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**St. Johns River
Water Management District**

**CRANE CREEK POST ASSESSMENT
WATER QUALITY, SEDIMENT QUALITY,
AND SEDIMENT TRAPPING
FINAL REPORT**

BCI Project No. 19-10847.2



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Final Report to the
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**Post-Dredge Evaluation of Crane Creek:
Sediment Trapping Efficiency and Sediment Quality**



John H. Trefry, Robert P. Trocine, Robert D. Rember,
and Christopher R. Little

Florida Institute of Technology
February 2004

Final Report to the
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Post-Dredge Evaluation of Crane Creek: Sediment Trapping Efficiency and Sediment Quality

John H. Trefry, Robert P. Trocine, Robert D. Rember and Christopher R. Little
Florida Institute of Technology

EXECUTIVE SUMMARY

In this portion of the post-dredge report for Crane Creek, results are presented for the following: (1) thicknesses of fine-grained, organic-rich (muck) sediment, (2) sedimentation rates and (3) concentrations of major elements and potential trace metal contaminants in sediments. These data will be used for the following: (1) to determine the sediment trapping efficiency of the creek, (2) to help establish long-term plans for future dredging and (2) to assess sediment quality.

The thicknesses of layers of fine-grained, organic-rich (muck) sediment overlying base sand were measured during 2002 at 54 sites with an overall mean of 77 ± 82 cm and the following results by section: (1) 47 ± 49 cm at locations to the west of the railroad bridge in the Sewage Treatment Plant (STP) Basin, (2) 85 ± 63 cm in the Manatee Basin between the railroad bridge and highway US 1, (3) 180 ± 102 cm in the Harbor Basin between US 1 and the region where the creek becomes oriented in a southward direction and (4) 65 ± 65 cm in the Mouth Basin, an area that extends from the Harbor Basin to the mouth of the creek.

Data for muck depths collected during summer 1998, following dredging, yielded mean values of 57, 153, 126 and 159 cm, respectively, in the STP, Manatee, Harbor and Mouth Basins with an overall mean of 112 ± 81 cm. The overall means for muck depth in 2002 versus 1998 were not significantly different for the STP and Harbor Basins. However, the muck depths were significantly lower in 2002 for the Manatee and Mouth Basins relative to 1998. The results for 1998 show that considerable amounts of muck sediment remained in Crane Creek following dredging. When the 1998 and 2002 data are compared, the data suggest that some shifting of sediment toward the Harbor Basin may have occurred and that there has not been a large influx of sediment during the four-year period between surveys.

Reliable determinations of sedimentation rates were difficult due to the degree to which sediments had undergone slumping and *in situ* physical and biological mixing. The activities of excess ^{210}Pb and ^{137}Cs were determined for six cores and the resulting rates that were calculated are most likely high due to the influences of sediment mixing because such mixing can extend the penetration depth of the radionuclides. The rates are as follows: (1) 0.5 ± 0.1 cm/yr west of the railroad bridge in the STP Basin, (2) 0.2 ± 0.1 cm/yr in the Manatee Basin between the railroad bridge and US 1, and (3) 1.4 ± 0.7 cm/yr in the Harbor Basin. The overall mean for the six cores was 0.7 ± 0.6 cm/yr (n =12, two rates per core).

Executive Summary (Continued)

To address questions related to sediment sources, sediment quality and sediment history, the data for major elements and trace metals in soils, suspended sediments, surface sediments, and sediment cores were used collectively. No clear differences in concentrations of Fe, K or Mg versus Al were observed and thus these elements did not provide a straightforward tracer of sources of sediments to the creek. Aluminum provides a useful frame of reference because Al is resistant to chemical weathering in soils and sediments and it is a good indicator of the aluminosilicate (clay) fraction of the sample. Uniform As/Al and V/Al relationships show no detectable inputs of contaminant As or V; however, the uniform metal/Al ratios do not facilitate identification of distinct natural sources for these metals within the drainage basin.

Concentrations of silver (Ag) mercury (Hg) are 50 to more than 100 times above natural levels in sediments from Crane Creek. The core data suggest that peak inputs of Ag and Hg were 30-60 years ago. When sediment concentrations of Ag are plotted versus Hg, a strong linear fit ($r = 0.92$) is observed. This trend for Hg versus Ag supports a common source or source area for both metals such as dental waste and/or photographic/art wastes. Fourteen samples had Ag levels greater than the Effects Range Median (ERM) guideline and seven samples had Hg levels above the ERM. At such levels, adverse effects to sediment biota are predicted to occur frequently. Most of the remaining samples contained Ag and Hg at levels that exceeded the Effects Range Low (ERL), indicating that adverse biological effects for sediment organisms would be occasional.

Concentrations of Pb were elevated over natural levels by two to six-fold at many sites throughout the creek with the highest values in suspended sediment from the Harbor Basin. None of the Pb values exceeded the ERM; however, more than half the Pb concentrations exceeded the ERL. Overall, the spatial distribution of anthropogenic Pb throughout the creek is rather ubiquitous. Data from sediment cores show that the onset of Pb contamination dates back about 50 years. All concentrations of Cd were below the ERM and only three values exceeded the ERL. In contrast, many of the Zn concentrations were greater than the ERL with none greater than the ERM.

Concentrations of Cu in sediments from Crane Creek were typically two to ten times greater than in natural sediments. None of the Cu values exceed the ERM. The highest concentrations of Cu were found in suspended sediments, surface sediments and sediment cores from the Harbor Basin. This is consistent with a primary source for Cu from anti-fouling paints that have leached from boat hulls. No clear shifts in Cu concentrations or, more importantly, the Cu/Al ratios were observed during the past 50 years. Concentrations of Ni and Cr seem to be within expected, background levels except for a few samples from cores collected in the STP Basin where levels are elevated over natural levels by about 20-60%.

At one station (#703) in the Harbor Basin of Crane Creek, sediments were collected during 1992 and 2003. Overall, we conclude that metal levels in creek sediments collected during 2003 are not significantly different than in 1992. All concentrations of

As and all except one value for Cr were within the State of Florida Guidelines established for sediments. Many samples contained levels of Cd that were significantly enriched relative natural sediments in Florida. Most sediment samples, but no soil samples, had Cu concentrations that exceeded the state guidelines. Likewise, sediments contaminated with Pb and Zn, based on the Florida guidelines were ubiquitous in the creek.

The total amount of sediment removed from Crane Creek by dredging January-April 1998 was $\sim 60,000 \text{ m}^3$. The present-day (post-dredging) volume of muck in Crane Creek is estimated to be $\sim 82,000 \text{ m}^3$, with more than half of that volume in the Harbor + Mouth Basins. The creek appears to be a good trap for incoming sediments with sedimentation rates that range from 0.2 to 2 cm/yr and average $\sim 0.7 \text{ cm/yr}$. Based on these sedimentation rates, the annual volume of sediment deposited in Crane Creek is $800 \pm 300 \text{ m}^3/\text{yr}$. This annual volume is more than likely an overestimate because we are reasonably certain that sediment has slumped from the perimeter to the center of the creek. Assuming that the calculated filling rate of $800 \text{ m}^3/\text{yr}$ stays reasonably constant, an amount of sediment equivalent to the $60,000 \text{ m}^3$ of sediment that were dredged in 1998 would be deposited in ~ 75 years. Based on the standard deviation for the filling rate of $\pm 300 \text{ m}^3/\text{yr}$, the calculated range of filling times is from 55 to 120 years.

Post-Dredge Evaluation of Crane Creek: Sediment Trapping Efficiency and Sediment Quality

John H. Trefry, Robert P. Trocine, Robert D. Rember and Christopher R. Little
Florida Institute of Technology

INTRODUCTION

The study described in this chapter was designed to (1) determine the rates of sedimentation and the potential trapping efficiency of Crane Creek for incoming suspended sediments and (2) to determine sediment quality in Crane Creek with respect to possible metal contaminants. To help address these two broad goals, the following specific objectives were completed:

1. Determine depths of fine-grained, organic-rich sediment (muck) and the rates of sediment accumulation at key sites in Crane Creek.
2. Determine whether any fine-grained sediment in the dredged, central portions of the creek may be derived from perimeter areas of the creek that were not dredged or from other sources.
3. Determine the composition of creek sediment as a component to identifying sediment sources and confirming sediment accumulation rates.
4. Determine concentrations of selected metals in creek sediments to assess levels of possible contaminants in sediments from the present-day and recent past.

The supporting data set is large and diverse, as outlined in Table 1, and includes the following:

1. Depth of fine-grained, organic-rich sediment above a base of sand.
2. Activities of excess ^{210}Pb and ^{137}Cs in sediments and sedimentation rates where possible.
3. Concentrations of five (5) major elements, aluminum (Al), calcium (Ca), iron (Fe), potassium (K), and magnesium (Mg) and twelve (12) trace metals, silver (Ag), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb), selenium (Se), vanadium (V) and zinc (Zn), as well as total organic carbon (TOC) in samples of soil and bottom sediments (Table 1). A subset of these analytes was determined for suspended sediments.

Table 1. Summary of samples collected and analyzed for various parameters in this study of Crane Creek and the adjacent Indian River Lagoon (IRL).

Sample Type	Number of Samples	Overview of Locations	Analytes
Sediment Muck Depths	54	Throughout Crane Creek	Depth of layer of fine-grained, organic-rich sediment (muck) above sand base
Sediment Cores: Geochronology	7 cores, 76 layers	Throughout Crane Creek	Excess ^{210}Pb , ^{137}Cs (^7Be , 3 cores), water content, pore water salinity
Surface Sediments, Creek perimeter	18	Circumscribing Crane Creek	<i>Major elements:</i> Al, Ca, Fe, K, Mg <i>Trace Metals:</i> Ag, As, Cd, Cr, Cu, Hg, Mn, Ni, Pb, Se, V, Zn Total Organic Carbon
Surface Sediments, Creek Center*	10	Throughout Crane Creek plus adjacent IRL	<i>Major elements:</i> Al, Ca, Fe, K, Mg <i>Trace Metals:</i> Ag, As, Cd, Cr, Cu, Hg, Mn, Ni, Pb, Se, V, Zn Total Organic Carbon
Sediment Cores: Chemistry	4 cores, 76 samples	Throughout Crane Creek	<i>Major elements:</i> Al, Ca, Fe, K, Mg <i>Trace Metals:</i> Ag, As, Cd, Cr, Cu, Hg, Mn, Ni, Pb, Se, V, Zn Total Organic Carbon
Extra Sediment Cores: Chemistry	3 cores, 59 samples	Throughout Crane Creek	Total Organic Carbon and Hg
Soils	12	From Crane Creek west to Highway US 95 and south to Eber Road	<i>Major elements:</i> Al, Ca, Fe, K, Mg <i>Trace Metals:</i> Ag, As, Cd, Cr, Cu, Hg, Mn, Ni, Pb, Se, V, Zn Total Organic Carbon
Suspended Sediment	12	Ruffner Park, Babcock St. bridge, Hickory Ditch, Crane Creek, IRL	TSS and Particulate Organic Carbon <i>Major elements:</i> Al, Ca, Fe, K, Mg <i>Trace Metals:</i> Ag, Cu, Mn, Pb, Zn

* Same samples for which data for PAH are available for this study.

The data for depths of fine-grained, organic-rich sediment (i.e., muck depths) provide a valuable overview of the extent of current sediment deposits in Crane Creek. These new muck depths are compared with historical data and help set a revised baseline for evaluating the long-term, trapping efficiency of Crane Creek with respect to new incoming suspended sediment or slumping sediment from the perimeter of the creek. The data for geochronology (excess ^{210}Pb and ^{137}Cs) are used to calculate present-day sedimentation rates, to determine the degree of physical and biological mixing of the sediments, and to define layers of sediment that were deposited prior to 1950 (pre- ^{137}Cs as no ^{137}Cs was present on Earth prior to atmospheric testing of nuclear weapons in the early 1950s).

Concentrations of major elements, trace metals and TOC in bottom sediments, suspended sediments and area soils help identify sediment sources. The trace metal data also help determine the overall sediment quality of Crane Creek. The data set for surface sediments identifies present-day conditions and the sediment cores provide an historical record of metal levels.

In this chapter, the **Results and Discussion** are presented in the following order: (1) muck depths and related data, (2) sedimentation rates, (3) sediment sources, and (4) sediment quality. Finally, an overview section that addresses the issue of sediment trapping efficient and projects future needs for dredging is presented.

Methods

Sampling

Surficial sediments were collected using Ponar and Smith-McIntyre grab samplers deployed from boats, as well as sampling by a diver. The top 1-cm was collected using a Teflon spatula and placed in an acid-washed, 30-mL, polystyrene vial.

Sediment cores were collected by a diver or by using a gravity corer deployed from the vessel Barb-NT (Figure 1a). In each case, the sediment was collected in 7-cm diameter, cellulose acetate butyrate (CAB) tubing. After collection, a rubber stopper was placed in the bottom of the core tube and plastic caps were taped onto each end of the core. The cores were kept upright throughout the sampling and recovery operations. Each core was returned to the laboratory at Florida Institute of Technology (FIT) and sub-sampled within 24 hours.

Sediment cores were subsectioned in 1-cm intervals over the top 10 cm and in 2-cm intervals through the remainder of the core. The sediment was extruded by pushing up on the stopper inside the CAB tubing with soda cans while the core was supported in a wooden rack (Figure 1). The outer few millimeters of sediment that may have been smeared during extrusion were scraped away with a small Teflon spatula and the remaining sediment was placed in polystyrene vials.

Soil samples were collected by scooping a representative portion of soil and placing it into a plastic Ziploc bag. Transportation to each site was by car.

Water for suspended sediment was collected directly in 1-L, acid-washed, low-density, polyethylene bottles (LDPE) that were uncapped and filled at a depth of a few centimeters below the surface from the bow of a pontoon boat that was slowly moving up current. Upon return to the FIT laboratory, the water samples were vacuum filtered through polycarbonate filters (Poretics, 47-mm diameter, 0.4- μ m pore size). Prior to the field effort, the filters were acid washed in 5N HNO₃, rinsed three times with distilled-deionized water (DDW), dried and then weighed to the nearest μ g using a Sartorius Model M3P electronic balance under cleanroom conditions. Vacuum filtration was carried out in a Class-100 laminar-flow hood using acid-washed glassware. The particle-bearing filters were placed in acid-washed petri dishes, dried in a clean rack and re-weighed.

Chemical Analysis

Major Elements and Trace Metals in Sediments, Soils and Suspended Sediments

Prior to metal analysis, each wet sediment sample was homogenized in the original plastic vial using a Teflon mixing rod. Then, a portion (~ 2 grams) of each sample was transferred into a pre-weighed plastic vial to determine water content. Once transferred, the wet sediment and the vial were re-weighed. In addition, about 2 to 4 grams of sample

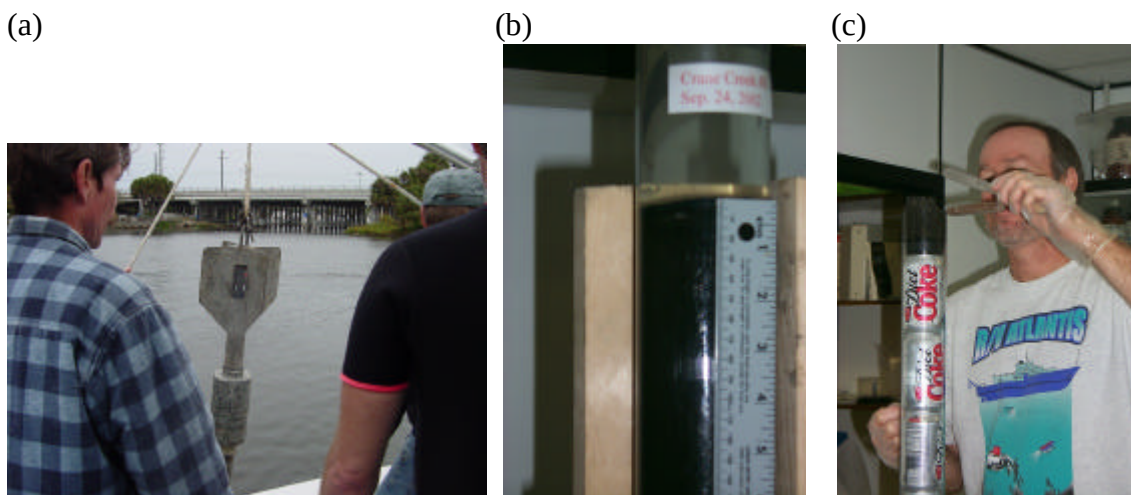


Figure 1. Pictures showing (a) gravity corer, (b) core tube containing sediment and (c) processing subsections of a core.

were transferred into polypropylene-copolymer centrifuge tubes to determine the Hg content of the sediments. Samples intended for water content measurement were frozen, freeze-dried, and re-weighed to determine the water content. The dried sediment samples were again homogenized using a Teflon mixing rod.

About 0.45 grams of freeze-dried, homogenized sediment, soil and certified reference material (CRM) sediment (BCSS-1 from the National Research Council of Canada) were totally digested in Teflon beakers using concentrated, high-purity HF-HNO₃-perchloric acid (HClO₄). This method was chosen because a total digestion accounts for the entire amount of metal in the sample. In the digestion process, 1 mL HClO₄, 1 mL HNO₃ and 3 mL HF were added to the sediment in the Teflon beaker, covered with a Teflon watch cover, and heated at 50°C until a moist paste formed. The mixture was heated for another 3 hours at 80°C with an additional 2 mL HNO₃ and 3 mL HF before bringing the sample to dryness. Finally, 1 mL HNO₃ and about 30 mL DDW were added to the sample and heated strongly to dissolve perchlorate salts and reduce the volume. The completely dissolved and clear samples were diluted to 20 mL with DDW.

Sediment samples to be analyzed for Hg were digested by heating 2 to 4 grams of wet sediment in acid-washed, polypropylene-copolymer centrifuge tubes with 4 mL HNO₃ and 2 mL sulfuric acid (H₂SO₄). Sample tubes were heated for 1 hour in a 90°C water bath and allowed to cool. Each tube was centrifuged at 2,000 rpm and the supernatant decanted into a 25-mL graduated cylinder. The sediment pellet was rinsed twice with 5 mL DDW, centrifuged, and decanted into the graduated cylinder before diluting to a final volume of 20 mL with DDW.

Labware used in the digestion process was acid washed with hot, 8N HNO₃ and rinsed three times with DDW. Two procedural blanks, two duplicate samples, and two CRMs

were prepared with each set of 40 samples. The CRMs used were MESS-2 and MESS-3; both are sediment samples issued by the National Research Council (NRC) of Canada. Sediment samples, CRMs, and procedural and reagent blanks were analyzed by one of the following: (1) flame atomic absorption spectrometry (FAAS) using a Perkin-Elmer Model 4000 instrument, (2) graphite furnace AAS using a Perkin-Elmer Model 4000 AAS equipped with an HGA-400 graphite furnace, an AS-40 autosampler and Zeeman or Continuum background correction or a Perkin-Elmer model 5100 instrument equipped with an HGA-600 graphite furnace and an AS-60 autosampler, or (3) inductively coupled plasma-mass spectrometry (ICP-MS) using a Perkin-Elmer ELAN 5000 spectrometer. Mercury concentrations were measured by cold vapor atomic absorption spectrometry (CVAAS) using a Laboratory Data Control Model 1235 Mercury Monitor. The method used for each element and the corresponding MDLs are presented in Table 2. All analytical techniques followed manufacturers' specifications and laboratory SOPs. These methods are based on EPA methods described for Series 7000 (FAAS and GFAAS), Series 7470 (CVAAS), and Series 6010A (ICP-MS) (U.S. EPA, 1991).

Table 2. Summary of instrumental methods and method detection limits (MDL) for metal analysis of bottom and suspended sediment.

Metal	Bottom and Suspended Sediments	
	Method	MDLs ($\mu\text{g metal/g dry sediment}$)
Ag – silver	GFAAS	0.007
Al – aluminum	FAAS	30
As – arsenic	GFAAS	0.1
Ca – calcium	FAAS	10
Cd – cadmium	ICP-MS	0.03
Cr – chromium	FAAS	0.33
Cu – copper	FAAS	0.4
Fe – iron	FAAS	25
K – potassium	FAAS	10
Hg – mercury	CVAAS	0.001
Mg – magnesium	FAAS	40
Mn – manganese	FAAS	170
Ni – nickel	ICP-MS	0.7
Pb – lead	ICP-MS	0.2
Se – selenium	GFAAS	0.07
V – vanadium	FAAS	3
Zn – zinc	FAAS	0.5
TOC and POC	Shimadzu Carbon System	0.01%

Notes: CVAAS = Cold Vapor Atomic Absorption Spectrometry
FAAS = Flame Atomic Absorption Spectrometry
GFAAS = Graphite Furnace Atomic Absorption Spectrometry
ICP-MS = Inductively Coupled Plasma-Mass Spectrometry
MDL = Method Detection Limit

Filters bearing suspended sediment and milligram quantities of standard reference material (SRM) #2704, a river sediment issued by the U.S. National Institute of Standards and Technology (NIST), were digested in stoppered, 15-mL Teflon test tubes using Ultrex II® HNO₃, HF and HCl. The sealed test tubes were placed in an 80°C water bath where refluxing of the acids completely decomposed and dissolved the particles on the filters. After digestion, the resultant solutions were transferred to acid-washed, 15-mL polyethylene bottles, diluted to ~6 mL with DDW rinses of the Teflon test tubes and stored in a plastic bag until analyzed.

Metal concentrations for the digested samples of suspended sediment, SRMs and blanks were determined by FAAS, GFAAS or ICP-MS in a manner compatible with EPA Series 7000, 6010A and 7470 (U.S. EPA, 1991), respectively, and using the instruments previously identified. Particulate Al, Fe and Zn concentrations were quantified by FAAS. Concentrations of Cr and Cu were determined by GFAAS. Values for Ba, Cd and Pb were determined by ICP-MS. In all cases, the instrument manufacturers' specifications were followed and adherence to QA/QC requirements was maintained.

Total Organic Carbon

A 0.5-1 gram portion of the freeze-dried bottom sediment was placed in a 10-mL Pyrex beaker and wetted with 1 mL of DDW followed by the addition of 5 mL of 10% phosphoric acid (H₃PO₄) to remove any inorganic carbon present. The sediment was dried at 60°C and re-weighed to determine the increase in weight due to the formation of calcium phosphate as a result of adding H₃PO₄. Then, approximately 200-400 mg of pre-treated sediment were weighed into ceramic boats and combusted at 900°C in a Shimadzu TOC-5050A carbon system with SSM-5000A solid sampling module following the manufacturer's instructions. The total organic carbon (TOC) content of the sediment samples was determined using a four-point calibration curve with pure sucrose as the standard. The TOC concentrations were corrected to account for the increase in sediment mass following the addition of H₃PO₄. The calibration curve was checked every 10 samples by analyzing standard reference material (SRM) MESS-2 or MESS-3, marine sediments issued by the NRC of Canada.

Samples for particulate organic carbon (POC) were prepared by filtration of water through pre-combusted Gelman Type A/E glass fiber filters mounted on acid-washed filtration glassware within a Class-100 laminar-flow hood. The POC filters were sealed in acid-washed Petri dishes, labeled, and double bagged in plastic until analyzed. The POC filters were treated with H₃PO₄ to remove inorganic carbon phases, rinsed with DDW, dried and their particulate mass determined. The filters were then placed in ceramic boats and combusted at 900°C in a Shimadzu TOC-5050A carbon system with SSM-5000A solid sampling module following the manufacturer's instructions. The POC content of the samples was determined using a four-point calibration curve with pure sucrose as the standard. The calibration curve was checked every 10 samples by analyzing the CRM MESS-2 or MESS-3.

Radionuclides

Sediment samples used for age dating were sub-sectioned in 1-cm intervals. Approximately 8-10 grams of freeze dried sediment from each layer (1-cm thick) of the sediment cores were ground to a fine powder using a Spex 8000 mixer mill. The samples were then tightly packed into 2-cm diameter, 5-cm long polycarbonate vials to a depth of 30 ± 1 mm. A rubber stopper was cemented into place in the vial with two-part epoxy to prevent leakage of ^{222}Rn and disruption of secular equilibrium between ^{226}Ra and ^{210}Pb . The samples were then set aside for at least 20 days to establish secular equilibrium.

The activities of ^{210}Pb , ^{214}Pb , ^{214}Bi and ^{137}Cs were determined using a well-type, intrinsic germanium detector (WiGe, Princeton Gamma Tech). Vials containing about 10 g of freeze-dried sediment were counted for about 2 days until all peak areas were sufficient to provide <10% counting error. Detector efficiency was determined using the following: NBS 4350B, river sediment and NBS 4354, freshwater lake sediment from National Institute of Standards and Technology (NIST) and standards RGU-1 and RGTh-1 from the International Atomic Energy Agency. The specific activity (dpm/g) of each sediment sample was calculated from the detector efficiency, gamma intensity, geometry factor and sample weight. All values are reported as the activity on the date of coring. Errors are shown on the basis of 1-sigma counting statistics.

Sedimentation rates (S) in cm/yr were calculated using the following equations:

^{137}Cs :

$$S = \frac{\text{Depth in cm at which Activity } ^{137}\text{Cs} = \text{zero}}{[\text{Year} - (1950)] \text{ in years}}$$

^{210}Pb :

$$S = \frac{(-) \text{ decay constant for } ^{210}\text{Pb-210} (0.0311 \text{ yr}^{-1})}{\text{Slope for plot of natural logarithm (ln) excess } ^{210}\text{Pb vs. sediment depth}}$$

The activity of excess ^{210}Pb is calculated by subtracting the mean of $A(^{214}\text{Pb}, ^{214}\text{Bi})$ from $A(\text{total } ^{210}\text{Pb})$. The activities of ^{214}Pb and ^{214}Bi are assumed to be in secular equilibrium with ^{226}Ra .

Quality Assurance and Quality Control

Sample Tracking Procedure

All sediment samples were collected by, transported by and stored by personnel from FIT. Upon return-to or arrival at the laboratory, each sample was carefully inspected to insure that it was intact and that the identification number was clearly readable.

Quality Control Measurements for Analysis

For this project, QC measures included balance calibration, instrument calibration (FAAS, GFAAS, CVAAS, ICP-MS, TOC analyzer), matrix spike analysis for each metal, duplicate sample analysis, analysis of CRMs and SRMs, procedural blank analysis and standard checks. With each batch of up to 20 samples, two procedural blanks, two CRMs or SRMs, two duplicate samples and two matrix-spiked samples were analyzed. Data quality objectives (DQOs) for these quality control measurements are provided in Table 3.

Instrument Calibration

Electronic balances used for weighing samples and reagents were calibrated prior to each use with certified NIST-traceable standard weights. All pipets (electronic or manual) were calibrated prior to use. Each of the spectrometers used for metal analysis was initially standardized with a three- to five-point calibration; a linear correlation coefficient of $r \geq 0.999$ was required before experimental samples were analyzed. Analysis of complete three- to five-point calibrations and/or single standard checks alternated every 5-10 samples until all the analyses were complete. The relative standard deviation (RSD) between complete calibration and standard check was required to be <15% or recalibration and reanalysis of the affected samples were performed.

Matrix Spike Analysis

Matrix spikes were prepared for a minimum of 5% of the total number of samples analyzed and included each metal to be determined. Results from matrix spike analysis using the method of standard additions provide information on the extent of any signal suppression or enhancement due to the sample matrix. If necessary (i.e., spike results outside 80-120% limit), spiking frequency was increased to 20% and a correction applied to the metal concentrations of the experimental samples.

Duplicate Sample Analysis

Duplicate samples from homogenized field samples (as distinct from field replicates) were prepared in the laboratory for a minimum of 5% of the total samples. These laboratory duplicates were included as part of each set of sample digestions and analyses and provide a measure of analytical precision.

Table 3. Data quality objectives and criteria.

Element or Sample Type Criteria	Minimum Frequency	Data Quality Objective/Acceptance
Initial Calibration	Prior to every batch of samples	3-5 point curve depending on the element and a blank.
	Standard Curve	correlation coefficient $r = 0.999$ for all analytes.
Continuing Calibration	Must end every analytical sequence; for flame, repeat all standards every 5 samples; for graphite furnace and ICP-MS recheck standard after every 8-10 samples	% RSD < 15% for all analytes
Certified and Standard Reference Materials	Two per batch of 20 samples	Values must be within 20% of accepted values for >85% of the certified analytes and within 25% for Hg.
Method Blank	Two per batch of 20 samples	No more than 2 analytes to exceed 5x MDL
Matrix Spike and Spike Method Blank	Two per batch of 20 samples	% RSD 80-120%
Lab Duplicate	Two per batch of 20 samples	RSD < 25% for 65% analytes

Procedural Blank Analysis

Two procedural blanks were prepared with each set of 20 samples to monitor potential contamination resulting from laboratory reagents, glassware and processing procedures. These blanks were processed using the same analytical scheme, reagents and handling techniques as used for the experimental samples.

CRM and SRM analysis

A common method used to evaluate the accuracy of environmental data is to analyze reference materials, samples for which consensus or "accepted" analyte concentrations exist. The following CRMs and SRMs were used: Marine Sediment CRM MESS-2 and MESS-3 (NRC) and Buffalo River sediment SRM#2704 (NIST). Metal concentrations obtained for the reference materials were required to be within 20% of accepted values for >85% of other certified analyses. Results for the CRM MESS-2(3) are given in Table 4. The complete data for reference materials are tabulated in the Appendix.

Table 4. Results for reference materials.

	MESS-2 certified concentrations ^a (µg/g)	This study ^b (µg/g)
Ag (n = 6)	0.017 ± 0.01	0.018 ± 0.02
Al (n = 6)	8.68 ± 0.19 (%)	8.57 ± 0.26 (%)
As (n = 6)	20.3 ± 0.6	20.7 ± 0.8
Ca (n = 8) ^c	1.36 ± 0.07 (%)	1.47 ± 0.06 (%)
Cd (n = 6)	0.24 ± 0.01	0.24 ± 0.01
Cr (n = 6)	102 ± 2	106 ± 8
Cu (n = 6)	38.8 ± 1.2	39.5 ± 2.0
Fe (n = 6)	4.23 ± 0.11 (%)	4.35 ± 0.22 (%)
Hg (n = 12)	0.093 ± 0.008	0.092 ± 0.009
K (n = 8) ^{c,d}	2.43 ± 0.13 (%)	2.6 (%)
Mg (n = 8) ^{c,d}	1.58 ± 0.06 (%)	1.6 (%)
Mn (n = 6)	350 ± 5	365 ± 21
Ni (n = 6)	48.2 ± 0.9	49.3 ± 1.8
Pb (n = 6)	21.3 ± 0.7	21.9 ± 1.2
Se (n = 6)	0.64 ± 0.16	0.72 ± 0.09
V (n = 6)	252 ± 5	252 ± 10
Zn (n = 6)	160 ± 3	172 ± 16
POC (n = 6) ^{c,d}	2.07 ± 0.01 (%) ^c	2

^a ± 95 confidence limits.

^c MESS-3 (NRC).

^b ± 1 standard deviation.

^d Reference value, not certified.

Data for all QA/QC measurements are given with the complete data sets in the Appendix. All DQOs for this project were met as shown in Table 4 and the Appendix.

Results and Discussion

Thickness of Layers of Fine-Grained, Organic-Rich Sediment (Muck Depths)

The thickness of fine-grained, organic-rich sediment that typically overlies a sand base (i.e., muck depth) was determined at 54 locations in Crane Creek during September 2002 (Figure 2). The information from this survey provided an overview of the present-day amounts of fine-grained sediment in the creek and helped guide the selection of sites for sediment coring. The muck depths were determined by pushing a calibrated, 5-cm diameter, polyvinyl chloride (PVC) rod, with an end cap, into the soft sediment until stiff resistance was encountered. The water depth to the soft sediment (muck) and the depth of the muck layer were recorded.

For the purposes of this report, Crane Creek has been divided into the following four sub-basins: (1) Sewage Treatment Plant (STP) Basin between the STP and the railroad bridge, (2) Manatee Basin between the railroad bridge and highway US 1, (3) Harbor Basin between US 1 and the area where the creek becomes oriented in a southward direction, and (4) Mouth Basin from the Harbor Basin to the mouth of the creek.

The average muck depth from 50 probings throughout the creek during 2002 was 77 ± 82 cm with a range of 0 to 392 cm, excluding four values of 0 cm under the railroad bridge (Figure 2). The large range and standard deviations in the depths of the muck layers show that distribution of muck is patchy. Overall, the thickest layers of muck, averaging 180 ± 102 cm, were found in the harbor area (Figure 2). Along the STP Basin, the thickest layers of muck were found along the southern perimeter of the creek. A large pocket of fine-grained sediment was found in the center portion of the Manatee Basin. The muck in the center portion of the Manatee Basin graded to depths that approached zero to the west, south and east (Figure 2).

Data for muck depths were previously collected during summer 1998, following dredging that took place from January 27 to April 2, 1998 (Windsor et al., 1998). The grand mean of 112 ± 81 cm ($n = 31$) for summer 1998 is not significantly different from the mean observed during 2002 (t-test, $\alpha = 0.05$, $p = 0.05$). In the 1998 survey, the mean thicknesses of the muck layers for the Manatee, Harbor and Mouth Basins were not significantly different from one another at depths of 153, 126 and 159 cm, respectively (Figure 3). These results for 1998 show most clearly that considerable amounts of muck sediment remained in Crane Creek following dredging.

Further comparison of the 2002 muck depths with the 1998 results (Figure 4) shows that mean values were greater, but not significantly different ($p = 0.04$), in the Harbor Basin during 2002 relative to 1998. Likewise, no significant differences in muck depths were found for the Manatee and STP Basins for 2002 versus 1998. Average muck depths in the Mouth Basin were significantly greater in 1998 and than in 2002 ($p = 0.06$). At most, the data show some shifting of sediment toward the Harbor Basin between 1998 and 2002. At minimum, they suggest that there has not been a large influx of sediment during the four-year period between surveys (Figure 4).

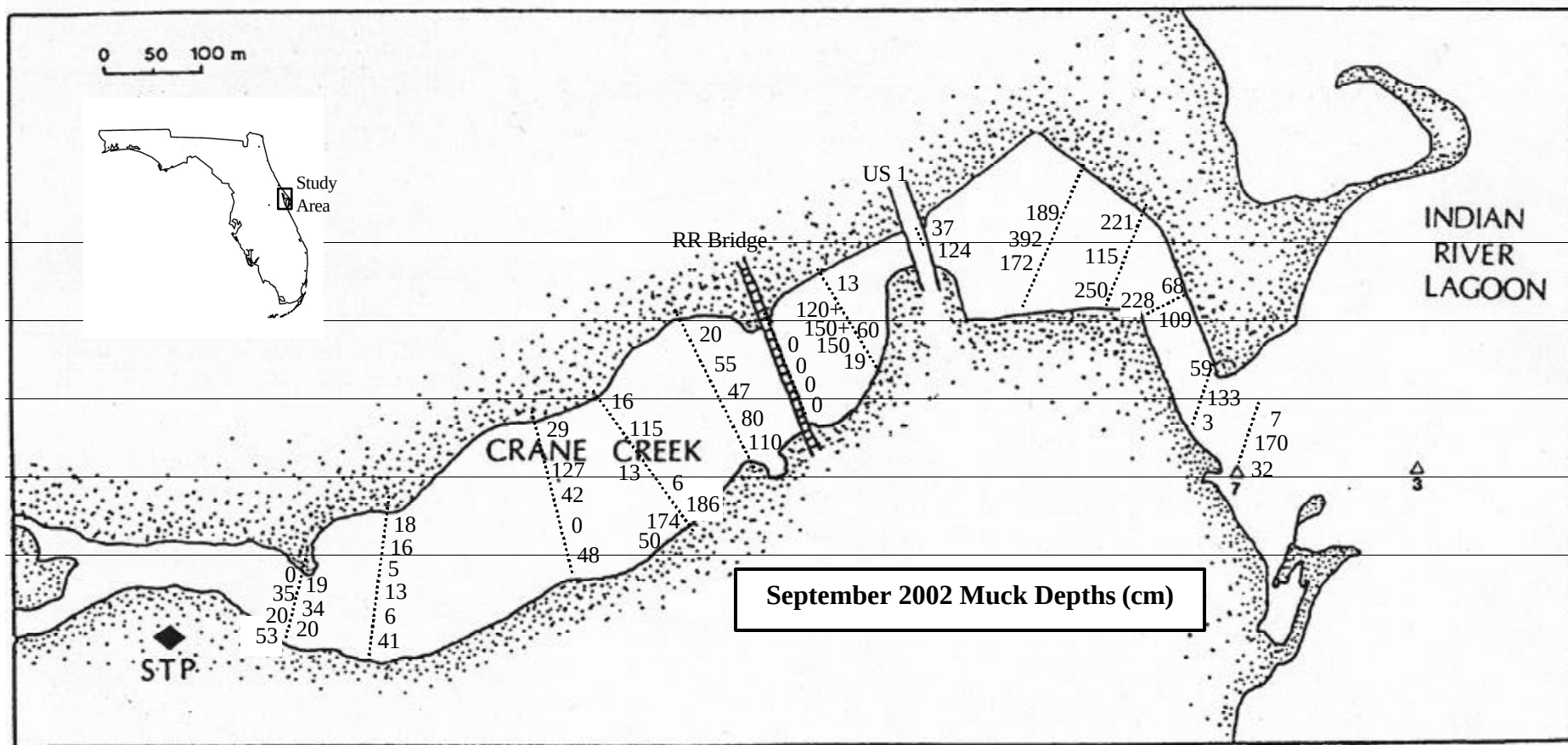


Figure 2. Depths (in centimeters) of organic rich, fine-grained sediments (muck) in Crane Creek during September 2002 (RR = railroad; STP = Sewage Treatment Plant). Inset map shows location of Crane Creek along the coast of east, central Florida.

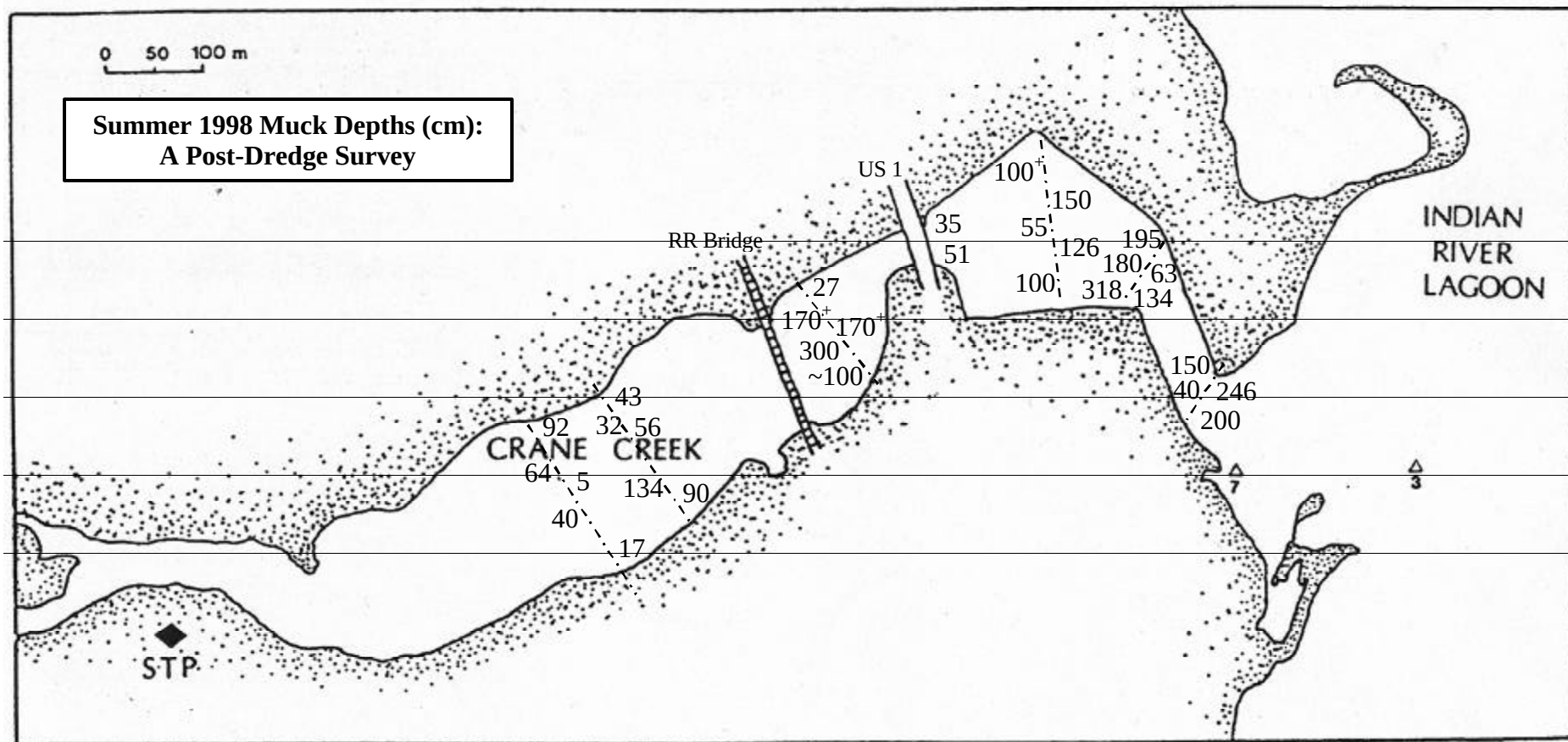


Figure 3. Depths (in centimeters) of organic rich, fine-grained sediment (muck) in Crane Creek during Summer 1998 (RR = railroad; STP = Sewage Treatment Plant).

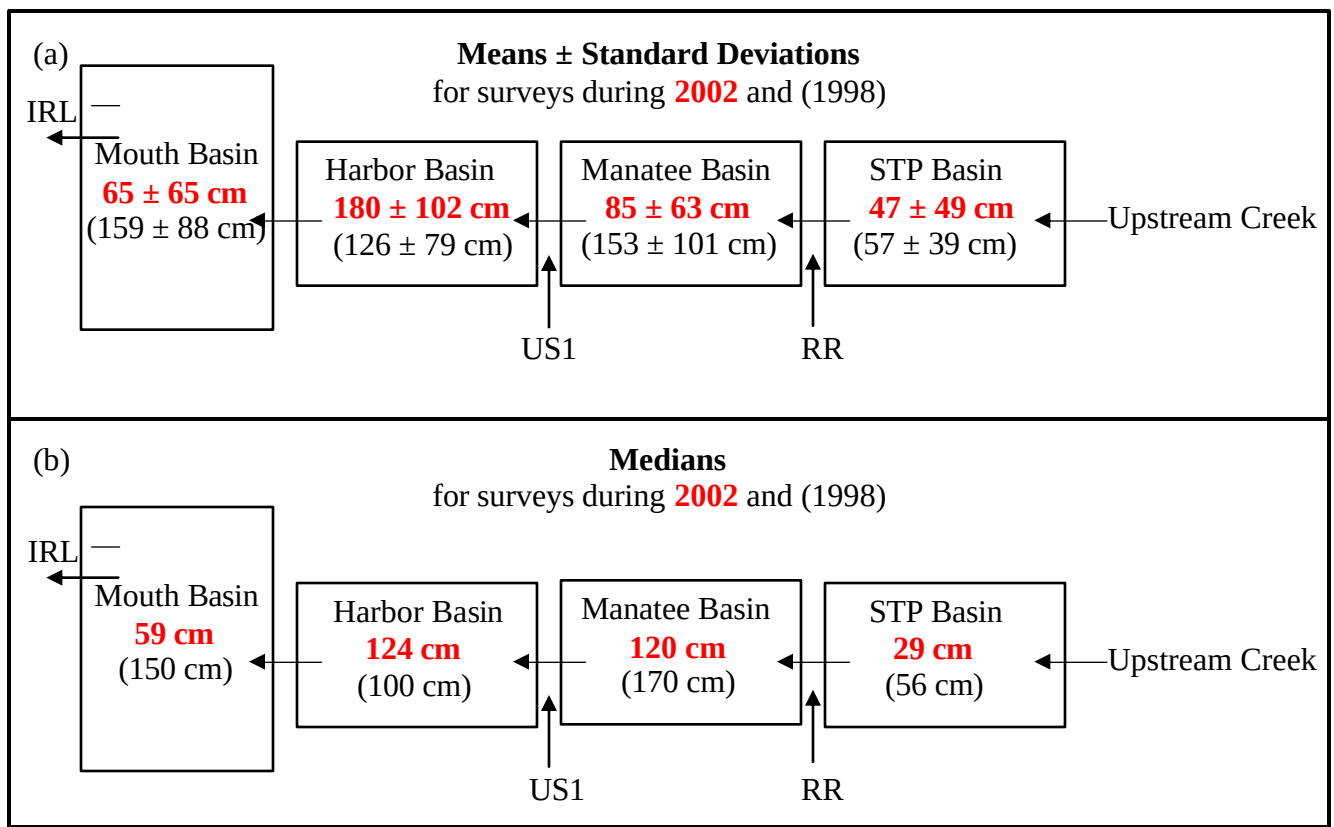


Figure 4. (a) Means and standard deviations and (b) medians for depths of fine-grained, organic-rich sediment in Crane Creek during this study (2002) compared with results from summer 1998 (numbers in parentheses) from Windsor et al. (1998). (RR = railroad; STP = Sewage Treatment Plant, IRL = Indian River Lagoon; US1 = highway US 1).

Sediment Geochronology

To calculate sedimentation rates in Crane Creek, the activities of excess ^{210}Pb and ^{137}Cs were determined for samples from seven of the eight cores collected (Figure 5, excluding the core from station 2). Thus, data for cores from the following sub-basins of the creek were available: three from the STP Basin (west of the railroad bridge), two from the Manatee Basin (between the railroad bridge and US 1), and two from the Harbor Basin (Figure 5). In most instances, the top layer (varying from ~2 to 50 cm) of the sediment had been mixed by *in situ* physical or biological processes; and, sand layers were observed at varying depths in several cores. Thus, no core was ideal for age-dating. However, we have made reasonable use of the pertinent data from each core to estimate or bracket sedimentation rates and sediment ages.

The fallout radionuclide ^{137}Cs (half-life = 30 years) was introduced to the atmosphere during nuclear weapons testing in the 1950s and early 1960s. Atmospheric fallout and deposition in sediments present ^{137}Cs as a stratigraphic marker of the initial years of fallout circa 1950 and maximum fallout in 1963 (Robbins and Edgington, 1975). Results from ^{137}Cs are commonly used to help validate recent sediment ages and sedimentation rates from other techniques. In this study, we used excess ^{210}Pb to determine sedimentation rates. Lead-210 (half-life = 22.3 years) is a naturally occurring decay product of ^{238}U . Along the decay series, the gas ^{222}Rn (half-life = 3.8 days) is formed and a portion of that ^{222}Rn escapes from continental crust to the atmosphere where it decays to ^{210}Pb and is removed from the atmosphere within days to months (Burton and Stewart, 1960; Moore et al, 1973). The atmospherically-derived ^{210}Pb enters rivers and oceans as unsupported or excess ^{210}Pb (parent isotopes are absent). The atmospherically-derived

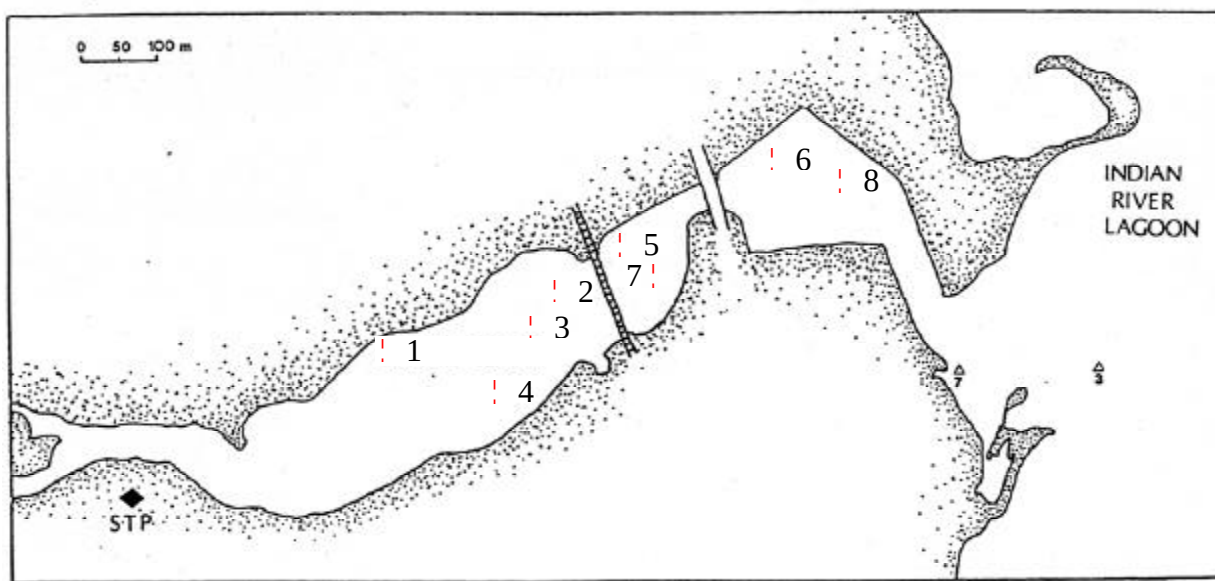


Figure 5. Locations of stations in Crane Creek where sediment cores were collected during 2002.

excess ^{210}Pb , along with ^{210}Pb formed by decay in the water column, are removed to the sediments via adsorption on particles or by biological processes (Bruland et al., 1974). This excess ^{210}Pb that accumulates in the sediments decays away to non-detectable levels in 4 to 5 half-lives. Analytically, the excess ^{210}Pb is distinguished from total ^{210}Pb as follows:

$$\text{Activity of Excess } ^{210}\text{Pb} = \text{Activity of Total } ^{210}\text{Pb} - \text{Activity of } ^{226}\text{Ra}$$

where the activity of ^{226}Ra is equal to the supported ^{210}Pb that was carried into the system with its parent isotopes via suspended sediments. The activities of ^{214}Pb and ^{214}Bi are used as proxies for ^{226}Ra in this study.

The excess ^{210}Pb profiles in each of three cores from the STP Basin (cores 1, 3 and 4, Figures 6 and 7) show three anomalously low values at varying depths in the top 15 cm relative to 7 to 8 points that follow more predicted behavior and are used here to calculate a slope and sedimentation rate. The anomalous points may result from addition of older sediment, with a lower activity of excess ^{210}Pb , from the perimeter of the creek to more recent, incoming sediment. The anomalous layers do not appear to contain different amounts of sand or shell than the other layers, based on data for Al and other elements to be presented below. Initially, the three anomalous points for excess ^{210}Pb in each core were omitted from the regression calculation, a procedure that was defended by Kang et al. (2000) and Kang and Trefry (2003). With this modification, sedimentation rates for stations 1, 3 and 4 are 0.38, 0.43 and 0.42 cm/yr, respectively, with $r > 0.89$ in each case (Figures 6 and 7). As a point of reference, if all the data points are used for each station, the sedimentation rates based on excess ^{210}Pb are as follows: station 1 at 0.26 cm/yr ($r = 0.72$), station 3 at 0.60 cm/yr ($r = 0.43$) and station 4 at 0.45 cm/yr ($r = 0.49$). The agreement between the adjusted and complete data sets for station 4 are quite similar whereas the results for stations 1 and 3 vary by ± 40 to 50%.

Using the 1950 marker in the ^{137}Cs profiles for cores from stations 1, 3 and 4 (Figures 6 and 7), the sedimentation rates at these three stations are 0.6, 0.3 and 0.6 cm/yr, respectively. The activities of ^{137}Cs in the three layers from each core with anomalously low levels of excess ^{210}Pb do not appear to be as significantly affected in the same manner as the excess ^{210}Pb values. This observation further demonstrates the inherent difficulties in determining sedimentation rates in a hydraulically active, shallow-water system such as Crane Creek. Despite the apparent incongruities, the sedimentation rates obtained using ^{137}Cs are within 30 to 50% of values obtained using the excess ^{210}Pb data.

The activities of ^7Be (half life = 53.3 days) also were determined for the top layers (0-6 cm) of sediment from stations 1, 3 and 4 (Figure 8). These results show the degree surface mixing of the sediments by physical and biological processes. In the cores from sites 1 and 3, the activity of ^7Be is decreased by about 5-fold below a sediment depth of 2 cm, suggesting that rapid mixing (over a several month period) is restricted to the top 2-3 cm in each of these cores.

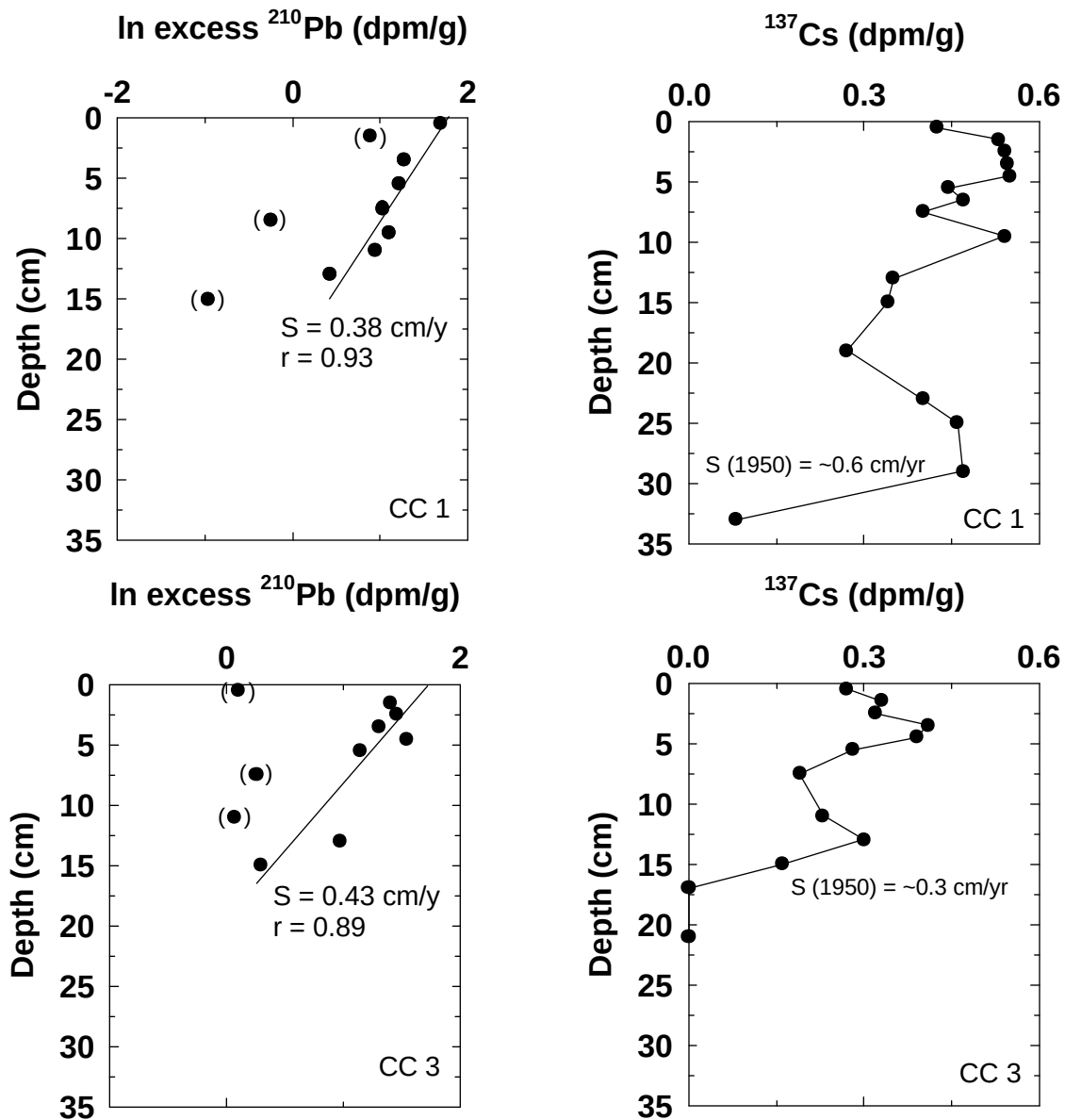


Figure 6. Vertical profiles for the natural logarithm ($\ln$) of excess ^{210}Pb activity and the total activity of ^{137}Cs for sediment cores from stations 1 and 3 in the STP Basin of Crane Creek. Markers in parentheses on the plots for excess ^{210}Pb identify anomalously low activities for excess ^{210}Pb ; these values have not been included in the linear regression calculation for sedimentation rate. S is the sedimentation rate and r is the correlation coefficient for the linear regression.

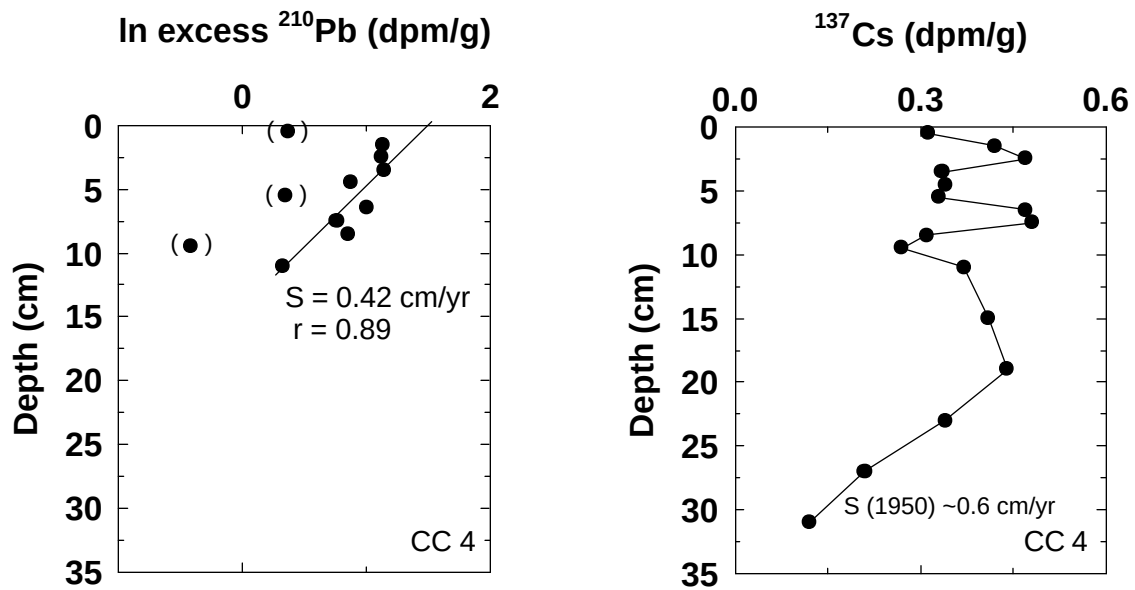


Figure 7. Vertical profiles for the natural logarithm (ln) of excess ^{210}Pb activity and the total activity of ^{137}Cs for sediment cores from station 4 in the STP Basin of Crane Creek. Markers in parentheses on the plot for excess ^{210}Pb identify anomalously low activities for excess ^{210}Pb ; these values have not been included in the linear regression calculation for sedimentation rate. S is the sedimentation rate and r is the correlation coefficient for the linear regression.

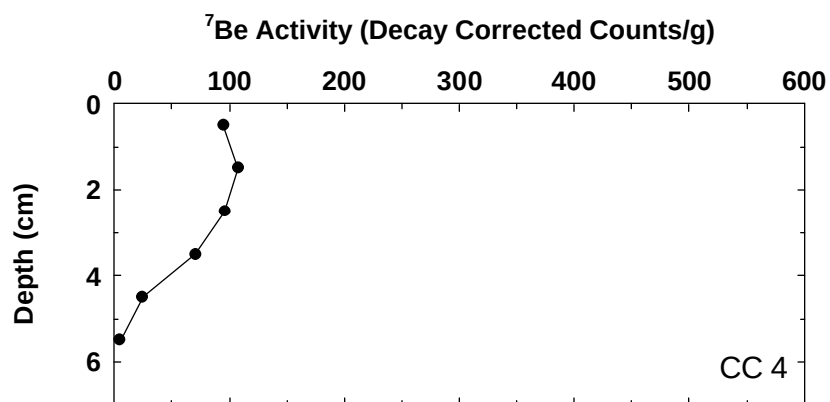
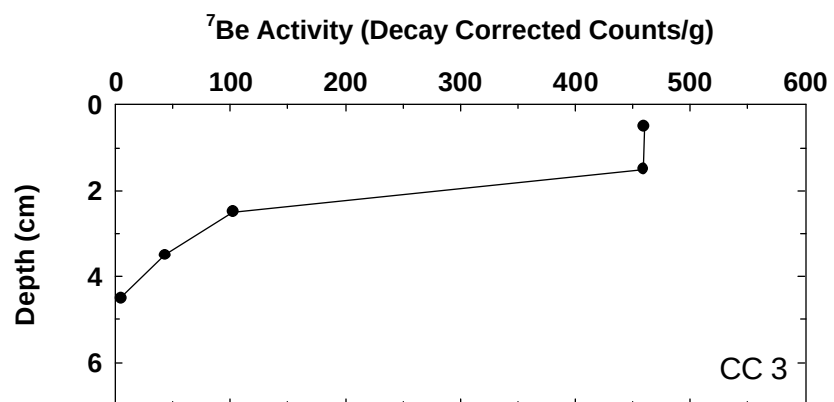
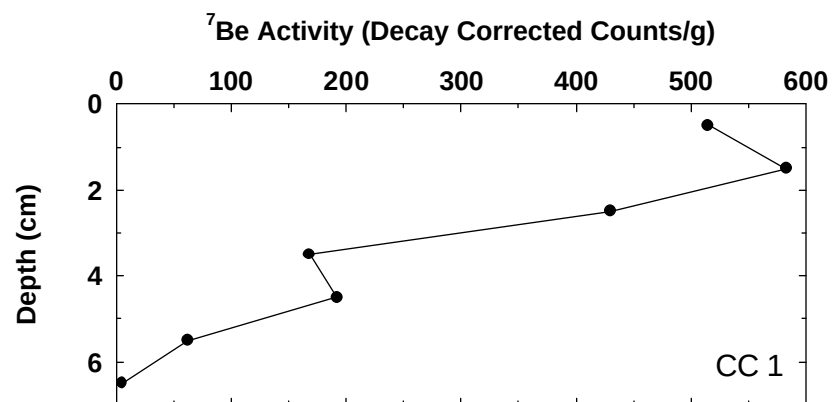


Figure 8. Vertical profiles for the activity of ^7Be in sediment cores from stations 1, 3 and 4 from the STP Basin of Crane Creek.

The core from station 7, on the southern side of the Manatee Basin, provided the best agreement between sedimentation rates calculated using data for excess ^{210}Pb and ^{137}Cs (Figure 9). An average of $\sim 0.23 \pm 0.06$ cm/yr was obtained using the excess ^{210}Pb data and both the 1950 and 1963 ^{137}Cs markers. In sharp contrast, the data for core 5, collected on the north side of the Manatee Basin, show sediment mixing to a depth >40 cm and the core is not valuable for age determinations. The decrease in activities of ^{137}Cs and excess ^{210}Pb at a depth of ~ 60 cm are related to the presence of a sand layer, rather than a time-relevant decrease in activities. The shallow water (<2 m) and manatee activity in the area are consistent with the observed mixing.

The core from station 8 was collected in an area with somewhat less boat traffic on the eastern portion of the Harbor Basin (Figure 5). The data for both excess ^{210}Pb and ^{137}Cs support sediment accumulation at a relatively rapid rate of ~ 2 cm/yr (Figure 10). At station 6, located near the fuel dock in the central portion of the Harbor Basin, the sediment was mixed (or slumped) to a depth of ~ 50 cm and thus calculation of sedimentation rates is difficult. Nevertheless, values obtained using each isotope are 0.6 to ~ 1 cm/yr (Figure 10).

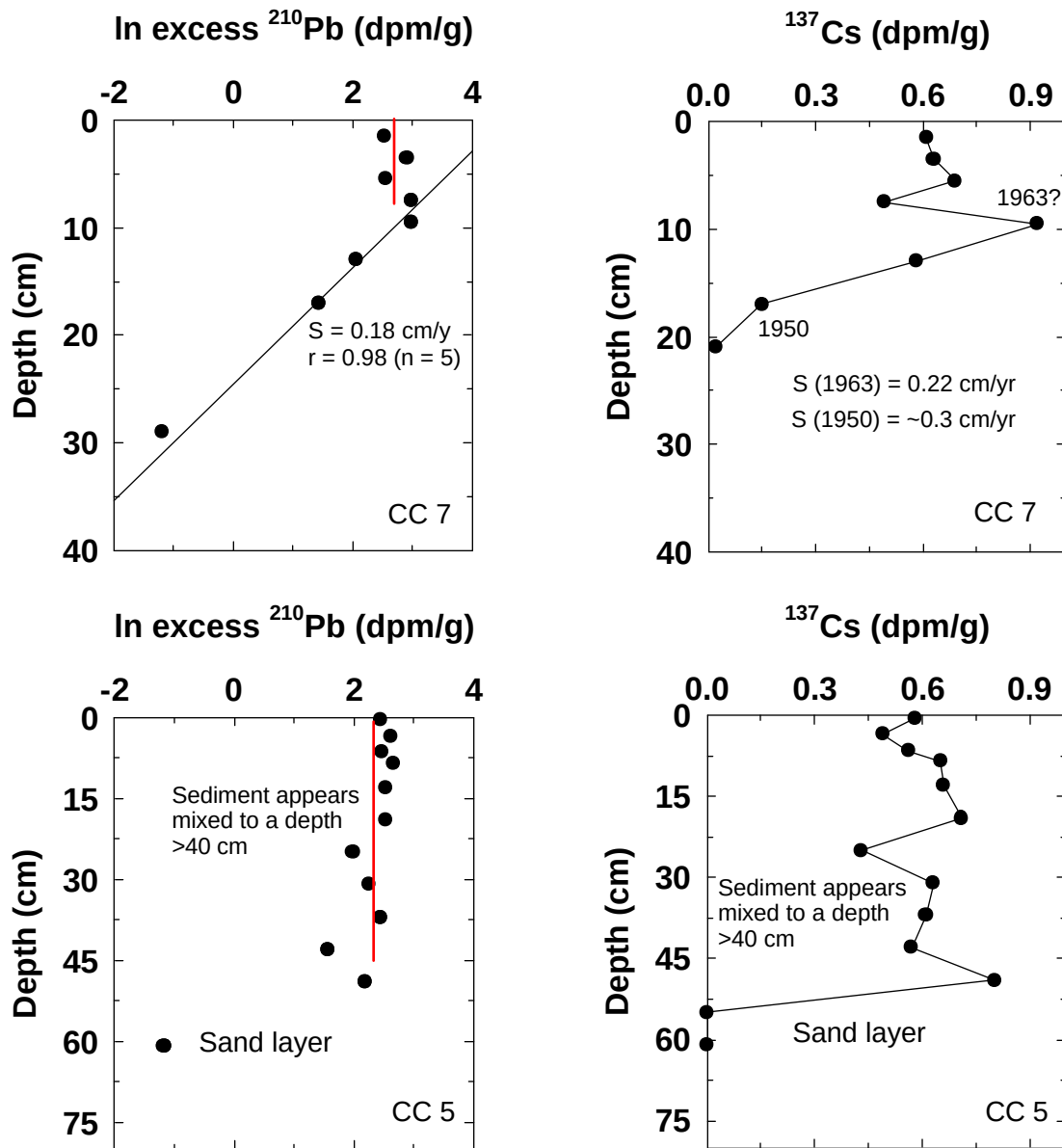


Figure 9. Vertical profiles for the natural logarithm ($\ln$) of excess ^{210}Pb activity and the total activity of ^{137}Cs for sediment cores from stations 7 and 5 from the Manatee Basin in Crane Creek. Vertical line shows estimated extent of vertical mixing of sediment. S is the sedimentation rate and r is the correlation coefficient for the linear regression.

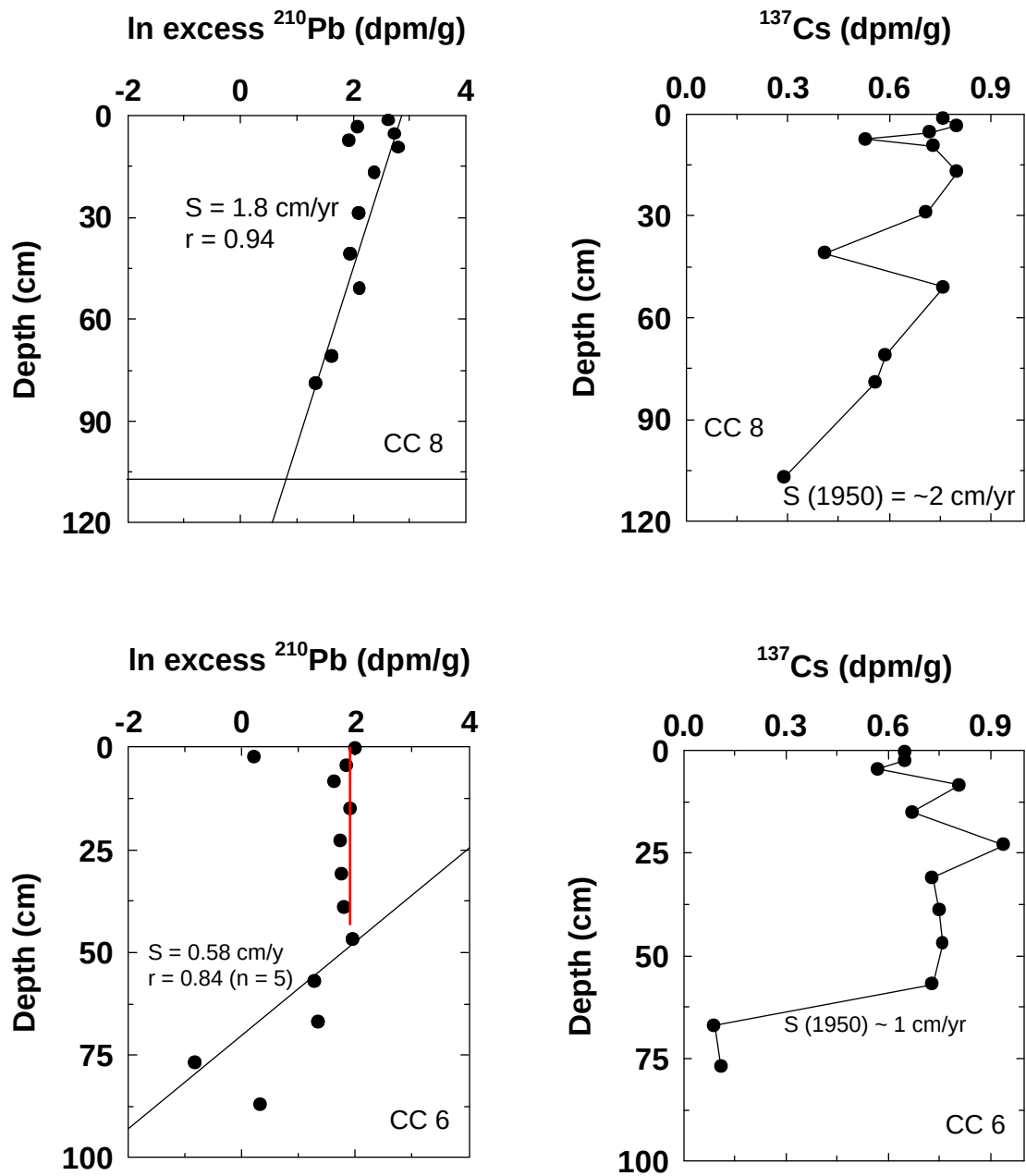


Figure 10. Vertical profiles for the natural logarithm ($\ln$) of excess ^{210}Pb activity and the total activity of ^{137}Cs for sediment cores from stations 6 and 8 from the Harbor in Crane Creek. Vertical line shows estimated extent of vertical mixing of sediment. S is the sedimentation rate and r is the correlation coefficient for the linear regression.

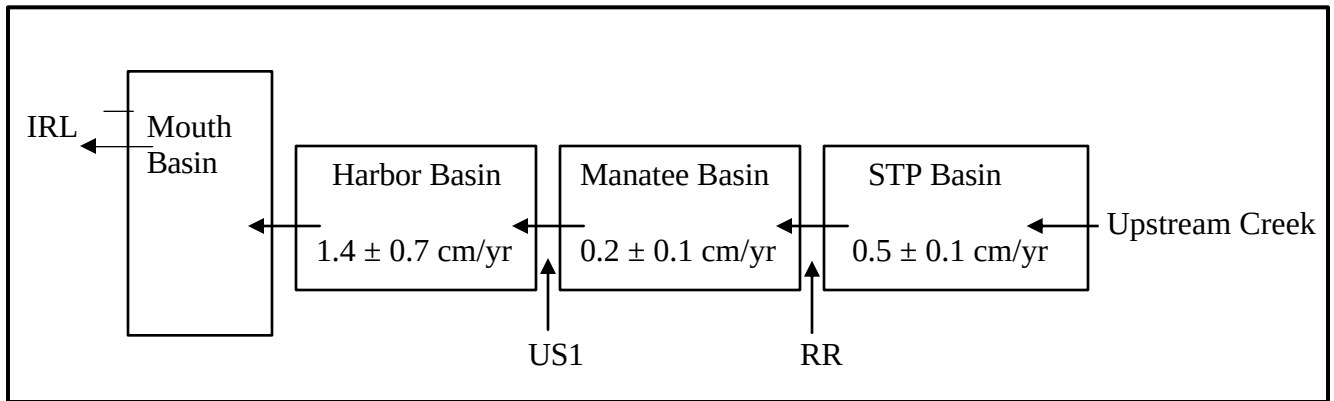


Figure 11. Summary of sedimentation rates for three basins in Crane Creek (RR = railroad; STP = Sewage Treatment Plant, IRL = Indian River Lagoon; US1 = highway US 1).

A summary of the sedimentation rates obtained from the six cores using both excess ^{210}Pb and ^{137}Cs data (Figure 11) shows the highest rates of sedimentation in the Harbor Basin with almost three times lower levels in the STP Basin and ~seven times lower levels in the Manatee Basin. The grand average for the six cores is 0.7 ± 0.6 cm/yr (n=12, two rates per core).

Major Elements and Trace Metals in Sediments

Overview of Data Set and Use of Interelement Relationships

To address questions related to sediment sources, sediment quality and sediment history, the data for major elements and trace metals in soils, suspended sediments, surface sediments, sediment cores are used collectively. Summary data for soils and sediments are given in Table 5 (major elements) and Table 6 (trace metals). The data for suspended sediments are listed in Table 7. The complete data set is compiled in the appendix. Maps showing the locations of sampling sites are presented here for soils (Figure 12), surface sediments (Figure 13) and suspended sediments (Figures 12 and 14). Locations of sediment coring stations were shown previously in Figure 5.

Concentrations of major elements, trace metals and TOC are higher in sediment samples than in soils because the sediments are more fine-grained and clay rich (Tables 5 and 6). One approach to gaining an overview of this large and diverse data set for soils, suspended sediments, surface sediments and sediment cores is by graphically presenting concentrations of various elements versus Al or another appropriate element. Aluminum provides a useful frame of reference because Al is resistant to chemical weathering in soils and sediments and it is a good indicator of the aluminosilicate (clay) fraction of the sample, where 8-10% Al usually represents a sample that is dominated by (>80%) clay or other aluminosilicate minerals.

Concentrations of Al and Fe in all sediment samples were used to calculate a linear regression for the data and fit a 95% prediction interval to the sediment data set (Figure 15). The Al and Fe data for the sediment samples fit the linear regression well ($r = 0.94$). Values for ten of the twelve soil samples plotted within the 95% prediction interval, excluding soils from sites 5 and 6, both located in the southern portion of the drainage basin (Figure 15). These two samples were Fe-poor (or Al-rich) relative to the sediment or other soil samples. In contrast, all six of the samples of suspended sediment from Crane Creek with $TSS < 7$ mg/L had Fe/Al ratios that plotted above the upper prediction interval (Figure 15). The high Fe/Al ratios of some samples of suspended sediment and the low Fe/Al ratios of two soil samples do not fit the overall observed relationship found in the sediments. However, the distinct differences in the Fe/Al ratios for the suspended sediment are most likely transient and quantitatively unimportant with respect to the composition of creek sediments as described in more detail later in this report. In the case of the soils, Fe can be leached from soils more easily than Al to create the observed anomalies.

The Al versus K relationship is almost as good as the Fe/Al trend with a few samples of soil and suspended sediment having low K levels (Figure 15). The outliers were all below the lower prediction interval and included one soil sample (soil site 6) and a few of the same samples of suspended sediment that had elevated ratios of Fe/Al (figure 15). As in the case of Fe, no clear differences in concentrations of the metal (in this case K) versus Al were observed and thus no straightforward tracer for sources of sediments to the creek was identified.

Table 5. Means and standard deviations for concentrations of Al, Ca, Fe, K, Mg, Mn and total organic carbon (TOC) for soils, surface sediments and sediment cores from Crane Creek.

Location		Al (%)	Ca (%)	Fe (%)	K (%)	Mg (%)	Mn (µg/g)	TOC (%)
Soils (n = 12)	Mean (±Std. Dev.)	1.66 ±2.48	1.82 ±1.98	0.58 ±0.66	0.16 ±0.13	0.09 ±0.12	41 ±22	1.94 ±1.64
Perimeter Surface Sediments (n = 18)	Mean (±Std. Dev.)	4.32 ±1.21	1.19 ±0.38	2.63 ±0.65	0.52 ±0.15	0.98 ±0.44	164 ±79	3.89 ±0.82
Center Surface Sediments (n = 10)	Mean (±Std. Dev.)	3.77 ±2.60	1.71 ±1.09	2.37 ±1.60	0.42 ±0.30	0.91 ±0.74	161 ±128	4.22 ±2.94
Core 1 (n = 9)	Mean (±Std. Dev.)	3.40 ±1.36	1.89 ±1.56	2.33 ±0.77	0.34 ±0.10	0.55 ±0.33	115 ±31	2.78 ±1.12
Core 4 (n = 14)	Mean (±Std. Dev.)	2.41 ±1.13	0.94 ±0.33	2.06 ±1.02	0.33 ±0.07	0.35 ±0.21	112 ±20	2.32 ±1.57
Core 7 (n = 10)	Mean (±Std. Dev.)	3.48 ±2.57	2.11 ±1.00	2.50 ±1.44	0.32 ±0.18	0.41 ±0.32	151 ±67	4.51 ±2.72
Core 8 (n = 13)	Mean (±Std. Dev.)	4.64 ±1.53	1.52 ±0.36	2.92 ±0.99	0.58 ±0.18	1.23 ±0.50	244 ±71	5.03 ±1.28

Table 6. Means and standard deviations for concentrations of Ag, As, Cd, Cr, Cu, Hg, Ni, Pb, Se, V and Zn for soils, surface sediments, and sediment cores from Crane Creek.

Location		Ag (µg/g)	As (µg/g)	Cd (µg/g)	Cr (µg/g)	Cu (µg/g)	Hg (µg/g)	Ni (µg/g)	Pb (µg/g)	Se (µg/g)	V (µg/g)	Zn (µg/g)
Soils (n = 12)	Mean (±Std. Dev.)	0.04 ±0.04	1.8 ±1.5	0.08 ±0.07	10 ±23	9 ±8	0.04 ±0.03	4 ±6	12 ±9	0.6 ±0.4	22 ±30	36 ±32
Perimeter Surface Sediments (n = 18)	Mean (±Std. Dev.)	1.4 ±0.7	6.4 ±2.1	0.64 ±0.16	55 ±14	80 ±50	0.25 ±0.06	16 ±4	53 ±14	1.8 ±0.4	61 ±17	223 ±63
Center Surface Sediments (n = 10)	Mean (±Std. Dev.)	1.1 ±0.9	5.8 ±3.5	0.52 ±0.36	54 ±35	67 ±46	0.18 ±0.11	14 ±9	71 ±58	1.0 ±0.7	54 ±37	183 ±126
Core 1 (n = 9)	Mean (±Std. Dev.)	3.9 ±1.7	4.6 ±2.2	0.95 ±0.36	60 ±18	52 ±25	0.48 ±0.30	17 ±5	67 ±24	1.1 ±0.2	46 ±19	212 ±108
Core 4 (n = 14)	Mean (±Std. Dev.)	4.5 ±3.9	2.4 ±1.2	0.53 ±0.33	56 ±38	41 ±33	0.43 ±0.38	15 ±10	61 ±44	1.1 ±0.6	33 ±14	170 ±130
Core 7 (n = 10)	Mean (±Std. Dev.)	1.4 ±1.2	5.5 ±3.7	0.70 ±0.52	50 ±37	55 ±47	0.23 ±0.17	12 ±9	53 ±44	1.5 ±0.2	48 ±38	198 ±162
Core 8 (n = 13)	Mean (±Std. Dev.)	1.7 ±0.7	6.7 ±3.5	1.5 ±0.4	66 ±20	82 ±35	0.29 ±0.11	18 ±6	67 ±15	1.1 ±0.3	71 ±26	168 ±77

Table 7. Means and standard deviations for concentrations of Ag, Al, Ca, Cu, Fe, K, Mg, Mn, Pb, Zn and particulate organic carbon (POC) for suspended sediments from Crane Creek.

Location	Ag (µg/g)	Al (%)	Ca (%)	Cu (µg/g)	Fe (%)	K (%)	Mg (%)	Mn (µg/g)	Pb (µg/g)	Zn (µg/g)	POC (%)
Ruffner Park	0.09	5.47	4.68	41.6	2.04	0.29	0.36	90.2	48.9	312	11.1
Babcock Street Bridge	0.22	5.59	4.71	55.4	3.1	0.26	0.38	162	68.7	403	14.6
Hickory Ditch	0.27	3.28	3.11	78.2	1.33	0.32	0.27	106	107	408	17.6
West of RR	1.44	3.50	1.02	44.5	5.59	0.29	0.57	641	49.6	291	-
Manatee Basin	0.76	5.50	1.47	68.1	8.17	0.21	0.45	399	124	320	-
Harbor Basin, east US 1	1.03	5.09	1.28	72.2	6.85	0.25	0.60	594	90.6	295	4.67
Center of Harbor (0.2 m)	1.97	4.43	0.98	134	6.58	0.15	0.56	723	109	257	2.59
Center of Harbor (2 m)	1.00	4.21	0.49	107	3.26	0.47	1.46	569	34.9	288	-
Harbor FIT (0.2 m)	1.97	4.43	0.98	134	6.58	0.15	0.56	723	109	257	2.59
Harbor FIT (2 m)	0.98	4.70	0.83	120	3.75	0.44	1.29	653	48.7	312	8.90
IRL (0.2 m)	0.27	2.83	0.59	32.3	2.15	0.50	1.35	755	32.1	132	-
IRL (2 m)	0.24	2.90	1.11	17.9	2.17	0.46	1.24	575	26.1	381	-

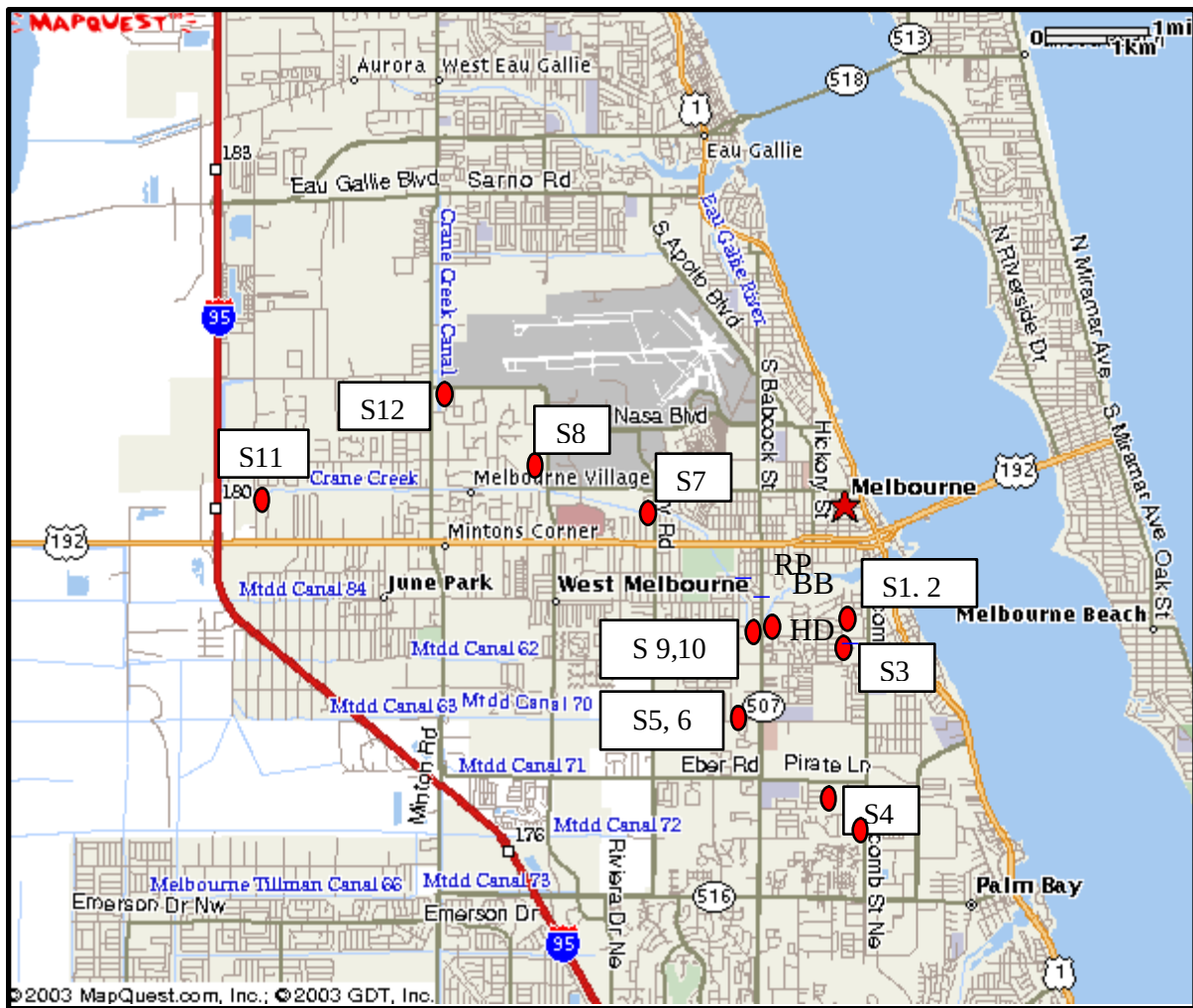


Figure 12. Locations of sites where soil samples (●) and upstream suspended sediment samples (–) were collected during 2003.

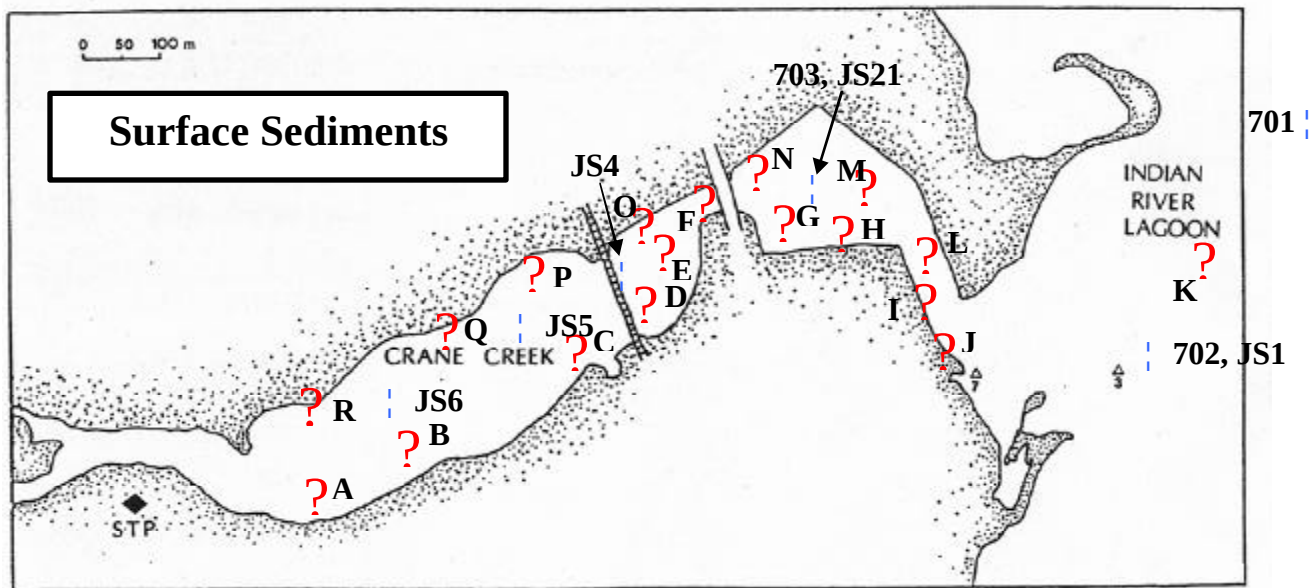


Figure 13. Locations of stations in Crane Creek where surface sediments were collected during 2002.

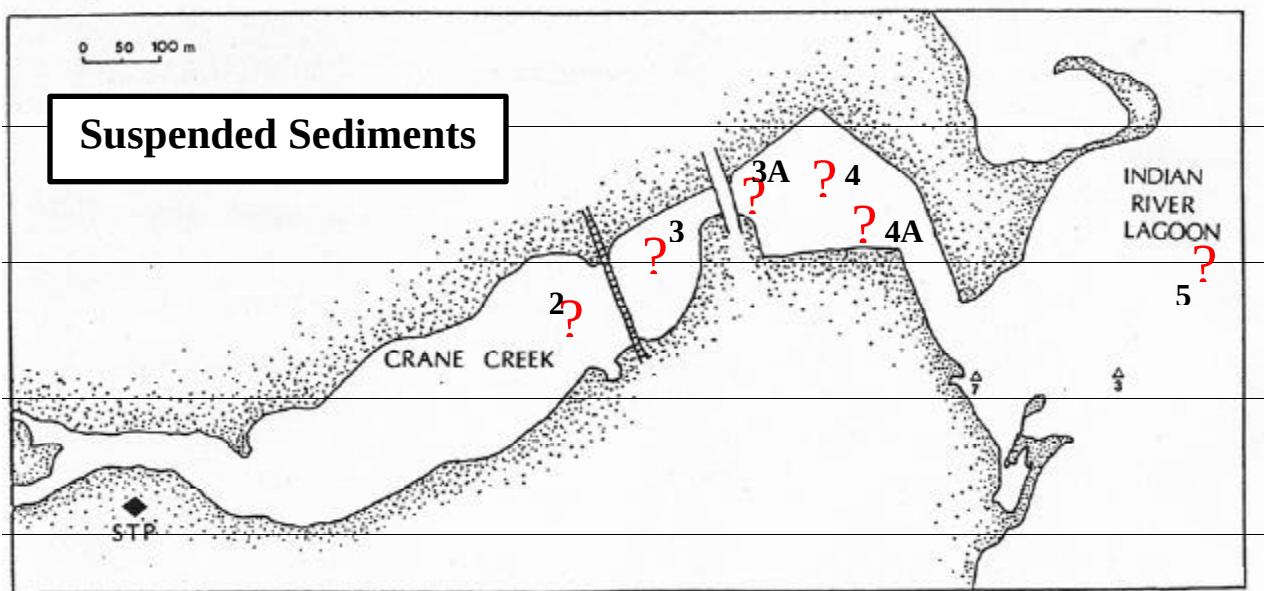


Figure 14. Locations of stations in Crane Creek where suspended sediments were collected during 2002. Locations of sampling sites for suspended sediments at upstream location are shown on Figure 12.

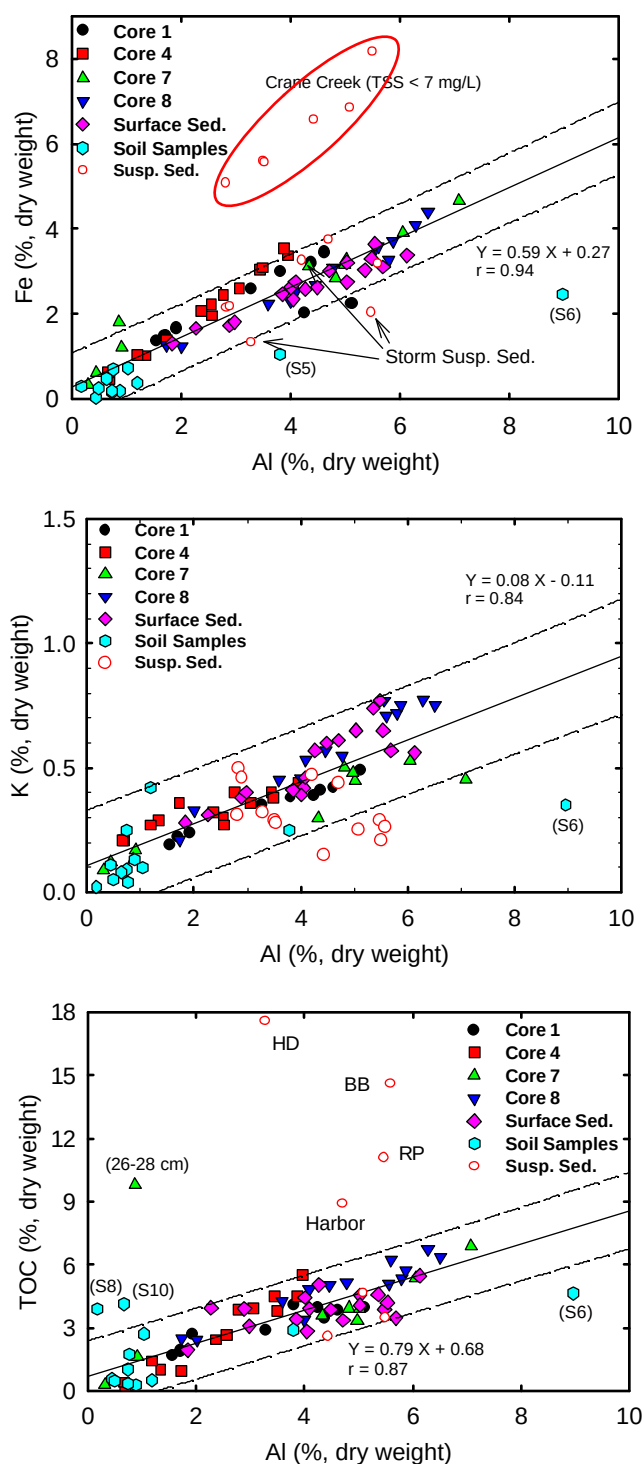


Figure 15. Concentrations of Al versus (a) Fe, (b) K and (c) total organic carbon (TOC) for sediments, soils and suspended sediments from the study area. Linear regression with 95% prediction interval was constructed using sediment data and excluded any points that are labeled in the graph. (HD = Hickory Ditch, BB = Babcock St. Bridge, RP = Ruffner Park).

Concentrations of TOC in sediments also correlated well with concentrations of Al (Figure 15) with only one sediment sample (core 7, 26-28 cm) that contained anomalously high levels of TOC. All three of the suspended sediment samples collected during a storm event (at Ruffner Park, Babcock Street Bridge and Hickory Ditch) with TSS levels of 312-408 mg/L contained >10% TOC, suggesting that storm flow carries a higher fraction of organic matter with the suspended sediment than commonly found in bottom sediments. Most likely, this excess organic matter is decomposed in creek sediments leading to the high oxygen demand described by Windsor et al. (2004, this study).

Concentrations of Ca are relatively uniform at 0.5 to 2% in sediment samples (Figure 16); therefore, no linear regression was carried out for the Al versus Ca data. Most of the samples contain relatively low levels of CaCO_3 because 2% Ca is equivalent to ~5% CaCO_3 . Four of the soil samples, all collected north of route 192 contained >4% Ca (Figure 16), or most likely > 10% CaCO_3 . Only two sediment samples contained >4% Ca, one from near the bottom (36-38 cm) of core 1 and one from 22-24 cm in core 7. Both these anomalies are most likely due to some residual shell material. Two samples of suspended sediment from near the same area (Ruffner Park and the Babcock Street bridge, locations in Figure 12) contained >4% Ca (Figure 16). A limey suspension has been observed in unpaved roads in area of Ruffner Park during rain storms. This observation is consistent with the storm period when these samples were collected. Overall, CaCO_3 is not being preserved to any significant levels in Crane Creek and use of Ca or Ca/Al ratios as an indicator of sources seems useful mainly during storm transport.

Concentrations of Mg in sediments from Crane Creek correlate well with Al (Figure 16), but not Ca. This distinction suggests that Mg is part of the aluminosilicate fraction, rather than the carbonate fraction. Vermiculite and kaolinite are the two clay minerals identified in Crane Creek (D'Arcy, 1987). Vermiculite is Mg-rich as demonstrated by the following typical formula: $\text{Mg}_{1.8}\text{Fe}^{2+}_{0.9}\text{Al}_{4.3}\text{SiO}_{10}(\text{OH})_2 \cdot 4(\text{H}_2\text{O})$. However, the strong relationship between Mg and Al in the sediment samples suggests that the sources of Mg and Al must be similar or proportional in creek sediments. Most of the soil samples collected contained low levels of both Mg and Al and therefore did not contain any significant amounts of vermiculite or other clays. The Mg/Al ratio, in concert with the absolute Mg concentrations, may be a good indicator of the amount of vermiculite clay deposited at a given site in creek sediments.

Concentrations of Mn (100-300 $\mu\text{g/g}$) and the Mn/Al ratios ($20\text{-}40 \times 10^{-4}$) in sediments from Crane Creek (Figure 16) are low relative to average continental crust where Mn levels average ~700 $\mu\text{g/g}$ and the Mn/Al ratio is $\sim 90 \times 10^{-4}$ (Wedepohl, 1995). This observation is consistent with reductive dissolution of Mn oxides in the highly reducing creek sediments with subsequent release of dissolved Mn^{2+} to the overlying water column. In sharp contrast with the bottom sediments, the suspended sediments are enriched with Mn (Figure 16), most likely the result of oxidative precipitation of Mn oxide on particles being carried in oxic creek water. The source of this excess Mn is most likely from diffusion from bottom sediments. The Mn content of the suspended sediment helps show whether that suspended sediment has been carried in oxygenated

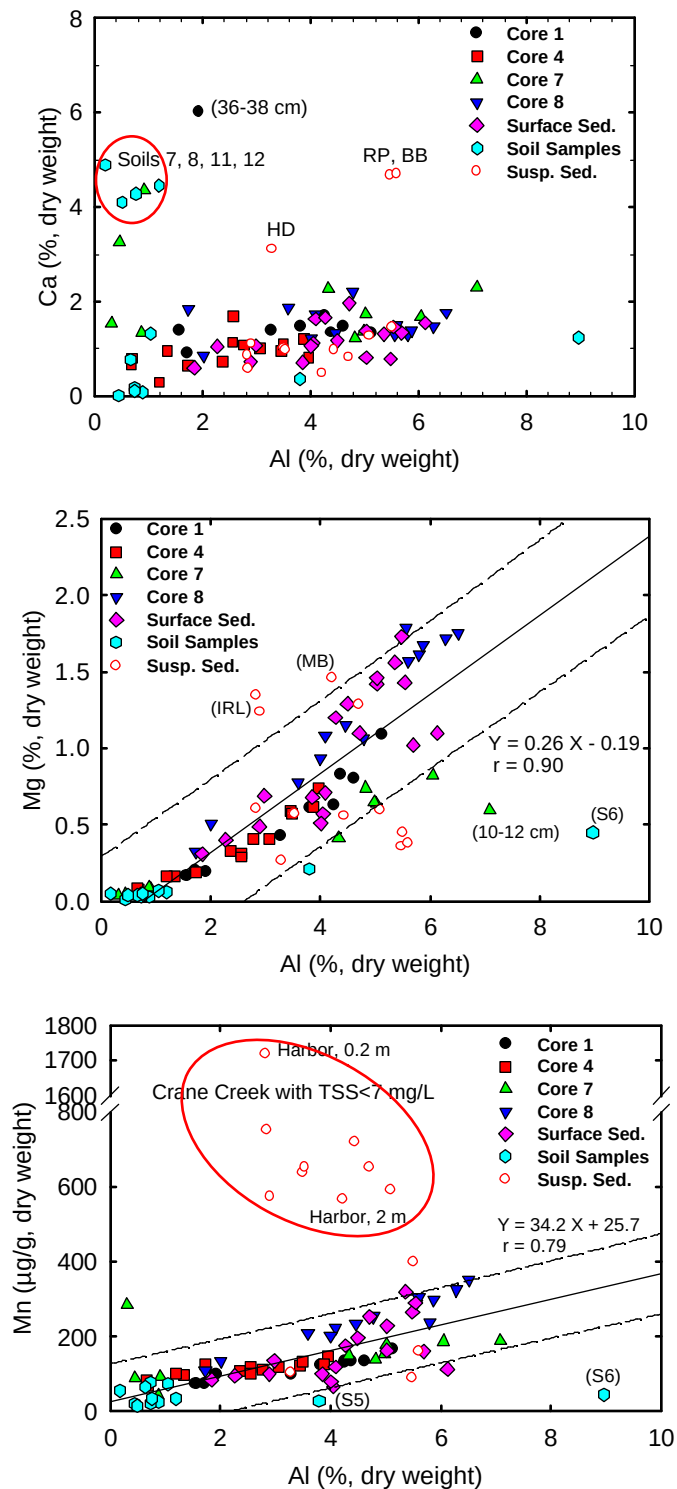


Figure 16. Concentrations of Al versus (a) Ca, (b) Mg and (c) Mn for sediments, soils and suspended sediments from the study area. Linear regression with 95% prediction interval was constructed using sediment data and excluded any points that are labeled in the graph.

water that was enriched with Mn that may have been released from reducing sediments. For example, the sample of suspended sediment collected from the harbor in more oxic water at a depth of 0.2 m has a Mn content of 1720 µg/g relative to the sample collected at 2 m in hypoxic water with a Mn content of 570 µg/g (Figure 16).

A strong positive correlation was found for Al versus V (Figure 17) with essentially all data points for sediments, soils and suspended sediments plotting within the 95% prediction interval established using sediment data. A similar degree of constancy was observed for Al versus As (Figure 17). Thus, concentrations of these two trace metals are at natural levels in the drainage basin. However, the uniform metal/Al relationship does not easily facilitate identification of distinct natural sources for these metals within the drainage basin.

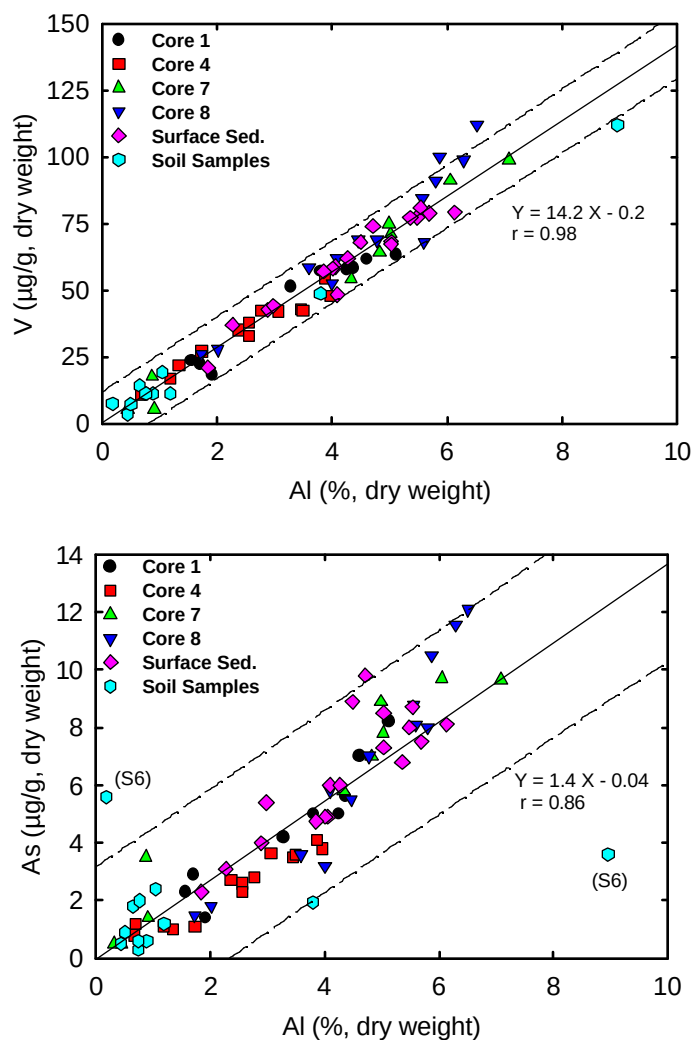


Figure 17. Concentrations of Al versus (a) V and (b) As for sediments, soils and suspended sediments from the study area. Linear regressions with 95% prediction interval were constructed using sediment data and excluded any points that are labeled in the graph.

Sediment Trace Metals: Tracing Sediment Sources and Assessing Sediment Quality

Most of the sediments from Crane Creek are contaminated with Ag and Hg (Figure 18). Sediments from cores 1 and 4, collected in the STP Basin, are the most contaminated with Ag and Hg at concentrations that are as much as 50 to more than 100 times greater than natural levels (Figure 18). These results suggest that a present or past source for anthropogenic Ag and Hg exists somewhere in the western (STP) basin or upstream. However, suspended sediments collected from the upper creek during storm runoff were low in Ag ($<0.3 \mu\text{g/g}$), suggesting that inputs may have occurred closer to the area between the STP and the railroad bridge. When sediment concentrations of Ag are plotted versus Hg (Figure 18), a strong linear fit ($r = 0.92$) is observed. The trend for Hg versus Ag supports a common source or source area for both metals. Based on the sediment data shown in Figure 18, the Ag and Hg was most likely introduced to the system west of the railroad bridge because concentrations of both metals (and the metal/Al ratios) are lower in the cores from stations 7 and 8 in the Manatee and Harbor Basins, respectively.

An historical perspective of the Ag and Hg contamination is shown in vertical profiles for the two metals in cores 1 and 4 from the STP Basin (Figure 19). Concentrations of Ag and the Ag/Al ratios are highest at depths of 15-30 cm, which equates to about 30 to 60 years ago. A similar trend is observed for Hg in core 4, but not in core 1 due to elevated surface values for Hg. Maximum concentrations of Ag and Hg and their ratios to Al in cores 7 and 8 from the Manatee and Harbor Basins, respectively, are 3 to 10 times lower than found to the west of the railroad bridge (Figure 20).

Data for Hg, but not Ag, are available for cores 3, 5 and 6 (Figure 20, bottom row of graphs). Mercury levels in core 3 (maximum of $0.39 \mu\text{g/g}$ in the surface layer) are about the same as those for cores 7 and 8 (Figure 20). However, high levels of Hg were found in core 5 ($0.6\text{-}1.1 \mu\text{g/g}$ at depths of 28-46 cm) and core 6 ($0.5\text{-}1.4 \mu\text{g/g}$ over a range of 28-90 cm). All the core data suggest that peak inputs of Ag and Hg were several decades ago. This conclusion is supported by the data for surface sediments (Figure 18) where generally lower concentrations of Ag and Hg were found relative to the older samples from sediment cores. Common sources for the co-occurrence of these two metals are dental wastes and photographic/art wastes.

