
2. Identify the water year of interest,

3. Calculate the farm's total UAL for the given WY,
4. Obtain the Thiessen-weighted monthly rainfall values specific to the WY and EAA sub-basin, and
5. Obtain the "fixed coefficients" (rainfall variation, skewness, and adjustment factors) specific to the EAA sub-basin that are used in the model equation.

At this writing, the Thiessen-weighted rainfall values and fixed coefficients were available from the SFWMD Web site at

ftp://www.sfwmd.gov/pub/reg/ever_reg.

Download the archived "eaabasin.zip" file and "unzip" this file into its various components. Within the newly created folder "eaabasin" are additional folders. Within the folder titled "Basin" is an Excel file titled "eaabasin.xls" which contains numerous pages. For Thiessen-weighted monthly rainfall values, select the page tab titled "Monthly" to access the data table titled "Basin Compliance Calculations - EAA Regulatory Rule", scroll to the table subheading

titled "Monthly Calculated Values: Basin Average Rainfall (inches)" which includes Thiessen-weighted rainfall values (beginning October 1978) for EAA sub-basins S5A, S6, S7, and S8. To obtain the fixed coefficients for each EAA sub-basin, select the page tab titled "Coefficients" to access the data table titled "Fixed Coefficients for EAA Basin Calculations (From Rule Text)", and scroll to the table subheading titled "Base Period Mean Rainfall Statistics".

AUAL Calculation

An example of an AUAL calculation is provided below using monthly load data collected during WY96 from a research farm site located in the S5A sub-basin. These data are provided in Table 4a along with a listing of S5A sub-basin Thiessen-weighted monthly rainfall values for WY96. For the readers convenience, the fixed coefficients for all four sub-basins are provided as well (Table 4b).

In order to calculate the estimated farm AUAL, eight sequential calculations must be performed (SFWMD, 1992). First, calculate three different factors (m_1 , m_2 , and m_3) specific to the Thiessen-weighted sub-basin rainfall values, where r_i =individual monthly rainfall values from $i=1$ (May) to $i=12$ (April). Note that m_1 is simply the average monthly rainfall for the WY in question. The factor m_2 is the average of the squared differences between individual monthly rainfall values and the average WY rainfall value, while m_3 is the average of the cubed deviations (Equation 12, Equation 13, and Equation 14):

$$m_1 = \frac{\sum(r_i)}{12} \quad (12)$$

$$m_2 = \frac{\sum(r_i - m_1)^2}{12}, \text{ and} \quad (13)$$

$$m_3 = \frac{\sum(r_i - m_1)^3}{12} \quad (14)$$

Second, calculate the "predictors" (X, C, and S) from the first three rainfall factors. Note that X is actually the natural log (\ln) of the total WY rainfall, C is the standard deviation of the monthly rainfall values divided by the average monthly rainfall value (also known as the coefficient of variation), and S is a rainfall skewness coefficient (Equation 15, Equation 16 and Equation 17):

$$X = \ln(12 \times m_1) \quad (15)$$

$$C = \frac{\left[\left(\frac{12}{11} \right) \times m_2 \right]^{-0.5}}{m_1}, \text{ and} \quad (16)$$

$$S = \frac{\left[\left(\frac{12}{11} \right) \times m_3 \right]}{(m_2)^{1.5}} \quad (17)$$

Third, calculate the adjusted sub-basin rainfall value (R_a) for the WY using the "predictors" and the fixed coefficients (C_m and S_m) specific to sub-basin of interest (Table 4b), where "exp" signifies the inverse of the natural log function (Equation 18):

$$R_a = \exp[X + 1.053 \times (C - C_m) - 0.1170 \times (S - S_m)] \quad (18)$$

Finally, calculate the adjusted unit area load for the WY, using the adjusted sub-basin rainfall value (R_a) and the fixed rainfall coefficient (R_{am}) specific to the sub-basin of interest (Table 4b) (Equation 19):

$$AUAL = UAL \times \left(\frac{R_{am}}{R_a} \right)^{2.868} \quad (19)$$

Using the data provided in Table 4a and Table 4b, these equations produce the following calculated values to arrive at a WY96 AUAL estimate of 0.5112 lbs/acre:

