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CHAPTER 1

ON-FARM PARTICULATE PHOSPHORUS MEASUREMENT AND CONTROL

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On-Farm Particulate Phosphorus Measurement and Control

INTRODUCTION

Phosphorus (P) transport in runoff can occur in soluble and particulate forms. Dissolved P is comprised mostly of orthophosphates, which are immediately available for algal uptake (Sharpley et al., 1992). Particulate P consists of all solid phase forms including P sorbed by soil particles and organic material transported during runoff. The primary objective for studying particulate P transport is the potential for developing or modifying management practices to affect significant reductions in P export from the Everglades Agricultural Area (EAA) farms. In general, particulate P constitutes the major portion of the (75 to 90%) P transported in runoff from conventional tilled land (Sharpley et al., 1987; Sharpley et al., 1993). Studies in the EAA have shown that a great portion of total P loading in drainage waters is in the particulate form (Izuno and Bottcher, 1991). Izuno and Rice (1999) reported that particulate P accounted for 20% to 70% of the total phosphorus (TP) exported from EAA farms, and that particulate P export was frequently the cause of spikes in TP loads.

This report covers the latest findings of our particulate P research from the year 2003. The report contains some material included from our more comprehensive report on the subject published in April 2003.

Biological Contribution Mechanism

Stuck et al. (2001) studied farm-scale particulate P transport at an EAA test farm and proposed a supplementary mechanism for particulate P export from EAA farms that possibly explained the difficulty of trapping recently deposited light flocculant organic sediments. They showed that the mass fraction of P in exported suspended solids was frequently much higher than that of farm soil or field litter, and that the chemical characteristics of the exported suspended solids often more closely resembled those of aquatic flora than those of farm soil. They concluded that a significant fraction of particulate P in the EAA originates from in-stream biological growth rather than from soil erosion, and proposed that a major contributing factor to particulate P discharge is the “Biological Contribution Mechanism”.

Sediment that contributes significantly to P export was postulated to be, for the most part, recently deposited biological material such as settled plankton, filamentous algae, and macrophyte detritus. For example, Reddy and DeBusk (1991) showed that detrital production from *Eichhornia crassipes* (water hyacinths) could be as high as 15 gr/day/m^2 of hyacinth mat. Exported solids may also be contributed directly by floating or suspended plants when loosely bound material is detached by turbulent shear forces.

The root structure of aquatic plants such as *Pistia stratiotes* (water lettuce) can account for a large fraction of the total plant biomass, and may also provide an ideal location for growth of attached microorganisms (epiphytic growth). Engle and Melack (1990) studied mats of mixed aquatic weeds and found epiphyton concentrations as high as 146 gr/m^2 of mat. They also found that up to 70% of the attached epiphyton could be detached by wind-driven movement of the mats, and that the population remaining on the roots regenerated itself completely with in 1-2 weeks. Studies by Stuck (1996) showed that from 29% to 38% of the total mass of *Pistia stratiotes* could be dislodged by vigorous agitation.

In addition to floating aquatic weeds, contributions to particulate P are made by submerged aquatic plants and planktonic growth. The filamentous algae *lyngbya* is found in water systems throughout Florida. The conditions in the EAA canals of high pH and high temperature are favorable for the growth of *lyngbya*. Tubea et al. (1981) showed that *lyngbya* populations could exhibit doubling times of 0.8 to 2.0 days in favorable conditions. Stuck (1996) found that the field ditch surficial sediments in a representative EAA sugarcane farm contained approximately 15% by mass of readily identifiable *lyngbya* detritus.

The Biological Contribution Mechanism includes sediment erosion as a source of exported particulate P, but it modifies the character of the sediment that contributes particulate P, allowing that sediment to consist of a heterogeneous mixture of organic matter in various stages of decomposition, with various levels of P content and variable transport properties. The mechanism has been supported on the farm scale by the evidence of large differences between the physical and chemical characteristics of farm soils, farm sediments, and exported particulate matter. Specifically, the exported particulate matter frequently had characteristics that were more akin to viable plant matter than to farm soils or most of the farm sediments. Figure 1.1 shows a scene of total macrophyte coverage in an EAA farm ditch that is representative of macrophyte coverage potential when aggressive weed control is not practiced. Aerial reconnaissance studies have shown that the aquatic weed coverage may average as much as 50% of the total drainage conveyance area on a farm that does not practice weed control. On the farm that practiced aggressive weed control, the coverage still averaged more than 20% (Daroub et al., 2003). However, many growers in the EAA recognize the problem and implement cleaning programs to prevent weeds to accumulate close to the pump station. Figure 1.2 shows an example of a typical pump station in the EAA where the grower implements a good cleaning program to prevent the accumulation of aquatic weeds in the vicinity of the pump intake.

The current hypothesis is that particulate P is sourced from farm canals rather than from overland flow erosion. Soluble P may be converted to insoluble plant matter, and vice versa, depending on the physiological state of the biota in the canals. Processes inside the canal allow for the immobilization and remobilization of sediments, depending on interevent times and hydrodynamic conditions. The location of P inventories may change within the canal system as the biological population changes and as collections of biomass change their positions because of flow or wind patterns.

The development of the biological contribution mechanism has included the use of the P content of a particulate mass (expressed as a phosphorus mass fraction, mg P/kg total dry mass) as an approximate biomarker to estimate the source of the particulate matter. Figure 1.3 shows a typical P mass fraction range of a number of potential particulate P sources. Soil in the EAA typically has P mass fraction in the range of 750-1000 mg/kg (Fiskell and Nicholson, 1986; Stuck, 1996). Several recent studies have shown that the base sediments in EAA canals typically have P mass fraction in the range of 900-2500 mg/kg (Stuck, 1996; Izuno et al., 1998). Detritus from the floating water-weeds is in the range of 1500-3500 mg/kg (Stuck, 1996), while the plants themselves may have a P mass fraction in the range of 3000-7000 mg/kg (Stuck, 1996). Previous studies in the EAA have reported that the average floating aquatic plant P content of several farms over a two-year period averaged about 4200 mg/kg. The P mass fraction of planktonic growth may be in the range of 9000-15000 mg/kg or higher (Behrendt, 1990; Atkinson, 1991). Figure 1.3 shows this range graphically.

Figure 1.1. Aquatic weed coverage of an EAA drainage canal.

Figure 1.2. Good cleaning program to keep weed away from the pump station

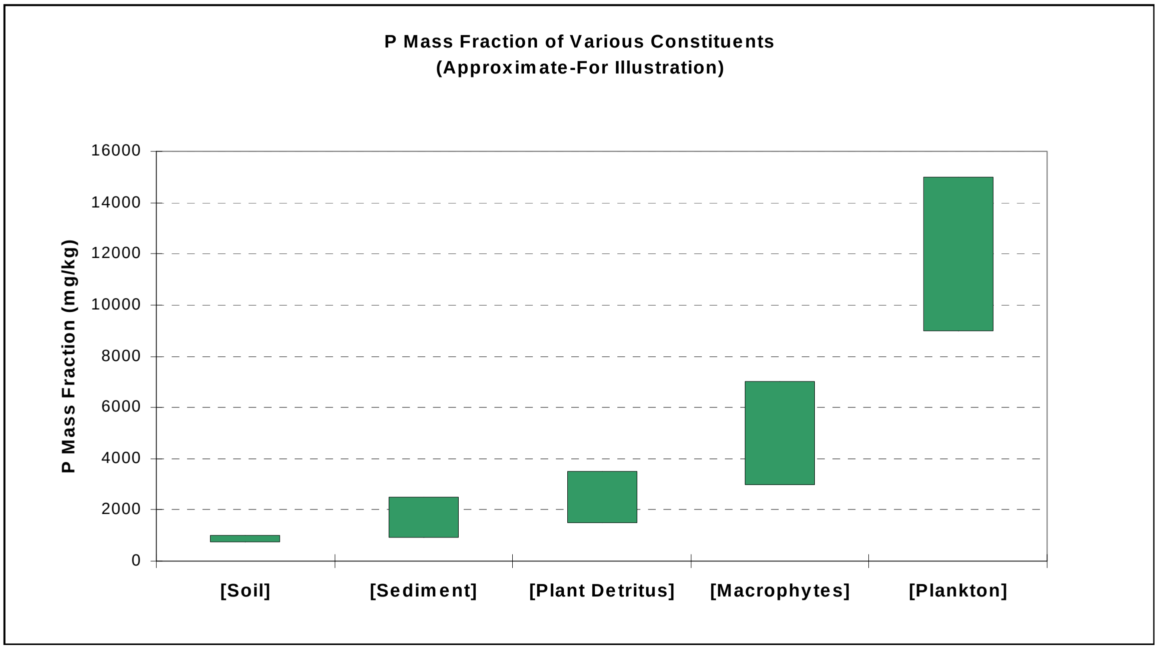

Figure 1.3. Phosphorus mass fraction of typical particulate phosphorus sources.

It must be stressed that Figure 1.3 represents typical historical ranges, and that local environmental conditions may give rise to results that may differ from this illustration.

The natural result of having heterogeneity of sources is that the resulting collection, for example the surficial layer of farm canal sediment, may contain a diverse collection of particles with various ages, P content, particle size, and specific gravity. This gives rise to selective transport under various conditions, which will be illustrated in the next section.

Particle Erosion and Transport

The organic sediments of the EAA are similar to cohesive clay sediments in their erosion characteristics (Stuck, 1996). The behavior of cohesive sediments may be illustrated briefly in simplified form as follows.

As water flows over material, its energy may cause some of the material to disengage and enter the flowing water. Resistance to this disengagement is referred to as shear strength. An idealized sediment bed will have a shear-strength and a yield-strength. Hydraulic stresses less than the bed shear strength will cause minimal erosion. As shear stress on the bed increases beyond the shear strength, erosion from the surface of the bed will proceed at a rate that is proportional to the *excess* of the shear stress compared to the shear strength. This is called the *Bed Erosion Regime*. At some point the shear stress will exceed the *yield strength* of the bed. At this point the forces on the bed exceed the cohesive forces holding the bed together and the bed starts to break up. As water velocity increases, the bed continues to break up more rapidly. Solids mobilization in this region is much greater than in the Bed Erosion Regime. This phase is called the *Bed Transport Regime.*

In both regimes erosion rate is directly proportional to shear stress. It is extremely important to understand, however, that shear stress is proportional to the square of velocity. In the most simplified form the relationship between erosion rate and velocity in the Bed Erosion Regime is given by the equation

$$\varepsilon = K(v_b^{\ 2} - v_c^{\ 2}) \qquad (1)$$

where ε = Erosion rate, mass/time/area

K = Rate constant and conversion factor

v_b = Channel velocity

v_c = Velocity at which shear stress equals bed shear strength (critical velocity)

Figure 1.4 shows this relationship in qualitative form with arbitrary units. In this idealized case, no erosion takes place until the critical velocity of 0.05 units is reached. At that point, the erosion rate increases as a function of the difference between the square of the channel velocity and the square of the critical velocity. At a velocity of 0.32 units the yield strength of the bed is exceeded, the bed starts to disintegrate, and the regime shifts to Bed Transport. The bed transport region may be described by an equation similar to Equation 1, but with a different critical velocity, and a much higher erosion coefficient.

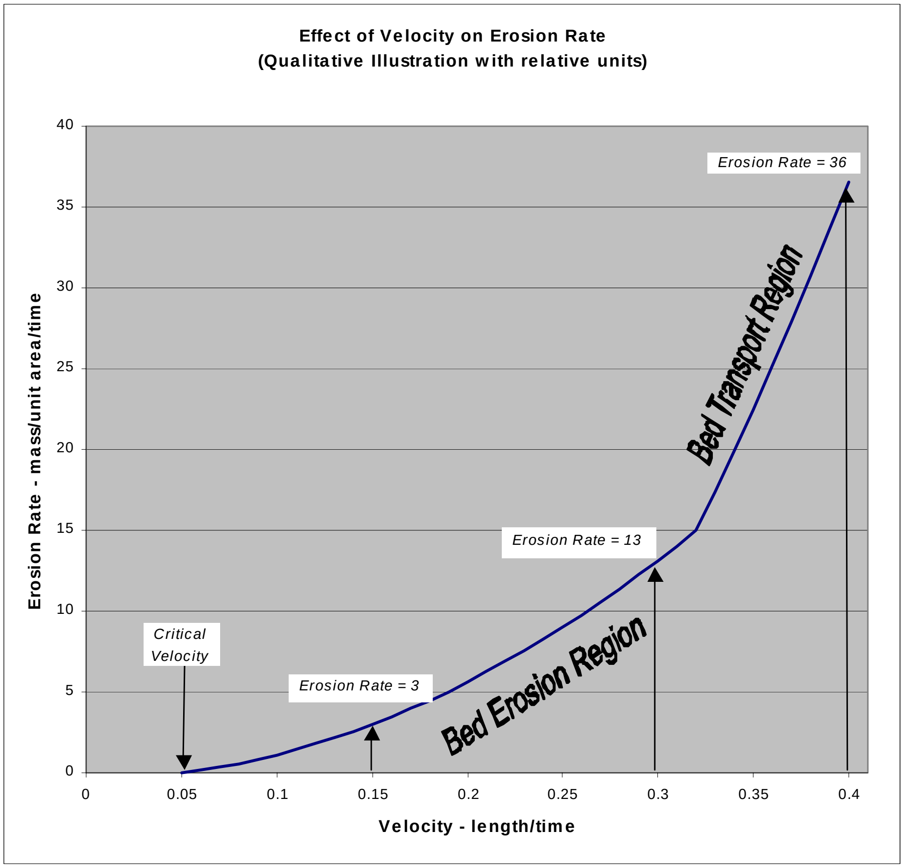

Figure 1.4. Effect of Velocity on Erosion Rates.

Several important points may be made from this simplified illustration.

- First, at relatively low velocities, there is zero to minimal erosion and particle mobilization.
- Beyond the critical velocity, the particle-mobilization rate increases with the *square* of the velocity. In our example, the erosion rate at a velocity of 0.15 velocity units is 3 rate units. Doubling the velocity to 0.30 velocity units increases the erosion to 13 rate units, more than a *four-fold increase* in particle mobilization.
- An additional increase in velocity to 0.40 units causes the system to enter the Bed Transport Region. Here, where mobilization is even greater, the erosion rate increases to 36 units, almost a three-fold increase arising from a 25% increase in velocity.

This example illustrates the significant changes that may occur within relatively narrow flow rates. In the EAA, pumping rates may easily be doubled or tripled by running multiple pumps or switching from small to large capacity pumps. Velocities may also change rapidly when canals are drawn down to low levels. These operating factors can have profound impact on particle mobilization rates.

The amount and physiological condition of the various types of organic matter present in a water conveyance system varies with time and flow. Biological growth incorporates soluble P into particulate matter, represented by the plant biomass. Plant death and decomposition releases some P as soluble P, and releases some plant biomass as mobile particulate matter. In stagnate conditions the particulate matter accumulates in place. In irrigated conditions, this matter may be transported upstream. With drainage conditions, particulates may be transported downstream and ultimately discharged. The response to all these conditions causes a continuing change in the amounts and locations of particulate P.

Inter-event time (the time between pumping events) can have an influence on the amount and location of transportable organic material in EAA farm canals. The longer the interevent time, the more time is available for biological growth and accumulation in the canal system. Stuck et al. (2001) and Izuno et al. (1998) showed that there could be a positive correlation between the length of the interevent time and the amount of particulate mass available for transport at start up.

Primary Processes and Illustrative Examples

This section defines the primary transport processes that occur in the farm canals. These primary processes have been discussed at length elsewhere (Stuck, 1996; Stuck et al., 2001, Daroub et al., 2003). For the purposes of this report, the processes are classed into several categories, and are described as follows:

<u>First Flush</u> – During the (relatively) quiescent period between pumping events biological material can grow and accumulate in the canals. This fresh material, *along with solids that were suspended at the time of shutdown in the preceding event*, can be readily suspended under the turbulent conditions that exist at pump start-up. This highly mobile material causes a high concentration of suspended solids during the early periods of pump events. Eventually this highly mobile material flushes out and the process of erosion proceeds on the less mobile particulate matter in the canals.

Cumulative High Velocity – The normal erosion process at constant velocity produces (in the idealized case) a steadily increasing discharge concentration of suspended solids. The reason for this is that water farther upstream has a longer time to accumulate eroded suspended solids as it moves downstream to the discharge point. If there is a substantial increase in velocity, there will not necessarily be an immediate increase in suspended solids concentration, because of the lag time for the flowing water to accumulate additional suspended solids. There are often circumstances during pumping events when velocity may change significantly, such as when a larger pump is started up or when canal depth becomes shallow, significantly reducing crossectional area available for flow. If there is a large volume of water in the canal, as is usually the case when a large pump is started up, the effects of this velocity increase are not seen until sometime later, so changes in concentration may be affected by *cumulative high velocity*.

This process also proceeds after first flush, as long as velocity is sufficiently high. First flush mobilizes the material remaining close to the pump station from the previous event as well as the highly mobile new material that was produced in the interevent period. After first flush, the sustained high velocity will continue to mobilize particulate P, the continued export of which will exhibit the lag just described.

Restart Flush – When pumping is terminated, suspended solids in the canal system settle out in place. If there had been a significant concentration of suspended solids in the downstream reaches of the canal system at shutdown, there will be a high initial concentration in the discharge when the pump is restarted. This is similar to First Flush, except that the time between pump shut down and restart is less than that for First Flush. In fact the break between First Flush and Restart Flush is somewhat arbitrary, in that an event is defined as the start of pumping after more than twenty-four hours of quiescence, so a pump start after twenty-three hours would give rise to a Restart Flush, whereas a pump start after twenty-five hours would give rise to First Flush. Because they are similar, both these phenomena are grouped into the category “Start-Up Flush”.

Particulate Phosphorus Spike – This is described by a somewhat arbitrary definition that if the particulate P concentration for a particular sample is more than twice that of either the preceding or succeeding samples, then a spike has occurred. The spike is assumed to originate from a random release of particulate material from upstream sources, such as a collection of floating macrophytes. By this definition, a sustained concentration increase and decrease that covers several consecutive samples would not be classified as a spike.

Pump Cycling – This category differs from pump restart in that the pump cycles through on-off oscillations over relatively short time periods, e.g. 30 minutes to two hours. This condition occurs when a farm pump is on automatic on-off control that is tied to canal level. One of three of the farms studied employs this control system. The other two rely on manual pump control for start up and shut down.

Other – Obviously this is the catchall category, but it is relatively narrow. Any sample that exhibits high particulate P and is not explained by the other categories falls in the "Other" category. This category can include sustained spikes, which might arise from some upstream disturbance, such as starting a booster pump or unblocking a culvert in a rice field or any other special event.

These categories are well illustrated by Year 2000 Event 276 that started at Station UF9200A on October 2, 2000 and lasted for over eight days (Figure 1.5). The grower typically pumps either with one large or one small electrical pump, both of which are under on-off level control. Prior to this event, he had pumped relatively infrequently, using the small pump for a total of 82 hours and the large pump for less than 2 hours over the preceding 83 days, so there was ample opportunity for biological material to accumulate in the canals. During the event he switched from the large pump to the small one, and back, several times. There were also several instances of pump oscillation under the on-off control mechanism.

The suspended solids, flow, and level profiles for this event are shown in Figure 1.5. Large pump operation is indicated by flow rates that start at 2.5 m^3/s, small pump operation is indicated by flow rates that start at 0.5 m^3/s. The effect of the interevent buildup is clearly illustrated by the initial suspended solids surge, which rose to more than 3500 mg/L. The figure clearly shows two subsequent waves of suspended solids that are associated with the operation of the large pump, and illustrate the lag effect of prior high velocity.

Figure 1.6 shows the velocity and particulate P profiles of this same event. Here the start-up flush of particulate P is evident at the start of the event. At Decimal Date (DD) 277.09 there is a particulate P spike. At DD 278.51 the large pump is started and at DD 279.14 the effect of this increase in velocity begins to be seen. The particulate P concentration increases steadily until the pump goes into oscillation mode from the level control, at which point concentration starts to decrease because of the decreasing average velocity. Although the concentrations are decreasing, they are still appreciable, because there is still high velocity when the pump is running. The particulate P export that occurred during pump cycling was in fact a continuation of the cumulative high velocity in effect prior to the start of pump cycling because the suspended solids do not have sufficient time to settle and consolidate between pump cycles.

At DD 281.35, when the large pump is restarted there is an immediate surge of particulate P, which is categorized as re-start flush. When the large pump went into cycle mode on DD 279.65, particulate P began to settle in the region just upstream of the pump. This final surge of particulate P is from immediate resuspension of the material that was settled out when the large pump went into cycle mode and then when flow was switched over to the small pump.

Comparison of the shape of the TSS curve and the shape of the particulate P curve in the period from DD 281.3 through DD 282.0 shows that the particulate P surge *led* the suspended solids surge. This is an illustration that the light, flocculent, readily transported material, which is high in P content, does not necessarily move in the same way that the bulk of the suspended solids moves.

This example of categorization is generally representative of what is seen at the study farm UF9200A. The other farms operate under different hydraulic control schemes, and at times present more complicated and extreme conditions, particularly when the canals are drawn down to very low levels. The basic categorization technique, however, applies reasonably well to the major contributing events for all study farms.

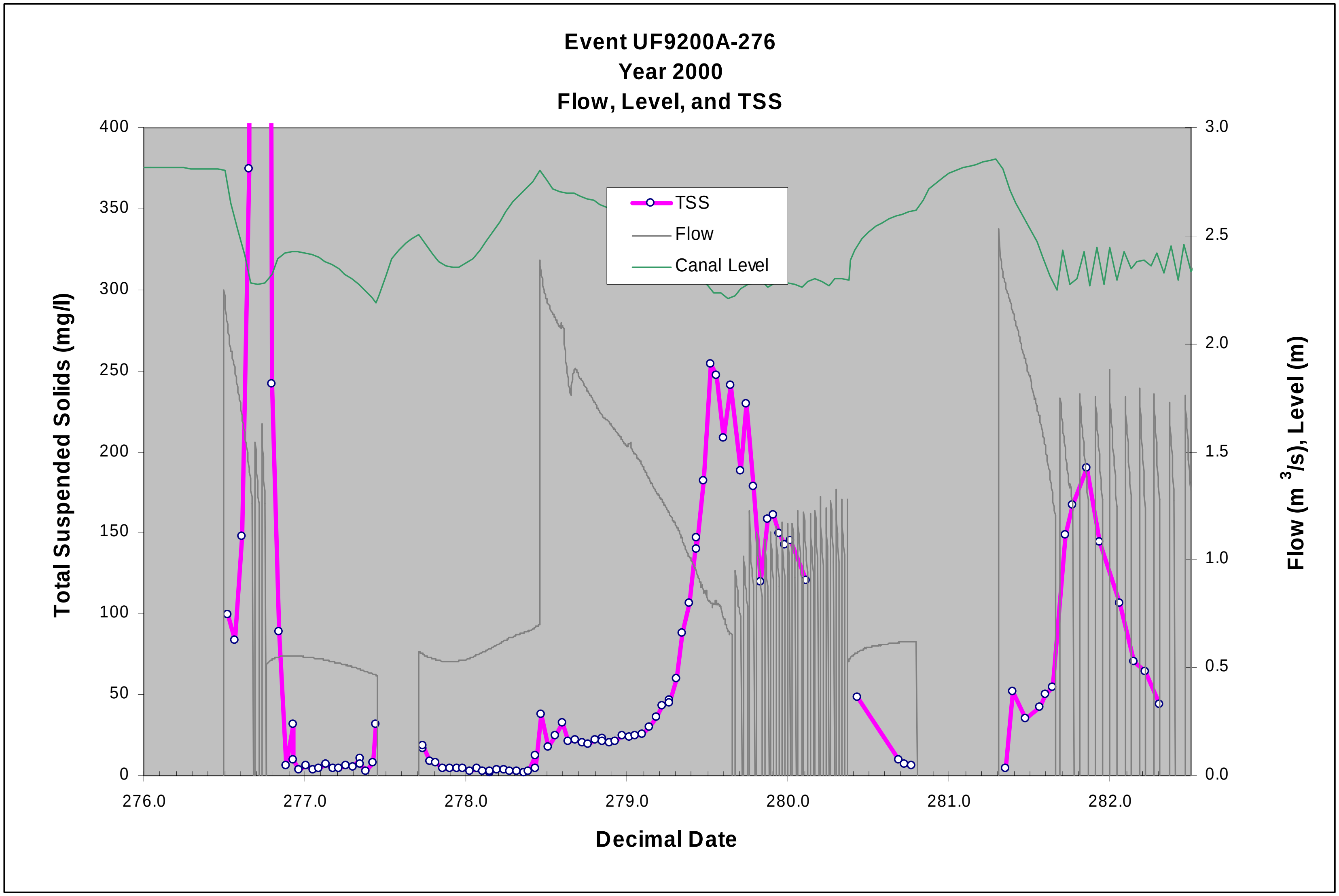

Figure 1.5. Flow, Canal Level, and Total Suspended Solids Profiles for Year 2000 Event 276 at UF9200A.