Sediment quality criteria for Ag and Hg have been added to Figure 18. Such criteria have been used extensively worldwide to assess possible adverse biological effects to sediment biota from trace metals and PAH. One set of criteria introduced by Long et al. (1995) uses an Effects Range-Low (ERL) and Effects Range-Median (ERM). These guidelines are based on field, laboratory, and modeling studies conducted in the United States that coupled concentrations of contaminants in sediments with adverse biological effects (Long and Morgan, 1990; Long et al., 1995). The ERM is defined as the concentration of a substance in the sediment that results in an adverse biological effect in about 50 percent of the test organisms. The ERL is defined as the concentration of a substance that affects about 10 percent of the test organisms. For general application, the criteria have been

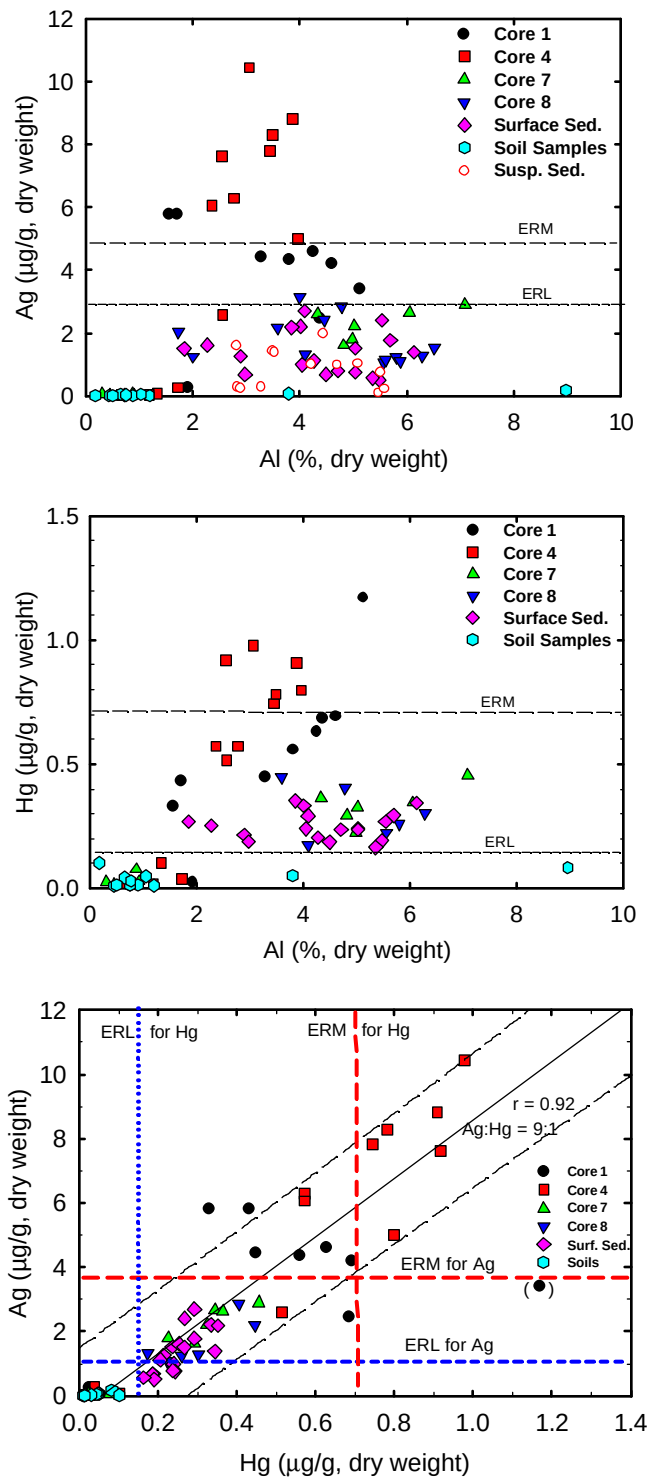


Figure 18. Concentrations of Al versus (a) Ag and (b) Hg and (c) concentrations of Hg versus Ag for sediments and soils from the study area. The linear regression with 95% prediction interval was constructed using sediment data and excluded any points that are in parentheses in the graph. Lines for Effects Range Median (ERM) and Effects Range Low (ERL) are from Long et al. (1995).

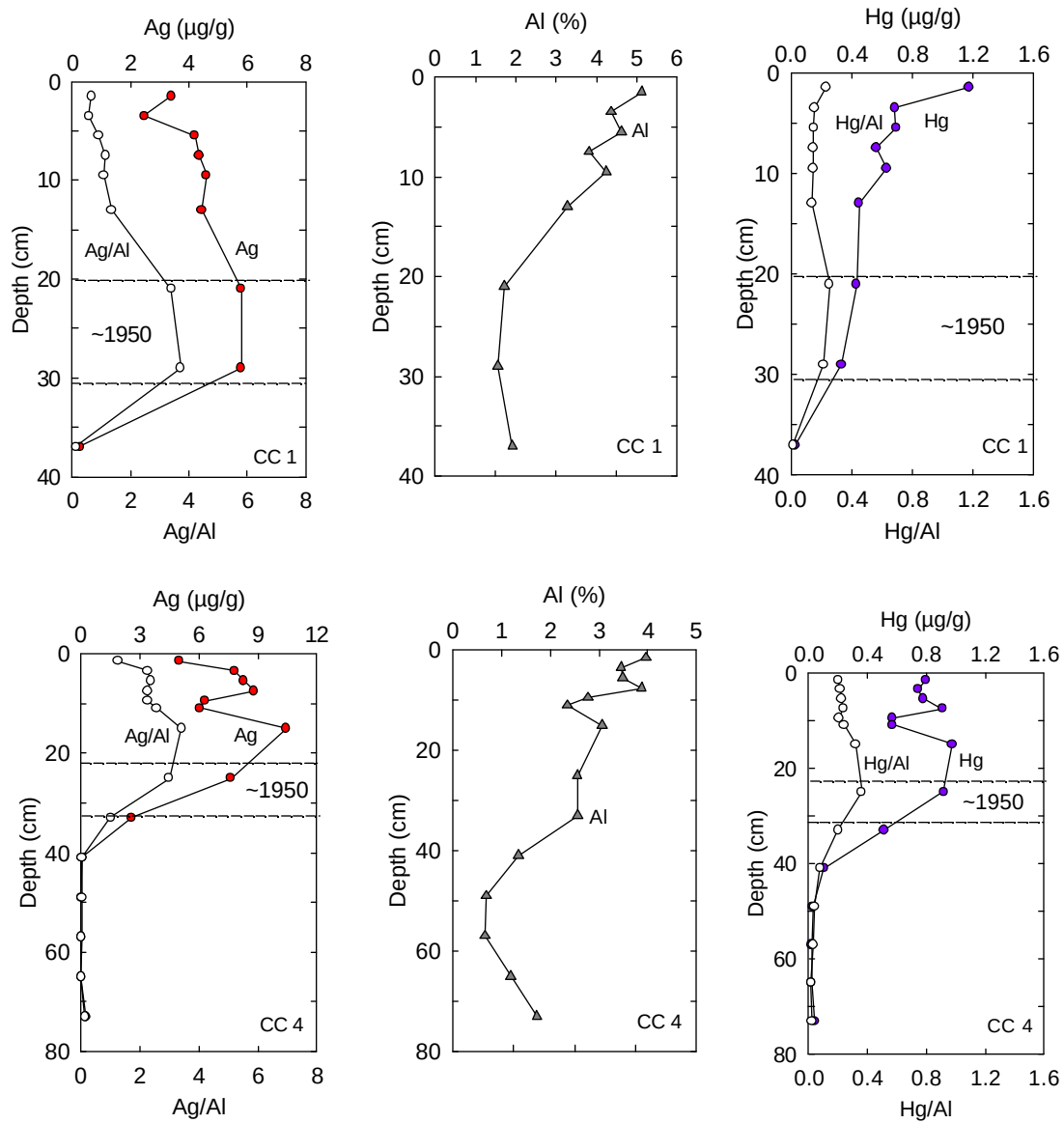


Figure 19. Vertical profiles for concentrations of Ag, Ag/Al, Al, Hg and Hg/Al in sediment cores from stations 1 and 4 in Crane Creek. Shaded areas show estimated range in depths that correspond to ~1950 based on results of age-dating.

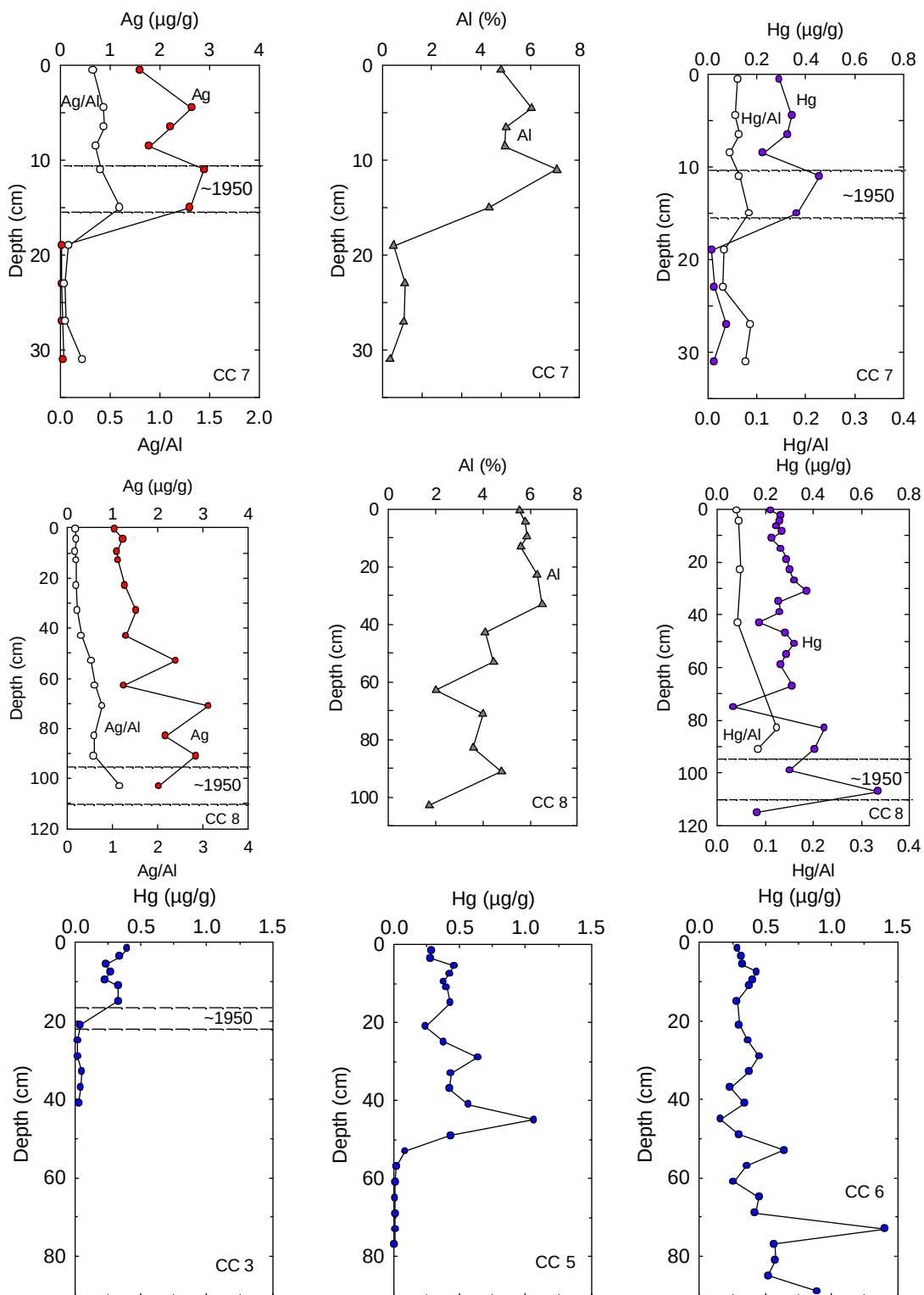


Figure 20. Vertical profiles for concentrations of Ag, Ag/Al, Al, Hg and Hg/Al in sediment cores from stations 7 and 8; and concentrations of Hg in cores 3, 5 and 6 in Crane Creek. Shaded areas show estimated range in depths that correspond to ~1950 based on results of age-dating where available.

applied as follows: adverse biological effects are “rarely” observed when metal or PAH levels are <ERL, “occasionally” observed when contaminants are present at levels between the ERL and ERM and “frequently” observed when concentrations are >ERM. Values for the ERM and ERL for six metals investigated during this study (Ag, As, Cd, Pb, Hg and Zn) have been developed by Long et al. (1995). Presently available ERL values for Cr, Cu and Ni are lower than values for average continental crust and seem to have evolved from data sets where concentrations of these metals in sediments were determined following an acid leach, rather than total digestion, of the sediment. Therefore, they are not included in this report.

Fourteen samples (from cores 1 and 4) had Ag levels greater than the ERM and seven samples had Hg levels above the ERM (Figure 18). Most of the remaining sediment samples contained Ag and Hg at levels that exceeded the ERL. Thus, based on the sediment quality criteria introduced above, the sediments at core sites 1 and 4 would be conducive to frequent adverse biological effects to any organisms dwelling in those sediments. Furthermore, sediments at most locations in Crane Creek could be characterized as promoting adverse biological effects on an occasional basis.

Concentrations of Pb were elevated over natural levels by two to six-fold at many sites throughout the creek with the highest values in suspended sediment from the Harbor Basin (Figure 21). None of the Pb values exceeded the ERM; however, more than half exceeded the ERL (Figure 21). Overall, the spatial distribution of Pb throughout the creek is rather ubiquitous. In the cores (Figure 22), Pb levels are highest in the top 20-30 cm of sediment at stations 1, 4 and 7 and throughout the core at station 8. In each case, the higher levels of Pb show that the onset of Pb contamination dates back about 50 years. The persistence of high Pb levels to greater depths in the sediment core from station 8 supports the faster sedimentation rate determined for this site in the Harbor Basin.

All concentrations of Cd were below the ERM and only three exceeded the ERL (Figure 21). In contrast, many of the Zn concentrations were greater than the ERL (Figure 21) with none greater than the ERM. The vertical distributions of Cd and Zn were similar to those described for Pb with high values restricted to the top 20 to 40 cm of cores 1, 4 and 7, yet throughout core 8 (Figure 22). These results also are consistent with the onset of metal contamination in Crane Creek that dates back about 50 years. Concentrations of Cd correlate well with concentrations of Zn ($r = 0.94$, Figure 23). This observation is common because Cd is a natural impurity in Zn ores and tends to go into the environment along with anthropogenic Zn inputs from galvanized metals, sacrificial anodes and other Zn-bearing alloys and materials.

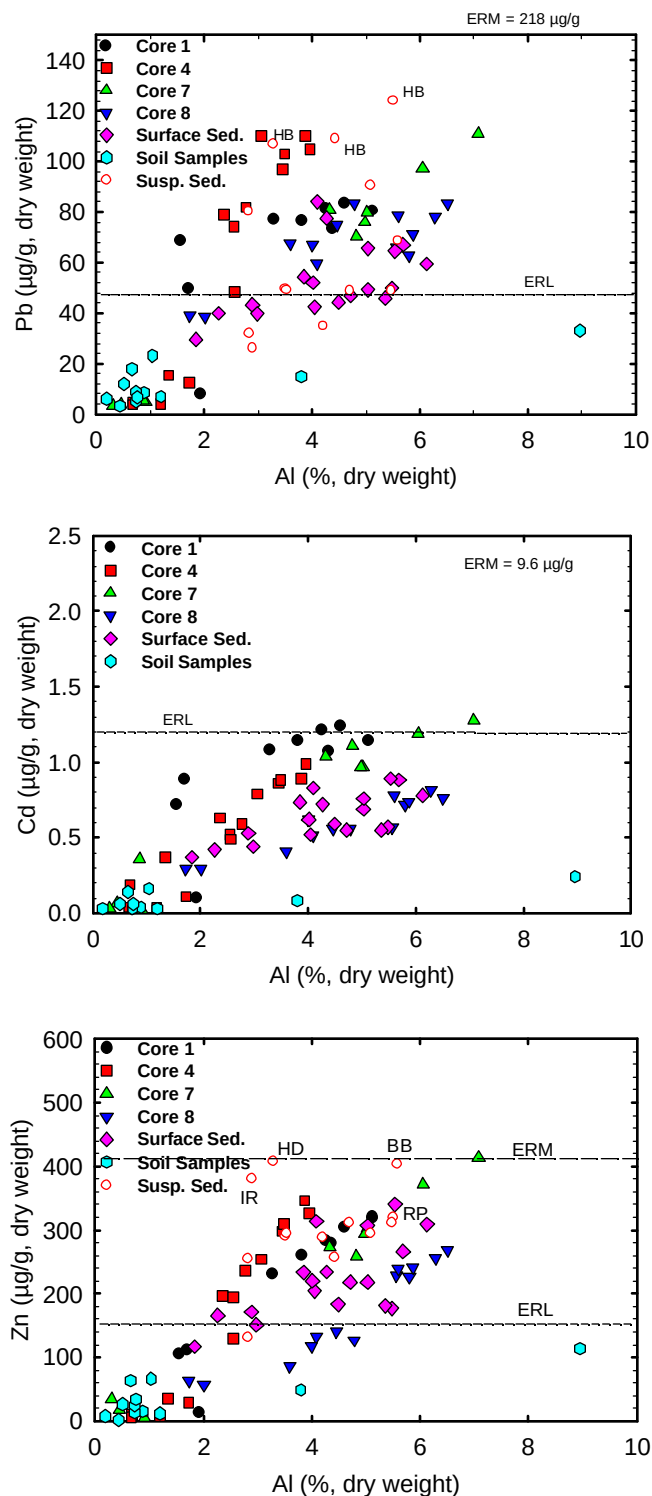


Figure 21. Concentrations of Al versus (a) Pb, (b) Cd and (c) Zn for soils, suspended sediments and bottom sediments from the study area. Lines for Effects Range Median (ERM) and Effects Range Low (ERL) are from Long et al. (1995). (HB = Harbor Basin, HD = Hickory Ditch, BB = Babcock Street Bridge, IR = Indian River Lagoon, and RP = Ruffner Park).

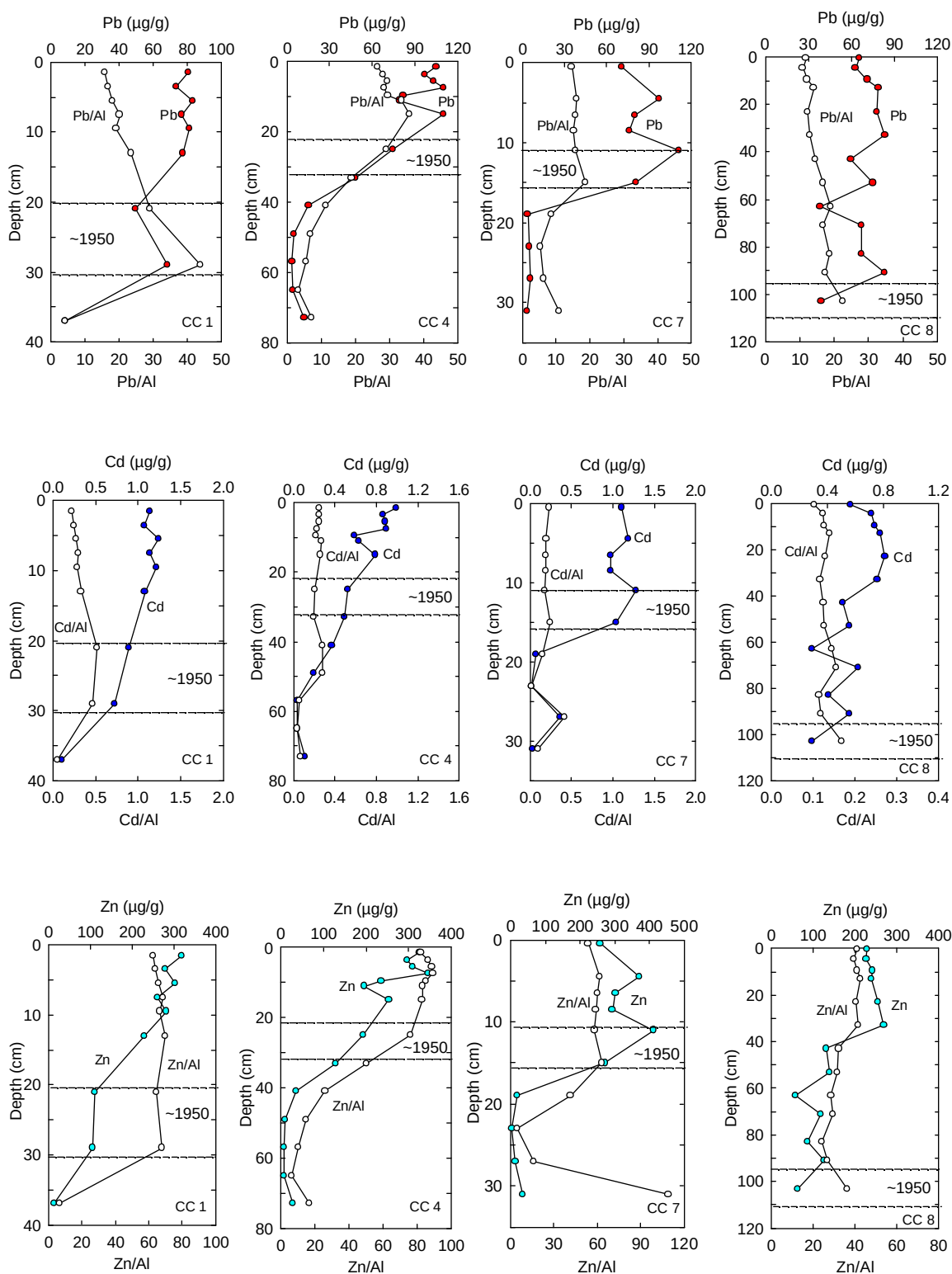


Figure 22. Vertical profiles for concentrations of Pb, Pb/Al, Cd, Cd/Al, Zn and Zn/Al in sediment cores from stations 1, 4, 7 and 8 in Crane Creek. Shaded areas show estimated range in depths that correspond to ~1950 based on results of age-dating.

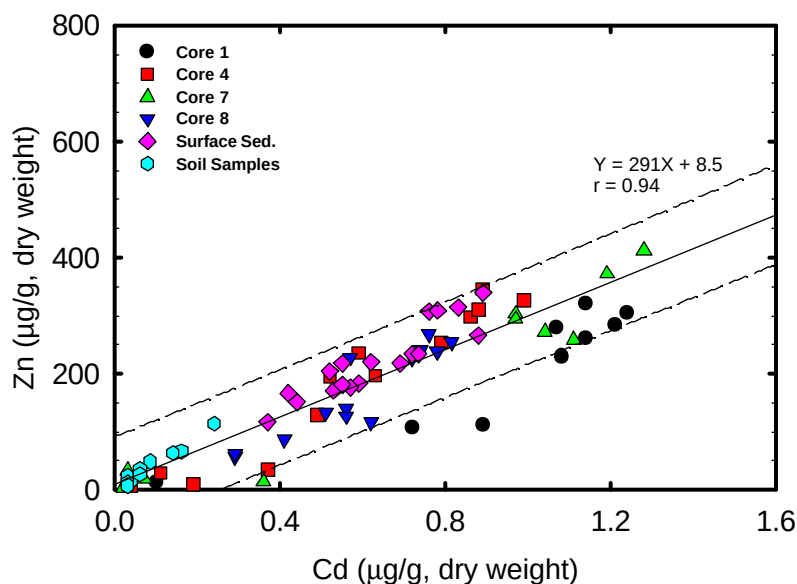


Figure 23. Concentrations of Cd versus Zn for soils and bottom sediments from the study area. Linear regression with 95% prediction interval was constructed using sediment data. Lines for Effects Range Median (ERM) and Effects Range Low (ERL) are from Long et al. (1995).

Concentrations of Cu are two to ten times greater than creek sediments than natural levels. None of the Cu values exceed the ERM. The ERL is under evaluation because it is close to levels found in average continental crust and normal marine sediments. The highest concentrations of Cu were found in suspended sediments, surface sediments and sediment cores from the Harbor Basin (Figure 24). This observation is consistent with a primary source for Cu from anti-fouling paints that have leached from boat hulls (Trefry et al., 1983). In contrast, anthropogenic inputs of Cd, Zn and Pb were ubiquitous. However, as observed for these other four metals, concentrations of Cu are elevated in sediments that are typically <50 years old (Figure 25). No clear shifts in Cu concentrations or, more importantly, the Cu/Al ratios were observed during the past 50 years.

Concentrations of Ni seem to be within expected, background levels except for a layer of sediment between 10 and 30 cm in core 4 from the STP Basin and a few samples from core 1 (Figures 24 and 25). These are the same cores that were notably enriched with Ag and Hg (Figures 18 and 19). The few samples from cores 1 and 4 with elevated levels of Ni are enriched over natural levels by about 25-50%, with one sample containing about double background levels (Figure 24). The vertical profiles for the Ni/Al ratios in sediments from cores 7 and 8 (Figure 25) are uniform and suggest that Ni levels in these sediments have been at natural levels for many decades. In contrast, the Ni/Al ratios for core 4 are 2-4 times greater than in the other cores in support of the anomalous inputs to a portion of the STP Basin.

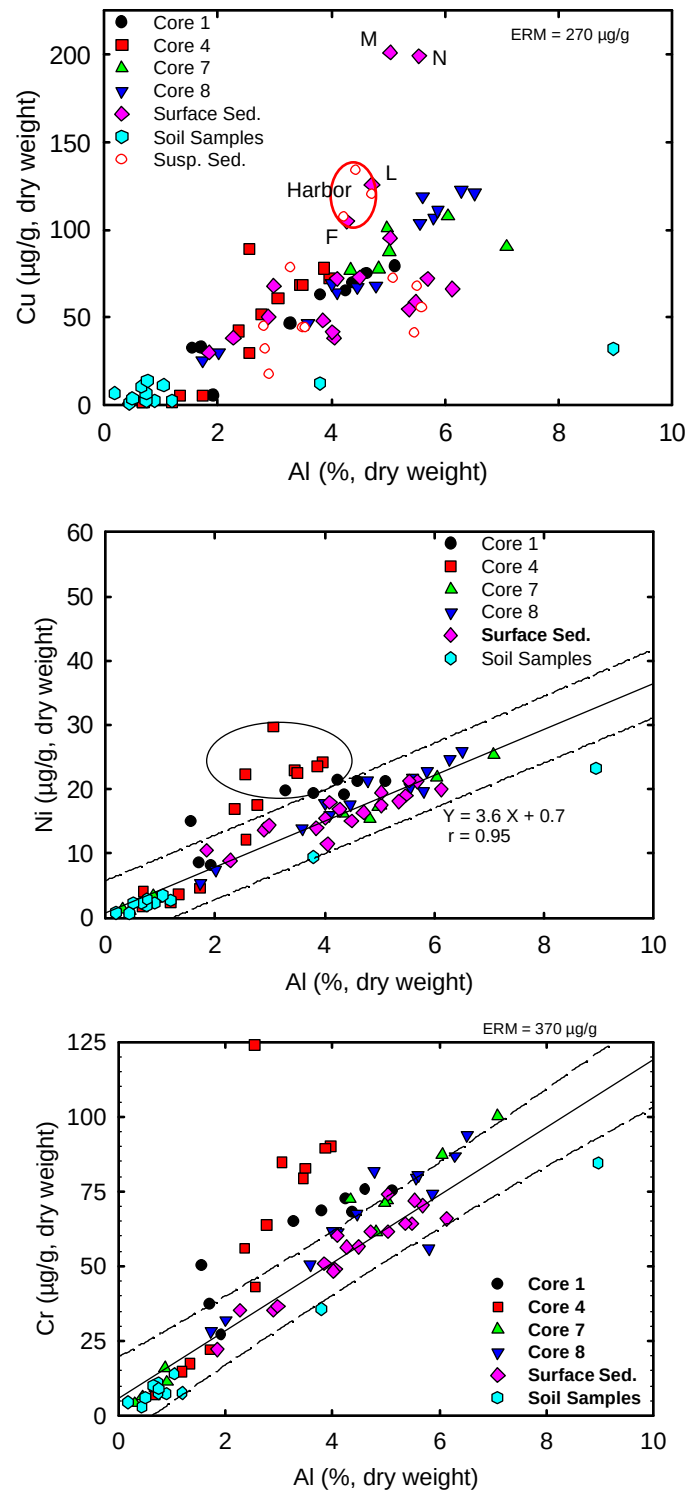


Figure 24. Concentrations of Al versus (a) Cu, (b) Ni and (c) Cr for soils, suspended sediments (Cu only) and bottom sediments from the study area. Linear regressions with 95% prediction intervals were constructed using sediment data. Data for Effects Range Median (ERM) are from Long et al. (1995).

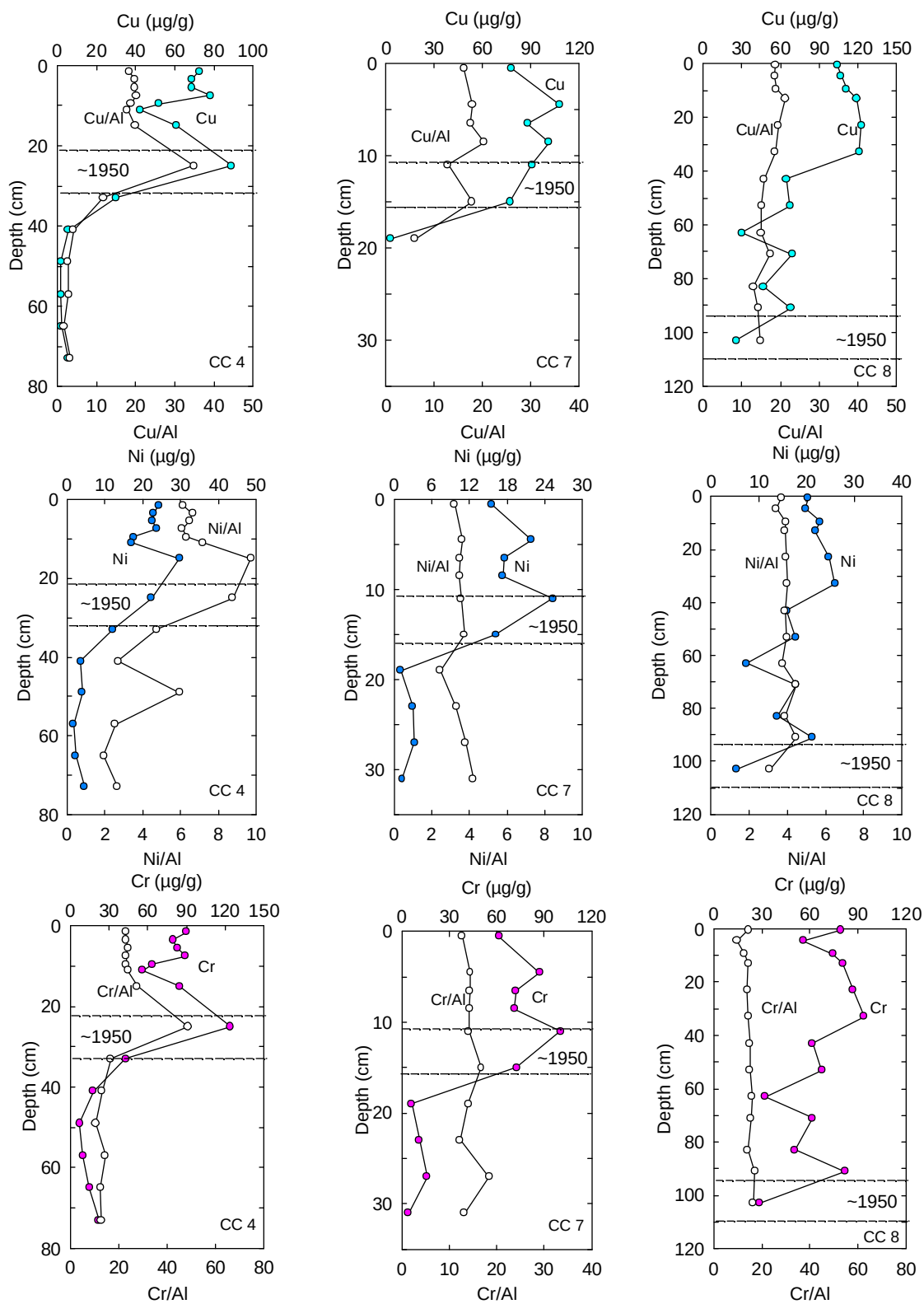


Figure 25. Vertical profiles for concentrations of Cu, Cu/Al, Ni, Ni/Al, Cr and Cr/Al in sediment cores from stations 4, 7 and 8 in Crane Creek. Shaded areas show estimated range in depths that correspond to ~1950 based on results of age-dating.

Concentrations of Cr, like Ni, seem to be within expected, background levels except for samples from cores 1 and 4 from the STP Basin (Figures 24 and 25). The few samples from cores 1 and 4 with elevated levels of Cr are enriched over natural levels by about 20-60%, with one sample containing more than double background levels (Figure 24; the sample with the highest level of Cr was not the same sample that contained the highest level of Ni). The vertical profiles for the Cr/Al ratios in sediments from cores 7 and 8 (Figure 25) show that values are uniform and suggest that, like Ni, Cr levels in these sediments have been at natural levels for many decades. The Cr/Al ratios for a few samples from core 4 are more than 2 times greater than in the other cores; however, the extent of thickness of this anomaly is slightly less than observed in core 4 for Ni. Overall, the sediments are not contaminated with Cr or Ni, excluding the exceptions described above.

In addition to the historical record provided by metal data from the sediment cores, we also have a comparison of metal concentrations in surface sediments collected from three locations (701, 702 and 703; map in Figure 13, page 32) during 1992 and 2003 (Table 8). Sediments from the two stations located outside the creek in the Indian River Lagoon were very different between years with more sandy, lower Al-containing sediment at station 701 during 2003 than 1992 and vice versa for station 702 (Table 8). Useful comparisons of metal concentrations between years at these sites require use of metal/Al ratios. From a metal/Al perspective, differences between years at the same site are small; however, no dredging was carried out in the areas of stations 701 and 702.

At station 703 in the Harbor Basin of Crane Creek, sediments collected during 1992 and 2003 were more similar with respect to texture and Al content (Table 8 and Figure 26). Concentrations of Ag, As, Cd, Cr, Hg, Ni and V and their metal/Al in sediment from station 703 during both years also did not differ by more than 10-20%. In contrast, concentrations of Cu and Pb in sediments collected during 2003 were about double values found during 1992. Concentrations of Zn in the 2003 sediment from station 703 were about 50% higher than in 1992. We have no simple explanation for this apparent enrichment in Cu, Pb and Zn between years. Concentrations of these three metals in the 2003 samples from station 703 are within the range of values found for other samples from the throughout the creek in 2003. Thus, overall, we can conclude that metal levels in creek sediments collected during 2003 are not significantly lower or higher than in 1992. However, sediments collected during 2003 and 1992 from station 703 are clearly contaminated with Cu, Pb and Zn at levels that generally exceed the ERL and the State of Florida guidelines for metals in sediments as described in the next section of this report.

Table 8. Concentrations of metals and total organic carbon (TOC) at stations 701,702 and 703 from 2002 and 1992.

Location	Al (%)	TOC (%)	Ag (µg/g)	As (µg/g)	Cd (µg/g)	Cr (µg/g)	Cu (µg/g)	Hg (µg/g)	Ni (µg/g)	Pb (µg/g)	V (µg/g)	Zn (µg/g)
Station 701 (1992)	1.07		0.10	2.1	0.01	12	5	0.02	3	2	13	20
Station 701 (2003)	0.14	<0.2	0.01	0.5	0.01	3	<1	0.006	0.4	1.2	<3	5
Station 702 (1992)	2.34		0.18	4.6	0.13	26	15	0.06	5	7	31	49
Station 702 (2003)	5.82	6.4	0.55	8.4	0.54	82	54	0.17	21	21	85	179
Station 703 (1992)	4.73		0.75	9.8	0.75	64	66	0.19	15	37	65	169
Station 703 (2003)	5.33	6.3	1.1	8.9	0.88	75	123	0.23	20	81	79	261

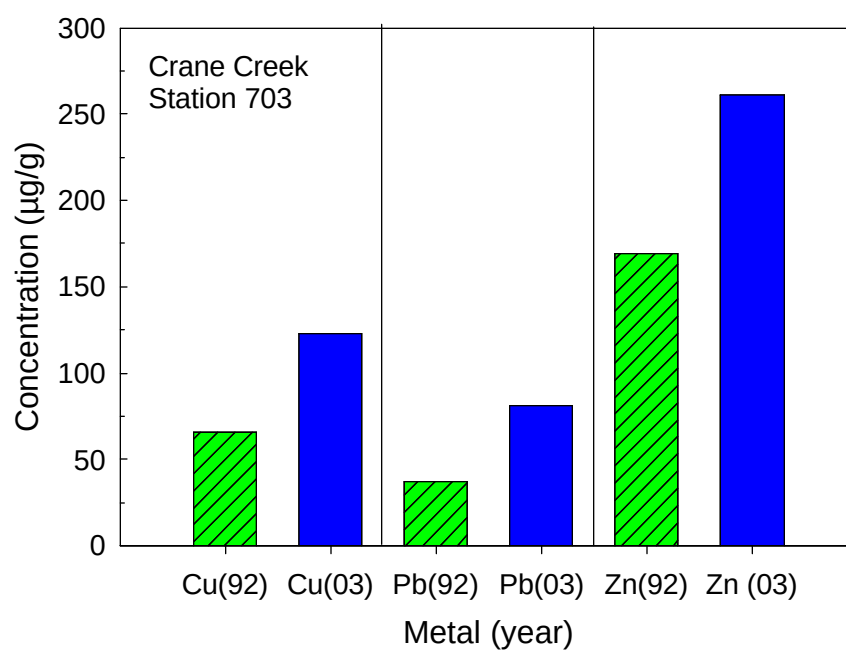
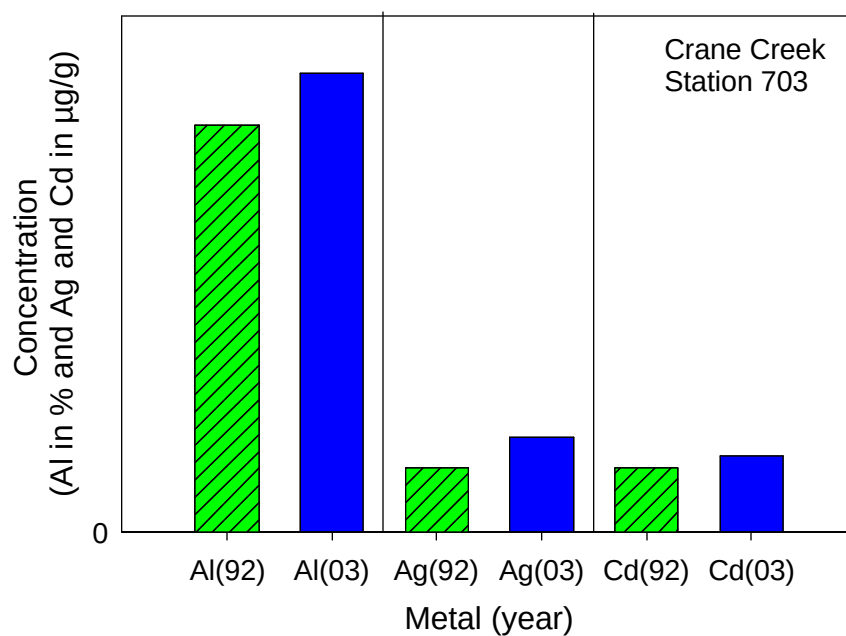


Figure 26. Concentrations of selected metals in sediments collected from station 703 in Crane Creek during 1992 and 2003.

Florida Sediment Quality Criteria

The State of Florida has established guidelines for assessing metal contamination in estuarine sediments using metal/Al relationships for natural sediments (Schropp et al., 1990). Metal concentrations for natural estuarine sediments from Florida were plotted versus Al and a linear regression and 95% prediction interval were constructed. As in the plots shown earlier in this report, when metal concentrations plot above the upper prediction interval, the sediments are considered to be contaminated with that metal.

Plots of As, Cd, Cr, Cu, Pb and Zn versus Al are presented here for sediments and soils from the Crane Creek study (Figures 27-29). All concentrations of As (Figure 27) and all except one value for Cr (Figure 28) were within the State of Florida Guidelines. Many samples from cores 1, 4 and 7 contained levels of Cd that plot above the upper prediction interval on Figure 27 and are thus significantly enriched relative natural sediments in Florida. As previously discussed, only three of those Cd concentrations were greater than the ERL and adverse biological effects for sediment organism would rarely be expected based only on Cd.

Most sediment samples, but no soil samples, had Cu concentrations that plotted above the upper prediction interval on the Cu/Al graph (Figure 28). The only sediment samples with Cu levels that plotted within the 95% prediction interval were from deep in sediment cores from stations 1, 4 and 7. Copper contamination has been a long-standing problem in many Florida creeks, including Crane Creek (Trefry et al., 1983; Trocine and Trefry, 1996). Data for Pb and Zn show a similar distribution on the metal/Al graphs as observed for Cu (Figure 29) with most sediment samples having values that plot above the upper prediction interval. Sediments contaminated with Pb and Zn were ubiquitous in the creek.

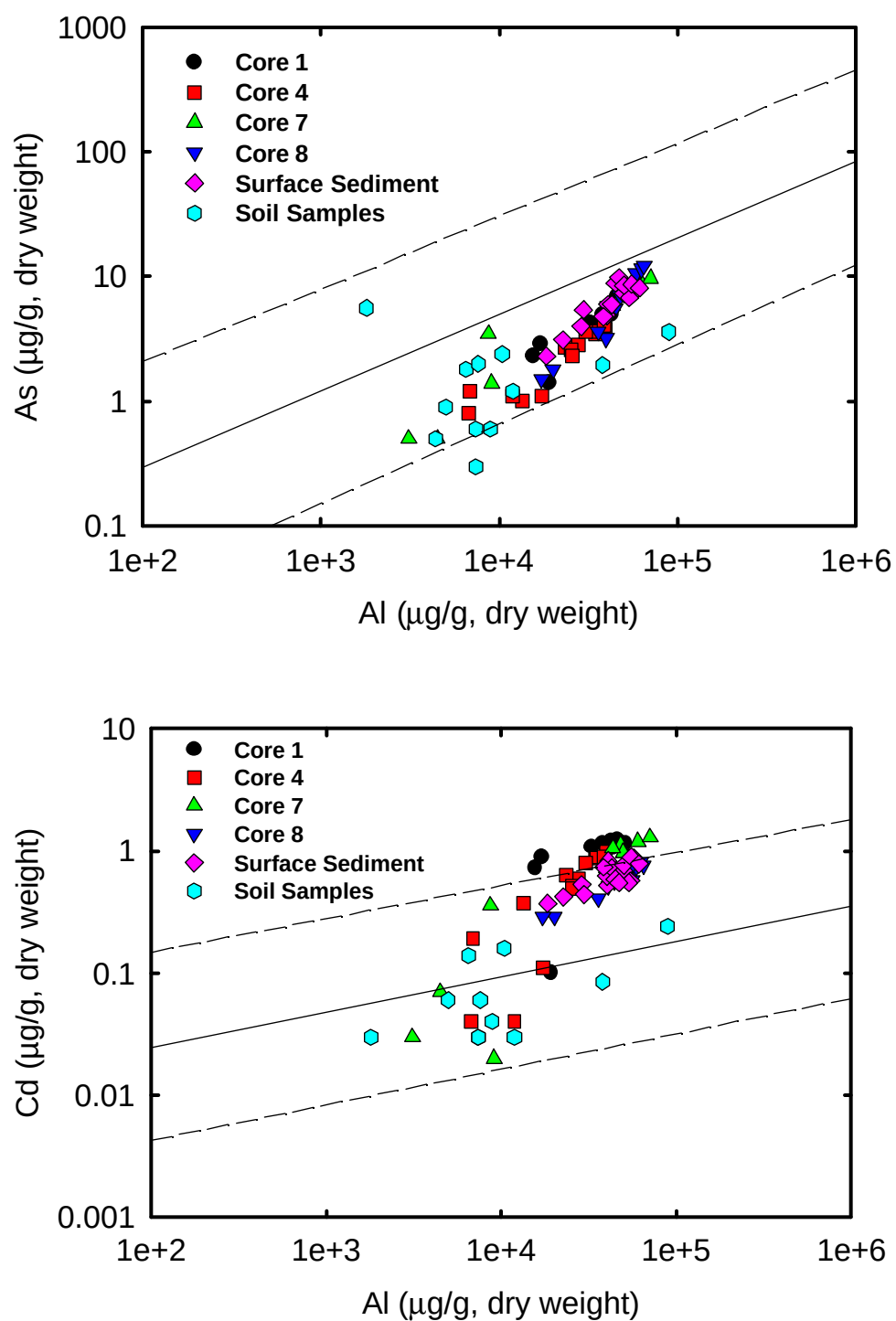


Figure 27. Concentrations of Al versus (a) As and (b) Cd for bottom sediments and soils from Crane Creek. Regression line with 95% prediction interval is from Shropp et al. (1990) with points that plot above the upper prediction interval considered to have an anthropogenic input of the metal.

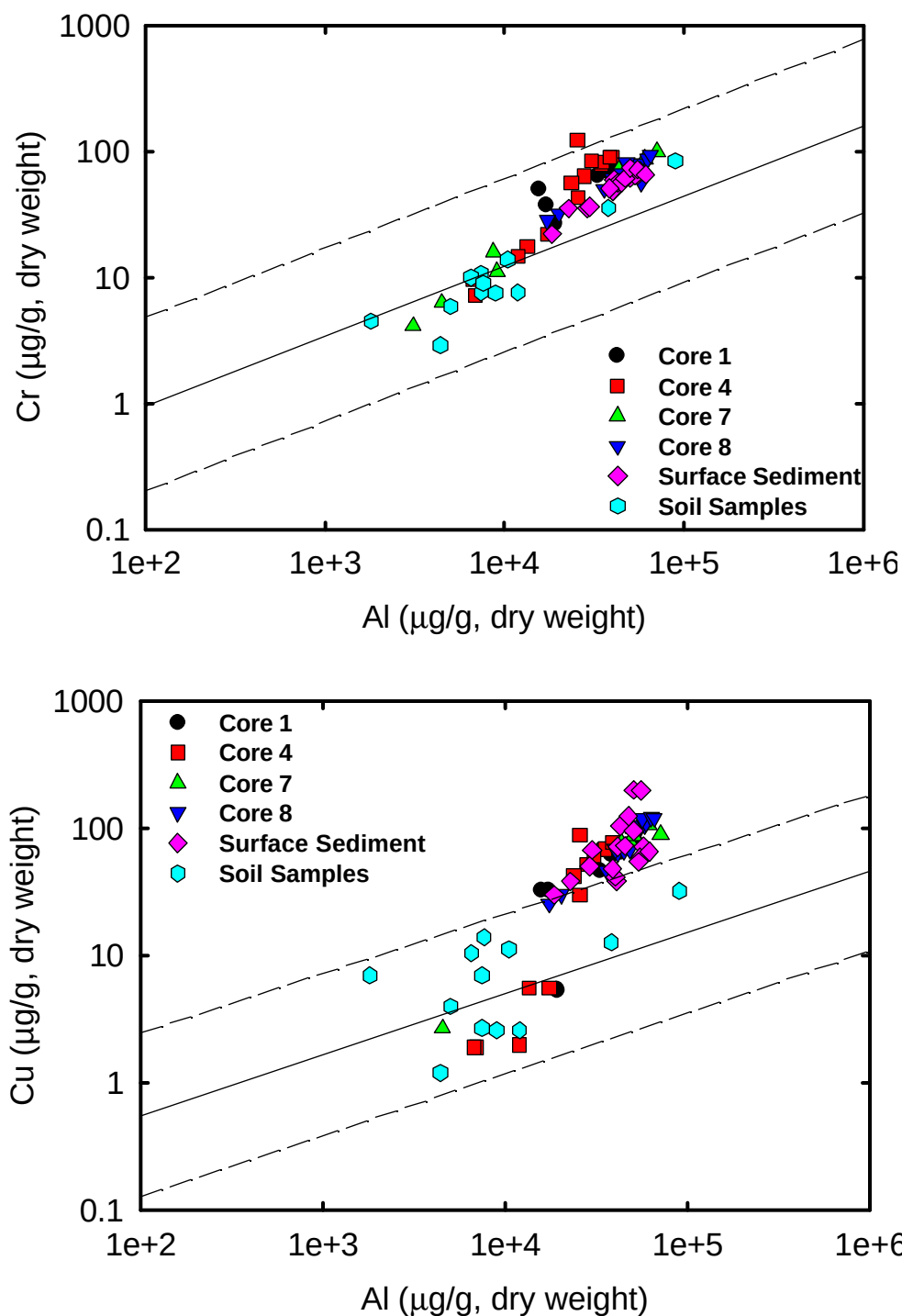


Figure 28. Concentrations of Al versus (a) Cr and (b) Cu for bottom sediments and soils from Crane Creek. Regression line with 95% prediction interval is from Shropp et al. (1990) with points that plot above the upper prediction interval considered to have an anthropogenic input of the metal.

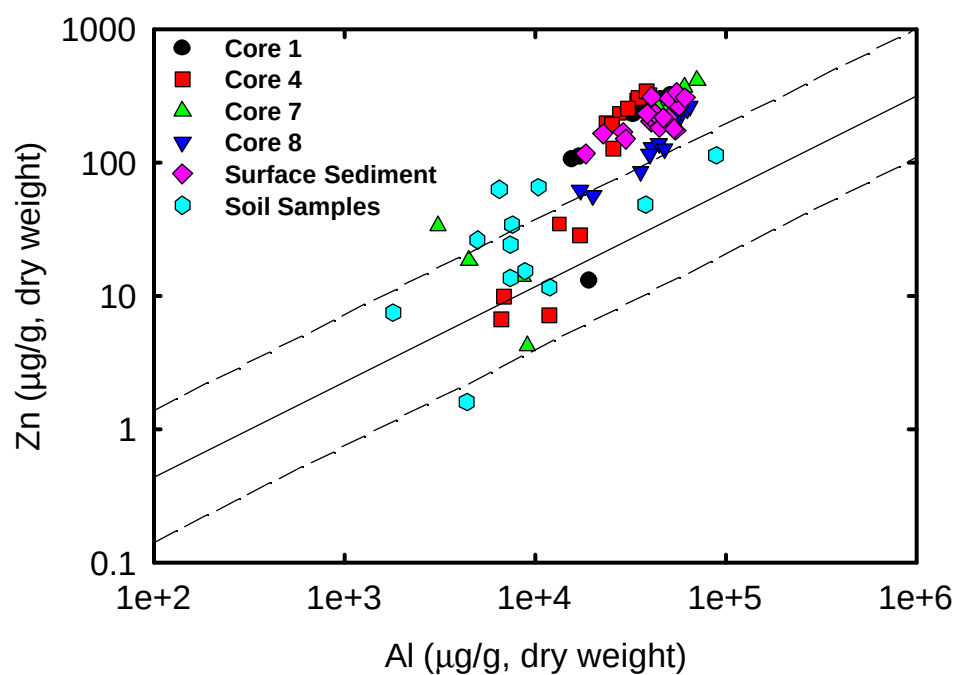
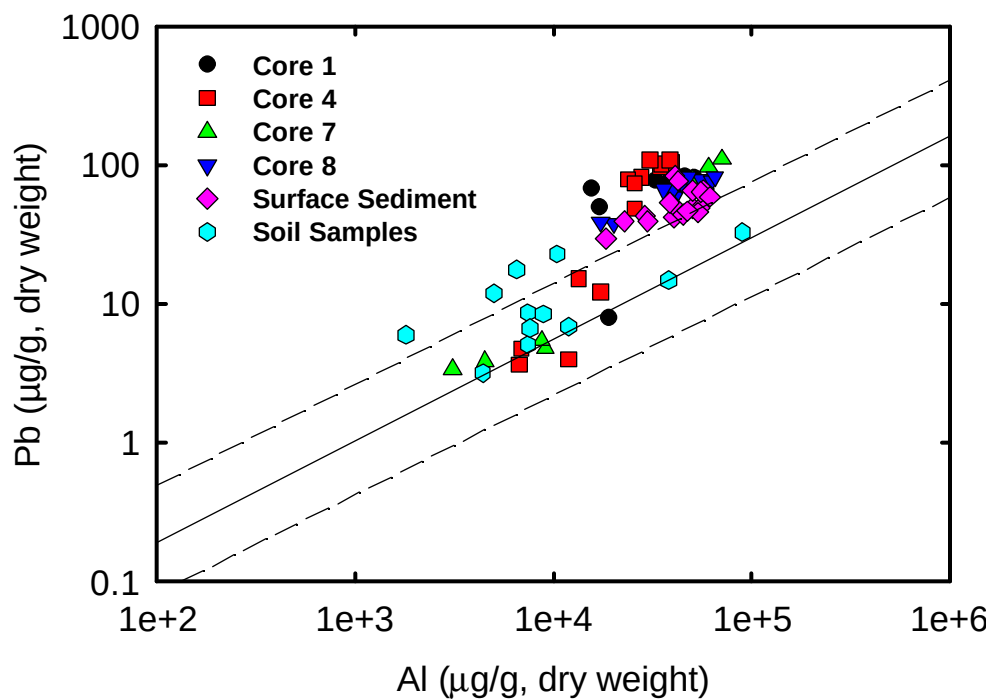


Figure 29. Concentrations of Al versus (a) Pb and (b) Zn for bottom sediments and soils from Crane Creek. Regression line with 95% prediction interval is from Shropp et al. (1990) with points that plot above the upper prediction interval considered to have an anthropogenic input of the metal.

Overview of Sediment Trapping Efficiency

The data for muck depths and sedimentation rates determined during this study can be used to estimate the rate of filling of Crane Creek with sediment and thus how long before dredging is again necessary. For the calculations used in this section of the report, the Mouth and Harbor Basins have been combined as one area. The areas of the three basins total 104,000 m² (Figure 30). The total amount of sediment removed from Crane Creek during dredging in 1998 is estimated at 60,000 m³ (Windsor, this study). The present-day volume of muck in Crane Creek is calculated to be about 82,000 m³ (Figure 31) with more than half of that volume in the Harbor + Mouth Basins.

The rate of accumulation of sediment in Crane Creek, based on sedimentation rates determined during this study (Figure 11, page 26), is 800 ± 300 m³/yr (Figure 32). This annual volume is more than likely an overestimate because we are reasonably certain that sediment has slumped from the perimeter to the center of the creek. Such slumping creates the anomalies in activities of excess ²¹⁰Pb previously discussed (e.g., Figure 6, page 20) and leads to thick layers such as observed at core station 6 in the Harbor Basin (Figure 10, page 25).

Assuming that the calculated filling rate of 800 m³/yr stays reasonably constant, an amount of sediment equivalent to the 60,000 m³ of sediment that were dredged would be deposited in ~75 years. Based on the standard deviation for the filling rate of ± 300 m³/yr, the calculated range of filling times is from 55 to 120 years. These estimates support the conclusion of Windsor (this study) using annual inputs of suspended sediments that >50 years will pass before dredging needs to be carried out. Windsor (this study) made the conclusion of >50 years by assuming that his calculations may have underestimated sediment inputs by as much as a factor of three.

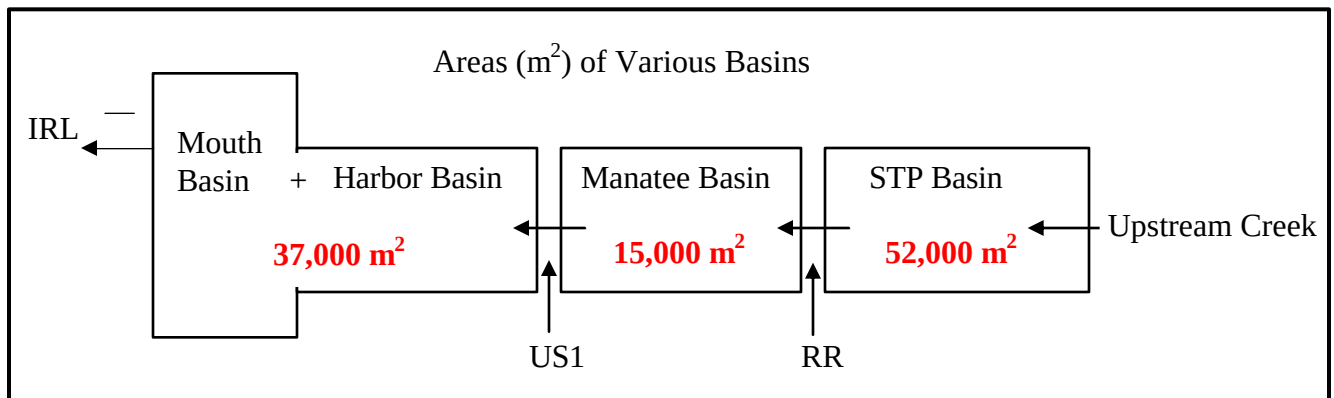


Figure 30. Areas in square meters for each of three basins in Crane Creek (RR = railroad; STP = Sewage Treatment Plant, IRL = Indian River Lagoon; US1 = highway US 1). The Mouth and Harbor Basins have been combined for calculations of sediment trapping in the creek.

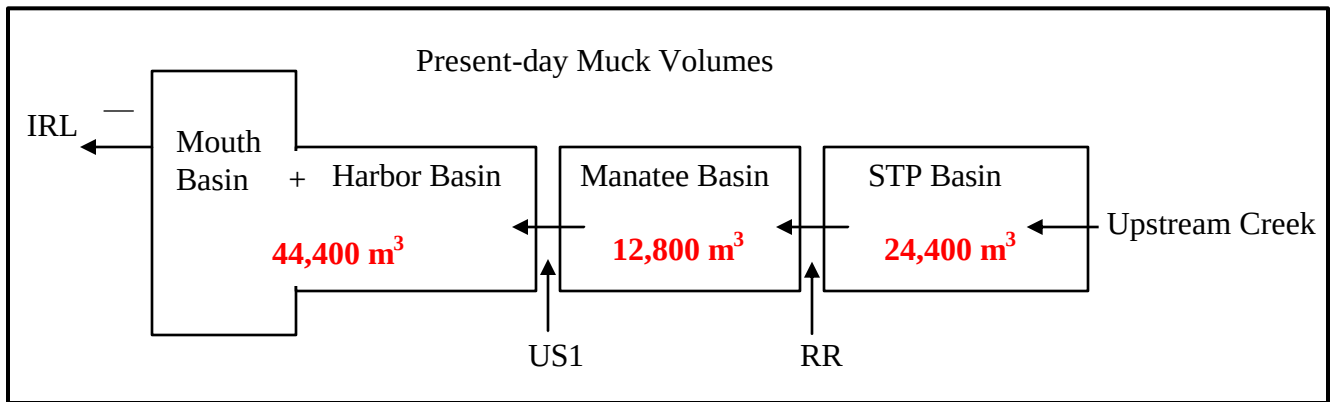


Figure 31. Volume of muck sediment during 2002 in cubic meters for each of three basins in Crane Creek (RR = railroad; STP = Sewage Treatment Plant, IRL = Indian River Lagoon; US1 = highway US 1). The Mouth and Harbor Basins have been combined for calculations of sediment trapping in the creek. The muck depths are listed in Figure 4 (page 17) and the areas of each basin are listed in Figure 30.

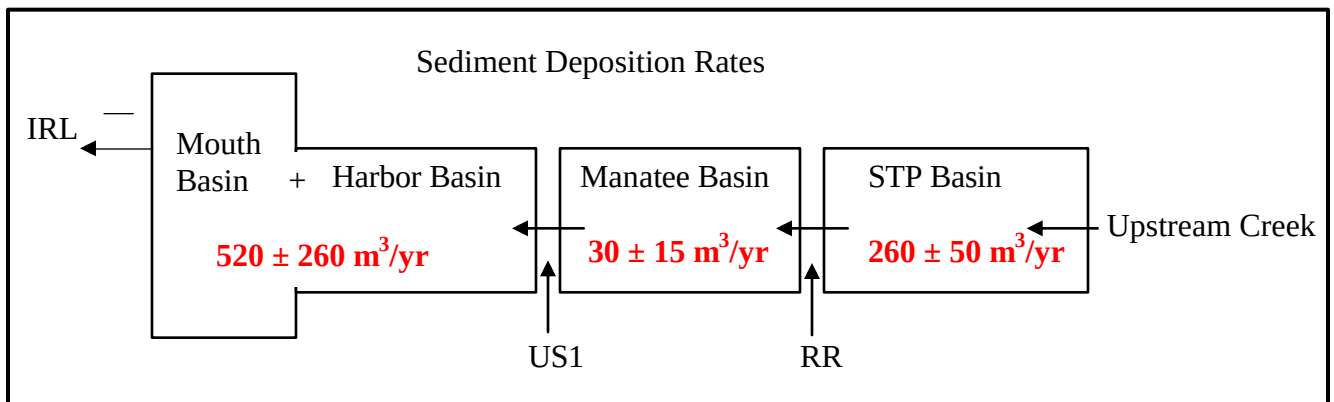


Figure 32. Annual volume of sediment in cubic meters deposited in each of three basins of Crane Creek (RR = railroad; STP = Sewage Treatment Plant, IRL = Indian River Lagoon; US1 = highway US 1). The Mouth and Harbor Basins have been combined for calculations of sediment trapping in the creek. The sedimentation rates are listed in Figure 11 (page 26) and the areas of each basin are listed in Figure 30.

Conclusions

The measured thicknesses of layers of fine-grained, organic-rich (muck) sediment overlying base sand in Crane Creek were 77 ± 82 cm during 2002 relative to 112 ± 81 cm in 1998, shortly after dredging. The results for 1998 are not significantly different from the 2002 results; however the 1998 data show that considerable amounts of muck sediment remained in Crane Creek following dredging from January 27 to April 2, 1998. The data also suggest show some shifting of sediment toward the Harbor Basin may have occurred and that there has not been a large influx of sediment during the four-year period between surveys.

Sedimentation rates for Crane Creek were determined using the activities of excess ^{210}Pb and ^{137}Cs . The sedimentation rates are as follows: (1) 0.5 ± 0.1 cm/yr west of the railroad bridge in the STP Basin, (2) 0.2 ± 0.1 cm/yr in the Manatee Basin between the railroad bridge and US 1, and (3) 1.4 ± 0.7 cm/yr in the Harbor Basin. The overall mean for the six cores was 0.7 ± 0.6 cm/yr ($n=12$, two rates per core). These rates may be an over estimate of actual values due to inputs from slumping and distortion of vertical profiles for radionuclides from sediment mixing.

The total amount of sediment removed from Crane Creek during dredging in 1998 was $\sim 60,000 \text{ m}^3$. The present-day (post-dredging) volume of muck in Crane Creek is estimated to be $\sim 82,000 \text{ m}^3$, with more than half of that volume in the Harbor + Mouth Basins. Based on sedimentation rates determined during this study, the annual volume of sediment deposited in Crane Creek is $800 \pm 300 \text{ m}^3/\text{yr}$. Assuming that the calculated filling rate of $800 \text{ m}^3/\text{yr}$ stays reasonably constant, an amount of sediment equivalent to the $60,000 \text{ m}^3$ of sediment that were dredged would be deposited in ~ 75 years. Based on the standard deviation for the filling rate of $\pm 300 \text{ m}^3/\text{yr}$, the calculated range of filling times is from 55 to 120 years.

To address questions related to sediment sources, sediment quality and sediment history, the data for major elements and trace metals in soils, suspended sediments, surface sediments, and sediment cores were used collectively. No clear differences in concentrations of Fe, K or Mg versus Al were observed and thus these elements did not provide a straightforward tracer of sources of sediments to the creek was identified. Aluminum provides a useful frame of reference because Al is resistant to chemical weathering in soils and sediments and it is a good indicator of the aluminosilicate (clay) fraction of the sample. The uniform As/Al and V/Al relationships show no detectable inputs of contaminant As or V; however, they do not easily facilitate identification of distinct natural sources for these metals within the drainage basin.

Concentrations of silver (Ag) mercury (Hg) are 50 to more than 100 times above natural levels in sediments from Crane Creek. The core data suggest that peak inputs of Ag and Hg were 30-60 years ago. When sediment concentrations of Ag are plotted versus Hg, a strong linear fit ($r = 0.92$) is observed. This trend for Hg versus Ag supports a common source or source area for both metals such as dental waste and/or photographic/art wastes.

Fourteen samples had Ag levels greater than the Effects Range Median (ERM) guideline and seven samples had Hg levels above the ERM. At such levels, adverse effects to sediment biota are predicted to occur frequently. Most of the remaining samples contained Ag and Hg at levels that exceeded the Effects Range Low (ERL), indicating that adverse biological effects for sediment organisms would be occasional.

Concentrations of Pb were elevated over natural levels by two to six-fold at many sites throughout the creek with the highest values in suspended sediment from the Harbor Basin. None of the Pb values exceeded the ERM; however, more than half the Pb concentrations exceeded the ERL. Overall, the spatial distribution of anthropogenic Pb throughout the creek is rather ubiquitous. Data from sediment cores show that the onset of Pb contamination dates back about 50 years. All concentrations of Cd were below the ERM and only three values exceeded the ERL. In contrast, many of the Zn concentrations were greater than the ERL with none greater than the ERM.

Concentrations of Cu in sediments from Crane Creek are typically two to ten times greater than in natural sediments from the study area. None of the Cu values exceed the ERM. The highest concentrations of Cu were found in suspended sediments, surface sediments and sediment cores from the Harbor Basin. This is consistent with a primary source for Cu from anti-fouling paints that have leached from boat hulls. No clear shifts in Cu concentrations or, more importantly, the Cu/Al ratios were observed during the past 50 years. Concentrations of Ni and Cr seem to be within expected, background levels except for a few samples from cores collected from the STP Basin where levels are elevated over natural levels by about 20-60%.

At one station (#703) in the Harbor Basin of Crane Creek, sediments were collected during 1992 and 2003. Overall, we conclude that metal levels in creek sediments collected during 2003 are not significantly different than in 1992. All concentrations of As and all except one value for Cr were within the State of Florida Guidelines established for sediments. Many samples contained levels of Cd that were significantly enriched relative to natural sediments in Florida. Most sediment samples, but no soil samples, had Cu concentrations that exceeded the state guidelines. Likewise, sediments contaminated with Pb and Zn were ubiquitous in the creek.

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The Long-Term Effects of Dredging on Water Quality and Sediment Transport in Crane Creek and the Indian River Lagoon (IRL), Melbourne Florida

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Abstract

Salinity, temperature, dissolved oxygen, percent saturation of oxygen, total suspended solids, turbidity, and secchi depth were measured at four stations in Crane Creek Melbourne, Florida from January 2001 to March 2002. Streamflow was also measured and related to suspended sediment concentrations to determine sediment transport. The effects on water quality as a result of the dredging of muck sediments (January 29 to April 2, 1998) from Crane Creek were studied.

Residence time calculations were used to determine the effectiveness of a potential sediment trap created by the dredging activity. By relating settling velocities of clays, silts, and fine sands to the residence time (based on Crane Creek streamflow) at the sediment trap it was determined that fine sands should be removed 100% of the time, silts 50%, and finally clays are likely to be removed only 10% of the time. Mean sediment transport from July to November 2001 and January to March 2002 were 1.7 ± 1.7 tons/day and 1.2 ± 1.3 tons/day.

The effects on water quality following the dredging include increased salinity as a result of saltwater intrusion from the Indian River Lagoon. Salinity ranged from 0 to 27 ppt prior to the dredging, and 0.2 to 35 ppt following the removal of sediments. Temperature in Crane Creek varies with seasonal air temperature and was not affected by the dredging. Percent saturation of oxygen at station 3 has increased as a result of an additional 1 meter of oxygenated water provided after the removal of muck sediments. The overall dissolved oxygen concentrations at the surface of station 3 increased from 74% in April to September 1998 to 92% during this study (January 2001 to March 2002). Mean total suspended solids decreased from 12.9 ± 12.5 mg/L just after dredging to 7.7 ± 2.1 mg/L from July to November 2001 and 8.9 ± 3.0 mg/L from January to March 2002. Turbidity actually showed an increase from 3.8 ± 1.0 NTU after dredging to 6.1 ± 3.0 NTU from July to November 2001 and 4.6 ± 1.3 NTU from January to March 2002. Finally mean secchi depth showed a slight decrease from 1.0 ± 0.3 m after dredging to 0.8 ± 0.2 m from January 2001 to March 2002.

In summary, the water quality in Crane Creek has improved in terms of mean percent saturation of oxygen and mean total suspended solids concentrations. The additional oxygen, as a result of the removal of muck sediments, is important for the survival of aerobic marine organisms. Also, the increased oxygen concentrations enhance aesthetics by preventing foul odors associated with anaerobic waters. The decline in total suspended solids may in fact represent the effectiveness of the sediment trap. On the other hand, TSS concentrations may have been diluted during the wet season as the volume of water in Crane Creek increased, but the delivery of materials was limited by the non-storm (< 2.5 cm) rainfall.

Since suspended particulate matter attenuate light, which is necessary for photosynthesis, as well as carry nutrients and other pollutants, lower concentrations in Crane Creek following the dredging represent enhanced water quality. However, sediment transport and the presence of suspended matter have been linked to meteorological conditions. Runoff produced by rainfall has been known to elevate suspended solids in waterways. Therefore, the decline in mean total suspended solids, based on this study, may also be due to the fact no significant storm events (> 2.5 cm) occurred during the sampling periods.

The overall objectives of this phase of the water quality study are to:

1. Determine if the water quality of Crane Creek (inherent parameters such as salinity, temperature, dissolved oxygen, and total suspended solids) has improved, declined, or stayed the same as a result of the removal of fine-grained, organic-rich sediments.
2. Determine sediment transport in Crane Creek following dredging in 1998 between US1 and the Railroad Bridge.

2.0 STUDY AREA

Crane Creek flows through downtown Melbourne, Florida which is located on the East Coast in Brevard County (**Figure 2.1**). Upstream, the creek flows through a municipal golf course where it then travels downstream through the botanical gardens at FIT. Still heading east, the creek passes under Babcock Street and flows parallel to Melbourne Avenue as it passes the Grant Street Sewage Treatment Plant. At this point the creek widens and residential properties line the banks. From here, the creek flows further east through the Melbourne Harbor Marina and finally empties into its receiving waters, the Indian River Lagoon.

Crane Creek is about 8.5 km in length with a drainage area of approximately 47 km² (USGS, 2002). The mean daily net streamflow over 14 years of record (1987 – 2000) was 1.3 m³/sec (USGS, 2002). Various inputs to the creek include stormwater runoff, groundwater intrusion, tidal influx, runoff including fertilizers from the municipal golf course, and residential septic tanks (Garcia, 1998). Since 1987, the sewage treatment plant employs deep-well injection techniques so it is not included as a point source discharge. Of these sources, stormwater in the wet season (June – September) is probably the most significant in terms of materials and freshwater delivered.

The geographic location of Crane Creek as well as the respective sampling locations are shown in **Figure 2.1**. The mouth has a southeast orientation which allows for strong winds (0 > 20 knots) to funnel up through the creek causing IRL water to migrate upstream, while at the same time disturbing bottom sediments (**Figure 2.1**). The Creek is also affected by northeast winds traveling parallel to the Melbourne causeway due to its orientation prior to the bend at the mouth (**Figure 2.1**).

Station 2 is located furthest upstream in between the Grant STP and the railroad trestle. With an average depth of 1.2 m, it is the shallowest site in the creek. This location exhibits stratification at times of low freshwater input, but becomes uniform in terms of low salinity from top to bottom during storm events. Being the most upstream site and, therefore, furthest from the source of saline water, station 2 is the freshest of all four sampling locations.

Station 3 is located in between the railroad trestle and US Highway 1, also known as Manatee Park. This site is of particular interest since it is the deepest location as a result of the dredging operation in 1997-1998. In addition to improving the water quality in the creek, another purpose of the removal of sediments at this station was to increase water depth, thus creating a sediment trap. The mean depth at the present time is approximately 4.0 m versus roughly 2.0 m prior to the dredging operation. The station is typically stratified year round. Seasonal variation in density can be seen between the summer and winter seasons.



Station 4 is located in the Melbourne Harbor Marina yielding an average depth of 3.0 m. This location is also typically stratified. Since sites 3 and 4 are the closest to the Indian River Lagoon they experience regular exchanges of saltwater, and most likely other materials.

This influx of saltwater can be due to low rainfall which decreases the hydrostatic pressure of the downstream flow allowing saltwater migration, or simply easterly winds causing IRL waters to migrate upstream.

Station 5 is located in the Indian River Lagoon slightly past the last channel marker. With an approximate depth of 2.1 m, this location is typically well-mixed as a result of its large fetch and constant wind and wave action. Even though site 5 is located outside of the immediate creek area, it was included in order to study the quality of the receiving waters of the creek – the IRL.

Stations 2, 3, and 5 were chosen to study the spatial variation of water quality from upstream in Crane Creek to downstream in the IRL. Samples from sites 2, 3, and 4 were gathered to study sediment transport. The intent was to investigate the effectiveness of the sediment trap due to the dredging at station 3. This was accomplished by gathering TSS and turbidity data at stations 2,3, and 4 with the assumption that TSS and turbidity should be lower at station 4 than at station 2 (**Figure 2.1**). A decrease in TSS and turbidity, if any, was attributed to increased flocculation at higher salinities and deposition of sediments at station 3 acting as a sink due to its greater depth. If a decrease was not seen after station 3, it was concluded that downstream sediment transport was not always the major source. Instead, sediment transported upstream from the IRL may be introducing more significant amounts of sediment to the channel.

The following table is included to provide a summary of the four stations' characteristics and locations. GPS coordinates were taken with a *Magellan GPS ColorTrak*. Sediment grain sizes and compositions were performed during the marine field projects by Florida Tech investigators in the summer of 1998 after dredging.

Table 2.1

Station Locations and Sediment Characteristics of all four sampling locations (MFP, 1998)

ID	Latitude	Longitude	Description
Station 2	28 ⁰ 04.512 N	80 ⁰ 36.359 W	Shallow, Depth (1.2 m) fine to very fine sand
Station 3	28 ⁰ 04.611 N	80 ⁰ 36.193 W	Depth (4.0 m– up to 6.0 m) coarse silt
Station 4	28 ⁰ 04.678 N	80 ⁰ 36.039 W	Depth (3.0 m) very fine sand
Station 5	28 ⁰ 04.594 N	80 ⁰ 35.644 W	Depth(2.1 m) fine to medium sand

3.0 RESULTS

Data for the *in situ* water quality measurements collected from January 30 to March 15, 2002, including salinity, water temperature, dissolved oxygen, percent saturation, and secchi depth, are located in Appendices A - C. Total suspended solids, turbidity, sediment transport and streamflow are presented in Appendices D - E from July 17 to March 15, 2002. The following four sections present the results of water quality observations for 2001 and 2002 and meteorological conditions during the study. Variations in the water structure of Crane Creek and the Indian River Lagoon are addressed first. Next, dissolved oxygen concentrations and percent saturation values are examined. The third section presents total suspended solids (TSS) and turbidity measurements, followed by secchi depth observations in the fourth section.

A summary for all water quality results during the entire study period including the mean, standard deviation, range, and number of observations for each parameter (salinity, water temperature, dissolved oxygen, percent saturation, secchi depth, total suspended solids, turbidity, streamflow) is shown in **Table 4.1**. The January through June 2001 data do not include TSS or turbidity. To provide data from both the wet and dry seasons, total suspended solids and turbidity measurements were made from July to November 2001 (wet) and January to March 2002 (dry).

Table 4.1
Summary of water quality results for Crane Creek Melbourne, FL
from January 2001 to March 2002 for all stations and depths

Parameter		Jan – June 2001	July – Nov 2001	Jan – Mar 2002
Salinity (ppt)	Mean	24.9	13.7	16.6
	Stdev	6.2	7.0	4.1
	Range	0.5 – 35.3	0.2 – 29.0	2.8 – 21.8
	#OBS	589	544	304
Temperature (°C)	Mean	27.2	27.9	20.1
	Stdev	3.7	3.0	3.1
	Range	15.7 – 33.7	20.1 – 33.3	12.6 – 27.1
	#OBS	589	544	304
Dissolved Oxygen (mg/L)	Mean	5.6	4.5	6.6
	Stdev	2.6	2.6	2.5
	Range	ND – 15.2	ND – 12.2	ND – 13.4
	#OBS	589	544	304
DO Percent Saturation (%)	Mean	80.4	60.8	79.6
	Stdev	37.1	37.2	29.7
	Range	ND – 208	ND – 194	ND – 145
	#OBS	589	544	304
TSS (mg/L)	Mean	NA	7.7	8.9
	Stdev		2.1	3.0
	Range		4.2 – 15.6	2.8 – 18.3
	#OBS		120	88
Turbidity (NTU)	Mean	NA	6.1	4.6
	Stdev		3.0	1.3
	Range		2.9 - 22	1.5 – 7.4
	#OBS		120	88
Secchi Depth (m)	Mean	0.9	0.8	0.8
	Stdev	0.4	0.1	0.3
	Range	0.5 – 2.1	0.5 – 1.2	0.5 – 1.5
	#OBS	63	57	33
Streamflow (m ³ /sec)	Mean	NA	2.5	1.6
	Stdev		2.1	1.5
	Range		0.8 – 8.9	0.4 – 4.9
	#OBS		16	11

NA = Not Determined, ND = Non-Detectable

4.1 Water Quality in Crane Creek and the Indian River Lagoon in 2001 and 2002.

4.1.1 Salinity and Temperature

Salinities ranged from 0.5 to 35.3 parts per thousand (ppt) from the upstream location, station 2, to the IRL site, station 5 from January to June 2001. Mean salinity for this time period was 24.9 ± 6.2 ppt (**Figure 4.1**). Mean water temperature was 27.2 ± 3.7 °C and increased from January to June 2001. Temperatures ranged from 15.7 – 33.7 °C throughout all stations (**Figure 4.2**).

From the period July to November 2001 salinities ranged from 0.2 – 29.0 ppt with a mean value of 13.7 ± 7.0 ppt for all stations and depths. Mean salinity decreased by 45% when compared to the January to June 2001 values (**Table 4.2**). Additionally, the maximum salinity was 6.3 ppt lower from July to November 2001. Mean water temperature increased slightly (2.5%) during July to November 2001 to a mean value of 27.9 ± 3.0 °C (**Table 4.2**). Values ranged from 20.1 to 33.3 °C, thus exhibiting a higher minimum water temperature when compared to January to June 2001 data. Finally, mean water and air temperatures decreased from July to November 2001 (**Figure 4.2**).

Mean salinity from January to March 2002 was 16.6 ± 4.1 ppt for all locations and depths, which represents a 17% increase from the July to November 2001 mean salinity (**Table 4.2**). Values ranged from 2.8 to 21.8 ppt, thus yielding the highest minimum and lowest maximum salinity values of all three time periods. The mean water temperature was 20.1 ± 3.1 °C, representing a decrease of 28% when compared to July to November 2001 (**Table 4.2**), with a range of 12.6 – 27.1 °C for all stations and depths. January to March 2002 had the lowest mean water temperature when compared to January to November 2001 (**Figure 4.2**).

Seasonal variation in both salinity and temperature can be seen over the entire sampling period from January 2001 to March 2002. Mean salinity is the greatest from January to June 2001, decreases from July to November 2001, and begins to rise once again from January to March 2002. Salinity increases from station 2 upstream to site 5 downstream in the IRL for all sampling periods (**Figure 4.1**). Furthermore, salinity typically increased with depth at all stations except site 5 where wind and wave action mixed the water column resulting in near uniform salinities from top to bottom.

Mean water temperatures for all stations and depths in Crane Creek and mean air temperatures in Melbourne, Florida steadily increased from January to June 2001, with elevated temperatures towards the end of this sampling period particularly in May and June. Temperatures remained elevated in July, August, and September, eventually subsiding in October and November. Decreased temperatures in January and February 2002 can be seen followed by an increase in March 2002. Both water and air temperatures follow the same trends each month (**Figure 4.2**). Finally, temperatures usually decreased with depth in the afternoon and evenings, but increases with depth were often observed during a number of morning samplings. Such behavior is due to evaporative and conductive heat loss from the surface water during the night, leading to cooler surface waters in the morning at times.

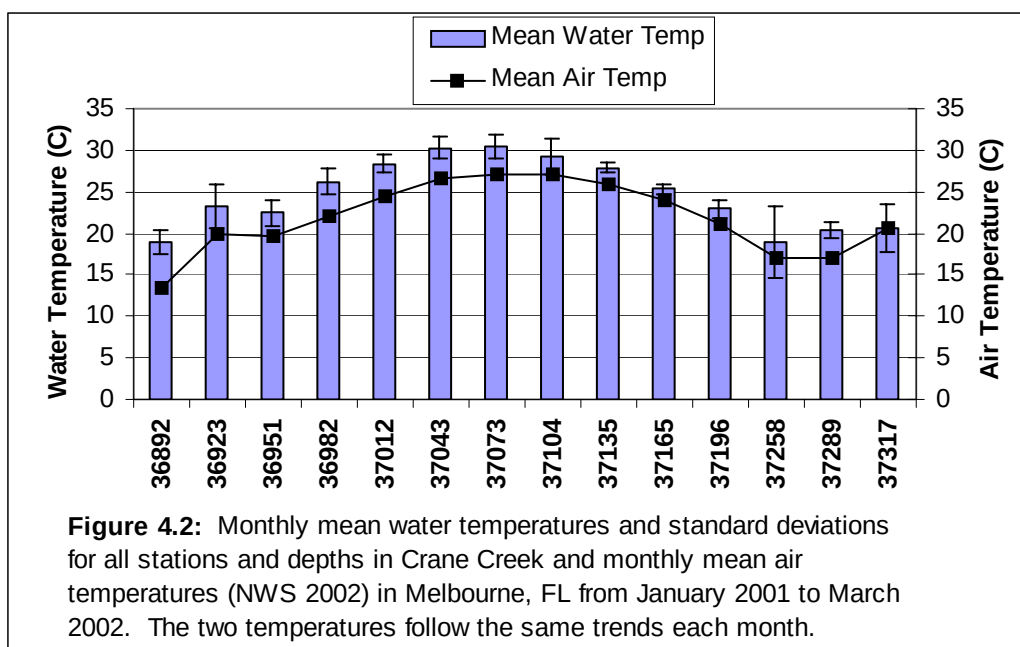
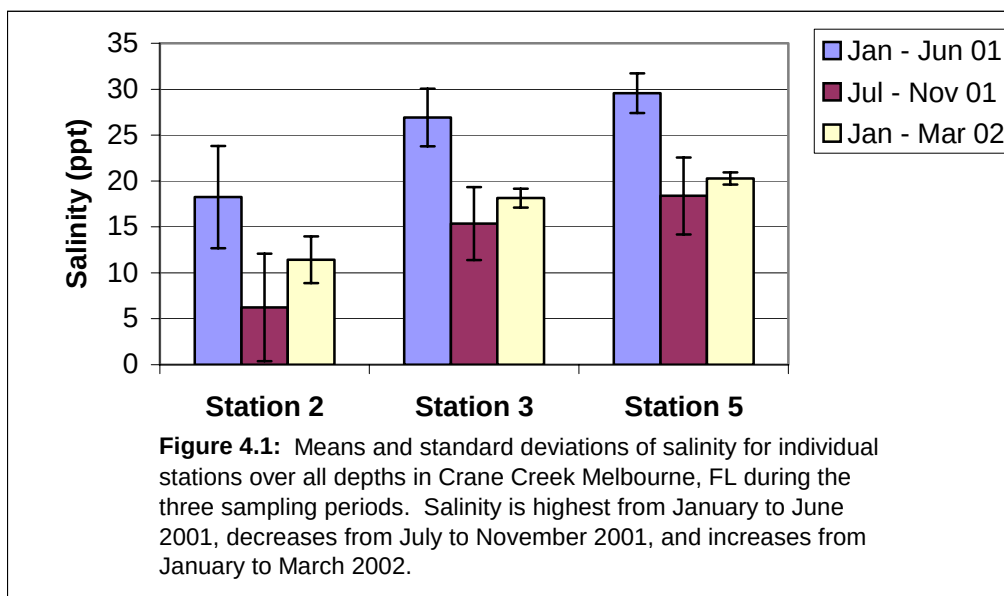


Table 4.2
Summary of changes in mean salinity and mean temperature between
the three sampling periods in Crane Creek Melbourne, Florida.

	Jan – Jun 01	Jul – Nov 01	Jan – Mar 02
Salinity (ppt) Change	24.9 ± 6.2	13.7 ± 7.0 -45%	16.6 ± 4.1 +17%
Temperature (°C) Change	27.2 ± 3.7	27.9 ± 3.0 +2.5%	20.1 ± 3.1 -28%

4.1.2 Dissolved Oxygen and Percent Saturation

Since salinity and temperature vary throughout Crane Creek and the Indian River Lagoon, dissolved oxygen saturation will be used here to compare the three sampling locations. The mean dissolved oxygen saturation from January to June 2001 for all stations and depths was $80.4 \pm 37.1\%$ (**Table 4.3**). Values ranged from below detection to 208% during this time period. Anoxia was observed at the bottom of station 3 causing the lowest mean oxygen saturation at this location during all sampling periods (**Figure 4.3**).

From July to November 2001 the dissolved oxygen saturation in Crane Creek and the IRL for all stations and depths ranged from below detection to 194%. The mean dissolved oxygen saturation was found to be $60.8 \pm 37.2\%$, which is a mean decrease of 25% when compared to the January to June 2001 data (**Figure 4.3 and Table 4.3**).

Mean dissolved oxygen saturation for all stations and depths for January to March 2002 was $79.6 \pm 29.7\%$, which is a 24% increase when compared to July to November 2001 (**Table 4.3**). Values ranged from below detection to 145%. The highest mean dissolved oxygen saturation was found at station 5 (**Figure 4.3**).

A comparison of all three sampling periods revealed higher mean dissolved oxygen percent saturation during the January to June 2001 and January to March 2002 sampling periods. Mean percent saturation was found to be the lowest during the months of July to November 2001. Depressed oxygen levels with depth for site 3 are responsible for the lowest mean oxygen percents found within Crane Creek and the IRL (**Figure 4.3**). Values were typically highest in surface waters and decreased with depth for all stations and time periods.

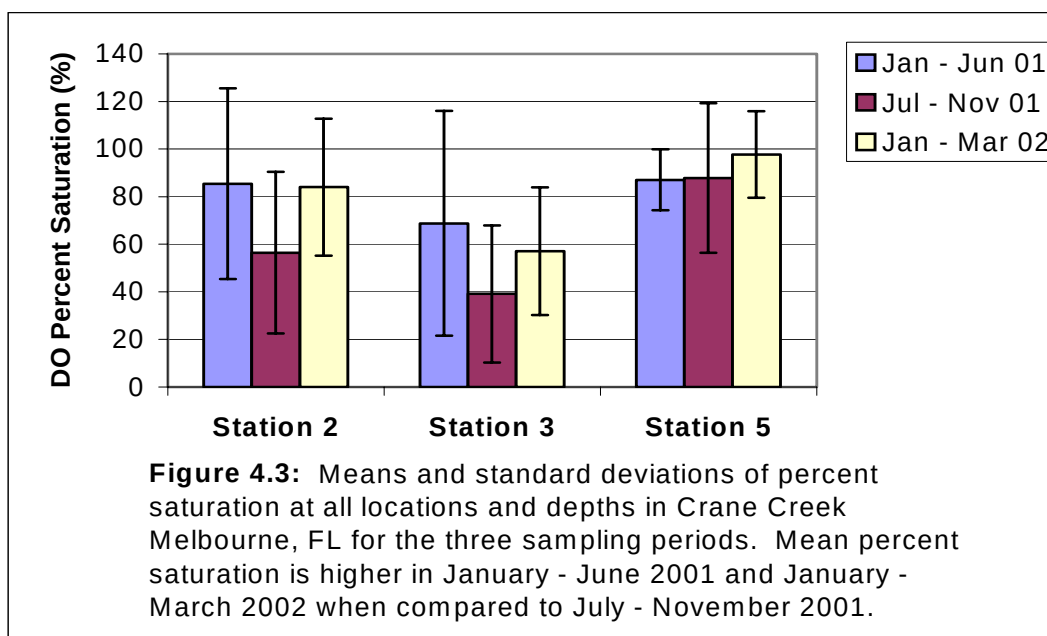


Table 4.3

Summary of changes in mean percent saturation of oxygen between the three sampling periods in Crane Creek Melbourne, Florida.

	Jan – Jun 01	Jul – Nov 01	Jan – Mar 02
Percent Saturation (%)	80.4 ± 37.1	60.8 ± 37.2	79.6 ± 29.7
Change		-25%	+24%

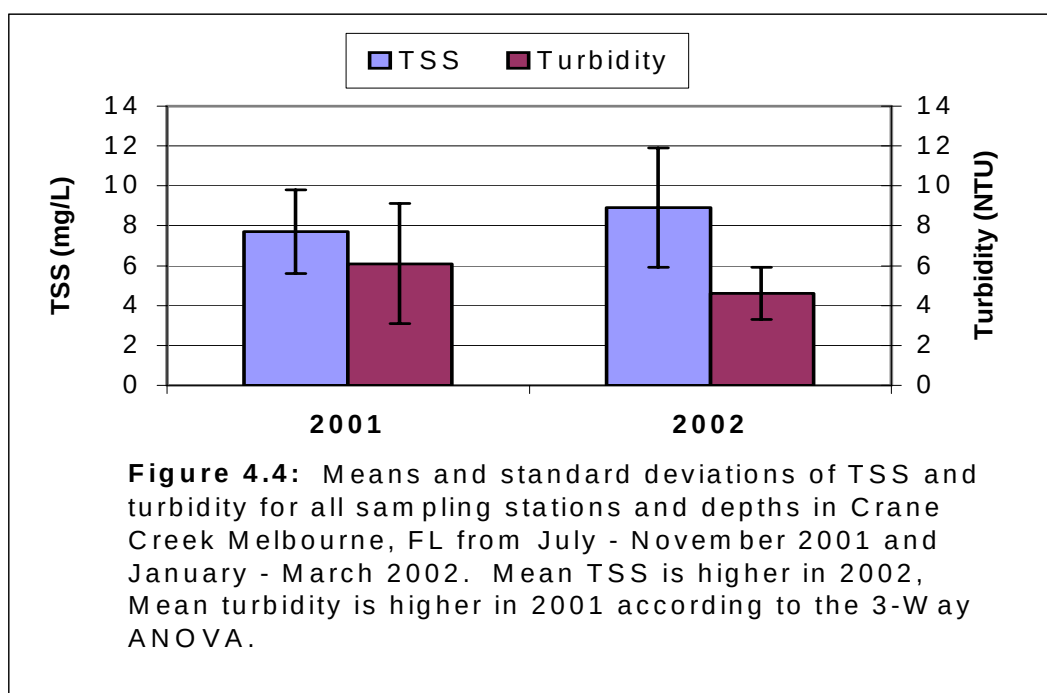
4.1.3 Total Suspended Solids and Turbidity

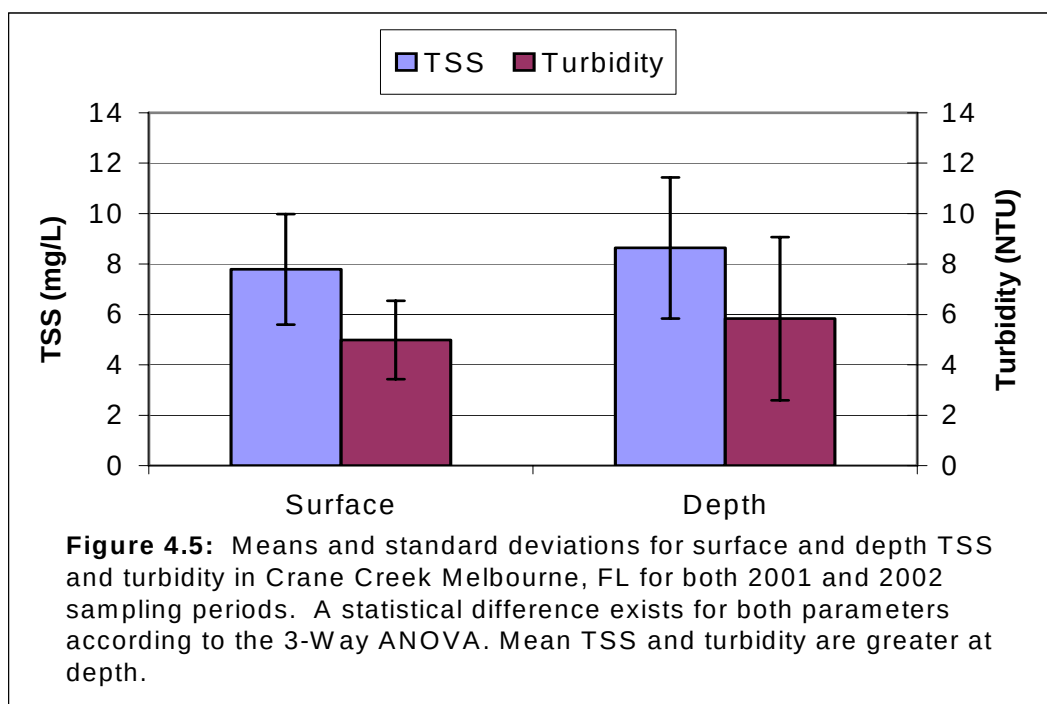
Mean TSS and turbidity from July to November 2001 were 7.7 ± 2.1 mg/L and 6.1 ± 3.0 NTU. TSS had a range of 4.2 – 15.6 mg/L and turbidity varied from 2.9 – 22 NTU from July to November 2001. From January to March 2002 TSS and turbidity ranged from 2.8 – 18.3 mg/L and 1.5 – 7.4 NTU. Mean TSS was 8.9 ± 3.0 mg/L and turbidity had an mean value of 4.6 ± 1.3 NTU. Mean total suspended solids showed an increase of 16% from July to November 2001 and January to March 2002, while mean turbidity decreased by 25% between the two sampling periods (**Figure 4.4**).

Total suspended solids and turbidity measurements were taken from July to November 2001 and January to March 2002. The Scheirer-Ray-Hare Extension of the Kruskal-Wallis Non-Parametric Test, applied to a 3-Way Analysis of Variance or ANOVA (**Section 3.5**), indicated that the only significant differences in TSS and turbidity existed between the 2001 mean and 2002 mean data for all stations and depths (years). In other words, mean TSS was

higher for January to March 2002 and mean turbidity was greater in July to November 2001 (**Figure 4.4**).

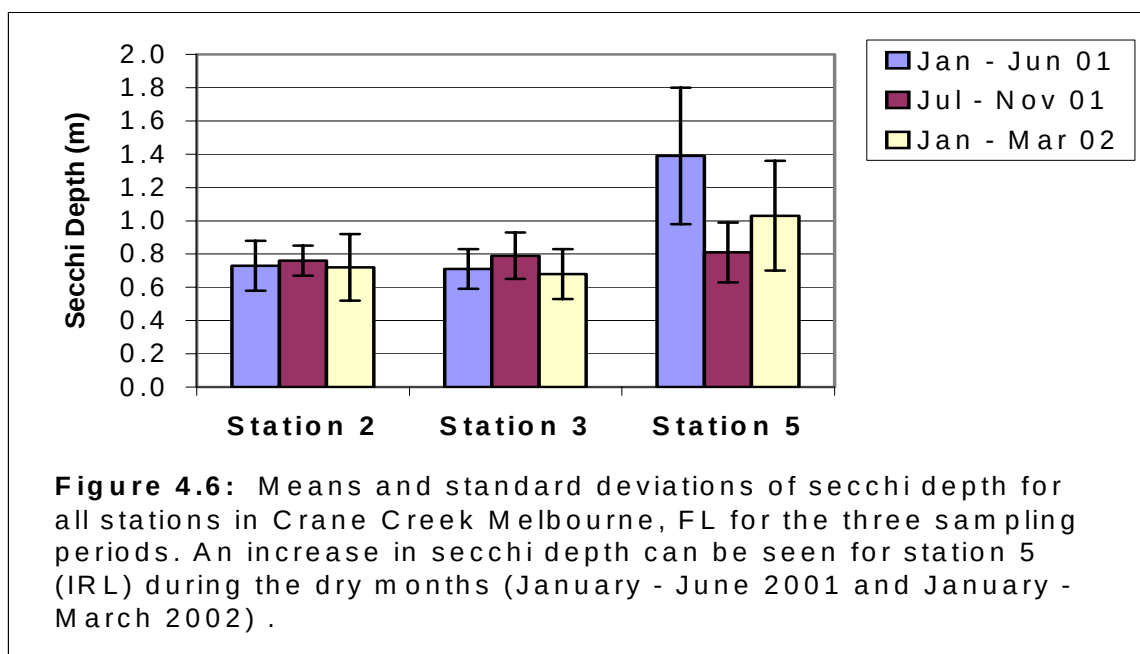
The difference in year represents the wet and dry seasons. Additionally, the test also found a statistical difference between mean surface TSS and turbidity and mean depth TSS and turbidity. Both mean TSS and mean turbidity, for all three stations, were higher at depth than at the surface from January 2001 to March 2002 (**Figure 4.5**). Variation of TSS and Turbidity from the surface to depth is most likely a sign of benthic sediment resuspension or materials settling from the surface. No statistically significant difference was found between stations, which may have indicated removal by the sediment trap, nor were any interactions found between years, stations, or depths.



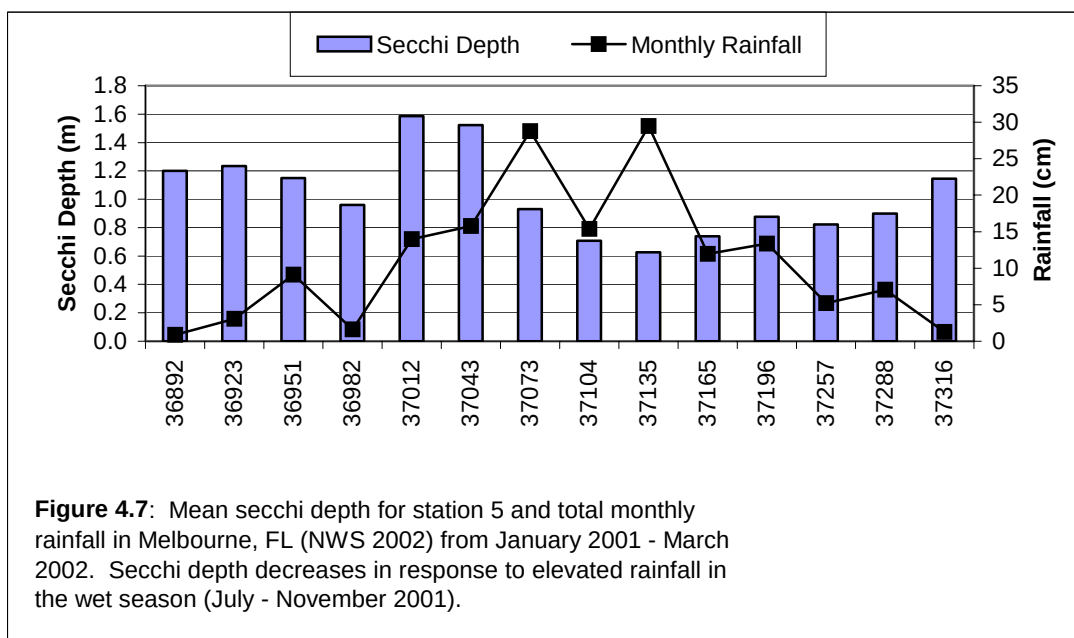


4.1.4 Secchi Depth

Mean secchi depth for the January to June 2001 sampling period for all stations was 0.9 ± 0.4 m. Values ranged from 0.5 to 2.1 m. The greatest mean secchi depth was found at site 5 in the IRL. Sampling areas 2 and 3, located in Crane Creek, both yielded lower mean secchi depths. From July to November 2001, the mean secchi depth throughout Crane Creek and the IRL was 0.8 ± 0.1 m with a range of 0.5 – 1.2 m, showing a slight decrease in the overall mean. More importantly, the maximum secchi depth recorded for station 5 decreased by 43% (2.1 vs 1.2 m). Overall, mean secchi depths during this time period did not vary between the three sampling locations. Finally, the mean secchi depth from January to March 2002 was 0.8 ± 0.3 m for all stations. A range of 0.5 – 1.5 m during the sampling period indicates an increase of 20% (1.2 vs 1.5 m) in the maximum secchi depth from January to March 2002 when compared to July to November 2001. In summary, when examining the three time periods, including all stations, no change in secchi depth is apparent. However, an increase in mean secchi depth is seen for station 5 during the dry months (January to June 2001 and January to March 2002) (**Figure 4.6**).



Water clarity in Crane Creek and the Indian River Lagoon, as defined by secchi depth here, seems to increase in response to depressed rainfall. Following a low total monthly rainfall of only 1.04 cm in May 2001, the secchi disk at station 5 in the IRL could be seen at the bottom (2.1m) on several occasions (May 20 and June 7, 2001). On the other hand, secchi depth decreased in response to the effects of elevated precipitation from July to November 2001. Mean secchi depths can be seen rebounding once again in accordance with depressed rainfall from January to March 2002 (NWS 2002) (**Figure 4.7**).



5.0 DISCUSSION

Salinity and temperature control the water structure in Crane Creek. For the most part, Crane Creek can be typically thought of as a classic salt wedge estuary in which less dense, freshwater is overlying more dense, saline water. The presence of these two water layers is depicted by stratification at various locations in the creek. In salt wedge estuaries river flow is dominant and little tidal mixing occurs. A wedge of saline water enters the estuary (or in this case creek) beneath the less dense waters flowing downstream at the surface (Berner *et.al.*, 1996). Here, the source of the saline water feeding the salt wedge is the Indian River Lagoon (IRL). “A small amount of this saline water is mixed upward by entrainment into the fresh outflowing upper layer, which becomes somewhat more saline seaward, but there is no mixing of freshwater downward so the salt wedge retains its original oceanic (or in this case lagoonal) salinity” (Berner *et.al.*, 1996). Therefore, a distinct salinity change at depth between the two layers exists (**Figure 5.1**). Finally, a weak flow of saltwater upstream occurs to replace the small quantity of saltwater being lost to the freshwater, downstream flow. (Berner *et.al.*, 1996).

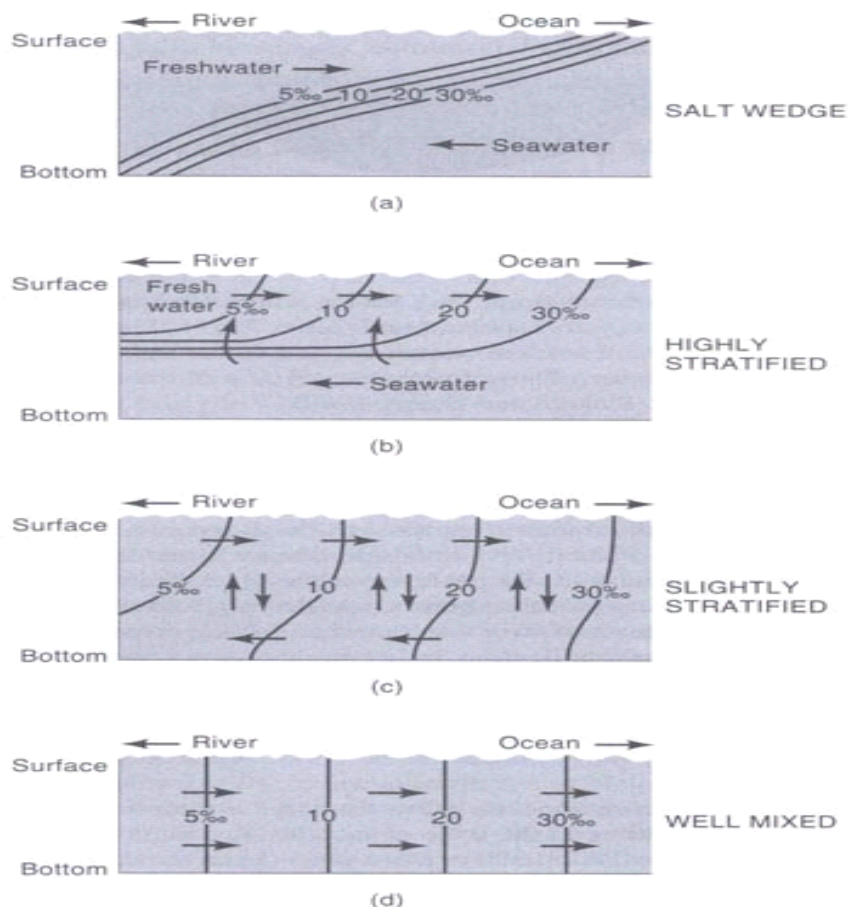


Figure 5.1: Types of Estuaries. Crane Creek behaves as a typical salt wedge estuary (a) due to its close proximity to the Indian River Lagoon (Berner *et.al.*, 1996). Adapted from G.L. Pickard and W.J. Emery. *Descriptive Physical Oceanography*. 4th ed., p.220. Copyright © 1982 by G.L Pickard, reprinted with permission of the author and Prentice Hall Inc.

5.1 Daily Variation in the Water Structure of Crane Creek

Salinity in Crane Creek not only varies from upstream to downstream locations, but also with depth on a daily time scale. As mentioned above, the less dense fresh water floats on top of the denser saline water in the salt wedge system. As the two layers of differing densities flow past one another, a small amount of saltwater is transferred to the upper, fresher water layer. This mixing, which is caused by cyclical internal waves generated at the fresh-salt interface between the two density layers, is further enhanced by wind and wave action on the surface which increases the turbulence (Brown *et.al*, 1989). Evaporation concentrating surface waters is extremely minor and can be dismissed as a significant factor elevating surface salinities on a daily scale. Therefore, wave action due to overlying surface winds is mainly responsible for the partial integration of fresh and salt layers, thus increasing the surface salinities in Crane Creek. In contrast, rainfall has the ability lower surface salinities.

On June 7, 2001 surface salinities rose from 5.5 ppt to 15.0 ppt (**Figure 5.2**). No significant rainfall (> 2.5 cm) occurred for two weeks prior to sampling to affect the salinity. Several hours prior to the morning cruise, no wind was measured. Southeast winds prevailed throughout the day increasing from approximately 7 knots at the time of morning sampling to 12 knots during the afternoon sampling (NCDC, 2001). Most likely these winds aided in the mixing process at site 3 and were responsible for the delivery of saltwater to the upper fresh layer, thus increasing salinity from 5 – 15 ppt (**Figure 5.2**).

In contrast, observations on July 7, 2001 revealed interesting data. Rather than showing increased salinities as a result of elevated wind speed, the data on July 7, 2001 show constant surface salinities in response to decreased wind speeds (**Figure 5.3**). During the morning sampling no wind was present. By the afternoon east winds rose to only 7 knots following the calm morning, with southeast winds only at 6 knots by the evening sampling. Rainfall of 3.7 cm on July 5, 2001 may have deepened the freshwater layer, thus making it more difficult for the relatively weak winds to induce sufficient mixing and increase surface salinities. As mentioned earlier, some degree of mixing will occur in the absence of wind due to the density gradient between the fresh and salt water layers. However, wind mixing has been shown to enhance the exchange of fresh and salt water in Crane Creek.

