Chapter 2

Water Conservation Area Canal Sediment Phosphorus Studies – Inventory, Release and Transport

Introduction

This report on the Water Conservation Area Canal Sediment Phosphorus Studies is presented in Project Report format. Because of this it contains some material that has been reported, all or in part, in previous progress reports and presentations.

Treated water from the Stormwater Treatment Areas (STA's) discharges into an extensive network of canals for distribution throughout the Water Conservation Areas (WCA's). The ultimate goal of the treatment system is to deliver water of low phosphorus concentration to the downstream system. The current long-term goal is to deliver a concentration of 10 ppb or less. The work of the BMP project has shown that the farm canals have a significant impact on the total phosphorus concentration discharged from EAA farms. It is reasonable to ask whether the canals in the WCA water distribution network downstream of the STA's could have a similar impact, particularly in view of the low concentrations of phosphorus that will ultimately be discharged into them.

This study was undertaken in an attempt to evaluate the potential impact of existing phosphorus-containing matter in the WCA canals on low-phosphorus water discharged from the STA's. The project objectives were:

Determine the current bathymetry of the canals
Conduct an inventory of the sediment in the canals
Determine the phosphorus content of the canal sediments
Estimate potential release rates of phosphorus from sediments under low phosphorus concentration conditions

Evaluate the potential impact of these releases on the treated water in the overlying water column

Conduct transport studies of particulate and dissolved phosphorus species under representative conditions in a target WCA canal system downstream of a working STA

EREC personnel conducted sediment inventories, sediment sampling and analysis for total phosphorus and physical properties, canal bathymetry measurements, and canal transport studies. Personnel from the University of Florida Wetlands Biogeochemistry Laboratory (WBL) took separate samples at selected locations. These samples were transported to Gainesville, where they were used for more detailed phosphorus speciation and for extended phosphorus flux studies. The detailed results of these flux and speciation studies are reported in Attachment 2A. These results were used to estimate potential contributions of phosphorus by WCA canal sediment into the overlying water column.

Sampling Transect Locations

Sediment samples and canal measurements were taken at transects located at approximately one-mile longitudinal increments along over 120 miles of canals in the WCA's. Core samples for physical and chemical analyses were taken at each transect at the canal center and at points half way between the canal center and each bank. Transect locations are shown in Attachment 2B, Figures 2B.1-7. Core samples for phosphorus flux and speciation studies were taken at twenty pre-determined locations, different from the transect locations. Flux core sample locations are also shown in Attachment 2B, Figure 2B.8.

All canals downstream of existing or under-construction STA's were sampled. These are shown in Table 2.1. Two canals upstream of STA discharge points were sampled, because these canals may receive flow by by-pass during conditions when the STA's might suffer from hydraulic overload. These are shown in Table 2.1, labeled as “Upstream”.

Table 2.1 – Canal and Transect Identification

Canal Designation	Location	Length (mi)	Number of Transects
L7S	From G-310 to S-6	9.2	9
L39	From S-6 to S-39A	13.0	13
L40S	From S-362 to S-39A	24.9	24
L6	From G-335 to G-339	7.0	8
L5	From G-201 to S-150	5.5	5
L38	From G-7 to S-141	13.0	13
Miami Canal-North	From S-8Z to S-8	10.7	11
Miami Canal	From S-8 to S-151	27.9	28
L7N (Upstream)	From G-310 to G-301	6.8	7
L40N (Upstream)	From S-362 to G-300	3.9	4

Methods

The measuring, sampling and analytical methods for the canal bathymetry and sediment phosphorus and physical characterization procedures are included in Attachment 2C. Methods for the phosphorus flux and speciation procedures are summarized in Attachment 2C. Detailed descriptions of the phosphorus flux and speciation procedures are included in Attachment 2A.

Results Summary – Sediment Inventories

Figure 2.1 shows the expected relationship between organic matter content and sediment bulk density for all canal samples taken together. As sediment organic matter fraction increases, the sediment becomes less dense and more transportable because the average specific gravity of the sediment decreases, and because the water content of the sediment increases. Figure 2.2 shows the relationship between organic matter content and phosphorus content for all canal samples. There is a cluster of points around a center of correlation (bracketed by the high and low, but there is also considerable scatter, particularly in the direction of high phosphorus content at low organic matter content. This scatter is resolved somewhat when the canals are considered separately. Table 2.2 shows the average value of several basic sediment parameters for each canal segment.

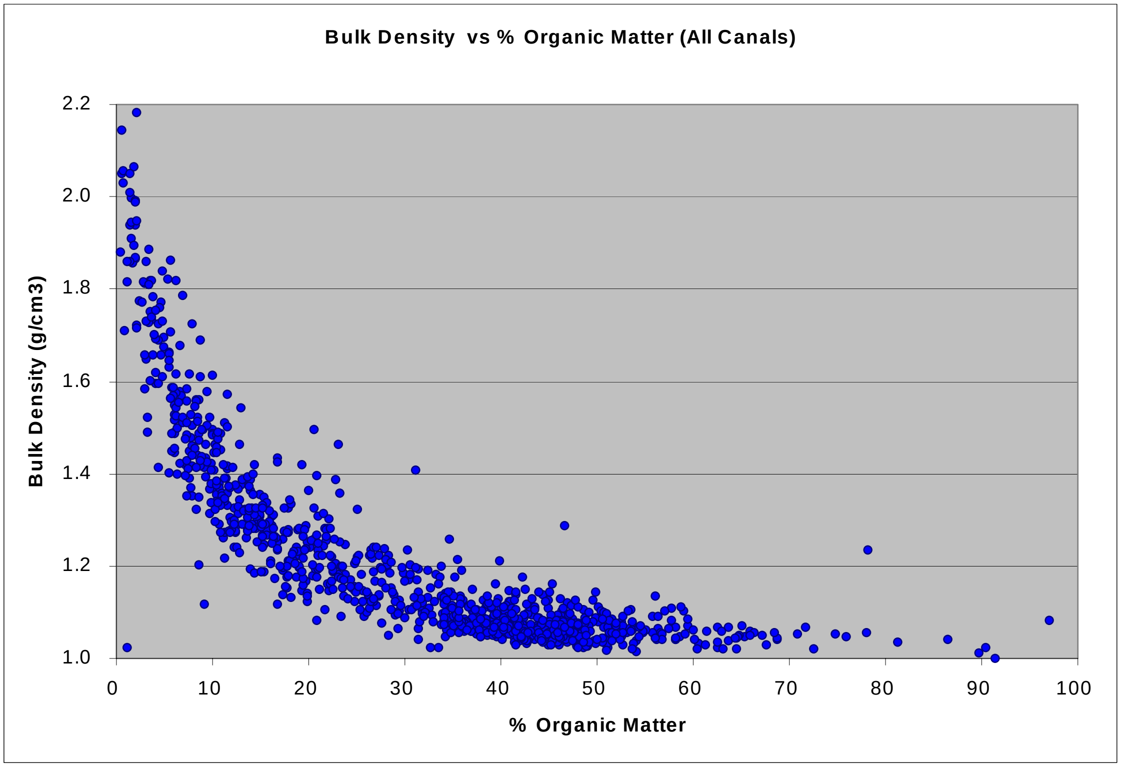


Figure 2.1 – Sediment Bulk Density vs. Organic Matter Fraction (All Canals)

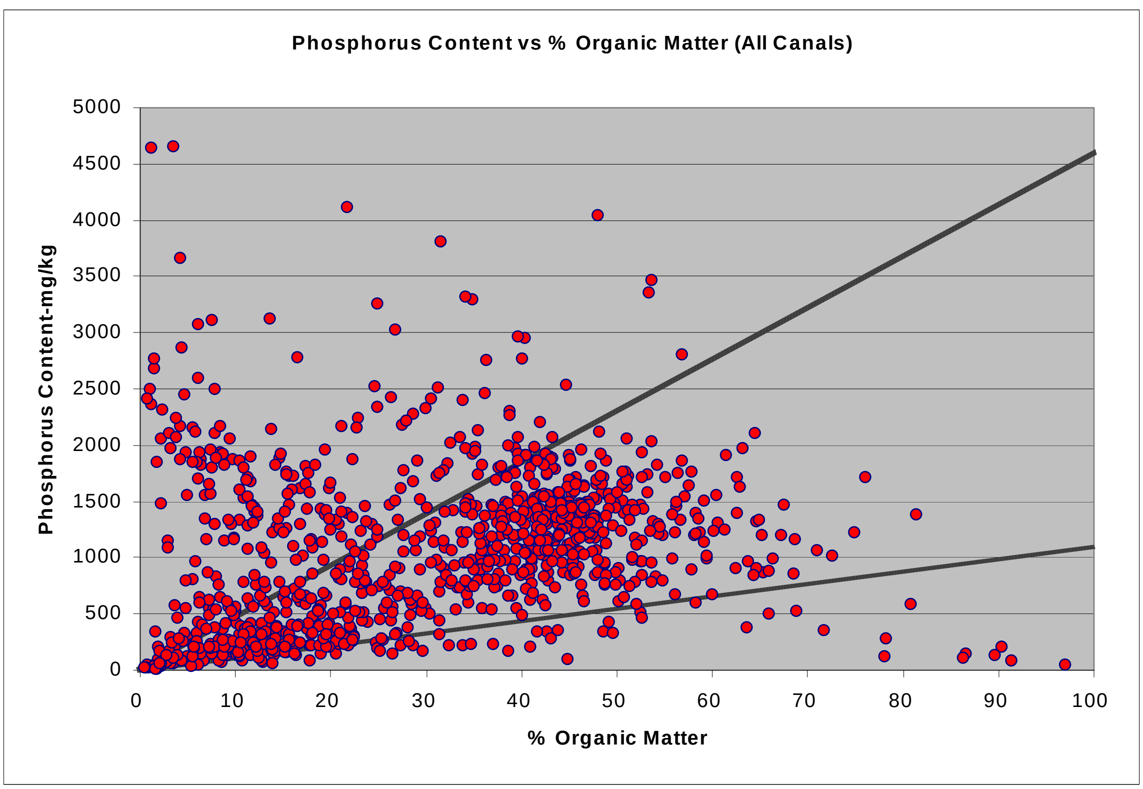


Figure 2.2 - Sediment Phosphorus Content vs. Organic Matter Fraction (All Canals)

Table 2.2 – Average Sediment Properties by Canal

Canal	Bulk Density (g/cm^3)	% Dry Mass	% Organic Matter	Phosphorus Content (mg/kg)
L7S	1.14	18.19	38.81	932
L39	1.21	24.17	34.55	735
L40S	1.24	25.10	33.11	1071
L6	1.31	37.05	23.11	285
L5	1.20	26.72	28.79	583
L38	1.22	29.06	28.54	1123
MC	1.24	28.02	26.62	1477
MCN	1.32	38.70	14.90	1362
L7N	1.07	12.79	48.13	1282
L40N	1.07	12.56	41.82	1168

It is clear from Table 2.2 that the basic sediment properties may vary considerably from canal to canal. Figure 2.3 shows the relationship between organic fraction and phosphorus content for the canal averages.

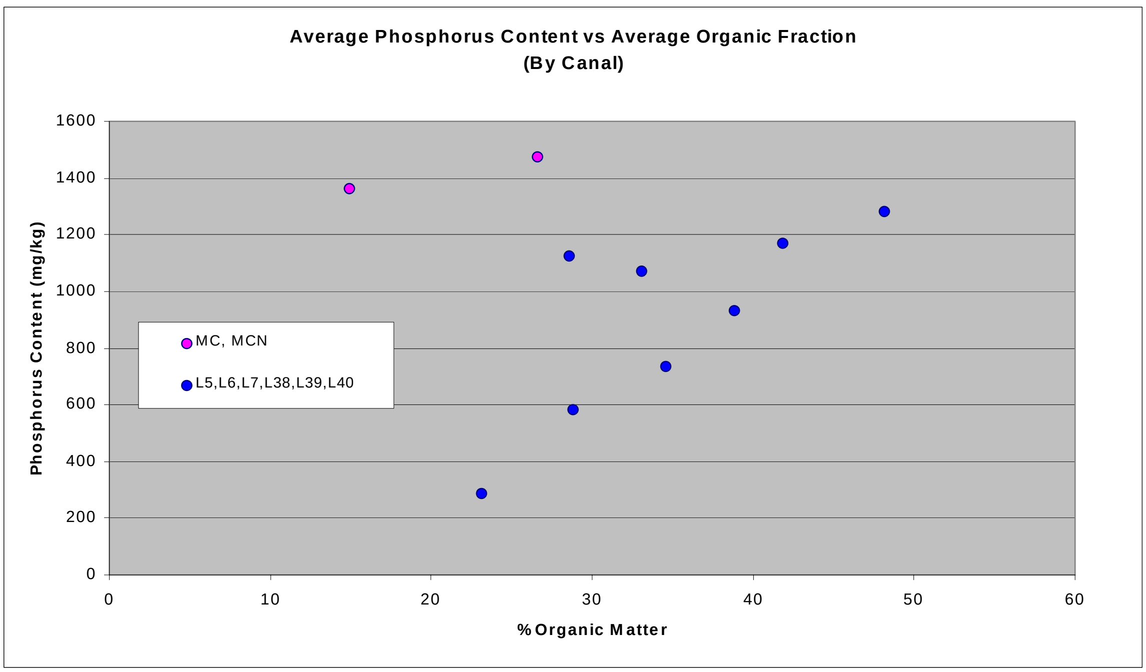


Figure 2.3 - Average Phosphorus Content vs. Average Organic Fraction by Canal

It is evident here that the Miami Canal sections exhibit different phosphorus characteristics from the other canals. Phosphorus speciation will be discussed later, but this difference is attributable to the fact that the sediments in the Miami Canal have a high fraction of phosphorus bound to inorganic compounds.

Sediment depths are quite variable, both across a given transect and longitudinally down any given canal. Not surprisingly, the deepest sediment generally tends to be near the center of the canal, while the shallowest sediment generally tends to be at the banks. Canal midpoint sediment depths varied from zero for several transects in L-38 that were bare of sediment to over ten feet at the far north end of L-7, where stagnate conditions generally prevail. Basin-wide canal sediment depths averaged about 2.65 feet. Individual canal average sediment depths are shown in Table 2.3.

There was considerable variability in sediment phosphorus content and sediment density. However, the product of sediment phosphorus content (kg P per kg dry sediment) and sediment dry density (kg dry sediment per cubic meter of sediment volume), which is the sediment phosphorus concentration (kg P per cubic meter of sediment volume) showed much less variability. In most cases the light organic matter, which tends to have high phosphorus content, also has a relatively low bulk density and dry density. Conversely, sediment that has a higher inorganic content tends to have a lower phosphorus content and higher bulk and dry density. Variation of phosphorus concentration with depth for each canal is shown in Figure 2.4. With the exception of the Miami Canal North reach, there appeared to be a relatively constant phosphorus concentration with depth.

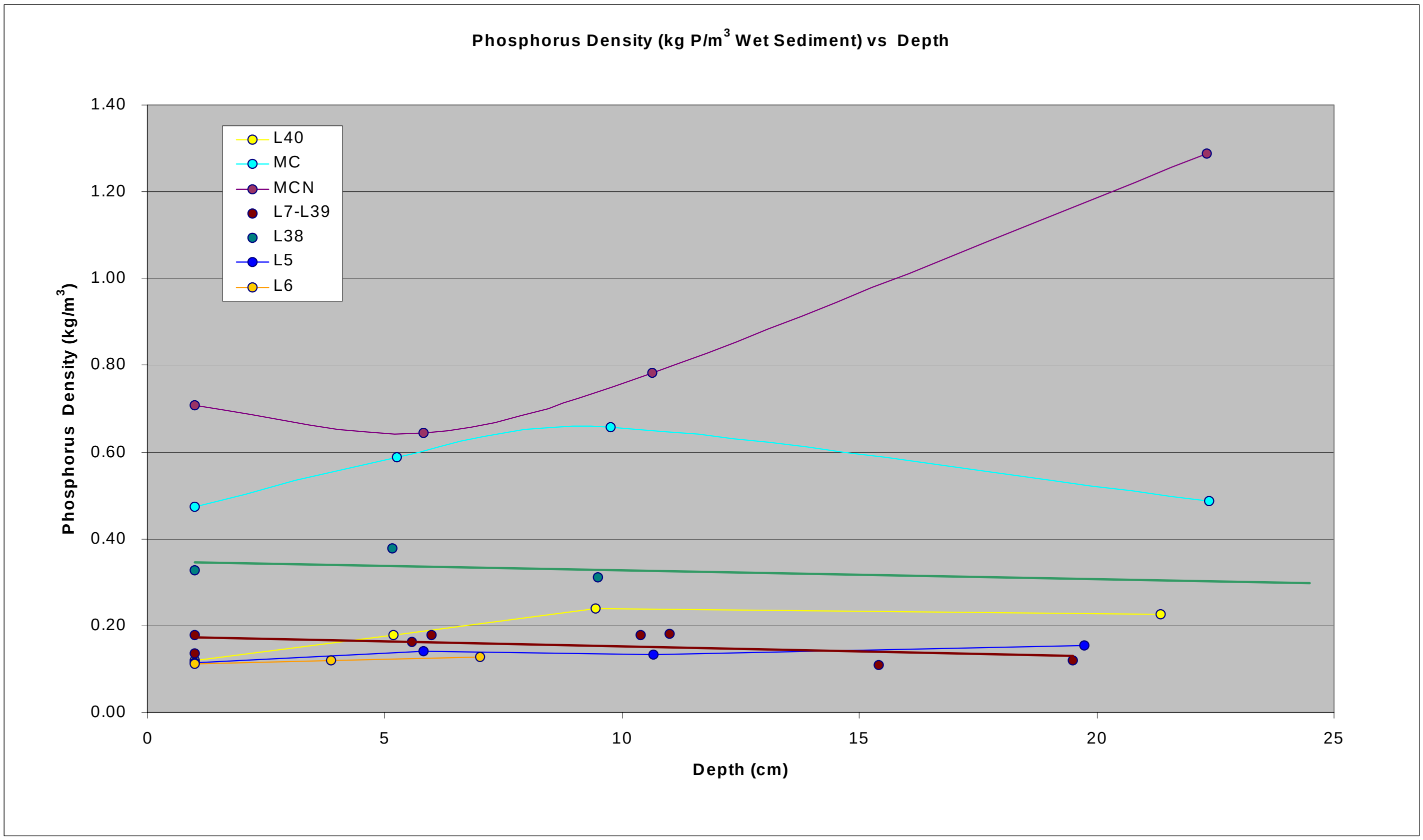


Figure 2.4 - Sediment Phosphorus Density as a Function of Depth for Various Canals

Total phosphorus mass in the canals is being reported two ways. First, the estimated phosphorus mass present *in the entire sediment column* is reported, second the estimated phosphorus mass present *in the top twelve centimeters of canal sediment* is presented. This somewhat arbitrary division is done to differentiate the phosphorus that is near the surface and potentially readily available for release from the total phosphorus mass, some of which may be buried several meters deep.

The “top twelve centimeter” calculations are based on measured values over the twelve-centimeter layer. The “entire sediment column” calculations are based on an extrapolation of the top layer data, using the data shown in Figure 2.4 for each canal to estimate the average phosphorus density throughout the whole sediment column. Table 2.3 reports the entire sediment column; table 2.4 reports the top twelve centimeters.

Table 2.3 - Average Values for Canal Sediment (Total Depth)

Canal	Transect Numbers	Avg. Sed. Depth (Ft)	Avg. Sed. Depth (m)	Avg. Width (Ft)	Avg. Width (m)	Length (Mi)	Length (m)	Canal Bed Area (m^2)	Sed. Vol (m^3)	Est. Avg. P Density kg/m^3	Est. Sed P Mass (kg)
L7S	L7-01 to L7-09	3.51	1.07	181.1	55.20	9.2	14,725	812,837	869,612	0.12	104,353
L39	L39-01 to L39-12	2.98	0.91	140.4	42.79	13.0	20,921	895,312	813,215	0.12	97,586
L40S	L40-01 to L40-24	2.48	0.76	122.7	37.40	24.9	40,073	1,498,676	1,132,855	0.23	260,557
L6	L6-01 to L6-08	1.78	0.54	136.1	41.49	7.0	11,265	467,412	252,947	0.13	32,529
L5	L5-01 to L5-05	2.70	0.82	64.0	19.51	5.5	8,851	172,666	141,967	0.15	21,820
L38	L38-01 to L38-13	2.10	0.64	82.1	25.02	13.0	20,921	523,541	335,108	0.30	100,532
MCN	MCN-01 to MCN-11	3.18	0.97	102.4	31.21	10.7	17,220	537,462	520,942	1.29	672,016
MC	MC-01 to MC-28	2.46	0.75	74.45	22.69	27.9	44,901	1,018,903	719,657	0.11	79,162
Totals						111.2	178,879	5,926,808	4,786,303		1,368,555
L7N	L7-10 to L7-16	8.04	2.45	185.7	56.60	6.8	10,863	614,865	1,506,782	0.12	180,814
L40N	L40-25 to L40-28	5.83	1.78	143.8	43.83	3.9	6,276	275,098	488,845	0.23	112,434
Totals						10.7	17,140	889,963	1,995,627		293,248

Table 2.4 - Average Values for Canal Sediment (Top 12 cm)

Canal	Transects Numbers	Avg. Width (ft)	Avg. Width (m)	Length (mi)	Length (m)	Area (m^2)	Rep. Water Depth (ft)	Rep. Water Depth (m)	Top Layer Sed. Vol (m^3)	Est. Top Sed Layer P Mass (kg)	Normalized P Mass (kg/m^2)
L7S	L7-01 to L7-09	181.1	55.2	9.2	14,725	812,837	5.3	1.6	81,284	14,654	0.0180
L39	L39-01 to L39-12	140.4	42.8	13.0	20,921	895,312	5.3	1.6	89,531	17,281	0.0193
L40	L40-01 to L40-24	122.7	37.4	24.9	40,073	1,498,676	6.8	2.1	149,868	24,866	0.0166
L6	L6-01 to L6-08	136.1	41.5	7.0	11,265	467,412	6.6	2.0	46,741	6,830	0.0146
L5	L5-01 to L5-05	64.0	19.5	5.5	8,851	172,666	8.4	2.6	17,267	2,890	0.0167
L38	L38-01 to L38-13	82.1	25.0	13.0	20,921	523,541	10.7	3.3	52,354	11,617	0.0222
MCN	MCN-01 to MCN-11	102.4	31.2	10.7	17,220	537,462	16.3	5.0	53,746	45,444	0.0846
MC	MC-01 to MC-28	74.5	22.7	27.9	44,901	1,018,903	9.5	2.9	101,890	51,744	0.0508
Totals				111.2	178,879	5,926,808			592,681	175,327	
L7N	L7-10 to L7-16	185.7	56.6	6.8	10,944	619,467	10.8	3.3	61,947	10,887	0.0176
L40N	L40-25 to L40-28	143.8	43.8	4.1	6,598	289,105	8.8	2.7	28,910	4,380	0.0151
Totals				10.9	17,542	908,572			90,857	15,266	

Table 2.3 shows that the total phosphorus mass in all the canal reaches downstream of the STA's is estimated to be in excess of 1.3 million kg. The total phosphorus mass upstream of the STA's is estimated to be on the order of an additional 290 thousand kg. Table 2.4 is perhaps more relevant. It shows that the top-12-cm.-layer phosphorus mass in all the canal reaches downstream of the STA's is estimated to be in excess of 175,000 kg., with an additional 15,000 kg upstream of the STA's. The top layer phosphorus mass is normalized by the canal sediment surface area in the last column of Table 2.4 to eliminate the effect of canal length and width. This is shown in Figure 2.5.