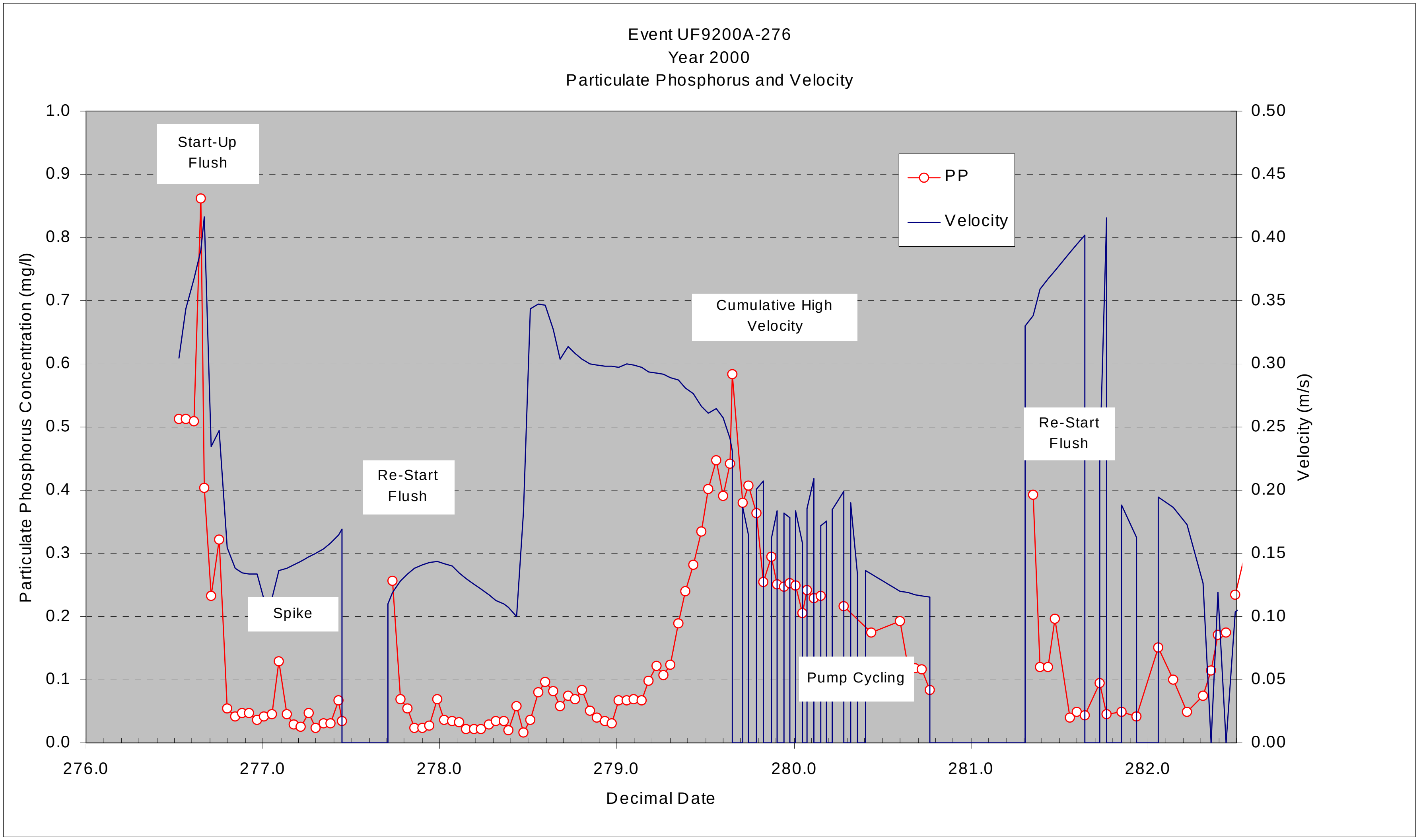

Figure 1.6. Velocity and Particulate Phosphorus Profiles for Year 2000 Event 276 at UF9200A.

MATERIAL AND METHODS

Farm Descriptions

Three typical farms from the EAA were chosen for the study of a detailed analysis of particulate P transport in drainage canals (Figure 1.7). These farms were chosen from the existing group of farms monitored by UF/IFAS since 1992 for the BMP implementation and efficacy project. These farms were chosen to represent a typical range of farm sizes, soil types and geographical distribution within the EAA. Their detailed characteristics, which have been described frequently in previous reports, are available in Appendix 1.A of this report and will not be repeated here. The farms, and the reason for their inclusion in the particulate P intensive analysis studies are as follows.

UF9200A – This location represents a medium-size (1280 acre) sugarcane monoculture farm on the eastern side of the EAA. The farm canal grid is relatively simple, and the pump design and operation are typical. The grower has two high capacity (9000-28,000 gpm range) and one lower capacity (5000-8,500 gpm range) single speed electrical pumps, which can be operated with automatic on-off level control. The water control philosophy on this farm is best described as attentive but not aggressive. Historically the fraction of discharged P that is in the particulate form has averaged about 50% on a time-weighted basis.

UF9206A and UF9206B – This location represents a medium-size (1750 acre) mixed crop farm on the eastern side of the EAA. The grower frequently rotates various plots among cane, vegetables, rice, and sod. The farm canal grid has been extensively modified to allow for internal water movement and storage, and is relatively complex. There are two separate pump stations on this farm, each of which has two variable-speed diesel pumps (3000-23,000 gpm range), which are operated manually. The water control philosophy on this farm is best described as aggressive. Historically the fraction of discharged P that is in the particulate form has averaged slightly less than 50% for UF9206A and slightly more than 50% for UF9206B on a time-weighted basis.

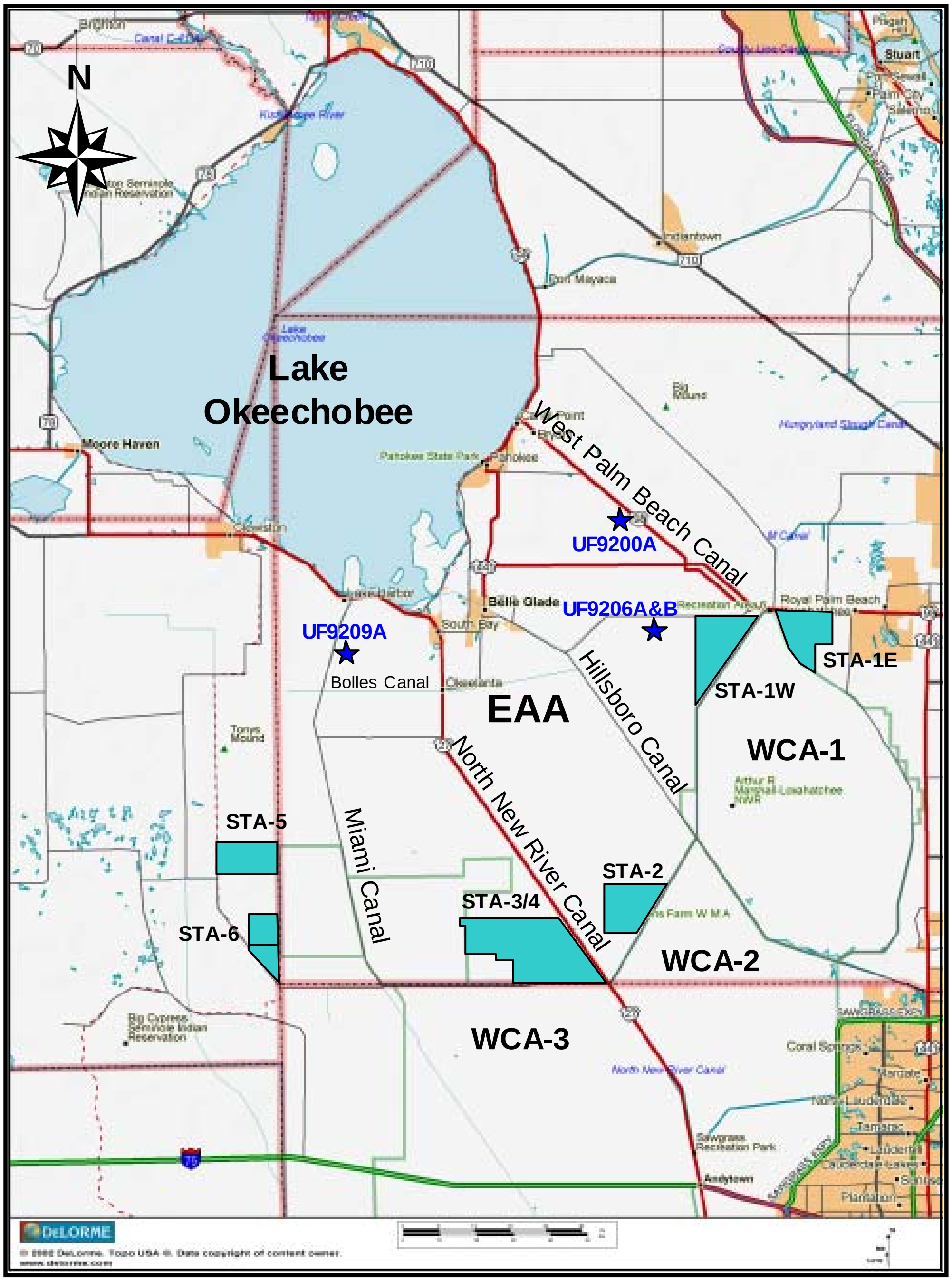

Figure 1.7. Location of experimental farms (★) in the EAA.

UF9209A – This location represents a medium-size (3072 acre) sugarcane monoculture farm on the western side of the EAA. The farm canal grid is relatively simple, and the pump design and operation are typical. The grower has three pumps (6000-35,000 gpm range), which are operated manually. The water control philosophy on this farm is best described as attentive but not aggressive. The primary differentiating characteristics between This farm and UF9200A and UF9206A/B is that UF9209A typically has lower discharge total P concentrations, and that, historically, the fraction of discharged P that is in the particulate form has averaged greater than 70% on a time-weighted basis. The original program plan included only the evaluation of UF9200A and UF9206A and B. Because of its historically low dissolved P levels, and relatively high fraction of particulate P, UF9209A was added to the intensive study plan late in 2000 to give additional breadth to the program.

Preparation and installation of all necessary sampling equipment at study farms UF9200A and UF9206A and B was completed and intensive event monitoring at these sites started in early July 2000. The first pumping event at UF9200A started July 3, 2000, and at UF9206A and B started July 8 and 9, 2000, respectively. Preparation and monitoring at farm UF9209A was completed until October 2000. However, because of drought conditions, there were no pumping events at this location until March 19, 2001.

There were periodic malfunctions associated with the discrete sampling equipment at all farms, which included lighting strikes, torn hoses, jammed distribution arms, microprocessor programming bugs, and emergent intake lines at extremely low canal levels. In spite of these issues, approximately 80% of the total monitored flow was sampled at UF9200A, 79% at UF9209A, 84% at UF9206A, and 81% at UF9206B. Most important, the majority of the flow associated with major events was sampled at all locations.

Event Analysis

This element constitutes the predominant effort of the program in 2003. The four pump stations on the three study farms are monitored continuously for pumping events. At pump start-up sampling of the pump inlet water is started. Each pump station is equipped with 3700 portable ISCO® automatic samplers that collect water samples every 15 minutes. Four consecutive 15-minute samples are composited into one-hour discrete samples for analysis. Sample caddies are collected every 24 hours for the duration of the pumping event.

Water samples are placed in a water cooler with ice and immediately transported to the EREC Water Quality Laboratory for analysis. All samples are analyzed for total suspended solids (TSS), total phosphorus (TP), and total dissolved phosphorus (TDP). Particulate P is calculated as the difference between TP and TDP. Water samples for TDP analysis are immediately filtered though a 0.45 µm filter-membrane, samples for TP analysis are not filtered. Analysis for TP and TDP are performed using the mercury oxide digestion method (Method 365.4, EPA 1993). Total suspended solids analysis is done following SOP No 13 from the EREC (EREC-SOP, 2002) and Method 160.2 (EPA, 1993).

The pump stations are instrumented and monitored continuously for, among other variables, rainfall, pump flow rates, and inlet and outlet water levels. The monitored data are downloaded twice daily via telemetry to a central data processing location. Each pump station also has a Hydrolab Datasonde® located in close proximity to the water sampling point. The Datasonde monitors a number of variables, including water temperature, pH, conductivity, and turbidity. Data from the Datasondes are downloaded manually on a weekly basis.

RESULTS

Event Summary Statistics

Tables 1.1 through 1.4 details the event summary statistics for the four pump stations from 2000 to 2003. The sampling program did not start until the middle of year 2000, but event hydraulic statistics are included for all of 2000 for the stations at farms UF9200A and UF9206A and B in order to follow annual pumping volumes for each farm. The data sets discussed in this report cover four wet seasons and three and half calendar years for UF9200A and UF9206A and B and three wet seasons and three and quarter calendar years for UF9209A. Pump station at farm UF9209A has followed a pumping scheme that is more regular than the other two farms. Its pumping events tend to be more frequent, of shorter duration, with shorter inter-event times. Thus it has more pumping events than the other two study farms.

Data collected during the last four years is considered to be adequate to draw preliminary inferences regarding particulate P transport in the EAA. Unless otherwise noted, subsequent analysis will refer only to those flow events or part of events where samples were successfully collected, with no attempt to estimate the parameters associated with missing samples. The data presented in Tables 1.1 through 1.4 includes equivalent concentrations and P content for each event and each year. The equivalent concentrations are calculated numbers and represent the total sampled mass of the component of interest. e.g. total suspended solids, divided by the total pumping volume (during sampling) of the event or year. They represent a characteristic or mass average concentration of the sampled portions of the event or year. Similarly, the P content is calculated as the total sampled mass of particulate P divided by the total sampled mass of suspended solids, and represent the mass average P content for the sampled portion of each event or year. The characteristic concentrations may be used to estimate the total annual loads, compensating for un-sampled periods. Summary of key elements of the data sets in Tables 1.1 through 1.4 are presented in Tables 1.5-1.7 and Figures 1.8-1.13.

Table 1.5 summarizes the annual contributions from the particulate P loads to the total P loads for each farm during the last four years. Values from UF9200A increased from 47% in 2000 to 56% in 2002. However in 2003, particulate P contribution to total P loads dropped to 28%. At UF9209A the contribution from particulate P to the total P load was almost constant, 67% in 2001, 68% in 2002. But in 2003, UF9209A pumped their canals lower and longer than previous years, resulting in more sediments being scoured from bottom of the canal and transported out of the farm, ensuing in a particulate P contribution of 80% to the total P load. The particulate P load contributions of UF9206A increased from 26% in year 2000 to 36% in years 2001 and 2002, and decreased to 27% in 2003. Particulate load contributions from farm UF9206B decreased from 40% in 2000 to an average contribution of 36% during the last three years. Table 1.6 summarizes the annual average data for equivalent concentrations, estimated loads, and suspended solids P content for each farm.

Table 1.1A. Hydraulic Event Statistics for UF9200A.

Start Date	Event Number	Interevent Time (days)	Start Decimal Date	Finish Decimal Date	Duration (hrs)	Volume Pumped (m3)	Cumulative Volume (m3)	Volume Sampled (m3)
01/05/2000	00A-000105		01/05/2000 10:20	01/05/2000 14:35	4	17,605	17,605	*
01/17/2000	00A-000117	12	01/17/2000 11:06	01/17/2000 17:35	6	7,603	25,208	*
02/09/2000	00A-000209	22	02/08/2000 17:30	02/09/2000 11:05	18	125,358	150,566	*
03/20/2000	00A-000320	40	03/20/2000 07:10	03/21/2000 07:30	24	130,138	280,704	*
03/31/2000	00A-000331	9	03/30/2000 13:54	03/30/2000 18:20	4	28,014	308,718	*
04/13/2000	00A-000413	14	04/13/2000 11:20	04/19/2000 20:50	154	218,329	527,047	*
07/03/2000	00A-000703	74	07/03/2000 08:05	07/04/2000 14:16	30	57,922	584,969	57,923
07/08/2000	00A-000708	4	07/08/2000 10:39	07/11/2000 07:45	69	144,708	729,677	102,682
09/20/2000	00A-000920	70	09/19/2000 13:40	09/22/2000 07:30	66	172,210	901,887	154,432
09/25/2000	00A-000925	3	09/25/2000 09:05	09/26/2000 03:30	18	48,052	949,939	46,957
10/02/2000	00A-001002	6	10/02/2000 11:55	10/11/2000 02:05	206	458,581	1,408,520	451,306
							Total or Avg.	813,300
								92%
07/12/2001	00A-010712	273	07/11/2001 13:20	07/12/2001 17:30	28	87,256	87,256	82,334
07/15/2001	00A-010715	2	07/14/2001 16:00	07/19/2001 20:50	125	610,374	697,630	297,271
07/23/2001	00A-010723	3	07/23/2001 07:00	07/26/2001 06:35	72	429,633	1,127,263	411,283
08/02/2001	00A-010802	7	08/02/2001 10:15	08/06/2001 16:00	102	644,974	1,772,237	544,759
08/08/2001	00A-010808	2	08/08/2001 07:00	08/08/2001 16:30	9	43,873	1,816,110	**
09/09/2001	00A-010909	32	09/09/2001 09:30	09/11/2001 16:15	55	100,324	1,916,434	**
09/13/2001	00A-010913	2	09/13/2001 11:25	09/15/2001 15:55	53	166,602	2,083,036	**
09/27/2001	00A-010927	12	09/27/2001 08:40	10/02/2001 09:30	121	517,544	2,600,580	298,837
10/25/2001	00A-011025	23	10/25/2001 08:35	10/25/2001 16:00	7	39,180	2,639,760	38,825
11/05/2001	00A-011105	11	11/05/2001 07:20	11/08/2001 17:45	82	113,771	2,753,531	89,456
							Total or Avg.	1,762,765
								64%
02/11/2002	00A-020211	95	02/11/2002 07:10	02/18/2002 17:09	178	340,916	340,916	279,547
02/25/2002	00A-020225	7	02/25/2002 07:50	02/25/2002 20:25	13	21,073	361,989	21,073
03/04/2002	00A-020304	6	03/04/2002 07:15	03/04/2002 16:25	9	44,490	406,479	43,073
06/22/2002	00A-020622	109	06/21/2002 14:45	07/05/2002 17:20	339	1,248,944	1,655,423	731,525
07/08/2002	00A-020708	3	07/08/2002 07:20	07/16/2002 18:05	203	555,333	2,210,756	411,122
09/06/2002	00A-020906	52	09/06/2002 08:05	09/07/2002 17:10	33	77,374	2,288,130	75,913
10/12/2002	00A-021012	35	10/12/2002 09:25	10/13/2002 11:40	26	44,464	2,332,594	43,401
10/16/2002	00A-021016	3	10/16/2002 07:20	10/17/2002 20:20	37	39,369	2,371,963	36,452
10/26/2002	00A-021026	8	10/25/2002 17:35	10/28/2002 08:10	63	121,406	2,493,369	90,502
11/18/2002	00A-021118	20	11/17/2002 12:00	11/22/2002 01:20	109	158,387	2,651,756	99,087
							Total or Avg.	1,831,694
								82%
03/17/2003	00A-030317	115	03/17/2003 10:00	03/17/2003 17:00	7	42,476	42,476	42,476
04/26/2003	00A-030426	40	04/26/2003 10:00	05/02/2003 09:00	143	222,546	265,022	139,770
05/28/2003	00A-030528	26	05/28/2003 07:00	05/30/2003 16:00	57	117,781	382,803	117,781
06/20/2003	00A-030620	21	06/20/2003 14:00	06/24/2003 20:00	102	360,077	742,880	168,503
07/23/2003	00A-030723	29	07/23/2003 08:00	07/28/2003 17:00	129	130,783	873,663	130,783
07/31/2003	00A-030731	3	07/31/2003 08:00	08/02/2003 17:00	57	220,440	1,094,103	203,079
08/05/2003	00A-030804	2	08/04/2003 20:00	08/21/2003 08:00	396	1,530,276	2,624,379	931,712
08/26/2003	00A-030826	5	08/26/2003 08:00	08/27/2003 07:00	23	28,070	2,652,449	**
08/29/2003	00A-030829	2	08/29/2003 09:00	08/30/2003 11:00	26	49,819	2,702,268	49,819
09/04/2003	00A-030904	5	09/04/2003 07:00	09/09/2003 03:00	116	149,008	2,851,276	145,635
09/29/2003	00A-030929	21	09/29/2003 16:00	10/01/2003 08:00	40	78,600	2,929,876	78,600
11/05/2003	00A-031105	35	11/05/2003 15:00	11/11/2003 03:00	132	116,151	3,046,027	116,151
12/15/2003	00A-031213	34	12/14/2003 21:00	12/18/2003 06:00	81	20,007	3,066,033	20,007
							Total or Avg.	2,533,606
								83%

* Events prior to installation of sample stations.

** Malfunction of discrete sampling system – No samples taken.

Table 1.1B. Physical-Chemical Event Statistics for UF9200A.

Start Date	Event Number	TSS Load Sampled (kg)	TP Load Sampled (kg)	TDP Load Sampled (kg)	PP Load Sampled (kg)	TSS Equiv Conc (ppm)	TP Equiv Conc (ppb)	TDP Equiv Conc (ppb)	PP Equiv Conc (ppb)	% PP	P Content of TSS (mg/kg)
01/05/2000	00A-000105	*	*	*	*	*	*	*	*	*	*
01/17/2000	00A-000117	*	*	*	*	*	*	*	*	*	*
02/09/2000	00A-000209	*	*	*	*	*	*	*	*	*	*
03/20/2000	00A-000320	*	*	*	*	*	*	*	*	*	*
03/31/2000	00A-000331	*	*	*	*	*	*	*	*	*	*
04/13/2000	00A-000413	*	*	*	*	*	*	*	*	*	*
07/03/2000	00A-000703	537	25.2	20.7	4.4	9.3	434	358	76	18%	8233
07/08/2000	00A-000708	1,174	73.2	54.4	18.8	11.4	713	530	183	26%	16005
09/20/2000	00A-000920	717	23.3	13.7	9.6	4.6	151	89	62	41%	13342
09/25/2000	00A-000925	1,521	7.6	1.9	5.8	32.4	163	40	123	75%	3785
10/02/2000	00A-001002	41,153	107.8	35.3	72.5	91.2	239	78	161	67%	1762
	Total or Avg.	45,103	237.0	126.0	111.0	55.5	291	155	137	47%	2462
07/12/2001	00A-010712	3,047	8.8	2.8	5.9	37.0	106	34	72	68%	1950
07/15/2001	00A-010715	18,932	28.5	11.7	16.8	63.7	96	39	57	59%	888
07/23/2001	00A-010723	4,492	38.6	24.0	14.6	10.9	94	58	35	38%	3245
08/02/2001	00A-010802	8,898	117.8	53.7	64.1	16.3	216	99	118	54%	7204
08/08/2001	00A-010808	**	**	**	**	**	**	**	**	**	**
09/09/2001	00A-010909	**	**	**	**	**	**	**	**	**	**
09/13/2001	00A-010913	**	**	**	**	**	**	**	**	**	**
09/27/2001	00A-010927	6,398	55.5	37.0	18.5	21.4	186	124	62	33%	2892
10/25/2001	00A-011025	1,738	15.2	10.4	4.8	44.8	392	269	123	31%	2759
11/05/2001	00A-011105	2,552	12.8	4.3	8.6	28.5	143	48	96	67%	3356
	Total or Avg.	46,056	277.2	143.9	133.3	26.1	157	82	76	48%	2894
02/11/2002	00A-020211	12,612	29.8	7.8	22.0	45.1	107	28	79	74%	1748
02/25/2002	00A-020225	459	1.7	0.6	1.2	21.8	82	27	55	68%	2544
03/04/2002	00A-020304	772	1.4	0.7	0.7	17.9	33	16	17	51%	943
06/22/2002	00A-020622	25,308	93.2	54.4	38.8	34.6	127	74	53	42%	1535
07/08/2002	00A-020708	8,852	53.6	31.0	22.6	21.5	130	75	55	42%	2558
09/06/2002	00A-020906	5,772	25.0	11.8	13.2	76.0	330	156	174	53%	2289
10/12/2002	00A-021012	2,051	6.8	2.0	4.8	47.3	157	46	111	71%	2345
10/16/2002	00A-021016	7,882	12.5	1.9	10.6	216.2	343	51	291	85%	1347
10/26/2002	00A-021026	11,681	20.0	1.9	18.1	129.1	221	21	200	90%	1549
11/18/2002	00A-021118	5,624	15.1	3.2	11.9	56.8	153	33	120	79%	2117
	Total or Avg.	81,012	259.2	115.2	144.1	44.2	142	63	79	56%	1778
03/17/2003	00A-030317	930	3.3	1.5	1.8	21.9	77	35	41	54%	1890
04/26/2003	00A-030426	6,261	18.7	7.0	11.6	44.8	134	50	83	62%	1859
05/28/2003	00A-030528	974	3.9	2.2	1.8	8.3	34	19	15	44%	1798
06/20/2003	00A-030620	2,782	23.3	13.8	9.5	16.5	138	82	57	41%	3426
07/23/2003	00A-030723	1,550	4.0	1.6	2.4	11.9	31	13	18	59%	1548
07/31/2003	00A-030731	5,061	19.8	16.5	3.3	24.9	98	81	16	16%	646
08/05/2003	00A-030804	73,294	335.3	289.8	45.5	78.7	360	311	49	14%	621
08/26/2003	00A-030826	**	**	**	**	**	**	**	**	**	**
08/29/2003	00A-030829	717	4.9	2.6	2.4	14.4	99	52	47	48%	3294
09/04/2003	00A-030904	7,127	29.6	4.9	24.7	48.9	203	34	169	83%	3460
09/29/2003	00A-030929	1,746	23.7	9.7	13.9	22.2	301	124	177	59%	7964
11/05/2003	00A-031105	3,145	21.1	3.4	17.7	27.1	182	29	152	84%	5628
12/15/2003	00A-031213	398	2.6	0.8	1.9	19.9	132	38	94	71%	4713
	Total or Avg.	103,988	490.3	353.9	136.4	48.5	229	165	64	28%	1311

* Events prior to installation of sample stations.
** Malfunction of discrete sampling systems – No samples taken.