$$\begin{aligned} m_1 &= (1.33 + 6.56 + \dots + 1.73)/12 \\ &= 4.4900, \end{aligned}$$

$$\begin{aligned} m_2 &= [(1.33 - 4.49)^2 + (6.56 - 4.49)^2 + \dots \\ &\quad + (1.73 - 4.49)^2]/12 \\ &= 14.1591, \end{aligned}$$

$$\begin{aligned} m_3 &= [(1.33 - 4.49)^3 + (6.56 - 4.49)^3 + \dots \\ &\quad + (1.73 - 4.49)^3]/12 \\ &= 39.4395, \end{aligned}$$

$$\begin{aligned} X &= \ln(12 \times 4.49) \\ &= 3.9868, \end{aligned}$$

$$\begin{aligned} C &= [(12/11) \times 14.1591]^{0.5}/4.49 \\ &= 3.9302/4.49 \end{aligned}$$

$$\begin{aligned}
&= 0.8753, \\
S &= [(12/11)*39.4395]/(14.1591)^{1.5} \\
&= 43.0249/53.2787 \\
&= 0.8075, \\
R_a &= \exp[3.9868 + 1.053*(0.8753 - 0.7636) - \\
&\quad 0.1170*(0.8075 - 0.9999)] \\
&= \exp(4.1269) \\
&= 61.9855, \text{ and} \\
AUAL &= 0.9319*(50.31/61.9855)^{2.868} \\
&= 0.9319*0.5496 \\
&= 0.5122 \text{ lbs/acre.}
\end{aligned}$$

The above AUAL calculation is specific to WY96 for a farm site located in the S5A sub-basin. The procedure can be used to calculate AUAL estimates for any farm and WY period, given the use of monthly Thiessen-weighted rainfall values and farm UAL data specific to the WY of interest. For any given farm location within a given sub-basin, the same fixed coefficients (C_m , S_m , and R_{am} ; Table 4b) are used for any WY period. Keep in mind that baseline and BMP monitoring periods for any given farm site will not coincide with the WY calendar period. In general, water quality monitoring data collected from EAA farms during WY94 will predominantly reflect baseline practices, WY95 data will represent the transition from baseline to BMP operations, and WY96 data will exclusively reflect BMP operating conditions. For any given farm, evidence of P-reductions under BMPs will be found with lower AUAL values for WY95 and WY96 relative to WY94.

These comparisons can be quantified by finding the relative AUAL difference across any two WYs of interest (Equation 20), where WY_i is the most recent WY and WY_j is the oldest WY in the given comparison (Equation 20):

$$\text{relative UAL difference} = \left[\frac{(AUAL_{WY_i} - AUAL_{WY_j})}{(AUAL_{WY_j})} \right] \quad (20)$$

In Table 4c is a summary of UAL and AUAL values for three different WY. The WY95 to WY94 comparison of AUALs is calculated as follows:

$$\begin{aligned}
&\text{relative AUAL difference} \\
&= [(0.9735 - 1.9502)/(1.9502)]*100 \\
&= -50.1\%.
\end{aligned}$$

Thus, the 12-month AUAL incurred during the transition from baseline to BMP operations (WY95) represents a 50.1% reduction in P discharge relative to the AUAL discharge under baseline operations (WY94). Under full BMP implementation (WY96 AUAL value of 0.5122 lbs/acre), a reduction of 73.7% was realized (Table 4c).

Summary

With less than four years of monitoring data, researchers and water managers are challenged to assess the effectiveness of farm-level P-reduction BMPs in south Florida. Straight comparisons between baseline and BMP period UAL data are inadequate because calendar time frames and rainfall distributions differ for the two monitoring periods. Meaningful comparisons require some measure of hydrologic adjustment to UAL data.

Three methods for comparing water quality monitoring data were discussed. The first method minimizes rainfall differences (which influence drainage pumping) across monitoring periods by comparing baseline period total UAL to rainfall (UAL:R) ratios to those for the BMP period. The second method involved the re-expression of water quality databases into cumulative UAL and cumulative rainfall values. These cumulative databases are plotted to assess differences in baseline and BMP UAL discharge trends over incremental rainfall. Linear regression applied to these distributions allows differences to be quantified through slope comparisons. Finally, the application of a hydrologic model (developed for P discharge regulatory compliance assessments) to farm UAL data allows the calculation of rainfall-adjusted UALs (AUALs) for different water year (WY) periods. Subsequent AUAL comparisons across different WYs serves to quantify P discharge trends over time.

