UNIVERSITY OF FLORIDA
EXTENSION
Institute of Food and Agricultural Sciences

BULLETIN 906

Calculating Nutrient Loads[1]

Ronald W. Rice and Forrest T. Izuno [2]

Introduction

A chemical "load" is simply defined as a mass of a chemical element or chemical compound, being moved from one location to another. Plant nutrients are chemicals that support and sustain plant growth and development. Although nutrients are beneficial to agricultural crops, they can be deleterious to ecologically sensitive areas if present in quantities that would adversely affect the growth of native plant or animal species. Nutrients can be translocated via aeolian (wind-borne), water, or human activity. For example, in the case of the Everglades Agricultural Area (EAA), any particular farm incurs chemical loads to the farm from aeolian deposits of particulate matter, particulate and dissolved fractions of a chemical in rainfall, fertilization of fields, particulate and dissolved species of chemicals introduced in irrigation water, and seepage. Chemical loads leave the farm via aeolian transport, harvested crop matter, drainage water, and seepage. A nutrient load can be represented as either a mass of the chemical being translocated to or from a particular piece of land, or as a mass of chemical per unit area relative to either its destination or its origin.

Chapter 40E-63 (SFWMD, 1992) of the Everglades Forever Act (1994) requires that the phosphorus (P) load leaving the EAA must be reduced by 25% relative to the baseline years of 1979 through 1988. This basin-level regulatory target is to be achieved by EAA growers through their collective implementation of "best management practices" (BMPs) designed specifically to reduce P loads discharged from their farms. Yet, the Everglades Forever Act specifically states that a threshold P concentration level will be set for waters entering the Water Conservation Areas from the EAA. Hence, the focus on loads in 40E-63 appears to be somewhat puzzling. However, the hydrology and hydraulics of the region are such that drainage water cannot leave the EAA (except via seepage which is traditionally small due to the higher water levels maintained around the EAA borders) unless enabled by man. Additionally, the EAA receives more rainfall in a year than can leave through evapotranspiration (ET). Hence, if growers and water managers ceased pumping activities, the EAA would remain flooded for much of the year. Therefore, there are naturally imposed limits on how much water can and cannot be pumped during a year, enabling water managers to

1. This document is Research Technical Bulletin 906, Florida Agricultural Experiment Station, Institute of Food and Agricultural Sciences, University of Florida. First Published: August 1998; Revised September 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.

2. Ronald W. Rice is Assistant Professor, Horticultural Sciences Department, Everglades Research and Education Center-Belle Glade, FL, Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL 32611. Forrest T. Izuno is Station Head, Southern Research and Outreach Center at Waseca, Waseca, MN; Department of Biosystems and Agricultural Engineering, College of Agricultural, Food, and Environmental Sciences, University of Minnesota, St. Paul MN 55108.

make reasonable estimates of concentrations given loads, and vice versa.

Reducing loads can be accomplished simply by reducing the amount of water pumped. Hence, if there was not the propensity for the EAA basin to flood (geologic bedrock structure and high water table), one could conceivably stop pumping and let water percolate through the root zone, effectively eliminating surface water P loading. Since this is not the case, there is a natural limit as to how much pumping can be reduced relative to historical patterns. Now, if one takes the maximum ET rate for the area and compares it to rainfall inputs, the amount of "excess" water can be determined. Then, comparing this volume with what was historically pumped for drainage, one could actually determine what the maximum reduction in drainage could be in the EAA without reversion to a swamp. For example, if rainfall is assumed to be about 53 inches per year and the maximum ET is assumed to be around 45 inches per year, 8 inches of water would have to be removed to avoid accruing water in the basin. If historical drainage from the area was 11 inches per year, then drainage under BMPs can be reduced by no more than 3 inches (about 27%). Using this information, a load reduction can be translated into a concentration reduction (mass of P divided by the estimated volume of water pumped under maximum retention). In fact, although 40E-63 requires the achievement of a 25% P load reduction effected by BMP implementation, parallel calculations were occurring during Rule development to determine what that would mean in terms of concentrations assuming different levels of off-farm pumping reduction. An additional clause in the Rule states that water retention practices used to alleviate P loading could be revisited if water supply were to become a problem.

As illustrated above, it is necessary to understand the concepts of nutrient concentrations, nutrient loads, and the relationship between the two, in order to understand how to effectively achieve a reduction in the amount of P leaving the EAA. Additionally, there are many ways of expressing concentration and load values in terms of units. Many of these methods are being used, often interchangeably, in research, monitoring, and regulatory presentations and documents. These units of reporting shall be explained herein.

Concentrations, Volumes, and Loads: Units of Measure

Concentrations, volumes, and loads are all expressed in a myriad of ways. These include traditional, single dimensioned, and dimensionless units. To further confuse matters, English and metric units are, at times, equivalent and are often seen mixed in a single equation, figure, or table.

A nutrient load is a mass, or weight, of a chemical entering or leaving an area, and is the product of the volume of water that the chemical is using as its transport medium and the concentration of the chemical in the water. Hence, it is necessary to understand how both concentrations and volumes are expressed in order to perform the appropriate calculations to obtain loads. The actual procedures used to measure flow volumes and chemical concentrations in water are beyond the scope of this publication.

Volume

Water volume is expressed in many ways. Some of the more common terms are listed below along with their definitions and necessary explanations:

1. Acre-foot (ac-ft) - The volume of water represented by one foot (ft) of water uniformly covering an acre (ac) of land. Since an ac is 43,560 square feet (ft^2), an ac-ft is 43,560 cubic feet (ft^3) of water. (325,872 gallons (gal)/ac-ft or 1,233,426 liters (L)/ac-ft).

2. Acre-inch (ac-in) - The volume of water represented by an inch (in) of water uniformly covering an ac of land. Since an ac is 43,560 ft^2, an ac-in is 3,630 ft^3 (43,560 ft^2 x 1 in/12 ft) of water. (27,156 gal/ac-in or 102,785 L/ac-in).

3. Inch or Foot (in or ft) - At times, a water volume is expressed as a single dimensioned quantity. Implicit to the use of these dimensions is a common or unit area. For example, "the average rainfall in the EAA is around 53 in/yr" implies that 53 in of water falls uniformly across the EAA. Hence the actual volume of rainfall in ft^3

would be (53 in)*(1 ft/12 in)*(the EAA area in ft^2). Likewise, expressing drainage as a single dimensioned value (i.e. "farms in the EAA drain about 11 in of water annually") is actually a volume of water (in^3) divided by the area (in^2) being referred to.