Table 1.2A. Hydraulic Event Statistics for UF9206A.

Start Date	Event Number	Interevent Time (days)	Start Decimal Date	Finish Decimal Date	Duration (hrs)	Volume Pumped (m3)	Cumulative Volume (m3)	Volume Sampled (m3)
01/25/2000	06A-000125		01/25/2000 08:35	01/25/2000 17:05	9	31,266	31,266	*
02/09/2000	06A-000209	15	02/09/2000 06:55	02/09/2000 13:30	7	23,128	54,394	*
03/20/2000	06A-000320	39	03/19/2000 15:05	03/22/2000 07:59	65	133,827	188,221	*
04/14/2000	06A-000414	22	04/13/2000 16:26	04/17/2000 16:00	96	286,084	474,305	*
05/09/2000	06A-000509	21	05/08/2000 17:40	05/09/2000 10:35	17	33,130	507,435	*
05/17/2000	06A-000517	7	05/16/2000 14:30	05/17/2000 10:40	20	21,339	528,774	*
07/06/2000	06A-000706	49	07/05/2000 14:25	07/05/2000 17:25	3	14,690	543,464	*
07/08/2000	06A-000708	3	07/08/2000 06:45	07/12/2000 09:30	99	572,458	1,115,922	319,712
07/14/2000	06A-000714	1	07/13/2000 16:50	07/15/2000 07:40	39	160,952	1,276,874	158,094
07/22/2000	06A-000722	6	07/21/2000 18:10	07/23/2000 07:25	37	185,857	1,462,731	118,234
08/03/2000	06A-000803	10	08/02/2000 14:25	08/06/2000 08:05	90	230,112	1,692,843	215,795
09/08/2000	06A-000908	33	09/08/2000 07:50	09/11/2000 02:20	66	78,610	1,771,453	72,952
09/18/2000	06A-000918	7	09/18/2000 07:10	09/21/2000 11:10	76	132,300	1,903,753	99,201
09/29/2000	06A-000929	7	09/28/2000 21:25	10/01/2000 09:24	60	105,829	2,009,582	105,728
10/03/2000	06A-001003	1	10/02/2000 18:00	10/10/2000 17:00	191	719,066	2,728,648	675,455
							Total or Avg.	1,765,173
								81%
03/20/2001	06A-010320	160	03/19/2001 14:50	03/21/2001 16:45	50	161,148	161,148	161,148
03/30/2001	06A-010330	8	03/29/2001 23:00	03/31/2001 07:40	33	87,641	248,789	87,641
06/09/2001	06A-010609	69	06/08/2001 12:25	06/09/2001 15:25	27	94,939	343,728	86,414
06/28/2001	06A-010628	18	06/27/2001 15:25	06/29/2001 16:00	49	172,278	516,006	171,392
07/10/2001	06A-010710	10	07/09/2001 18:25	07/26/2001 02:25	392	975,777	1,491,783	836,294
08/02/2001	06A-010802	6	08/01/2001 12:35	08/08/2001 13:54	169	590,732	2,082,515	589,225
09/10/2001	06A-010910	32	09/09/2001 12:25	09/10/2001 21:45	33	75,426	2,157,941	**
09/14/2001	06A-010914	3	09/14/2001 09:15	09/14/2001 15:35	6	22,942	2,180,883	**
09/27/2001	06A-010927	12	09/26/2001 20:35	10/02/2001 15:40	139	350,889	2,531,772	346,870
10/22/2001	06A-011022	20	10/22/2001 08:00	10/24/2001 07:45	48	91,910	2,623,682	33,308
11/05/2001	06A-011105	12	11/04/2001 21:25	11/05/2001 08:05	11	26,389	2,650,071	26,287
							Total or Avg.	2,338,578
								88%
02/11/2002	06A-020211	98	02/10/2002 22:39	02/12/2002 22:10	48	140,548	140,548	74,531
02/17/2002	06A-020217	4	02/16/2002 14:40	02/16/2002 22:45	8	10,937	151,485	4,861
02/24/2002	06A-020224	7	02/23/2002 13:05	02/24/2002 16:30	27	47,831	199,316	46,888
06/16/2002	06A-020616	112	06/16/2002 07:10	06/23/2002 00:10	161	622,502	821,818	296,761
06/24/2002	06A-020624	1	06/24/2002 07:15	06/29/2002 15:00	128	103,978	925,796	79,682
06/30/2002	06A-020630	1	06/30/2002 10:20	07/02/2002 15:00	53	106,925	1,032,721	87,144
07/08/2002	06A-020708	6	07/08/2002 09:19	07/12/2002 12:15	99	235,958	1,268,679	169,561
07/15/2002	06A-020715	3	07/15/2002 07:30	07/16/2002 07:00	24	71,270	1,339,949	44,054
08/22/2002	06A-020822	36	08/21/2002 15:40	08/23/2002 07:55	40	121,887	1,461,836	119,784
08/28/2002	06A-020828	4	08/27/2002 15:30	09/01/2002 08:50	113	251,526	1,713,362	242,906
10/15/2002	06A-021015	43	10/14/2002 16:10	10/16/2002 08:55	41	67,784	1,781,146	66,487
10/26/2002	06A-021026	10	10/26/2002 07:40	10/28/2002 07:20	48	94,119	1,875,265	94,051
11/17/2002	06A-021117	19	11/16/2002 15:05	11/17/2002 17:00	26	61,227	1,936,492	60,693
11/21/2002	06A-021121	4	11/21/2002 07:50	11/21/2002 16:50	9	36,472	1,972,964	36,472
							Total or Avg.	1,423,874
								72%

* Events prior to installation of sample stations.
** Malfunction of discrete sampling system – No samples taken.

Table 1.2A. Hydraulic Event Statistics for UF9206A (continued).

Start Date	Event Number	Interevent Time (days)	Start Decimal Date	Finish Decimal Date	Duration (hrs)	Volume Pumped (m3)	Cumulative Volume (m3)	Volume Sampled (m3)
01/25/2003	06A-030125	65	01/25/2003 05:00	01/26/2003 08:00	27	84,450	84,450	84,450
03/13/2003	06A-030313	47	03/13/2003 20:00	03/19/2003 12:00	136	277,476	361,926	277,476
03/27/2003	06A-030327	8	03/27/2003 15:00	03/28/2003 15:00	24	87,119	449,045	87,119
04/27/2003	06A-030427	30	04/27/2003 20:00	04/28/2003 07:00	11	76,615	525,661	72,261
04/30/2003	06A-030430	2	04/30/2003 10:00	04/30/2003 16:00	6	15,953	541,614	15,953
05/18/2003	06A-030518	18	05/18/2003 14:00	05/21/2003 08:00	66	149,851	691,465	144,243
05/27/2003	06A-030527	7	05/27/2003 22:00	05/29/2003 07:00	33	127,039	818,504	127,039
06/18/2003	06A-030618	21	06/18/2003 19:00	06/19/2003 06:00	11	58,235	876,739	-
08/04/2003	06A-030804	46	08/04/2003 07:00	08/06/2003 16:00	57	108,569	985,308	104,721
08/11/2003	06A-030811	5	08/11/2003 07:00	08/28/2003 21:00	422	736,186	1,721,493	716,686
09/18/2003	06A-030918	21	09/18/2003 18:00	09/22/2003 15:00	93	74,150	1,795,643	74,150
09/26/2003	06A-030926	4	09/26/2003 08:00	10/02/2003 14:00	150	367,262	2,162,905	356,522
11/03/2003	06A-031103	32	11/03/2003 10:00	11/03/2003 13:00	3	14,015	2,176,920	14,015
11/06/2003	06A-031106	3	11/06/2003 06:00	11/07/2003 01:00	19	67,077	2,243,997	23,652
11/25/2003	06A-031125	18	11/25/2003 12:00	11/25/2003 15:00	3	3,893	2,247,890	-
12/05/2003	06A-031204	9	12/04/2003 12:00	12/04/2003 13:00	1	8,505	2,256,396	8,505
12/14/2003	06A-031214	10	12/14/2003 14:00	12/17/2003 07:00	65	210,021	2,466,417	207,056
12/21/2003	06A-031221	4	12/21/2003 08:00	12/21/2003 14:00	6	26,599	2,493,016	26,599
							Total or Avg.	2,340,447
								94%

Table 1.2B. Physical-chemical Event Statistics for UF9206A.

Start Date	Event Number	TSS Load Sampled (kg)	TP Load Sampled (kg)	TDP Load Sampled (kg)	PP Load Sampled (kg)	TSS Equiv Conc (ppm)	TP Equiv Conc (ppb)	TDP Equiv Conc (ppb)	PP Equiv Conc (ppb)	% PP	P Content of TSS (mg/kg)
01/25/2000	06A-000125	*	*	*	*	*	*	*	*		*
02/09/2000	06A-000209	*	*	*	*	*	*	*	*		*
03/20/2000	06A-000320	*	*	*	*	*	*	*	*		*
04/14/2000	06A-000414	*	*	*	*	*	*	*	*		*
05/09/2000	06A-000509	*	*	*	*	*	*	*	*		*
05/17/2000	06A-000517	*	*	*	*	*	*	*	*		*
07/06/2000	06A-000706	*	*	*	*	*	*	*	*		*
07/08/2000	06A-000708	21,624	130.7	95.1	35.6	67.6	409	297	111	27%	1648
07/14/2000	06A-000714	7,925	32.1	22.2	9.9	50.1	203	140	63	31%	1254
07/22/2000	06A-000722	4,121	18.3	11.0	7.3	34.9	155	93	62	40%	1771
08/03/2000	06A-000803	7,193	52.9	39.6	13.3	33.3	245	184	62	25%	1852
09/08/2000	06A-000908	3,501	7.5	4.1	3.4	48.0	102	56	47	46%	971
09/18/2000	06A-000918	12,703	20.1	7.7	12.4	128.1	203	78	125	62%	979
09/29/2000	06A-000929	5,648	7.2	2.3	5.0	53.4	69	22	47	68%	876
10/03/2000	06A-001003	85,470	415.6	327.7	87.9	126.5	615	485	130	21%	1028
	Total or Avg.	148,184	684.5	509.7	174.8	83.9	388	289	99	26%	1180
03/20/2001	06A-010320	17,887	28.6	22.6	6.0	111.0	178	140	37	21%	336
03/30/2001	06A-010330	2,884	4.3	2.3	2.0	32.9	49	26	23	47%	704
06/09/2001	06A-010609	340	8.9	6.5	2.4	3.9	103	75	28	27%	7202
06/28/2001	06A-010628	1,812	13.4	9.4	4.1	10.6	78	55	24	30%	2248
07/10/2001	06A-010710	17,436	104.6	70.6	34.0	20.8	125	84	41	33%	1950
08/02/2001	06A-010802	27,797	114.2	76.4	37.8	47.2	194	130	64	33%	1361
09/10/2001	06A-010910	**	**	**	**	**	**	**	**		**
09/14/2001	06A-010914	**	**	**	**	**	**	**	**		**
09/27/2001	06A-010927	33,378	89.8	46.4	43.4	96.2	259	134	125	48%	1301
10/22/2001	06A-011022	4,922	4.7	1.1	3.6	147.8	141	34	107	76%	723
11/05/2001	06A-011105	58	0.1	0.0	0.1	2.2	5	1	4	84%	1821
	Total or Avg.	106,514	368.8	235.3	133.5	45.5	158	101	57	36%	1253
02/11/2002	06A-020211	12,820	39.1	31.9	7.2	172.0	524	428	96	18%	561
02/17/2002	06A-020217	308	0.6	0.3	0.3	63.3	127	62	65	51%	1026
02/24/2002	06A-020224	3,300	6.7	5.7	1.1	70.4	144	121	23	16%	322
06/16/2002	06A-020616	9,668	51.3	37.8	13.6	32.6	173	127	46	26%	1402
06/24/2002	06A-020624	4,729	5.9	3.0	2.9	59.4	75	38	37	49%	621
06/30/2002	06A-020630	5,043	5.9	4.0	2.0	57.9	68	46	23	33%	392
07/08/2002	06A-020708	8,970	17.6	9.7	7.9	52.9	104	57	46	45%	879
07/15/2002	06A-020715	5,757	4.0	1.2	2.8	130.7	90	27	63	70%	480
08/22/2002	06A-020822	6,015	12.2	5.3	6.9	50.2	102	44	58	57%	1149
08/28/2002	06A-020828	9,569	24.8	17.0	7.9	39.4	102	70	32	32%	821
10/15/2002	06A-021015	2,905	6.2	1.7	4.5	43.7	94	26	68	73%	1557
10/26/2002	06A-021026	5,890	13.1	4.2	8.9	62.6	140	45	95	68%	1517
11/17/2002	06A-021117	1,860	3.0	1.1	2.0	30.6	50	18	33	65%	1062
11/21/2002	06A-021121	2,701	4.1	1.3	2.8	74.0	113	36	77	68%	1033
	Total or Avg.	79,536	194.7	124.0	70.7	55.9	137	87	50	36%	889

* Events prior to installation of sample stations.
** Malfunction of discrete sampling systems – No samples taken.

Table 1.2B. Physical-chemical Event Statistics for UF9206A (continued).

Start Date	Event Number	TSS Load Sampled (kg)	TP Load Sampled (kg)	TDP Load Sampled (kg)	PP Load Sampled (kg)	TSS Equiv Conc (ppm)	TP Equiv Conc (ppb)	TDP Equiv Conc (ppb)	PP Equiv Conc (ppb)	% PP	P Content of TSS (mg/kg)
01/25/2003	06A-030125	2,994	23.5	18.8	4.7	35.4	278	222	55	20%	1565
03/13/2003	06A-030313	33,086	101.6	76.1	25.6	119.2	366	274	92	25%	772
03/27/2003	06A-030327	9,586	64.0	51.4	12.6	110.0	735	590	145	20%	1317
04/27/2003	06A-030427	6,562	18.4	7.7	10.7	90.8	254	106	148	58%	1628
04/30/2003	06A-030430	701	1.7	0.6	1.1	43.9	107	39	68	64%	1554
05/18/2003	06A-030518	4,961	30.7	24.0	6.8	34.4	213	166	47	22%	1361
05/27/2003	06A-030527	11,202	28.7	22.1	6.7	88.2	226	174	53	23%	597
06/18/2003	06A-030618	**	**	**	**	**	**	**	**	**	**
08/04/2003	06A-030804	3,115	36.0	33.2	2.8	29.8	343	317	26	8%	889
08/11/2003	06A-030811	20,761	132.3	111.2	21.2	29.0	185	155	30	16%	1020
09/18/2003	06A-030918	5,573	15.8	4.9	10.9	75.2	214	66	147	69%	1959
09/26/2003	06A-030926	13,530	69.7	46.1	23.6	38.0	195	129	66	34%	1743
11/03/2003	06A-031103	**	13.4	6.1	7.3	0.0	954	435	518	54%	**
11/06/2003	06A-031106	2,491	5.2	0.7	4.5	105.3	220	30	191	87%	1809
11/25/2003	06A-031125	**	**	**	**	**	**	**	**	**	**
12/05/2003	06A-031204	507	1.2	0.4	0.7	59.6	135	48	87	64%	1460
12/14/2003	06A-031214	13,146	22.4	7.9	14.6	63.5	108	38	70	65%	1108
12/21/2003	06A-031221	585	2.5	1.1	1.4	22.0	95	42	52	55%	2384
	Total or Avg.	128,800	567.2	412.2	155.0	55.0	242	176	66	27%	1461

** Malfunction of discrete sampling system – No samples taken.

Table 1.3A. Hydraulic Event Statistics for UF9206B.

Start Date	Event Number	Interevent Time (days)	Start Decimal Date	Finish Decimal Date	Duration (hrs)	Volume Pumped (m3)	Cumulative Volume (m3)	Volume Sampled (m3)
01/24/2000	06B-000124		01/24/2000 07:20	01/24/2000 16:55	10	40,996	40,996	*
01/29/2000	06B-000129		01/28/2000 16:55	01/30/2000 14:54	46	123,502	164,498	*
02/09/2000	06B-000209		02/09/2000 06:45	02/11/2000 16:20	58	226,132	390,630	*
03/19/2000	06B-000319		03/19/2000 11:50	03/23/2000 14:19	98	212,675	603,305	*
04/14/2000	06B-000414		04/13/2000 16:24	04/20/2000 16:50	168	418,984	1,022,289	*
05/09/2000	06B-000509		05/08/2000 17:45	05/09/2000 10:44	17	71,693	1,093,982	*
05/17/2000	06B-000517		05/17/2000 08:54	05/17/2000 12:55	4	21,090	1,115,072	*
06/29/2000	06B-000629		06/29/2000 11:50	06/30/2000 11:10	23	31,079	1,146,151	*
07/09/2000	06B-000709	9	07/09/2000 09:45	07/13/2000 08:55	95	292,485	1,438,636	135,629
08/03/2000	06B-000803	20	08/02/2000 14:39	08/06/2000 08:15	90	272,647	1,711,283	259,130
09/17/2000	06B-000917	42	09/17/2000 10:25	09/23/2000 15:45	149	320,040	2,031,323	303,513
09/30/2000	06B-000930	6	09/29/2000 17:15	09/29/2000 23:10	6	13,416	2,044,739	13,416
10/03/2000	06B-001003	3	10/02/2000 17:40	10/14/2000 15:36	286	1,135,627	3,180,366	1,119,777
							Total or Avg.	1,831,465
								90.0%
03/20/2001	06B-010320	156	03/19/2001 16:30	03/23/2001 10:25	90	201,129	201,129	187,081
03/30/2001	06B-010330	7	03/29/2001 22:50	04/01/2001 08:49	58	131,238	332,367	84,587
07/12/2001	06B-010712	101	07/11/2001 14:05	07/12/2001 06:35	17	50,003	382,370	18,255
07/17/2001	06B-010717	5	07/17/2001 07:55	07/18/2001 07:25	24	72,101	454,471	31,783
07/23/2001	06B-010723	5	07/23/2001 08:05	07/30/2001 08:40	169	530,462	984,933	158,927
08/02/2001	06B-010802	3	08/02/2001 10:15	08/04/2001 15:00	53	172,289	1,157,222	168,067
08/06/2001	06B-010806	2	08/06/2001 09:00	08/08/2001 10:35	50	132,835	1,290,057	132,657
09/09/2001	06B-010909	31	09/08/2001 22:00	09/17/2001 11:25	205	590,899	1,880,956	500,099
09/27/2001	06B-010927	9	09/26/2001 17:35	10/04/2001 09:00	183	543,177	2,424,133	542,861
10/09/2001	06B-011009	5	10/09/2001 08:35	10/10/2001 09:10	25	75,874	2,500,007	74,457
10/22/2001	06B-011022	12	10/22/2001 08:50	10/28/2001 07:50	143	312,893	2,812,900	244,513
11/05/2001	06B-011105	8	11/04/2001 21:30	11/07/2001 16:20	67	117,148	2,930,048	111,783
11/09/2001	06B-011109	2	11/09/2001 11:00	11/09/2001 14:20	3	15,471	2,945,519	**
11/12/2001	06B-011112	3	11/12/2001 07:50	11/14/2001 15:15	55	46,698	2,992,217	**
11/19/2001	06B-011119	5	11/19/2001 07:35	11/19/2001 11:50	4	10,869	3,003,086	8,137
12/31/2001	06B-011231	42	12/31/2001 16:15	01/01/2002 07:50	16	47,001	3,050,087	40,992
							Total or Avg.	2,304,198
								75.5%
02/10/2002	06B-020210	40	02/10/2002 09:10	02/18/2002 16:45	200	558,311	558,311	433,027
02/23/2002	06B-020223	4	02/22/2002 17:45	02/23/2002 16:25	23	25,392	583,703	21,949
07/01/2002	06B-020701	128	07/01/2002 09:10	07/02/2002 14:10	29	58,605	642,308	42,265
07/09/2002	06B-020709	7	07/09/2002 08:35	07/15/2002 07:25	143	381,493	1,023,801	244,136
08/25/2002	06B-020825	41	08/25/2002 11:10	09/02/2002 08:10	189	349,682	1,373,483	330,282
09/06/2002	06B-020906	3	09/05/2002 17:05	09/06/2002 08:30	15	36,260	1,409,743	**
09/12/2002	06B-020912	5	09/11/2002 16:55	09/12/2002 08:40	16	38,560	1,448,303	37,968
10/14/2002	06B-021014	32	10/14/2002 07:35	10/15/2002 23:05	40	87,962	1,536,265	87,396
10/26/2002	06B-021026	10	10/25/2002 20:00	10/28/2002 07:30	60	156,561	1,692,826	43,646
11/17/2002	06B-021117	19	11/16/2002 14:50	11/18/2002 07:05	40	84,754	1,777,580	72,052
11/21/2002	06B-021121	3	11/21/2002 07:30	11/22/2002 13:35	30	89,544	1,867,124	87,841
							Total or Avg.	1,400,562
								75.0%

* Events prior to installation of sample stations.
** Malfunction of discrete sampling system – No samples taken.

Table 1.3A. Hydraulic Event Statistics for UF9206B (continued).

Start Date	Event Number	Interevent Time (days)	Start Decimal Date	Finish Decimal Date	Duration (hrs)	Volume Pumped (m3)	Cumulative Volume (m3)	Volume Sampled (m3)
01/08/2003	06B-030108	47	01/08/2003 05:00	01/08/2003 08:00	3	7,931	7,931	7,931
01/18/2003	06B-030118	10	01/18/2003 05:00	01/21/2003 07:00	74	23,231	31,161	23,231
01/25/2003	06B-030125	4	01/25/2003 05:00	01/26/2003 07:00	26	96,498	127,659	96,498
03/13/2003	06B-030313	47	03/13/2003 20:00	03/18/2003 07:00	107	146,413	274,072	134,938
03/23/2003	06B-030323	5	03/23/2003 18:00	03/24/2003 15:00	21	54,577	328,649	53,135
03/27/2003	06B-030327	3	03/27/2003 15:00	03/30/2003 07:00	64	211,394	540,044	204,114
04/26/2003	06B-030426	27	04/26/2003 07:00	05/01/2003 07:00	120	224,498	764,542	218,984
05/18/2003	06B-030518	17	05/18/2003 14:00	05/23/2003 09:00	115	278,844	1,043,386	276,515
05/27/2003	06B-030527	4	05/27/2003 16:00	05/31/2003 14:00	94	205,860	1,249,245	169,170
06/22/2003	06B-030622	22	06/22/2003 09:00	06/24/2003 17:00	56	118,397	1,367,642	43,924
08/04/2003	06B-030804	41	08/04/2003 08:00	08/04/2003 16:00	8	27,494	1,395,136	**
08/08/2003	06B-030808	4	08/08/2003 15:00	08/09/2003 09:00	18	51,836	1,446,973	51,836
08/13/2003	06B-030813	4	08/13/2003 07:00	08/15/2003 07:00	48	117,107	1,564,079	117,107
08/21/2003	06B-030821	6	08/21/2003 15:00	08/30/2003 12:00	213	408,109	1,972,189	348,062
09/05/2003	06B-030905	6	09/05/2003 08:00	09/06/2003 15:00	31	103,590	2,075,779	100,429
09/11/2003	06B-030911	5	09/11/2003 09:00	09/11/2003 11:00	2	9,942	2,085,720	9,942
09/18/2003	06B-030918	7	09/18/2003 18:00	09/22/2003 16:00	94	139,257	2,224,977	137,408
09/26/2003	06B-030926	4	09/26/2003 07:00	10/05/2003 15:00	224	610,456	2,835,433	293,038
11/05/2003	06B-031105	31	11/05/2003 15:00	11/09/2003 08:00	89	173,203	3,008,636	173,203
12/14/2003	06B-031214	35	12/14/2003 13:00	12/14/2003 17:00	4	13,587	3,022,222	13,587
12/17/2003	06B-031217	3	12/17/2003 08:00	12/17/2003 11:00	3	5,909	3,028,132	5,909
12/21/2003	06B-031221	4	12/21/2003 08:00	12/23/2003 13:00	53	65,272	3,093,403	65,272
							Total or Avg.	2,544,232
								82.2%

** Malfunction of discrete sampling system – No samples taken.

Table 1.3B. Physical-Chemical Event Statistics for UF9206B.