Although not specifically addressed in this publication, it may be instructive to briefly summarize water quality trends recorded at 10 EAA research farm sites from late-1992 through April 1996 (Izuno and Rice, 1997). Using the UAL:R ratio comparison method, BMP data for six of 10 sites reflected P reductions of 3 to 33%. Using cumulative databases, the BMP distribution slope magnitudes for six sites were 6 to 35% lower than for baseline, evidence of long-term P load reductions under BMP strategies. Eight of 10 sites reflected reductions after omitting nonrepresentative UAL data collected under flooded conditions caused by a 3-day tropical storm. Applying the hydrologic adjustment model, average AUALs for eight sites declined by 73% over a 3-year period. Across all three analytical exercises, two sites consistently demonstrated declining water quality trends as a consequence of large cropping system modifications in the absence of adequate hydraulic BMP technologies. Despite short baseline monitoring periods and less than four years of data collected under conditions of highly variable rainfall, analytical methods discussed herein consistently verify BMP reductions for a wide range of agricultural cropping systems.

References

- Bottcher, A.B., F.T. Izuno, and E.A. Hanlon. 1995. Procedural guide for the development of farm-level best management practices for phosphorus control in the Everglades Agricultural Area. Univ. of Florida Cooperative Extension Service Circular No. 1177. Gainesville, Fla.
- Davis, S.M. 1994. Phosphorus inputs and vegetation sensitivity in the Everglades. In *Everglades: The Ecosystem and Its Restoration*, S.M. Davis and J.C. Ogden (eds), ch. 15, 357-378. St. Lucie Press, Delray Beach, Fla.
- Everglades Forever Act. 1994. Amendment of the 1991 Marjory Stoneman Douglas Everglades Protection Act. Chapter 373.4592, Florida Statutes. Tallahassee, Fla.
- Federico, A.C., F.E. Davis, K.G. Dickson, and C.R. Kratzer. 1981. Lake Okeechobee water quality studies and eutrophication assessment. South Florida Water Management District Technical Publication No. 81-2. West Palm Beach, Fla.
- Izuno, F.T., and R.W. Rice (eds). 1997. Implementation and verification of BMPs for reducing P loading in the EAA. Phase V Final Report (vol. 1) submitted to the EAA Environmental Protection District. Belle Glade, Fla.
- Izuno, F.T., A.B. Bottcher, F.J. Coale, C.A. Sanchez, and D.B. Jones. 1995. Agricultural BMPs for phosphorus reduction in South Florida. *Transactions of the ASAE*. 38:735-744.
- Pickering, N.B., A.B. Bottcher, and J.D. Stuck. 1997. EAAMOD-FARM: Everglades agricultural area farm-scale hydrologic and phosphorus transport model version 2.0. In F.T. Izuno and R.W. Rice (eds). Implementation and verification of BMPs for reducing P loading in the EAA. Phase V Annual Report (vol. 2) submitted to the EAA Environmental Protection District. Belle Glade, Fla.
- Rice, R.W., and F.T. Izuno. 2001. Calculating nutrient loads. Univ. of Florida Cooperative Extension Service Technical Bulletin 906. Gainesville, Fla.
- SFWMD. 1992. Rules of the South Florida Water Management District -- Everglades Regulatory Program. Chapter 40E-63, Florida Annotated Code. New: Jan. 22, 1992; Amended: July 7, 1992. South Florida Water Management District, West Palm Beach, Fla.
- SFWMD. 1995. Managing a very wet year. South Florida Water Management District, West Palm Beach, Fla.
- SFWMD. 1996. Rule 40E-63 information update: EAA basin total phosphorus levels (June 24). South Florida Water Management District, West Palm Beach, Fla.
- Whalen, P.J., and B.M. Whalen. 1996. Nonpoint source best management practices program for the Everglades Agricultural Area. ASAE Paper No. 96-2071. St. Joseph, Mich.: ASAE.

