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SEDIMENT CHARACTERISTICS AND TOXIC SUBSTANCES IN THE ST. LUCIE ESTUARY, FLORIDA

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SEDIMENT CHARACTERISTICS AND TOXIC SUBSTANCES IN THE ST. LUCIE ESTUARY, FLORIDA

by
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July 1988

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ABSTRACT

Physical characteristics of submerged sediments were determined for the St. Lucie Estuary watershed and related to concentrations of toxic substances. Sand substrates located along shorelines and in the St. Lucie Canal typically contained minimum levels of organic material, pesticides, PCBs, and heavy metals. Concentrations of heavy metals and organics, however, proportionately increased with the quantity of silt and clay sized particles. Mud substrates (all silt and clay) in deep areas with minimal water movement normally contained high levels of organic matter. Exceptionally high levels of organics and relatively elevated concentrations of copper occurred in the central portion of the north fork of the estuary. Mud sediments in Manatee Pocket contained high concentrations of copper, chlordane, and PCBs probably attributable to the presence of anti-fouling paints on boats, residential termite control efforts in the watershed, and spillage of hydraulic lubricants, plasticizers and paints, respectively. Copper and DDT levels in sediments from C-24 and C-25 were associated with agricultural activities. If the sediments are transported to the north fork or the Indian River Lagoon they may degrade the environmental quality there.

KEY WORDS: St. Lucie Estuary, Manatee Pocket, Sediments, Pesticides, Heavy Metals.

EXECUTIVE SUMMARY

Previous studies indicate biota of the St. Lucie Estuary are stressed by adverse water quality and sedimentation. Rates of sedimentation are 1 to 2 cm/yr in much of the estuary. Pesticide residues and heavy metals originating in the watershed tend to accumulate in sediments and may become part of the food chain. The purpose of this study was to: (1) characterize sediments within the estuary and tributary canals on the basis of particle size and organic content; (2) survey the concentrations and distribution of pesticides, heavy metals, and polychlorinated biphenyls (PCBs); and (3) determine the relationships between sediment composition and levels of toxic substances.

Sediment composition is influenced by hydrodynamics. Sand substrates, with minimal organic content, occurred along the shallow shoreline of the estuary and in the St. Lucie Canal (C-44) due to frequent exposure to wave turbulence or rapid currents. Substrates composed of mud and moderate quantities of sand (transitional sediments) were present in low energy environments subjected to transient high energy events. Estuarine portions of C-23, C-24, C-44, and the Manatee Pocket contained transitional sediments. Mud substrates were associated with low energy environments such as deep dredged areas and deep central locations of the estuary. These mud sediments typically contained extremely high concentrations of organic materials when compared to other similar estuarine systems.

Increasing concentrations of most heavy metals occurred as the amount silt/clay sized particles increased. Therefore, low energy areas with mud substrates generally contained the highest concentrations of most metals. The distributions of metals in relation to sediment composition indicate that arsenic, cadmium, copper, mercury, nickel, and zinc may have originated from agricultural areas; whereas cadmium, copper, mercury, lead and zinc were associated with marinas in the Manatee Pocket.

Exclusively, copper occurred at concentrations worthy of concern. The extremely high level (229 mg/kg) in Manatee Pocket was nearly twice the maximum value reported from eight other estuarine sediment studies. The probable source of this copper is anti-fouling paints. Relatively high concentrations of copper in canal C-24 may have resulted from the common practice of using copper as a trace metal for citrus.

Although average concentrations of chlordane, DDT, and PCB were similiar to those detected in other south Florida sediment studies, several locations had high enough values to be noteworthy. Chlordane is primarily used to control termites and the highest concentrations were detected at the mouth of Bessey Creek and in marina sediments at Manatee Pocket. Marina sediments also contained extremely high levels of PCB which can probably be attributed to spillage of hydraulic lubricants, plasticizers, and paints. Mud sediments upstream of S-49 and S-50 had the greatest concentrations of DDT and are associated with agricultural activities in the C-24 and C-25 drainage basins. Although the Environmental Protection Agency banned DDT in 1973, a commonly used pesticide in the citrus industry (dicofol) contains 10% DDT. A reduction from 10% to 0.1% DDT in dicofol was required by Federal agencies by July 1987.

In summary, pesticide and heavy metal concentrations are highest in mud sediments found in relatively deep, low energy benthic environments. Marina sediments in the Manatee Pocket are contaminated with copper, chlordane, and PCB while C-24 sediments can contribute potentially harmful quantities of DDT and copper to the St. Lucie Estuary.

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INTRODUCTION

The St. Lucie Estuary (SLE) is a major coastal resource of east central Florida that supports a variety of commercial and recreational activities and provides an important habitat for many important aquatic organisms. This estuary is located at the east end of the Okeechobee Waterway which crosses south central Florida and acts as a navigational channel and an outlet for discharges of excess fresh water from Lake Okeechobee.

The biological integrity of the SLE has been an issue of concern for many years. Large fresh water discharges from Lake Okeechobee into the estuary cause rapid salinity changes throughout the area and have both short-term and long-term adverse impacts on the biological communities. Sand and silt transported to the estuary during fresh water discharges and surface water runoff create navigational problems and can produce unfavorable environmental conditions, especially in benthic habitats.

Results of biological studies indicate that benthic communities in the SLE are stressed by factors such as adverse water quality and sedimentation (Haunert and Startzman, 1980, 1985). Fine particle sediments are accumulating at a rate of 1 to 2 cm/yr in much of this estuary (Davis and Schrader, 1984; Schrader, 1984). Moreover, pesticide residues and heavy metals that originate in the watershed are found in association with fine sediment particles that tend to settle in deep, low energy zones. These toxic substances may accumulate in benthic dwelling organisms and become part of the food chain. Significant amounts of DDT and chlordane residues are present in SLE sediments (Bearden, 1972; Wang et. al., 1980; Pfeuffer, 1985) and relatively high concentrations of copper and zinc are found in oysters taken from the inner SLE (Davis, 1985).

Although sediments and toxic materials are potential problems in the SLE, a synoptic survey of these parameters has not been undertaken. This study complements the sedimentation analysis by Davis and Schrader (1984) and Schrader (1984) and was designed to: (1) characterize sediment environments within the estuary and tributary canals on the basis of particle size and organic content; (2) survey the concentrations and distribution of toxic substances such as heavy metals, pesticides and polychlorinated biphenyls (PCBs) in sediments; and (3) establish relationships between concentrations of toxic materials and sediment composition that would provide a basis for determining the origin and a means of comparing them with other estuaries.

DESCRIPTION OF THE STUDY AREA

The SLE watershed lies northeast of Lake Okeechobee and has a surface area of about 781 mi^2. The watershed is divided into five major drainage basins and several small basins (Figure 1). Land use in the three western basins (C-23, C-24, and C-44) is predominantly agricultural, with about 60% of the area devoted to citrus and improved pasture. The remainder of land is native and undeveloped. About 45% of the two eastern basins (North St. Lucie and Tidal St. Lucie) is devoted to agriculture, with much of the remainder in urban development. Natural surficial flow of water in all drainage basins has been extensively modified. Numerous secondary drainage systems flow into primary canals (C-23, C-24, and C-44) which provide rapid transport of water from cultivated areas to the estuary.

The SLE is divided into three main areas (Figure 2)*. The north fork is about four miles long and has a surface area of 4.5 mi^2. Depths in the central portion of the north fork reach 10 ft and increase to 20 ft at the confluence of the north and south forks. The south fork has about half the surface area of the north fork, and is relatively shallow except for an 8 ft navigation channel. This channel is part of the Okeechobee Waterway and is periodically dredged to maintain depth. Depths in the western section of the middle estuary gradually increase to 10 ft, whereas bottom slopes in the eastern section are greater. The middle estuary narrows to the south, where depths reach 26 ft at Hell Gate Point.

During ebb tide, water flows by Hell Gate Point into the Indian River Lagoon, where tidal currents in the St. Lucie Inlet mix estuarine waters with the Atlantic Ocean. Daily tides fluctuate about 3 ft near the ocean and diminish to about 2 ft in the inner estuary. Tidal currents are nominal throughout the estuary except at the confluence of the north and south forks and Hell Gate Point where ebb velocities may exceed 3 ft sec^{-1} near the surface (Morris, 1985). Considering tidal fluctuations and velocities, the SLE may be classified as a low energy, microtidal estuarine system (Walton, 1974).

*Detailed bathymetry can be found in: Morris, F.W., South Florida Water Management District Technical Publication #86-4.

