

L40 Canal Water Quality Survey Study Progress Report for 2006



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INTRODUCTION

Impact of stream sediments on surface water quality has been an area of active water-science research (Bostrom et al., 1988; Brunke and Gonser, 1997; Brunke et al., 1998; Dahm et al., 1998; Daroub et al., 2003; DiToro, 2001; Grimm and Fisher, 1984; Perkins and Underwood, 2001; Vollmer et al., 2002; Waldon and McCormick, 2003). Sediments play an important role in P cycling of shallow water bodies such as lakes, wetlands, streams, and main drainage canals. Studies have shown that sediments can function as sink or source for P depending on water column physicochemical properties (Reddy et al., 1995; Richardson, 19985). The research project described here will further increase our understanding of these processes in the L-40 Canal and surrounding conservation areas.

The Arthur R. Marshall Loxahatchee National Wildlife Refuge includes one of three areas in South Florida designated to maintain water storage, provide flood control, and provide refuge for the remnant Everglades ecosystem. In the 1950s and 1960s the refuge was surrounded by perimeter canals and hydrologically isolated from its watershed by levees. Stormwater runoff, primarily from the Everglades Agricultural Area (EAA) and surrounding communities, is pumped into the perimeter canal where it may flow to discharge structures or mix into the rainwater-dominated interior wetland. Nearly a half-century of high-phosphorus (P) and highly organic sediments have accumulated in the L-40 Canal to a depth of several feet that has the potential to interact with the above water column (Daroub et al., 2003; Diaz et al., 2006).

As documented in the U.S. Fish and Wildlife Service (USFWS) comments to the Florida DEP regarding the STA-1E NPDES permit application, there is concern that sediments in the L-40 Canal may be suspended into the water column by relatively high velocities associated with STA-1E discharges. This could mobilize P stored in sediments and other nutrients and be transported into the A.R.M Loxahatchee National Wildlife Refuge wetlands. In general, canals bordering the A.R.M. Loxahatchee National Wildlife Refuge are full of sediments that have the potential to be disturbed and resuspended during strong drainage events. Sediments from the L-40 Canal in particular are light and highly organic making them more susceptible to resuspension and transport during strong drainage events. These sediments also have a higher Fe- and Al-bound P fraction that could result in a long-term release of Fe-bound P to the overlying water column as a consequence of changes in the redox potential of these sediments (Diaz et al., 2006). This expected additional flow from an active STA-1E, will generally have higher P and other dissolved nutrients than the background levels found in the refuge, and more likely will have the potential to impact a considerable area inside the refuge. The objective of these and future water surveys are to characterize how total P and other water properties are influenced along the L40 Canal during different flow conditions.

METHODOLOGY

Twelve sampling locations; three above and nine below the STA-1E discharge (S-362) were selected for the water quality survey study (Table 1, Figure 1). The decision on the number of sampling locations for this study was made in cooperation between UF/IFAS and A.R.M. Loxahatchee National Wildlife Refuge personnel. The set of sampling sites for this study were selected from a broader sampling study done previously by UF/IFAS (Daroub et al., 2003, Diaz et al., 2006). Site names are consistent with those used in the previous study for easy comparison purposes. Selected locations have been marked by GPS coordinates using a Trimble Unit Pro-XR DGPS Unit for future reference. Each sampling location has been marked with rebar post permanently installed on both sides of the L-40 Canal.

During each survey, a grab water sample was collected from the middle of the canal at each designated sampling location. Sample information and time of collection was recorded in a field book, as well as any other information observed in the field during each sampling event. At the beginning or end of each water sampling day, the status of water flow at the following drainage structures was recorded from the South Florida Water Management District (SFWMD) real time web interface: G-300, S-362, G-94B, G-94C, G-94D, and ACME-1. Each grab sample was properly labeled, stored in a cooler with ice and immediately transported to the Everglades Research and Education Center (EREC) Water Quality Laboratory for analysis. All water samples were analyzed for total P (TP), total dissolved P (TDP), soluble reactive P (SRP), total suspended solids (TSS), specific conductance (SC), and turbidity. Particulate P (PP) was calculated as the difference between TP and TDP. Detailed analytical procedures are contained in the Standard Methods for the Examination of Water and Wastewater (APHA, 1998), and EREC Standard Operating Procedures (Chen, 2001).

A total of nine water surveys are reported for year 2006. Water surveys reported in this progress report are divided in two categories: flow and no flow conditions. A total of six water surveys throughout the 2006 wet season were completed under different flow drainage conditions in the L40 Canal. Another three surveys were completed during quiescent times (no flow conditions). The same strategy will be followed for future water surveys to cover different flow conditions in the L40 Canal as a result of drainage activity from STA-1E. Selection of sampling dates will considerably depend upon drainage schedule of structure S-362. A website operated by the SFWMD showing real time data from structure S-362 will be monitored on a regular basis to verify drainage activity.

Table 1. Water sampling locations and distance below structure G-300.

Site	Distance (km)	Latitude (degrees)	Longitude (degrees)
G-300 [†]	0	26.6773	-80.3630
L40-28	0.27	26.6753	-80.3615
L40-26	3.32	26.6503	-80.3486
L40-24	6.57	26.6292	-80.3258
S-362	7.57	26.6250	-80.3170
L40-23	8.20	26.6211	-80.3122
L40-22	9.82	26.6131	-80.2986
ACME#1	11.00	26.6075	-80.2886
L40-20	13.00	26.5949	-80.2739
G-94D	13.33	26.5926	-80.2719
L40-18	16.24	26.5712	-80.2548
L40-16	19.49	26.5469	-80.2367
G-94C	20.19	26.5411	-80.2330
L40-14	22.72	26.5197	-80.2249
L40-12	25.93	26.4908	-80.2220
L40-10	29.14	26.4619	-80.2231
L40-08	32.34	26.4338	-80.2306

[†]G-300, S-362, ACME#1, G-94D, and G94C are drainage structure along the L40 Canal.

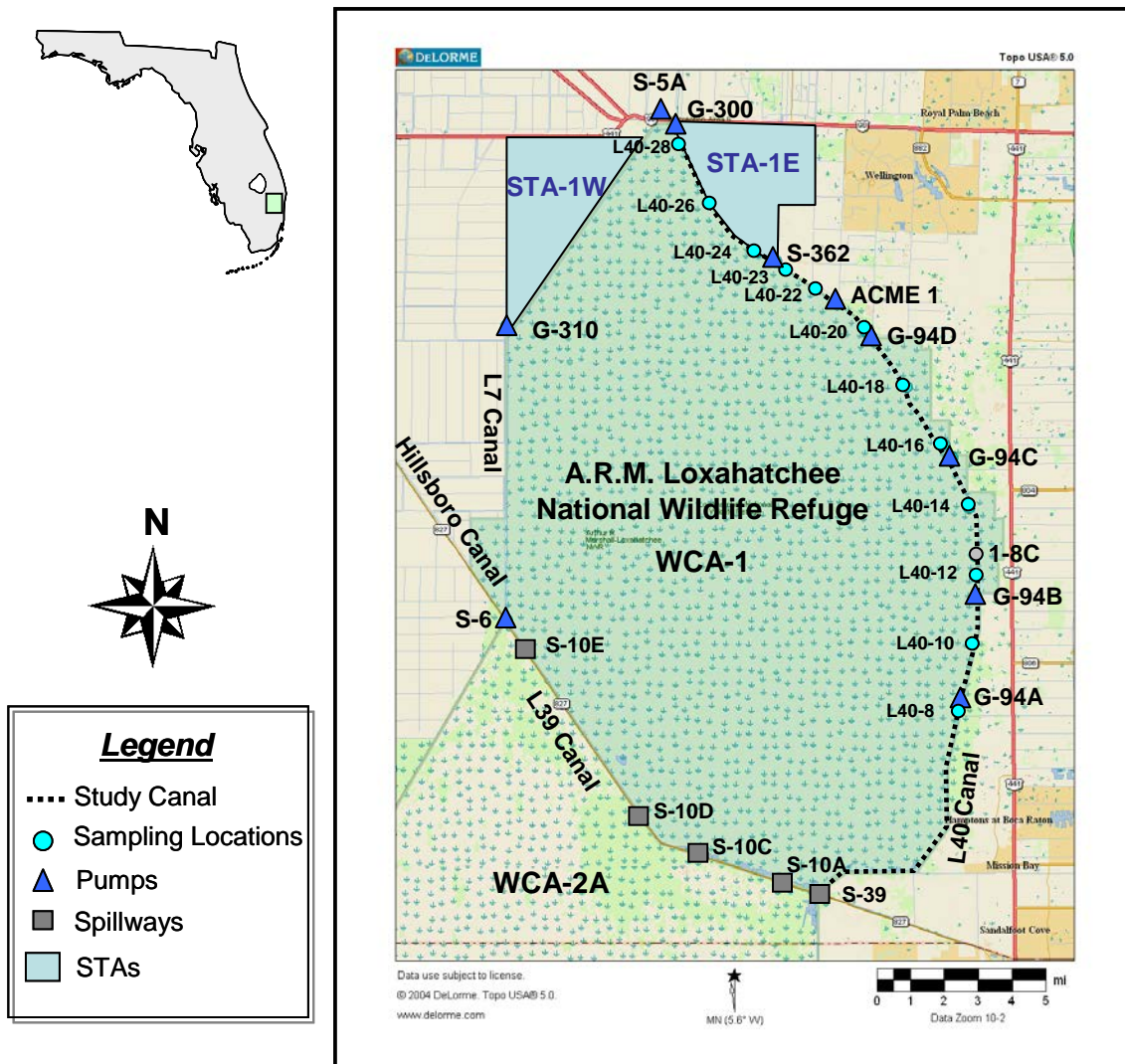


Figure 1. Sampling locations and main structures in the L40 Canal.

RESULTS AND DISCUSSION

The original project was designed to use a Lagrangian sampling design. The Lagrangian sampling, also termed plug sampling, is a method of stream sampling that tags a parcel of water using a tracer, and follows the tagged parcel using the tracer so that the same water parcel is sampled repeatedly through time (Mills et al., 1986). This method was tested in a water survey in May 2005, injecting the dye rhodamine WT just south of STA-1E outfall channel. However, the following day, we were unable to find the dye at several downstream locations in the L40 Canal. Some of the difficulties of this technique in the L40 Canal are boat traffic and extra flow coming into the canal through other structures such as ACME #1, G-94D, and G-94C, which may break the peak of the dye or further dilute the dye concentration, making it difficult to find the following days. Other attempts were made in June 2005, and finally it was decided that this was not the best method for this study. It was decided that at least six grab sampling survey at predetermined locations downstream and upstream of STA-1E outfall (S-362) will be performed during each year through the duration of the project. The idea is to perform the different sampling survey under different drainage flow conditions in the L40 Canal. The data presented in this progress report correspond to water samples collected during year 2006.

The hydraulic flow pattern for STA-1E (S-362), ACME #1, G-94D, G94C, and G94B for 2006 are shown in Figures 2 and 3. After some drainage activity in the middle of January and early February in 2006, structure S-362 had a period of relative quiescence that lasted until the last week of June, with only some sporadic low flow events in the months between February and June (Figure 2A). From June 27th through August 2nd, there were several drainage events that averaged 350-ft³/s. Drainage flow data from this structure shows that the highest drainage activity occurred between the months of July and September, with some sporadic pumping the rest of the year. Similar drainage flow patterns are shown for ACME #1 and G-94D structures for the same period, with the exception that these structures have a considerably lower drainage capacity than pump S-362 (Figures 2B and 2C). Structure G-94C showed some drainage activity only at the beginning and at the end of the year (Figure 3A), while structure G-94B showed drainage activity only from late March to the end of May (Figure 3B). Water samples collected on April 25th, May 10th and October 24th; correspond to a no drainage flow period from structures S-362, ACME #1, and G-94D. In contrast, samples collected on May 30th, June 28th, July 25th, August 23rd, September 1st, and November 14th correspond samples collected under different drainage flow conditions from the above mentioned drainage structures.