Table 1. Example of farm-level water quality monitoring data.

Day	Raw Data			Calculated Data				
	Rainfall (inches)	Drainage volume (gallons)	Total P Concentration (mg/L)	P load (kg)	P load (lbs)	UAL ¹ (lbs/acre)	Cumulative UAL (lbs/acre)	Cumulative Rainfall (inches)
1	0	0		0	0	0	0	0
2	0	0		0	0	0	0	0
3	0	0		0	0	0	0	0
4	0	0		0	0	0	0	0
5	2.23	5119240	0.0882	1.709	3.768	0.0017	0.0017	2.23
6	1.32	47847160	0.0882	15.973	35.221	0.0156	0.0173	3.55
7	0.08	43287950	0.0839	13.747	30.311	0.0135	0.0308	3.63
8	0.43	25141490	0.0796	7.573	16.698	0.0074	0.0382	4.06
9	0	10248115	0.0796	3.087	6.806	0.0030	0.0412	4.06
10	0	0		0	0	0	0.0412	4.06
11	0	0		0	0	0	0.0412	4.06
12	0	0		0	0	0	0.0412	4.06
13	1.21	0		0	0	0	0.0412	5.27
14	0.19	22917153	0.0974	8.449	18.629	0.0083	0.0495	5.46
15	1.27	6505400	0.0811	1.997	4.403	0.0020	0.0515	6.73
16	0.15	32179070	0.0648	7.892	17.403	0.0077	0.0592	6.88
17	0.28	20449179	0.0648	5.016	11.059	0.0049	0.0641	7.16
18	0	12774840	0.0613	2.964	6.536	0.0029	0.0670	7.16
19	0	6309890	0.0578	1.380	3.044	0.0014	0.0684	7.16
20	0	0		0	0	0	0.0684	7.16
21	0	0		0	0	0	0.0684	7.16
22	0.29	0		0	0	0	0.0684	7.45
23	0	0		0	0	0	0.0684	7.45
24	0.75	0		0	0	0	0.0684	8.20
25	0	21791085	0.0848	6.994	15.422	0.0069	0.0752	8.20
26	0	0		0	0	0	0.0752	8.20
27	0	0		0	0	0	0.0752	8.20
28	0.44	0		0	0	0	0.0752	8.64
29	0	11845960	0.0779	3.493	7.702	0.0034	0.0787	8.64
30	0	0		0	0	0	0.0787	8.64
31	0	0		0	0	0	0.0787	8.64
Total	8.64	266416532	n.a.	80.274	177.003	0.0787	n.a.	n.a.

Table 1. Example of farm-level water quality monitoring data.

Raw Data		Calculated Data						
Day	Rainfall (inches)	Drainage volume (gallons)	Total P Concentration (mg/L)	P load (kg)	P load (lbs)	UAL ¹ (lbs/acre)	Cumulative UAL (lbs/acre)	Cumulative Rainfall (inches)
¹ UAL = unit area load (assume farm area = 2250 acres).								

Table 2. Example of calculating and comparing unit area load (UAL) to rainfall ratios (UAL:R) for baseline and BMP water quality monitoring data.

Site name	Farm area (acres)	Monitoring period	Calendar period	Time (days)	Rain (inches)	P load (lbs)	UAL (lbs/acre)	UAL:R ratio (lbs/acre/inch)	Relative UAL:R difference ¹ (%)
Farm A	1280	baseline	07/23/92 - 12/31/93	527	85.4	2823.1	2.206	0.02583	
		BMP	01/01/94 - 03/31/96	821	122.6	4161.0	3.251	0.02652	+2.7
Farm B	4608	baseline	07/24/92 - 12/31/94	891	131.0	5308.1	1.152	0.00879	
		BMP	01/01/95 - 03/31/96	456	58.5	1947.9	0.423	0.00723	-17.7
Farm C	640	baseline	07/15/92 - 12/31/94	900	159.0	1029.0	1.608	0.01011	
		BMP	01/01/95 - 03/31/96	456	65.9	768.2	1.200	0.01821	+80.1

¹A negative "relative UAL:R difference" indicates that the BMP period UAL:R ratio is smaller than the baseline UAL:R ratio by the given percentage.