Start Date	Event Number	TSS Load Sampled (kg)	TP Load Sampled (kg)	TDP Load Sampled (kg)	PP Load Sampled (kg)	TSS Equiv Conc (ppm)	TP Equiv Conc (ppb)	TDP Equiv Conc (ppb)	PP Equiv Conc (ppb)	% PP	P Content of TSS (mg/kg)
01/24/2000	06B-000124	*	*	*	*	*	*	*	*	*	*
01/29/2000	06B-000129	*	*	*	*	*	*	*	*	*	*
02/09/2000	06B-000209	*	*	*	*	*	*	*	*	*	*
03/19/2000	06B-000319	*	*	*	*	*	*	*	*	*	*
04/14/2000	06B-000414	*	*	*	*	*	*	*	*	*	*
05/09/2000	06B-000509	*	*	*	*	*	*	*	*	*	*
05/17/2000	06B-000517	*	*	*	*	*	*	*	*	*	*
06/29/2000	06B-000629	*	*	*	*	*	*	*	*	*	*
07/09/2000	06B-000709	969	40.1	34.1	5.9	7.1	295	252	44	15%	6137
08/03/2000	06B-000803	12,717	50.5	34.0	16.6	49.1	195	131	64	33%	1303
09/17/2000	06B-000917	21,057	46.8	18.4	28.4	69.4	154	61	94	61%	1350
09/30/2000	06B-000930	782	1.3	0.3	1.0	58.3	94	21	74	78%	1265
10/03/2000	06B-001003	215,104	521.3	311.3	210.0	192.1	466	278	188	40%	976
	Total or Avg.	250,630	660	398	262	136.8	360	217	143	40%	1045
03/20/2001	06B-010320	17,755	23.3	18.2	5.2	94.9	125	97	28	22%	292
03/30/2001	06B-010330	3,148	9.1	4.9	4.2	37.2	108	58	50	47%	1345
07/12/2001	06B-010712	590	2.7	1.4	1.3	32.3	147	77	70	48%	2169
07/17/2001	06B-010717	902	1.1	0.6	0.5	28.4	35	20	15	43%	530
07/23/2001	06B-010723	520	8.7	6.4	2.3	3.3	55	40	15	26%	4435
08/02/2001	06B-010802	2,414	26.7	20.7	5.9	14.4	159	123	35	22%	2461
08/06/2001	06B-010806	2,790	11.2	5.9	5.3	21.0	84	44	40	47%	1889
09/09/2001	06B-010909	10,377	25.5	17.1	8.3	20.8	51	34	17	33%	803
09/27/2001	06B-010927	22,127	117.4	88.2	29.2	40.8	216	163	54	25%	1320
10/09/2001	06B-011009	2,780	7.6	1.5	6.1	37.3	102	20	82	81%	2204
10/22/2001	06B-011022	18,716	24.3	9.5	14.9	76.5	99	39	61	61%	794
11/05/2001	06B-011105	52,023	20.7	4.9	15.9	465.4	185	43	142	77%	305
11/09/2001	06B-011109	**	**	**	**	**	**	**	**	**	**
11/12/2001	06B-011112	**	**	**	**	**	**	**	**	**	**
11/19/2001	06B-011119	201	1.0	0.2	0.8	24.8	127	23	104	82%	4210
12/31/2001	06B-011231	784	4.7	3.0	1.7	19.1	116	74	42	36%	2205
	Total or Avg.	135,130	284.1	182.5	101.7	58.6	123	79	44	36%	752
02/10/2002	06B-020210	39,615	124.4	97.8	26.7	91.5	287	226	62	21%	673
02/23/2002	06B-020223	863	3.9	2.6	1.3	39.3	177	116	61	34%	1544
07/01/2002	06B-020701	5,110	6.9	4.3	2.6	120.9	162	102	60	37%	499
07/09/2002	06B-020709	1,729	22.6	11.9	10.7	7.1	93	49	44	47%	6193
08/25/2002	06B-020825	10,039	35.3	17.7	17.6	30.4	107	54	53	50%	1754
09/06/2002	06B-020906	**	**	**	**	**	**	**	**	**	**
09/12/2002	06B-020912	401	1.9	0.5	1.4	10.6	51	13	38	74%	3562
10/14/2002	06B-021014	#N/A	7.6	2.0	5.6	#N/A	87	23	64	74%	**
10/26/2002	06B-021026	4,036	6.3	2.1	4.2	92.5	143	48	96	67%	1036
11/17/2002	06B-021117	3,400	6.7	2.3	4.3	47.2	93	32	60	65%	1279
11/21/2002	06B-021121	4,148	8.3	4.5	3.7	47.2	94	52	43	45%	901
	Total or Avg.	69,341	223.9	145.7	78.2	49.5	160	104	56	35%	1128

* Events prior to installation of sample stations.
** Malfunction of discrete sampling system – No samples taken.

Table 1.3B. Physical-Chemical Event Statistics for UF9206B (continued).

Start Date	Event Number	TSS Load Sampled (kg)	TP Load Sampled (kg)	TDP Load Sampled (kg)	PP Load Sampled (kg)	TSS Equiv Conc (ppm)	TP Equiv Conc (ppb)	TDP Equiv Conc (ppb)	PP Equiv Conc (ppb)	% PP	P Content of TSS (mg/kg)
01/08/2003	06B-030108	518	1.2	0.4	0.9	65	157	45	112	71%	1718
01/18/2003	06B-030118	1,478	4.5	1.6	2.9	64	196	69	126	65%	1986
01/25/2003	06B-030125	7,728	34.9	20.9	14.0	80	361	216	145	40%	1815
03/13/2003	06B-030313	20,254	121.1	83.3	37.9	150	898	617	281	31%	1870
03/23/2003	06B-030323	3,746	10.7	4.3	6.3	70	201	82	119	59%	1692
03/27/2003	06B-030327	35,440	151.2	98.5	53.0	174	741	483	260	35%	2388
04/26/2003	06B-030426	20,437	40.7	16.0	24.7	93	186	73	113	61%	1207
05/18/2003	06B-030518	8,513	42.1	28.1	14.0	31	152	101	51	33%	1650
05/27/2003	06B-030527	147	19.4	8.8	10.7	1	115	52	63	55%	72629
06/22/2003	06B-030622	303	8.2	6.1	2.1	7	186	139	47	25%	6817
08/04/2003	06B-030804	**	**	**	**	**	**	**	**	**	**
08/08/2003	06B-030808	623	14.9	13.4	1.5	12	287	259	28	10%	2351
08/13/2003	06B-030813	768	13.1	9.6	3.5	7	112	82	30	27%	4535
08/21/2003	06B-030821	3,053	68.4	58.9	9.5	9	197	169	27	14%	3127
09/05/2003	06B-030905	1,346	9.7	4.7	5.1	13	97	47	50	52%	3755
09/11/2003	06B-030911	99	0.6	0.3	0.3	10	62	32	30	48%	3003
09/18/2003	06B-030918	2,457	17.1	7.5	9.6	18	125	54	70	56%	3920
09/26/2003	06B-030926	21,036	91.0	52.0	38.9	72	310	178	133	43%	1851
11/05/2003	06B-031105	6,515	35.5	18.0	17.5	38	205	104	101	49%	2688
12/14/2003	06B-031214	300	2.9	1.1	1.7	22	210	84	126	60%	5710
12/17/2003	06B-031217	63	1.1	0.4	0.7	11	190	69	121	64%	11352
12/21/2003	06B-031221	799	4.3	1.7	2.6	12	66	25	40	61%	3304
	Total or Avg.	135,621	692.8	435.5	257.5	53.3	272	171	101	37%	1899

** Malfunction of discrete sampling system – No samples taken.

Table 1.4A. Hydraulic Event Statistics for UF9209A.

Start Date	Event Number	Interevent Time (days)	Start Decimal Date	Finish Decimal Date	Duration (hrs)	Volume Pumped (m3)	Cumulative Volume (m3)	Volume Sampled (m3)
03/20/2001	09A-010320		03/20/2001 07:25	03/22/2001 19:45	60	251,798	251,798	180,539
03/24/2001	09A-010324	2	03/24/2001 10:45	03/24/2001 17:10	6	37,429	289,227	**
03/30/2001	09A-010330	6	03/30/2001 07:05	03/31/2001 03:05	20	167,496	456,723	**
06/02/2001	09A-010602	63	06/02/2001 07:20	06/02/2001 16:25	9	91,919	548,642	91,919
06/10/2001	09A-010610	8	06/10/2001 07:40	06/10/2001 15:05	7	62,547	611,189	**
06/13/2001	09A-010613	3	06/13/2001 07:15	06/13/2001 15:35	8	49,618	660,807	49,618
06/16/2001	09A-010616	3	06/16/2001 07:55	06/17/2001 15:10	31	112,191	772,998	**
06/19/2001	09A-010619	2	06/19/2001 07:59	06/20/2001 15:50	32	174,683	947,681	131,370
06/22/2001	09A-010622	2	06/22/2001 08:30	06/29/2001 15:30	175	330,956	1,278,637	164,743
07/12/2001	09A-010712	13	07/12/2001 11:05	07/13/2001 16:05	29	120,926	1,399,563	**
07/15/2001	09A-010715	2	07/15/2001 08:25	07/20/2001 14:20	126	440,616	1,840,179	384,082
07/22/2001	09A-010722	2	07/22/2001 07:45	07/25/2001 16:15	80	242,047	2,082,226	114,372
07/27/2001	09A-010727	2	07/27/2001 07:30	07/27/2001 15:20	8	48,719	2,130,945	48,719
08/02/2001	09A-010802	6	08/02/2001 10:50	08/06/2001 15:40	101	245,285	2,376,230	157,639
08/08/2001	09A-010808	2	08/08/2001 08:05	08/08/2001 15:10	7	39,996	2,416,226	39,996
08/23/2001	09A-010823	15	08/23/2001 09:55	08/23/2001 15:35	6	34,711	2,450,937	34,711
09/05/2001	09A-010905	13	09/05/2001 08:30	09/06/2001 14:45	30	86,291	2,537,228	82,227
09/08/2001	09A-010908	2	09/08/2001 08:05	09/19/2001 15:55	272	1,355,337	3,892,565	1,157,917
09/29/2001	09A-010929	10	09/29/2001 08:35	10/04/2001 16:20	128	574,648	4,467,213	364,667
10/24/2001	09A-011024	20	10/24/2001 07:59	10/24/2001 15:55	8	71,256	4,538,469	59,477
10/26/2001	09A-011026	2	10/26/2001 08:15	10/27/2001 17:15	33	136,691	4,675,160	133,647
10/30/2001	09A-011030	3	10/30/2001 11:30	10/31/2001 14:30	27	71,983	4,747,143	47,957
							Total or Avg.	3,243,601
								68%
12/31/2001	09A-011231	62	12/31/2001 09:35	01/01/2002 16:20	31	104,290	104,290	103,701
01/15/2002	09A-020115	14	01/15/2002 10:55	01/15/2002 18:50	8	97,186	201,476	82,108
01/17/2002	09A-020117	2	01/17/2002 09:35	01/17/2002 16:05	7	86,424	287,900	86,424
01/20/2002	09A-020120	2	01/19/2002 12:45	01/19/2002 16:15	4	42,629	330,529	42,629
02/11/2002	09A-020211	23	02/11/2002 08:15	02/13/2002 08:40	48	309,361	639,890	291,402
02/14/2002	09A-020214	1	02/14/2002 10:28	02/15/2002 07:05	21	90,532	730,422	86,244
02/19/2002	09A-020219	4	02/19/2002 07:20	02/19/2002 16:20	9	63,411	793,833	48,621
02/24/2002	09A-020224	5	02/24/2002 09:15	02/24/2002 14:25	5	66,870	860,703	66,013
03/09/2002	09A-020309	13	03/09/2002 10:05	03/09/2002 16:35	6	72,194	932,897	70,671
05/20/2002	09A-020520	72	05/20/2002 08:35	05/20/2002 15:55	7	56,189	989,086	**
06/09/2002	09A-020609	20	06/09/2002 08:45	06/09/2002 15:10	6	44,564	1,033,650	43,415
06/13/2002	09A-020613	4	06/13/2002 07:20	06/22/2002 16:45	225	1,146,795	2,180,445	746,717
06/24/2002	09A-020624	2	06/24/2002 07:35	06/28/2002 16:20	105	413,055	2,593,500	379,017
06/30/2002	09A-020630	2	06/30/2002 09:20	06/30/2002 14:40	5	56,252	2,649,752	18,627
07/02/2002	09A-020702	2	07/02/2002 07:35	07/04/2002 16:25	57	226,726	2,876,478	183,823
07/08/2002	09A-020708	4	07/08/2002 09:15	07/15/2002 13:00	172	547,177	3,423,655	188,824
07/22/2002	09A-020722	7	07/22/2002 07:30	07/25/2002 14:55	79	402,593	3,826,248	248,889
08/12/2002	09A-020812	18	08/12/2002 07:10	08/12/2002 14:10	7	50,508	3,876,756	**
08/14/2002	09A-020814	2	08/14/2002 06:45	08/16/2002 14:25	56	468,071	4,344,827	460,951
08/18/2002	09A-020818	2	08/18/2002 10:05	08/19/2002 14:25	28	230,886	4,575,713	228,949
08/21/2002	09A-020821	2	08/21/2002 07:20	08/22/2002 07:45	24	186,650	4,762,363	180,949
08/28/2002	09A-020828	6	08/28/2002 07:00	09/02/2002 05:55	119	783,895	5,546,258	588,480
09/04/2002	09A-020904	2	09/04/2002 07:55	09/05/2002 09:50	26	126,259	5,672,517	126,259
09/12/2002	09A-020912	7	09/12/2002 07:10	09/12/2002 14:30	7	60,813	5,733,330	58,710
09/22/2002	09A-020922	10	09/22/2002 09:55	09/22/2002 15:30	6	30,148	5,763,478	29,715
09/25/2002	09A-020925	3	09/25/2002 06:55	09/26/2002 14:45	32	201,630	5,965,108	139,168
09/30/2002	09A-020930	4	09/30/2002 10:10	10/02/2002 07:15	45	244,524	6,209,632	243,342
10/30/2002	09A-021030	28	10/30/2002 06:30	10/30/2002 15:00	8	39,558	6,249,190	36,234
11/18/2002	09A-021118	19	11/18/2002 09:15	11/21/2002 11:15	74	259,388	6,508,578	258,481
11/24/2002	09A-021124	3	11/24/2002 09:30	11/24/2002 17:45	8	41,012	6,549,590	41,013
11/27/2002	09A-021127	3	11/27/2002 07:10	11/28/2002 13:15	30	47,950	6,597,540	47,874
							Total or Avg.	5,127,250
								78%

** Malfunction of discrete sampling system – No samples taken.

Table 1.4A. Hydraulic Event Statistics for UF9209A (continued).

Start Date	Event Number	Interevent Time (days)	Start Decimal Date	Finish Decimal Date	Duration (hrs)	Volume Pumped (m3)	Cumulative Volume (m3)	Volume Sampled (m3)
01/01/2003	09A-030101	35	01/01/2003 09:00	01/05/2003 16:00	103	214,023	214,023	161,283
02/21/2003	09A-030221	47	02/21/2003 08:00	02/24/2003 13:00	77	245,311	459,334	245,311
03/17/2003	09A-030317	21	03/17/2003 08:00	03/19/2003 13:00	53	227,390	686,724	224,312
03/24/2003	09A-030324	5	03/24/2003 08:00	03/31/2003 05:00	165	262,472	949,197	262,472
04/28/2003	09A-030428	28	04/28/2003 09:00	05/01/2003 07:00	70	404,455	1,353,652	267,267
05/28/2003	09A-030528	27	05/28/2003 07:00	05/30/2003 14:00	55	292,792	1,646,444	292,792
06/10/2003	09A-030610	11	06/10/2003 08:00	06/10/2003 14:00	6	46,586	1,693,029	42,845
06/19/2003	09A-030619	9	06/19/2003 08:00	06/25/2003 15:00	151	618,520	2,311,549	617,142
07/16/2003	09A-030716	21	07/16/2003 08:00	07/17/2003 03:00	19	134,028	2,445,577	130,997
07/24/2003	09A-030724	7	07/24/2003 07:00	07/25/2003 05:00	22	120,989	2,566,566	120,989
08/05/2003	09A-030805	11	08/05/2003 08:00	08/06/2003 15:00	31	146,739	2,713,305	146,739
08/11/2003	06A-030811	5	08/11/2003 08:00	08/14/2003 05:00	69	338,166	3,051,471	152,225
08/22/2003	09A-030822	8	08/22/2003 08:00	08/29/2003 13:00	173	841,568	3,893,039	801,569
09/02/2003	09A-030902	4	09/02/2003 13:00	09/03/2003 05:00	16	117,500	4,010,539	117,500
09/28/2003	09A-030928	25	09/28/2003 08:00	10/01/2003 15:00	79	313,360	4,323,900	313,360
11/05/2003	09A-031105	35	11/05/2003 07:00	11/07/2003 05:00	46	162,193	4,486,093	162,193
12/17/2003	09A-031217	40	12/17/2003 08:00	12/17/2003 16:00	8	103,961	4,590,054	103,131
12/23/2003	09A-031223	6	12/23/2003 07:00	12/23/2003 14:00	7	76,802	4,666,856	76,802
12/27/2003	09A-031227	4	12/27/2003 07:00	12/27/2003 15:00	8	60,648	4,727,503	60,648
							Total or Avg.	4,299,578
								91%

Table 1.4B. Physical-Chemical Event Statistics for UF9209A.

Start Date	Event Number	TSS Load Sampled (kg)	TP Load Sampled (kg)	TDP Load Sampled (kg)	PP Load Sampled (kg)	TSS Equiv Conc (ppm)	TP Equiv Conc (ppb)	TDP Equiv Conc (ppb)	PP Equiv Conc (ppb)	% PP	P Content of TSS (mg/kg)
03/20/2001	09A-010320	11,276	7.0	3.7	3.3	62.5	39	20	19	48%	296
03/24/2001	09A-010324	**	**	**	**	**	**	**	**	**	**
03/30/2001	09A-010330	**	**	**	**	**	**	**	**	**	**
06/02/2001	09A-010602	1,694	2.4	0.7	1.7	18.4	26	7	19	72%	1029
06/10/2001	09A-010610	**	**	**	**	**	**	**	**	**	**
06/13/2001	09A-010613	243	1.4	0.2	1.2	4.9	29	4	25	87%	5130
06/16/2001	09A-010616	**	**	**	**	**	**	**	**	**	**
06/19/2001	09A-010619	474	1.6	0.8	0.9	3.6	13	6	7	54%	1889
06/22/2001	09A-010622	445	2.3	0.4	1.9	2.7	14	2	11	83%	4247
07/12/2001	09A-010712	**	**	**	**	**	**	**	**	**	**
07/15/2001	09A-010715	7,517	7.6	3.3	4.2	19.6	20	9	11	56%	564
07/22/2001	09A-010722	222	2.4	1.5	1.0	1.9	21	13	8	39%	4302
07/27/2001	09A-010727	60	0.3	0.1	0.3	1.2	7	1	6	84%	4766
08/02/2001	09A-010802	2,174	4.4	0.9	3.5	13.8	28	6	22	79%	1613
08/08/2001	09A-010808	74	0.6	0.3	0.3	1.8	14	6	8	54%	4188
08/23/2001	09A-010823	148	0.4	0.0	0.4	4.3	11	-	11	100%	2589
09/05/2001	09A-010905	223	2.8	1.1	1.7	2.7	34	13	20	60%	7467
09/08/2001	09A-010908	7,250	50.1	14.5	35.5	6.3	43	13	31	71%	4901
09/29/2001	09A-010929	2,582	9.6	3.8	5.8	7.1	26	10	16	61%	2245
10/24/2001	09A-011024	782	2.3	0.5	1.8	13.1	39	8	30	78%	2313
10/26/2001	09A-011026	3,079	4.5	1.7	2.8	23.0	34	13	21	62%	906
10/30/2001	09A-011030	475	2.1	0.5	1.6	9.9	44	10	33	76%	3341
	Total or Avg.	38,718	101.9	33.9	68.0	11.9	31	10	21	67%	1756
12/31/2001	09A-011231	2,253	5.8	1.0	4.8	21.7	56	9	46	83%	2131
01/15/2002	09A-020115	3,499	1.6	0.3	1.3	42.6	20	4	16	82%	384
01/17/2002	09A-020117	4,333	1.8	1.0	0.9	50.1	21	12	10	48%	198
01/20/2002	09A-020120	1,447	0.6	0.3	0.3	33.9	13	7	7	51%	201
02/11/2002	09A-020211	12,289	13.9	4.0	9.9	42.2	48	14	34	71%	806
02/14/2002	09A-020214	336	2.9	0.8	2.2	3.9	34	9	25	74%	6401
02/19/2002	09A-020219	271	1.8	0.7	1.2	5.6	37	14	25	66%	4409
02/24/2002	09A-020224	3,550	1.6	1.0	0.6	53.8	24	15	9	37%	166
03/09/2002	09A-020309	3,975	3.9	2.1	1.8	56.2	55	29	26	47%	457
05/20/2002	09A-020520	**	**	**	**	**	**	**	**	**	**
06/09/2002	09A-020609	936	1.7	0.5	1.2	21.6	40	12	28	71%	1319
06/13/2002	09A-020613	7,901	16.8	8.6	8.3	10.6	23	12	11	49%	1046
06/24/2002	09A-020624	3,322	8.4	5.1	3.4	8.8	22	13	9	41%	1036
06/30/2002	09A-020630	245	0.7	0.4	0.3	13.2	38	24	15	38%	1108
07/02/2002	09A-020702	1,260	4.3	1.2	3.1	6.9	23	7	17	72%	2443
07/08/2002	09A-020708	1,267	5.3	1.8	3.6	6.7	28	9	19	67%	2810
07/22/2002	09A-020722	1,869	9.9	3.5	6.3	7.5	40	14	25	64%	3384
08/12/2002	09A-020812	**	**	**	**	**	**	**	**	**	**
08/14/2002	09A-020814	940	11.5	5.8	5.8	2.0	25	13	12	50%	6123
08/18/2002	09A-020818	1,228	6.8	2.4	4.5	5.4	30	10	20	66%	3656
08/21/2002	09A-020821	604	4.5	2.4	2.1	3.3	25	13	12	48%	3528
08/28/2002	09A-020828	4,428	27.1	7.3	19.8	7.5	46	12	34	73%	4480
09/04/2002	09A-020904	1,164	2.4	1.4	1.0	9.2	19	11	8	41%	856
09/12/2002	09A-020912	640	5.6	1.7	3.9	10.9	96	30	66	69%	6035
09/22/2002	09A-020922	170	0.8	0.2	0.6	5.7	28	8	20	71%	3476
09/25/2002	09A-020925	2,174	4.9	1.9	3.0	15.6	36	14	22	61%	1381
09/30/2002	09A-020930	22,958	20.5	2.5	18.0	94.3	84	10	74	88%	784
10/30/2002	09A-021030	7,306	5.3	0.5	4.9	201.6	147	13	135	91%	667
11/18/2002	09A-021118	22,354	22.6	3.0	19.5	86.5	87	12	76	87%	874
11/24/2002	09A-021124	483	1.8	0.9	0.8	11.8	43	23	20	47%	1717
11/27/2002	09A-021127	778	1.1	0.6	0.5	16.2	23	13	10	43%	605
	Total or Avg.	113,980	196.0	63.0	133.5	22.2	38	12	26	68%	1171

** Malfunction of discrete sampling system – No samples taken.

Table 1.4B. Physical-Chemical Event Statistics for UF9209A (continued).