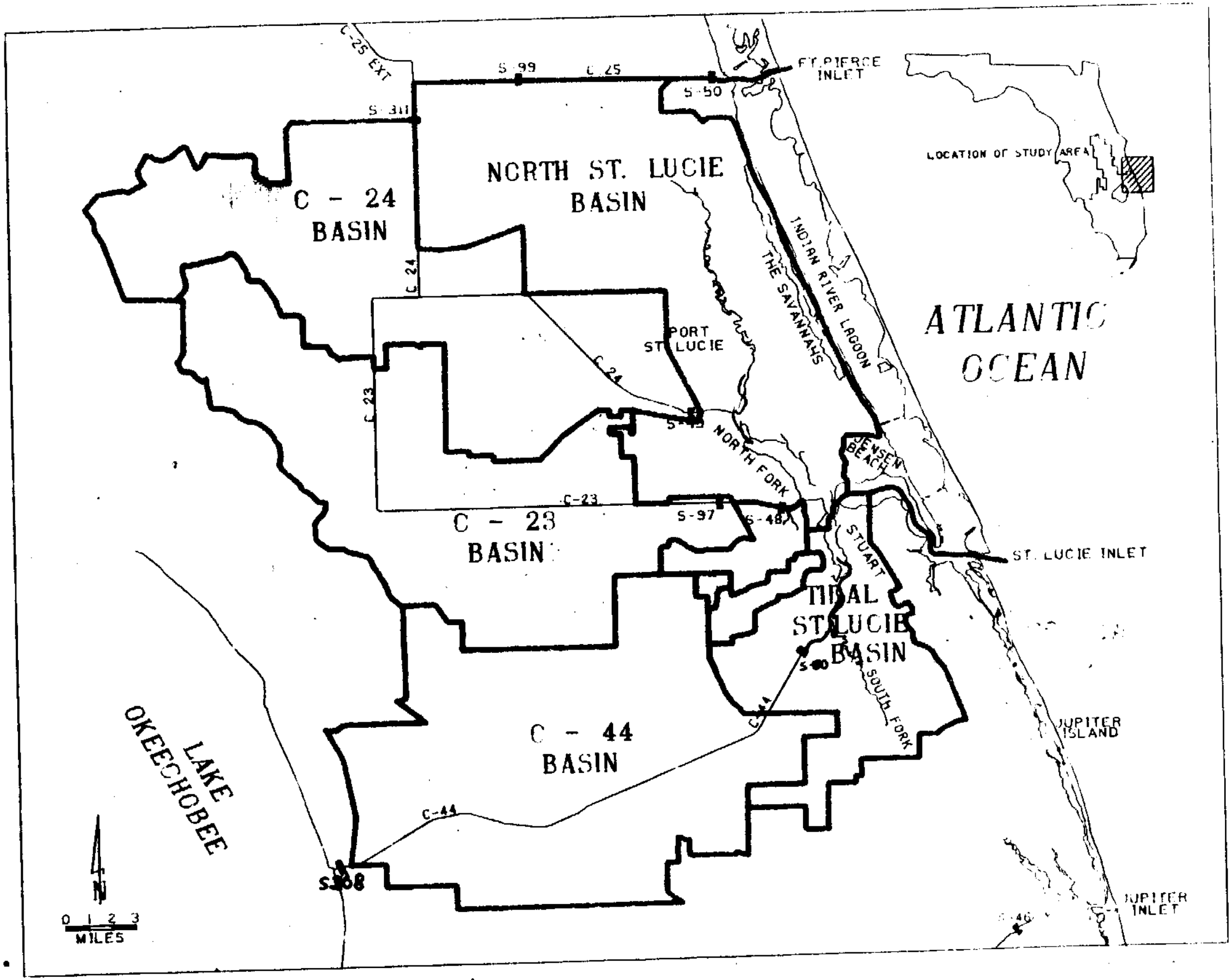

FIGURE 1. St. LUCIE ESTUARY WATERSHED

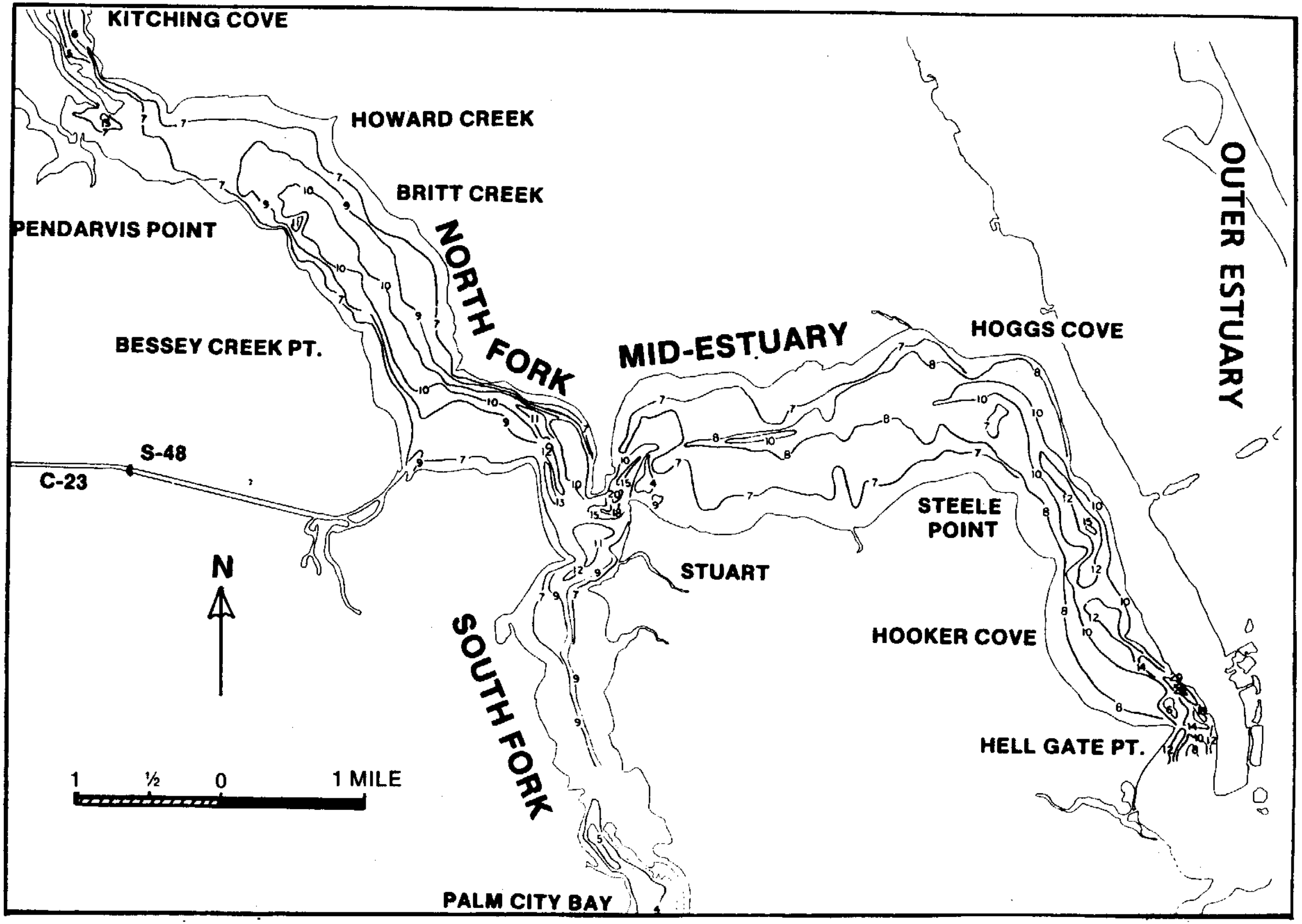

FIGURE 2. BATHYMETRY (in ft) OF THE ST. LUCIE ESTUARY

MATERIALS AND METHODS

Pilot Field Program

Several sediment sampling devices were evaluated for their effectiveness in obtaining representative samples. It was determined that silt and/or clay sized materials were best sampled using a modified coring device (Holz et al., 1972) and pipe extensions (Appendix A) while a ponar dredge proved reliable for sand substrates.

Preliminary sampling was conducted directly downstream of S-80 where toxic residues had been documented (Wang et al., 1980; Pfeuffer, 1985). After obtaining a sediment core sample, the surficial oxidized layer (about 0.1 in) of mud sediment was scraped off before retaining the top inch of the core for a subsample (Forstner and Salomons, 1980). A composite sample composed of approximately 15 cores was separated into three glass containers with Teflon cap liners. Samples were frozen and later analyzed for texture, organic content, trace metals, pesticides, and PCBs. Field collection and sample preservation techniques were verified and the coefficient of variation for laboratory methods was near 10% (Appendix B).

Full Scale Program

Three field trips were taken from January to May 1982 to collect 135 sediment samples from the SLE watershed. Twenty-nine samples were collected from fresh water agricultural canals (C-23, C-24, C-25, and C-44) and 106 samples were taken from tidewater transects and mid-channel locations (Figures 3 and 4).

An aliquot from each sample was analyzed for particle size distribution and percent organics, and the remaining sample was frozen. Once texture and organic content data were compiled, 27 samples containing high amounts of organic matter and silt/clay were selected for trace metal, pesticide, and PCB analyses (Figures 3 and 4). Concentrations of these substances were expected to be highest in sediments having these characteristics (Hassett et al., 1980; Karichoff, 1979). Four additional samples were selected from areas suspected of contamination (i.e., near sewage outfalls).

Laboratory Methods

Particle size analyses were performed with an aliquot of sample treated with 30% H_2O_2 solution to oxidize organic material (Skougstad et al., 1979). The remainder of the sample was rinsed with deionized water by centrifugation and wet sieved through a 0.0625 mm sieve. Material passing through this sieve (finer than 4 phi, Appendix C) was dispersed with sodium hexametaphosphate and mixed in a blender. The solution was then transferred to a one liter cylinder. Bouyoucos hydrometer readings were taken at specified time intervals which correspond to phi fractions 4 to 8 (Bouyoucos, 1926).

The coarse fraction was then dried and subjected to mechanical sieve analysis to fractionate into phi sizes -2 to 4 (Folk, 1974). To test the accuracy of this procedure, coarse sediment was resieved and comparisons were made between results.

Organic matter was determined as weight loss on ignition (LOI) at 550°C for 15 minutes (APHA, 1980).

Trace metal samples were dried and pulverized to a uniform powder and subsampled for digestion by atomic absorption (APHA, 1980).

For determination of pesticides and PCB's, a mechanical dispersion-extraction, acetonitrile method was employed. The acetonitrile extracts were transferred to hexane, subjected to desulfurization followed by florisil column cleanup. Concentration was determined by gas chromatography with electron capture detection. Duplicate analyses, spikes of samples and preparation of blanks insured accuracy (Wershaw et al., 1983).

Statistical Methods

Statistical parameters for bottom sediments include: mean phi, standard deviation, skewness and kurtosis, (Appendix D) and were derived using methods outlined by Folk (1974).

A computer mapping program, Synagraphic Mapping System (SYMAP), spatially illustrated the mean phi and percent organic material (LOI) in sediments by linear interpolation of measured values within tidal estuary boundaries (Dougenik and Sheehan, 1975).

Particle size distributions of 99 estuarine samples were grouped using a cluster analysis computer program (Pinkham and Pearson, 1976). Due to a program limitation, data from canal samples and the remaining seven estuarine locations were assigned to the most similar sediment distributions produced by the cluster analysis.

Stepwise multiple regression procedures determined correlations among mean phi, percent organic matter, trace metal and pesticide concentrations.

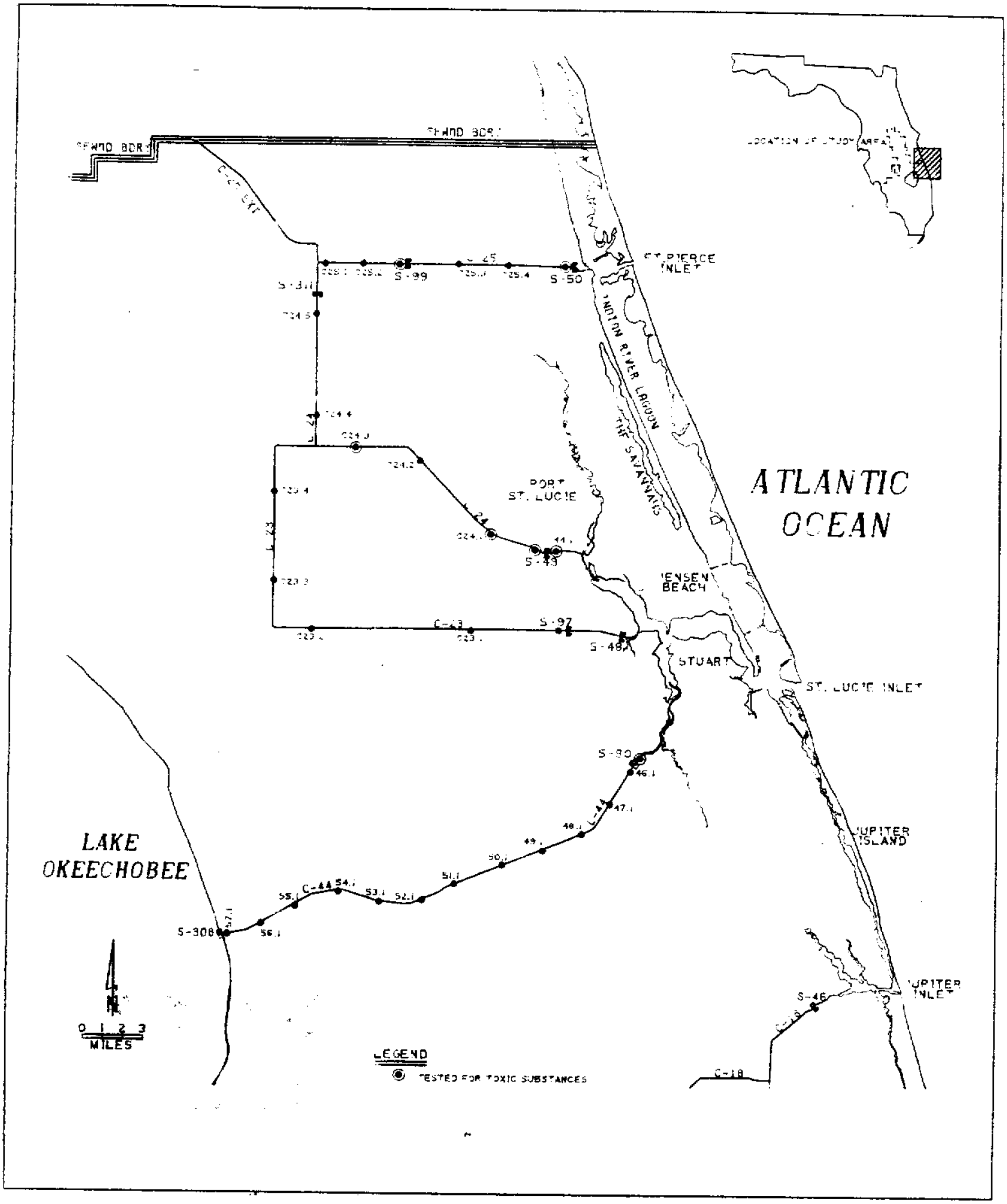

FIGURE 3. SEDIMENT SAMPLING SITES IN CANALS OF THE ST. LUCIE ESTUARY WATERSHED

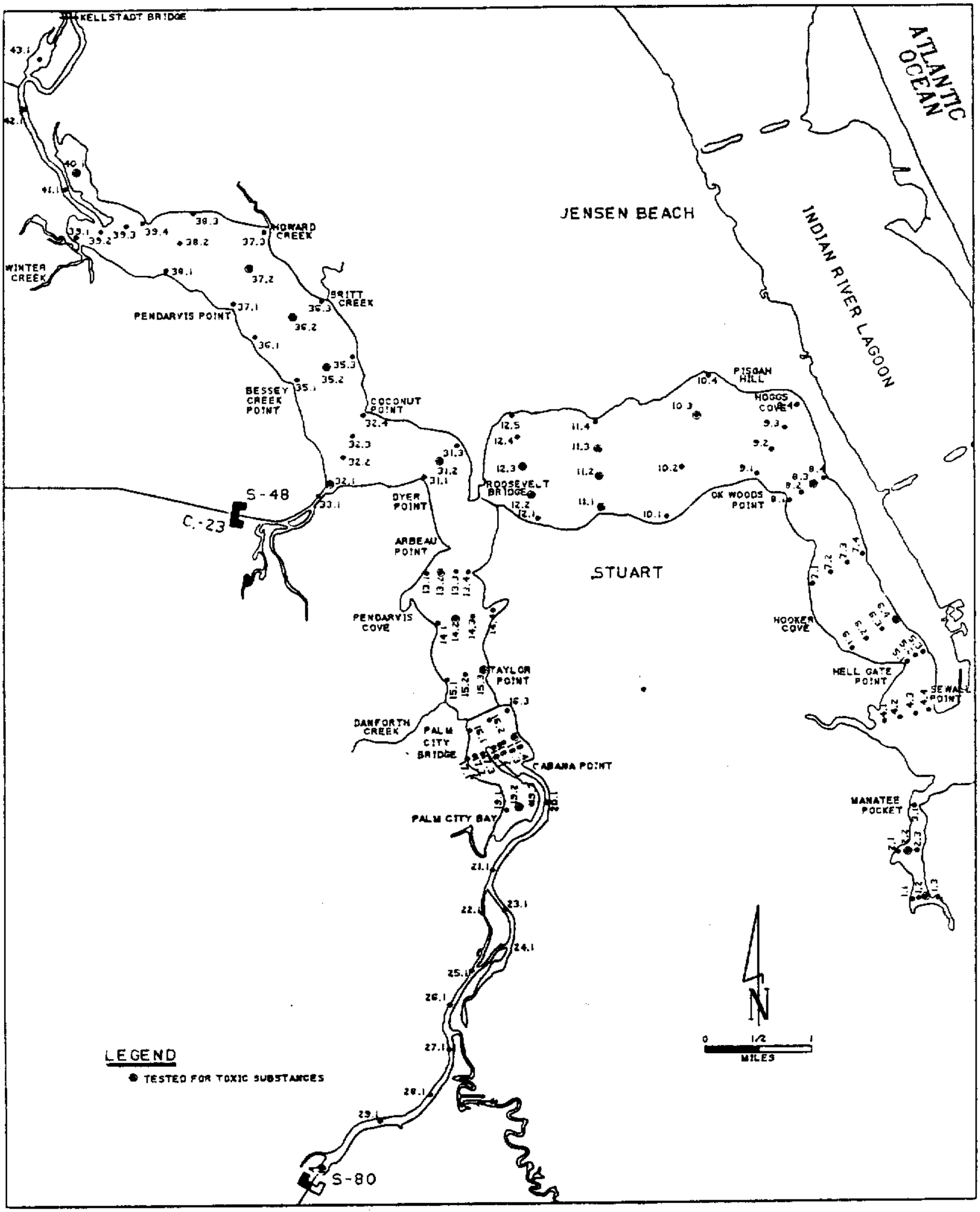

FIGURE 4. ST. LUCIE ESTUARY SEDIMENT SAMPLING LOCATIONS

RESULTS

Mean Particle Size

Distribution of mean grain size for sediments throughout the estuary shows coarse material (0 to 3 phi) along the shoreline and fine sediments (>5 phi) in deeper areas (Figure 5). Prevailing estuarine water velocities and depths provide a sorting environment for sediments and flocculent material. The main body of the north fork, for example, exhibits concentric mean particle size contours ranging from silt and clay sized sediments (7 to 9 phi) in the deep area, to well sorted, quartz sands (0 to 3 phi) along the margins. This same type of sorting occurs in the western portion of the middle estuary. As prevailing tidal velocities increase in the eastern portion of the middle estuary, the percentage of small particles decreases. As a result, a "tongue" of larger mean sized particles (3 to 5 phi) extends along the center region. Similar types of sediment gradients occur where Danforth Creek (northwest of Palm City Bridge), Palm City Bay, Kitching Cove, C-23, C-24, and Manatee Pocket tributaries enter the estuary.