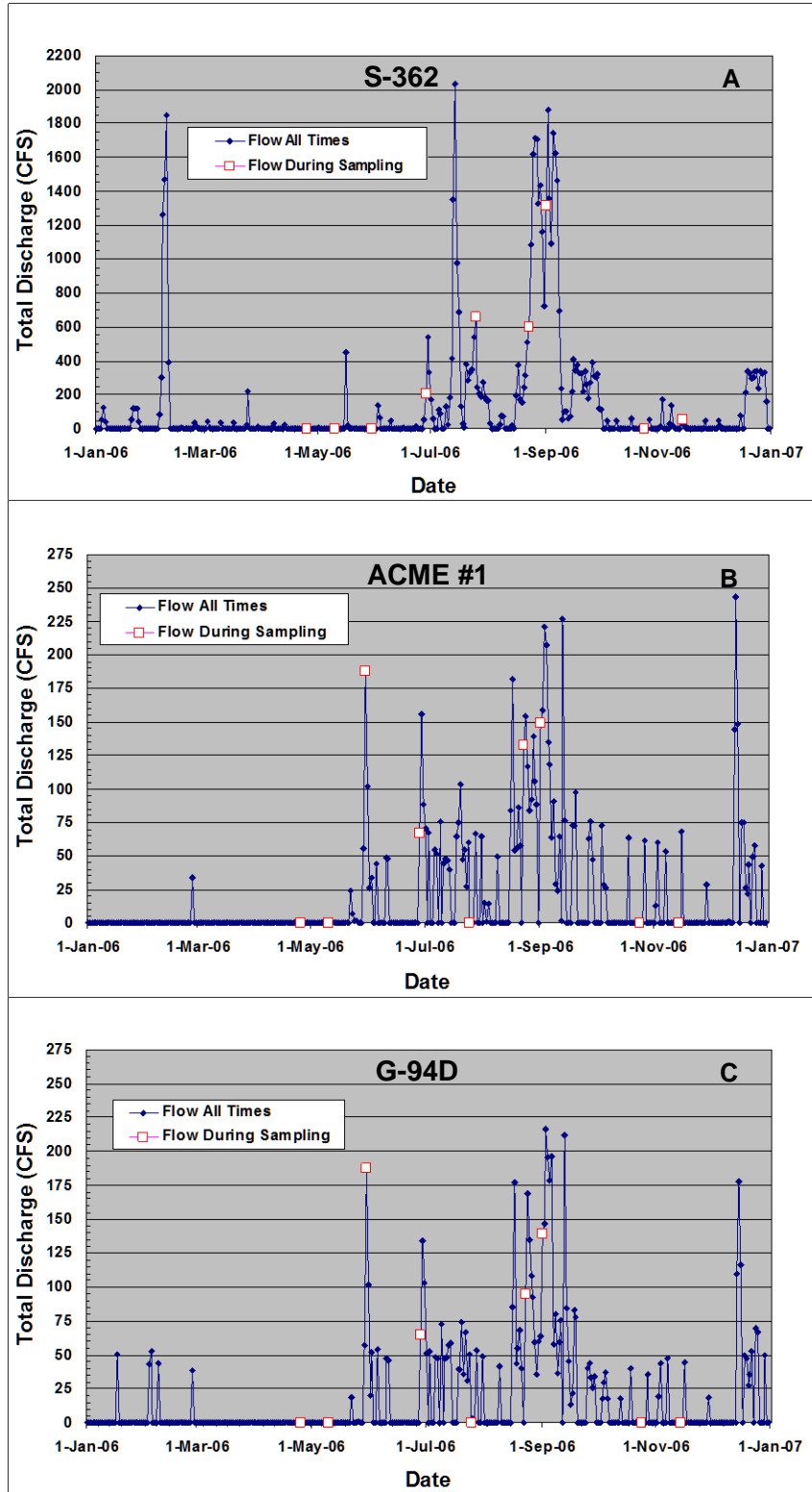


Figure 2. Discharge flows from S-362, ACME #1, and G-94D during 2006.

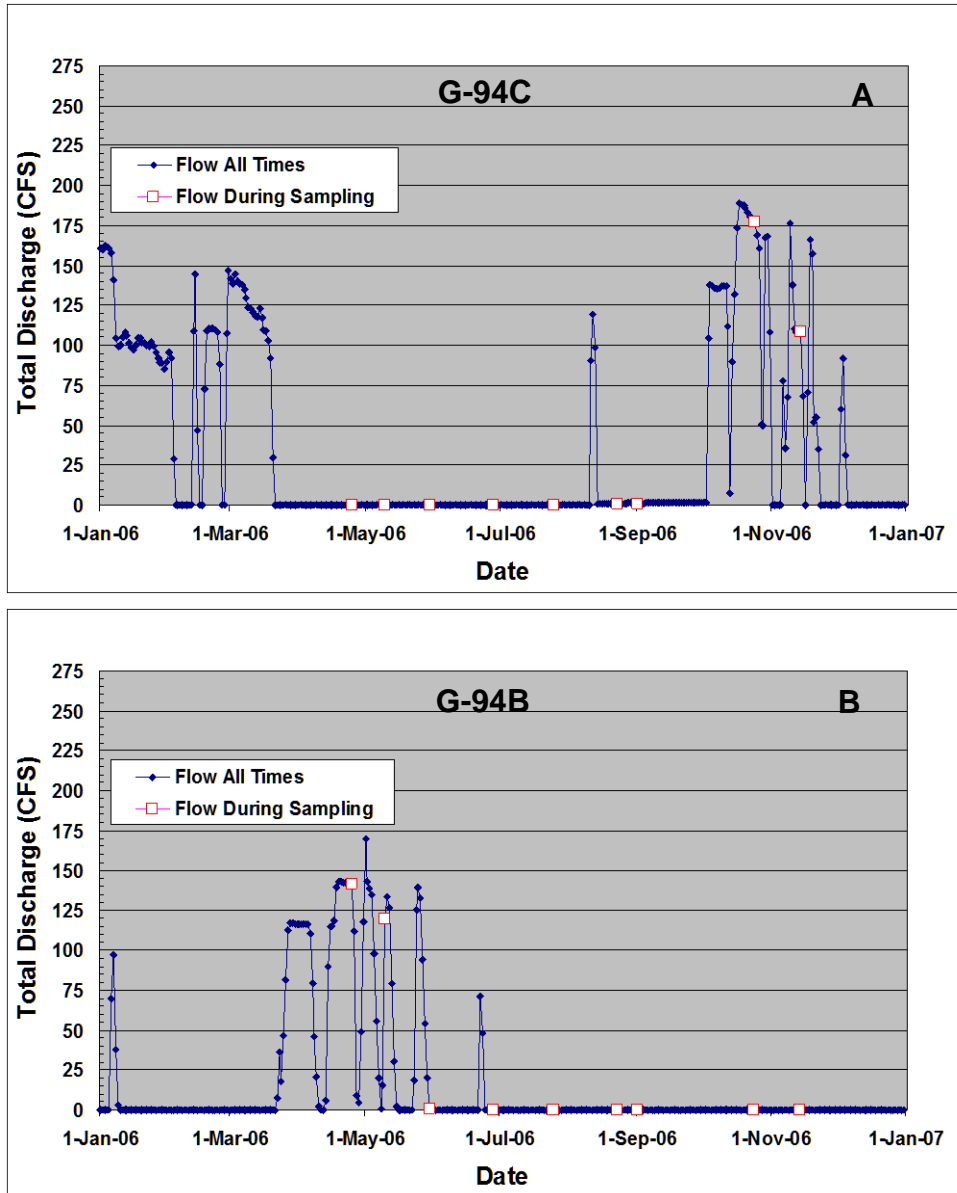


Figure 3. Drainage flow from culverts G-94C and G-94B during 2006.

Selected Water Properties under Flow and No Flow Conditions

Phosphorus

Phosphorus concentrations along the L40 Canal showed differences due to the effect of drainage flow intensity and timing of water sampling. Phosphorus concentrations presented in Figure 4A are the averages of six water samplings done under different flow drainage conditions that ranged from as low as 162 ft³/s on November 14th, to as high as 1604 ft³/s on September 1st. Figure 4B is the average of three water samplings done under no drainage flow conditions in the L40 Canal. Total P concentrations from samples collected under drainage flow conditions averaged 77 µg/L with concentrations ranging from 86 µg/L at the sampling station south of structure S-362 (L40-22) to 57 µg/L at the southernmost sampling station (L40-08) (Table 2, Figure 4A). Overall average TP concentrations from samples collected under flow drainage conditions north of structure S-362 were fairly uniform, averaging 78 µg/L, with concentrations slightly decreasing downstream of structure G-300. Total P concentrations north of ACME #1 (L40-22) and south of G-94C structure (L40-14) were also uniform averaging 84 µg/L, however, TP concentrations steadily decreased in the last 10 km of the canal reaching a TP concentration of 57 µg/L at the L40-08 sampling station. Similar TP concentrations (mean TP, 76 µg/L) for the L40 canal for WY2006 were reported by Payne et al. (2007), with concentrations decreasing from north to south, with the highest concentrations measured at the inflow points. As high TP water enters the northern part of the L40 canal, processes such as settling, sorption, biological assimilation and other biochemical processes results in the decrease of TP concentrations as water flows south in the canal.

Total P concentrations from samples collected during no drainage flow conditions followed the same pattern observed in samples collected under flow conditions, however, TP concentrations were consistently lower throughout the entire canal. Total P from no drainage flow samples averaged 56 µg/L, with concentrations ranging from 71 µg/L at sampling station L40-16 to 20 µg/L at sampling station L40-08 (Table 3, Figure 4B). Total P concentrations from the northern half of the canal (from G-300 to L40-16) were variable with concentrations ranging from 51 to 71 µg/L, with TP concentrations rapidly decreasing in the southern half of the canal reaching the lowest concentration (20 µg/L) at sampling station L40-08.

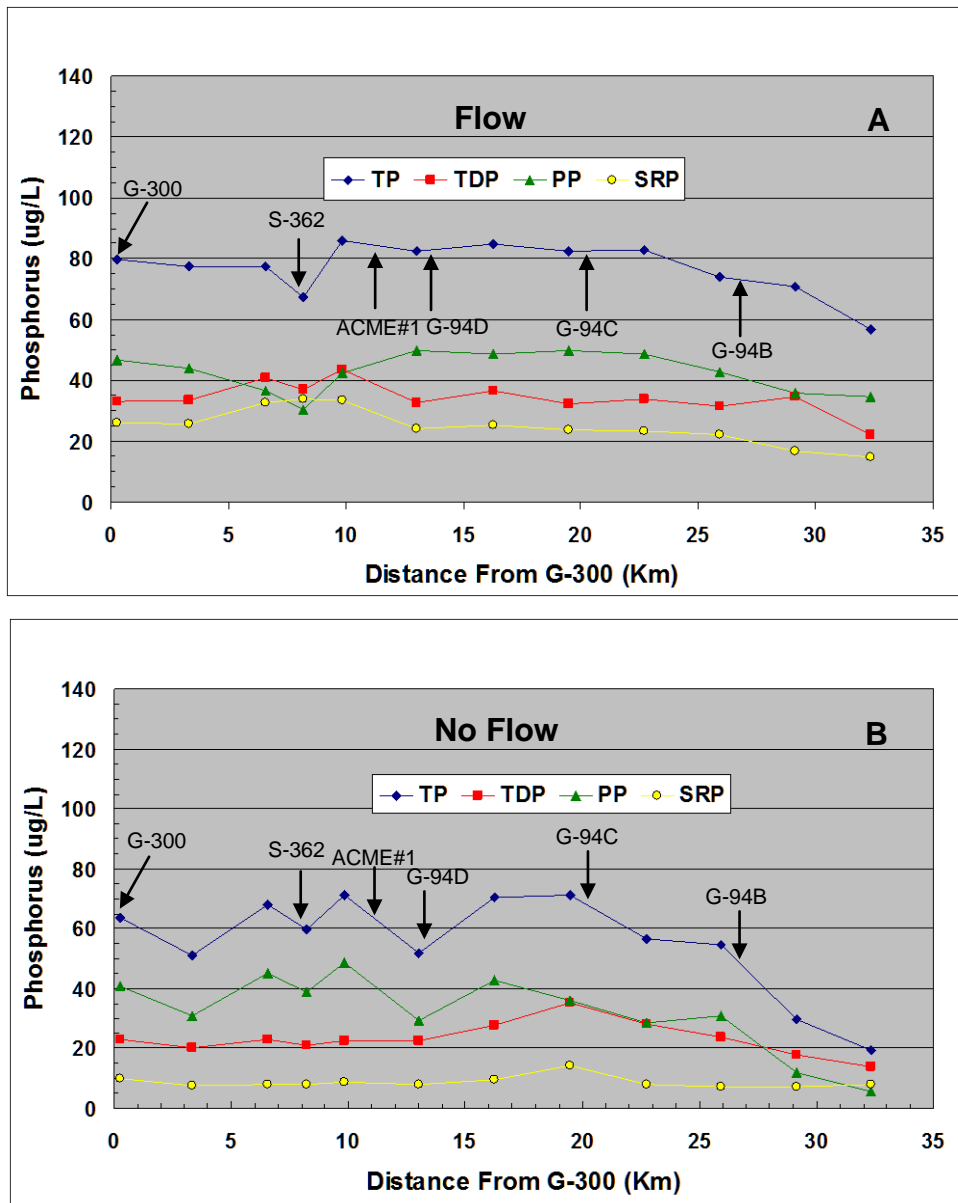


Figure 4. Phosphorus averages of water samples collected during flow and no flow conditions in the L40 Canal, 2006.

Table 2 .Selected physical and chemical properties of surface water samples from the L40 canal collected during flow conditions, 2006.