Start Date	Event Number	TSS Load Sampled (kg)	TP Load Sampled (kg)	TDP Load Sampled (kg)	PP Load Sampled (kg)	TSS Equiv Conc (ppm)	TP Equiv Conc (ppb)	TDP Equiv Conc (ppb)	PP Equiv Conc (ppb)	% PP	P Content of TSS (mg/kg)
01/01/2003	09A-030101	13,006	7.5	1.9	5.6	80.6	46	12	35	75%	429
02/21/2003	09A-030221	55,345	28.1	4.0	24.0	225.6	114	16	98	86%	434
03/17/2003	09A-030317	140,030	23.2	3.3	19.9	624.3	103	15	89	86%	142
03/24/2003	09A-030324	39,046	8.0	3.1	4.9	148.8	31	12	19	61%	125
04/28/2003	09A-030428	5,781	8.4	2.5	5.9	21.6	32	9	22	70%	1021
05/28/2003	09A-030528	19,655	6.4	2.6	3.7	67.1	22	9	13	59%	190
06/10/2003	09A-030610	10,756	6.9	0.5	6.4	251.0	160	12	149	93%	592
06/19/2003	09A-030619	136,763	46.0	5.4	40.6	221.6	75	9	66	88%	297
07/16/2003	09A-030716	1,595	2.8	1.3	1.5	12.2	21	10	11	53%	935
07/24/2003	09A-030724	5,007	5.4	1.6	3.8	41.4	44	13	31	70%	751
08/05/2003	09A-030805	2,612	3.4	1.6	1.8	17.8	23	11	13	54%	706
08/11/2003	06A-030811	3,404	3.9	1.5	2.4	22.4	26	10	16	62%	709
08/22/2003	09A-030822	7,277	18.4	7.4	11.0	9.1	23	9	14	60%	1514
09/02/2003	09A-030902	1,398	2.8	0.5	2.3	11.9	24	4	20	83%	1656
09/28/2003	09A-030928	12,709	19.9	2.6	17.3	40.6	64	8	55	87%	1359
11/05/2003	09A-031105	10,109	15.0	2.0	13.0	62.3	92	12	80	87%	1288
12/17/2003	09A-031217	3,083	7.2	1.3	5.9	29.9	70	13	58	82%	1924
12/23/2003	09A-031223	2,393	5.9	1.1	4.8	31.2	77	15	62	81%	1991
12/27/2003	09A-031227	2,801	2.0	0.9	1.1	46.2	33	14	18	56%	400
	Total or Avg.	472,771	221.1	45.2	176.0	110.0	51	11	41	80%	372

Table 1.5. Particulate P Contributions to Total P Loads.

Farm	2000	2001	2002	2003
UF9200A	47%	48%	56%	28%
UF9206A	26%	36%	36%	27%
UF9206B	40%	36%	35%	37%
UF9209A	NA	67%	68%	80%

Table 1.6. Summary of Annual Averages of Key Parameters from Study Farms.

Farm	Year	Total Drainage (10^6 m^3)	TSS Equiv. Conc. (ppb)	TP Equiv. Conc. (ppb)	TDP Equiv. Conc. (ppb)	PP Equiv. Conc. (ppb)	Estimated TP Load (kg)	Estimated TDP Load (Kg)	Estimated PP Load (kg)	TSS P Content (mg/kg)
UF9200A	2000	1.408	56	291	155	137	410	218	193	2462
	2001	2.753	26	157	82	76	432	226	209	2894
	2002	2.651	44	142	63	79	376	167	209	1778
	2003	3.066	48	229	165	64	701	506	195	1311
UF9206A	2000	2.728	84	388	289	99	1058	788	270	1180
	2001	2.650	46	158	101	57	419	268	151	1253
	2002	1.972	56	137	87	50	270	172	99	889
	2003	2.493	55	242	176	66	603	414	156	1461
UF9206B	2000	3.180	137	360	217	143	1145	690	455	1045
	2001	3.050	59	123	79	44	375	241	134	752
	2002	1.867	50	160	104	56	299	194	105	1128
	2003	3.093	53	272	171	101	841	436	257	1899
UF9209A	2000	-	-	-	-	-	-	-	-	-
	2001	4.747	12	31	10	21	147	47	100	1756
	2002	6.597	22	38	12	26	251	79	172	1171
	2003	4.728	110	51	11	41	241	45	176	372

Sampling at Farm UF9209A started in 2001.

Table 1.7. Summary of Annual Rainfall and Pumping Data.

Farm	Year	Total Drainage (10^6 m^3)	Total Drainage (inches)	Rainfall (inches)	Pumping to Rainfall Ratio (in/in)
UF9200A	2000	1.408	10.7	34.4	0.31
	2001	2.753	20.9	48.3	0.43
	2002	2.651	20.1	37.8	0.53
	2003	3.066	23.6	49.6	0.48
UF9206A/B	2000	5.908	32.8	45.2	0.73
	2001	5.700	31.7	45.6	0.69
	2002	3.839	21.3	36.8	0.58
	2003	5.605	31.0	45.9	0.67
UF9209A	2000	4.714	14.9	37.6	0.40
	2001	4.747	15.0	46.8	0.32
	2002	6.597	20.9	40.9	0.51
	2003	4.728	15.0	39.7	0.38

Table 1.7 summarizes the rainfall and pumping data for each farm. In Table 1.7 the data for stations UF9206A and UF9206B have been consolidated. This is done because the farm has integrated cross-connections, which makes any allocation of rainfall to either pump station a dubious value. The data summarized in these two tables allows some basic comparisons to be made among farms, over time, and with other sources.

The normalized or unit area loads (UAL) for particulate P and dissolved P are presented in mass per unit farm area (kg P/acre) in Figure 1.8. Particulate P loads from farm UF9200A have been fairly constant over the four-year period, averaging about 0.15 kg particulate P/acre (0.33 lb P/acre). Loads from farm UF9206A and B were combined and presented for the farm as an overall entity. Particulate P loads from this farm have been steadily decreasing during the first three years of the study, reaching loads values similar to those observed in UF9200A. However, in year 2003 particulate P load slightly increased to about 0.24 kg/acre (0.53 lb/acre). The loads for UF9209A were substantially lower than the other two farms, averaging 0.05 kg particulate P/acre (0.11 lb/acre) during the last three years (Figure 1.8A).

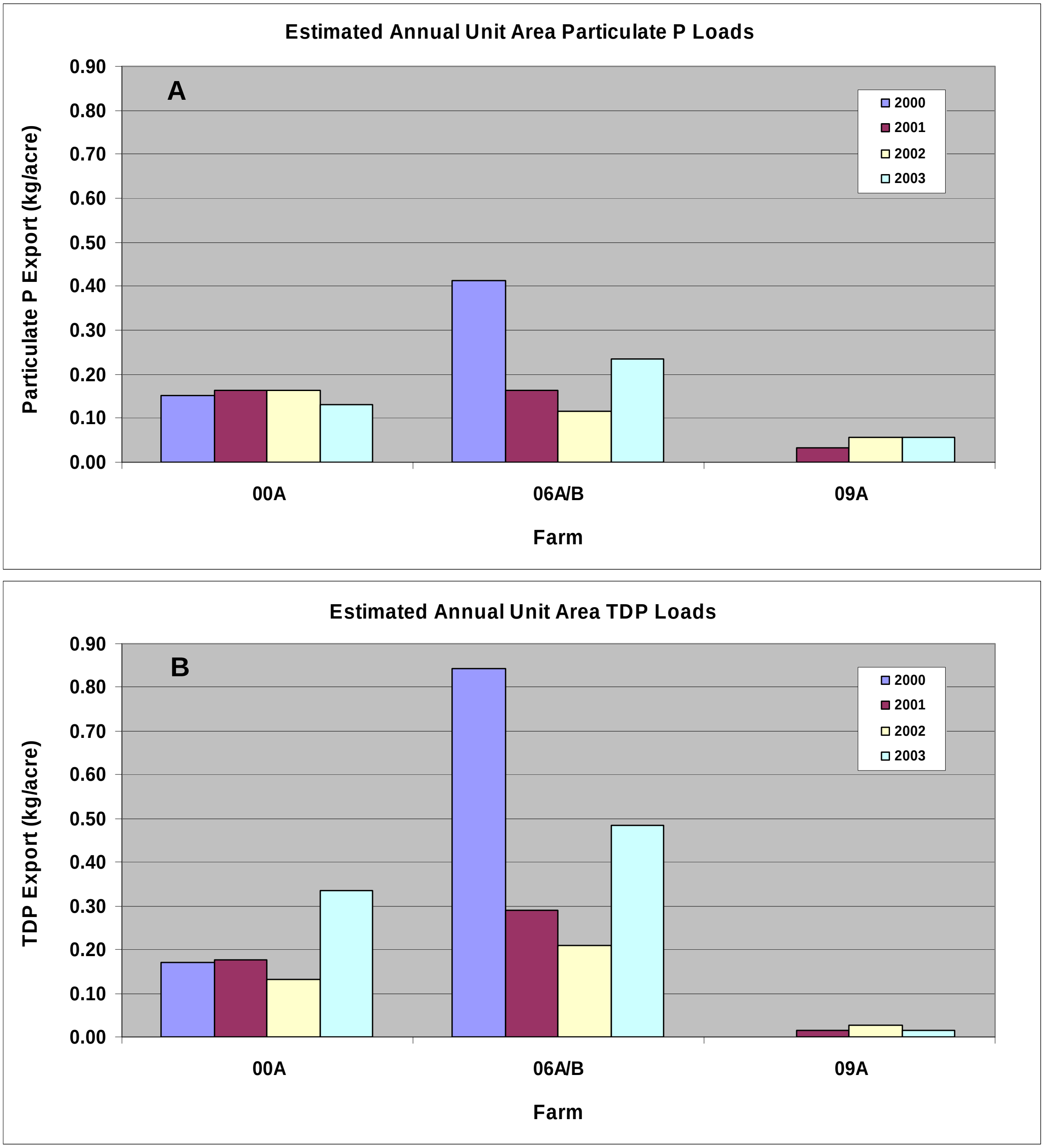

Figure 1.8. Annual Unit Area Particulate, and Dissolved P Loads from 2000 through 2003.

Dissolved P loads from farm UF9200A followed the same pattern observed with the particulate P values, averaging about 0.16 kg dissolved P/acre during the first three years of the study (Figure 1.8B). However, in year 2003 total load due to dissolved P increased to an average of 0.34 kg P/acre. Dissolved P loads from farm UF9206A and B have been steadily decreasing during the first three years of the study, reaching an average load value of 0.21 kg P/acre in 2002. But, in 2003 dissolved P load values increased, averaging 0.48 kg P/acre. The loads for UF9209A were substantially lower than the other two farms, averaging 0.02 kg dissolved P/acre during the last three years.

Figure 1.9 shows the volume of drainage water pumped during the last four years of the study, expressed as inches to normalize to farm area. Figure 1.10 shows the annual pumping-to-rainfall ratios, in inches of water pumped per inch of rain for each farm. Farm UF9206A and B are combined and shown as a single farm.

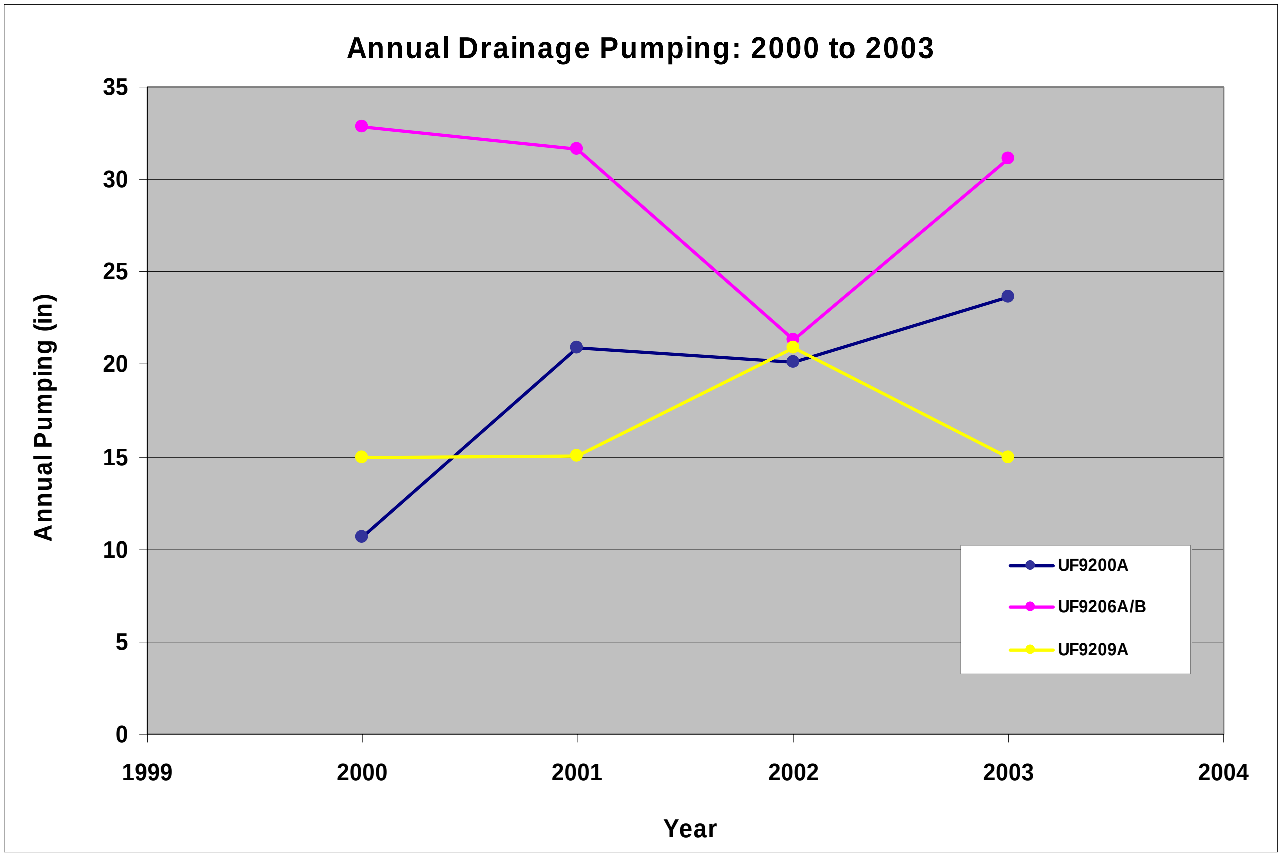

Figure 1.9. Annual Drainage Pumping from 2000 through 2003.

For the years 2000 and 2001 the normalized volumes pumped from UF9206A/B were 50-100% higher than those from the other two farms (Figure 1.9). In 2002 the normalized volumes were almost identical for all three farms. But in 2003, volumes pumped from UF9206A/B increased to about the same values observed during the first two years. Farm UF9200A also showed a slight increase in water pumped, while farm UF9209A showed a decrease to about the same values observed in 2000 and 2001. A similar relationship is observed in the relative volume ratios presented in Figure 1.10. Data from Figures 1.9 and 1.10 shows the existing variability of these parameters over the study period for all three farms. Farm UF9206A/B started with high volumes and ratios in 2000 and decreased through 2002, but it went back again to about the volumes and ratios of the first two years. Farm UF9200A started with low volumes and ratios and steadily increased for the rest of the study, with a slight decrease in the pumping to rainfall ratio in 2003. Farm UF9209A started with low volumes and ratio during the first years, but those values decreased to about the original levels for year 2003.

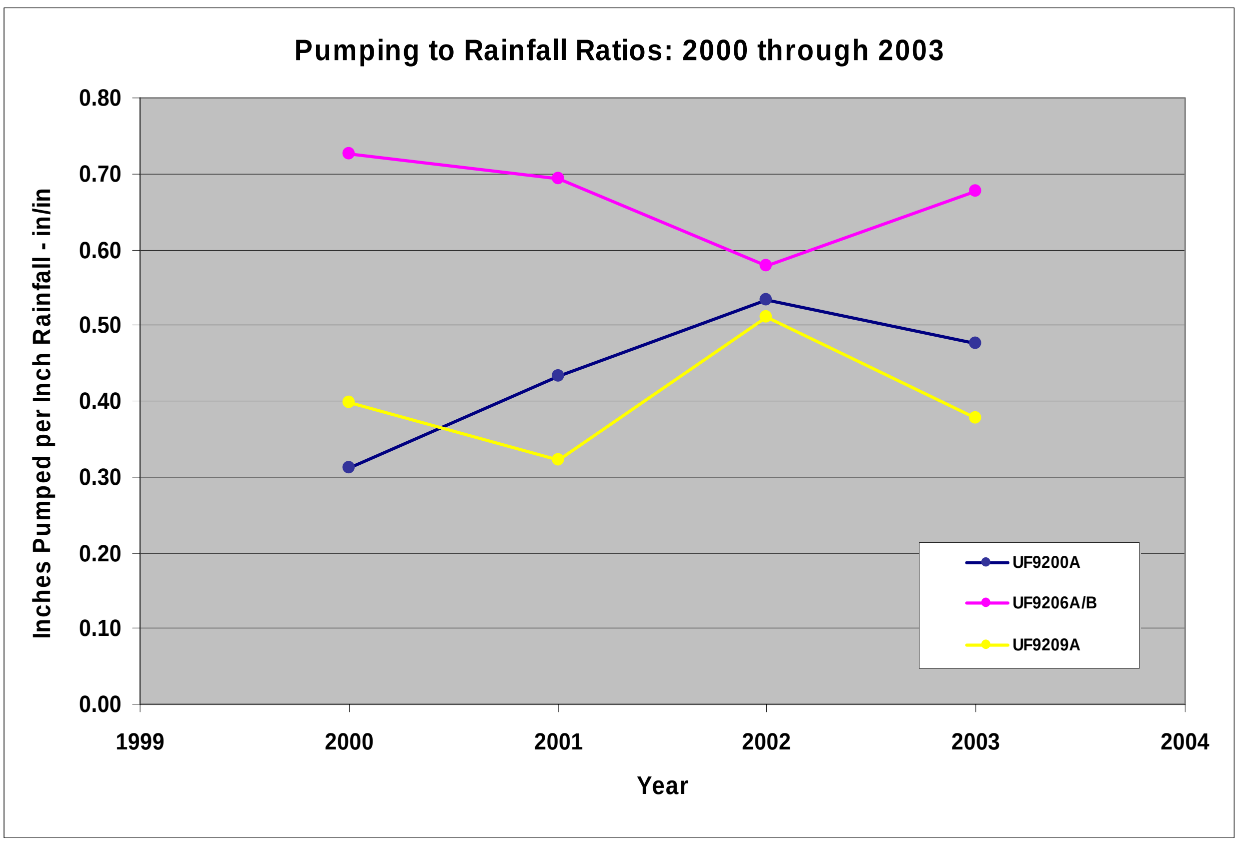

Figure 1.10. Annual Pumping to Rainfall Ratios 2000 - 2003.

It is expected that UF9206A/B, with its large acreage planted to vegetables, would have a higher pumping ratio than the sugarcane farms. However, it is interesting to see the ratios of all three farms converge to a similar value in 2002. However, in 2003 pumping to rainfall ratios came back to the same pattern observed in the first two years of the study.

The equivalent concentrations of total suspended solids (TSS) and particulate P are shown in Figures 1.11 and 1.12 respectively. Equivalent concentrations for both TSS and particulate P showed a decline from 2000 to 2001 at UF9200A and at UF9206A and B and then remained relatively constant or showed a slight increase from 2001 to 2002. In 2003, average TSS concentrations from these three farms remained constant. Equivalent concentrations for TSS and particulate P at UF9209A showed a steady increase from 2001 to 2002, but TSS values for 2003 increased from 22 mg/L to 110 mg/L.

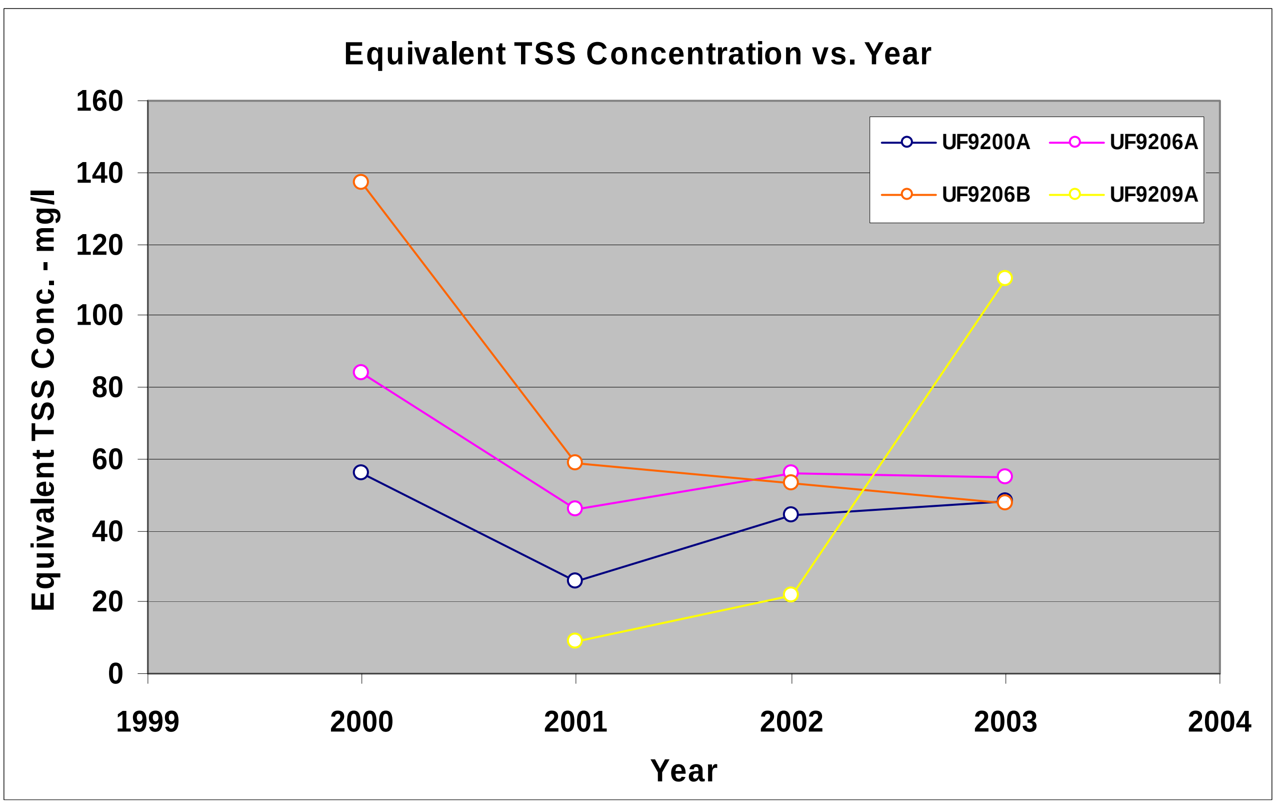

Figure 1.11. Equivalent Total Suspended Solids Concentration from 2000 to 2003.

Particulate P changes observed during the last four years are important to this study. Equivalent particulate P concentrations at UF9200A and UF9206A/B significantly declined from 2000 to 2001, and then remained almost constant for all three farms from 2001 to 2002 (Figure 1.12). In 2003, average particulate P concentrations at UF9200A decreased from 79 ppb to 64 ppb, however, farm UF9206A and B showed a notable increase, with the highest value observed at UF9206B. Average particulate P concentrations from farm UF9209A have been steadily increasing during the last three years, but they are still lower than the other three farms.

The P content of TSS gives us an indication to the nature of the particulate P as illustrated in Figure 1.13. Phosphorus concentrations of TSS from farm UF9200A averaged 2462 mg/kg for year 2000 and 2894 mg/kg for 2001. After year 2001, P concentrations decreased to 1778 mg/kg for 2002 and 1311 mg/kg for 2003. A similar pattern was observed at farm UF9209A, where P concentrations from TSS steadily decreased from 1756 mg/kg in 2001 to 373 mg/kg in 2003. In Year 2003, this farm pumped the canals significantly lower and for longer periods of time than previous years increasing the amount of bottom soils or sediments, which are low in P content compared to biologically produced particulate matter, to be exported from this farm.