Canal sediments ranged in size from well-sorted clay to sand. St. Lucie Canal (C-44) substrates were predominantly sand (mean phi from 1.02 to 1.74) except where fine particles deposited in deeper portions near structures (S-308 and S-80) located at both ends of the canal. Small quantities of silt and clay with medium, fine sands were prevalent in C-25. The largest quantities of fine particles in C-25 (mean phi 3.98 and 6.89) occurred in deeper portions immediately upstream of structures S-99 and S-50 (Figure 3, Appendix D). Comparatively, sediment samples from C-23 and C-24 agricultural canals contained large quantities of fine sized particles with the majority of samples having mean phi values near 7.

Particle Size Distribution

To better illustrate bottom sediment particle size differences between sites, ten representative particle size distributions (or sediment frequency curves) were statistically culled with a cluster analysis (Appendix E). By combining similar distributions, it was possible to reduce the number to six representative distributions (Figure 6). Three distinct types of sands were included within distributions A, B, and C with phi modes near 1 and 2 and mean phi ranging from 0.68 to 1.64. Distributions D and E represent transitional sediments (sandy-muds and muddy-sands) comprised of sands and fine muds. Distribution D sediments contained primarily quartz sands (similar to distribution B) and a moderate quantity of fine sized particles. Distribution E contained quartz sands that closely resembled sands found in distribution C, although mud was more prevalent. Mud sediments had particle sizes principally within phi 9 (clay-sized particles) range and were considered a component of distribution F. Some sample sites, such as downstream of Roosevelt Bridge (stations 12.2 and 12.3), contained shells and shell fragments of the coot clam, Mulinia lateralis, that were in the -2 to 1 phi size class range (Appendix D), but were still categorized as F distributions. Figures 7 and 8 show particle size distributions that were assigned to each site.

Organic Material

Several areas of the estuary contained sediments with high organic content as deduced from LOI data (Figure 9). Surface sediments collected from deep, central portions of the north fork contained an extraordinarily high amount of organic material (i.e., a maximum volume of 64% was measured at station 36.2). Organically rich sediments were limited to the channel area in the south fork (station 14.2 had a value of 49%). Organics increased in south fork sediments from upstream of Palm City Bay to the confluence of C-44 and the natural south fork tributary. In the mid-estuary, a plume of organically enriched sediments (20 to 30%) occurred near the City of Stuart Sewage Treatment Plant outfall. Discharges from this outfall were discontinued in 1982. High organic deposits were also found in Manatee Pocket.

Loss on ignition values for sediments from canals C-44 and C-25 were commonly low, with the exception of areas immediately upstream of the saltwater barrier structures S-80 and S-50. Organic content in C-23 and C-24 samples ranged from 2.6% at S-97 (C-23), to 29% at station C-24.3 with an average LOI of approximately 16% for both canals.

Significant linear relationships existed between percent organics and mean particle size for the entire estuary ($r=0.77$) and for each of the three main tidewater areas (Table 1). The highest correlation

TABLE 1. Linear Relationships Between Percent Organic Material and Mean Particle Size in PHI Units (99% Confidence Level).

Location	n	r
Estuary	77	0.77
North Fork	21	0.87
South Fork	24	0.72
Mid-Estuary	32	0.66