Locations	TSS†	Turbidity	Conductivity	TP	TDP	PP	SRP
	mg/L	NTU	µS/cm	-----	µg/L	-----	
L40-28	11.9 (9.0)‡	11.9 (11.2)	847 (145)	79.6 (19.3)	33.0 (24.3)	46.7 (25.1)	26.0 (26.4)
L40-26	10.8 (8.6)	10.7 (10.5)	856 (109)	77.4(22.4)	33.6(26.2)	43.8 (18.6)	25.5 (28.4)
L40-24	6.8 (5.7)	5.7 (7.0)	903 (107)	77.2 (52.4)	40.7 (49.3)	36.6 (10.6)	32.5 (53.0)
L40-23	6.0 (3.8)	4.9 (4.2)	820 (112)	67.3 (40.7)	36.9 (49.2)	30.4 (19.8)	33.9 (50.8)
L40-22	9.4 (9.7)	9.5 (11.7)	795 (75)	86.1 (41.5)	43.6 (49.1)	42.4 (33.5)	33.5 (51.0)
L40-20	14.2 (14.9)	11.9 (14.7)	807 (70)	82.6 (30.4)	32.8 (29.5)	49.8 (33.0)	24.1 (29.9)
L40-18	11.8 (6.4)	9.7 (7.0)	709 (87)	85.0 (19.6)	36.5 (23.9)	48.5 (26.9)	25.5 (25.2)
L40-16	11.7 (4.0)	8.4 (4.7)	753 (78)	82.4 (16.1)	32.5 (19.7)	50.0 (17.9)	23.7 (25.3)
L40-14	10.8 (5.2)	7.7 (4.8)	678 (179)	82.7 (32.8)	33.9 (13.0)	48.8 (28.8)	23.3 (17.6)
L40-12	10.2 (6.1)	7.2 (4.3)	620 (142)	74.0 (30.7)	31.4 (11.2)	42.6 (26.7)	22.0 (15.3)
L40-10	9.1 (4.8)	6.3 (4.0)	633 (178)	70.7 (28.6)	34.7 (18.4)	35.9 (30.9)	16.6 (13.6)
L40-08	7.5 (4.1)	5.1 (2.5)	614 (168)	56.8 (16.8)	22.3 (10.6)	34.5 (12.1)	14.7 (11.0)

†TSS = Total Suspended Solids; TP = Total P; TDP = Total Dissolved P; PP = Particulate P; SRP = Soluble Reactive P.

‡ Mean of six sampling date values with standard deviation in parenthesis.

Table 3 .Selected physical and chemical properties of surface water samples from the L40 canal collected during no flow conditions, 2006.

Locations	TSS†	Turbidity	Conductivity	TP	TDP	PP	SRP
	mg/L	NTU	µS/cm	-----	µg/L	-----	
L40-28	8.1 (3.1)‡	7.1 (4.0)	1015 (251)	63.5 (13.5)	22.8 (2.3)	40.6 (13.5)	9.9 (6.9)
L40-26	13.5 (6.1)	10.8 (7.1)	997 (263)	50.9 (12.8)	20.1(2.5)	30.9 (10.8)	7.4 (4.3)
L40-24	14.5 (8.3)	11.1 (8.2)	1000 (239)	68.1 (19.6)	23.0 (7.8)	45.1 (13.9)	7.8 (3.9)
L40-23	13.2 (7.6)	9.3 (6.0)	995 (211)	59.9 (18.0)	21.1 (5.7)	38.8 (17.2)	8.1 (3.6)
L40-22	13.7 (9.2)	10.2 (7.6)	960 (231)	71.1 (25.3)	22.5 (8.6)	48.6 (16.8)	8.8 (4.2)
L40-20	13.4 (7.1)	9.9 (5.9)	976 (210)	51.8 (15.1)	22.5 (9.7)	29.3 (10.1)	8.0 (1.9)
L40-18	11.3 (5.1)	8.0 (3.9)	964 (180)	70.3 (28.3)	27.5 (4.2)	42.8 (24.2)	9.6 (4.1)
L40-16	10.2 (4.1)	7.1 (2.7)	872 (153)	71.2 (27.3)	35.4 (14.6)	35.8 (17.1)	14.4 (10.7)
L40-14	9.0 (3.1)	5.3 (1.1)	768 (340)	56.7 (13.1)	28.2 (12.2)	28.5 (4.3)	8.1 (3.1)
L40-12	6.8 (2.5)	3.8 (1.0)	626 (240)	54.5 (30.5)	23.6 (6.0)	30.9 (24.7)	7.1 (1.9)
L40-10	3.3 (0.5)	2.1 (0.3)	526 (129)	29.6 (5.5)	17.9 (2.5)	11.7 (4.8)	7.3 (1.9)
L40-08	2.9 (0.5)	2.1 (0.6)	550 (73)	19.5 (7.7)	13.9 (5.8)	5.7 (3.8)	8.0 (2.0)

†TSS = Total Suspended Solids; TP = Total P; TDP = Total Dissolved P; PP = Particulate P; SRP = Soluble Reactive P.

‡ Mean of three sampling date values with standard deviation in parenthesis.

Water samples were also filtered and analyzed for soluble (TDP and SRP) and particulate P to quantify the different P fractions under drainage flow and no flow conditions along the L40 Canal. Total dissolved P concentrations from water samples collected under drainage flow conditions averaged 34 $\mu\text{g/L}$, representing 45% of the total P in the water column (Figure 4A). Average TDP concentrations from water samples collected under drainage flow conditions were fairly uniform along the entire canal, with TDP concentrations ranging from 44 $\mu\text{g/L}$ at sampling station L40-22 which is in the vicinity of drainage structures S-362 and ACME #1 to only 22 $\mu\text{g/L}$ at sampling location L40-08 located at the end of the canal reach under study. However, TDP concentrations from individual sampling surveys showed higher variability depending on the intensity of the drainage flow in the canal at the time of sampling (Appendix B). The contribution of TDP to total P in the water column from individual surveys ranged from as low as 21% in samples collected on June 28th to as high as 75% on samples collected on September 1st. Total dissolved P concentrations of samples from June 28th correspond to a low drainage flow (339-ft³/s) averaging only 18 $\mu\text{g/L}$, with TDP concentrations slightly increasing from north to south (Figure 5A). In contrast, TDP concentrations from the September 1st water sampling survey correspond to one of the highest drainage flow periods in 2006 (1604 ft³/s), with TDP concentrations averaging 83 $\mu\text{g P/L}$, which also corresponded to the highest P concentrations measured in 2006 (Figure 6A). Total dissolved P concentrations from samples collected on September 1st showed the highest concentrations around structure S-362. In contrast, TDP concentrations from samples collected during no drainage flow conditions were more uniform during all surveys, averaging 23 $\mu\text{g/L}$. Average TDP concentrations of water samples collected under no drainage flow conditions represented 44% of the total P, with concentrations ranging from 35 $\mu\text{g/L}$ (L40-16) to only 14 $\mu\text{g/L}$ at the L40-08 sampling station (Table 3, Figure 4B).

Particulate P represents all solid phase forms including P sorbed by sediment particles and organic and inorganic material transported in the water column during drainage events. These results shows that particulate P accounted for 55% (42 $\mu\text{g/L}$) of the total P in the water column of samples collected during the different water sampling surveys under different levels of drainage flow along the L40 Canal. Average particulate P concentrations showed three distinct patterns along the L40 Canal reach under study. The upper most section of the L40 Canal averaged 39 $\mu\text{g/L}$, with concentrations gradually decreasing from about 47 $\mu\text{g/L}$ south of structure G-300 to 30 $\mu\text{g/L}$ (L40-23) immediately south of structure S-362 (Figure 4B). South of S-362 (L40-22), particulate P concentrations steadily increased and reached an average concentration of 48 $\mu\text{g/L}$ for the following 13 km of the L40 Canal. However, particulate P concentrations steadily decreased during the last 10 km reaching the lowest average concentration (35 $\mu\text{g/L}$) at the last sampling station (L40-08) in the L40 Canal.

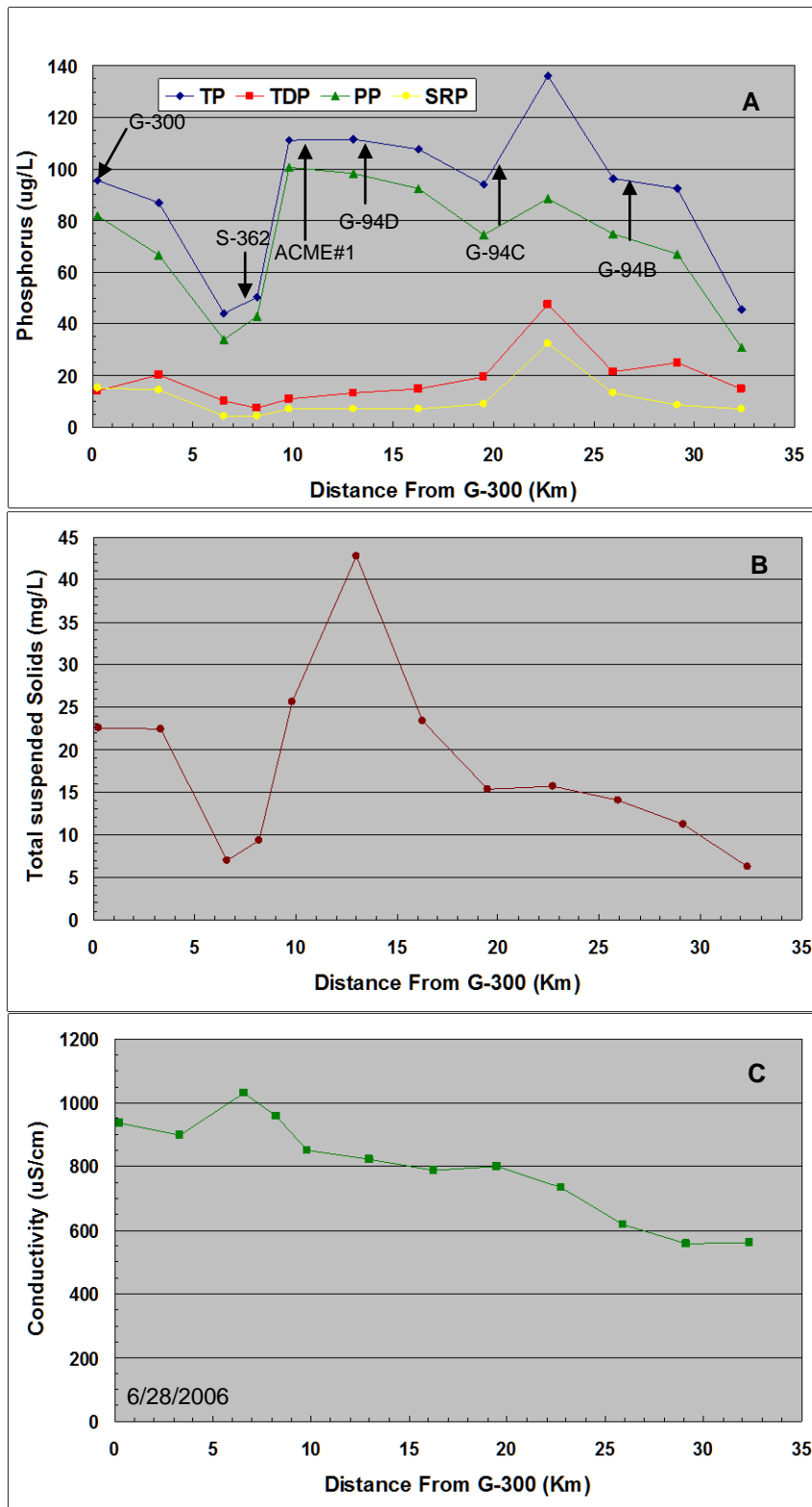


Figure 5. Selected profiles along the L40 Canal of water samples collected on June 28th, 2006: A) Phosphorus, B) TSS, and C) Conductivity.

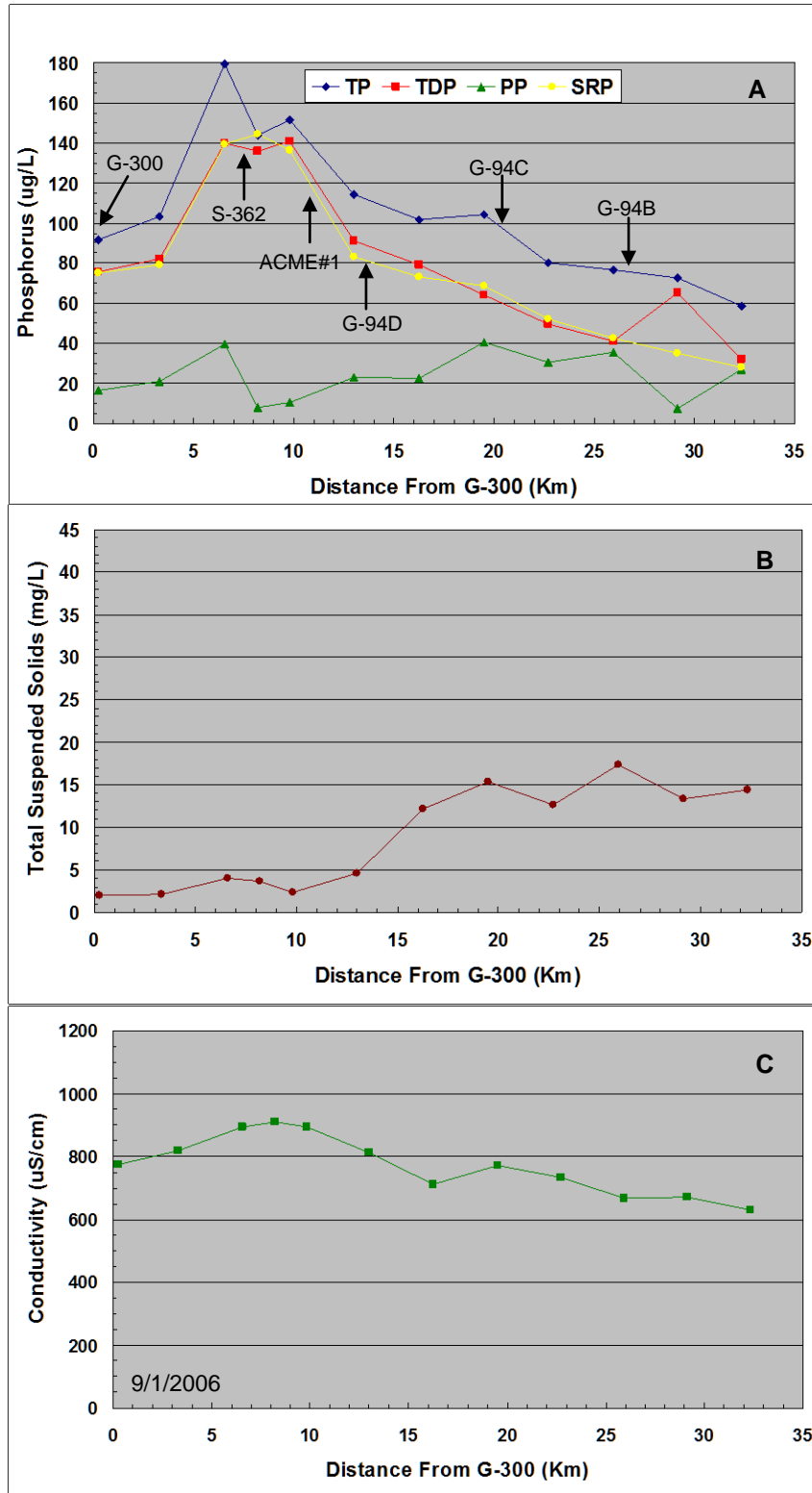


Figure 6. Selected profiles along the L40 Canal of water samples collected on September 1st, 2006: A) Phosphorus, B) TSS, and C) Conductivity.