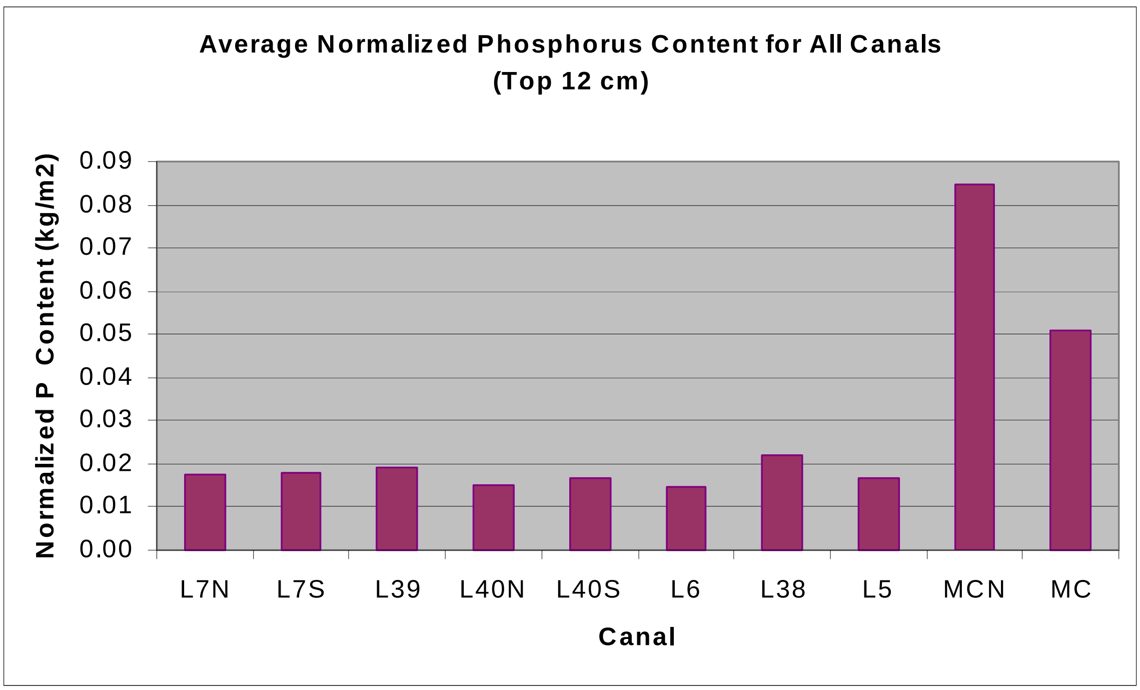
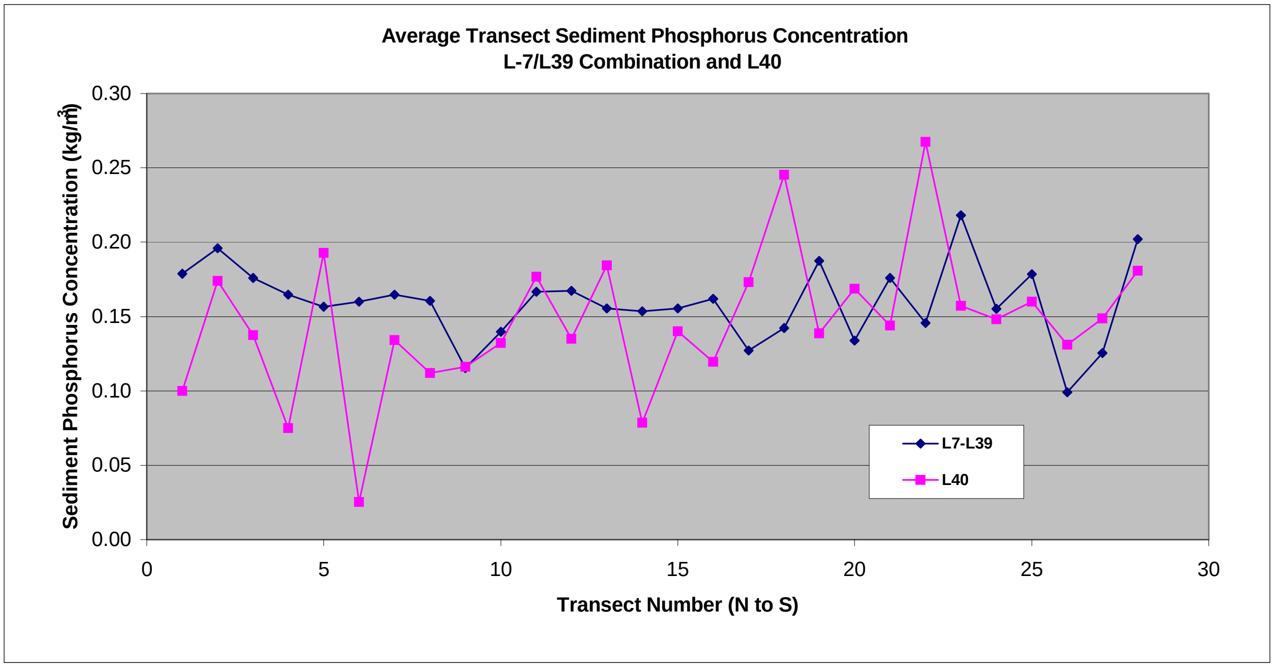
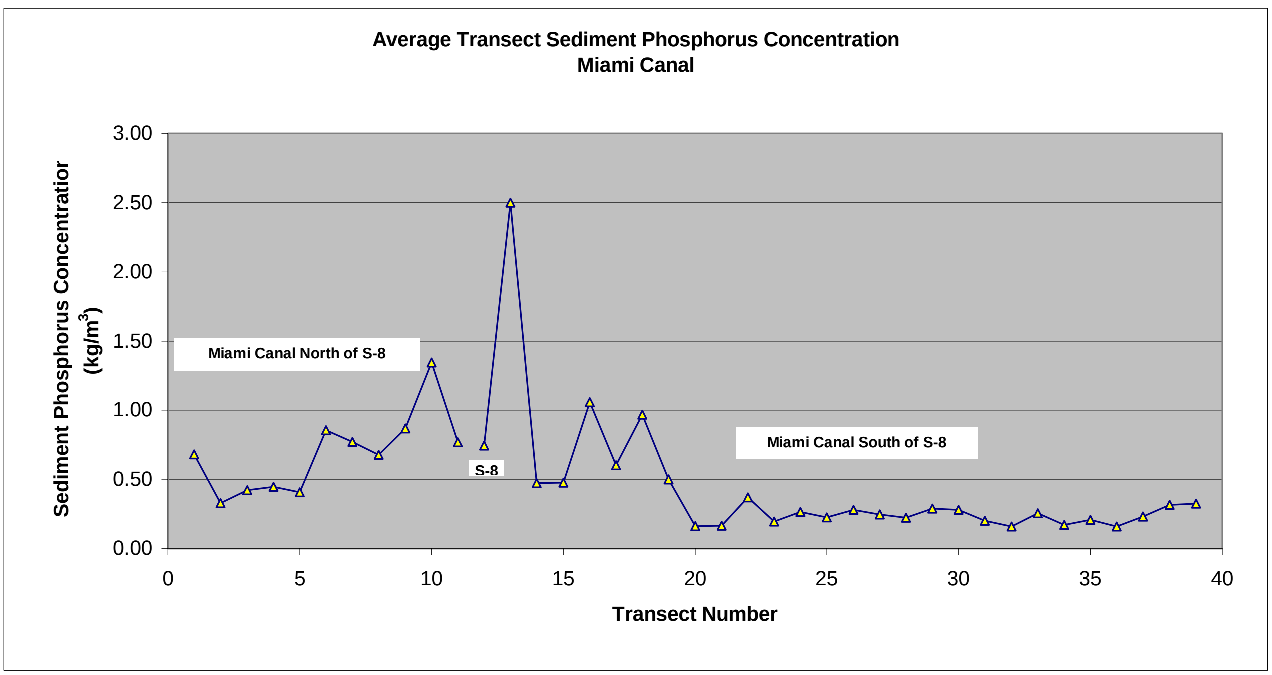


Figure 2.5 – Normalized Phosphorus Content (Top 12 cm Layer) for All Canals

The results illustrated in Figure 2.4 indicate that the canals in the eastern part of the WCA's have roughly similar top layer phosphorus content, while the top layer phosphorus content of the Miami Canal is much higher, presumably because of the high mineral content of the Miami Canal sediments.

The longer canals showed interesting longitudinal variation of phosphorus concentration. Figure 2.6a shows the profiles for the combined L7S-L39 reach and for the L-40S reach; Figure 2.6b shows the profile for the entire Miami Canal reach both north and south of S-8. Both the L7-L39 combination and L-40 show apparent periodic fluctuations of phosphorus concentration. The fluctuations are most apparent in the southern portion of L7-L39, and appear over the entire length of L40.





Figures 2.6a and b – Wet Sediment Phosphorous Concentration

These profiles may coincide with regions of organic material concentration arising from locally high populations of floating macrophytes that often form bridges across the canals.

The shape of the Miami Canal profile shows the impact of the dense high phosphorus, high inorganic-content matter that is present in the Miami Canal section north of S-8 and apparently is carried over to the upper section of the canal south of S-8.

Results Summary – Sediment Phosphorus Fractionation and Flux

Phosphorus Fractionation

The fractionation of the canal cores is treated in some detail in the WBL report in Attachment 2A (Clark and Reddy, 2002). A summary of phosphorus types is contained in that report and is reproduced here as Figure 2.7. In Figure 2.7, "NaOH-Pi" represents the *inorganic* fraction extractable by sodium hydroxide, which corresponds to phosphorus bound by iron and aluminum, "NaOH-Po" represents the *organic* fraction extractable by sodium hydroxide, which corresponds to phosphorus associated with humic and fulvic acids, "HCl-Pi" represents phosphorus that is extractable by hydrochloric acid, which corresponds to phosphorus bound by inorganic carbonates, and "Recalcitrant-P" represents phosphorus not extractable by any of these methods. Recalcitrant-P is stated in the report to represent a stable pool of phosphorus, however it should be noted that the organic fraction of the Recalcitrant -P may supply phosphorus over time arising from biological conversion or mineralization.

The canal fractions are grouped by upstream STA (current or eventual). If the phosphorus fractions are further consolidated to NaOH soluble (relatively available) and HCl/ Recalcitrant (relatively unavailable), the canals show an interesting breakdown of relatively available with geography. L40S (STA 1E) sediment has 35% relatively available phosphorus, L7/L39 (STA 1W) sediment has 19%, L6/L38/L5 (STA's 2, 3, and 4) sediment has 18%, and the Miami Canal sediment (STA's 5 and 6) has 12%. There appears to be a decline in available phosphorus moving from east to west through the WCA's.

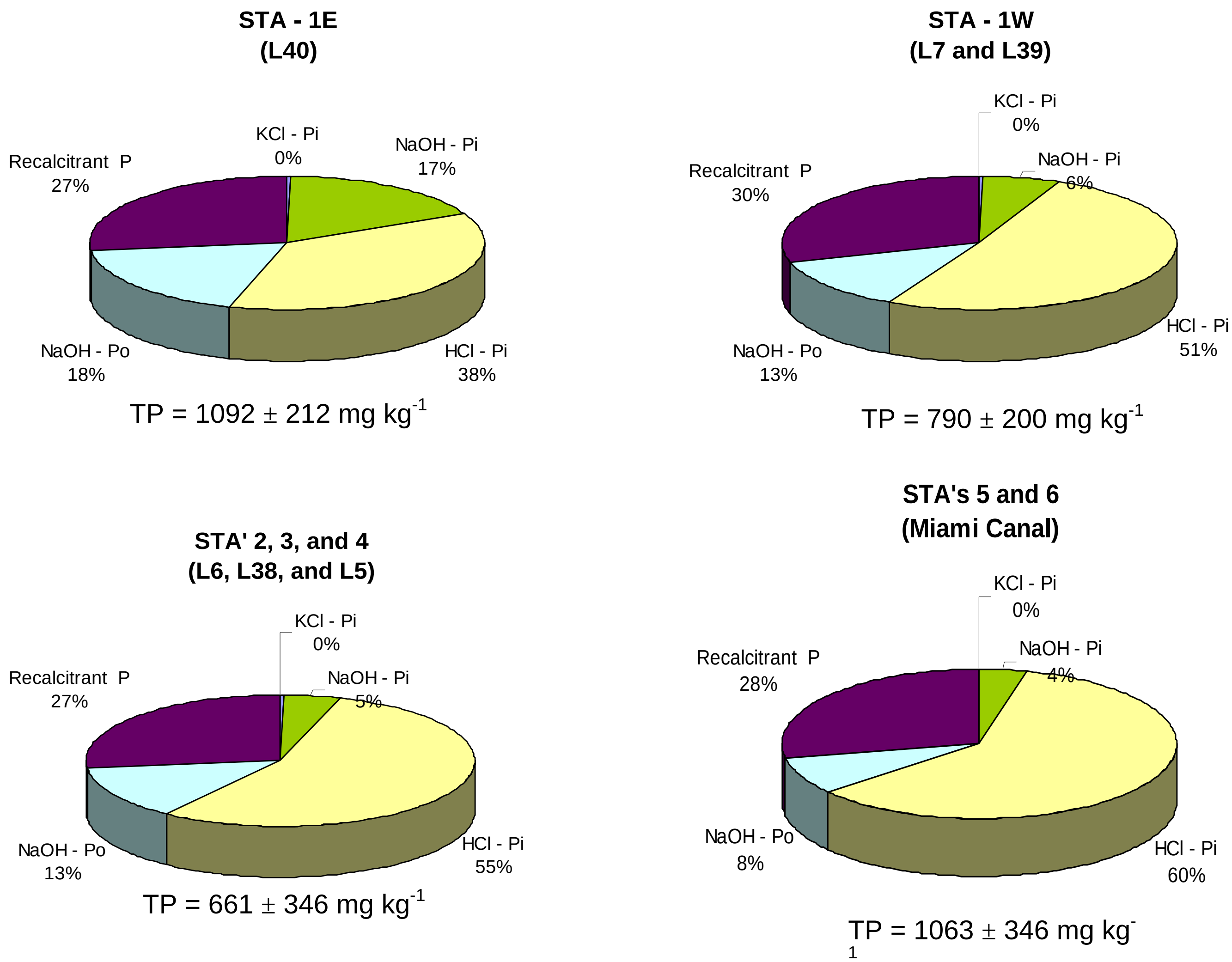


Figure 2.7 – Phosphorus in Canal Sediments Based on Extraction Sequence

Revising the phosphorus mass shown in Table 2.4 to include only relatively available phosphorus gives an estimate of 30,300 kg of relatively available phosphorus in the top 12 cm layer of the active canals, and 3600 kg of relatively available phosphorus in the top 12 cm layer of the upstream reaches of L7 and L40.

Phosphorus Flux

Attachment 2A details the methodology and results of the phosphorus flux studies. A brief summary is presented here to expedite discussion. Two sets of core samples were taken. The first set, from twenty different transect locations, was taken in June of 2001. The second set was an abbreviated group taken from five of the twenty original sites in April of 2002. Triplicate sediment core samples from the transect locations were transported to the Gainesville laboratory, where the overlying sampled water column was carefully replaced with low-phosphorus floodwater obtained from the Everglades Nutrient Removal project effluent (Cell 4, STA 1-W) and held at controlled conditions. The overlying water was then sampled periodically and analyzed for phosphorus species. The sampled water volume was replaced with an equal volume of low-phosphorus makeup water. After thirty days the floodwater was removed and replaced with fresh low-phosphorus floodwater. This cycle was extended through three more sixty-day exchanges, over an elapsed time period of about 210 days. Phosphorus flux was calculated from an analysis of the change in phosphorus content of the floodwater (corrected for phosphorus removed by sampling) over time for each floodwater exchange.

To facilitate an order-of-magnitude evaluation, two methods were used to estimate phosphorus flux. Floodwater in the test columns was replaced every 30 or 60 days, depending on how long the test had been running. Method 1 consisted of taking the <u>maximum flux</u> observed during each floodwater exchange cycle and assuming that represented the release rate per unit area available early on in the contact of the sediment with the low-phosphorus floodwater, when the driving force for diffusion would be greatest. Method 2 consisted of dividing the total phosphorus mass accumulation in the floodwater column over the floodwater period by the column area and the period duration. This was called the average flux.

These two methods were felt appropriate to bracket the most probable slopes of the flux curves. They also have a physical interpretation. The maximum flux may be said to represent the rate of release of dissolved phosphorus by fresh sediment when initially exposed to a low-phosphorus water column. The maximum flux might be expected to be sustainable for a matter of several (2-5) days. The average flux may be said to represent the rate of release of dissolved phosphorus by fresh sediment when exposed to a low-phosphorus water column for an extended period. This flux might be expected to be sustainable for a matter of weeks or months.

Figure 2.8 shows the mean “Maximum Flux” for the June 2001 sample sets by canal group, Figure 2.9 shows the mean “Average Flux” for the June 2001 sample sets by canal group. The maximum fluxes are roughly one order of magnitude higher than the average fluxes.

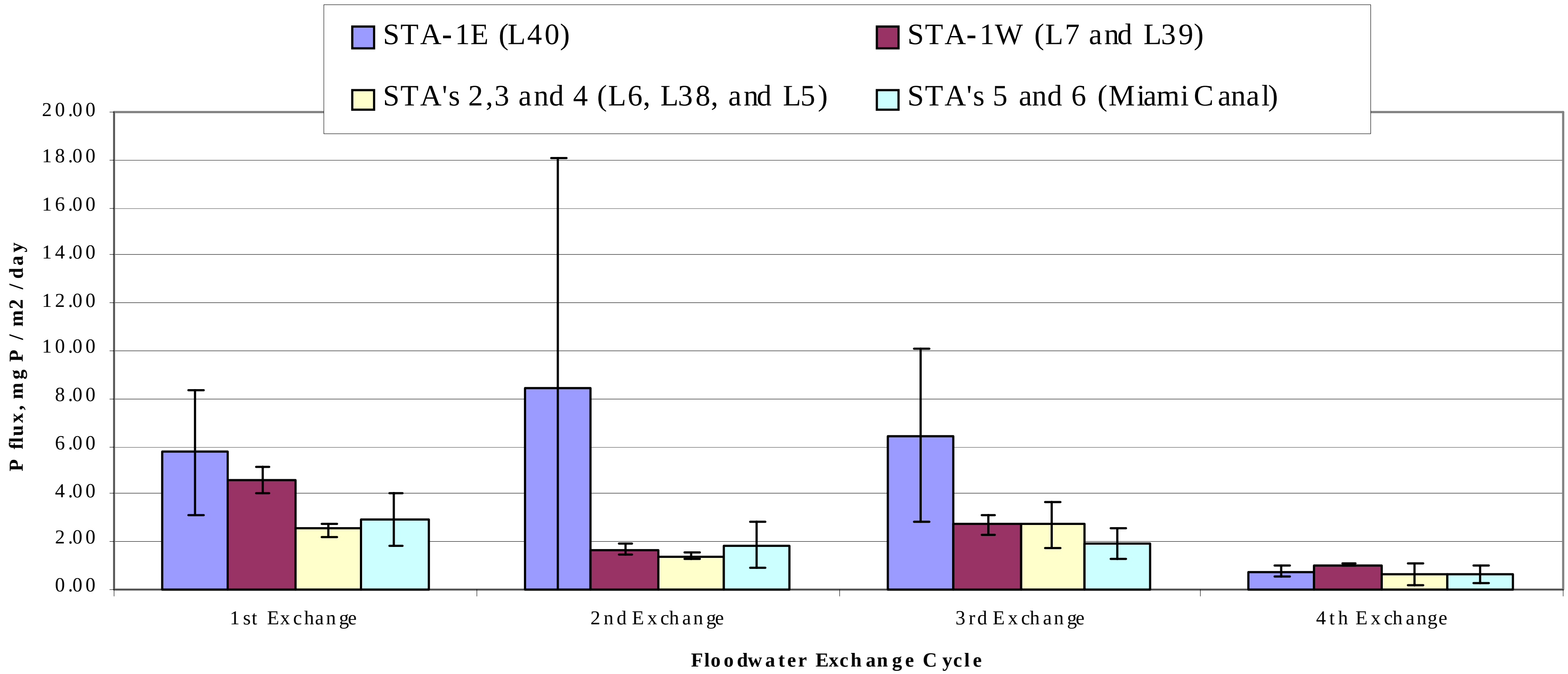


Figure 2.8 – Maximum Flux Rates from Canal Sediments

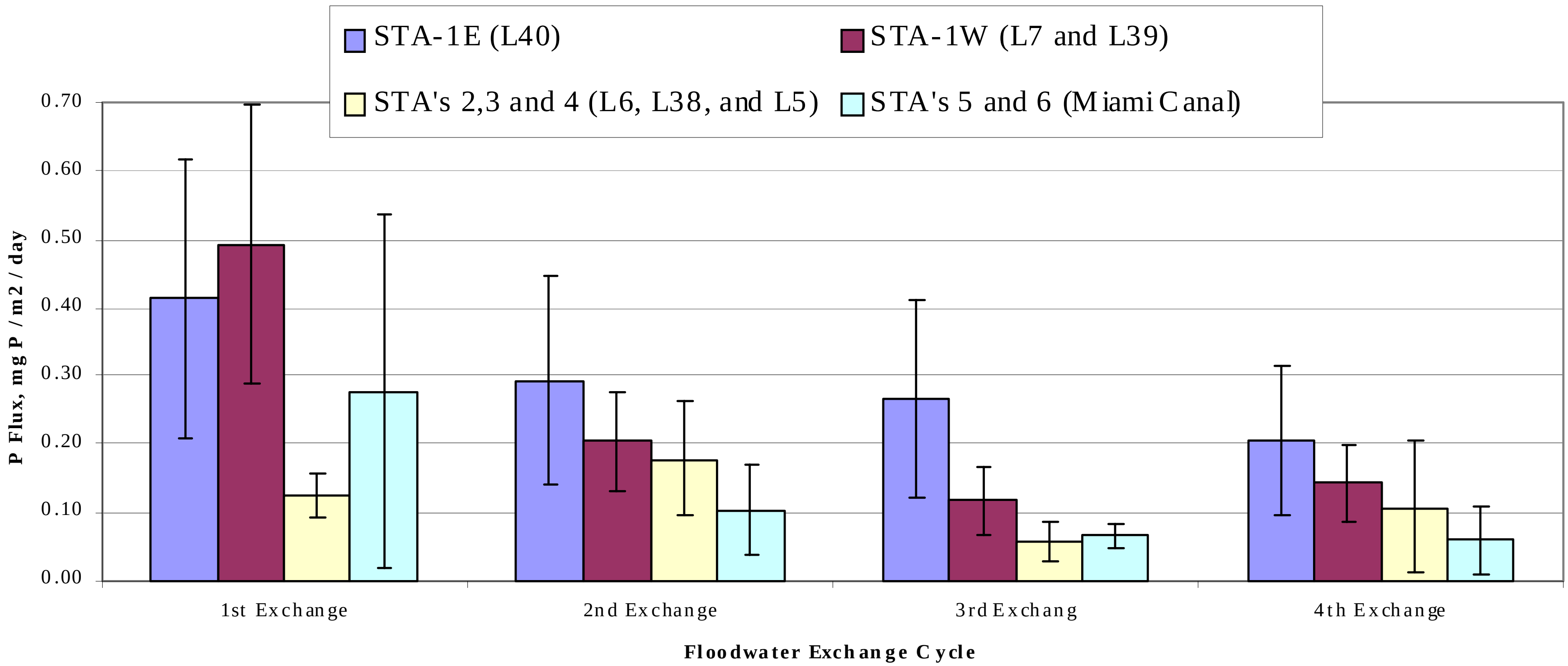


Figure 2.9 – Average Flux Rates from Canal Sediments

The information shown in Figure 2.7 may be combined with the information shown in Figures 2.8 and 2.9 to evaluate the potential relationship of phosphorus flux with phosphorus speciation. Figure 2.10 shows the correlation between the fraction of the sediment that is NaOH extractable (relatively available) and the composite flux rates for the four set groupings shown in Figures 2.7-2.9.