Figure 5

See Map located in pocket inside back cover

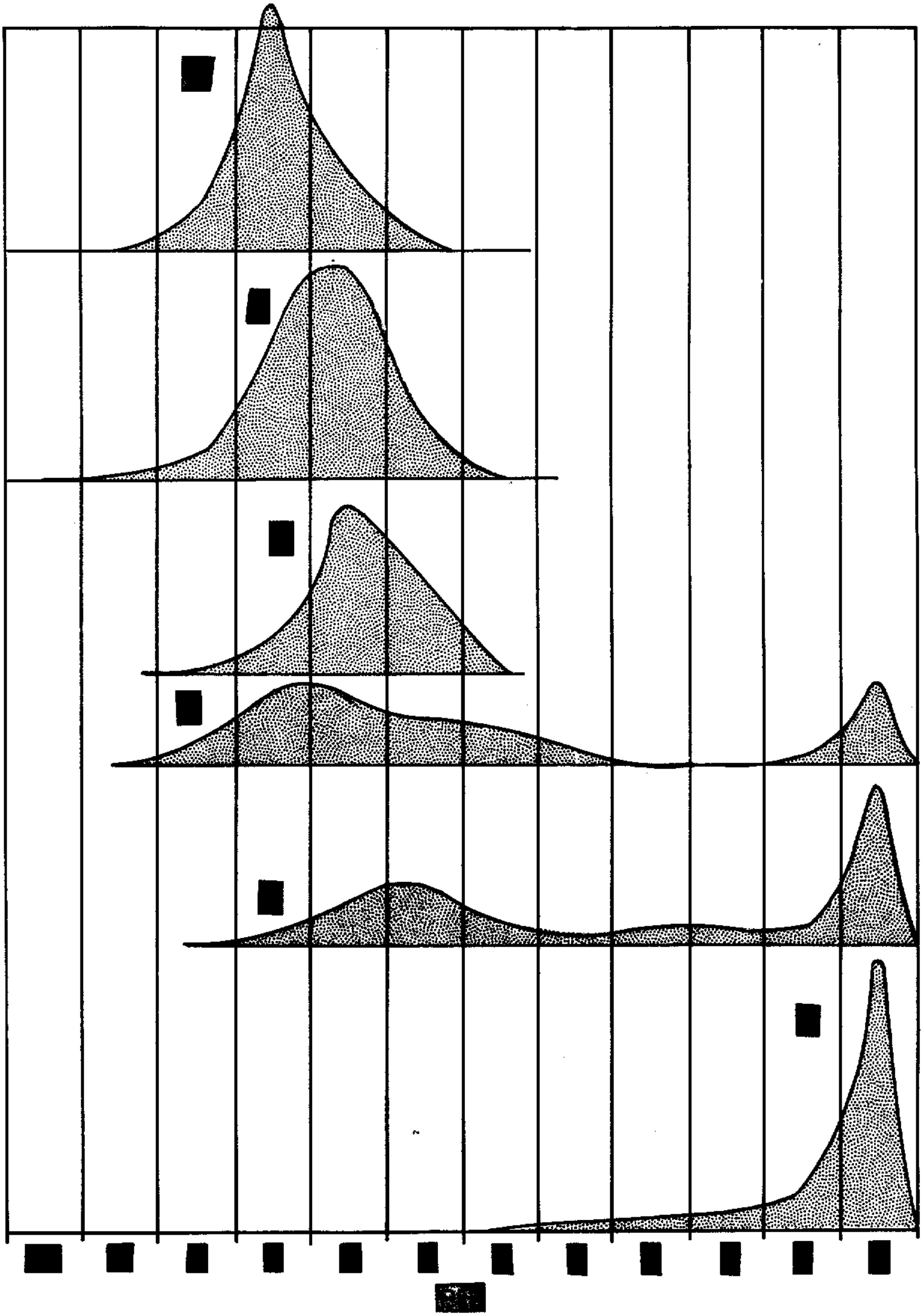

FIGURE 6. REPRESENTATIVE FREQUENCY CURVES FOR ST. LUCIE ESTUARY SURFACE SEDIMENT

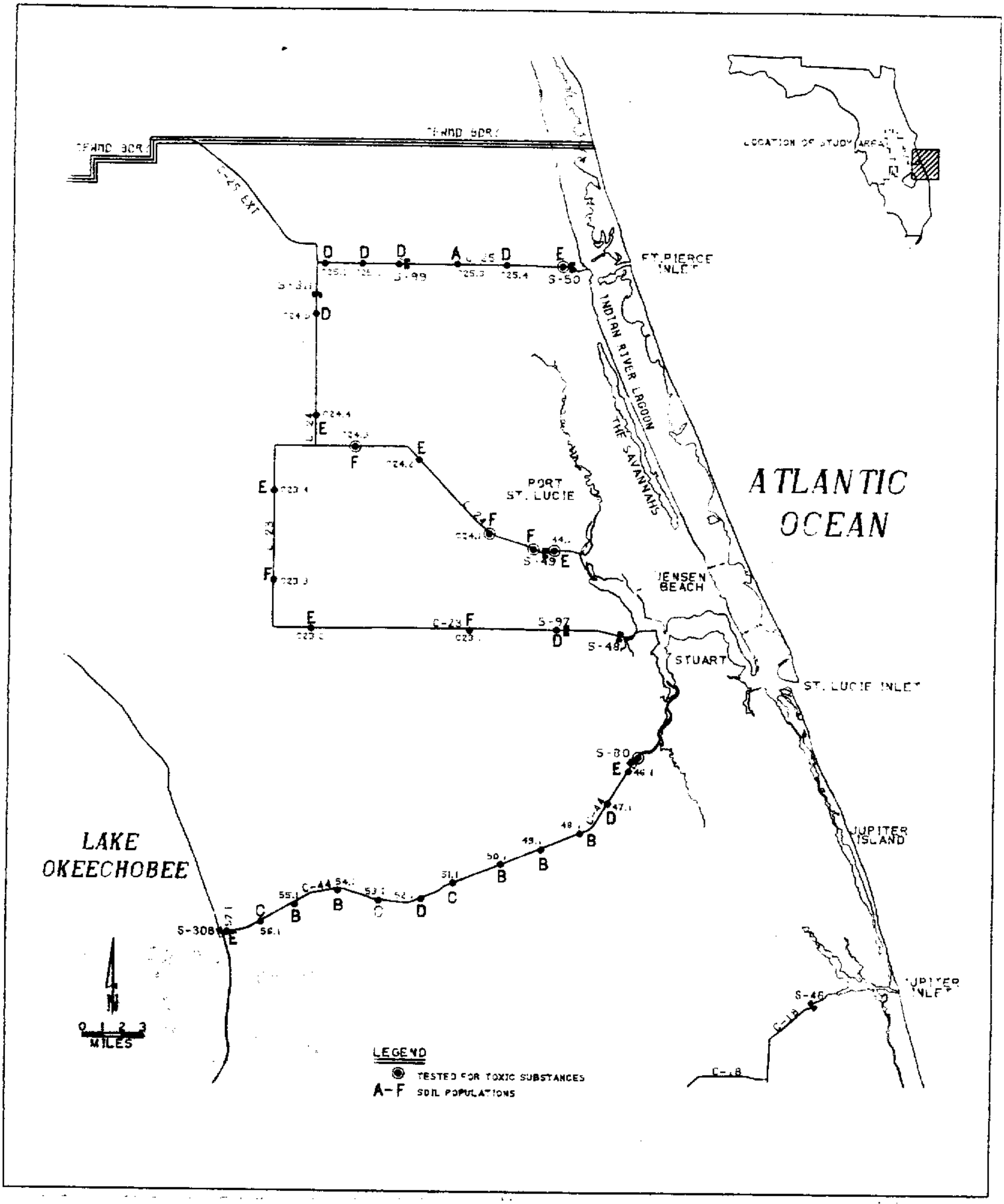

FIGURE 7. SEDIMENT DISTRIBUTION TYPES IN CANALS OF THE ST. LUCIE ESTUARY WATERSHED

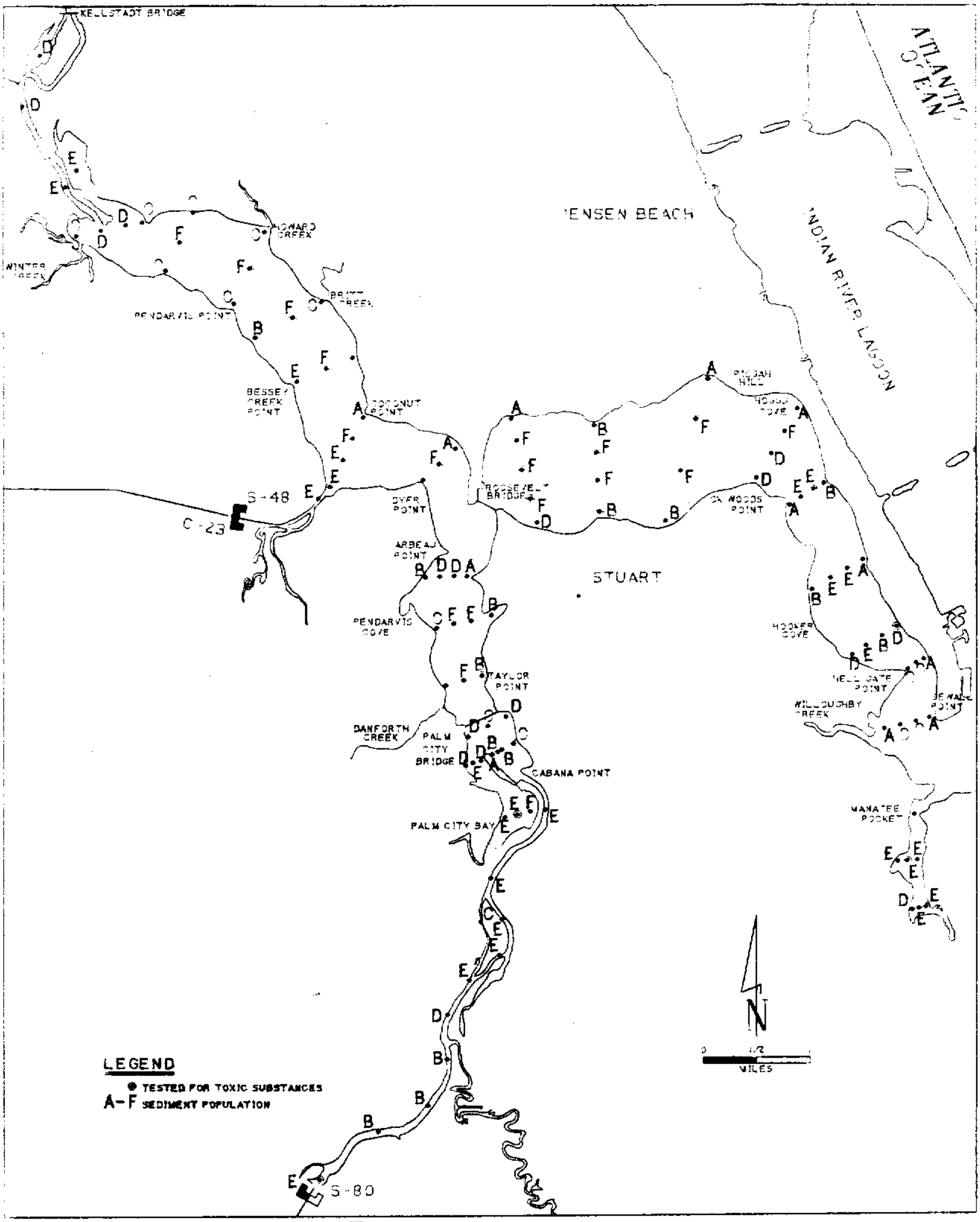

FIGURE 8. SEDIMENT DISTRIBUTION TYPES IN ST. LUCIE ESTUARY

Figure 9

See Map located in pocket inside back cover.

TABLE 2. HEAVY METALS (mg/kg) IN SURFACE SEDIMENTS AT THE ST. LUCIE ESTUARY AND PRIMARY CANALS

Station	Silver Ag	Arsenic As	Cadmium Cd	Copper Cu	Mercury Hg	Nickel Ni	Lead Pb	Zinc Zn
1.3	0.04	36(5)	1.2(2)	229(1)	4.3(4)	21	62(1)	235(1)
2.2	0.23(5)	28	0.8	75	1.0	17	46	43
6.4	0.25(3)	23	0.5	8	0.2	8	17	3
8.3	0.05	33	0.8	15	0.4	17	39	4
10.3	0.24(4)	27	0.3	13	0.5	27	40	54
11.1	0.20	2	0.0	2	0.1	4	1	2
11.2	0.09	46(2)	1.0(4)	37	0.7	27	54(5)	27
11.3	0.23(5)	32	0.7	15	0.6	23	43	59
12.2	0.04	32	0.7	23	0.5	19	49	27
12.3	0.04	45(3)	0.9	22	0.4	16	55(4)	43
13.2	0.22	13	0.4	6	0.4	22	12	20
14.2	0.24(4)	32	0.7	29	0.5	38(2)	35	65
15.3	0.21	3	0.0	1	0.0	4	0	2
18.4	0.24(4)	23	0.4	15	0.2	13	24	38
19.2	0.94(1)	30	0.9(5)	22	0.5	34(4)	31	66
21.1	0.22'	30	0.5	28	0.3	21	39	62
24.1	0.24(4)	24	0.9	15	0.2	26	25	58
26.1	0.25(3)	12	0.3	13	0.1	30	17	34
31.2	0.24(4)	28	0.6	17	0.2	23	42	61
32.1	0.04	30	0.8	29	0.4	29	40	63
35.2	0.20	27	0.8	20	0.6	37(3)	41	71
36.2	0.05	45(3)	1.1(3)	32	7.8(2)	23	59(2)	55
37.2	0.04	45(3)	0.9(5)	59	0.7	29	56(3)	100
40.1	0.04	31	0.8	36	0.4	14	31	34
42.1	0.05	25	0.7	27	8.5(1)	9	22	15
44.1	0.04	43(4)	0.8	60	0.4	19	42	69
C24.1	0.05	63(1)	1.3(1)	88(3)	4.9(3)	32(5)	45	182(4)
C24.3	0.05	46(2)	0.8	172(2)	2.5(5)	21	42	219(2)
S49	0.24(4)	28	0.8	83(4)	1.3	25	30	183(3)
S50	0.24(4)	27	0.4	77(5)	1.0	50(1)	44	139(5)
S80	0.30(2)	31	0.5	18	0.0	19	22	46
MEAN	.18	30	0.7	41	1.3	22	36	67
MIN.	.04	2	0.0	1	0.0	4	0	2
MAX.	.94	63	1.3	229	8.5	50	62	235

KEY (#) A Range of High Values

(r = 0.87) occurred for north fork sediments (Figures 5 and 9). The relatively low correlation found for the mid-estuary (r = 0.66) was probably influenced by the continuous introduction of organic material from the Stuart Sewage Treatment Plant.

Heavy Metals

Highest concentrations of all metals except silver were generally found in sediments from five areas (Table 2).

1. C-24 canal, especially immediately upstream of S-49
2. Directly upstream of S-50 in canal C-25
3. Deep, central portion of north fork
4. Deep, central portion of the west, middle estuary
5. Manatee Pocket

Distribution of high concentrations of metals indicate that arsenic, cadmium, copper, mercury, nickel and zinc generally originated from agricultural areas; whereas, presence of cadmium, copper, mercury, lead, and zinc were also associated with a full service marina (i.e., Manatee Pocket).

Concentrations of metals were related to particle size and organic content. As the amount of silt and clay sized particles increased, a proportional increase in the levels of five of the eight heavy metals resulted (Table 3). Therefore, the highest levels of metals can be identified with areas that normally accumulate small sized sediments. Exclusively, concentrations of mercury and organic material increased concurrently (r = 0.59).

TABLE 3. Linear Relationships Between Heavy Metal Concentrations and Mean Particle Size in PHI Units (99% Confidence Level, n = 31).

Metal	r
Pb	0.81
As	0.76
Cd	0.69
Zn	0.67
Cu	0.62

Pesticides

Most samples selected for pesticide and PCB analyses contained high concentrations of organic compounds, causing analytical difficulties. As a result, some of the reported "less than" values found or noted herein are above standard minimum detection limits for the compounds.

Aldrin, dieldrin, endrin, heptachlor, mirex, and toxaphene were detected at few locations and in low concentrations (Table 4, Figures 3 and 4). In contrast, chlordane was detected at 77% of the sample sites, with values ranging from 3 to 81 µg/kg and a mean value of 17 µg/kg. Chlordane levels were highest (63 and 81 µg/kg) in Manatee Pocket (station 1.3) and at the mouth of Bessey Creek (station 32.1). DDT and/or its breakdown derivatives, DDE and DDD, were detected in 30 of 31 samples analyzed, although combined concentrations (DDT-r) exceeded 10 µg/kg at only eight sites (Table 4). DDT concentrations were particularly high at structures S-49 (53 µg/kg) and S-50 (46 µg/kg). Two other stations, 1.3 in Manatee Pocket and C-24.3 in canal C-24, had higher than average levels of DDT-r. Regression analyses revealed a low but significant relationship (r = 0.36) between DDT-r and mean particle size. An exceptionally high PCB concentration of 918 µg/kg was also found at station 1.3 in Manatee Pocket.

DISCUSSION

The present study was designed to: (1) characterize sediment environments within the estuary and canal systems on the basis of particle size and organic content; (2) survey the concentrations and distribution of potentially toxic substances such as heavy metals, pesticides and polychlorinated biphenyls (PCBs) in sediments; and (3) establish relationships between concentrations of toxic materials and sediment composition. These data will provide a basis for determining the origin of sediments and toxic substances from within the St. Lucie Estuary (SLE) watershed and a data base to compare to other estuaries.

1. Characterize sediment environments within the estuary on the basis of particle size and organic content

Sediment Components

Sands. Bearden (1972) reported that Pamlico sand deposits of the Pleistocene Age occupy much of St. Lucie County. These sands are very fine to medium in size and white to light grey in color. In the present study, five of the six grain size distributions documented for the SLE contained quantities of very fine to coarse sands.

Coarser sands are remnants of barrier sand dunes of the Pleistocene Age and are most evident at

TABLE 4. Pesticides and PCBs (µg/kg) in Surface Sediments at the St. Lucie Estuary

Station	Aldrin	Chlordane	DDD	DDE	DDT	DDT-r	Dieldrin	Heptachlor	Mirex	Toxaphene	Endrin	PCBs
1.3	*	81	<1	22	*	23	<1.0	*	*	*	*	918**
2.2	*	18	4	5	<2	11	<1.0	*	*	*	*	<5
6.4	*	11	<2	1	*	3	*	*	*	*	*	<8
8.3	*	37	<1	4	*	5	*	*	*	*	*	<9
10.3	*	8	<1	3	*	4	*	*	*	*	*	<5
11.1	*	*	<1	*	*	1	*	*	*	*	*	<2
11.2	<0.3	<3	<1	<4	<2	7	<0.6	<0.3	< 1.4	<23	*	<54
11.3	*	11	1	3	*	4	*	*	*	*	*	<7
12.2	*	*	*	8	*	8	*	*	*	*	*	<10
12.3	*	11	1	4	*	5	*	*	*	*	*	<9
13.2	*	13	<1	3	*	4	<0.7	*	*	*	*	3
14.2	*	30	7	9	*	16	*	*	*	*	*	<6
15.3	*	3	<1	*	*	1	*	*	*	*	*	<2
18.4	*	8	2	2	*	4	*	*	*	*	*	<5
19.2	*	15	3	4	<2	9	*	<0.3	*	*	*	<9
21.1	*	28	4	6	<2	12	*	*	*	*	*	<9
24.1	*	26	5	7	<2	14	*	<0.3	<1.4	*	*	<9
26.1	*	17	2	2	<2	6	*	*	*	*	*	<5
31.2	*	17	<2	6	*	8	*	*	*	*	*	<6
32.1	*	63	<1	8	<2	11	*	*	*	*	*	<13
35.2	*	21	<2	6	*	8	*	*	*	*	*	<7
36.2	*	*	*	8	*	8	*	*	*	*	*	<16
37.2	*	24	<1	7	*	8	*	*	*	*	*	<18
40.1	*	*	<1	*	<2	3	*	*	*	*	*	<48
42.1	*	*	*	3	*	3	*	*	*	*	*	<9
44.1	*	*	*	3	*	3	*	*	*	*	*	<12
C24.1	*	*	<1	11	*	12	*	*	*	*	*	<14
C24.3	*	14	32	15	<1	48	*	*	*	*	*	<27
S49	*	15	<1	6	53	60	*	<0.4	*	*	*	<11
S50	*	36	<1	31	46	78	*	<0.3	*	*	*	<10
S80	*	<4	*	*	*	*	*	*	*	30.0	*	<21
*	0.25	2.5	0.5	0.5	1.0		0.5	0.25	1.0	15.0	1.0	
MEAN		17	3	6	4	12						42
MAX	0.3	81	32	31	53	78	1.0	0.4	1.4	30.0		918

KEY:
* Below approximate minimum detection limit
** Aroclor 1016 308
Aroclor 1248 119
Aroclor 1254 108
Total PCBs 918

Pisgah Hill north of the middle estuary where coarse sand deposits rise 65 ft above sea level (Davis and Schrader, 1984).

Clays. Clay-sized particles from the SLE were analyzed by Schrader (1984) using x-ray diffraction. Surficial clay mineral distribution of the SLE is smectite-kaolinite-illite and randomly mixed-layer varieties probably derived from "the weathering and/or reworking of Piedmont and coastal plain rocks" (Schrader, 1984). Three of the grain size distributions for the SLE contained clay-sized material.

Organic Materials. Pitt (1972) determined that suspended material in discharges from C-23 and C-24 canals into the SLE was predominantly silt/clay-sized particles (48 to 98%). Organic matter is part of the fine grain particulate load to estuaries and therefore behaves in the same manner as clay sized material (Anonymous, 1978). Very fine-grained, Population F, sediments from the SLE usually contained significant quantities of organic material, especially in the north fork of the estuary. The unusually high levels of organic material in relation to mean particle size of sediment in the middle estuary has been documented in other estuarine systems (Folger, 1972) and can be partially attributed to operation of the Stuart Sewage Treatment Plant. Discharges from this treatment plant are now being injected into a deep well.

Overall, the levels of organic materials in fine sediments in the SLE were extremely high in comparison to other estuaries in the United States (Folger, 1972). Evidently, organics are being added to the estuary more rapidly than they can be assimilated. As a result, anaerobic conditions and the production of toxic hydrogen sulfide may occur (Werner and Hyslop, 1968) which can negatively impact biota.

Sediment Distribution

Sandy Sediments. Deposits of very fine to coarse sands occurred in all the agricultural canals and within a large portion of the estuary. High percentages of larger sand particles (medium to coarse in size) were located in the western portion of the C-25 canal and on the north and east shoreline of the middle estuary.