Similarly to TDP, the particulate P contribution to total P in the water column was more variable during individual surveys depending on the intensity of drainage flow along the L40 Canal (Appendix B). The contribution of particulate P to total P in the water column from individual surveys ranged from 79% on samples collected on June 28th to only 25% on samples collected on September 1st. Particulate P concentrations of water samples collected on June 28th, reported the highest contribution of particulate P to the water column (79%) measured during 2006, with concentrations averaging 71 µg/L (Figure 5). June 28th was the first significant drainage activity from structure S-362 since the first week of February and also from ACME #1 and G-94 D drainage structures since the end of May. Particulate P that have been accumulated in the L40 canal during this long quiescent period was more likely to be disturbed and transported even at a low drainage flow (339 ft³/s) as that reported on this date. The same phenomenon called “first flush effect” is observed in farm drainage canals in the EAA, where biological material can grow and accumulate in the canals during long quiescent periods. This fresh and highly mobile material is readily suspended and transported during the first significant pumping event, resulting in high concentrations of suspended solids high in P content during the early periods of drainage events.

The opposite circumstances occurred on water samples collected on September 1st, which reported the lowest contribution of particulate P to the water column measured during 2006. Particulate P concentrations of water samples from September 1st correspond to the highest drainage flow in 2006 (1604 ft³/s), as a result of the tropical storm Ernesto that passed through this area on August 30th (Figure 6). However, particulate P concentrations for this date averaged only 24-µg/L, which represents only 25% of the total P in the water column. These results were unexpected considering the high flow activity and the volume of sediment stored in this canal. In anticipation to the projected rainfall from tropical storm Ernesto, the SFWMD had been heavily pumping this area during the previous week, which may have flushed downstream the light sediment material that generally accumulates in the surface few cm of the canal bottom, explaining the low particulate P concentrations measured during this water sampling survey. However, total P concentrations measured during this survey were the highest measured during 2006, averaging 107 µg/L, with TDP concentrations (83 µg/L) accounting for 75% of total P in the water column. These high TDP concentrations may suggest the influence of soluble P sources from surrounding urban areas that under heavy rainfall and pumping activity are more likely to be transported in drainage waters impacting the overall total P loading coming into the Refuge.

Particulate P under no flow conditions averaged 32 µg/L, with concentrations steadily decreasing from north to south (Figure 4B). Average particulate P values under no flow conditions represented 56% of the total P, with concentrations ranging from as high as 49 µg/L at sampling station L40-22 (north of ACME #1) to as low as 6 µg/L at sampling station

L40-08 located at southernmost point in the canal under study (Table 3, Figure 4B). Particulate P concentrations from the first 15 km of the canal were more variable averaging 41 µg/L, with concentrations steadily decreasing during the last 17 km of the canal reach.

Soluble reactive P is an inorganic, soluble form of P that is considered to be readily biologically available, and therefore has the greatest and most rapid effect on the ecosystem. Soluble reactive P concentrations from samples collected under drainage flow conditions averaged 25 µg/L, with concentration ranging from 15 µg/L at sampling station L40-08 to 34 µg/L at sampling station L40-23, which is located immediately south of structure S-362 (Table 2, Figure 4A). These results show that SRP concentrations during sampling surveys under drainage flow conditions accounted for 73% of the TDP in the water column. Soluble reactive P in the first 10 km in the north part of the L40 Canal steadily increased from 26 µg/L south of structure G-300; to 34 µg/L south of structure S-362 (L40-23). South of structure S-362 SRP concentrations remained fairly uniform at about 24 µg/L, with concentrations steadily decreasing toward the southern most sampling stations of the study. Soluble reactive P concentrations from individual sampling surveys behaved similar to TDP, with higher concentrations associated with the intensity of the drainage flow in the canal during sample collection (Appendix B). Average SRP concentrations from individual sampling surveys under drainage flow conditions ranged from as low as 8 µg/L from samples collected on May 30th to as high as 80 µg/L from samples on September 1st. Most of the sampling surveys reported average SRP values around 10 µg/L; except for concentrations from July 25th and September 1st which averaged 32 and 80 µg/L, respectively. The contribution of SRP values to TDP in the water column from individual sampling surveys ranged from as low as 33% on samples collected on May 30th to as high as 95% on samples collected on September 1st, with both sampling surveys reporting TDP as the dominant P fraction in the water column. In contrast, SRP concentrations of samples under no flow conditions were uniform throughout the L40 Canal, averaging only 9 µg/L (Table 3, Figure 4B). Average particulate P values under no flow conditions represented only 38% of the TDP in the water column.

Total Suspended Solids

Total suspended solids concentration is used as the measure of particulate matter present in the drainage water. In this study, TSS is used as a measure of particulate matter in the water column due to disturbances in the water column such as drainage flow along the L40 canal. The overall TSS average concentrations during flow and no flow conditions did not show any differences, averaging 10 mg/L (Figure 7). However, there were differences in concentrations along the 32 km of canal reach under study. Under drainage flow conditions, average TSS concentrations steadily decreased from 12 mg/L just south of G-300 to 6 mg/L south of structure S-362 (L40-23). South of structure S-362, TSS concentrations rapidly

increased at stations in the vicinity of ACME #1 and G-94D structures to as high as 14 mg/L, following a steady decrease for the remaining 20 km of the canal (Figure 7A). Although average TSS concentrations from water samples collected under drainage flow conditions did not change considerable, concentrations from individual sampling surveys showed higher variability, especially during drainage flows after long inter-event times. Inter-event time is the time from cessation of pumping in the prior event to the start of pumping of the current event.

Total suspended solids concentrations from individual surveys under drainage flow conditions were higher at the beginning of the rainy season and gradually decreased toward the end of the year. Water samples collected on May 30th (Figure B3) and June 28th (Figure 5B) yielded average TSS concentrations of 16 and 18 mg/L, respectively. May 30th was the first significant drainage activity from structures ACME #1 and G-94D for 2006 (Figures 2B and 2C). Similarly, June 28th was the first significant drainage activity from structure S-362 since the first week of February (Figures 2A). Studies in EAA farm canals have observed a clear pattern of increasing TSS concentrations with increasing inter-event times. This pattern is interpreted as an indication of the build-up of living biomass and detritus during the quiescent period in the canal, followed by the partial flushing of the mobile fraction of the build-up biomass during the first pumping events. As times passes, detritus released by plant senescence becomes compacted and more difficult to mobilize, thus the decrease of TSS with time tends to taper off as long inter-event times are encountered (Daroub et al., 2003).

Specific Conductance

Specific conductance (conductivity) is an indirect measure of the total concentration of ions (e.g., Ca^{2+} , Mg^{2+} , Na^+ , K^+ , Cl^- , HCO_3^- , SO_4^{2-} , and F^-) in the water. Changes in conductivity beyond natural backgrounds variability can result in potentially deleterious effects to aquatic life. The Refuge is naturally a rainfall-dominated system with surface water exhibiting a low mineral or ion content. The refuge represents one of the last remnants of the historic soft-water Everglades, as evidenced by the low conductivity levels of surface waters in the marsh interior compared with concentrations in the canals surrounding the Refuge. However, there is concern that restoration efforts associated with the Everglades Construction Project and Comprehensive Everglades Restoration Plan may increase intrusion of water with higher specific conductance into the interior of the Refuge which may impact water chemistry on sensitive biota (Weaver and Payne, 2006).

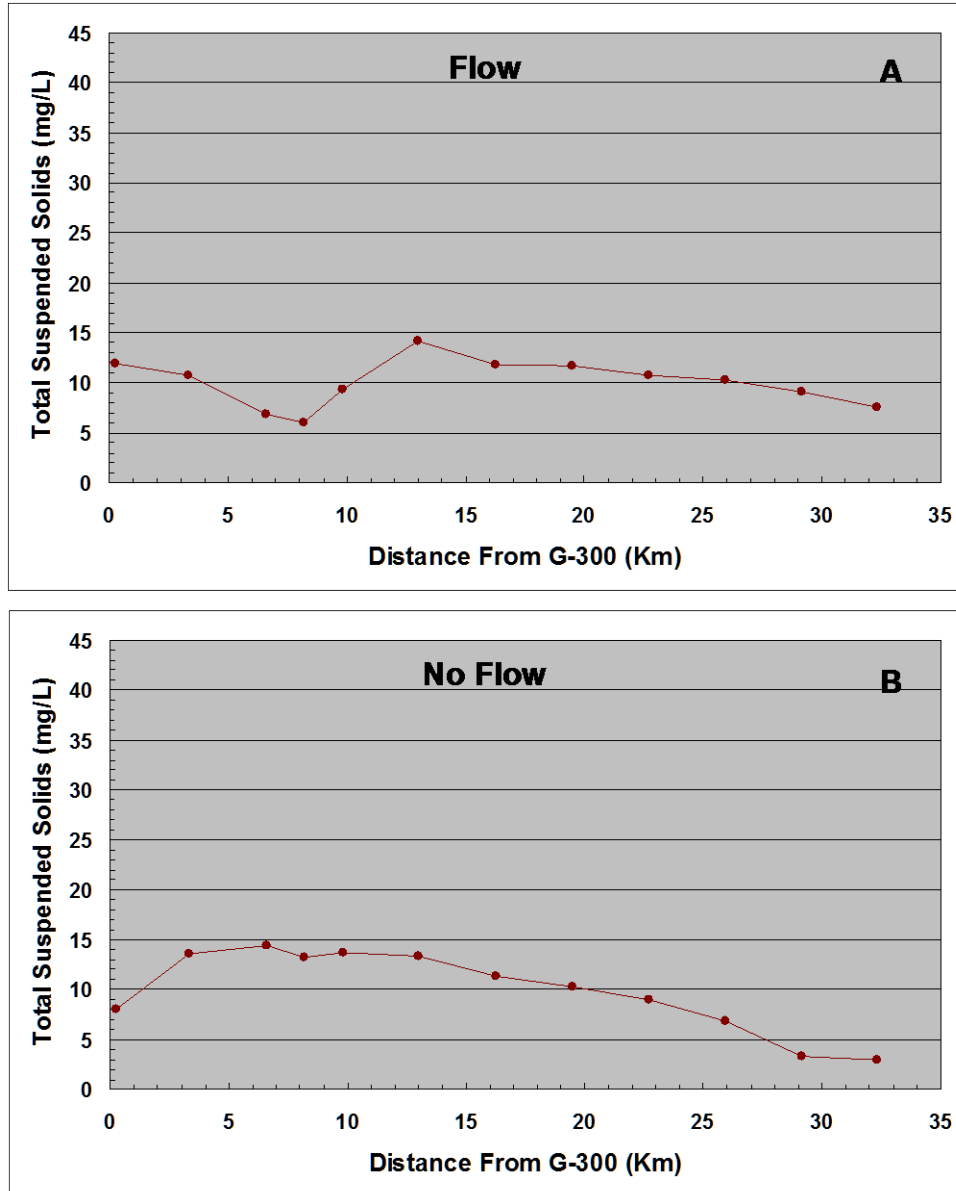


Figure 7. Total suspended solids averages of water samples collected during flow and no flow conditions in the L40 Canal, 2006.