4. Cubic foot (ft^3) - Arguably the most commonly used English unit dimension for expressing large volumes of water, equivalent to the amount of water that would fit in a cube with 1 ft long sides. (7.481 gal/ft^3 or 28.31559 L/ft^3).

5. Gallon (gal) - Arguably the most common everyday English unit representation of a liquid volume. There are 7.481 gal of water in 1 ft^3. (3.785 L/gal).

6. Liter (L) - Arguably the most common everyday metric unit representation of a liquid volume. There are 1000 milliliters (mL) of water in a L. (0.2642 gal/L or 0.03532 ft^3/L).

7. Cubic meter (m^3) - Arguably the most common metric unit representation of large liquid volumes. A cubic meter (m^3) of water is the volume of water that will fit in a cube with sides 1 m in length. There are 1000 L in a m^3.

8. Cubic centimeters (cm^3 or cc) - A metric unit representation of small liquid volumes, equivalent to the amount of water that will fit in a cube with sides 1 cm in length. There are 1000 cm^3 in a L.

9. Milliliter (mL) - A metric unit volume equal to 1/1000 of a liter. A mL is a volume equivalent to a cm^3.

10. Centimeter or Meter (cm or m) - The metric units of length used to express a volume of water as is done with the English units in and ft.

Mass or Weight

1. Pound (lb) - The most common English unit for mass or weight. (0.4536 kg/lb). There are 2000 lb in a ton. A gal of water is generally estimated to weigh 8.33 lb.

2. Kilogram (kg) - Arguably the most common metric unit representation of mass or weight. There are 1000 kg in a metric ton (MT) and 1000 grams in a kg. A kg is equivalent to approximately 2.2046 lb.

3. Gram (g) - A metric unit of mass equal to 1/1000 of a kg. There are approximately 453.6 g in a lb.

4. Milligram (mg) - A metric unit of mass equal to 1/1000 of a gram or 1/1,000,000 of a kg.

5. Microgram (µ g) - A metric unit of mass equal to 1/1,000 of a mg, 1/1,000,000 of a g, or 1/1,000,000,000 of a kg.

Concentration

1. Milligram per liter (mg/L) - The most common metric unit describing a mass of chemical present in a L of water (mass/volume). A mg/L is equivalent to the English unit "parts per million" (ppm) when the assumption that 1 mL of water weighs 1 g (density of water is 1 g/mL, cc, or cm^3) holds true. Therefore, 1 mg/L is the same as saying a mg of chemical per 1,000 mg of water (mass/mass). Small variations in the density of water occur due to atmospheric pressures, temperatures, and water purity. However, for general purposes the variations cause inconsequential differences.

2. Microgram per liter (µg/L) - A metric concentration unit equivalent to 1/1,000 of a mg/L. A µg/L is equivalent to the English unit "parts per billion" (ppb) subject to the assumptions described above. A µg/L is a mass/volume unit, and is numerically equivalent to a mass/mass unit since the density of water in metric units is one g/cm^3.

3. Parts per million (ppm) - A dimensionless English unit expression of the mass of a chemical in a mass of water. For example, the concentration of a chemical in water may be expressed as 1 lb of chemical in 1,000,000 lb of water. Here again, the density of water is assumed to be a constant although it changes slightly with changes in atmospheric pressure, temperature, and water purity. A ppm is equal to

a mg/L assuming that the density of water is a constant 1g/cm^3. A concentration of 1 ppm phosphorus is equivalent to 1 lb of phosphorus in approximately 120,048 gal of water (1 gal of water = 8.33 lb).

4. Parts per billion (ppb) - A dimensionless English unit expression of the mass of a chemical in a mass of water. For example, the concentration of a chemical in water may be expressed as 1 lb of a chemical in 1,000,000,000 lb of water. Here again, the density of water is assumed to be constant. A ppb is equal to a µg/L assuming that the density of water is a constant 1g/cm^3. A concentration of 1 ppb is 1/1,000 of a ppm.

Dispelling the Magic: 1 ppm (English units, mass) = 1 mg/L (metric units, mass/volume)

The concentration units ppm (English units, mass/mass) and mg/L (metric units, mass/volume) are perhaps the most widely used interchangeable units in water quality research and monitoring. In fact, one often sees load calculated as a concentration expressed in ppm multiplied by a volume expressed in L to attain a load in mg, g, or kg (mass). This interchangeable use of units receives little derisive comment, in spite of the fact that the user is apparently mixing English and metric units, as well as mass and volume expressions. Although the scientific community views mixed units with either disdain or amusement, the calculated values are numerically identical since 1 ppm = 1mg/L. To illustrate this fact, assume that there is 1 lb of P in 1,000,000 lb of water (mass/mass). One lb of P = 0.4536 kg of P, applying the appropriate conversion factor from lb to kg discussed above. To convert 0.4536 kg to mg, the multiplication factor of 1,000,000 mg/kg (1x10^6 mg/kg) is used, yielding 4.536x10^5 mg P in 1,000,000 lb of water. Now, addressing the 1,000,000 lb of water, dividing by 2.2046 lb/kg yields 4.536x10^5 kg of water. Multiplying by 1,000 yields 4.536x10^8 g of water. Since 1 mL of water weighs 1 g, 4.5360x10^8 g of water = 4.5360x10^8 mL of water. Dividing 4.536x10^8 mL of water by 1,000 to convert from mL to L yields 4.536x10^5 L of water. Hence, we now have 4.536x10^5 mg P in 4.536x10^5 L of water. Dividing both by 4.536x10^5 to reduce the fraction to its lowest common denominator yields 1 mg P in 1 L of water (1 mg/L) , having started the exercise with 1 lb P in 1,000,000 lb of water, or 1 ppm.

Typical Pump Flow Rate and Nutrient Concentration Distributions

Although P has been the nutrient of concern in much of the debate regarding the mitigation/remediation efforts relative to potential negative impacts of agricultural drainage water quality on the Everglades ecosystem, other nutrients, chemical elements, and chemical compounds are also receiving research and monitoring attention. The load calculations, and associated pump flow and concentrations to be discussed can apply to any nutrient or chemical species. However, for the purpose of illustrating the load calculation methods, P will be used as the example nutrient, water will be the transport medium, and the geographic setting will be the EAA.