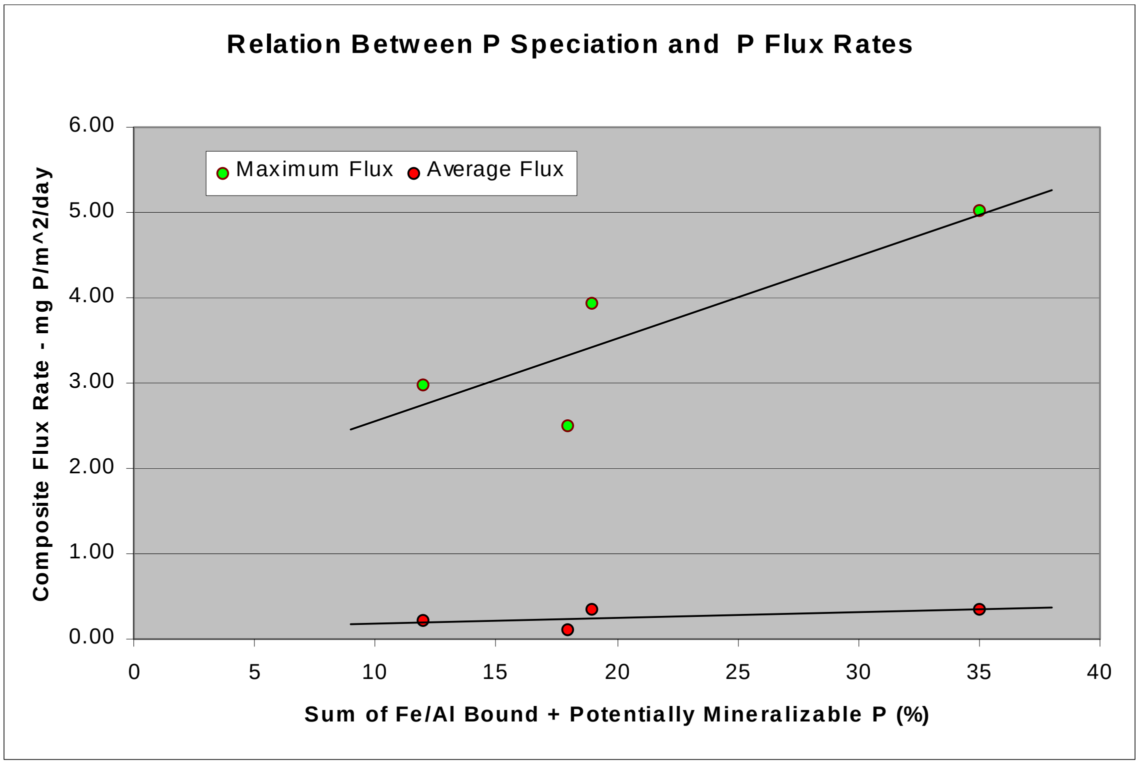


Figure 2.10 – P Speciation and P Flux

This illustration implies a direct relationship between the fraction of relatively available phosphorus present in the sediment and both the maximum and average flux rates observed in the release studies. This information may be useful in future studies to obtain a rapid estimate of the release potential of sediments by chemical extraction and phosphorus speciation.

The maximum fluxes from the first floodwater cycle were used to estimate the upper limit of the potential impact of sediment phosphorus release on the concentration of overlying floodwater in the WCA canals. The estimation process is simple but illustrative. It is assumed that the canals contain water at an SRP concentration equivalent to that prevalent in the flux tests (5-8 ppb), and that the water depth in the canals is similar to that observed during the canal measurement periods (April-August, 2001). The sediment projected area is calculated from the average canal width times the length and multiplied by the flux to get an estimated daily phosphorus mass flow from sediment into overlying water. The water volume in the canal is estimated from the average depth times the area, and then divided into the daily phosphorus mass flow to get an estimated change in floodwater phosphorus concentration over a twenty-four hour period. This assumes that the water is motionless over the sediment. If the water were moving, an estimate of the concentration increase under flow conditions can be obtained by prorating the 24-hour value by the residence time in the canal.

Table 2.5 shows the results of these hypothetical calculations. The results using the average flux yield 24-hour concentration elevations ranging from 0.04 to 0.20 ppb/day. The results using the maximum fluxes are more interesting. Estimates of 24-hour elevation on the order of 1.4-2.9 ppb/day were obtained for the eastern canals, L7, L39, and L40 (STA's 1-E and 1-W). An estimate of 1.0 ppb/day was obtained for L6 (STA 2). L5 and L38 yielded estimates in the range of 0.7-0.9 ppb/day, and the Miami Canal showed an estimate in the range of 0.6-1.2 ppb/day.

Table 2.5 – Hypothetical 24-hour Phosphorus Concentration Increases in Various Canals Using Maximum and Average Flux Calculation Methods

Canal	Length (m)	Sediment Area (m^2)	Rep. Water Depth (m)	Rep. Water Vol. (m^3)	Method 1 Maximum (kg/m^2-day)	Method 1 Daily P Mass Flow (kg)	Method 1 Nominal 24 hr. P Delta C (ppb)	Method 2 Avg. Flux (kg/m^2-day)	Method 2 Daily P Mass Flow (kg)	Method 2 Nominal 24 hr. P Delta C (ppb)
L7S	14,725	812,820	2.48	2,015,794	4.20E-06	3.41	**1.69**	5.00E-07	0.41	**0.20**
L39	20,921	988,308	2.93	2,895,743	4.20E-06	4.15	**1.43**	5.00E-07	0.49	**0.17**
L40S	40,073	1,498,329	2.02	3,026,626	5.90E-06	8.84	**2.92**	4.10E-07	0.61	**0.20**
L6	11,265	467,272	2.02	943,890	2.20E-06	1.03	**1.09**	1.20E-07	0.06	**0.06**
L5	8,851	172,595	2.55	440,116	2.20E-06	0.38	**0.86**	1.20E-07	0.02	**0.05**
L38	20,921	523,234	3.28	1,716,208	2.20E-06	1.15	**0.67**	1.20E-07	0.06	**0.04**
MCN	17,220	537,264	4.96	2,664,829	2.80E-06	1.50	**0.56**	2.80E-07	0.15	**0.06**
MC	44,901	977,120	2.42	2,361,647	2.80E-06	2.74	**1.16**	2.80E-07	0.27	**0.12**

Potential Impact of Flux on Water Column Phosphorus Under Flow Conditions

To conduct flow scenario analyses, estimates were made for the L7/L39 canal system (STA 1-W) and the Miami Canal (STA's 5 and 6) for multiple flow scenarios assuming that water with phosphorus concentration of 5-8 ppb was being released from the STA's. An example of the estimation procedure follows.

After startup in 2000, the maximum sustained 14-day flow from STA-1W averaged 710 ft^3/s ($20.1 m^3/s$) over the period 10/3/00-10/16/00. During the year 2001, when large releases were being made to the WCA's, the maximum sustained 14-day flow averaged 1790 ft^3/s ($50.7 m^3/s$) over the period 7/27/01-8/9/01.

The L7 and the L39 canal channels had almost identical wetted average crossectional areas (136.9 m^2 and 138.4 m^2, respectively) so dividing the discharge rate by the average of 137.6 m^2 allows a representative canal velocity to be calculated. If it is assumed that the average distance the water travels in the canal before it is discharged into the WCA is all of L7 and half of L39, the transit length is about 25.2 km (15.7 miles). Dividing this distance by the representative canal velocity gives a representative residence time. Multiplying this time by the average hypothetical maximum 24-hr concentration increase of about 1.56 ppb/day for L7 and L39 gives the hypothetical total concentration increase for an average packet of sub-10-ppb water by the time it reaches the WCA. This process is shown in Table 2.6.

Table 2.6 – Hypothetical Concentration Increase for Discharge from STA-1W

Discharge Rate (m^3/s)	Average Velocity (m/s)	Residence Time (days)	Total P Concentration Increase (ppb)
20.1	0.146	2.00	3.1
50.7	0.368	0.79	1.2

This example calculation indicates that the lower discharge rate could have resulted in an elevation of 3.1 ppb before entry into the WCA's, while the higher discharge rate could have resulted in an elevation of 1.2 ppb.

These example calculations for STA 1-W were based on the maximum sustained 14-day flows observed in 2000 and 2001. It is also instructive to evaluate the potential phosphorus elevation that might occur over shorter time periods at more typical flows. This is done here for the L7/L39 system (STA 1-W) and the Miami Canal System (STA 5 and 6). A historical flow analysis was conducted where the daily average flows in each canal were ranked over the two-year period from July 2000 to July 2002 to obtain a percentile distribution of flows. This is shown in Figure 2.11.

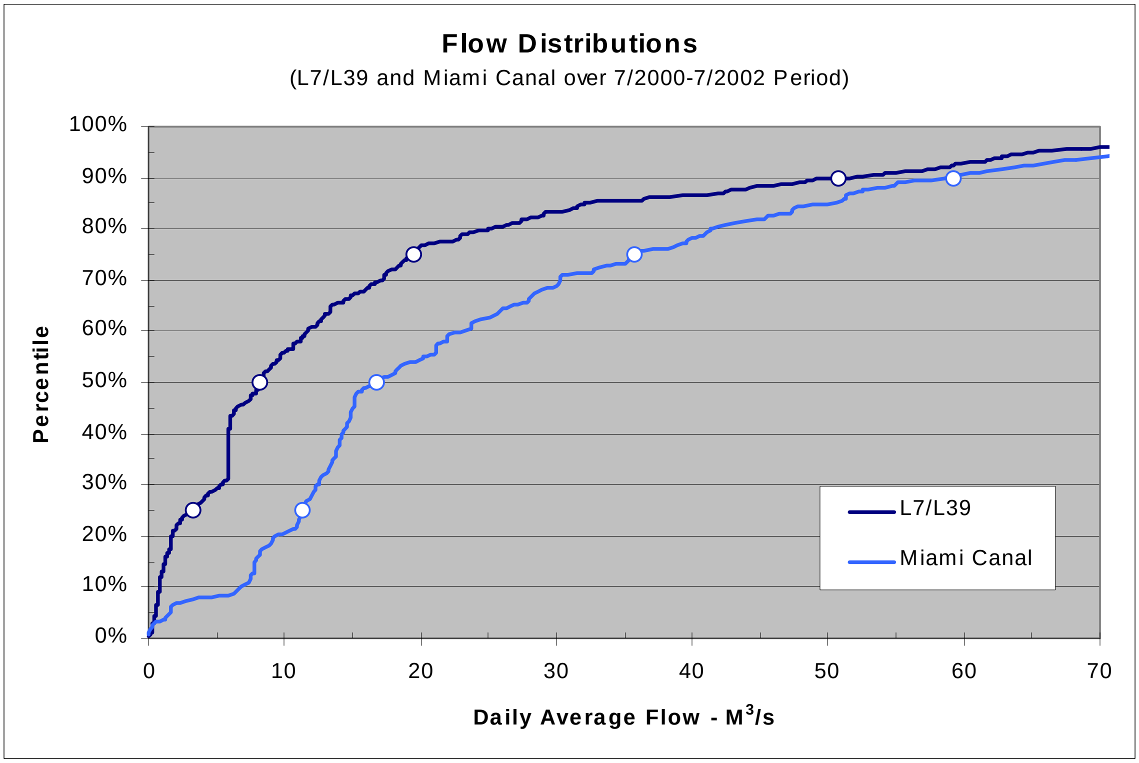


Figure 2.11 – Flow distributions for L7/L39 and the Miami Canal

The flows corresponding to the 25th, 50th, 75th, and 90th percentile were selected for the example calculations. It was assumed that the canal depth was the average of that observed during flow periods for both canals.

The same procedure illustrated above was used to estimate the potential elevation of dissolved phosphorus in each canal at the various flows. The residence time in the L7/L39 system was estimated using the distance of 25.2 km noted in the example. The residence time in the Miami Canal was estimated using the distance of 45 km from S-8 to S-151 (28 miles). The calculation results for the selected flows are shown for L7/L39 in Figure 2.12 and for the Miami Canal in Figure 2.13.

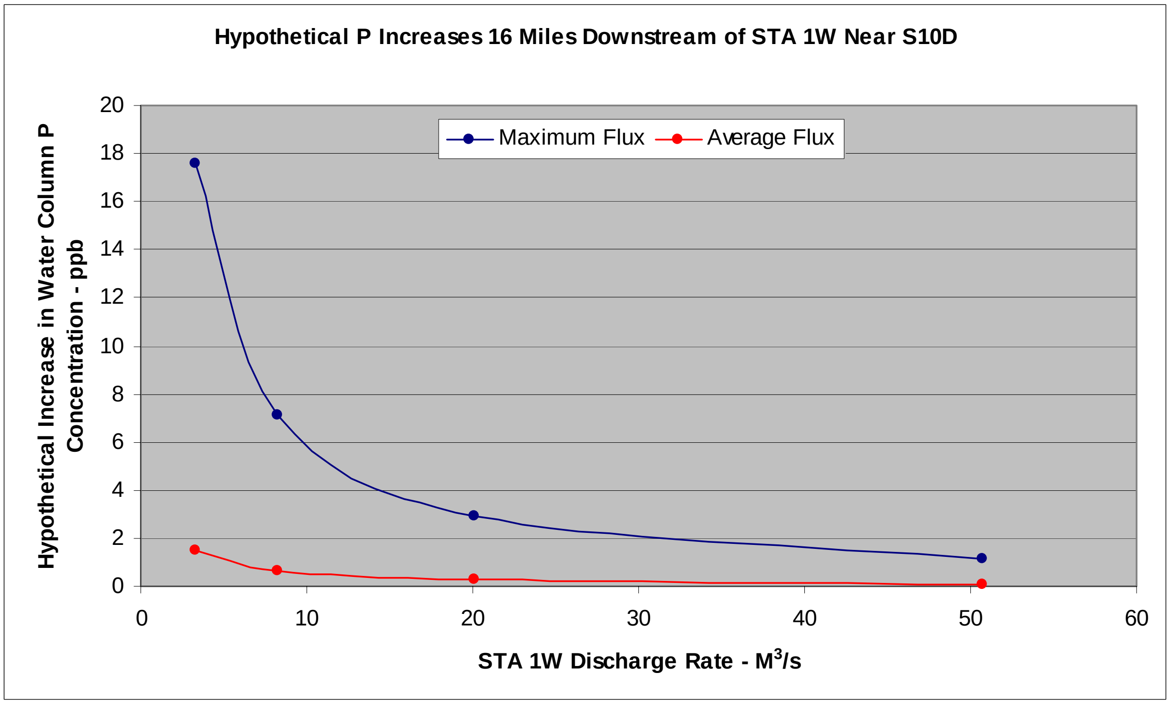


Figure 2.12 – Hypothetical Dissolved Phosphorus increase for the L7/L39 Canal System

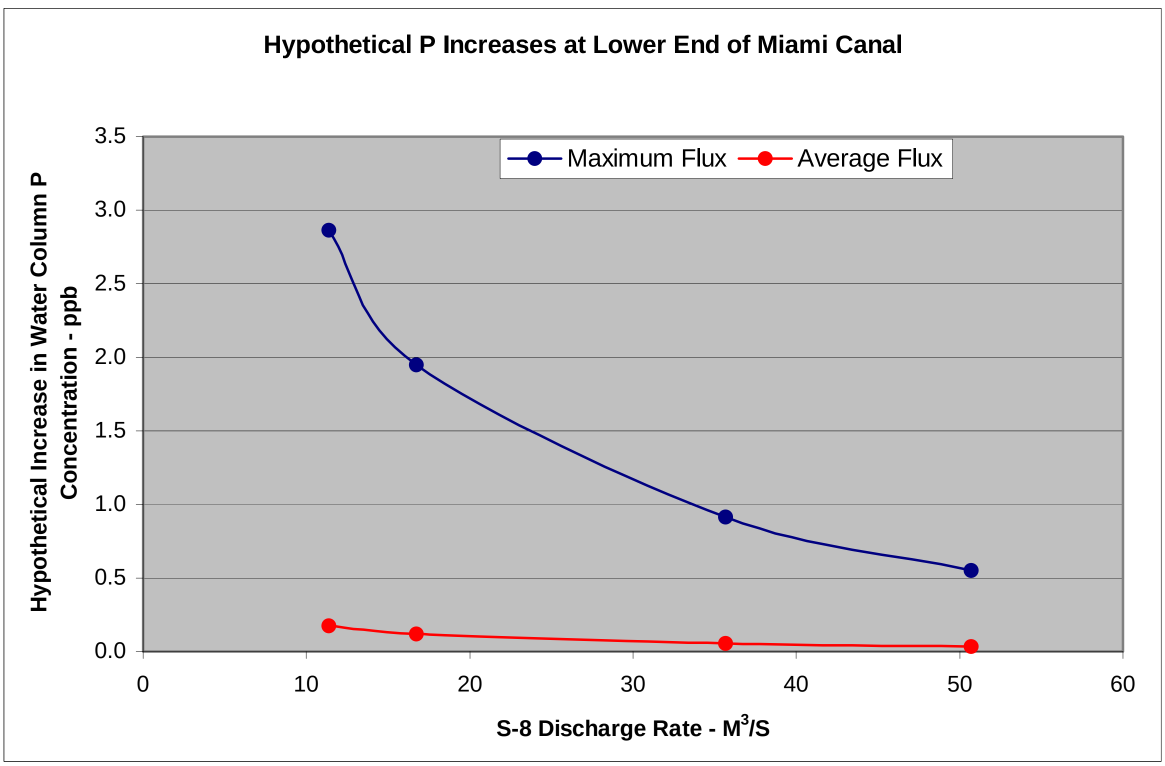


Figure 2.13 – Hypothetical Dissolved Phosphorus increase for the Miami Canal System

Figure 2.12 shows that the calculated hypothetical increase in dissolved phosphorus in the L7/L39 system was in the range of 7-18 ppb for daily average flow rates in the 25-50th percentile using the maximum flux, and in the range of 1-2 ppb for the same conditions using the average flux.

Figure 2.13 shows that for the Miami Canal the calculated hypothetical increase in dissolved phosphorus was the range of 2-3 ppb for daily average flow rates in the 25-50th percentile using the maximum flux, and in the range of 0.1-0.2 ppb for the same conditions using the average flux.

The reasons for the difference between the L7/L39 and Miami Canal results are multiple. First, the L7/L39 sediment phosphorus flux rates were higher than those of the Miami Canal sediments, so a given sediment area in L7/L39 contributes more phosphorus flux than in the Miami Canal. Second, the L7/L39 system has a higher sediment-area to water-volume ratio than the Miami Canal, so a given water volume in L7/L39 is exposed to a larger sediment area than in the Miami Canal. Third, for any given percentile flow the residence time in the Miami Canal is less than the residence time in the L7/L39 system, so a volume element of water moving through the canal is in contact with the canal sediment longer in L7/L39 than in the Miami Canal. The combination of these three factors produces the four to six fold differences between the two canal analyses.

Clearly the calculations based on maximum flux gave results of more significance than the calculations based on average flux. The maximum flux is sustainable for a matter of days, while the average flux represents the contribution to the water column for a matter of weeks. This emphasizes the transient nature of the phenomena being evaluated and raises the caution that these evaluations based on flow conditions must be considered to apply to short time frames only.

Potential Impact of Flux on Water Column Phosphorus Under Stagnate Conditions

It is also worthwhile to evaluate phosphorus flux to stagnate water residing in the canals between STA discharge periods. The “average flux” reported for the flux studies is based on a direct measure of the phosphorus flux over 30-60 day periods, and should be representative of long term phosphorus diffusion rates from the sediments under study. For this evaluation, the average flux for the L7/L39 combination of 0.5×10^{-6} kg/m^2/day over a 30-day period would give a phosphorus mass flow into the overlying water column of 15 mg. At a representative average depth of 2.7m the volume of water over a unit area of one meter would be 2700 liters, giving a hypothetical concentration increase of 15mg/2700 liters or 5.6 ppb.

This example calculation indicates that, in the absence of any biological or chemical reactions, the water column starting at 10 ppb could possibly increase by 50% in phosphorus concentration over a one-month stagnation period. This water would be displaced to the WCA's upon startup of discharge from the STA's.

The average total phosphorus discharge from the L7/L39 sediment cores was about 28 mg/m^2 over the first 210 days of study. This gives an upper limit to the amount of phosphorus available for concentration elevation of the overlying water. At a maximum flux rate of 4.2 mg/m^2/day (see Table 2.5) the flux could be sustained for a maximum of about 6.7 days. At an average flux rate of 0.5 mg/m^2/day the flux could be sustained for a maximum of about 56 days.

Temporal Variations in Sediment Phosphorus Flux

In April 2002, ten months after the first set of sediment flux samples were taken, a second abbreviated set was taken from five of the original twenty locations to check flux measurements. Phosphorus flux was measured over two thirty-day floodwater exchanges. Because of the limited nature of the study no sediment analyses were conducted. The maximum and average fluxes measured for the first floodwater exchange at each of the five locations for 2001 and 2002 are shown in Table 2.7.