Sand substrates normally free of silt and clay sized particles and organic materials occurred in three high energy environments: (a) throughout the St. Lucie Canal (C-44), where Lake Okeechobee regulation discharges produce currents that are capable of translocating small particles to the estuary; (b) mid-channel area at Hell Gate Point, where the highest tidal velocities in the system occur (Morris, 1985); and (c) shoreline areas (less than about 3 ft deep) that are subjected to wave turbulence and shoreline currents.*

Transitional Sediments. In most cases, the standard deviation of particle size is indicative of the amount of wave energy and/or current velocity at a location (Figures 10 and 11). Well-sorted sediments have a low standard deviation and are either located in low energy (sediments are silt/clay) or high energy (sands substrates) SLE sediment environments. Mixed or transitional sediments which contain sand and silt are poorly sorted, have a higher standard deviation and occur in areas that are exposed to transient, high energy events. The section of estuary between Cabana Point and the natural south fork tributary (stations 26.1 to 20.1) is exposed to intermittent high water velocities resulting from fresh water releases at S-80. These releases may be responsible for the presence of transitional sediments in that area. Similarly, discharges from canal C-24 were likely accountable for the transitional sediments that occurred in the northern portion of the north fork (station 41.1 and 42.1). Poorly sorted sediments also existed in the eastern portion of the middle estuary, representing the transition from estuarine muds to the sand substrates of the outer estuary where tidal velocities may vary considerably.

Clay Sediments. Clay and silt sediments are derived from the gradual settling of very fine, suspended materials from the water column. Well-sorted clay sediments occurred in low energy environments that are represented by population F on Figure 11. All of the population F sediments were in deeper areas of the estuary and within C-23 and C-24.** These locations are generally sinks for small particles, however, these sediments can be translocated during high energy events (Folk, R.L. and Ward, 1957). The rate of deposition for fine sediments and flocculates in the SLE is 1 to 2 cm yr^{-1} (Davis, 1984).

Sources of Sediments

C-23 and C-24 Canals. Much of the sediment transfer to the SLE occurs during the wet season when major canals are discharging surface water runoff.

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* Samples were not obtained at the Roosevelt Bridge, however, previous benthic sampling revealed a sand and shell bottom in this area.

** The high standard deviations for stations 12.2, 12.3, 12.4 and others resulted from the presence of shells, primarily Mulinia, which distorted particle size analysis interpretation.

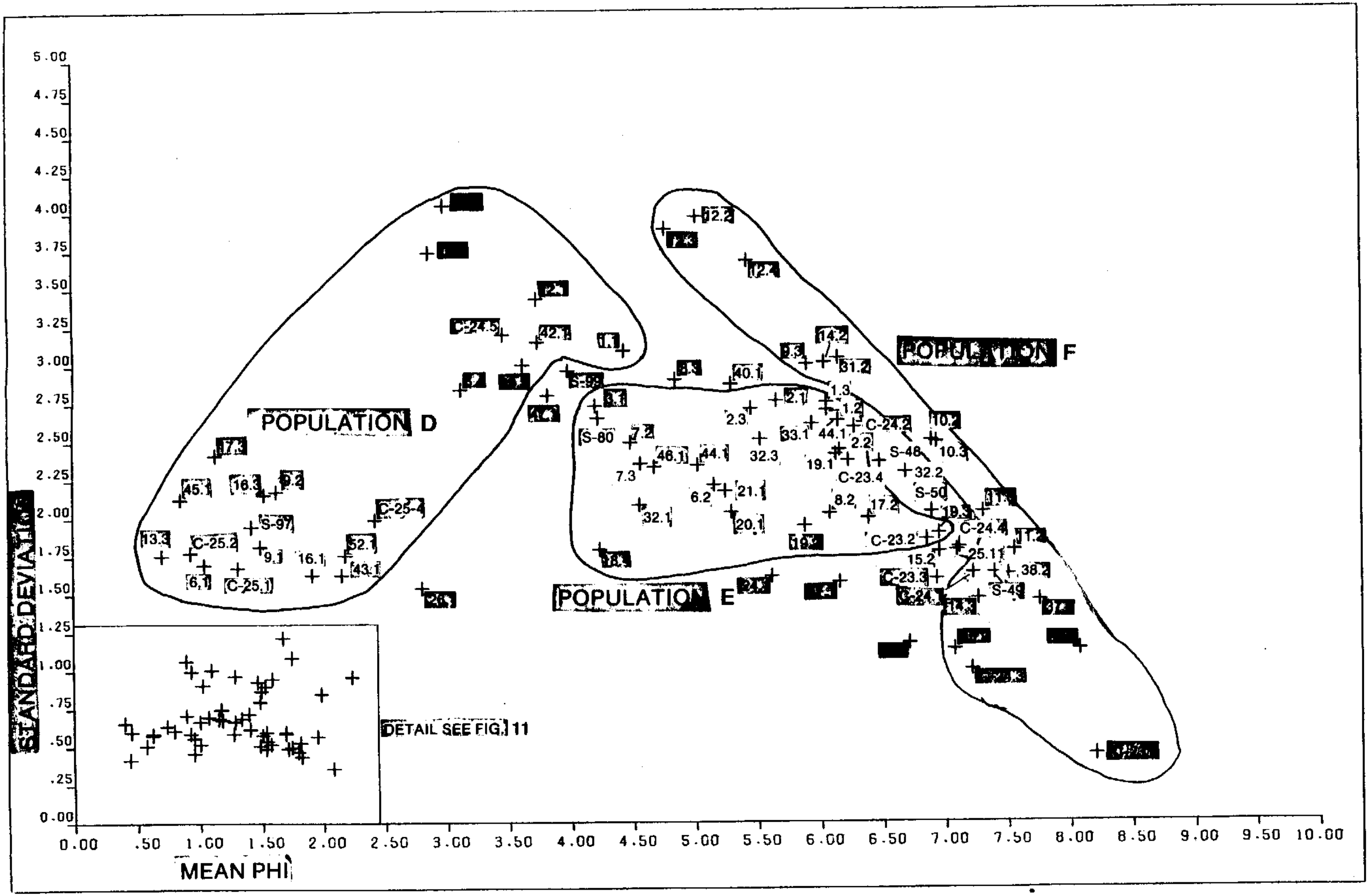

FIGURE 10. ST. LUCIE ESTUARY SEDIMENT POPULATIONS

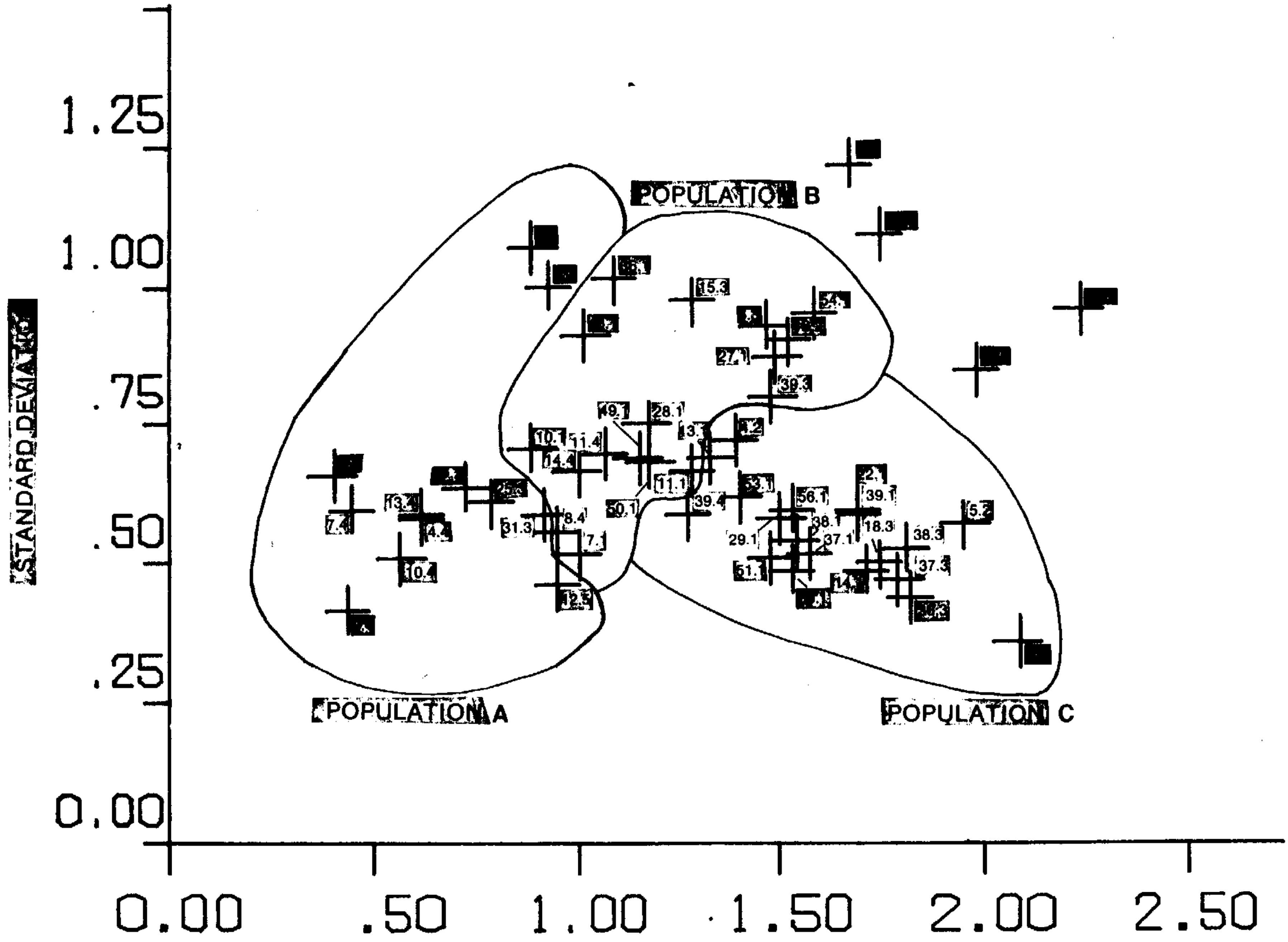

FIGURE 11. ST. LUCIE ESTUARY SEDIMENT POPULATIONS (DETAIL)

Water quality studies of canals C-23 and C-24 show the highest turbidity (suspended solids) levels typically occurred during discharge events (Federico, 1983). Relationships between the quantities of discharge and concentrations of suspended sediment (primarily silts and clays) from these canals were established by Pitt (1972). Based on these relationships, sediment input to the north fork of the estuary from Canals C-23 and C-24 during 1969 (a year with average rainfall) was estimated as 4500 and 9000 tons respectively. Furthermore, when insoluble organic matter mixes with brackish waters (0.5 to 5 ppt salinity), colloidal humus and clay materials flocculate and may also deposit in the estuary (Day, 1976).

Fresh Water Discharges from Lake Okeechobee. Large amounts of sediment can be introduced into the south fork of the estuary when fresh water releases occur from Lake Okeechobee. In addition to the suspended solids originating from the Lake, discharges exceeding 1000 cfs can also translocate fine sediments that have settled in canal (C-44) during the interim between moderate to large fresh water releases (Haunert and Startzman, 1981, 1985). Suspended solids were monitored in 1983 during a period when large discharges were occurring (Haunert, unpublished). The quantity of suspended solid material passing structure S-80 reached a maximum of 8000 tons/day when discharges reached about 7000 cfs. Much of this material was transported out of the estuary into the Indian River Lagoon and Atlantic Ocean. Discharges in excess of 4500 cfs can also transport sand from the canal to the Palm City Bridge area. Large releases in the past have deposited more than 8 ft of fine to medium grain sand in this portion of the south fork (Davis, 1984).

2. Survey the concentrations and distribution of toxic materials in sediments

Note: Caution is suggested when average levels of toxic materials from this study are compared with data from other estuaries. Samples taken within the SLE were selected for toxic substances analyses if they contained high amounts of fine material and organics or were located near a possible point source of contamination. This selection process was not random and tends to bias the results towards higher concentrations.

<u>Heavy Metals</u>

Criteria. Even though sediment studies are frequently used for pollution reconnaissance, few criteria have been established for safe levels of heavy metals in sediments (Williams, et al., 1973; Allen and Hall, 1980; Rabe and Stephen, 1977). Contaminated sediments constitute a potential hazard to water quality since they can be released as a result of erosion, dredging, or bioturbation (Forstner et al., 1976).

The Environmental Protection Agency (EPA) has established "Dredge Criteria" for maximum allowable concentrations in mg/kg of lead (50), zinc (50), mercury (10), copper (50), and cadmium (2) in sediments (Clark, 1977). These five metals are among the most potentially harmful to estuarine biota.

Distribution. The highest concentrations of heavy metals in the SLE region occurred in canal C-24, the central section of the north fork of the estuary, the central portion of the eastern mid-estuary, and in Manatee Pocket. Sediments in the agricultural canal C-24 contained high concentrations of arsenic (As), cadmium (Cd), mercury (Hg), zinc (Zn), and copper (Cu). Levels of copper and zinc decreased from canal C-24 into the estuary, definitely suggesting that the agricultural area draining into this canal is a major source of these metals (Vivian and Massie, 1977). The highest concentrations of copper, zinc, and lead occurred in the Manatee Pocket, near a full service marina (station 1.3).

Arsenic. Arsenic is used as a herbicide (Brown, 1978). Sediment studies of other locations show higher concentrations of arsenic than those determined for the SLE (Groot et al., 1975).

Cadmium and Mercury. Cadmium and mercury are often applied as fungicides (Brown, 1978), but levels of both of these metals within the SLE were below EPA Dredge Criteria (Lindberg et al., 1975). Cadmium levels were less than or equal to those found in other estuaries (Table 5).

Copper. Copper is commonly used in agriculture as a trace metal for citrus crops and copper sulfate can be employed to control aquatic weeds in canals and ditches and as a fungicide (Brown, 1978). These agricultural uses of copper may account for the relatively high concentrations of this metal in canal C-24. Anti-fouling paints on boat hulls constantly leach copper into the water and are considered the primary source of copper in marina sediments (Young et al., 1978; Trefry et al., 1983). In Manatee Pocket marina sediments (station 1.3, 229 mg/kg) the concentration of copper was nearly twice the maximum value reported by eight other estuarine studies (Table 6).