The basic load equation is Equation 1:

$$Nutrient\ Load(mass) = Concentration\ (mass/volume\ or\ mass/mass) \times Flow\ (volume\ or\ mass) \quad \textbf{(1)}$$

Equation I.

The calculation appears to be simple enough, but it can become troublesome given the range of acceptable protocols for measuring flows and collecting water samples, and the wide range of data collection frequencies. Applying standard and uniform data management techniques to data sets is extremely important, especially when combining hundreds of load measurements into a single database.

In Figure 1 is a typical pumped flow rate versus time curve. Figure 2 depicts a typical P concentration versus time curve. The two curves show how each parameter in the load equation (Equation 1) can change during a drainage event. These distributions can be seen in the EAA for P load monitoring when water samples and pump flow rates are collected or monitored continuously, or on short discrete time intervals, throughout the drainage event. These distributions are perhaps the most characteristic of

flows and P concentrations leaving farms in the EAA during pumped drainage events in response to rainfall.

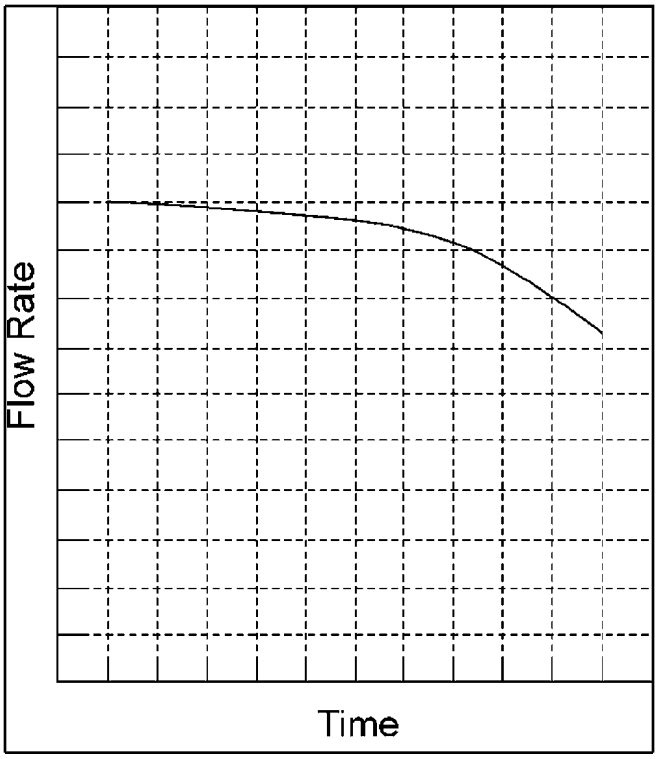

Fig 1. Typical phosphorus flow rate curve showing changes over time.

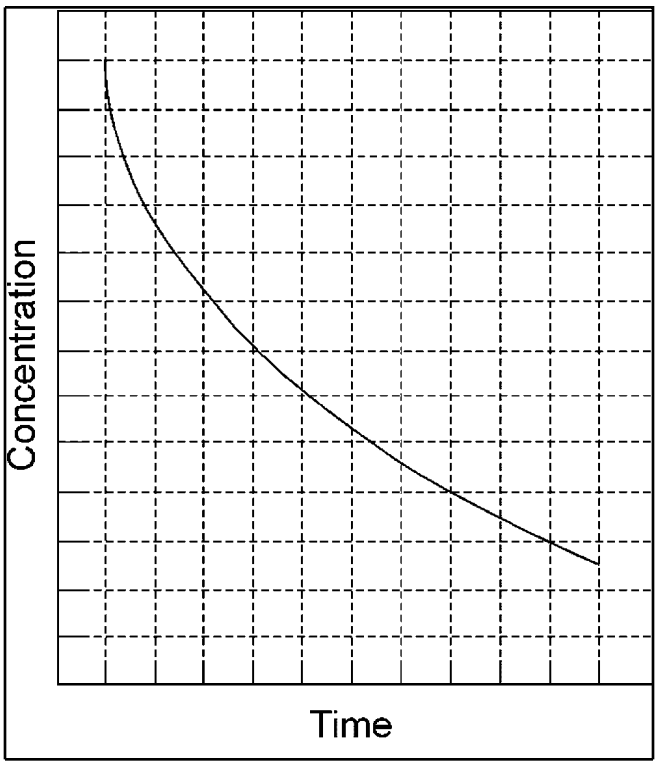

Fig 2. Typical phosphorus concentration curve showing changes over time, typical of an event with a "first-flush."

The flow rate curve in Figure 1 shows a slowly declining flow rate over time as hydraulic heads in the system increase. Over time, as the EAA main canal levels rise, and farm canal levels drop, pumps must work harder to lift water from a falling water level within the intake sump (on-farm) and discharge it to a sump or canal (off-farm) where water levels are rising. As the discharge event progresses, this hydraulic head that the pump must work against increases and pump efficiencies decline, yielding an accelerated decrease in flow rate towards the end of the pumping event. The concentration curve in Figure 2 shows an initially high P concentration, typical of a "first-flush" type event, where large amounts of P-bearing particulate matter and sediments near the pump intake are initially discharged. As the event continues, concentrations decline as rain water and open canal/ditch water P species dominate the P concentration characteristics of the water in the drainage stream.

Another typical P concentration distribution is shown in Figure 3. In this case, the drainage water concentration starts low, indicative of a situation where there is little particulate matter transport or channel bottom sediment scouring when the pump starts up. Farm canal water dissolved-P concentrations could also be relatively low. Events that could cause this phenomenon are dilution of the farm canal P concentrations due to initially heavy rainfall, antecedent pumping where much of the particulate matter or sediment near the pump had already been moved during the preceding pumping event, area main canal leakage through the pump station into the farm canal, seepage into the farm canal through the fractured bedrock, irrigation occurring just prior to drainage pumping, and/or a slow initial pump speed. As the event progresses, P concentrations rise. This could be attributed to the transport of particulate matter and sediments from the downstream reaches of the farm canal, lower water levels accompanied by higher flow velocities and canal bottom scouring, increased pump speed, and/or the addition to the drainage stream of rain water which has fallen on the field surfaces and passed through, or over, the P-rich upper soil layer carrying mobile particulates and dissolved-P.