Table 2.7 – 2001 and 2002 Phosphorus Fluxes at Selected Locations

Location	2001 Max. Flux (mg P/m^2/day)	2002 Max. Flux (mg P/m^2/day)	2001 Avg. Flux (mg P/m^2/day)	2002 Avg. Flux (mg P/m^2/day)
L7-C26	4.07	0.41	0.396	0.013
L39-C25	5.30	0.27	0.776	0.005
L40-C24	2.38	0.37	0.132	0.004
L38-C6	2.94	4.29	0.138	0.152
MC-C2	4.44	0.68	0.643	0.005

There was a significant reduction in both maximum and average flux rates from 2001 to 2002 for four of the five locations. The maximum flux observed at four of the five locations decreased by about an order of magnitude, the average flux decreased almost two orders of magnitude. The single exception was location L38-C6, which showed increases in both maximum and average flux from 2001 to 2002. The maximum flux results are shown graphically in Figure 2.14.

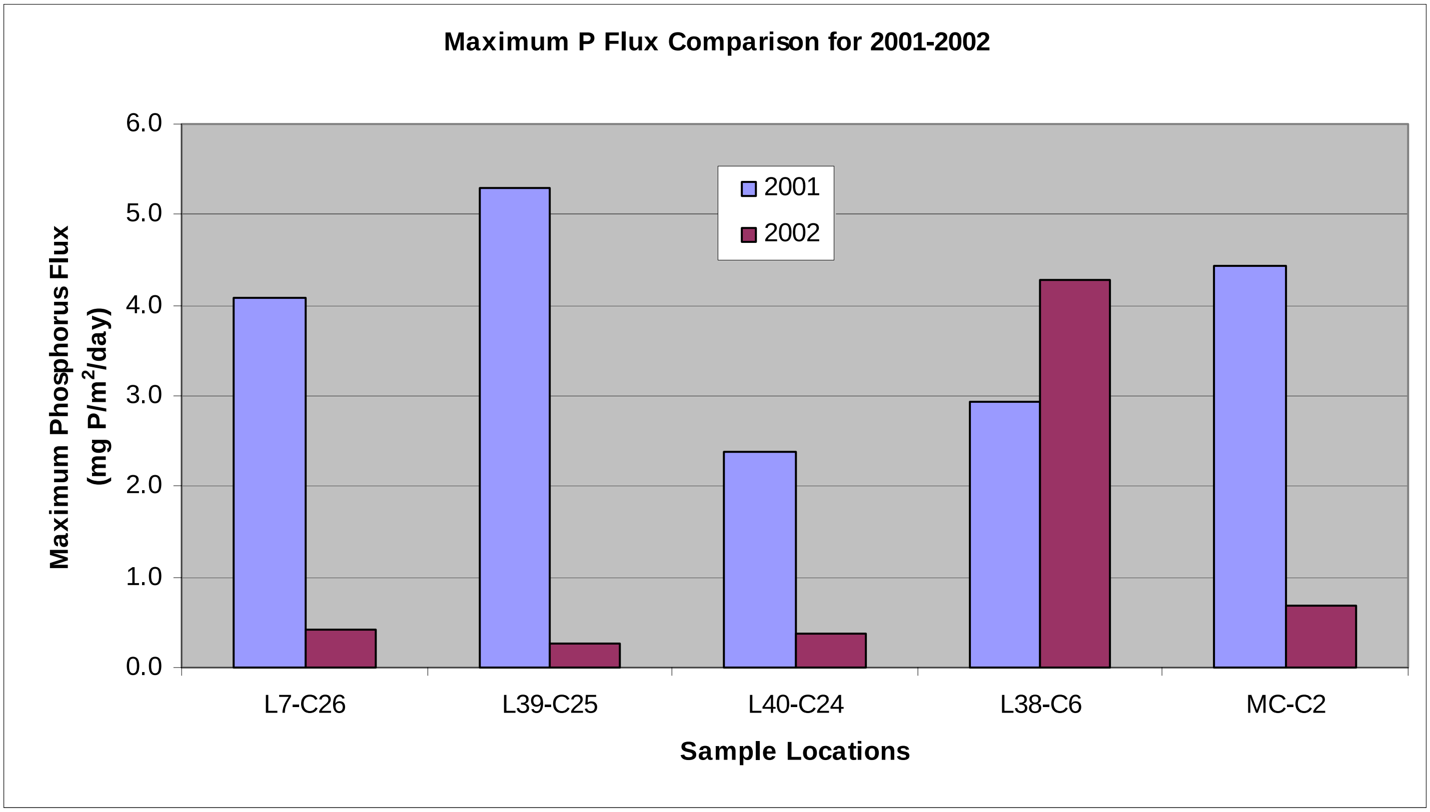


Figure 2.14 – Maximum P Flux Comparison for 2001-2002 Samples

These results indicated a strong temporal change in the phosphorus availability from the sediments over a ten-month period. An indication of why this dramatic change took place might be found by examining the flow history in the canals from which these samples were taken. The L7 and L39 canals receive flow from STA 1-W. The L40 canal does not normally receive flow directly from STA I-W, but it may be influenced by cross flow from the L7/L39 system. The L38 canal receives flow directly from the S-7 structure, and the Miami Canal receives flow directly from the S-8 structure.

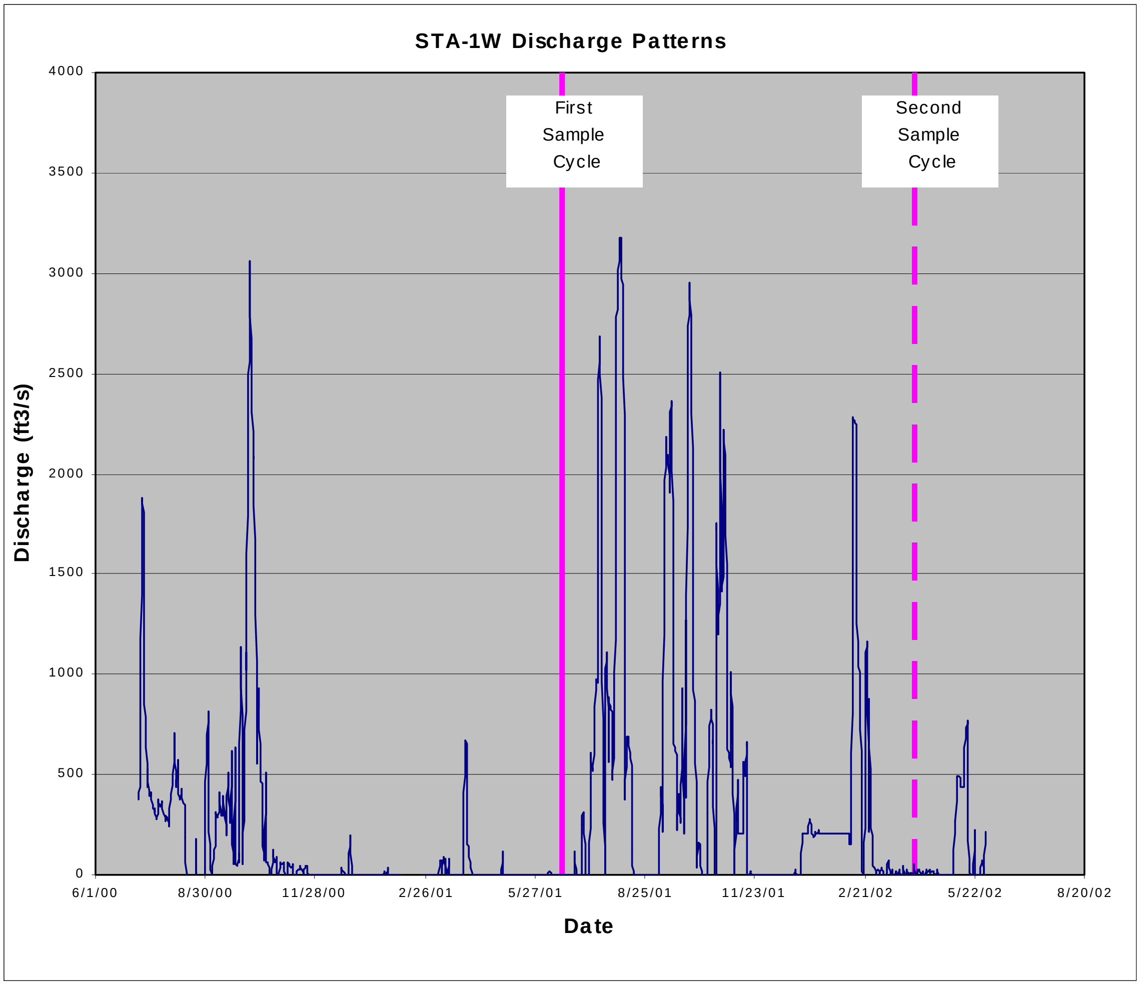


Figure 2.15 – STA 1-W Flow History for 7/00 through 5/02

Figure 2.15 shows the flow history from STA 1-W from July 2000 through May 2002. Also shown in this figure is the time when the two sets of samples were taken. The first sample set, taken in June 2001, was preceded by a dry season during which there was relatively little discharge from STA 1-W. The total flow from STA 1-W for the three months prior to the sampling of the first set was about 4.7 million cubic meters. By contrast, during the dry season of 2002 there was considerably more water discharged from STA 1-W. The total flow from STA 1-W for the three months prior to the sampling of the second set was about 61.5 million cubic meters, a thirteen-fold increase over the flow prior to the first set.

It is hypothesized that the modest flows prior to the first sampling allowed phosphorus-containing material deposited by biological activity to accumulate in the canal sediment, while the more substantial flows prior to the second sampling mobilized the readily transportable material and swept this material downstream into the WCA's. The same flow pattern that was seen from STA 1-W was seen at structure S-8, which feeds the Miami Canal. Figure 2.16 shows the flow pattern for S-8 over the same period.

Figure 2.16 – S-8 (Miami Canal) Flow History for 7/00 through 5/02

Here also the flow to the canal was low prior to the first sampling, 0.15 million m^3 for the three months prior to the first sampling. The flow in the three months prior to the second sampling was 18.7 million m^3, or more than two orders of magnitude greater than the first period.

The one sample of the five that showed an increase in flux rates was from L38, the North New River Canal. The S-7 structure that feeds this canal operated differently from STA 1-W and S-8. Like the other structures, this structure contains gated spillways that can allow back flow to occur in the upstream direction when water transfer in that direction is necessary. Unlike the other structures, the gates in S-7 were used for this purpose frequently during the study period. Figure 2.17 shows the flow pattern for the S-7 structure over the period of interest. Positive values of flow indicate downstream pumping from S-7 into L38. Negative values indicate the use of the S-7 spillways to move water *upstream* in L38 from the WCA's back into the EAA.

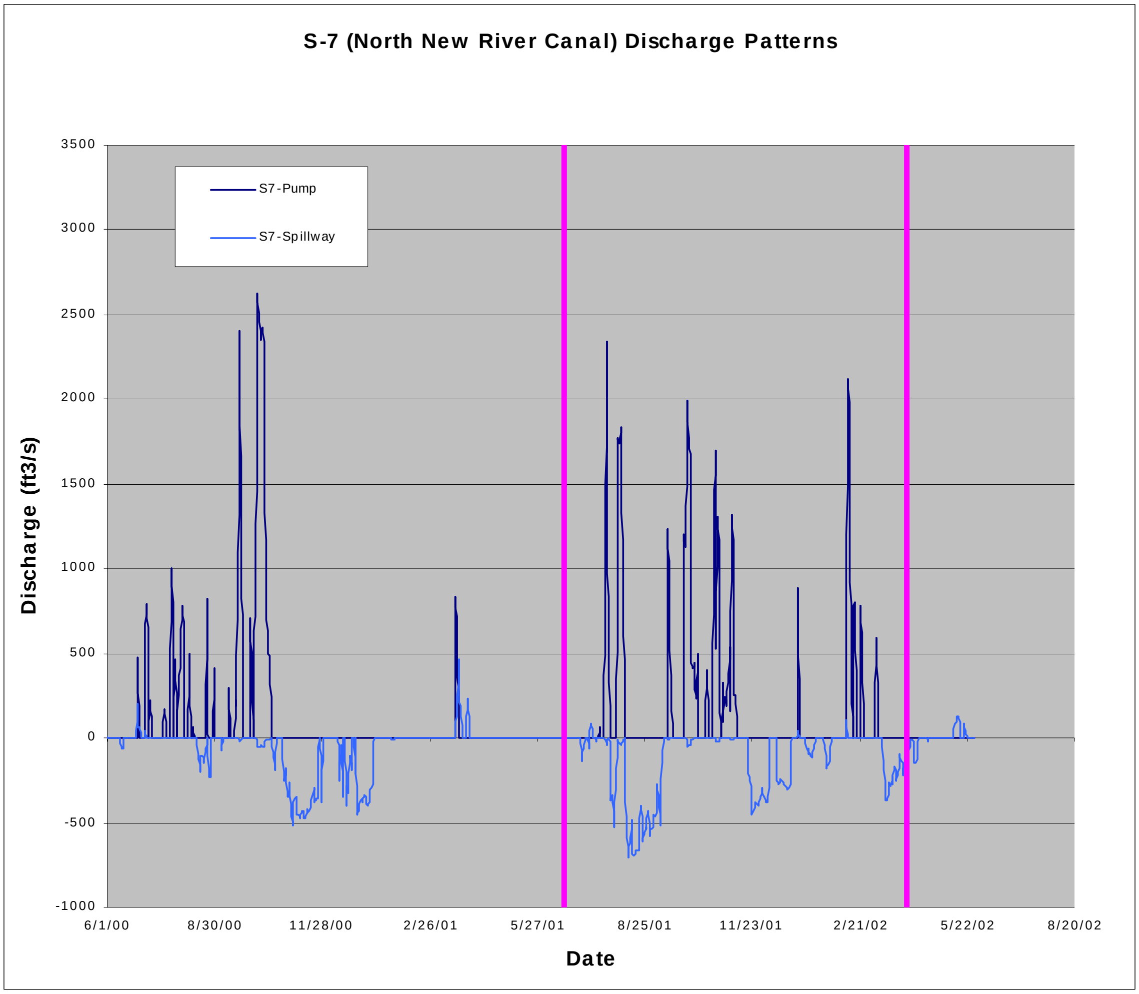


Figure 2.17 – S-7 (North New River Canal) Flow History for 7/00 through 5/02

In the three-month period prior to the first sampling the downstream flow through S-7 was 6.7 million m^3. In the three-month period prior to the second sampling the downstream flow through S-7 was 22.4 million m^3, which follows the same downstream flow pattern as the other structures. The difference with S-7, however, is that for the twenty-one day period just prior to the second sampling, there was a total flow of 10.8 million m^3 *upstream* through L38. This upstream flow brought water from the WCA's into the EAA, and, by extension, could possibly have brought *sediment* from the WCA's back into L38.

In summary, the four samples that showed lower flux rates from 2001 to 2002 were from canals that had seen prior hydraulic conditions conducive to sediment accumulation in 2001 and conducive to sediment scouring in 2002. The one sample that showed higher flux rates from 2001 to 2002 was from a canal that had seen reverse flow in 2002 with the accompanying potential for sediment transport from the WCA's back into the canal. The proposed explanation for the flux differences seen between 2001 and 2002 is preliminary and hypothetical, but it is consistent with the nature of sediment transport seen in the EAA and documented in Chapter 1 of this report. The wide temporal variations seen in the phosphorus flux rates provide further evidence of the transient nature of the phosphorus transport phenomena being studied.

Phosphorus Transport Studies in the WCA

Introduction

During the 2002 wet season a program was conducted to monitor the longitudinal and temporal changes in water column phosphorus content and speciation in the L7/L39 canal system downstream of STA 1-W under flow conditions. This program was conducted as an initial range-finding study to evaluate the potential for transport in the WCA canals to affect phosphorus content downstream of the STA's.

The objectives were to develop reliable techniques to monitor the time-series variations in phosphorus concentration and speciation in the WCA canals, and to use these techniques to monitor the changes in the canals under flow conditions over periods of one to four days. The results of these studies would be used to evaluate whether significant changes were taking place in the canals, and to determine what, and to what extent, additional work should be done.

Site description

The first phase of this study included only STA-1W. This is the most advanced STA, with the longest discharge run, and thus should be the best model. This part of the study included three sampling stations in the canals downstream of the outlet of STA-1W, L-7 and L-39. The sampling locations are shown in Fig. 2.18.

The selected sampling locations provided approximately 14 miles of canal that are being used to transport treated water discharged from STA-1W. Transect locations at each sampling site were marked by GPS coordinates using a Trimble Unit. Station 1 (at transect L7-02) is on L-7 approximately 1.5 miles downstream from the discharge pumps (G-310 and G-251) of STA-1W. Station 2 (at transect L7-09) is located at the south end of L-7, approximately 7 miles from Station 1. Station 3 (at transect L39-05) is located midway down L-39, approximately 6 miles from Station 2, and is approximately two miles upstream of S10-D, the first gate structure for the release of STA-treated water into WCA 2.

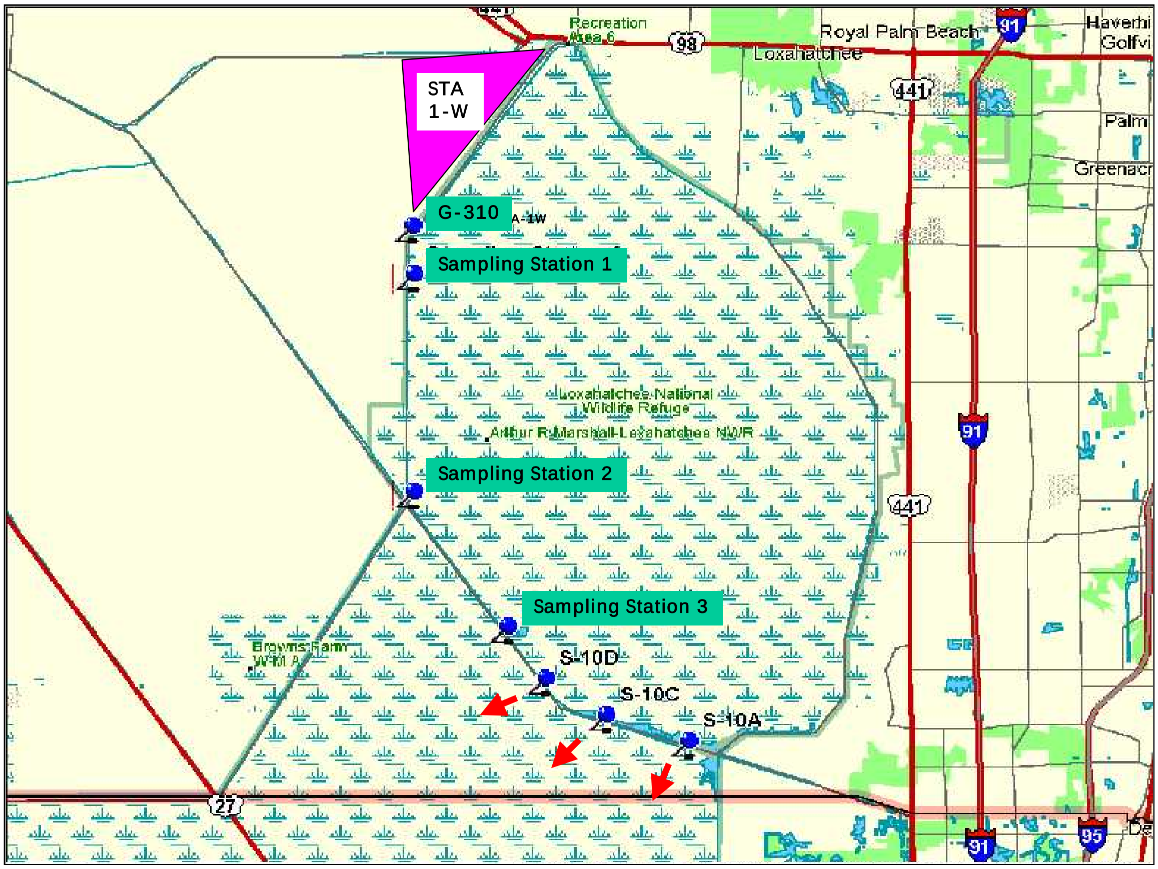


Figure 2.18 – WCA Phosphorus Transport Study Sample Locations

Experimental set-up and sample collection

At each sampling station a 55-gal drum filled with sand was placed in the canal and used as an anchor to hold in place a 12 ft aluminum boat that was used as a sampling station. At each station a buoy was attached to the 55-gal drum to identify the sampling site. Initially, each sampling station was set up with three portable ISCO Model 3700 automatic samplers that were programmed to collect one-hour discrete samples at three different depths. Each sampler was equipped with separate intake lines and strainers that were positioned at the same lateral location on the canal transect. Sampler A collected samples two feet below the water surface, sampler B collected samples at the mid-depth of the water column, and sampler C collected samples two feet above the canal bottom sediment surface. Figure 2.19 shows a schematic representation of the sampling layout, Figure 2.20 shows a photograph of one of the sampling platforms in place.