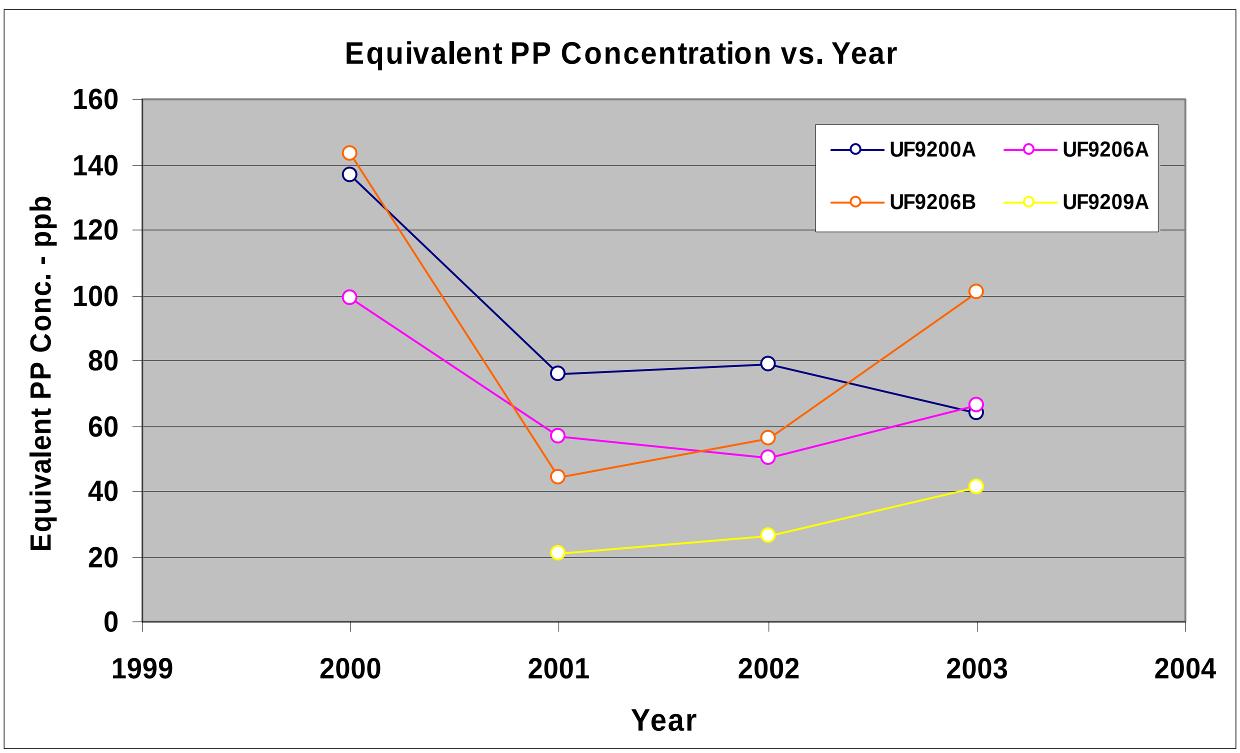

Figure 1.12. Equivalent Particulate P Concentration from 2000 through 2003.

The mixed crop farm, UF9206A and B showed P concentrations of TSS ranging from 752 to 1253 mg/kg from 2000 to 2002. In 2003, P concentrations increased to 1461 mg/kg for UF9206A and 1899 mg/kg for UF9206B. In discussions of the Biological Contribution Mechanisms presented earlier in this chapter it was noted that biologically sourced particulates would be expected to have P content in the range of 3000-5000 mg/kg for plant material, and 1500-3000 mg/kg for plant detritus. On an annual average basis these conditions are satisfied for 2000 and 2001 for the sugarcane farms, UF9200A and UF9209A, but not in 2002 and 2003. The mixed-crop farm UF9206A/B did not satisfy this condition from 2000 to 2002, and only marginal in 2003. These results show that a given population of TSS during a pumping event is highly heterogeneous with a wide range in P content and transport properties. Also farm UF9206A/B has implemented an aggressive aquatic weed control program that minimizes the amount of biologically produced particulate matter.

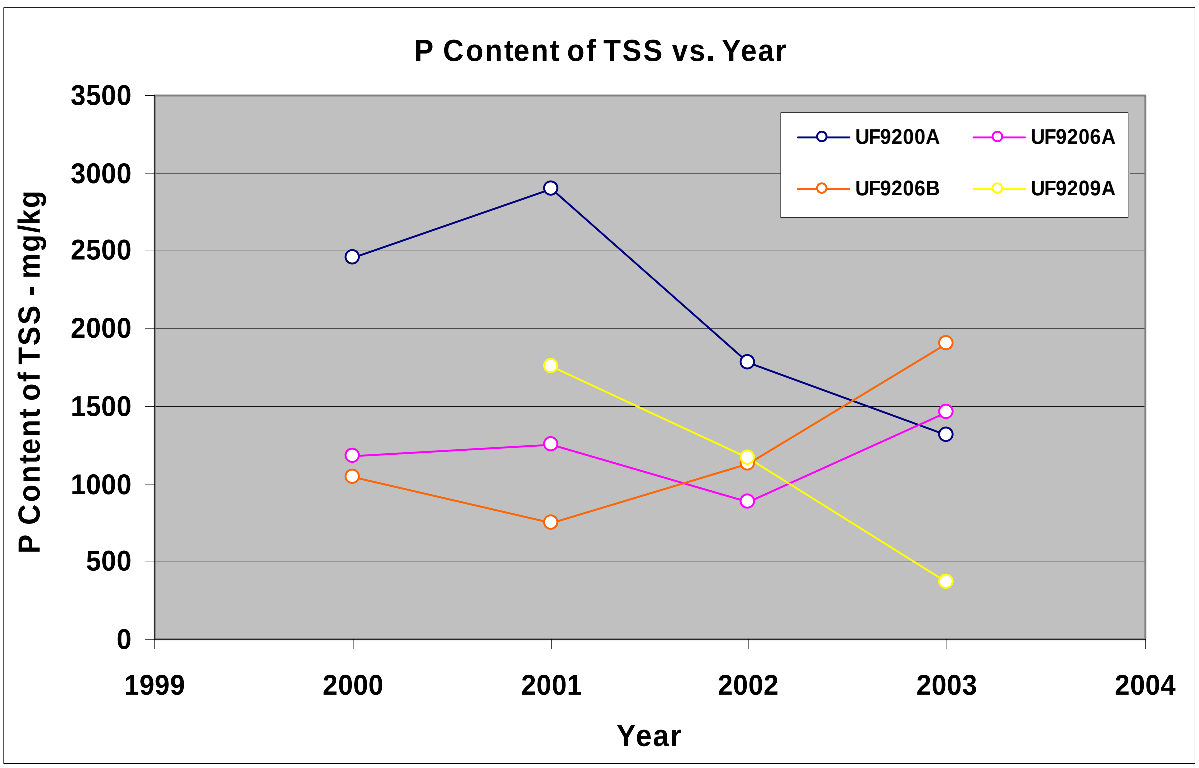

Figure 1.13. Average Phosphorus Content of TSS from 2000 through 2003.

Event Data Analysis

The illustrations presented in Figures 1.4-1.6 of the introduction of this chapter were intended to illustrate the non-linearity of system responses in particulate P transport and the inherent potential for time displacement between cause and effect. The results presented in the next section confirm this and imply added complexity with year-to-year changes in system responses.

The most thorough way to study a non-linear system is with the use of a mathematical system model. A model has been developed for particulate P transport and has been applied to detailed transport from one EAA farm over a one-year period (Stuck, 1996). This model, however, requires extensive contour mapping of the hydraulic system of a farm, and is dependent on empirically derived parameters that may change from farm to farm, and from year to year. In its present state of development it is not applicable to the analysis of data without extensive calibration to each farm of interest.

The approach that has been adopted here is to conduct various forms of cluster analysis to attempt to identify primary parameters that have had the most impact on particulate P transport at the study farms. The analyses performed are:

- Load Distribution Analysis – Divides all events into smaller sub-events, typically one-hour increments, and determines the distribution of particulate P loads in comparison to the distribution of hydraulic loads in these sub-events.
- Process Distribution Analysis – Determines the most probable mechanism for particulate P transport in the sub-events that contribute most to annual loads, i.e. those in the top 50% of the load distribution.
- Event Analysis – Evaluates the events that contain the highest number of high contribution sub-events for defining characteristics.
- Farm System Synthesis – Description of the characteristics of each farm that caused the high contribution sub-events.

Particulate Phosphorus Load Distribution Analysis

In addition to suspended solids and P analysis, every sample taken during the study has an associated set of supporting data, which includes sample time, sample duration, instantaneous flows, instantaneous levels, cumulative time since event start, and cumulative flow since event start. This data may be used to calculate derived parameters such as loads, load rates, and velocities at sections of known configuration. This was done with all samples taken in this program.

For the purpose of analysis, the parameter particulate P load rate, defined as the kg of particulate P exported per hour, was of special importance. The use of load rate causes normalization among samples that might have had different sampling time durations. The load rate of a sub-event (or pack of water) defines its levels of importance based on the contribution to the overall annual particulate P load. The higher the load rate, the more the particular sub-event or packet of water contributed to the annual load. The data in each annual location data set were ranked by particulate P load rate, from lowest to highest. Once this was done, the cumulative hydraulic and particulate P loads of the data points as ranked, were determined. Figures 1.14 to 1.17 show the results of this analysis, with the cumulative loads expressed as a fraction of the total load.

Data in Figures 1.14 to 1.17 may be interpreted as follows. Moving from left to right along the X-axis traces the accumulation of packets of water that contributed to the overall hydraulic load for the year. Moving from bottom to top of the Y-axis traces the cumulative contribution to the overall particulate P load of the particulate P contained in the corresponding packet of water. The slope of the curve is a direct indicator of the relative contribution to the particulate P load of a given packet of water. The shallower the slope, the less particulate P a given packet of water contributes, the steeper the slope, the more a specific packet contributes. Adjacent data points (packets of water) on the curve may be widely separated in time; what they have in common is a similar load rate, or contribution priority. This is important, because the data (water packets) are now sorted by priority of importance relative to particulate P export.

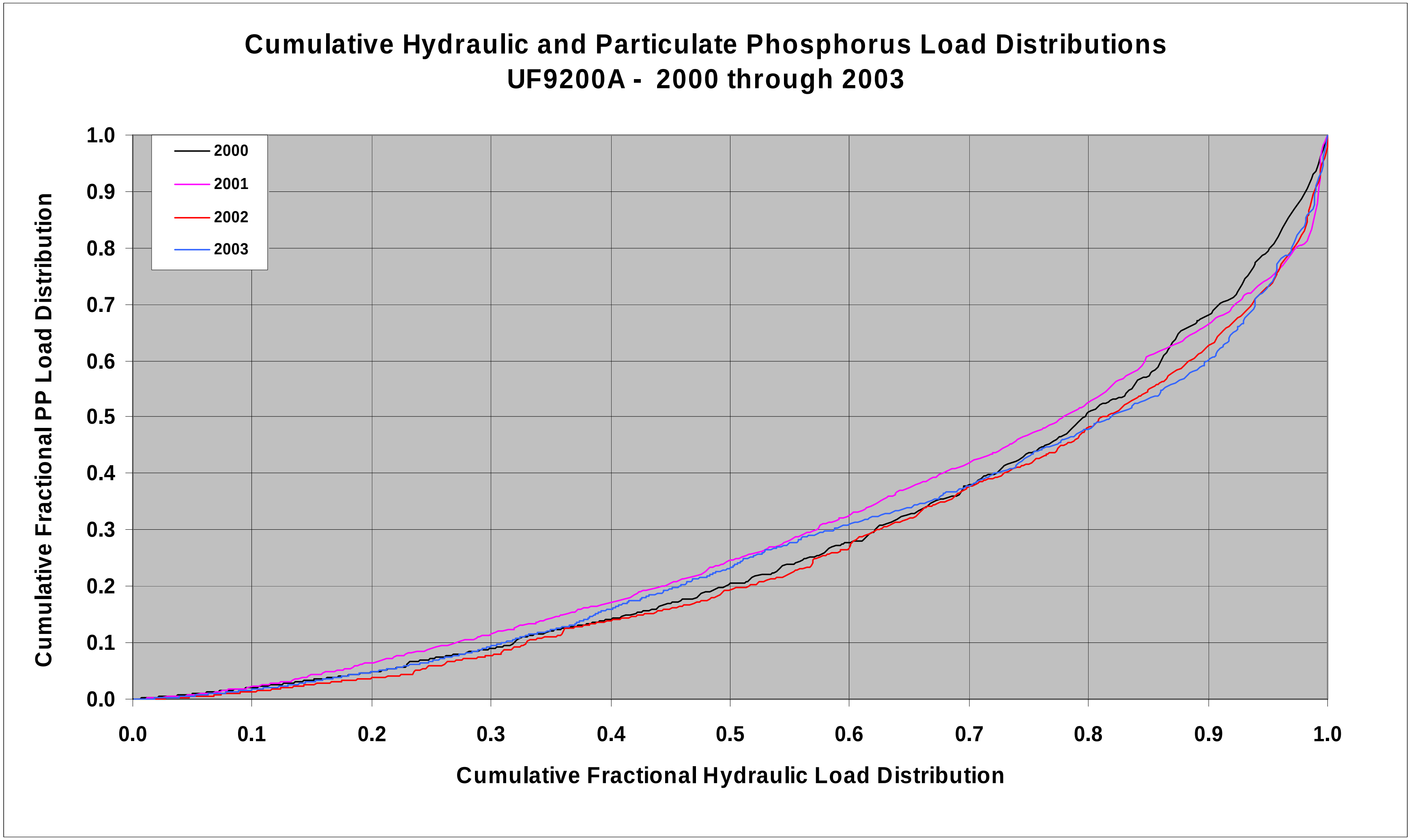

Figure 1.14. Cumulative Hydraulic and Particulate P Load Distributions for UF9200A.

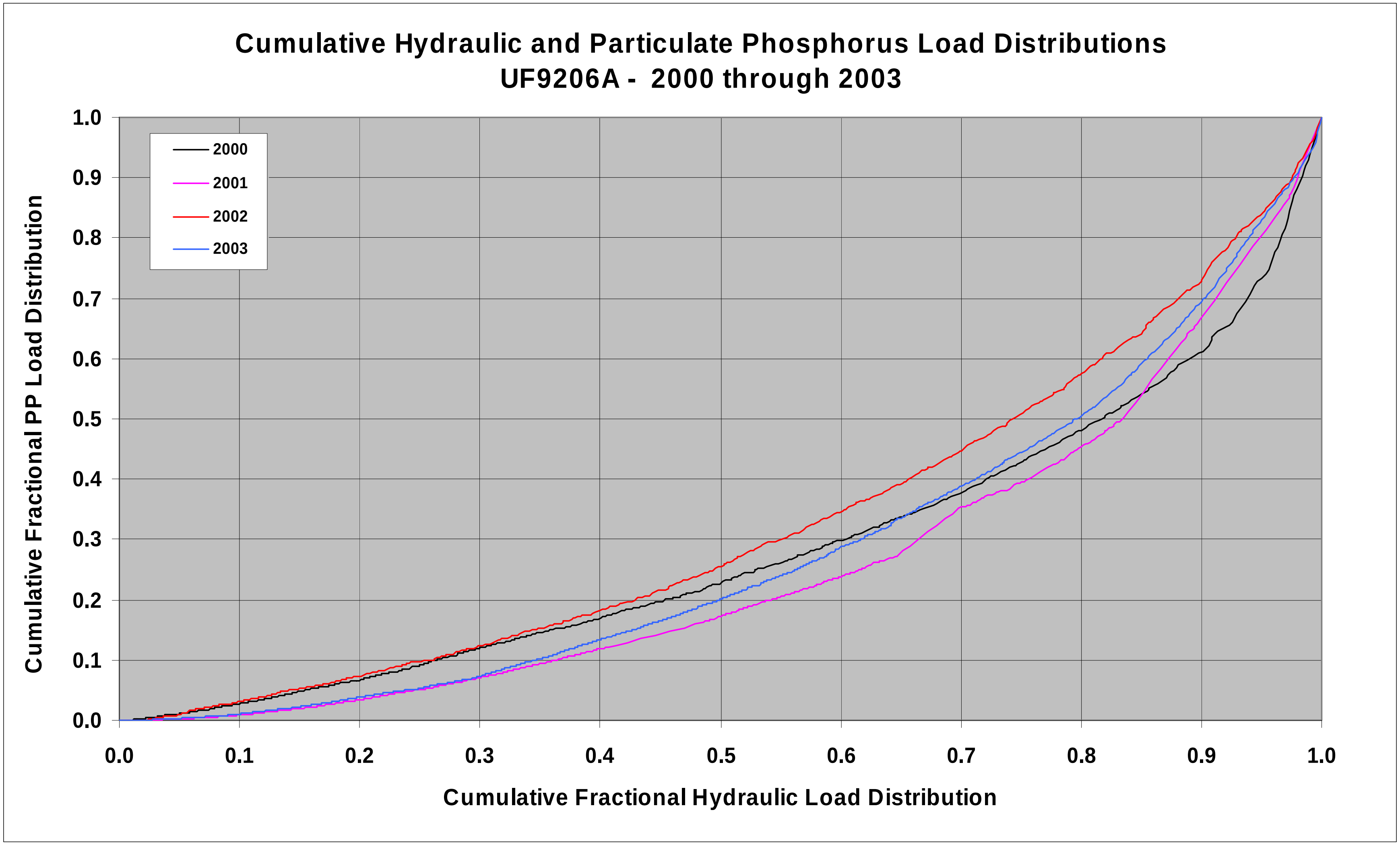

Figure 1.15. Cumulative Hydraulic and Particulate P Load Distributions for UF9206A.

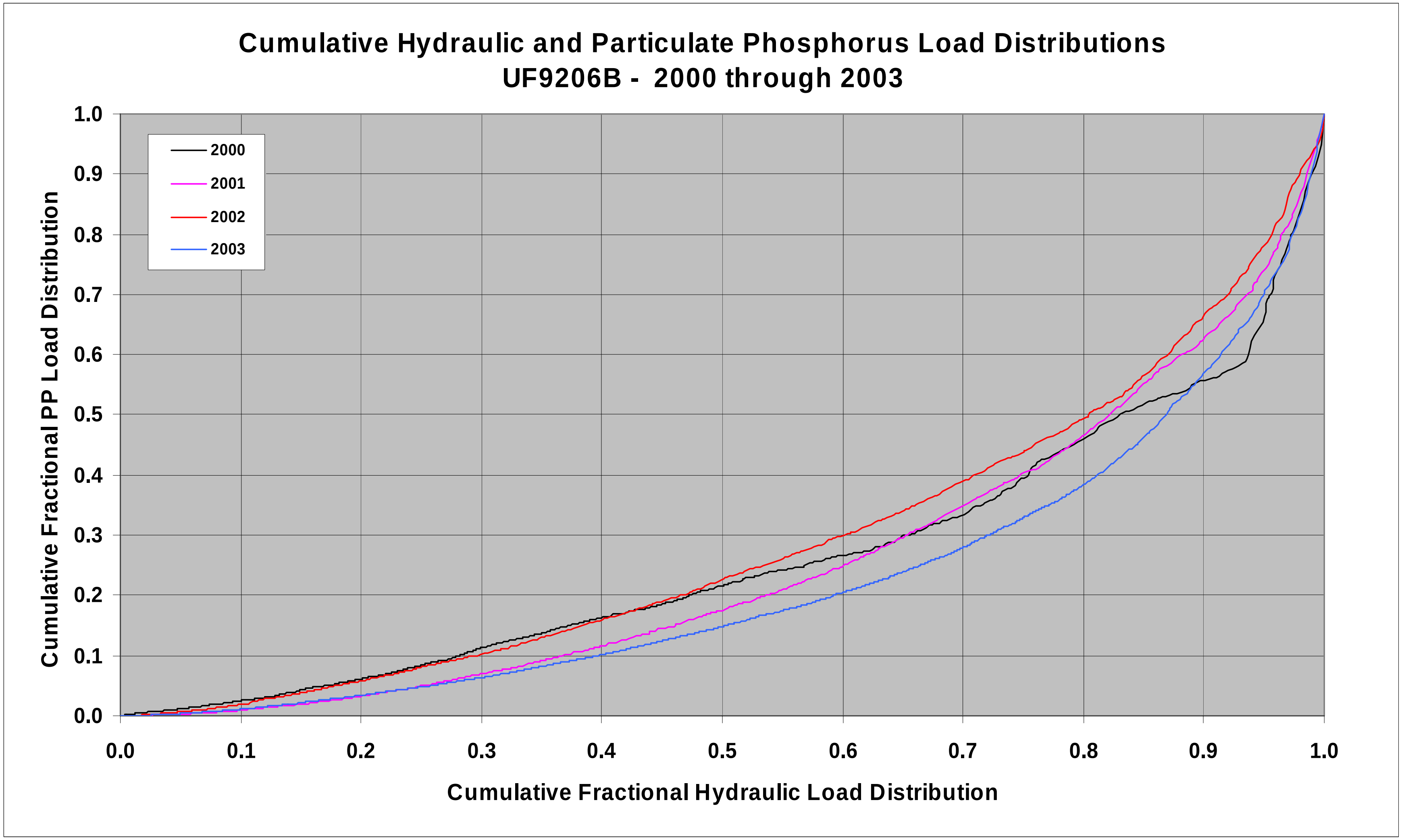

Figure 1.16. Cumulative Hydraulic and Particulate Load Distributions for UF9206B.

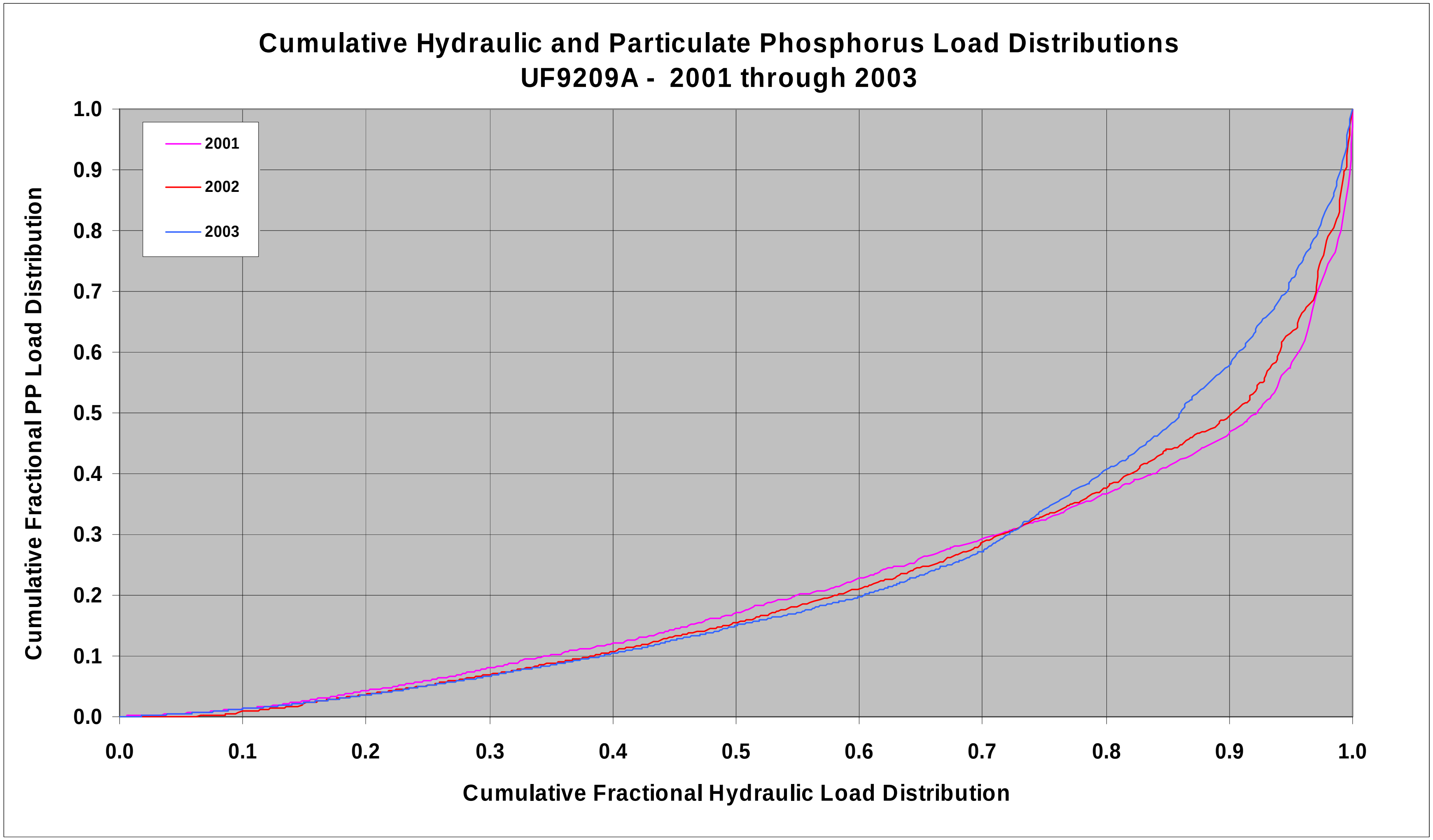

Figure 1.17. Cumulative Hydraulic and Particulate P load Distributions for UF9209A.