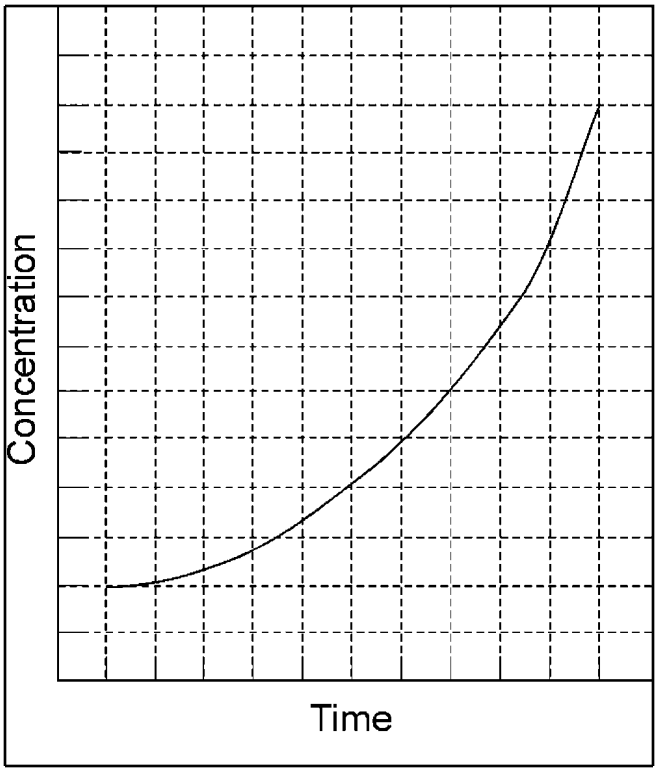

Fig 3. Phosphorus concentration change over time typical of an event where concentrations increase as soil water and particulate matter enter the drainage stream late in the event.

Shown in Figure 4 is another typical P distribution found in the EAA. In this case, concentrations start low, peak sometime during the event, and then fall off later in the event. This distribution can generally be attributed to a different time distribution of the occurrences discussed above that cause the distributions shown in Figure 1 and Figure 2.

For additional information on water sampling strategies and load calculations applicable to the EAA, the reader is referred to Izuno, Bottcher, and Davis (1992), Izuno et al. (1996), Izuno and Rice, eds. (1997), and Rice and Izuno (1997).

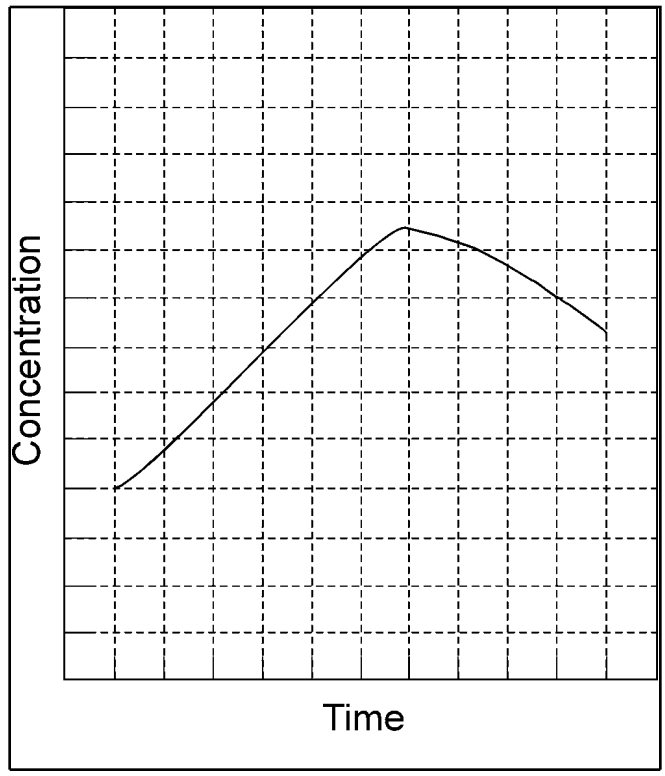

Fig 4. Phosphorus concentration change over time typical of an event where concentrations increase as soil water and particulate matter enter the drainage stream in the middle of the event before declining.

Calculating Nutrient Loads For Typical Data Collection Protocols

Beginning and End of Event Sampling

Shown in Figure 5 and Figure 6 are data derived from one of the most rudimentary sampling protocols acceptable for nutrient load determinations. In this case, water samples are collected at the beginning and end of the drainage event. Flow rates are also calculated only for the beginning and end of the event, usually by collecting hydraulic head and pump rpm data when turning the pump(s) on and off and applying a pump calibration equation.

To calculate the nutrient load using these available data, the beginning and end concentrations and flow rates can simply be averaged. The average flow rate is then multiplied by the length of time that the pump ran (pumping duration) to determine the total volume of water discharged. The equation to apply to calculate load with these data, using the

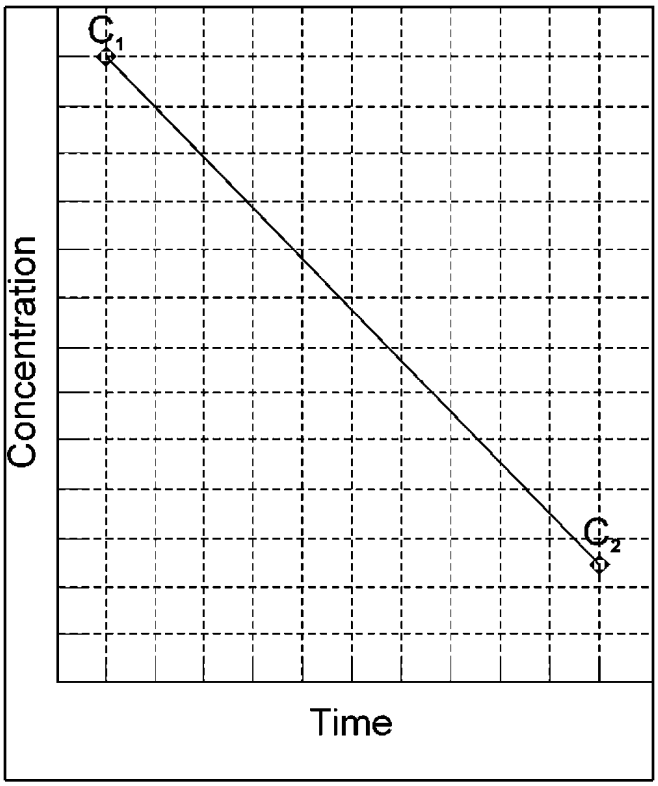

Fig 5. Typical phosphorus concentration curve showing changes over time when data are collected only at the beginning and end of the pumping event.