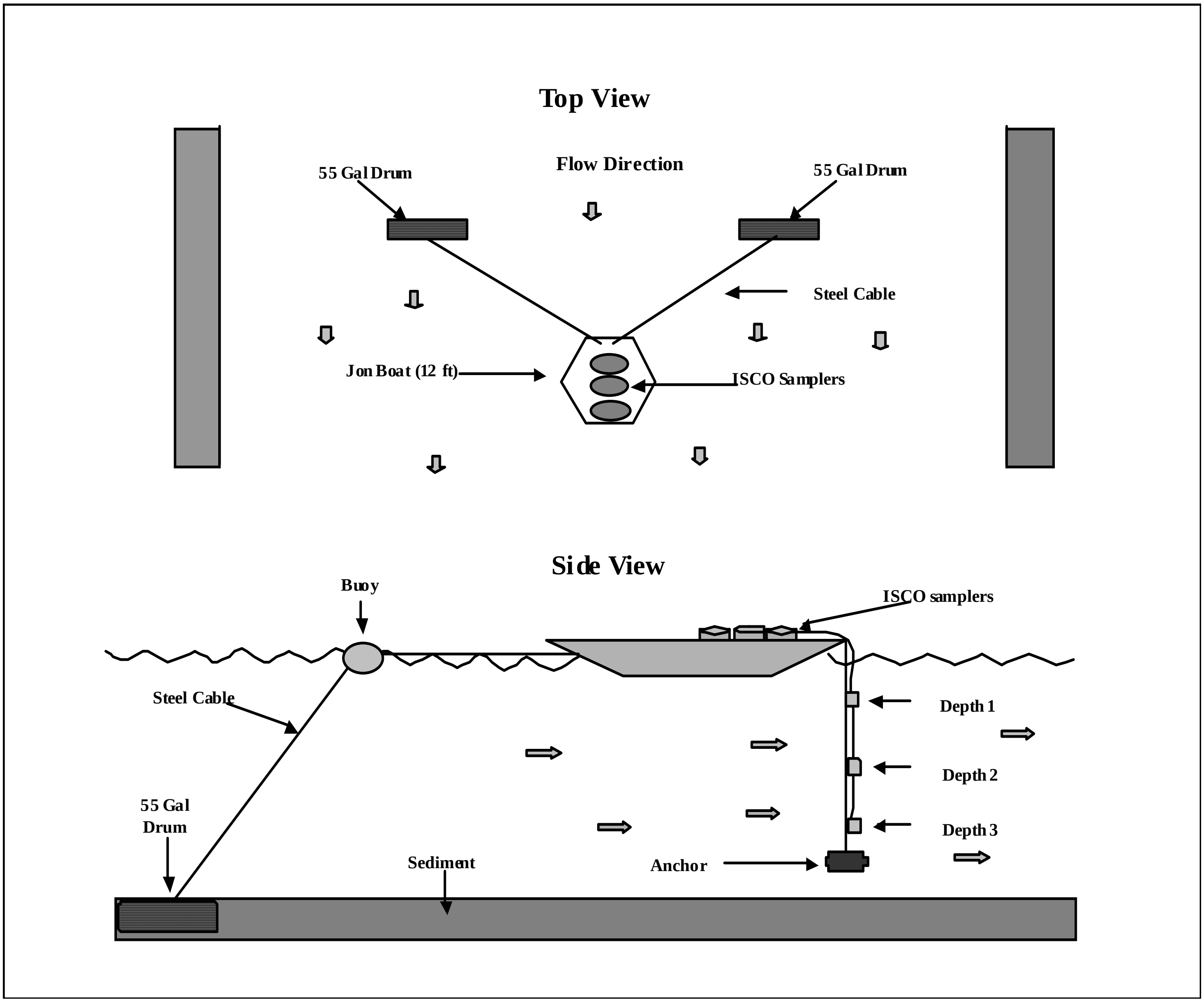


Figure 2.19 – WCA Phosphorus Transport Sampling Platform Schematic

Figure 2.20 – WCA Phosphorus Transport Sampling Platform Photograph

The platforms were transported to the sampling sites for each sampling event and were removed from the canals after each event. Development of logistics took some time because of the location of the sites, but the system was operational by mid-July 2002. Depending on the frequency of the drainage events, attempts were made to collect samples every other week or when the amount of water discharged was significant. Half way through the wet season two changes were made to the sampling protocol. The frequency of the discrete sampling was changed from one hour to two hours and the middle sampling depth (sample B) was eliminated. These changes allowed for sampling of up to 96 hours of the discharge event with back to back- 48 hours sampling events.

The South Florida Water Management District was unable to provide forecasts of pumping schedules; therefore it was necessary to monitor the status of STA 1-W on a regular basis to determine when to sample. Prior to each sampling event, a website from the SFWMD was consulted to make sure that a significant amount of water was being discharged from G-310 and G-251 discharge pumps. The website displays only the number of pumps running. Because of delays in posting data, the actual flow and antecedent conditions of each sampling event was not known until several weeks after sampling took place.

Equipment blanks from all the ISCO samplers and hoses were collected each time the equipment was taken to the experimental sites for a sampling event. After every sampling event, all hoses were cleaned with de-ionized water and stored in plastic bags until the next sampling event. The same procedure was done with the grab sampling equipment. An instrument blank was collected before and after each sampling event.

During several periods of no pumping activity grab samples were collected at one-mile intervals from the middle of L7 and L39 canals, respectively. Grab samples were collected in triplicate and at about the midpoint of the water column depth at each designated transect.

Water analysis

Water samples from each sampling station were collected immediately after either 24 or 48 hours of discrete sampling. Collected samples were immediately transported to the EREC Water Quality Laboratory for analysis. All water samples were analyzed for the following parameters: Total P (TP), Total Dissolved P (TDP), Particulate P (PP), Total Suspended Solids (TSS), and electrical Conductivity (EC). Detailed descriptions of the analytical techniques are contained in the Standard Methods for the Examination of Water and Wastewater (APHA, 1995). All analysis were subjected to a QA/QC protocol which is described in Attachment 2C.

Results

The hydraulic flow pattern from STA 1-W for the period of interest is shown in Figure 2.21. After the January and February 2002 discharges there was a period of quiescence that lasted a little over two months into the first week of May. From May 5 through June 10 there was sporadic low flow from STA 1-W. From June 15 on there were four periods during which the discharge went through a pattern of relatively steady increase to a maximum of 1200-2800 ft^3/s followed by a relatively steady decrease to less than 300 ft^3/s. Between the first and second of these periods there was a four-week period when the discharge fluctuated erratically between 0-1400 ft^3/s. Figure 2.21 also shows the flow sampling periods. Flow samples were taken during all four discharge cycles of the 2002 wet season.

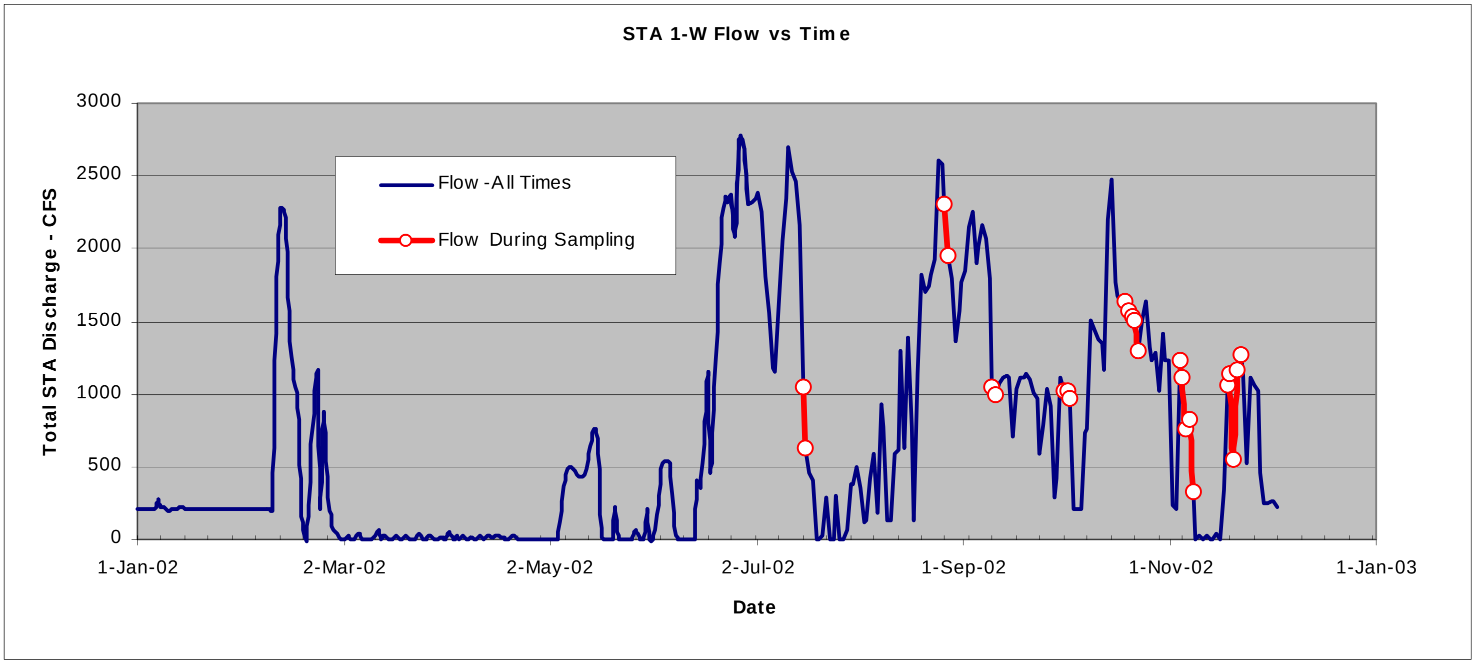


Figure 2.21 – STA 1-W Discharge Flow Jan.-Nov. 2002

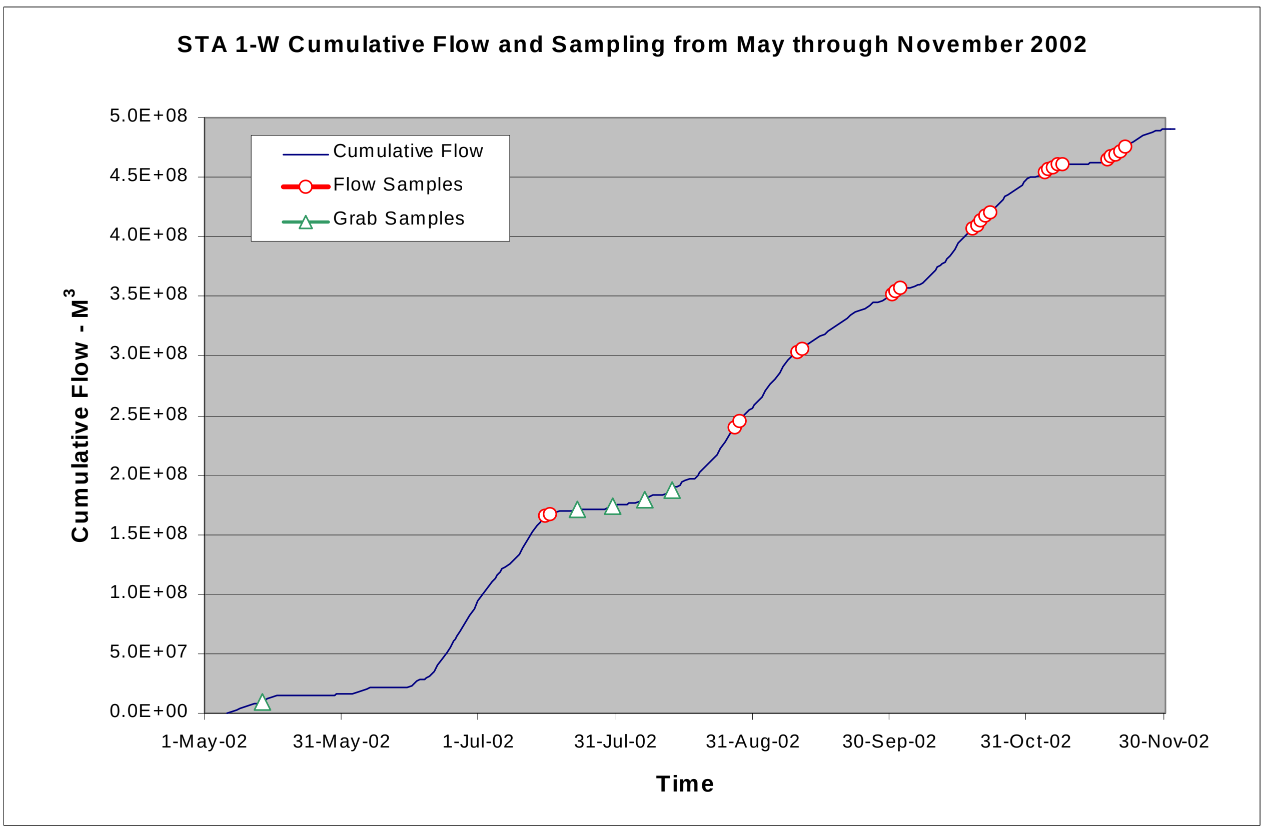


Figure 2.22 – STA 1-W Cumulative Flow and Sampling

The flow from the beginning of the wet season forward is shown in cumulative form as a function of time in Figure 2.22. In this figure, both the flow sample and the grab sampling times are shown. This display puts the sampling in a context that is important for subsequent interpretation. The first flow samples were taken after about one-third of the total seasonal flow had been discharged from STA 1-W. After this first sampling event, discharge from STA 1-W was very modest for about a month. During this low-flow period, triplicate grab samples were taken at all L7 and L39 transects on a weekly basis. Following the resumption of elevated flow from STA 1-W, flow samples were taken on a relatively regular spacing over the final 60% of the wet season discharge.

The type of data obtained during the flow sampling is shown in Figures 2.23 and 2.24. Here the total dissolved phosphorus (TDP) and particulate phosphorus (PP) profiles for each flow sampling station during the 8/27-8/28/02 sampling event are shown as examples. There is obvious variation over time at each station, there is no apparent overlying trend with time at any station, and the particulate phosphorus profiles show more hour-by-hour variation than the dissolved phosphorus samples. These profiles are typical of those seen for the flow samples throughout the study period.

The lack of obvious trends over the sampling periods and the scatter of the time series data, especially the particulate phosphorus data, precluded detailed analysis of individual events. Instead, the location average concentrations for each event were used to estimate the downstream change of phosphorus species concentration. Figures 2.25 through 2.31 show the results for each flow-sampling event. A linear estimate was made of the slope of the concentration versus distance curve for each event. The equation for each estimate is shown on the respective graph. The slopes and intercepts of all the estimation equations are shown in Table 2.8.