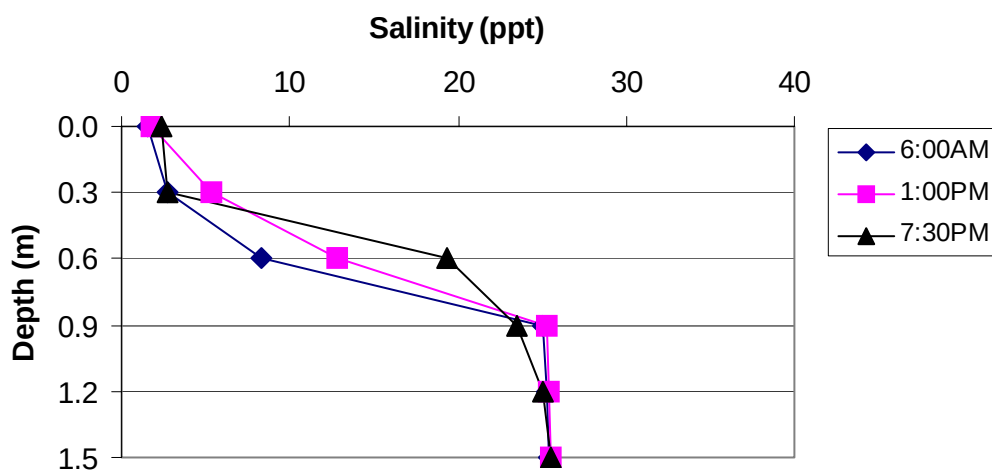


Figure 5.3: Salinity profile on July 7, 2001 recorded for station 3 in Crane Creek Melbourne, FL from the morning to evening. No significant increase in surface salinity can be seen as weak winds (0 - 7 Knots) were not sufficient for mixing.

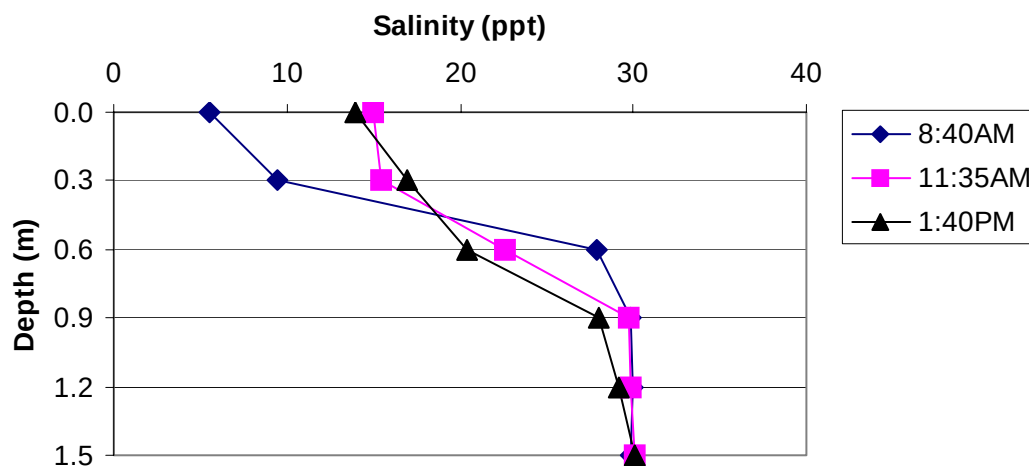
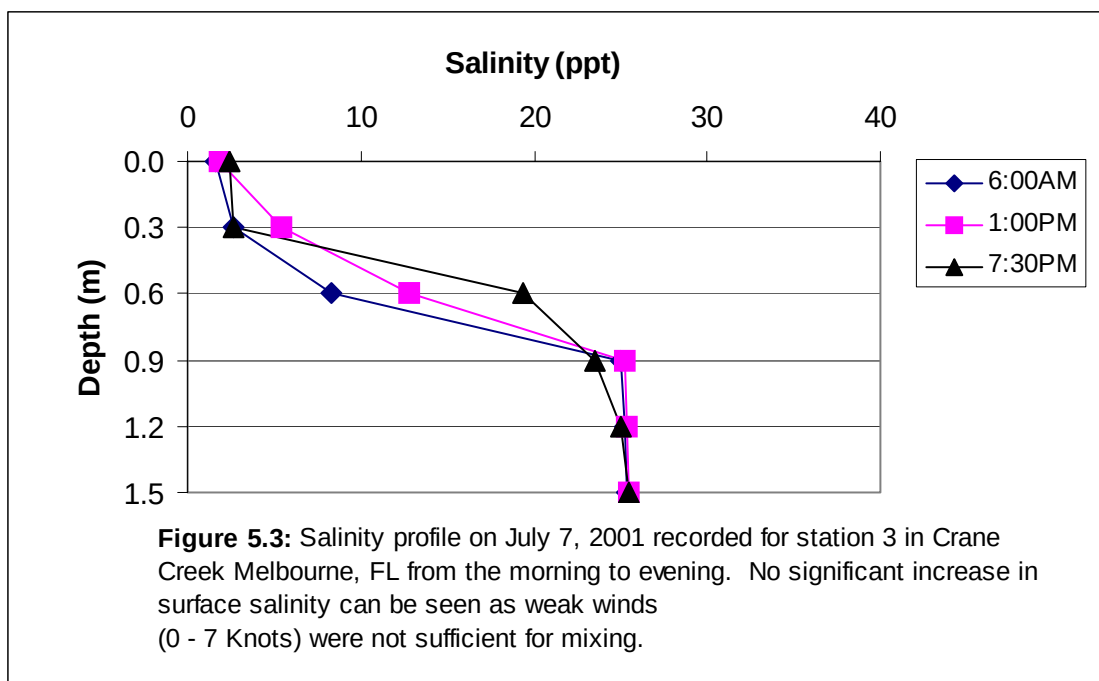
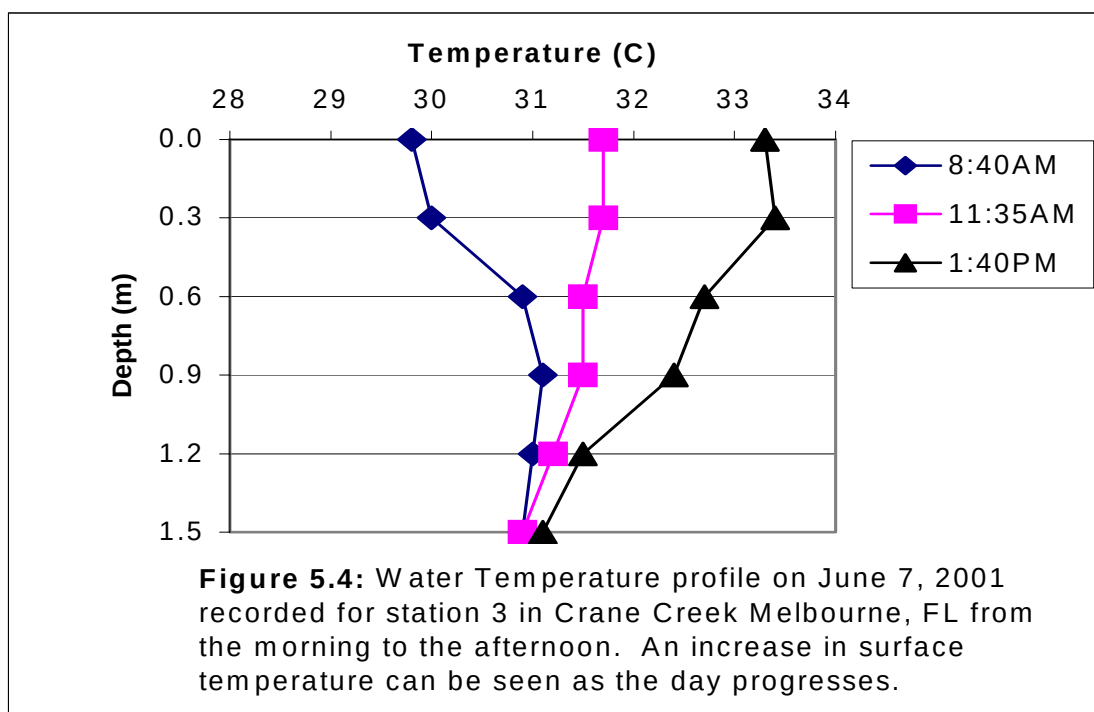


Figure 5.2: Salinity profile on June 7, 2001 recorded for station 3 in Crane Creek Melbourne, FL from the morning to afternoon. An increase in surface salinity can be seen as the day progresses due to elevated wind speed and mixing.



Variations in temperature at depth may occur on a daily basis as well. In fact, such behavior is mainly due to the identical mechanism that causes daily variation in salinity. Surface waters are cooler in the morning and warmer as the day progresses as a result of the loss of heat from surface waters to the overlying atmosphere throughout the night, and warming of this upper water layer during the day. Upwelling, caused by wind, allows these deeper, warmer waters to heat the cooler surface waters when sufficient mixing occurs. The same wind that mixes the fresh and salt layers, simultaneously, transports warmer bottom waters to the cooler upper layer. As a result, warmer surface temperatures are generated throughout the day as winds typically grow stronger throughout the afternoon.

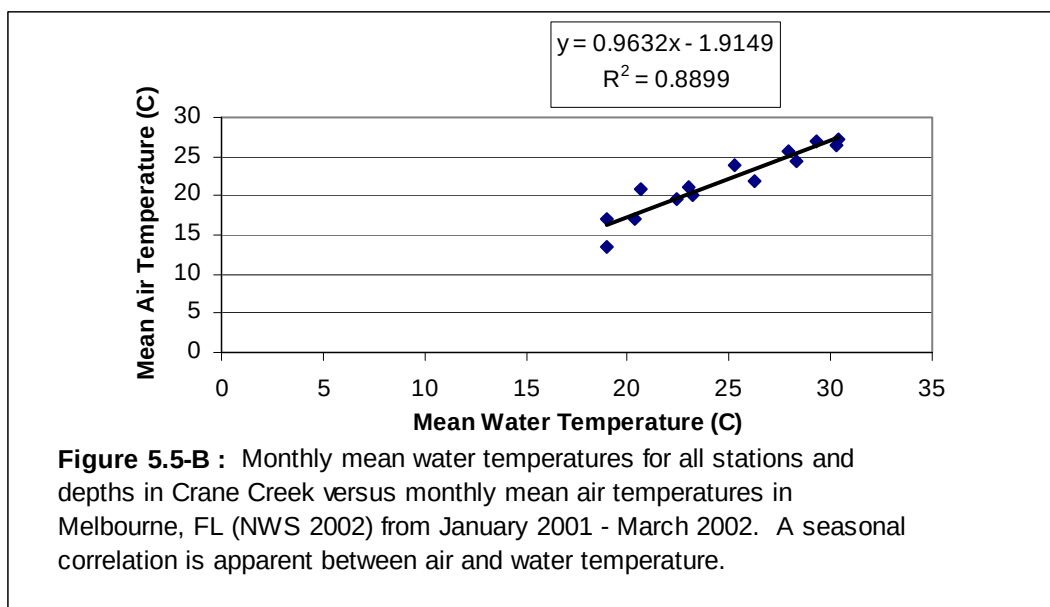
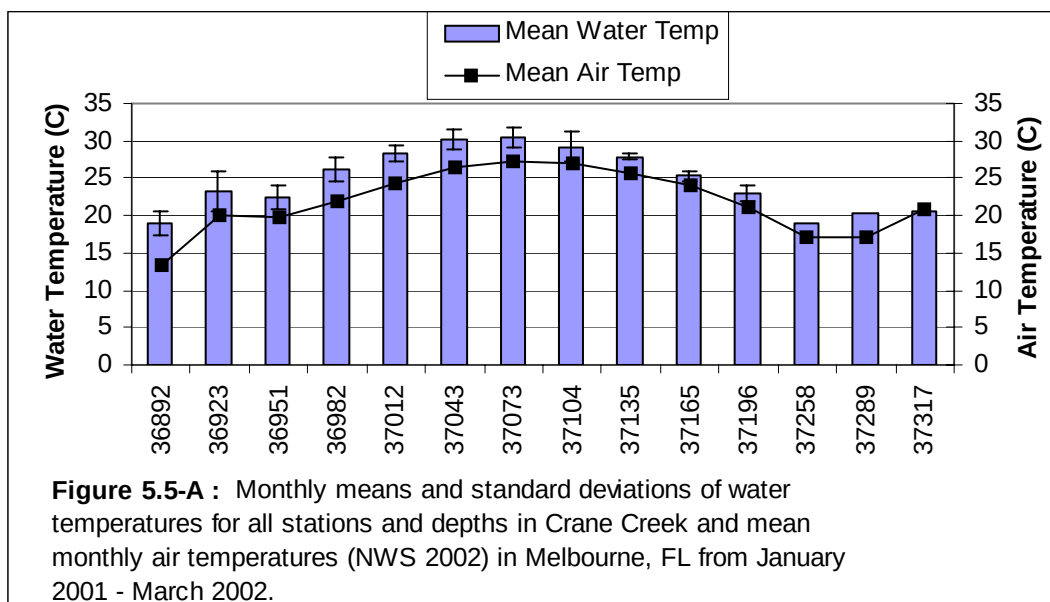
In addition to wind mixing, solar radiation adds to the heating of the surface layers. Therefore, daily temperatures are typically higher on the surface in Crane Creek. On June 7, 2001 surface temperatures rose from 29.8 °C to 33.3 °C as a direct result of increasing wind speed from 6 knots in the morning sampling to 12 knots by the afternoon cruise (**Figure 5.4**). As shown above, salinity also increased in response to elevated wind speed on June 7, 2001, thus further representing mixing on the sampling day (**Figure 5.2**).

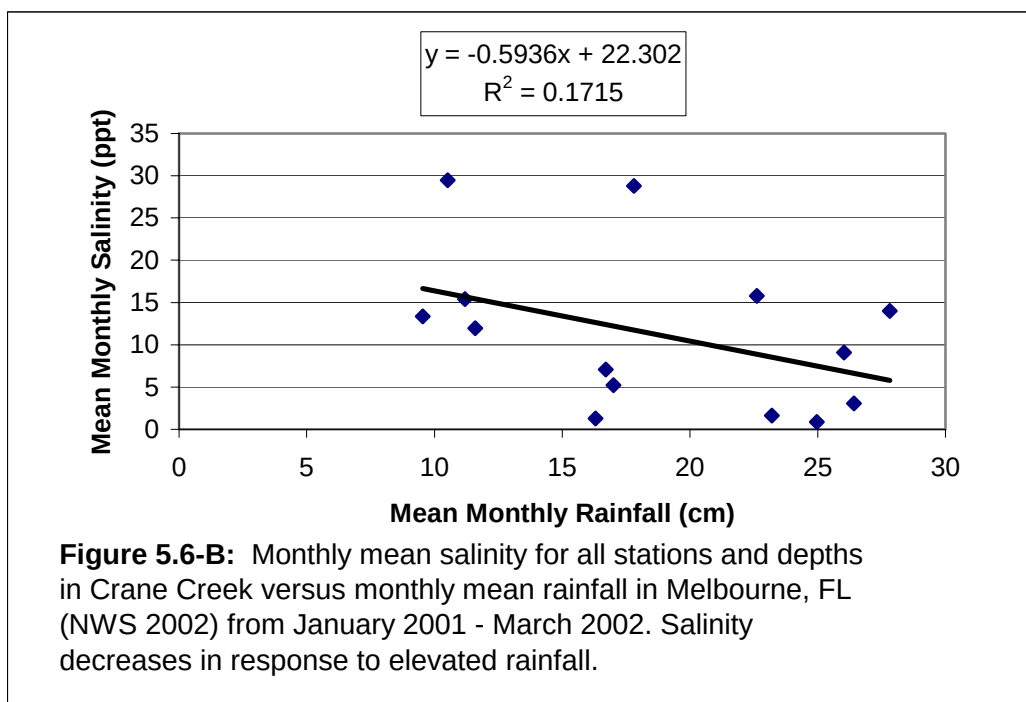
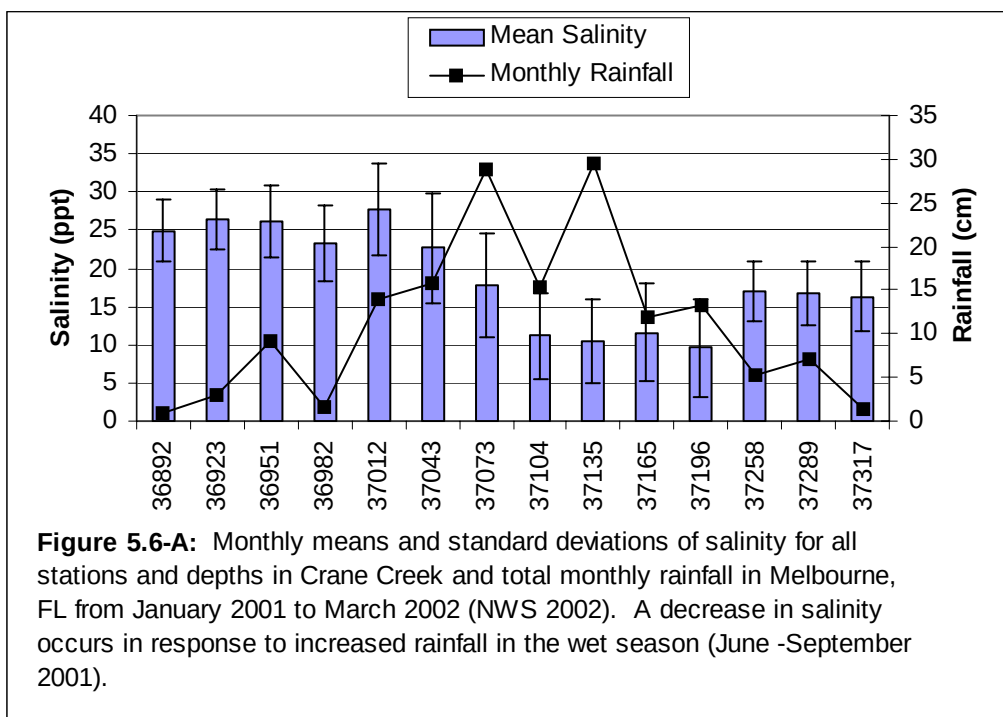


Understanding the daily variation in the water structure of Crane Creek allows one to predict changes in other parameters as well. If physical processes such as wind and rainfall can alter the salinity and temperature by transporting water, then they can also carry other materials such as TSS within those water layers. Therefore, the delivery of materials to the surface layers of Crane Creek via direct runoff from rainfall, or upwelling of bottom waters due to wind action can be expected if changes in salinity or temperature are observed. Additionally, significant changes in the salinity of stagnant bottom waters most likely represents flushing or mixing, which can cause re-aeration of oxygen-depleted bottom waters.

5.2 Seasonal Variation in the Water Structure of Crane Creek

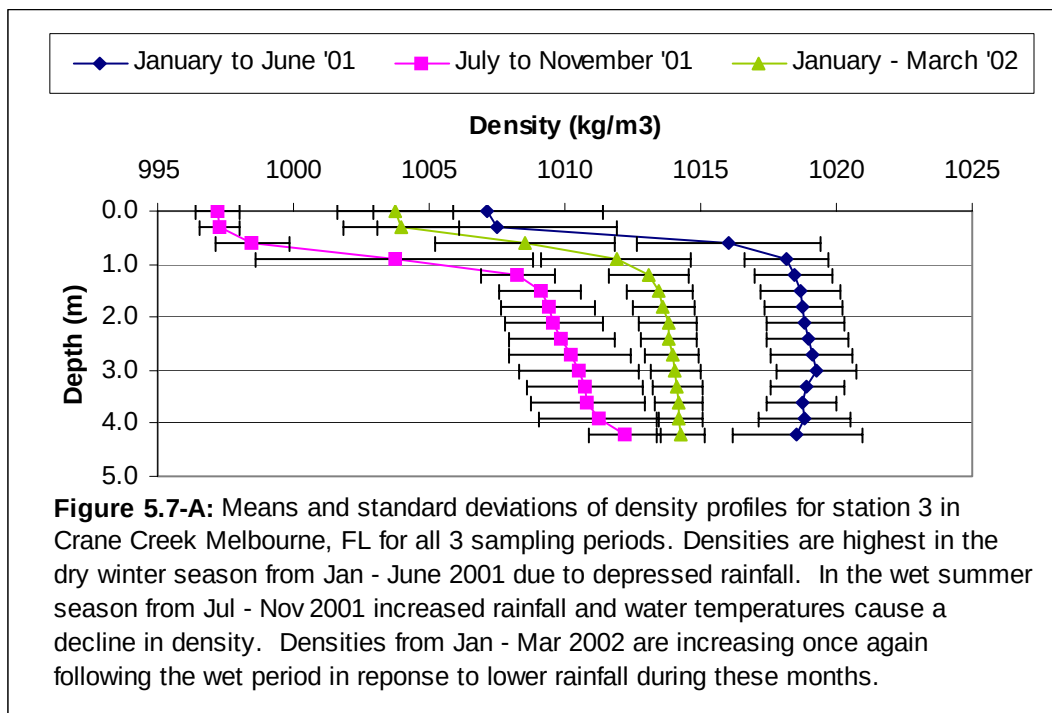
The Indian River Lagoon basin, which includes Crane Creek, is situated between the 27° and 29° north latitudes and is thus classified as subtropical (Rao, 1987). Due to this location, southeast Florida does not experience the typical four seasons like many other areas in the United States. Instead, it is primarily confined to a rainy, wet season from June through September, and a relatively dry season from October through May (Rao, 1987). Seasonal variation in water temperature and air temperature (**Figures 5.5 A and B**) and the response of salinity to rainfall (**Figures 5.6 A and B**) were observed during this study. The weak relationship between salinity and rainfall in **Figure 5.6-B** is most likely due to a lagged response by salinity. In other words, salinity in Crane Creek probably does not decrease immediately following the first storm events of the season. For example, groundwater recharge may be occurring following periods of low rainfall so freshwater is not being delivered to the creek to lower salinity.

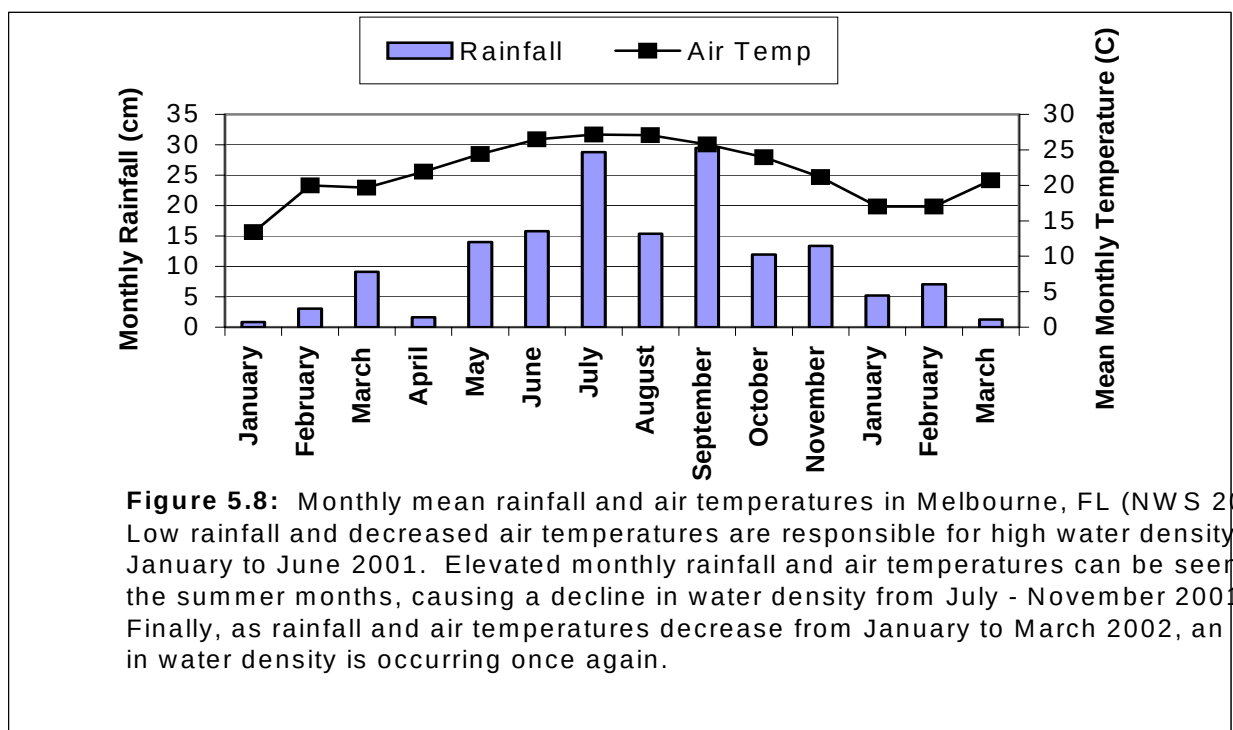
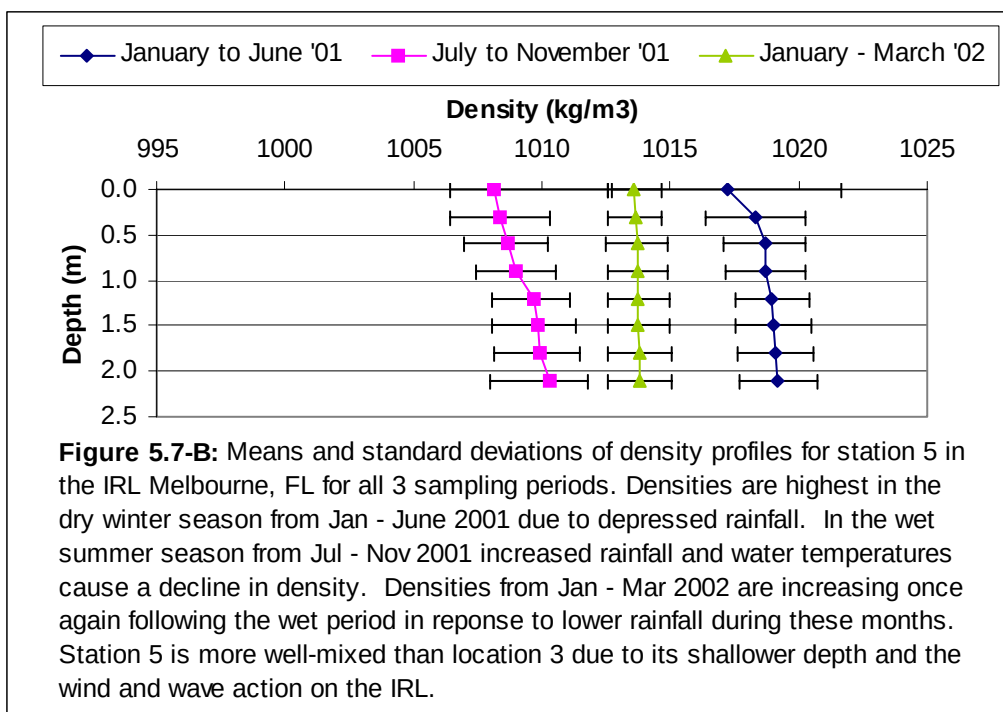




As illustrated above, rainfall in the wet season can lower salinity. Additionally, water temperatures are higher in the summer in Crane Creek. Runoff from rainfall delivers large quantities of fresh water to the creek provided that groundwater saturation has occurred. The resultant decline in salinity, which, when coupled with the increased water temperature due to the elevated atmospheric temperature, causes a decline in the density of the water column.

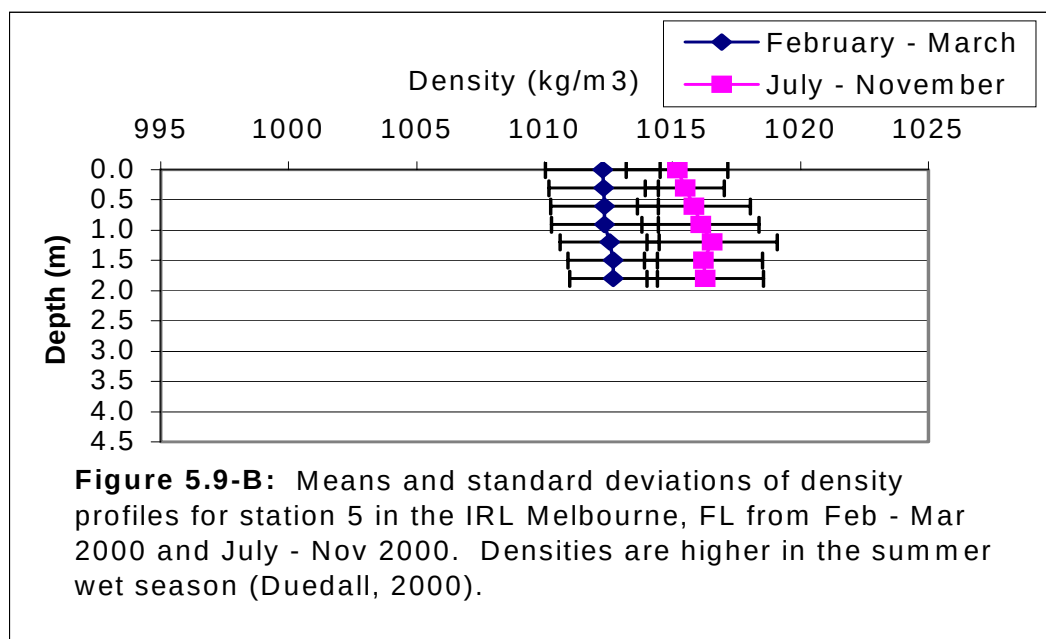
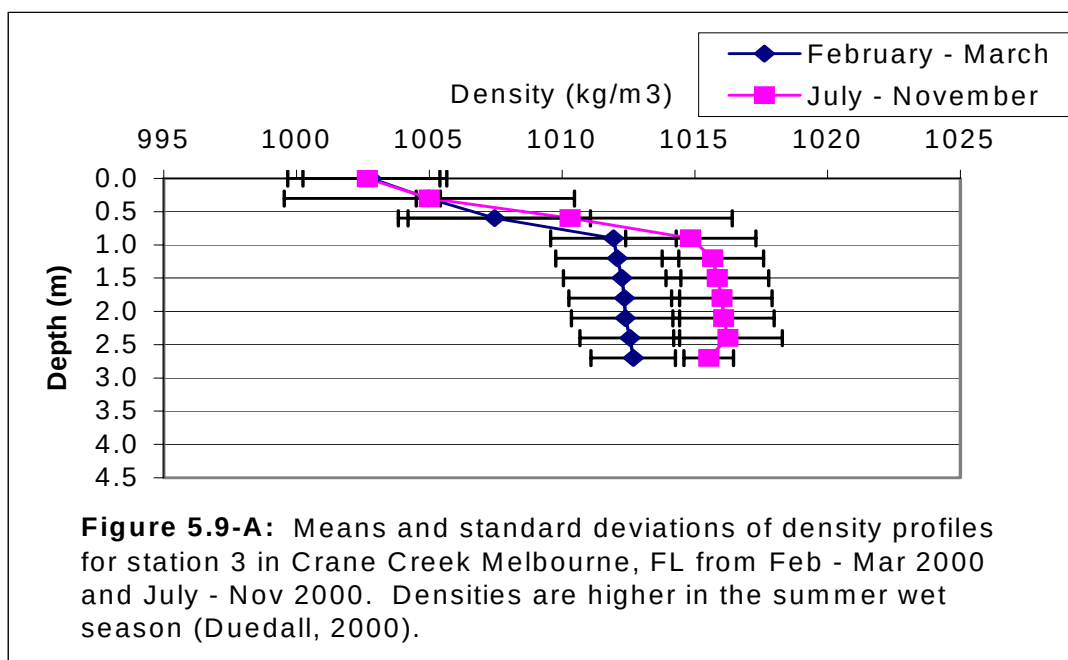
Using the salinity, temperature and pressure observations, density profiles can be generated to illustrate the variation in the water structure for Crane Creek and the IRL. Densities are greatest during the January to June 2001 sampling period as a result of higher salinity and lower temperatures. A decrease in density can be seen from July to November 2001 due to a decline in salinity and a slight increase in water temperature. Finally, densities can be seen rising once again from January to March 2002 as a result of increasing salinity during this time period (**Figures 5.7 A and B**). Monthly mean rainfall and mean air temperatures were greatest during the sampling period with the lowest density (July – November 2001). Mean precipitation and mean air temperatures were significantly lower when density was greater from January to June 2001 and January to March 2002 (**Figure 5.8**).





The decline in density during the summer wet season shown above is representative of sampling period from January 2001 to March 2002. This anticipated density behavior is not always seen. In fact the year 2000 density profiles exhibit a different trend (**Figures 5.9 A and B**). The higher densities in the summer months in the year 2000 can be attributed to the reduced

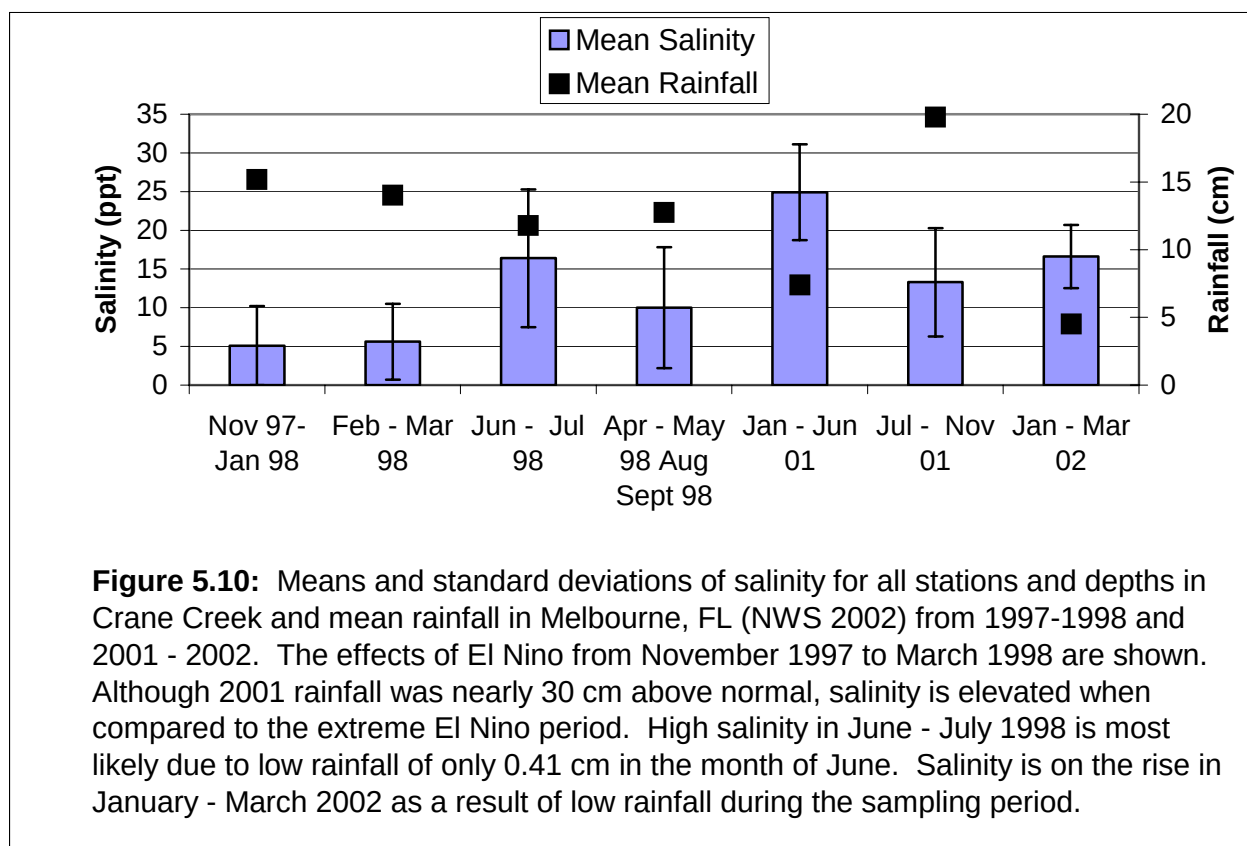
rainfall during this particular year. Total monthly precipitation from July to November 2000 was 7.6 cm above normal. In contrast, July to November 2001 total monthly precipitation values were slightly higher above normal (38 cm) (NWS Melbourne, 2000 - 2001). Although the 2001 wet season can be considered normal in terms of meteorological conditions, rainfall was still higher when compared to the 2000 summer months. Therefore, rainfall seems to control the water structure on a seasonal scale, rather than wind action or temperature.



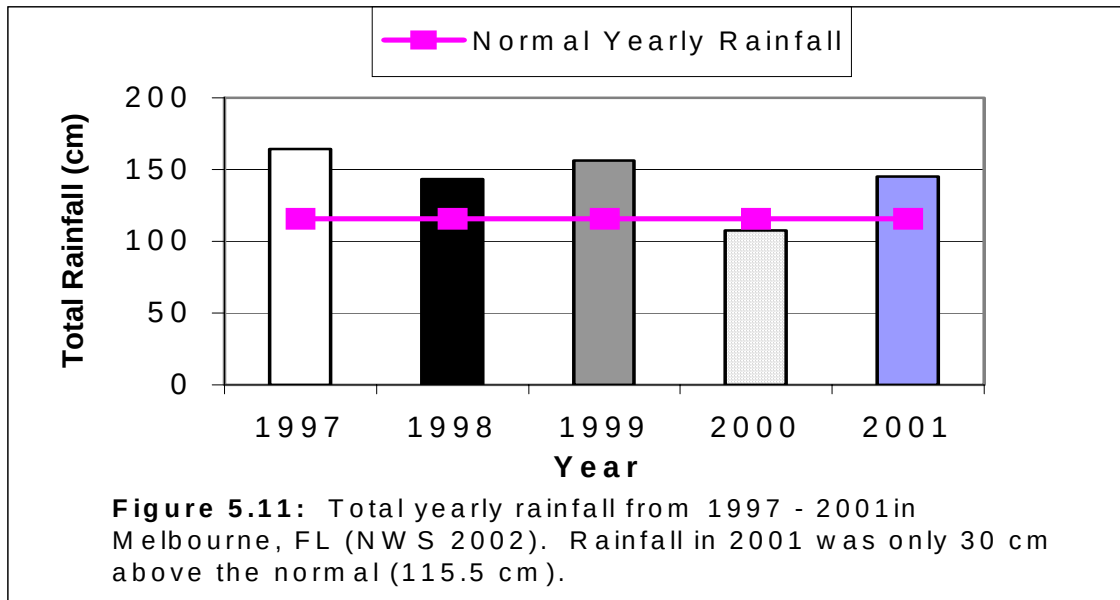
5.3 Annual Variation in the Water Structure of Crane Creek

Variations on a greater time scale can also be brought about by natural events which change the amount of precipitation delivered to the Crane Creek watershed. The year 2001 may have been slightly above normal (30 cm) in terms of rainfall, however, more extreme conditions have occurred in the past. “During strong El-Ninos such as in 1982-83 and 1997-98, storminess is greatly increased over Florida and the Gulf of Mexico leading to well above mean rainfall and perhaps widespread flooding” (Hagemeyer, 2001). Higher annual precipitation amounts in Florida can be expected during an El Nino (wet year), and lower precipitation amounts occur during a La Nina (dry year) (Sun *et.al.*, 1997). For example, El-Nino delivered a record setting 73.5 cm of precipitation between the winter months of November 1997 and March 1998 (Garcia, 1998). This amounted to 41.2 cm of rainfall above the normal for Melbourne, Florida for these 5 months alone (NWS, 1997-98) (**Figure 5.10**). Such a large volume of rainfall in a relatively short period of time would have an effect on the density and water structure of Crane Creek in terms of salinity (**Figure 5.10**).

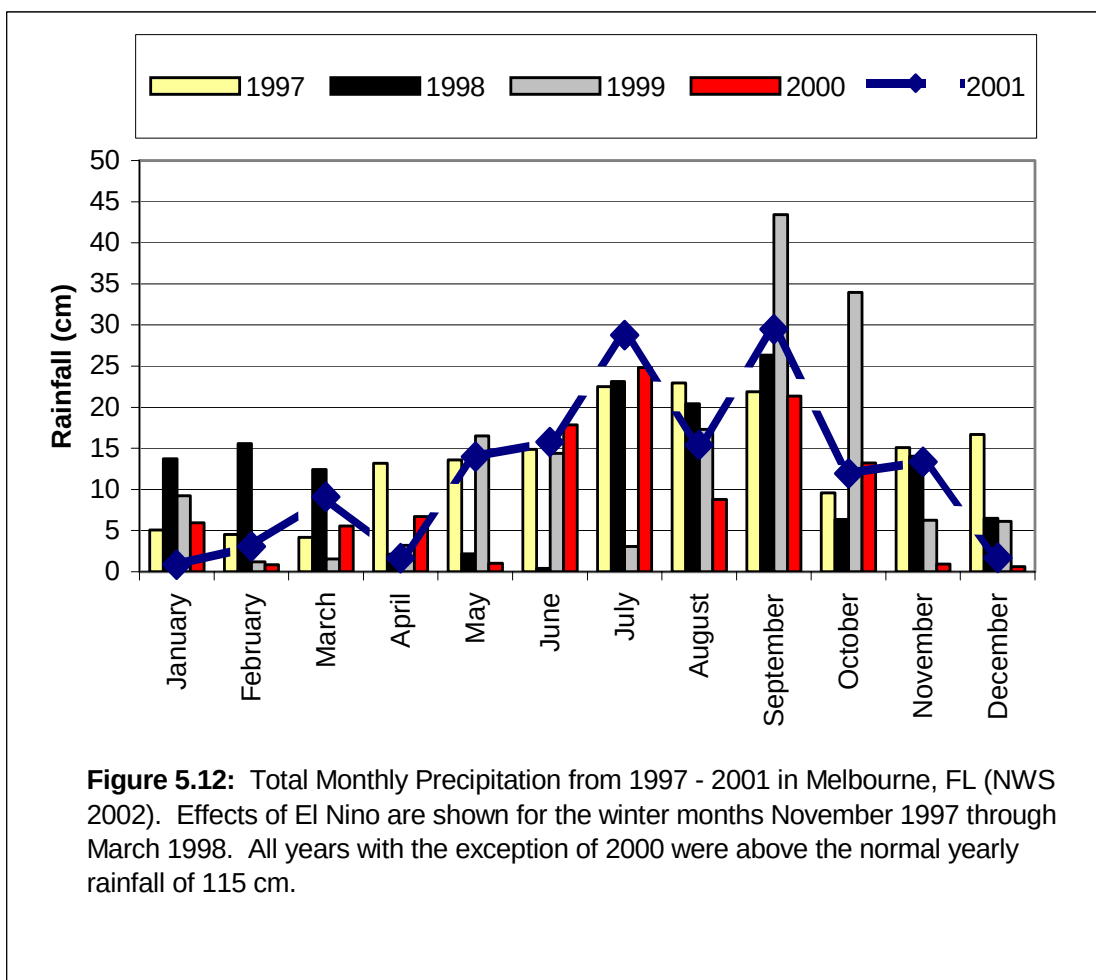
Most of the streams in Florida are gaining streams so discharge is dependent upon the height of the groundwater table. Stronger streamflows can be expected as the height of the groundwater table increases throughout an El Nino year. Therefore, greater amounts of freshwater delivered to an estuary are anticipated during an El Nino year and less freshwater recharge to an estuary in a La Nina period. Consequently, neither events occurred during this study. Still, all streams in Florida eventually discharge into an estuary since they originate inland and flow towards the coasts. For that reason, water salinities are greatly affected during such events (Sun *et.al.*, 1997).



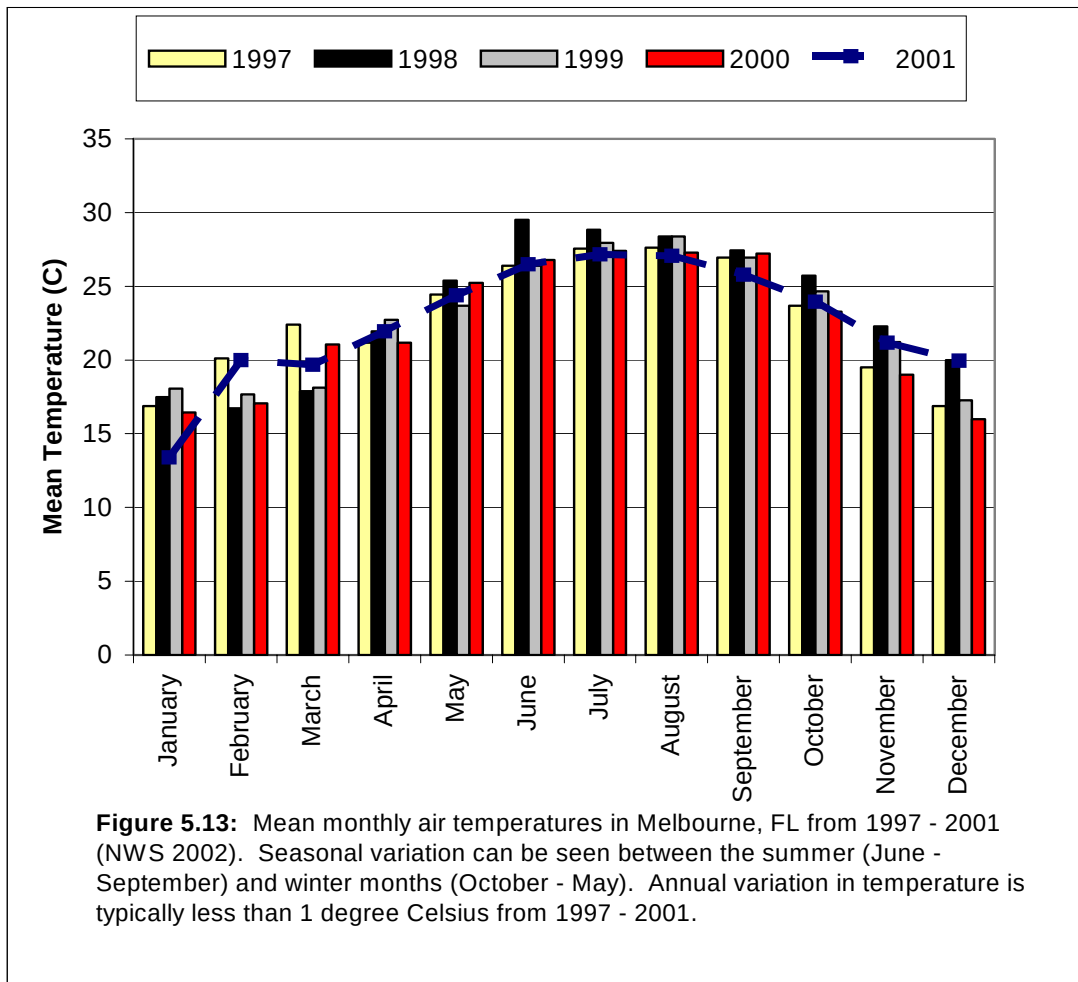
The normal yearly rainfall for Melbourne, Florida is 115 cm (NWS, 2002). As mentioned above, the total annual rainfall for 2001 was 145 cm, which is only 30 cm above the normal rainfall for Melbourne, FL (NWS, 2002). Rainfall in 2001 was compared to the previous four years in Melbourne in order to show the small deviation from the normal since precipitation amounts can influence the water structure of Crane Creek and the Indian River Lagoon (**Figure 5.11**).



Annual rainfall in 2001 was only twenty percent over the typical yearly amount. As shown in (**Figures 5.9 A and B**) above, low monthly precipitation from July to November 2000 (only 7.6 cm above normal) resulted in greater densities in the summer season due to a lack of freshwater input. Additionally, high monthly rainfall in September and October of 1999 (43.4 cm and 34.0 cm) most likely affected the water structure in the beginning of 2000, yielding lower densities in the dry winter season as shown in the 2000 density profiles (**Figures 5.9 A and B**). Monthly precipitation for the years 1997 – 2001 are shown below in **Figure 5.12**.



The yearly variability in rainfall can be significant and depends upon the factors discussed above. However, mean monthly and yearly temperatures do not seem to vary greatly (**Figure 5.13**). Therefore, annual deviations in the water structure of Crane Creek are most likely related to the amount of precipitation in any given year.



5.4 Factors Controlling the Amount of Total Suspended Solids in Crane Creek

From previous studies, three main controlling factors of estuarine, fine-grained sediment dynamics have been identified:

1.) The *availability of the sediment* (sources and budgets of the sediment) is one of the most important factors. Sources include sediments from rivers, the ocean, erosion areas, biological production, and waste discharges. Sediment transport studies of fine-grained materials often fail because of lack of knowledge of this factor.

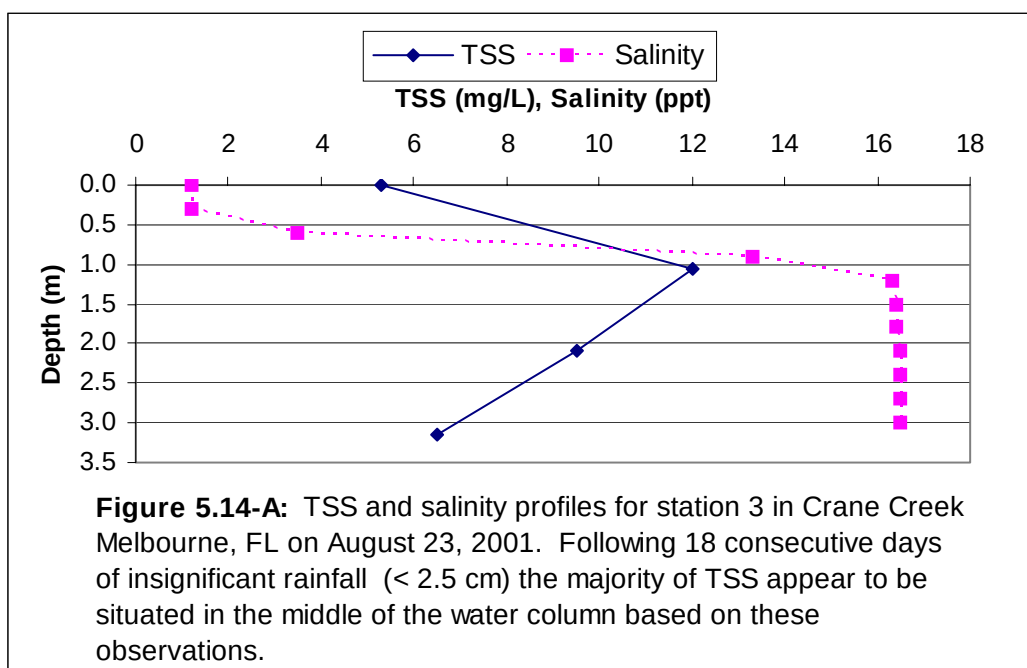
2.) *Water Movements* caused by tides, freshwater flow, and waves increase the complexity of a system. Such actions cause transport, sorting, and modification of suspended particles. Increased water movements tend to keep sediments in suspension until the velocity falls below a critical suspension value. Therefore, fine-grained sediment particles may be repeatedly deposited, resuspended, or consolidated.

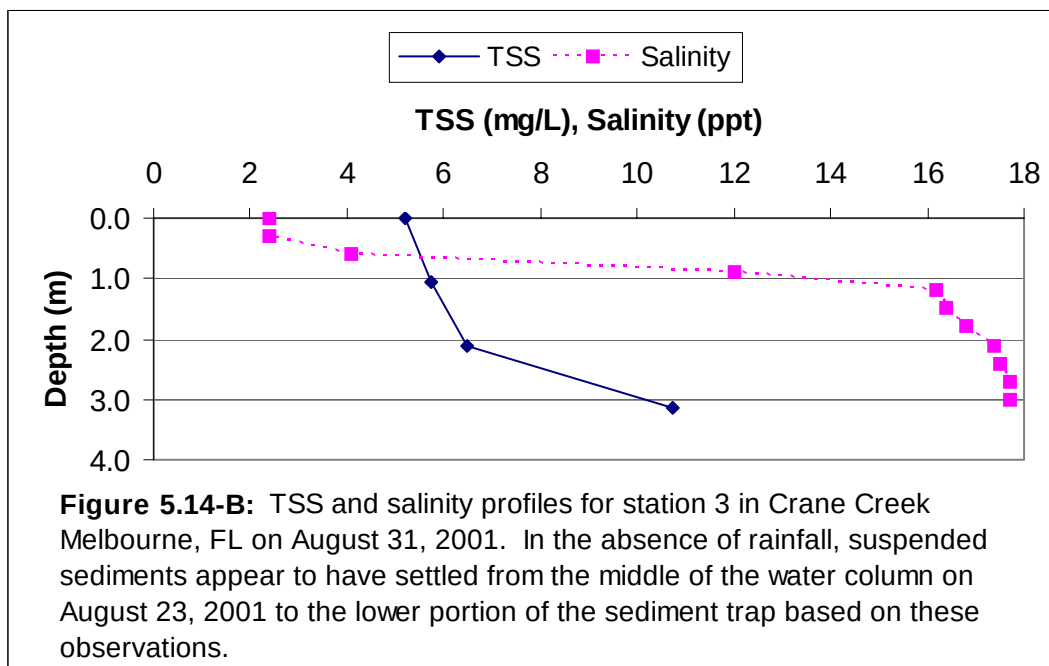
3.) *Sediment Properties* govern the transport behaviors mentioned above. These include flocculation, sedimentation, consolidation, and erosion. Fluid mud layers are sometimes formed, yielding their own unique properties of transport sediment (Leussen, 1996). The following four sections outline the factors controlling TSS concentrations and sediment transport in Crane Creek.

5.4.1 Rainfall Effects on Total Suspended Solids

Precipitation has the ability to increase suspended solid concentrations in Crane Creek via runoff in the watershed and re-suspension of bottom materials due to turbulent flow. Once in suspension, these particles are then transferred horizontally due to advective and diffusive processes. Bottom re-suspension is a function of water velocity yielding a critical shear stress on benthic sediments. Erosion is a function of this velocity as well as the composition of the sediments themselves which possess unique properties and determine rates of transport. Allochthonous inputs (those from outside the water column) are comprised of those sediments stored within the watershed that are washed into the receiving waterbody during a storm event (Koenig *et.al.*, 1996). The following observations may provide evidence of settling at the trap in the absence of rainfall, and downstream sediment transport, due to elevated precipitation increasing turbulent flow.

Following 18 days of insignificant rainfall (< 2.5 cm), on August 23, 2001 TSS at station 3 were concentrated in the middle of the water column. Approximately one week later on August 31, 2001, with no rainfall occurring during this time period, the majority of total suspended solids were observed near the bottom of the water column which most likely represents settling and removal. (**Figures 5.14 A and B**), bottom re-suspension may also be occurring to elevate TSS.





In contrast to the settling and removal which seemed to occur in August 2001, the influence of rainfall on downstream sediment transport was observed later in the July to November 2001 sampling period. On October 23, 2001 slightly elevated surface concentrations of TSS were noticed in response to a storm event delivering 1.3 cm of rainfall on October 22, 2001. More importantly, just three days later on October 26, 2001 surface TSS concentrations were significantly elevated from 5 mg/L to 10 mg/L following storm events on October 24 and 25, 2001 delivering 2.8 and 2.9 cm of rainfall (**Figures 5.15 A and B**). Rather than decreased precipitation leading to lower streamflows and longer residence time (**Figures 5.14 A and B**), the residence time on October 26, 2001 was shortened due to the elevated streamflow of 2.7 m³/sec. Therefore, less removal at the trap may have occurred.

From March 1988 to February 1989, a sediment transport study was conducted in Turkey Creek, which is located south of Crane Creek and also discharges to the IRL. Following a storm event yielding 15 cm of rainfall suspended sediments dramatically increased from background levels of 3 mg/L to 500 mg/L.

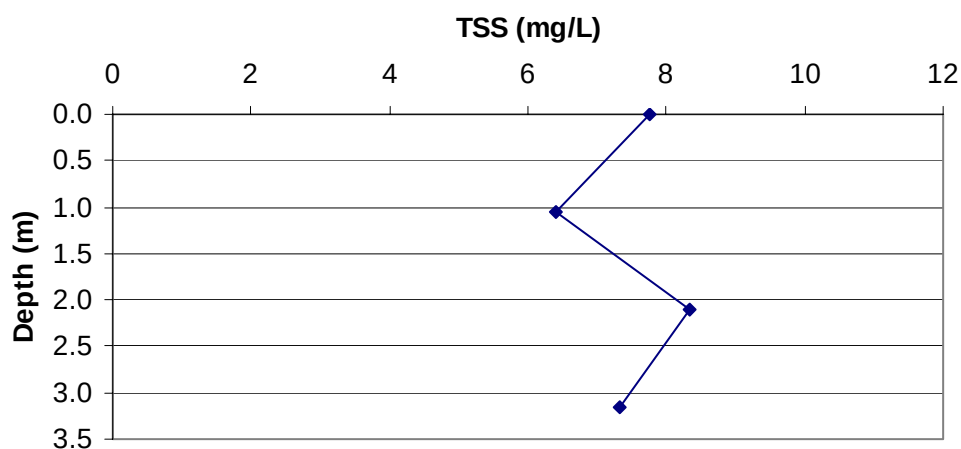


Figure 5.15-A: TSS profile for station 3 in Crane Creek Melbourne, FL on October 23, 2001. Surface concentrations appear to have increased slightly based on these observations, following a rainfall event of 1.27 cm on October 22, 2001.

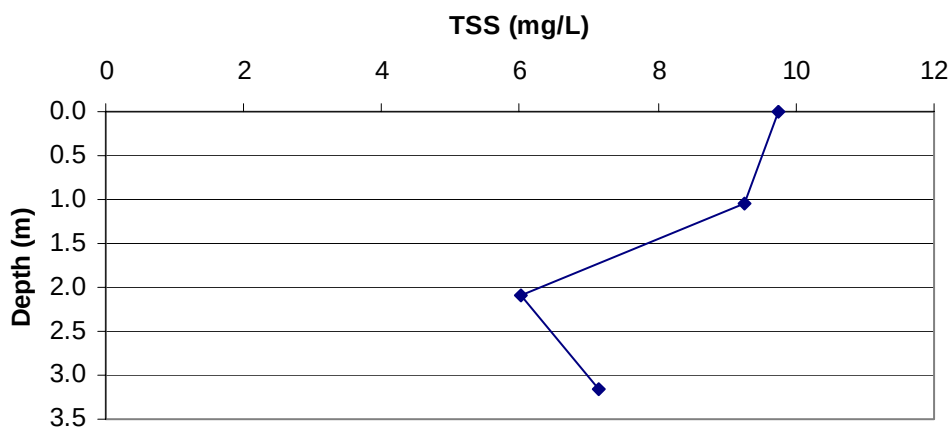
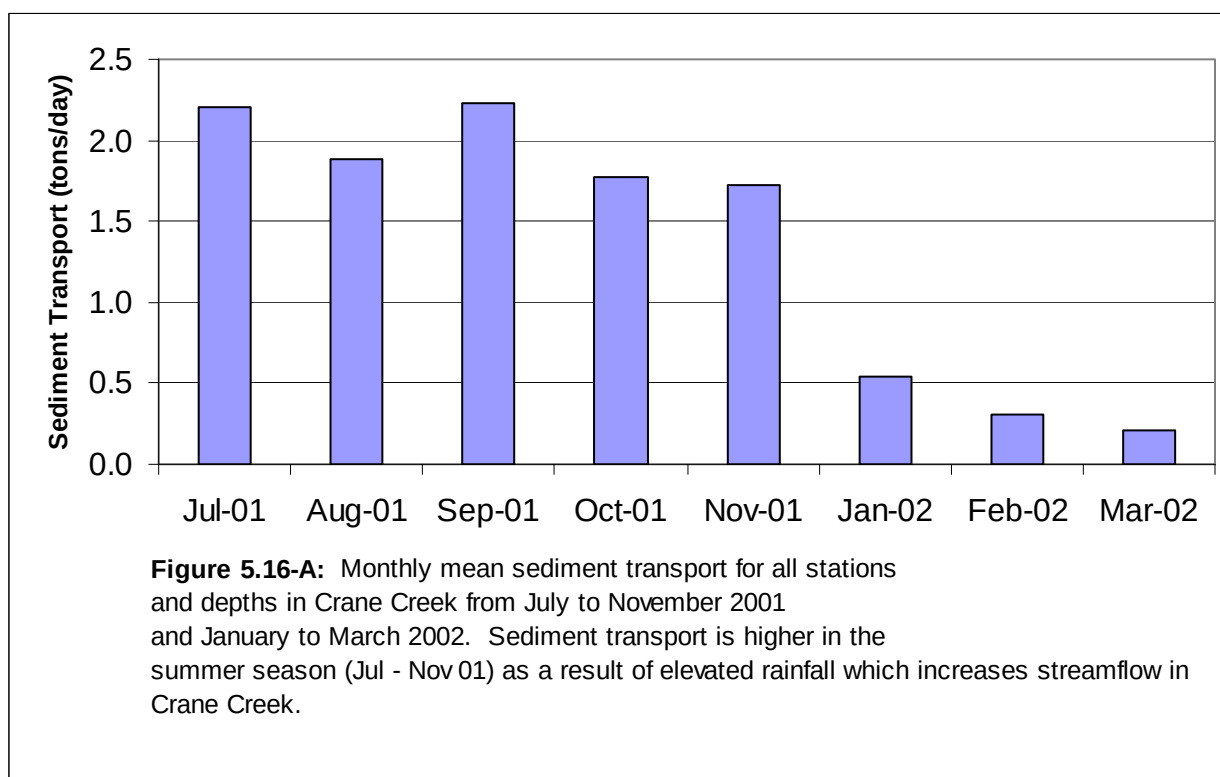


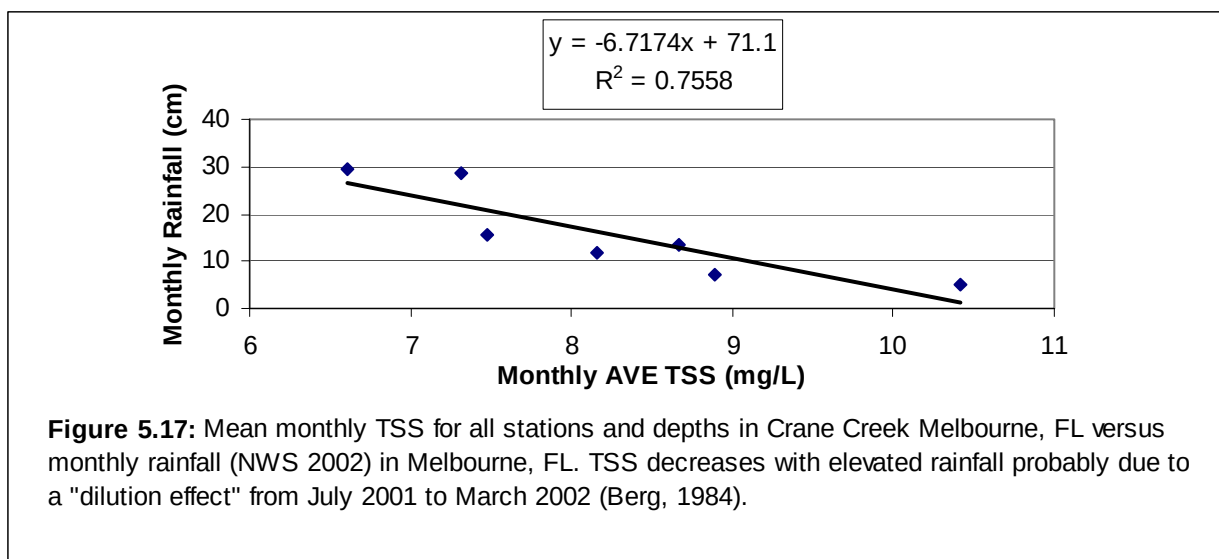
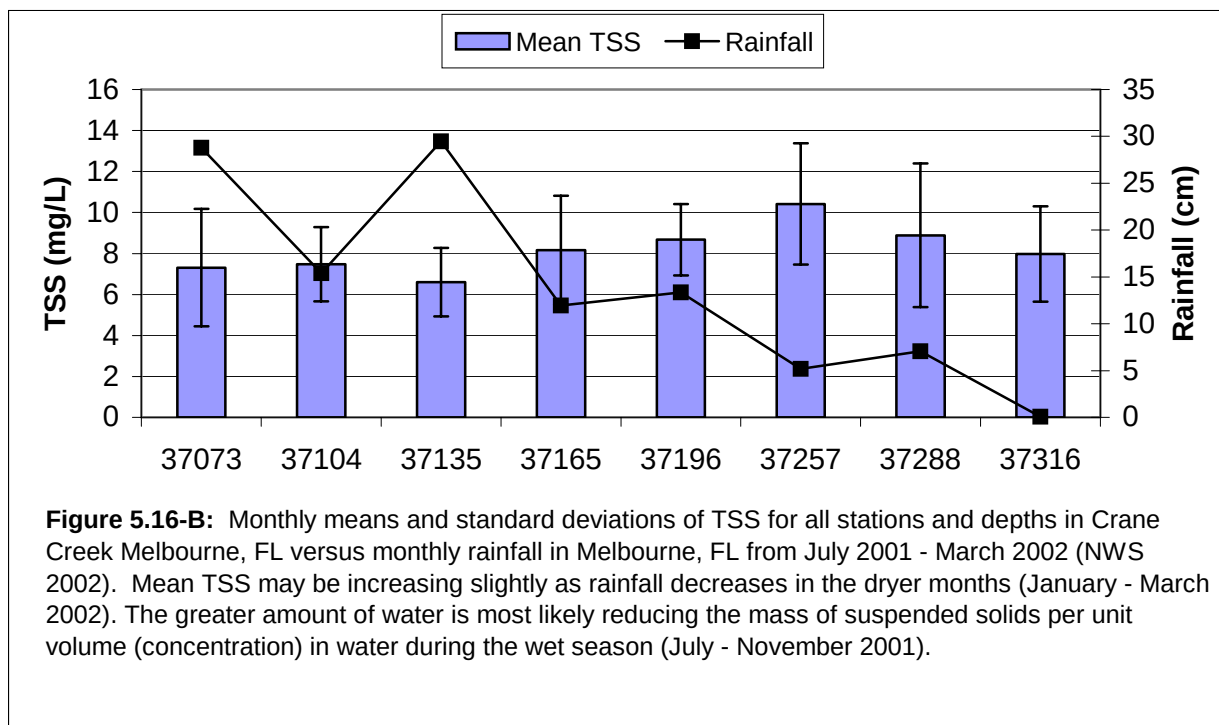
Figure 5.15-B: TSS profile for station 3 in Crane Creek Melbourne, FL on October 26, 2001. Surface concentrations appear to be elevated based on these observations, following two storm events delivering 2.8 and 2.9 cm of rainfall on October 24 and 25, 2001.

Such high TSS coupled with elevated streamflow resulted in the transport of 240 metric tons of sediment in a 72-hour period – or the equivalent to what is transported over 2–4 years of normal flow. Although the magnitude of the storm event for Crane Creek is much less than that of the Turkey Creek study, similar sediment transport behavior can be expected in Crane Creek based on the observations made on October 26, 2001 and the Turkey Creek data.

Downstream sediment transport caused by elevated streamflow in times of intense rainfall has been well-documented (Eyre, 1995; Koenig *et.al.*, 1996; Qasim, 1979; Ray *et.al.*, 1984; Saad *et.al.*, 1996). **Figures 5.15 A and B**, as well as **Figure 5.16-A**, show similar behavior in Crane Creek. However, increased rainfall may not always result in elevated concentrations of TSS, which can be explained by a “Dilution Effect” in the wet season (July – November 2001). Even though more material is being transported, the amount of fluid is also increasing. Mass transport of suspended sediments will increase, but no significant change may be seen on a concentration basis when related to the volume of water (Berg, 1984). In fact, mean TSS concentrations in Crane Creek were actually higher in the dry season from January to March 2002 (**Figure 5.16-B**). An association can be seen between rainfall and TSS in the creek.

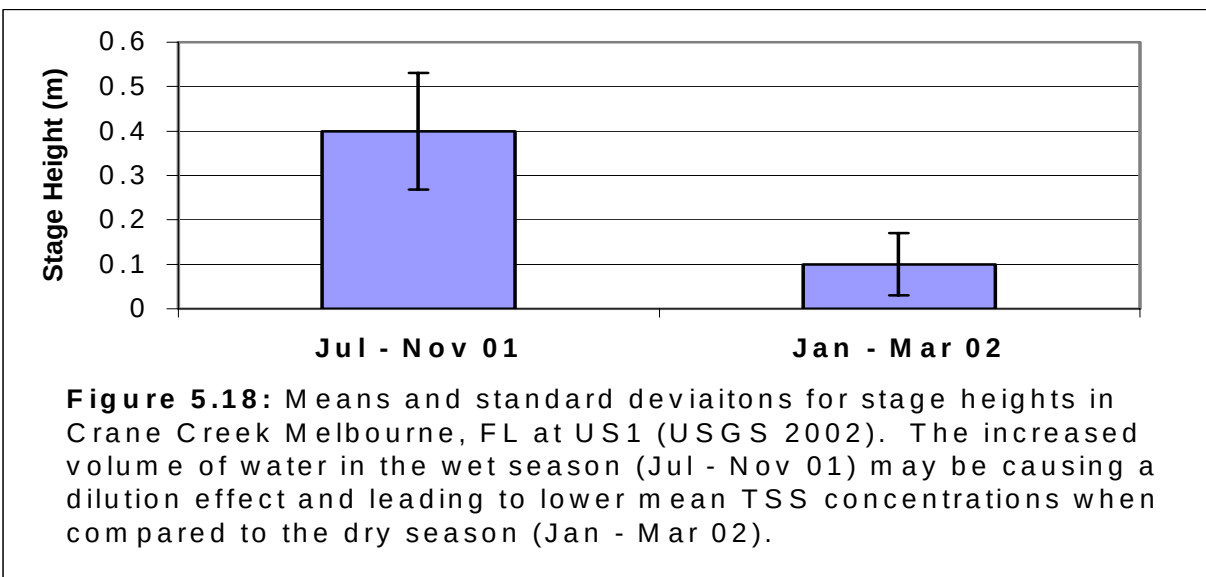
As rainfall increases in the wet season (July to November 2001) mean TSS concentrations subside (**Figure 5.17**). In addition to the dilution effect, TSS in Crane Creek may also be lower during some parts of the wet season due to the source reduction of particulates because storms occurring in rapid succession may produce successively lower amounts of suspended matter, since most of the more easily transported sediments in the watershed would have already been scavenged in preceding events (Jordan *et.al.*, 1986). On the other hand, long periods of little or no rain in the dry season allow for the accumulation of washout materials in the catchment. Such materials are easily suspended and transported. High rainfall events in the dry season alone can be responsible for transporting over 80 to 90% of the annual suspended sediments and nutrients to tropical estuaries (Qasim, 1979; Ray *et.al.*, 1984; Eyre, 1995).



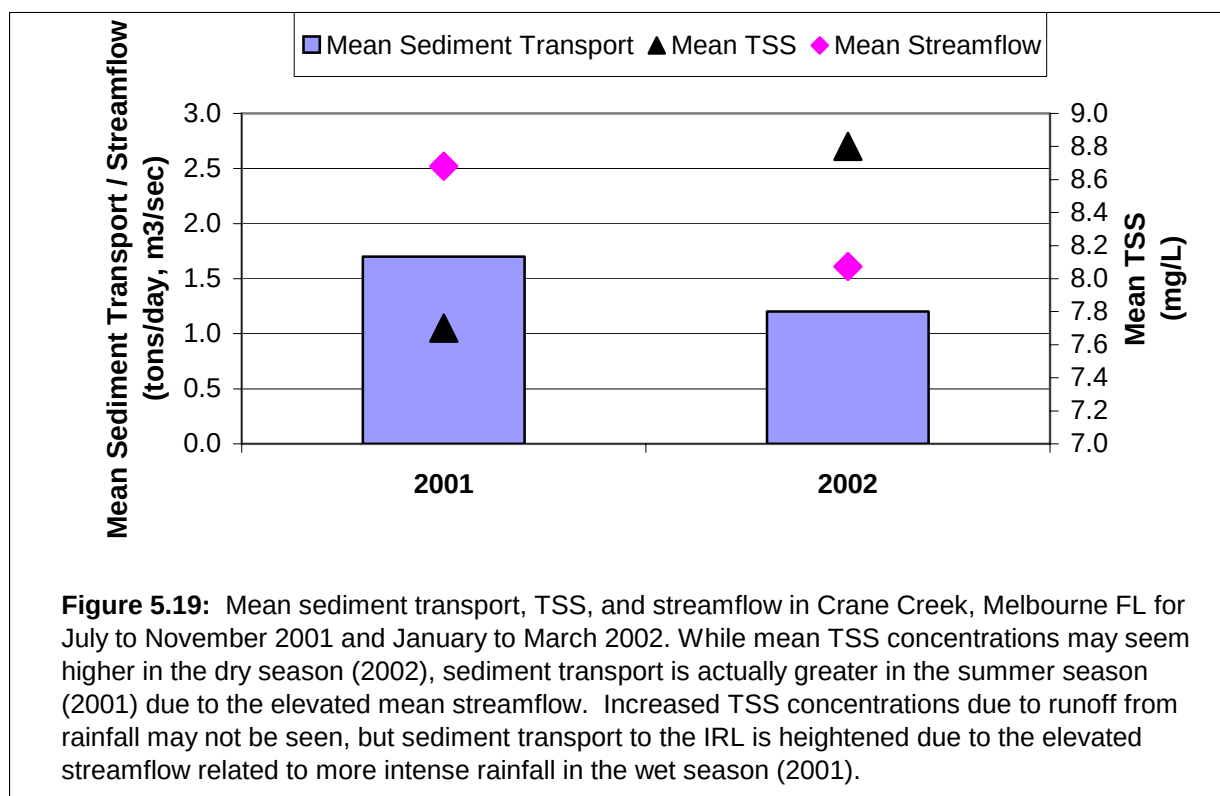


To further support the notion of a dilution effect in the wet season where the increased volume of water in Crane Creek results in lower TSS concentrations, USGS stage height data at US1 has been obtained. As expected, the mean stage height from July to November 2001 was greater than the mean from January to March 2002. In addition to the increased volume of water delivered to Crane Creek via rainfall, seiches (standing waves) caused by the typical easterly winds during the summer months may also elevate the stage height. USGS stage heights are recorded in feet above the datum of the gage. The datum is 3.0 m below sea level, so it is necessary to subtract 3.0 m to adjust the stage height to mean sea level. The mean stage height

from July to November 2001 was 0.4 ± 0.1 m. From January to March 2002, the mean stage height was 0.1 ± 0.1 m (USGS, 2002) (**Figure 5.18**). Therefore, the increased volume of water during the wet season sampling period (July to November, 2001) may be reducing TSS concentrations.



Considering the TSS data above, it seems as if TSS pose a greater threat to water quality in the dry season (January to March 2002). However, when TSS was related to streamflow, which is elevated in the wet, summer season (July – November 2001), sediment transport increased (**Figure 5.16-A**). Hence, water quality in the IRL during July to November is most likely reduced when compared to the dry season (January to March 2002) which actually shows elevated TSS concentrations. TSS may be higher in the dry season, but more suspended sediments are being delivered to the IRL in the wet season due to the elevated streamflow (**Figure 5.19**). Values for sediment transport during the two sampling periods were estimated using mean daily streamflows and mean TSS at all sampling stations and depths. Mean sediment transport from July to November 2001 and January to March 2002 were 1.7 ± 1.7 tons/day and 1.2 ± 1.3 tons/day.

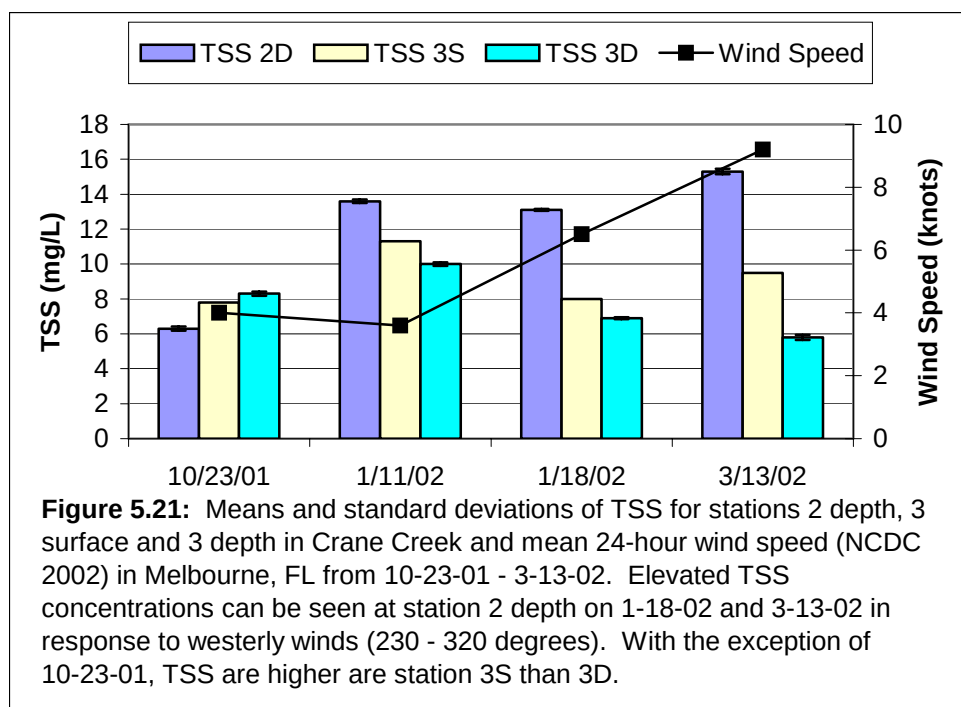
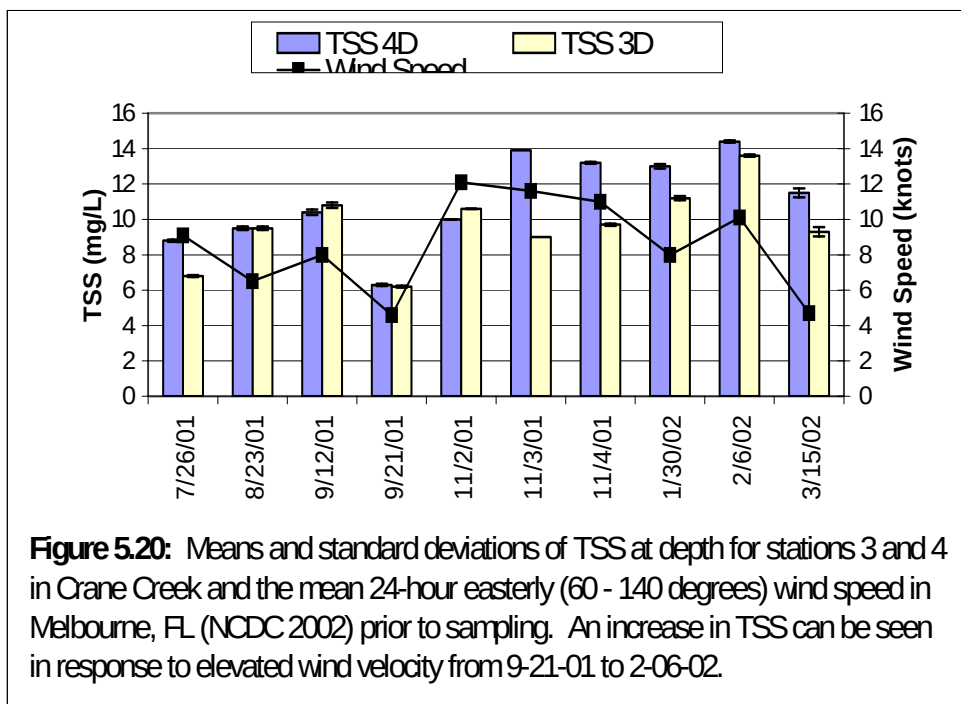


5.4.2 Influence of Wind Speed and Direction on Total Suspended Solids

Three types of turbulent processes exist in estuaries. Those originating at or near the estuary bed which may be caused by elevated rainfall and streamflow (**Section 5.4.1**), those in the interior of the fluid where density gradients are important (**Section 5.2**), and finally those originating at or near the free surface due to wind stress and wave action (Bowden, 1977). Having discussed the first two processes, the third will be addressed here.

Increased wind activity, in the absence of rainfall, has resulted in elevated TSS concentrations at depth particularly at station 4. Due to its close proximity to the mouth of Crane Creek, this station is most likely affected by northeast and southeast winds (60 – 140°) funneling up through the creek and re-suspending bottom materials (**Figure 2.1**). Removal may occur at station 3, but elevated TSS concentrations due to wind at site 4 do not allow for a mass balance calculation between stations 2 and 4 to quantify the removal at site 3. Such behavior is most likely why no statistical difference in TSS was seen between stations 3 and 4.

Three consecutive days of sampling during strong winds (10 – 20 knots) from November 2 to November 4, 2001 yielded higher TSS concentrations at depth at location 4. These same east winds re-suspending bottom sediments at station 4 also cause the upstream movement of IRL water into Crane Creek. As a result, increased TSS concentrations have also been seen at depth at sites 3 and 4 probably due to the delivery of sediments in the intruding IRL water – representing upstream sediment transport (**Figure 5.20**).



To strengthen this observation of migrating IRL water in Crane Creek, higher salinities have been seen at the bottom of site 3 than at location 5 '32 out of 53' sampling days (60%). More importantly, the aeration of bottom waters, on occasion, at station 3 provide evidence of flushing by IRL waters. West winds (230 – 320°) also disturb bottom sediments at location 2 due to its shallow depth of only 1.2 m. These west winds disturbed bottom material at station 2

and elevated surface TSS levels at site 3 (57% of the time) – representing downstream sediment transport (**Figure 5.21**).

Surface waves produced by wind can be significant causes of re-suspension and elevated TSS levels, especially in shallow estuaries with small tidal ranges as in Crane Creek and the IRL. Depths in Crane Creek range from approximately 1 to 4 meters, with a small tidal range in the IRL of less than 10 cm (Dombrowski *et.al.*, 1987). The energy of the waves created by overlying winds can be transmitted vertically in the water column through turbulent processes. Under wave action, fluidized mud, such as exists in Crane Creek, is subjected to horizontal transport when strong winds influence streamflow (Mehta, 1991). Wind intensity is not the only factor determining the amount of re-suspension. Wind direction is also important depending upon the location of the study area (Schoelhamer, 1995).

In the case of Crane Creek, the waterway is most susceptible to northeast and southeast winds due to its orientation (**Figure 2.1**). The re-suspension of bottom materials has been observed on several occasions during this study. Similar to the rainfall observations, wind speed and direction prior to sampling must be examined. Therefore, the 24-hour mean wind speed has been used to examine the exposure of Crane Creek to such winds (NCDC, 2001-2002).

Although the mean wind speeds recorded seem low, it has been documented that winds of less than 13 knots are capable of re-suspending bottom materials in shallow waters of less than 2 m (Ward, 1984). Increases in TSS were also noticed in Old Tampa Bay in response to wind speeds of approximately 20 knots in shallow water areas of 1 m and 4 m respectively (Schoelhamer, 1995b). Crane Creek water depths are within this range and have also been subjected to winds gusting at 15 – 20 knots during the study. Therefore, the disturbance of benthic sediments by westerly breezes at site 2, and by easterly winds at location 4 is feasible.

5.4.3 Influence of Tidal Range and Boat Traffic on Total Suspended Solids in Crane Creek

In a study of the upper Tamar Estuary (UK), increasing tidal range led to elevated daily mean TSS concentrations due to the re-suspension of bed sediments (Uncles *et.al.*, 1996). The amount of suspended sediments disturbed varies with tidal ranges and sediment type.

The northern section of the Indian River Lagoon extends from the Mosquito Lagoon to the Sebastian Inlet. Crane Creek exists within this section and is therefore subjected to changes in the water level of the northern IRL. However, with a minimal tidal range of less than 10 cm in the section north of the Melbourne Causeway, the tidal influence on Crane Creek is negligible (Dombrowski, 1987). Based on this study, sediment transport in Crane Creek is more than likely due to rainfall increasing streamflow and winds disturbing bottom sediments, rather than tidal exchange with the IRL.

Station 4 is located next to a fueling dock in the Melbourne Harbor Marina. Since larger vessels have the ability to disturb bottom sediments with their propellers and momentum, the possibility of sediment transport due to boat traffic must be considered. After consulting with an employee of the marina and checking the logbooks, the researcher found that during the busy tourist seasons (September to November and March to April) a mean of only 2 yachts per week

(> 65 feet) visited the Marina for fueling in 2000. According to the dock master, the number of boats they service is consistent from year to year, with virtually no large vessels visiting outside the tourist months (Melbourne Harbor Boat Marina, 2001). Therefore, the influence of boats on total suspended solids and sediment transport in Crane Creek is probably minor.

5.4.4 Biological Influence on Bottom Re-suspension

Not all aquatic fauna have the same impact on suspended solids concentrations in Crane Creek. Bioturbation is the relative biological influence controlling sediment erosion and transport, and leading to the vertical mixing of the sediment (Ross *et.al.*, 1996). Physical properties of bottom materials themselves are important in determining sediment fate. However, one must also consider the various biological factors of benthic organisms. The prediction of transport is challenging with just abiotic sediments, but biotic benthic organisms add complexity due to their ability to either stabilize (mucus binding from microbes) or destabilize the sediment surface via macrofaunal burrowing (Grant *et.al.*, 1994).

The degree of disturbance of bottom materials in a waterway via aquatic organisms depends on the size of the inhabitant. For instance, *Trichechus senegalensis*, commonly known as manatees or sea cows, migrate to the tributaries lining the IRL particularly in the Spring and Summer months (April – September). A recent census estimated 790 manatee live in Brevard county, representing 52% of the Florida east coast population (FDEP, 1999). Due to their large size and mass and the shallow depth of Crane Creek, a manatee in flight has the ability to disturb bottom sediments. In fact, the force was often great enough for the researcher to observe a turbidity plume at the surface of the water from where the manatee fled. While most disturbances of this type were localized, the re-suspension of once deposited materials may facilitate downstream sediment transport if the fine sands, silts, or clays are introduced to the surface flow.

Water clarity is important to maintain since submerged aquatic vegetation (SAV) are highly sensitive to the amount of light received. Without sufficient light penetration, primary production may be hindered leading to seagrass death and declined oxygen levels as photosynthesis ceases. Total suspended solids (TSS) is a measure of all materials, both organic and inorganic, present in the water column that are available for transport. Tributaries emptying into the Indian River Lagoon, such as Crane Creek, carry suspended solids in the water column. Therefore, the factors controlling the amount of sediments in Crane Creek are of interest since a portion of the materials may eventually be discharged to the Indian River Lagoon, thus decreasing water clarity.

5.5 Sediment Removal in Crane Creek based on Streamflow and Residence Time

Streamflow on sampling days was calculated from current velocities under US Highway 1 on Crane Creek using a mechanical flow meter and ranged from 0.8 to 8.9 m³/sec from July to November, 2001 and 0.4 to 4.9 m³/sec from January to March 2002. Mean discharge during the 2001 sampling period was 2.5 ± 2.1 m³/sec and 1.6 ± 1.5 m³/sec during the 2002 collection period (**Table 4.1**).

Sediment removal between US Highway 1 and the Florida East Coast (FEC) railroad trestle was estimated from residence times of the water, TSS values, and Stoke's settling velocity for clays, silts, and fine sands since these are the three major constituents identified in Crane Creek (D'Arcy, 1987). The mean depth of the fresh-salt interface at station 3 is approximately 1.25 m and was calculated from density profiles generated from field observations. The theory is if the sediments reach the fresh-salt interface (1.25 m) that they will be removed from the overflowing, fresh, surface layer and the probability of further downstream transport decreases. However, since the mean depth of the interface is only 1.25 m and the sill at US1 is approximately 1.70 m, some suspended materials may still be transported downstream with the outgoing flow and not be removed by the sediment trap.

Therefore, the settling time of the particles needs to be less than the residence time of the station 3 surface water, so the particles will have enough time to reach the interface and may be removed at this location. However, if the settling time of the particles to reach 1.25 m is greater than the residence time between the railroad trestle and US1, then the particles will most likely continue to move downstream as they will not settle out before the surface water keeping them in suspension moves further downstream. In general, high streamflow reduces residence time and the prospect of removal, and low streamflow enhances residence time and removal probability.

A settling time to this interface was calculated for each constituent using Stoke's settling velocities (Dyer, 1986). Since residence time is defined as the volume of water divided by the streamflow, the surface area of the sediment trap was digitized in Arcview GIS and related to the mean depth of the fresh-salt interface (1.25 m) to obtain the mean volume of surface water at station 3. The residence time was calculated from the streamflow (m^3/sec) on any given sampling day. Since clays are the smallest particles in diameter and have the least mass, they have the longest settling time, followed by silts. Fine sands possess the largest diameter and mass, therefore, they have the greatest probability for removal (**Table 5.1**).

Table 5.1

Mean Stoke's Settling Velocities for clays, silts, and fine sands present in Crane Creek and their relative settling times, based on settling velocities, to the fresh-salt interface (1.25m).

Suspended Matter	Mean Settling Velocity (cm/sec)	Mean Settling Time to Interface (Hours)
Clays (0.1 – 2um)	3.5×10^{-4}	9.9×10^1
Range	$(5.0 \times 10^{-7} - 7.0 \times 10^{-4})$	$(4.9 \times 10^1 - 6.9 \times 10^4)$
Silts (2 – 20um)	1.0×10^{-2}	3.4
Range	$(7.0 \times 10^{-4} - 2.0 \times 10^{-2})$	$(1.7 - 4.9 \times 10^1)$
Fine Sands (20 -200um)	9.9×10^{-1}	4.0×10^{-2}
Range	$(2.0 \times 10^{-2} - 2.0)$	$(2.0 \times 10^{-2} - 1.7)$

Source: Coastal and Estuarine Sediment Dynamics (Dyer, 1986).

As stated above, if the settling time is significantly less than the residence time, then the particles should reach the fresh-salt interface and reduce the likelihood of downstream transport . Assuming the volume of water remains constant, the fluctuation in daily streamflow will control the residence time at the sediment trap. The results from this study show a critical streamflow of $5.0 \times 10^{-2} \text{ m}^3/\text{sec}$ for clays. $1.5 \text{ m}^3/\text{sec}$ for silts, and $2.0 \times 10^2 \text{ m}^3/\text{sec}$ for fine sands. Therefore, streamflow in Crane Creek between the railroad trestle and US1 should not exceed the critical discharges in order for the removal of each constituent to occur. In summary, removal probability increases when streamflows are below the calculated critical values, but the probability of removal decreases as streamflow approaches and/or exceeds the critical value (Table 5.2).

Table 5.2

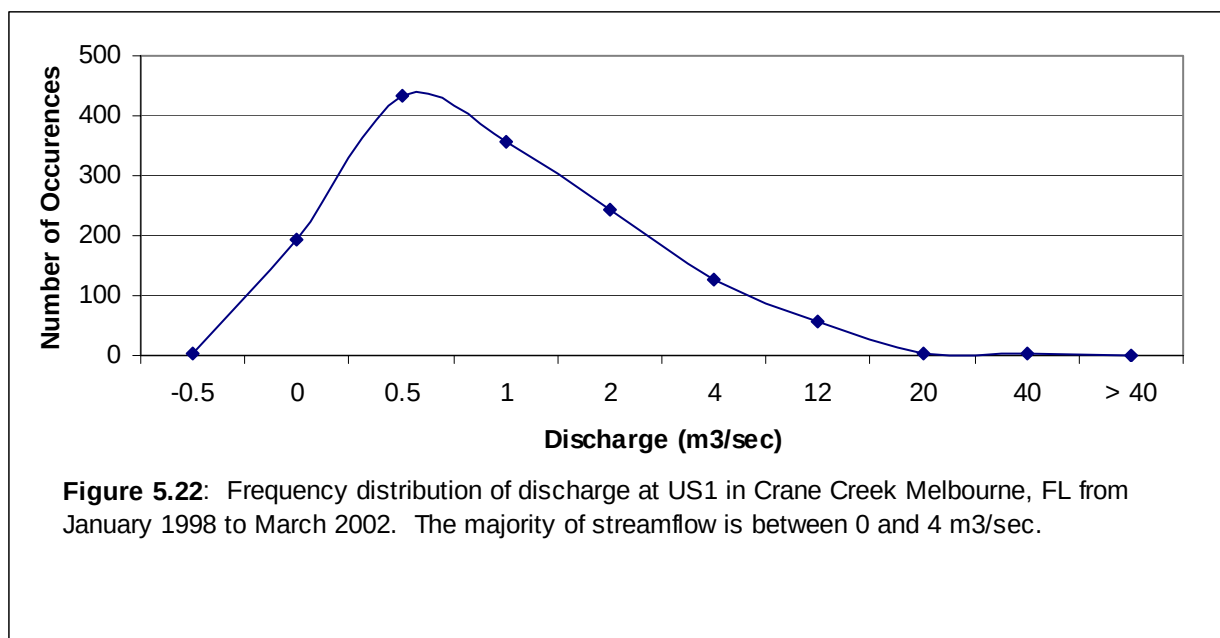
Ranges of streamflow and the corresponding residence time between the FEC Railroad Trestle and US1 in Crane Creek Melbourne, FL. If the settling time required is less than the residence time, removal probability is increased. (****Critical Streamflow****)

Sediment Type	Ranges of Streamflow (m3/sec)	Residence Time Based on Streamflow (Hours)	Mean Settling Time of Sediments (Hours)	Removal *
Clay	1.0×10^{-2}	5.0×10^2	9.9×10^1	Likely
	2.0×10^{-2}	2.5×10^2	9.9×10^1	Likely
	4.0×10^{-2}	1.3×10^2	9.9×10^1	Likely
	<i>*5.0 x 10⁻²*</i>	1.0×10^2	9.9×10^1	Possible
	6.0×10^{-2}	8.4×10^1	9.9×10^1	Unlikely
Silt	0.1	5.0×10^1	3.4	Likely
	0.5	1.0×10^1	3.4	Likely
	1.0	5.0	3.4	Likely
	<i>*1.5*</i>	3.4	3.4	Possible
	1.6	3.2	3.4	Unlikely
Fine Sand	2.5×10^1	0.2	3.0×10^{-2}	Likely
	5.0×10^1	0.1	3.0×10^{-2}	Likely
	1.0×10^2	5.0×10^{-2}	3.0×10^{-2}	Likely
	<i>*2.0 x 10²*</i>	3.0×10^{-2}	3.0×10^{-2}	Possible
	2.5×10^2	2.0×10^{-2}	3.0×10^{-2}	Unlikely

***Likely** = Residence Time is sufficiently greater than Settling Time.

***Possible** = Residence Time and Settling Time are similar, removal may occur.

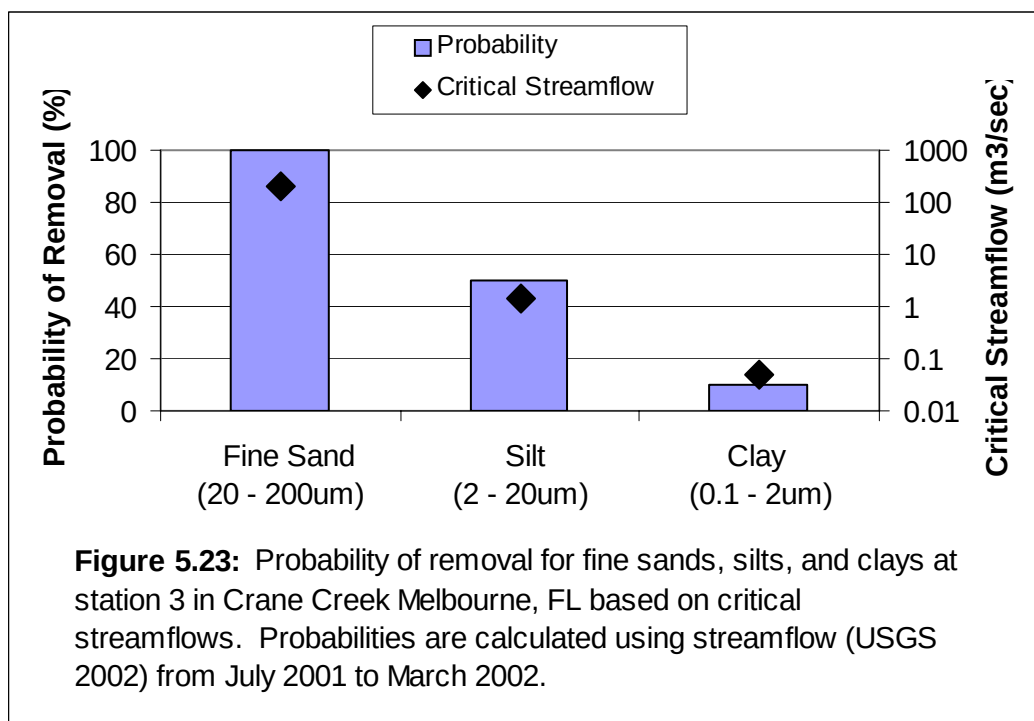
***Unlikely** = Residence Time is sufficiently less than Settling Time.



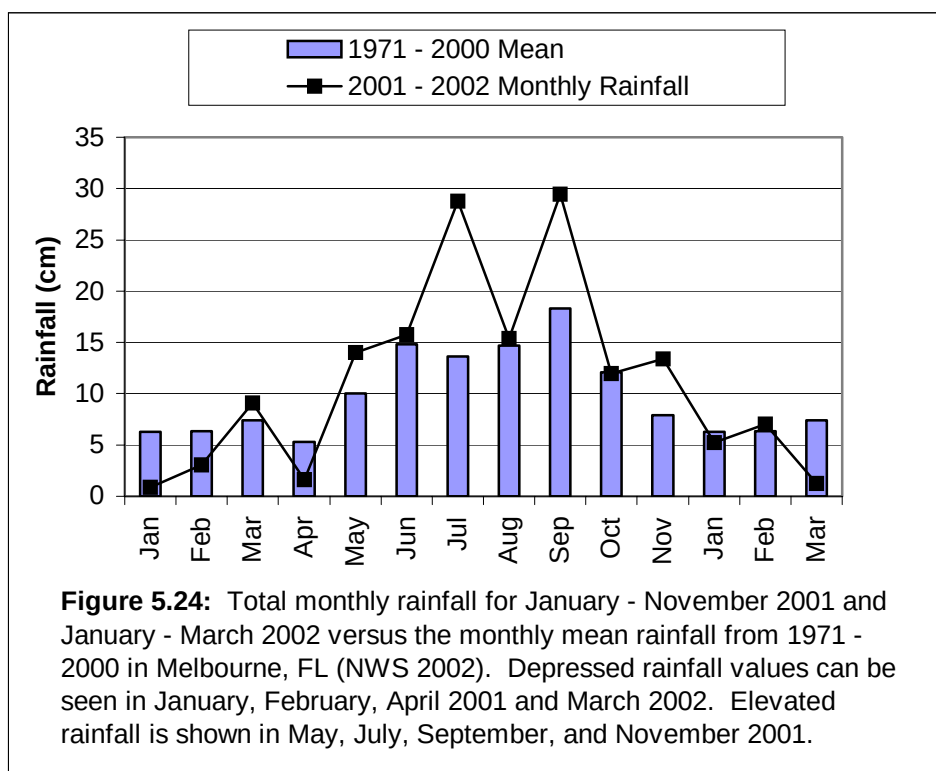
The most frequent values for streamflow in Crane Creek ranged between 0 and 4 m³/sec from January 1998 to March 2002 under normal conditions (**Figure 5.22**). According to USGS data (USGS 2002) peak daily streamflow in Crane Creek never exceeded 2×10^2 m³/sec from July 2001 to March 2002. In fact, the highest peak daily streamflow recorded from 1987 – 2002 was only 61 m³/sec.

Theoretically, 100% of fine sands should be removed based on the residence time calculation and streamflow in Crane Creek. Streamflow exceeded 1.4 m³/sec in Crane Creek 46% of the time during the July 2001 to March 2002 sampling period. From this data, the removal of silts seems possible approximately 50% of the time. Finally, streamflow in Crane Creek was greater than 5×10^{-2} m³/sec 91% of the time from July 2001 to March 2002, which means removal of clays was possible only 10% of the time (**Figure 5.23**).

Due to their small size (0.1 – 2 μ m) and slow mean settling velocity (3.5×10^{-4} cm/sec) clays have the lowest probability for removal between the railroad trestle and US1, followed by silts, and fine sands (**Figure 5.23**). As mentioned previously, these calculations are theoretical. Most likely not all fine sands will be trapped, and the removal probability of silts and clays will deviate from their estimated percentages based on varying streamflow and sediment characteristics.



From July 2001 to March 2002 a mean streamflow of 2.1 m³/sec in Crane Creek also represents normal discharge which is to be expected since rainfall during the wet season from July to November 2001 was only slightly elevated in the months of July and September 2001 (**Figure 5.24**).



Mean sediment transport, calculated from a mean TSS concentration of 8.3 ± 2.7 mg/L and a mean streamflow of 2.1 m³/sec from July 2001 to March 2002, was 1.5 ± 2.7 tons/day. However, these data represent sediment transport under normal conditions. Based on 14 years of streamflow data (USGS 2002) indicating a peak daily streamflow of 61 m³/sec under US1 and assuming a mean TSS concentration of 8.3 ± 2.7 mg/L, sediment transport in Crane Creek could reach 44 tons/day. Most likely the amount of material transported would exceed this value since TSS concentrations increase during turbulent flow, as was the case in Turkey Creek during storm events where TSS at one sampling location increased from 3 mg/L to 500 mg/L during a particular storm event (Trefry *et.al.*, 1989).

Under the same assumptions, a streamflow of 0.5 m³/sec, which occurs most frequently (Figure 5.22), would result in a mass transport of 0.4 tons/day in Crane Creek. Based on these estimations, a streamflow of 61 m³/sec produced by a storm event would result in the mass loading equal to that of 110 days under normal conditions having a streamflow of 0.5 m³/sec. In summary, a few storm events in Crane Creek are probably more important sources of sediment transport than all other days of the year with normal rainfall activity.

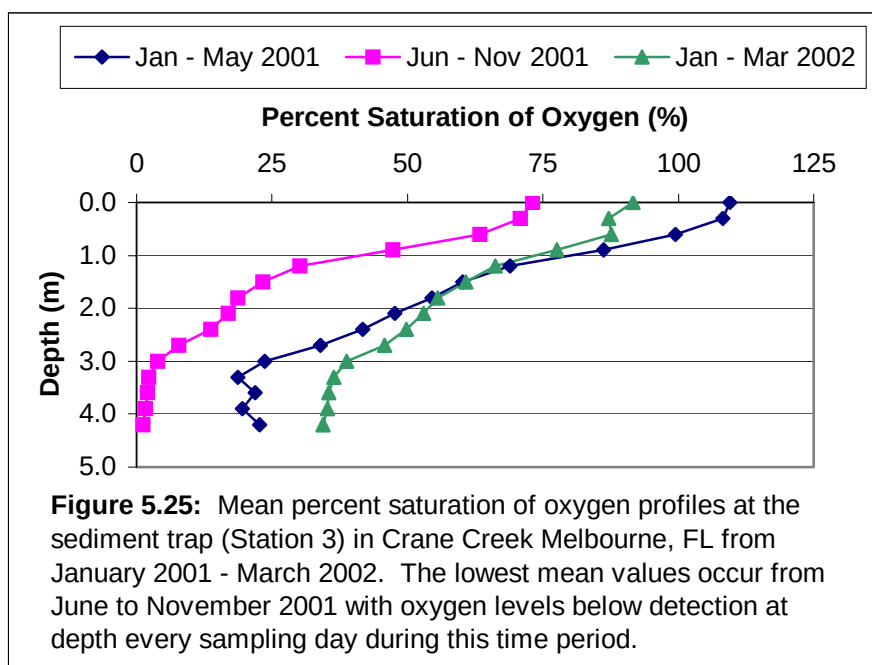
5.6 Effects of Dredging on Dissolved Oxygen in Crane Creek

Several factors may be to blame for anoxic conditions at site 3 in Crane Creek. The proposed sediment trap was designed to reduce the amount of suspended materials, both organic and inorganic, entering the Indian River Lagoon. When the organic portion is deposited at site 3, it begins the natural process of decomposition. The decay of organic materials consumes

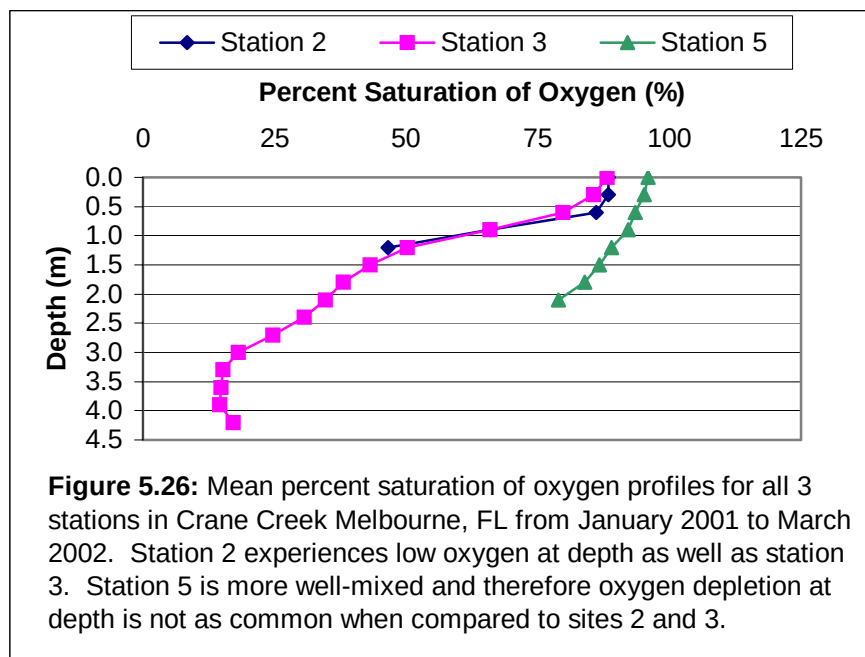
oxygen. If this oxygen is not replaced via photosynthesis, re-aeration, or by the renewal of the oxygen depleted waters (flushing), then DO concentrations will eventually become unsatisfactory.

In addition to the decomposition of organic materials in Crane Creek causing anoxia at depth, decreased light penetration is also a contributing factor. Total suspended solids in the water column cause light attenuation. As previously mentioned, TSS are composed of both organic and inorganic materials such as humic organics, which add color to a waterbody, are known to be strong absorbers of light, and contribute to the total attenuation of light in the water column. Such constituents are typical in Florida waters in the wet season due to runoff (Thurman, 1985). In Charlotte Harbor (Southwest Florida), photosynthetically active radiation (PAR) in colored water was greatly attenuated in the first few centimeters of the water column, with the color maximum coinciding with periods of elevated freshwater discharge (McPherson *et.al.*, 1987). The reduction of PAR results in respiration increasing over photosynthesis. Similar water clarity conditions have been observed in Crane Creek and the IRL with decreased secchi depths in the wet season as a result of freshwater discharge coloring the water (**Figure 4.7**).

Dissolved oxygen concentrations of less than 2 mg/L at depth (> 2 m) were noticed 75.6% of the time (34 out of 45 sampling days) from January 2001 to March 2002 at station 3. Of these days with depleted oxygen, 61.8% occurred in the sampling period from June to November 2001 where oxygen concentrations were below detection every sampling day (n = 21). Therefore, depletion of oxygen at depth in Crane Creek occurs more frequently in the warmer, wet season than in the cooler dry season (**Figure 5.25**). Oxygen solubility decreases with warmer water temperature and organisms tend to respire more during warm conditions (Engle *et.al.*, 1999). More importantly, the delivery of organic materials via runoff and their subsequent decomposition contribute to the declining oxygen levels in the summer.



Since station 3 is the deepest location with a mean depth of 4.0 m, and is stratified on most of the time (**Figure 5.7-A**) the water's resistance to mixing is strong and therefore replenishment of oxygen is more difficult. Salinity and temperature stratification limit vertical mixing and have been linked to hypoxia (Engle *et.al.*, 1999). Stations 2 and 3 both experience low dissolved oxygen at depth as a result of stratification. Mean percent saturation at the bottom of station 2 (1.2 m) was 46.6 % while the mean at the bottom of station 3 (4.2 m) was only 17.3 %. Site 5 is more well-mixed and therefore oxygen replenishment at depth occurs more frequently. The mean oxygen value at the bottom of station 5 (2.1 m) was 78.9% (**Figure 5.26**).