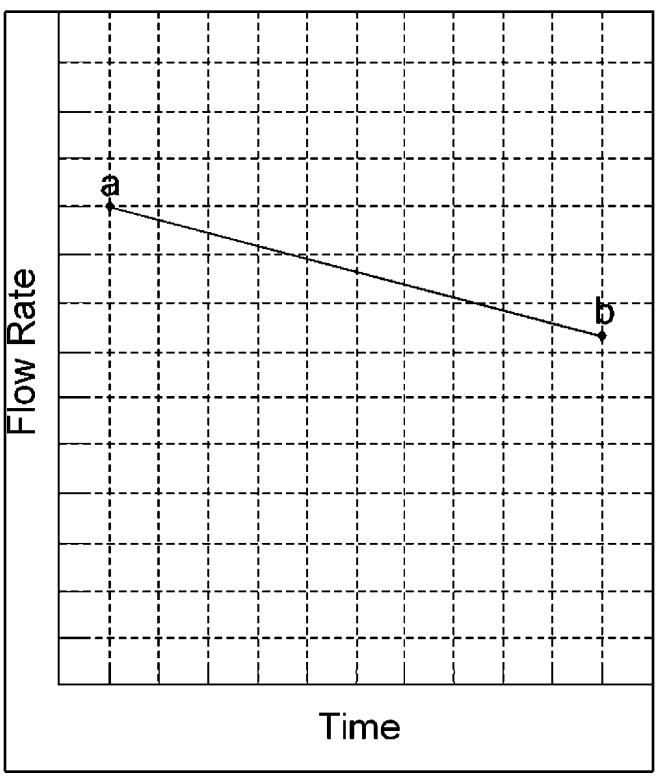

Fig 6. Typical phosphorus flow rate curve showing changes over time when data are collected only at the beginning and end of the pumping event.

variable names assigned in Figure 5 and Figure 6, is Equation 2:

$$Load = \left[\frac{(C_1 + C_2)}{2}\right] \times \left[\frac{(a+b)}{2} \times Time\right] \qquad \textbf{(2)}$$

Equation 2.

where C_1 and C_2 are the beginning and end of event concentrations, respectively, a and b are the beginning and end of event flow rates, respectively, and Time is the pumping duration.

Looking back at Figure 1, Figure 2, Figure 3, and Figure 4, one can see that this equation would yield a fairly representative load for the event, except when the concentration distribution depicted in Figure 4 applies. Flow rates in the EAA are generally flat over the normal pump operating range. Hence, an event average flow rate calculated as in Equation 2 is probably sufficient unless head differences across the pump change greatly during the event, or the pump is not installed to operate under its recommended efficient operating range.

Time Discrete Water Sampling With Continuous Flow Monitoring

At times it is desirable to know the distribution characteristics of drainage water P concentrations over time for the purpose of identifying factors which cause the distribution to appear as it does. In this case, time discrete water sampling (collecting water samples on predetermined, closely spaced, time intervals) is useful. Concentration data typical of the above water sampling protocol are shown in Figure 7. Again, Figure 8 again shows the typical continuously monitored flow rate versus time curve.

In Figure 7, it is evident that drainage water sample concentrations have been determined on two-hour intervals. Load calculations are still relatively simple. However, one must consider

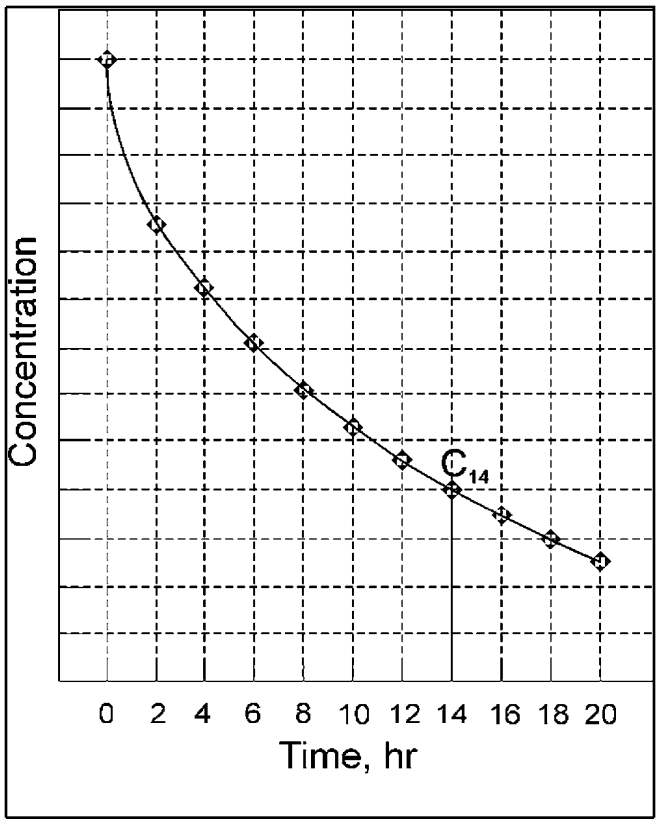

Fig 7. Phosphorus concentration distribution through a drainage event with water samples collected every two hours.