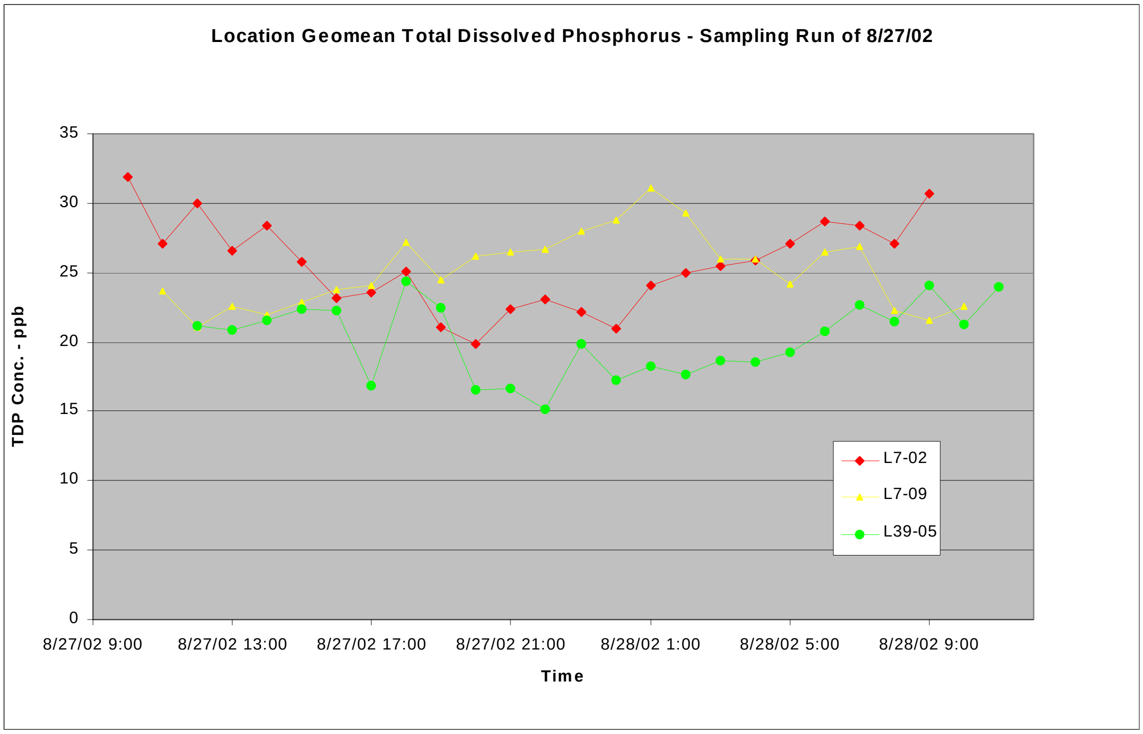


Figure 2.23 – Total Dissolved Phosphorus Profiles, 8/27-8/28/02 Sampling Event

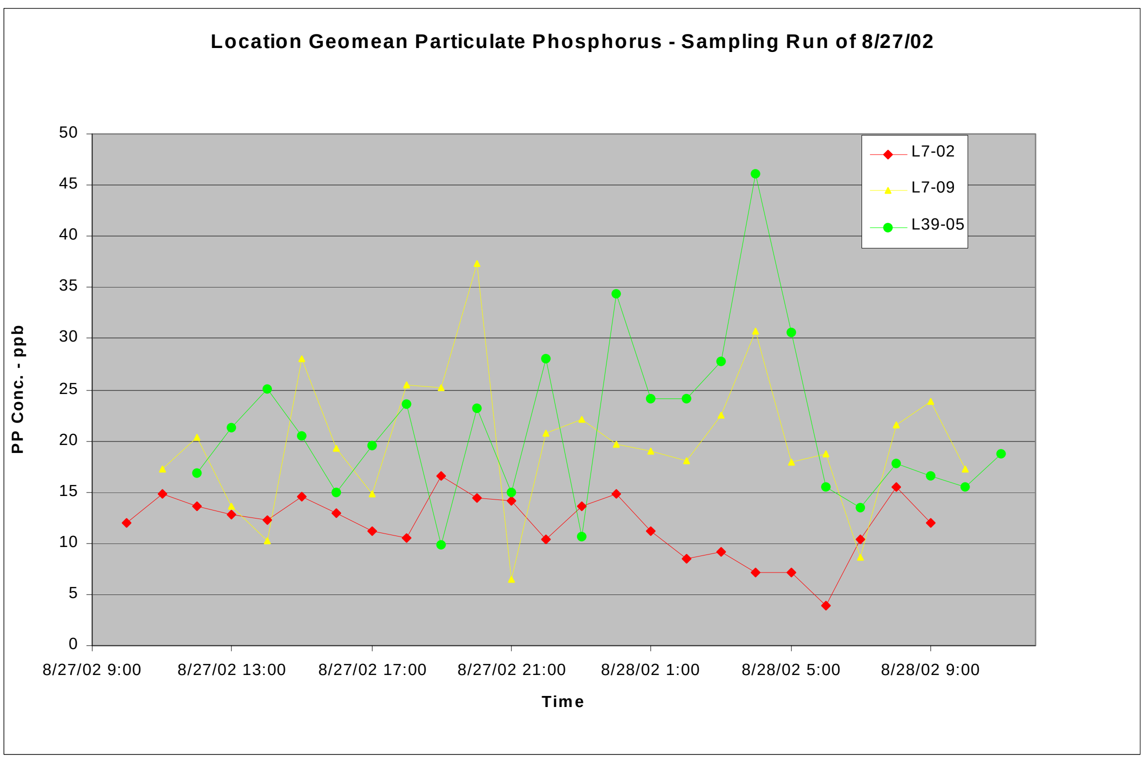


Figure 2.24 – Particulate Phosphorus Profiles, 8/27-8/28/02 Sampling Event

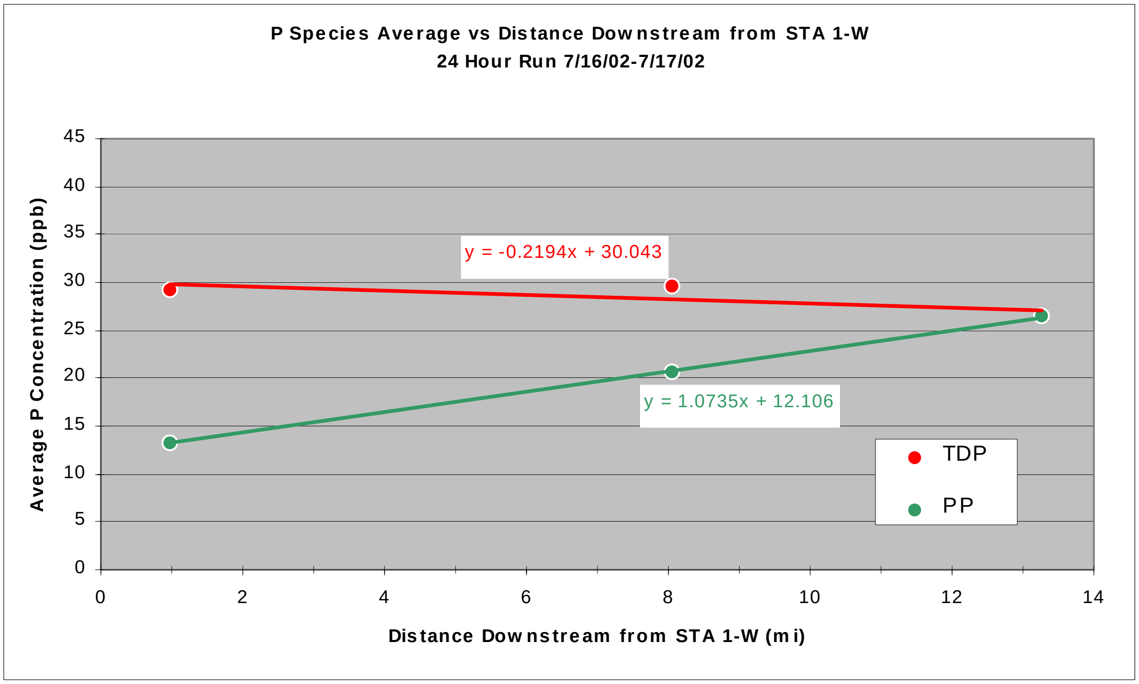


Figure 2.25 – Downstream Phosphorus Gradient, Sampling Event Starting 7/16/02

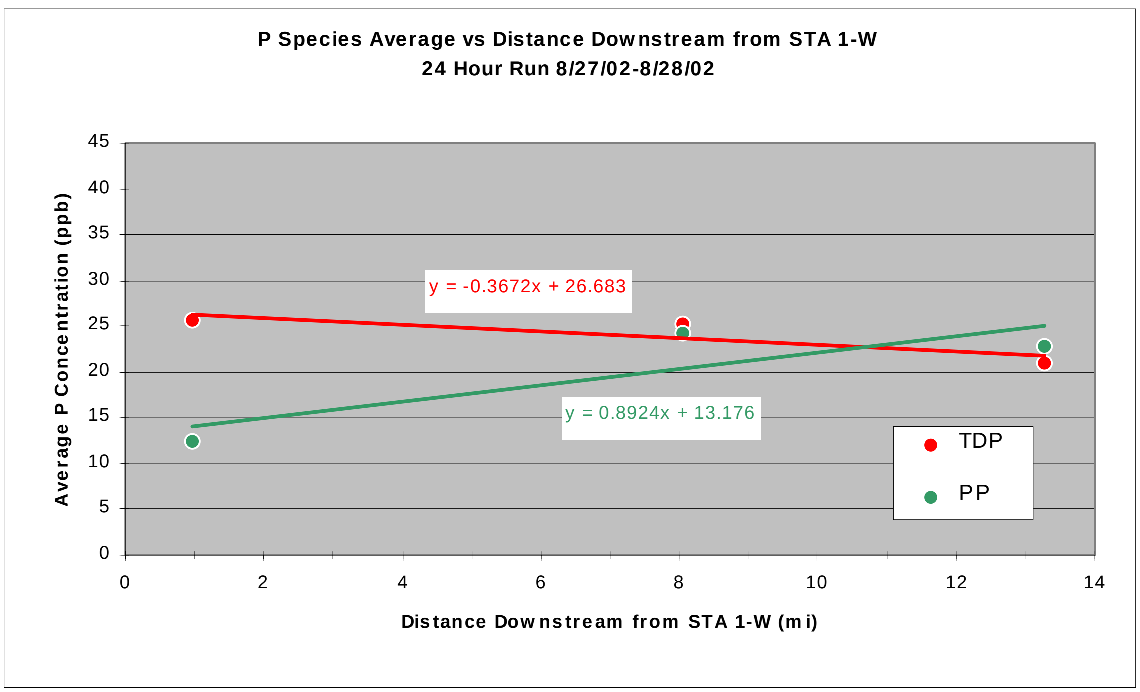


Figure 2.26 – Downstream Phosphorus Gradient, Sampling Event Starting 8/27/02

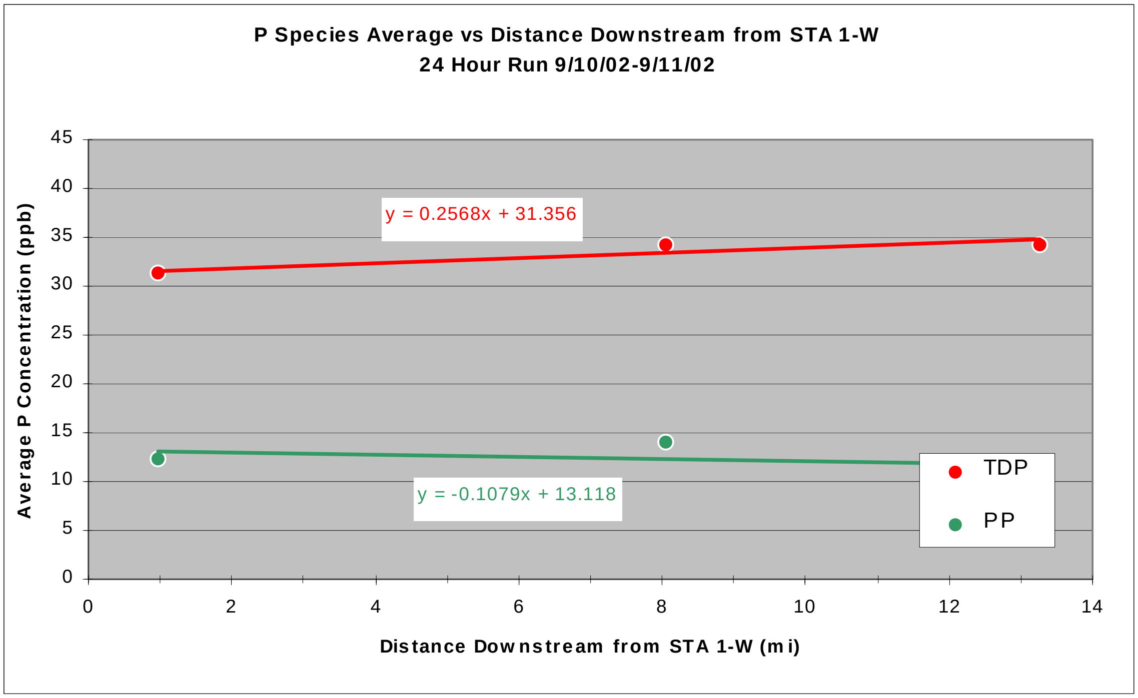


Figure 2.27 – Downstream Phosphorus Gradient, Sampling Event Starting 9/10/02

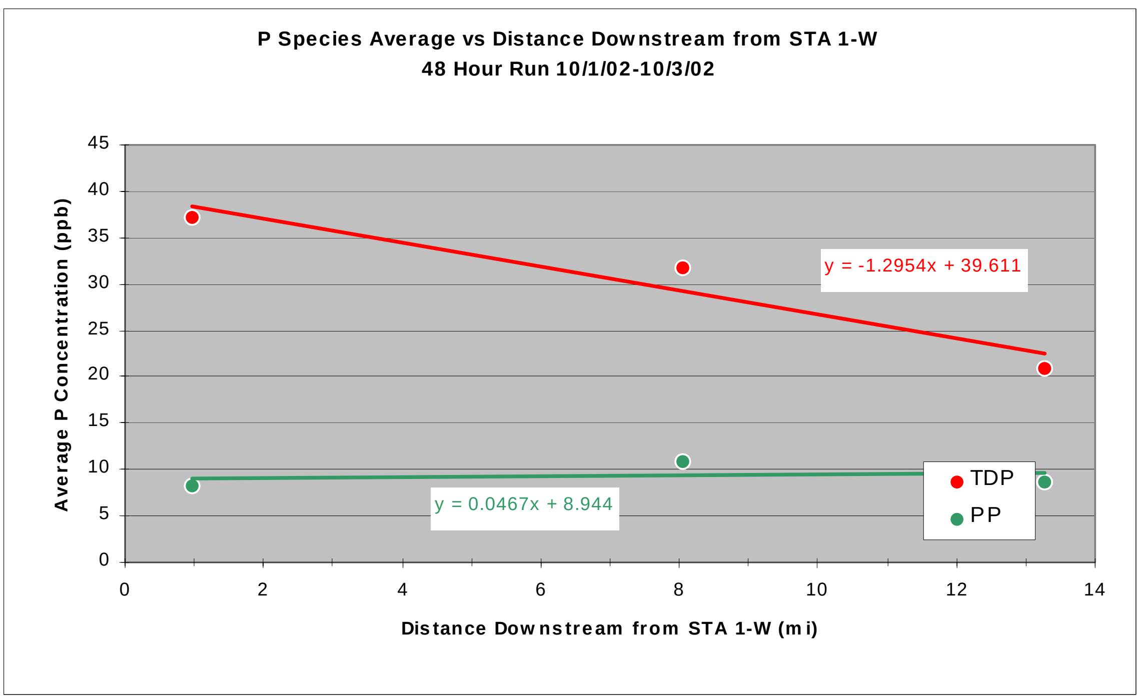


Figure 2.28 – Downstream Phosphorus Gradient, Sampling Event Starting 10/1/02

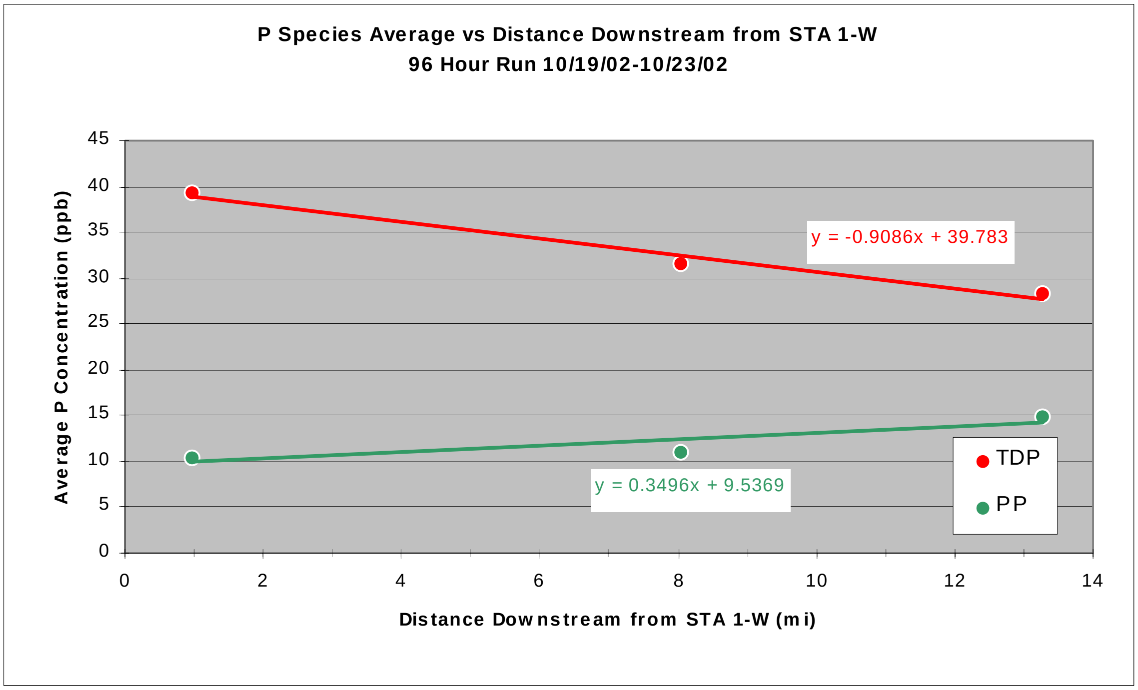


Figure 2.29 – Downstream Phosphorus Gradient, Sampling Event Starting 10/19/02

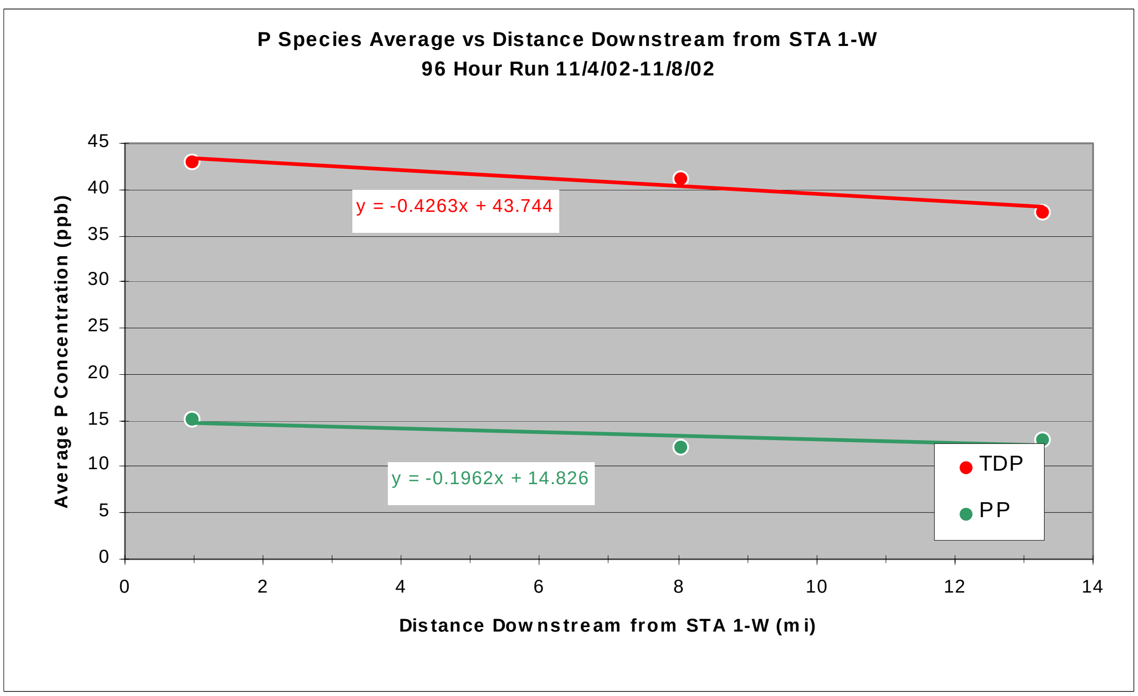


Figure 2.30 – Downstream Phosphorus Gradient, Sampling Event Starting 11/4/02

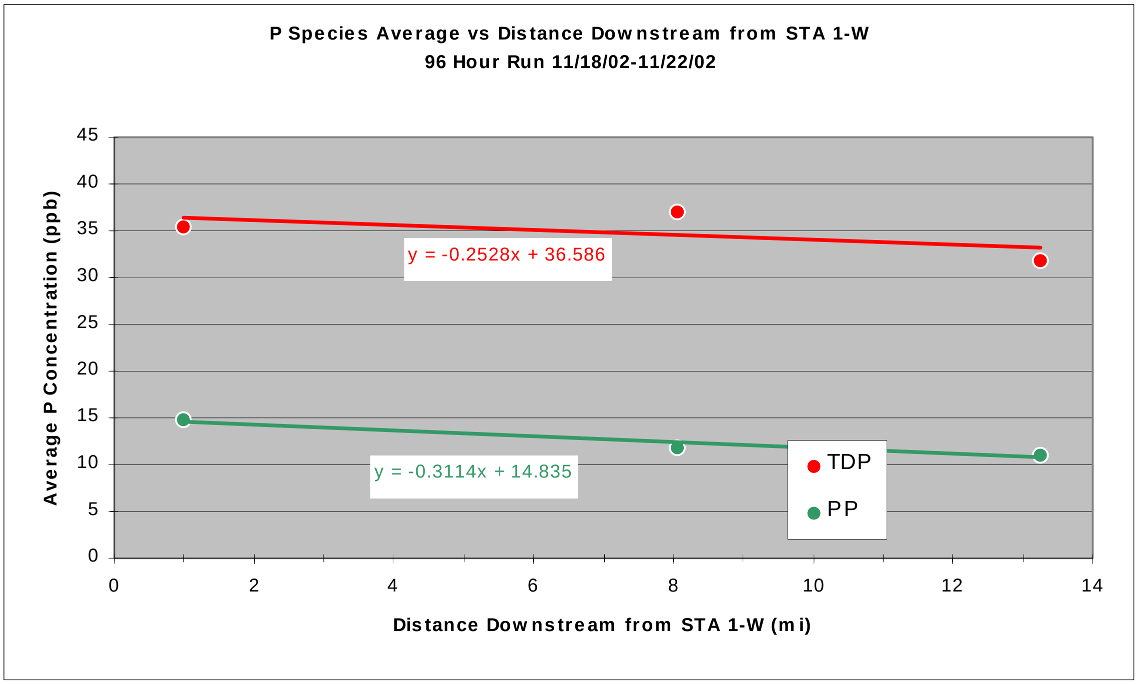


Figure 2.31 – Downstream Phosphorus Gradient, Sampling Event Starting 11/18/02

Table 2.8 – Slopes and Intercepts of Regression Equations for Each Flow Sampling Event

Date	TDP Slope ppb/mile	TDP Intercept ppb	PP Slope ppb/mile	PP Intercept ppb
7/16/02	-0.219	30.0	1.074	12.1
8/27/02	-0.367	26.7	0.892	13.2
9/10/02	0.257	31.4	-0.108	13.1
10/1/02	-1.295	39.6	0.047	8.9
10/19/02	-0.909	39.8	0.350	9.5
11/4/02	-0.426	43.7	-0.196	14.8
11/18/02	-0.253	36.6	-0.311	14.8
Average	-0.459	35.4	0.250	12.4

Discussion of Transport Studies

Several points are evident in the graphs and in Table 2.8. In six of seven instances the total dissolved phosphorus showed a negative gradient downstream, indicating a decrease in TDP concentration with downstream location for the majority of the sampled events. Conversely, the particulate phosphorus showed positive gradients in four of the seven sampling events and negative gradients in the other three, indicating an increase in PP concentration with downstream location in four instances and a decrease in three.

On average, over the 13-mile distance that constituted the sampling reach, TDP concentration decreased about 0.46 ppb/mile, while the PP concentration increased about 0.25 ppb/mile. The intercepts of the graphs provide an estimate of the concentrations at a downstream distance of zero, which corresponds to the receiving water location at the discharge of STA 1-W. The average intercept for total dissolved phosphorus was about 35.4 ppb; the average intercept for particulate phosphorus was about 12.4 ppb.

An evaluation of the temporal patterns of the gradients was conducted. This evaluation yields interesting results that allow some preliminary hypotheses to be drawn about the physical and biological processes in the canals and their floodplains that may be affecting the downstream phosphorus species. Figure 2.32 shows a cluster analysis of the average particulate phosphorus gradients over the full sampling reach as a function of time. It is clear from this graphic that the downstream PP gradient started high and decreased with time over the four-month period during which flow sampling was conducted.

During the May through November 2002 period, the average flow (excluding days of no discharge) from STA 1-W was about 1100 ft^3/s (CFS). In Figure 2.33, the cluster analysis has been subdivided into two flow rate categories. One category contains the five sampled flow events that were at or below the period average flow. These events had flow in the range of 830-1100 CFS. The other two sampled events had flows of 1500 and 2100 CFS, which were in the 70-85th percentile ranges of the period flows.

There appears to be a clear differentiation between the lower and higher flows. Both showed the same trend of decreasing gradients with time and the rate of change with time appeared to be similar. The difference between the two groups was that the higher flow rates appeared to produce higher absolute values of the downstream particulate phosphorus gradient at any given time. With the exception of the 9/10/02 sampling event, the data points appear to have a consistent linear relationship.

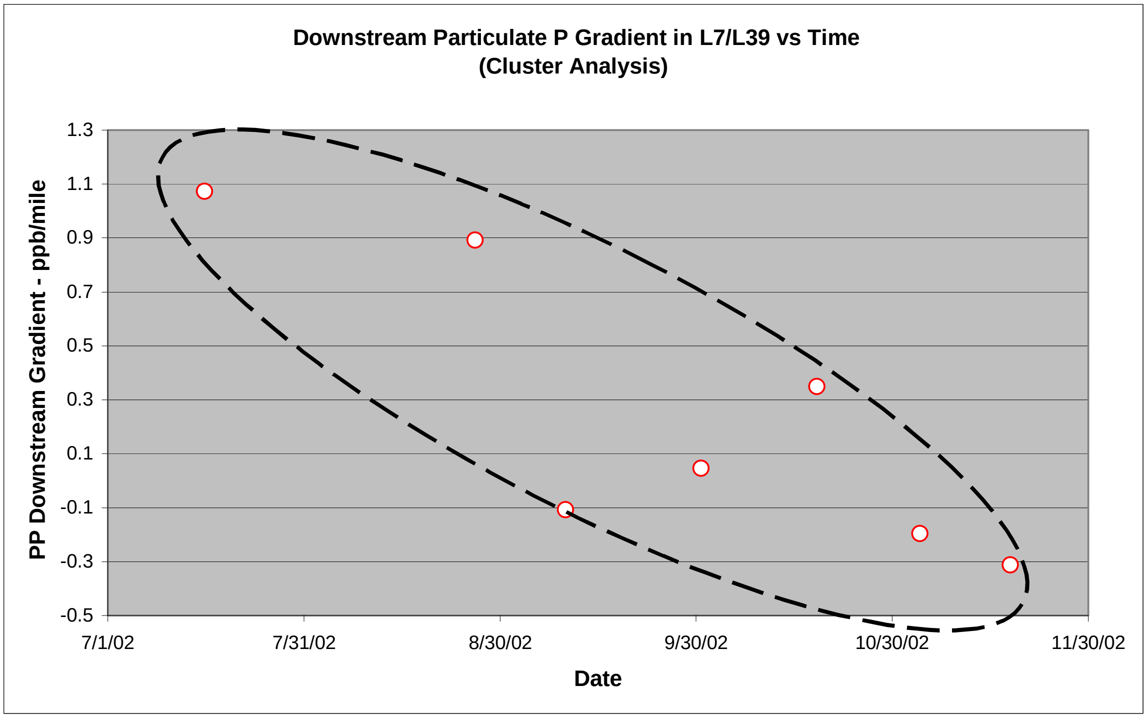


Figure 2.32 – Downstream PP Gradient vs. Time (Cluster Analysis)

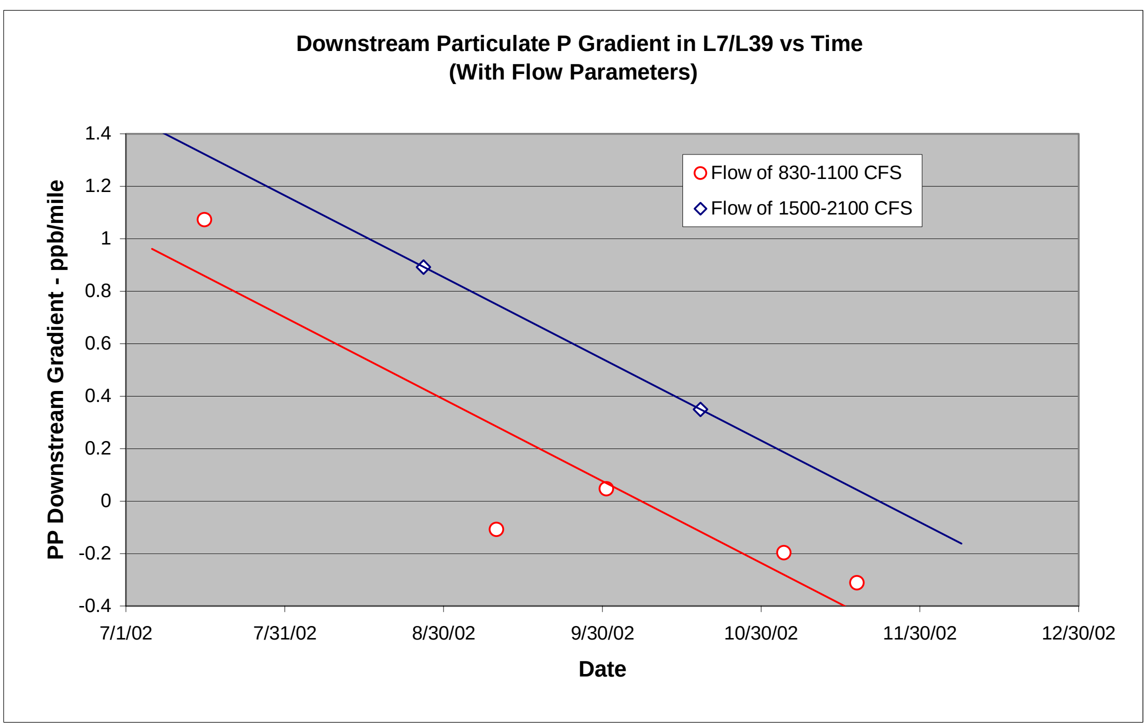


Figure 2.33 – Downstream PP Gradient vs. Time (With Flow Parameters)

The “Y” axes (PP Downstream Gradient) scales of Figures 2.32 and 2.33 run from negative to positive. Positive values of the gradient denote an increase of PP concentration with distance downstream, negative values denote a decrease of PP concentration with distance downstream. An initial interpretation of Figure 2.33 may be that prior to October 2002 the L7/L39 conveyance system (which includes the canal floodplains) was contributing particulate phosphorus to the STA 1-W discharge and after October 2002 the conveyance system was removing particulate phosphorus from the STA 1-W discharge. The rate of contribution of PP appears to be an increasing function of the STA discharge rate. It should be recalled from Figure 2.22 that flow sampling was started at the time when about 42% of the May-November flow had already been discharged; therefore the flow-sampled data represents only about 60% of the flow events.