From the oxygen profile data above, it appears as if the dredging did not improve oxygen conditions at location 3 in Crane Creek. However, prior to the dredging, site 3 was approximately 2 m deep, with only 1 m of oxygenated surface water (Garcia, 1998). After the dredging, station 3 now has a depth of roughly 4 m. More importantly, oxygenated waters now exist in the first 2 m. Therefore, an additional 1 m of oxygenated surface water now exists at site 3.

Dissolved oxygen is an important water quality parameter to study since it is required by most living organisms. Therefore, the health of a water body such as Crane Creek or the IRL can be determined partly by studying the oxygen concentration.

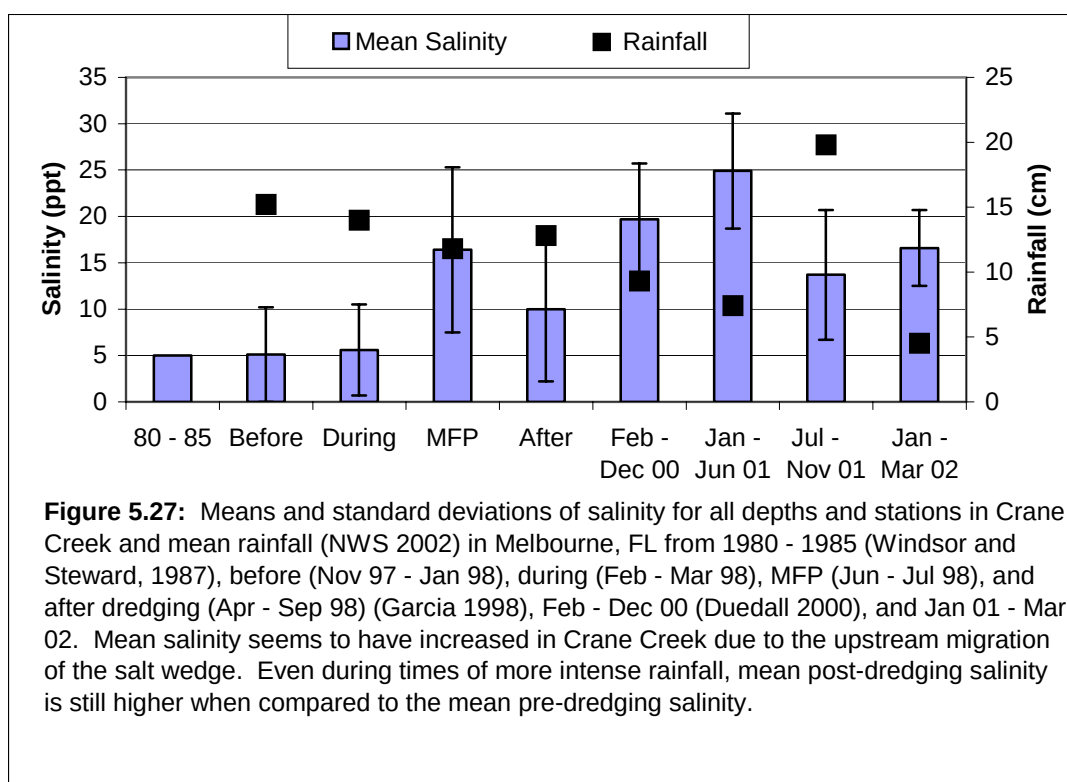
5.7 Has Water Quality Changed Since the Dredging in 1998?

Two main goals of the dredging operation were to improve navigation in Crane Creek, and to reduce the amount of suspended solids entering the Indian River Lagoon, thus enhancing water clarity to preserve the seagrass population. Since seagrasses depend on light penetration for photosynthesis, water clarity must be preserved. At the same time, it is important to study any effects the sediment removal had on Crane Creek. The modification of the waterway may in

fact be advantageous for the IRL by reducing sediment loads, but at what cost or benefit to Crane Creek?

5.7.1 Salinity

Prior to the dredging operation, the area west of the railroad bridge (approaching station 2) consisted of freshwater only (Garcia, 1998). As a result of the increased depth in Crane Creek, due to the removal of muck sediments, the salt wedge migrated further upstream (Garcia, 1998). Such behavior can be seen in the elevated salinity levels at station 2. Therefore, one of the effects of dredging in Crane Creek is higher mean salinity (**Figure 5.27**). The figure shows greater mean salinity after dredging, even during times of increased mean rainfall as in July to November 2001. Thus, further supporting the notion that overall salinity has indeed risen, and is not simply fluctuating in response to meteorological conditions.



5.7.2 Total Suspended Solids and Turbidity

The fine-grained bottom sediments in Crane Creek are easily re-suspended by turbulent processes such as streamflow and wind. Additionally, materials are delivered to the creek in runoff from rainfall events. Both turbulent processes have the ability to increase the amount of suspended solids in the waterway. FDEP measured suspended solids at US1 from 1991 to 1995 and calculated a mean of 6 mg/L during this time period. Since the measurements were only taken once a month and at one location in the creek, they may not represent the entire system. Mean TSS during the Garcia study ranged from 12.9 to 17.1 mg/L. The increase may be

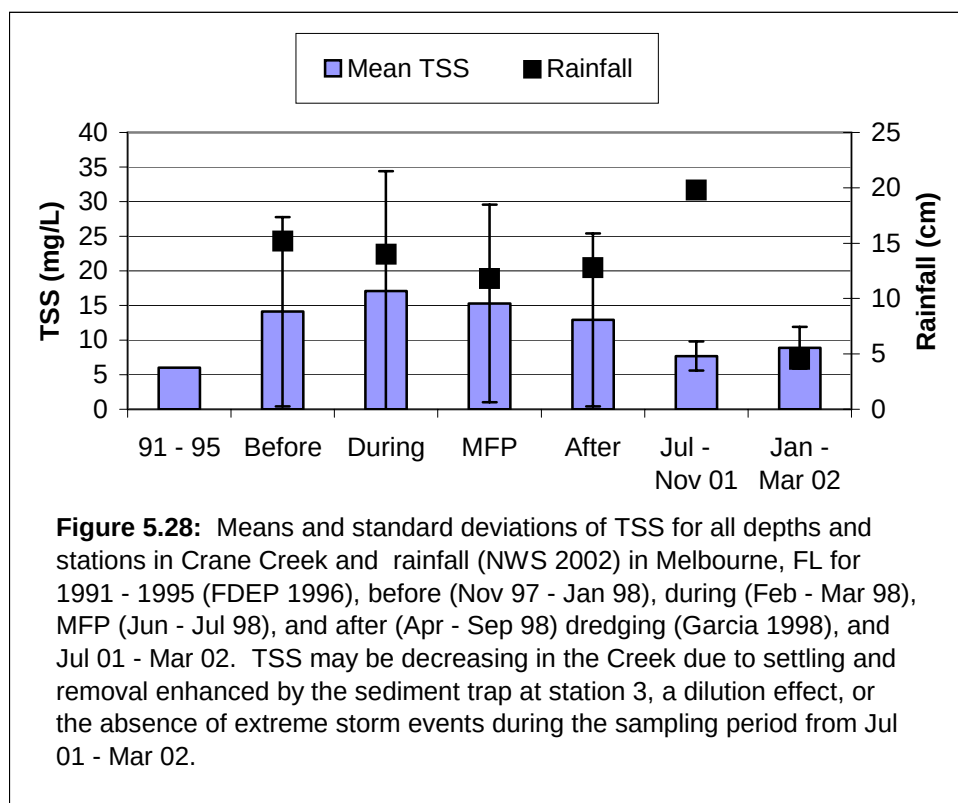
attributed to disturbance of bottom materials caused by the dredging operation and the return water from the spoil location upstream of site 2. Also, high storm activity late in the summer after dredging may have been responsible for elevated TSS (Garcia, 1998). Refer to **Figure 5.12**, which illustrates the high rainfall during the summer sampling months. Mean TSS from July to November 2001 and January to March 2002 were 7.7 ± 2.1 mg/L and 8.9 ± 3.0 mg/L.

The apparent decrease in mean TSS from before, during, and after the dredging when compared to the data from this study (2001 – 2002) may indicate the effectiveness of the proposed sediment trap. Salinity has also increased (**Figure 5.27**), thus enhancing flocculation and removal. Settling velocities of clays in varying salinities have been studied. An increase from 10 to 20 ppt in salinity has been reported to increase the settling velocity for clays from 0.02 to 0.05 cm/sec. As salinities rise from 20 to 40 ppt, settling velocity increases from 0.05 to 0.08 cm/sec (Dyer, 1986).

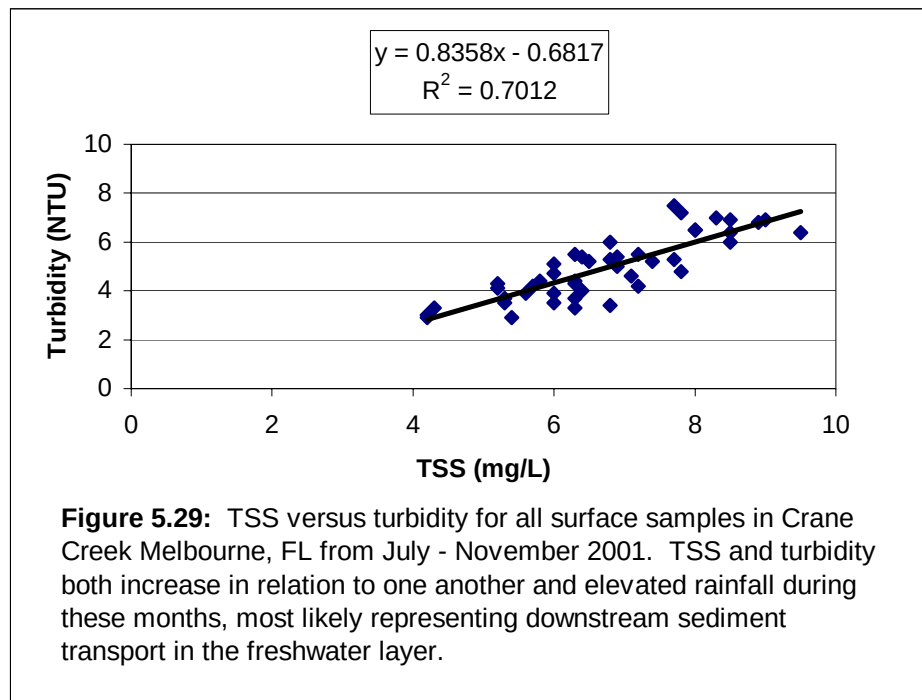
Therefore, since salinity at the bottom of the sediment trap (site 3) has been known to range from 20 – 35 ppt, the elevated salinity should enhance removal by shortening the time it takes for the suspended particles to reach the bottom.

While the total yearly rainfall was approximately 30 cm above the normal in the year 2001, mean TSS are still lower when compared to previous years with above mean rainfall. Precipitation in 1998 was nearly 28 cm above the normal, and TSS concentrations were 40% higher than in 2001. Monthly rainfall for the respective sampling periods were all above normal in 1997 and 1998. The before dredging monthly rainfall was 27 cm above normal, during dredging monthly rainfall was 14 cm above normal, and after dredging monthly rainfall was 7.1 cm above the normal. In 2001 from July to November rainfall was 38 cm above normal, and 6.5 cm below normal from January to March 2002 (NWS, 2002).

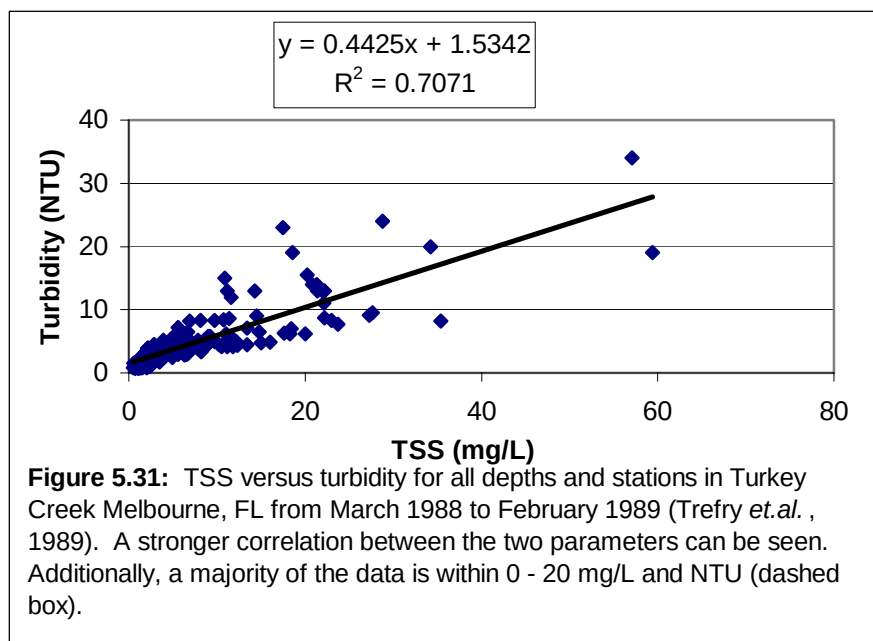
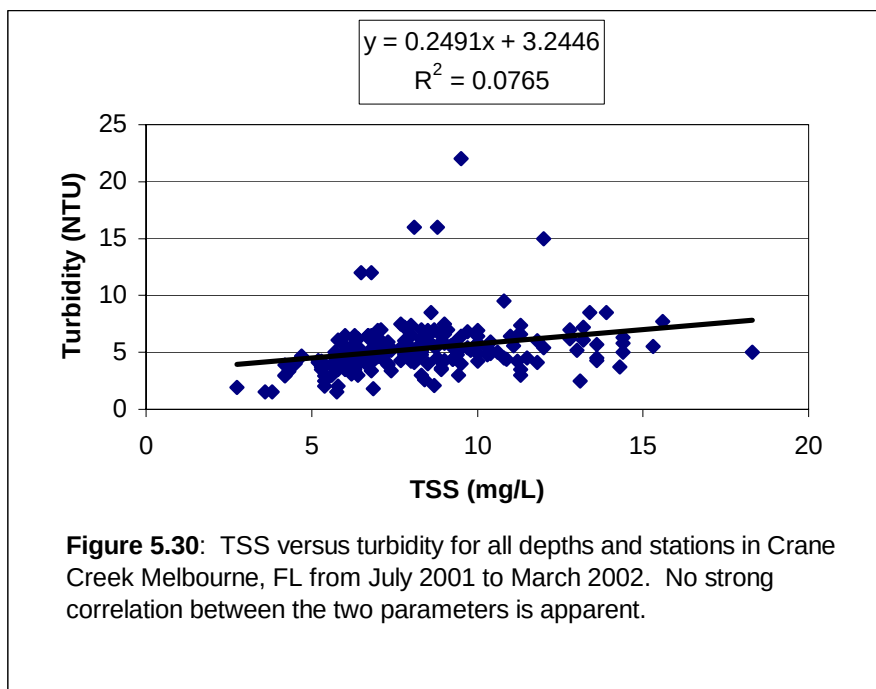
Thus, removal at the sediment trap seems to be occurring since the July to November 2001 sampling period has the highest rainfall above normal and the lowest TSS concentrations when compared to the Garcia study (**Figure 5.28**). However, several other factors may explain this post-dredging decrease in TSS. First, the dredging activity involved heavy machinery and disturbed bottom materials in the process. Second, water returning from the spoil site via Hickory Ditch in Crane Creek contained sediments and was more turbid than the water in Crane Creek (Garcia, 1998). Another possible explanation for a decrease in TSS is the dilution of suspended sediment concentrations as the volume of water in Crane Creek increased in the wet season from July to November 2001. Finally, weather conditions during the 2001 and 2002 sampling were not as extreme when compared to the 1997 and 1998 sampling period.



Total suspended solids decreased in response to elevated rainfall in 2001 (**Figure 5.16**). However turbidity in Crane Creek actually increased during this time period, and decreased once again in 2002 when rainfall subsided. Overall, mean turbidity seems to rely on the amount of rainfall. During the July to November 2001 sampling period, a statistical correlation between TSS and turbidity was noticed at all surface stations in Crane Creek (**Figure 5.29**). Such behavior may suggest suspension of sediments in the freshwater layer and pollutant loading to the IRL related to higher rainfall during the wet sampling period (July – November 2001). As a result, no statistical correlation was found between TSS and turbidity at depth from July to November 2001. Additionally, TSS concentrations were higher at depth (Statistically proven by the 3-Way ANOVA), due to the increased salinity at the bottom of station 3 enhancing flocculation, than at the surface - whereas turbidity does not vary as much in the water column.

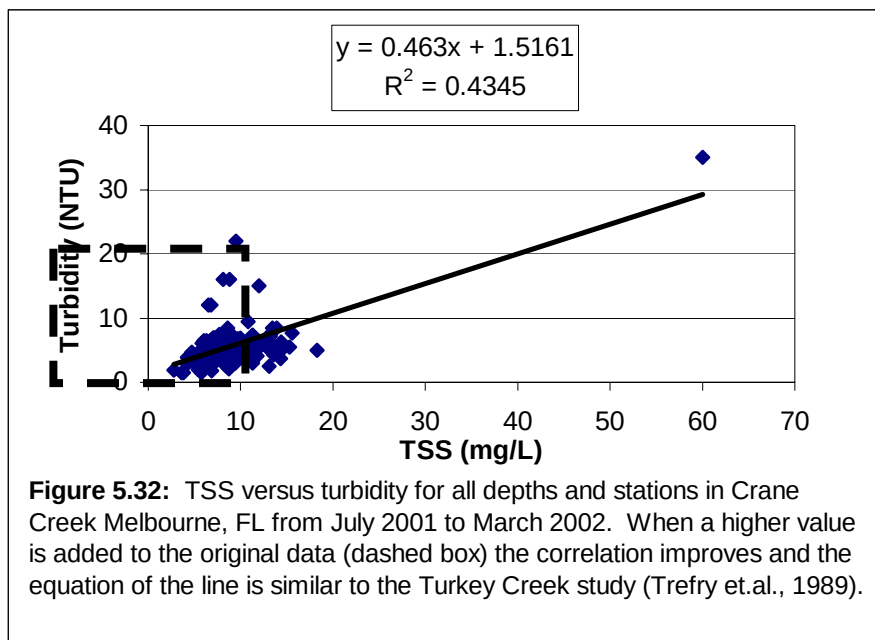


No statistical correlation was found between TSS and turbidity for all stations and depths from July 2001 to March 2002 (**Figure 5.30**). However, a comparison of Crane Creek data from this study to TSS and turbidity data from the Turkey Creek study (Trefry *et.al.*, 1989) produced interesting results. A scatter plot of non-storm TSS and turbidity for all depths and stations in Turkey Creek showed a stronger statistical correlation between the two parameters than the Crane Creek data (**Figure 5.31**).



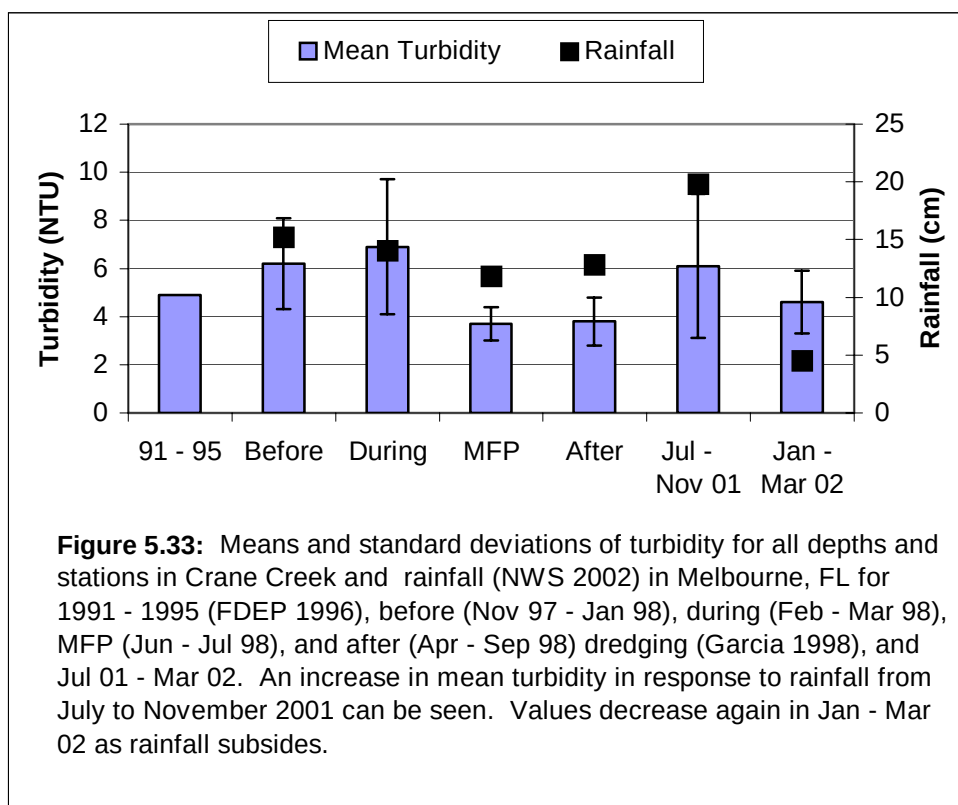
Several reasons may explain the divergent behavior between TSS and turbidity in Crane Creek, while the two parameters seemed to show a relationship in Turkey Creek. Both studies used surface and depth data, so location in the water column cannot explain such a difference. However, larger ranges in values for both parameters in Turkey Creek expanded the scatter plot and resulted in a higher statistical correlation (**Figure 5.31**). Such behavior can be seen in the Crane Creek data if a larger value for both TSS and turbidity is added to the plot (**Figure 5.32**).

Focus attention to the boxes drawn on **Figure 5.31** and **Figure 5.32**. Ranges for TSS and turbidity are 0 – 20 mg/L and NTU. The majority of data in both Creeks falls within this range. More importantly, when one additional higher value is added to the Crane Creek plot (**Figure 5.32**) the equation of the line is very similar to that of the Turkey Creek plot (**Figure 5.32**). Therefore, if higher values for TSS and turbidity were seen in Crane Creek, a better linear relationship would most likely have occurred. A strong statistical correlation between the two parameters would allow the determination of TSS concentrations from readily obtainable turbidity measurements (Trefry *et.al.*, 1989).



Additionally, more uniform particle composition occurs when streamflow is higher (Trefry *et.al.*, 1989). Most study sites for the Turkey Creek study were located further upstream including narrow, faster flowing canals. Slower moving water in Crane Creek stations, located closer to the mouth of the waterway, most likely resulted in varying particle composition. Since TSS is based on the mass of the particles, and turbidity measures the light scattering ability, it is possible to have high TSS and low turbidity, or vice versa. For example, larger sand particles may weigh more and increase TSS, but not effectively scatter light. The decrease in light scatter may be due to light-absorbing properties of the sediment itself, or since larger particles result in a smaller amount of surface areas for light reflection.

On the other hand, a greater amount of smaller particles such as fine silts and clays may increase turbidity since the overall surface area will be greater, but their smaller mass may not significantly elevate TSS concentrations. Turbidity seems to rely on meteorological conditions and does not appear to have been significantly influenced by the dredging operation since no obvious decrease can be seen (**Figure 5.33**)



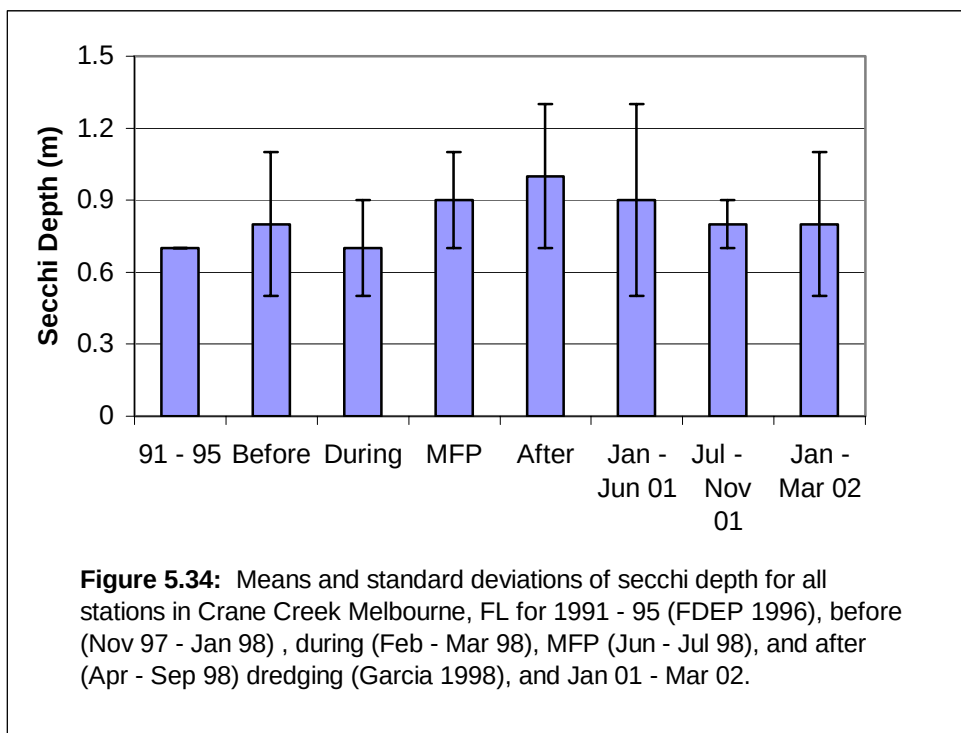
The Florida State Water Quality Criteria for surface water does not list an exact standard for TSS concentrations. However, ranges of quality have been assigned based on measurements taken throughout the state: “Best Quality” water bodies have a TSS concentration of 2.00 to 4.00 mg/L. “Median Values” range from 5.50 mg/L to 12.50 mg/L with a mean of 6.50 mg/L, while “Worst Quality” refers to concentrations of 18.00 to 26.50 mg/L (FDEP, 1994). Crane creek TSS fall within the median value range.

Ranges of water quality based on turbidity are also given by the FDEP: “Best quality” refers to those areas having values of 1.5 to 4.0 NTU, “Median Values” are between 4.5 – 12.2 NTU with a mean of 5.2 NTU, and “Worst Quality” refers to values of 16.5 – 21.0 NTU (FDEP, 1994). Crane creek turbidity falls within the median value range.

5.7.3 Secchi Depth

Secchi depth is a measure of water clarity and is affected by water color and the amount of suspended material in the water column, including phytoplankton cells or inorganic suspended solids (McPherson *et.al.*, 1987, Borkman *et.al.*, 1998). Since no relationship was found between TSS and secchi depth, the decreased secchi depths in the summer months (**Figure 4.7**) are most likely caused by phytoplankton or algal blooms, and colored water resulting from freshwater runoff. More transparent waters during the winter months were also noticed in Narragansett Bay, Rhode Island (Borkman *et.al.*, 1998).

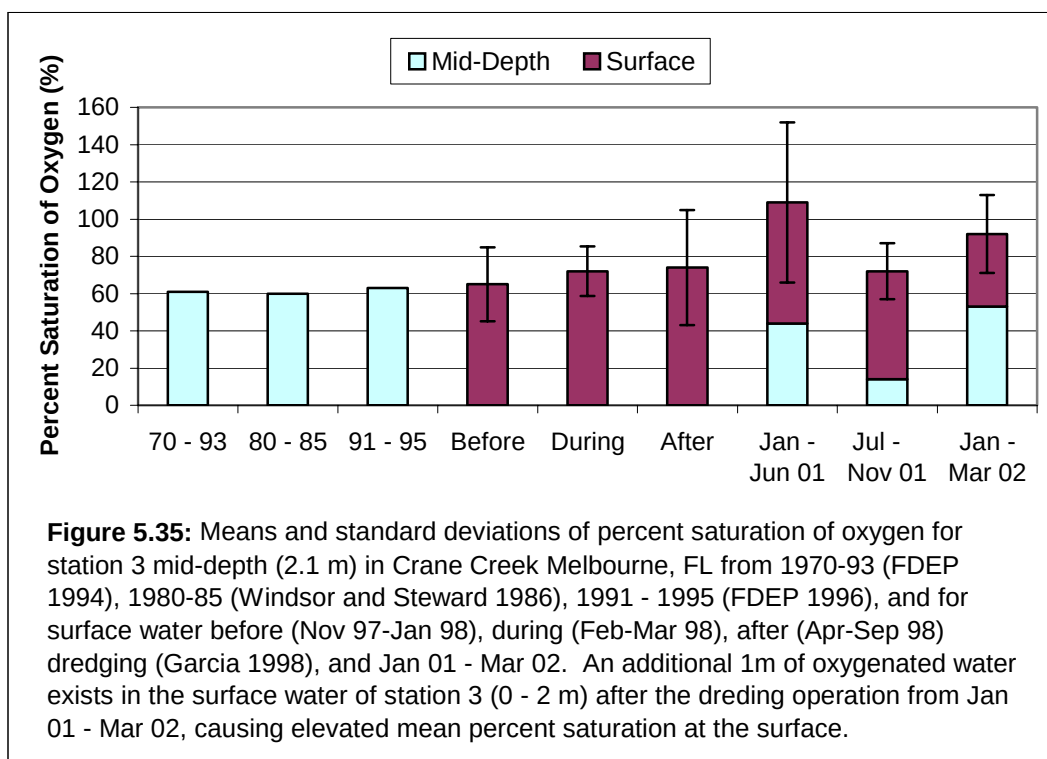
A secchi depth < 1.0m is considered poor water quality, 1.0 to 1.5 m is classified as fair water quality, and > 1.5 m is considered good water quality (FDEP, 1996). With a mean secchi depth of 0.9 m for this study, Crane Creek would be classified as poor water quality in terms of water clarity. No change seems to have occurred following dredging (**Figure 5.34**).



5.7.4 Percent Saturation of Oxygen

Since all aerobic organisms require oxygen, it can be considered an important water quality parameter to examine and maintain. The sources and sinks of dissolved oxygen in Crane Creek have already been discussed. The removal of the oxygen-demanding muck sediments should have a positive effect on the saturation levels of oxygen in the creek. A comparison of oxygen

saturation values at the surface and mid-depth at station 3, used here to make a non-biased comparison between different sampling strategies and water structures, reveals an increase in mean percent saturation values in the surface water of station 3 (**Figure 5.35**).



One observation from this study is that mean percent oxygen levels in the Crane Creek system were lowest in the summer, wet season (July – November 2001). Several reasons discussed previously may be to blame for undersaturation and include: increased water temperature causing organisms to respire at higher rates, the inflow of suspended sediments decreasing water clarity and thus light penetration, hindering photosynthesis, or the influx of waters with a low oxygen status. Additionally, increased decomposition of organic material in the warmer summer months may be occurring - or simply the disturbance of oxygen-consuming muck sediments, due to turbulent flow, acting as an oxygen sink.

Caution must be taken when comparing oxygen levels between the time periods. First, the historical data from 1970 – 1993 and 1980 – 1985 represent much larger periods of record than the others. Next, FDEP measurements are taken once a month at one location and depth in Crane Creek. Also, the elevated percent saturation from January to June 2001 may be due to the low rainfall during this time period (**Figure 5.10**). Depressed oxygen levels from July to November 2001 coincide with higher mean rainfall during these months (**Figure 5.10**). Therefore, the delivery of organics and other potentially decomposing materials may be using more oxygen during this sampling period. From January to March 2002, a rise in mean oxygen concentrations can be seen once again coinciding with low rainfall. Still, it appears as if mean oxygen at the surface has increased in the Creek as a result of the dredging operation.

6.0 CONCLUSIONS AND RECOMMENDATIONS FOR PART I OF WATER QUALITY INVESTIGATIONS

The removal of muck sediments has increased mean salinity in Crane Creek by allowing further upstream migration of the salt wedge from the Indian River Lagoon. Water temperature fluctuates with seasonal air temperature, and does not seem to have been affected by the dredging operation.

Percent saturation of oxygen increased in Crane Creek, following the removal of oxygen-depleted bottom sediments. Although the bottom 2 meters at site 3 are sometimes anoxic due to insufficient mixing, an additional 1 meter of oxygenated surface water now exists. Oxygen profiles show higher levels in the winter months when compared to summer months. Finally, stations 2 and 5 yielded higher mean percent saturation values due to their shallower depths allowing enhanced mixing.

Total suspended solids were measured at three sampling stations from upstream to downstream of the sediment trap, providing spatial variation, in an attempt to determine sediment removal. No statistically significant difference in TSS was found between the stations upstream and downstream of the dredged area. Most likely this is due to the elevated TSS concentrations at depth at station 4. Such increases in TSS at this location are believed to be caused by easterly winds re-suspending bottom materials, and delivery of IRL sediments with the migrating salt wedge. Therefore, future attempts to quantify the removal of sediments at station 3 must first determine the amount of material being delivered upstream back into the Creek from the IRL. However, the decrease in mean TSS concentrations at all stations and depths, when compared to pre-dredging values, may be due to sediment removal by the trap, a dilution effect, or the slightly above normal rainfall conditions during the sampling period limiting the delivery of sediments to Crane Creek.

Mean sediment transport, calculated from TSS and streamflow data, was 1.7 ± 1.7 tons/day from July to November 2001 and 1.2 ± 1.3 tons/day from January to March 2002, with an overall mean of 1.5 ± 2.7 tons/day for the entire sampling period from July 2001 to March 2002. Previous researchers estimated mean sediment transport in Crane Creek to be 1.7 tons/day (Sigua *et.al.*, 2000). Therefore, even though TSS concentrations were higher from January to March 2002, sediment transport poses a greater problem from July to November 2001 due to the increased streamflow during this time period, as a result of elevated rainfall.

Residence time calculations were used to determine the potential effectiveness of the sediment trap created by the dredging activity. By relating settling velocities of clays, silts, and fine sands to the residence time (based on Crane Creek streamflow) at the sediment trap it was determined that fine sands should be removed 100% of the time, silts 50%, and finally clays are likely to be removed only 10% of the time.

Turbidity showed no improvement when compared to the pre-dredging values. Instead, turbidity seems to depend upon the amount of rainfall at any given time. Secchi depth, the additional water clarity indicator, also showed no obvious improvement when compared to pre-

dredging values. Mean turbidity was elevated, and mean secchi depth decreased in the wet months from July to November 2001.

Overall, the water quality in Crane Creek following the dredging has improved in two ways: Elevated mean percent saturation of oxygen, and lower mean total suspended solids. The increased oxygen concentrations are important for the survival of aerobic marine life, as well as preserving the aesthetics of the creek by preventing foul odors associated with anaerobic conditions. The apparent decline in total suspended solids, based on this study, is a positive effect of the removal of muck sediments. Enhanced light penetration for photosynthesis should occur if suspended sediments are lower compared to pre-dredging values, thus adding to the improved percent saturation of oxygen in Crane Creek.

Based on the Florida Department of Environmental Protection guidelines, Crane Creek can be classified in the median range between best and worst quality for TSS and turbidity. Secchi depths are considered poor, since they are typically less than the minimum desired depth of 1.5 meters. Finally, the percent saturation of oxygen falls within the median to best quality range with the highest values recorded in the winter months.

For further studies on the water quality of Crane Creek the investigator suggests using the same sampling protocol for stations and number of visits, and possibly increasing the number of sampling stations. The reason for this suggestion is that future data will be easier to compare and contrast to data collected in this study. Previous investigators in Crane Creek measured water quality parameters at various depths and stations. As a result, differences or similarities over time periods may not be strictly due to true changes in the water quality, but rather in the sampling strategies.

In terms of suspended solids and sediment transport, the use of an optical or acoustical backscattering device would be beneficial to examine suspended solids prior to, during, and after storm events. These data would allow the investigator to construct hydrographs of peak discharge versus TSS in order to predict sediment transport in Crane Creek depending upon streamflow. However, the cost involved with such equipment may not allow such an exercise. Also, the collection and dating of sediment cores from the bottom of the proposed sediment trap may allow future researchers to estimate accumulation rates.

Finally, weather conditions (including rainfall and wind) influence Crane Creek as was shown in the seasonal variation for most parameters studied. Although the year 2001 can be considered a normal year in terms of rainfall, a database with a longer period of record might be helpful when making comparisons between years. If meteorological conditions are similar between two different time periods, then a future investigator may be able to attribute change directly to the dredging operation, and not weather conditions. Future studies on similar tributaries would also be useful to see if other creeks respond in the same manner as Crane Creek to dredging activity.

**Sediment Trapping Efficiency:
What Can be inferred about the rate of sediment accumulation in
Crane Creek based on the water quality measurements?**

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Abstract

The key question addressed here is how long will it be until Crane Creek will require dredging again. Based on mean discharge rates and mean TSS values at US 1, Babcock Street and Hickory Ditch, from 400 to 600 tons of total suspended matter were estimated to have been trapped within the Crane Creek system annually between 1998 and 2000. Storm impacts could raise those estimates by as much as a factor of 2. Sedimentation rates based on total suspended sediment concentration and flow rates suggest that the Crane Creek will not have to be dredged again for at least fifty years.

Background

Nearly 69,000m³ of sediment was removed from Crane Creek Florida in 1998 to improve navigation and to remove sinks of anthropogenically derived nutrients, metals and toxic organic compounds. An important resource management question to address is how long will it be before Crane Creek needs to be dredged again?

Methods

How much sediment has accumulated since the 1998 dredging?

The approach selected here was to estimate how much sediment was being transported annually through Hickory Ditch and through Crane Creek at Babcock Street and at US 1. The difference between sediment being added upstream and what is passing US 1 downstream is assumed to be collected in Crane Creek. In order to estimate annual TSS loading at each of these locations, mean annual discharge rates and mean TSS values are required for each of the locations.

Mean annual discharges for Crane Creek at US 1, Crane Creek at Babcock Street and Hickory Ditch.

The daily discharge rates (provisional) were provided by USGS. Annual summaries of mean discharge and the associated descriptive statistics for 1997 to 2002 are shown in **Table 1**. The USGS data sets cover 1997 to 2002 for US 1, 1998 to 2000 for Babcock Street and 1998 to 2002 for Hickory Ditch. Mean annual discharge rates at US 1 (1997 to 2002) range from 17.5 cfs to 49.4 cfs. The range of discharge values at US 1 is from -18 cfs to 1390 cfs. Mean annual discharge rates at Babcock St. (1998 to 2000) range from 26.9 cfs to 49.2 cfs.

The range of discharge values at Babcock Street is from 9.9 cfs to 552 cfs. Mean annual discharge rates at Hickory Ditch (1998 to 2002) range from 7.4 cfs to 12.2 cfs. The range of discharge values at Hickory Ditch is from 2.2 cfs to 180 cfs. The mean annual rainfall for Melbourne is 48.3". Rainfall recorded at the NWS office in Melbourne was 65" for 1997, 56.6" for 1998, 61.6" for 1999, 42.4" for 2000, 55.7" for 2001 and 34.4" for 2002 (up to 9/30/02). Three of the years were above average rainfall, one year was below average rainfall and the partial year (2002) primarily represents the drier part of the year.

Table 1

Mean Annual Discharge (cfs) for Crane Creek at US 1 and Babcock Street and Hickory Ditch Based on Daily Discharge Rates from USGS

1997 Mean Discharge, cfs				1998 Mean Discharge, cfs			1999 Mean Discharge, cfs		
	US 1	BS	HD	US 1	BS	HD	US 1	BS	HD
Mean	49.4			42.5	33.7	11.1	49.4	48.2	12.2
Std. Err.	3.61			3.26	1.19	0.56	6.00	2.46	0.84
Median	33			31	29	9	21.5	34.5	7.4
Mode	11			38	25	11	21	30	12
Std. Dev.	68.9			59.0	22.8	10.7	113.0	47.0	16.1
Sample Var.	4751.7			3483.5	518.6	114.7	12760.5	2208.8	260.1
Kurtosis	36.9			57.73	41.32	64.46	64.9	42.7	42.3
Skewness	5.1			6.31	4.94	6.86	6.9	5.3	5.5
Range	710.7			717.6	266.1	130.7	1401	538	177.2
Minimum	-1.7			-8.6	9.9	2.3	-11	14	2.8
Maximum	709			709	276	133	1390	552	180
Sum	18038			13950	12290	4069	17485	17542	4437
Count	365			328	365	365	354	364	365
2000 Mean Discharge, cfs				2001 Mean Discharge, cfs			2002 Mean Discharge, cfs		
	US 1	BS	HD	US 1	BS	HD	US 1	BS	HD
Mean	17.5	26.9	7.37	46.4		8.12	22.1		12.9
Std. Err.	1.42	0.93	0.30	4.46		0.57	1.71		0.85
Median	14	24	6.1	18		5.5	16		11
Mode	14	21	4	5.7		3.6	11		16
Std. Dev.	27.3	13.4	5.80	85.2		7.9	28.2		10.5
Sample Var.	742.7	180.7	33.6	7255.0		62.0	798.0		110.2
Kurtosis	83.7	43.7	40.2	29.1		12.7	2.4		9.1
Skewness	7.0	5.2	5.2	4.4		3.2	1.4		2.2
Range	395	145	59.7	882		52.7	169		74.8
Minimum	-18	12	2.3	-14		2.3	-17		2.2
Maximum	377	157	62	868		55	152		77
Sum	6413	5625	2697	16946		1567	6035		1992
Count	366	209	366	365		193	273		154

Mean TSS and turbidity

The descriptions of sampling locations and methods for TSS and turbidity are included under Water Quality Investigations Part II (Tab 4 in this report). All the TSS and turbidity data for the samples used for these calculations are included in the appendices for Task 2. The descriptive statistics for all TSS and turbidity samples collected at all stations for this study in 2002 and 2003 are shown in **Table 2**. The mean TSS for all samples collected at all locations and under all conditions is 8.9 mg/l. The TSS values range from 0.2 to 299 mg/l. Means for TSS and turbidity by station and by surface and deep water for stations 2, 3 and 4 are also shown in **Table 2**. For comparison purposes SJRWMD turbidity and TSS values from 1992 to 2003 are shown in **Table 3**.

Table 2

Mean TSS (mg/l) and Turbidity (NTU) for all Samples Collected
During 2002 and 2003

2002 -June 2003		
	TURB	TSS
Mean	5.6	9.9
Std. Err.	1.3	0.8
Median	3.7	6.8
Mode	4.0	7
Std. Dev.	32.8	19.8
Sample Var.	1075.8	390.3
Kurtosis	579.2	105.0
Skewness	23.9	9.3
Range	799.3	298.8
Minimum	0.7	0.2
Maximum	800	299
Sum	3366	5975
Count	598	601

Sediment Trapping Efficiency:

What can be inferred about the rate of sediment accumulation in Crane Creek based on the water quality measurements?

Table 2 Continued

ALL STATION 2 DATA			2 SURFACE		2 DEEP	
	TURB	TSS	TURB	TSS	TURB	TSS
Mean	4.7	9.3	4.4	7.4	5.1	11.2
Std. Err.	0.2	0.5	0.2	0.4	0.3	0.9
Median	4.5	7.8	4.2	7.0	5.0	9.5
Mode	4.5	5.0	4.5	7.0	5.4	5.0
Std. Dev.	2.1	5.6	1.9	3.2	2.3	6.8
Sample Var.	4.4	30.9	3.5	10.0	5.1	45.7
Kurtosis	6.3	6.8	7.4	8.5	5.9	3.6
Skewness	1.8	2.3	1.8	2.2	1.8	1.7
Range	13.7	32.3	12.0	20.1	13.4	32.3
Minimum	1.3	2.8	1.3	2.9	1.6	2.8
Maximum	15.0	35.0	13.3	23.0	15.0	35.0
Sum	601.7	1185.7	283.3	482.1	318.4	703.5
Count	127	128	65	65	62	63
ALL STATION 3 DATA			3 SURFACE		3 DEEP	
	TURB	TSS	TURB	TSS	TURB	TSS
Mean	3.7	7.6	3.8	7.4	3.6	7.8
Std. Err.	0.1	0.4	0.2	0.3	0.3	0.7
Median	3.5	6.8	3.8	7.0	2.8	6.0
Mode	4.0	8.5	4.0	8.5	2.5	6.0
Std. Dev.	2.3	5.7	2.0	3.1	2.7	7.7
Sample Var.	5.3	32.6	3.9	9.5	7.1	59.4
Kurtosis	12.9	97.5	15.1	0.8	11.2	63.3
Skewness	2.8	8.1	2.8	0.8	2.8	7.0
Range	17.3	77.3	15.7	16.3	17.3	77.3
Minimum	0.7	1.1	1.0	2.0	0.7	1.1
Maximum	18.0	78.4	16.7	18.3	18.0	78.4
Sum	904.0	1847.7	500.5	961.0	403.5	886.7
Count	244	243	131	130	113	113

Table 2
Mean TSS (mg/l) and Turbidity (NTU)
for all Samples Collected During 2002 and 2003 (continued)

ALL STATION 4 DATA			4 SURFACE		4 DEEP	
	TURB	TSS	TURB	TSS	TURB	TSS
Mean	3.6	7.4	3.9	6.8	3.4	7.9
Std. Err.	0.2	0.4	0.2	0.4	0.2	0.6
Median	3.5	6.5	3.7	6.6	3.0	6.5
Mode	3.0	6.5	3.0	7.0	2.5	13.0
Std. Dev.	1.7	3.8	1.8	3.3	1.6	4.3
Sample Var.	2.8	14.8	3.1	11.0	2.6	18.5
Kurtosis	5.2	2.0	8.7	1.2	0.2	1.7
Skewness	1.6	1.1	2.4	0.7	0.8	1.2
Range	11.0	23.5	10.5	17.8	7.0	22.0
Minimum	1.0	0.2	1.5	0.2	1.0	1.8
Maximum	12.0	23.8	12.0	18.0	8.0	23.8
Sum	419.5	860.4	217.1	382.7	193.2	460.1
Count	115	116	56	56	57	58
BABCOCK STREET			RUFFNER PARK		HICKORY DITCH	
	TURB	TSS	TURB	TSS	TURB	TSS
Mean	4.9	17.5	5.5	20.1	5.0	13.3
Std. Err.	0.9	6.4	1.3	9.2	0.8	4.0
Median	3.7	3.9	3.4	3.6	3.8	8.0
Mode	5.5	3.6	2.8	3.6	3.0	5.3
Std. Dev.	5.5	39.6	7.5	56.0	4.1	22.1
Sample Var.	30.0	1566.4	56.6	3138.1	16.9	489.1
Kurtosis	13.5	12.0	14.4	18.2	5.7	22.5
Skewness	3.6	3.4	3.7	4.1	2.4	4.5
Range	28.7	188.8	38.7	298.0	16.7	122.3
Minimum	1.1	1.3	1.6	1.0	1.3	0.7
Maximum	29.8	190.0	40.3	299.0	18.0	123.0
Sum	187.7	665.8	199.3	743.7	135.0	397.9
Count	38	38	36	37	27	30

The mean TSS for station 4 from this study, 7.4 mg/l, is similar to the SJRWMD data base covering the same time period for Crane Creek at US 1, 6.9 mg/l. The mean TSS values for station 4 (same as SJRWMD US 1), Babcock Street and Hickory Ditch will be used to estimate average annual transport of suspended matter at each of these locations.

Sediment Trapping Efficiency:
 What can be inferred about the rate of sediment accumulation in
 Crane Creek based on the water quality measurements?

Table 3

TSS (mg/L) and Turbidity (NTU) from SJRWMD Database for Crane Creek at US 1 1992-2003

1992-2003			2002 - Jun 2003			Apr 1998 - Sep 2003			1992 - Mar 1998		
	TURB	TSS		TURB	TSS		TURB	TSS		TURB	TSS
Mean	6.1	10.4		5.6	6.9		5.1	9.8		7.2	11.0
Std. Err.	0.32	0.69		1.00	1.4		0.31	0.96		0.53	0.98
Median	5.15	8		4.7	6		4.6	7.6		6	8.4
Mode	4.6	5		4.8	5		3.8	5		5.3	10
Std. Dev.	3.7	7.9		4.2	5.5		2.6	7.9		4.3	8.0
Sample Var.	13.6	63.0		17.8	30.2		6.5	62.0		18.8	64.2
Kurtosis	11.1	4.3		15.7	0.7		28.7	7.3		6.6	2.3
Skewness	3.1	2.0		3.8	0.9		4.7	2.5		2.5	1.7
Range	21.5	42		19.6	20		19.6	42		21.5	31.6
Minimum	1.6	0		2.4	0		2.4	0		1.6	3.4
Maximum	23.1	42		22	20		22	42		23.1	35
Sum	828.7	1397.3		100.1	111		349.5	659.1		479.2	738.2
Count	136	134		18	16		69	67		67	67

Estimated annual TSS loading at US 1, BS and HD

Estimated annual TSS loading (tons/yr) based on mean annual discharge and mean TSS are shown in **Table 4**. Mean discharges are from **Table 1**, Mean TSS for this study from **Table 2** and mean TSS for SJRWMD from **Table 3**. Statistics from **Tables 1, 2, and 3** are not reproduced in **Table 4**. Estimated annual TSS loading at Hickory Ditch and Babcock Street range from 87.5 tons to over 700 tons.

Table 4

Estimated Annual TSS Loading (tons/yr) in the Crane Creek System Based on Mean Annual Discharge and Mean TSS

	Mean Discharge	Mean TSS This Study	Mean TSS 2002-2003 SJRWMD	Mean TSS Post Dredging SJRWMD	Annual Loading This Study	Annual Loading 2002-2003 SJRWMD	Annual Loading Post Dredging SJRWMD
US 1	cfs	mg/l	mg/l	mg/l	tons/yr	tons/yr	tons/yr
1997	49.4	7.4	6.9	9.8	327	304	432
1998	42.5	7.4	6.9	9.8	281	262	372
1999	49.4	7.4	6.9	9.8	327	305	433
2000	17.5	7.4	6.9	9.8	116	108	154
2001	46.4	7.4	6.9	9.8	307	286	407
2002	22.1	7.4	6.9	9.8	146	136	193
BS							
1998	33.7	17.5			527		
1999	48.2	17.5			753		
2000	26.9	17.5			420		
HD							
1998	11.1	13.3			132		
1999	12.2	13.3			145		
2000	7.37	13.3			87.5		
2001	8.12	13.3			96.5		
2002	12.9	13.3			153		

How much suspended sediment is removed in Crane Creek now?

The difference in the TSS loading upstream at Hickory Ditch and Babcock Street and the TSS loading at US 1 provides an "estimate" of sediment removed between those two locations. Approximately 400 to 600 tons of suspended solids are removed annually in Crane Creek based on the calculations shown in **Table 5**.

Table 5

Estimated Annual TSS Loading (Tons/Year) at US 1, Babcock Street and Hickory Ditch and Estimated "Trapped" TSS 1998 - 2000

	US 1	BS + HD	"Trapped"
	Tons/Year	Tons/Year	Tons/Year
1998	281	659	378
1999	327	895	568
2000	116	516	400

If 400 to 600 tons of suspended solids (dry weight) are being deposited annually in Crane Creek how long will it take to replace the sedimentary material removed in 1998?

Nearly 69,000 m³ of wet sediment was estimated to be removed from within Crane Creek in 1998. The volume removed was primarily based on a benthic survey prior to and again after the completion of dredging. Although the 1998 dredging was described as a muck removal project considerable quantities of sand were observed during routine monitoring at the dredge spoil site (Garcia, 1998).

Water contents of sediment in Crane Creek range from 80% by weight for the soupy surficial muck to 20% as the sand fraction increases. The volume of the sediment varies considerably with the water content. The replacement time calculation for sediments removed from Crane Creek are shown for 40% water content, 50% water content and 60% water content. With annual sediment loading of 400 to 600 tons, replacement times range from 60 to 160 years. Because the sand fraction was so abundant in the sediment removed, replacement time calculations based on 40-50% water content by weight are probably the best estimates. These calculations are rather conservative replacement time estimates, assuming little sand is removed or is accumulating.

Approximately 69,000m³ of wet sediment was removed in 1998 from approximately 0.1 km² area, or an average increase in depth of 69 cm over the area. If the replacement time for the sediment is 100 to 160 years (40% water by weight assumption) the sedimentation rate would range from 0.4-0.7 cm/yr. Even if these estimates of sediment accumulation are underestimated by a factor of three, the next dredging should not be necessary for 50 years.

Table 6

Assumptions for Calculating Replacement Times and the Replacement Times for Sediment Dredged from Crane Creek in 1998

% Water by weight	40%	50%	60%
% Water by volume	65%	72%	80%
Wet sediment density, tons.m³	1.61	1.45	1.33
Mass dry sediment removed, thousand tons	63	50	36
Annual loading of suspended matter to Crane Creek, thousand tons/year	0.4-0.6	0.4-0.6	0.4-0.6
Estimated replacement time for dredged sediment, years	100-160	80-120	60-90

What are the impacts of storms on these sediment accumulation calculations?

The mean annual discharge rates and the mean annual TSS loading used for the calculation of sediment accumulating in Crane Creek includes both storm and non storm data. The mean discharge rates are based on daily measurements but TSS is not measured continuously. Therefore, some storm events may increase the annual TSS loading estimates developed above (**Table 5**). What is the potential impact of storm events on estimates of sediment loading and removal in the Crane Creek system? Concentrations of TSS from 100 to 300 mg/l were recorded at HD, RP and BS during several storm events over the course of the study. Based on previous studies (Trefry et al., 1987; Straccione, 2002 and Chanson, 2003) the TSS concentration usually peaks near the beginning of the rainfall event and decreases rapidly, often falling to values lower than preceding the storm event. The mean discharge values surrounding storm events, the maximum TSS encountered during storms, and the frequency of storm events will be used here to assess the potential impact of storms on the calculations for sediment accumulation in Crane Creek after the 1998 dredging.

Wet and Dry Storm Discharges

From a preliminary review of rainfall and discharge data for US 1, HD and BS, two general categories of storm events evolved. One that occurred under relatively dry conditions which did not create large discharges for extended periods of time, and one that occurred under wet conditions and created a much larger discharge for longer periods of time. Storms from 1997 to 2002 were classified as wet or dry and the mean flows for the day of peak discharge were compared to the three previous days and the following 5 to 10 days. A mean discharge was developed for wet storm events and dry storm events at HD, BS and US 1 for the day of peak flow, 3 days before peak flow and approximately 10 days after peak flow (**Table 7**). A comparison of the wet and dry storm flow rates at HD, BS and US 1 is shown in **Figure 1**.

Maximum Daily TSS Load from Storm Events

The maximum storm related values measured for TSS were 190 mg/l at BS, 123 mg/l at HD and 28.8 mg/l at US 1. These values were used with the mean wet and dry storm discharge rates from **Table 7** to develop a daily load (tons/day) at the peak of the storm event. The daily suspended matter loads in tons/day potentially created by wet storms and dry storms at BS, HD and US are shown in **Table 8**. The choice to use the maximum storm related TSS was to anticipate the maximum additional loading to Crane Creek resulting from storm events. The suspended matter loads associated with wet storm events are all higher than the dry storm events. However, it is unlikely that the very high TSS values used for these calculations would be typical for all wet storm events. As described in the water quality section of this report, higher suspended matter loading is anticipated when the river system has not been flushed for some time, i.e., after a period of dry weather, but where there is sufficient rainfall to create runoff. Based on the daily suspended matter loads at the peak of the storm in **Table 8**, five to ten storm events per year with a maximum TSS loading could produce annual TSS loads equivalent to those calculated from the mean annual discharge rates and mean TSS (**Table 7**).

How many storm events are there per year in the Melbourne area?

From 1997 to 2000, one inch or more of rain occurred on the average 21 times per year, more than 1.5" occurred eight times per year and more than two inches occurred 4 times per year. Most of the storms occur during the wet season and most likely have lesser storm TSS loads than the maximum storm TSS values used for the calculations above. These storms might have a significant impact on annual TSS loads, but most likely by no more than doubling the 0.4 to 0.7 cm/yr estimated sedimentation rates calculated based on the mean annual discharge rates and the mean measured TSS. Doubling the rate of sediment accumulation to 0.8 to 1.4 cm/yr will still require at least 50 years to replace the sediments removed by the 1998 dredging project.

Sediment Trapping Efficiency:
 What can be inferred about the rate of sediment accumulation in
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Table 7a

Wet and Dry Storm Discharge Rates (cfs) for Hickory Ditch, Babcock Street and US 1 1997 to 2002

Dry Storm Discharges (cfs) for Babcock Street															
	-3	-2	-1	Peak	1	2	3	4	5	6	7	8	9	10	Rain, in
Mean	26.3	26.1	38.8	80.8	53.1	38.0	33.9	33.4	32.8	31.6	31.2	31.5	30.4	30.4	3.0
Std. Error	2.4	2.4	7.0	12.7	5.2	2.8	2.9	2.8	2.9	2.6	2.6	3.0	2.5	2.2	0.5
Median	29	29	34	62	53	38	33	31	32	33	30	27.5	30	31	2.8
Mode	17	17	30	62	34	#N/A	#N/A	30	32	#N/A	30	27	30	31	#N/A
St. Dev.	7.1	7.3	21.0	38.2	15.6	8.3	8.7	8.3	8.8	7.8	7.7	8.4	7.0	6.3	1.46
Sample Var.	49.8	53.6	442.9	1456.9	242.9	68.8	75.6	68.8	78.2	61.0	59.7	70.0	48.6	40.3	2.14
Kurtosis	-1.61	-1.56	6.11	0.41	-0.58	-1.05	-0.56	0.40	0.85	-1.12	0.01	1.01	1.90	1.52	1.44
Skewness	-0.54	-0.60	2.17	1.15	0.45	0.18	-0.18	0.48	0.64	-0.15	0.29	1.28	0.76	-0.86	1.13
Range	17	19	77	114	45	24	27	28	30	23	25	25	24	21	4.78
Minimum	17	16	14	43	34	26	19	21	20	20	19	23	20	18	1.27
Maximum	34	35	91	157	79	50	46	49	50	43	44	48	44	39	6.05
Sum	237	235	349	727	478	342	305	301	295	284	281	252	243	243	26.93
Count	9	9	9	9	9	9	9	9	9	9	9	8	8	8	9

Sediment Trapping Efficiency:
 What can be inferred about the rate of sediment accumulation in
 Crane Creek based on the water quality measurements?

Table 7b

Wet and Dry Storm Discharge Rates (cfs) for Hickory Ditch, Babcock Street and US 1 1997 to 2002 (Continued)

Wet Storm Discharges (cfs) for Babcock Street															
	-3	-2	-1	Peak	1	2	3	4	5	6	7	8	9	10	Rain, in
Mean	56.1	60.8	91.9	186.4	105.8	85.7	73.2	66.3	56.3	54.0	43.0	40.2	38.6	33.7	3.40
Std. Error	8.1	8.6	17.7	38.6	16.6	10.9	8.2	7.7	6.7	8.6	4.7	4.3	3.6	3.8	0.52
Median	41	55.5	69	167	89	69.5	65	58	52	47.5	41	41	39	37	2.97
Mode	33	89	#N/A	#N/A	89	#N/A	65	69	#N/A	#N/A	#N/A	41	#N/A	#N/A	#N/A
St. Dev.	26.7	29.9	63.9	139.3	59.8	37.8	25.9	23.2	17.8	21.1	10.5	9.58	8.08	6.66	1.87
Sample Var.	714.9	891.2	4082.1	19404.8	3580.8	1429.3	671.1	540.5	317.2	444.8	110.5	91.7	65.3	44.3	3.50
Kurtosis	-1.92	-2.13	-0.14	3.19	3.72	-0.31	0.59	1.15	0.72	2.56	1.64	2.03	1.10		2.77
Skewness	0.33	0.09	0.98	1.71	1.88	0.94	1.12	1.19	1.22	1.58	0.67	-0.36	-0.99	-1.69	1.61
Range	66	75	196	491	216	115	81	75	49	58	29	27	21	12	6.67
Minimum	26	25	25	61	50	44	46	39	40	35	30	26	26	26	1.57
Maximum	92	100	221	552	266	159	127	114	89	93	59	53	47	38	8.24
Sum	617	730	1195	2423	1376	1028	732	597	394	324	215	201	193	101	44.18
Count	11	12	13	13	13	12	10	9	7	6	5	5	5	3	13

Sediment Trapping Efficiency:

What can be inferred about the rate of sediment accumulation in Crane Creek based on the water quality measurements?

Table 7c

Wet and Dry Storm Discharge Rates (cfs) for Hickory Ditch, Babcock Street and US 1 1997 to 2002 (Continued)

Dry Storm Discharges (cfs) for Hickory Ditch															
	-3	-2	-1	Peak	1	2	3	4	5	6	7	8	9	10	Rain, in
Mean	5.8	5.8	11.8	38.7	19.7	12.9	11.1	10.0	9.2	8.4	8.2	8.3	8.0	8.2	2.87
Std. Error	0.7	0.7	2.4	9.0	2.4	1.5	1.2	1.0	0.8	0.7	0.7	0.6	0.6	0.7	0.39
Median	6.3	5.7	9.1	25	19.5	11.5	11.5	9.7	8.6	8.2	7.9	7.8	7.3	8.2	2.6
Mode	3.2	5.7	8.6	#N/A	29	11	12	16	15	13	7.9	7.8	6.7	11	#N/A
St. Dev.	2.55	2.45	9.08	33.73	8.92	5.51	4.59	3.66	3.11	2.73	2.45	2.20	2.14	2.29	1.46
Sample Var.	6.48	6.03	82.41	1137.75	79.63	30.33	21.11	13.39	9.68	7.45	5.98	4.84	4.57	5.23	2.12
Kurtosis	-1.37	0.08	5.02	3.97	-1.45	-0.94	-1.26	-1.11	-0.23	-0.97	-0.28	-0.17	0.30	-0.76	0.22
Skewness	0.23	0.72	2.05	1.84	0.26	0.63	0.40	0.49	0.80	0.54	0.68	0.38	0.44	-0.17	0.82
Range	7.3	8.1	35.2	124.5	25.1	16.4	12.8	10.2	9.5	7.9	7.8	7.1	7.6	6.9	4.95
Minimum	2.7	2.9	2.8	8.5	7.9	6.6	6.2	5.8	5.5	5.1	5.2	4.9	4.4	4.1	1.1
Maximum	10	11	38	133	33	23	19	16	15	13	13	12	12	11	6.05
Sum	69.6	74.9	165.6	541.5	275.9	181.1	155.9	139.5	129.1	117.5	106.8	100	88.5	89.7	40.17
Count	12	13	14	14	14	14	14	14	14	14	13	12	11	11	14

Sediment Trapping Efficiency:
 What can be inferred about the rate of sediment accumulation in
 Crane Creek based on the water quality measurements?

Table 7d

Wet and Dry Storm Discharge Rates (cfs) for Hickory Ditch, Babcock Street and US 1 1997 to 2002 (Continued)

Wet Storm Discharges (cfs) for Hickory Ditch															
	-3	-2	-1	Peak	1	2	3	4	5	6	7	8	9	10	Rain, in
Mean	14.5	16.9	27.3	58.2	37.8	26.9	21.6	17.6	16.0	15.2	15.8	11.7	11.1	9.2	3.21
Std. Error	2.8	3.5	5.1	13.3	7.2	4.7	3.2	2.7	2.7	2.2	4.1	1.5	1.4	1.8	0.51
Median	12	13	24	41	29.5	23.5	21	16	14	15	14	12	11.5	9.2	2.54
Mode	#N/A	13	12	27	15	12	11	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
St. Dev.	9.3	12.3	18.6	48.1	25.1	16.3	10.0	7.97	7.15	5.34	9.07	3.07	2.85	2.55	1.82
Sample Var.	86.9	150.9	344.2	2314.8	629.2	266.2	100.0	63.5	51.2	28.5	82.2	9.43	8.14	6.48	3.33
Kurtosis	4.85	3.81	-0.44	2.37	0.71	-1.20	-0.77	-1.50	-0.32	-1.71	2.77	-0.26	1.39	#N/A	4.49
Skewness	2.03	1.90	0.95	1.61	1.09	0.57	0.48	0.29	0.63	0.02	1.59	-0.50	-0.88	#N/A	2.03
Range	32.8	42.9	53.1	165	82	45.4	28.5	21.4	20.1	13.7	23	7.2	6.8	3.6	6.67
Minimum	6.2	6.1	8.9	15	12	9.6	9.5	8.6	7.9	8.3	8	7.8	7.2	7.4	1.57
Maximum	39	49	62	180	94	55	38	30	28	22	31	15	14	11	8.24
Sum	159.8	203	354.9	756	454	322.6	215.5	158.4	111.8	91.3	79	46.8	44.2	18.4	41.77
Count	11	12	13	13	12	12	10	9	7	6	5	4	4	2	13

Sediment Trapping Efficiency:

What can be inferred about the rate of sediment accumulation in Crane Creek based on the water quality measurements?

Table 7e

Wet and Dry Storm Discharge Rates (cfs) for Hickory Ditch, Babcock Street and US 1 1997 to 2002 (Continued)

Wet Storm Discharges at US 1															
	-3	-2	-1	PEAK	1	2	3	4	5	6	7	8	9	10	Rain, in
Mean	56.7	85.5	243.7	566.1	261.7	138.5	102.6	88.3	80.3	63.5	58.8	56.3	49.2	48.0	3.52
Std. Error	13.0	19.8	40.8	87.0	41.2	15.5	10.0	9.3	14.3	5.7	5.5	5.6	5.3	7.9	0.50
Median	47.5	68	215.5	492	255	131	94	80	66	56.5	54	53	48	45	3.37
Mode	#N/A	#N/A	404	709	#N/A	163	94	68	#N/A	#N/A	54	#N/A	48	#N/A	2
Std. Dev.	41.2	71.3	152.8	325.6	148.6	55.8	36.1	33.4	49.4	19.9	18.3	17.7	15.9	22.4	1.89
Sample Var.	1696.2	5079.3	23351.5	105987.1	22069.1	3117.4	1304.3	1113.9	2438.1	394.1	335.0	312.0	252.9	503.4	3.57
Kurtosis	2.96	0.04	-1.91	2.05	1.30	1.68	2.00	0.31	8.35	0.34	0.01	0.68	4.17	-0.30	0.86
Skewness	1.59	0.75	-0.02	1.13	1.09	1.10	1.16	0.93	2.77	1.06	0.51	0.78	1.49	0.60	0.90
Range	138	246.4	407	1241	515	199	132	115	183	61	60	60	59	67	6.74
Minimum	16	-7.4	23	149	102	76	60	44	44	40	33	31	27	17	1.24
Maximum	154	239	430	1390	617	275	192	159	227	101	93	91	86	84	7.98
Sum	567	1111.6	3412	7926	3402	1801	1334	1148	964	762	647	563	443	384	49.32
Count	10	13	14	14	13	13	13	13	12	12	11	10	9	8	14

Sediment Trapping Efficiency:
 What can be inferred about the rate of sediment accumulation in
 Crane Creek based on the water quality measurements?

Table 7f

Wet and Dry Storm Discharge Rates (cfs) for Hickory Ditch, Babcock Street and US 1 1997 to 2002 (Continued)

Dry Storm Discharges at US 1.															
	-3	-2	-1	PEAK	1	2	3	4	5	6	7	8	9	10	Rain, in
Mean	17.9	16.1	71.9	221.1	94.0	55.5	43.2	36.2	32.7	27.4	26.9	27.9	28.6	26.4	2.97
Std. Error	4.1	4.4	18.7	40.2	11.8	7.6	6.5	5.2	4.4	4.5	4.9	6.5	5.3	5.1	0.22
Median	16	17	47	126	76	45	42.5	39	36	29	32	28	27	28.5	2.97
Mode	16	36	23	#N/A	#N/A	30	#N/A	28	#N/A	56	32	#N/A	27	-6.9	#N/A
Std. Dev.	19.0	20.0	85.5	184.2	54.0	34.8	29.0	23.4	19.4	19.0	20.1	26.8	20.0	17.7	1.01
Sample Var.	359.6	398.4	7318.8	33918.2	2919.3	1212.7	842.8	547.0	376.0	360.5	404.2	719.8	400.3	311.8	1.02
Kurtosis	-1.04	-1.58	6.80	1.52	-0.21	0.08	-0.96	-1.07	-0.40	-0.99	-1.27	-0.19	-0.06	0.54	-0.31
Skewness	0.12	0.00	2.42	1.47	0.76	0.60	0.21	-0.27	-0.68	-0.24	-0.06	0.57	0.08	-1.11	0.59
Range	65	61	386	651	180	140.6	95.25	75	63	61.8	64.2	87.9	74.7	54.9	3.4
Minimum	-11	-14	-18	58	19	-2.6	0.75	-7	-6	-5.8	-5.2	-6.9	-6.7	-6.9	1.66
Maximum	54	47	368	709	199	138	96	68	57	56	59	81	68	48	5.06
Sum	376.6	338.6	1509.8	4643	1975	1165.1	863.95	723	621.9	493.3	457.4	474.2	400	317.2	62.3
Count	21	21	21	21	21	21	20	20	19	18	17	17	14	12	21

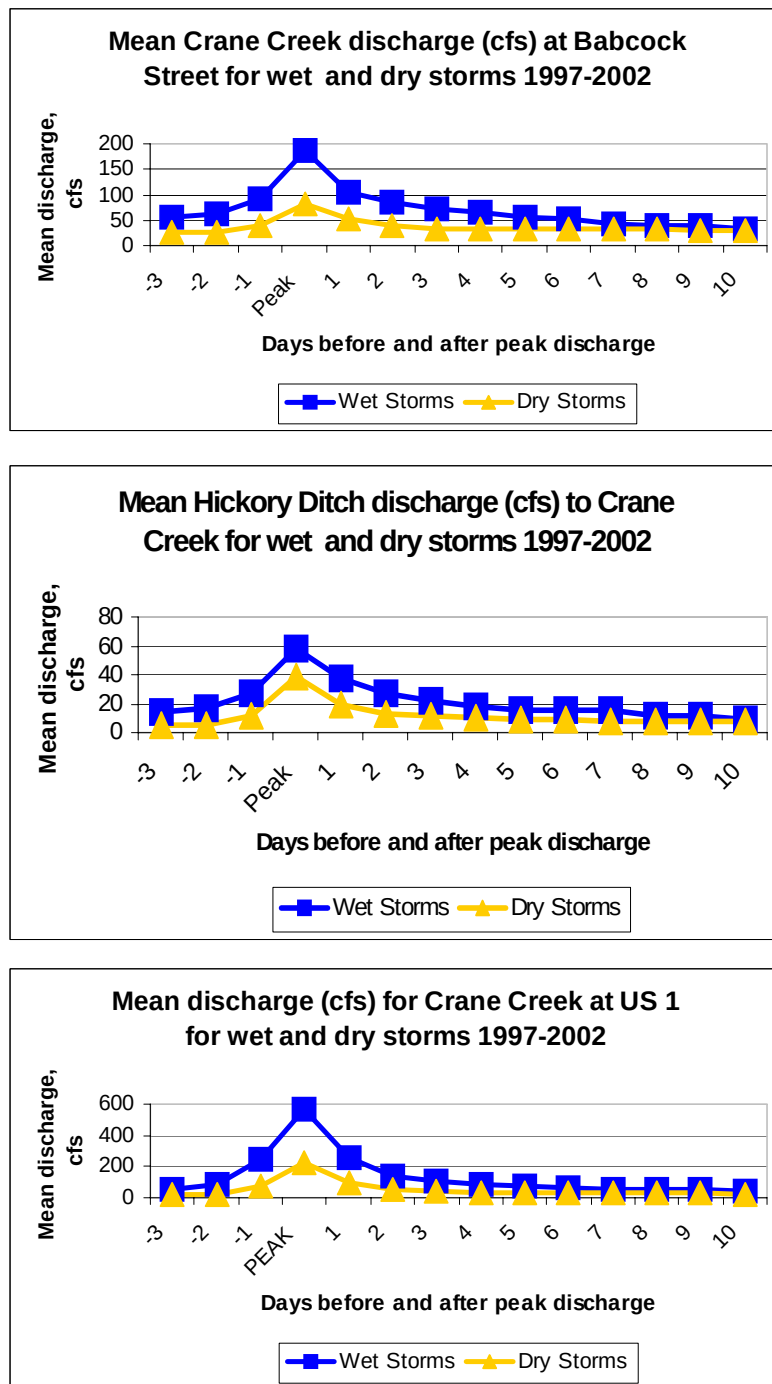


Figure 1

Mean Wet and Dry Storm Discharge rates (cfs) at Hickory Ditch, Babcock Street and US

1.

Table 8

Estimates of Storm Related TSS Loading (Dry Tons/Day) Based on Maximum
 TSS (mg/L) and Mean Daily Discharge Rates During Storm Events

	BS	HD	US 1
Maximum TSS concentration, mg/L	190	123	28.8
Mean Discharge Wet, cfs	186.4	58.2	566
Mean Discharge Dry, cfs	80.8	38.7	221
Tons/day Wet	86.7	17.5	39.9
Tons/day Dry	37.6	11.6	15.6

Other evidence supporting the results of these calculations

One of the reasons for dredging Crane Creek was to improve the trapping of sediment being transported from upstream. Many resource managers felt that the accumulation of muck sediment in Crane Creek prevented any further accumulation of sediment and that suspended matter loads from upstream were simply being transported directly to the IRL (Windsor, 1985; Windsor and Steward, 1987.) Sigua et al., 1999 reported the average annual loading of TSS from Crane Creek to IRL from 1988 to 1994 to be 625 tons/yr. If Crane Creek was not "trapping" any upstream sediment at that time, then 625 tons/yr also represents the upstream loading at that time. The values reported by Sigua et al.(1999) are similar to the 400 to 600 tons/yr reported here.

The SJRWMD district water quality data base for Crane Creek at US 1 has a mean value for TSS of 6.9 mg/l for 2002-2003. This value is comparable to the mean value of 7.4 mg/l (n = 116) for the samples collected at station 4 in this study (similar to SJRWMD US 1). While not statistically significant, there appears to be a trend for mean TSS in the SJRWMD data base at US 1 (**Table 3**). Values for TSS are higher before the dredging than after the dredging of Crane Creek. In addition, the lower means for 2002 and 2003 might suggest that upstream management practices are having an impact on reducing suspended matter loads to the Crane Creek system.

What recommendations result from the assessment of sediment trapping efficiency based on calculations from water quality data?

Measurement of TSS is very labor intensive and requires great care. Continuous measurement of TSS and turbidity would be of great value for a study like this. Estimates of TSS loading could be improved with continuous measurements of TSS. A better model of the relationships between TSS and turbidity would most likely make the continuous monitoring strategy easier and more cost effective.

The estimates of sedimentation rates established here suggest that the dredging of Crane Creek will not be necessary for at least 50 years. However, the distribution of muck sediment in Crane Creek right now suggests that the deeper pockets are filling in far more rapidly than the sedimentation rates above would indicate. In 1998 students from Florida Tech repeated a muck survey conducted in 1997 by another group of Florida Tech students. These field projects focused on the differences before and after dredging.

Their results suggested that the volume of muck removed based on their survey was quite similar to what the dredging project reported for removal. However, they still found muck depths up to several meters throughout the area dredged, primarily toward the flanks of the creek bottom. (Windsor, 1998 unpublished data) Sediment redistribution between 1998 and now is not very significant and supports the calculation above that sedimentation rates are very slow right now ($<1\text{cm/yr}$). A better assessment of the effectiveness of the dredging is necessary as the dredging project is underway. The depth to hard bottom measurements (proxy for muck thickness) should be included as part of the dredging contract requirement and should be done as each section of dredging is completed (before the dredge is moved).

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Crane Creek Post-Dredge Assessment Water Quality, Sediment Quality, and Sediment Trapping

Introduction, Summary of Findings, Recommendations

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1.0 INTRODUCTION

This study addresses the long term effects of a dredging project on the water quality, sediment quality, and sediment trapping efficiency of Crane Creek, an urban stream located at Melbourne, Florida tributary to the Indian River Lagoon (**Figure 1**). The channel was dredged from near its mouth at the Indian River Lagoon to about 3,600 feet up the creek in 1997 to restore navigability. The project was also anticipated to provide environmental benefits to the in-stream habitat of the creek as well as its receiving water body related to sediment trapping and surface water quality transformations. The St. John's River Water Management District (SJRWMD) was interested in the following questions, relative to the post-dredging condition of the creek;

- 1) Has the sediment quality improved?
- 2) Has the water quality improved?
- 3) What are the sediment material and sediment trapping efficiencies of the dredged areas?

These are important questions relative to potential effects on the Indian River Lagoon (IRL), Crane Creek's receiving water body. The IRL and Crane Creek watersheds are under intense development pressure, high pollutant loads, and other stressors. Despite these pressures, the IRL remains one of the most ecologically diverse, economically significant, and unique estuarine ecosystems in the United States. It will most likely take a multifaceted approach of watershed restoration and pollutant source reductions, sediment removal/management, and aquatic habitat enhancements/ restoration to keep it that way. Removing culturally derived or polluted sediments from the depositional areas of urban or agricultural streams tributary to the IRL is one potential tool to include in an integrated approach to improving and maintaining the biological function of the IRL. Essentially, the purpose of this study was to use Crane Creek as a case study for potentially elucidating what role such sediment removal projects can play in that objective, and perhaps how to best approach the design of such projects for greatest effect.

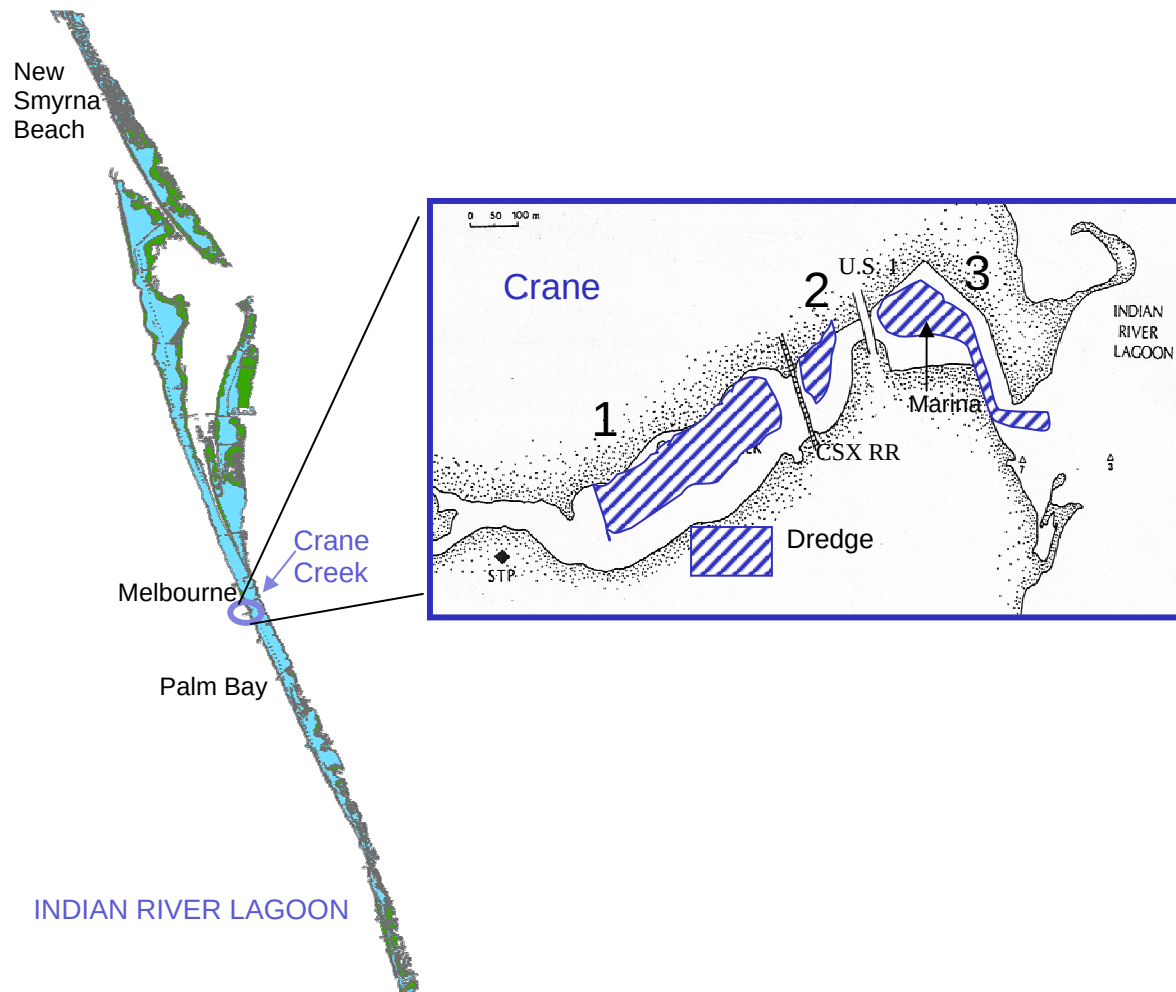


Figure 1. Indian River Lagoon and Crane Creek (showing three dredge zones).

Building on existing studies and data from Crane Creek and the IRL in its vicinity, the SJRWMD's questions were addressed by a series of post-dredge studies conducted from 1998 through 2003 by several authors who are compiled within this single binder, each under a separate tab. The tabs include the following reports:

- Tab 1: Introduction and Summary of Findings
- Tab 2: Sediment Trapping Efficiency based on Repeat Cross Section Surveys
- Tab 3: Water Quality and Sediment Transport
- Tab 4: Turbidity and Suspended Solids
- Tab 5: Sediment Trapping Efficiency based on Water Quality

- Tab 6: Polycyclic Aromatic Hydrocarbons and Phthalate Esters
- Tab 7: Sediment Trapping Efficiency based on Sediment Quality

The purpose of this summary is to tie these reports together, providing an overview of the findings and a discussion of the approaches when findings differed among methods. The summary also provides a synopsis of recommendations concerning the future role and design of such dredging projects. Where applicable, the Tab number is referenced in a manner analogous to citing a journal reference. In some cases, especially the recommendations section, I have inserted personal opinions not expressed elsewhere in this volume. In those cases, for clarity of source, I switch to first-person narrative.

2.0 FINDINGS: SEDIMENT QUALITY

Pre-dredge samples of Crane Creek during 1992 indicated elevated levels of organic compounds, especially polycyclic aromatic hydrocarbons (PAH) and phthalate esters, and selected trace metals (Tabs 6 and 7). PAHs are essentially petroleum breakdown compounds, mostly from combusted oils and fuels that can enter the creek via atmospheric deposition and runoff. Phthalate esters are derived from plastics which can enter the stream via wastewater and litter such as plastic bags (Tab 6). Certain metals were also of interest including silver, cadmium, chromium, copper, mercury, lead, zinc, arsenic, nickel, and vanadium (Tab 7).

The concentration of PAH was lower at sediment sites in Zone 1 which suggests dredging removed some of the contaminated surficial sediments (Tab 6) (**Figure 1**). However, west of the US 1 bridge (Zone 2), PAH concentration levels were equal to or higher than they were in 1992 (Tab 6). These elevated concentrations of PAH appear to be a combination of recent input of PAH and slumping of muck sediments not removed in 1998 (Tab 6). If sedimentation rates are 0.8 inches per year or greater the PAH levels may be the result of new input of contaminant material alone (Tab 6). Phthalate esters were not reported above detection limits in 2003 (Tab 6). Phthalate ester levels may have been reduced through better waste management practices such as diverting sewage effluent from Crane Creek (Tab 6).

Overall metals concentrations in Crane Creek's sediments were not changed from 1992 to 2003 as a result of dredging (Tab 7). Cadmium, lead, and copper concentrations are higher than background levels as inferred by aluminum-to-trace metal ratios in sediment parent materials, but generally not at concentrations that frequently affect biota (Tab 7). However, silver and mercury levels occurred at sediment concentrations 50 to 100 times background concentrations and they exceeded thresholds that frequently result in adverse effects to biota (Tab 7).

Silver and mercury concentrations correlated to one another and appeared to be associated with sediments dated to be significantly older than the dredging period (Tab 7). Ultimate common sources of these two metals often include dental and photographic processing wastewaters (Tab 7). Current conditions appeared to be providing reasonably low loads of these metals to the creek, implying that these metals concentrations reflect historic loads trapped in the organic sediments that remained in the system after dredging (Tab 7).

3.0 FINDINGS: WATER QUALITY

Two general categories of water quality controls emerged, 1) water quality controlled primarily by meteorological conditions and 2) water quality transformations related to the changes in morphology of the creek (Tab 3). Salinity in the creek generally increased in response to lowered base level of the bed which allowed for increased water depths and upstream migration of the salt wedge. This was a desired response (Joel Steward, personal communication). The deeper water also added 1 meter of oxygenated surface water (Tab 3). However, bottom anoxia/hypoxia still exists (Tab 3). Suspended solids decreased slightly (Tab 3).

Turbidity and secchi depth remained unchanged, influenced substantially by weather (Tab 3). The increased oxygen concentrations are important for the survival of aerobic marine life, as well as preserving the aesthetics of the creek by preventing foul odors associated with anaerobic conditions (Tab 3). The apparent decline in total suspended solids was determined to be a positive effect of the removal of muck sediments (Tab 3).

Salinity, water flow, precipitation and wind speed were all factors that appeared to influence suspended material transport in Crane Creek (Tab 4). Turbidity was not influenced by water density (Tab 4). Suspended sediment concentrations increased with depth (Tab 4). Suspended sediment concentrations correlated well with turbidity (Tab 4). Large solids loads appeared to be generated from storm runoff events (Tab 4).

4.0 FINDINGS: SEDIMENT TRAPPING EFFICIENCIES

The creek generally appeared to be a good sediment trap. It probably had functioned that way for a long time prior to reaching capacity in recent history, and the dredging project merely acted to “reset” the clock on the creek’s ability to provide that function (Tab 2). Based on residence times and settling velocities of unconsolidated grains, sands should be removed close to 100 percent of the time, silts 50 percent, and clays 10 percent (Tab 3). The trap’s longevity may be as little as 11 years and as much as 120 depending on which method is used to develop a model for sedimentation rates and sediment distribution.

Sediment trapping rates were estimated based on the net difference of mean annual suspended sediment loads measured upstream versus downstream of the dredged reach (Tab 5). Crane Creek was assumed to be passing virtually its entire sediment load to the IRL prior to the dredging project (Tab 5). The site appeared to be trapping anywhere from 378 to 568 dry tons of sediment per year for the first three years after dredging (Tab 5). Trapping rates were calculated to be depositing significantly less than an inch per year on average across the dredged footprint (Tab 5). Those sedimentation rates suggest that Crane Creek will not have to be dredged again for at least 50 years (Tab 5).

Even smaller mean sedimentation rates of about 0.25 inches per year were estimated using excess ^{210}Pb and ^{37}Cs signatures in the sediment profile (Tab 7). However, it was difficult to obtain widespread reliable sediment cores due to nearly ubiquitous vertical mixing of sediments, likely from bioturbation (e.g. manatees stirring the bottom), bank slumping after dredging, fluvial mixing of sediments, etc. (Tab 7). However, the suspended sediment load calculations and the radionuclide signatures in the sediments provide a reasonably consistent picture of sedimentation rates (Tabs 5 and 7). Both methods led to predictions of project capacity for sediment trapping that will exceed 50 years and more likely approach a century. This assumed that the entire 90,000 cubic yards of dredged volume is available for storage.

That may not be a safe assumption. Repeat cross-section surveys suggested that sediment accumulation zones varied in time and space subsequent to dredging and that some areas of the footprint are likely to reach capacity sooner than others (Tab 2). Based on the accumulation rates and patterns inferred from the change in cross-section configurations from 2001-2003, the project may only have a useful life of 11 years (Tab 2). This conclusion, however, is tempered by the degree of accuracy of the various bathymetric surveys (Tab 2).

The weight of the evidence from the three approaches taken in this study (repeat cross section surveys, mass balance of suspended sediment loads, and radionuclide sediment signatures) suggests that the recently created (1998) trap’s longevity most likely ranges from 11 to 50 years. Bedload, which can contribute fill to the dredged basins, was not measured for this study. Trap filling rates are a function of all sources of the net movement of sediment including suspended load and bedload. Therefore, mass balance studies relying solely on suspended load can under-predict filling rates in the traps. Likewise, the tractive forces that cause bed load and other mass redistributions of sediment lead to vertical sediment mixing that can confound radionuclide signatures. This means that areas with significant bedload can be omitted from

consideration for that type of analysis as well. Also, the period of study lacked infrequent, heavy storm events/surges (e.g. 100-year 24-hour storm). These could move sufficient sediments to rather quickly consume much of the available volume. Finally, trapping efficiencies may decrease as volume and residence time are “consumed” as the basins fill. Therefore, in my opinion, it is unlikely that significant sediment trapping will occur for more than 50 years.

It should be noted that all three methods (suspended sediment measurements, radionuclide sediment signatures, and repeat cross-section bathymetric surveys) led to conclusions that the dredged area of Crane Creek has been an effective sediment trap (Tabs 2, 5, and 7).

5.0 FUTURE STUDY RECOMMENDATIONS

Studies addressing meteorological versus morphologic controls on water quality, especially suspended solids, turbidity, secchi depth, and dissolved oxygen as they relate to sediment trapping efficiencies should be continued at Crane Creek and studied at additional dredged sites in the region for comparison over a wider range of wet and dry cycles (Tab 3). Methods should be standardized and the studies should be long-term if possible (Tab 3). Suspended sediment loads and turbidity correlated well and these loads can be rather spiked during and shortly after storm events (Tab 4). This suggests that future studies in similar settings could substitute continuous monitoring of turbidity for grab samples of turbidity and suspended solids to generate a more precise picture of the effects of these important events while keeping monitoring costs reasonable (Tabs 4 and 5).

Depth to hard-bottom measurements (proxy for muck thickness) should be included as part of the pre- and post-dredging surveys when projects are intended to ultimately serve as sediment traps (Tab 5). I think this should be approached on a case-by-case basis. It is an important variable to measure if the goal of the project is to remove all the muck or establish a firm bottom in portions of the bed of the waterbody. This was not a design objective of the Crane Creek sediment removal project, which was predominantly designed to improve navigation with secondary potential benefits related to improved water quality and sediment quality. Also, the accuracy of certain types of depth to resistance probing as an approach to determining muck thickness can be insufficient to resolve accumulations that can occur in a few years. A similar approach failed to detect sediment accumulations between 1998 and 2002 that other methods in this volume detected (Tab 7).

Survey methods could be improved by assuring that stations are carried out across the entire cross-section from shoreline to shoreline as opposed to termination at the boundaries of the dredging footprint (Tab 2). Also, bank pins and scour chains could be used to supplement bathymetric surveys, resulting in increased precision of measured changes in erosion and deposition for short intervals between repeat surveys (Tab 2).

Although this series of studies implies good trapping efficiency in Crane Creek, I do not believe that they provide hard data or quantification of net trapping efficiency improvements as a result of the dredging project. This compilation makes the best of the empirical evidence that could be derived, but it does not substitute for a more controlled experimental design. There appears to be a need for a more systematic pre- versus post-dredging experimental evaluation in this type of environment. Special focus should be paid to the location of the dredged depositional zones relative to the salinity gradients and salt-wedge dynamics that will be induced by the change in morphology.

I believe that the speciation of metals determined to be at unacceptably high total concentrations in Crane Creek's sediments, particularly mercury and silver, should be evaluated. This may lead to targeted recommendations for remediation strategies that could affect the solubility and bioavailability of these metals as a function of their speciation.

6.0 DESIGN RECOMMENDATIONS

In-stream trapping is difficult for fine particulates (Tab 3) and runoff should be directed to detention ponds or other forms of adequate stormwater treatment before it reaches the creek and loads it with culturally induced upland sediment yields (Tab 4).

To minimize the potential for sediment quality to continue to be affected by redistribution of an urban creek's cultural loading and trapping history, I believe that all the culturally impacted muck in the target dredging area should be removed—consistent with the findings of Tabs 6 and 7. This may entail more detailed and expensive engineering and geotechnical field studies to enable fine-scale, surgical dredging around structures as opposed to imposing blanket 50 foot buffers around all structures (Joel Steward, personal communication). I believe that Crane Creek's remaining silver and mercury-contaminated sediments may warrant such a project pending the results of metals speciation and bioavailability studies, if they are pursued.

The locations and depths of trapping zones in systems such as Crane Creek should carefully consider and model the effects of salinity, salt wedge dynamics, velocity regimes, shear-stresses on the beds and banks, and other factors on sediment transport. I believe that this study demonstrates value in engineering the traps using a combination of empirical and analytical design approaches. It is not merely sufficient to rely on platitudes as a substitute for design (e.g. deepening a creek may allow for trapping more sediments as a rule of thumb—but perhaps not much more than the pre-dredge condition unless certain threshold changes in velocity, shear, ionic strength, and/or stream power are attained).

If benefits related to sediment trapping and other water quality and sediment quality improvements are primary objectives of a dredging project they should be evaluated and designed explicitly. Although this volume of studies indicates that such benefits can be likely outcomes of projects designed for other purposes, this case study suggests that it is not sufficient to merely remove sediments to improve navigation and expect optimal or even highly significant results for sediment trapping and positive environmental quality for all of the important issues of a given stream.

In this case, there were overall improvements in dissolved oxygen and phthalate esters in Crane Creek. Total suspended sediment loads to the IRL appeared to be improved as well. Sediment trapping was probably enhanced versus the pre-dredge condition, but the degree of this benefit is not firmly quantifiable. Turbidity, secchi depths, bottom anoxia, sediment trace metals, and sediment PAH's were all largely unaffected by the project. Possibly all of these, but especially the latter two, could have been better affected if design objectives and budgets were targeted accordingly.

January 31, 2001 to June 28, 2001
Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Rainfall: None

[illegible]

Appendix A

Crane Creek Water Quality Monitoring

January 31, 2001 to June 28, 2001

Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Crane Creek Water Quality Study

Rainfall: None

Date: 2-16-01

[illegible]

January 31, 2001 to June 28, 2001
Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Rainfall: 2-24-2001 = 2.59 cm

[illegible]

January 31, 2001 to June 28, 2001
Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Rainfall: 3-04-01 = 0.76 cm

[illegible]

January 31, 2001 to June 28, 2001
Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Rainfall: None

[illegible]

January 31, 2001 to June 28, 2001
Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Rainfall: 4-04-01 = 1.88 cm

[illegible]

January 31, 2001 to June 28, 2001
Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Rainfall: None

[illegible]

January 31, 2001 to June 28, 2001
Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Rainfall: None

[illegible]

January 31, 2001 to June 28, 2001
Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Rainfall: None

[illegible]

Appendix A **Crane Creek Water Quality Monitoring**

January 31, 2001 to June 28, 2001
Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Crane Creek Water Quality Study

Rainfall: 5-22-01 = 0.43 cm
5-23-01 = 3.28 cm

Date: 5-24-01

TEMPERATURE (°C)				SALINITY (ppt)				DISSOLVED OXYGEN (mg/L)				PERCENT SATURATION			
Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5
0.0	26.9	26.8	28.1	0.0	1.9	3.7	32.9	0.0	4.15	3.91	5.60	0.0	51.5	52.7	86.0
0.3	26.9	26.8	28.0	0.3	2.0	3.2	33.0	0.3	4.27	2.89	5.55	0.3	54.0	40.4	85.6
0.6	27.4	27.7	28.1	0.6	12.4	22.1	33.0	0.6	2.49	3.72	5.55	0.6	33.8	48.0	85.5
0.9	28.8	28.9	28.0	0.9	29.5	33.7	33.0	0.9	1.56	3.16	5.69	0.9	27.4	49.5	87.8
1.2	29.0	28.9	28.1	1.2	31.1	34.0	33.0	1.2	1.23	2.65	5.71	1.2	20.7	44.8	87.9
1.5		29.0	28.0	1.5		34.4	33.0	1.5		2.24	5.72	1.5		34.7	88.0
1.8		29.0	28.1	1.8		34.5	33.0	1.8		2.00	5.73	1.8		32.1	87.8
2.1		29.0	28.1	2.1		34.7	33.1	2.1		1.82	5.75	2.1		29.1	88.2
2.4		28.9	28.1	2.4		35.0	33.1	2.4		1.55	5.66	2.4		22.3	87.0
2.7		28.8		2.7		35.1		2.7		1.30		2.7		21.9	
3.0		28.8		3.0		35.2		3.0		1.20		3.0		19.3	
3.3		28.8		3.3		35.2		3.3		1.37		3.3		21.8	
3.6		28.8		3.6		35.2		3.6		1.34		3.6		21.3	
3.9		28.7		3.9		35.3		3.9		1.29		3.9		20.6	
4.2		28.7		4.2		35.2		4.2		1.04		4.2		16.7	
4.5		28.6		4.5		35.2		4.5		0.75		4.5		12.0	
4.8		28.6		4.8		35.3		4.8		0.71		4.8		9.9	
5.1				5.1				5.1				5.1			
FreshAVE	26.9	26.8	28.1		2.0	3.5	33.0		4.21	3.40	5.58		52.8	46.6	85.8
STDEV	0.00	0.00	0.07		0.07	0.35	0.07		0.08	0.72	0.04		1.77	8.70	0.3
SaltAVE	28.4	28.8	28.1		24.3	33.8	33.0		1.76	1.90	5.69		27.3	29.4	87.5
STDEV	0.87	0.34	0.05		10.37	3.56	0.05		0.65	0.83	0.07		6.55	11.52	0.9
Weather:	Clouds (10%) 84F														
Wind:	E 5 Knots														
Time of Day:	10:30 AM														
SECCHI DEPTH (m)															
	Station 2	Station 3	Station 5												
1	0.60	0.55	1.55												
2	0.59	0.58	1.60												
3	0.56	0.60	1.45												
Average	0.58	0.58	1.53												

Appendix A **Crane Creek Water Quality Monitoring**

January 31, 2001 to June 28, 2001
 Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Crane Creek Water Quality Study

Rainfall: None

Date: 6-07-01 A

TEMPERATURE (°C)				SALINITY (ppt)				DISSOLVED OXYGEN (mg/L)				PERCENT SATURATION					
Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5		
0.0	31.0	29.8	29.9	0.0	9.5	5.5	30.2	0.0	6.06	5.20	4.57	0.0	89.5	68.9	71.2		
0.3	31.2	30.0	30.0	0.3	10.9	9.5	30.2	0.3	5.98	5.01	4.52	0.3	85.0	69.0	70.2		
0.6	32.2	30.9	30.0	0.6	23.5	27.9	30.5	0.6	6.00	2.80	4.48	0.6	90.5	44.6	70.1		
0.9	32.3	31.1	29.9	0.9	27.3	29.8	30.8	0.9	3.02	2.74	4.48	0.9	45.0	42.5	70.0		
1.2	32.1	31.0	29.9	1.2	27.7	30.0	30.8	1.2	2.30	2.10	4.51	1.2	39.0	35.0	70.6		
1.5		30.9	29.9	1.5		29.9	30.8	1.5		2.15	4.47	1.5		33.7	70.0		
1.8		30.7	29.9	1.8		30.2	30.8	1.8		2.10	4.49	1.8		22.4	70.1		
2.1		30.7	29.9	2.1		30.3	30.8	2.1		0.10	4.40	2.1		11.5	69.0		
2.4		30.6		2.4		30.7		2.4		0.02		2.4		0.5			
2.7		30.2		2.7		30.8		2.7		0.01		2.7		0.3			
3.0		30.1		3.0		31.1		3.0		0.01		3.0		0.1			
3.3		29.5		3.3		31.3		3.3		0.00		3.3		0.1			
3.6		29.1		3.6		31.6		3.6		0.00		3.6		0.1			
3.9		29.0		3.9		31.7		3.9		0.00		3.9		0.1			
4.2		28.9		4.2		31.7		4.2		0		4.2		0			
4.5				4.5				4.5				4.5					
4.8				4.80				4.80				4.80					
5.1				5.1				5.1				5.1					
FreshAVE	31.10	29.90	29.95		10.20	7.50	30.20		6.02	5.11	4.55		87.25	68.95	70.7		
STDEV	0.141421	0.141421	0.070711		0.989949	2.828427	0		0.056569	0.13435	0.035355		3.181981	0.070711	0.7		
SaltAVE	32.2	30.20769	29.91667		26.16667	30.53846	30.75		3.773333	0.925385	4.471667		58.16667	14.68462	70.0		
STDEV	2:24 AM	0.812877	0.040825		2.318045	1.048442	0.122474		1.961666	1.213409	0.037639		28.16174	18.22818	0.5		
Weather:	Sunny, Clouds (10%) 72F																
Wind:	SE 0-5 Knots																
Time of Day:	0.36																
SECCHI DEPTH (m)																	
	Station 2	Station 3	Station 5														

1	0.7	0.6	2.1
2	0.7	0.6	2.1
3	0.7	0.9	2.1
Average	0.7	0.7	2.1

January 31, 2001 to June 28, 2001
Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Rainfall: None

[illegible]

January 31, 2001 to June 28, 2001
Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Rainfall: 6-07-01 = 0.20 cm
6-08-01 = 0.99 cm
6-09-01 = 0.20 cm

[illegible]

Factors Affecting Turbidity and Total Suspended Solids and the Relationship Between These Parameters in Crane Creek, Melbourne Florida

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Abstract

The factors that affect turbidity and total suspended solids (TSS) and the relationship between these variables were investigated in Crane Creek, Melbourne Florida with the aim of simplifying the management of the watershed. A total of 461 water samples were collected during thirteen months from January 2002 to February 2003.

Kruskal-Wallis one-way ANOVAs demonstrated that TSS concentrations and turbidity values were significantly different at the surface of the creek than deeper in the water column. The statistical analyses showed evidence that density was not a factor that affects these variables in the creek. Landward flow and flow $< 0.5 \text{ m}^3/\text{s}$ increased TSS from $5.6 \pm 1.6 \text{ mg/L}$ to $7.9 \pm 2.1 \text{ mg/L}$. Alternatively, landward flow and flow greater than $0.5 \text{ m}^3/\text{s}$ decreased turbidity from $4.0 \pm 1.5 \text{ NTU}$ to $3.1 \pm 0.8 \text{ NTU}$. Turbidity and TSS increased with increasing rainfall when water was sampled during storm events. The mixing of creek and sea water at salinities between 11 and 20 psu led TSS to increase from $6.1 \pm 1.6 \text{ mg/L}$ to $8.1 \pm 2.9 \text{ mg/L}$. Turbidity decreased from $3.7 \pm 1.1 \text{ NTU}$ to $2.6 \pm 0.5 \text{ NTU}$ in saline water ($>20 \text{ psu}$). While wind speed did not have a significant affect on turbidity, it had for TSS. When wind speed was greater than 20 km/h , TSS increased from $5.5 \pm 1.9 \text{ mg/L}$ to $9.2 \pm 1.5 \text{ mg/L}$.

The survey indicated that turbidity and total suspended solids were strongly correlated with a Spearman coefficient $r = 0.68$. The linear regression line between these two variables had a slope of $1.87 \text{ mg/L per NTU}$ and an intercept of 0.94 mg/L . The coefficient of determination r^2 was 0.47 . As a result of this research, data loggers that measure turbidity should be installed at US.1 and Babcock Street for instance, so that the concentration of total suspended solids could be estimated using the above relationship in Crane Creek, Melbourne, Florida.

Total suspended solids and turbidity behavior in the river system were investigated. Two questions were addressed:

- What are the factors that affect turbidity and total suspended solids in Crane Creek?
- Is there a significant mathematical relationship between turbidity and total suspended solids in Crane Creek?

1.0 METHODS

Site Description

Crane Creek is located in the North Central Indian River Lagoon, flows through Melbourne, Florida and has a drainage area of 46.9 km² (US. Geological Survey, 2002). The creek has a southwest-northeast orientation and is mainly influenced by northeast winds (Straccione, 2002). In 2002, the City of Melbourne was approximately 91.7 square kilometers in size, with about 75% of that land in use and a population of 72,806 that is growing by ~2% each year (City of Melbourne, 2002). Between 1988 and 2000, the creek discharged annually about 1.2 ± 0.4 m³/s of water with a minimum of 0.5 m³/s in 2000 (US. Geological Survey, 2002).

An extensive survey of the Indian River Lagoon in 1989 indicated that 10 percent of the Indian River Lagoon bottom was covered with varying thickness of muck sediment. 3.8 million cubic meters of muck sediment were identified between Cocoa and Palm Bay (St John's River Water Management District, 2002). Muck sediments are rich in silt and clay (50%) and organic matter (10%) (Trefry and Stauble, 1987).

Estuaries can act as a filter for fine-grained sediments (Schubel and Carter, 1984). Muck was mainly distributed close to the creeks, where water was deep and where communities had developed. The filtering efficiency can be reduced when the length of the estuary decreases. The length of an estuary starts at the mouth and ends at the last measurable traces of sea salt (Schubel and Carter, 1984). The longer the estuary, the greater the gravitational flow. In that case, saline water penetrates farther in the estuary where flocculation is also induced; and, the null zone (the landward limit of sea salt) can not be displaced during high river flow (Schubel and Carter, 1984). The estuary becomes less efficient when its depth, volume and area decrease. In that case, the river flow dominates the landward flow.

When the estuary becomes less efficient, the fine-grained suspended sediments end up in the ocean or the Indian River lagoon for this study. Muck sediments also are a sink for oxygen and heavy metals such as mercury and a source for nitrogen and phosphorous (Trefry and Stauble, 1987). In 1998, about 90,000 m³ of muck was removed (St John's River Water Management District, 2002) from Crane Creek to improve navigation, to improve water quality and to restore the filtering ability of the creek according to the Indian River Lagoon Comprehensive Conservation and Management Plan (1996). Garcia (1998) studied the short term impact on the water quality from the dredging and found increasing levels of dissolved oxygen and water clarity. Levels of dissolved oxygen increased from 80 ± 20 % to 88 ± 30 %, mean turbidity decreased from 6.2 ± 1.9 NTU to 3.2 ± 0.7 NTU, mean Secchi disk depth increased of about 10 cm but the mean TSS were still at about 14 mg/L (Garcia, 1998).

In order to answer the questions stated above, Crane Creek was studied longitudinally and vertically from January 2002 to February 2003 (**Table 1 and Figure 1**). The longitudinal transect referred to surface water where the upstream creek had stations at Ruffner Park (RP), Babcock Street (BS) and Hickory Ditch (HD). BS was Station 1 in Garcia's survey (1998). RP and HD were newer stations added in June 2002 both having a water depth of 0.4 m.

The central creek had two stations: station 2 on the west side of the rail road bridge and station 3 in Manatee Park between the rail road bridge and US1. The downstream creek had one station referred to as station 4 in the harbor. Stations 2, 3 and 4 were similar to those surveyed by Garcia (1998) and Straccione (2002). The vertical profiles refer to various depths at stations 2, 3 and 4. The deep water was collected at 2D (0.6m), 3I (0.9m), 3II (2.1m), 3III (3.3m), and 4D (1.5m). Field trips were scheduled once every week or biweekly and between noon and 2 PM for consistency. In case of storm events *i.e.* over 50 mm of rain in a 2 hour period, sampling before, during and after the storm was scheduled.

Table 1

Station identifications, sampling depth, and coordinates
for the Crane Creek system, Melbourne, Florida.