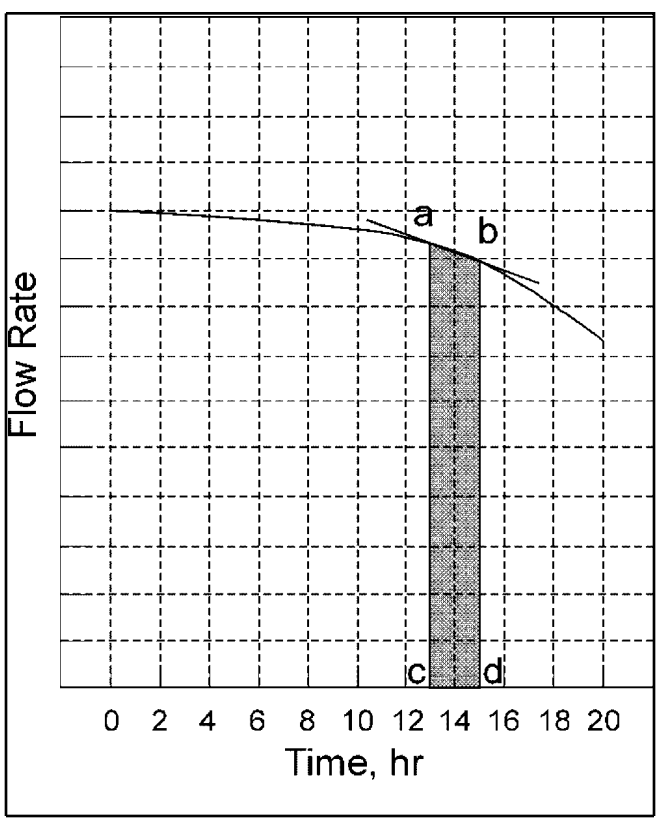

Fig 8. Flow rate distribution through a drainage event with flows calculated every two hours.

several calculation options, select one, and apply the selected option consistently. The primary determination that one must make is "what volume of pumped water corresponds to each concentration value". Options are: 1) Use the two-hour flow time period following the concentration time; 2) Use the two-hour flow time period preceding the concentration time; 3) Average two adjacent concentrations to obtain an average concentration for each two-hour flow period; or 4) Average the flow rates measured an hour before and an hour after the concentration was measured. For time discrete water sampling (Figure 7), where a water sample represents a point-in-time measurement, option 4 is the most desirable. The representative flow rate is then multiplied by the time interval to determine flow volume, and load is then calculated.

In this example, it is assumed that each concentration data point is a time discrete measurement representing the drainage stream concentration at a point-in-time. Hence, one must infer that the concentration distribution is a smooth curve (Figure 7). The load calculation option of choice is to select the flow rates at appropriate times and use them to calculate the flow volume. Illustrating this example, Figure 7 shows a concentration C at time=14 hours. Water samples were collected every two hours. Hence, the sample concentration should be assumed to apply to the volume of water pumped an hour before and an hour after the time that the water sample was collected (half the time step before plus half the time step after the time that the water sample was collected). In Figure 8, the flow rates at time=13 hours and time=15 hours are different, and should be averaged and multiplied by two hours to calculate the flow volume for concentration C. This flow volume is represented by the shaded area in Figure 8. Since there are 10 discrete water sample concentrations, the total event load would then be the summation of all the incremental loads associated with each two-hour time period as written in Equation 3:

$$Load = \sum load_i, \; i = 0 \; to \; 10 \qquad \textbf{(3)}$$

Equation 3.

where $load_0$ is calculated using the flow volume that occurred during the first hour after pump start-up, $load_{10}$ is calculated using the flow volume that occurred during the last hour prior to pump shut-down, and $loads_{1-9}$ are calculated using the two-hour flow volumes (the total volume pumped starting one hour preceding water sample collection and ending one hour after sample collection). The calculation for the example in Figure 7 and Figure 8 is shown in Equation 4:

$$Load_{14} = C_{14} \times \left[\frac{(a+b)}{2} \times (Time_d - Time_c) \right] \quad \textbf{(4)}$$

Equation 4.

where $Time_c$=13 hours, $Time_d$=15 hours, a=flow rate at 13 hours, and b=flow rate at 15 hours, C_{14}=water sample concentration at 14 hours, and $Load_{14}$=two-hour incremental load associated with C_{14}.

Flow Composite Discrete Sampling With Continuous Flow Monitoring

Shown in Figure 9 is a typical flow-weighted P concentration distribution where water samples are collected several times during an event, based on the pumping of a predetermined volume of water. In other words, each water sample is collected after a predetermined and equal volume of water is pumped. Hence, each concentration value is representative of an equal volume of water. This differs from time discrete water sampling (discussed above) where water samples were collected at predetermined time intervals, regardless of actual flow conditions.

In this example, the "equal volume of water pumped" is shown as the shaded areas "a" in Figure 10. The flow volumes between water sample concentrations used in the load equation are fixed, equal, and predetermined. Now, it becomes simply a matter of multiplying that fixed volume by each concentration and summing the incremental loads (Equation 5):

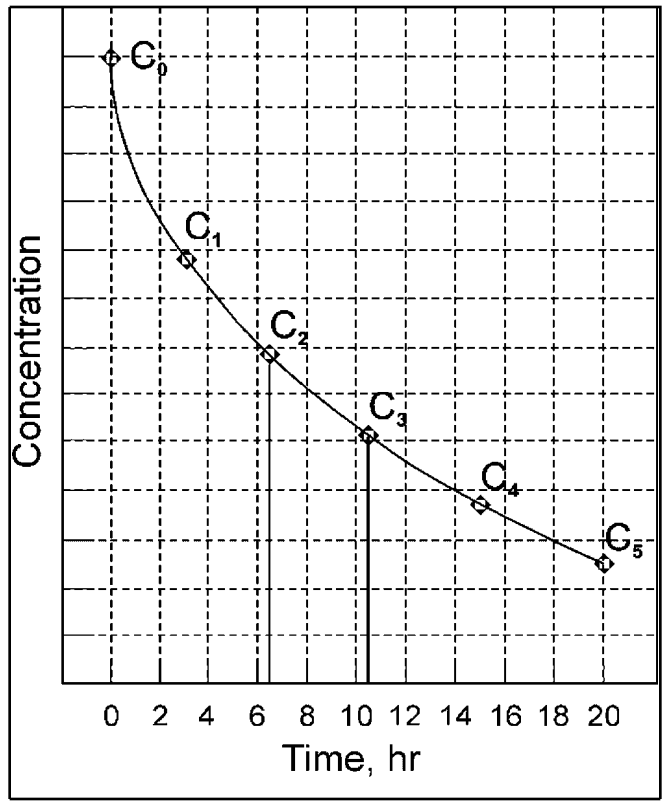

Fig 9. Flow-weighted phosphorus concentrations.