Given the data at hand, a working hypothesis is presented here regarding the effect of the conveyance systems on water column phosphorus. This hypothesis is consistent with the Biological Contribution Mechanism (Stuck et al, 2002). That is, the biota of the canals and their floodplains produce particulate phosphorus by the process of plant growth and senescence, which entails the uptake of dissolved phosphorus and its conversion to biomass, followed by the release of both dissolved and particulate phosphorus as the plant matter ages and loses viability. Under these circumstances, the dissolved phosphorus concentration in the water column would be expected to decrease with time under conditions of low or no flow, while the mass of particulate phosphorus would be expected to increase. This particulate matter may remain in suspension and contribute to water column total phosphorus concentration if it is sufficiently light and mobile, e.g. planktonic, or it may be deposited on canal and floodplain plant and sediment surfaces to serve as a reservoir for subsequent mobilization.

When there is flow in the system two significant processes can take place. Increased water velocity imparts turbulent forces to the system plant and sediment surfaces, which can cause mobilization of some or all of the deposited particulate reservoir. This mobilization of particulate matter would cause a corresponding increase in the particulate phosphorus concentration of the water column. In Water Conservation Area 1 there are considerable submerged floodplain areas adjacent to the canals, particularly when the canals are at high stage, which was the case during the sampling period. During periods of flow there can be mixing of the canal water with the floodplain water. If the floodplain has been in a net dissolved phosphorus removal mode during quiescent periods its dissolved phosphorus concentration would be expected to be lower than that of the upstream STA which discharges to it. Mixing of this floodplain water with the STA discharge could cause the lower phosphorus-content floodplain water to dilute the dissolved phosphorus in the canal, causing the canal dissolved phosphorus concentration to decrease. Mobilization of particulate matter from the floodplains could also have contributed to an increase in the canal particulate phosphorus content.

The quiescent and low flow periods from late February through mid-June could have provided the time necessary for the biological conversion of water column dissolved phosphorus to particulate phosphorus (biomass) which would result in an accumulation of particulate matter in the conveyance system. This conversion would also produce a reservoir of low dissolved phosphorus water in the floodplain water column. Subsequent to the start of large, consistent discharge flows from mid-June through the end of November these reservoirs could have seen net depletion. The depletion of the particulate phosphorus reservoir would cause the *positive* gradient of downstream particulate phosphorus to decrease with time, while the depletion of the low dissolved phosphorus reservoir would cause the *negative* gradient of downstream dissolved phosphorus to also decrease in absolute magnitude with time.

Figure 2.33 clearly demonstrates the reduction of the positive gradient with time for particulate phosphorus. Figure 2.34 shows a similar graphic for the dissolved phosphorus gradients. Here the trend is not so clear. The expected reduction of the magnitude of the negative dissolved phosphorus gradient is observed for the last four flow sampling events, but the first three events are not consistent with the simple dilution hypothesis. Evidently there are other phenomena impacting the dissolved phosphorus processes. Examination of some additional data may shed some light on these other processes.

In addition to the flow samples, there were also systematic grab samples taken at several times during the study. Over the low flow period of 7/23/02 through 8/13/02, triplicate grab samples were taken at all L7 and L39 transects approximately once per week. It is useful to compare this data with the phosphorus species gradients obtained in the flow samples taken before and after these grab samples. Figures 2.35 and 2.36 show the transect average particulate and dissolved phosphorus concentrations respectively for the flow samples taken starting 7/16/02, the grab samples taken from 7/23 to 8/13/02, and the flow samples taken starting 8/27/02.

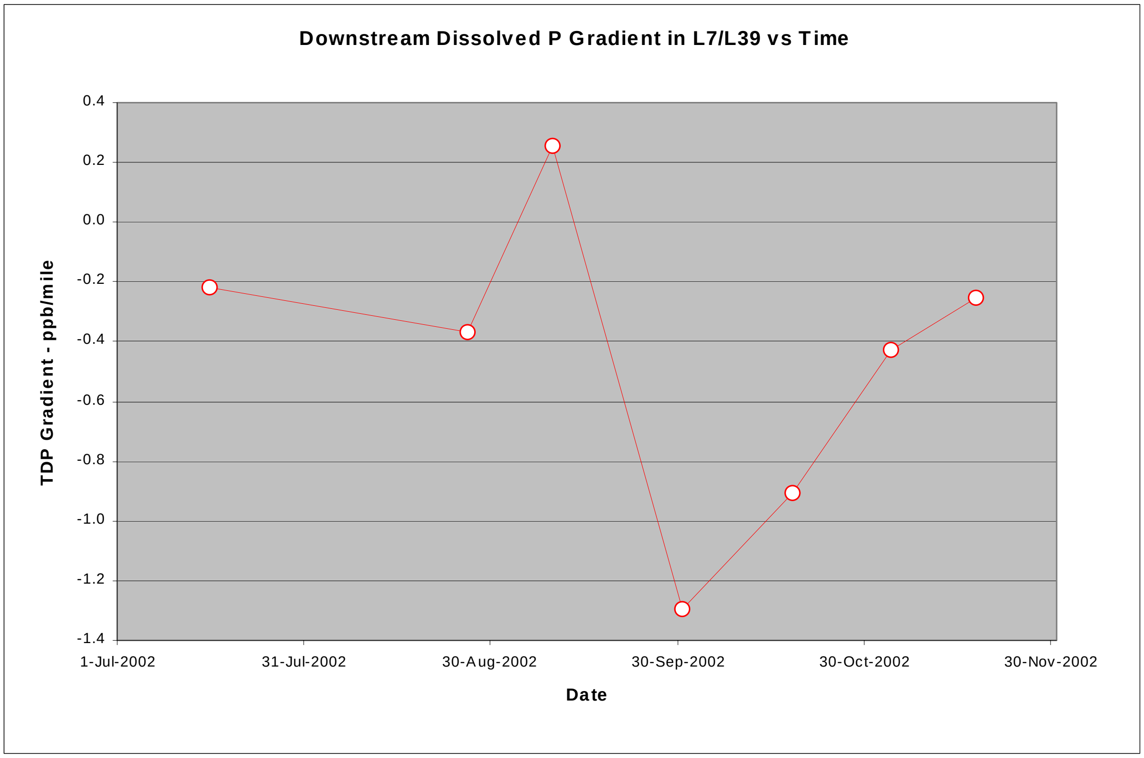


Figure 2.34 – Downstream Dissolved P Gradient vs. Time

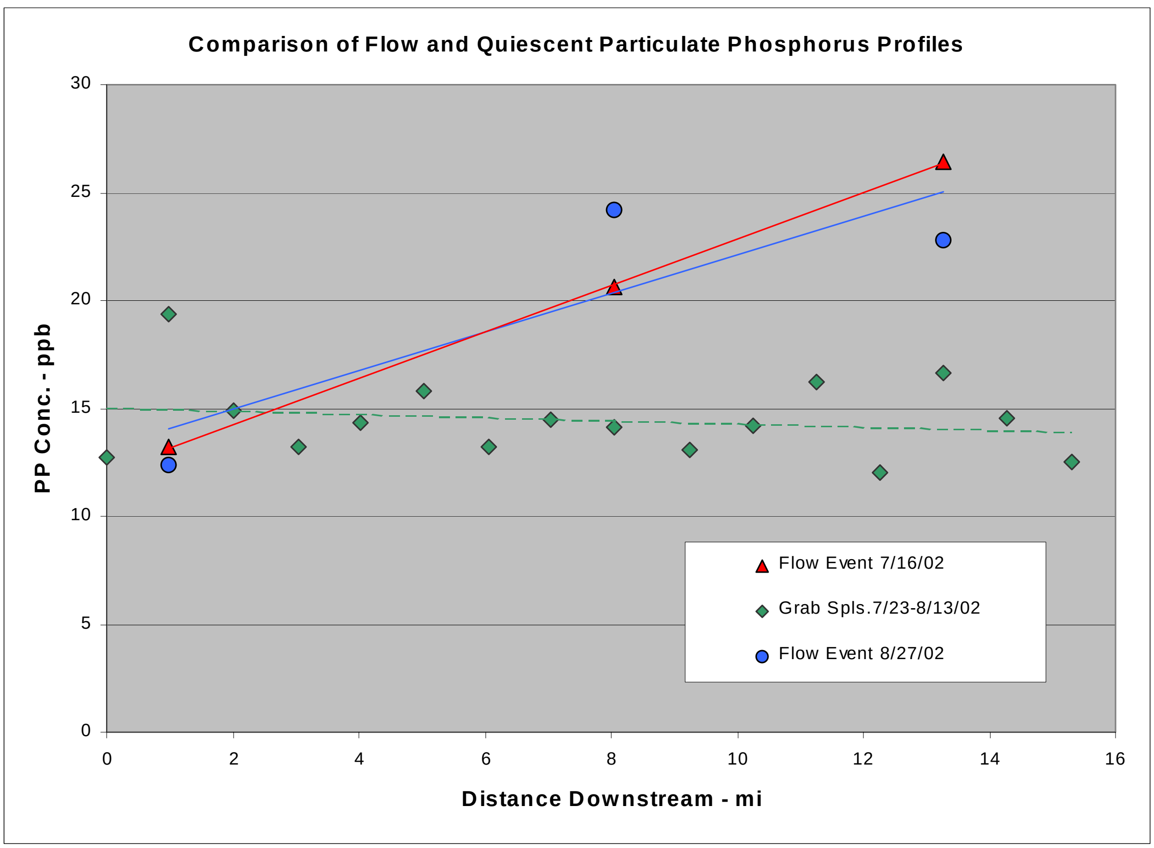


Figure 2.35 – Comparison of Flow and Quiescent Particulate P Profiles

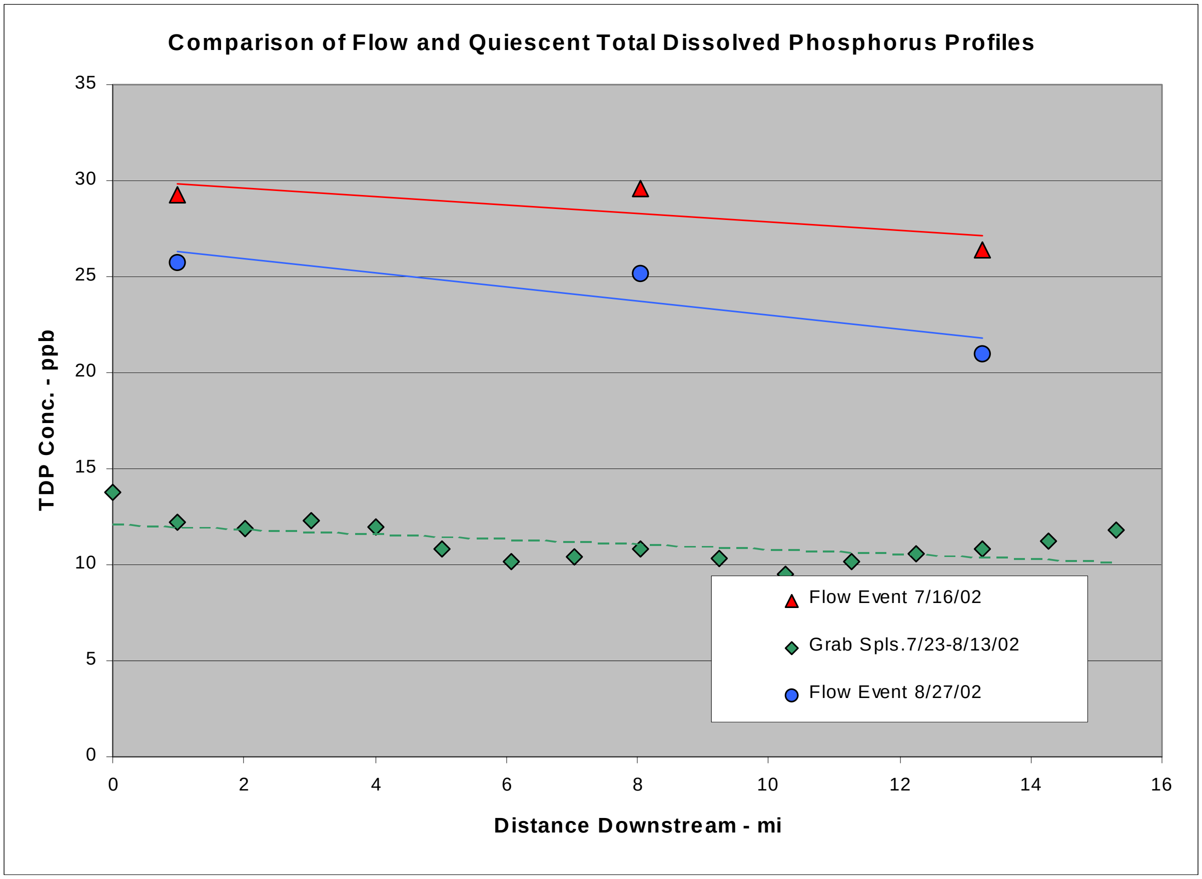


Figure 2.36 – Comparison of Flow and Quiescent Dissolved P Profiles

Figure 2.35 shows the quiescent-time particulate phosphorus concentration to be in the range of 12.5-16.5 ppb. During the flow period monitored prior to the quiescent time, the particulate phosphorus concentration in the canal near the STA discharge was 13.2 ppb, near the midpoint of the quiescent time range. In the flow period monitored after the quiescent time the corresponding upstream particulate phosphorus concentration was 12.4 ppb, which was at the low end of the quiescent period range. In both cases the imposition of flow caused a positive downstream gradient in particulate phosphorus. An interpretation of these results is that there may have been a steady state water column particulate phosphorus concentration that was in the 12-17 ppb range. This may represent the phosphorus content of particulate matter that is neutrally buoyant or mobilized by Brownian motion. Both flow events appeared to start in this steady state concentration and then re-mobilize deposited particulate material downstream. The mobilized material suspended at the end of the early flow event appeared to settle from the water column by the time the first set of quiescent period samples were taken, and then appeared to be re-mobilized during the later flow event.

In contrast, Figure 2.36 shows a different picture for dissolved phosphorus. The quiescent period dissolved phosphorus concentration was in the range of 10-13 ppb. The dissolved phosphorus concentration for the flow-sampling event prior to the quiescent time averaged 28.4 ppb. For the flow-sampling event after the quiescent time the corresponding average TDP was 24.0 ppb. Both flow events showed a negative TDP gradient, which is consistent with dilution by lower TDP water. What is particularly interesting in Figure 2.36, however, is the rapidity with which the water column reduced from an average TDP of 28.4 ppb on 7/16/02 to an average of 11.5 ppb in the 7/23-8/13/02 quiescent period.

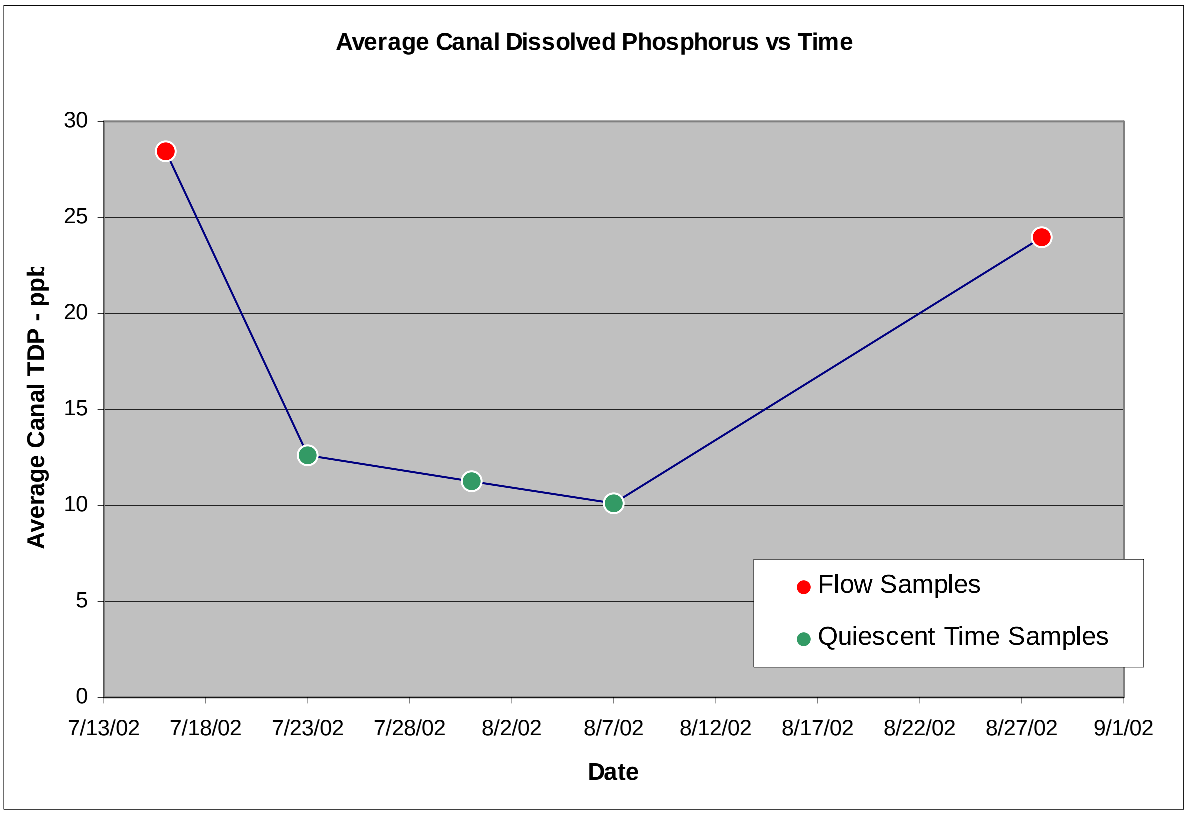


Figure 2.37 – Canal Average TDP During the Period 7/16-8/28/02

The time profile of TDP over this period is shown in Figure 2.37. It is clear that there was a very rapid reduction in canal TDP with time, in fact almost all of that reduction took place in the week from 7/16 (flow) to 7/23 (quiescent). The average for the samples taken on 7/23 was already down to 12.6 ppb. Given the subsequent apparent STA discharge TDP concentration of around 26 ppb, it might be inferred that the WCA floodplain appeared to be doing a better job of removing dissolved phosphorus than the STA was.

An important observation to make from this analysis is the apparent difference in the dynamic rates of the particulate and dissolved phosphorus processes in the conveyance systems. In the short term the particulate processes appear to be dominated by physical and hydraulic phenomena. The dissolved phosphorus processes, however, appear to be more sensitive than the particulate processes to biochemical phenomena over the short term. Figure 2.34 may be describing a complex interaction between dissolved phosphorus production and removal in the canal floodplains that is sensitive to seasonal variations. An increase in biological activity in the late summer and early autumn, when water temperatures are highest, followed by a decrease in biological activity as the water temperatures decrease could explain the general shape of the curve in Figure 2.34.

It was noted earlier that the first flow sampling was done after over 40% of the wet season flow had already been discharged. There was, however, a set of samples taken earlier, which, with the appropriate qualifications, can be used to draw some additional inferences from the data. On 5/14/02 a set of triplicate grab samples was taken at each of the flow sampling transects. Antecedent flow from STA 1-W had been relatively quiescent for the preceding two and a half months. Based on then-current data from the SFWMD it was assumed that there was no flow in the canals. Subsequently, updated data acquired from the SFWMD showed that the average discharge to the canal was 548 CFS. The grab samples were taken at this time to obtain a background profile of canal phosphorus species concentration prior to the onset of the wet season STA discharge.

Figure 2.38 shows the profile of the average phosphorus species concentration for the 5/14/02 sampling event. With the appropriate qualifications, this sample set may serve as a limited-sampling representative of a low flow event early in the wet season. Referencing back to Figure 2.22 shows that this sample set was taken after about 2% of the total wet season flow had been discharged from STA 1-W.

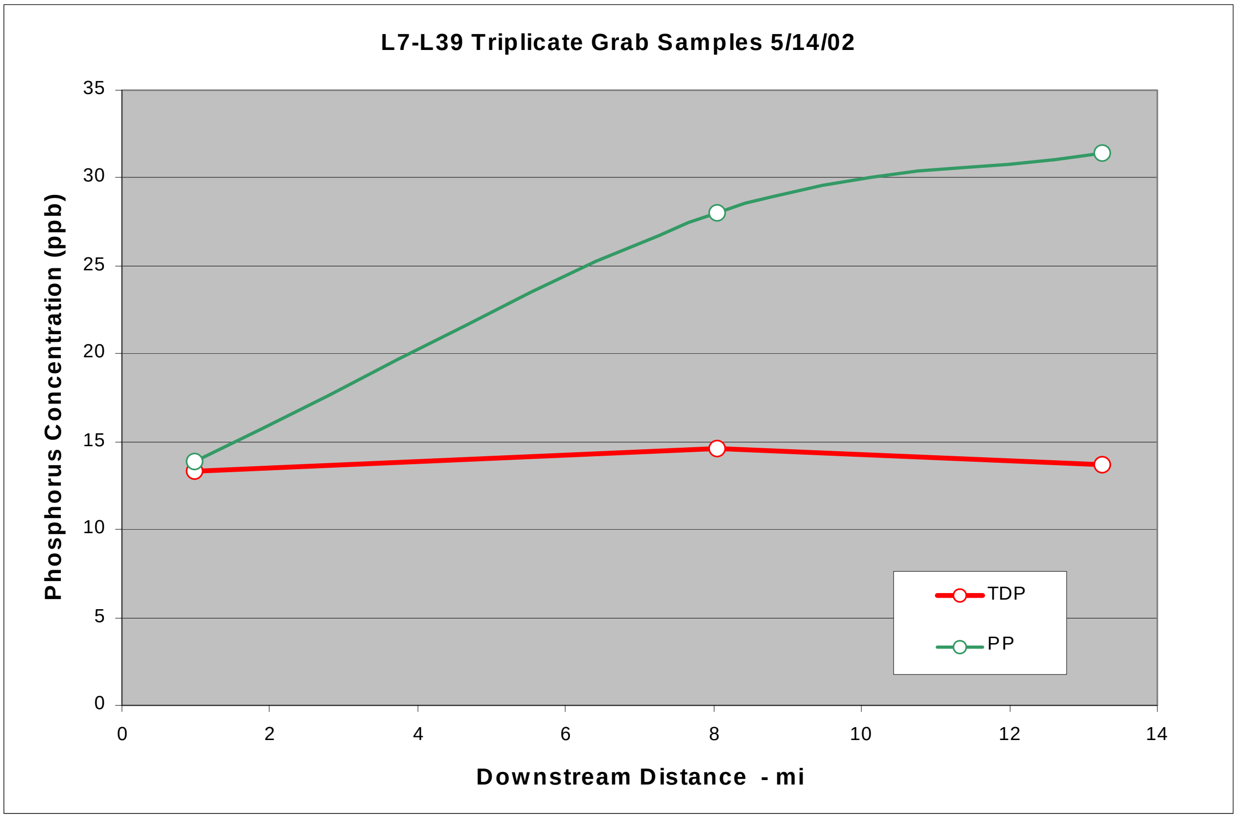


Figure 2.38 – Phosphorus Gradients Observed during 5/14/02 Sampling

The flow data may be parsed further and combined with the 5/14 data to supplement the interpretation of phosphorus transport observed over the discharge period. The clear relationships between particulate phosphorus gradients and time suggest that evaluation of the relationships between phosphorus gradients and cumulative flow may also be fruitful.