Station	Latitude	Longitude
RP (Ruffner Park)	28°04.127' N	080°37.273' W
BS (Babcock Street)	28°04.326' N	080°37.463' W
HD (Hickory Ditch)	28°04.283' N	080°36.786' W
Station 2	28°04.502' N	080°36.367' W
Station 3	28°04.596' N	080°36.191' W
Station 4	28°04.651' N	080°36.068' W

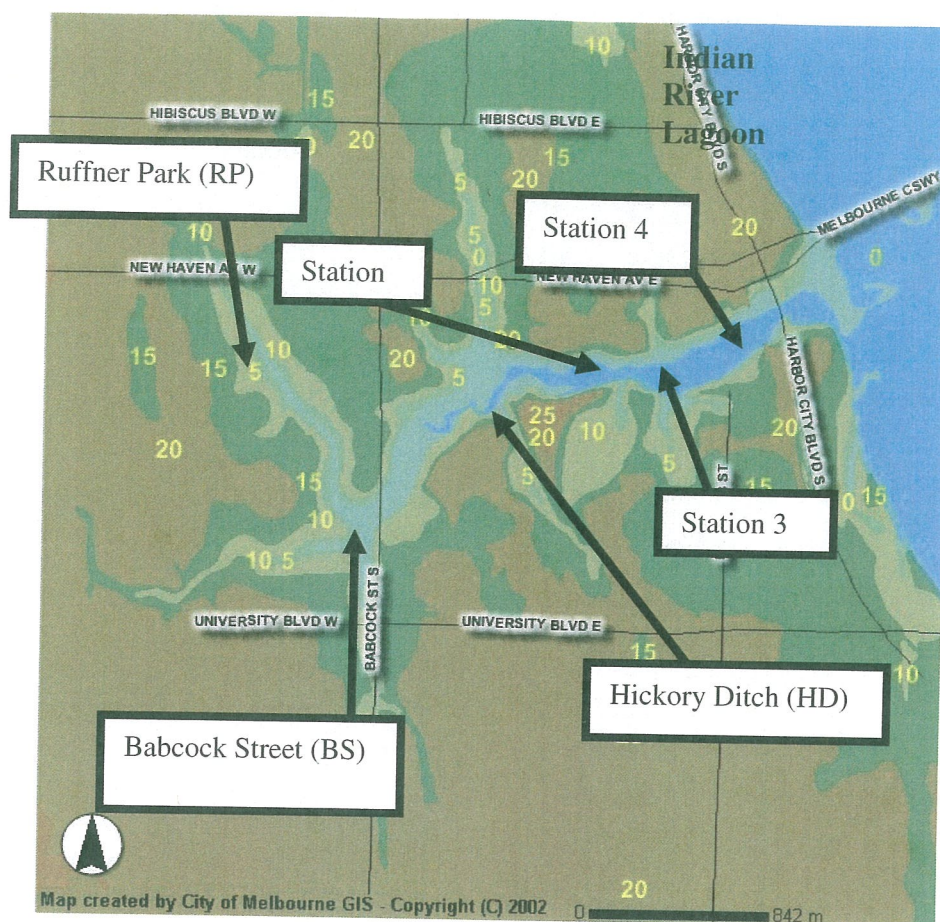


Figure 1

Sampling stations in Crane Creek, Melbourne Florida.
Stations are shown on a contour map.

0 ft - 5 ft - 10 ft - 15 ft - 20 ft - 25 ft

2.0 METHODS

2.1 Field Studies

Temperature, salinity, dissolved oxygen and percent saturation were directly measured in the field using a YSI model 85 (Yellow Spring Instruments) and used to generate density profiles in the water body employing the International Equation of State of Sea Water, 1980 (Millero and Poisson, 1981), that is meant to be used in water with similar chemical composition as standard seawater. Small errors are involved by the Equation of State when it is used for water masses different in composition from standard seawater (United Nations Educational Scientific and Cultural Organization, 1981). The density of a seawater sample with practical salinity (s psu), temperature ($t^{\circ}\text{C}$) and sea pressure (p bars) is given by:

$$\rho(s, t, p) = \frac{\rho(s, t, 0)}{1 - \frac{p}{K(s, t, p)}}$$

where $K(s, t, p)$ is the secant bulk modulus given by:

$$\begin{aligned} K(s, t, p) = & 19.652.21 + 148.4206 \times t - 2.327105 \times t^2 + 1.360477 \times t^3 - 5.155288 \times 10^{-5} \times t^4 \\ & + 3.239908 \times p + 1.43713 \times 10^{-3} \times t \times p + 1.16092 \times 10^{-4} \times t^2 \times p \\ & - 5.77905 \times 10^{-7} \times t^3 \times p + 8.50935 \times 10^{-5} \times p^2 - 6.12293 \times 10^{-6} \times t \times p^2 \\ & + 5.2787 \times 10^{-8} \times t^2 \times p^2 + 54.6746 \times s - .603459 \times t \times s + 1.09987 \times 10^{-2} \times t^2 \times s \\ & - 6.1670 \times 10^{-5} \times t^3 \times s + 7.944 \times 10^{-2} \times s^{3/2} + 1.6483 \times 10^{-2} \times t \times s^{3/2} \\ & - 5.3009 \times 10^{-4} \times t^2 \times s^{3/2} + 2.2838 \times 10^{-3} \times p \times s - 1.0981 \times 10^{-5} \times t \times p \times s \\ & - 1.6078 \times 10^{-6} \times t^2 \times p \times s + 1.91075 \times 10^{-4} \times p \times s^{3/2} - 9.9348 \times 10^{-7} \times p^2 \times s \\ & + 2.0816 \times 10^{-8} \times t \times p^2 \times s + 9.1697 \times 10^{-10} \times t^2 \times p^2 \times s \end{aligned}$$

The density of sea water at one standard atmosphere pressure *i.e.* $p = 0$ is given by:

$$\begin{aligned} \rho(s, t, 0) = & + 999.842594 + 6.793952 \times 10^{-2} \times t - 9.095290 \times 10^{-3} \times t^2 + 1.001685 \times 10^{-4} \times t^3 \\ & - 1.120083 \times 10^{-6} \times t^4 + 6.536332 \times 10^{-9} \times t^5 + 8.24493 \times 10^{-1} \times s \\ & - 4.0899 \times 10^{-3} \times t \times s + 7.6438 \times 10^{-5} \times t^2 \times s - 8.2467 \times 10^{-7} \times t^3 \times s \\ & + 5.3875 \times 10^{-9} \times t^4 \times s - 5.72466 \times 10^{-3} \times s^{3/2} + 1.0227 \times 10^{-4} \times t \times s^{3/2} \\ & - 1.6546 \times 10^{-6} \times t^2 \times s^{3/2} + 4.8314 \times 10^{-4} \times s^2 \end{aligned}$$

Streamflow at Ruffner Park and Hickory Ditch were calculated from current measurements using a Pygmy Meter model AA. This is one method that the United States Geological Survey (Rantz, 1982) uses to find the average velocity of a stream. During the whole period of sampling, the water level was less than 0.8 meter so the instrument was deployed at six-tenths of the total depth where the average velocity is assumed. Streamflow at US.1 (provisional data) was personally communicated by Howard G. George, supervisory hydrologic technician of the USGS Florida Integrated Science Center.

2.2 Total Suspended Solids, Turbidity and Weather

Sample collection and analysis for TSS were similar to those described by American Public Health Association et al. (1989). Briefly, samples were collected in 1000 mL nalgene HDPE (High Density Poly Ethylene) bottles that were acid washed and labeled prior to entering the field. Bottles were rinsed three times with sample water before use. Water was retrieved at various depths using a horizontal water sampler. Prior to filtration, blank filters were stored in 48 mm Millipore Petri dishes that were dried to a constant weight. A Welch Thomas Dry Vacuum Pump model 2545B was employed to filter the samples through a 0.45 μm Whatman Nuclepore synthetic filter. After filtering ~ 400 mL of sample, the filters were rinsed with deionized water to dilute the salts. Then, the same procedure was followed for drying and weighing filters. A final mass was determined by subtracting the post mass to the pre mass and converted to the total suspended solids concentration in milligrams per liter of filtrate.

Sample collection and analysis for turbidity were similar to those described by American Public Health Association et al. (1989). The Hach model 2100A turbidimeter was calibrated with standard formazine concentrations (0.61, 10 and 100 NTU).

Air temperature, precipitation and wind direction and intensity, were downloaded from the National Weather Service web site and compared to the normal temperature and rainfall data for the years 1971-2000 (National Oceanic and Atmospheric Administration, 2003b).

2.3 Statistics

Wind speed, precipitation, water density and flow were separated into groups (**Table 2**) to explore graphically and statistically the distribution and variation of TSS and turbidity in Crane Creek. All statistical analyses were performed using SigmaStat for Windows version 2.03. Normality and homogeneity tests were automatically verified when doing the Kruskal-Wallis one-way analysis of variance (ANOVA) on ranks. This ANOVA is a nonparametric test that does not require the assumption that all the samples were drawn from normally distributed populations with equal variances. This test ranks the median values but not the means. The median is the middle observation computed by ordering all observations from smallest to largest, then selecting the largest value of the smaller half of the observations. The mean is the average value of a group of observations. In a normally distributed data set, the mean is the median of the distributions. Each Kruskal-Wallis ANOVA performs a normality test, a H statistic test and a multiple comparison if a difference is found among the groups. For each test, the P -value is given and

compared to 0.05. The P -value is the probability of being wrong in concluding that there is a true difference in the groups. The smaller the P -value ($P < 0.05$), the greater the probability that the samples are significantly different.

A Kruskal-Wallis one-way ANOVA on ranks was performed to test the hypothesis that is TSS and turbidity were significantly different among stations (horizontal and vertical) throughout the creek. The null hypothesis tested here was that there is no difference in the distribution of TSS and turbidity values between the different stations. when a difference was found among the groups (large H and $P < 0.05$) the ANOVA was followed by a pairwise multiple comparison using Dunn's method that computes the Q test statistic. The difference of the two groups being compared is statistically significant if Q is large.

Five Kruskal-Wallis one-way ANOVA on ranks were performed to test the hypothesis that is TSS and turbidity were significantly different within the different categories described in **Table 2**. Pairwise multiple comparisons were also performed using the Dunn's method.

Table 2
Subcategories and ranges for the factors investigated

Factors	Sub-category	Ranges
Density (kg/m ³)	Low density	<1000
	Medium density	1000-1050
	High density	>1050
Flow (m ³ /s)	Landward	<0
	Seaward low flow	0.0-0.5
	Seaward medium flow	0.5-1.0
	Seaward high flow	>1.0
Precipitation (mm)	No precipitation	0
	Medium precipitation	<25
	Storm	>25
Salinity (psu)	Fresh water	0-10
	Mixed water	11-20
	Saline water	>20
Wind Speed (km/h)	Low wind speed	6-10
	Medium wind speed	11-15
	High wind speed	16-20
	Strong wind speed	>20

Correlation coefficients between total suspended solids and turbidity at each station (horizontal and vertical) and for the whole creek were calculated using STATISTICA 6.1 for the Spearman Rank Order Correlation Coefficient method, which is a non-parametric test that does not require the data points to be linearly related with a normal distribution about the regression line with constant variance. The Spearman Rank Order Correlation Coefficient is computed by ranking all values of each variable, then computing the Pearson Product Moment Correlation coefficient of the ranks.

3.0 RESULTS AND DISCUSSION

A total of 461 samples were analyzed for total suspended solids and turbidity from the Crane Creek estuary from January 2002 to February 2003. Water quality variables such as water temperature, salinity, dissolved oxygen and percent saturation were also recorded and are contained in **Appendix A** and **Appendix B** for samples collected at stations 2 and 3 respectively. Raw TSS and turbidity data and the environmental factors such as water density, flow, precipitation, salinity and wind speed are listed in **Appendix C**.

Five sections follow the overview of the TSS, turbidity and water quality data given in **Table 3** and **Figure 3**. The first section is about the weather conditions when the samples were collected. The second section discusses the complexity of the creek while analyzing samples collected at the surface and within the water body. The third section discusses the factors that affect TSS and turbidity in Crane Creek. The relationship between these variables is given in the fourth section. Finally, the fifth and last section addresses some of the limitations of this methodology.

Table 3 describes TSS, turbidity, water density and the water quality variables giving the mean, standard deviation and range for each station of Crane Creek, Melbourne, Florida from January 2002 to February 2003. The number of observations N varies from station to station and from variable to variable because there were days when water could not be sampled. Water at station 3III for instance was always collected at 3.3 m. Therefore, during the dry season when the water level is low, water at station 3III could not be collected. Mean TSS and turbidity were highest at station 2D (11.9 ± 7.4 mg/L and 5.0 ± 2.5 NTU). Values were lowest at Ruffner Park for TSS (6.3 ± 10.6 mg/L) and station 3II for turbidity (3.1 ± 1.9 NTU).

Figure 2 shows typical temperature, salinity, density, dissolved oxygen concentration and percent saturation profiles for Crane Creek, Florida from January 2002 to February 2003. This figure will often be referred to discuss the other sections.

Figure 3 groups the TSS and turbidity histograms of the samples. About 77% (350/461) of the samples had a TSS value ranging from 0 to 10 mg/L, 20% (92/461) from 10 to 20 mg/L and 3% (14/461) greater than 20 mg/L. The turbidity histogram (**Figure 3**) shows that 44% (202/461) of the samples collected had a value of 2 to 4 NTU, 26% (120/461) between 4 and 6 NTU, less than 19% (88/461) between 0 to 2 NTU, 7% (32/461) greater than 6 NTU and 4% (18/461) over 8 NTU.

Table 3

Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum and Number of Observation) for Turbidity, Total Suspended Solids, Water Temperature, Salinity, Dissolved Oxygen, Percent Saturation and Water Density at Each Station in the Crane Creek System, Melbourne, Florida From January 2002 to February 2003.

Stations		RP	BS	HD	2S	2D	3S	3I	3II	3III	4S	4D
Turbidity (NTU)	# Obs	26	27	21	49	46	48	48	48	42	48	48
	Mean	4.0	4.2	5.0	4.2	5.0	4.3	3.2	3.1	3.2	3.9	3.4
	Min.	1.6	1.1	0.9	1.3	1.6	1.2	1.0	0.7	0.9	1.5	1.0
	Max.	18.0	22.0	18.0	13.3	15.0	16.7	8.0	10.0	8.0	12.0	8.0
	Stdev.	3.2	3.8	4.7	2.0	2.5	2.6	1.5	1.9	1.9	1.9	1.7
TSS (mg/L)	# Obs	26	27	21	49	46	48	48	48	42	48	48
	Mean	6.3	10.1	10.2	7.5	11.9	7.6	7.5	7.2	7.0	7.4	7.9
	Min.	1.0	1.8	0.7	3.0	3.6	2.0	3.0	2.6	1.1	1.6	2.8
	Max.	57.0	72.4	39.0	14.8	35.0	16.8	18.3	19.4	17.6	18.0	23.8
	Stdev.	10.6	18.1	8.9	2.6	7.4	3.3	3.4	4.1	3.7	3.3	4.4
Temperature (°C)	# Obs	11	12	12	55	55	55	55	55	49		
	Mean	26.5	26.5	27.7	25.8	25.7	25.9	25.0	24.4	24.2		
	Min.	25.6	25.5	26.1	17.4	15.3	17.2	13.5	12.7	13.0	N/A	N/A
	Max.	27.7	27.7	29.4	32.4	32.3	32.7	32.6	32.4	31.6		
	Stdev.	0.7	0.7	1.0	4.3	4.5	4.4	5.1	5.3	5.3		
Salinity (psu)	# Obs	11	12	12	55	55	55	55	55	49		
	Mean	0.6	0.6	0.4	5.7	12.0	7.5	19.7	22.6	23.1		
	Min.	0.4	0.4	0.3	0.5	0.3	0.5	1.2	15.0	15.1	N/A	N/A
	Max.	0.7	0.8	0.5	19.3	31.7	25.0	35.2	35.5	35.5		
	Stdev.	0.1	0.1	0.1	4.6	7.0	5.7	6.0	5.3	5.4		

Table 3

Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum and Number of Observation) for Turbidity, Total Suspended Solids, Water Temperature, Salinity, Dissolved Oxygen, Percent Saturation and Water Density at Each Station in the Crane Creek System, Melbourne, Florida From January 2002 to February 2003. Continued

Stations		RP	BS	HD	2S	2D	3S	3I	3II	3III	4S	4D
Dissolved Oxygen (mg/L)	# Obs	11	12	12	55	55	55	55	55	49		
	Mean	5.1	4.7	5.5	9.5	7.1	7.3	5.3	3.0	1.9		
	Min.	4.0	3.8	3.6	4.3	0.1	3.5	0.7	0.0	0.0	N/A	N/A
	Max.	5.9	5.5	11.0	110.6	16.0	11.3	12.8	11.2	10.3		
	Stdev.	0.5	0.4	2.2	14.0	3.1	2.1	2.8	2.5	2.4		
Percent Saturatio n (%)	# Obs	11	12	12	55	55	55	55	55	49		
	Mean	63.4	58.1	65.3	96.8	88.9	94.0	68.4	38.1	23.2		
	Min.	50.1	47.0	7.0	56.1	0.8	44.8	11.0	0.0	0.0	N/A	N/A
	Max.	73.4	70.0	138.5	151.4	176.0	166.7	138.5	118.1	111.9		
	Stdev.	6.5	5.6	33.6	25.4	37.2	28.8	33.3	27.8	27.8		
Density (kg/m ³)	# Obs	11	12	12	55	55	55	55	55	49		
	Mean	982.5	985.0	988.6	982.8	994.9	990.6	986.8	992.3	996.0		
	Min.	977.6	979.3	975.4	970.4	970.4	970.4	970.4	970.7	970.9	N/A	N/A
	Max.	988.8	990.1	1023.4	1083.1	1309.4	1202.1	1024.1	1001.0	1001.2		
	Stdev.	3.1	2.6	13.0	19.3	52.3	48.0	13.0	8.4	7.9		

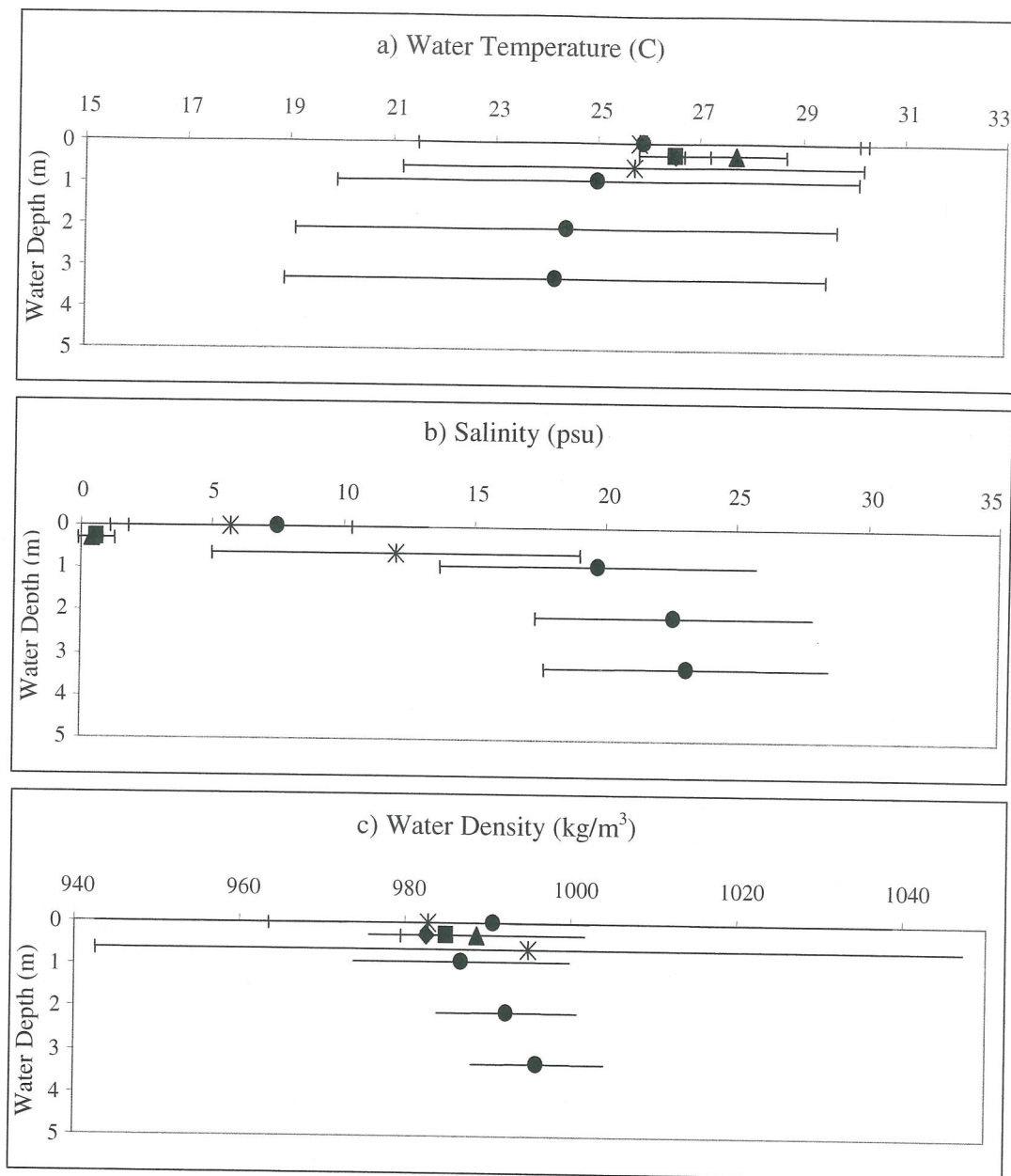


Figure 2

Markers show average water temperature (C), salinity (psu), water density (kg.m³), dissolved oxygen (mg/L) and percent saturation (%) at Ruffner Park (♦), Babcock Street (■), Hickory Ditch (▲), Station 2 (*) and Station 3 (●) in Crane Creek, Florida from January 2002 to February 2003. lines show standard deviations.

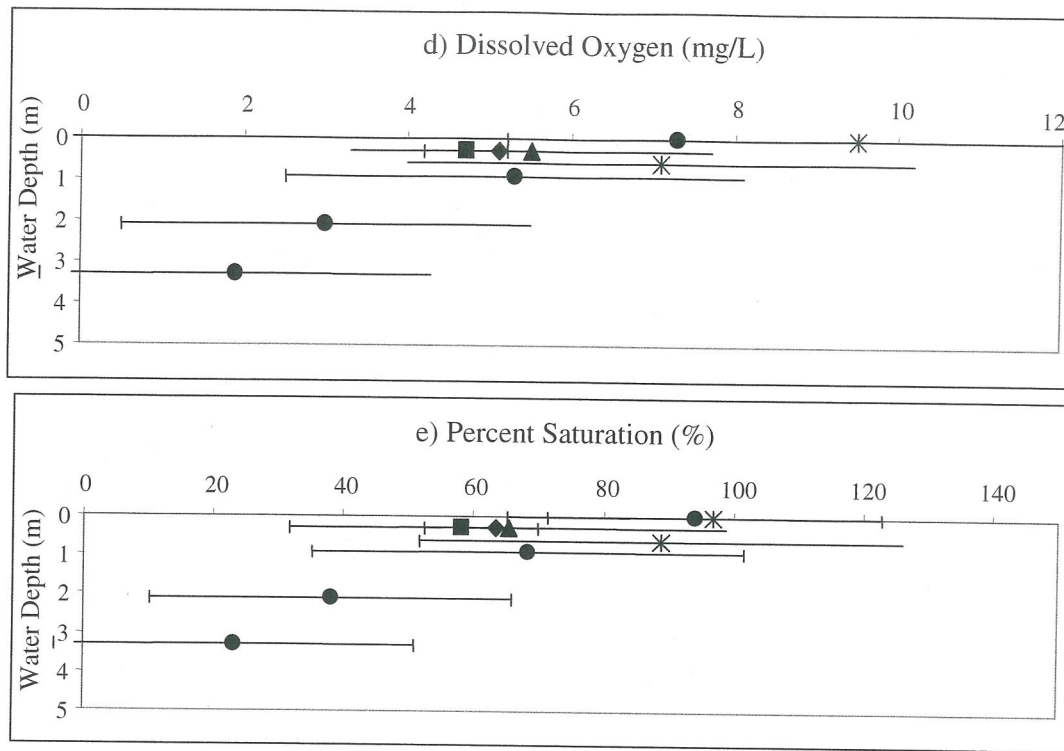


Figure 2 Cont.

Markers show average water temperature (C), salinity (psu), water density (kg.m^3), dissolved oxygen (mg/L) and percent saturation (%) at Ruffner Park (◆), Babcock Street (■), Hickory Ditch (▲), Station 2 (*) and Station 3 (●) in Crane Creek, Florida from January 2002 to February 2003. lines show standard deviations. Continued

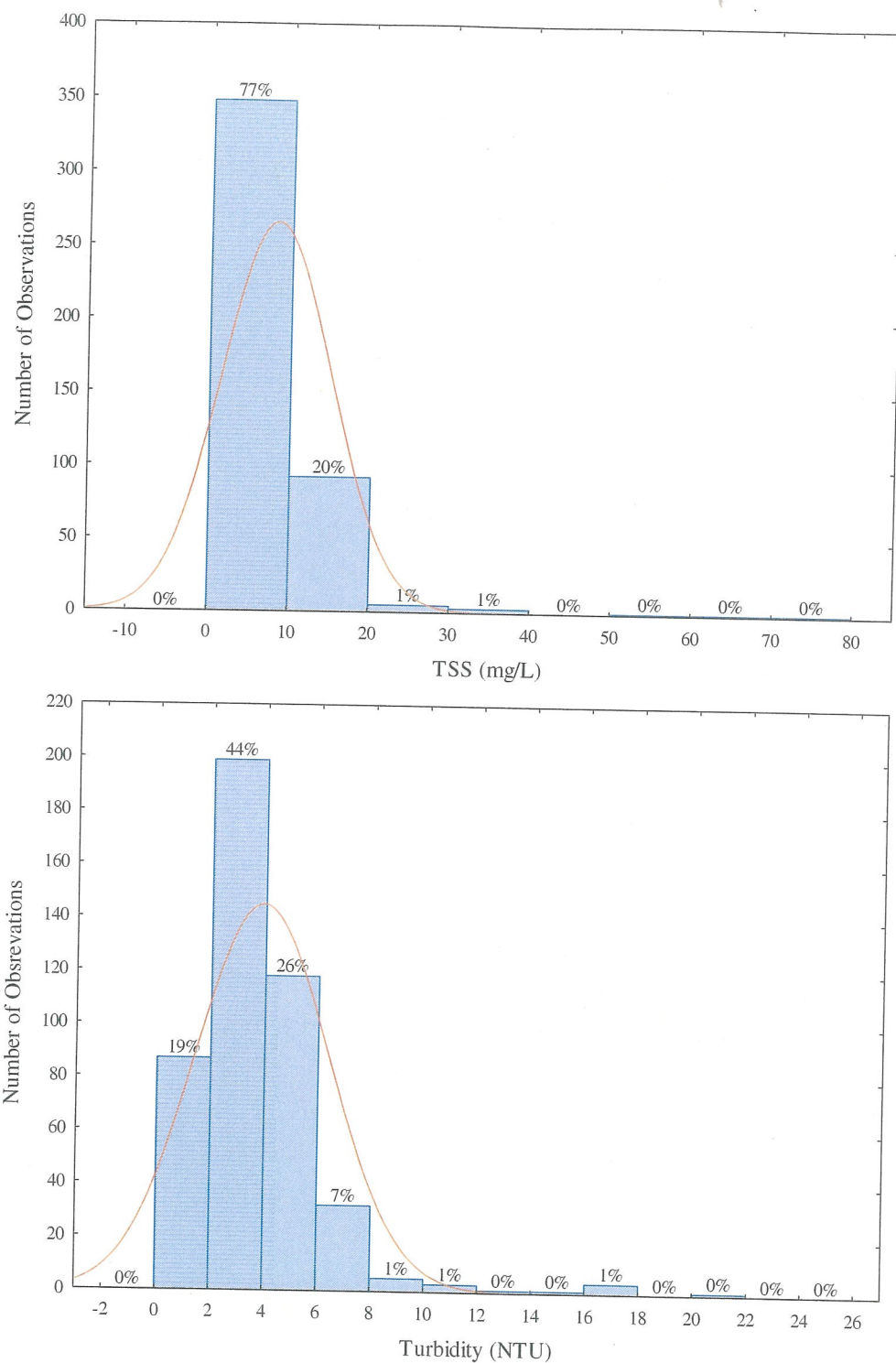


Figure 3

TSS (mg/L) and turbidity (NTU) histograms from samples collected from January 2002 to February 2003 in Crane Creek, Melbourne, Florida.

3.1 What were the Weather Conditions over the Study Period?

Water quality variables in Crane Creek also were recorded over the past years so the weather conditions over the study period will be discussed here. Since Garcia (1998) and Straccione (2002) had measured TSS and turbidity that are to be discussed in this thesis, the weather conditions during which they monitored Crane Creek also are reviewed in this section. Monthly mean precipitation and air temperature (National Oceanic and Atmospheric Administration, 2003b) are shown in **Figure 4**. Normal monthly values (National Oceanic and Atmospheric Administration, 2003c) that are monthly mean data collected for the period 1971-2000 are also represented to compare them with those recorded first in 1997 and 1998 by Garcia (1998), second in 2001 by Straccione (2002) and third between January 2002 and February 2003 for this research.

During Garcia's study, temperatures were the warmest in the past 119 years according to the National Oceanic and Atmospheric Administration (2003a). The period of November 1997 to March 1998 was excessively wet according to experts of the National Oceanographic and Atmospheric Administration (1999) who reported 736 mm of water which was 431 mm more than the normal. The excessive wet period was caused by the passage of numerous cold fronts. In 1998, an excessive dry period followed the wet season until July 1998. It rained 305 mm less than normal (National Oceanic and Atmospheric Administration, 1999). Then, two hurricanes arrived consecutively, hurricane Georges in September 1998 and hurricane Mitch in October 1998. These hurricanes did not directly hit Melbourne but they certainly brought rain and flooded the streets of the city. During Straccione's study, the year 2001 was believed to be the second warmest year after 1998 (National Oceanic and Atmospheric Administration, 2002).

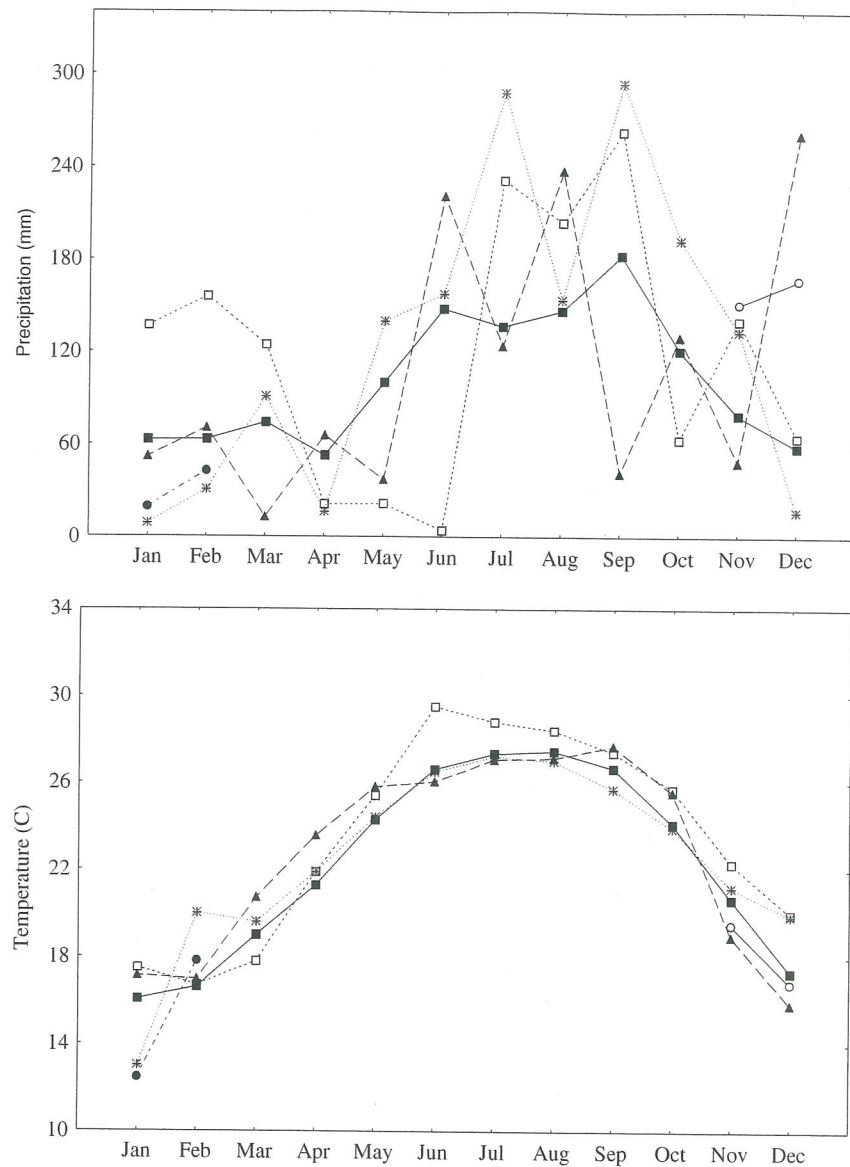


Figure 4

Monthly mean precipitation (mm) and air temperature (C) data recorded at the Melbourne International Airport, Florida from 1997 to 2003.

-○- 1997, -□- 1998, -* 2001, -▲- 2002, -●- 2003 and -■- Normal (1971-2000)

Florida received a large amount of rain in some localities from March 2001 but still remained quite dry like in May 2001. For instance, Lake Okeechobee dropped to 2.7 m above sea level (National Oceanic and Atmospheric Administration, 2002). But in the middle of the year, Florida recovered from the nearly three and half year drought (**Figure 4**).

Monthly mean rainfall during seven out of twelve months of the year 2002 was normal. The other months such as March, May, September 2002 and January 2003 had monthly mean precipitation under the normal values. Dry conditions were observed in March, May and September when rain did not fall or traces were recorded. On the other hand, monthly mean precipitation during June, August and December 2002 were above normal. These months were two to eight times wetter in 2002 than the average for thirty years. While precipitation was not “normal”, monthly mean air temperature at Melbourne, Florida followed a similar trend to the thirty years mean ($\pm 2^\circ\text{C}$). Now, NOAA (2003a) placed the year 2002 instead of 2001 as the second warmest year on record after 1998 during which a strong El Nino contributed to an increase of air temperature.

Mean TSS and turbidity from November 1997 to February 2003 are plotted in **Figure 5**. The highest mean TSS values are from November 1997 to September 1998 and are those measured by Garcia (1998) before and during the 1998 dredging and during the excessively wet months of the year (National Oceanic and Atmospheric Administration, 1999). Since 2001, TSS decreased from 17.1 ± 17.3 mg/L (Feb-Mar 98) to 10.9 ± 6.8 mg/L (Jan-Feb 03). This could be either due to the sediment trap efficiency of the deepening of Crane Creek, or to the weather conditions; or, both reasons could explain the trend because the period July-November 2001 and the months of June, August and December 2002 were the wettest.

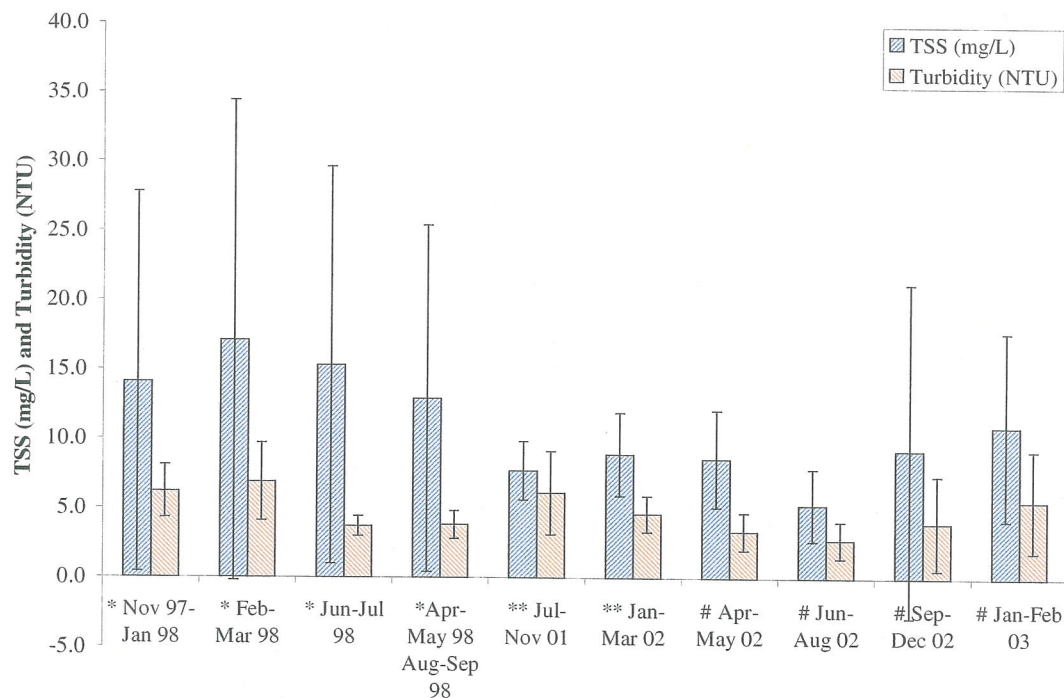


Figure 5

Mean TSS (mg/L) and turbidity (NTU) during Garcia (*) (1998), Straccione (**) (2002) and this current (#) Crane Creek study in Melbourne, Florida.

3.2 Why Compare Surface Water to Deeper Water in Crane Creek?

Temperature, salinity, density, dissolved oxygen and percent saturation profiles from **Figure 2** show that Crane Creek is a typical salt-wedge estuary. Therefore, statistical analyses were performed to test if TSS and turbidity varied from stations to stations. Results of the Kruskal-Wallis one-way ANOVA on ranks and the pairwise multiple comparisons are shown in **Table 4** for TSS and **Table 5** for turbidity. TSS median concentrations and turbidity median values were highest at station 2D and lowest at Ruffner Park (RP) for TSS and 3II for turbidity. **Figure 6** is a graphical representation of these statistical results. A circle indicates that the two stations have significant statistically different median values. TSS concentrations at station 2D were significantly different ($P < 0.05$) to those at stations BS, 3II and 3III. A statistical difference between concentrations was also found at station RP and concentrations at all the other stations except BS, 3II and 3III.

Median turbidity values at 2D were significantly different from values at stations 4D, 3I, 3II and 3III. In other words, all surface water samples (RP, BS, HD, 2S, 3S, and 4S) had the same median turbidity during the whole year of 2002 whereas the deep water samples *i.e.* the ones collected below 0.6 meters were different.

Table 4

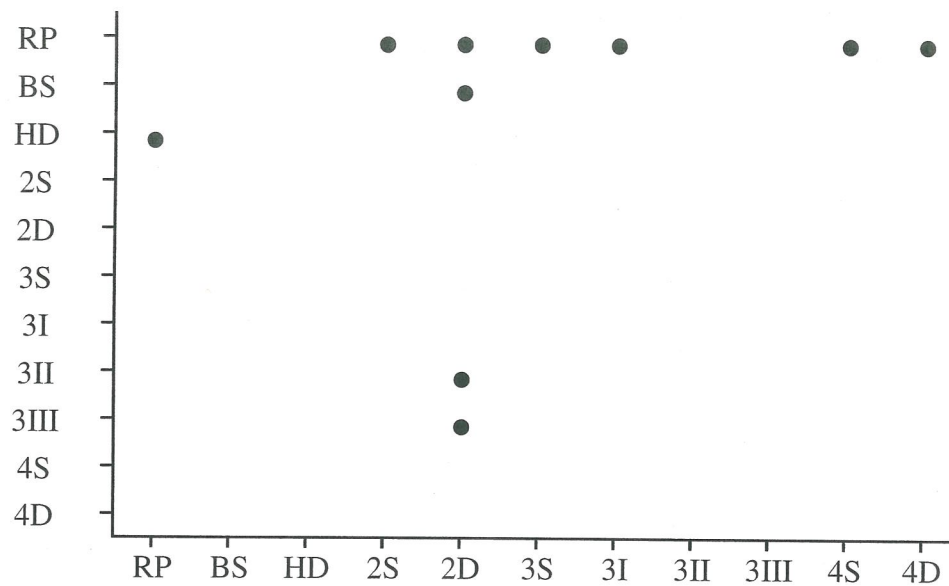
Left: Kruskal-Wallis One Way Analysis of Variance on ranks on TSS in each station. The normality test failed ($P \leq 0.001$). $H = 53.529$ with 10 degrees of freedom ($P \leq 0.001$). The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference ($P \leq 0.001$). Right: All Pairwise Multiple Comparison Procedures (Dunn's Method).

Group	N	Median	25%	75%	Comparison	Diff of Ranks	Q	P<0.05
2S	48	7.1	5.4	8.5	2D vs RP	195	6.1	Yes
2D	47	9.8	6.8	15.1	2D vs BS	171	5.4	Yes
3S	48	7.2	5.1	9.6	2D vs 3III	106	3.8	Yes
3I	48	6.9	4.5	9.4	2D vs 3II	104	3.9	Yes
3II	48	6.0	3.7	9.2	2D vs 4D	81	3.0	No
3III	42	5.9	4.3	8.5	HD vs RP	129	3.4	Yes
4S	48	7.3	5.0	9.5	HD vs BS	105	2.8	No
4D	48	6.5	4.6	11.6	2S vs RP	121	3.8	Yes
RP	26	3.6	2.8	5.8	3S vs RP	120	3.8	Yes
BS	27	4.0	2.8	6.6	4S vs RP	116	3.7	Yes
HD	21	6.5	5.0	13.0	3I vs RP	114	3.6	Yes
					4D vs RP	113	3.6	Yes
					3II vs RP	91	2.8	No

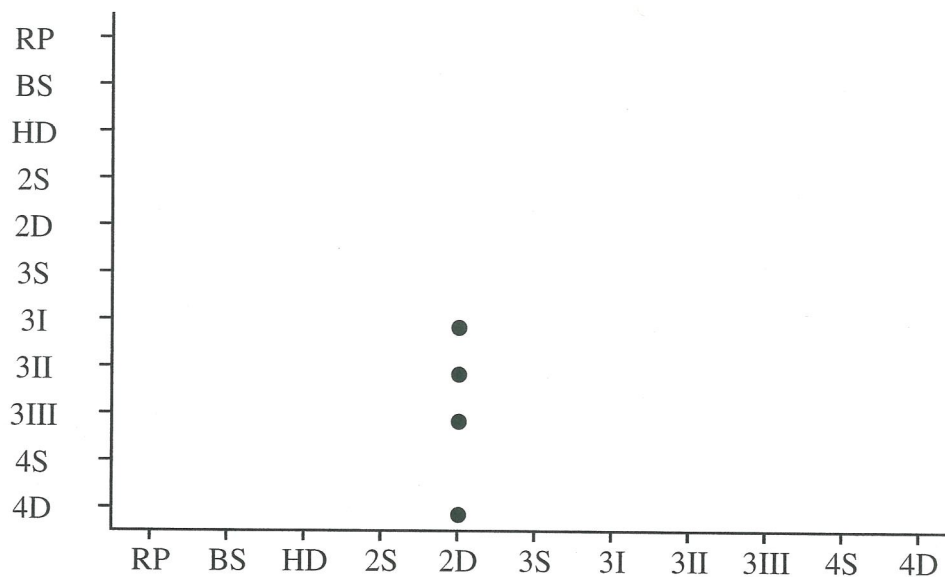
Table 5

Left: Kruskal-Wallis One Way Analysis of Variance on Ranks on Turbidity in each station. The normality test failed ($P \leq 0.001$). $H = 38.415$ with 10 degrees of freedom ($P \leq 0.001$). The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference ($P \leq 0.001$). Right: All Pairwise Multiple Comparison Procedures (Dunn's Method).

Group	N	Median	25%	75%	Comparison	Diff of Ranks	Q	P<0.05
2S	48	3.9	2.6	5.4	2D vs 3II	125	4.7	Yes
2D	47	4.5	3.4	6.0	2D vs 3III	114	4.1	Yes
3S	48	4.0	2.8	5.0	2D vs 3I	110	4.1	Yes
3I	48	3.1	2.0	4.3	2D vs 4D	97	3.6	Yes
3II	48	2.5	1.8	4.2	2D vs RP	77	2.4	No
3III	42	2.7	2.0	4.5	2S vs 3II	85	3.2	No
4S	48	3.5	2.6	4.7				
4D	48	3.0	2.1	4.4				
RP	26	3.2	2.3	4.5				
BS	27	3.7	2.6	4.6				
HD	21	3.6	2.3	5.4				



a) TSS



b) Turbidity

Figure 6

Multiple comparison graphs for TSS (a) and Turbidity (b). Symbols represent a significant difference of median between the two stations.

Salinity is often used to trace water masses. Therefore, water quality variables measured at depth increments of 0.3 m in the creek suggest that fresh water at the top, saline water at the

bottom and mixed water in the center are often encountered in Crane Creek. Garcia (1998) and Straccione (2002) have previously shown that Crane Creek is a salt wedge. The water is shallow (less than 1.2 m) upstream at Ruffner Park, Babcock Street, Hickory Ditch and Station 2 but the creek becomes deeper downstream at Station 3 (maximum 4 m deep) and Station 4 (3 m). The deepening of the creek allows the seaward water to mix with the landward water but also traps the water and so the suspended matter (Garcia, 1998; Straccione, 2002). Therefore one might think that TSS concentrations and turbidity values would differ from upstream to downstream and from surface to bottom water.

Because mean settling velocity is low for clay particles (3.5×10^{-4} cm/s), moderate for silts (1.0×10^{-2} cm/s) and fast for fine sands (9.9×10^{-1} cm/s) (Dyer, 1986), the suspended matter concentration at the surface can differ from the one at the bottom. Fine sands settle faster than clay and silt so the bottom water accumulates particles from the surface and from re-suspension. This could explain why the highest median TSS concentrations and turbidity values were measured at station 2D. On the other hand, station 3 at Manatee Park has the lowest turbidity values maybe because the water color is darker and/or macro-flocs are more abundant in the deep pocket than at the surface.

The results also suggest there should be a slightly dissimilar sampling strategy for the future. Station 3D should combine stations 3I, 3II and 3III when sampling turbidity and/or total suspended solids, as statistical analysis shown no significant difference between these stations (**Table 4 and Table 5**).

3.3 What are the Factors that Affect TSS and Turbidity?

In addition to the influence of weather and water depth on total suspended solids and turbidity, water density, salinity, flow, precipitation and wind speed also impact TSS and turbidity. The factors considered in this research were water density, flow, precipitation, salinity and winds speed (**Figure 7**). Measured values for the density of water in the Crane Creek estuary system fell between 950 and 1000 kg/m³ ~ 80% of the time. Stream flow values were between 0 and 0.5 m³/s (~ 43%). Negative numbers (20%) measured under the US.1 bridge indicate a reverse flow direction. These conditions were commonly seen in April and May 2002 (appendix C) when there is too little fresh water input to overcome the incoming Indian River Lagoon River water.

About 25% of the time water flowed between 0.5 and 1.0 m³/s and over 1.0 m³/s in the remaining 15%. The sampling period was particularly dry because it did not rain or traces (less than 6 mm) were barely detectable during 80% of the sampling phase. But, Crane Creek was also monitored when it rained between 6 to 20 mm of water and exceptions were made during two storm events, one relatively small event when it rained about 40 mm on October 24, 2002 and a bigger storm when the National Weather Service recorded some rainfall over 60 mm on November 16, 2002. TSS and turbidity were measured when salinity in the estuary was considered as fresh (0 to 10 psu) and as mixed (11 to 20 psu). Sampling was also performed when salinity was considered as saline (>20 psu). Wind speed averaged 14 km/h and ranged between 6 and 28 km/h.

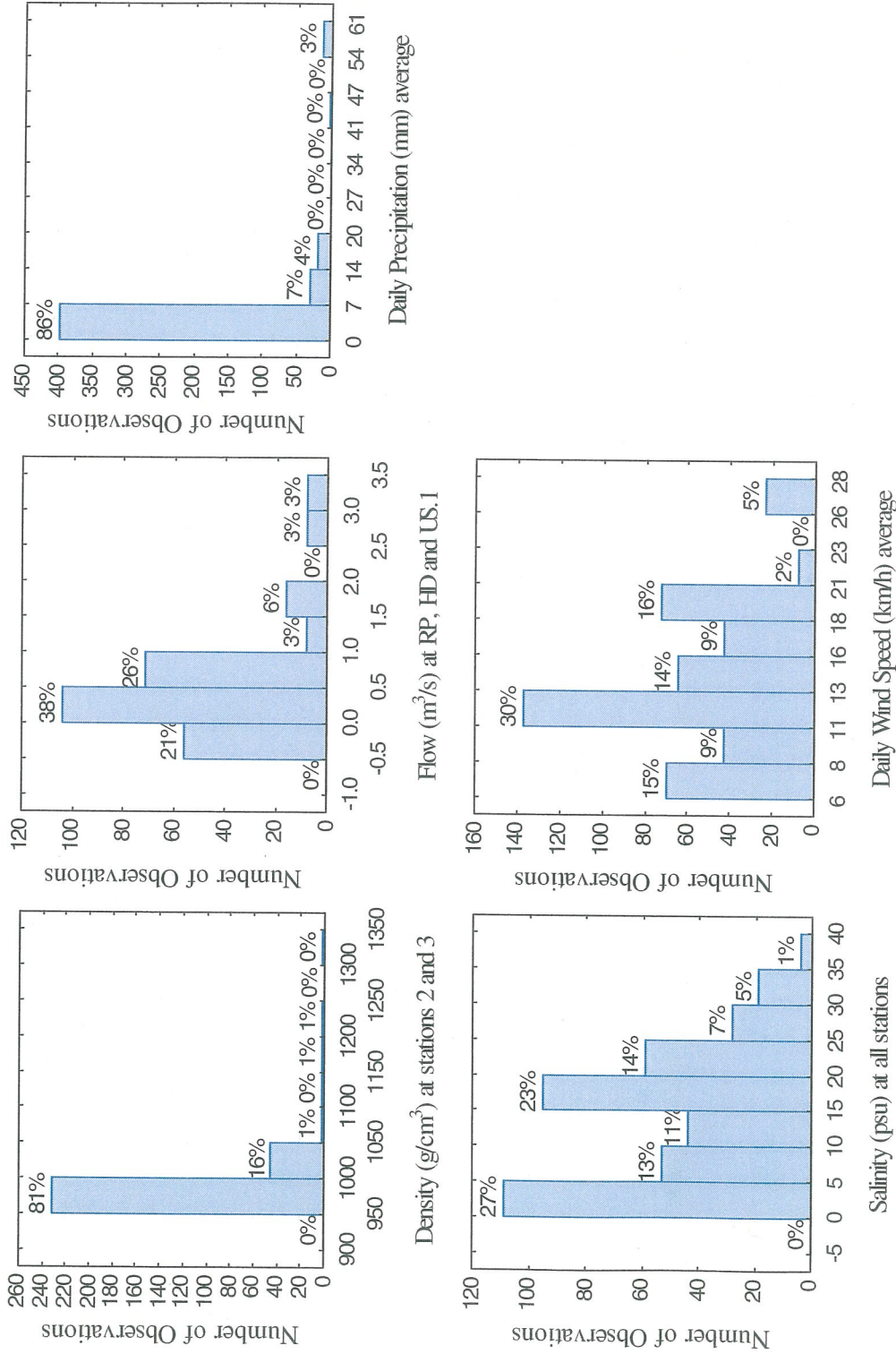


Figure 7

Histograms for each environmental factors such as water density, flow, precipitation, salinity and wind speed that were recorded when water samples were collected during the year 2002 and in February 2003.

The results of the five Kruskal-Wallis ANOVA on ranks were used to test if TSS and turbidity were significantly different within the different categories. For the density factor, the differences in the median TSS and turbidity values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistical significant difference because $P=0.130$ and is greater than 0.05 for TSS (**Table 6**) and $P=0.332$ for turbidity (**Table 7**). Water density did not have a statistically significant effect on TSS and turbidity although the highest median concentrations were measured at densities greater than 1050 kg/m^3 then at densities lower than 1000 kg/m^3 and the lowest values were found at densities between 1000 and 1050 kg/m^3 . The third category of density was calculated when dissolved oxygen was greater than around 10 mg/L and water temperature and salinity were measured to be between 15 and 30 °C and 15 to 30 psu (appendices A, B and C). Also notice that these densities were measured at the surface or mid-depth and in the Indian River Lagoon where dissolved oxygen was at maximum.

For the other factors, flow, precipitation, salinity and wind speed, the differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistical significant difference because $P \leq 0.001$. Median TSS values are statistically greater ($8.0 \pm 3.0 \text{ mg/L}$) when the flow of the river is equal to or less than $0.5 \text{ m}^3/\text{s}$, when it did not rain at all, when salinity is between 11 and 20 psu, and when the wind speed is greater than 20 km/h. Median turbidity values are greater and statistically different when the flow of the river is between 0 and $0.5 \text{ m}^3/\text{s}$, when it did not rain at all, when salinity is less than 20 psu. Wind speed has no statistical significant affect on turbidity ($P \leq 0.05$). Median TSS concentrations are greater ($8.0 \pm 3.0 \text{ mg/L}$ vs. $5.6 \pm 1.6 \text{ mg/L}$) and statistically different when the river-flow is equal to or less than $0.5 \text{ m}^3/\text{s}$ whereas median turbidity values are greater ($4.0 \pm 1.6 \text{ NTU}$ vs. $3.1 \pm 1.7 \text{ NTU}$) and statistically different when the river flows between 0 and $0.5 \text{ m}^3/\text{s}$.

Table 6

Left: Kruskal-Wallis One Way ANOVA on Ranks on TSS within each factor category.
The normality tests failed ($P \leq 0.001$).

Right: All Pairwise Multiple Comparison Procedures (Dunn's Method).

Density $H = 4.081$ with 2 degrees of freedom. ($P = 0.130$)

Group	N	Median	25%	75%
<1000	231	7.0	5.3	9.4
1000-1050	46	6.4	4.3	11.4
>1050	8	14.5	6.1	16.3

Flow $H = 22.167$ with 3 degrees of freedom. ($P \leq 0.001$)

Group	N	Median	25%	75%	Comparison	Diff of ranks	Q	P<0.05
<0	56	7.9	5.8	9.7	<0 vs 0.5-1	62.8	3.3	Yes
0-0.5	193	8.0	5.0	11.0	<0 vs >1	59.1	2.7	Yes
0.5-1	90	5.6	4.0	7.3	<0 vs 0-0.5	7.7	0.5	No
>1	46	5.9	5.2	7.0	0-0.5 vs 0.5-1	55.1	3.8	Yes
					0-0.5 vs >1	51.4	2.8	Yes
					>1 vs 0.5-1	3.6	0.2	No

Precipitation H = 20.800 with 2 degrees of freedom. ($P \leq 0.001$)

Group	N	Median	25%	75%	Comparison	Diff of Ranks	Q	P<0.05
0	335	7.3	5.0	10.8	0 vs <25	64.6	4.4	Yes
<25	111	5.5	4.0	7.3	0 vs >25	54.4	1.5	No
>25	15	4.2	3.7	10.5	>25 vs <25	10.2	0.3	No

Salinity H = 17.986 with 2 degrees of freedom. ($P \leq 0.001$)

Group	N	Median	25%	75%	Comparison	Diff of Ranks	Q	P<0.05
0_10	161	6.3	4.5	8.0	11_20 vs 0_10	58.4	4.2	Yes
11_20	134	8.1	5.2	11.1	11_20 vs >20	39.4	2.6	Yes
>20	116	6.1	4.5	9.8	>20 vs 0_10	19.0	1.3	No

Wind speed H = 23.619 with 3 degrees of freedom. ($P \leq 0.001$)

Group	N	Median	25%	75%	Comparison	Diff of Ranks	Q	P<0.05
6_10	114	5.5	3.6	8.5	>20 vs 6_10	122.2	4.6	Yes
11_15	202	7.1	4.7	10.0	>20 vs 16_20	94.8	3.5	Yes
16_20	114	6.5	4.6	9.0	>20 vs 11_15	74.7	2.9	Yes
>20	32	9.2	7.7	11.4	11_15 vs 6_10	47.6	3.0	Yes
					11_15 vs 16_20	20.1	1.3	No
					16_20 vs 6_10	27.5	1.6	No

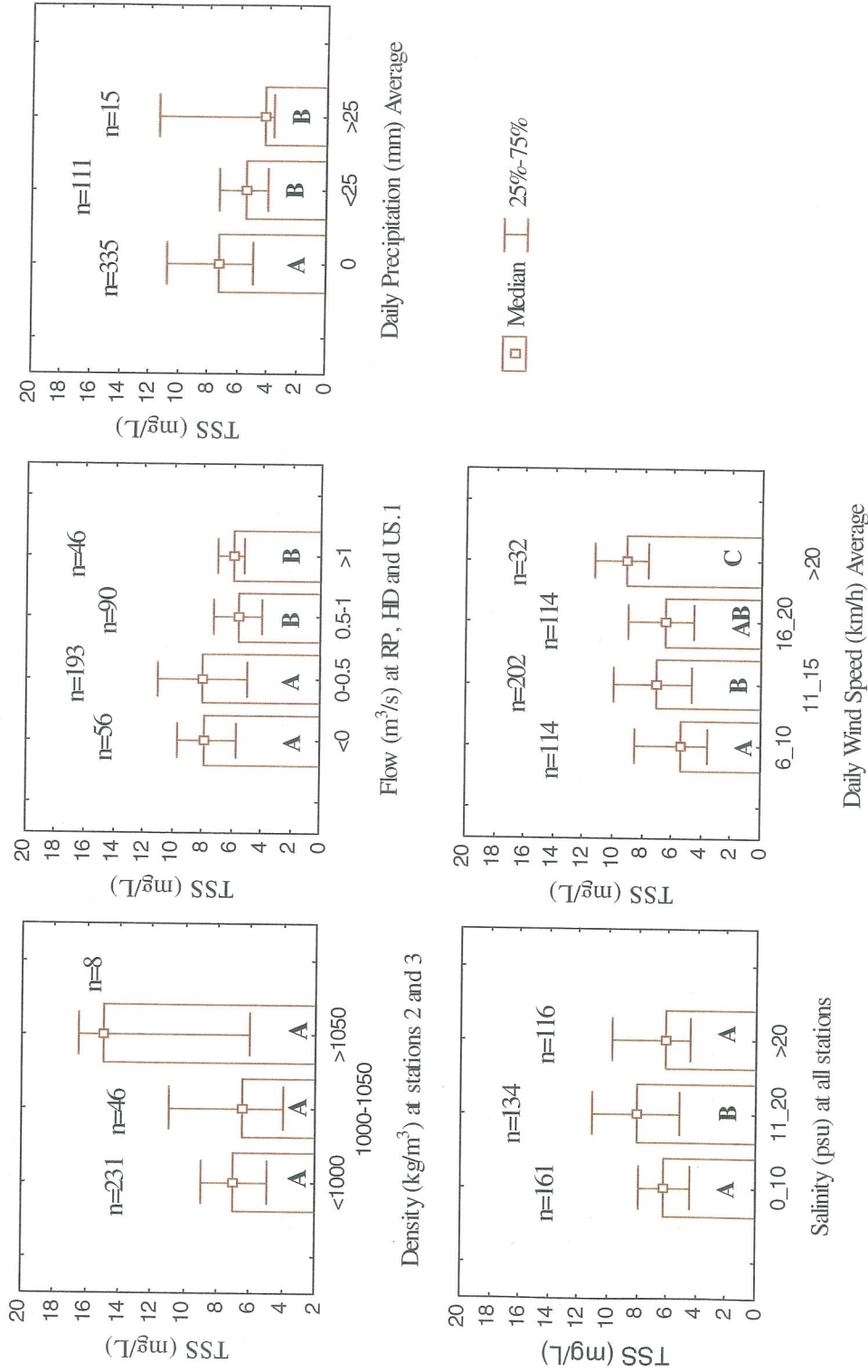


Figure 8

Multiple comparison graphs for median TSS concentrations within each category of factors (water density, flow, precipitation, salinity and wind speed). For each graph, columns that have the same letter are statistically not different. For instance, median TSS is statistically equal when flow is less than 0 m³/s or between 0 and 0.5 m³/s. conversely, median TSS is statistically significantly different (P<0.05) when flow is in the 0-0.5 m³/s and the group 0.5-1 m³/s.

Table 7

Left: Kruskal-Wallis One Way ANOVA on Ranks on turbidity within each factor category. The normality tests failed ($P \leq 0.001$). Right: All Pairwise Multiple Comparison Procedures (Dunn's Method).

Density $H = 2.204$ with 2 degrees of freedom. ($P = 0.332$)

Group	N	Median	25%	75%
<1000	230	3.5	2.3	4.9
1000-1050	46	2.9	2.1	4.6
>1050	8	4.2	2.7	5.4

Flow $H = 10.970$ with 3 degrees of freedom. ($P = 0.012$)

Group	N	Median	25%	75%	Comparison	Diff of Ranks	Q	P<0.05
<0	56	3.1	2.3	4.0	0-0.5 vs <0	47.0	2.8	Yes
0-0.5	194	4.0	2.5	5.1	0-0.5 vs 0.5-1	34.0	2.4	No
0.5-1	90	3.2	2.0	4.5	>1 vs <0	19.9	0.9	No
>1	46	3.5	2.2	4.3				

Precipitation $H = 25.889$ with 2 degrees of freedom. ($P \leq 0.001$)

Group	N	Median	25%	75%	Comparison	Diff of Ranks	Q	P<0.05
0	336	3.7	2.5	5.0	0 vs >25	91.8	2.6	Yes
<25	110	2.9	2.0	3.9	0 vs <25	67.5	4.6	Yes
>25	15	2.3	1.3	4.0	<25 vs >25	24.3	0.7	No

Salinity $H = 19.796$ with 2 degrees of freedom. ($P \leq 0.001$)

Group	N	Median	25%	75%	Comparison	Diff of Ranks	Q	P<0.05
0-10	159	3.7	2.6	5.0	0-10 vs >20	63.4	4.4	Yes
11-20	134	3.5	2.3	4.5	0-10 vs 11-20	18.0	1.3	No
>20	116	2.6	1.9	4.0	11-20 vs >20	45.4	3.0	Yes

Wind Speed $H = 8.391$ with 3 degrees of freedom. ($P = 0.039$)

Group	N	Median	25%	75%	Comparison	Diff of Ranks	Q	P<0.05
6-10	113	3.2	2.0	4.9	>20 vs 6-10	66.8	2.5	No
11-15	202	3.2	2.1	4.5				
16-20	114	3.6	2.5	4.6				
>20	32	4.0	3.3	5.3				

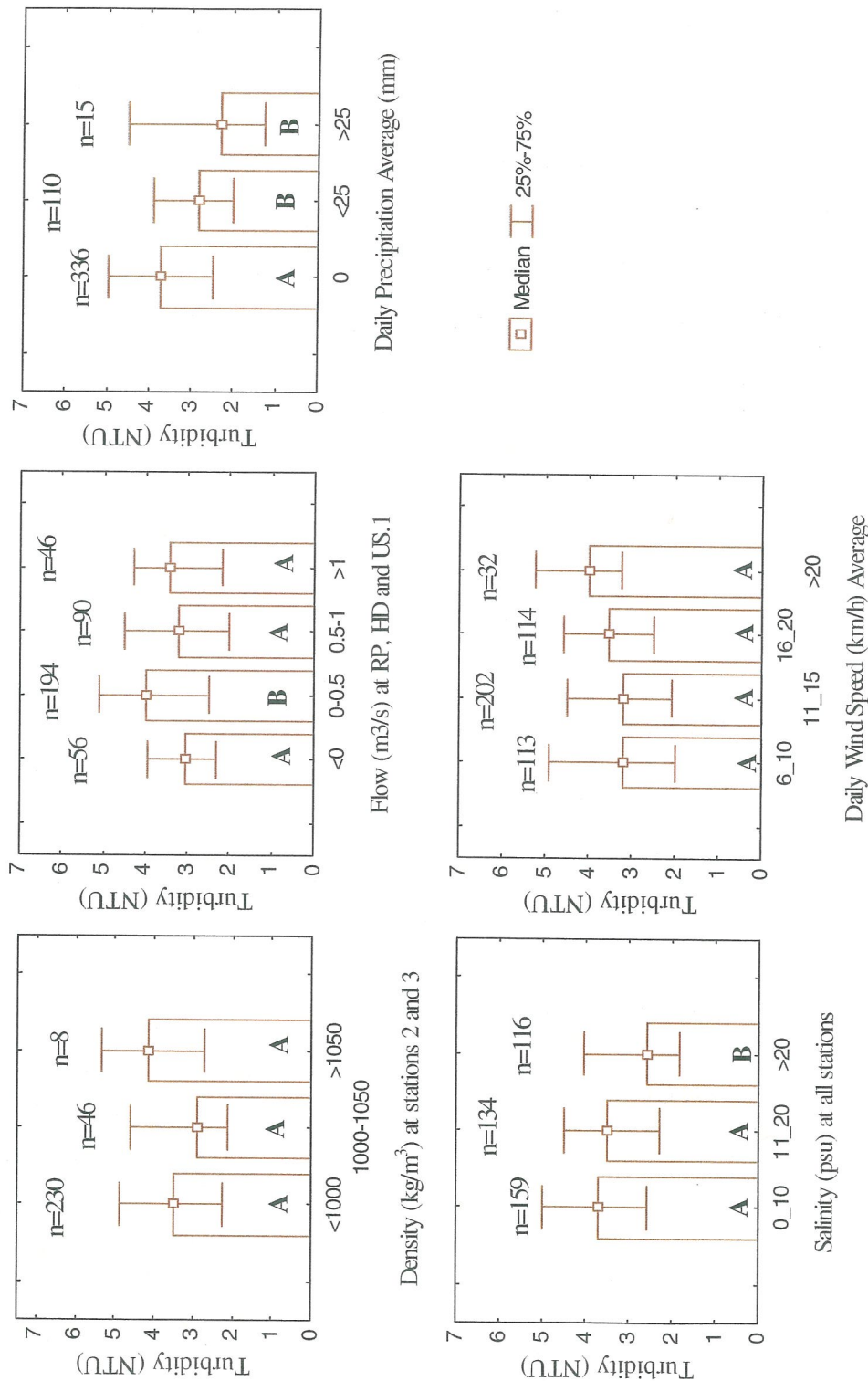


Figure 9

Multiple comparison graphs for median turbidity within each category of factors (water density, flow, precipitation, salinity and wind speed). For each graph, columns that have the same letter are statistically not different. For instance, median turbidity is statistically equal whenever it rained. Conversely, median turbidity is statistically significantly different ($P < 0.05$) when it didn't rain than when it did.

Water from the Indian River Lagoon, characterized by a negative flow is clearer (low turbidity) than fresh water coming from upstream. Low water flow is due to the widening of the creek pass the sewage treatment plant and the deepening in Manatee Park. Particulates that come from upstream are slowed down and since they have a long residence time according to Straccione (2002) (0.03, 3.4 and 99 hours for fine sand, silt and clay respectively), their concentrations increase. Silt and clay might stay longer in the water column in this range of river-flow and could explain the high turbidity values measured.

Trying to relate TSS and turbidity with rainfall can be difficult and contradictory. The concentration of the suspended matter in the water column can be subject to previous rainfall or dry events. The precipitation data collected for this research represent the average of rainfall of the day the water was sampled; although, considering all the days of rainfall might be more valuable but not taken into account because of the difficulty to analyze the data. Therefore one must be careful when interpreting the results and must not mix these data with those collected when the storm event that was monitored on October 24th 2002 (see 0 p. 35). Indeed, statistical analysis proved that median TSS and turbidity are higher when it did not rain at all than when it did. This 'dilution' effect was explained above with the effect of the weather during monitoring Crane Creek. The category >25mm for the factor precipitation represents the storm event so the 25-75% interval also suggests that the TSS and turbidity values could increase drastically.

Salinity was strongly correlated with TSS in the Loxahatchee Estuary, Florida (Noel et al., 1995). The opposite correlation is usually found in such a water system because TSS is normally expected to decrease with salinity. On the other hand, statistical analysis of this study shows that TSS is higher and different (8.0 ± 3.0 mg/L vs. 5.6 ± 1.6 mg/L) when salinity is between 11 and 20 psu than when it is less than 11 psu or greater than 20 psu.

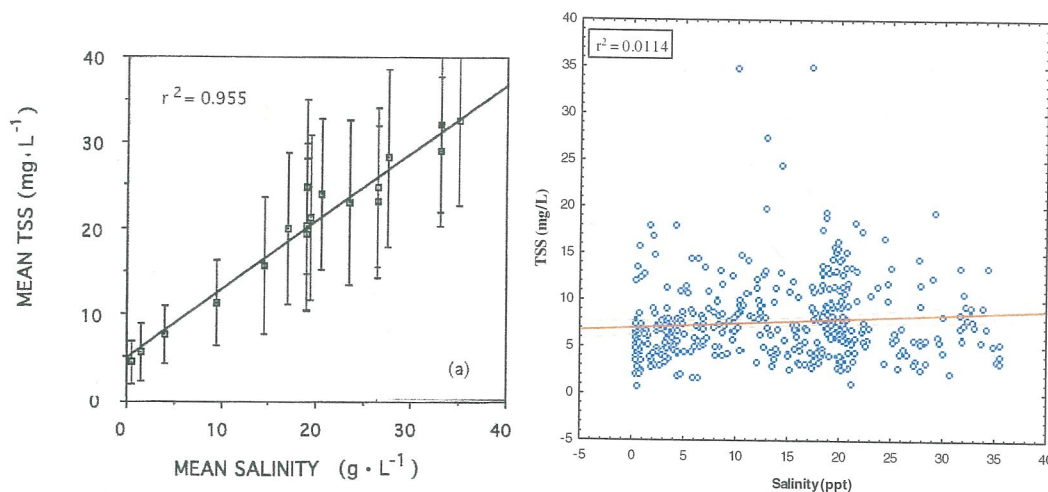


Figure 10

TSS-salinity relationship in the Loxahatchee Estuary, Florida (Noel et al., 1995) on the left, and in Crane Creek, Melbourne Florida between January 2002 to February 2003 on the right. Turbidity is lower (2.5 NTU) when salinity is greater than 20 psu.

This suggests that mixing fresh water and saline water increases the suspended sediment concentration and that seawater brings clearer water into the creek. During the mixing process that mainly occurs in Station 3 or Manatee Park, flocculation is enhanced. The zone where this phenomenon occurs is trapped between two layers (**Figure 11**). The first one is the seaward-moving surface layer and the second one is the landward-moving bottom water coming from the Indian River lagoon. The mixing zone is commonly known as the 'turbidity maxima' (Pickard and Emery, 1990) but it is more appropriate to call it the 'TSS maxima' because the results indicate a TSS maximum but not a turbidity maximum in this zone. Flocculation is important for the settling of the suspended matter. Macro-flocs have a high settling rates and the formation is enhanced by low turbulence and high particulate concentration (Kranck, 1984).

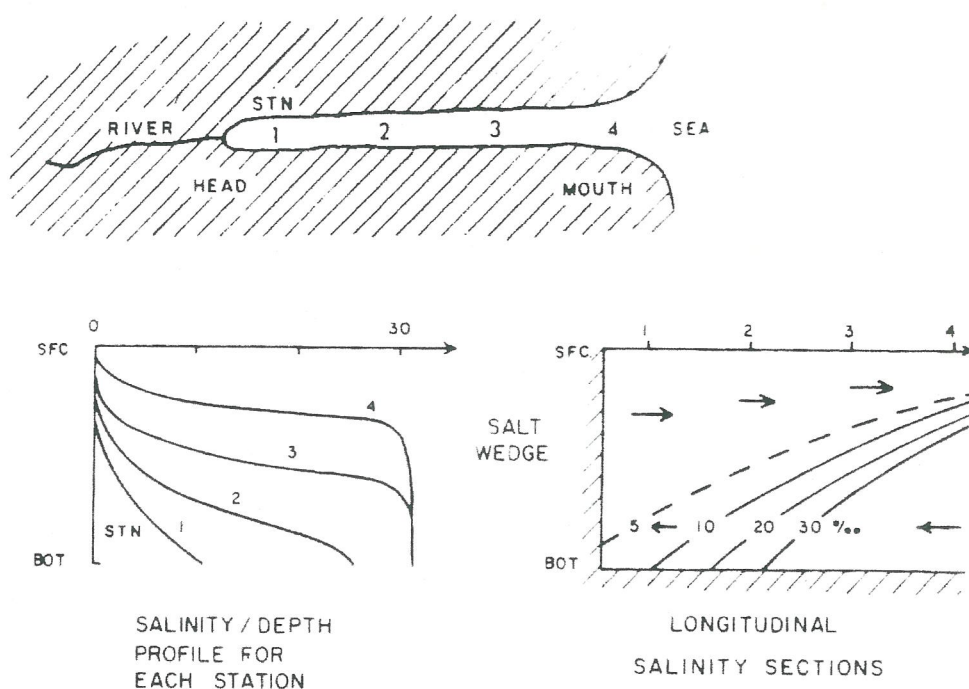


Figure 11

Schematic of a salt wedge type estuary. Top: stations 1 to 4 of an estuary. Bottom left: typical salinity/depth profiles. Bottom right: longitudinal salinity sections. Source: (Pickard and Emery, 1990).

Wind speed had an influence on TSS but not on turbidity (**Table 6**, **Table 7**, **Figure 8** and **Figure 9**). Median TSS concentrations was about 9.0 mg/L when the wind speed was greater than 20 km/h but only ~5.5 mg/L between 6 and 10 km/h. Conversely to this findings, in the Loxahatchee Estuary, Florida, statistical analysis revealed no significant difference in TSS attributed to wind speed (Noel et al., 1995). Strong winds especially affected shallow water. The shear stress on the surface of the water caused by the wind induces turbulence so the top sediment layer is re-suspended (**Figure 12**).

Laenen and Le Tourneau (1996) found out that wind speed greater than 16 km/h can create a bottom shear stress great enough to re-suspend the bed sediment in Upper Klamath Lake. Although Crane Creek is not a lake, station 2D is the best illustration of the effect of wind on suspended matter. Since wind direction was mainly coming from the east, saline and clearer water from the Indian River Lagoon was pushed towards the creek; therefore, turbidity decreased instead of increasing.

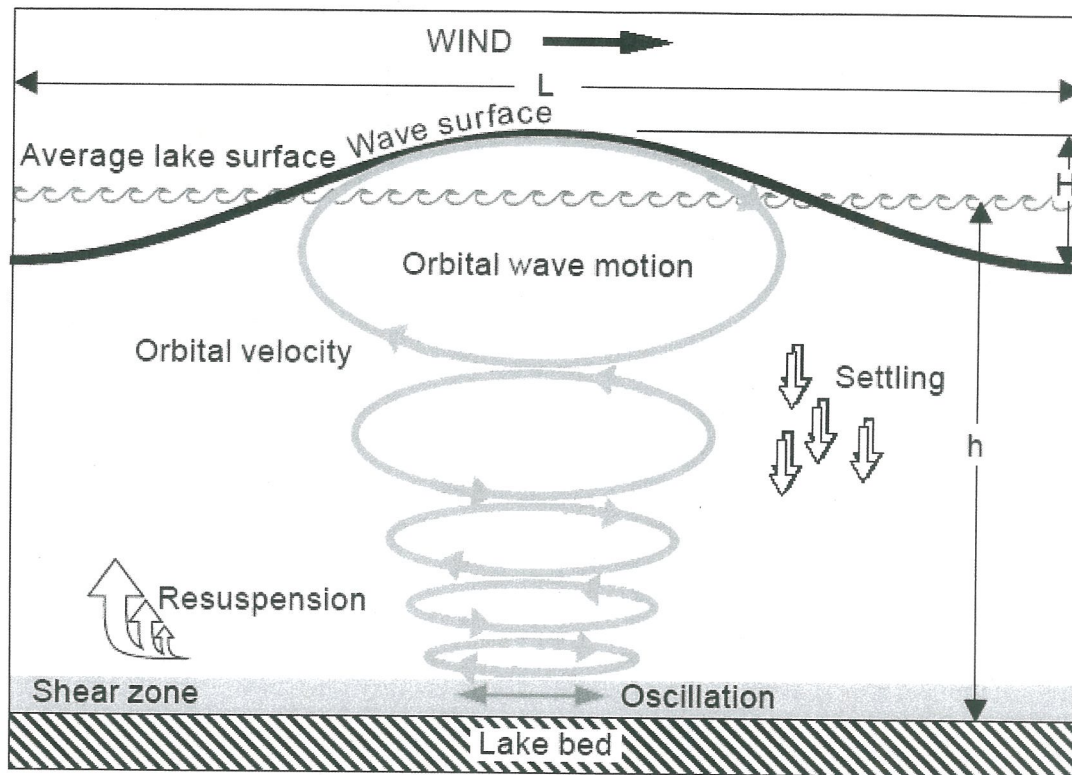


Figure 12

Sediment re-suspension due to wind stressing on the surface of a water body. Source: (Laenen and LeTourneau, 1996).

3.4 What is the Relationship between TSS and Turbidity in Crane Creek?

Results from the Kruskal-Wallis one-way ANOVAs suggest that TSS and turbidity are significantly different at each station so individual correlations were performed as well as an overall one. For the purpose of this research and for a simpler interpretation of the data, the overall correlation and regression equation were considered here. The overall correlation (**Figure 13**) between total suspended solids and turbidity was performed on 461 samples. The sign of the Spearman correlation coefficient r indicates that both variables increase together while the number 0.68 and the P-value that is less than 0.05 provide evidence that there is a significant correlation between TSS and turbidity.

The coefficient of determination $r^2 = 0.47$ tells us that only 47 % of the data points fit in the regression line and are within the 95% prediction interval area. If one measures turbidity from water sampled at Ruffner Park, the linear regression relationship had a determination coefficient of 0.47, which means that the conversion into TSS has a 47 percent chance of being the true value. In Schooner Creek, New Jersey, the correlation coefficient was 0.826 and the linear regression relationship and a slope of 1.543 (mg/L per FTU) and an intercept of 2.548 (mg/L) (Suk et al., 1997). In the latter study, the determination coefficient was 0.99. The difference is that this thesis includes storm events in the data set and measured turbidity at a 90 degrees angle whereas theirs measured the scatterness at angles between 140 and 165 degree.

Other relationships are presented in **Table 8**. Slopes vary from 0.8 to 4.0 and intercept from -990 to +20.1 mg/L. Therefore, the variation of relationship proves that each water system is unique with respect to TSS-Turbidity relationship because the land use and morphology of the watershed where the water system belongs to are different from area to area. Data from **Table 8** also suggest that these relationships are not necessarily linear but could be logarithmic. For instance, creeks in Washington State have a natural log relationship (Packman et al., 1999).

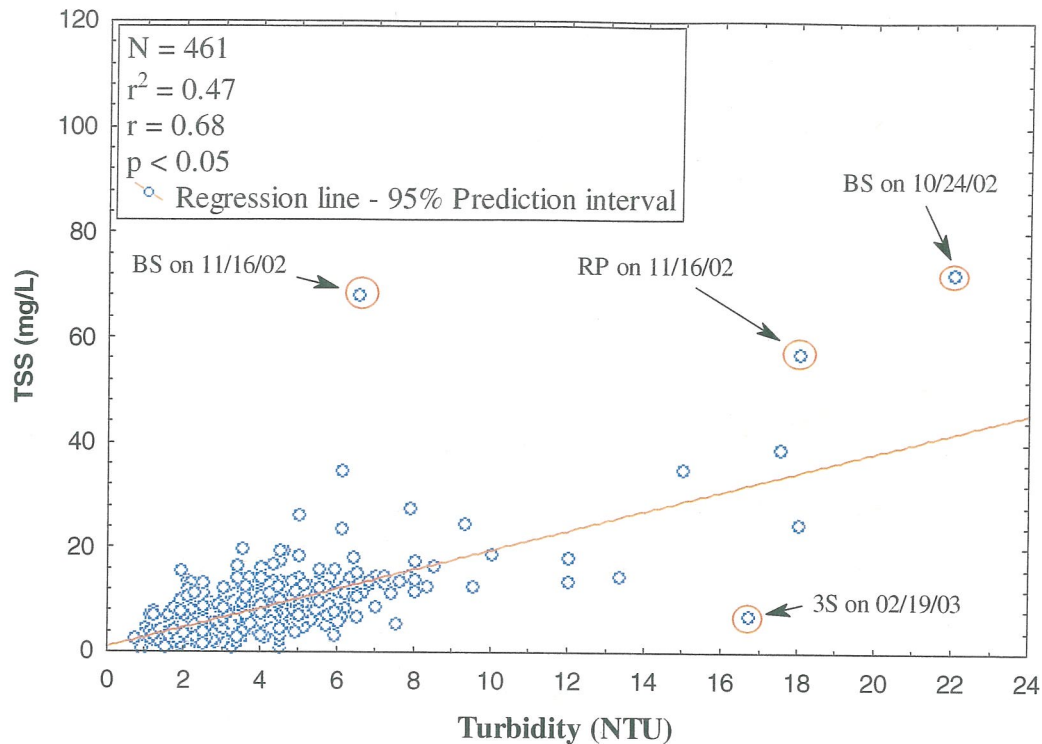


Figure 13

Correlation between TSS and turbidity in Crane Creek, Melbourne, Florida from January 2002 to February 2003.

The linear relationship equation is: $TSS(mg/L) = 1.86 \times Turbidity(NTU) + 0.94$

Four data points are double circled in **Figure 13**. They are outliers according to STATISTICA 6.1 but three of them represent the values during the storms events that were monitored on October 24, 2002 and November 16, 2002. Without these data points, the coefficients would be $r^2=0.66$ and $r=0.44$. The two highest data points were recorded at BS only because access to sampling sites was not practicable during the storms otherwise, HD would be expected to have the highest values.

Table 8

TSS-Turbidity relationship of various water bodies. TSS are reported in mg/L and turbidity in NTU otherwise specified. FAU or Formazin Attenuation Units signify that the instrument is measuring the decrease in transmitted light through the sample at an angle of 180 degrees to the incident light.

Area	TSS-Turbidity relationship	r ²	References
Latrobe River, Australia	April 1992 $TSS = 0.92 \times Turbidity(FAU) - 0.76$	0.904	(Grayson et al., 1996)
	September 1992 $TSS = 0.85 \times Turbidity(FAU) + 20.1$	0.862	
	September 1993 $TSS = 2.70 \times Turbidity(FAU) - 990$	0.875	
Rutherford Creek, Washington	$\ln(TSS) = 1.32 \times \ln(Turbidity) - 0.68$	0.96	(Packman et al., 1999)
All others, Washington	$\ln(TSS) = 1.32 \times \ln(Turbidity) + 0.15$		(Packman et al., 1999)
L'Anguille River, Arkansas	$TSS = 0.801 \times Turbidity - 1.282$	0.66	(State of Arkansas, 2000)
Crane Creek, Florida	$TSS = 4.014 \times Turbidity - 13.026$	0.08	(Straccione, 2002)
Schooner Creek, New Jersey	$TSS = 1.543 \times Turbidity + 2.458$	0.68	(Suk et al., 1997)
Indian River Lagoon, Florida	$TSS = 4.0 \times Turbidity - 3.6$	0.98	(Trefry and Stauble, 1987)

Relationships differ from river to river, from place to place because each water body is different in its morphology, hydrography, chemical and biological compositions and concentrations. The equations all have an intercept that is either close to zero or high in absolute value. For example, in the Latrobe River, the relationship is different from month to month because the weather could be part of these changes.

All pairs of variables have a positive correlation coefficients r and P values below 0.050 so they tend to increase together (**Table 9**). Scatter plots are also presented in **Figure 14** with the regression line and the 95% confidence interval. The surface water at station 2 (2S) has the poorest coefficients and $r = 0.48$, $r^2 = 0.23$; whereas Hickory Ditch (HD) has the highest ones and $r = 0.91$, $r^2 = 0.83$. **Table 9** and **Figure 14** demonstrate the complexity of relating TSS and turbidity for the whole creek. Variations could be due to the salt-wedge characteristic of the estuary. If one wants to estimate the suspended matter concentrations using turbidity, care must be taken and water samples must be collected at those stations.

Table 9

Relationship between TSS and Turbidity at each Station.

Each cell contents the number of observations, the Spearman correlation coefficient r and coefficient of determination r^2 . P-values were less than 0.05 for all stations.

Stations	n	r^2	r
RP	26	0.26	0.51
BS	28	0.50	0.71
HD	22	0.83	0.91
2S	49	0.23	0.48
2D	48	0.24	0.49
3S	49	0.44	0.66
3I	49	0.53	0.73
3II	48	0.34	0.58
3III	44	0.41	0.64
4S	49	0.36	0.60
4D	49	0.46	0.68

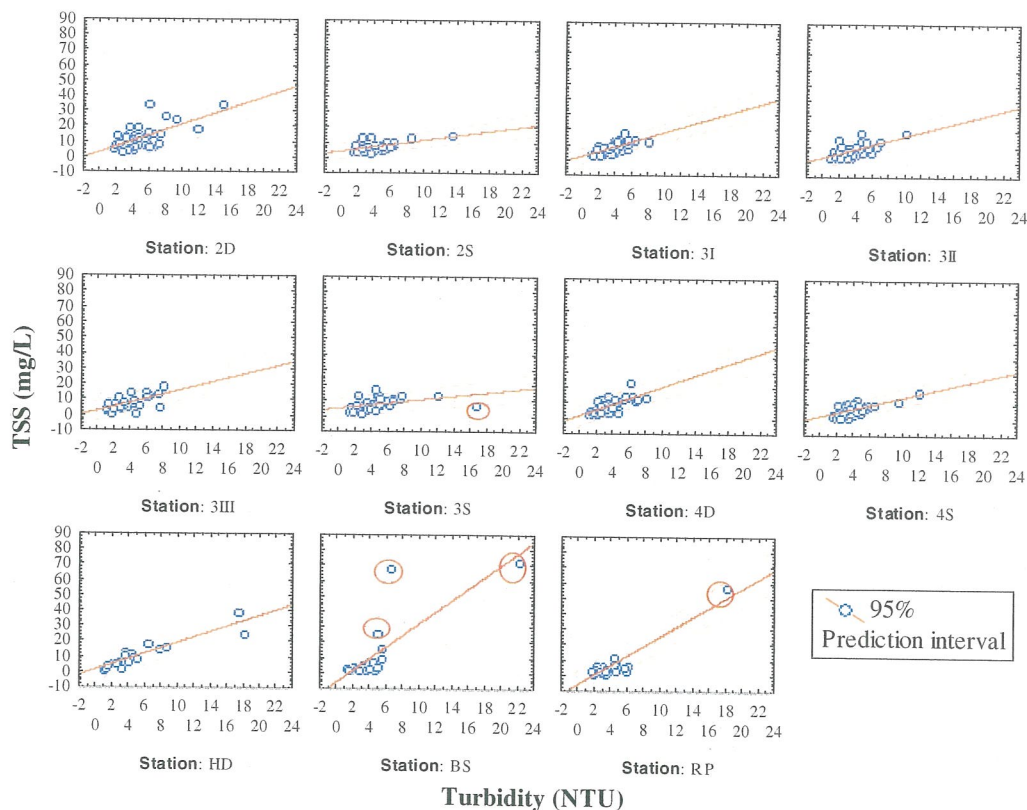


Figure 14

Correlation between TSS and turbidity at each station. Double circled data points are records from the storms events (10/24/02 and 11/16/02).

3.5 Continuous Turbidity and TSS Measurement vs. Grab Samples?

The behavior of total suspended solids and turbidity has been observed during a storm event that was monitored on October 24th, 2002 at 10 PM and the following day at 6 AM and at 1 PM. **Figure 15** shows their behavior prior to the storm event on October 16th, 2002, during the storm and after on the 28th. **Table 10** displays the hourly precipitation recorded at the Melbourne International Airport for the month of October 2002. Babcock Street was the only station that was monitored during the storm event. The other stations were not accessible at this time. **Figure 15** (BS) shows that at time 0 h, TSS was 72.4 mg/L. Seven hours later, TSS dropped to 26.3 mg/L and 18 hours later, it decreased to 7.0 mg/L. Four days later (time = 86 h), total suspended solids reached 1.8 mg/L which is the concentration measured before the storm.

The concentration of TSS increased 18 h after the storm by about 50% at stations RP, HD, 2S, 3S, 4S and 2D. These stations represent water at the surface of the creek except 2D. The storm did not have any impact for the stations in the water column such as 3I, 3II, 3III and 4D. The run-off might have flown too fast at the surface of the creek separating the top from the bottom layer. Turbidity behaved the same way TSS did during and after the storm and at the water surface. Values went up to 22.0 NTU at station BS and progressively decreased to 3.4 NTU with time.

All data collected from January 2002 to February 2003 was collected weekly or biweekly; thus it represents a consecutive data set. In a similar study, Suk et al. (1997) collected real-time data using *in-situ* water samplers for TSS triggered by signals from the turbidimeter. Particulate matter and flocs are very fragile and their form and shape can be physically altered during sampling (Kranck, 1984). Therefore, the turbidity of the same sample can vary depending on where and when it was read. Samples for turbidity reading are homogenized by carefully shaking bottles.

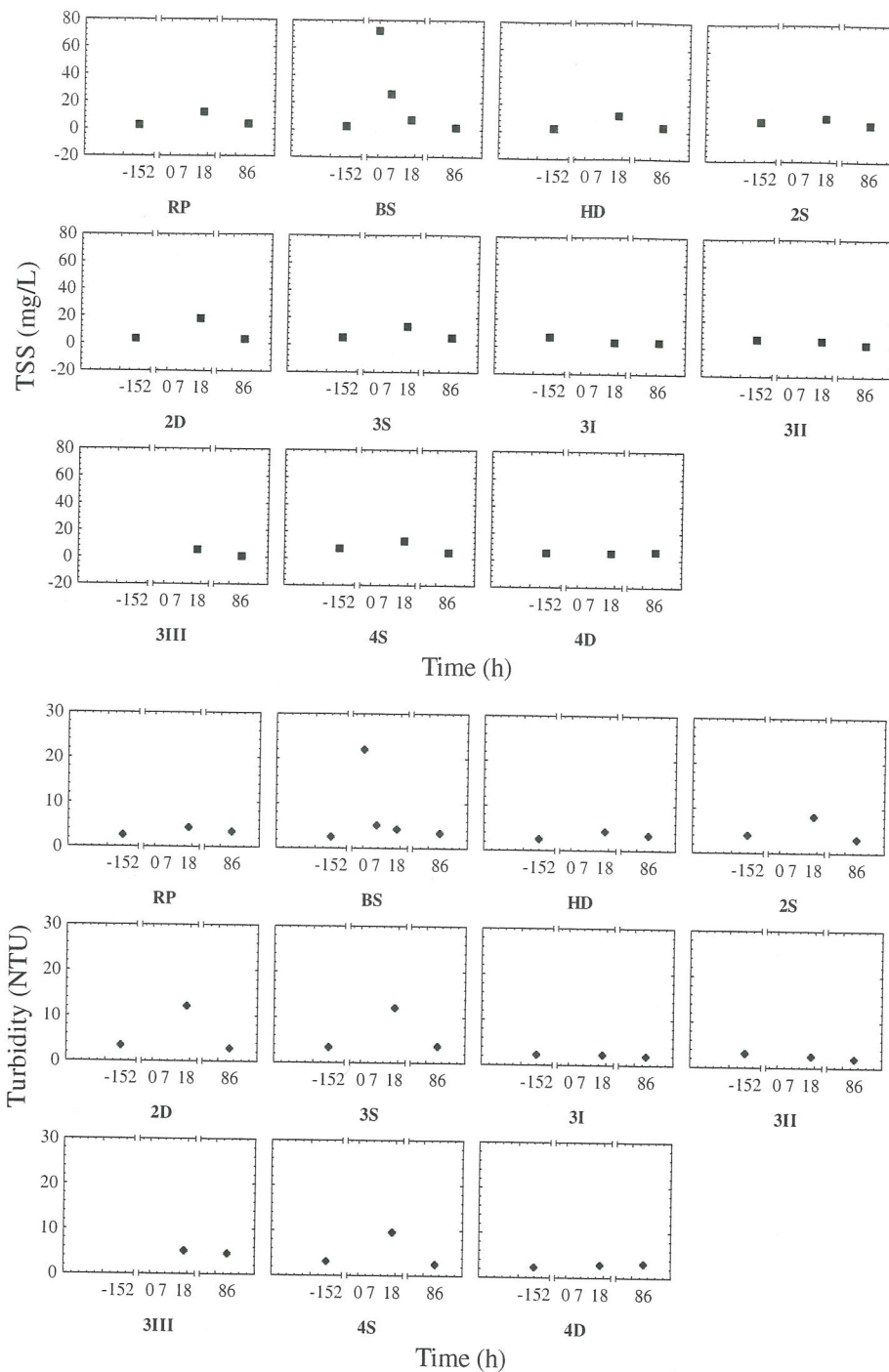


Figure 15

Total suspended solids and turbidity at Crane Creek, Melbourne, Florida during a storm event on October 24, 2002 (time = 0h), before on October 16, 2002 (time = -152h), and after on October 25, 2002 (time = +7h and +18h) and October 28, 2002 (time = +86h).

Table 10

Hourly precipitation (mm) recorded at the Melbourne International Airport for October 2002. T=traces, M=missing.

[illegible]

This process could destroy the macro-flocs into smaller flocs and disrupt the turbidity values. *In-situ* instruments are preferred and have been used extensively (Bale and Morris, 1987; Droppo and Ongley, 1994; Fennessy et al., 1994; Kranck, 1984; Walling and Woodward, 1993) because “the in situ particle size distributions are more representative of the true nature of the particles that are held in suspension and eliminate the need for sample handling and therefore minimize the possibility of floc/aggregate breakage” (Droppo and Ongley, 1994).

Real-time data logging can also have an advantage during storm events. Statistical analysis proved that TSS and turbidity significantly varied with precipitation, salinity, water flow and wind speed. They tended to decrease with increasing precipitation. This ‘dilution effect’ was also demonstrated by Straccione (2002) but the contrary was also proved during the storm event of October 24th, 2002. Values increased with flow and precipitation for a short period of time; then, they quickly returned to normal four days after the storm.

4.0 CONCLUSION AND RECOMMENDATIONS FOR PART II OF WATER QUALITY INVESTIGATIONS

The investigation of total suspended solids and turbidity in Crane Creek has demonstrated the complexity of comparisons with previous and similar studies. The following conclusions are based on the results of this study.

Statistical analysis established that turbidity was not influenced by water density and wind speed. Water flow, salinity, precipitation and wind speed are the factors that affect TSS. TSS was low when (1) water flowed seaward with a flow greater than $0.5 \text{ m}^3/\text{s}$, (2) in the mixing zone with salinity ranging from 11 to 20 psu, and (3) the wind blew less than 11 km/h. Turbidity was high when (1) water flowed between 0 to $0.5 \text{ m}^3/\text{s}$, and (2) salinity was less than 20 psu. The monitoring of storm events proved that TSS and turbidity also increased with precipitation. Therefore, salinity, water flow, precipitation and wind speed are the factors that should be considered for future suspended material transport monitoring in Crane Creek, Florida. Run-off water should be directed and stored in retention ponds before it reaches the creek and loads it with terrigenous and anthropogenic deposits.

The concentrations of suspended matter compared well with those from Straccione (2002). The turbidity values were slightly lower than those found by Straccione (2002) and Garcia (1998). Statistical analysis has shown that values from water collected at the surface of the Creek were different from those collected deeper in the water body. Results of this investigation suggest that a Station 3D could combine Station 3I, 3II, and 3III as there is no statistical difference in TSS and turbidity between these sites, which means analyzing only one water samples instead of three. But, since turbidity can be used to predict total suspended solids concentration, a series of data loggers could be installed along the creek to record turbidity values automatically. Among 461 water samples collected over thirteen months from January 2002 to February 2003, TSS significantly correlated with turbidity with a correlation coefficient of 0.68.

The linear regression relationship had a slope of 1.87 mg/L per NTU and an intercept of 0.94 with a coefficient of determination of 0.46. In addition to underwater turbidimeters, automatic water samplers could also be installed and triggered by turbidity thresholds previously determined. US.1, Babcock Street and Hickory Ditch bridges could be valuable sites for the installation of these new real-time data collectors. The whole data set represents data from consecutive monitoring and laboratory analyses. Real-time data monitoring should be considered for future investigation in order to improve the management of the watershed and to lower the sediment loading into the Creek and the Indian River lagoon.

A Comparison of Polycyclic Aromatic Hydrocarbons and Phthalate Esters Levels in Crane Creek Florida Sediment for 1992 and 2003

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Abstract

On August 8, 2003, ten surficial sediment samples were collected in Crane Creek and Indian River Lagoon and were analyzed for PAH and phthalate esters, toxic organic compounds reported in sediments at elevated levels at these same locations in 1992. The 1998 dredging of Crane Creek was designed, in part, to remove fine-grained, organic-rich sediment and thus remove some of these potentially toxic organic compounds. The concentration of PAH was lower at sediment sites east of the US 1 Bridge suggesting that dredging removed some of the contaminated surficial sediments. However, west of the US 1 bridge, PAH concentration levels were equal to or higher than they were in 1992. These elevated concentrations of PAH appear to be a combination of recent input of PAH and slumping of muck sediments not removed in 1998. If sedimentation rates are ~2cm/yr or greater the PAH levels may be the result of new input of contaminant material alone. Phthalate esters were not reported above detection limits in 2003. Phthalate ester levels may have been reduced through better waste management practices such as diverting sewage effluent from Crane Creek.

Background

Crane Creek Florida was dredged in 1998 to improve navigation and remove sinks of anthropogenically derived nutrients, trace metals and two classes of organic compounds, polycyclic aromatic hydrocarbons and phthalate esters. PAH and phthalate esters were reported to occur in sediment at elevated levels during a 1992 toxic substances survey of Indian River Lagoon (Windsor and Surma, 1992.) The objective of this investigation is to compare the current levels of PAH and phthalate esters to those reported ten years ago, five years prior to dredging Crane Creek.

Methods

Sample locations and methods are similar to those described in the Toxic Substances Survey report (Windsor and Surma, 1993; Surma, 1992.) The sample locations are near the ICCW(701), two in the entrance channel to Melbourne Harbor (702, JS01), two in the area of the Fuel Dock east of US 1(703, JS02), under US 1(JS03), east of the FEC RR(JS04), west of the FEC RR(JS05), east of the Grant Street STP(JS06), and near Babcock St.(JS07) All samples were collected and analyzed using comparable techniques to those employed in the Toxic Substances Survey. Sediment samples were analyzed by STL Tampa Laboratories, a certified environmental analysis laboratory. EPA Method 8270 was employed for the analysis of PAH and phthalate esters. These methods are comparable to the methods employed in 1992 for the identification of organic contaminants in Crane Creek and IRL sediment.

Results and Discussion

Polycyclic Aromatic Hydrocarbons

Results of the individual and total PAH concentrations by location for 2003 and 1992 are shown in **Table 1**. A comparison of total PAH levels in 1992 and 2003 (**Figure 1**) indicates a significant reduction in the total PAH levels to the East of US 1. Perhaps the Table 1 Polycyclic aromatic hydrocarbons (PAH) concentration in Crane Creek sediments 1992 and 2003 in ug/g dry weight simplest explanation for this observation is that the removal of the contaminated sediments during the 1998 dredging reduced the levels of TPAH in sediments. Increases in upstream depth (west of US 1) should be permitting greater removal of suspended sediments transported from upstream. However, sediments to west of US 1 appear to be near the same or higher TPAH levels in 2003 compared to 1992. This was quite a surprise. The case could be made that the sediments that had been transported to the IRL prior to the Crane Creek dredging are now being collected upstream. There is little reason to believe that sources of TPAH to Crane Creek have significantly decreased in recent years. One other concern is that the upstream (West of US 1) dredging upstream was not very effective in removing fine grain particles from Crane Creek. The sediments west of US 1 may simply be the result of a rearrangement of muck sediment that was not removed during the dredging process. Post dredging bathymetry, in 1998 and the 2003 should be of some assistance in this interpretation. (See bathymetry section of this report.)

The only location with and increase in sediment PAH in 2003 is under the US 1 bridge. Specific PAH sources associated with the road traffic above may be responsible for this increase. For example, tire dust, large diesel particles or other debris from the roadway may influence sediment here.

All TPAH values are now under the Apparent Effects Threshold (AET) for PAH (Long and Morgan, 1989), thus reducing risks from these contaminants. There is an overall improvement in the quality of sediment in the Crane Creek system. Based on these results alone, dredging resulted in some improvement in sediment quality.

1992	701	701	702	703	JS01	JS02	JS03	JS04	JS05	JS06	JS07
Naphthalene			0.06	0.16	0.009	0.015	0.004	0.005	0.010	0.006	
2-Methyl naphthalene											
Acenaphthylene							0.003	0.007	0.008	0.003	
Acenaphthene						0.023	0.005	0.014	0.008	0.042	
Fluorene					0.012	0.026	0.007	0.011	0.011	0.031	
Phenanthrene			0.19	1.20	0.034	0.350	0.081	0.150	0.019	0.440	0.002
Anthracene			0.08	1.30	0.021	0.076	0.019	0.029	0.037	0.050	
Fluoranthene	BD	BD	0.47	4.60	0.200	1.800	0.440	0.980	1.200	1.400	0.006
Pyrene	BD	BD	0.35	2.60	0.190	2.900	0.490	0.890	1.400	1.200	0.007
Benz(a)anthracene			0.20	2.60	0.053	0.410	0.150	0.320	0.400	0.530	0.003
Chrysene			0.23	2.60	0.095	1.100	0.270	0.650	0.680	0.870	0.004
Benzo(b)fluoranthene			0.29	2.70	0.180	1.500	0.280	0.940	0.860	0.860	
Benzo(k)fluoranthene			0.12	2.60	0.087	0.780	0.220	0.520	0.630	0.630	
Benzo(a)pyrene			0.17	3.60	0.074	0.710	0.200	0.430	0.460	0.480	
Indeno(cd)pyrene				2.80	0.120	1.200	0.270	0.490	0.820	0.590	
Dibenz(ah)anthracene						0.210	0.053	0.100	0.160	0.120	
Benzo(ghi)perylene				2.60	0.100	0.880	0.200	0.350	0.680	0.440	
TOTAL	BD	BD	2.16	29.36	1.175	11.980	2.692	5.886	7.383	7.692	0.022

2003	701-03	702-03	703-03	JS01-03	JS02-03	JS03-03	JS04-03	JS05-03	JS06-03	JS07-03
Naphthalene						0.360				
2-Methyl naphthalene						0.110				
Acenaphthylene										
Acenaphthene						0.300				
Fluorene						0.340				
Phenanthrene		0.037	0.180	0.037	0.640	2.200	0.240	0.240	0.099	
Anthracene			0.038		0.280	0.650	0.042	0.054	0.021	
Fluoranthene		0.082	0.710	0.084	1.300	2.600	1.000	1.100	0.450	
Pyrene			0.460		0.760	2.100	0.750	0.870	0.290	
Benz(a)anthracene		0.033	0.280	0.036	0.280	1.200	0.410	0.470	0.180	
Chrysene		0.065	0.460	0.058	0.580	1.000	0.660	0.780	0.270	
Benzo(b)fluoranthene		0.071	0.520	0.074	0.620	0.880	0.810	1.900	0.440	
Benzo(k)fluoranthene		0.064	0.440	0.044	0.420	1.100	0.700	0.740	0.320	
Benzo(a)pyrene		0.061	0.440	0.060	0.480	0.990	0.680	0.850	0.330	
Indeno(cd)pyrene		0.090	0.520	0.086	0.560	0.880	0.640	0.870	0.310	
Dibenz(ah)anthracene			0.300	0.061	0.300	0.600	0.330	0.420	0.160	
Benzo(ghi)perylene			0.420	0.060	0.440	0.760	0.500	0.700	0.250	
TOTAL	BD	0.503	4.768	0.600	6.660	16.070	6.762	8.994	3.120	BD

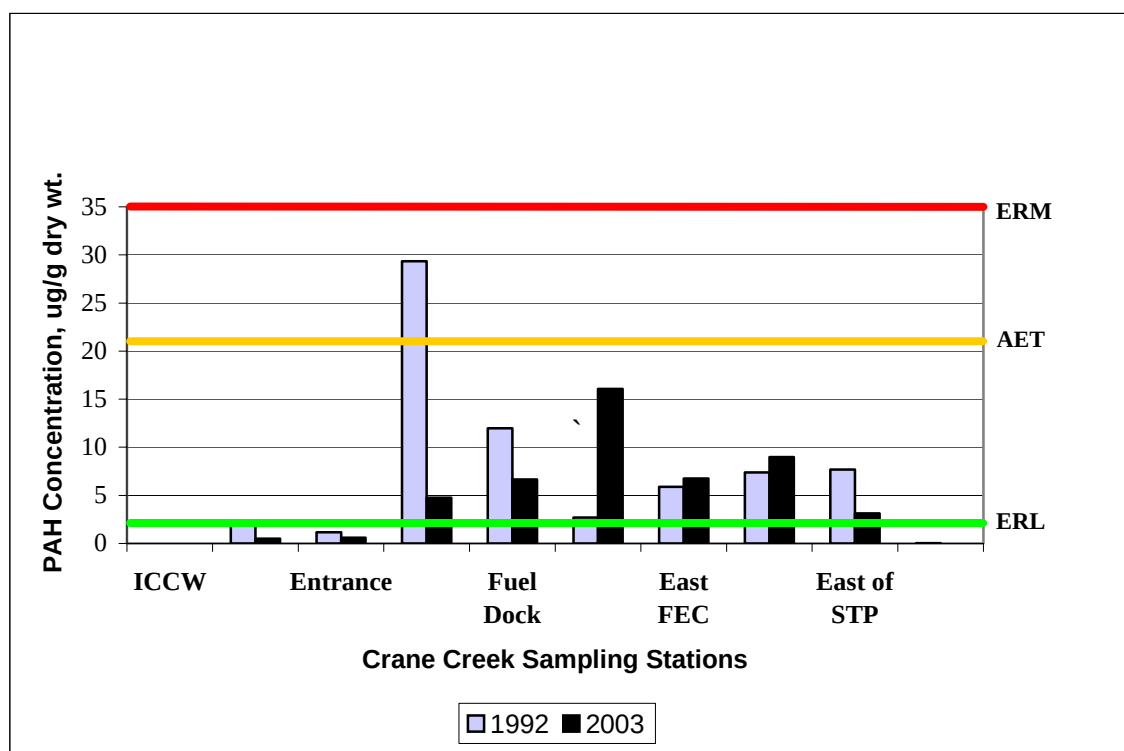


Figure 1

Total PAH concentration in Crane Creek sediment 1992 and 2003 in ug/g dry weight. AET is apparent effects threshold, ERM and ERL are effects range medium and effects range low.

Phthalate Esters

A comparison of phthalate ester concentrations for three Crane Creek sediments in 1992 and August 2003 is shown in **Figure 2**. In 1992 only three sediment samples were analyzed for phthalate esters (701, 702 and 703). Only PAH were analyzed at the Surma sites (JS01-JS07) in Crane Creek and included in the final Toxic Substances Survey Report (Windsor and Surma, 1993). The sample locations are near the ICCW (701), one in the entrance channel to Melbourne Harbor (702), and one near the Fuel Dock (703). During the August 2003 survey, sediments from all sampling locations were analyzed for phthalate esters.

All phthalate ester levels for sediments near ICCW, the entrance channel and the fuel dock are below detection limits in August 2003. The most direct interpretation is that the removal of contaminated sediments reduced the phthalate ester concentrations. This was one of the goals of the dredging project. The reduction in phthalate ester levels east of the US 1 bridge parallels the reduction in PAH east of the US 1 bridge. The same processes are believed to be responsible for the reduction of phthalate esters and PAH, the dredging of Crane Creek sediments in 1998.

Sediment samples collected west of US 1 bridge in 2003 have no detectable levels of phthalate esters. Although no data are available for phthalate esters in these sediments in 1992, it should be safe to assume that if phthalate concentrations were elevated in Melbourne Harbor sediment in 1992, then upstream sediment should also contain elevated levels of phthalates. Therefore, when the sediments were dredged, phthalate ester concentration was reduced.