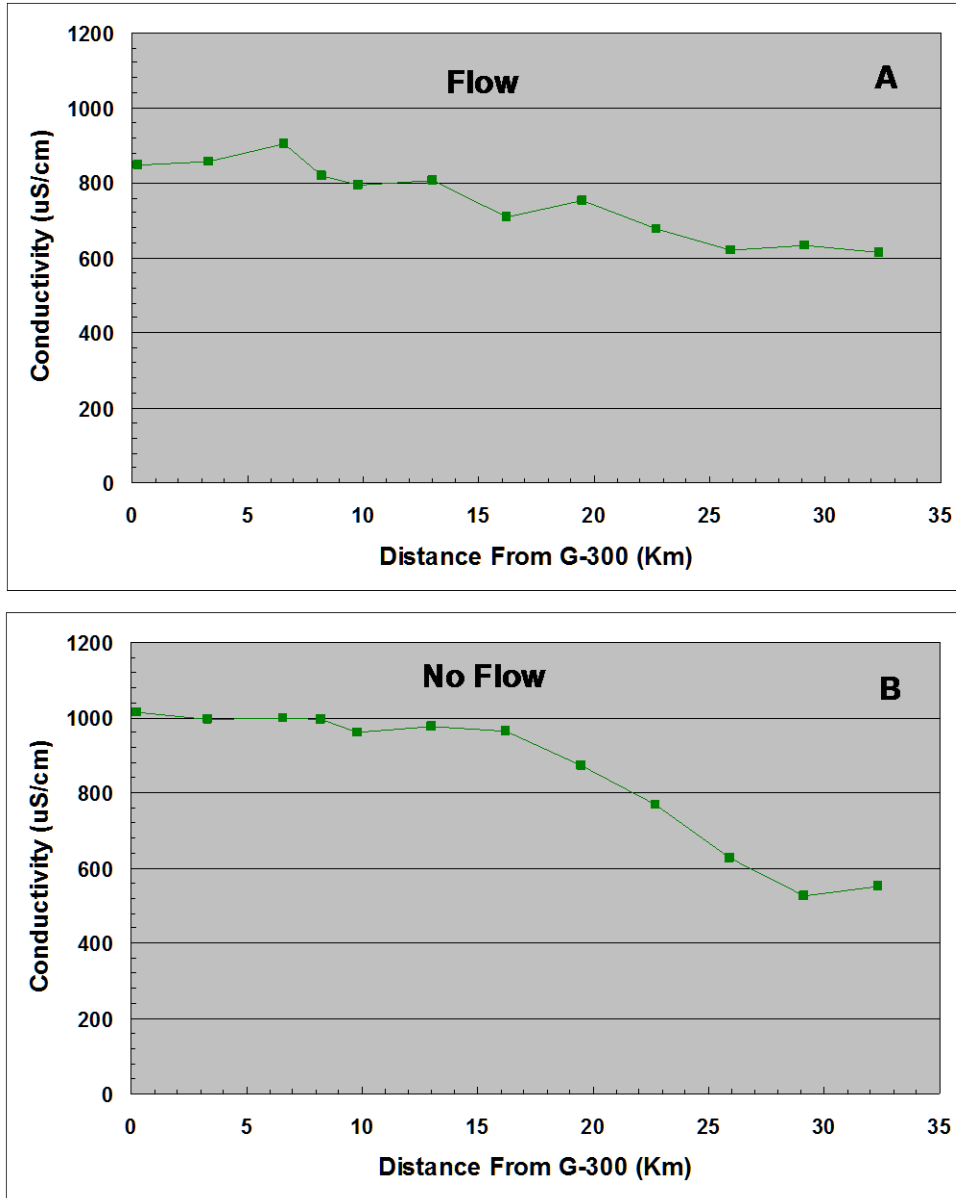


Figure 8. Conductivity averages of water samples collected during flow and no flow conditions in the L40 Canal, 2006.

Conductivity values under flow conditions averaged 753 $\mu\text{S}/\text{cm}$, with values steadily decreasing from north to south (Figure 8A). In contrast, average conductivity values under no flow conditions were higher (854 $\mu\text{S}/\text{cm}$), with the highest values measured in the northern half of the canal under study (Figure 8B). South of the structure G-94D (L40-18), conductivity levels rapidly decreased reaching the lowest values at the southern most sampling stations in the canal. Conductivity values from individual surveys showed more variability, with the higher values measured at the beginning of the year, regardless of flow conditions. In fact, the highest values were measured in water samples collected on April 25th and May 10th, with the highest values (values >1000 $\mu\text{S}/\text{cm}$) measured in the first 16 km of the canal under study (Appendix B). Similarly, conductivity levels under flow conditions were higher at the beginning of the pumping season, with values more evenly distributed along the entire canal, and gradually decreasing toward the end year.

SUMMARY

Total P concentrations in the Everglades Protection Areas (EPA) for WY2006 have been reported to have returned to the pre-WY2005 levels, when high P levels throughout the EPA were influenced by multiple hurricanes and intensive rainfall periods (Payne et al., 2007). The reduction of major events such as hurricanes or tropical storms in this region resulted in the reduction of major drainage events on the drainage structures along the L40 Canal during the 2006 rainy season. However, results from individual water sampling surveys showed differences in P concentrations as a result of time of sampling and drainage flow conditions. Total P concentrations from water samples under drainage flow conditions averaged 77 $\mu\text{g}/\text{L}$, with concentrations steadily decreasing away from the main drainage structures. A similar decreasing north to south gradient has been reported for TP concentrations in the EPA, with the highest concentrations measured at the inflow points to the A.R.M. Loxahatchee National Wildlife Refuge and WCA-2 (Payne et al., 2007). As high TP water from EAA and adjacent urban areas enters the northern part of the L40 Canal, processes such as settling, sorption, biological assimilation and other biochemical processes results in the decrease of TP concentrations as water flows southward through in the L40 canal and adjacent bordering vegetation on both sides of the canal. Total P concentrations from individual water sampling surveys under drainage flow conditions showed more variability, with the higher concentrations measured at the beginning of the pumping season, steadily decreasing toward the end of the year. Total P concentrations from samples collected during no flow conditions averaged 56 $\mu\text{g}/\text{L}$, with concentrations also decreasing away from the main drainage structures.

Total dissolved P concentrations from samples under drainage flow conditions averaged 34 $\mu\text{g}/\text{L}$, representing 45% of the total P in the water column. However, the contribution of this P fraction from individual sampling surveys ranged from as low as 21% on samples

collected on June 28th to as high as 75% on samples collected on September 1st, which also corresponded to one of the highest drainage period for 2006. These high TDP concentrations measured on September 1st demonstrate the effect that inorganic soluble P sources either from agricultural or urban areas can have on total P loading of drainage waters entering Refuge. Total dissolved P concentrations from samples collected during no flow conditions were lower and more uniform during all surveys, averaging 23 µg/L; however, their contribution to the total P in the water column was similar (44%) to samples collected under drainage flow conditions.

Similarly to TDP, particulate P concentrations in water samples varied depending on drainage intensity and time of sampling. Average particulate P under drainage flow conditions accounted for 55% of the total P, with concentrations steadily decreasing away from the main drainage structures. The contributions of this P fraction from individual surveys ranged from as low as 25% on samples collected on September 1st to as high as 79%, on samples collected on June 28th, which corresponded to the first major drainage activity from structures S-362, ACME #1 and G-94D after a long inter-event time period. The same phenomenon is observed in farm drainage canals from the EAA; where biological material grows and accumulates in the canal during long quiescent periods. This fresh and highly mobile organic material is easily suspended and transported during significant drainage events. As the drainage season progressed, the particulate P mobilized by any given flow rate is reduced as shown by the steadily decrease of the particulate P contribution on samples collected toward the end of the year.

Average TSS concentrations from individual surveys behaved similarly to particulate P, with higher concentrations measured after long inter-event times between pumping periods. Total suspended solids were higher at the beginning of the pumping season and gradually decreased toward the end of the year. This behavior is similar to that explained for particulate P in farm drainage canals in the EAA. Particulate matter produced by the process of plant growth and senescence may remain in suspension and contribute to the total P concentration in the water column if it is sufficiently light and mobile or it may be deposited on the canal bottom to serve as a reservoir for subsequent mobilization during later drainage events. As the pumping season progresses, particulate matter accumulated in the canals is depleted and the amount transported by any given flow rate is reduced.

It is probably too early to draw any major conclusions about this study, but the data from 2006 shows that there are definite differences in P concentrations due to intensity and time of drainage events during the rainy season. There are some environmental factors such as rainfall distribution and intensity and the occurrence of major events such hurricanes and tropical storms that play a key role on drainage frequency and intensity in this area. However any increase in drainage activity in this area has the potential to mobilize P and

other nutrients stored on canal sediments into the refuge and other downstream areas. Water quality data from the next two years will give us a better understanding of the effect of drainage activity in the L40 canal water quality.

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APPENDIX A: Water Quality Data from Sampling Surveys in 2006

Table A 1. Selected properties of water samples from the L40 Canal collected under no flow conditions on April 25, 2006.

Location	Sampling Date	Sample Type	Time	TP†	TDP	SRP	EC	TSS	Turbidity
				mg/L	mg/L	mg/L	uS/cm	mg/L	NTU
L40-08	4/25/06	Grab	10:10 AM	0.0207	0.0115	0.0031	544	2.34	1.68
L40-10	4/25/06	Grab	10:20 AM	0.0261	0.0192	0.0038	536	3.58	1.77
L40-12	4/25/06	Grab	10:27 AM	0.0458	0.0235	0.0066	652	9.09	4.35
L40-14	4/25/06	Grab	10:35 AM	0.0653	0.0320	0.0099	932	12.22	6.49
L40-16	4/25/06	Grab	10:42 AM	0.0723	0.0451	0.0122	991	13.33	8.87
L40-18	4/25/06	Grab	10:52 AM	0.0777	0.0297	0.0079	1028	14.90	9.57
L40-20	4/25/06	Grab	11:02 AM	0.0692	0.0312	0.0049	1062	19.18	12.8
L40-22	4/25/06	Grab	11:08 AM	0.0815	0.0247	0.0051	1080	18.95	11.2
L40-23	4/25/06	Grab	11:12 AM	0.0582	0.0271	0.0047	1075	19.57	11.3
L40-24	4/25/06	Grab	11:16 AM	0.0654	0.0271	0.0060	1107	14.80	9.56
L40-26	4/25/06	Grab	11:24 AM	0.0647	0.0229	0.0063	1115	13.61	10.3
L40-28	4/25/06	Grab	11:30 AM	0.0561	0.0251	0.0089	1141	7.60	5.9

†TP = Total P; TDP = Total Dissolved P; SRP = Soluble Reactive P; EC = Conductivity; TSS = Total Suspended Solids.

Table A 2. Selected properties of water samples from the L40 Canal collected under no flow conditions on May 10, 2006.

Location	Sampling Date	Sample Type	Time	TP†	TDP	SRP	EC	TSS	Turbidity
				mg/L	mg/L	mg/L	uS/cm	mg/L	NTU
L40-08	5/10/06	Grab	11:05 AM	0.0096	0.0113	0.0057	626	3.41	2.69
L40-10	5/10/06	Grab	11:11 AM	0.0268	0.0151	0.0060	650	2.73	2.37
L40-12	5/10/06	Grab	11:18 AM	0.0884	0.0296	0.0061	852	7.11	4.35
L40-14	5/10/06	Grab	11:25 AM	0.0631	0.0380	0.0107	994	8.71	5.21
L40-16	5/10/06	Grab	11:32 AM	0.0980	0.0424	0.0261	926	11.80	8.47
L40-18	5/10/06	Grab	11:39 AM	0.0942	0.0302	0.0127	1103	13.60	10.9
L40-20	5/10/06	Grab	11:45 AM	0.0426	0.0243	0.0062	1129	15.42	13.8
L40-22	5/10/06	Grab	11:51 AM	0.0895	0.0298	0.0041	1106	19.00	17.3
L40-23	5/10/06	Grab	11:55 AM	0.0787	0.0202	0.0039	1154	15.32	14.1
L40-24	5/10/06	Grab	12:00 PM	0.0889	0.0279	0.0046	1166	22.61	19.9
L40-26	5/10/06	Grab	12:05 PM	0.0395	0.0193	0.0064	1180	19.60	18.1
L40-28	5/10/06	Grab	12:12 PM	0.0790	0.0229	0.0096	1178	11.36	11.6

†TP = Total P; TDP = Total Dissolved P; SRP = Soluble Reactive P; EC = Conductivity; TSS = Total Suspended Solids.

Table A 3. Selected properties of water samples from the L40 Canal collected under drainage flow conditions on May 30, 2006.