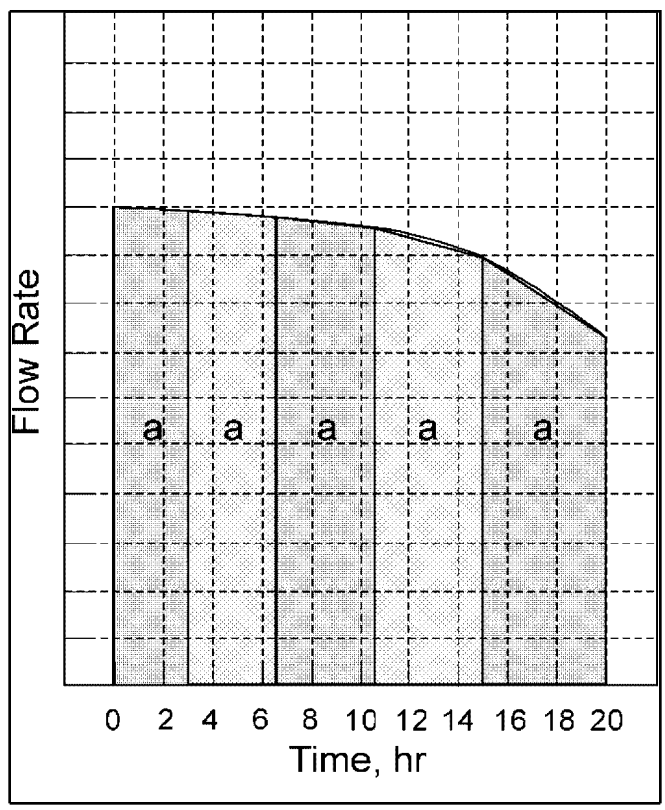

Fig 10. Predetermined equal flow volumes between hours 0 and 20.

$$Load = \sum\{[(C_i + C_{i+1})/2] \times Volume\} \quad \textbf{(5)}$$

Equation 5.

where i=0 through the number of the last water sample collected and Volume is fixed at a predetermined value.

Concentration C_0 in Figure 9 is the concentration of the initial water sample collected immediately at pump start-up. Concentration C_1 is the concentration of the water sample collected after the first predetermined volume is pumped. Hence, between concentrations C_0 and C_1, the predetermined volume of water is pumped. Averaging C_0 and C_1 yields the concentration applicable to the first volume increment. This average concentration is then multiplied by the predetermined volume to attain load for the first incremental volume pumped. During the time between the collection of C_1 and C_2, an equal volume of water was pumped. Hence, averaging C_1 and C_2 and multiplying the average concentration by the predetermined volume will yield the load for the second incremental volume of water pumped. To find the total load for the event, the process continues as shown in Equation 6:

$$\begin{aligned} Load = & \left[\frac{(C_0 + C_1)}{2} \times Volume\ a\right] + \\ & \left[\frac{(C_1 + C_2)}{2} \times Volume\ a\right] + \\ & \left[\frac{(C_2 + C_3)}{2} \times Volume\ a\right] + \\ & \left[\frac{(C_3 + C_4)}{2} \times Volume\ a\right] + \\ & \left[\frac{(C_4 + C_5)}{2} \times Volume\ a\right] \end{aligned} \quad \textbf{(6)}$$

Equation 6.

In essence, when flow composite samples are collected, and total flows are measured using the appropriate instruments, the flow monitoring and water sampling equipment are performing the above calculation automatically, yielding an event average concentration C and the total volume pumped which are then simply multiplied together to attain the total event load.

Flow Composite Water Sampling When a Pumping Event Spans More Than One Sampling Period

Another common scenario that occurs in the EAA when monitoring for P loads is when the flow composite water sampling protocol is being used, the pumping duration is long, and the water sample pick-up time occurs sometime during the pumping event. This yields a situation where the volume drained during a single pumping event is associated with two composite water sample concentrations as depicted in Figure 11 and Figure 12. The load calculation procedure in this case is actually a subset of the scenario described in Figures 9 and 10, where averaging of the period concentration is done by the autosampler yielding concentrations C_1 and C_2 as shown in Figure 11. To calculate the two load components that make up the total event load in this example, the volume of water pumped between hours 0 and 12 (area abde in Figure 12) is multiplied by C_1 and the volume of water pumped between hours 12 and 20 (area bcef in Figure 12) is multiplied by C_2. The two component loads are then simply added together to attain the total event load. This calculation is done using Equation 7:

In Figure 12, note that the two shaded areas (abde and bcef) delineating the two pumped volumes represent approximations of water volumes pumped when data are collected only three times during the event, at hours 0, 12, and 20. In this case, approximate water volumes pumped are calculated assuming straight lines for curve segments ab and bc. The unshaded areas between the two straight lines (ab and bc) are the error in volume calculation that occurs if one samples three times during the event rather than continuously. If the continuous flow monitoring protocol is being used, the volumes pumped would be represented by abde and bcef, following the curved line rather than the straight line segments. If the monitoring equipment is set up for continuous monitoring and flow totalizing, the volumes reported would be those under the curved

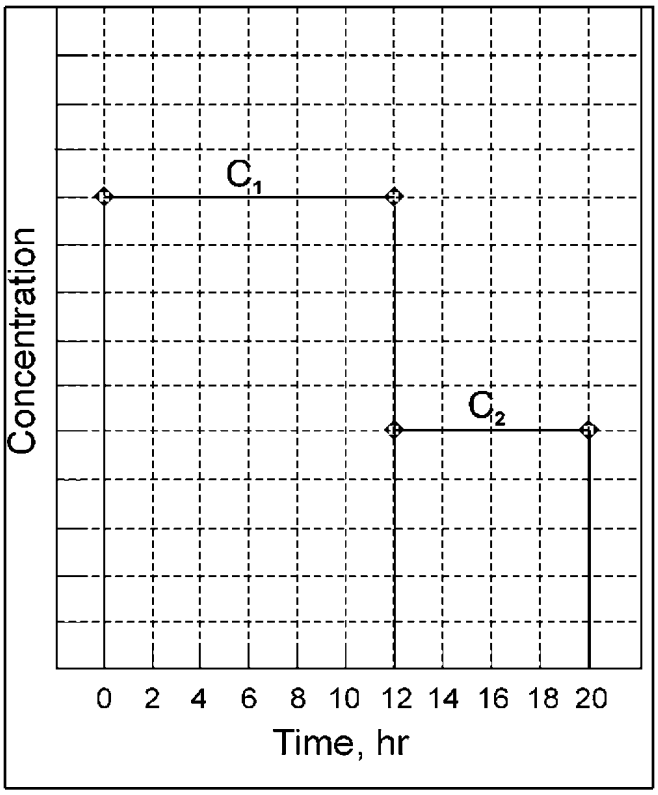

Fig 11. Flow-weighted composite phosphorus concentrations and the time period that a concentration represents.