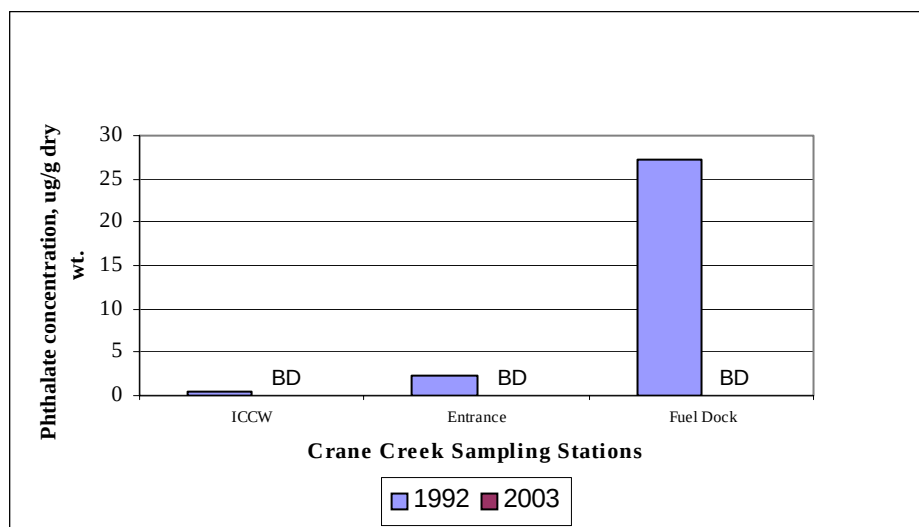


Figure 2

A comparison of phthalate ester concentrations in sediments from Crane Creek and Indian River Lagoon near the mouth of Crane Creek (ug/g dry weight.)

If phthalates and PAH in sediment behave similarly, then a reduction of PAH concentration would be expected with the reduction of phthalate concentrations in the sediments. West of the US 1 bridge, total PAH levels in surficial sediments (top 10 cm) are not lower than they were in 1992. The explanation for this apparent dichotomy appears to be in the sources for PAH and phthalate esters in Crane Creek sediment.

How can PAH levels remain similar to 1992 levels but phthalate esters levels be reduced?

In the original Toxic Substances Survey (Windsor and Surma, 1993), some skepticism was expressed about phthalate ester data due to the potential for contamination in the field and in the laboratory by plastics and improperly cleaned glassware. However, due to the distribution of phthalate esters in IRL sediment, the report concluded that the majority of these phthalates were a result of anthropogenic activity. In heavily contaminated sediment, like Boston Harbor, thousands of kilograms of phthalate esters are discharged annually with both sewage sludge and sewage effluent (Harte et al., 1991; Dolan, 1992). Over the history operation of the wastewater treatment plant at Grant Street (Melbourne) sewage effluent and some sludge have been released to Crane Creek. With the cessation of sewage discharge to Crane Creek prior to dredging, one source of phthalate esters to the Crane Creek had been eliminated.

During the processing of the 1992 sediment samples for PAH and phthalate analysis from throughout the Indian River Lagoon some sediment samples had what appeared to be very small pieces of plastic that looked similar to degraded plastic grocery store bags. These fine pieces were removed from sediments (where seen), but some smaller pieces may have been incorporated into the sediments. None of these pieces were observed during the August 2003 sediment sampling in Crane Creek.

During the 1998 dredging of Crane Creek hundreds of beer and soft drink cans were brought to the surface from the sediments. The labels on many of the cans were intact and it was clear that they had been thrown into the creek more than 20 years earlier. Evidence for the age of these cans includes the artwork on the cans and the removable snap tabs. Very few newer cans resulted from dredging. More than 20 years ago cans appear to have been discarded to Crane Creek. Perhaps plastic bags used to carry the cans and ice to the Creek were disposed of in a similar manner. Implementation of recycling programs for aluminum cans and the degradation of the recreational fishing environment in Crane Creek over the years may have been responsible for fewer new cans being deposited into the creek.

What might have happened to these very small, near neutrally buoyant plastic bits during dredging? Dredging may have been effective at removing these remnants of plastic bags from the sediments. Some of the plastic bits may have followed the same pathway as the beer cans brought to the surface by the dredging process. Very small neutrally buoyant pieces of plastic (most likely resulting from the decomposition of plastic grocery store like bags) when stirred up during the dredging might have been transported out to the IRL. Therefore, reduction in phthalate ester levels in sediments appears to have resulted from both the diversion of sewage effluent from Crane Creek and the reduction in disposal of plastic bags to Crane Creek.

How do the observations about phthalates compare to the PAH observations?

As mentioned above, the observation that no significant level of PAH reduction was observed west of the US 1 was quite a surprise. A case could be made that the sediments that were transported to the IRL prior to the Crane Creek dredging are now being collected upstream where the water depth is greater allowing suspended matter to be more effectively trapped. Atmospheric sources of PAH to Crane Creek have not significantly decreased in recent years. The deposition of pyrogenic PAH throughout the Crane Creek drainage basin continues to contribute to the PAH levels in Crane Creek sediment.

More than five years have elapsed between the dredging project and the chemical analyses for PAH and phthalate esters in August 2003 and the upper 10 cm of sediment was collected at each site. If the sedimentation rate was 2 cm/yr, PAH concentration could indicate the level of input of these chemical contaminants over the last five years. Because the sources for phthalate esters to Crane Creek sediments have been considerably reduced, no significant increase has occurred over the last five years. Sedimentation rates determined elsewhere in this report indicate far lower sedimentation rates in Crane Creek. If dredging upstream was not very effective in removing fine grain particles, the level of PAH in sediments west of US 1 could have resulted from a combination of new input and a rearrangement of sediments that were not

effectively removed during the 1998 dredging. However, if this were the case, phthalate esters most likely should have been observed at higher levels.

A greater emphasis has been placed on environmental education in recent years. There is greater public awareness about the disposal of waste in or near coastal waters than ever before. With the cessation of disposal of sewage effluent and sludge to Crane Creek, with a reduction in the disposal of plastic bags in the coastal environment, and with a greater emphasis on recycling, the sources of phthalates to Crane Creek may have been significantly reduced in recent years.

Volatile Solids and Organic Contaminants

For each of the sediment samples collected in 1992 and 2003, volatile solids were measured. **Figure 3** compares volatile solids at each of the sampling locations for 1992 and 2003. Surficial sediments are still as rich in organic matter as they were in 1992. Of what significance is the occurrence of high levels of organic matter in sediments? In the Toxic Substance Survey Report (Windsor and Surma, 1992) high levels of PAH and phthalate esters were most commonly associated sediments rich in organic matter. If the surficial sediments that are accumulating in Crane Creek are a result of new deposited suspended matter (rather than movement of previously deposited organic rich sediment) the new material is rich in organic matter.

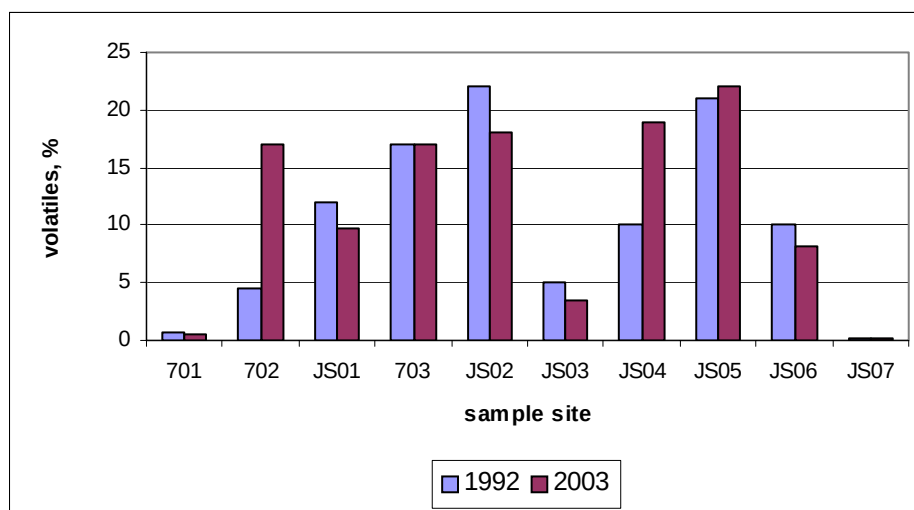


Figure 3

Volatile solids (%) in Crane Creek and Indian River Lagoon sediment near the mouth of Crane Creek in 1992 and 2003.

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Repeat Cross-Section Surveys of Crane Creek: Trends in Bathymetry and Sediment Distribution

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1.0 INTRODUCTION

Repeat cross-section surveys conducted over reasonably long time-frames, or in close association with known channel-altering events, can provide a good indication of the trends and/or magnitude of the geomorphic changes of fluvial systems. One such change can be the accumulation of sediments in depositional zones, also referred to as “sediment trapping.” This report includes the results of 4 cross-section surveys on Crane Creek, a brackish, muck-bottom stream at Melbourne, Florida. The first was conducted in 1997 to establish baseline bed levels prior to a dredging operation. The dredging was conducted in an effort to improve navigability of the Creek, with additional potential benefits cited as improvements in sediment trapping and associated water quality. The second survey, conducted in 1998, was engaged to confirm that dredging had occurred at sufficient depths and volumes in accordance with project objectives and contractual obligations. Two additional surveys were conducted in 2001 and 2003 to assess post-dredge changes in channel morphology, with anticipation that improved understanding of sediment trapping efficiency might be gleaned from the surveys.

Repeat surveys alone are not likely to pick up anything other than rather strong trends in complex and dynamic tidal streams and this portion of the research was intended to be somewhat complimentary to other approaches for determining sediment trapping described later (see Trefry et al. 2003, Tab 7 of this report). These repeat surveys provide an opportunity to discuss the pros and cons of using this technique versus other investigative approaches in sediment transport studies involving urban, tidally influenced streams.

Channel morphology changes can include aggradation, degradation, or combinations thereof. Aggradation is the net long-term accumulation of sediments leading to higher bed elevations, while degradation is the opposite—sediment losses leading to reductions in bed elevations through time. If net changes are substantial, the differences in channel configuration can be used to derive net values in long-term sediment trapping. Cross-sectional dimensions are usually the first and most obvious means by which a stream changes shape in response to sufficiently altered sediment availability and flow volumes. Changes in longitudinal profile or in meander (planform) often take longer to occur (Knighton 1998).

Changes in channel morphology can occur due to chronic stresses such as changes in land use leading to increased or decreased stream velocity, shear stress, or stream power regimes. For example, increased urbanization in watersheds often leads to greater unit runoff volumes and peak flows from the watershed (Knighton 1998). This repeated increase in flow can cause a threshold shift in sediment transport within the channel forcing the stream to adjust its shape to accommodate the excessive energy from the force of the water.

Channels can also change shape in response to rare or catastrophic storm-flow events such as hurricanes and tropical storms that may occur on an average return interval in excess of once every 10 years. These storms can move orders of magnitude more sediments than smaller, more routine storms—per event. Typical or “average” flows move relatively minor amounts of sediment in stable channels. Some intermediate flow volume with an intermediate frequency of occurrence and sediment transport power does the most work maintaining channel dimension at its typical condition. This is referred to as the dominant or effective discharge (Wolman and Miller 1960). Nationally, it is the flow that occurs on a 1.5 year return interval (Leopold 1992), although it is likely to occur more frequently in the southeastern coastal plain (Warne et al. 2000, Doll et al. 2004). It is important to note that most of the research on this concept of dominant discharge has been conducted in freshwater streams with unidirectional flow. Sediment transport is much more complex in tidal streams with salinity gradients and bi-directional flow, such as Crane Creek.

Intra-coastal environments complicate fluvial processes such as sediment transport, and associated stream channel shapes, for several reasons including,

- 1) Increasing ionic strength along salinity gradients can cause fine particles to coagulate and settle faster.
- 2) The salinity gradient can establish a pycnocline (salt wedge) that prevents mixing among the upper fresh layer and lower salt layer of the water column. This can reduce the interaction between freshwater flow to the stream and its bed, which can have two distinct and opposing effects on sediment transport. One aspect is that freshwater flows can at least occasionally be “sealed-off” from creating sufficient bottom shear or velocities to initiate sediment transport from sources near the bed (commonly referred to as “bed load”). This means that the salt wedge effectively “armors” the bed from sediment losses. Conversely, fine sediment deposition from basin sources (commonly referred to as “washload”) can be hindered from depositing on the bed by this density wedge. In the latter case, sediment deposition is prevented allowing the sediments to be transported into the lagoon.
- 3) The salinity gradient can establish density currents that have their own effects on sediment movement, particularly near the mouth of the stream near the lagoon.
- 4) Tides and storm surges can create substantial shear stresses independent of freshwater stream flow, often moving in the opposite direction, creating more scour than the freshwater flow does.

- 5) Tides and storm surges can also export bay or lagoon sediments to upstream stream channel reaches, allowing for net sediment accruals in depositional zones in excess of upstream sources alone.

It is important to understand these characteristics in relation to the timing, frequency, and time intervals of repeat surveys, insofar as channel conditions are dynamic. Even what is referred to as a stable channel typically is not static but is under some state of dynamic equilibrium. Therefore, conclusions drawn from repeat surveys must be made with a good understanding of the context of the surveys relative to their location within a salinity gradient, general precipitation patterns between the surveys, and the timing of any large storm events.

2.0 STUDY AREA

Crane Creek flows through downtown Melbourne, Florida which is located on the East Coast in Brevard County (**Map 1, see foldout**). Crane Creek is about 5.3 miles in length with a drainage area of approximately 18 square miles (USGS, 2002). The mean daily net streamflow over 14 years of record (1987 – 2000) was 46 cubic feet per second (cfs) at US Highway 1 (USGS, 2002).

The repeat-survey study area concentrates on the downstream reach of the creek where it is relatively broad, ranging from about 150 to 400 feet wide, and exhibits a salinity gradient. A total of 19 cross-sections, roughly spaced every 150 feet, were established in 1997. Residential properties line the banks from Cross-Sections 1 through 7. Sections 8 and 9 are located between the Florida East Coast Railroad and U.S. Highway 1 bridges. From there Sections 10 through 18 progress downstream along the creek as it flows further east through the Melbourne Harbor Marina and finally empties into its receiving waters, the Indian River Lagoon. Sections 11 through 15 are within the general confines of the Harbor, while 16 through 18 approach the mouth of the Lagoon with 19 extending into the Intra Coastal Waterway (**Map 1, see foldout**).

3.0 METHODS

The first two surveys were intended to provide a basis for assessing the contractual obligations of the dredging project. The 1997 survey provided a baseline of the Creek bottom and much of the banks prior to dredging and is largely irrelevant to this report, while the 1998 survey provided confirmation that the final dredge volumes and bottom elevations had been achieved. Unfortunately, neither survey extended fully up the banks as the dredging operation was confined to more than 50 feet from the edge of structures such as seawalls and docks (which are quite ubiquitous in this stream reach). The 2001 and 2003 surveys were designed to repeat the cross sections surveyed during 1998. The purpose of these surveys was to determine what changes had occurred in bed and bank elevations during the intervening times frames. Surveys were performed using a small vessel (e.g. Jon-Boat).

The 1998 post-dredge survey was conducted on February 25, as a hydrographic survey as defined in Chapter 61G17-6.002(8) Florida Administrative Code. Elevations were based on NGVD 1929 and referenced to Coast and Geodetic Disk M171, elevation 21.41 feet and P132, elevation 21.94 feet. The horizontal datum was NAD 1983. The survey was conducted by Lidberg Land Surveying Inc., by David C. Lidberg, Professional Surveyor and Mapper (No. 3613) under contract with Ludlum Construction (the dredging company). The survey was performed using a Raytheon 719D Survey Recorder, Differential GPS and Hypack Software. It is unknown if the 1998 survey was verified by use of probes or poles.

The 2001 survey was conducted on January 19, as a hydrographic survey as defined in Chapter 61G17-6.002(8)(F) Florida Administrative Code. Elevations were based on NGVD 1929 and referenced to Coast and Geodetic Disk M171, elevation 21.41 feet and P132, elevation 21.94 feet. The horizontal datum was NAD 1983. The survey was conducted by BCI Engineers and Scientists Inc., by Dennis A. Miller, Professional Surveyor and Mapper (No. 5626) under contract with the St. John's River Water Management District. The survey was performed using a Leica Wild 200 GPS system with an Insight 212 Sonar Head and DGPS Software, and processed using AutoCAD Land Development Desktop software. The survey was confirmed by use of pole probes and lines attached to a wide disc to determine if the Sonar Head was reading a false bottom as can occur in areas with a loose organic layer over a firmer layer. No such layer was reported.

The 2003 survey was conducted from September 16 through the 18th, as a hydrographic survey as defined in U.S Army Corps of Engineers Class 1 Hydrographic Surveys (EM 1110-2-1003), which establishes quality assurance criteria more stringent than that of Chapter 61G17-6.002(8)(F) Florida Administrative Code. Elevations were based on NGVD 1929 and referenced to Coast and Geodetic Disk M171, elevation 21.41 feet and P132, elevation 21.94 feet. The horizontal datum was NAD 1983. The survey was conducted by Arc Surveying and Mapping, Inc., by G. Marsh, on behalf of BCI Engineers & Scientists, Inc. under contract with the St. John's River Water Management District. The survey was performed using a Differential GPS for positioning and a Knudsen 320M Fathometer (a dual frequency sounder operating at 200 and 28 kHz) for bottom data. There was very little separation noted, meaning the creek bottom does

not have much in the way of fluid suspended sediments. The surveyor sounded bottom with a surveyor pole in a few locations and confirmed the bottom is generally firm.

The surveys have generally increased in quality at each iteration. However, it is likely that the 1998, 2001, and 2003 surveys, based on the particular equipment employed and qualifications of the surveyors, provide bottom elevations within 0.3 feet of actual conditions at any given survey point. Therefore, sediment accumulations measured at less than 0.3 feet changes in elevation should be regarded with caution when employing these methods.

AutoCAD Land Development Desktop software was used to calculate cuts and fills at each cross section by quantifying the difference in cross sectional area in square feet between selected surveys. A “cut” represents the total area at a cross section that decreased in elevation and a “fill” represents the total area at a cross section that increased in elevation. The net accumulation of sediment per unit channel length ($\text{ft}^3/\text{ft} = \text{ft}^2$) was represented by subtracting the cuts from the fills calculated at each measured cross section. Net sediment accumulation was compared in this manner for the periods 1998-2001 and 2001-2003. The actual durations of each period were approximately 3 years and 1.7 years respectively. The results were also expressed in units of mean sediment accumulation depths (inches) by dividing the unit area accumulations by the cross section width.

Sediment grain size distribution and textural classifications/descriptions were determined in accordance with ASTM D422. The following sieves were used:

Sieve Number	Sieve Opening (mm)
1/2	12.7
4	4.750
10	2.000
40	0.420
80	0.178
100	0.149
200	0.074
400	0.037
Pan	

This method provides a series of progressively smaller sieve sizes for materials ranging from pebble to fine sand. Very fine particles such as most silts and all clays are not retained by these sieves. Particles finer than 0.062 mm are generally considered to be silt/clay size grains.

The locations of the sediment classification sample sites corresponded to Sites 7, 6, 5, 4, 3, 2, 1, 701, 702, and 703 in Windsor and Surma (1993) (see **Figure 1**, this Tab). The samples were collected by Dr. John Windsor at the Florida Institute of Technology, stored and transported in plastic bags to BCI’s soils testing lab in Lakeland, Florida where they were

weighed and sieved. The sampling event coincided with sediment chemistry sampling conducted by FIT as described in Tab 6 of this volume. Site 7 is located in a narrow section of the creek located more than 3,000 feet upstream of the repeat-survey study area. Sites 6 and 5 are within or close to Zone 1 of the study area, Site 4 is at the boundary of Zones 1 and 2, Site 3 is at the boundary of Zones 2 and 3, Sites 2 and 703 are within the marina vicinity in Zone 1 (**Figure 1**). Sites 1, 702, and 701 are in the Indian River Lagoon (702 at the mouth of the creek, 703 about 3000 feet east of the mouth) (**Figure 1**).

4.0 RESULTS

Please refer to **Map 2** located in the folder attached at the end of this Tab for the most recent bathymetry (2003 Survey). **Map 3** (see folder) depicts the comparative elevations at each cross-section from the 1997, 1998, 2001, and 2003 surveys. The results of these surveys collectively show a general pattern of substantial increase in depth due to the dredging operation, with three distinct dredging areas (**Map 2 and Figure 1**).

The upstream area (Zone 1) corresponds to Cross Sections 1 through 7, located west of the FEC Railroad Crossing (FECRR) in the broadest section of the study reach. Zone 1 was an area of relatively shallow dredging, averaging removal of about 3 to 4 feet of material from the channel. Cross Sections 8 and 9 were located within Zone 2, a small area of the deepest dredging between the FECRR and U.S. Highway 1 (Harbor City Blvd.) bridges. Zone 2 was dredged to remove sediment thicknesses in excess of 10 feet. Zone 3 encompassed the remaining Cross Sections 10 through 19. Zone 3 was an area of intermediate dredge depths located closest to the Lagoon, downstream of the Highway 1 Bridge.

Typical dredge removal thicknesses were about 5 to 10 feet. Much of Zone 3 is within a broad section of the channel with an active marina. Docks protrude across as much as 75 percent of the channel from both sides of the shoreline in this subsection (Cross Sections 11 through 14). Cross Sections 15-19 are found in a relatively narrow part of the channel during the last 600 feet before it enters the Indian River Lagoon.

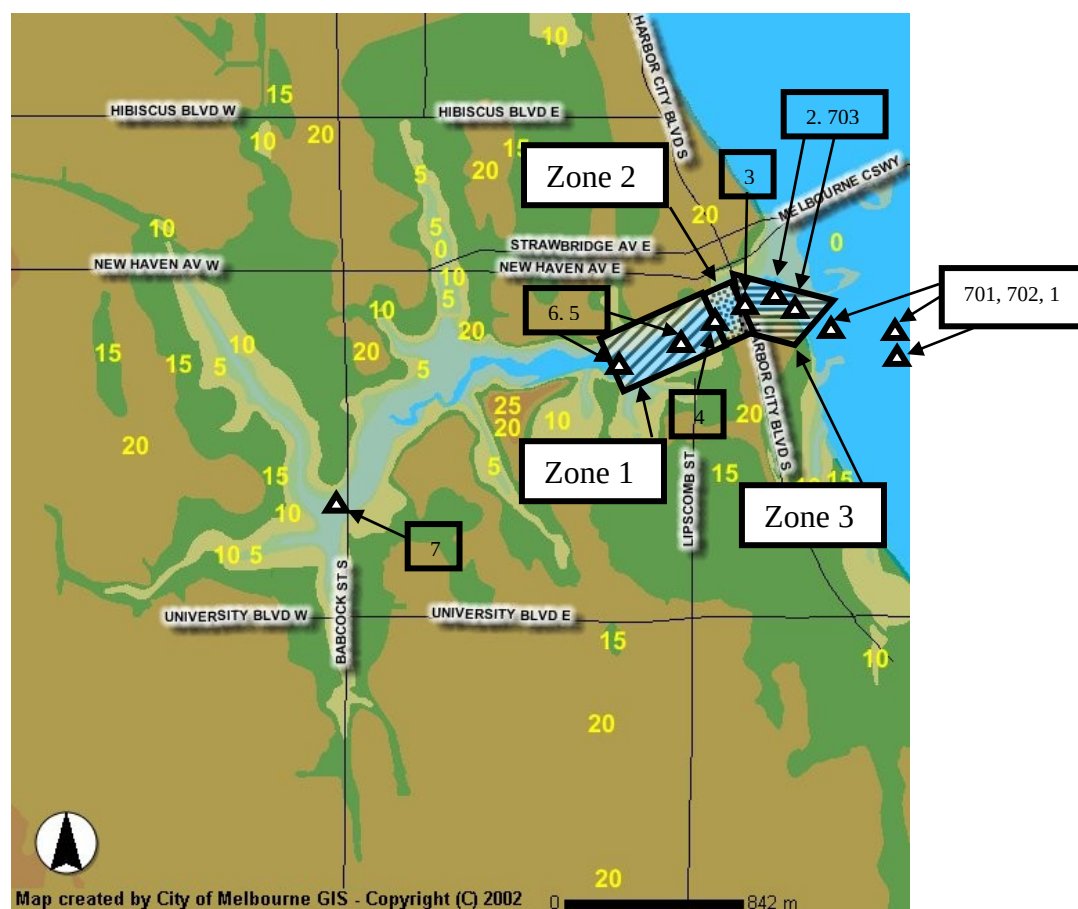


Figure 1. Map of the Study Area, Dredge Zones, and Sediment Sample Locations.

Source: adapted from <http://gis.melbourneflorida.org>

Table 1 summarizes the sediment accumulation calculated for each cross section. Data is provided for two adjustment periods, 1998-2001 and 2001-2003. The change in cross-section area represents the volume of sediment accumulation for the period per unit length of stream channel (cubic feet per foot). The change in depth is the difference in mean depth at each cross-section for the period. Since the accumulation period is also known the change in depth can be converted into a rate of accumulation in units of inches per year.

Table 1
Sediment Accumulation Calculations

C1	C2	C3	C4	C5	C6	C7
	Cross Section Area Change (Square Feet)		Mean Depth Change (Feet)		Sed Accumulation Rate (inches/year)	
X-Sect	1st Adj	2nd Adj	1st Adj	2nd Adj	1st Adj	2nd Adj
1	34	205	0.12	0.73	0.49	5.29
2	16	111	0.05	0.39	0.22	2.81
3	155	157	0.38	0.39	1.53	2.78
4	191	248	0.52	0.67	2.06	4.83
5	224	186	0.55	0.45	2.19	3.25
6	122	226	0.31	0.58	1.25	4.18
7	105	103	0.32	0.32	1.29	2.28
8	859	222	2.70	0.70	10.81	5.02
9	641	-20	2.28	-0.07	9.13	-0.51
10	37	-16	0.53	-0.23	2.10	-1.63
11	438	21	3.32	0.16	13.29	1.14
12	866	-146	4.01	-0.67	16.02	-4.86
13	771	-188	4.79	-1.17	19.16	-8.43
14	369	48	3.55	0.46	14.18	3.29
15	156	61	1.71	0.67	6.83	4.84
16	207	45	2.27	0.49	9.06	3.53
17	163	44	1.99	0.53	7.95	3.83
18	304	37	3.67	0.45	14.67	3.25
19	250	62	1.93	0.48	7.71	3.43
Mean	311	74	1.84	0.28	7.37	2.02
Std Dev	276	119	1.51	0.50	6.04	3.58
Notes						
C1 = Cross section name						
C2 = Net sediment accumulation in cross section area, 1998-2001						
C3 = Net sediment accumulation in cross section area, 2001-2003						
C4 = Net sediment accumulation depth, 1998-2001						
C5 = Net sediment accumulation depth, 2001-2003						
C6 = Sediment accumulation rate (inches per year). 1998-2001						
C7 = Sediment accumulation rate (inches per year). 2001-2003						

Sediment accumulation (aggradation) occurred at all cross sections between the 1998 and 2001 surveys (**Table 1 and Figure 2**). Zones 1, 2, and 3 are as described earlier. Zone 3M is within the marina and Zone 3N is not. It is apparent that unit volume accumulations were greatest within the deep sump between the bridges (Zone 2) and within the marina (Zone 3M).

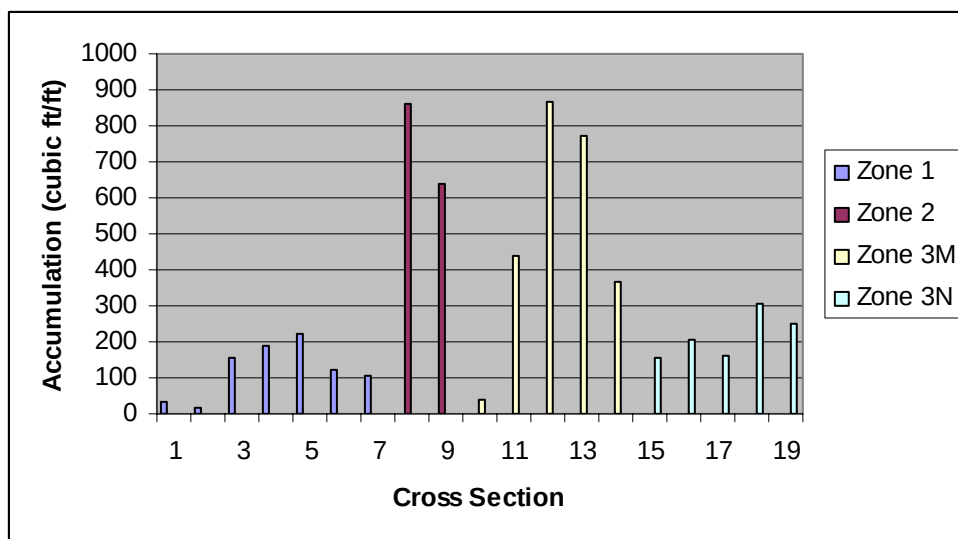


Figure 2. Sediment Accumulation Volume per Unit Channel Length—1998-2001.

Sediment accumulation patterns were more complex during the second period from 2001 to 2003. The highest accumulations occurred in Zone 1 (Sections 1-7) and within the first cross-section downstream of Zone 1 in Zone 2 (Section 8). Cross Sections 9 through 11 showed negligible change, while Sections 12 and 13 appeared to have lost substantial amounts of sediment. Sections 14 through 19 accumulated sediments, but at less than half the unit volume as in the first adjustment period.

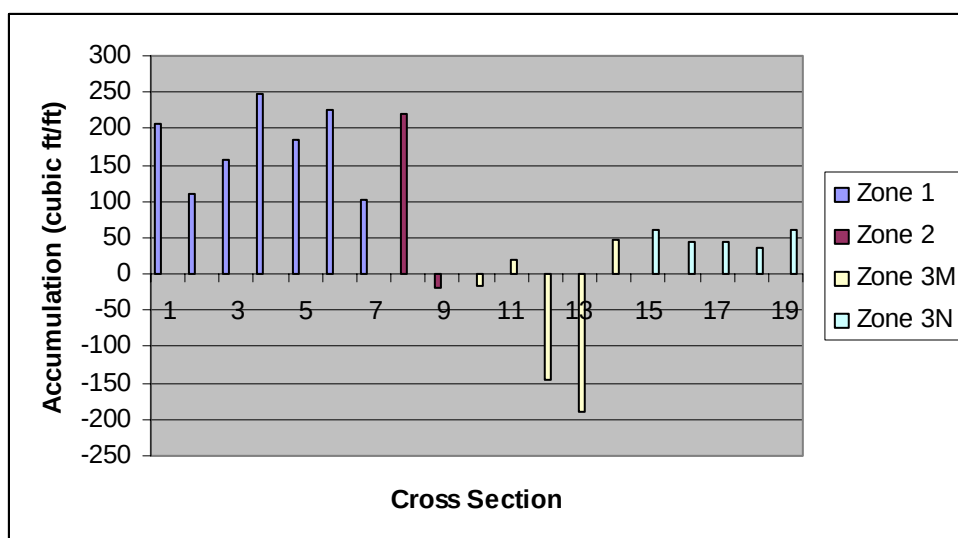


Figure 3. Sediment Accumulation Volume per Unit Channel Length—2001-2003.

During the first period, 1998-2001, sediment filling rates (inches of sediment per year) followed a pattern of increasing rate downstream with perhaps a threshold effect occurring at the bridges, marina, and downstream versus the upstream portion of the reach in Zone (**Figure 4**).

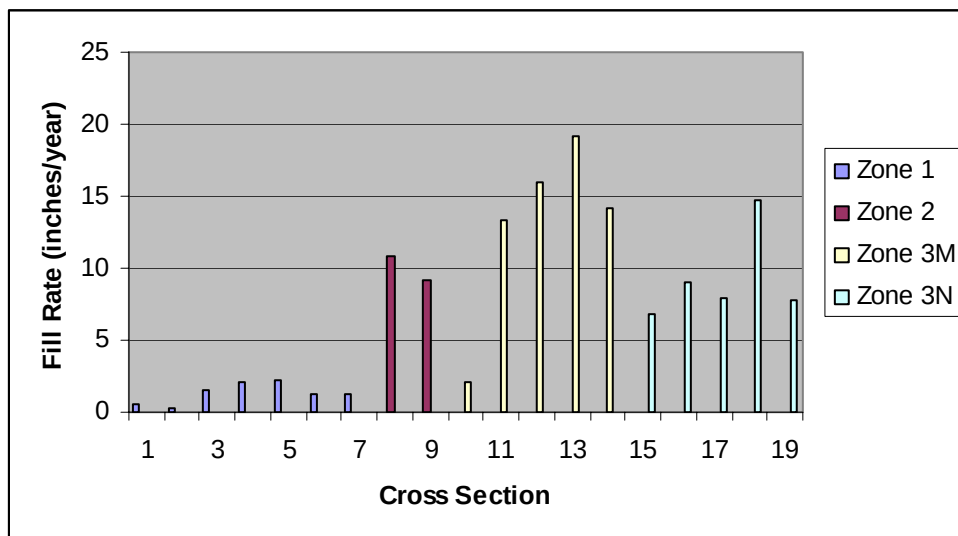


Figure 4. Sediment Accumulation Rate—1998-2001.

During the second period, 2001-2003, sediment filling rates were constant at about 3 to 5 inches per year for all cross sections except 9 through 13. These were mostly within the marina and showed generally variable net losses of sediment (**Figure 5**).

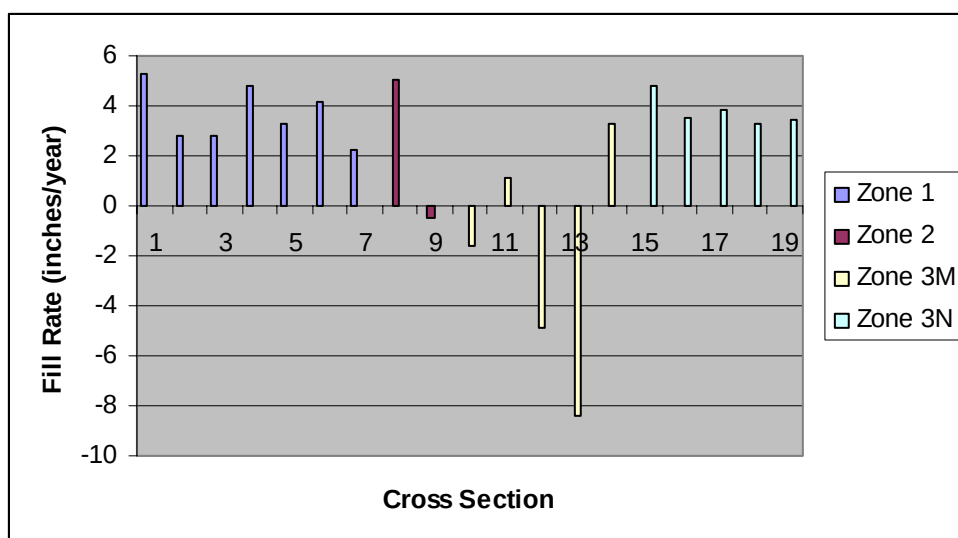


Figure 5. Sediment Accumulation Rate—2001-2003.

All of the sediments within the study area classify as muck (**Table 2**). These sediments, by volume, are dominated by fine black or brown organic material and water in a cohesive matrix. The dominant material is generally as small as silts and clays. Some sediments had intermixed sand and/or shell, and although described as muck by general texture and dominant volume, would classify as fine sands or sands by grain-size distribution based on dry weight. No obvious longitudinal pattern of gross changes in grain size distribution or textural classification emerged within the study area. However, Sites 4 and 3 are close to bridges and may be influenced by the hydraulics of those structures and by local fill material used during their construction (often sand and shell). If these sites are omitted, a general pattern of increasing fine organic material emerges as one moves from the narrow, relatively fresh portion of the creek toward the broad and increasingly saline mouth at the Lagoon (**Figure 6**). This is a common pattern in creeks as one moves downstream toward an estuary or other salt-water environment (Knighton 1998).

Table 2
Sediment Classification, Texture, and Grain Size

Site	Zone	Description	D ₅₀	Percent Finer than Sand (by weight)
7	upstream	Grayish brown shell & sand	0.35 mm	0
6	Zone 1	Dark Brownish black muck w/sand & shell	0.10 mm	34
5		Dark Brownish black muck w/sand	<0.037 mm	85
4	Zone 1/2	Dark Brownish black muck	<0.074 mm	63
3	Zone 2/3	Dark Brownish black muck w/sand & shell	0.22 mm	10
2	Zone 3	Dark Brownish black muck	<0.037 mm	92
703		Dark Brownish black muck	<0.037 mm	94
702	Indian River Lagoon	Dark Brownish black muck w/sand & shell	<0.037 mm	92
1		Dark Brownish black muck w/some shell	<0.037 mm	91
701		Brownish black muck w/sand & shell	0.55 mm	2

Notes: D₅₀ = median grain size diameter. Percent finer than sand is nominally defined as material passing 200 mesh screen (0.074 mm).

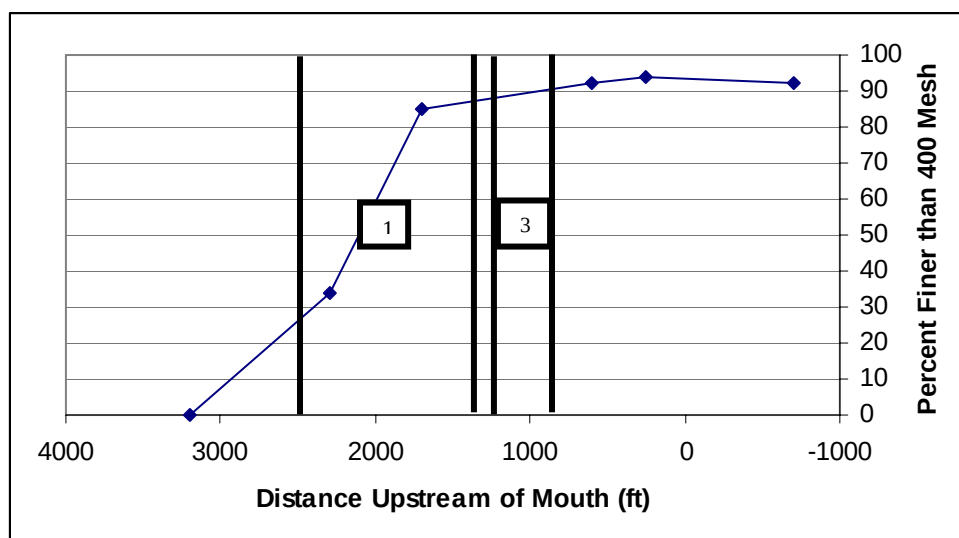


Figure 6. General Longitudinal Pattern of Sediment Size Along Crane Creek

Note: Vertical lines and labels depict approximate limits of the dredge Zones as described.

5.0 CONCLUSIONS AND DISCUSSION

The general longitudinal pattern of sediment grain size and muck accumulation suggests that the study reach of Crane Creek has long served as a depositional environment for fine-grained sediments (**Figure 6**). Subsequent to dredging in 1998, the repeat-surveys suggest substantially different sediment accumulation patterns between the initial adjustment period (1998-2001) and the second period (2001-2003). These differences appear to be unlikely due to chance (a single-factor analysis of variance gives a p-value equal to 0.002). Mean accumulation rates were approximately 7.4 inches per year during the first period and 2.0 inches per year during the latter.

It is conceivable that the first adjustment period involved mass-wasting (sloughing or slumping) of sediments from the undredged banks. These bank sediments could have contributed to the apparent net accumulation of bed sediments. Unfortunately, this can not be readily verified as the near-shore, upper-bank environments were not surveyed in 1997, 1998, or 2001. Another possibility that can not be ruled out by the survey alone is that sediment yields to the creek from the basin or upstream reaches decreased between the two periods.

A higher rate of accumulation could also simply be attributed to better trapping efficiency when the sumps were deeper and at lower average velocity regimes. By the time the second period arrived, the site simply had less capacity for accumulation. Decreased trapping efficiency is a common pattern in reservoirs as they accumulate sediments. However, it seems unlikely that this has happened in Crane Creek when we rank the amounts of accumulation by mean depth by Zone during the second period (**Table 3**). One important factor may be reflected in the effective width of the channel, especially since in this case the channel cross sectional area corresponds consistently with width when ranking the dredge Zones (wider widths lead to greater cross-sectional area). Larger cross-section channels offer lower overall velocities for a given volumetric flow rate. Although we see a pattern of mean accumulation within a Zone that does increase with channel width (**Table 4**), this pattern is perhaps misleading as the mean accumulation rate is skewed heavily downward in Zone 3 by effects that are occurring within the marina. Accumulation rates during the second period were just as high in the relatively narrow sections of Crane Creek near the lagoon mouth as they were in the 4 to 5 times wider cross sections upstream of the FEC rail line (**Map 3, Figure 5**).

Table 3
Sediment Accumulation Rates versus Typical Channel Depth (2001-2003)

Zone	Sump Depth	Sediment Accumulation
	<i>(feet)</i>	<i>(inches/year)</i>
Zone 2	15	2.3
Zone 3	8	0.7
Zone 1	4	3.6

Table 4
Sediment Accumulation Rates versus Typical Channel Width (2001-2003)

Zone	Sump Width	Sediment Accumulation
	<i>(feet)</i>	<i>(inches/year)</i>
Zone 3	115	0.7
Zone 2	300	2.3
Zone 1	352	3.6

It is apparent that the depositional rates and patterns can not be satisfactorily explained by hydraulic geometry as it relates to sediment transport alone. This is not a surprising conclusion for this type of environment—a near coastal setting with a salinity wedge effect.

The surveys should be used with caution when predicting sediment accumulation rates. The first period's apparent sediment accumulation may have included some mass-adjustments within the stream bed and banks not long after the dredging due to local sediment instabilities at the dredge limits. Therefore, it would be questionable to rely on the accumulation rates calculated from this data. Also, we are essentially using mean accumulations that have occurred at apparent thicknesses of roughly 22 inches during the first period with an additional accumulation of about 3 inches during the second. These thicknesses were calculated from surveys that are likely to have a point-by-point accuracy within 3 inches. Based on that level of accuracy, the first period of accumulation may be sufficient for forming opinions on how much sediment accumulated (although the process is unknown and questionable), while the second period's mean accumulations are close to the single-point margin of error in the survey and are questionable on that basis.

However, we can use the numbers cautiously to estimate the long-term sediment accumulation times necessary to fill each Zone to its 1997 pre-dredge elevations. The first adjustment period is omitted to avoid overestimating rates due to the potential for "one-time" adjustments. Using the second period's data, the limiting area is likely to be Zone 1, which had a mean accumulation rate of 3.6 inches per year and a capacity of about 2 to 3 feet as of the 2003 survey. If these numbers are accurate and the rate remains on that average, this Zone would reach its 1997 pre-dredge bed stage sometime between 2009 and 2013. This gives a total life of about 11 to 15 years for that Zone before a re-dredge is necessary. Similar calculations were made for Zone 3, outside of the marina at Cross Sections 15 through 19, using a mean accumulation rate of 3.8 inches/year within a capacity of roughly 2.5 feet as of 2003. This gave a remaining life of about 8 years for the non-marina section of Zone 3 (to 2011). That represents a 13-year total life for that portion of the project. Much of Zone 2 and the marina portion of Zone 3 did not significantly accumulate sediments, based on the results of this survey from 2001 to 2003.

Bathymetric surveys alone are unlikely to be sufficient predictors of net sediment trapping efficiencies except in cases where trapping has led to changes in bed levels well in excess of 3 inches between surveys and in cases where bank erosion can be ruled out. However, both of these potential limitations could be overcome if the bathymetric survey is supplemented

by additional survey techniques. These should simply include the use of traditional soundings or rod and level surveys that are carried fully from bank to bank. It is not sufficient to halt the survey prior to reaching the top of bank.

Also, the survey could be augmented by the use of bank pins (perhaps in both the dredge cut bank and the creek shoreline bank), which are series of metal or plastic pins inserted horizontally into the banks along the cross section from top to toe of the bank. These could be placed during the initial survey and checked periodically between surveys and during subsequent cross-section surveys. The amount of each pin that has been exposed (or buried) can be measured with a rule at a high level of accuracy (to within 0.25 inches). The pins are typically reset at each visit. Likewise, scour chains can be placed in the bed for analogous purpose. The length of exposed or buried chain can be measured to determine scour or deposition thicknesses to the accuracy of the observer's ability to read a ruler. These approaches are easy and inexpensive to implement in wadable, relatively clear streams. However, they would require divers and associated costs in systems as large and deep as Crane Creek, and may not be worth the additional resources necessary to implement them.

6.0 REFERENCES

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Appendix B: Crane Creek Water Quality Monitoring

July 5, 2001 to November 4, 2001

Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Crane Creek Water Quality Study										Rainfall:	None							
Date: 7-05-01																		
TEMPERATURE (°C)				SALINITY (ppt)				DISSOLVED OXYGEN (mg/L)				PERCENT SATURATION						
Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5			
0.0	33.1	32.7	31.3	0.0	8.8	8.1	25.6	0.0	6.72	6.86	6.16	0.0	99.0	99.5	95.5			
0.3	33.1	32.7	31.3	0.3	9.4	10.6	25.6	0.3	6.79	6.69	6.04	0.3	99.2	98.6	93.7			
0.6	33.3	33.0	31.3	0.6	18.8	20.8	25.6	0.6	8.49	6.30	6.15	0.6	122.2	101.6	95.7			
0.9	33.0	32.3	31.3	0.9	22.1	24.0	25.6	0.9	5.34	7.10	6.17	0.9	82.4	108.3	95.9			
1.2	32.6	31.9	31.3	1.2	23.5	25.1	25.6	1.2	3.63	4.08	6.12	1.2	50.5	64.2	95.0			
1.5		31.6	31.3	1.5		25.2	25.6	1.5		3.55	6.00	1.5		52.3	89.2			
1.8		31.5	31.3	1.8		25.2	25.6	1.8		3.41	5.77	1.8		52.2	90.1			
2.1		31.3	31.1	2.1		25.2	25.7	2.1		1.73	4.40	2.1		27.6	67.6			
2.4		31.2		2.4		25.3		2.4		1.83		2.4		29.6				
2.7		31.2		2.7		25.3		2.7		1.28		2.7		20.2				
3.0		30.5		3.0		25.5		3.0		0.01		3.0		0.1				
3.3		30.1		3.3		25.8		3.3		0.00		3.3		0.0				
3.6		30.0		3.6		25.8		3.6		0.00		3.6		0.0				
3.9		30.0		3.9		25.9		3.9		0.00		3.9		0.0				
4.2				4.2				4.2				4.2						
4.5				4.5				4.5				4.5						
4.8				4.8				4.8				4.8						
5.1				5.1				5.1				5.1						
FreshAVE	33.1	32.7	31.3		9.1	9.4	25.6		6.76	6.78	6.10		99.1	99.1	94.6			
STDEV	0.00	0.00	0.00		0.42	1.77	0.00		0.05	0.12	0.08		0.14	0.64	1.27			
SaltAVE	33.0	31.2	31.3		21.5	24.9	25.6		5.82	2.44	5.77		85.0	38.0	88.9			
STDEV	0.35	0.94	0.08		2.41	1.39	0.04		2.47	2.48	0.69		35.92	38.55	10.84			
Weather:	Partly Cloudy (40%) 87F																	
Wind:	SE 15 Knots																	
Time of Day:	2:00 PM																	
SECCHI DEPTH (m)																		
	Station 2	Station 3	Station 5															
1	0.78	0.80	1.00															
2	0.80	0.75	1.20															
3	0.80	0.60	1.00															
Average	0.79	0.72	1.07															

July 5, 2001 to November 4, 2001

[illegible]

Appendix B: Crane Creek Water Quality Monitoring (continued)

July 5, 2001 to November 4, 2001

Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

[illegible]

Appendix B: Crane Creek Water Quality Monitoring (continued)

July 5, 2001 to November 4, 2001

Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Crane Creek Water Quality Study								Rainfall:	7-05-01 = 3.66 cm						
									7-06-01 = 0.33 cm						
Date: 7-07-01C															
TEMPERATURE (°C)				SALINITY (ppt)				DISSOLVED OXYGEN (mg/L)				PERCENT SATURATION			
Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5
0.0	32.0	32.0	32.7	0.0	1.9	2.4	25.6	0.0	6.42	6.51	12.20	0.0	90.4	89.1	194.3
0.3	32.1	32.1	32.7	0.3	1.9	2.7	25.5	0.3	6.27	6.43	12.18	0.3	88.4	88.7	193.9
0.6	32.7	32.6	32.6	0.6	14.1	19.4	25.6	0.6	10.07	6.93	12.07	0.6	164.8	101.6	192.2
0.9	32.6	31.9	32.5	0.9	19.2	23.5	25.7	0.9	12.20	6.18	12.04	0.9	186.3	97.2	190.4
1.2	32.6	31.8	32.3	1.2	20.3	25.0	25.8	1.2	11.75	6.48	12.02	1.2	184.6	96.9	190.3
1.5		31.5	32.2	1.5		25.5	25.9	1.5		4.15	11.49	1.5		57.8	183.8
1.8		31.4	32.2	1.8		25.6	25.9	1.8		3.22	11.02	1.8		45.3	172.6
2.1		31.3	32.2	2.1		25.6	25.9	2.1		2.22	9.64	2.1		36.6	152.7
2.4		31.2		2.4		25.7		2.4		1.52		2.4		22.8	
2.7		31.1		2.7		25.7		2.7		0.54		2.7		8.6	
3.0		31.0		3.0		25.7		3.0		0.03		3.0		0.8	
3.3		30.8		3.3		25.7		3.3		0.01		3.3		0.1	
3.6		30.4		3.6		26.2		3.6		0.00		3.6		0.0	
3.9		29.8		3.9		26.4		3.9		0.00		3.9		0.0	
4.2		29.7		4.2		26.5		4.2		0.00		4.2		0.0	
4.5				4.5				4.5				4.5			
4.8				4.8				4.8				4.8			
5.1				5.1				5.1				5.1			
FreshAVE	32.1	32.1	32.7		1.9	2.6	25.6		6.35	6.47	12.19		89.4	88.9	194.1
STDEV	0.07	0.07	0.00		0.00	0.21	0.07		0.11	0.06	0.01		1.41	0.28	0.28
SaltAVE	32.6	31.1	32.3		17.9	25.1	25.8		11.34	2.41	11.38		178.6	36.0	180.3
STDEV	0.06	0.81	0.18		3.31	1.87	0.13		1.12	2.71	0.95		11.95	40.48	15.34
Weather:	Partly Cloudy (20%) 80F														
Wind:	SE 5-10 Knots														
Time of Day:	7:30 PM														
SECCHI DEPTH (m)															
	Station 2	Station 3	Station 5												
1	0.80	0.90	0.80												
2	0.80	0.90	0.85												
3	0.85	0.85	0.85												
Average	0.82	0.88	0.83												

Appendix B: Crane Creek Water Quality Monitoring (continued)

July 5, 2001 to November 4, 2001

Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Crane Creek Water Quality Study										Rainfall:	7-10-01 = 4.95 cm						
Date: 7-17-01											7-12-01 = 0.81 cm						
											7-13-01 = 0.56 cm						
											7-14-01 = 0.84 cm						
TEMPERATURE (°C)				SALINITY (ppt)				DISSOLVED OXYGEN (mg/L)				PERCENT SATURATION					
Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5		
0.0	29.5	29.0	28.8	0.0	1.4	0.9	8.0	0.0	4.12	4.19	7.20	0.0	53.6	54.7	95.1		
0.3	29.0	29.0	28.6	0.3	3.9	1.0	12.4	0.3	3.71	4.15	7.61	0.3	48.1	54.3	107.6		
0.6	29.1	28.8	28.5	0.6	17.8	1.7	20.8	0.6	2.03	4.12	6.15	0.6	25.9	52.8	89.9		
0.9	28.7	28.1	28.3	0.9	19.2	20.8	21.6	0.9	0.73	1.74	6.04	0.9	13.5	25.2	87.4		
1.2	28.5	28.1	28.3	1.2	20.0	21.5	21.9	1.2	0.51	1.57	6.38	1.2	5.7	20.5	90.6		
1.5		28.0	28.5	1.5		21.8	22.8	1.5		1.18	5.65	1.5		17.1	82.5		
1.8		28.2	28.4	1.8		22.1	23.2	1.8		0.50	4.47	1.8		7.8	66.5		
2.1		28.4	28.1	2.1		22.6	23.2	2.1		0.14	2.31	2.1		1.3	32.3		
2.4		28.6		2.4		23.1		2.4		0.02		2.4		0.4			
2.7		28.8		2.7		23.4		2.7		0.00		2.7		0.1			
3.0		28.9		3.0		23.6		3.0		0.00		3.0		0.0			
3.3		29.0		3.3		23.7		3.3		0.00		3.3		0.0			
3.6		29.0		3.6		23.9		3.6		0.00		3.6		0.0			
3.9		29.0		3.9		24.0		3.9		0.00		3.9		0.0			
4.2		29.0		4.2		29.0		4.2		0.00		4.2		0.0			
4.5				4.5				4.5				4.5					
4.8				4.8				4.8				4.8					
5.1				5.1				5.1				5.1					
FreshAVE	29.3	28.9	28.7		2.7	1.2	10.2		3.92	4.15	7.41		50.9	53.9	101.4		
STDEV	0.35	0.12	0.14		1.77	0.44	3.11		0.29	0.04	0.29		3.89	1.00	8.84		
SaltAVE	28.8	28.6	28.4		19.0	23.3	22.3		1.09	0.43	5.17		15.0	6.0	74.9		
STDEV	0.31	0.41	0.15		1.11	2.07	0.98		0.82	0.67	1.55		10.19	9.41	22.68		
Weather:	Partly Cloudy (25%) 80F																
Wind:	SE 0-2 Knots																
Time of Day:	9:15 AM																
SECCHI DEPTH (m)																	
	Station 2	Station 3	Station 5														
1	0.70	1.15	0.90														
2	0.70	1.00	1.00														
3	0.65	1.10	1.10														
Average	0.68	1.08	1.00														

July 5, 2001 to November 4, 2001

[illegible]

July 5, 2001 to November 4, 2001

Crane Creek Water Quality Study									Rainfall:	None						
Date: 7-26-01																
TEMPERATURE (°C)				SALINITY (ppt)				DISSOLVED OXYGEN (mg/L)				PERCENT SATURATION				
Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	
0.0	31.1	31.4	29.8	0.0	0.9	1.2	15.2	0.0	5.18	4.97	7.42	0.0	70.6	67.2	105.5	
0.3	31.0	31.1	29.8	0.3	0.9	1.2	15.2	0.3	5.21	4.95	7.30	0.3	71.0	66.6	104.8	
0.6	31.0	30.8	29.9	0.6	1.2	1.5	15.2	0.6	4.94	4.52	7.45	0.6	70.1	61.4	107.1	
0.9	30.3	29.5	29.9	0.9	4.2	4.6	15.2	0.9	3.76	2.64	7.34	0.9	54.1	36.6	105.1	
1.2	30.0	29.3	29.9	1.2	8.3	15.9	15.2	1.2	3.06	2.02	7.32	1.2	41.7	33.8	106.4	
1.5		28.7	29.9	1.5		18.4	15.2	1.5		0.73	7.22	1.5		8.8	104.1	
1.8		28.3	29.9	1.8		19.4	15.3	1.8		0.26	7.09	1.8		2.8	102.8	
2.1		28.2	29.9	2.1		19.9	15.4	2.1		0.03	6.05	2.1		0.7	81.2	
2.4		28.2		2.4		20.0		2.4		0.02		2.4		0.3		
2.7		28.1		2.7		20.3		2.7		0.02		2.7		0.2		
3.0		28.1		3.0		20.4		3.0		0.01		3.0		0.1		
3.3		28.3		3.3		21.0		3.3		0.01		3.3		0.1		
3.6		28.3		3.6		21.5		3.6		0.00		3.6		0.0		
3.9		28.5		3.9		22.0		3.9		0.00		3.9		0.0		
4.2		28.6		4.2		22.5		4.2		0.00		4.2		0.0		
4.5				4.5				4.5				4.5				
4.8				4.8				4.8				4.8				
5.1				5.1				5.1				5.1				
FreshAve	31.0	30.7	29.8		1.0	2.1	15.2		5.11	4.27	7.36		70.6	58.0	105.2	
STDEV	0.06	0.84	0.00		0.17	1.66	0.00		0.15	1.11	0.08		0.45	14.47	0.49	
SaltAve	30.2	28.4	29.9		6.3	20.1	15.3		3.41	0.28	7.08		47.9	4.3	101.1	
STDEV	0.21	0.35	0.00		2.90	1.83	0.08		0.49	0.62	0.52		8.77	10.15	9.88	
Weather:	Partly Cloudy (50%) 85F															
Wind:	ESE 10-15 Knots															
Time of Day:	1:30 PM															
SECCHI DEPTH (m)																
	Station 2	Station 3	Station 5													
1	0.70	0.75	0.60													
2	0.75	0.80	0.60													
3	0.80	0.80	0.60													
Average	0.75	0.78	0.60													

Appendix B: Crane Creek Water Quality Monitoring (continued)

July 5, 2001 to November 4, 2001

Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

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July 5, 2001 to November 4, 2001

Crane Creek Water Quality Study								Rainfall:	None						
Date: 8-23-01															
TEMPERATURE (°C)				SALINITY (ppt)				DISSOLVED OXYGEN (mg/L)				PERCENT SATURATION			
Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5
0.0	28.8	29.2	30.6	0.0	0.7	1.2	14.4	0.0	4.75	5.29	6.66	0.0	62.3	69.8	95.7
0.3	28.7	29.3	30.6	0.3	0.7	1.2	14.4	0.3	4.71	5.31	6.65	0.3	61.4	69.7	95.5
0.6	28.7	29.5	30.6	0.6	1.0	3.5	15.9	0.6	4.46	3.86	5.20	0.6	61.1	69.3	74.4
0.9	30.4	31.3	30.6	0.9	7.4	13.3	16.3	0.9	1.28	0.46	4.69	0.9	17.8	7.1	68.0
1.2	31.2	31.5	30.7	1.2	13.2	16.3	16.8	1.2	0.09	0.05	3.96	1.2	2.2	0.3	57.6
1.5		31.4	30.8	1.5		16.4	16.9	1.5		0.01	3.93	1.5		0.2	57.6
1.8		31.4	30.7	1.8		16.4	17.0	1.8		0.01	3.08	1.8		0.1	46.2
2.1		31.4	30.8	2.1		16.5	17.1	2.1		0.01	2.28	2.1		0.1	32.7
2.4		31.3		2.4		16.5		2.4		0.01		2.4		0.1	
2.7		31.1		2.7		16.5		2.7		0.01		2.7		0.1	
3.0		30.9		3.0		16.5		3.0		0.01		3.0		0.1	
3.3		30.2		3.3		16.6		3.3		0.01		3.3		0.1	
3.6		30.0		3.6		16.7		3.6		0.00		3.6		0.0	
3.9		29.5		3.9		16.8		3.9		0.00		3.9		0.0	
4.2				4.2				4.2				4.2			
4.5				4.5				4.5				4.5			
4.8				4.8				4.8				4.8			
5.1				5.1				5.1				5.1			
FreshAVE	28.7	29.3	30.6		0.8	2.0	14.9		4.64	4.82	6.17		61.6	69.6	88.5
STDEV	0.06	0.15	0.00		0.17	1.33	0.87		0.16	0.83	0.84		0.62	0.26	12.24
SaltAVE	30.8	30.9	30.7		10.3	16.2	16.8		0.69	0.05	3.59		10.0	0.7	52.4
STDEV	0.57	0.69	0.08		4.10	0.98	0.31		0.84	0.14	0.93		11.03	2.11	13.45
Weather:	Partly Cloudy (40%) 80F														
Wind:	ENE 5 Knots														
Time of Day:	10:00 AM														
SECCHI DEPTH (m)															
	Station 2	Station 3	Station 5												
1	0.80	0.70	0.60												
2	0.75	0.60	0.70												
3	0.75	0.60	0.65												
Average	0.77	0.63	0.65												

July 5, 2001 to November 4, 2001

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July 5, 2001 to November 4, 2001

<u>Crane Creek Water Quality Study</u>									Rainfall:	9-11-01 = 1.07 cm					
Date: 9-12-01										9-12-01 = 1.98 cm					
<u>TEMPERATURE (°C)</u>				<u>SALINITY (ppt)</u>				<u>DISSOLVED OXYGEN (mg/L)</u>				<u>PERCENT SATURATION</u>			
Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5
0.0	27.0	26.8	27.8	0.0	0.5	0.8	10.9	0.0	4.94	5.24	5.96	0.0	61.0	62.9	82.8
0.3	27.0	26.8	27.9	0.3	0.8	1.0	11.5	0.3	4.90	4.95	5.72	0.3	61.6	62.2	78.2
0.6	27.0	26.8	28.0	0.6	1.4	1.1	15.6	0.6	4.88	4.92	5.43	0.6	61.5	61.5	74.6
0.9	27.5	27.4	28.1	0.9	3.5	8.7	15.8	0.9	3.76	3.04	5.28	0.9	46.4	44.6	74.2
1.2	29.1	28.7	28.2	1.2	8.9	12.5	16.1	1.2	1.62	1.35	5.09	1.2	29.1	19.2	71.5
1.5		29.1	28.3	1.5		15.0	16.5	1.5		0.66	4.93	1.5		9.6	66.4
1.8		29.2	28.3	1.8		15.7	16.5	1.8		0.42	4.67	1.8		3.9	66.0
2.1		29.2	28.3	2.1		16.0	16.5	2.1		0.07	4.64	2.1		2.4	65.2
2.4		29.1		2.4		16.3		2.4		0.03		2.4		0.5	
2.7		29.1		2.7		16.4		2.7		0.03		2.7		0.4	
3.0		29.1		3.0		16.4		3.0		0.03		3.0		0.4	
3.3		29.1		3.3		16.6		3.3		0.02		3.3		0.3	
3.6		29.0		3.6		16.8		3.6		0.02		3.6		0.3	
3.9		28.9		3.9		17.0		3.9		0.02		3.9		0.3	
4.2				4.2				4.2				4.2			
4.5				4.5				4.5				4.5			
4.8				4.8				4.8				4.8			
5.1				5.1				5.1				5.1			
FreshAve	27.0	26.8	27.9		0.9	1.0	12.7		4.91	5.04	5.70		61.4	62.2	78.5
STDEV	0.00	0.00	0.10		0.46	0.15	2.56		0.03	0.18	0.27		0.32	0.70	4.11
SaltAve	28.3	28.9	28.2		6.2	15.2	16.3		2.69	0.52	4.92		37.8	7.4	68.7
STDEV	1.13	0.52	0.09		3.82	2.50	0.32		1.51	0.93	0.27		12.23	13.65	3.97
Weather:	Clouds (100%) 75F														
Wind:	S 5 Knots														
Time of Day:	11:30 AM														
SECCHI DEPTH (m)															
	Station 2	Station 3	Station 5												
1	0.75	0.70	0.50												
2	0.75	0.75	0.50												
3	0.75	0.75	0.50												
Average	0.75	0.73	0.50												

July 5, 2001 to November 4, 2001

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July 5, 2001 to November 4, 2001

Crane Creek Water Quality Study										Rainfall:	9-25-01 = 1.91 cm							
											9-26-01 = 2.16 cm							
Date: 9-28-01											9-27-01 = 2.18 cm							
TEMPERATURE (°C)				SALINITY (ppt)				DISSOLVED OXYGEN (mg/L)				PERCENT SATURATION						
Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5			
0.0	27.4	27.6	28.7	0.0	0.4	0.4	16.7	0.0	5.17	4.87	6.25	0.0	63.0	62.7	98.0			
0.3	27.3	27.3	28.6	0.3	0.4	0.4	16.7	0.3	5.10	4.83	6.24	0.3	65.0	61.2	89.0			
0.6	27.2	26.4	28.5	0.6	0.4	0.6	16.7	0.6	4.91	4.50	6.17	0.6	62.4	55.5	87.6			
0.9	26.2	26.5	28.2	0.9	1.3	3.3	16.7	0.9	3.95	2.58	6.12	0.9	47.5	32.2	86.2			
1.2	27.2	27.9	27.9	1.2	6.8	16.3	16.7	1.2	0.28	0.77	5.81	1.2	3.6	11.6	76.5			
1.5		28.1	27.6	1.5		16.4	16.8	1.5		0.53	5.35	1.5		7.4	72.1			
1.8		28.1	27.6	1.8		16.5	16.8	1.8		0.38	4.53	1.8		5.6	61.5			
2.1		28.1	27.5	2.1		16.5	16.8	2.1		0.70	3.60	2.1		10.5	51.5			
2.4		28.1	27.5	2.4		16.5	16.8	2.4		0.90	3.23	2.4		13.0	44.1			
2.7		28.1		2.7		16.6		2.7		0.76		2.7		9.5				
3.0		28.1		3.0		16.6		3.0		0.73		3.0		8.8				
3.3		28.1		3.3		16.6		3.3		0.61		3.3		4.4				
3.6		28.0		3.6		16.6		3.6		0.55		3.6		7.6				
3.9		28.0		3.9		16.6		3.9		0.21		3.9		2.7				
4.2		27.8		4.2		16.7		4.2		0.02		4.2		0.2				
4.5				4.5				4.5				4.5						
4.8				4.8				4.8				4.8						
5.1				5.1				5.1				5.1						
FreshAVE	27.0	27.0	28.5		0.6	1.2	16.7		4.78	4.20	6.20		59.5	52.9	90.2			
STDEV	0.56	0.59	0.22		0.45	1.42	0.00		0.57	1.09	0.06		8.06	14.14	5.32			
SaltAVE	27.2	28.0	27.6		6.8	16.5	16.8		0.28	0.56	4.50		3.6	7.4	61.1			
STDEV		0.10	0.16			0.11	0.04			0.26	1.10			3.89	13.60			
Weather:	Mostly Cloudy (75%) 85F																	
Wind:	NE 5 Knots																	
Time of Day:	1:00 PM																	
SECCHI DEPTH (m)																		
	Station 2	Station 3	Station 5															
1	0.70	0.80	0.60															
2	0.70	0.80	0.60															
3	0.70	0.80	0.70															
Average	0.70	0.80	0.63															

July 5, 2001 to November 4, 2001

Crane Creek Water Quality Study								Rainfall:	None						
Date: 10-12-01															
TEMPERATURE (°C)				SALINITY (ppt)				DISSOLVED OXYGEN (mg/L)				PERCENT SATURATION			
Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5
0.0	27.1	26.7	25.2	0.0	0.9	1.3	14.8	0.0	7.14	7.90	8.78	0.0	91.6	105.0	115.7
0.3	27.1	26.9	25.2	0.3	0.9	1.1	14.8	0.3	7.12	8.20	8.68	0.3	89.2	104.2	115.0
0.6	27.0	25.8	25.2	0.6	1.8	2.9	14.8	0.6	7.10	6.00	8.68	0.6	97.3	77.6	113.7
0.9	25.4	25.3	25.0	0.9	6.4	10.0	14.8	0.9	2.70	5.20	8.50	0.9	38.4	63.4	112.7
1.2	25.4	25.0	24.7	1.2	11.3	15.4	15.0	1.2	2.91	3.43	7.82	1.2	29.4	46.5	102.6
1.5		24.8	24.5	1.5		15.6	15.5	1.5		3.30	6.67	1.5		40.0	90.1
1.8		24.8	24.4	1.8		15.8	16.9	1.8		2.51	5.03	1.8		33.0	67.0
2.1		24.8	24.4	2.1		15.9	17.7	2.1		2.42	4.06	2.1		31.2	54.2
2.4		24.9		2.4		16.0		2.4		2.10		2.4		25.8	
2.7		25.0		2.7		16.1		2.7		1.51		2.7		22.4	
3.0		25.1		3.0		16.2		3.0		1.03		3.0		13.7	
3.3		25.7		3.3		16.7		3.3		0.11		3.3		0.7	
3.6		26.0		3.6		17.0		3.6		0.02		3.6		0.2	
3.9		26.2		3.9		17.2		3.9		0.01		3.9		0.1	
4.2		26.3		4.2		17.2		4.2		0.01		4.2		0.1	
4.5				4.5				4.5				4.5			
4.8				4.8				4.8				4.8			
5.1				5.1				5.1				5.1			
FreshAVE	27.1	26.5	25.0		1.2	1.8	15.0		7.12	7.37	8.19		92.7	95.6	108.3
STDEV	0.06	0.59	0.30		0.52	0.99	0.28		0.02	1.19	0.82		4.16	15.59	10.12
SaltAVE	25.4	25.3	24.4		8.9	15.8	17.3		2.81	1.80	4.55		33.9	23.1	60.6
STDEV	0.00	0.57	0.00		3.46	1.91	0.57		0.15	1.67	0.69		6.36	20.89	9.05
Weather:	Sunny, Clouds (0%) 85F														
Wind:	SE 10 Knots														
Time of Day:	1:00 PM														
SECCHI DEPTH (m)															
	Station 2	Station 3	Station 5												
1	0.90	0.90	0.75												
2	0.90	0.90	0.70												
3	0.90	0.90	0.70												
Average	0.90	0.90	0.72												

July 5, 2001 to November 4, 2001

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July 5, 2001 to November 4, 2001

Crane Creek Water Quality Study								Rainfall:		10-24-01 = 2.87 cm							
										10-25-01 = 2.89 cm							
Date: 10-26-01																	
TEMPERATURE (°C)				SALINITY (ppt)				DISSOLVED OXYGEN (mg/L)				PERCENT SATURATION					
Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5		
0.0	24.2	24.0	25.0	0.0	0.2	0.4	18.6	0.0	4.84	4.94	5.44	0.0	59.3	59.4	73.8		
0.3	24.2	24.2	25.0	0.3	0.2	0.4	18.6	0.3	4.83	4.93	5.34	0.3	54.5	58.5	72.6		
0.6	24.3	24.2	25.0	0.6	0.2	0.6	18.6	0.6	4.83	4.92	5.42	0.6	55.5	58.7	73.4		
0.9	24.3	24.3	25.0	0.9	0.2	0.7	18.6	0.9	4.73	4.90	5.32	0.9	55.6	57.4	70.6		
1.2	24.2	24.7	25.0	1.2	0.2	2.7	18.6	1.2	4.72	3.69	5.35	1.2	58.6	40.3	71.1		
1.5		25.7	25.0	1.5		15.5	18.6	1.5		2.20	5.26	1.5		24.2	72.1		
1.8		25.7	25.0	1.8		16.7	18.6	1.8		1.85	5.37	1.8		24.5	72.9		
2.1		25.8	25.0	2.1		17.1	18.6	2.1		1.80	5.48	2.1		27.5	73.1		
2.4		25.7		2.4		17.3		2.4		1.32		2.4		19.3			
2.7		25.7		2.7		17.3		2.7		1.30		2.7		16.6			
3.0		25.7		3.0		17.4		3.0		1.12		3.0		14.5			
3.3		25.6		3.3		17.5		3.3		0.55		3.3		16.0			
3.6		25.6		3.6		17.5		3.6		0.46		3.6		11.7			
3.9		25.6		3.9		17.6		3.9		0.55		3.9		5.7			
4.2				4.2				4.2				4.2					
4.5				4.5				4.5				4.5					
4.8				4.8				4.8				4.8					
5.1				5.1				5.1				5.1					
FreshAVE	24.2	24.5	25.0		0.2	1.0	18.6		4.79	4.68	5.39		56.7	54.9	73.2		
STDEV	0.05	0.62	0.00		0.00	0.98	0.00		0.06	0.55	0.07		2.11	8.17	0.85		
SaltAVE		25.7	25.0			17.1	18.6			1.24	5.37			17.8	72.2		
STDEV		0.07	0.00			0.66	0.00			0.63	0.08			6.90	1.14		
Weather:	Light Rain Clouds (100%) 75F																
Wind:	NE 15-20 Knots																
Time of Day:	9:00 AM																
SECCHI DEPTH (m)																	
	Station 2	Station 3	Station 5														
1	0.60	0.45	0.65														
2	0.60	0.55	0.70														
3	0.60	0.55	0.60														
Average	0.60	0.52	0.65														

July 5, 2001 to November 4, 2001

Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Crane Creek Water Quality Study								Rainfall:	None						
Date: 11-02-01A															
TEMPERATURE (°C)				SALINITY (ppt)				DISSOLVED OXYGEN (mg/L)				PERCENT SATURATION			
Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5
0.0	24.0	23.6	22.3	0.0	0.9	1.7	10.5	0.0	5.56	5.38	7.84	0.0	65.7	60.7	95.7
0.3	23.9	23.7	22.3	0.3	0.9	1.5	13.4	0.3	5.43	5.34	7.64	0.3	66.3	60.3	93.1
0.6	23.9	23.6	22.2	0.6	0.9	1.6	13.4	0.6	5.35	5.23	7.63	0.6	62.7	62.8	95.0
0.9	23.9	23.6	22.2	0.9	1.1	1.8	13.6	0.9	5.36	4.85	7.54	0.9	63.9	59.5	95.6
1.2	23.0	23.0	22.2	1.2	6.5	4.7	13.5	1.2	2.50	3.19	7.28	1.2	28.1	34.7	90.0
1.5		22.4	22.1	1.5		9.3	14.1	1.5		2.53	7.42	1.5		34.6	92.8
1.8		22.1	22.1	1.8		16.2	14.2	1.8		1.67	7.33	1.8		20.2	92.1
2.1		21.0	22.1	2.1		16.7	14.2	2.1		1.67		2.1		19.1	90.3
2.4		20.6		2.4		17.8		2.4		1.62		2.4		20.2	
2.7		20.4		2.7		18.5		2.7		1.08		2.7		13.2	
3.0		20.2		3.0		18.8		3.0		1.16		3.0		11.7	
3.3		20.1		3.3		18.9		3.3		0.99		3.3		11.9	
3.6		20.1		3.6		18.9		3.6		0.64		3.6		8.2	
3.9		20.1		3.9		19.0		3.9		0.78		3.9		9.8	
4.2		20.1		4.2		19.0		4.2		0.75		4.2		9.2	
4.5				4.5				4.5				4.5			
4.8				4.8				4.8				4.8			
5.1				5.1				5.1				5.1			
FreshAVE	23.9	23.3	22.3		1.0	3.4	10.5		5.43	4.42	7.84		64.7	52.1	95.7
STDEV	0.05	0.52			0.10	3.12			0.10	1.24			1.65	13.56	
SaltAVE	23.0	20.5	22.2		6.5	18.2	13.8		2.50	1.15	7.47		28.1	13.7	92.7
STDEV		0.67	0.08			1.07	0.38			0.41	0.15			4.83	2.13
Weather:	Partly Cloudy (50%) 75F														
Wind:	E 15-20 Knots														
Time of Day:	10:00 AM														
SECCHI DEPTH (m)															
	Station 2	Station 3	Station 5												
1	0.75	0.80	0.85												
2	0.80	0.80	0.90												
3	0.80	0.85	0.90												
Average	0.78	0.82	0.88												

Appendix B: Crane Creek Water Quality Monitoring (continued)

July 5, 2001 to November 4, 2001

Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Crane Creek Water Quality Study								Rainfall:	11-02-01 = 0.71 cm									
Date: 11-02-01B								St 5. Sampling aborted due to darkness and wind										
TEMPERATURE (°C)				SALINITY (ppt)				DISSOLVED OXYGEN (mg/L)				PERCENT SATURATION						
Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5			
0.0	24.7	24.6		0.0	0.7	1.1		0.0	5.80	6.06		0.0	70.3	72.2				
0.3	24.7	24.6		0.3	0.7	1.1		0.3	5.77	5.80		0.3	69.6	70.4				
0.6	24.8	24.6		0.6	0.7	1.1		0.6	5.82	5.76		0.6	70.2	68.7				
0.9	24.8	24.5		0.9	0.7	1.5		0.9	5.83	5.53		0.9	70.0	67.3				
1.2	24.7	24.2		1.2	0.8	3.6		1.2	5.47	3.53		1.2	65.1	50.2				
1.5		22.2		1.5		12.1		1.5		2.05		1.5		25.4				
1.8		21.6		1.8		14.3		1.8		1.89		1.8		19.9				
2.1		21.5		2.1		16.6		2.1		1.39		2.1		17.9				
2.4		20.5		2.4		18.1		2.4		1.27		2.4		13.9				
2.7		20.5		2.7		18.3		2.7		1.01		2.7		11.4				
3.0		20.5		3.0		18.6		3.0		0.87		3.0		10.5				
3.3		20.3		3.3		18.7		3.3		0.73		3.3		8.9				
3.6		20.3		3.6		18.7		3.6		0.70		3.6		8.0				
3.9				3.9				3.9				3.9						
4.2				4.2				4.2				4.2						
4.5				4.5				4.5				4.5						
4.8				4.8				4.8				4.8						
5.1				5.1				5.1				5.1						
FreshAVE	24.7	24.1			0.7	3.4			5.74	4.79			69.0	59.0				
STDEV	0.05	0.95			0.04	4.36			0.15	1.63			2.22	18.30				
SaltAVE		20.7				17.6				1.12				12.9				
STDEV		0.56				1.64				0.43				4.53				
Weather:	Clouds (100%) 70F																	
Wind:	E 15-20 Knots																	
Time of Day:	6:00 PM																	
SECCHI DEPTH (m)																		
	Station 2	Station 3	Station 5															
1	Dark																	
2																		
3																		
Average																		

Appendix B: Crane Creek Water Quality Monitoring (continued)

July 5, 2001 to November 4, 2001

Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Crane Creek Water Quality Study								Rainfall:	11-02-01 = 0.71 cm							
Date: 11-03-01																
TEMPERATURE (°C)				SALINITY (ppt)				DISSOLVED OXYGEN (mg/L)				PERCENT SATURATION				
Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	
0.0	24.6	25.0	23.4	0.0	0.8	1.2	13.5	0.0	6.30	6.24	8.93	0.0	76.0	78.2	112.3	
0.3	24.6	24.9	23.3	0.3	0.8	1.2	13.4	0.3	6.19	6.26	9.07	0.3	75.7	75.5	114.8	
0.6	24.6	24.0	23.2	0.6	0.8	1.6	13.6	0.6	6.25	5.63	9.04	0.6	74.5	70.4	112.3	
0.9	24.6	23.8	23.1	0.9	0.8	2.9	13.7	0.9	6.15	4.97	8.85	0.9	74.3	60.3	112.4	
1.2	24.6	22.7	23.0	1.2	0.8	9.0	14.6	1.2	3.15	3.26	8.44	1.2	50.2	39.2	107.0	
1.5		22.0	22.9	1.5		14.7	15.3	1.5		2.13	8.03	1.5		27.2	100.8	
1.8		21.5	22.6	1.8		16.0	16.0	1.8		1.53	6.53	1.8		19.2	82.4	
2.1		21.3	22.3	2.1		16.5	18.7	2.1		1.27	5.36	2.1		15.1	68.7	
2.4		21.0		2.4		17.8		2.4		0.74		2.4		7.4		
2.7		20.5		2.7		18.4		2.7		0.50		2.7		6.6		
3.0		20.4		3.0		18.5		3.0		0.27		3.0		2.9		
3.3		20.4		3.3		18.7		3.3		0.16		3.3		1.2		
3.6		20.3		3.6		18.7		3.6		0.20		3.6		2.6		
3.9		20.3		3.9		18.8		3.9		0.09		3.9		1.5		
4.2				4.2				4.2				4.2				
4.5				4.5				4.5				4.5				
4.8				4.8				4.8				4.8				
5.1				5.1				5.1				5.1				
FreshAVE	24.6	24.1	23.3		0.8	3.2	13.6		5.61	5.27	8.97		70.1	64.7	113.0	
STDEV	0.00	0.94	0.13		0.00	3.33	0.13		1.38	1.24	0.10		11.17	15.82	1.23	
SaltAVE		20.9	22.7			17.6	16.2			0.77	7.09			9.3	89.7	
STDEV		0.62	0.32			1.48	1.79			0.72	1.42			9.19	17.48	
Weather:	Partly Cloudy (40%) 75F															
Wind:	E 10-15 Knots															
Time of Day:	10:30 AM															
SECCHI DEPTH (m)																
	Station 2	Station 3	Station 5													
1	0.85	0.85	0.90													
2	0.85	0.85	0.90													
3	0.85	0.90	0.90													
Average	0.85	0.87	0.90													

Appendix B

July 5, 2001 to November 4, 2001

Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Crane Creek Water Quality Study

Rainfall: 11-03-01 = 0.91 cm

Date: 11-04-01

[illegible]

Appendix C: Crane Creek Water Quality Monitoring

January 11, 2002 to March 15, 2002

Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Crane Creek Water Quality Study								Rainfall:	None							
Date: 1-11-02																
TEMPERATURE (°C)				SALINITY (ppt)				DISSOLVED OXYGEN (mg/L)				PERCENT SATURATION				
Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	
0.0	18.5	18.2	14.7	0.0	8.3	5.1	21.4	0.0	11.68	8.09	8.41	0.0	122.5	86.9	93.7	
0.3	18.4	18.3	14.5	0.3	10.9	5.3	21.5	0.3	10.71	8.37	8.38	0.3	145.3	91.2	93.8	
0.6	15.3	14.8	13.5	0.6	15.1	18.3	21.6	0.6	13.40	11.38	8.51	0.6	141.1	136.6	93.6	
0.9	15.8	13.5	13.2	0.9	18.3	21.5	21.6	0.9	10.39	12.75	8.64	0.9	117.7	138.5	93.9	
1.2		13.2	12.9	1.2		21.6	21.6	1.2		12.25	8.49	1.2		128.0	93.7	
1.5		13.2	12.8	1.5		21.7	21.6	1.5		11.53	8.47	1.5		126.2	91.7	
1.8		13.1	12.7	1.8		21.7	21.6	1.8		11.29	8.45	1.8		123.1	88.5	
2.1		13.0	12.6	2.1		21.7	21.7	2.1		11.23	8.13	2.1		118.1	89.0	
2.4		13.0		2.4		21.7		2.4		10.70		2.4		117.0		
2.7		13.0		2.7		21.7		2.7		10.62		2.7		115.4		
3.0		13.0		3.0		21.7		3.0		10.60		3.0		114.2		
3.3		13.0		3.3		21.7		3.3		10.33		3.3		111.9		
3.6		13.0		3.6		21.7		3.6		10.45		3.6		113.4		
3.9		13.0		3.9		21.7		3.9		10.31		3.9		113.5		
4.2		13.0		4.2		21.7		4.2		10.29		4.2		112.6		
4.5		13.0		4.5		21.8		4.5		10.12		4.5		109.8		
4.8				4.8				4.8				4.8				
5.1				5.1				5.1				5.1				
FreshAve		18.5	18.3	14.6	9.6		5.2	21.5	11.20		8.23	8.40	133.9		89.1	93.8
STDEV		0.05	0.07	0.14	1.84		0.14	0.07	0.69		0.20	0.02	16.12		3.04	0.07
SaltAve		15.6	13.2	13.0	16.7		21.4	21.6	11.90		11.06	8.45	129.4		120.7	91.7
STDEV		0.35	0.50	0.34	2.26		0.94	0.04	2.13		0.78	0.17	16.55		9.12	2.45
Weather:		Sunny, Clouds (0%) 70F														
Wind:		W 5 Knots														
Time of Day:		12:30 PM														
SECCHI DEPTH (m)																
Station 2		Station 3	Station 5													
1	0.70	0.60	0.90													
2	0.70	0.60	0.90													
3	0.65	0.70	0.90													
Average	0.68	0.63	0.90													

January 11, 2002 to March 15, 2002

Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Crane Creek Water Quality Study								Rainfall:	1-14-02 = 1.70 cm						
									1-15-02 = 2.36 cm						
Date: 1-18-02															
TEMPERATURE (°C)				SALINITY (ppt)				DISSOLVED OXYGEN (mg/L)				PERCENT SATURATION			
Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5
0.0	21.1	20.9	17.9	0.0	4.8	4.4	20.9	0.0	6.25	6.23	10.79	0.0	73.1	71.7	131.1
0.3	21.0	20.9	18.1	0.3	5.4	4.6	20.3	0.3	6.16	6.11	10.59	0.3	69.9	68.1	126.1
0.6	19.6	18.8	17.6	0.6	11.1	15.1	21.0	0.6	6.09	8.77	10.71	0.6	70.7	98.3	128.2
0.9	18.8	17.4	17.6	0.9	16.7	20.9	21.1	0.9	6.05	8.03	10.79	0.9	72.1	95.1	130.2
1.2	18.7	17.0	17.4	1.2	18.0	21.0	21.2	1.2	5.69	7.54	11.01	1.2	72.0	85.3	130.8
1.5		16.9	17.3	1.5		21.0	21.2	1.5		6.40	10.66	1.5		77.1	126.3
1.8		16.5	17.3	1.8		21.1	21.2	1.8		5.53	10.58	1.8		64.2	120.8
2.1		16.3	17.2	2.1		21.1	21.2	2.1		5.50	9.74	2.1		58.3	119.0
2.4		16.2		2.4		21.1		2.4		4.79		2.4		55.5	
2.7		16.1		2.7		21.2		2.7		4.45		2.7		53.7	
3.0		15.8		3.0		21.2		3.0		3.40		3.0		29.1	
3.3		15.5		3.3		21.3		3.3		1.28		3.3		24.6	
3.6		15.1		3.6		21.3		3.6		0.17		3.6		3.1	
3.9		14.9		3.9		21.3		3.9		0.04		3.9		0.5	
4.2		14.8		4.2		21.3		4.2		0.02		4.2		0.2	
4.5		14.8		4.5		21.4		4.5		0.04		4.5		0.4	
4.8				4.8				4.8				4.8			
5.1				5.1				5.1				5.1			
FreshAVE	21.1	20.9	18.0		5.1	4.5	20.6		6.21	6.17	10.69		71.5	69.9	128.6
STDEV	0.07	0.00	0.14		0.42	0.14	0.42		0.06	0.08	0.14		2.26	2.55	3.54
SaltAVE	19.0	16.3	17.4		15.3	20.7	21.2		5.94	4.30	10.58		71.6	49.6	125.9
STDEV	0.49	1.11	0.17		3.67	1.68	0.08		0.22	3.10	0.44		0.78	35.20	4.93
Weather:	Mostly Cloudy (75%) 70F														
Wind:	W 0-5 Knots														
Time of Day:	1:00 PM														
SECCHI DEPTH (m)															
	Station 2	Station 3	Station 5												
1	0.60	0.60	0.90												
2	0.60	0.60	0.90												
3	0.60	0.60	0.90												
Average	0.60	0.60	0.90												

January 11, 2002 to March 15, 2002

Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

[illegible]

January 11, 2002 to March 15, 2002

Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Crane Creek Water Quality Study								Rainfall:	None						
Date: 2-06-02															
TEMPERATURE (°C)				SALINITY (ppt)				DISSOLVED OXYGEN (mg/L)				PERCENT SATURATION			
Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5
0.0	21.5	21.5	19.9	0.0	2.8	4.0	19.5	0.0	7.68	7.25	9.01	0.0	89.4	83.7	109.8
0.3	21.4	21.1	19.7	0.3	2.8	4.0	19.5	0.3	7.76	6.91	9.08	0.3	87.5	79.8	112.0
0.6	21.4	20.9	19.7	0.6	9.6	10.4	19.5	0.6	6.41	6.08	9.16	0.6	81.2	71.3	113.5
0.9	21.6	20.9	19.7	0.9	13.7	14.4	19.5	0.9	3.98	4.43	9.16	0.9	51.4	59.0	112.4
1.2	21.6	20.8	19.7	1.2	14.1	17.8	19.5	1.2	3.40	2.80	9.10	1.2	40.5	36.0	111.8
1.5		20.7	19.7	1.5		18.6	19.5	1.5		2.44	9.03	1.5		30.9	110.9
1.8		20.7	19.7	1.8		18.7	19.5	1.8		2.26	9.05	1.8		28.4	110.8
2.1		20.7	19.7	2.1		18.8	19.5	2.1		2.11	8.95	2.1		26.6	110.0
2.4		20.7		2.4		18.9		2.4		1.81		2.4		23.7	
2.7		20.6		2.7		19.3		2.7		0.15		2.7		13.1	
3.0		20.2		3.0		19.9		3.0		0.05		3.0		0.7	
3.3		19.7		3.3		20.1		3.3		0.03		3.3		0.4	
3.6		19.0		3.6		20.2		3.6		0.02		3.6		0.3	
3.9		18.8		3.9		20.2		3.9		0.02		3.9		0.2	
4.2		18.6		4.2		20.3		4.2		0.00		4.2		0.0	
4.5				4.5				4.5				4.5			
4.8				4.8				4.8				4.8			
5.1				5.1				5.1				5.1			
FreshAVE	21.5	21.3	19.8		2.8	4.0	19.5		7.72	7.08	9.05		88.5	81.8	110.9
STDEV	0.07	0.28	0.14		0.00	0.00	0.00		0.06	0.24	0.05		1.34	2.76	1.56
SaltAVE	21.5	20.2	19.7		12.5	18.3	19.5		4.60	1.71	9.08		57.7	22.4	111.6
STDEV	0.12	0.85	0.00		2.49	2.84	0.00		1.60	1.94	0.08		21.07	23.39	1.26
Weather:	Sunny, Clouds (15%) 70F														
Wind:	SE 15-20 Knots														
Time of Day:	1:15 PM														
SECCHI DEPTH (m)															
	Station 2	Station 3	Station 5												
1	0.70	0.50	0.60												
2	0.70	0.60	0.50												
3	0.70	0.60	0.60												
Average	0.70	0.57	0.57												

January 11, 2002 to March 15, 2002

Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

[illegible]

January 11, 2002 to March 15, 2002

Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

[illegible]

January 11, 2002 to March 15, 2002

Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Crane Creek Water Quality Study								Rainfall:							
Date: 3-1-02															
TEMPERATURE (°C)				SALINITY (ppt)				DISSOLVED OXYGEN (mg/L)				PERCENT SATURATION			
Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5
0.0	17.4	18.0	17.1	0.0	4.7	9.9	20.1	0.0	8.70	8.50	7.80	0.0	91.2	94.4	92.5
0.3	17.5	18.1	17.1	0.3	4.7	10.0	20.3	0.3	8.60	8.40	7.83	0.3	92.6	94.8	91.4
0.6	17.5	18.1	17.1	0.6	4.9	10.5	20.3	0.6	8.50	8.50	7.80	0.6	93.0	92.5	91.4
0.9	19.1	18.5	17.1	0.9	4.6	15.8	20.3	0.9	3.10	6.20	7.80	0.9	53.8	71.0	91.5
1.2	19.7	18.4	17.1	1.2	14.2	17.0	20.3	1.2	3.00	5.10	7.80	1.2	38.0	56.0	92.3
1.5		18.0	17.1	1.5		18.7	20.3	1.5		4.20	7.80	1.5		54.0	91.6
1.8		18.0	17.1	1.8		19.0	20.3	1.8		4.20	7.80	1.8		51.0	91.7
2.1		18.0	17.1	2.1		19.4	20.3	2.1		4.30	7.80	2.1		51.6	91.6
2.4		17.9		2.4		19.6		2.4		4.30		2.4		52.0	
2.7		17.8		2.7		19.7		2.7		4.40		2.7		51.7	
3.0		17.8		3.0		19.7		3.0		4.50		3.0		52.5	
3.3		17.7		3.3		19.8		3.3		4.60		3.3		54.4	
3.6		17.7		3.6		19.8		3.6		4.50		3.6		54.0	
3.9		17.5		3.9		19.9		3.9		4.50		3.9		53.0	
4.2		17.5		4.2		19.9		4.2		4.50		4.2		53.0	
4.5				4.5				4.5				4.5			
4.8				4.8				4.8				4.8			
5.1				5.1				5.1				5.1			
FreshAVE	18.2	18.1	17.1		4.7	10.1	20.2		7.23	8.47	7.82		82.7	93.9	92.0
STDEV	0.82	0.06	0.00		0.13	0.32	0.12		2.75	0.06	0.02		19.25	1.23	0.78
SaltAVE	19.7	17.9	17.1		14.2	19.0	20.3		3.00	4.61	7.80		38.0	54.5	91.7
STDEV		0.31	0.00			1.30	0.00			0.56	0.00			5.38	0.32
Weather:	Clouds (100%) 65F														
Wind:	E 20 Knots														
Time of Day:	12:00 PM														
SECCHI DEPTH (m)															
	Station 2	Station 3	Station 5												
1	1.10	0.90	1.00												
2	1.20	0.80	1.40												
3	1.30	0.90	1.30												
Average	1.20	0.87	1.23												

January 11, 2002 to March 15, 2002

Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Crane Creek Water Quality Study								Rainfall:	None							
Date: 3-04-02																
TEMPERATURE (°C)				SALINITY (ppt)				DISSOLVED OXYGEN (mg/L)				PERCENT SATURATION				
Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	
0.0	18.4	18.9	18.6	0.0	7.1	5.7	20.1	0.0	7.40	6.83	6.99	0.0	85.7	76.0	83.2	
0.3	19.0	19.4	18.6	0.3	7.1	6.0	20.1	0.3	6.97	6.22	6.99	0.3	76.3	69.3	83.9	
0.6	20.5	20.3	18.7	0.6	17.4	19.3	20.1	0.6	4.90	5.65	6.83	0.6	60.0	69.5	82.7	
0.9	20.5	20.4	18.7	0.9	19.6	20.8	20.1	0.9	4.35	5.50	6.96	0.9	53.6	68.7	84.5	
1.2	20.5	20.3	18.7	1.2	19.9	21.0	20.1	1.2	4.05	5.35	6.99	1.2	45.2	65.8	84.2	
1.5		20.4	18.7	1.5		21.0	20.1	1.5		5.25	6.94	1.5		65.8	83.1	
1.8		20.4	18.6	1.8		21.0	20.1	1.8		5.23	7.02	1.8		66.5	84.2	
2.1		20.4	18.6	2.1		21.1	20.1	2.1		5.24	7.01	2.1		67.2	84.2	
2.4		20.4		2.4		21.1		2.4		5.35		2.4		66.8		
2.7		20.4		2.7		21.2		2.7		5.41		2.7		67.4		
3.0		20.4		3.0		21.2		3.0		5.20		3.0		66.9		
3.3		20.4		3.3		21.2		3.3		5.22		3.3		65.7		
3.6		20.4		3.6		21.2		3.6		5.14		3.6		64.5		
3.9		20.4		3.9		21.2		3.9		4.96		3.9		62.2		
4.2		20.4		4.2		21.2		4.2		4.95		4.2		61.8		
4.5				4.5				4.5				4.5				
4.8				4.8				4.8				4.8				
5.1				5.1				5.1				5.1				
FreshAve									18.7	19.2	18.6		7.1	5.9	20.1	
STDEV									0.42	0.35	0.00		0.00	0.21	0.00	
SaltAve									20.5	20.4	18.7		19.0	21.0	20.1	
STDEV									0.00	0.04	0.05		1.37	0.51	0.00	
Weather:								Clouds (100%) 55F								
Wind:								NW 5 - 7 Knots								
Time of Day:								1:30 PM								
SECCHI DEPTH (m)																
Station 2								Station 3								
1								0.80								
2								0.80								
3								0.80								
Average								0.80								

Appendix C: Crane Creek Water Quality Monitoring (continued)

January 11, 2002 to March 15, 2002

Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Crane Creek Water Quality Study										Rainfall:	None						
Date: 3-06-02																	
TEMPERATURE (°C)				SALINITY (ppt)				DISSOLVED OXYGEN (mg/L)				PERCENT SATURATION					
Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5		
0.0	19.8	19.7	16.6	0.0	3.7	6.7	19.5	0.0	8.16	7.92	8.33	0.0	91.7	90.8	98.2		
0.3	19.8	19.7	16.5	0.3	3.7	7.1	19.7	0.3	8.08	7.76	8.17	0.3	91.3	89.6	96.2		
0.6	19.7	18.9	16.5	0.6	3.8	9.7	19.8	0.6	8.11	6.32	8.27	0.6	90.8	71.3	94.3		
0.9	19.6	18.7	16.4	0.9	13.9	15.6	19.8	0.9	4.04	5.93	8.18	0.9	38.5	68.2	94.7		
1.2	19.9	18.4	16.4	1.2	16.5	17.9	19.9	1.2	1.78	5.46	8.19	1.2	23.6	65.1	94.3		
1.5		18.2	16.4	1.5		18.8	19.9	1.5		4.69	8.20	1.5		55.2	95.0		
1.8		18.1	16.3	1.8		19.4	20.2	1.8		4.47	7.63	1.8		50.0	90.1		
2.1		18.0	16.2	2.1		19.7	20.5	2.1		3.77	7.18	2.1		44.6	84.2		
2.4		18.0		2.4		19.8		2.4		3.88		2.4		45.7			
2.7		17.9		2.7		19.9		2.7		4.09		2.7		49.1			
3.0		17.8		3.0		20.0		3.0		4.57		3.0		53.8			
3.3		17.7		3.3		20.0		3.3		4.58		3.3		54.0			
3.6		17.8		3.6		20.1		3.6		3.92		3.6		44.7			
3.9		17.8		3.9		20.1		3.9		3.89		3.9		46.1			
4.2		17.8		4.2		20.1		4.2		4.00		4.2		47.1			
4.5				4.5				4.5				4.5					
4.8				4.8				4.8				4.8					
5.1				5.1				5.1				5.1					
FreshAVE	19.8	19.4	16.6		3.7	7.8	19.6		8.12	7.33	8.25		91.3	83.9	97.2		
STDEV	0.06	0.46	0.07		0.06	1.63	0.14		0.04	0.88	0.11		0.45	10.93	1.41		
SaltAVE	19.8	18.0	16.4		15.2	19.3	20.0		2.91	4.44	7.94		31.1	52.0	92.1		
STDEV	0.21	0.29	0.10		1.84	1.33	0.28		1.60	0.67	0.44		10.54	7.81	4.27		
Weather:	Partly Cloudy (50%) 70F																
Wind:	E 5 Knots																
Time of Day:	12:30 PM																
SECCHI DEPTH (m)																	
	Station 2	Station 3	Station 5														
1	0.90	0.90	1.50														
2	0.90	0.75	1.40														
3	0.90	0.75	1.50														
Average	0.90	0.80	1.47														

January 11, 2002 to March 15, 2002

Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

Crane Creek Water Quality Study									Rainfall:	None																				
Date: 3-13-02																														
TEMPERATURE (°C)				SALINITY (ppt)				DISSOLVED OXYGEN (mg/L)				PERCENT SATURATION																		
Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5	Depth (m)	Station 2	Station 3	Station 5															
0.0	24.7	24.6	23.0	0.0	11.3	10.6	20.3	0.0	9.65	9.30	7.95	0.0	124.0	119.5	102.7															
0.3	24.7	24.7	23.0	0.3	11.4	10.6	20.3	0.3	9.58	9.14	7.97	0.3	123.1	116.9	104.7															
0.6	24.8	24.7	23.0	0.6	12.0	11.0	20.3	0.6	9.48	9.10	7.96	0.6	123.8	111.2	104.4															
0.9	24.2	24.7	23.0	0.9	14.5	18.5	20.3	0.9	8.46	8.26	7.86	0.9	105.0	114.5	103.4															
1.2		23.0	23.0	1.2		19.6	20.3	1.2		6.88	7.92	1.2		86.5	103.8															
1.5		22.6	23.0	1.5		20.1	20.3	1.5		5.18	8.03	1.5		66.4	104.5															
1.8		22.2	23.0	1.8		20.2	20.3	1.8		4.39	8.05	1.8		56.9	104.8															
2.1		20.1	23.0	2.1		20.2	20.3	2.1		3.72	7.96	2.1		48.8	103.1															
2.4		21.8		2.4		20.2		2.4		3.30		2.4		43.1																
2.7		21.6		2.7		20.2		2.7		3.01		2.7		36.5																
3.0		21.1		3.0		20.1		3.0		2.06		3.0		26.0																
3.3		20.6		3.3		20.2		3.3		1.88		3.3		20.9																
3.6		20.1		3.6		20.1		3.6		1.42		3.6		18.1																
3.9		19.9		3.9		20.1		3.9		1.40		3.9		18.5																
4.2		19.5		4.2		20.1		4.2		0.95		4.2		13.3																
4.5		19.4		4.5		20.2		4.5		0.68		4.5		9.0																
4.8				4.8				4.8				4.8																		
5.1				5.1				5.1				5.1																		
FreshAVE										24.7	24.7	23.0		11.4	10.7	20.3		9.62	9.18	7.96		123.6	115.9	103.7						
STDEV										0.00	0.07	0.00		0.07	0.23	0.00		0.05	0.11	0.01		0.64	4.25	1.41						
SaltAVE										24.5	21.4	23.0		13.3	20.0	20.3		8.97	3.54	7.96		114.4	45.8	104.0						
STDEV										0.42	1.53	0.00		1.77	0.49	0.00		0.72	2.30	0.07		13.29	31.05	0.67						
Weather:									Partly Cloudy (40%) 75F																					
Wind:									W 15 - 20 Knots																					
Time of Day:									1:30 PM																					
SECCHI DEPTH (m)																														
Station 2									Station 3									Station 5												
1									0.70									0.60									1.00			
2									0.70									0.50									1.00			
3									0.70									0.60									1.00			
Average									0.70									0.57									1.00			

Appendix C: Crane Creek Water Quality Monitoring (continued)

January 11, 2002 to March 15, 2002

Salinity, Temperature, Dissolved Oxygen, Percent Saturation, Secchi Depth, and Meteorological Observations.