All curves presented in Figures 1.14 to 1.17 show similar results. Taking farm UF9200A, year 2003 (Figure 1.14) as an example, the lowest 25% of the load rate ranked hydraulic load contributed about 7% of the annual load, the lowest 50% of the load rate ranked hydraulic load contributed about 23% of the annual particulate P load, the lowest 75% contributed about 43%. The most important point of this analysis is the upper end of the curves. For the example of UF9200A, year 2003, the last 20% of the hydraulic load contributed 52% of the annual particulate P load.

In all cases, 50% of the annual particulate P load was contributed by less than 25% of the hydraulic load. For farm UF9200A, 18-22% of the annual hydraulic load during the last four year of the study, contributed to 50% of the annual particulate P load (Figure 1.14). For farm UF9206A, 16-26% of the annual hydraulic load contributed to 50% of the annual particulate P load (Figure 1.15). For farm UF9206B, 13-19% of the annual hydraulic load contributed to 50% of the annual particulate P load (Figure 1.16), and for farm UF9209A, only 8-14% of the annual hydraulic load contributed to 50% of the annual particulate P load (Figure 1.17). This analysis now allows the study of particulate P loading to be concentrated on the event sub-elements that made the most contribution.

Once the distribution were analyzed, the data points that represented contributions in the top 50% were identified and tagged. The top contributors were then analyzed for unique characteristics and processes that would contribute to elevated particulate P transport. This analysis is intimately tied to the farm management practices characteristics of each farm, so a summary of those characteristic practices is appropriate.

Farm management practices that may impact particulate P export

<u>UF9200A</u>

- Sugarcane is the main crop.
- Average canal sediment dredging program.

  Cleans canals on as-needed basis.

  No major canal-work over last four years.
- Controls aquatic weeds with herbicides on a periodic basis when weed build-up is extensive.

  Has weed boom within 50 meters (164 ft) of pump station.

- Has encountered upward of 50% coverage of canal surface by aquatic plants as measured by aerial survey (Daroub et al., 2003).
- Reduces discharge by pumping to fallow fields when available.
- Practices flow reduction during dry season, which leads to long periods of no discharge.
- Pumping is done with three fix speed electric pumps, two high and one low capacity.

  Flow control achieved by choice of high or low capacity pump.
- On-off level controllers control all pumps.
- Maintains a minimum canal depth at pump station of 0.72 meters (2.4 ft), however, average canal depths have ranged from 0.97-1.12 m (3.2-3.67 ft) during the last four years.
- Encounters frequent occasions of on-off pump cycling because of level control.
- Pump cycles typically have a period of 30 to 60 minutes.
- No major operational changes over the study period, but the pumping to rainfall ratio steadily increased from 2000 to 2002 and slightly decreased in 2003 (Figure 1.10).
- The use of the small pump during drainage events increased from 52% in 2002 to 71% in 2003.

<u>UF9206A and B</u>

- Mixed crop farm including sugarcane, sod, vegetables, and rice.
- Aggressive canal maintenance and improvement program.
- Contains multiple control structures that allow extensive flexibility in water management.
- Aggressive aquatic weed control, preventing extensive build-up.
- Has encountered on the order of 20% coverage of canal surfaces by aquatic weeds (Daroub et al., 2003).
- Has weed booms within 50 meters (164 ft) of pump stations, but also has upstream structures that impound aquatic plants.

- Reduces discharge by redistribution to fallow or planted fields, primarily rice.
- Discharge reduction typically practiced during wet season, leading to discharges in dry season.
- Pumping is at two pump stations, each with two, variable speed, high capacity diesel pumps.
- Level control is manual by speed reduction or pump shut down.
- Canal level is reduced to the bottom of the canal on occasion.
- No major changes in operation from 2000 through 2003.

UF9209A

- Sugarcane is the main crop.
- Aggressive canal and dredging and maintenance program.
- Canals are larger in size relative to pump capacity compared to the other farms, so typical velocity in canals is lower than other two farms.
- Aggressive weed control program in main canals to prevent aquatic plant build-up.
- Weed booms within 50 meters (164 ft) of pump station.
- Not a part of aerial survey program but visual observation indicated that aquatic coverage is equal to or less than UF9206A/B for main canals, with occasional extensive build-up in field canals.
- Pumping is done with three variable speed high capacity diesel pumps. Discharge control is primarily by number of pumps operating.
- No automatic level control, but levels were manually controlled to a minimum canal depth at the pump station of 1.1 meters (3.6 ft) in 2001, 0.4 meters (1.3 ft) in 2002 and 0.8 meters (2.6 ft) for 2003. The change in minimum canal depth has constituted a major change in the operational mode of this farm during the last two years.
- Operational mode typically includes shutting down at night, so there is a typically pump cycling of 8 hours on and 16 hours off.

Analysis of Major Event Contributing to Top 50% Particulate P Loads

The objective of this analysis is to identify conditions that give rise to the higher particulate P transport events. "High P load events" have been defined as those sub-events that had a particulate P load rate contributing 50% of the annual particulate P load in only 10-25% of the annual hydraulic load. It must be emphasized that throughout this analysis what is being studied is the precursor conditions leading to the event and the sub-events within the event that contribute to the top 50% particulate P loads.

The percentage points referred to for an event do not represent the total contribution of that event to the annual particulate P load. Rather they refer to the percentage of the annual particulate P load that was contained in the event that fell into the top 50% of the annual particulate P load. As an example, a large, long hydraulic event that ran at low particulate P loads rates could contributes substantially to the total annual particulate P load, while having few sub-events that qualified for inclusion into the top 50%. In this case the event would not appear as an excessive contributing event even though, by its duration, it contributed significantly to the total annual load. A short event that contained numerous sub-events that were excursions into high particulate P load rates might be ranked higher than the larger event, even though its total load was much lower than the larger event.

Table 1.8 shows the events that contained sub-events that were in the top 50% and the percentage point distribution by each event to the top 50%. Totals for each farm-year do not add up to exactly 50% because the sub-events chosen did not add up to exactly 50%. The most distinctive pattern observed from this data is the number of farm-years that were dominated by few events. Data from this table shows that six of the 15 farm-years sampled had a single event that contributed 30% or more to the top 50% particulate P load. Three farm-years had two events that contributed a total of 30% or more. Three farm-years had three events that contributed a total of 30% or more. Only two of the 15 farm-years had their load rates distributed such that it took more than three events to contribute a total of 30% or more to the top 50%.

Table 1.8. Percentage Point Distributions of Top 50% Load events.

Farm	2000		2001		2002		2003	
	Event Number	Percentage Points	Event Number	Percentage Points	Event Number	Percentage Points	Event Number	Percentage Points
UF9200A	00A-001002	42.9	00A-010802	30.0	00A-020621	9.5	00A-030904	23.9
	00A-000925	3.3	00A-011105	6.0	00A-021025	9.1	00A-031105	14.3
	00A-000708	2.2	00A-010927	4.4	00A-020211	7.7	00A-030620	13.5
	00A-000703	2.0	00A-010711	3.9	00A-020906	7.2		
			00A-010723	3.6	00A-020708	6.7		
			00A-010714	2.3	00A-021016	6.1		
					00A-021117	3.8		
					00A-020225	0.3		
UF9206A	06A-001002	32.8	06A-010709	14.3	06A-020616	13.7	06A-030313	10.8
	06A-000708	12.8	06A-010801	11.1	06A-020210	8.2	06A-030427	8.5
	06A-000713	1.3	06A-010926	10.7	06A-021026	7.4	06A-030327	8.1
	06A-000918	1.2	06A-011022	4.3	06A-020821	5.5	06A-031103	7.3
	06A-000721	0.8	06A-010319	4.3	06A-021121	3.9	06A-031214	4.7
	06A-000802	0.5	06A-010608	2.9	06A-020708	3.8	06A-030926	4.6
	06A-000908	0.4	06A-010627	1.7	06A-021014	3.0	06A-031106	3.9
	06A-000928	0.3	06A-010329	1.1	06A-020827	2.0	06A-030327	3.5
					06A-020624	1.4		
					06A-020715	1.3		
					06A-020630	0.4		
UF9206B	06B-001002	49.5	06B-010926	18.5	06B-020210	24.4	06B-030327	24.7
	06B-000802	0.5	06B-011022	11.0	06B-020825	11.0	06B-030426	14.4
			06B-011104	10.3	06B-021025	4.6	06B-030313	12.3
			06B-010806	1.9	06B-021116	3.0		
			06B-010801	1.8	06B-020709	2.0		
			06B-010329	1.7	06B-021014	2.0		
			06B-010908	1.4	06B-020701	1.5		
			06B-010319	1.0	06B-021121	1.4		
			06B-011231	0.9				
			06B-010711	0.8				
			06B-011119	0.8				
			06B-010717	0.4				
UF9209A			09A-010908	33.7	09A-020930	11.6	09A-030619	33.3
			09A-011231	5.7	09A-021118	11.5	09A-030221	15.3
			09A-010929	2.2	09A-020828	10.4	09A-030317	12.6
			09A-011026	2.0	09A-020211	4.8		
			09A-010802	1.7	09A-021030	4.6		
			09A-010715	1.1	09A-020722	2.6		
			09A-010602	1.1	09A-020912	2.4		
			09A-011030	0.9	09A-020613	1.1		
			09A-010905	0.7	09A-020214	0.9		
			09A-011024	0.6	09A-020630	0.5		
			09A-010320	0.5	09A-020309	0.4		

The timing of these clusters is also interesting. In 2000, all three stations under study at the time (UF9209A did not start sampling until 2001) were dominated by one event. In 2001, two stations out of four were dominated by one event. In 2002, one out of four stations was dominated by one event, and in 2003, three out of four stations were dominated by one event.

The focus of the event analysis is by priority. First priority is annual-dominant events and second priority the lesser events that still contributed 10% or more to the top 50%. UF9206A and UF9206B both operate under the same control policy and, because of intensive interconnections, do not have a watershed within the farm that stays constant over time. In the aggregate, analysis of these two stations yields the same conclusions.

What follows is the analysis of some of the highest particulate P load rate events and sub-events in year 2003. The highest particulate P load rate events from 2000 through 2002 are discussed in Chapter 1 of the 2003 Annual Report (Daroub et al., 2003). The objective of this analysis is to identify operating parameters and conditions that give rise to high particulate P load rates. The event statistics used are referenced from Tables 1.1-1.4. Where it is appropriate for illustration purposes selective graphical presentations are made.

Event Analysis for UF9200A

UF9200A – Year 2003

There were no dominant events in 2003 contributing more than 30 percentage points to the top 50%. However three major events contributed most of the percentage points to the top 50% during this year (Table 1.8). The top contributor in 2003 was Event 00A-030904 (Sept. 4, 2003). This event had an inter-event time of 5 days, lasted for 116 hours, but only contributed 5% of the total hydraulic load, and yet contributed 23.9 percentage points to the top 50% particulate P load.

Event 00A-031105 (Nov. 5, 2003) was also a top contributor in 2003. This event had an inter-event time of 35 days, lasted for 132 hours, but only contributed 4% of the total hydraulic load and yet contributed 14.3 percentage points to the top 50% particulate P load. This was a typical event observed during this year, and some of its profiles are shown in Figure 1.18. Flow, velocity and canal level profiles for this event are shown in Figure 1.18A, TSS, TDP and particulate P concentrations and loads are presented in Figures 1.18B and C, respectively.

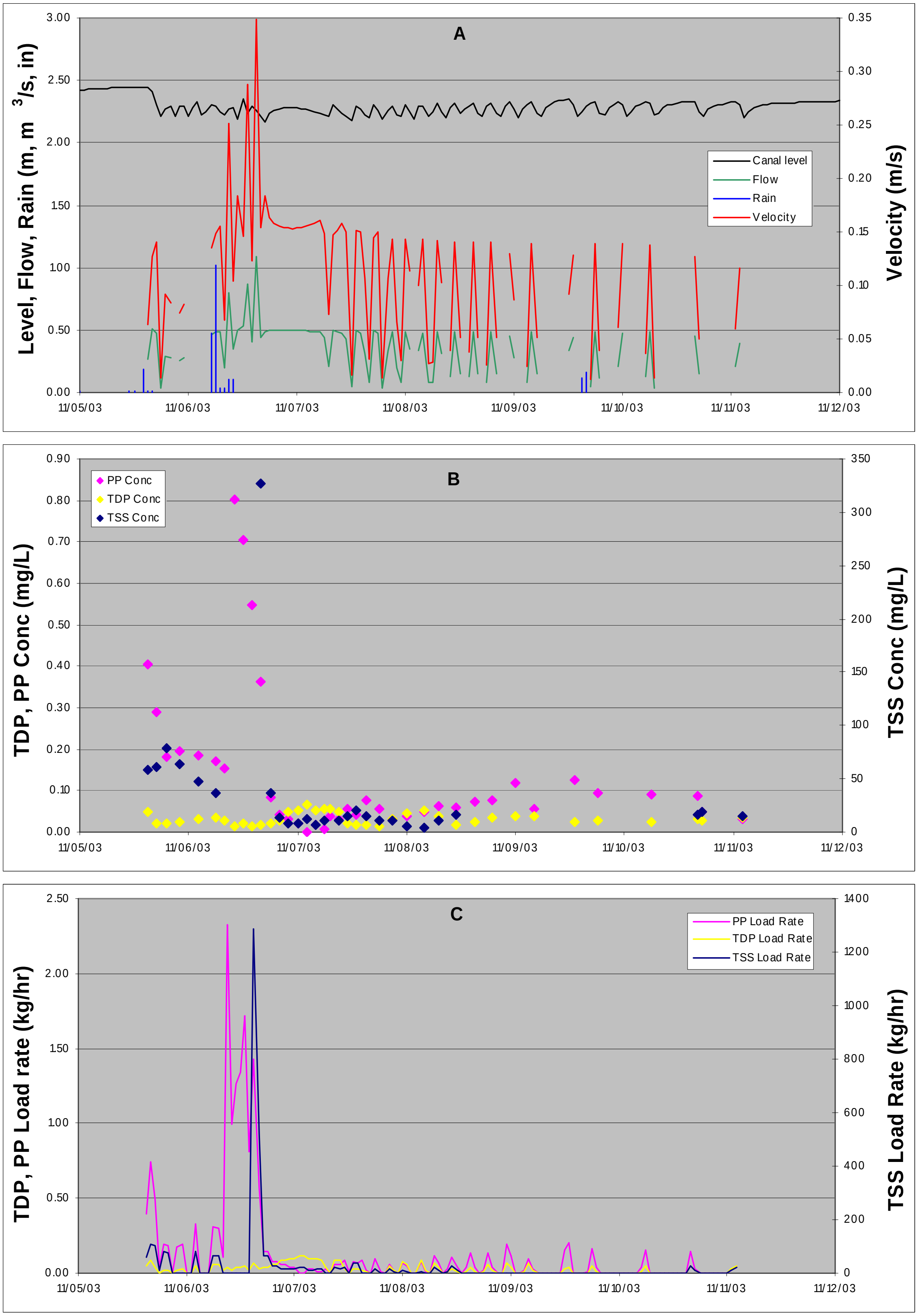

Figure 1.18. Profiles for Event UF9200A-031105.

This event started November 5, 2003 in response to some rainfall that occurred around the same time. At the beginning of the event, only the small pump was operated for several hours (flow rate for that period was lower than 0.5 m^3/s). Figure 1.18B and C show the start-up flush of particulate P at the beginning of the event. On November 6, the larger pump was used for several hours and the effect on flow velocity and suspended solids during that period are well evident. Flow velocity increased from about 0.12 m/s to 0.35 m/s, similarly, TSS concentrations increased from about 40 mg/L to more than 300 mg/l.

Particulate P concentrations experienced the same increase until the large pump was turned off and only the small pump was operating, at which point concentrations started to decrease because of the decrease in average canal velocity. The events observed in 2003 exhibited various combinations of small and large pumps cycling due to the combination of the large and small pumps used. In general the majority of the events in 2003 showed high load rates at start-up after long inter-event times, high load rates after continued high velocity, and relative high load rates during short-period pump cycling.

Event Analysis for UF9206A

UF9206A – Year 2003

There were no dominant events in 2003 for station UF9206A. Contribution to the top 50% were concentrated in four events, 06A-030313, 06A-030427, 06A-030327, and 06A-031103, which together accounted for 34.7 percentage points to the top 50% (Table 1.8). The remaining contributions were spread among four other events. The top contributor in 2003 was Event 06A-030313 (March 13, 2003). This event had an inter-event time of 47 days and lasted 136 hours. This was the second major event in the season, accounting for 11% of the total hydraulic load (277,476 m^3), and 17% of the total particulate P load for 2003 (Tables 1.2A and 1.2B).

Figure 1.19 shows key profiles for Event UF9206A-030313. Flow and canal level profiles are shown in Figure 1.19A, TSS, TDP, and particulate P concentrations and loads profiles are presented in Figures 1.19B and C, respectively. This event started late afternoon on March 13, in response to a rainfall event that occurred around the same time.

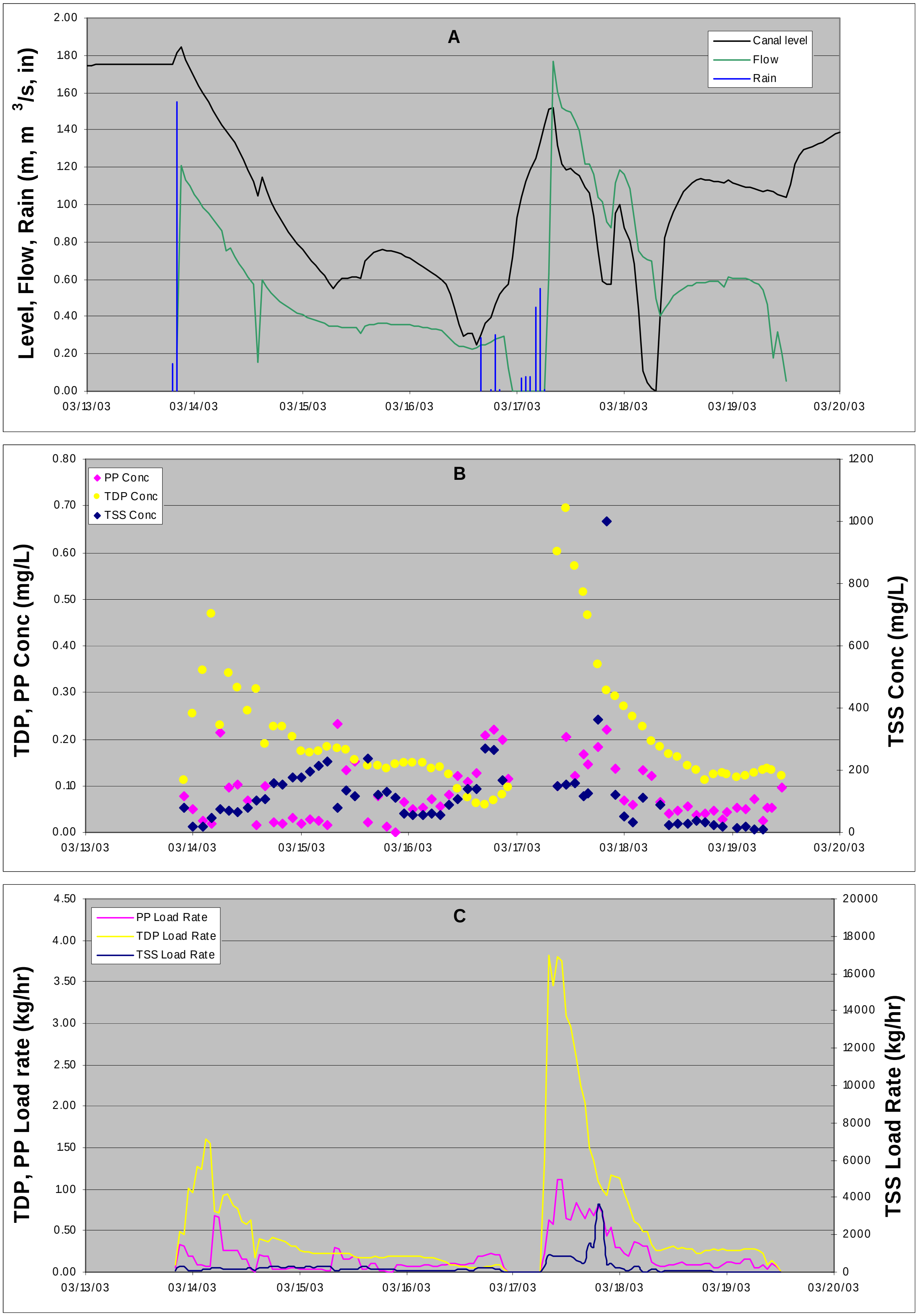

Figure 1.19. Profiles for Event UF9206A-030313.

Canal level rapidly decreased from about 1.8 m (5.9 ft) to about 0.6 m (2.0 ft) during the first 36 hours of the event. As pumping continued, canal level continued decreasing until about 0.25 m (0.8 ft) at the end of this pumping period. Flow rate also rapidly increased up to 1.2 m^3/s at the start of the event, then steadily decreased until the end of this continuous pumping event late on March 16.

Late March 16 and early March 17 more rainfall occurred in the area, causing the canal level to rapidly increase from about 0.25 m (0.8 ft) to about 1.5 m (4.9 ft). At that point, the grower started pumping again, with the canal level decreasing to about 0.6 m (2.0 ft) during the first 12 hours of the event, it went back again to about 1.0 m (3.3 ft) as pumping intensity decreased, but then pumping rate increased again and the canal water level went down close to the canal floor. Figure 1.19B and C shows the start-up flush of particulate P at the beginning of the event. Particulate P concentrations increased from < 0.05 mg/L to about 0.22 mg/L, during the first few hours of the event, then as pumping intensity decreased particulate P concentrations and loads steadily decreased for the remaining of the first continuous pumping event. Pumping rate during the second continuous pumping event was higher leading to increases in particulate P and TDP concentrations and loads at the beginning of this pumping event. As the event progressed, particulate P concentrations and loads decreased to background levels (Figures 1.19B and C, respectively). Something to note about this event is the amount of total dissolved P in the water. Total dissolved P concentrations rapidly increased from about 0.1 mg/L to 0.48 mg/L, then steadily decreased for the remaining of the first pumping period. A similar pattern was observed in the second pumping event. Increases in TDP concentrations at the beginning of each pumping event are difficult to explain because they do not respond to transport factors as particulate P and will not be discussed as this is beyond the scope of this research.

Event Analysis for UF9206B

UF9206B – Year 2003

There were also no dominant events in 2003 contributing more than 30 percentage points to the top 50% at this station. However three major events contributed most of the percentage points to the top 50% during this year (Table 1.8). The top contributor in 2003 was Event 06B-030327 (March 27, 2003). This event had an interevent time of 3 days, lasted for 64 hours, but only contributed 7% of the total hydraulic load, and yet contributed 24.7 percentage points to the top 50% particulate P load. Total discharge during the event was

211,400 m^3. This event was responsible for the largest particulate P load of the year, accounting for 20% of the annual load.

Figure 1.20 shows the profiles of event 06B-030327. Flow, velocity and canal level profiles for this event are shown in Figure 1.20A, TSS, TDP and particulate P concentrations and loads are presented in Figures 1.20B and C, respectively. This event started in the late afternoon of March 27, 2003 in response to a heavy rainfall in the area that lasted for a few hours. Canal levels rapidly increased from about 1.2 m to 1.7 m (3.9 to 5.6 ft) in a couple of hours. In response, the grower started pumping with the flow rates rapidly increasing up to 1.75 m^3/s. There was a particulate P first flush and a load rate response as flow rate and velocity increased. Figure 1.19B and C show the start-up flush of particulate P concentration and load at the beginning of the event. Particulate P concentration rapidly increased from about 0.1 mg/L to 1.0 mg/L, then as pumping intensity decreased particulate P concentration and load steadily decreased for the remaining of the event. This was a long continuous pumping event that lowered the canal levels from 1.7 m (5.6 ft) early in the event (March 27) to about 0.8 m (2.6 ft) in the last 24 hours of the event (March 29). Flow rate and velocity were maintained during that period, as pumping continued, canal level considerably decreased and velocity in the canal rapidly peaked up at about 0.55 m/s before it came down as the event ended. This is a good example of what can happen to flow velocity when canal levels are brought down too low. This event is a good example of high water velocities and supply and exhaustion conditions. Most of the easily transportable particulate material accumulated during the inter-event period was transported out of the farm during the first 24 hours of the event. Although water velocity drastically increased during the last few hours of the event, the supply of easily transported material has been already exhausted, so no more significant amounts of particulate P was transported out of the farm. Total dissolved P concentrations also rapidly increased at the beginning of the event from <0.05 mg/L to about >1.0 mg/L, then steadily decreased for the remaining of the event. As stated earlier, increases in TDP at the beginning of the event are difficult to explain because they respond differently than particulate P and will not be discussed as it is beyond the scope of this study.