The topography of the L7 canal and the L39 canal is somewhat different. Both canals have large floodplains that are usually submerged at the stages that prevail during the wet season, and both canals have generally identifiable channels. The southern part of WCA 1, however, is more open and lake-like than the northern part. L39, which is in the southern 40% of WCA 1, frequently has a less well-defined channel than does L7. There are numerous locations in L39 where the eastern side of the channel is defined by periodic piles of rocks with open gaps between them. Under the configuration that existed during the sampling, the only structures that influenced L7 were G-251 and G-310, the two discharge structures from STA 1-W. L39 is influenced by the flow it receives from L7, but it is also possible for L39 to receive flow on occasion from structures located in the vicinity of S-6. The flow in L39 and its floodplain may also be influenced by the relative withdrawal rates at the S10-A, C, and D structures. From a hydraulic standpoint, the L7 system appears to have a simpler flow pattern than the L39 system.

For this final analysis of data, an evaluation of phosphorus gradients in the L7 system alone was conducted. The correlating parameter was cumulative hydraulic discharge from STA 1-W. The gradient data from the 5/14 sampling event was treated as a flow-sampling event and included with the rest of the flow data. For this analysis the gradients that were included in the data set were those that prevailed in the seven-mile long L7 section of the sampling reach. Figure 2.39 shows the results for particulate phosphorus.

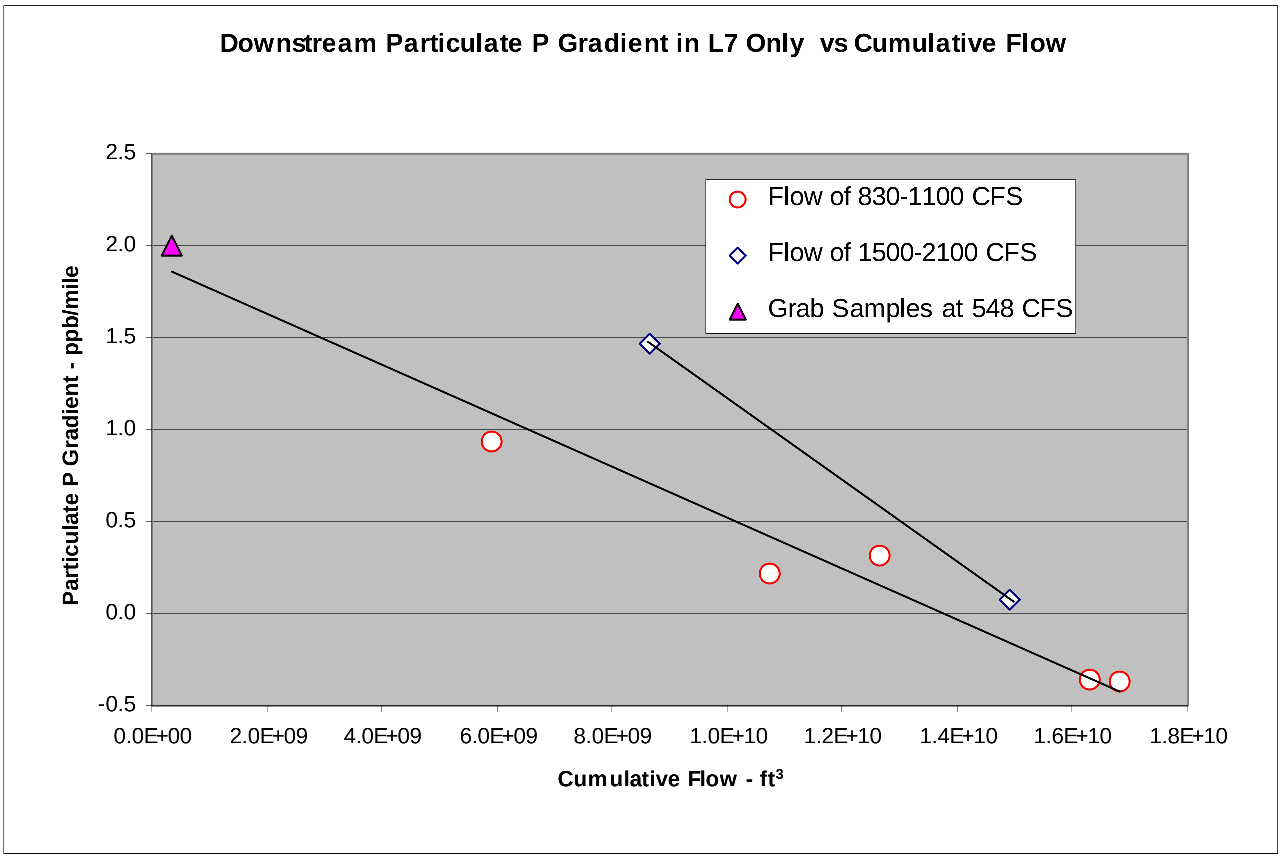


Figure 2.39 – Particulate P Gradients in L7 as a Function of Cumulative Flow

In Figure 2.39 the 5/14 sampling event, at 548 CFS, is included as part of the sample sets taken at flows less that the season average. There is a good correlation (R^2=0.97) between cumulative flow and particulate phosphorus gradient for the lower flow samples. There were not enough events sampled at the higher flows to estimate a correlation, but there appears to be a logical pattern to the higher flows that is consistent with the lower flows and with what has been hypothesized earlier. Figure 2.39 is interpreted as follows. Early in the seasonal discharge period relatively modest flows were sufficient to mobilize relatively large quantities of particulate phosphorus. As the seasonal discharge progressed and particulate phosphorus was washed out of the system faster than it was produced, the amount of particulate phosphorus mobilized by any given flow rate reduced, although higher flows mobilized more particulate phosphorus than lower flows. After a cumulative discharge of around 1.4 E+10 ft^3 (390 million cubic meters), flows at the mean or less ceased to mobilize particulate phosphorus. After a cumulative discharge of around 1.5 E+10 ft^3 (430 million cubic meters), flows at the 85^{th} percentile or less ceased to mobilize particulate phosphorus. Beyond the break point for a given flow, flow particulate phosphorus decreased downstream, indicating a switch from net contribution of particulate phosphorus to net removal by the canal/floodplain system. A linear extension of the trend implies that mobilization would have ceased for *any* flow rate beyond a cumulative discharge of about 1.7 E+10 ft^3 (490 million cubic meters), which is about the total volume discharged during the wet 2002 season.

When a similar analysis is applied to the total dissolved phosphorus gradients in L7 there is no correlation whatsoever with flow rates. This is not unexpected, nor is it inconsistent with the hypotheses previously presented for the transport of dissolved phosphorus in the WCA canals. Figure 2.40 shows the relationship between dissolved phosphorus gradients and cumulative flow. In this discussion, one adjustment has been made to the data. There appears to be a general pattern of increasingly negative gradients with cumulative discharge until near the end of the season, when the pattern reversed itself. The single exception to this pattern is the flow-sampling event of 9/10/02 (300 million cubic meters cumulative flow). This data point is being included in the graph for completeness, but it is being treated as anomalous, and is excluded from the pattern analysis.

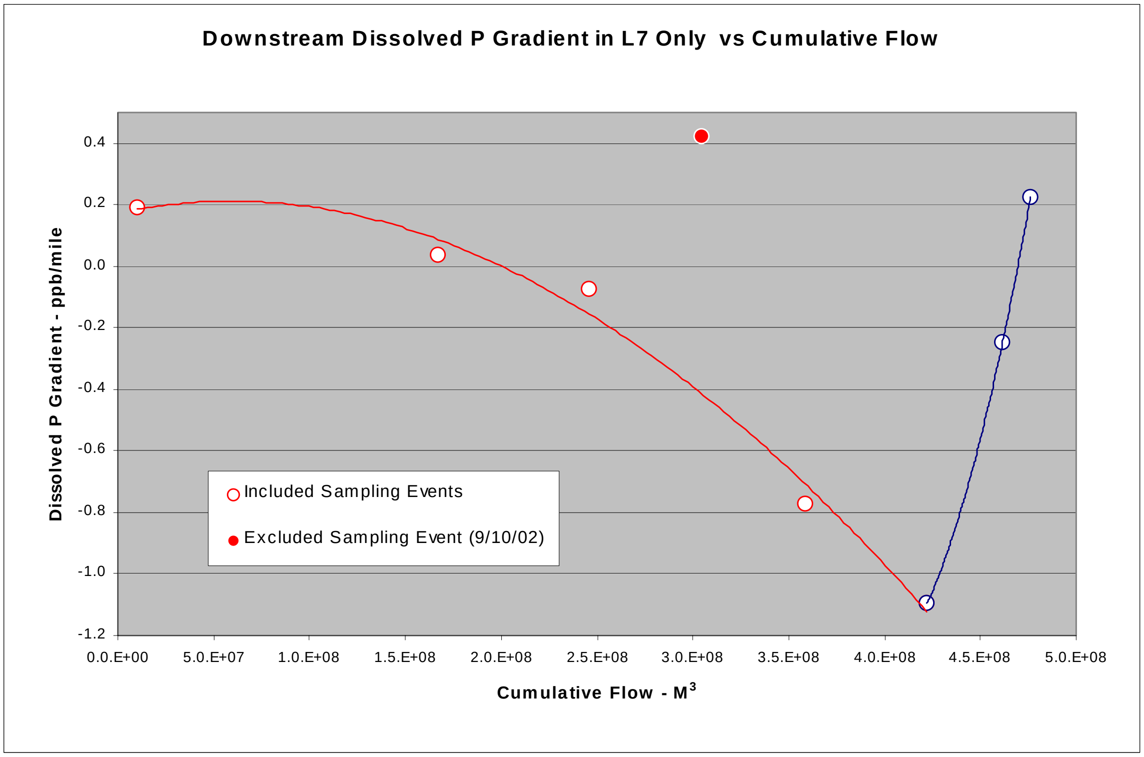


Figure 2.40 - Dissolved P Gradients in L7 as a Function of Cumulative Flow

With the qualification in place, the pattern exhibited in Figure 2.40 starts with a slightly positive downstream dissolved phosphorus gradient of 0.19 ppb/mile (water column dissolved phosphorus increases in the L7 conveyance system) at the beginning of the wet season. As the season progressed, the gradients became increasingly negative (water column dissolved phosphorus decreases in the L7 conveyance system), showing strong negative values when cumulative flows were in the range of 350-420 million cubic meters. At a cumulative flow of 420 million cubic meters the largest negative gradient of –1.1 ppb/mile was recorded. After the cumulative flows exceeded 420 million cubic meters there was a sharp reversal of the trend, and the magnitude of the gradients became less negative, winding up at a slightly positive value of 0.23 ppb/mile, which was almost identical to the initial gradient recorded at the start of the season.

The highest negative gradients were observed during late September and early October, at the end of the summer season. The trend reversal of movement back toward positive gradients started in mid-October and progressed through the fall to mid November, when pumping essentially stopped. The removal pattern of dissolved phosphorus from the water column in the conveyance systems exemplified in Figure 2.37 indicates that the conveyance system (canal and floodplain) can have significant impact on water column dissolved phosphorus, most likely by biological uptake. Aquatic biological activity will, in general, be positively correlated with water temperature and solar radiation, which in turn is positively correlated with season and time-in-season.

A hypothesis is proposed here to explain the general shape of the dissolved phosphorus gradient curves seen in Figure 2.40. Early in the wet season aquatic biological growth, which removes dissolved phosphorus from the water column, is less than plant senescence, which contributes dissolved phosphorus to the water column. This results in a net contribution of dissolved phosphorus, which is manifested as a positive downstream dissolved phosphorus gradient. As the season progresses the water temperature increases, solar insolation increases, biological activity increases, and the biological population increases. These factors combine to produce an exponential change in the dissolved phosphorus removal capability of the conveyance system, giving rise to the increasingly negative gradients observed in late summer and early autumn. By mid autumn the seasonal conditions have become less conducive to biological growth and the process starts reversing itself with biological senescence becoming more predominant and biological growth becoming less pronounced. This change of balance causes the dissolved phosphorus removal capability of the conveyance system to decrease with time, which is manifested by a consistent reduction in the negative magnitude of the downstream gradients. At the end of the period in late autumn the balance between growth and senescence is about what it was at the start of the wet season discharge, and the gradients are similar to what they were seven months earlier in mid spring.

In summary, the characteristic concentrations seen during flow in the STA 1-W conveyance systems over the study period were about 35 ppb for total dissolved phosphorus and 12 ppb for particulate phosphorus. Over the entire discharge period, the conveyance systems appeared to affect a net reduction of total dissolved phosphorus and a net contribution of particulate phosphorus downstream of STA 1-W. The net reduction of dissolved phosphorus was hypothesized to result from biological activity in the canals and their floodplains, and appeared to be a function of time-in-season, higher in late summer and lower during spring and autumn. The net contribution of particulate phosphorus was hypothesized to result from remobilization of biologically generated particulate matter that had accumulated in the conveyance systems during the quiescent dry season. As the pumping season progressed this accumulation was subject to washout, so early in the period mobilization was high, while at the end of the period there was essentially no contribution by the conveyance systems. Sampling during quiescent periods indicated that there may have been a short-term steady state concentration in the canal-floodplain systems of about 10-12 ppb for both dissolved phosphorus and particulate phosphorus.

Summary and Discussion of All Studies

Sediment Phosphorus Inventory

The inventory showed that the upper 12 cm of the active canals in the WCA's contain a pool of readily available phosphorus on the order of 30 metric tons. This layer contains an additional 145 metric tons of phosphorus that is either carbonate-bound (approximately 90 metric tons) or "recalcitrant" phosphorus (approximately 55 metric tons). Recalcitrant phosphorus is primarily organic phosphorus that is not extractable by acid or base. This material is, however, subject to biological degradation in the environment prevailing in the canal sediments. Neither this inventory, nor the laboratory flux rate studies investigated the rate of conversion of recalcitrant phosphorus to readily available phosphorus, or vice versa.

It was observed that there were regions in the eastern canals that showed large variations of phosphorus content with longitudinal location, suggesting that local conditions within the canals (possibly biomass concentration) were contributing to phosphorus accumulation. The Miami Canal also showed a region of accumulation, but this accumulation was primarily inorganic phosphorus, and is not readily available for release. The high concentration regions in the eastern canals will be studied in more detail in the upcoming period.

The data as presented here show wide variations in canal sediment character from canal to canal. Generally, the canals on the east side of the WCA's (L7/L39/L40) have more organic matter, more readily available phosphorus, and higher flux rates. The canals on the west side of the WCA's (Miami Canal North and Miami Canal South) have lower organic matter, higher total phosphorus but lower readily available phosphorus, and lower flux rates. The canals central to the WCA's (L5/L6/L38) fall in between. This indicates that study efforts should be concentrated on the L7/L39L40 network of canals for the immediate future.

Sediment Phosphorus Flux

The studies showed that there can be extreme variations in phosphorus flux from the WCA sediments and that these variations can depend on geographical location, antecedent hydraulic conditions, and antecedent flux conditions, among other factors. The example calculations that were presented for the first set of flux measurements are hypothetical, but give an order of magnitude estimate of potential concentration increases arising from phosphorus flux out of the canal sediments. Maximum fluxes were typically sustained in the laboratory for the duration of a single floodwater-sampling interval, which was usually 2-5 days. It is safe to conclude that the impact of a maximum flux situation in the field would be less than one week. The hypothetical situations calculated in the examples would be expected to last for several days at most, and would be expected to occur one to three times during the life of a given sediment deposition. The differences between the first and second sediment sampling cycles demonstrated that the surficial sediment layer that can contribute to the phosphorus flux has a definite limited life span before it is mobilized, and this life span is highly dependent on hydraulic conditions.

Given these factors, it is concluded that phosphorus flux from the canal sediments would not typically be a significant *sustained* contributor to the elevation of dissolved phosphorus in the conveyance systems downstream of the STA's. Sediment phosphorus flux may, however, be a significant contributor to the elevation of dissolved phosphorus in the conveyance systems on a *periodic* basis under the appropriate conditions. These conditions would include stagnate or quiescent antecedent conditions, or upstream antecedent flow, which would allow internal deposition or importation of surficial sediments rich in readily available phosphorus. They would also include flows below the maximum sustained discharges. These lower flow rates cause less dilution of the phosphorus flux from the sediments and result in higher water column concentrations.

The flux studies indicate that phosphorus flux from the canal sediment will probably not be a major contributor to downstream phosphorus concentrations on an annual average basis. The study examples do indicate, however, that under certain circumstances the sediment flux could cause short-term phosphorus elevation in excess of 10 ppb. This would be most likely to happen early in a wet season, after prolonged quiescent periods, at flow rates in the lower 50 percentile of the seasonal distribution. If a compliance sampling schedule consisted of periodic grab samples taken with no regard for seasonal timing or flow distribution, it is possible that samples taken early in the wet season could be skewed upward by the sediment flux contribution. These samples could indicate that a well performing STA, discharging phosphorus in the range of 8-10 ppb, was discharging water at the end of the conveyance system with phosphorus in excess of 20 ppb.

The calculations of sustainable flux into stagnate water indicated that, in the absence of biological or chemical reactions, sediment flux might have a significant impact on water column dissolved phosphorus concentrations during quiescent periods. The results of field sampling illustrated in Figure 2.37 call into question the assumption of no biological or chemical reactions. The data illustrated in Figure 2.37 were collected during the summer months. The possibility still exists that sediment flux might contribute to elevation of water column phosphorus in the cooler months, but there was no direct evidence found during this study to support that contention.

Conveyance System Transport Studies

The transport studies gave evidence of significant interaction of the conveyance systems with both dissolved and particulate phosphorus species. The hypothesized mechanisms of these interactions are different for the dissolved and particulate species. Both mechanisms are based on the biological activity prevalent in the canal/floodplain systems, but their time responses are very different. The postulated dissolved phosphorus removal/contribution mechanisms depend on the biochemical balance between uptake and release of dissolved phosphorus by the aquatic population in the conveyance system, while the postulated particulate phosphorus removal/contribution mechanisms depend on the balance between the biochemical production of particulate phosphorus and the physical depletion of the particulate phosphorus reservoir by hydraulic forces.

The dissolved phosphorus mechanisms appear to respond relatively rapidly to changing conditions, and appear to be sensitive to seasonal changes. The particulate phosphorus mechanisms, on the other hand, appear to have more inertia, to be relatively insensitive to short term biochemical changes, and to be more dependent on the status of the particulate reservoir and on hydraulic conditions, both antecedent and current.

The positive dissolved phosphorus downstream gradients that were observed in L7 at the start and end of the pumping season are of interest because they indicate a net contribution of dissolved phosphorus to the water column in both the mid-spring and late autumn periods, both of which typically fall in the dry season. It is not possible, with the data in hand, to estimate how much of this contribution may have come from sediment flux and how much from aquatic plant senescence, but the positive gradients that were observed suggest that additional study should be done on the system dynamics of the canal/floodplain systems during the dry season. If the conveyance systems become net contributors of dissolved phosphorus in the dry season, then they could have a negative effect on system performance measures during times of winter storms.

The data presented in Figure 2.38, which was obtained in mid May, implies that the particulate phosphorus reservoir, which was presumably deposited prior to this sampling, was formed under dissolved phosphorus concentrations of less than 10-15 ppb, which is considerably lower than the average of about 35 ppb that was observed during the flow sampling events. If this is the case, then the extent of the particulate phosphorus reservoir may not be strongly related to the average dissolved phosphorus concentration that prevails during flow conditions. Stated more precisely, the extent of the particulate phosphorus reservoir may depend primarily on the standing population in the canal/floodplain system, which would be expected to respond slowly to changes in dissolved phosphorus concentration. This situation could have a major impact on the performance of the combined STA-canal-floodplain system if the phosphorus concentration in the discharge of the STA is reduced.

Figure 2.39 shows that the downstream particulate phosphorus gradients in L7 were in excess of 1 ppb/mile and were as high as 2 ppb/mile for the first half of the cumulative flow discharged during the pumping season. If the discharge from the STA were reduced to 10 ppb, but these magnitude gradients still prevailed because the extent of the particulate phosphorus reservoir formation had not been affected then the system could easily impose an additional 10-15 ppb concentration increase in total phosphorus at the discharge of the conveyance system. This is probably the most significant finding of this study.

The sediment flux samples taken at two different times with two different antecedent hydraulic conditions showed orders of magnitude reductions in dissolved phosphorus flux for most of the second sample set. The second sample set, however, was taken at the time when the particulate phosphorus reservoir that contributed to the high downstream gradients just mentioned was presumably being formed. This again highlights the differences between the dissolved phosphorus and the particulate phosphorus mechanisms. The apparent anomaly can be made consistent if the source of the particulate phosphorus reservoir is primarily from the floodplain rather than the canal sediment. Once again, this is a hypothesis, but it is one that is logical and consistent with the observed phenomena.

Recommendations for Future Work

The goal of this study was to obtain data sufficient to make first-order approximations of the system parameters, to determine if the canal systems downstream of the STA's could significantly affect phosphorus concentrations discharged to the WCA's, and to try to determine dominant processes. This goal was achieved. There is a significant reservoir of readily available phosphorus in the canal sediments, but this reservoir varies from location to location, with the eastern locations having the largest fraction of readily available phosphorus in their sediments. The rate of release of dissolved phosphorus from the sediments was found to be highly variable, but even at the maximum rates it appears that sediment release effects would have only transient impact on downstream dissolved phosphorus.

The transport studies suggested that the effects of the dynamic interactions between the canal/floodplain system and the water column appear to have impacts that are of large magnitude and long duration. Particulate phosphorus mobilization was significant early in the pumping season, and the apparent washout of the particulate phosphorus reservoir took about half the season to complete. The apparent uptake of dissolved phosphorus by the canal/floodplain system was significant for the last half of the season, and showed some dynamic positive and negative changes as the season progressed.

There appeared to be fairly rapid removal by the canal/floodplain system of dissolved phosphorus from levels of 25-30 ppb down to levels of 10-12 ppb, but the 10-12 ppb range appeared to be an asymptotic or steady state level. Similarly, levels of 10-15 ppb appeared to be an asymptotic or steady state level for particulate phosphorus during the quiescent periods.

These findings suggest the future studies should focus on the interaction between the canal/floodplain mobile sediments and aquatic systems and the water column. Emphasis should be expanded to investigate dry season and early wet season phenomena. A more detailed evaluation of the source, character, and mobilization characteristics of the particulate matter should be conducted. Additional studies are needed to evaluate the dissolved phosphorus removal and contribution mechanisms, rates, capacities and seasonal responses. The apparent asymptotic or steady state levels of both dissolved and particulate phosphorus that were observed need to be investigated in more detail, over longer time frames, and under varied seasonal conditions. Finally, a better understanding of the hydraulic interactions between the canals and their floodplains is needed in order to project future performance when lower phosphorus discharges are achieved from the STA's.

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