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Appendix D
Crane Creek Total Suspended Solids and Turbidity (continued)

July 17, 2001 to November 4, 2001

Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL							Rainfall:	7-10-01 = 4.95 cm
Date: 7-17-01								7-12-01 = 0.81 cm
Time: 9:15 AM								7-13-01 = 0.56 cm
Weather: Partly Cloudy (25%) 80F								7-14-01 = 0.84 cm
Wind: SE 0-2 Knots								
Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
2S (A)	14.5	16.0	1.5	250	6.4	31173	2.69	1.4
2S (B)	14.6	16.2	1.6					
2S (C)	14.5	16.2	1.7					
		Mean	1.6					
		STDEV	0.10					
		RSD (%)	6					
2D	14.8	17.3	2.5	250	10.0	48707	4.21	17.8
3S	14.4	16.0	1.6	300	5.3	25977	2.24	0.9
3D	14.5	15.9	1.4	300	4.7	22730	1.96	22.6
4S	14.8	16.1	1.3	300	4.3	11385	0.98	N/A
4D	14.7	16.6	1.9	300	6.3	16640	1.44	N/A
Sample Location	Turbidity (NTU)		Stream Velocity (ft/s)	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	Ave Streamflow (m3/s)	
2S (A)	4.1		RailRoad					
2S (B)	4.0		Surface	0.4	0.12192	79.9	9.7	4.9
2S (C)	4.0		Mid-Depth	0.2	0.06096	79.9	4.9	
MEAN	4.0		Bottom	0	0	79.9	0.0	
STDEV	0.1		US1					
RSD (%)	1.4		Surface	0.5	0.1524	43.1	6.6	2.6
			Mid-Depth	0.1	0.03048	43.1	1.3	
2D	4.2		Bottom	0	0	43.1	0.0	
3S	3.5							
3D	4.7		Flow Direction:	Downstream				
4S	3.3							
4D	3.5							

Appendix D
Crane Creek Total Suspended Solids and Turbidity (continued)

July 17, 2001 to November 4, 2001
 Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL							Rainfall:	7-17-01 = 1.35 cm
Date: 7-19-01								7-18-01 = 8.13 cm
Time: 2:00 PM								
Weather: Mostly Cloudy (75%) 85F								
Wind: E 10 Knots								
Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
3S (A)	14.5	16.1	1.6	250	6.4	31173	2.69	0.2
3S (B)	14.5	16.1	1.6	250				
3S (C)	14.4	16.0	1.6	250				
		Mean	1.6					
		STDEV	0.00					
		RSD (%)	0					
3D	14.3	17.1	2.8	250	11.2	54552	4.71	20.8
2S	14.3	16.1	1.8	250	7.2	35069	3.03	0.4
2D	14.4	17.0	2.6	250	10.4	50655	4.38	0.4
4S	14.4	16.2	1.8	250	7.2	23646	2.04	N/A
4D	14.4	18.1	3.7	650	5.7	18695	1.62	N/A
Sample Location	Turbidity (NTU)		Stream Velocity (ft/s)	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)	
3S (A)	5.4		RailRoad					
3S (B)	5.3		Surface	0.5	0.1524	79.9	12.2	4.9
3S (C)	5.4		Mid-Depth	0.1	0.03048	79.9	2.4	
MEAN	5.4		Bottom	0	0	79.9	0.0	
STDEV	0.1		US1					
RSD (%)	1.1		Surface	0.65	0.19812	43.1	8.5	3.3
			Mid-Depth	0.1	0.03048	43.1	1.3	
3D	4.2		Bottom	0	0	43.1	0.0	
2S	4.2							
2D	4.9		Flow Direction:	Downstream				
4S	5.5							
4D	5.0							

Appendix D
Crane Creek Total Suspended Solids and Turbidity (continued)

July 17, 2001 to November 4, 2001

Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL							Rainfall:	None
Date: 7-26-01								
Time: 1:30 PM								
Weather: Partly Cloudy (50%)								
Wind: ESE 10 - 15 Knots								
Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
2D (A)	14.5	17.7	3.2	400	8.1	39372	3.40	1.2
2D (B)	14.6	17.9	3.3	400				
2D (C)	14.8	18.0	3.2	400				
		Mean	3.2					
		STDEV	0.06					
		RSD (%)	2					
2S	14.6	17.8	3.2	400	8.0	38966	3.37	0.9
3S	14.8	16.7	1.9	300	6.3	30848	2.67	1.2
3D	14.8	18.9	4.1	600	6.8	33283	2.88	19.9
4S	14.8	17.1	2.3	300	7.7	6714	0.58	N/A
4D	14.8	18.3	3.5	400	8.8	7663	0.66	N/A
Sample Location	Turbidity (NTU)		Stream Velocity (ft/s)	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)	
2D (A)	16.0		RailRoad					
2D (B)	16.0		Surface	0.3	0.09144	79.9	7.3	4.9
2D (C)	16.0		Mid-Depth	0.3	0.09144	79.9	7.3	
MEAN	16.0		Bottom	0	0	79.9	0.0	
STDEV	0.0		US1					
RSD (%)	0.0		Surface	0.1	0.03048	43.1	1.3	0.9
			Mid-Depth	0.1	0.03048	43.1	1.3	
			Bottom	0	0	43.1	0.0	
2S	6.5							
3S	5.5							
3D	12.0		Flow Direction:	Downstream				
4S	5.3							
4D	16.0							

Appendix D
Crane Creek Total Suspended Solids and Turbidity (continued)

July 17, 2001 to November 4, 2001

Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL							Rainfall:	8-01-01 = 0.23 cm
Date: 8-03-01								8-02-01 = 2.87 cm
Time: 9:45 AM								
Weather: Clouds (100%) 75 F								
Wind: ESE 15 Knots								
Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED (mL)	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
4S (A)	14.7	18.5	3.8	400	9.5	22279	1.92	1.1
4S (B)	14.7	18.5	3.8	400				
4S (C)	14.5	18.3	3.8	400				
		Mean	3.8					
		STDEV	0.00					
		RSD (%)	0					
4D	14.7	17.6	2.9	400	7.3	17002	1.47	11.1
3S	14.7	17.8	3.1	400	7.8	18175	1.57	0.7
3D	14.8	18.3	3.5	450	7.8	18240	1.58	12.1
2S	14.7	18.1	3.4	400	8.5	19934	1.72	0.5
2D	14.9	17.9	3	400	7.5	17589	1.52	0.5
Sample Location	Turbidity (NTU)			CTS/Sec	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)
4S (A)	6.4		RailRoad					
4S(B)	6.5		Surface	N/A				
4S (C)	6.4		Mid-Depth	N/A				
MEAN	6.4		Bottom	N/A				
STDEV	0.1		US1					
RSD (%)	0.9		Surface	2.07	0.111405	43.1	4.8	2.3
			Mid-Depth	0.82	0.04703	43.1	2.0	
4D	5.2		Bottom	0	0.0048	43.1	0.2	
3S	7.2							
3D	5.3		Flow Direction:	Downstream				
2S	6.4							
2D	6.2	mechanical current meter now employed						

Appendix D
Crane Creek Total Suspended Solids and Turbidity (continued)

July 17, 2001 to November 4, 2001

Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL						Rainfall:	None	
Date: 8-23-01				3D I = 1.05 m				
Time: 10:00 AM				3D II = 2.1 m (Mid-Depth)				
Weather: Partly Cloudy (40%) 80F				3D III = 3.15 m				
Wind: ENE 5 Knots								
Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED (mL)	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
3 D II (A)	14.5	16.5	2.0	200	9.5	14055	1.21	16.2
3 D II (B)	14.8	16.6	1.8					
3 D II (C)	14.5	16.4	1.9					
		Mean	1.9					
		STDEV	0.10					
		RSD (%)	5					
3S	14.5	16.1	1.6	300	5.3	7891	0.68	1.2
3 D I	15	17.4	2.4	200	12.0	17754	1.53	14.6
3 D III	14.7	16.0	1.3	200	6.5	9617	0.83	16.2
4S	14.7	16.5	1.8	300	6.0	8877	0.77	1.5
4D	14.6	16.5	1.9	200	9.5	14055	1.21	16.4
2S	14.7	16.6	1.9	300	6.3	9370	0.81	0.7
2D	14.5	16.6	2.1	300	7.0	10356	0.89	1.2
Sample Location	Turbidity (NTU)			CTS/Sec	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)
3 D II (A)	21.0		RailRoad					
3 D II (B)	22.0		Surface	N/A				
3 D II (C)	21.0		Mid-Depth	N/A				
MEAN	21.3		Bottom	N/A				
STDEV	0.6		US1					
RSD (%)	2.7		Surface	1.49	0.081535	43.1	3.5	1.5
			Mid-Depth	0.23	0.016645	43.1	0.7	
3S	3.7		Bottom	0	0.0048	43.1	0.2	
3 D I	15.0							
3 D III	12.0		Flow Direction:	Downstream				
4S	3.9							
4D	22.0							
2S	4.3							
2D	4.6							

Appendix D
Crane Creek Total Suspended Solids and Turbidity (continued)

July 17, 2001 to November 4, 2001

Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL							Rainfall:	None
Date: 8-31-01								
Time: 10:00 AM								
Weather: Partly Cloudy (50%) 85F								
Wind: S 5 Knots								
Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED (mL)	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
4S (A)	14.7	17.5	2.8	500	5.7	8803	0.76	3.6
4S (B)	14.5	17.3	2.8					
4S (C)	14.7	17.6	2.9					
		Mean	2.8					
		STDEV	0.06					
		RSD (%)	2					
4D	14.8	17.0	2.2	350	6.3	9765	0.84	16
3S	14.7	17.3	2.6	500	5.2	8078	0.70	2.4
3I	14.7	17.0	2.3	400	5.8	8932	0.77	11.5
3II	14.7	17.3	2.6	400	6.5	10098	0.87	17.7
3III	14.7	19.0	4.3	400	10.8	16700	1.44	17.8
2S	14.8	18.7	3.9	600	6.5	10098	0.87	3.5
2D	14.5	17.8	3.3	450	7.3	11392	0.98	6.5
Sample Location	Turbidity (NTU)			CTS/Sec	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)
4S (A)	4.1		RailRoad					
4S (B)	4.3		Surface	N/A				
4S (C)	4.1		Mid-Depth	N/A				
MEAN	4.2		Bottom	N/A				
STDEV	0.1		US1					
RSD (%)	2.8		Surface	1.82	0.09853	43.1	4.2	1.6
			Mid-Depth	0	0.0048	43.1	0.2	
			Bottom	0	0.0048	43.1	0.2	
4D	6.2							
3S	4.1							
3I	4.0		Flow Direction:	Downstream				
3II	4.6							
3III	9.5							
2S	5.2							
2D	5.3							

Appendix D
Crane Creek Total Suspended Solids and Turbidity (continued)

July 17, 2001 to November 4, 2001

Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL							Rainfall:	9-11-01 = 1.07 cm
Date: 9-12-01								9-12-01 = 1.98 cm
Time: 11:30 AM								
Weather: Clouds (100%) 75F								
Wind: S 5 Knots								
Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED (mL)	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
2S (A)	14.8	17.0	2.2	400	5.6	14457	1.25	0.5
2S (B)	14.7	17.1	2.4					
2S (C)	14.7	16.8	2.1					
		Mean	2.2					
		STDEV	0.15					
		RSD (%)	7					
2D	14.7	17.3	2.6	400	6.5	16830	1.45	1.6
3S	14.7	17.1	2.4	400	6.0	15536	1.34	0.8
3I	14.6	17.0	2.4	300	8.0	20714	1.79	8.1
3II	14.9	17.6	2.7	250	10.8	27964	2.42	16.3
3III	14.6	16.9	2.3	250	9.2	23822	2.06	16.7
4S	14.5	17.0	2.5	400	6.3	16183	1.40	3.3
4D	14.7	17.3	2.6	250	10.4	26929	2.33	5.9
Sample Location	Turbidity (NTU)			CTS/Sec	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)
2S (A)	3.8		RailRoad					
2S (B)	3.8		Surface	N/A				
2S (C)	4.0		Mid-Depth	N/A				
MEAN	3.9		Bottom	N/A				
STDEV	0.1		US1					
RSD (%)	3.0		Surface	2.9	0.15415	43.1	6.6	2.6
			Mid-Depth	0.32	0.02128	43.1	0.9	
			Bottom	0	0.0048	43.1	0.2	
2D	4.5							
3S	4.7							
3I	5.4		Flow Direction:	Downstream				
3II	4.5							
3III	5.6							
4S	3.3							
4D	5.9							

Appendix D
Crane Creek Total Suspended Solids and Turbidity (continued)

July 17, 2001 to November 4, 2001

Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL							Rainfall:	None
Date: 9-21-01								
Time: 1:00 PM								
Weather: Partly Cloudy (30%) 85F								
Wind: SE 5 Knots								
Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED (mL)	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
4D (A)	14.6	17.7	3.1	500	6.3	3934	0.34	14.9
4D (B)	14.5	17.7	3.2					
4D (C)	14.6	17.8	3.2					
		Mean	3.2					
		STDEV	0.06					
		RSD (%)	2					
4S	14.6	17.1	2.5	600	4.2	2588	0.22	2.1
2S	14.7	17.4	2.7	500	5.4	3355	0.29	1.8
2D	14.6	18.3	3.7	500	7.4	4597	0.40	4.1
3S	14.7	17.0	2.3	550	4.2	2598	0.22	1.9
3I	14.5	17.3	2.8	500	5.6	3479	0.30	12.8
3II	14.5	17.3	2.8	450	6.2	3865	0.33	15
3III	14.7	17.6	2.9	500	5.8	3603	0.31	16.2
Sample Location	Turbidity (NTU)			CTS/Sec	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)
4D (a)	3.6		RailRoad					
4D (B)	3.6		Surface	N/A				
4D (C)	3.7		Mid-Depth	N/A				
MEAN	3.6		Bottom	N/A				
STDEV	0.1		US1					
RSD (%)	1.6		Surface	0.56	0.03364	43.1	1.4	0.6
			Mid-Depth	0	0.0048	43.1	0.2	
			Bottom	0	0.0048	43.1	0.2	
4S	2.9							
2S	2.9							
2D	3.4		Flow Direction:	Downstream				
3S	3.0							
3I	3.0							
3II	3.4							
3III	3.5							

Appendix D
Crane Creek Total Suspended Solids and Turbidity (continued)

July 17, 2001 to November 4, 2001

Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL							Rainfall:	9-25-01 = 1.91 cm
Date: 9-28-01								9-26-01 = 2.16 cm
Time: 1:00 PM								9-27-01 = 2.18 cm
Weather: Mostly Cloudy (75%) 85F								
Wind: NE 5 Knots								
Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED (mL)	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
3D III (A)	14.9	17.2	2.3	400	5.8	9188	0.79	16.6
3D III (B)	14.8	17.1	2.3					
3D III (C)	14.7	17.0	2.3					
		Mean	2.3					
		STDEV	0.00					
		RSD (%)	0					
3S	14.5	18.1	3.6	600	6.0	9587	0.83	0.4
3I	14.9	17.0	2.1	400	5.3	8389	0.72	3.9
3II	14.6	16.9	2.3	400	5.8	9188	0.79	16.1
2S	14.5	17.2	2.7	400	6.8	10786	0.93	0.4
2D	14.8	17.3	2.5	400	6.3	9987	0.86	0.4
4S	14.8	17.3	2.5	400	6.3	9987	0.86	0.7
4D	14.5	17.8	3.3	400	8.3	13182	1.14	16.1
Sample Location	Turbidity (NTU)			CTS/Sec	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)
3D III (A)	6.2		RailRoad					
3D III (B)	6.1		Surface	N/A				
3D III (C)	6.1		Mid-Depth	N/A				
MEAN	6.1		Bottom	N/A				
STDEV	0.1		US1					
RSD (%)	0.9		Surface	1.75	0.094925	43.1	4.1	1.6
			Mid-Depth	0.13	0.011495	43.1	0.5	
3S	3.5		Bottom	0	0.0048	43.1	0.2	
3I	4.1							
3II	4.1		Flow Direction:	Downstream				
2S	3.4							
2D	5.5							
4S	3.7							
4D	5.1							

Appendix D

July 17, 2001 to November 4, 2001

Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL						Rainfall:	None		
Date: 10-12-01									
Time: 1:00 PM									
Weather: Sunny, Clouds (0%) 85F									
Wind: SE 10 Knots									
Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED (mL)	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)	
4S (A)	14.6	16.9	2.3	400	5.8	4919	0.42	1.6	
4S (B)	14.5	16.9	2.4						
4S (C)	14.6	16.9	2.3						
		Mean	2.3						
		STDEV	0.06						
		RSD (%)	2						
4D	14.5	17.0	2.5	250	10.0	8432	0.73	15.5	
3S	14.6	17.0	2.4	400	6.0	5059	0.44	1.2	
3I	14.7	17.4	2.7	350	7.7	6505	0.56	15	
3II	14.6	16.6	2	300	6.7	5621	0.49	15.8	
3III	14.7	16.7	2	300	6.7	5621	0.49	16.5	
2S	14.6	17.2	2.6	500	5.2	4385	0.38	0.8	
2D	14.7	17.7	3	500	6.0	5059	0.44	1.8	
Sample Location	Turbidity (NTU)			CTS/Sec	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)	
4S (A)	4.4		RailRoad						
4S (B)	4.4		Surface	N/A					
4S (C)	4.3		Mid-Depth	N/A					
MEAN	4.4		Bottom	N/A					
STDEV	0.1		US1						
RSD (%)	1.3		Surface	0.8	0.046	43.1	2.0	0.8	
			Mid-Depth	0.06	0.00789	43.1	0.3		
4D	6.9		Bottom	0	0.0048	43.1	0.2		
3S	5.1								
3I	5.4		Flow Direction:	Downstream					
3II	6.5								
3III	6.5		0.2 x Depth	0.76	0.04394	43.1	1.9	0.798786667	
2S	4.3		0.8 x Depth	0.04	0.00686	43.1	0.3		
2D	5.5		Bottom	0	0.0048	43.1	0.2		
		Therefore, my Method and FDEP Method of Sampling agree.							

Appendix D
Crane Creek Total Suspended Solids and Turbidity (continued)

July 17, 2001 to November 4, 2001

Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL							Rainfall:	10-21-01 = 1.70 cm
Date: 10-23-01								10-22-01 = 1.27 cm
Time: 2:00 PM								
Weather: Mostly Cloudy (75%) 80F								
Wind: W 0 -2 Knots								
Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED (mL)	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
3DI (A)	14.7	16.5	1.8	300	6.4	17831	1.54	17.7
3DI (B)	14.7	16.7	2.0					
3DI (C)	14.5	16.5	2.0					
		Mean	1.9					
		STDEV	0.12					
		RSD (%)	6					
3S	14.6	17.7	3.1	400	7.8	21443	1.85	1.8
3II	14.7	17.2	2.5	300	8.3	23057	1.99	18.2
3III	14.8	17.0	2.2	300	7.3	20290	1.75	18.2
2S	14.6	17.3	2.7	400	6.8	18676	1.61	2.2
2D	14.7	16.6	1.9	300	6.3	17524	1.51	2.7
4S	14.7	17.2	2.5	400	6.3	17293	1.49	1.7
4D	14.8	18.7	3.9	250	15.6	43163	3.73	18.1
Sample Location	Turbidity (NTU)			CTS/Sec	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)
3DI (A)	5.0		RailRoad					
3DI (B)	5.0		Surface	N/A				
3DI (C)	5.0		Mid-Depth	N/A				
MEAN	5.0		Bottom	N/A				
STDEV	0.0		US1					
RSD (%)	0.0		Surface	3.4	0.1799	43.1	7.8	2.8
			Mid-Depth	0.06	0.00789	43.1	0.3	
3S	4.8		Bottom	0	0.0048	43.1	0.2	
3II	5.0							
3III	5.6		Flow Direction:	Downstream				
2S	5.3							
2D	6.5							
4S	4.4							
4D	7.7							

Appendix D
Crane Creek Total Suspended Solids and Turbidity (continued)

July 17, 2001 to November 4, 2001

Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL							Rainfall:	10-24-01 = 2.87 cm
Date: 10-26-01								10-25-01 = 2.89 cm
Time: 9:00 AM								
Weather: Light Rain, Clouds (100%)								
Wind: NE 15-20 Knots								
Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED (mL)	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
2S (A)	14.5	19.0	4.5	350	12.8	33517	2.90	0.2
2S (B)	14.5	18.9	4.4					
2S (C)	14.7	19.2	4.5					
		Mean	4.5					
		STDEV	0.06					
		RSD (%)	1					
2D	14.5	19.2	4.7	350	13.4	35267	3.05	0.2
3S	14.5	18.4	3.9	400	9.8	25606	2.21	0.4
3I	14.6	18.3	3.7	400	9.3	24293	2.10	1.2
3II	14.6	17.0	2.4	400	6.0	15758	1.36	17
3III	14.6	17.1	2.5	350	7.1	18759	1.62	17.6
4S	14.7	17.8	3.1	350	8.9	23262	2.01	0.4
4D	14.4	17.8	3.4	350	9.7	25513	2.20	18.6
Sample Location	Turbidity (NTU)			CTS/Sec	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)
2S (A)	7.0		RailRoad					
2S (B)	7.1		Surface	N/A				
2S (C)	7.0		Mid-Depth	N/A				
MEAN	7.0		Bottom	N/A				
STDEV	0.1		US1					
RSD (%)	0.8		Surface	3.2	0.1696	43.1	7.3	2.6
			Mid-Depth	0.07	0.008405	43.1	0.4	
2D	8.5		Bottom	0	0.0048	43.1	0.2	
3S	5.2							
3I	5.8		Flow Direction:	Downstream				
3II	6.5							
3III	7.0							
4S	3.6							
4D	6.8							

Appendix D
Crane Creek Total Suspended Solids and Turbidity (continued)

July 17, 2001 to November 4, 2001

Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL							Rainfall:	None
Date: 11-02-01A								
Time: 10:00 AM								
Weather: Clouds (50%) 75F								
Wind: East 15-20 Knots (White Capping in IRL)								
Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED (mL)	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
3S (A)	14.7	18.1	3.4	400	8.5	75340	6.51	1.6
3S (B)	14.5	17.9	3.4					
3S (C)	14.6	18.0	3.4					
		Mean	3.4					
		STDEV	0.00					
		RSD (%)	0					
3I	14.8	17.9	3.1	350	8.9	78505	6.78	1.8
3II	14.7	18.4	3.7	350	10.6	93700	8.10	16.5
3III	14.7	16.9	2.2	350	6.3	55714	4.81	18.7
2S	14.5	18.1	3.6	400	9.0	79772	6.89	0.9
2D	14.7	18.3	3.6	400	9.0	79772	6.89	0.9
4S	14.9	17.5	2.6	350	7.4	65843	5.69	3.5
4D	14.7	18.2	3.5	350	10.0	88635	7.66	10.2
Sample Location	Turbidity (NTU)			CTS/Sec	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)
3S (A)	5.9		RailRoad					
3S (B)	6.0		Surface	N/A				
3S (C)	6.0		Mid-Depth	N/A				
MEAN	6.0		Bottom	N/A				
STDEV	0.1		US1					
RSD (%)	1.0		Surface	6.8	0.355	43.1	15.3	8.9
			Mid-Depth	4.9	0.25715	43.1	11.1	
			Bottom	0	0.0048	43.1	0.2	
3I	6.5							
3II	5.0							
3III	5.5		Flow Direction:	Downstream				
2S	6.9							
2D	6.6							
4S	5.2							
4D	6.4							

Appendix D
Crane Creek Total Suspended Solids and Turbidity (continued)

July 17, 2001 to November 4, 2001

Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL							Rainfall:	11-02-01 = 0.71 cm
Date: 11-02-01B								
Time: 6:00 PM								
Weather: Rain, Clouds (100%) 70F								
Wind: E 15-20 Knots								
Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED (mL)	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
4S (A)	14.5	17.1	2.6	350	7.7	N/A	N/A	2.4
4S (B)	14.5	17.2	2.7					
4S (C)	14.5	17.3	2.8					
		Mean	2.7					
		STDEV	0.10					
		RSD (%)	4					
4D	14.7	17.7	3	350	8.6	N/A	N/A	8.9
2S	14.4	17.8	3.4	400	8.5	N/A	N/A	0.7
2D	14.5	18.1	3.6	400	9.0	N/A	N/A	0.7
3S	14.5	17.6	3.1	350	8.9	N/A	N/A	1.1
3I	14.4	17.6	3.2	350	9.1	N/A	N/A	1.9
3II	14.6	17.4	2.8	300	9.3	N/A	N/A	16.7
3III	14.5	17.0	2.5	300	8.3	N/A	N/A	18.6
Sample Location	Turbidity (NTU)			CTS/Sec	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)
4S (A)	7.4		RailRoad					
4S (B)	7.5		Surface	N/A				
4S (C)	7.5		Mid-Depth	N/A				
MEAN	7.5		Bottom	N/A				
STDEV	0.1		US1					
RSD (%)	0.8		Surface	N/A		43.1		
			Mid-Depth	N/A		43.1		
			Bottom	N/A		43.1		
4D	8.5							
2S	6.9							
2D	7.5		Flow Direction: > Risky in High Winds					
3S	6.8							
3I	7.0							
3II	5.6							
3III	6.2							

Appendix D
Crane Creek Total Suspended Solids and Turbidity (continued)

July 17, 2001 to November 4, 2001

Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL							Rainfall:	11-02-01 = 0.71 cm
Date: 11-03-01								
Time: 10:30 AM								
Weather: Partly Cloudy (40%) 75F								
Wind: E 10-15 Knots								
Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED (mL)	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
4D (A)	14.6	18.8	4.2	300	13.9	10889	0.94	14.5
4D (B)	14.5	18.7	4.2					
4D (C)	14.4	18.5	4.1					
		Mean	4.2					
		STDEV	0.06					
		RSD (%)	1					
4S	14.8	17.5	2.7	400	6.8	5292	0.46	2.2
2S	14.7	18.0	3.3	400	8.3	6468	0.56	0.8
2D	14.6	17.8	3.2	400	8.0	6272	0.54	0.8
3S	14.8	18.0	3.2	400	8.0	6272	0.54	1.2
3I	14.6	17.7	3.1	300	10.3	8101	0.70	9
3II	14.7	17.4	2.7	300	9.0	7056	0.61	16.2
3III	14.5	17.1	2.6	300	8.7	6795	0.59	18.3
Sample Location	Turbidity (NTU)			CTS/Sec	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)
4D (A)	8.6		RailRoad					
4D (B)	8.5		Surface	N/A				
4D (C)	8.5		Mid-Depth	N/A				
MEAN	8.5		Bottom	N/A				
STDEV	0.1		US1					
RSD (%)	0.7		Surface	0.46	0.02849	43.1	1.2	0.8
			Mid-Depth	0.32	0.02128	43.1	0.9	
			Bottom	0	0.0048	43.1	0.2	
4S	6.0							
2S	7.0							
2D	7.4		Flow Direction:	Downstream				
3S	6.5							
3I	5.4							
3II	5.8							
3III	5.5							

Appendix D
Crane Creek Total Suspended Solids and Turbidity (continued)

July 17, 2001 to November 4, 2001
 Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL

Rainfall:

11-03-01 = 0.91 cm

Date: 11-04-01

Time: 11:30 AM

Weather: Clouds (100%) 75F

Wind: E 15-20 Knots

Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED (mL)	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
2D (A)	14.4	16.9	2.5	350	7.0	6222	0.54	0.8
2D (B)	14.8	17.3	2.5					
2D (C)	14.7	17.0	2.3					
		Mean	2.4					
		STDEV	0.12					
		RSD (%)	5					
2S	14.3	16.7	2.4	350	6.9	6137	0.53	0.8
3S	14.5	16.9	2.4	350	6.9	6137	0.53	1
3I	14.5	17.3	2.8	300	9.3	8353	0.72	10.3
3II	14.8	17.7	2.9	300	9.7	8651	0.75	16.4
3III	14.5	16.1	1.6	300	5.3	4773	0.41	18.1
4S	14.6	17.1	2.5	350	7.1	6393	0.55	2.3
4D	14.8	18.1	3.3	250	13.2	11814	1.02	15.2
Sample Location	Turbidity (NTU)			CTS/Sec	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)
2D (A)	6.9		RailRoad					
2D (B)	6.9		Surface	N/A				
2D (C)	6.8		Mid-Depth	N/A				
MEAN	6.9		Bottom	N/A				
STDEV	0.1		US1					
RSD (%)	0.8		Surface	0.88	0.05012	43.1	2.2	0.9
			Mid-Depth	0.05	0.007375	43.1	0.3	
2S	5.4		Bottom	0	0.0048	43.1	0.2	
3S	5.0							
3I	5.6		Flow Direction:	Downstream				
3II	5.4							
3III	4.2							
4S	4.6							
4D	6.1							

Appendix E **Crane Creek Total Suspended Solids and Turbidity**

January 11, 2002 to March 15, 2002

Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL

Rainfall: None

Date: 1-11-02

Time: 12:30 PM

Weather: Sunny, Clouds (0%) 70F

Wind: W 5 Knots

Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED (mL)	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
3II (A)	14.8	18.2	3.4	250	13.2	24901	2.15	21.8
3III (B)	14.7	17.9	3.2					
3III (C)	14.5	17.8	3.3					
		Mean	3.3					
		STDEV	0.10					
		RSD (%)	3					
3S	14.7	19.2	4.5	400	11.3	21222	1.83	5.1
3I	14.9	20.4	5.5	300	18.3	34584	2.99	20.5
3II	14.4	17.4	3	300	10.0	18864	1.63	21.0
2S	14.8	17.7	2.9	350	8.3	15630	1.35	8.3
2D	14.8	18.1	3.3	300	11.0	20751	1.79	14.8
4S	14.7	18.2	3.5	400	8.8	16506	1.43	7.8
4D	14.8	18.2	3.4	250	13.6	25655	2.22	21.1
Sample Location	Turbidity (NTU)			CTS/Sec	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)
3II (A)	7.2		RailRoad					
3III (B)	7.2		Surface	N/A				
3III (C)	7.3		Mid-Depth	N/A				
MEAN	7.2		Bottom	N/A				
STDEV	0.1		US1					
RSD (%)	0.8		Surface	2.07	0.111405	43.1	4.8	1.9
			Mid-Depth	0.2	0.0151	43.1	0.7	
3S	7.4		Bottom	0	0.0048	43.1	0.2	
3I	5.0							
3II	4.9		Flow Direction:	Downstream				
2S	6.2							
2D	6.4							
4S	5.6							

4D 5.7

Appendix E **Crane Creek Total Suspended Solids and Turbidity**

January 11, 2002 to March 15, 2002
 Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL

Rainfall: 1-14-02 = 1.70 cm
 1-15-02 = 2.36 cm

Date: 1-18-02
 Time: 1:00 PM
 Weather: Mostly Cloudy (75%) 70F
 Wind: W 3-5 Knots

Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED (mL)	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
2S (A)	14.2	17.9	3.7	450	8.3	17387	1.50	4.8
2S (B)	14.2	17.9	3.7					
2S (C)	14.5	18.3	3.8					
		Mean	3.7					
		STDEV	0.06					
		RSD (%)	2					
2D	14.3	20.0	5.7	400	14.3	29865	2.58	11.5
3S	14.6	18.2	3.6	450	8.0	16766	1.45	4.4
3I	14.4	17.7	3.3	350	9.4	19760	1.71	20.6
3II	14.7	17.1	2.4	350	6.9	14371	1.24	20.8
3III	14.8	17.1	2.3	400	5.8	12051	1.04	21.2
4S	14.5	18.5	4	450	8.9	18629	1.61	5.6
4D	14.9	19.5	4.6	350	13.1	27545	2.38	19.6
Sample Location	Turbidity (NTU)			CTS/Sec	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)
2S (A)	4.5		RailRoad					
2S (B)	4.9		Surface	N/A				
2S (C)	5.0		Mid-Depth	N/A				
MEAN	4.8		Bottom	N/A				
STDEV	0.3		US1					
RSD (%)	5.5		Surface	2.55	0.136125	43.1	5.9	2.1
			Mid-Depth	0.003	0.0049545	43.1	0.2	
			Bottom	0	0.0048	43.1	0.2	
2D	3.7							
3S	4.2							
3I	3.0		Flow Direction:	Downstream				
3II	1.8							
3III	1.5							
4S	3.5							
4D	2.5							

Appendix E **Crane Creek Total Suspended Solids and Turbidity**

January 11, 2002 to March 15, 2002

Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL

Rainfall: None

Date: 1-30-02

Time: 1:30 PM

Weather: Sunny, Clouds (5%) 80F

Wind: SE 10-12 Knots

Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED (mL)	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
3I (A)	14.8	17.6	2.8	300	9.4	6845	0.59	19.5
3I (B)	14.9	17.7	2.8					
3I (C)	14.7	17.6	2.9					
		Mean	2.8					
		STDEV	0.06					
		RSD (%)	2					
2S	14.5	17.7	3.2	450	7.1	5154	0.45	3.0
2D	14.9	18.5	3.6	300	12.0	8698	0.75	15.0
3S	14.8	18.0	3.2	450	7.1	5154	0.45	6.5
3II	14.9	17.7	2.8	250	11.2	8118	0.70	20.0
3III	14.6	17.8	3.2	250	12.8	9277	0.80	20.4
4S	14.8	17.7	2.9	350	8.3	6005	0.52	8.4
4D	14.8	18.7	3.9	300	13.0	9422	0.81	19.2
Sample Location	Turbidity (NTU)			CTS/Sec	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)
3I (A)	4.8		RailRoad					
3I (B)	4.8		Surface	N/A				
3I (C)	4.9		Mid-Depth	N/A				
MEAN	4.8		Bottom	N/A				
STDEV	0.1		US1					
RSD (%)	1.2		Surface	0.66	0.03879	43.1	1.7	0.7
			Mid-Depth	0.04	0.00686	43.1	0.3	
			Bottom	0	0.0048	43.1	0.2	
2S	5.9							
2D	5.4							
3S	6.0		Flow Direction:	Downstream				
3II	6.5							
3III	6.2							
4S	5.4							
4D	5.2							

Appendix E **Crane Creek Total Suspended Solids and Turbidity**

January 11, 2002 to March 15, 2002

Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL

Rainfall: None

Date: 2-06-02

Time: 1:15 PM

Weather: Partly Cloudy (15%) 70F

Wind: SE 15-20 knots

Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED (mL)	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
4S (A)	14.8	17.6	2.8	400	7.3	N/A	N/A	7.8
4S (B)	14.8	17.5	2.7	450				
4S (C)	14.8	18.0	3.2	400				
		Mean	2.9					
		STDEV	0.26					
		RSD (%)	9					
2S	14.5	17.9	3.4	550	6.2	N/A	N/A	2.8
2D	14.6	17.3	2.7	400	6.8	N/A	N/A	8.8
3S	14.8	16.9	2.1	400	5.2	N/A	N/A	4
3I	14.9	18.5	3.6	250	14.4	N/A	N/A	17.2
3II	14.6	18.0	3.4	250	13.6	N/A	N/A	18.8
3III	14.5	18.1	3.6	250	14.4	N/A	N/A	20.1
4D	14.7	18.3	3.6	250	14.4	N/A	N/A	18.5
Sample Location	Turbidity (NTU)			CTS/Sec	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)
4S (A)	3.6		RailRoad					
4S (B)	4.1		Surface	N/A				
4S (C)	4.2		Mid-Depth	N/A				
MEAN	4.0		Bottom	N/A				
STDEV	0.3		US1					
RSD (%)	8.1		Surface	N/A		43.1		
			Mid-Depth	N/A		43.1		
			Bottom	N/A		43.1		
2S	5.5							
2D	6.5							
3S	4.0		Flow Direction:	Below detection				
3I	5.0							
3II	4.5							
3III	5.8							
4D	6.3							

Appendix E **Crane Creek Total Suspended Solids and Turbidity**

January 11, 2002 to March 15, 2002

Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL

Rainfall: None

Date: 2-13-02

Time: 1:15 PM

Weather: Mostly Cloudy (90%) 65F

Wind: NE 7-10 Knots

Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED (mL)	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
2D (A)	14.8	18.0	3.2	300	11.1	16850	1.46	17.7
2D (B)	14.7	18.0	3.3					
2D (C)	14.8	18.3	3.5					
		Mean	3.3					
		STDEV	0.15					
		RSD (%)	5					
2S	14.5	17.8	3.3	400	8.3	12511	1.08	6.7
3S	14.6	18.6	4	400	10.0	15165	1.31	12.1
3I	14.9	17.1	2.2	300	7.3	11121	0.96	20.1
3II	14.5	17.3	2.8	350	8.0	12132	1.05	20.1
3III	14.9	16.7	1.8	300	6.0	9099	0.79	20.1
4S	14.5	17.5	3	300	10.0	15165	1.31	20.2
4D	14.7	18.1	3.4	300	11.3	17187	1.48	20.6
Sample Location	Turbidity (NTU)			CTS/Sec	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)
2D (A)	5.6		RailRoad					
2D (B)	5.6		Surface	N/A				
2D (C)	5.5		Mid-Depth	N/A				
MEAN	5.6		Bottom	N/A				
STDEV	0.1		US1					
RSD (%)	1.0		Surface	1.77	0.095955	43.1	4.1	1.5
			Mid-Depth	0	0.0048	43.1	0.2	
			Bottom	0	0.0048	43.1	0.2	
2S	5.8							
3S	5.8							
3I	5.5		Flow Direction:	Downstream				
3II	5.0							
3III	4.6							
4S	5.8							
4D	6.6							

Appendix E **Crane Creek Total Suspended Solids and Turbidity**

January 11, 2002 to March 15, 2002

Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL

Rainfall:

2-23-02 = 3.05 cm

Date: 2-27-02

Time: 1:00 PM

Weather: Sunny, Clouds (0%) 60F

Wind: WNW 15-20 Knots

Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED (mL)	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
4D (A)	14.8	17.1	2.3	400	6.4	21552	1.86	20.4
4D (B)	14.7	17.1	2.4					
4D (C)	14.5	17.5	3.0					
		Mean	2.6					
		STDEV	0.38					
		RSD (%)	15					
2S	14.9	18.4	3.5	400	8.8	29389	2.54	6.7
2D	14.8	17.5	2.7	600	4.5	15115	1.31	12.1
3S	14.5	19.4	4.9	450	10.9	36573	3.16	20.1
3I	14.4	16.5	2.1	250	8.4	28214	2.44	20.1
3II	14.8	15.9	1.1	400	2.8	9237	0.80	20.1
3III	14.6	16.4	1.8	500	3.6	12092	1.04	20.2
4S	14.8	18.2	3.4	250	13.6	45679	3.95	20.6
Sample Location	Turbidity (NTU)			CTS/Sec	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)
4D (A)	3.0		RailRoad					
4D (B)	3.0		Surface	N/A				
4D (C)	3.0		Mid-Depth	N/A				
MEAN	3.0		Bottom	N/A				
STDEV	0.0		US1					
RSD (%)	0.0		Surface	3.45	0.182475	43.1	7.9	3.4
			Mid-Depth	0.81	0.046515	43.1	2.0	
			Bottom	0	0.0048	43.1	0.2	
2S	4.5							
2D	4.0							
3S	4.4		Flow Direction:	Downstream				
3I	2.6							
3II	1.9							
3III	1.5							
4S	4.3							

Appendix E **Crane Creek Total Suspended Solids and Turbidity**

January 11, 2002 to March 15, 2002

Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL

Rainfall: None

Date: 3-01-02

Time: 12:00 PM

Weather: Clouds (100%) 65F

Wind: E 20 Knots

Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED (mL)	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
3 II (A)	14.7	16.8	2.1	350	6.0	1330	0.11	19.3
3 II (B)	14.7	16.9	2.2					
3 II (C)	14.6	16.6	2.0					
		Mean	2.1					
		STDEV	0.10					
		RSD (%)	5					
3S	14.8	18.5	3.7	450	8.2	1823	0.16	9.9
3I	14.5	16.9	2.4	350	6.9	1520	0.13	17.3
3III	14.6	17.3	2.7	350	7.7	1710	0.15	19.8
2S	14.8	18.3	3.5	450	7.8	1724	0.15	4.7
2D	14.9	18.8	3.9	450	8.7	1921	0.17	6.3
4S	14.8	18.1	3.3	350	9.4	2090	0.18	10.4
4D	14.7	16.8	2.1	350	6.0	1330	0.11	20.2
Sample Location	Turbidity (NTU)			CTS/Sec	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)
3 II (A)	4.1		RailRoad					
3 II (B)	3.9		Surface	N/A				
3 II (C)	3.9		Mid-Depth	N/A				
			Bottom	N/A				
MEAN	4.0							
STDEV	0.1		US1					
RSD (%)	2.9		Surface	0	0.0048	43.1	0.2	0.2
			Mid-Depth	0.02	0.00583	43.1	0.3	
			Bottom	0	0.0048	43.1	0.2	
3S	4.9							
3I	4.4							
3III	4.3		Flow Direction:	Strong surface winds cancelled out surface flow				
2S	6.0							
2D	7.0							
4S	5.0							
4D	3.6							

Appendix E **Crane Creek Total Suspended Solids and Turbidity**

January 11, 2002 to March 15, 2002

Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL

Rainfall: None

Date: 3-04-02

Time: 1:30 PM

Weather: Clouds (100%) 55F

Wind: NW 5-7 Knots

Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED (mL)	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
3S (A)	14.9	18.1	3.2	500	6.6	13720	1.19	5.7
3S (B)	14.6	17.8	3.2					
3S (C)	14.4	17.9	3.5					
		Mean	3.3					
		STDEV	0.17					
		RSD (%)	5					
3I	14.7	17.8	3.1	500	6.2	12888	1.11	20.8
3II	14.6	17.3	2.7	500	5.4	11225	0.97	21.3
3III	14.9	17.6	2.7	500	5.4	11225	0.97	21.3
2S	14.5	16.9	2.4	400	6.0	12473	1.08	7.1
2D	14.7	18.3	3.6	400	9.0	18709	1.62	17.2
4S	15.0	17.6	2.6	450	5.8	12011	1.04	9.6
4D	14.6	19.9	5.3	450	11.8	24483	2.12	20.8
Sample Location	Turbidity (NTU)			CTS/Sec	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)
3S (A)	4.1		RailRoad					
3S (B)	4.1		Surface	N/A				
3S (C)	4.1		Mid-Depth	N/A				
MEAN	4.1		Bottom	N/A				
STDEV	0.0		US1					
RSD (%)	0.0		Surface	2.48	0.13252	43.1	5.7	2.1
			Mid-Depth	0.05	0.007375	43.1	0.3	
3I	3.1		Bottom	0	0.0048	43.1	0.2	
3II	2.5							
3III	2.0		Flow Direction:	Downstream				
2S	3.9							
2D	4.3							
4S	4.0							
4D	4.1							

Appendix E **Crane Creek Total Suspended Solids and Turbidity**

January 11, 2002 to March 15, 2002

Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL

Rainfall: None

Date: 3-06-02

Time: 12:30 PM

Weather: Partly Cloudy (50%) 70F

Wind: E 5 Knots

Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED (mL)	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
2S (A)	14.8	17.6	2.8	450	6.3	3213	0.28	3.7
2S (B)	14.4	17.3	2.9					
2S (C)	14.8	17.6	2.8					
		Mean	2.8					
		STDEV	0.06					
		RSD (%)	2					
2D	14.5	17.8	3.3	450	7.3	3742	0.32	4.3
3S	14.9	18.2	3.3	450	7.3	3742	0.32	6.7
3I	14.7	17.1	2.4	350	6.9	3499	0.30	17.9
3II	14.7	16.9	2.2	350	6.3	3207	0.28	19.4
3III	14.6	16.9	2.3	350	6.6	3353	0.29	20.0
4S	14.7	16.6	1.9	450	4.2	2154	0.19	9.1
4D	14.8	17.3	2.5	350	7.1	3645	0.31	19.0
Sample Location	Turbidity (NTU)			CTS/Sec	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)
2S (A)	5.4		RailRoad					
2S (B)	5.2		Surface	N/A				
2S (C)	5.2		Mid-Depth	N/A				
MEAN	5.3		Bottom	N/A				
STDEV	0.1		US1					
RSD (%)	2.2		Surface	0.38	0.02437	43.1	1.1	0.5
			Mid-Depth	0.03	0.006345	43.1	0.3	
			Bottom	0	0.0048	43.1	0.2	
2D	5.9							
3S	5.1							
3I	4.5		Flow Direction:	Downstream				
3II	4.8							
3III	4.8							
4S	3.9							
4D	4.6							

Appendix E **Crane Creek Total Suspended Solids and Turbidity**

January 11, 2002 to March 15, 2002

Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL

Rainfall: None

Date: 3-13-02

Time: 1:30 PM

Weather: Partly Cloudy (40%) 80F

Wind: W 15-20 Knots

Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED (mL)	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
3I (A)	15.0	19.5	4.5	500	8.7	42191	3.65	19.3
3I (B)	14.9	19.2	4.3					
3I (C)	14.7	18.9	4.2					
		Mean	4.3					
		STDEV	0.15					
		RSD (%)	4					
3S	14.7	18.5	3.8	400	9.5	46247	4.00	10.2
3II	14.7	17.3	2.6	450	5.8	28127	2.43	20.0
3III	14.8	16.7	1.9	500	3.8	18499	1.60	20.0
2S	14.7	18.0	3.3	400	8.3	40162	3.47	11.3
2D	14.6	19.1	4.5	400	11.3	54767	4.73	12.0
4S	15.0	19.5	4.5	400	11.3	54767	4.73	13.8
4D	14.9	21.0	6.1	400	15.3	74239	6.41	19.6
Sample Location	Turbidity (NTU)			CTS/Sec	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)
3I (A)	2.2		RailRoad					
3I (B)	2.1		Surface	N/A				
3I (C)	2.1		Mid-Depth	N/A				
MEAN	2.1		Bottom	N/A				
STDEV	0.1		US1					
RSD (%)	2.7		Surface	3.9	0.20565	43.1	8.9	4.9
			Mid-Depth	2.4	0.1284	43.1	5.5	
3S	4.0		Bottom	0	0.0048	43.1	0.2	
3II	2.0							
3III	1.5		Flow Direction:	Downstream				
2S	3.0							
2D	3.5							
4S	3.0							
4D	5.5							

Appendix E **Crane Creek Total Suspended Solids and Turbidity**

January 11, 2002 to March 15, 2002

Total Suspended Solids (TSS), Turbidity, Streamflow, Sediment Transport, and Meteorological Observations.

TSS and Turbidity Database for Crane Creek, Melbourne, FL

Rainfall: None

Date: 3-15-02

Time: 12:00 PM

Weather: Sunny, Clouds (0%) 80F

Wind: E 2-3 Knots

Sample Location	Pre Filter Wt (mg)	Post Filter+TSS (mg)	Final Mass TSS (mg)	AMOUNT FILTERED (mL)	TSS Concentration (mg/L)	Sediment Transport (mg/sec)	Sediment Transport (tons/day)	Salinity (ppt)
4S (A)	14.7	17.8	3.1	350	8.1	3172	0.27	11.7
4S (B)	14.8	17.5	2.7					
4S (C)	14.8	17.5	2.7					
		Mean	2.8					
		STDEV	0.23					
		RSD (%)	8					
4D	14.4	19.0	4.6	400	11.5	4506	0.39	19.5
3S	14.5	17.9	3.4	400	8.5	3331	0.29	10.3
3I	14.4	18.1	3.7	400	9.3	3625	0.31	19.6
3II	14.6	18.3	3.7	400	9.3	3625	0.31	19.7
3III	14.3	20.2	5.9	500	11.8	4624	0.40	19.9
2S	14.9	17.8	2.9	400	7.3	2841	0.25	6.2
2D	14.6	17.7	3.1	300	10.3	4049	0.35	16.1
Sample Location	Turbidity (NTU)			CTS/Sec	Stream Velocity (m/s)	Area (m2)	StreamFlow (m3/s)	AVE Streamflow (m3/s)
4S (A)	4.1		RailRoad					
4S (B)	4.2		Surface	N/A				
4S (C)	4.1		Mid-Depth	N/A				
MEAN	4.1		Bottom	N/A				
STDEV	0.1		US1					
RSD (%)	1.4		Surface	0.2	0.0151	43.1	0.7	0.4
			Mid-Depth	0.05	0.007375	43.1	0.3	
4D	4.5		Bottom	0	0.0048	43.1	0.2	
3S	4.0							
3I	4.4		Flow Direction:	Downstream				
3II	4.4							
3III	6.0							
2S	3.9							
2D	4.8							

Final Report to the
St. Johns River Water Management District

**Post-Dredge Evaluation of Crane Creek:
Sediment Trapping Efficiency and Sediment Quality**



John H. Trefry, Robert P. Trocine, Robert D. Rember,
and Christopher R. Little

Florida Institute of Technology
February 2004

Final Report to the
St. Johns River Water Management District, February 2004

Post-Dredge Evaluation of Crane Creek: Sediment Trapping Efficiency and Sediment Quality

John H. Trefry, Robert P. Trocine, Robert D. Rember and Christopher R. Little
Florida Institute of Technology

EXECUTIVE SUMMARY

In this portion of the post-dredge report for Crane Creek, results are presented for the following: (1) thicknesses of fine-grained, organic-rich (muck) sediment, (2) sedimentation rates and (3) concentrations of major elements and potential trace metal contaminants in sediments. These data will be used for the following: (1) to determine the sediment trapping efficiency of the creek, (2) to help establish long-term plans for future dredging and (2) to assess sediment quality.

The thicknesses of layers of fine-grained, organic-rich (muck) sediment overlying base sand were measured during 2002 at 54 sites with an overall mean of 77 ± 82 cm and the following results by section: (1) 47 ± 49 cm at locations to the west of the railroad bridge in the Sewage Treatment Plant (STP) Basin, (2) 85 ± 63 cm in the Manatee Basin between the railroad bridge and highway US 1, (3) 180 ± 102 cm in the Harbor Basin between US 1 and the region where the creek becomes oriented in a southward direction and (4) 65 ± 65 cm in the Mouth Basin, an area that extends from the Harbor Basin to the mouth of the creek.

Data for muck depths collected during summer 1998, following dredging, yielded mean values of 57, 153, 126 and 159 cm, respectively, in the STP, Manatee, Harbor and Mouth Basins with an overall mean of 112 ± 81 cm. The overall means for muck depth in 2002 versus 1998 were not significantly different for the STP and Harbor Basins. However, the muck depths were significantly lower in 2002 for the Manatee and Mouth Basins relative to 1998. The results for 1998 show that considerable amounts of muck sediment remained in Crane Creek following dredging. When the 1998 and 2002 data are compared, the data suggest that some shifting of sediment toward the Harbor Basin may have occurred and that there has not been a large influx of sediment during the four-year period between surveys.

Reliable determinations of sedimentation rates were difficult due to the degree to which sediments had undergone slumping and *in situ* physical and biological mixing. The activities of excess ^{210}Pb and ^{137}Cs were determined for six cores and the resulting rates that were calculated are most likely high due to the influences of sediment mixing because such mixing can extend the penetration depth of the radionuclides. The rates are as follows: (1) 0.5 ± 0.1 cm/yr west of the railroad bridge in the STP Basin, (2) 0.2 ± 0.1 cm/yr in the Manatee Basin between the railroad bridge and US 1, and (3) 1.4 ± 0.7 cm/yr in the Harbor Basin. The overall mean for the six cores was 0.7 ± 0.6 cm/yr (n =12, two rates per core).

Executive Summary (Continued)

To address questions related to sediment sources, sediment quality and sediment history, the data for major elements and trace metals in soils, suspended sediments, surface sediments, and sediment cores were used collectively. No clear differences in concentrations of Fe, K or Mg versus Al were observed and thus these elements did not provide a straightforward tracer of sources of sediments to the creek. Aluminum provides a useful frame of reference because Al is resistant to chemical weathering in soils and sediments and it is a good indicator of the aluminosilicate (clay) fraction of the sample. Uniform As/Al and V/Al relationships show no detectable inputs of contaminant As or V; however, the uniform metal/Al ratios do not facilitate identification of distinct natural sources for these metals within the drainage basin.

Concentrations of silver (Ag) mercury (Hg) are 50 to more than 100 times above natural levels in sediments from Crane Creek. The core data suggest that peak inputs of Ag and Hg were 30-60 years ago. When sediment concentrations of Ag are plotted versus Hg, a strong linear fit ($r = 0.92$) is observed. This trend for Hg versus Ag supports a common source or source area for both metals such as dental waste and/or photographic/art wastes. Fourteen samples had Ag levels greater than the Effects Range Median (ERM) guideline and seven samples had Hg levels above the ERM. At such levels, adverse effects to sediment biota are predicted to occur frequently. Most of the remaining samples contained Ag and Hg at levels that exceeded the Effects Range Low (ERL), indicating that adverse biological effects for sediment organisms would be occasional.

Concentrations of Pb were elevated over natural levels by two to six-fold at many sites throughout the creek with the highest values in suspended sediment from the Harbor Basin. None of the Pb values exceeded the ERM; however, more than half the Pb concentrations exceeded the ERL. Overall, the spatial distribution of anthropogenic Pb throughout the creek is rather ubiquitous. Data from sediment cores show that the onset of Pb contamination dates back about 50 years. All concentrations of Cd were below the ERM and only three values exceeded the ERL. In contrast, many of the Zn concentrations were greater than the ERL with none greater than the ERM.

Concentrations of Cu in sediments from Crane Creek were typically two to ten times greater than in natural sediments. None of the Cu values exceed the ERM. The highest concentrations of Cu were found in suspended sediments, surface sediments and sediment cores from the Harbor Basin. This is consistent with a primary source for Cu from anti-fouling paints that have leached from boat hulls. No clear shifts in Cu concentrations or, more importantly, the Cu/Al ratios were observed during the past 50 years. Concentrations of Ni and Cr seem to be within expected, background levels except for a few samples from cores collected in the STP Basin where levels are elevated over natural levels by about 20-60%.

At one station (#703) in the Harbor Basin of Crane Creek, sediments were collected during 1992 and 2003. Overall, we conclude that metal levels in creek sediments collected during 2003 are not significantly different than in 1992. All concentrations of

As and all except one value for Cr were within the State of Florida Guidelines established for sediments. Many samples contained levels of Cd that were significantly enriched relative natural sediments in Florida. Most sediment samples, but no soil samples, had Cu concentrations that exceeded the state guidelines. Likewise, sediments contaminated with Pb and Zn, based on the Florida guidelines were ubiquitous in the creek.

The total amount of sediment removed from Crane Creek by dredging January-April 1998 was $\sim 60,000 \text{ m}^3$. The present-day (post-dredging) volume of muck in Crane Creek is estimated to be $\sim 82,000 \text{ m}^3$, with more than half of that volume in the Harbor + Mouth Basins. The creek appears to be a good trap for incoming sediments with sedimentation rates that range from 0.2 to 2 cm/yr and average $\sim 0.7 \text{ cm/yr}$. Based on these sedimentation rates, the annual volume of sediment deposited in Crane Creek is $800 \pm 300 \text{ m}^3/\text{yr}$. This annual volume is more than likely an overestimate because we are reasonably certain that sediment has slumped from the perimeter to the center of the creek. Assuming that the calculated filling rate of $800 \text{ m}^3/\text{yr}$ stays reasonably constant, an amount of sediment equivalent to the $60,000 \text{ m}^3$ of sediment that were dredged in 1998 would be deposited in ~ 75 years. Based on the standard deviation for the filling rate of $\pm 300 \text{ m}^3/\text{yr}$, the calculated range of filling times is from 55 to 120 years.

Post-Dredge Evaluation of Crane Creek: Sediment Trapping Efficiency and Sediment Quality

John H. Trefry, Robert P. Trocine, Robert D. Rember and Christopher R. Little
Florida Institute of Technology

INTRODUCTION

The study described in this chapter was designed to (1) determine the rates of sedimentation and the potential trapping efficiency of Crane Creek for incoming suspended sediments and (2) to determine sediment quality in Crane Creek with respect to possible metal contaminants. To help address these two broad goals, the following specific objectives were completed:

1. Determine depths of fine-grained, organic-rich sediment (muck) and the rates of sediment accumulation at key sites in Crane Creek.
2. Determine whether any fine-grained sediment in the dredged, central portions of the creek may be derived from perimeter areas of the creek that were not dredged or from other sources.
3. Determine the composition of creek sediment as a component to identifying sediment sources and confirming sediment accumulation rates.
4. Determine concentrations of selected metals in creek sediments to assess levels of possible contaminants in sediments from the present-day and recent past.

The supporting data set is large and diverse, as outlined in Table 1, and includes the following:

1. Depth of fine-grained, organic-rich sediment above a base of sand.
2. Activities of excess ^{210}Pb and ^{137}Cs in sediments and sedimentation rates where possible.
3. Concentrations of five (5) major elements, aluminum (Al), calcium (Ca), iron (Fe), potassium (K), and magnesium (Mg) and twelve (12) trace metals, silver (Ag), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb), selenium (Se), vanadium (V) and zinc (Zn), as well as total organic carbon (TOC) in samples of soil and bottom sediments (Table 1). A subset of these analytes was determined for suspended sediments.

Table 1. Summary of samples collected and analyzed for various parameters in this study of Crane Creek and the adjacent Indian River Lagoon (IRL).

Sample Type	Number of Samples	Overview of Locations	Analytes
Sediment Muck Depths	54	Throughout Crane Creek	Depth of layer of fine-grained, organic-rich sediment (muck) above sand base
Sediment Cores: Geochronology	7 cores, 76 layers	Throughout Crane Creek	Excess ^{210}Pb , ^{137}Cs (^7Be , 3 cores), water content, pore water salinity
Surface Sediments, Creek perimeter	18	Circumscribing Crane Creek	<i>Major elements:</i> Al, Ca, Fe, K, Mg <i>Trace Metals:</i> Ag, As, Cd, Cr, Cu, Hg, Mn, Ni, Pb, Se, V, Zn Total Organic Carbon
Surface Sediments, Creek Center*	10	Throughout Crane Creek plus adjacent IRL	<i>Major elements:</i> Al, Ca, Fe, K, Mg <i>Trace Metals:</i> Ag, As, Cd, Cr, Cu, Hg, Mn, Ni, Pb, Se, V, Zn Total Organic Carbon
Sediment Cores: Chemistry	4 cores, 76 samples	Throughout Crane Creek	<i>Major elements:</i> Al, Ca, Fe, K, Mg <i>Trace Metals:</i> Ag, As, Cd, Cr, Cu, Hg, Mn, Ni, Pb, Se, V, Zn Total Organic Carbon
Extra Sediment Cores: Chemistry	3 cores, 59 samples	Throughout Crane Creek	Total Organic Carbon and Hg
Soils	12	From Crane Creek west to Highway US 95 and south to Eber Road	<i>Major elements:</i> Al, Ca, Fe, K, Mg <i>Trace Metals:</i> Ag, As, Cd, Cr, Cu, Hg, Mn, Ni, Pb, Se, V, Zn Total Organic Carbon
Suspended Sediment	12	Ruffner Park, Babcock St. bridge, Hickory Ditch, Crane Creek, IRL	TSS and Particulate Organic Carbon <i>Major elements:</i> Al, Ca, Fe, K, Mg <i>Trace Metals:</i> Ag, Cu, Mn, Pb, Zn

* Same samples for which data for PAH are available for this study.

The data for depths of fine-grained, organic-rich sediment (i.e., muck depths) provide a valuable overview of the extent of current sediment deposits in Crane Creek. These new muck depths are compared with historical data and help set a revised baseline for evaluating the long-term, trapping efficiency of Crane Creek with respect to new incoming suspended sediment or slumping sediment from the perimeter of the creek. The data for geochronology (excess ^{210}Pb and ^{137}Cs) are used to calculate present-day sedimentation rates, to determine the degree of physical and biological mixing of the sediments, and to define layers of sediment that were deposited prior to 1950 (pre- ^{137}Cs as no ^{137}Cs was present on Earth prior to atmospheric testing of nuclear weapons in the early 1950s).

Concentrations of major elements, trace metals and TOC in bottom sediments, suspended sediments and area soils help identify sediment sources. The trace metal data also help determine the overall sediment quality of Crane Creek. The data set for surface sediments identifies present-day conditions and the sediment cores provide an historical record of metal levels.

In this chapter, the **Results and Discussion** are presented in the following order: (1) muck depths and related data, (2) sedimentation rates, (3) sediment sources, and (4) sediment quality. Finally, an overview section that addresses the issue of sediment trapping efficient and projects future needs for dredging is presented.

Methods

Sampling

Surficial sediments were collected using Ponar and Smith-McIntyre grab samplers deployed from boats, as well as sampling by a diver. The top 1-cm was collected using a Teflon spatula and placed in an acid-washed, 30-mL, polystyrene vial.

Sediment cores were collected by a diver or by using a gravity corer deployed from the vessel Barb-NT (Figure 1a). In each case, the sediment was collected in 7-cm diameter, cellulose acetate butyrate (CAB) tubing. After collection, a rubber stopper was placed in the bottom of the core tube and plastic caps were taped onto each end of the core. The cores were kept upright throughout the sampling and recovery operations. Each core was returned to the laboratory at Florida Institute of Technology (FIT) and sub-sampled within 24 hours.

Sediment cores were subsectioned in 1-cm intervals over the top 10 cm and in 2-cm intervals through the remainder of the core. The sediment was extruded by pushing up on the stopper inside the CAB tubing with soda cans while the core was supported in a wooden rack (Figure 1). The outer few millimeters of sediment that may have been smeared during extrusion were scraped away with a small Teflon spatula and the remaining sediment was placed in polystyrene vials.

Soil samples were collected by scooping a representative portion of soil and placing it into a plastic Ziploc bag. Transportation to each site was by car.

Water for suspended sediment was collected directly in 1-L, acid-washed, low-density, polyethylene bottles (LDPE) that were uncapped and filled at a depth of a few centimeters below the surface from the bow of a pontoon boat that was slowly moving up current. Upon return to the FIT laboratory, the water samples were vacuum filtered through polycarbonate filters (Poretics, 47-mm diameter, 0.4- μ m pore size). Prior to the field effort, the filters were acid washed in 5N HNO₃, rinsed three times with distilled-deionized water (DDW), dried and then weighed to the nearest μ g using a Sartorius Model M3P electronic balance under cleanroom conditions. Vacuum filtration was carried out in a Class-100 laminar-flow hood using acid-washed glassware. The particle-bearing filters were placed in acid-washed petri dishes, dried in a clean rack and re-weighed.

Chemical Analysis

Major Elements and Trace Metals in Sediments, Soils and Suspended Sediments

Prior to metal analysis, each wet sediment sample was homogenized in the original plastic vial using a Teflon mixing rod. Then, a portion (~ 2 grams) of each sample was transferred into a pre-weighed plastic vial to determine water content. Once transferred, the wet sediment and the vial were re-weighed. In addition, about 2 to 4 grams of sample

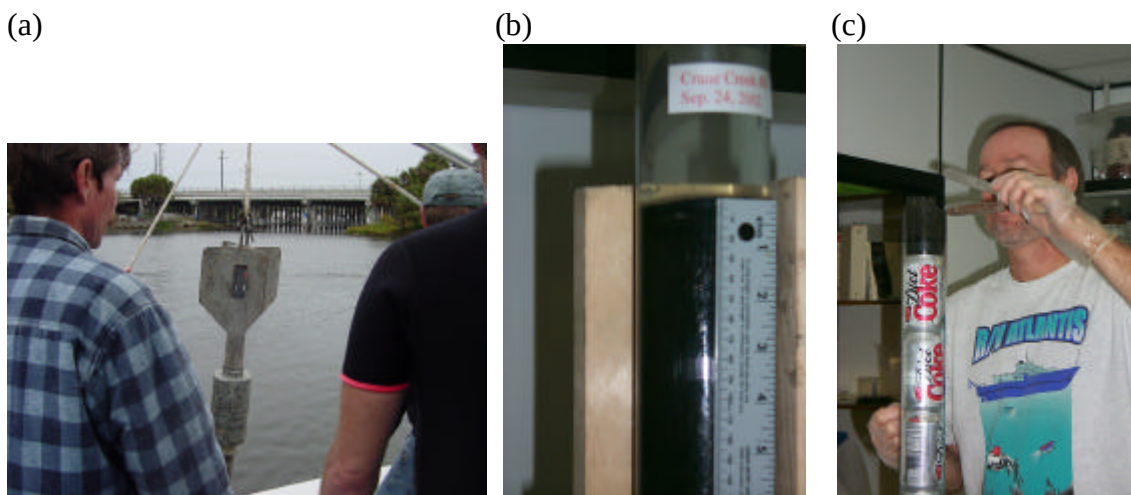


Figure 1. Pictures showing (a) gravity corer, (b) core tube containing sediment and (c) processing subsections of a core.

were transferred into polypropylene-copolymer centrifuge tubes to determine the Hg content of the sediments. Samples intended for water content measurement were frozen, freeze-dried, and re-weighed to determine the water content. The dried sediment samples were again homogenized using a Teflon mixing rod.

About 0.45 grams of freeze-dried, homogenized sediment, soil and certified reference material (CRM) sediment (BCSS-1 from the National Research Council of Canada) were totally digested in Teflon beakers using concentrated, high-purity HF-HNO₃-perchloric acid (HClO₄). This method was chosen because a total digestion accounts for the entire amount of metal in the sample. In the digestion process, 1 mL HClO₄, 1 mL HNO₃ and 3 mL HF were added to the sediment in the Teflon beaker, covered with a Teflon watch cover, and heated at 50°C until a moist paste formed. The mixture was heated for another 3 hours at 80°C with an additional 2 mL HNO₃ and 3 mL HF before bringing the sample to dryness. Finally, 1 mL HNO₃ and about 30 mL DDW were added to the sample and heated strongly to dissolve perchlorate salts and reduce the volume. The completely dissolved and clear samples were diluted to 20 mL with DDW.

Sediment samples to be analyzed for Hg were digested by heating 2 to 4 grams of wet sediment in acid-washed, polypropylene-copolymer centrifuge tubes with 4 mL HNO₃ and 2 mL sulfuric acid (H₂SO₄). Sample tubes were heated for 1 hour in a 90°C water bath and allowed to cool. Each tube was centrifuged at 2,000 rpm and the supernatant decanted into a 25-mL graduated cylinder. The sediment pellet was rinsed twice with 5 mL DDW, centrifuged, and decanted into the graduated cylinder before diluting to a final volume of 20 mL with DDW.

Labware used in the digestion process was acid washed with hot, 8N HNO₃ and rinsed three times with DDW. Two procedural blanks, two duplicate samples, and two CRMs

were prepared with each set of 40 samples. The CRMs used were MESS-2 and MESS-3; both are sediment samples issued by the National Research Council (NRC) of Canada. Sediment samples, CRMs, and procedural and reagent blanks were analyzed by one of the following: (1) flame atomic absorption spectrometry (FAAS) using a Perkin-Elmer Model 4000 instrument, (2) graphite furnace AAS using a Perkin-Elmer Model 4000 AAS equipped with an HGA-400 graphite furnace, an AS-40 autosampler and Zeeman or Continuum background correction or a Perkin-Elmer model 5100 instrument equipped with an HGA-600 graphite furnace and an AS-60 autosampler, or (3) inductively coupled plasma-mass spectrometry (ICP-MS) using a Perkin-Elmer ELAN 5000 spectrometer. Mercury concentrations were measured by cold vapor atomic absorption spectrometry (CVAAS) using a Laboratory Data Control Model 1235 Mercury Monitor. The method used for each element and the corresponding MDLs are presented in Table 2. All analytical techniques followed manufacturers' specifications and laboratory SOPs. These methods are based on EPA methods described for Series 7000 (FAAS and GFAAS), Series 7470 (CVAAS), and Series 6010A (ICP-MS) (U.S. EPA, 1991).

Table 2. Summary of instrumental methods and method detection limits (MDL) for metal analysis of bottom and suspended sediment.

Metal	Bottom and Suspended Sediments	
	Method	MDLs ($\mu\text{g metal/g dry sediment}$)
Ag – silver	GFAAS	0.007
Al – aluminum	FAAS	30
As – arsenic	GFAAS	0.1
Ca – calcium	FAAS	10
Cd – cadmium	ICP-MS	0.03
Cr – chromium	FAAS	0.33
Cu – copper	FAAS	0.4
Fe – iron	FAAS	25
K – potassium	FAAS	10
Hg – mercury	CVAAS	0.001
Mg – magnesium	FAAS	40
Mn – manganese	FAAS	170
Ni – nickel	ICP-MS	0.7
Pb – lead	ICP-MS	0.2
Se – selenium	GFAAS	0.07
V – vanadium	FAAS	3
Zn – zinc	FAAS	0.5
TOC and POC	Shimadzu Carbon System	0.01%

Notes: CVAAS = Cold Vapor Atomic Absorption Spectrometry
FAAS = Flame Atomic Absorption Spectrometry
GFAAS = Graphite Furnace Atomic Absorption Spectrometry
ICP-MS = Inductively Coupled Plasma-Mass Spectrometry
MDL = Method Detection Limit

Filters bearing suspended sediment and milligram quantities of standard reference material (SRM) #2704, a river sediment issued by the U.S. National Institute of Standards and Technology (NIST), were digested in stoppered, 15-mL Teflon test tubes using Ultrex II® HNO₃, HF and HCl. The sealed test tubes were placed in an 80°C water bath where refluxing of the acids completely decomposed and dissolved the particles on the filters. After digestion, the resultant solutions were transferred to acid-washed, 15-mL polyethylene bottles, diluted to ~6 mL with DDW rinses of the Teflon test tubes and stored in a plastic bag until analyzed.

Metal concentrations for the digested samples of suspended sediment, SRMs and blanks were determined by FAAS, GFAAS or ICP-MS in a manner compatible with EPA Series 7000, 6010A and 7470 (U.S. EPA, 1991), respectively, and using the instruments previously identified. Particulate Al, Fe and Zn concentrations were quantified by FAAS. Concentrations of Cr and Cu were determined by GFAAS. Values for Ba, Cd and Pb were determined by ICP-MS. In all cases, the instrument manufacturers' specifications were followed and adherence to QA/QC requirements was maintained.

Total Organic Carbon

A 0.5-1 gram portion of the freeze-dried bottom sediment was placed in a 10-mL Pyrex beaker and wetted with 1 mL of DDW followed by the addition of 5 mL of 10% phosphoric acid (H₃PO₄) to remove any inorganic carbon present. The sediment was dried at 60°C and re-weighed to determine the increase in weight due to the formation of calcium phosphate as a result of adding H₃PO₄. Then, approximately 200-400 mg of pre-treated sediment were weighed into ceramic boats and combusted at 900°C in a Shimadzu TOC-5050A carbon system with SSM-5000A solid sampling module following the manufacturer's instructions. The total organic carbon (TOC) content of the sediment samples was determined using a four-point calibration curve with pure sucrose as the standard. The TOC concentrations were corrected to account for the increase in sediment mass following the addition of H₃PO₄. The calibration curve was checked every 10 samples by analyzing standard reference material (SRM) MESS-2 or MESS-3, marine sediments issued by the NRC of Canada.

Samples for particulate organic carbon (POC) were prepared by filtration of water through pre-combusted Gelman Type A/E glass fiber filters mounted on acid-washed filtration glassware within a Class-100 laminar-flow hood. The POC filters were sealed in acid-washed Petri dishes, labeled, and double bagged in plastic until analyzed. The POC filters were treated with H₃PO₄ to remove inorganic carbon phases, rinsed with DDW, dried and their particulate mass determined. The filters were then placed in ceramic boats and combusted at 900°C in a Shimadzu TOC-5050A carbon system with SSM-5000A solid sampling module following the manufacturer's instructions. The POC content of the samples was determined using a four-point calibration curve with pure sucrose as the standard. The calibration curve was checked every 10 samples by analyzing the CRM MESS-2 or MESS-3.

Radionuclides

Sediment samples used for age dating were sub-sectioned in 1-cm intervals. Approximately 8-10 grams of freeze dried sediment from each layer (1-cm thick) of the sediment cores were ground to a fine powder using a Spex 8000 mixer mill. The samples were then tightly packed into 2-cm diameter, 5-cm long polycarbonate vials to a depth of 30 ± 1 mm. A rubber stopper was cemented into place in the vial with two-part epoxy to prevent leakage of ^{222}Rn and disruption of secular equilibrium between ^{226}Ra and ^{210}Pb . The samples were then set aside for at least 20 days to establish secular equilibrium.

The activities of ^{210}Pb , ^{214}Pb , ^{214}Bi and ^{137}Cs were determined using a well-type, intrinsic germanium detector (WiGe, Princeton Gamma Tech). Vials containing about 10 g of freeze-dried sediment were counted for about 2 days until all peak areas were sufficient to provide <10% counting error. Detector efficiency was determined using the following: NBS 4350B, river sediment and NBS 4354, freshwater lake sediment from National Institute of Standards and Technology (NIST) and standards RGU-1 and RGTh-1 from the International Atomic Energy Agency. The specific activity (dpm/g) of each sediment sample was calculated from the detector efficiency, gamma intensity, geometry factor and sample weight. All values are reported as the activity on the date of coring. Errors are shown on the basis of 1-sigma counting statistics.

Sedimentation rates (S) in cm/yr were calculated using the following equations:

^{137}Cs :

$$S = \frac{\text{Depth in cm at which Activity } ^{137}\text{Cs} = \text{zero}}{[\text{Year} - (1950)] \text{ in years}}$$

^{210}Pb :

$$S = \frac{(-) \text{ decay constant for } ^{210}\text{Pb-210} (0.0311 \text{ yr}^{-1})}{\text{Slope for plot of natural logarithm (ln) excess } ^{210}\text{Pb vs. sediment depth}}$$

The activity of excess ^{210}Pb is calculated by subtracting the mean of $A(^{214}\text{Pb}, ^{214}\text{Bi})$ from $A(\text{total } ^{210}\text{Pb})$. The activities of ^{214}Pb and ^{214}Bi are assumed to be in secular equilibrium with ^{226}Ra .

Quality Assurance and Quality Control

Sample Tracking Procedure

All sediment samples were collected by, transported by and stored by personnel from FIT. Upon return-to or arrival at the laboratory, each sample was carefully inspected to insure that it was intact and that the identification number was clearly readable.

Quality Control Measurements for Analysis

For this project, QC measures included balance calibration, instrument calibration (FAAS, GFAAS, CVAAS, ICP-MS, TOC analyzer), matrix spike analysis for each metal, duplicate sample analysis, analysis of CRMs and SRMs, procedural blank analysis and standard checks. With each batch of up to 20 samples, two procedural blanks, two CRMs or SRMs, two duplicate samples and two matrix-spiked samples were analyzed. Data quality objectives (DQOs) for these quality control measurements are provided in Table 3.

Instrument Calibration

Electronic balances used for weighing samples and reagents were calibrated prior to each use with certified NIST-traceable standard weights. All pipets (electronic or manual) were calibrated prior to use. Each of the spectrometers used for metal analysis was initially standardized with a three- to five-point calibration; a linear correlation coefficient of $r \geq 0.999$ was required before experimental samples were analyzed. Analysis of complete three- to five-point calibrations and/or single standard checks alternated every 5-10 samples until all the analyses were complete. The relative standard deviation (RSD) between complete calibration and standard check was required to be <15% or recalibration and reanalysis of the affected samples were performed.

Matrix Spike Analysis

Matrix spikes were prepared for a minimum of 5% of the total number of samples analyzed and included each metal to be determined. Results from matrix spike analysis using the method of standard additions provide information on the extent of any signal suppression or enhancement due to the sample matrix. If necessary (i.e., spike results outside 80-120% limit), spiking frequency was increased to 20% and a correction applied to the metal concentrations of the experimental samples.

Duplicate Sample Analysis

Duplicate samples from homogenized field samples (as distinct from field replicates) were prepared in the laboratory for a minimum of 5% of the total samples. These laboratory duplicates were included as part of each set of sample digestions and analyses and provide a measure of analytical precision.

Table 3. Data quality objectives and criteria.

Element or Sample Type Criteria	Minimum Frequency	Data Quality Objective/Acceptance
Initial Calibration	Prior to every batch of samples	3-5 point curve depending on the element and a blank.
	Standard Curve	correlation coefficient $r = 0.999$ for all analytes.
Continuing Calibration	Must end every analytical sequence; for flame, repeat all standards every 5 samples; for graphite furnace and ICP-MS recheck standard after every 8-10 samples	% RSD < 15% for all analytes
Certified and Standard Reference Materials	Two per batch of 20 samples	Values must be within 20% of accepted values for >85% of the certified analytes and within 25% for Hg.
Method Blank	Two per batch of 20 samples	No more than 2 analytes to exceed 5x MDL
Matrix Spike and Spike Method Blank	Two per batch of 20 samples	% RSD 80-120%
Lab Duplicate	Two per batch of 20 samples	RSD < 25% for 65% analytes

Procedural Blank Analysis

Two procedural blanks were prepared with each set of 20 samples to monitor potential contamination resulting from laboratory reagents, glassware and processing procedures. These blanks were processed using the same analytical scheme, reagents and handling techniques as used for the experimental samples.

CRM and SRM analysis

A common method used to evaluate the accuracy of environmental data is to analyze reference materials, samples for which consensus or "accepted" analyte concentrations exist. The following CRMs and SRMs were used: Marine Sediment CRM MESS-2 and MESS-3 (NRC) and Buffalo River sediment SRM#2704 (NIST). Metal concentrations obtained for the reference materials were required to be within 20% of accepted values for >85% of other certified analyses. Results for the CRM MESS-2(3) are given in Table 4. The complete data for reference materials are tabulated in the Appendix.

Table 4. Results for reference materials.

	MESS-2 certified concentrations ^a (µg/g)	This study ^b (µg/g)
Ag (n = 6)	0.017 ± 0.01	0.018 ± 0.02
Al (n = 6)	8.68 ± 0.19 (%)	8.57 ± 0.26 (%)
As (n = 6)	20.3 ± 0.6	20.7 ± 0.8
Ca (n = 8) ^c	1.36 ± 0.07 (%)	1.47 ± 0.06 (%)
Cd (n = 6)	0.24 ± 0.01	0.24 ± 0.01
Cr (n = 6)	102 ± 2	106 ± 8
Cu (n = 6)	38.8 ± 1.2	39.5 ± 2.0
Fe (n = 6)	4.23 ± 0.11 (%)	4.35 ± 0.22 (%)
Hg (n = 12)	0.093 ± 0.008	0.092 ± 0.009
K (n = 8) ^{c,d}	2.43 ± 0.13 (%)	2.6 (%)
Mg (n = 8) ^{c,d}	1.58 ± 0.06 (%)	1.6 (%)
Mn (n = 6)	350 ± 5	365 ± 21
Ni (n = 6)	48.2 ± 0.9	49.3 ± 1.8
Pb (n = 6)	21.3 ± 0.7	21.9 ± 1.2
Se (n = 6)	0.64 ± 0.16	0.72 ± 0.09
V (n = 6)	252 ± 5	252 ± 10
Zn (n = 6)	160 ± 3	172 ± 16
POC (n = 6) ^{c,d}	2.07 ± 0.01 (%) ^c	2

^a ± 95 confidence limits.

^c MESS-3 (NRC).

^b ± 1 standard deviation.

^d Reference value, not certified.

Data for all QA/QC measurements are given with the complete data sets in the Appendix. All DQOs for this project were met as shown in Table 4 and the Appendix.

Results and Discussion

Thickness of Layers of Fine-Grained, Organic-Rich Sediment (Muck Depths)

The thickness of fine-grained, organic-rich sediment that typically overlies a sand base (i.e., muck depth) was determined at 54 locations in Crane Creek during September 2002 (Figure 2). The information from this survey provided an overview of the present-day amounts of fine-grained sediment in the creek and helped guide the selection of sites for sediment coring. The muck depths were determined by pushing a calibrated, 5-cm diameter, polyvinyl chloride (PVC) rod, with an end cap, into the soft sediment until stiff resistance was encountered. The water depth to the soft sediment (muck) and the depth of the muck layer were recorded.

For the purposes of this report, Crane Creek has been divided into the following four sub-basins: (1) Sewage Treatment Plant (STP) Basin between the STP and the railroad bridge, (2) Manatee Basin between the railroad bridge and highway US 1, (3) Harbor Basin between US 1 and the area where the creek becomes oriented in a southward direction, and (4) Mouth Basin from the Harbor Basin to the mouth of the creek.

The average muck depth from 50 probings throughout the creek during 2002 was 77 ± 82 cm with a range of 0 to 392 cm, excluding four values of 0 cm under the railroad bridge (Figure 2). The large range and standard deviations in the depths of the muck layers show that distribution of muck is patchy. Overall, the thickest layers of muck, averaging 180 ± 102 cm, were found in the harbor area (Figure 2). Along the STP Basin, the thickest layers of muck were found along the southern perimeter of the creek. A large pocket of fine-grained sediment was found in the center portion of the Manatee Basin. The muck in the center portion of the Manatee Basin graded to depths that approached zero to the west, south and east (Figure 2).

Data for muck depths were previously collected during summer 1998, following dredging that took place from January 27 to April 2, 1998 (Windsor et al., 1998). The grand mean of 112 ± 81 cm ($n = 31$) for summer 1998 is not significantly different from the mean observed during 2002 (t-test, $\alpha = 0.05$, $p = 0.05$). In the 1998 survey, the mean thicknesses of the muck layers for the Manatee, Harbor and Mouth Basins were not significantly different from one another at depths of 153, 126 and 159 cm, respectively (Figure 3). These results for 1998 show most clearly that considerable amounts of muck sediment remained in Crane Creek following dredging.

Further comparison of the 2002 muck depths with the 1998 results (Figure 4) shows that mean values were greater, but not significantly different ($p = 0.04$), in the Harbor Basin during 2002 relative to 1998. Likewise, no significant differences in muck depths were found for the Manatee and STP Basins for 2002 versus 1998. Average muck depths in the Mouth Basin were significantly greater in 1998 and than in 2002 ($p = 0.06$). At most, the data show some shifting of sediment toward the Harbor Basin between 1998 and 2002. At minimum, they suggest that there has not been a large influx of sediment during the four-year period between surveys (Figure 4).

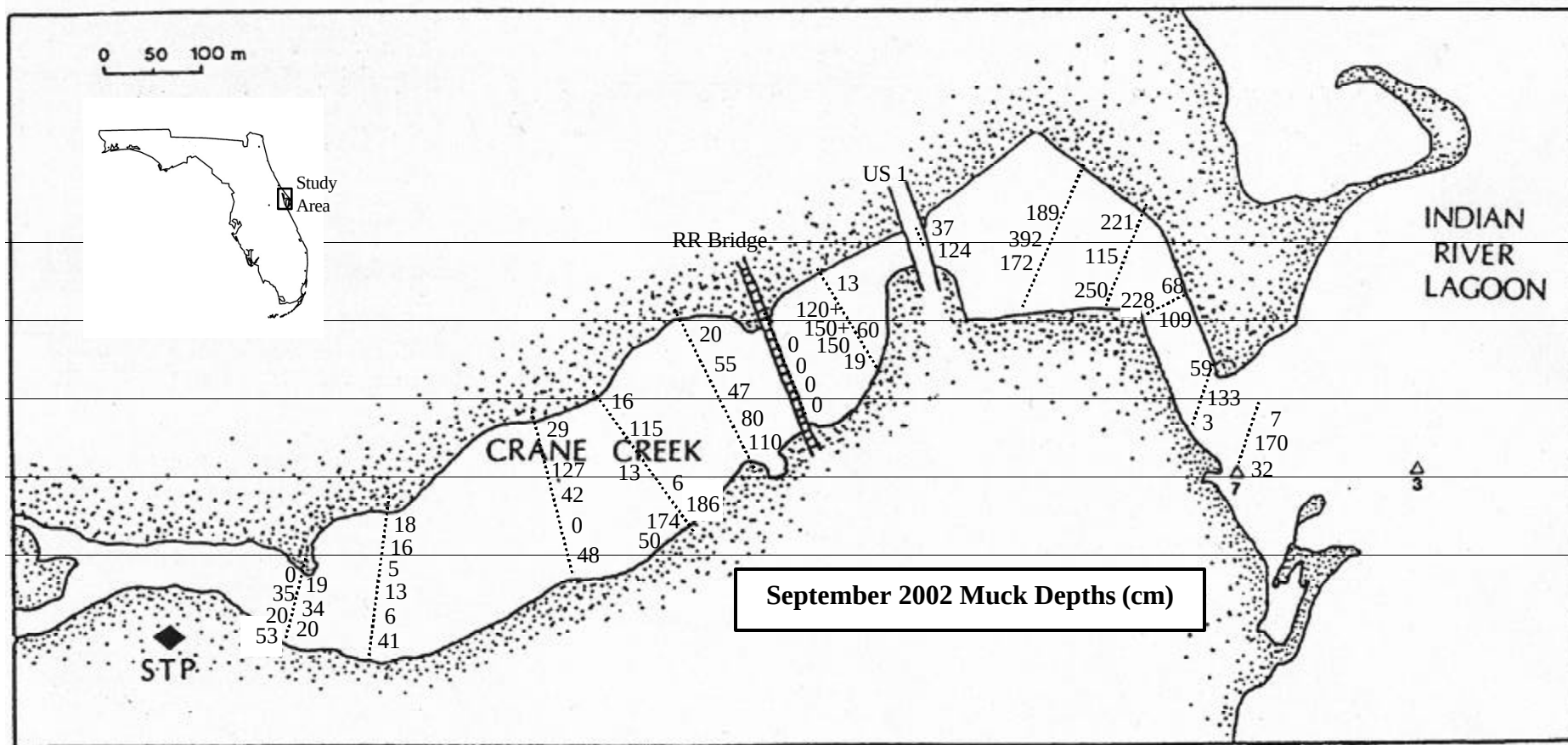


Figure 2. Depths (in centimeters) of organic rich, fine-grained sediments (muck) in Crane Creek during September 2002 (RR = railroad; STP = Sewage Treatment Plant). Inset map shows location of Crane Creek along the coast of east, central Florida.

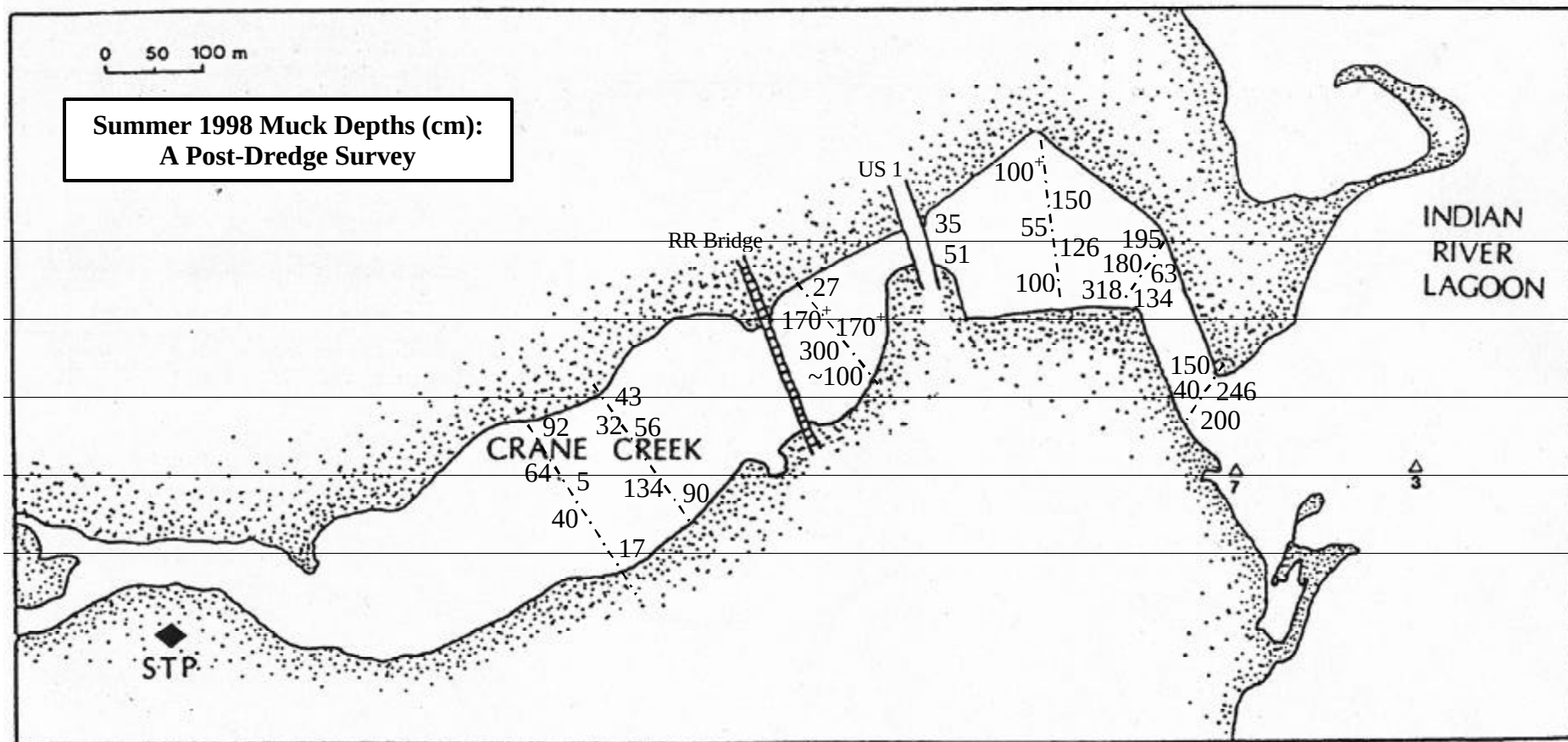


Figure 3. Depths (in centimeters) of organic rich, fine-grained sediment (muck) in Crane Creek during Summer 1998 (RR = railroad; STP = Sewage Treatment Plant).

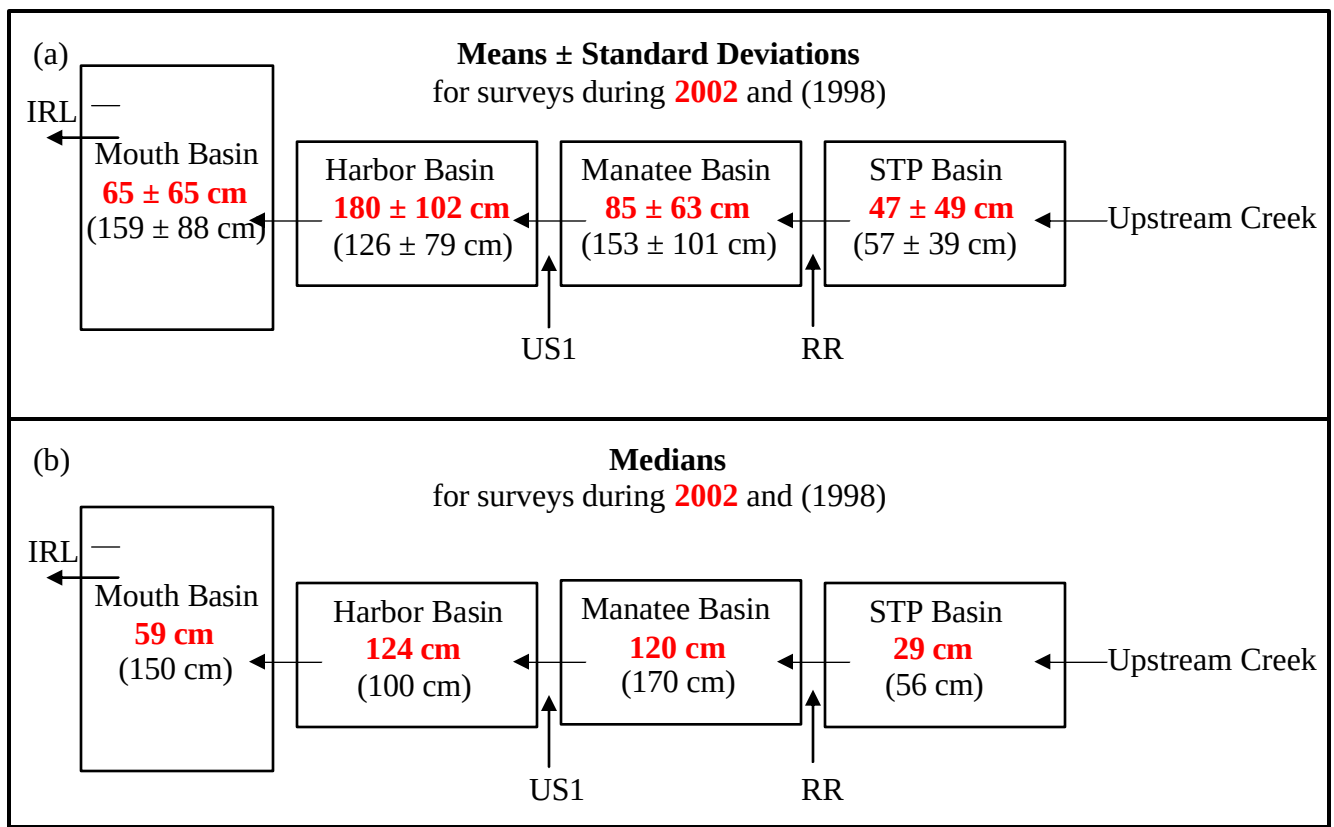


Figure 4. (a) Means and standard deviations and (b) medians for depths of fine-grained, organic-rich sediment in Crane Creek during this study (2002) compared with results from summer 1998 (numbers in parentheses) from Windsor et al. (1998). (RR = railroad; STP = Sewage Treatment Plant, IRL = Indian River Lagoon; US1 = highway US 1).

Sediment Geochronology

To calculate sedimentation rates in Crane Creek, the activities of excess ^{210}Pb and ^{137}Cs were determined for samples from seven of the eight cores collected (Figure 5, excluding the core from station 2). Thus, data for cores from the following sub-basins of the creek were available: three from the STP Basin (west of the railroad bridge), two from the Manatee Basin (between the railroad bridge and US 1), and two from the Harbor Basin (Figure 5). In most instances, the top layer (varying from ~2 to 50 cm) of the sediment had been mixed by *in situ* physical or biological processes; and, sand layers were observed at varying depths in several cores. Thus, no core was ideal for age-dating. However, we have made reasonable use of the pertinent data from each core to estimate or bracket sedimentation rates and sediment ages.

The fallout radionuclide ^{137}Cs (half-life = 30 years) was introduced to the atmosphere during nuclear weapons testing in the 1950s and early 1960s. Atmospheric fallout and deposition in sediments present ^{137}Cs as a stratigraphic marker of the initial years of fallout circa 1950 and maximum fallout in 1963 (Robbins and Edgington, 1975). Results from ^{137}Cs are commonly used to help validate recent sediment ages and sedimentation rates from other techniques. In this study, we used excess ^{210}Pb to determine sedimentation rates. Lead-210 (half-life = 22.3 years) is a naturally occurring decay product of ^{238}U . Along the decay series, the gas ^{222}Rn (half-life = 3.8 days) is formed and a portion of that ^{222}Rn escapes from continental crust to the atmosphere where it decays to ^{210}Pb and is removed from the atmosphere within days to months (Burton and Stewart, 1960; Moore et al, 1973). The atmospherically-derived ^{210}Pb enters rivers and oceans as unsupported or excess ^{210}Pb (parent isotopes are absent). The atmospherically-derived

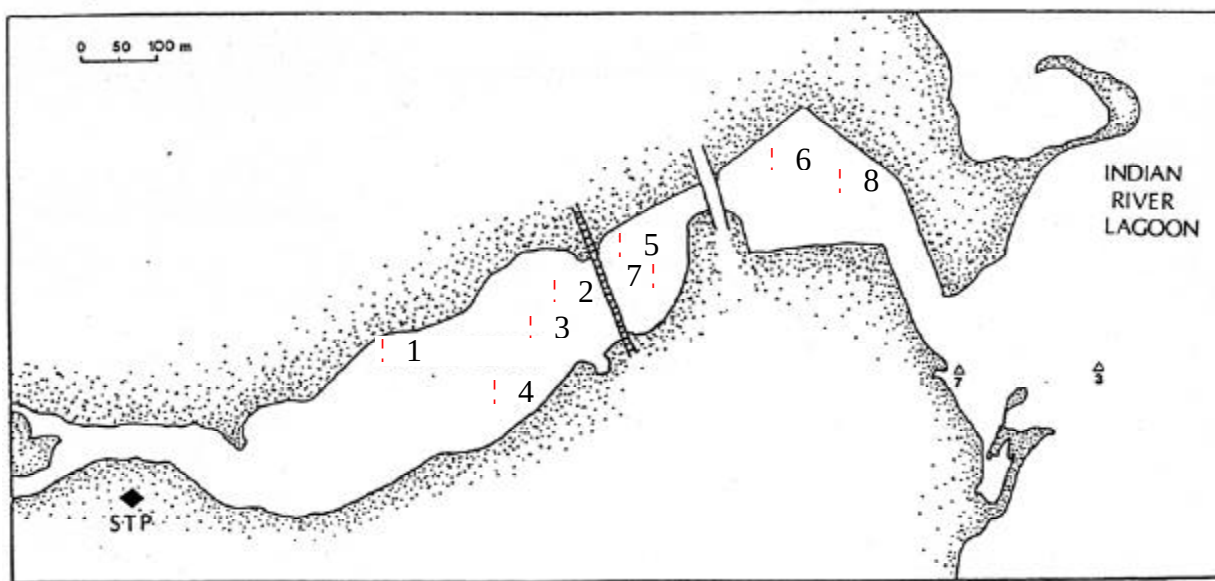


Figure 5. Locations of stations in Crane Creek where sediment cores were collected during 2002.

excess ^{210}Pb , along with ^{210}Pb formed by decay in the water column, are removed to the sediments via adsorption on particles or by biological processes (Bruland et al., 1974). This excess ^{210}Pb that accumulates in the sediments decays away to non-detectable levels in 4 to 5 half-lives. Analytically, the excess ^{210}Pb is distinguished from total ^{210}Pb as follows:

$$\text{Activity of Excess } ^{210}\text{Pb} = \text{Activity of Total } ^{210}\text{Pb} - \text{Activity of } ^{226}\text{Ra}$$

where the activity of ^{226}Ra is equal to the supported ^{210}Pb that was carried into the system with its parent isotopes via suspended sediments. The activities of ^{214}Pb and ^{214}Bi are used as proxies for ^{226}Ra in this study.

The excess ^{210}Pb profiles in each of three cores from the STP Basin (cores 1, 3 and 4, Figures 6 and 7) show three anomalously low values at varying depths in the top 15 cm relative to 7 to 8 points that follow more predicted behavior and are used here to calculate a slope and sedimentation rate. The anomalous points may result from addition of older sediment, with a lower activity of excess ^{210}Pb , from the perimeter of the creek to more recent, incoming sediment. The anomalous layers do not appear to contain different amounts of sand or shell than the other layers, based on data for Al and other elements to be presented below. Initially, the three anomalous points for excess ^{210}Pb in each core were omitted from the regression calculation, a procedure that was defended by Kang et al. (2000) and Kang and Trefry (2003). With this modification, sedimentation rates for stations 1, 3 and 4 are 0.38, 0.43 and 0.42 cm/yr, respectively, with $r > 0.89$ in each case (Figures 6 and 7). As a point of reference, if all the data points are used for each station, the sedimentation rates based on excess ^{210}Pb are as follows: station 1 at 0.26 cm/yr ($r = 0.72$), station 3 at 0.60 cm/yr ($r = 0.43$) and station 4 at 0.45 cm/yr ($r = 0.49$). The agreement between the adjusted and complete data sets for station 4 are quite similar whereas the results for stations 1 and 3 vary by ± 40 to 50%.

Using the 1950 marker in the ^{137}Cs profiles for cores from stations 1, 3 and 4 (Figures 6 and 7), the sedimentation rates at these three stations are 0.6, 0.3 and 0.6 cm/yr, respectively. The activities of ^{137}Cs in the three layers from each core with anomalously low levels of excess ^{210}Pb do not appear to be as significantly affected in the same manner as the excess ^{210}Pb values. This observation further demonstrates the inherent difficulties in determining sedimentation rates in a hydraulically active, shallow-water system such as Crane Creek. Despite the apparent incongruities, the sedimentation rates obtained using ^{137}Cs are within 30 to 50% of values obtained using the excess ^{210}Pb data.

The activities of ^7Be (half life = 53.3 days) also were determined for the top layers (0-6 cm) of sediment from stations 1, 3 and 4 (Figure 8). These results show the degree surface mixing of the sediments by physical and biological processes. In the cores from sites 1 and 3, the activity of ^7Be is decreased by about 5-fold below a sediment depth of 2 cm, suggesting that rapid mixing (over a several month period) is restricted to the top 2-3 cm in each of these cores.

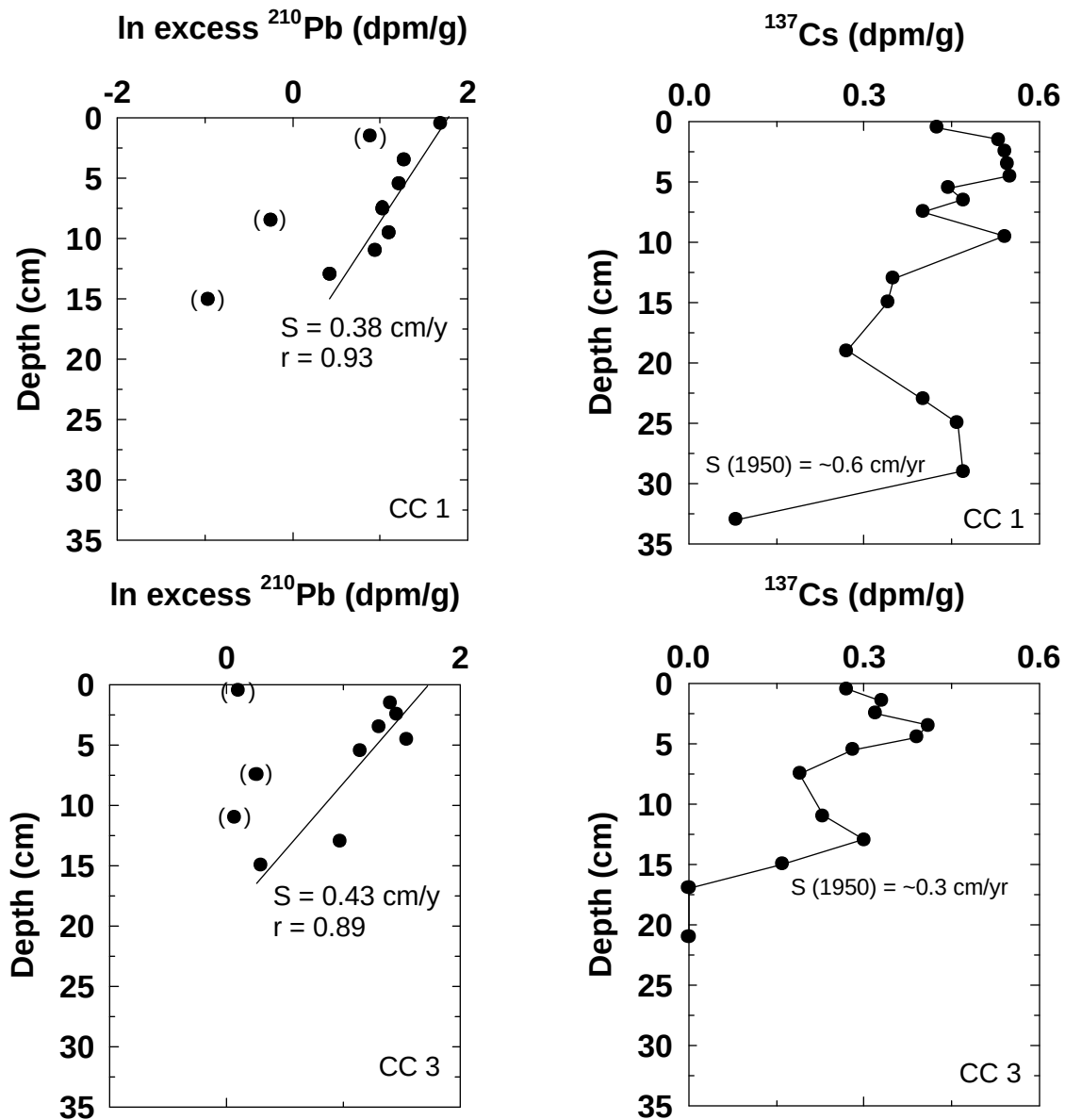


Figure 6. Vertical profiles for the natural logarithm ($\ln$) of excess ^{210}Pb activity and the total activity of ^{137}Cs for sediment cores from stations 1 and 3 in the STP Basin of Crane Creek. Markers in parentheses on the plots for excess ^{210}Pb identify anomalously low activities for excess ^{210}Pb ; these values have not been included in the linear regression calculation for sedimentation rate. S is the sedimentation rate and r is the correlation coefficient for the linear regression.

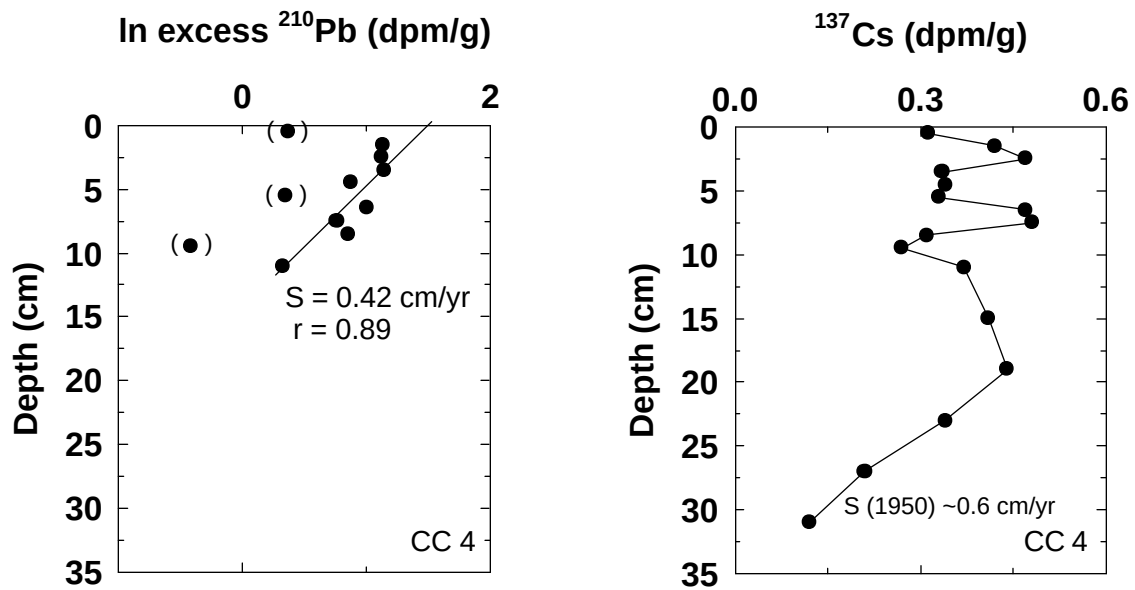


Figure 7. Vertical profiles for the natural logarithm (ln) of excess ^{210}Pb activity and the total activity of ^{137}Cs for sediment cores from station 4 in the STP Basin of Crane Creek. Markers in parentheses on the plot for excess ^{210}Pb identify anomalously low activities for excess ^{210}Pb ; these values have not been included in the linear regression calculation for sedimentation rate. S is the sedimentation rate and r is the correlation coefficient for the linear regression.

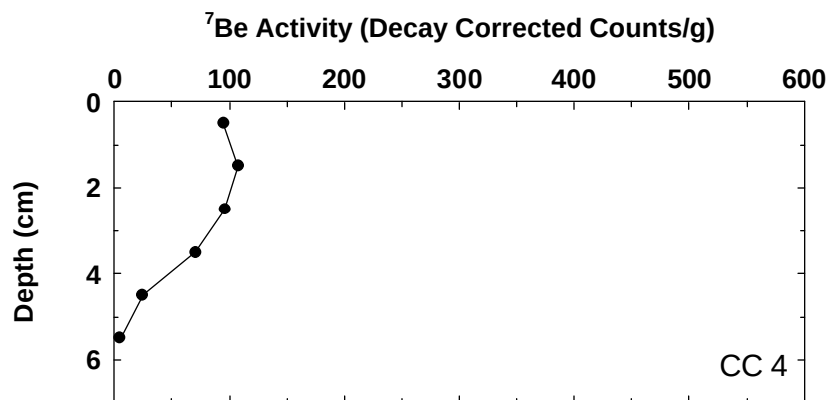
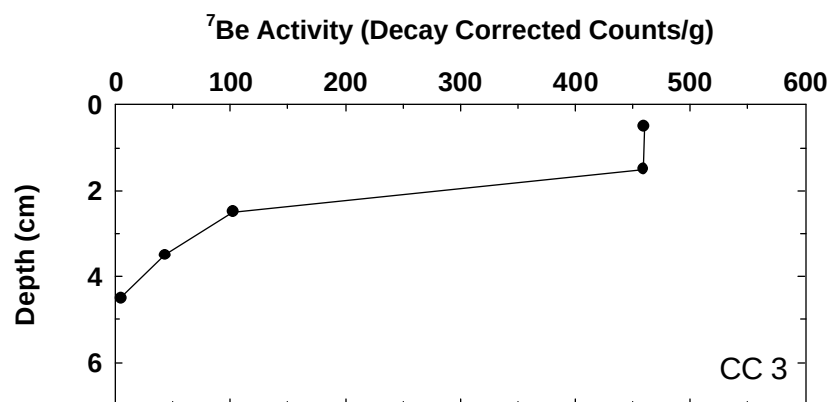
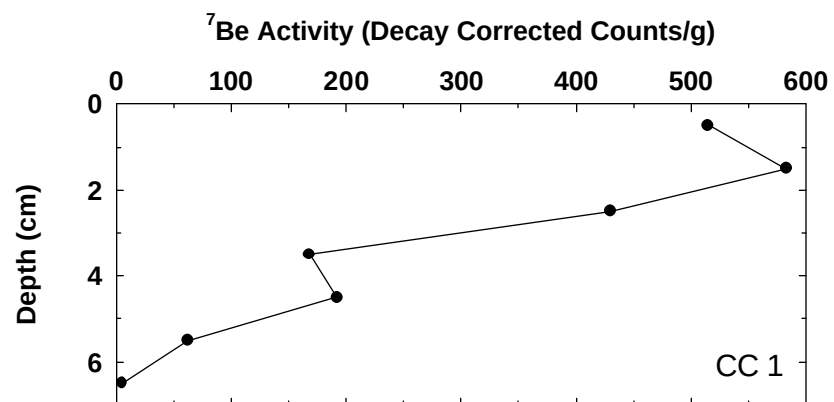


Figure 8. Vertical profiles for the activity of ^7Be in sediment cores from stations 1, 3 and 4 from the STP Basin of Crane Creek.

The core from station 7, on the southern side of the Manatee Basin, provided the best agreement between sedimentation rates calculated using data for excess ^{210}Pb and ^{137}Cs (Figure 9). An average of $\sim 0.23 \pm 0.06$ cm/yr was obtained using the excess ^{210}Pb data and both the 1950 and 1963 ^{137}Cs markers. In sharp contrast, the data for core 5, collected on the north side of the Manatee Basin, show sediment mixing to a depth >40 cm and the core is not valuable for age determinations. The decrease in activities of ^{137}Cs and excess ^{210}Pb at a depth of ~ 60 cm are related to the presence of a sand layer, rather than a time-relevant decrease in activities. The shallow water (<2 m) and manatee activity in the area are consistent with the observed mixing.

The core from station 8 was collected in an area with somewhat less boat traffic on the eastern portion of the Harbor Basin (Figure 5). The data for both excess ^{210}Pb and ^{137}Cs support sediment accumulation at a relatively rapid rate of ~ 2 cm/yr (Figure 10). At station 6, located near the fuel dock in the central portion of the Harbor Basin, the sediment was mixed (or slumped) to a depth of ~ 50 cm and thus calculation of sedimentation rates is difficult. Nevertheless, values obtained using each isotope are 0.6 to ~ 1 cm/yr (Figure 10).

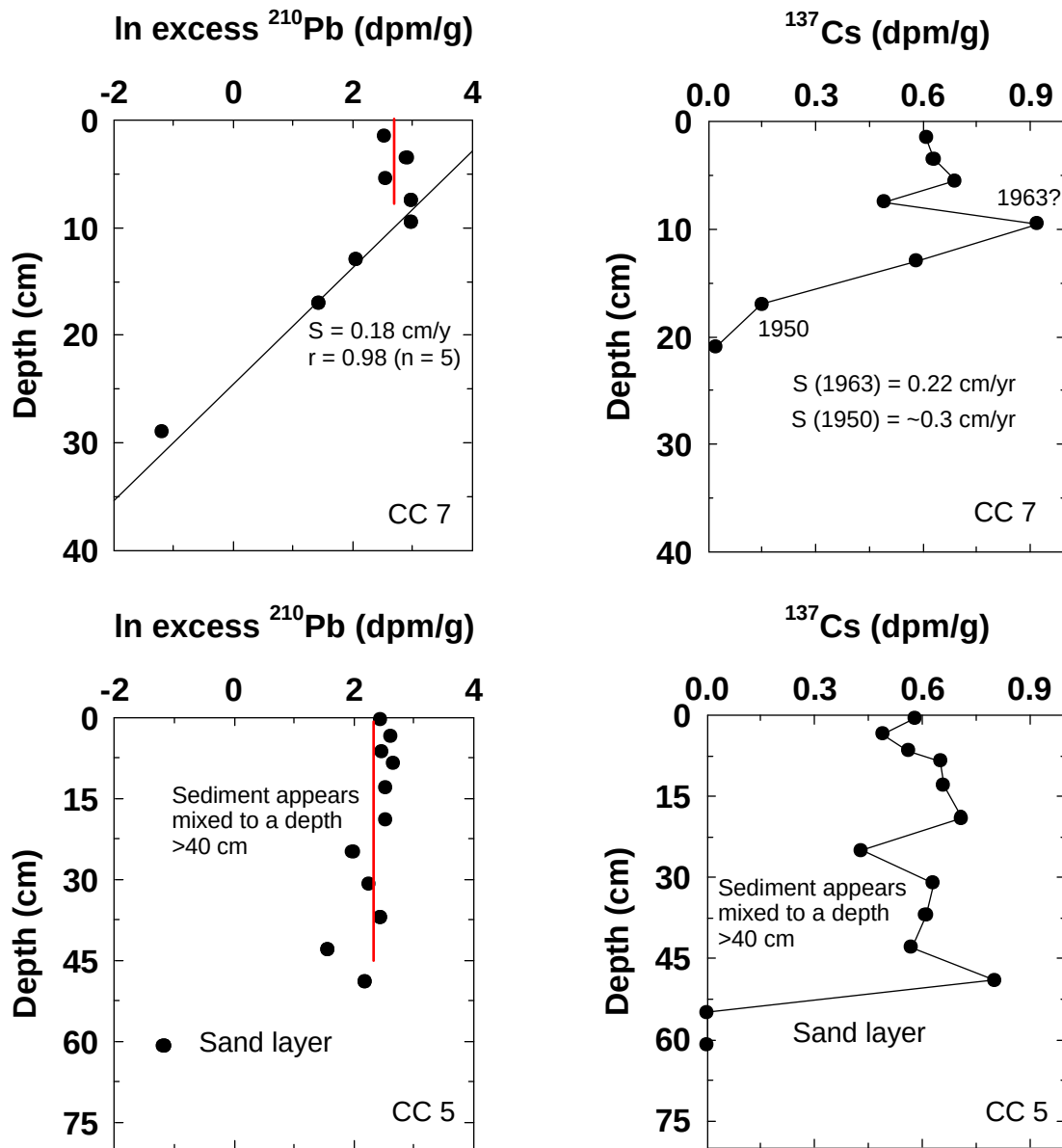


Figure 9. Vertical profiles for the natural logarithm ($\ln$) of excess ^{210}Pb activity and the total activity of ^{137}Cs for sediment cores from stations 7 and 5 from the Manatee Basin in Crane Creek. Vertical line shows estimated extent of vertical mixing of sediment. S is the sedimentation rate and r is the correlation coefficient for the linear regression.