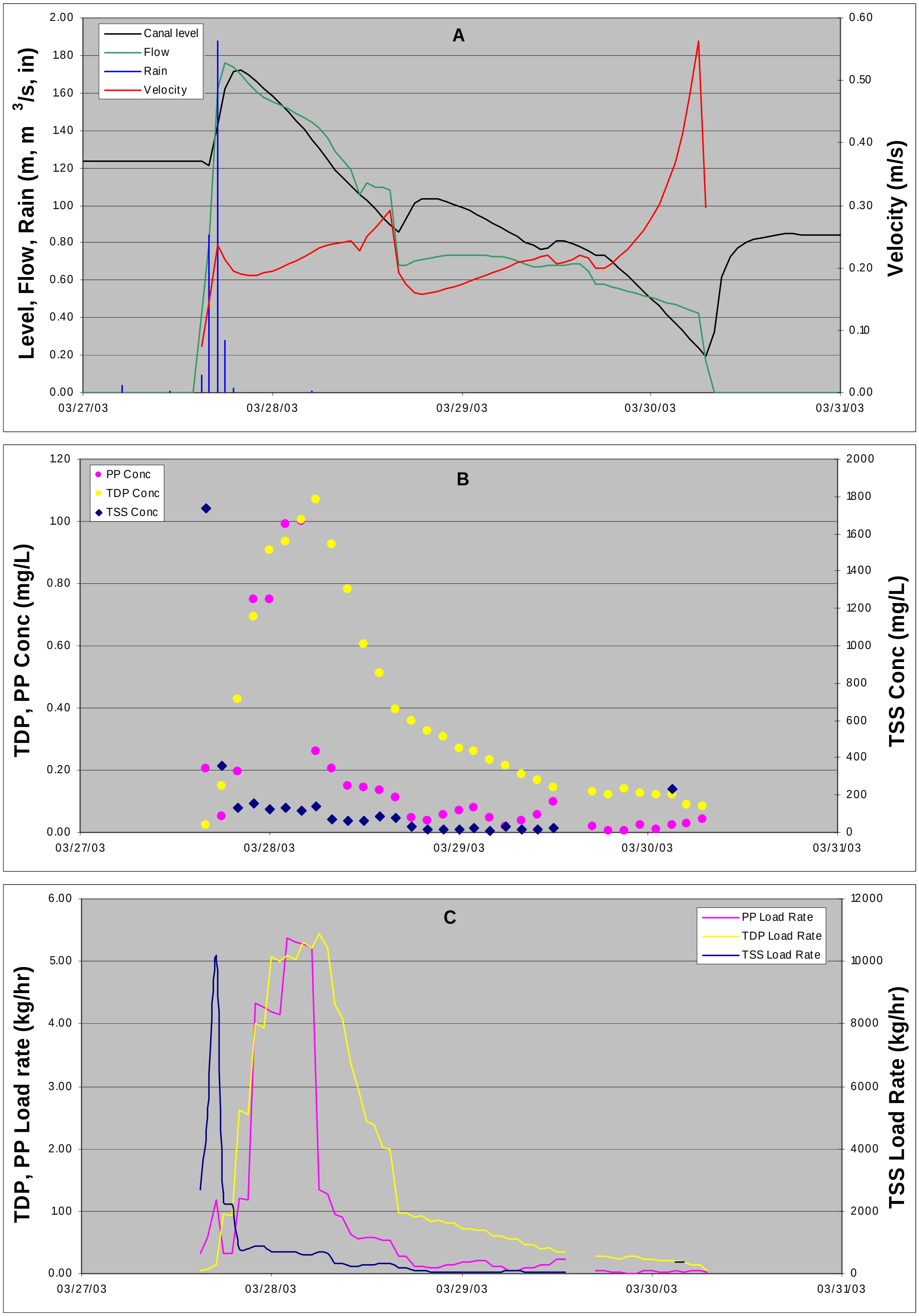

Figure 1.20. Profiles for Event UF9206B-030327.

Event Analysis for UF9209A

UF9209A – Year 2003

There was one dominant event during the year, Event 09A-030619 (June 19, 2003) that contributed 33.3 percentage points to the top 50% (Table1.8). There were two other events, 09A-030221 (Feb. 21, 2003) and 09A-030317 (March 17, 2003), which combined contributed 27.9% to the annual top 50% particulate P load. Event 09A-030619 had an inter-event time of 9 days, lasted for 151 hours, and contributed 13% of the total hydraulic load. Total discharge during the event was 211,400 m^3. This event was responsible for the largest particulate P load of the year, accounting for 23% of the annual load.

Figure 1.21 shows the profiles of event 09A-030619. Flow, velocity and canal level profiles for this event are shown in Figure 1.21A, TSS, TDP and particulate P concentrations and loads are presented in Figures 1.21B and C, respectively. This event started early the morning of June 19, 2003 in response to some rainfall that fell during the previous 24 hours. Canal levels steadily increased from about 1.9 m (6.2 ft) to about 2.2 m (7.2 ft) during the 24 hours before pumping started. On June 19, the grower pumped for a few hours and stopped. On June 21 there was another rainfall event that made the canal level to steadily increase from about 2.0 m (6.6 ft) to 2.6 m (8.5 ft). This prompted the grower to turn on the pumps, with flow rate rapidly increasing from about 0.75 m^3/s to 4.6 m^3/s in a short period of time (Figure 1.21A). This continuous pumping event lasted more than 24 hours with flow velocities increasing up to 0.25 m/s. Figures 1.21B and C show the start-up flush of particulate P concentration and load at the beginning of the event. Although, pumping on June 19 lasted for a few hours, particulate P concentration increased from about 0.26 mg/L to 0.58 mg/L. In the second pumping period of the event, particulate P concentrations increased from about 0.05 mg/L to about 0.28 mg/L, then as pumping intensity decreased, particulate P concentrations and loads steadily decreased for the remaining of the event. There was one last peak of particulate P concentrations at the end of event that coincides to several hours of pumping. This event showed evidence of supply and exhaustion, especially at the beginning, when particulate P concentration rapidly increased as a result of particulate P material accumulated during the nine days of inter-event period prior to the pumping event.

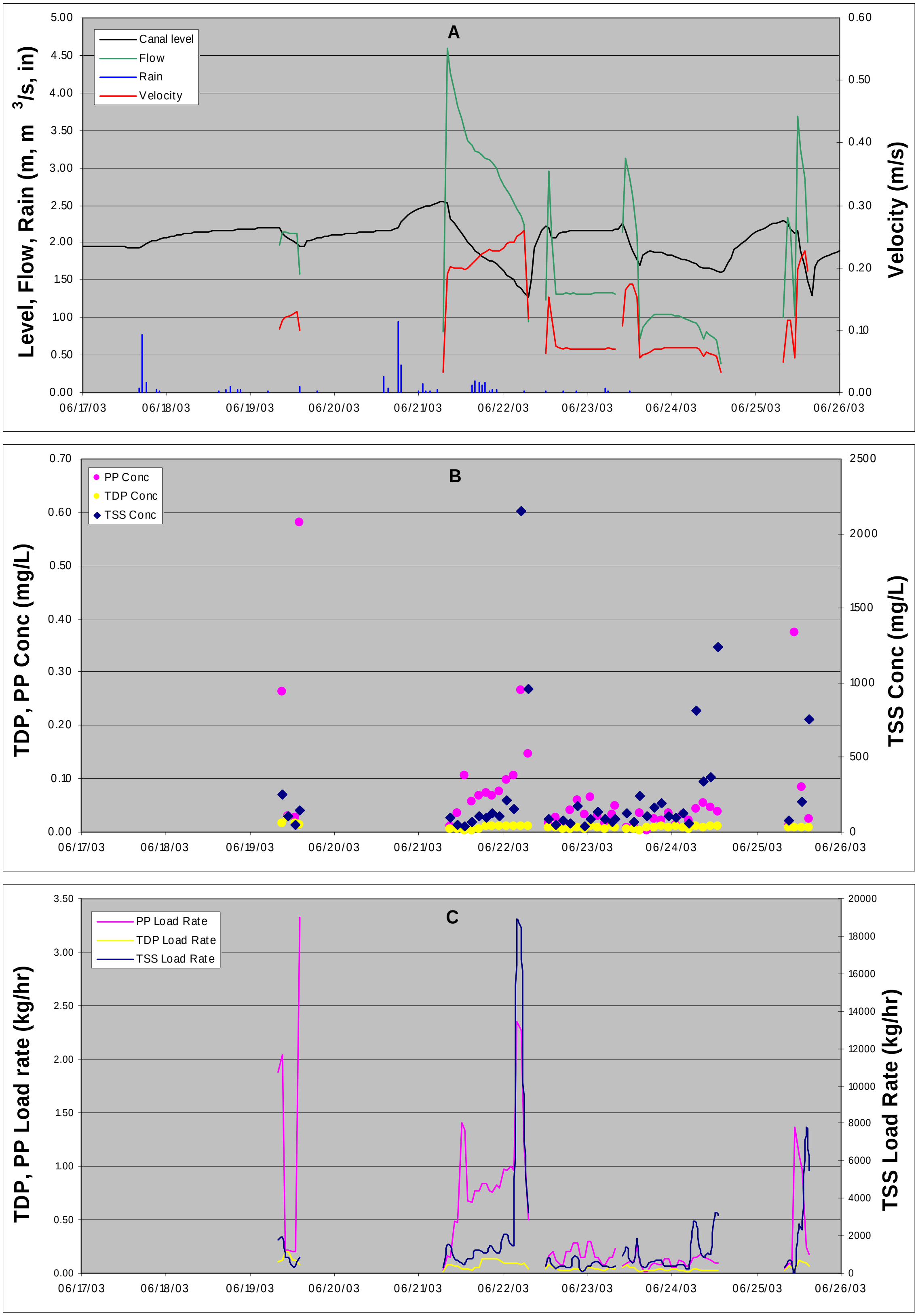

Figure 1.21. Profiles fro Event UF9209A-030619.

DISCUSSION AND SUMMARY

There is a substantial deal of heterogeneity when dealing with particulate P transport in agricultural systems. The supply of particulate P in a drainage event is generally heterogeneous, thus, transport of suspended solids is not always proportional to the transport of particulate P. The light and easily transportable material, which is generally high in P concentration, is easily mobilized under relatively mild hydraulic conditions. Continued mobilization and export leads to supply exhaustion of the material high in P concentration, although it may not lead to supply exhaustion of suspended solids low in P concentration. Biological activity in the water column can play a significant role in increasing the amount of transportable particulate P in canals, especially after long inter-event periods. However, sedimentation processes can work to slow down transportability through consolidation and mineralization of fresh deposited particulate matter. Hydraulic conditions may vary substantially over the course of a pumping event and also from event to event. Seasonal conditions can affect the physiological status of the biological population. There are some indications that changes in climatic and/or hydraulic conditions from year to year may give rise to annual changes in the physical-chemical properties of the transportable particulate P.

One of the primary goals of this study was to identify conditions that cause high particulate P load rates, and analyze those conditions to determine operating procedures that might reduce particulate P export. Load rate is the product of flow and concentration over a given unit time period. High particulate P loads may occur from transport of moderate amount of high P content material. This condition is more likely to occur whenever there is a large supply of readily transportable biological material close to the pump station. This light material can be transported at moderate flow rates, for example at pump start-up after long inter-event time periods. High particulate P load rates may also occur from transport of large amounts of lower P content sediment material over a short period of time. This type of high particulate P load rate could occur during high pumping rate events, that causes canal level to drop close to the bottom, increasing flow velocity, resulting in the dislodge and transport of base sediment material in the canal. There are obviously intermediate conditions with combination of flow and concentration that can cause high particulate P load rates. This study searched to isolate specific conditions at each farm that could be associated with high particulate P load rates.

Farms Summary

Farm UF9200A, is a sugarcane operation that has shown some of the highest average canal velocities during the study period (Table 1.9). This farm has an average canal improvement and aquatic weed management program, with some sections of the main canal covered with aquatic weeds. However, the grower makes an effort to keep aquatic weeds away from the pump station. Discharge is controlled by selection of either high or low capacity pumps. Level control is practiced by automatic shut down and start-up of the chosen pump at canal level set points. This lead to a minimum allowable canal level, but also causes short periods (less than one hour) of pump cycling. The imposition of level control also insures that canal velocities will not exceed a certain maximum, which can be detrimental to the annual P load of the farm.

Farm UF9206A/B is a mixed crop operation that has shown average canal velocities that fall in between the other two study farms (Table 1.9). This farm has an extensive canal improvement program and an aggressive aquatic weed management control. The elaborate and complex canal system of this operation allows the farmer to impound and transfer large volumes of water throughout the farm. The number and speed of pumps running at a particular station, controls the volume of water discharged. This farm does not have automatic level control, which sometimes leads to the canals being pumped close to the floor. The fact that this is a mixed crop operation that includes different kind of vegetables, require the grower to keep a closer management of the water table across the farm. Pumping is generally more extensive, frequent, and often of longer duration. This is indicated by the high pumping-to-rainfall ratios observed in Figure 1.10.

Farm UF9209A is mainly a sugarcane operation that has shown the lowest average canal velocities of the three farms during the study (Table 1.9). This farm has an aggressive canal management program, and an aquatic weed control that falls in between the other two farms. The main canals are kept reasonably clean of aquatic weeds, but some secondary canals and field ditches have extensive weed coverage. Typical procedure is to run the pumps on a long period cycle of 8 hours on, 16 hours off. Level is controlled manually, with the pumps being turned off when a predicted canal level is reached. However, during the last 15 months, this level has been reduced, resulting in a reduction of the minimum level in the canal and the increase in the maximum allowable canal velocity.

Table 1.9 Average Velocity and Canal Depths of Study Farms.

Farm	Year	Average Velocity (m/s)	Average Depth (m)
UF9200A	2000	0.152	1.12 (3.7 ft)
	2001	0.343	1.08 (3.5 ft)
	2002	0.302	1.01 (3.3 ft)
	2003	0.181	0.97 (3.2 ft)
UF9206B	2000	0.203	0.91 (3.0 ft)
	2001	0.263	0.84 (2.8 ft)
	2002	0.305	0.65 (2.1 ft)
	2003	0.326	0.77 (2.5 ft)
UF9209A	2001	0.114	2.08 (6.8 ft)
	2002	0.158	1.71 (5.6 ft)
	2003	0.124	1.86 (6.1 ft)

There were notable variations in some measured farm key parameters over the study period. Normalized annual average particulate P loads exported from farms UF9200A and UF9209A have been fairly constant, averaging about 0.15 and 0.05 kg P/acre, respectively (0.33 and 0.11 lb/acre) (Figure 1.8A). Particulate P loads from farm UF9206A/B have shown a notable decrease during the first-three years of the study, declining from an average value of 0.41 kg P/acre (0.90 lb/acre) in 2000 to 0.12 kg P/ acre (0.26 lb/acre) in 2002. However, in 2003 the average particulate P load values went back to 0.24 kg P/acre (0.53 lb/acre). This increase in particulate P load may be related to an increase in total drainage volume (45% increase) and number of drainage events observed at both stations (UF9206A and B) in 2003 (Table 1.6).

Annual average TSS and particulate P concentrations rapidly decreased from 2000 to 2001 at farms UF9200A and UF9206A/B, then remained relatively constant or showed a slight increase from 2001 to 2002 (Figures 1.11 and 1.12). In 2003, average TSS concentrations average for these three farms remained constant. Annual TSS and particulate P concentration for farm UF9209A have behaved in the opposite direction. Average TSS concentration at this farm increased from 12 mg/L in 2001 to 22 mg/L in 2002, but in 2003 the concentration significantly increased to 110 mg/L. Annual particulate P concentrations also showed a steady increase during the last three, but the change was not as drastic as that observed in the TSS concentration. Increases in TSS and particulate P concentrations at this farm during the last three-years, are mainly the result of changes in operations that started in the last quarter of 2002. Pumping records shows that during the last 15 months, canal levels have been pumped closer to the bottom and the average duration of each event increased from 41 hours in 2002 to 61 hours in 2003 (Table 1.4). These longer drainage events combined with low canal levels in 2003, resulted in the transport of large quantities of low P bottom canal sediments.

Dominant Events, Velocity, and Response Times

Event-percentage point distribution showed that six of the 15 farm-years studied were dominant events that contributed 30 percentage points or more to the top 50% of the annual particulate P load. In seven farm-years two or three events contributed 30 or more percentage points. In only two of the 15 station-years there were no dominant events. This implies that a large fraction of the particulate P transport was extremely periodic in nature.

These periods or episodes typically started when pumping operation deviated from typical practices, but these deviations were characteristics to each particular farm. At UF9200A, dominant events started from high pumping velocity after long inter-event times. At UF9206B, dominant events started from canal levels that were too low at the beginning of the event, or were allowed to get so low that extreme velocities were encountered. At UF9209A, dominant events started from extended pumping, and from and a deviation from the normal pattern of 8 hours on, 16 hours off. During the last 15 months of the study, this farm started to pump for longer period of time, which resulted in reduction of minimum canal depths and increases in canal velocity.

The impact in canal velocity was different at each study farm. The concept of supply exhaustion applies to the transportable supply. At a given farm, if a specific maximum velocity is not exceeded, there will be material that is not transportable because it requires a velocity greater than the maximum to be mobilized. This residual supply will vary from farm to farm depending on the maximum velocity. The higher the velocity, the greater the mobilization, so farms with greater velocity would be expected to have higher amounts of solids transported.

Figure 1.22 shows the annual average particulate P concentration versus annual average canal velocities for the three farms from 2001 to 2003. The year 2000 was excluded because there was no data from farm UF9209A, and also because the other two farms had dominant events that contributed large amounts to particulate P discharge loads.

Figure 1.22 shows the expected response of increase in particulate P concentration with increase in canal velocity. Farm UF9209A showed the lowest average velocities and particulate P concentrations of the three farms. Farm UF9206B showed a steady increase in both parameters from 2001 to 2003. Velocity and canal depth have an impact on the response times for continued high velocity. In the presentation of farm events, it was noted that the lower velocities and greater canal depths at UF9209A, caused to have a longer response time than the other two farms, before the effects of continued high velocities were observed. Thus, a velocity higher than normal will be able to mobilize previously un-mobilized material, regardless of the absolute value of the velocity.

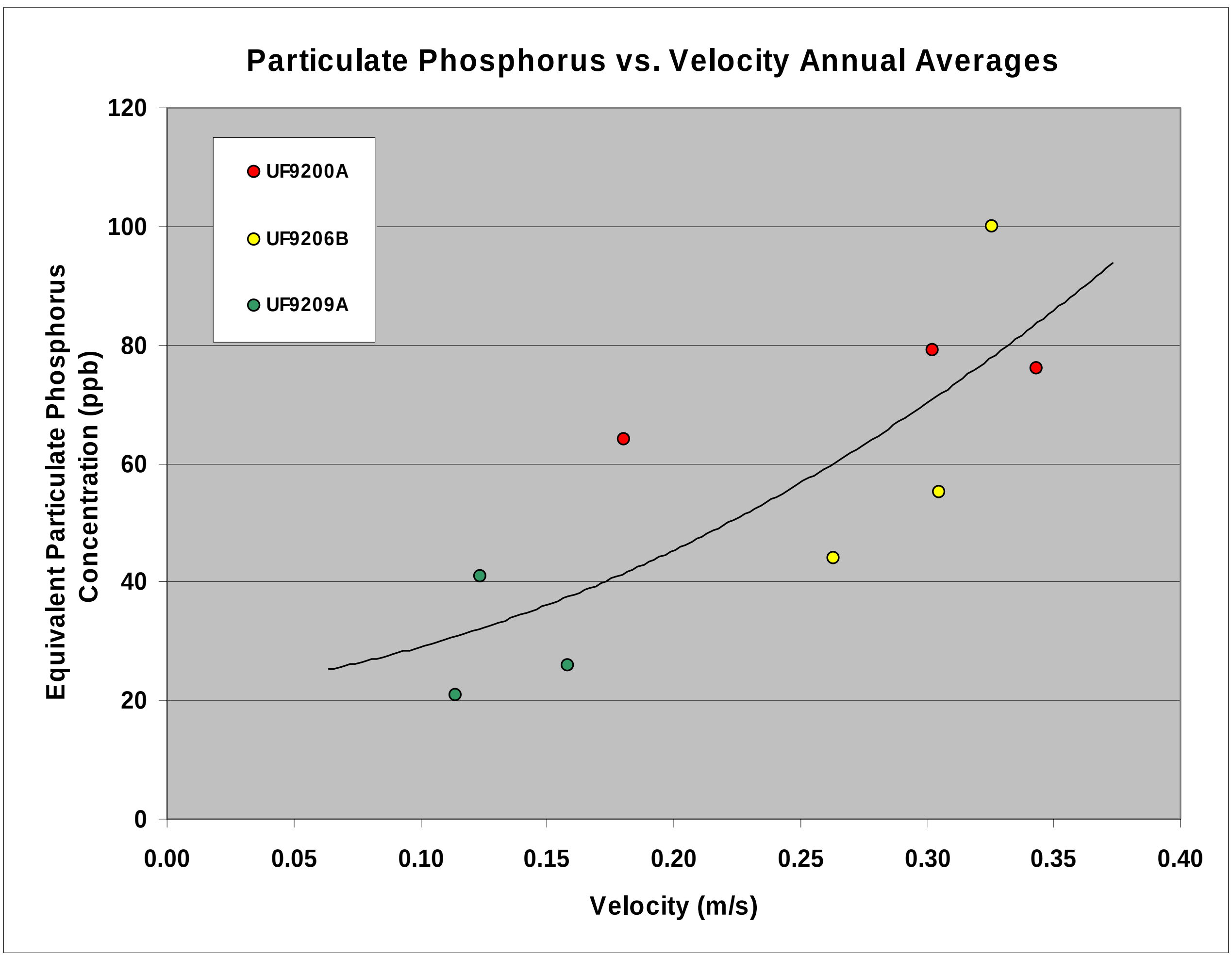

Figure 1.22. Annual Average Particulate P vs. Annual Average Velocity.

Key Processes Demonstrated at Each Farm

The diversity of the farms has allowed a number of observations to be made regarding the importance of various operating parameters in multiple contexts. Following there is a discussion of key points demonstrated at each farm.

UF9200A

- This farm showed the less aggressive aquatic weed control program and some the highest velocities of the three farms. This combination generally increases start-up after long inter-event times. This farm had two dominant events during the four year study that were characterized for their long duration and high velocities. Responses of the same magnitude were not seen at the other two farms.
- Short-period pump cycling continues to contribute far more than its hydraulic share to high particulate load rates, but their frequency was slightly reduced in 2003. Short period pump cycling leads to high particulate P loads and it is discouraged.
- Canal level control, when practiced without pump cycling, interrupted continued high velocity and reduced P load rates.
- Higher velocities and shallower canals give this farm a shorter response time than farm UF9209A. However, this farmer is reducing the average canal velocities of the farm by increasing the use of the small pump during the year.

UF9206A/B

- This farm practiced the most aggressive aquatic weed control and more complex water management program of the three farms. Results from this farm suggest that the supply-exhaust mode is a very frequent occurrence during the year. Part of this is due to the fact that it has a higher rainfall-to-pumping ratio than the other two farms, but part of it is also probably due to the fact that this farm has achieved a true reduction of its highly transportable particulate P inventory. Particulate P contribution at this farm ranges between 25 to 40% of the total P load, which is a considerable reduction from its historical value of around 50%.
- This farm does not practice level control, and average water velocities have been steadily increasing during the four years of the study. These high velocities have

resulted in the mobilization of large quantities of low P content suspended solids, resulting in an increase in the overall particulate P load rate in 2003.

- This farm showed the lowest annual average canal depth (UF9206B, 0.77 m or 2.5 ft) of all three farms. Elimination of low canal level practice, couple with continued aggressive weed and water management practices, could categorize this farm in a most favorable condition with respect to particulate P load reduction.

UF9209A

- This farm has the advantage of having few aquatic weed in the main canals combined with wide and deep canals, which results in the lower velocities observed in the three farms. Its relative particulate P contribution is high (65-80% of total P), but its absolute contribution is the lowest of the three farms.

- The practice of long-period pump cycling appears to be beneficial at this farm because of the long response times.

- Because of its low velocities, the farm has theoretically a reservoir of readily transportable material stored along the main canal. This has been observed during the last 15 months of the study. The farm has deviated from its normal operations, increasing the pump run time and lowering minimum canal levels, causing the increase in the amount of low P sediment material to be exported out of the farm in 2003. This farm appears to be more sensitive to moderate changes in operating conditions than the other two farms.

GENERAL RECOMMENDATIONS

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

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

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

Aquatic Weed Control and Retention – Aggressive weed control programs in the main canals is one of the most productive techniques in reducing the supply of high P content biomass. However, the physical removal along the entire length of the main canals can be expensive to implement. For that reason, the installation of weed-retention booms is recommended to be located at a distance >300 m (984 ft) upstream the main pump station.

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