Mean concentration of copper in this study was higher than that reported from other estuaries; however, this mean value included two extremely

TABLE 5. Cadmium Concentrations in Surface Sediments for St. Lucie Estuary and Selected Bays

System*	Concentration (mg/kg) Mean	Min.	Max.	n
Bayou Casotte, Miss.	2.0	-	-	3
Mississippi Sound	2.0	-	-	4
Panama City Bay, Fla.	1.0	-	-	9
Escambia Bay, Fla.	1.0	-	-	20
Pensacola Bay, Fla.	1.0	1.0	2.0	12
St. Lucie Estuary, Fla.	0.7	0.04	1.3	31

TABLE 6. Copper Concentrations in Surface Sediments for St. Lucie Estuary and Selected Bays

System*	Concentration (mg/kg) Mean	Min.	Max.	n
St. Lucie Estuary, Fla.	41.4	1.3	229.0	31
Chesapeake Bay	35.2	27.0	54.0	5
Galveston Bay, Texas	28.0	5.1	80.0	5
Pensacola Bay, Fla.	19.3	1.0	120.0	18
Bayou Casotte, Miss.	11.7	1.2	20.5	3
Panama City Bay, Fla.	11.6	3.0	42.0	9
Escambia Bay, Fla.	8.7	1.0	43.0	20
East Bay, Fla.	4.4	1.0	8.5	10
Mississippi Sound	3.7	1.6	6.6	4
Indian River, Fla.	<2 to 15; 200 in marina sediments			10

*From: Environmental and Recovery Studies of Escambia Bay and the Pensacola-Bay System Florida. EPA 904/9-76-016.

high levels detected in Manatee Pocket and C-24 which were outside the main body of the estuary. A mean concentration of copper without these extreme values (22 mg/kg) would make a better comparative value with other mean concentrations from studies in which samples were obtained within the main portion of the estuary (Table 6). The two extreme levels of copper, however, indicate a point source of copper and a potential hazard to biota and water quality if these sediments are disturbed.

Zinc. The EPA dredge criteria for zinc (50 mg/kg) was exceeded in 55% of the samples from the SLE. However, zinc concentrations in SLE sediments should not be considered as extremely high. Levels of 235 mg/kg zinc, which were sampled at the marina, were not especially high when compared to results from other investigations. Either the EPA criterion for zinc is too low, or zinc contamination is a major problem in most of the estuaries that are listed in Table 7.

Zinc is applied as a trace metal in citrus agriculture and this use probably accounts for the concentrations of zinc in the major drainage canals. In the marine industry, coating various iron and steel surfaces with zinc (galvanizing) is a common practice to retard corrosion of hardware. In addition, submerged zinc plates function as sacrificial anodes to reduce effects of electrolysis on valuable boat hardware. Zinc is released to the water, just as copper is from anti-fouling paint, and may become adsorbed to particulate matter that settles to the bottom.

Lead. The extensive use of tetraethyl lead as an anti-knock additive to gasoline has resulted in increased concentrations of lead from atmospheric fallout and surface water runoff (Young et al., 1978; Forstner et al., 1976). Furthermore, sediments near marinas often contain higher than background levels of lead (Klein, 1973) that may result from spillage of leaded gasoline. The highest level of lead sampled at the marina (62 mg/kg) compared favorably with other

TABLE 7. Zinc Concentrations in Surface Sediments in St. Lucie Estuary and Selected Bays

System*	Concentration (mg/kg) Mean	Min.	Max.	n
Pensacola Bay, Fla.	140.3	1.0	1200.0	18
Bayou Casotte, Miss.	90.5	14.6	151.1	3
Mobile Bay, Ala.	90.3	10.0	292.0	30
Escatawpa River Estuary	71.4	0.8	230.0	18
St. Lucie Estuary, Fla.	67.0	2.0	235.0	31
Galveston Bay, Texas	66.2	32.0	122.0	5
Escambia Bay, Fla.	43.2	1.0	98.0	20
Panama City Bay, Fla.	37.9	15.0	88.0	9

*From: Environmental and Recovery Studies of Escambia Bay and the Pensacola-Bay System Florida. EPA 904/9-76-016.

estuaries that are also affected by widespread use of leaded gasoline (Table 8).

Nickel. Concentrations of nickel are not considered to be a problem in the SLE. Table 9 shows the relative values of nickel among several studies.

The Florida Department of Environmental Regulation has recently described a methodology to assess the relative level of metal contamination in sediments within a given study area (Ryan and Windom, 1986). In efforts to standardize evaluations of estuarine sediments, this DER methodology should be used in future studies.

Pesticides and PCB

Criteria. Chlordane and DDT were the only chlorinated hydrocarbon pesticides detected with sufficient frequency, and high enough concentrations to warrant discussion (Tables 4 and 10). Both of these pesticides are highly persistent, bioaccumulate in aquatic organisms, and are toxic at extremely low concentrations (Train, 1974 and 1975). The Florida Department of Environmental Regulation has established the maximum acceptable levels of chlordane and DDT in marine waters to be 0.004 and 0.001 µg/kg respectively. Unfortunately, quality criteria have not been developed for sediments even though the resuspension of contaminated sediments increases the bioavailability of these chemicals (Edwards, 1977) and may cause water quality standard violations. Since these pesticides cause a threat to the environment, EPA has restricted the use of chlordane and has banned the use of DDT.

Distribution. Table 10 shows that the mean value of chlordane for this study was not substantially different from values documented in aquatic sediment surveys completed in south Florida by SFWMD and USGS (Pfeuffer, 1985). Highest concentrations of chlordane in the SLE occurred at the mouth of Bessey Creek (station 32.1; 81 µg/kg) and in Manatee Pocket (station 1.3; 63.3 µg/kg). Resuspension of these sediments may liberate toxic concentrations of chlordane. The same conclusion may be drawn about the two highest levels of DDT-r detected upstream of structures S-49 and S-50 (60 and 77 µg/kg respectively). The mean values of PCB obtained for the SLE were not significantly different from the values presented for south Florida (Table 10). The maximum value (918 µg/kg) in Manatee Pocket at station 1.3, however, was extremely high.

Chlordane. Chlordane controls termites and ants but it will not be available to the public after 1986. However, treatment of structural foundations with chlordane by licensed pest exterminators will continue until an alternative becomes available.

DDT. High concentrations of DDT within the agricultural canals C-24 and C-25 may be attributed to continued use of stock-piled supplies after the 1973 ban and persistence in the environment. Further, EPA has recently determined a commonly used chlorinated hydrocarbon pesticide in the citrus industry (dicofol) contains 10% DDT (EPA, 1985). The registrants of dicofol products will lower DDT concentrations to 0.1% by July 1987.

PCB. Polychlorinated biphenyls cause biological affects similar to those of organochlorine pesticides

TABLE 8. Lead Concentrations in Surface Sediments for St. Lucie Estuary and Selected Bays

System*	Mean	Concentration (mg/kg) Min.	Max.	n
Chesapeake Bay	42.6	17.0	60.0	5
Pensacola Bay, Fla.	39.8	5.0	64.0	18
St. Lucie Estuary, Fla.	35.6	0.3	61.9	31
Bayou Casotte, Miss.	30.8	4.7	49.0	3
Mobile Bay, Ala.	28.4	6.0	86.0	29
Galveston Bay, Texas	26.8	9.0	48.0	5
Panama City Bay, Fla.	23.2	12.0	42.0	9
Escambia Bay, Fla.	18.5	2.0	43.0	20

TABLE 9. Nickel Concentrations in Surface Sediments for St. Lucie Estuary and Selected Bays

System*	Mean	Concentration (mg/kg) Min.	Max.	n
Chesapeake Bay	44.8	33.0	57.0	5
Galveston Bay, Texas	27.8	11.0	57.0	5
St. Lucie Estuary, Fla.	22.5	3.7	50.1	31
Pensacola Bay, Fla.	15.7	2.0	28.5	18
Panama City Bay, Fla.	11.1	4.0	17.0	9
Escambia Bay, Fla.	8.8	2.0	19.0	20
East Bay, Fla.	8.7	2.0	15.0	10
Bayou Casotte, Miss.	8.6	2.0	12.4	3
Mississippi Sound	7.0	2.4	12.1	4

*From: Environmental and Recovery Studies of Escambia Bay and the Pensacola-Bay System Florida. EPA 904/9-76-016.

because of similar molecular shape and composition (Clark, 1977). PCB has broad application and it is widely distributed throughout the United States, as well as the SLE. High concentrations of PCB in the marina sediments (Manatee Pocket) can reasonably be attributed to the spillage of hydraulic lubricants, plasticizers and paints (Pfeuffer, 1985; Brown, 1978) that are frequently used in boat yards.

3. Establish relationships between concentrations of toxic materials and sediment composition.

This study as well as others (Forstner et al., 1976; Groot et al., 1975) has documented that the concentration of most metals in sediments increases as the amount of clay sized particles increases. Therefore, if sediments are to be studied for potential contamination, metal concentrations at natural sink areas for clay sized particles should provide a good indication of those metals that are potential problems in the watershed. Future monitoring for metals in the SLE sediments can be limited to a few natural sink areas in canals and the estuary.

Mercury was unique in demonstrating an affinity for fine organic material instead of clay sized minerals; which has been noted in other investigations (Klein, 1973).

The occurrence of high concentrations of pesticides has been related to the amount of clay-sized material and organic particulate material (Hasett et al., 1980). Generally, results from this study supported this association but the only significant relationship established was between mean particle size and DDT plus its metabolites (DDT-r).

TABLE 10. Number of observations, mean concentrations and percent presence of pesticides, PCBs in sediments for the St. Lucie Estuary (SLE) for this study and for waterways throughout South Florida (Data compiled by South Florida Water Management District (SFWMD) and United States Geological Survey (USGS) for the period 1976-1981).

PESTICIDE	MEAN CONCENTRATION (μg/kg) SLE	SFWMD	USGS	PERCENT PRESENCE SLE	SFWMD	USGS
Aldrin	n=31 *.01	n=89 ND	n=267 <.1	3	0	1.8
Chlordane	n=31 *11.9 16.6	n=94 8.0	n=264 18.0	77	26	55
DDD	n=30 *1.6 2.6	n=99 370.0	n=268 3.0	87	59	45
DDE	n=30 *4.9 6.3	n=99 312.0	n=224 13.0	90	76	66
DDT	n=31 *.5 3.7	n=99 4.3 1421.0	n=266 4.0	35	27	27
Dieldrin	n=31 0.1	n=99 8.0 22.0	n=246 1.0	13	19	30
Endrin	n=31 0	n=95 .1 25.6	n=269 <.1	0	5	1
Heptachlor	n=30 .05	n=95 ND	n=? ND	16	0	0
Mirex	n=31 .09	n=9 ND	n=? ND	7	0	0
Toxaphene	n=31 1.7	n=89 ND	n=? ND	7	0	0
PCBs	n=31 12.3	n=90 13.0	n=269	100	23	40

* without extreme values
ND = not detected

CONCLUSIONS

1. Sediments within the St. Lucie Estuary watershed are characterized by three types of sand, two transitional sediment types containing different portions of sand and mud, and mud consisting predominantly of clay-sized particles. Hydrodynamic energy and water depth are major forces influencing types of sediment present.

2. Mud within the central portion of the north fork contains an exceptionally high concentration of organic material that can degrade water quality and produce an undesirable benthic environment. Organics are being introduced to the north fork faster than the rate of assimilation.

3. A proportional increase between the concentrations of toxic substances and of clay-sized materials (mud) occurs in the estuary. Low energy areas with mud substrates contain the highest concentrations of most metals.

4. Sediment concentrations of copper, chlordane, and Pcbs in Manatee Pocket and copper and DDT in C-24 pose a potential environmental problem.

RECOMMENDATIONS

1. To reduce the amount of silt and organic material input to the St. Lucie Estuary, the South Florida Water Management District should consider initiating an investigation to improve soil conservation techniques (reducing and delaying runoff) in the C-44, C-23, C-24, and C-25 drainage basins. This study could recommend methods of integrating contemporary water quantity and quality management practices with agricultural drainage systems and crop management.

2. The District should continue efforts to reduce the rate and frequency of large fresh water discharges from Lake Okeechobee to the south fork of the estuary. Major emphasis should be placed on developing alternative lake regulation schedules that allow frequent low volume releases; avoiding large discharges that introduce massive quantities of sediment to the estuary.

3. To provide a more suitable benthic environment in the north fork, the feasibility of removing or oxidizing the highly organic sediments (30 to 70% LOI) should be investigated.

4. Waste substances resulting from maintaining boats in Manatee Pocket should not be allowed to enter the estuary. Existing operational procedures of marinas should be investigated by the Florida Department of Environmental Regulation.

5. Potentially harmful levels of toxic materials in sediments occur directly upstream of S-49, S-50, in the central portion of the north fork and in Manatee Pocket near marina facilities. These sediments should be monitored at least every five years to determine if proposed new management techniques are affecting the concentration of toxics in these indicator locations.