Location	Sampling Date	Sample Type	Time	TP†	TDP	SRP	EC	TSS	Turbidity
				mg/L	mg/L	mg/L	uS/cm	mg/L	NTU
L40-08	5/30/06	Grab	10:22 AM	0.0644	0.0177	0.0039	875	9.20	6.4
L40-10	5/30/06	Grab	10:29 AM	0.1077	0.0262	0.0073	858	14.42	13.2
L40-12	5/30/06	Grab	10:35 AM	0.1106	0.0413	0.0214	756	14.90	13.0
L40-14	5/30/06	Grab	10:44 AM	0.0977	0.0208	0.0074	882	16.25	15.5
L40-16	5/30/06	Grab	10:50 AM	0.0837	0.0180	0.0050	825	15.14	15.3
L40-18	5/30/06	Grab	10:57 AM	0.0958	0.0331	0.0182	550	12.86	13.9
L40-20	5/30/06	Grab	11:04 AM	0.1023	0.0165	0.0053	920	17.91	19.5
L40-22	5/30/06	Grab	11:10 AM	0.0961	0.0369	0.0077	681	16.82	18.1
L40-23	5/30/06	Grab	11:15 AM	0.0777	0.0143	0.0055	690	11.80	12.0
L40-24	5/30/06	Grab	11:19 PM	0.0788	0.0238	0.0050	934	17.92	19.8
L40-26	5/30/06	Grab	11:27 PM	0.0821	0.0185	0.0069	1055	20.83	23.2
L40-28	5/30/06	Grab	11:35 PM	0.0867	0.0198	0.0065	1094	23.72	28.1

†TP = Total P; TDP = Total Dissolved P; SRP = Soluble Reactive P; EC = Conductivity; TSS = Total Suspended Solids.

Table A 4. Selected properties of water samples from the L40 Canal collected under drainage flow conditions on June 28, 2006.

Location	Sampling Date	Sample Type	Time	TP†	TDP	SRP	EC	TSS	Turbidity
				mg/L	mg/L	mg/L	uS/cm	mg/L	NTU
L40-08	6/28/06	Grab	09:50 AM	0.0456	0.0148	0.0070	560	6.21	3.93
L40-10	6/28/06	Grab	10:05 AM	0.0923	0.0251	0.0085	558	11.26	6.01
L40-12	6/28/06	Grab	10:20 AM	0.0963	0.0215	0.0134	617	14.00	8.51
L40-14	6/28/06	Grab	10:35 AM	0.1362	0.0477	0.0325	734	15.75	11.0
L40-16	6/28/06	Grab	10:55 AM	0.0941	0.0196	0.0089	801	15.32	12.7
L40-18	6/28/06	Grab	11:05 AM	0.1075	0.0149	0.0070	788	23.40	22.0
L40-20	6/28/06	Grab	11:20 AM	0.1116	0.0133	0.0069	823	42.80	38.8
L40-22	6/28/06	Grab	11:35 AM	0.1113	0.0109	0.0071	851	25.66	29.5
L40-23	6/28/06	Grab	11:45 AM	0.0502	0.0072	0.0042	958	9.37	7.95
L40-24	6/28/06	Grab	12:00 PM	0.0440	0.0102	0.0042	1030	6.96	4.97
L40-26	6/28/06	Grab	12:20 PM	0.0869	0.0201	0.0146	899	22.45	24.9
L40-28	6/28/06	Grab	12:35 PM	0.0957	0.0139	0.0150	934	22.60	24.4

†TP = Total P; TDP = Total Dissolved P; SRP = Soluble Reactive P; EC = Conductivity; TSS = Total Suspended Solids.

Table A 5. Selected properties of water samples from the L40 Canal collected under drainage flow conditions on July 25, 2006.

Location	Sampling Date	Sample Type	Time	TP†	TDP	SRP	EC	TSS	Turbidity
				mg/L	mg/L	mg/L	uS/cm	mg/L	NTU
L40-08	7/25/06	Grab	10:15 AM	0.0761	0.0388	0.0284	698	5.25	3.90
L40-10	7/25/06	Grab	10:22 AM	0.0697	0.0483	0.0330	766	7.19	5.20
L40-12	7/25/06	Grab	10:29 AM	0.0848	0.0412	0.0387	721	7.96	5.59
L40-14	7/25/06	Grab	10:37 AM	0.0807	0.0374	0.0281	765	10.60	6.52
L40-16	7/25/06	Grab	10:44 AM	0.0819	0.0491	0.0393	811	9.89	6.21
L40-18	7/25/06	Grab	10:51 AM	0.0746	0.0471	0.0332	770	8.00	5.72
L40-20	7/25/06	Grab	10:58 AM	0.0500	0.0335	0.0256	752	6.04	4.27
L40-22	7/25/06	Grab	11:05 AM	0.0618	0.0358	0.0292	760	3.04	2.37
L40-23	7/25/06	Grab	11:09 AM	0.0608	0.0340	0.0297	692	3.48	2.28
L40-24	7/25/06	Grab	11:13 AM	0.0700	0.0319	0.0271	745	3.26	2.10
L40-26	7/25/06	Grab	11:19 AM	0.0921	0.0446	0.0256	824	5.96	4.29
L40-28	7/25/06	Grab	11:25 AM	0.0904	0.0487	0.0373	748	7.80	4.95

†TP = Total P; TDP = Total Dissolved P; SRP = Soluble Reactive P; EC = Conductivity; TSS = Total Suspended Solids.

Table A 6. Selected properties of water samples from the L40 Canal collected under drainage flow conditions on August 23, 2006.

Location	Sampling Date	Sample Type	Time†	TP	TDP	SRP	EC	TSS	Turbidity
				mg/L	mg/L	mg/L	uS/cm	mg/L	NTU
L40-08	8/23/06	Grab	10:05 AM	0.0662	0.0178	0.0137	545	7.84	6.67
L40-10	8/23/06	Grab	10:12 AM	0.0559	0.0285	0.0088	595	6.10	4.21
L40-12	8/23/06	Grab	10:20 AM	0.0467	0.0165	0.0096	603	5.41	3.84
L40-14	8/23/06	Grab	10:28 AM	0.0612	0.0197	0.0093	587	5.60	4.56
L40-16	8/23/06	Grab	10:35 AM	0.0593	0.0279	0.0102	658	7.83	5.13
L40-18	8/23/06	Grab	10:42 AM	0.0576	0.0269	0.0110	754	9.23	6.74
L40-20	8/23/06	Grab	10:50 AM	0.0493	0.0253	0.0129	806	5.77	3.18
L40-22	8/23/06	Grab	10:56 AM	0.0430	0.0266	0.0121	813	2.86	1.95
L40-23	8/23/06	Grab	11:00 AM	0.0382	0.0151	0.0116	803	2.00	1.68
L40-24	8/23/06	Grab	11:05 AM	0.0415	0.0151	0.0113	822	2.68	1.60
L40-26	8/23/06	Grab	11:10 AM	0.0528	0.0219	0.0089	756	6.32	4.78
L40-28	8/23/06	Grab	11:15 AM	0.0670	0.0167	0.0127	704	7.91	6.12

†TP = Total P; TDP = Total Dissolved P; SRP = Soluble Reactive P; EC = Conductivity; TSS = Total Suspended Solids.

Table A 7. Selected properties of water samples from the L40 Canal collected under drainage flow conditions on September 1, 2006.

Location	Sampling Date	Sample Type	Time†	TP	TDP	SRP	EC	TSS	Turbidity
				mg/L	mg/L	mg/L	uS/cm	mg/L	NTU
L40-08	9/01/06	Grab	11:45 AM	0.0589	0.0320	0.0282	631	14.41	8.37
L40-10	9/01/06	Grab	12:00 PM	0.0727	0.0651	0.0351	671	13.40	8.08
L40-12	9/01/06	Grab	12:14 PM	0.0766	0.0411	0.0425	669	17.40	10.60
L40-14	9/01/06	Grab	12:30 PM	0.0800	0.0495	0.0519	733	12.65	6.75
L40-16	9/01/06	Grab	12:44 PM	0.1045	0.0641	0.0686	771	15.31	7.85
L40-18	9/01/06	Grab	1:00 PM	0.1018	0.0791	0.0732	711	12.12	6.56
L40-20	9/01/06	Grab	1:13 PM	0.1144	0.0912	0.0834	813	4.57	2.78
L40-22	9/01/06	Grab	1:26 PM	0.1516	0.1411	0.1362	895	2.33	1.94
L40-23	9/01/06	Grab	1:38 PM	0.1437	0.1357	0.1442	909	3.64	1.93
L40-24	9/01/06	Grab	1:50 PM	0.1797	0.1401	0.1394	896	4.00	2.41
L40-26	9/01/06	Grab	2:05 PM	0.1032	0.0823	0.0791	820	2.11	1.80
L40-28	9/01/06	Grab	2:20 PM	0.0919	0.0755	0.0750	776	1.96	2.24

†TP = Total P; TDP = Total Dissolved P; SRP = Soluble Reactive P; EC = Conductivity; TSS = Total Suspended Solids.

Table A 8. Selected properties of water samples from the L40 Canal collected under no flow conditions on October 24, 2006.

Location	Sampling Date	Sample Type	Time†	TP	TDP	SRP	EC	TSS	Turbidity
				mg/L	mg/L	mg/L	uS/cm	mg/L	NTU
L40-08	10/24/06	Grab	10:05 AM	0.0266	0.0205	0.0093	481	2.95	1.82
L40-10	10/24/06	Grab	10:15 AM	0.0359	0.0195	0.0095	392	3.70	2.27
L40-12	10/24/06	Grab	10:23 AM	0.0294	0.0177	0.0093	375	4.19	2.67
L40-14	10/24/06	Grab	10:30 AM	0.0416	0.0146	0.0090	377	6.07	4.24
L40-16	10/24/06	Grab	10:40 AM	0.0434	0.0186	0.0119	700	5.56	4.08
L40-18	10/24/06	Grab	10:45 AM	0.0391	0.0227	0.0111	760	5.43	3.50
L40-20	10/24/06	Grab	10:53 AM	0.0437	0.0121	0.0100	737	5.45	3.11
L40-22	10/24/06	Grab	11:00 AM	0.0422	0.0130	0.0102	693	3.06	2.21
L40-23	10/24/06	Grab	11:03 AM	0.0428	0.0159	0.0104	755	4.73	2.62
L40-24	10/24/06	Grab	11:07 AM	0.0500	0.0141	0.0122	726	5.96	3.70
L40-26	10/24/06	Grab	11:13 AM	0.0486	0.0180	0.0121	695	7.42	3.93
L40-28	10/24/06	Grab	11:20 AM	0.0553	0.0205	0.0169	726	5.23	3.80

†TP = Total P; TDP = Total Dissolved P; SRP = Soluble Reactive P; EC = Conductivity; TSS = Total Suspended Solids.

Table A 9. Selected properties of water samples from the L40 Canal collected under drainage flow conditions on November 14, 2006.

Location	Sampling Date	Sample Type	Time†	TP	TDP	SRP	EC	TSS	Turbidity
				mg/L	mg/L	mg/L	uS/cm	mg/L	NTU
L40-08	11/14/06	Grab	9:40 AM	0.0293	0.0126	0.0070	373	2.22	1.45
L40-10	11/14/06	Grab	9:47 AM	0.0257	0.0151	0.0069	347	2.05	1.28
L40-12	11/14/06	Grab	9:54 AM	0.0291	0.0267	0.0062	356	1.69	1.49
L40-14	11/14/06	Grab	10:00 AM	0.0402	0.0283	0.0104	367	3.75	2.11
L40-16	11/14/06	Grab	10:10 AM	0.0710	0.0161	0.0099	650	6.94	2.97
L40-18	11/14/06	Grab	10:17 AM	0.0724	0.0178	0.0101	680	5.12	3.28
L40-20	11/14/06	Grab	10:23 AM	0.0680	0.0172	0.0106	721	7.95	3.53
L40-22	11/14/06	Grab	10:30 AM	0.0525	0.0105	0.0088	767	5.40	3.18
L40-23	11/14/06	Grab	10:34 AM	0.0334	0.0152	0.0083	868	5.71	3.26
L40-24	11/14/06	Grab	10:37 AM	0.0494	0.0231	0.0079	993	6.15	3.42
L40-26	11/14/06	Grab	10:45 AM	0.0471	0.0139	0.0080	783	6.83	4.99
L40-28	11/14/06	Grab	10:52 AM	0.0461	0.0231	0.0095	824	7.33	5.70

†TP = Total P; TDP = Total Dissolved P; SRP = Soluble Reactive P; EC = Conductivity; TSS = Total Suspended Solids.