Table 3. Linear regression statistics for baseline and BMP cumulative unit area load (UAL) vs. cumulative rainfall distributions for four research farm sites.

Site name	Baseline Period		BMP period		BMP to baseline comparison	
	r ^a	Slope	r	Slope	t _c ^c	Relative slope difference ^d (%)
(lbs/acre/inch)						
All monitoring data						
UF9201A ^e	0.925	0.15489	0.916	0.12421	1.28x10 ⁻³	-19.8
UF9204A	0.978	0.00859	0.993	0.01970	6.91x10 ⁻⁵	+129.3

Table 3. Linear regression statistics for baseline and BMP cumulative unit area load (UAL) vs. cumulative rainfall distributions for four research farm sites.

Site name	Baseline Period		BMP period			BMP to baseline comparison		
	r^a	Slope	s.e. ^b	r	Slope	s.e.	$ t_c ^c$	Relative slope difference ^d (%)
	(lbs/acre/inch)		(lbs/acre/inch)					(%)
UF9206A&B	0.971	0.04302	2.19×10^{-4}	0.982	0.04608	1.88×10^{-4}	10.6	+7.1
UF9209A	0.997	0.01011	1.65×10^{-5}	0.988	0.00807	2.31×10^{-5}	71.9	-20.2
November monitoring data omitted								
UF9201A	0.921	0.15228	1.52×10^{-3}	0.931	0.10835	1.22×10^{-3}	22.5	-28.8
UF9204A	0.984	0.00859	2.64×10^{-5}	0.993	0.01981	7.75×10^{-5}	137.0	+130.6
UF9206A&B	0.974	0.04512	2.22×10^{-4}	0.995	0.03355	1.17×10^{-4}	46.1	-25.6
UF9209A	0.996	0.01007	1.90×10^{-5}	0.995	0.00704	1.39×10^{-5}	128.7	-30.1
^a r = correlation coefficient.								
^b s.e. = standard error (square root of the variance) of the regression for the slope estimate.								
^c t_c = test statistic for comparing baseline and BMP regression slopes, which differ significantly at the 5% level when $ t_c > 1.97$ and at the 1% level when $ t_c > 2.60$.								
^d A negative "relative slope difference" indicates that the BMP slope value is of lower magnitude (by the given percentage) than the baseline slope value.								
^e Strict application of linear relationship estimates are not recommended for UF9201A data (see Fig. 5).								

Table 4A. Example data used in rainfall-adjusted unit area load (AUAL) calculation for the 1996 water year (WY96).

Month	Calendar year	Sub-basin rainfall ¹ (inches)	Farm P load (lbs)	Farm UAL ² (lbs/acre)
May	1995	1.33	0	0
June	1995	6.56	119.60	0.0934
July	1995	6.77	90.50	0.0707
August	1995	10.32	232.37	0.1815
September	1995	4.12	97.94	0.0765
October	1995	12.22	287.03	0.2242
November	1995	1.22	0	0
December	1995	0.81	0	0
January	1996	1.96	193.56	0.1512
February	1996	0.59	26.46	0.0207
March	1996	6.25	91.65	0.0716
April	1996	1.73	53.74	0.0420
1996 WY total		53.88	1192.85	0.9319
Monthly average		4.49	99.40	0.0777
¹ Thiessen-weighted rainfall values for EAA S5A sub-basin.				
² UAL = unit area load (assume farm area = 1280 acres).				
Shaded values are used in the WY96 AUAL calculation example.				

Table 4B. Fixed coefficients for EAA sub-basins.

Sub-basin	C_m	S_m	R_{am}
S5A	0.7636	0.9999	50.31
S6	0.7302	0.7476	49.77
S7	0.7198	0.6112	46.27
S8	0.7821	0.8409	45.68
Shaded values are used in the WY96 AUAL calculation example.			

Table 4C. Example of AUAL data comparisons for three consecutive WY.

UAL			AUAL			Relative AUAL difference from:	
WY94	WY95	WY96	WY94	WY95	WY96	WY95 to WY94	WY96 to WY94
lbs/acre/year						% change	
1.4461	2.1734	0.9319	1.9502	0.9735	0.5122	-50.1	-73.7