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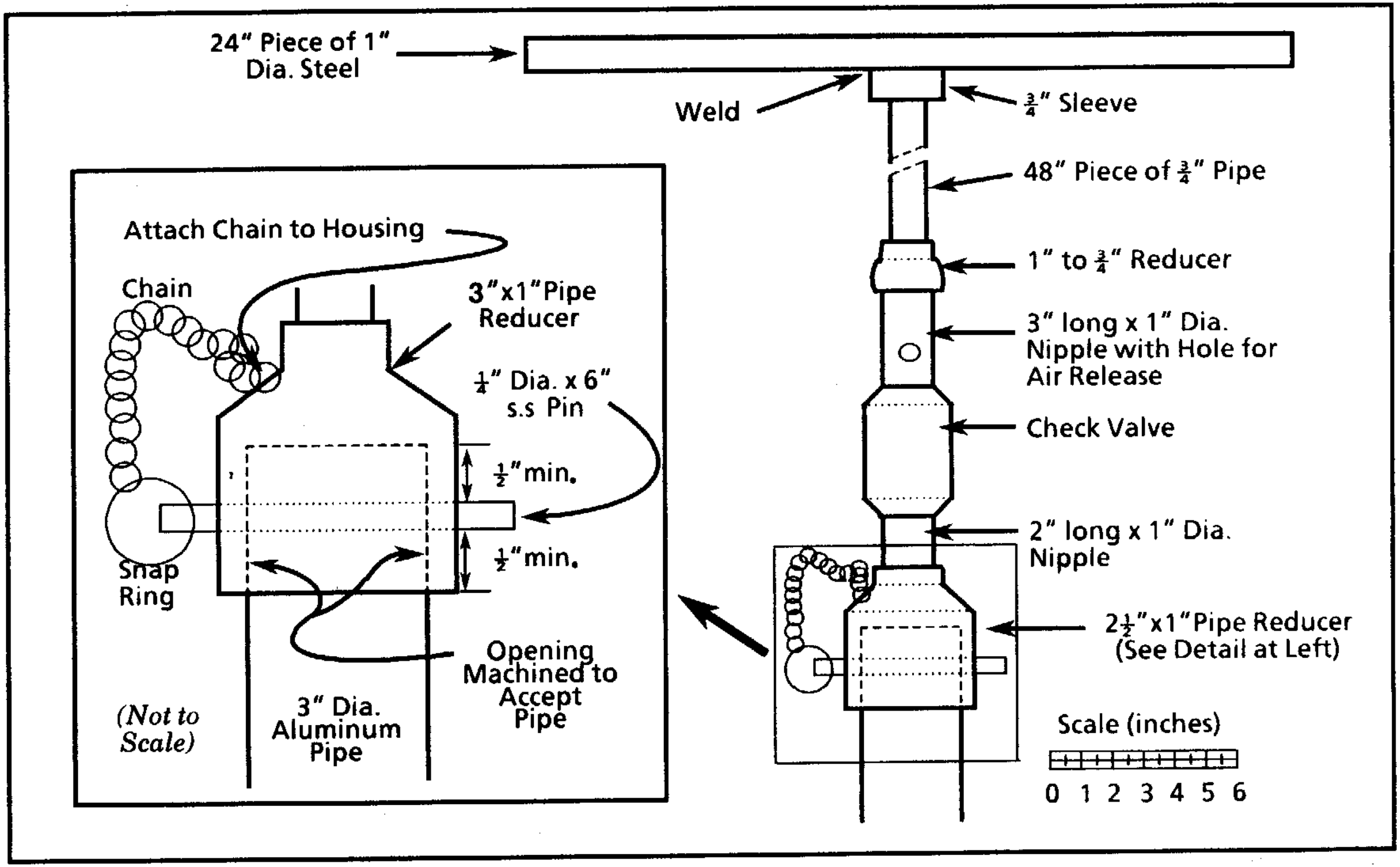
Appendix A

Modified Coring Tool used for Sediment Sampling in the St. Lucie Estuary



MODIFIED CORING TOOL USED FOR SEDIMENT SAMPLING IN THE ST. LUCIE

Appendix B

Pilot Program Results

TABLE A-1. HEAVY METALS (mg/kg) AND ORGANIC MATERIAL IN THREE REPLICATES

Aliquot	1	2	3	C.V. (%)*
Metal				
Ag	0.3	0.1	0.3	-
As	30.9	24.8	32.2	11.0
Cd	0.5	0.5	0.6	8.8
Cu	17.9	17.7	15.5	6.4
Hg	0.003	0.004	0.005	20.4
Ni	19.2	18.0	23.0	10.6
Pb	22.3	28.9	30.8	13.3
Zn	45.7	42.1	49.0	5.8
Organics (%)	9.6	8.5	11.0	10.7

*C.V. Coefficient of Variation

TABLE A-2. DETECTION LIMITS OF CHLORINATED HYDROCARBON PESTICIDES AND PCB (ALL SAMPLES WERE BELOW DETECTION LIMITS)

Aliquot	1	2	3
Pesticide µg/kg)			
Aldrin	1	1	1
Aroclor 1016	4	4	4
Aroclor 1242	4	4	4
Aroclor 1248	6	6	6
Aroclor 1254	4	4	4
Aroclor 1260	3	3	3
Chlordane 4	4	4	
DDT	3	3	3
Dieldrin	1	1	1
Endrin	1	1	1
Heptachlor	1	1	1
Lindane	1	1	1
Methoxychlor	3	3	3
Mirex	1	1	1
Toxaphene	30	30	30

Appendix C

Sieve Mesh Sizes and Particle Size Description

Sieve Mesh Sizes and Particle Size Description

Millimeters	Phi	Wentworth Size Classes
4.00	-2.0	Granule
2.00	-1.0	Very coarse sand
1.00	0.0	Coarse sand
0.50	1.0	Medium sand
0.25	2.0	Fine sand
0.125	3.0	Very fine sand
0.0625	4.0	Coarse silt
0.0310	5.0	Medium silt
0.0156	6.0	Fine silt
0.0078	7.0	Very fine silt
0.0039	8.0	Clay
0.0020	9.0	

Appendix D

Sediment Statistics and Percent Organics for St. Lucie Estuary Watershed

APPENDIX D. PHI FRACTIONS (%) FOR SURFACE SEDIMENT SAMPLES FROM THE ST. LUCIE ESTUARY

STATION

Phi Value	1.1	1.2	1.3*	2.1	2.2*	2.3	3.1	4.1	4.2	4.3	4.4
-2	0.19	0.01	0.17	0.04	0.18		0.01	0.01	0.02		0.07
-1	0.88	0.10	0.41	0.53	0.45	0.23	0.34	0.30	0.09	0.04	0.27
0	3.56	0.74	0.82	0.76	1.42	0.55	1.31	11.63	1.95	0.07	9.38
1	12.92	3.85	4.71	3.68	9.78	3.40	4.43	54.50	33.31	0.50	66.20
2	23.18	14.12	12.05	18.91	6.47	16.37	18.22	20.95	39.82	33.84	18.12
3	8.99	7.20	5.10	10.43	2.74	7.87	29.24	6.78	24.58	65.26	5.92
4	0.07	1.82	0.07	2.10	6.87	3.56	16.65	0.68	0.23	0.30	0.01
5	1.83	0.99	3.83	2.95	10.30	6.79	5.52	5.14			
6	0.57	5.97	3.74	4.82	7.73	8.56	2.40				
7	3.58	6.96	8.38	5.94	8.54	8.29	1.35				
8	4.32	7.39	6.52	3.74	45.54	6.86	3.46				
9	39.90	50.88	54.19	46.09		37.53	17.07				
M	4.43	6.05	6.05	5.65	6.15	5.45	4.20	0.89	1.39	2.08	0.73
σ	3.09	2.70	2.75	2.76	2.44	2.71	2.73	1.07	0.72	0.36	0.64
Sk	0.05	-0.90	-0.91	-0.62	-0.75	-0.43	0.52	0.38	-0.01	-0.11	0.18
K	0.5	0.57	0.81	0.50	0.80	0.54	1.07	1.72	0.77	1.17	1.42
LOI	11.24	12.36	59.81	2.10	12.85	10.46	7.89	0.81	0.87	0.86	0.61

Phi Value	5.1	5.2	5.3	6.1	6.2	6.3	6.4*	7.1	7.2	7.3	7.4
-2		0.01	0.61	0.13	0.03	0.70	0.32	0.52	0.05	0.03	0.82
-1	0.28	0.07	1.99	0.45	0.09	1.34	0.60	0.44	0.13	0.25	1.80
0	3.45	1.29	21.12	2.55	0.28	4.00	2.83	1.59	0.25	0.34	15.94
1	20.23	9.33	59.98	40.40	0.86	28.26	29.49	48.04	1.58	0.35	66.86
2	42.49	20.54	14.33	34.98	1.99	22.61	24.95	46.34	9.20	3.04	13.55
3	23.82	68.28	1.87	10.19	15.57	42.93	11.83	2.97	36.18	42.41	1.00
4	1.59	0.49	0.10	1.40	26.78	0.15	5.58	0.11	13.58	20.51	0.03
5	0.21				9.39		5.46		4.15	3.25	
6	8.13			1.07	4.79		0.80		5.23	4.60	
7				1.76	8.17		2.11		4.13	4.13	
8				1.10	9.36		2.28		4.54	0.65	
9				5.95	22.69		13.78		20.97	20.45	
M	1.67	1.95	0.40	1.04	5.15	1.49	3.12	1.00	4.48	4.56	0.45
σ	1.22	0.57	0.66	1.70	2.21	0.87	2.84	0.52	2.49	2.35	0.60
Sk	0.24	-0.53	-0.03	0.51	0.31	-0.37	0.65	0.01	0.58	0.69	-0.08
K	1.66	1.49	1.25	2.83	0.56	0.78	1.08	1.00	0.61	0.74	1.29
LOI	2.33	1.45	0.59	1.74	12.02	1.18	23.67	1.53	1.51	7.01	0.53

Phi Value	8.1	8.2	8.3*	8.4	9.1	9.2	9.3	9.4	10.1	10.2	10.3*
-2	0.11	0.18	0.02	0.09	0.25	0.06	1.04	0.25	0.93	1.25	3.95
-1	1.19	1.26	0.17	0.48	1.98	1.68	5.65	0.27	1.68	6.26	5.85
0	5.54	0.76	0.21	4.25	3.82	6.35	3.11	12.30	5.57	2.94	1.87
1	56.41	0.37	0.21	50.85	30.70	52.44	3.13	80.06	52.08	1.08	0.84
2	26.84	0.66	1.04	40.70	37.79	16.64	2.85	6.60	33.10	1.02	0.98
3	2.87	3.60	11.58	3.57	13.03	2.77	5.34	0.51	6.51	1.34	1.01
4	0.90	18.46	19.67	0.06	1.83	5.25	4.45		0.51	1.97	0.13
5	6.17	13.00	9.55		0.47	1.87	4.52			1.42	3.05
6		8.52	7.45			0.22	10.34			6.16	5.08
7		7.48	2.98		0.61	0.36	4.78			6.85	3.70
8		14.17	12.80		0.24	1.24	12.80			13.85	17.77
9		31.54	34.31		9.29	11.12	41.99			55.88	55.78
M	0.93	6.07	4.84	0.95	1.49	1.62	5.89	0.44	0.89	6.86	6.93
σ	1.00	2.02	2.90	0.56	1.82	2.18	3.00	0.42	0.71	2.50	2.49
Sk	0.40	-0.29	-0.39	0.05	0.41	0.68	-0.76	-0.04	0.08	-0.89	-0.89
K	1.93	0.59	0.55	0.95	2.70	2.52	0.93	1.20	1.14	2.07	2.61
LOI	0.63	10.89	21.94	0.60	12.23	3.30	14.40	0.42	0.84	11.01	14.87

Key: refer to last page

STATION

Phi Value	10.4	11.1*	11.2*	11.3*	11.4	12.1	12.2*	12.3*	12.4	12.5	13.1
-2	0.15	0.48	0.22	0.35	0.75	2.17	9.89	4.36	5.02	0.18	0.49
-1	0.39	0.49	2.58	2.96	0.98	5.53	9.05	14.49	7.51	0.22	0.48
0	10.95	1.21	2.16	1.77	2.48	5.27	4.13	7.51	4.21	0.56	2.86
1	71.45	29.48	1.45	0.67	50.85	10.58	2.09	2.99	2.17	60.88	29.77
2	16.16	57.13	1.63	0.68	31.52	19.59	1.55	2.40	2.18	35.79	52.96
3	0.90	11.16	0.81	0.39	13.40	10.51	0.78	2.01	1.64	2.36	13.36
4	0.01	0.05	0.16	0.03	0.02	3.27	3.47	2.40	4.69	0.01	0.07
5				5.74			3.65	4.53			
6			5.41	9.17		1.67	2.80	2.83	0.04		
7			7.38	6.23		4.08	7.80	6.04	3.37		
8			14.19	3.38			5.06	5.10	9.95		
9			64.00	68.64		37.35	50.44	45.34	59.21		
M	0.57	1.27	7.55	7.30	1.07	3.73	5.01	4.76	5.42	0.95	1.28
σ	0.51	0.59	1.78	2.03	0.70	3.43	3.97	3.89	3.68	0.46	0.67
Sk	0.03	-0.02	-0.83	-0.87	0.25	0.29	-0.93	-0.76	-0.93	0.17	-0.07
K	1.20	1.01	3.60	2.10	0.87	0.57	0.60	0.51	0.91	1.04	0.99
LOI	0.43	28.96	28.21	22.13	0.46	10.58	27.85	14.55	12.46	0.44	0.33