APPENDIX B: Figures from Individual Surveys during 2006

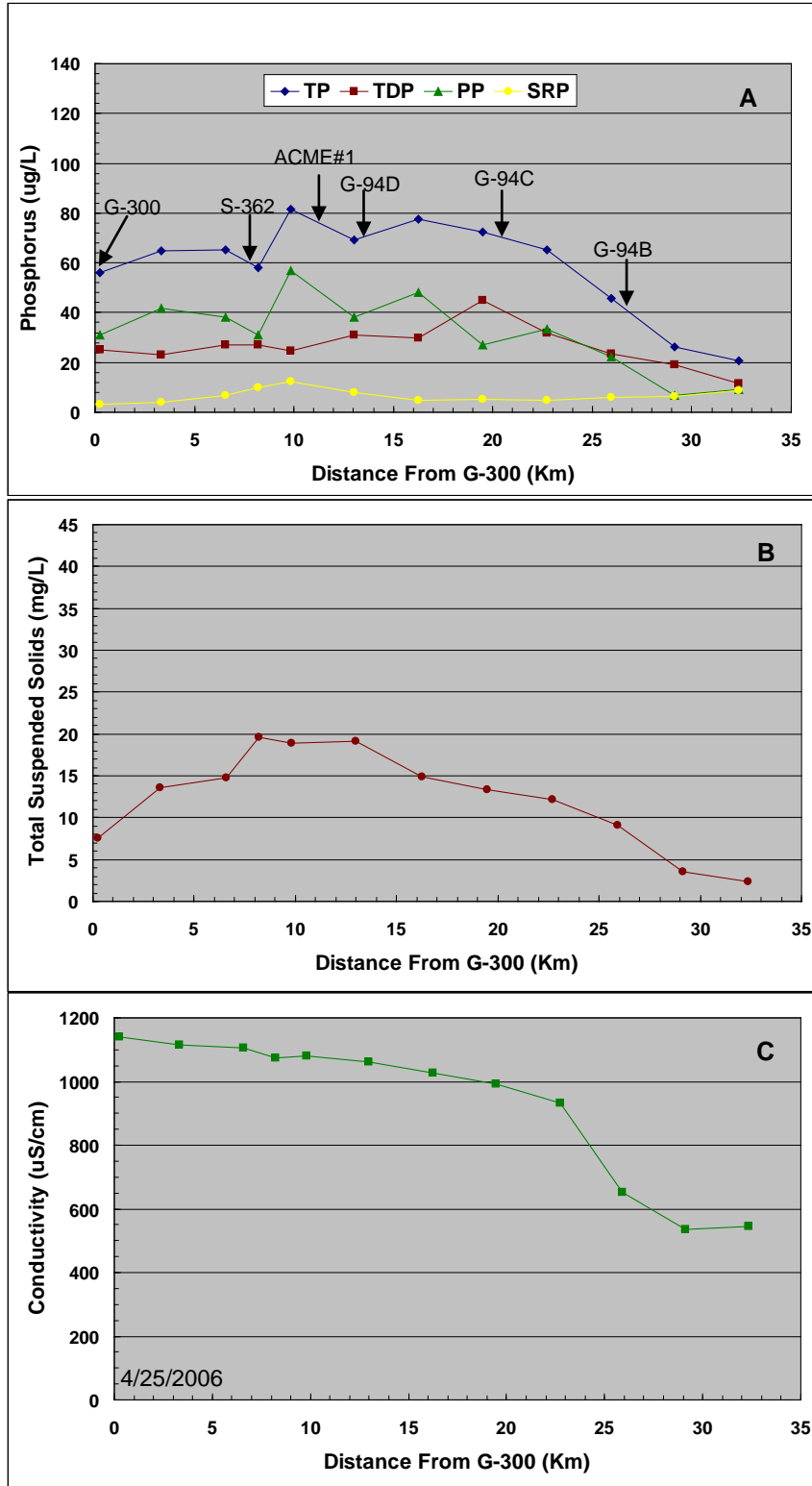


Figure B 1. Selected profiles along the L40 Canal of water samples collected on April 25, 2006: A) Phosphorus, B) TSS, and C) Conductivity.

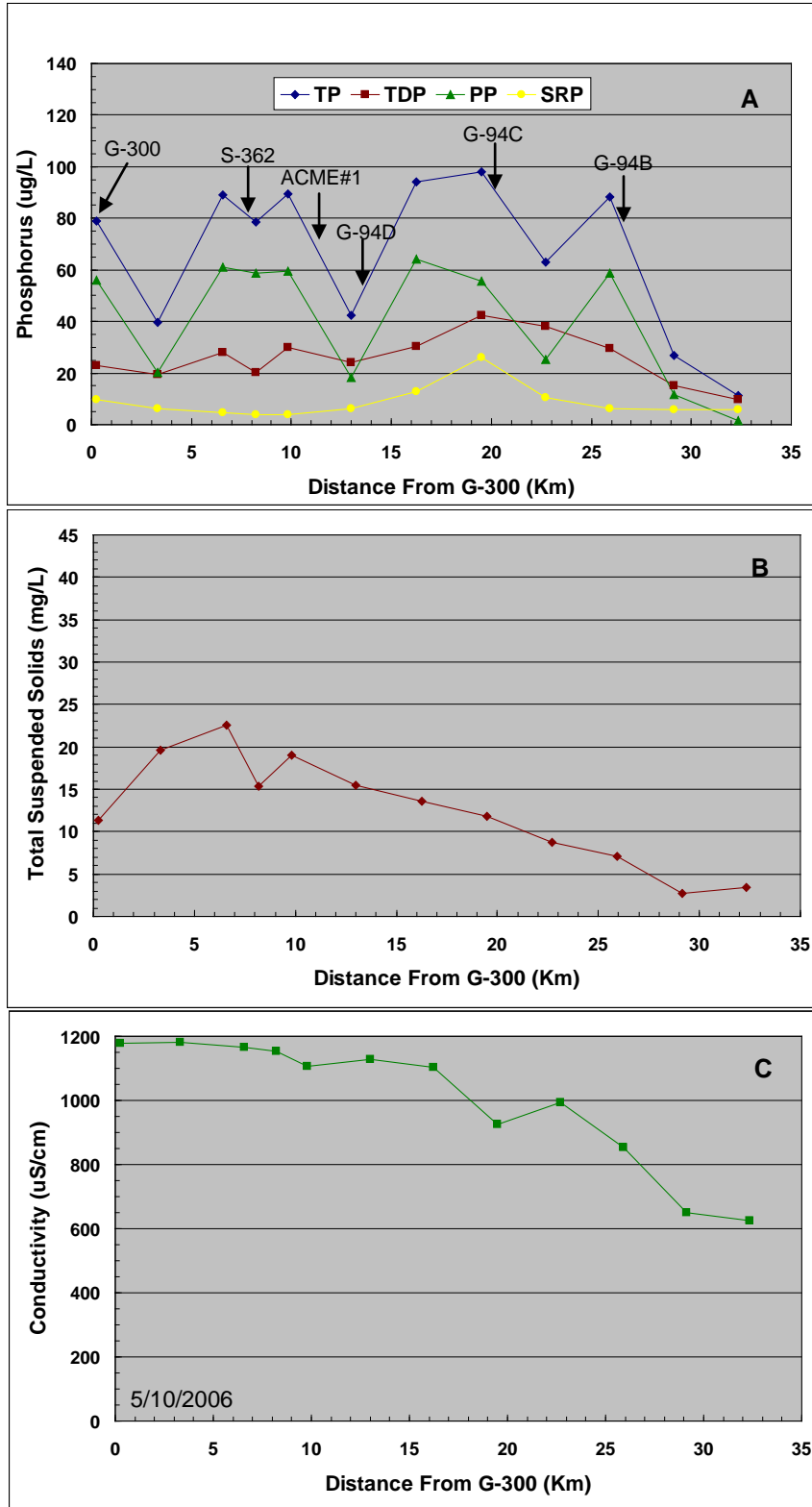


Figure B 2. Selected profiles along the L40 Canal of water samples collected on May 10, 2006: A) Phosphorus, B) TSS, and C) Conductivity.

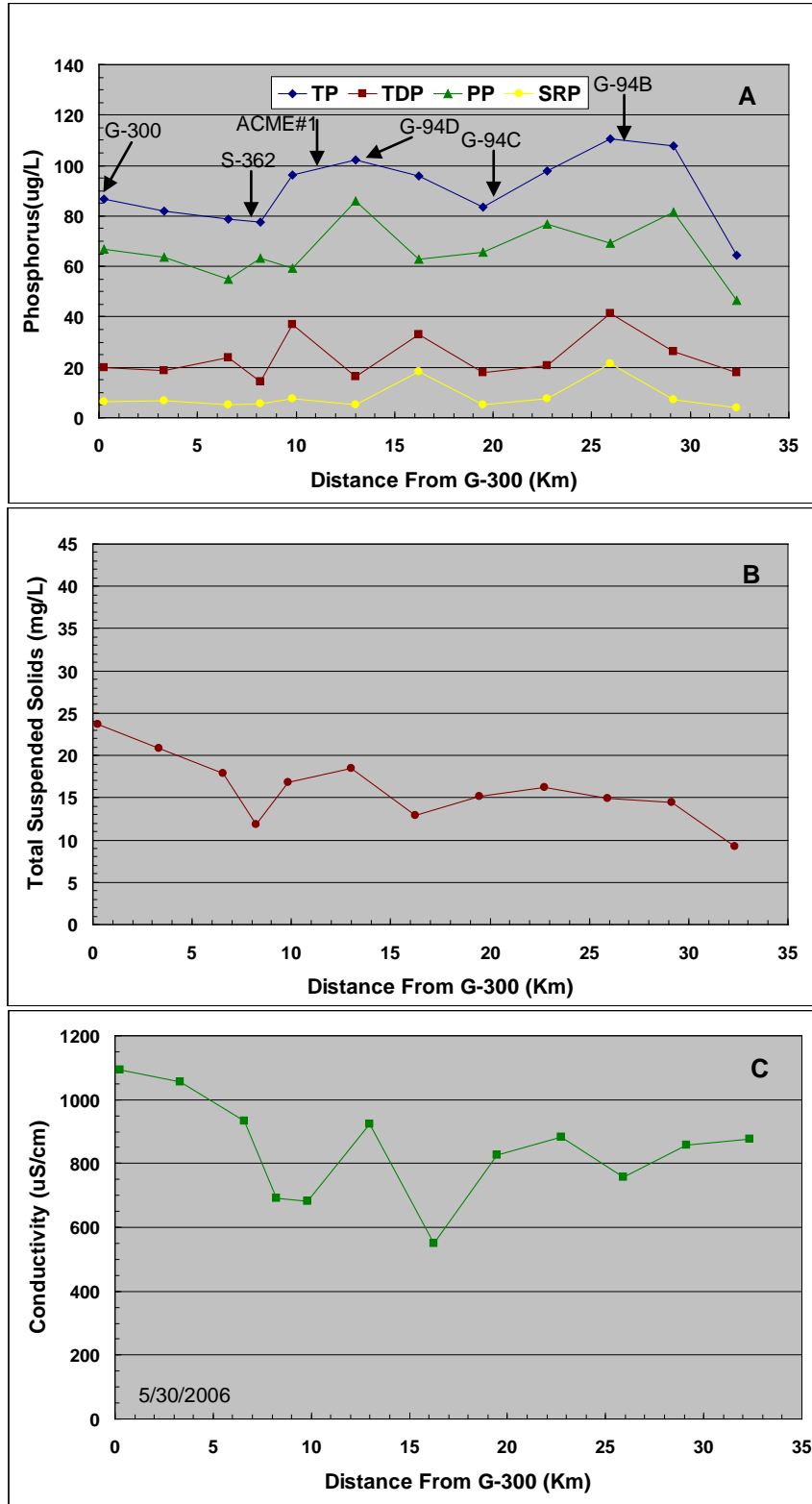


Figure B 3. Selected profiles along the L40 Canal of water samples collected on May 30, 2006: A) Phosphorus, B) TSS, and C) Conductivity.

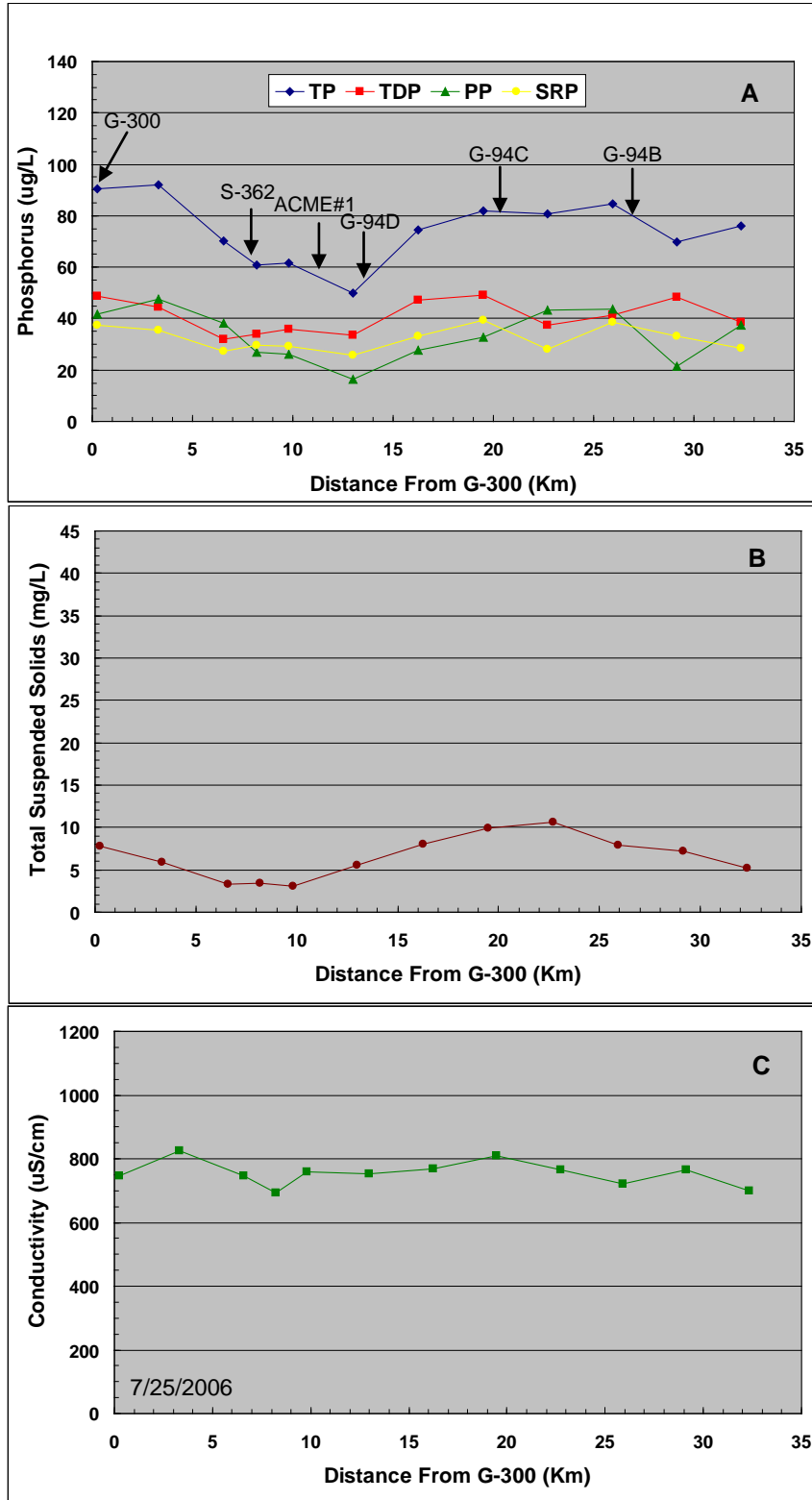


Figure B 4. Selected profiles along the L40 Canal of water samples collected on July 25, 2006: A) Phosphorus, B) TSS, and C) Conductivity.