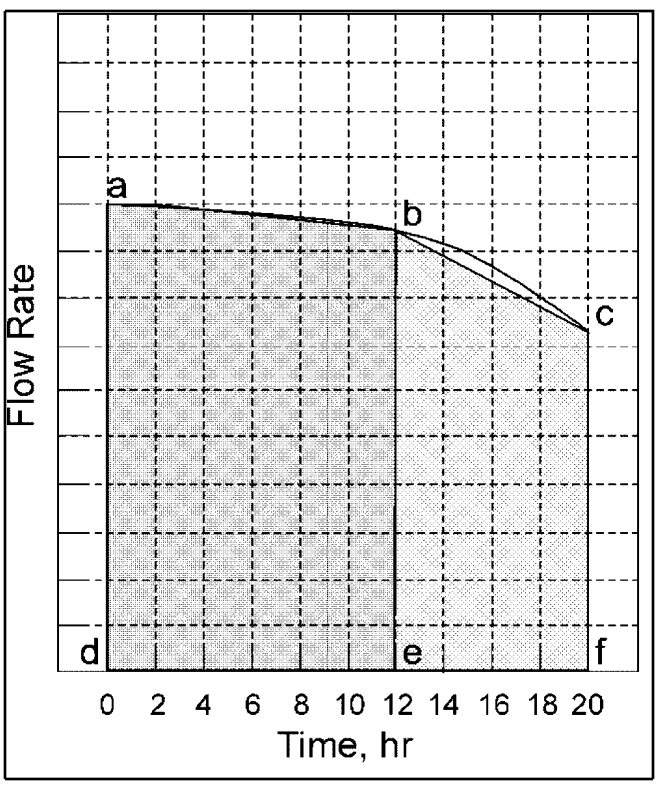

Fig 12. Estimated flow volumes between hours 0 and 12 and 12 through 20.

$$Load = (C_1 \times Volume\ \ abde) + (C_2 \times Volume\ \ bcef) \quad \textbf{(7)}$$

Equation 7.

line, where the instrumentation does the calculations automatically.

Adjustments to Load Measurements

It would be less than sensible to compare nutrient loads from different farms based on the total mass of a nutrient discharged alone. Assuming a uniform rainfall distribution over the area, a larger farm will discharge more water to maintain adequate crop root zone conditions than a small farm, simply because a larger volume of rain falls over the larger farm. In fact, the larger farm may actually be achieving less drainage on a per acre basis and lower drainage water nutrient concentrations. However, due to the farm size, absolute nutrient loads would appear to be much higher for large farms than for small ones. This makes comparing the relative load contributions and reductions between farms less than fair to the large farms. To account for the farm size differences, the absolute nutrient loads need to be adjusted. To normalize the data for farm size, one can simply divide the farm total load for the event or time period of interest by the gross farm area, yielding a loading expression "unit area load" (UAL) whose units are mass per unit area, typically lb/ac or kg/ha.

In addition to adjusting absolute loads for farm size, it is also useful to adjust the loads to account for hydrologic differences between years or other time periods. Nutrient loads leaving farms during wet years (high rainfall volume years) are higher than loads measured for dry years, simply because more rainfall occurs, requiring more pumping to achieve suitable root zone conditions during a wet year. Antecedent soil conditions and climatic conditions are also different between wet and dry years. These differences make it less than rational to simply compare absolute loads or UALs for a particular farm across years without factoring out the hydrologic differences. Data normalizing techniques that adjust for both farm size and hydrologic differences across time periods depend heavily on statistics and computer models, resulting in loading values expressed as "adjusted unit area loads" (AUALs).

Unit area loads and AUALs are discussed in depth in Rice and Izuno (1997).

Summary

Different units of measure for expressing pumped water volumes, chemical concentrations in water, and chemical loads were discussed. Conversion factors for English and metric units commonly used, sometimes interchangeably, were explained. The most commonly used methods and equations used for calculating P loads in the EAA were described. Finally, normalizing data to enable comparisons between farms and across different time periods was discussed briefly. Although load calculations are relatively simple, care must be exercised when determining which concentration should be considered to be representative of what volume of pumped water.

The selection of appropriate water sampling and flow volume measurement methods, and the consistent and uniform application of load calculation techniques, are preconditions for developing useful and interpretable load databases. The reader should be aware that it is essential to know how flow and concentration data were collected, and how load calculations were made, prior to drawing conclusions or making recommendations based on existing data sets. Additionally, many monitoring instruments can actually perform many of the cumbersome calculations automatically, if properly programmed to do so, reducing load calculations to a simple concentration multiplied by volume exercise.

References

Everglades Forever Act. 1994. Florida Statute Section 373.4592. Tallahassee, FL.

Izuno, F.T., A.B. Bottcher, and W.A. Davis. 1992. Agricultural water quality sampling strategies. Florida Cooperative Extension Service Circular 1036. Institute of Food and Agricultural Sciences, University of Florida. Gainesville, FL.

Izuno, F.T., R.W. Rice, R.M. Garcia, and L.T. Capone. 1996. Time versus flow composite water sampling for regulatory purposes in the Everglades Agricultural Area. ASAE Paper #962129 presented at the 1996 ASAE International Meeting on July 17 in Phoenix, Arizona. American Society of Agricultural Engineers. St. Joseph, MI.

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 submitted to the EAA Environmental Protection District. Belle Glade, FL.

Rice, R.W. and F.T. Izuno. 1997. Assessing phosphorus load reductions under agricultural best management practices. Florida Cooperative Extension Service Research Technical Bulletin 905. Institute of Food and Agricultural Sciences, University of Florida. Gainesville, FL.

SFWMD. 1992. EAA Regulatory Program. Part 1 of Chapter 40E-63 of the Florida Administrative Code. South Florida Water Management District. West Palm Beach, FL.