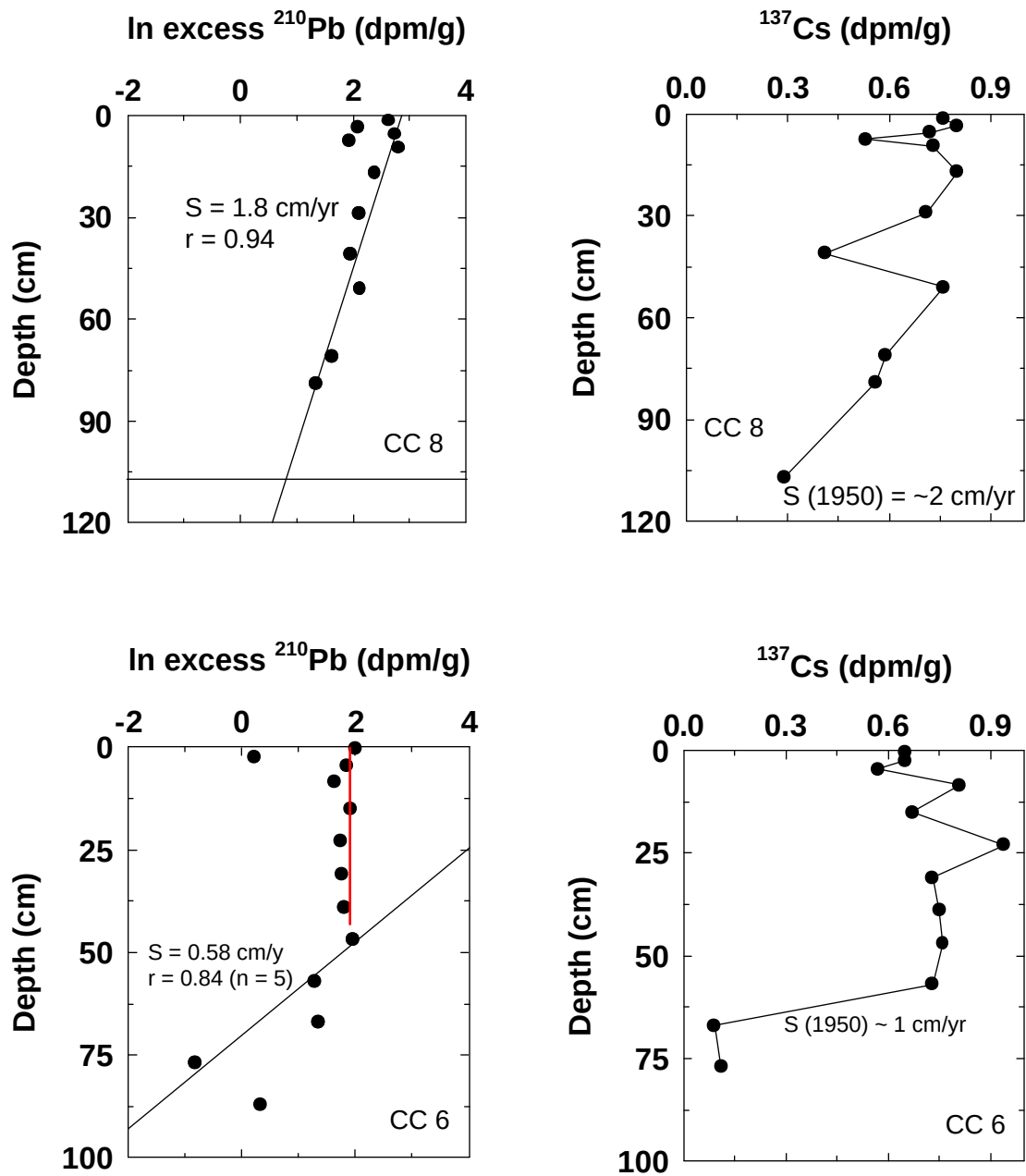


Figure 10. Vertical profiles for the natural logarithm ($\ln$) of excess ^{210}Pb activity and the total activity of ^{137}Cs for sediment cores from stations 6 and 8 from the Harbor in Crane Creek. Vertical line shows estimated extent of vertical mixing of sediment. S is the sedimentation rate and r is the correlation coefficient for the linear regression.

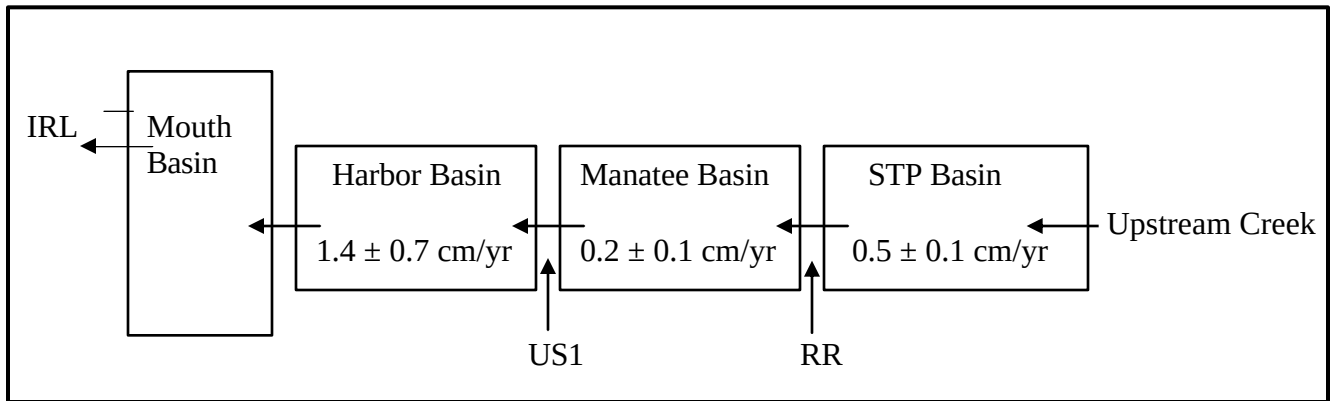


Figure 11. Summary of sedimentation rates for three basins in Crane Creek (RR = railroad; STP = Sewage Treatment Plant, IRL = Indian River Lagoon; US1 = highway US 1).

A summary of the sedimentation rates obtained from the six cores using both excess ^{210}Pb and ^{137}Cs data (Figure 11) shows the highest rates of sedimentation in the Harbor Basin with almost three times lower levels in the STP Basin and ~seven times lower levels in the Manatee Basin. The grand average for the six cores is 0.7 ± 0.6 cm/yr (n=12, two rates per core).

Major Elements and Trace Metals in Sediments

Overview of Data Set and Use of Interelement Relationships

To address questions related to sediment sources, sediment quality and sediment history, the data for major elements and trace metals in soils, suspended sediments, surface sediments, sediment cores are used collectively. Summary data for soils and sediments are given in Table 5 (major elements) and Table 6 (trace metals). The data for suspended sediments are listed in Table 7. The complete data set is compiled in the appendix. Maps showing the locations of sampling sites are presented here for soils (Figure 12), surface sediments (Figure 13) and suspended sediments (Figures 12 and 14). Locations of sediment coring stations were shown previously in Figure 5.

Concentrations of major elements, trace metals and TOC are higher in sediment samples than in soils because the sediments are more fine-grained and clay rich (Tables 5 and 6). One approach to gaining an overview of this large and diverse data set for soils, suspended sediments, surface sediments and sediment cores is by graphically presenting concentrations of various elements versus Al or another appropriate element. Aluminum provides a useful frame of reference because Al is resistant to chemical weathering in soils and sediments and it is a good indicator of the aluminosilicate (clay) fraction of the sample, where 8-10% Al usually represents a sample that is dominated by (>80%) clay or other aluminosilicate minerals.

Concentrations of Al and Fe in all sediment samples were used to calculate a linear regression for the data and fit a 95% prediction interval to the sediment data set (Figure 15). The Al and Fe data for the sediment samples fit the linear regression well ($r = 0.94$). Values for ten of the twelve soil samples plotted within the 95% prediction interval, excluding soils from sites 5 and 6, both located in the southern portion of the drainage basin (Figure 15). These two samples were Fe-poor (or Al-rich) relative to the sediment or other soil samples. In contrast, all six of the samples of suspended sediment from Crane Creek with $TSS < 7$ mg/L had Fe/Al ratios that plotted above the upper prediction interval (Figure 15). The high Fe/Al ratios of some samples of suspended sediment and the low Fe/Al ratios of two soil samples do not fit the overall observed relationship found in the sediments. However, the distinct differences in the Fe/Al ratios for the suspended sediment are most likely transient and quantitatively unimportant with respect to the composition of creek sediments as described in more detail later in this report. In the case of the soils, Fe can be leached from soils more easily than Al to create the observed anomalies.

The Al versus K relationship is almost as good as the Fe/Al trend with a few samples of soil and suspended sediment having low K levels (Figure 15). The outliers were all below the lower prediction interval and included one soil sample (soil site 6) and a few of the same samples of suspended sediment that had elevated ratios of Fe/Al (figure 15). As in the case of Fe, no clear differences in concentrations of the metal (in this case K) versus Al were observed and thus no straightforward tracer for sources of sediments to the creek was identified.

Table 5. Means and standard deviations for concentrations of Al, Ca, Fe, K, Mg, Mn and total organic carbon (TOC) for soils, surface sediments and sediment cores from Crane Creek.

Location		Al (%)	Ca (%)	Fe (%)	K (%)	Mg (%)	Mn (µg/g)	TOC (%)
Soils (n = 12)	Mean (±Std. Dev.)	1.66 ±2.48	1.82 ±1.98	0.58 ±0.66	0.16 ±0.13	0.09 ±0.12	41 ±22	1.94 ±1.64
Perimeter Surface Sediments (n = 18)	Mean (±Std. Dev.)	4.32 ±1.21	1.19 ±0.38	2.63 ±0.65	0.52 ±0.15	0.98 ±0.44	164 ±79	3.89 ±0.82
Center Surface Sediments (n = 10)	Mean (±Std. Dev.)	3.77 ±2.60	1.71 ±1.09	2.37 ±1.60	0.42 ±0.30	0.91 ±0.74	161 ±128	4.22 ±2.94
Core 1 (n = 9)	Mean (±Std. Dev.)	3.40 ±1.36	1.89 ±1.56	2.33 ±0.77	0.34 ±0.10	0.55 ±0.33	115 ±31	2.78 ±1.12
Core 4 (n = 14)	Mean (±Std. Dev.)	2.41 ±1.13	0.94 ±0.33	2.06 ±1.02	0.33 ±0.07	0.35 ±0.21	112 ±20	2.32 ±1.57
Core 7 (n = 10)	Mean (±Std. Dev.)	3.48 ±2.57	2.11 ±1.00	2.50 ±1.44	0.32 ±0.18	0.41 ±0.32	151 ±67	4.51 ±2.72
Core 8 (n = 13)	Mean (±Std. Dev.)	4.64 ±1.53	1.52 ±0.36	2.92 ±0.99	0.58 ±0.18	1.23 ±0.50	244 ±71	5.03 ±1.28

Table 6. Means and standard deviations for concentrations of Ag, As, Cd, Cr, Cu, Hg, Ni, Pb, Se, V and Zn for soils, surface sediments, and sediment cores from Crane Creek.

Location		Ag (µg/g)	As (µg/g)	Cd (µg/g)	Cr (µg/g)	Cu (µg/g)	Hg (µg/g)	Ni (µg/g)	Pb (µg/g)	Se (µg/g)	V (µg/g)	Zn (µg/g)
Soils (n = 12)	Mean (±Std. Dev.)	0.04 ±0.04	1.8 ±1.5	0.08 ±0.07	10 ±23	9 ±8	0.04 ±0.03	4 ±6	12 ±9	0.6 ±0.4	22 ±30	36 ±32
Perimeter Surface Sediments (n = 18)	Mean (±Std. Dev.)	1.4 ±0.7	6.4 ±2.1	0.64 ±0.16	55 ±14	80 ±50	0.25 ±0.06	16 ±4	53 ±14	1.8 ±0.4	61 ±17	223 ±63
Center Surface Sediments (n = 10)	Mean (±Std. Dev.)	1.1 ±0.9	5.8 ±3.5	0.52 ±0.36	54 ±35	67 ±46	0.18 ±0.11	14 ±9	71 ±58	1.0 ±0.7	54 ±37	183 ±126
Core 1 (n = 9)	Mean (±Std. Dev.)	3.9 ±1.7	4.6 ±2.2	0.95 ±0.36	60 ±18	52 ±25	0.48 ±0.30	17 ±5	67 ±24	1.1 ±0.2	46 ±19	212 ±108
Core 4 (n = 14)	Mean (±Std. Dev.)	4.5 ±3.9	2.4 ±1.2	0.53 ±0.33	56 ±38	41 ±33	0.43 ±0.38	15 ±10	61 ±44	1.1 ±0.6	33 ±14	170 ±130
Core 7 (n = 10)	Mean (±Std. Dev.)	1.4 ±1.2	5.5 ±3.7	0.70 ±0.52	50 ±37	55 ±47	0.23 ±0.17	12 ±9	53 ±44	1.5 ±0.2	48 ±38	198 ±162
Core 8 (n = 13)	Mean (±Std. Dev.)	1.7 ±0.7	6.7 ±3.5	1.5 ±0.4	66 ±20	82 ±35	0.29 ±0.11	18 ±6	67 ±15	1.1 ±0.3	71 ±26	168 ±77

Table 7. Means and standard deviations for concentrations of Ag, Al, Ca, Cu, Fe, K, Mg, Mn, Pb, Zn and particulate organic carbon (POC) for suspended sediments from Crane Creek.

Location	Ag (µg/g)	Al (%)	Ca (%)	Cu (µg/g)	Fe (%)	K (%)	Mg (%)	Mn (µg/g)	Pb (µg/g)	Zn (µg/g)	POC (%)
Ruffner Park	0.09	5.47	4.68	41.6	2.04	0.29	0.36	90.2	48.9	312	11.1
Babcock Street Bridge	0.22	5.59	4.71	55.4	3.1	0.26	0.38	162	68.7	403	14.6
Hickory Ditch	0.27	3.28	3.11	78.2	1.33	0.32	0.27	106	107	408	17.6
West of RR	1.44	3.50	1.02	44.5	5.59	0.29	0.57	641	49.6	291	-
Manatee Basin	0.76	5.50	1.47	68.1	8.17	0.21	0.45	399	124	320	-
Harbor Basin, east US 1	1.03	5.09	1.28	72.2	6.85	0.25	0.60	594	90.6	295	4.67
Center of Harbor (0.2 m)	1.97	4.43	0.98	134	6.58	0.15	0.56	723	109	257	2.59
Center of Harbor (2 m)	1.00	4.21	0.49	107	3.26	0.47	1.46	569	34.9	288	-
Harbor FIT (0.2 m)	1.97	4.43	0.98	134	6.58	0.15	0.56	723	109	257	2.59
Harbor FIT (2 m)	0.98	4.70	0.83	120	3.75	0.44	1.29	653	48.7	312	8.90
IRL (0.2 m)	0.27	2.83	0.59	32.3	2.15	0.50	1.35	755	32.1	132	-
IRL (2 m)	0.24	2.90	1.11	17.9	2.17	0.46	1.24	575	26.1	381	-

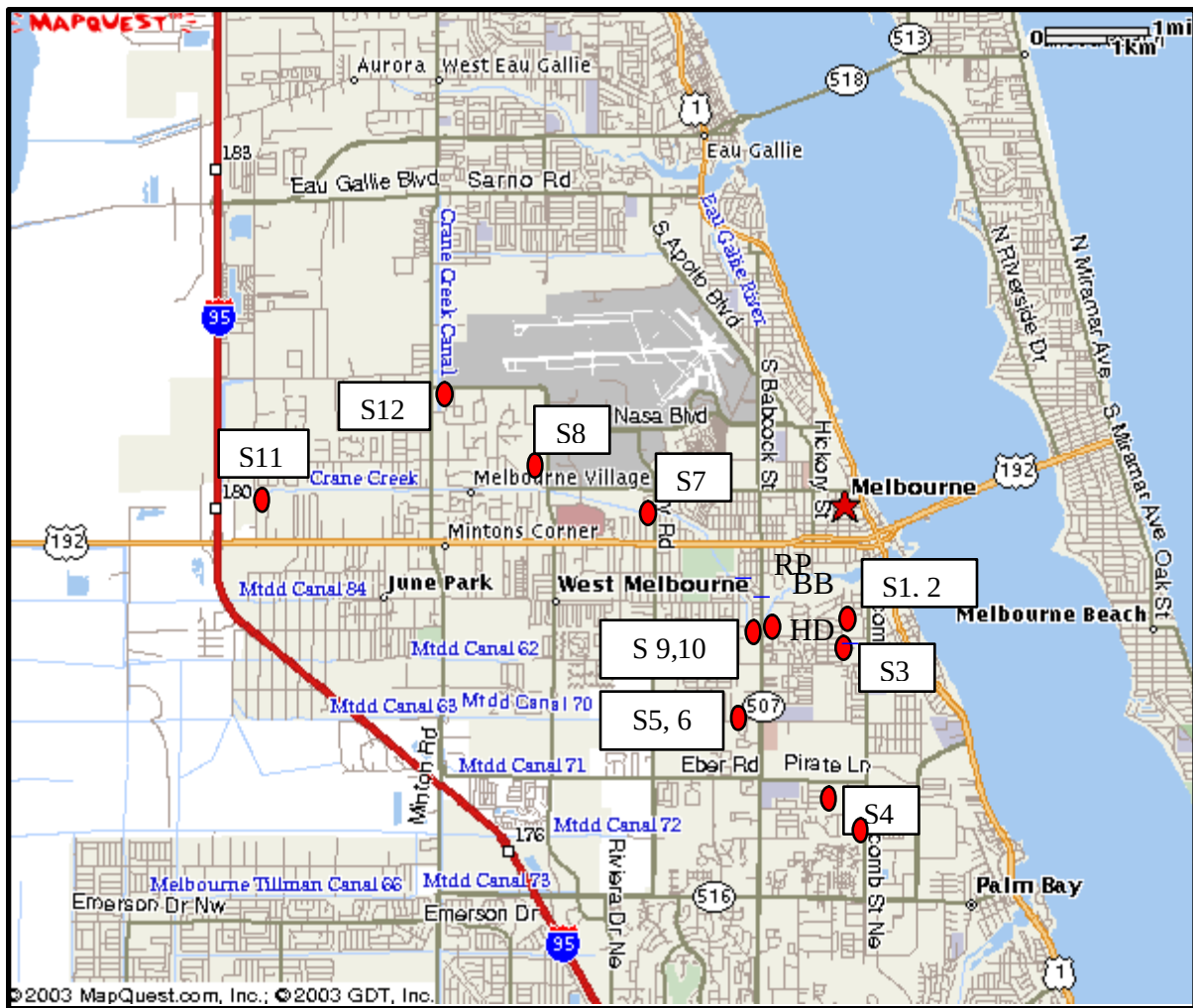


Figure 12. Locations of sites where soil samples (●) and upstream suspended sediment samples (–) were collected during 2003.

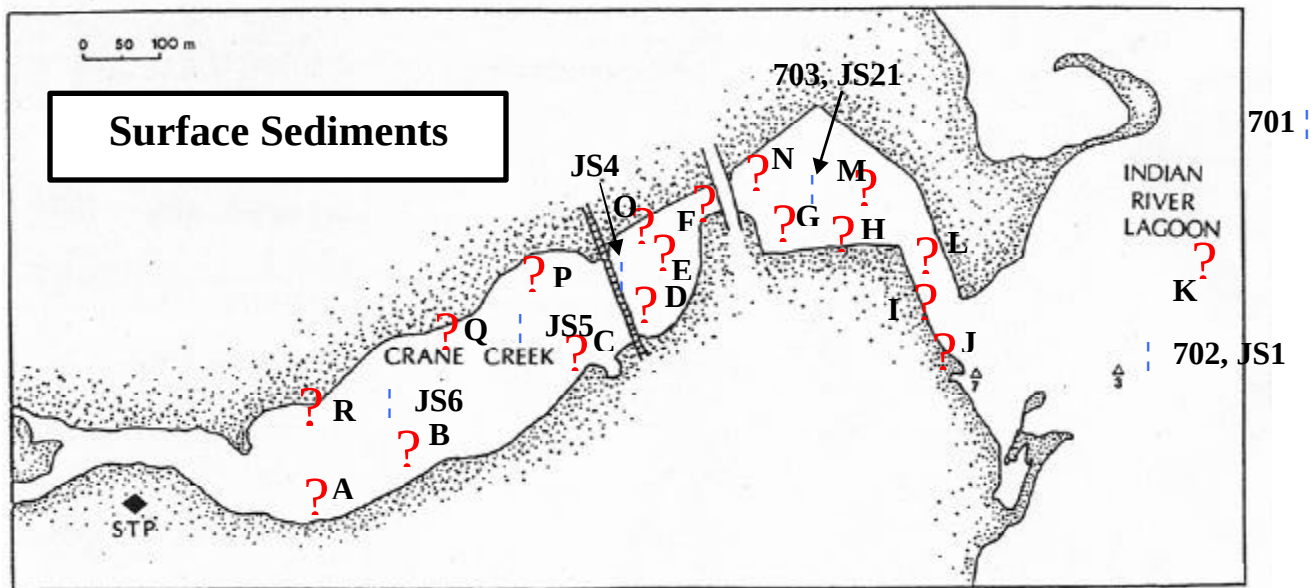


Figure 13. Locations of stations in Crane Creek where surface sediments were collected during 2002.

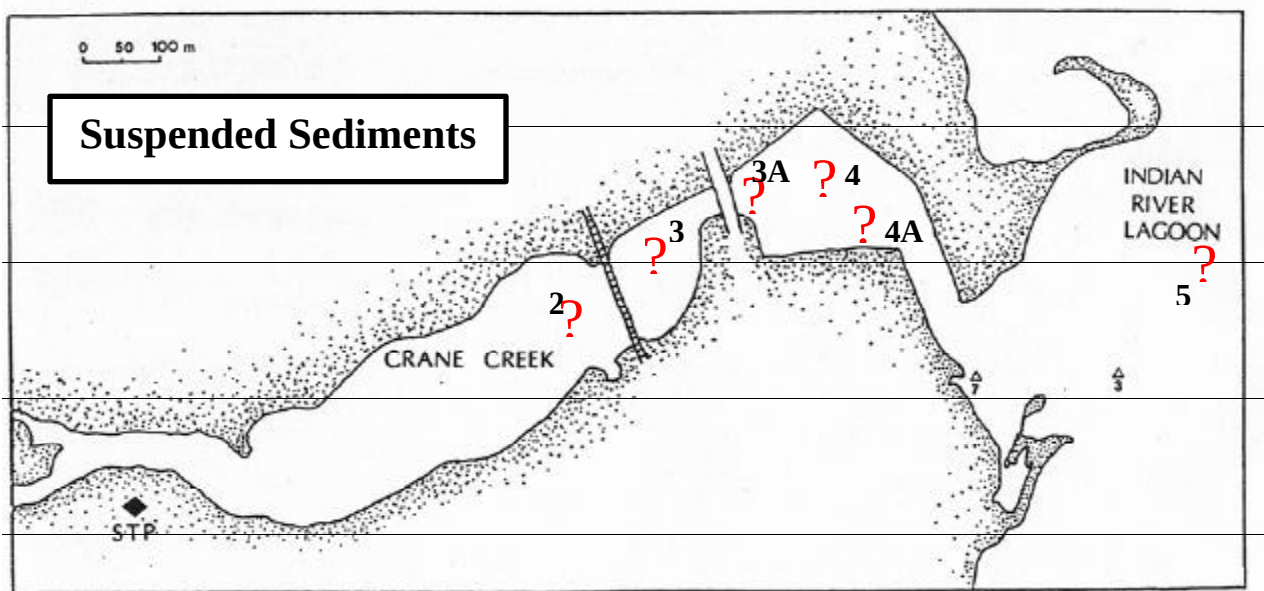


Figure 14. Locations of stations in Crane Creek where suspended sediments were collected during 2002. Locations of sampling sites for suspended sediments at upstream location are shown on Figure 12.

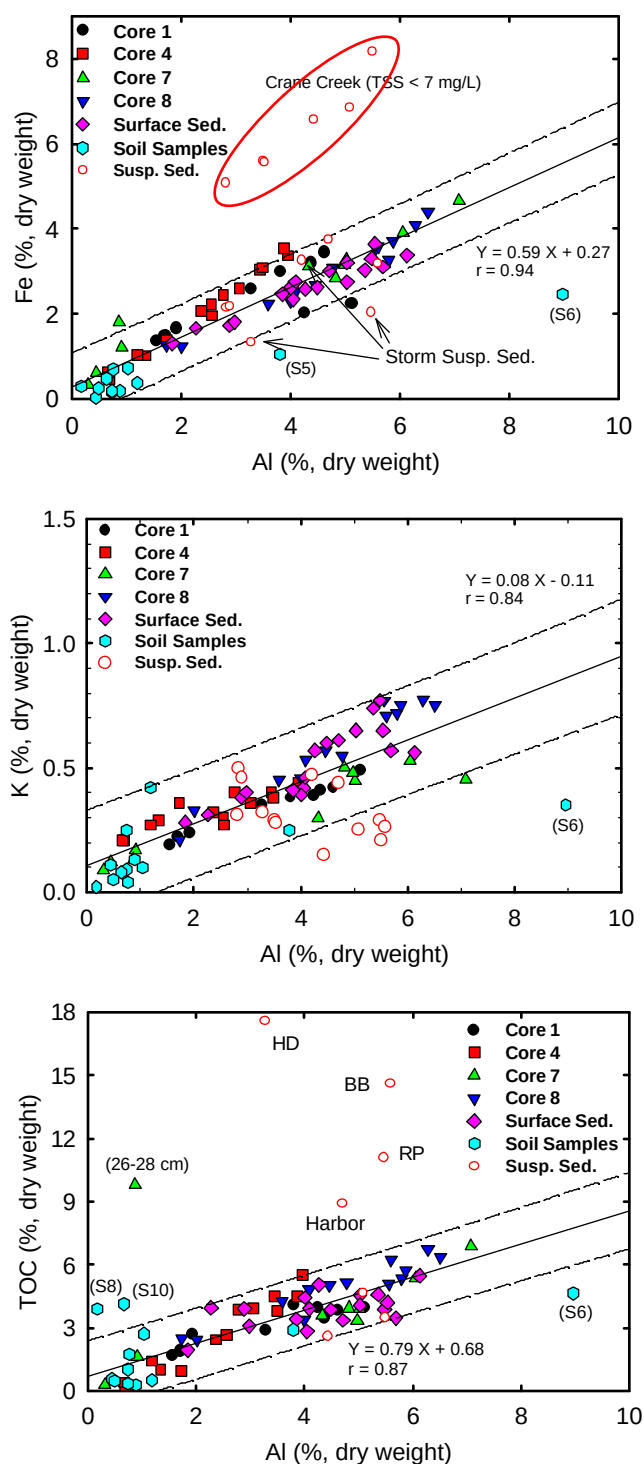


Figure 15. Concentrations of Al versus (a) Fe, (b) K and (c) total organic carbon (TOC) for sediments, soils and suspended sediments from the study area. Linear regression with 95% prediction interval was constructed using sediment data and excluded any points that are labeled in the graph. (HD = Hickory Ditch, BB = Babcock St. Bridge, RP = Ruffner Park).

Concentrations of TOC in sediments also correlated well with concentrations of Al (Figure 15) with only one sediment sample (core 7, 26-28 cm) that contained anomalously high levels of TOC. All three of the suspended sediment samples collected during a storm event (at Ruffner Park, Babcock Street Bridge and Hickory Ditch) with TSS levels of 312-408 mg/L contained >10% TOC, suggesting that storm flow carries a higher fraction of organic matter with the suspended sediment than commonly found in bottom sediments. Most likely, this excess organic matter is decomposed in creek sediments leading to the high oxygen demand described by Windsor et al. (2004, this study).

Concentrations of Ca are relatively uniform at 0.5 to 2% in sediment samples (Figure 16); therefore, no linear regression was carried out for the Al versus Ca data. Most of the samples contain relatively low levels of CaCO_3 because 2% Ca is equivalent to ~5% CaCO_3 . Four of the soil samples, all collected north of route 192 contained >4% Ca (Figure 16), or most likely > 10% CaCO_3 . Only two sediment samples contained >4% Ca, one from near the bottom (36-38 cm) of core 1 and one from 22-24 cm in core 7. Both these anomalies are most likely due to some residual shell material. Two samples of suspended sediment from near the same area (Ruffner Park and the Babcock Street bridge, locations in Figure 12) contained >4% Ca (Figure 16). A limey suspension has been observed in unpaved roads in area of Ruffner Park during rain storms. This observation is consistent with the storm period when these samples were collected. Overall, CaCO_3 is not being preserved to any significant levels in Crane Creek and use of Ca or Ca/Al ratios as an indicator of sources seems useful mainly during storm transport.

Concentrations of Mg in sediments from Crane Creek correlate well with Al (Figure 16), but not Ca. This distinction suggests that Mg is part of the aluminosilicate fraction, rather than the carbonate fraction. Vermiculite and kaolinite are the two clay minerals identified in Crane Creek (D'Arcy, 1987). Vermiculite is Mg-rich as demonstrated by the following typical formula: $\text{Mg}_{1.8}\text{Fe}^{2+}_{0.9}\text{Al}_{4.3}\text{SiO}_{10}(\text{OH})_2 \cdot 4(\text{H}_2\text{O})$. However, the strong relationship between Mg and Al in the sediment samples suggests that the sources of Mg and Al must be similar or proportional in creek sediments. Most of the soil samples collected contained low levels of both Mg and Al and therefore did not contain any significant amounts of vermiculite or other clays. The Mg/Al ratio, in concert with the absolute Mg concentrations, may be a good indicator of the amount of vermiculite clay deposited at a given site in creek sediments.

Concentrations of Mn (100-300 $\mu\text{g/g}$) and the Mn/Al ratios ($20\text{-}40 \times 10^{-4}$) in sediments from Crane Creek (Figure 16) are low relative to average continental crust where Mn levels average ~700 $\mu\text{g/g}$ and the Mn/Al ratio is $\sim 90 \times 10^{-4}$ (Wedepohl, 1995). This observation is consistent with reductive dissolution of Mn oxides in the highly reducing creek sediments with subsequent release of dissolved Mn^{2+} to the overlying water column. In sharp contrast with the bottom sediments, the suspended sediments are enriched with Mn (Figure 16), most likely the result of oxidative precipitation of Mn oxide on particles being carried in oxic creek water. The source of this excess Mn is most likely from diffusion from bottom sediments. The Mn content of the suspended sediment helps show whether that suspended sediment has been carried in oxygenated

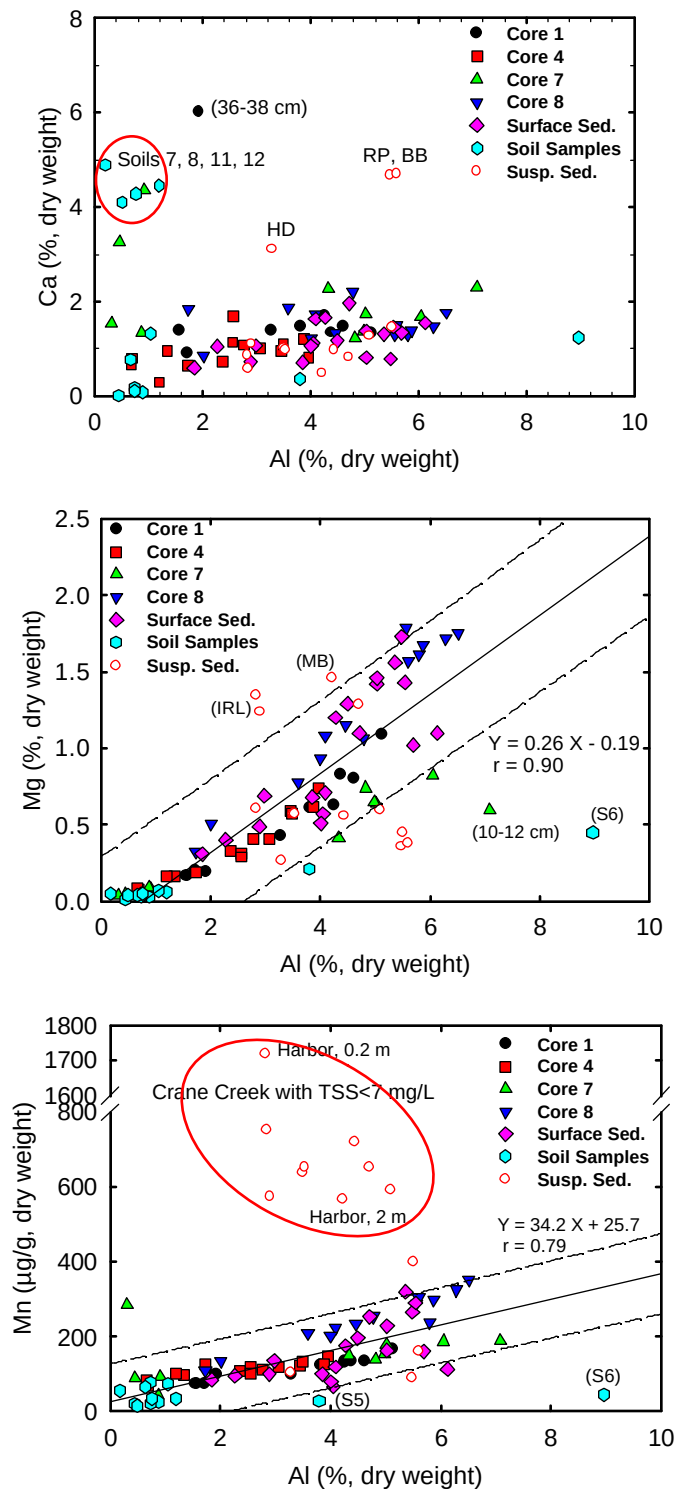


Figure 16. Concentrations of Al versus (a) Ca, (b) Mg and (c) Mn for sediments, soils and suspended sediments from the study area. Linear regression with 95% prediction interval was constructed using sediment data and excluded any points that are labeled in the graph.

water that was enriched with Mn that may have been released from reducing sediments. For example, the sample of suspended sediment collected from the harbor in more oxic water at a depth of 0.2 m has a Mn content of 1720 µg/g relative to the sample collected at 2 m in hypoxic water with a Mn content of 570 µg/g (Figure 16).

A strong positive correlation was found for Al versus V (Figure 17) with essentially all data points for sediments, soils and suspended sediments plotting within the 95% prediction interval established using sediment data. A similar degree of constancy was observed for Al versus As (Figure 17). Thus, concentrations of these two trace metals are at natural levels in the drainage basin. However, the uniform metal/Al relationship does not easily facilitate identification of distinct natural sources for these metals within the drainage basin.

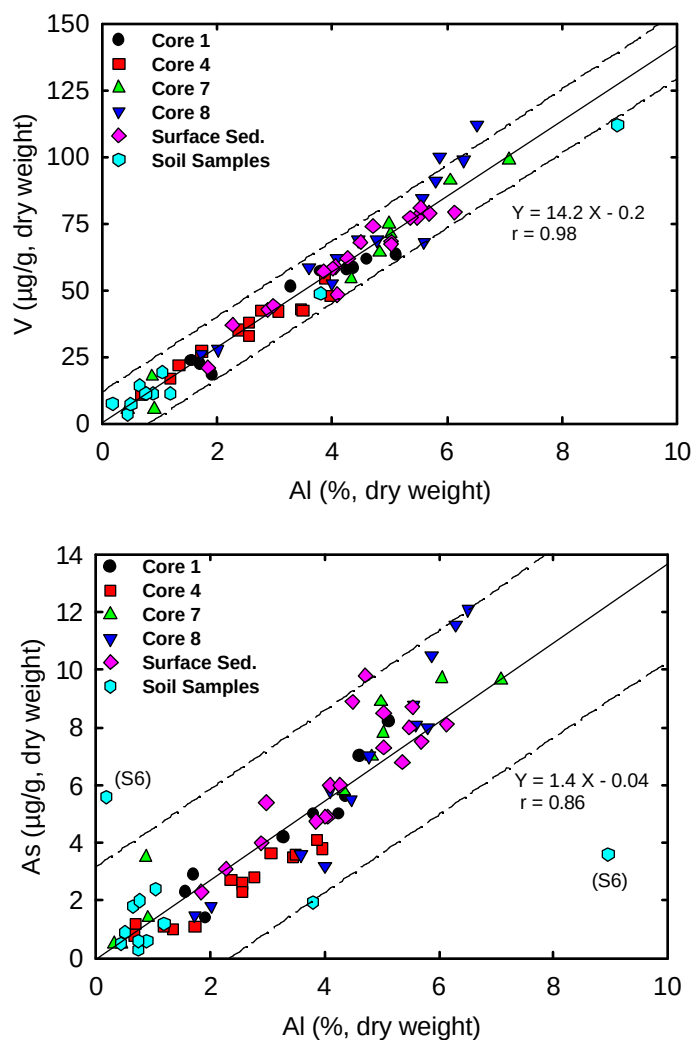


Figure 17. Concentrations of Al versus (a) V and (b) As for sediments, soils and suspended sediments from the study area. Linear regressions with 95% prediction interval were constructed using sediment data and excluded any points that are labeled in the graph.

Sediment Trace Metals: Tracing Sediment Sources and Assessing Sediment Quality

Most of the sediments from Crane Creek are contaminated with Ag and Hg (Figure 18). Sediments from cores 1 and 4, collected in the STP Basin, are the most contaminated with Ag and Hg at concentrations that are as much as 50 to more than 100 times greater than natural levels (Figure 18). These results suggest that a present or past source for anthropogenic Ag and Hg exists somewhere in the western (STP) basin or upstream. However, suspended sediments collected from the upper creek during storm runoff were low in Ag ($<0.3 \mu\text{g/g}$), suggesting that inputs may have occurred closer to the area between the STP and the railroad bridge. When sediment concentrations of Ag are plotted versus Hg (Figure 18), a strong linear fit ($r = 0.92$) is observed. The trend for Hg versus Ag supports a common source or source area for both metals. Based on the sediment data shown in Figure 18, the Ag and Hg was most likely introduced to the system west of the railroad bridge because concentrations of both metals (and the metal/Al ratios) are lower in the cores from stations 7 and 8 in the Manatee and Harbor Basins, respectively.

An historical perspective of the Ag and Hg contamination is shown in vertical profiles for the two metals in cores 1 and 4 from the STP Basin (Figure 19). Concentrations of Ag and the Ag/Al ratios are highest at depths of 15-30 cm, which equates to about 30 to 60 years ago. A similar trend is observed for Hg in core 4, but not in core 1 due to elevated surface values for Hg. Maximum concentrations of Ag and Hg and their ratios to Al in cores 7 and 8 from the Manatee and Harbor Basins, respectively, are 3 to 10 times lower than found to the west of the railroad bridge (Figure 20).

Data for Hg, but not Ag, are available for cores 3, 5 and 6 (Figure 20, bottom row of graphs). Mercury levels in core 3 (maximum of $0.39 \mu\text{g/g}$ in the surface layer) are about the same as those for cores 7 and 8 (Figure 20). However, high levels of Hg were found in core 5 ($0.6\text{--}1.1 \mu\text{g/g}$ at depths of 28-46 cm) and core 6 ($0.5\text{--}1.4 \mu\text{g/g}$ over a range of 28-90 cm). All the core data suggest that peak inputs of Ag and Hg were several decades ago. This conclusion is supported by the data for surface sediments (Figure 18) where generally lower concentrations of Ag and Hg were found relative to the older samples from sediment cores. Common sources for the co-occurrence of these two metals are dental wastes and photographic/art wastes.

Sediment quality criteria for Ag and Hg have been added to Figure 18. Such criteria have been used extensively worldwide to assess possible adverse biological effects to sediment biota from trace metals and PAH. One set of criteria introduced by Long et al. (1995) uses an Effects Range-Low (ERL) and Effects Range-Median (ERM). These guidelines are based on field, laboratory, and modeling studies conducted in the United States that coupled concentrations of contaminants in sediments with adverse biological effects (Long and Morgan, 1990; Long et al., 1995). The ERM is defined as the concentration of a substance in the sediment that results in an adverse biological effect in about 50 percent of the test organisms. The ERL is defined as the concentration of a substance that affects about 10 percent of the test organisms. For general application, the criteria have been

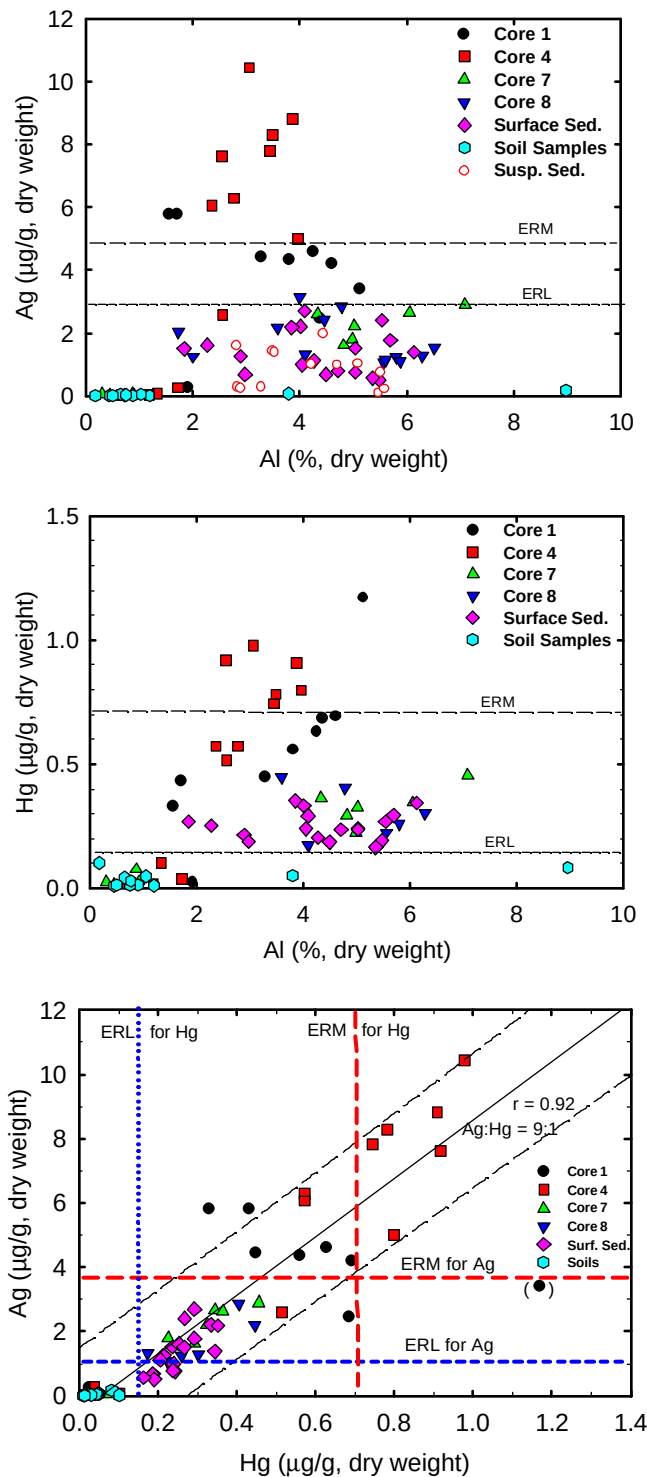


Figure 18. Concentrations of Al versus (a) Ag and (b) Hg and (c) concentrations of Hg versus Ag for sediments and soils from the study area. The linear regression with 95% prediction interval was constructed using sediment data and excluded any points that are in parentheses in the graph. Lines for Effects Range Median (ERM) and Effects Range Low (ERL) are from Long et al. (1995).

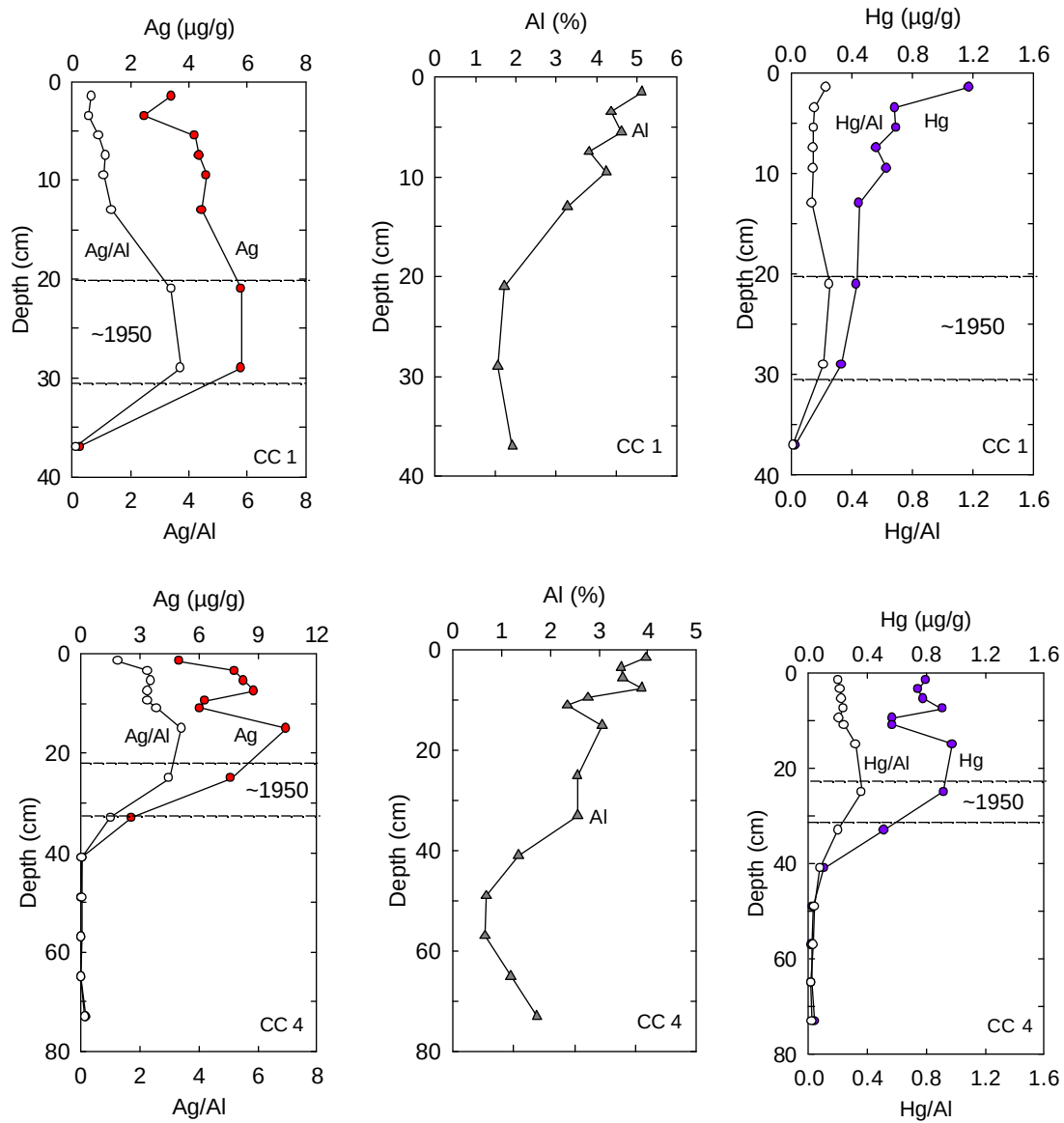


Figure 19. Vertical profiles for concentrations of Ag, Ag/Al, Al, Hg and Hg/Al in sediment cores from stations 1 and 4 in Crane Creek. Shaded areas show estimated range in depths that correspond to ~1950 based on results of age-dating.

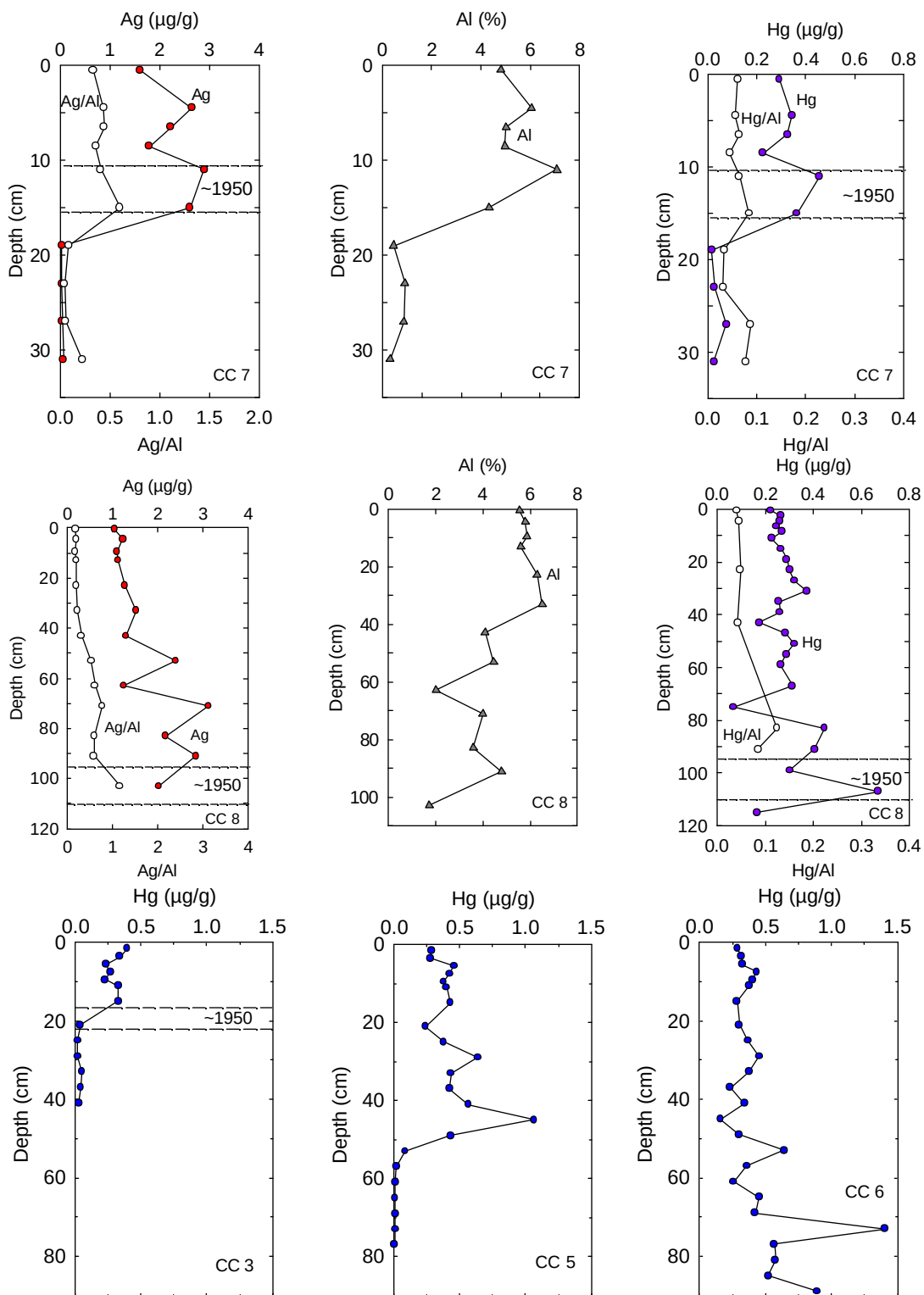


Figure 20. Vertical profiles for concentrations of Ag, Ag/Al, Al, Hg and Hg/Al in sediment cores from stations 7 and 8; and concentrations of Hg in cores 3, 5 and 6 in Crane Creek. Shaded areas show estimated range in depths that correspond to ~1950 based on results of age-dating where available.

applied as follows: adverse biological effects are “rarely” observed when metal or PAH levels are <ERL, “occasionally” observed when contaminants are present at levels between the ERL and ERM and “frequently” observed when concentrations are >ERM. Values for the ERM and ERL for six metals investigated during this study (Ag, As, Cd, Pb, Hg and Zn) have been developed by Long et al. (1995). Presently available ERL values for Cr, Cu and Ni are lower than values for average continental crust and seem to have evolved from data sets where concentrations of these metals in sediments were determined following an acid leach, rather than total digestion, of the sediment. Therefore, they are not included in this report.

Fourteen samples (from cores 1 and 4) had Ag levels greater than the ERM and seven samples had Hg levels above the ERM (Figure 18). Most of the remaining sediment samples contained Ag and Hg at levels that exceeded the ERL. Thus, based on the sediment quality criteria introduced above, the sediments at core sites 1 and 4 would be conducive to frequent adverse biological effects to any organisms dwelling in those sediments. Furthermore, sediments at most locations in Crane Creek could be characterized as promoting adverse biological effects on an occasional basis.

Concentrations of Pb were elevated over natural levels by two to six-fold at many sites throughout the creek with the highest values in suspended sediment from the Harbor Basin (Figure 21). None of the Pb values exceeded the ERM; however, more than half exceeded the ERL (Figure 21). Overall, the spatial distribution of Pb throughout the creek is rather ubiquitous. In the cores (Figure 22), Pb levels are highest in the top 20-30 cm of sediment at stations 1, 4 and 7 and throughout the core at station 8. In each case, the higher levels of Pb show that the onset of Pb contamination dates back about 50 years. The persistence of high Pb levels to greater depths in the sediment core from station 8 supports the faster sedimentation rate determined for this site in the Harbor Basin.

All concentrations of Cd were below the ERM and only three exceeded the ERL (Figure 21). In contrast, many of the Zn concentrations were greater than the ERL (Figure 21) with none greater than the ERM. The vertical distributions of Cd and Zn were similar to those described for Pb with high values restricted to the top 20 to 40 cm of cores 1, 4 and 7, yet throughout core 8 (Figure 22). These results also are consistent with the onset of metal contamination in Crane Creek that dates back about 50 years. Concentrations of Cd correlate well with concentrations of Zn ($r = 0.94$, Figure 23). This observation is common because Cd is a natural impurity in Zn ores and tends to go into the environment along with anthropogenic Zn inputs from galvanized metals, sacrificial anodes and other Zn-bearing alloys and materials.

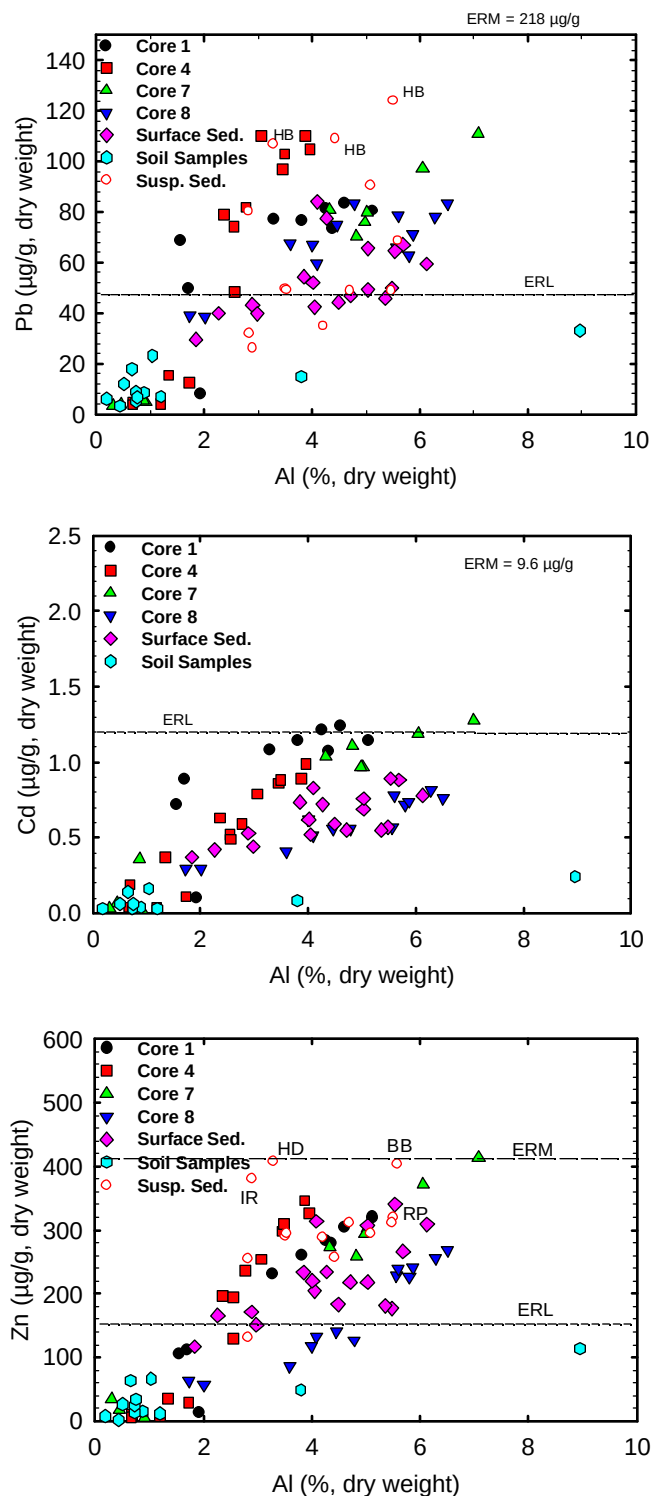


Figure 21. Concentrations of Al versus (a) Pb, (b) Cd and (c) Zn for soils, suspended sediments and bottom sediments from the study area. Lines for Effects Range Median (ERM) and Effects Range Low (ERL) are from Long et al. (1995). (HB = Harbor Basin, HD = Hickory Ditch, BB = Babcock Street Bridge, IR = Indian River Lagoon, and RP = Ruffner Park).

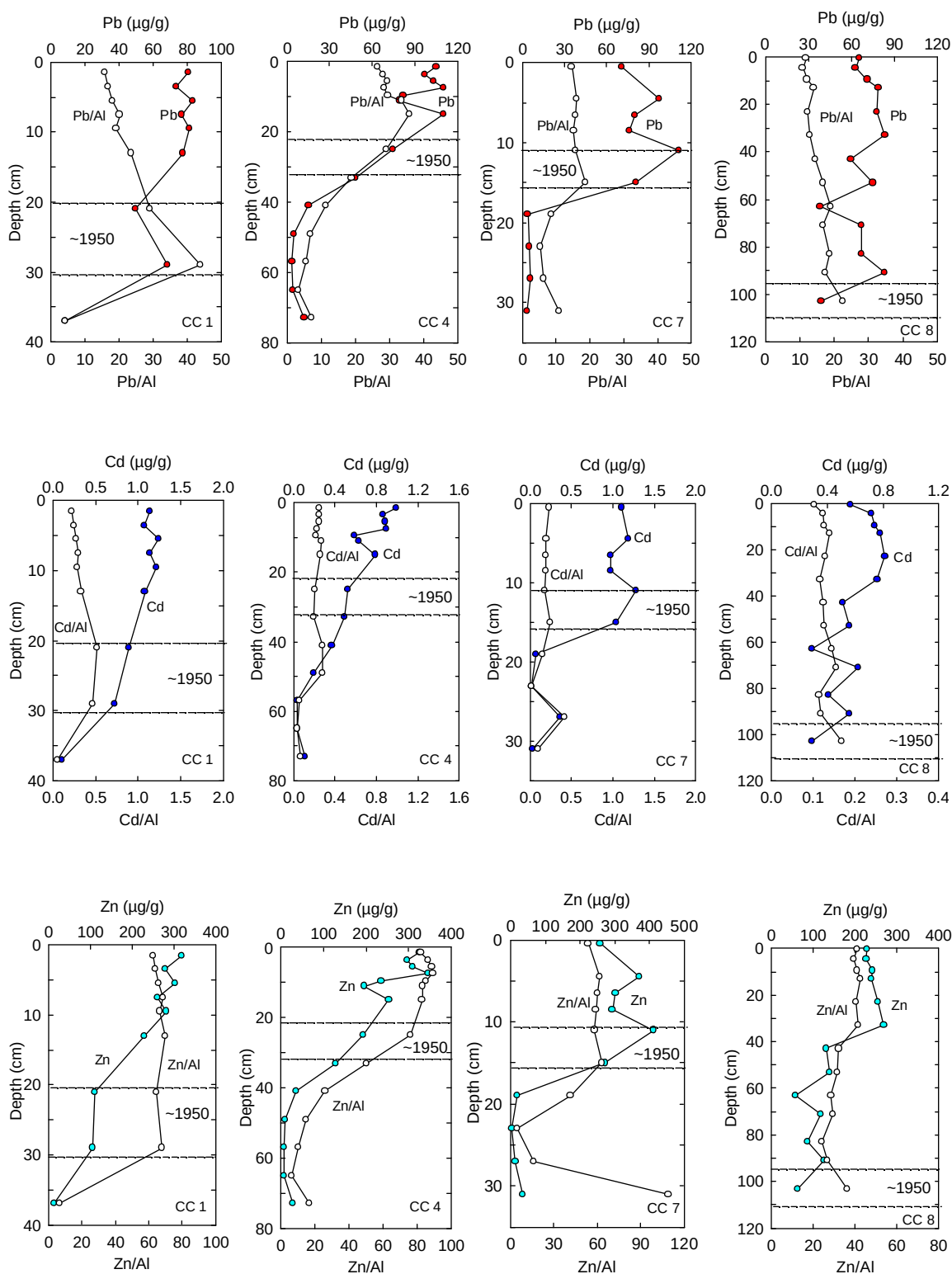


Figure 22. Vertical profiles for concentrations of Pb, Pb/Al, Cd, Cd/Al, Zn and Zn/Al in sediment cores from stations 1, 4, 7 and 8 in Crane Creek. Shaded areas show estimated range in depths that correspond to ~1950 based on results of age-dating.

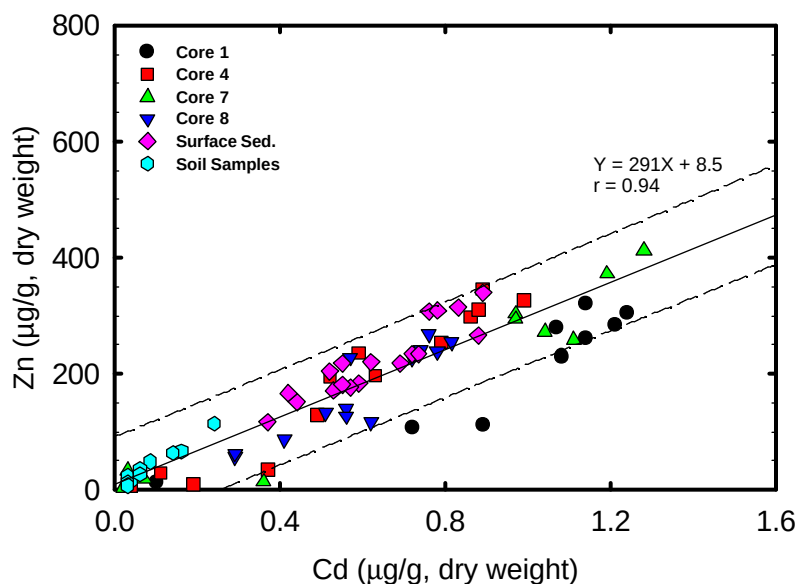


Figure 23. Concentrations of Cd versus Zn for soils and bottom sediments from the study area. Linear regression with 95% prediction interval was constructed using sediment data. Lines for Effects Range Median (ERM) and Effects Range Low (ERL) are from Long et al. (1995).

Concentrations of Cu are two to ten times greater than creek sediments than natural levels. None of the Cu values exceed the ERM. The ERL is under evaluation because it is close to levels found in average continental crust and normal marine sediments. The highest concentrations of Cu were found in suspended sediments, surface sediments and sediment cores from the Harbor Basin (Figure 24). This observation is consistent with a primary source for Cu from anti-fouling paints that have leached from boat hulls (Trefry et al., 1983). In contrast, anthropogenic inputs of Cd, Zn and Pb were ubiquitous. However, as observed for these other four metals, concentrations of Cu are elevated in sediments that are typically <50 years old (Figure 25). No clear shifts in Cu concentrations or, more importantly, the Cu/Al ratios were observed during the past 50 years.

Concentrations of Ni seem to be within expected, background levels except for a layer of sediment between 10 and 30 cm in core 4 from the STP Basin and a few samples from core 1 (Figures 24 and 25). These are the same cores that were notably enriched with Ag and Hg (Figures 18 and 19). The few samples from cores 1 and 4 with elevated levels of Ni are enriched over natural levels by about 25-50%, with one sample containing about double background levels (Figure 24). The vertical profiles for the Ni/Al ratios in sediments from cores 7 and 8 (Figure 25) are uniform and suggest that Ni levels in these sediments have been at natural levels for many decades. In contrast, the Ni/Al ratios for core 4 are 2-4 times greater than in the other cores in support of the anomalous inputs to a portion of the STP Basin.

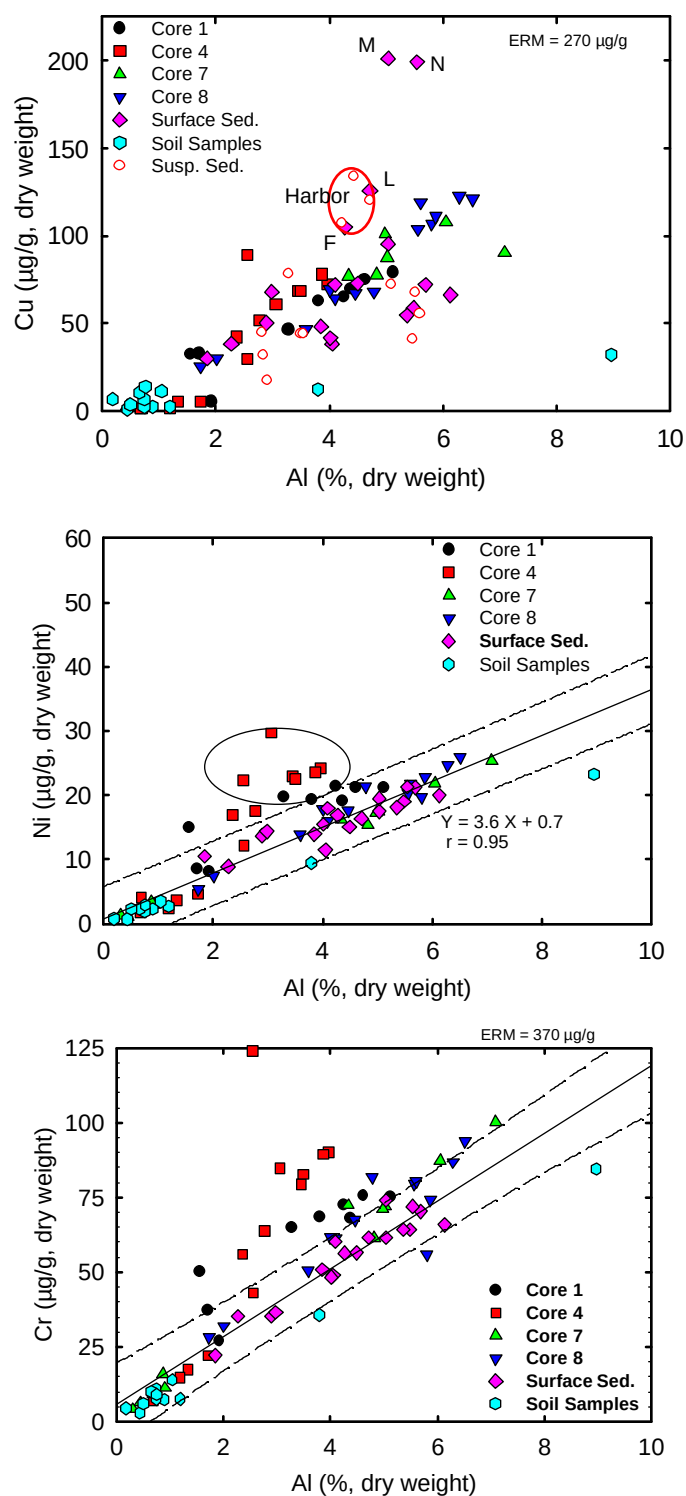


Figure 24. Concentrations of Al versus (a) Cu, (b) Ni and (c) Cr for soils, suspended sediments (Cu only) and bottom sediments from the study area. Linear regressions with 95% prediction intervals were constructed using sediment data. Data for Effects Range Median (ERM) are from Long et al. (1995).

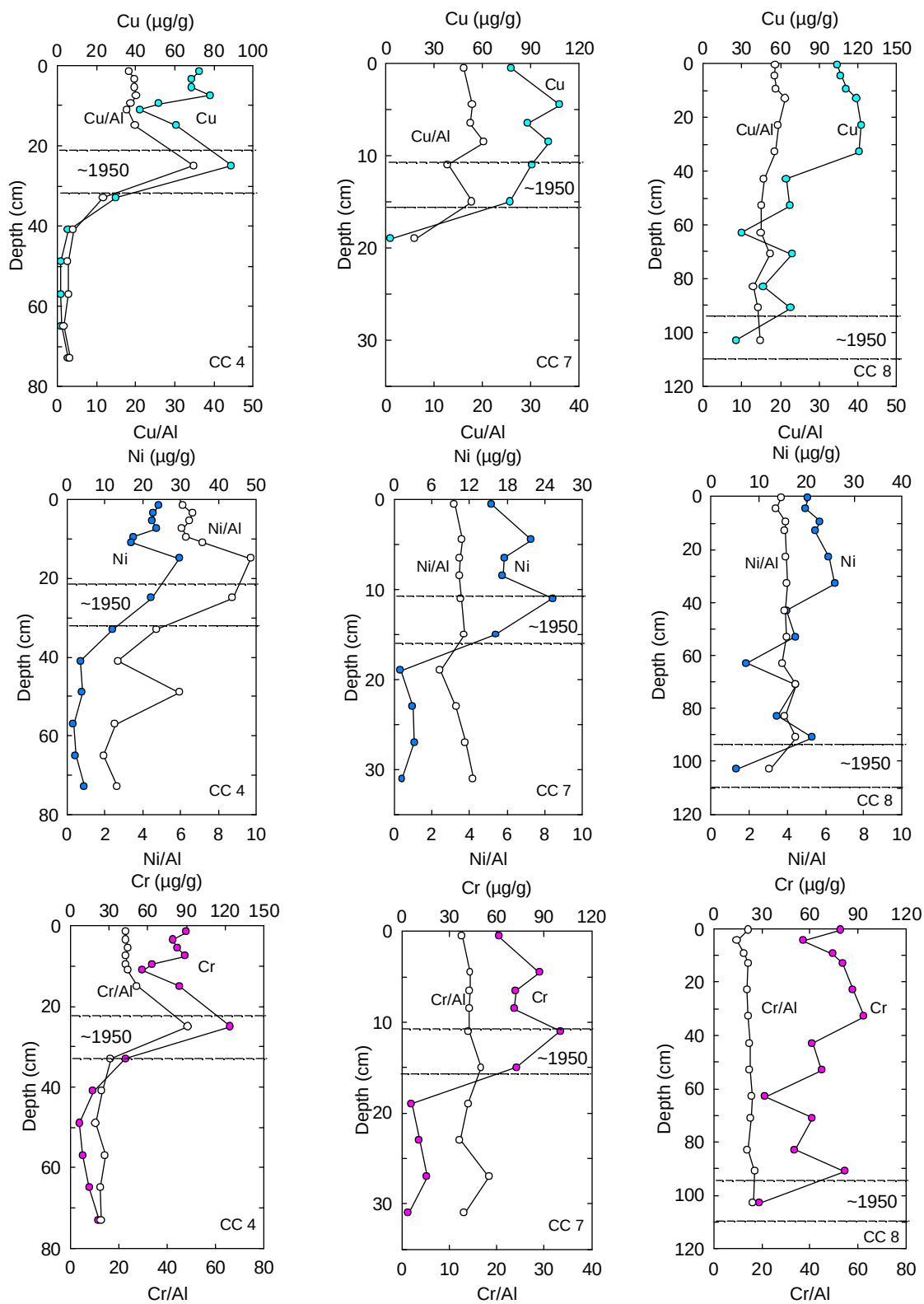


Figure 25. Vertical profiles for concentrations of Cu, Cu/Al, Ni, Ni/Al, Cr and Cr/Al in sediment cores from stations 4, 7 and 8 in Crane Creek. Shaded areas show estimated range in depths that correspond to ~1950 based on results of age-dating.

Concentrations of Cr, like Ni, seem to be within expected, background levels except for samples from cores 1 and 4 from the STP Basin (Figures 24 and 25). The few samples from cores 1 and 4 with elevated levels of Cr are enriched over natural levels by about 20-60%, with one sample containing more than double background levels (Figure 24; the sample with the highest level of Cr was not the same sample that contained the highest level of Ni). The vertical profiles for the Cr/Al ratios in sediments from cores 7 and 8 (Figure 25) show that values are uniform and suggest that, like Ni, Cr levels in these sediments have been at natural levels for many decades. The Cr/Al ratios for a few samples from core 4 are more than 2 times greater than in the other cores; however, the extent of thickness of this anomaly is slightly less than observed in core 4 for Ni. Overall, the sediments are not contaminated with Cr or Ni, excluding the exceptions described above.

In addition to the historical record provided by metal data from the sediment cores, we also have a comparison of metal concentrations in surface sediments collected from three locations (701, 702 and 703; map in Figure 13, page 32) during 1992 and 2003 (Table 8). Sediments from the two stations located outside the creek in the Indian River Lagoon were very different between years with more sandy, lower Al-containing sediment at station 701 during 2003 than 1992 and vice versa for station 702 (Table 8). Useful comparisons of metal concentrations between years at these sites require use of metal/Al ratios. From a metal/Al perspective, differences between years at the same site are small; however, no dredging was carried out in the areas of stations 701 and 702.

At station 703 in the Harbor Basin of Crane Creek, sediments collected during 1992 and 2003 were more similar with respect to texture and Al content (Table 8 and Figure 26). Concentrations of Ag, As, Cd, Cr, Hg, Ni and V and their metal/Al in sediment from station 703 during both years also did not differ by more than 10-20%. In contrast, concentrations of Cu and Pb in sediments collected during 2003 were about double values found during 1992. Concentrations of Zn in the 2003 sediment from station 703 were about 50% higher than in 1992. We have no simple explanation for this apparent enrichment in Cu, Pb and Zn between years. Concentrations of these three metals in the 2003 samples from station 703 are within the range of values found for other samples from the throughout the creek in 2003. Thus, overall, we can conclude that metal levels in creek sediments collected during 2003 are not significantly lower or higher than in 1992. However, sediments collected during 2003 and 1992 from station 703 are clearly contaminated with Cu, Pb and Zn at levels that generally exceed the ERL and the State of Florida guidelines for metals in sediments as described in the next section of this report.

Table 8. Concentrations of metals and total organic carbon (TOC) at stations 701,702 and 703 from 2002 and 1992.

Location	Al (%)	TOC (%)	Ag (µg/g)	As (µg/g)	Cd (µg/g)	Cr (µg/g)	Cu (µg/g)	Hg (µg/g)	Ni (µg/g)	Pb (µg/g)	V (µg/g)	Zn (µg/g)
Station 701 (1992)	1.07		0.10	2.1	0.01	12	5	0.02	3	2	13	20
Station 701 (2003)	0.14	<0.2	0.01	0.5	0.01	3	<1	0.006	0.4	1.2	<3	5
Station 702 (1992)	2.34		0.18	4.6	0.13	26	15	0.06	5	7	31	49
Station 702 (2003)	5.82	6.4	0.55	8.4	0.54	82	54	0.17	21	21	85	179
Station 703 (1992)	4.73		0.75	9.8	0.75	64	66	0.19	15	37	65	169
Station 703 (2003)	5.33	6.3	1.1	8.9	0.88	75	123	0.23	20	81	79	261

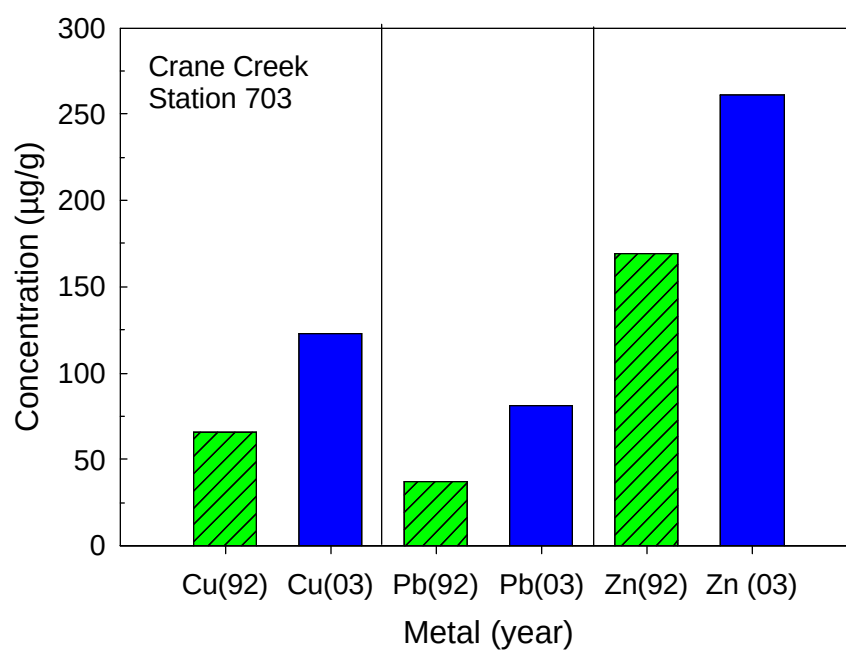
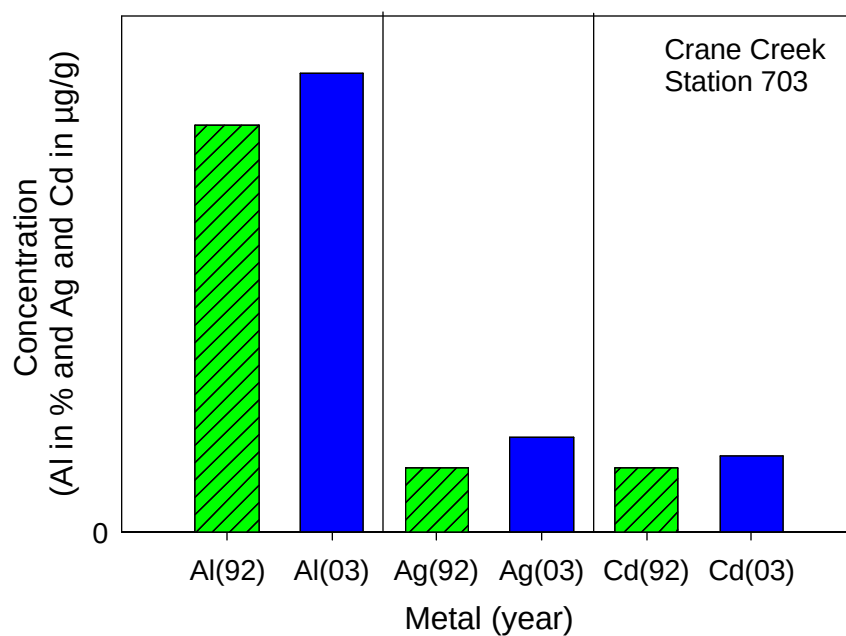


Figure 26. Concentrations of selected metals in sediments collected from station 703 in Crane Creek during 1992 and 2003.

Florida Sediment Quality Criteria

The State of Florida has established guidelines for assessing metal contamination in estuarine sediments using metal/Al relationships for natural sediments (Schropp et al., 1990). Metal concentrations for natural estuarine sediments from Florida were plotted versus Al and a linear regression and 95% prediction interval were constructed. As in the plots shown earlier in this report, when metal concentrations plot above the upper prediction interval, the sediments are considered to be contaminated with that metal.

Plots of As, Cd, Cr, Cu, Pb and Zn versus Al are presented here for sediments and soils from the Crane Creek study (Figures 27-29). All concentrations of As (Figure 27) and all except one value for Cr (Figure 28) were within the State of Florida Guidelines. Many samples from cores 1, 4 and 7 contained levels of Cd that plot above the upper prediction interval on Figure 27 and are thus significantly enriched relative natural sediments in Florida. As previously discussed, only three of those Cd concentrations were greater than the ERL and adverse biological effects for sediment organism would rarely be expected based only on Cd.

Most sediment samples, but no soil samples, had Cu concentrations that plotted above the upper prediction interval on the Cu/Al graph (Figure 28). The only sediment samples with Cu levels that plotted within the 95% prediction interval were from deep in sediment cores from stations 1, 4 and 7. Copper contamination has been a long-standing problem in many Florida creeks, including Crane Creek (Trefry et al., 1983; Trocine and Trefry, 1996). Data for Pb and Zn show a similar distribution on the metal/Al graphs as observed for Cu (Figure 29) with most sediment samples having values that plot above the upper prediction interval. Sediments contaminated with Pb and Zn were ubiquitous in the creek.

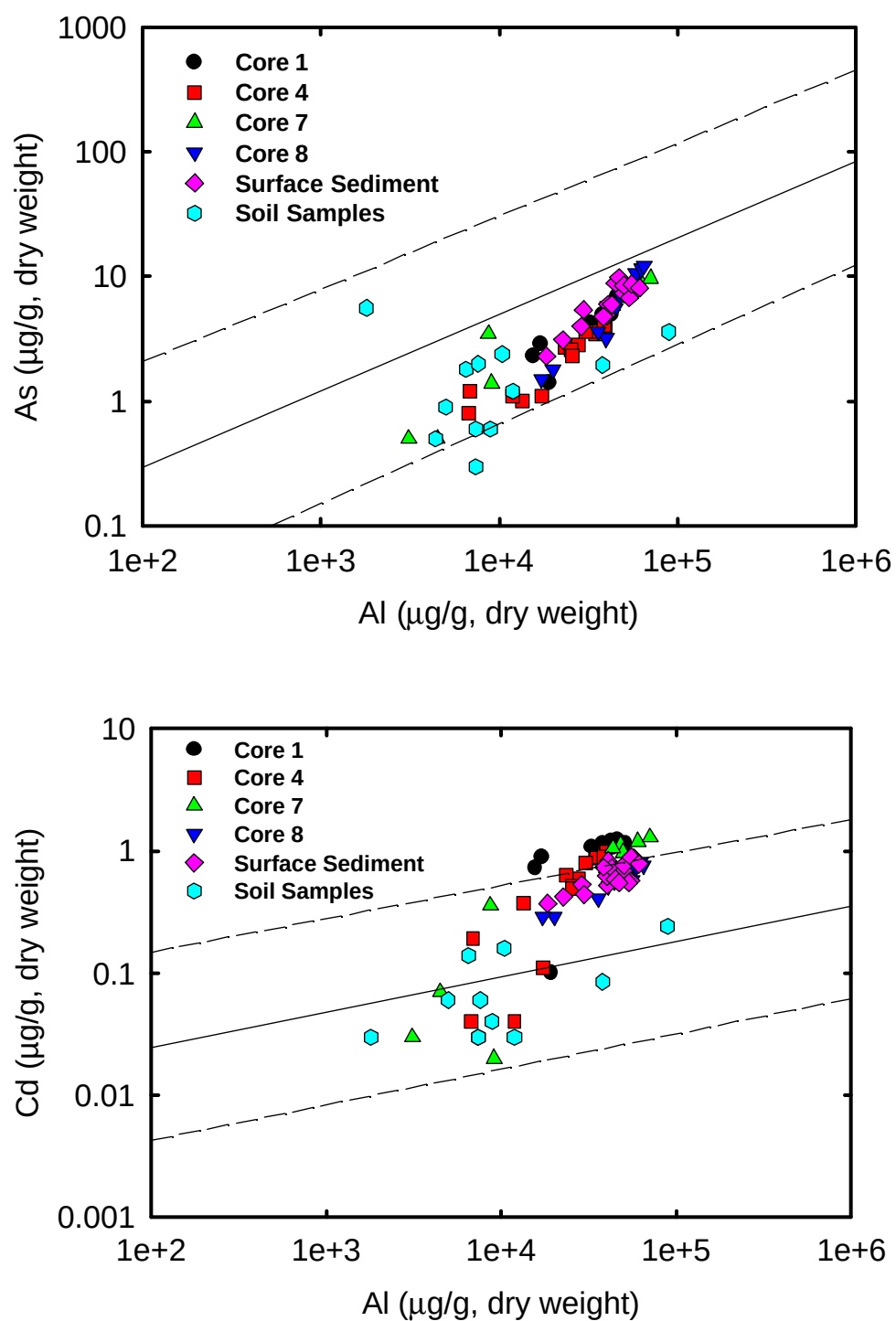


Figure 27. Concentrations of Al versus (a) As and (b) Cd for bottom sediments and soils from Crane Creek. Regression line with 95% prediction interval is from Shropp et al. (1990) with points that plot above the upper prediction interval considered to have an anthropogenic input of the metal.

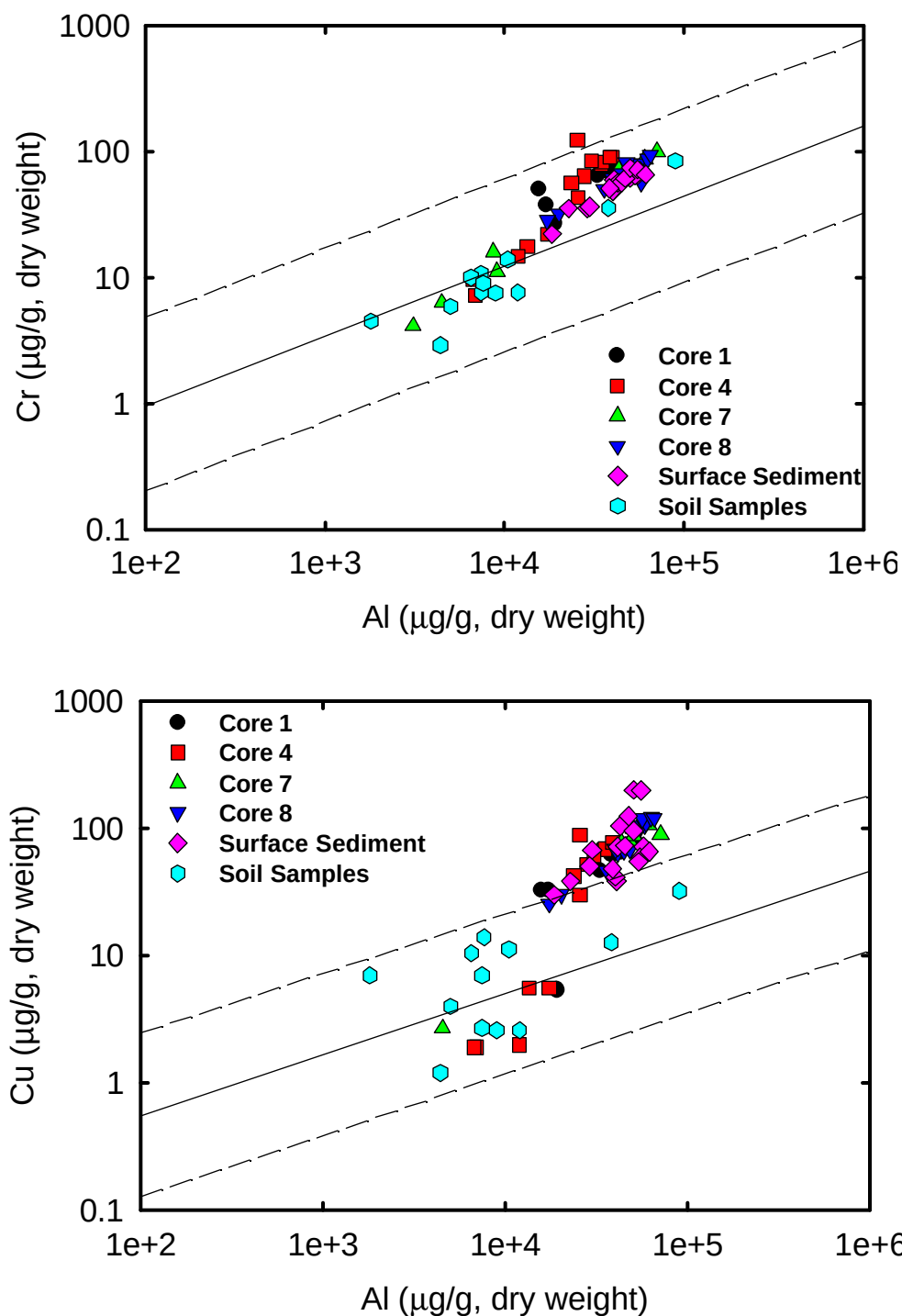


Figure 28. Concentrations of Al versus (a) Cr and (b) Cu for bottom sediments and soils from Crane Creek. Regression line with 95% prediction interval is from Shropp et al. (1990) with points that plot above the upper prediction interval considered to have an anthropogenic input of the metal.

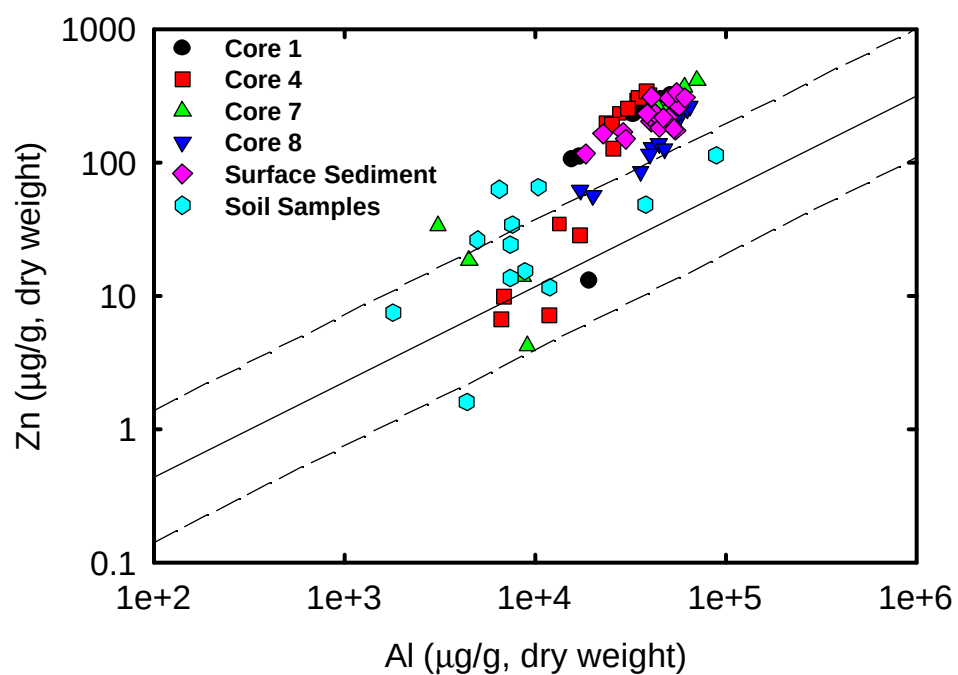
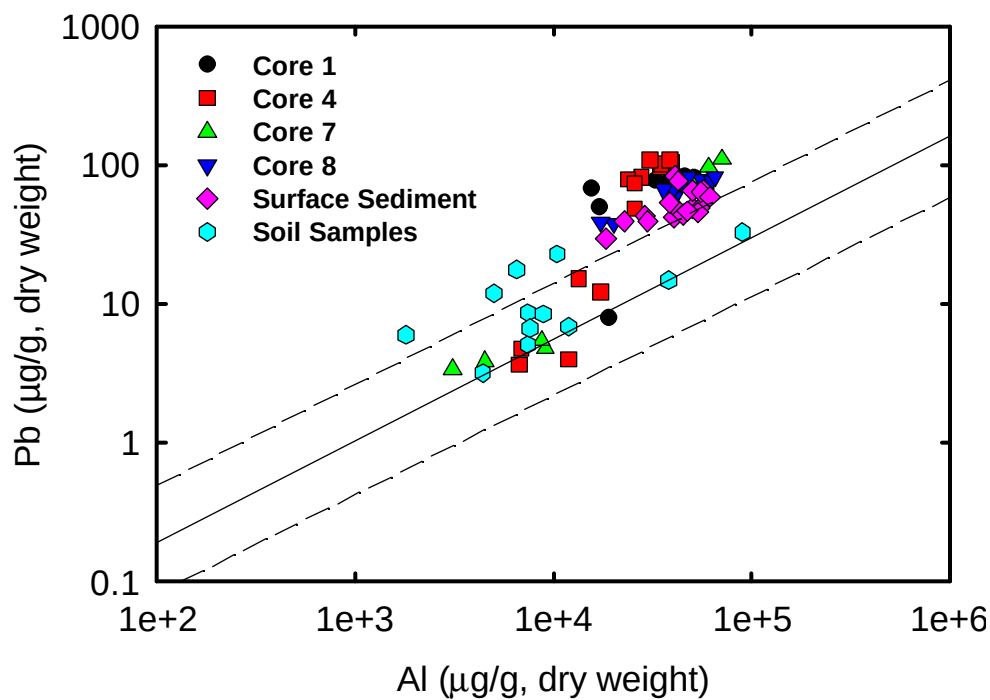


Figure 29. Concentrations of Al versus (a) Pb and (b) Zn for bottom sediments and soils from Crane Creek. Regression line with 95% prediction interval is from Shropp et al. (1990) with points that plot above the upper prediction interval considered to have an anthropogenic input of the metal.

Overview of Sediment Trapping Efficiency

The data for muck depths and sedimentation rates determined during this study can be used to estimate the rate of filling of Crane Creek with sediment and thus how long before dredging is again necessary. For the calculations used in this section of the report, the Mouth and Harbor Basins have been combined as one area. The areas of the three basins total 104,000 m² (Figure 30). The total amount of sediment removed from Crane Creek during dredging in 1998 is estimated at 60,000 m³ (Windsor, this study). The present-day volume of muck in Crane Creek is calculated to be about 82,000 m³ (Figure 31) with more than half of that volume in the Harbor + Mouth Basins.

The rate of accumulation of sediment in Crane Creek, based on sedimentation rates determined during this study (Figure 11, page 26), is 800 ± 300 m³/yr (Figure 32). This annual volume is more than likely an overestimate because we are reasonably certain that sediment has slumped from the perimeter to the center of the creek. Such slumping creates the anomalies in activities of excess ²¹⁰Pb previously discussed (e.g., Figure 6, page 20) and leads to thick layers such as observed at core station 6 in the Harbor Basin (Figure 10, page 25).

Assuming that the calculated filling rate of 800 m³/yr stays reasonably constant, an amount of sediment equivalent to the 60,000 m³ of sediment that were dredged would be deposited in ~75 years. Based on the standard deviation for the filling rate of ± 300 m³/yr, the calculated range of filling times is from 55 to 120 years. These estimates support the conclusion of Windsor (this study) using annual inputs of suspended sediments that >50 years will pass before dredging needs to be carried out. Windsor (this study) made the conclusion of >50 years by assuming that his calculations may have underestimated sediment inputs by as much as a factor of three.

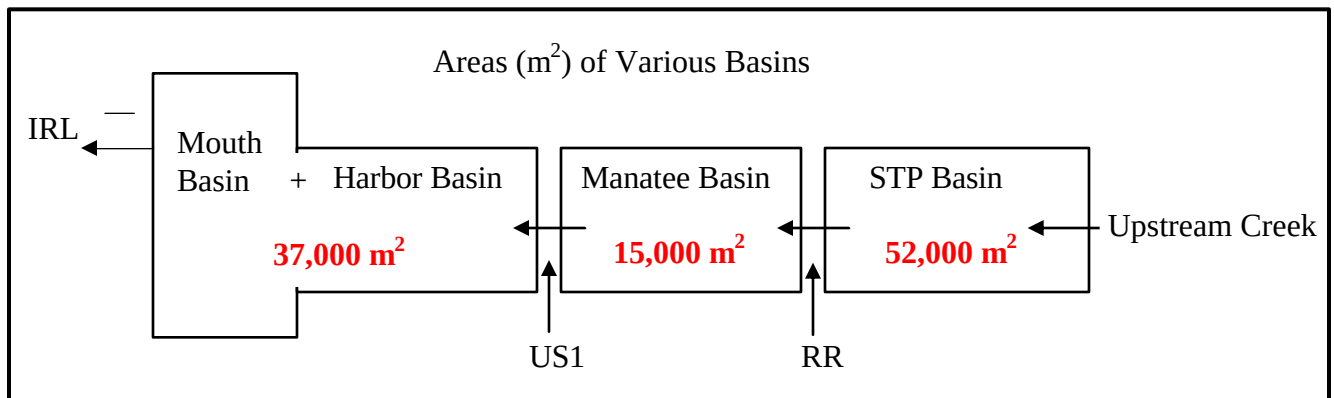


Figure 30. Areas in square meters for each of three basins in Crane Creek (RR = railroad; STP = Sewage Treatment Plant, IRL = Indian River Lagoon; US1 = highway US 1). The Mouth and Harbor Basins have been combined for calculations of sediment trapping in the creek.

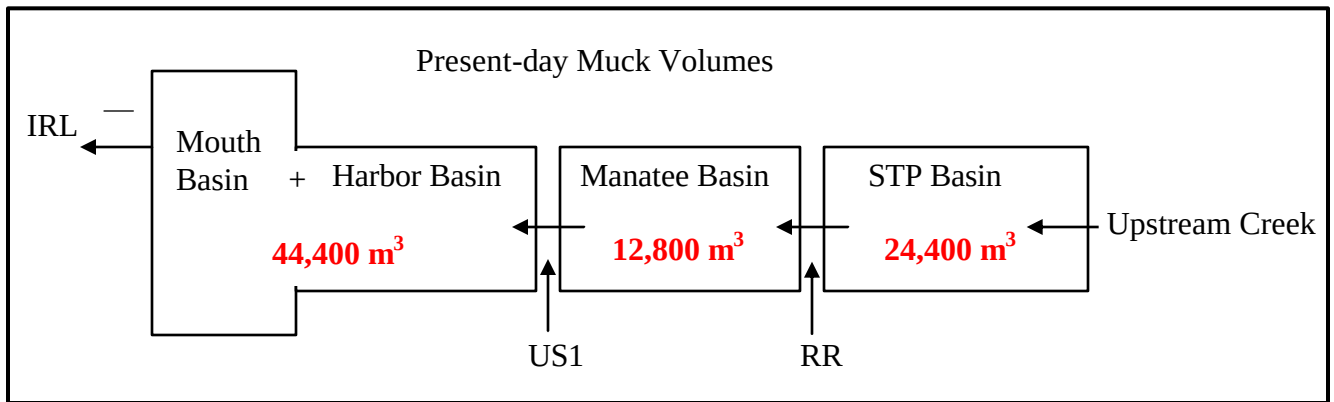


Figure 31. Volume of muck sediment during 2002 in cubic meters for each of three basins in Crane Creek (RR = railroad; STP = Sewage Treatment Plant, IRL = Indian River Lagoon; US1 = highway US 1). The Mouth and Harbor Basins have been combined for calculations of sediment trapping in the creek. The muck depths are listed in Figure 4 (page 17) and the areas of each basin are listed in Figure 30.

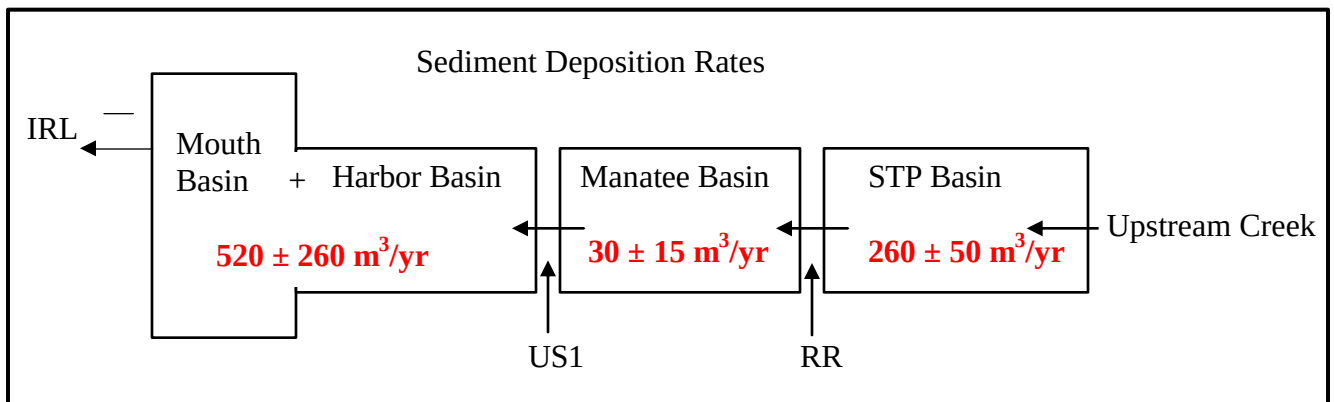


Figure 32. Annual volume of sediment in cubic meters deposited in each of three basins of Crane Creek (RR = railroad; STP = Sewage Treatment Plant, IRL = Indian River Lagoon; US1 = highway US 1). The Mouth and Harbor Basins have been combined for calculations of sediment trapping in the creek. The sedimentation rates are listed in Figure 11 (page 26) and the areas of each basin are listed in Figure 30.

Conclusions

The measured thicknesses of layers of fine-grained, organic-rich (muck) sediment overlying base sand in Crane Creek were 77 ± 82 cm during 2002 relative to 112 ± 81 cm in 1998, shortly after dredging. The results for 1998 are not significantly different from the 2002 results; however the 1998 data show that considerable amounts of muck sediment remained in Crane Creek following dredging from January 27 to April 2, 1998. The data also suggest show some shifting of sediment toward the Harbor Basin may have occurred and that there has not been a large influx of sediment during the four-year period between surveys.

Sedimentation rates for Crane Creek were determined using the activities of excess ^{210}Pb and ^{137}Cs . The sedimentation rates are as follows: (1) 0.5 ± 0.1 cm/yr west of the railroad bridge in the STP Basin, (2) 0.2 ± 0.1 cm/yr in the Manatee Basin between the railroad bridge and US 1, and (3) 1.4 ± 0.7 cm/yr in the Harbor Basin. The overall mean for the six cores was 0.7 ± 0.6 cm/yr ($n=12$, two rates per core). These rates may be an over estimate of actual values due to inputs from slumping and distortion of vertical profiles for radionuclides from sediment mixing.

The total amount of sediment removed from Crane Creek during dredging in 1998 was $\sim 60,000 \text{ m}^3$. The present-day (post-dredging) volume of muck in Crane Creek is estimated to be $\sim 82,000 \text{ m}^3$, with more than half of that volume in the Harbor + Mouth Basins. Based on sedimentation rates determined during this study, the annual volume of sediment deposited in Crane Creek is $800 \pm 300 \text{ m}^3/\text{yr}$. Assuming that the calculated filling rate of $800 \text{ m}^3/\text{yr}$ stays reasonably constant, an amount of sediment equivalent to the $60,000 \text{ m}^3$ of sediment that were dredged would be deposited in ~ 75 years. Based on the standard deviation for the filling rate of $\pm 300 \text{ m}^3/\text{yr}$, the calculated range of filling times is from 55 to 120 years.

To address questions related to sediment sources, sediment quality and sediment history, the data for major elements and trace metals in soils, suspended sediments, surface sediments, and sediment cores were used collectively. No clear differences in concentrations of Fe, K or Mg versus Al were observed and thus these elements did not provide a straightforward tracer of sources of sediments to the creek was identified. Aluminum provides a useful frame of reference because Al is resistant to chemical weathering in soils and sediments and it is a good indicator of the aluminosilicate (clay) fraction of the sample. The uniform As/Al and V/Al relationships show no detectable inputs of contaminant As or V; however, they do not easily facilitate identification of distinct natural sources for these metals within the drainage basin.

Concentrations of silver (Ag) mercury (Hg) are 50 to more than 100 times above natural levels in sediments from Crane Creek. The core data suggest that peak inputs of Ag and Hg were 30-60 years ago. When sediment concentrations of Ag are plotted versus Hg, a strong linear fit ($r = 0.92$) is observed. This trend for Hg versus Ag supports a common source or source area for both metals such as dental waste and/or photographic/art wastes.

Fourteen samples had Ag levels greater than the Effects Range Median (ERM) guideline and seven samples had Hg levels above the ERM. At such levels, adverse effects to sediment biota are predicted to occur frequently. Most of the remaining samples contained Ag and Hg at levels that exceeded the Effects Range Low (ERL), indicating that adverse biological effects for sediment organisms would be occasional.

Concentrations of Pb were elevated over natural levels by two to six-fold at many sites throughout the creek with the highest values in suspended sediment from the Harbor Basin. None of the Pb values exceeded the ERM; however, more than half the Pb concentrations exceeded the ERL. Overall, the spatial distribution of anthropogenic Pb throughout the creek is rather ubiquitous. Data from sediment cores show that the onset of Pb contamination dates back about 50 years. All concentrations of Cd were below the ERM and only three values exceeded the ERL. In contrast, many of the Zn concentrations were greater than the ERL with none greater than the ERM.

Concentrations of Cu in sediments from Crane Creek are typically two to ten times greater than in natural sediments from the study area. None of the Cu values exceed the ERM. The highest concentrations of Cu were found in suspended sediments, surface sediments and sediment cores from the Harbor Basin. This is consistent with a primary source for Cu from anti-fouling paints that have leached from boat hulls. No clear shifts in Cu concentrations or, more importantly, the Cu/Al ratios were observed during the past 50 years. Concentrations of Ni and Cr seem to be within expected, background levels except for a few samples from cores collected from the STP Basin where levels are elevated over natural levels by about 20-60%.

At one station (#703) in the Harbor Basin of Crane Creek, sediments were collected during 1992 and 2003. Overall, we conclude that metal levels in creek sediments collected during 2003 are not significantly different than in 1992. All concentrations of As and all except one value for Cr were within the State of Florida Guidelines established for sediments. Many samples contained levels of Cd that were significantly enriched relative to natural sediments in Florida. Most sediment samples, but no soil samples, had Cu concentrations that exceeded the state guidelines. Likewise, sediments contaminated with Pb and Zn were ubiquitous in the creek.

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