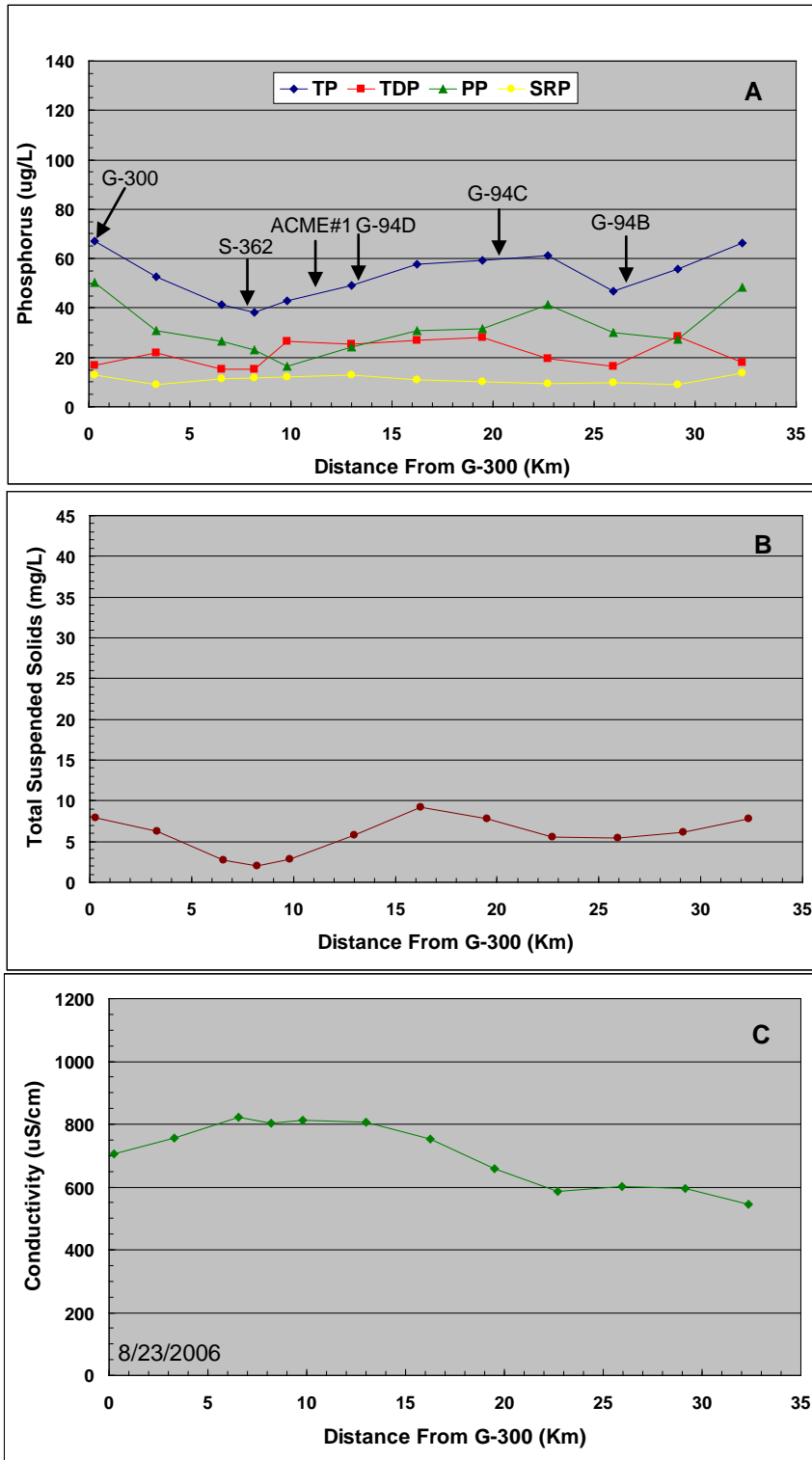


Figure B 5. Selected profiles along the L40 Canal of water samples collected on August 23, 2006: A) Phosphorus, B) TSS, and C) Conductivity.

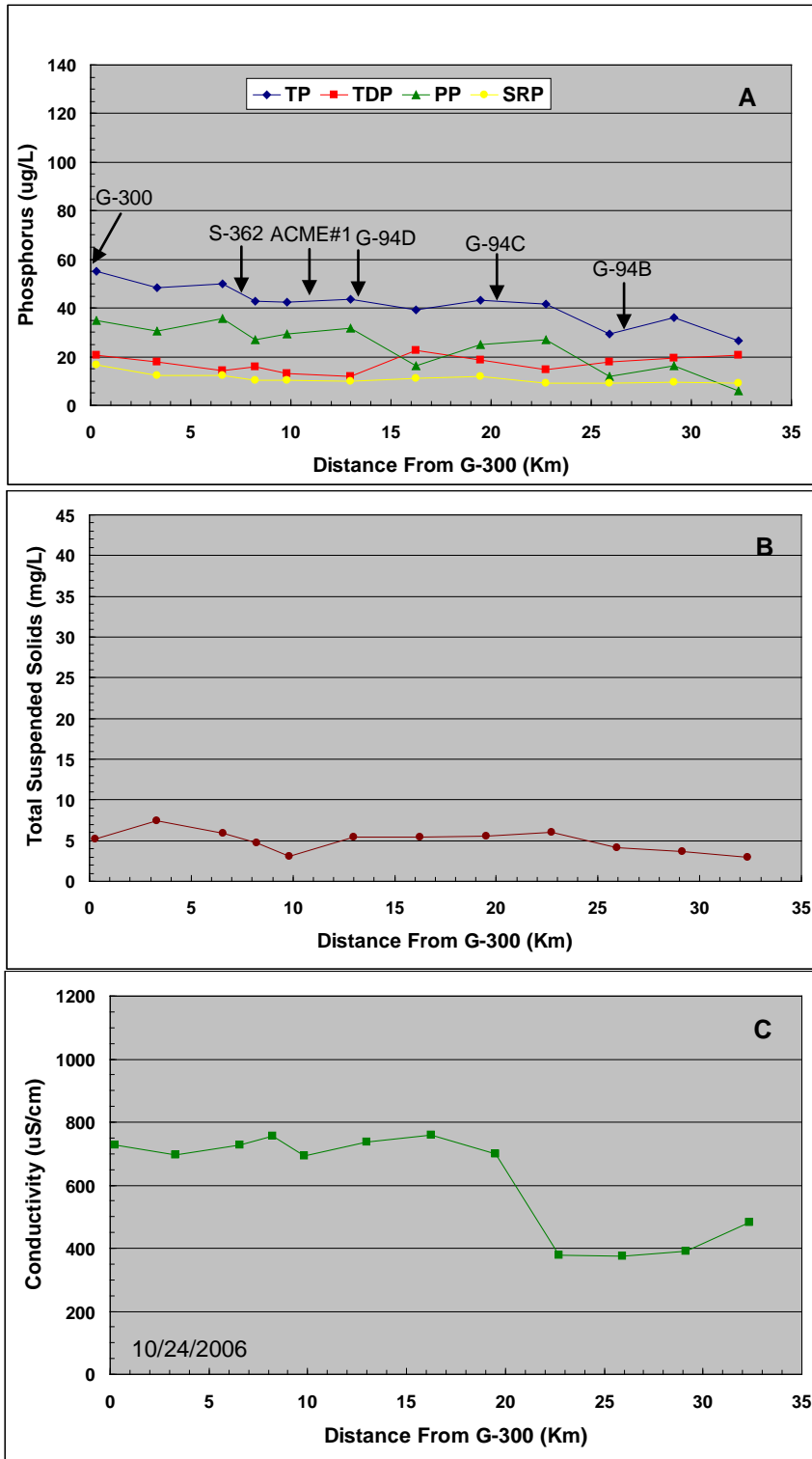


Figure B 6. Selected profiles along the L40 Canal of water samples collected on October 24, 2006: A) Phosphorus, B) TSS, and C) Conductivity.

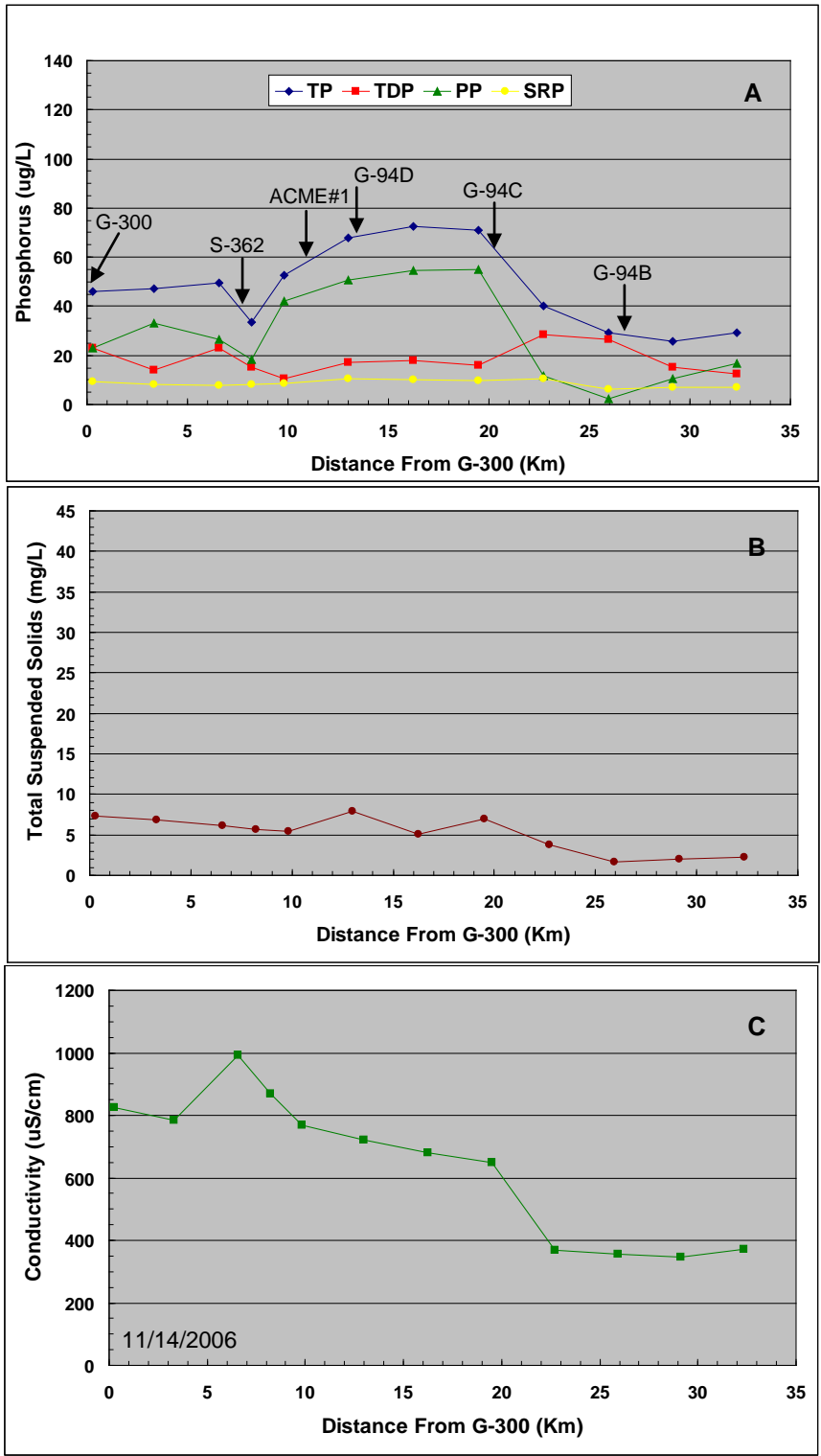


Figure B 7. Selected profiles along the L40 Canal of water samples collected on November 14, 2006: A) Phosphorus, B) TSS, and C) Conductivity.