Phi Value	13.2*	13.3	13.4	14.1	14.2*	14.3	14.4.	15.2	15.3*	16.1	16.2
-2	5.32	0.04	0.41	0.36	2.27	0.01	0.63	0.05		0.28	0.07
-1	7.77	1.71	0.68	0.29	4.80	0.11	1.11	0.17	1.33	0.97	0.56
0	7.57	17.50	10.27	0.72	2.79	0.11	3.67	0.10	5.98	2.34	.0.98
1	25.49	57.06	68.40	6.11	1.73	0.18	47.08	0.10	35.93	12.79	2.43
2	19.79	10.76	18.02	63.93	3.89	0.67	40.13	0.66	36.16	35.62	49.58
3	7.77	3.84	2.19	28.51	9.68	1.09	7.25	3.81	13.63	37.09	30.24
4	0.33	0.08	0.04	0.07	7.47	4.78	0.12	7.42	6.98	2.81	0.13
5					3.29	7.57		8.84		0.21	15.01
6	2.75				2.79	4.60		1.39		0.13	
7	1.64	0.32			6.53	7.79		7.06		1.01	
8	0.80	0.44			6.94	9.20		11.45		1.69	
9	20.77	8.27			41.81	63.89		58.96		5.07	
M	2.86	0.70	0.62	1.71	6.03	7.26	1.00	6.95	1.28	1.91	2.23
σ	3.74	1.76	0.58	0.49	3.01	1.46	0.67	1.77	0.97	1.63	0.96
Sk	0.48	0.49	0.05	-0.12	-0.85	-0.82	0.10	-0.86	0.12	0.24	0.41
K	0.85	4.20	1.32	1.04	0.77	1.31	1.00	1.19	1.09	2.67	1.22
LOI	14.16	2.43	0.92	0.93	48.94	43.10	0.56	24.52	27.58	8.97	3.30

Phi Value	16.3	17.1	17.2	17.3	18.1	18.2	18.3	18.4*	19.1	19.2*	19.3
-2	5.16	14.28	0.01	7.11	0.79	0.03	0.01				
-1	2.77	8.27	0.27	12.59	2.96	1.08	0.22	0.43	0.45	0.20	0.43
0	6.15	4.56	0.55	8.86	1.90	3.32	0.48	0.40	0.70	1.21	1.05
1	14.37	3.35	0.52	5.88	3.23	21.43	6.41	1.09	1.34	1.19	0.53
2	32.20	10.53	0.66	20.82	41.76	50.87	62.31	3.36	5.91	2.90	1.81
3	29.87	16.01	6.39	31.29	43.01	13.97	30.30	23.34	10.03	6.16	4.66
4	1.32	3.98	10.73	3.29	6.35	9.30	0.27	20.12	0.86	3.80	4.14
5	0.21	0.68	7.27	1.29				27.54	5.88	26.36	6.83
6	0.13	0.51	13.68	0.48				7.42	10.06	15.96	10.01
7	0.67	4.60	7.81	1.80				3.22	11.20	10.16	10.17
8		6.05	12.71	6.57				4.57	13.32	14.13	13.82
9	7.16	27.18	39.41					8.52	40.26	17.94	46.55
M	1.52	2.98	6.38	1.13	1.98	1.52	1.74	4.23	6.12	5.87	6.85
σ	2.16	4.05	1.99	2.42	0.85	0.90	0.50	1.79	2.41	1.94	1.85
Sk	0.02	0.11	-0.57	-0.13	-0.20	0.10	-0.12	0.24	-0.66	0.03	-0.78
K	2.58	0.49	0.72	1.24	1.43	1.32	1.04	1.22	0.88	0.83	0.96
LOI	3.30	11.63	17.2	4.02	3.72	3.05	0.66	15.41	26.08	22.97	25.55

Key: refer to last page

APPENDIX D (Con't)

STATION

Phi Value	20.1	21.1*	22.1	23.1	24.1*	25.1	26.1*	27.1	28.1	29.1
-2							0.02	0.04	0.08	0.10
-1	0.63	0.13	0.10		0.01		0.98	0.29	1.26	0.43
0	1.72	0.13	0.93		0.06		1.00	1.45	4.09	1.35
1	1.32	0.48	11.05	0.28	0.97	0.51	1.39	25.52	32.54	16.67
2	4.55	14.48	56.44	2.78	5.25	4.89	15.02	52.93	49.89	62.13
3	12.09	15.71	30.96	6.98	6.59	5.26	54.61	12.74	12.02	19.24
4	1.06	0.60	0.52	0.46	0.35	0.25	12.15	1.00	0.11	0.08
5	8.42	5.97		0.0	30.55	4.61	1.88	6.04		
6	21.00	8.64		7.93	12.08	7.34	0.13			
7	11.84	8.78		19.03	8.89	11.11	1.11			
8	37.37	45.20		62.53	35.27	19.29	3.47			
9						46.75	8.25			
M	5.29	5.24	1.69	6.71	5.61	7.09	2.80	1.46	1.17	1.50
σ	2.03	2.17	0.59	1.17	1.61	1.78	1.54	0.93	0.75	0.58
Sk	-0.48	-0.69	-0.10	-0.77	-0.14	-0.79	0.45	0.27	-0.10	-0.07
K	0.91	0.53	1.02	2.51	0.87	1.38	2.83	1.64	10.56	1.02
LOI	20.90	30.66	41.09	25.31	33.65	23.37	69.27	1.59	2.63	0.69

Phi Value	31.1	31.2*	31.3	32.1*	32.2	32.3	32.4	33.1	35.1	35.2*	36.1
-2		0.92	0.33	0.11	0.17	0.41	0.34	0.06	0.36	0.07	3.50
-1		5.20	0.21	0.32	1.42	3.09	0.95	0.11	0.31	1.59	1.84
0	N	2.93	3.38	0.50	1.64	3.20	9.47	0.20	0.44	1.21	7.32
1	O	2.34	59.05	1.40	1.21	2.69	69.19	1.50	11.26	0.96	36.26
2		4.66	31.29	5.81	3.67	6.15	17.41	13.47	71.66	4.13	30.54
3	D	5.64	5.72	15.00	6.12	6.55	2.62	14.44	15.94	5.08	20.41
4	A	0.23	0.04	2.61	3.28	0.21	0.01	10.45	0.01	0.07	0.13
5	T			1.08	0.13	3.29		0.76		0.0	
6	A	2.68		0.57	0.13	3.23		4.38		0.39	
7		5.42		5.79	4.16	6.51		3.46		4.98	
8		3.27		66.80	9.05	64.67		2.70		81.51	
9		66.70			68.02			48.47			
M		6.14	0.92	4.55	6.68	5.52	0.62	5.93	1.53	7.07	1.09
σ		3.04	0.59	2.08	2.29	2.51	0.59	2.61	0.49	1.13	1.01
Sk		-0.92	0.20	0.41	-0.89	-0.90	0.06	-0.75	-0.08	-0.69	-0.09
K		1.76	1.11	0.57	3.50	1.32	1.33	0.53	1.11	8.40	1.02
LOI		21.27	0.30	23.53	16.67	14.13	0.55	15.64	0.68	41.16	1.32

Phi Value	36.2*	36.3	37.1	37.2*	37.3	38.1	38.2	38.3	39.1	39.2	39.3
-2	0.03	0.32	0.13		0.03	0.35	0.02	0.13	1.00	0.17	1.48
-1	0.26	0.17	0.43	0.55	0.26	0.90	0.45	0.31	0.83	3.00	2.54
0	0.49	0.20	0.54	0.63	0.19	1.07	0.75	1.00	1.02	6.39	2.28
1	0.51	3.86	13.11	0.94	5.52	14.68	0.77	6.80	9.47	7.05	14.97
2	2.44	58.15	64.00	4.43	57.50	60.71	3.45	47.05	53.53	23.64	51.62
3	4.16	37.16	21.75	4.51	36.42	22.21	4.80	44.61	34.00	30.99	27.00
4	0.04	0.13	0.04	0.04	0.08	0.09	0.23	0.09	0.15	7.33	0.12
5										0.95	
6							3.58			1.02	
7	5.14			7.41			11.25			1.88	
8	5.38			2.93			4.35			2.42	
9	81.54			78.55			70.33			15.15	
M	8.07	1.82	1.57	7.75	1.79	1.53	7.50	1.81	1.69	3.62	1.48
σ	1.13	0.44	0.52	1.45	0.47	0.60	1.62	0.53	0.60	3.00	0.80
Sk	-0.69	-0.11	-0.09	-0.79	-0.14	-0.11	-0.86	-0.30	-0.22	0.47	-0.27
K	8.40	0.91	0.98	9.22	0.98	1.09	2.14	1.01	1.09	1.72	1.27
LOI	63.54	0.71	1.21	33.36	0.35	6.93	22.93	9.64	1.49	7.87	2.75

Key: refer to last page

APPENDIX D (Con't)

STATION

Phi Value	39.4	40.1*	41.1	42.1*	43.1	44.1*	45.1	46.1	47.1	48.1	49.1
-2	0.01	0.62		0.17	0.17	0.09	4.51		0.06	0.11	0.91
-1	0.13	1.31	0.47	1.14	0.53	0.63	7.08	0.12	0.32	0.68	1.82
0	3.52	2.18	2.29	4.86	1.74	0.89	8.47	0.29	0.71	5.96	3.44
1	30.47	4.17	4.28	19.40	8.67	2.82	33.02	4.24	7.36	45.07	25.62
2	45.39	12.47	9.41	14.36	31.64	9.48	30.45	31.68	38.24	35.72	60.38
3	20.44	20.87	15.82	19.44	40.38	17.00	5.09	8.25	26.87	3.58	7.71
4	0.05	0.47	7.81	4.43	4.59	3.92	0.07	3.04	1.94	8.87	0.13
5		2.21	5.38	3.69	2.14	0.82	0.73				
6		6.00	5.43	0.53	0.17	4.29	0.08	6.05	1.96		
7		4.37	2.83	2.67	0.68	1.42		23.47	3.25		
8		3.21	46.29	2.57	0.98	5.75	0.61	22.87	2.08		
9		42.12		26.72	8.30	52.90	9.89		17.21		
M	1.33	5.29	5.02	3.74	2.15	6.14	0.85	4.67	3.82	1.02	1.18
σ	0.69	2.87	2.34	3.15	1.63	2.63	2.13	2.33	2.80	0.91	0.68
Sk	-0.03	-0.35	-0.49	0.44	0.28	-0.90	0.19	0.40	0.71	0.17	-0.22
K	0.85	0.56	0.61	0.49	2.61	0.55	2.74	0.50	1.37	1.31	1.29
LOI	2.09	20.93	17.13	47.34	2.73	34.02	3.33	18.08	7.33	2.84	0.88

Phi Value	50.1	51.1	52.1	53.1	54.1	55.1	56.1	57.1	C23.1	C23.2	C23.3
-2	0.56	0.37	5.81	0.92	0.76	7.01	0.76		0.02	0.04	
-1	1.74	0.54	0.51	0.61	0.70	0.23	0.35	0.13	0.05	0.13	0.01
0	4.57	1.87	1.24	2.29	3.44	0.23	0.91	0.09	0.03	0.17	0.19
1	27.64	11.32	10.56	17.17	21.47	3.51	12.39	0.21	0.39	0.76	0.90
2	58.12	74.72	47.36	65.86	44.42	56.71	69.19	3.03	0.59	0.96	2.62
3	7.27	11.05	13.41	12.96	19.77	26.42	16.27	6.04	2.21	6.39	6.16
4	0.10	0.13	1.61	0.19	9.43	5.89	0.13	5.57	0.34	3.40	2.28
5			19.49					6.06		2.58	1.16
6								6.06		3.97	6.68
7								11.27	5.52	6.17	21.00
8								61.54	6.97	6.17	32.62
9									83.89	69.26	26.39
M	1.15	1.48	2.18	1.40	1.58	1.74	1.54	6.15	8.20	6.95	6.93
σ	0.69	0.51	1.76	0.62	0.95	1.09	0.54	1.57	0.44	1.89	1.59
Sk	-0.20	-0.10	0.13	-0.19	0.07	-0.21	-0.07	-0.84	-0.33	-0.87	-0.52
K	1.17	1.38	1.69	1.19	1.05	2.42	1.18	1.30	3.19	1.98	1.40
LOI	1.43	0.79	6.41	0.39	2.11	2.65	0.65	24.45	18.02	15.82	20.73

Phi Value	C23.4	C24.1*	C24.2	C24.3*	C24.4	C24.5	C25.1	C25.2	C25.3	C25.4	S-48
-2	0.01	0.05				0.13	0.27	3.33	0.15	0.12	0.03
-1	0.02	0.05	0.02		0.08	0.69	0.26	0.67	0.79	0.35	0.18
0	0.10	0.17	0.47	0.12	0.31	5.50	3.28	8.52	8.68	1.64	0.26
1	1.61	1.20	5.73	1.12	1.35	27.53	40.30	49.26	54.03	13.55	0.38
2	8.01	1.44	6.08	1.19	2.64	24.06	38.11	25.16	34.52	41.24	2.86
3	7.34	3.22	7.97	2.11	3.08	5.05	5.68	6.38	1.80	25.36	15.83
4	2.96	3.95	0.33	0.13	5.40	1.01	0.10	0.16	0.02	1.69	2.93
5	2.19	3.15			3.76	1.05		0.16		1.00	1.73
6	8.90	9.22	7.59	9.53	7.52	2.49	0.09	0.16		0.20	2.79
7	6.77	13.04	7.53	20.97	9.24	2.76	0.96	0.16		4.06	2.79
8	21.00	4.57	17.68	35.18	3.89	1.31	0.45	0.16		4.99	4.39
9	41.10	59.94	46.60	29.65	62.74	28.43	10.49	5.86		5.82	65.84
M	6.22	7.22	6.27	7.21	7.11	3.46	1.31	0.93	0.79	2.42	6.47
σ	2.37	1.63	2.59	1.00	1.80	3.20	1.68	1.78	0.61	1.99	2.36
Sk	-0.77	-0.84	-0.89	-0.35	-0.87	0.63	0.51	0.43	-0.05	0.57	-0.88
K	0.97	1.20	1.17	0.93	1.15	0.48	3.10	3.15	1.06	2.33	0.83
LOI	13.33	19.07	16.90	28.63	13.40	12.19	2.76	1.27	0.43	3.16	13.43

Key: refer to last page

APPENDIX D (Con't)

STATION

Phi Value	S-49*	S-50*	S-80*	S-97	S-99
-2			0.03	0.09	
-1		0.39	0.09	1.18	0.35
0	0.06	0.80	0.13	8.28	2.59
1	0.81	1.10	0.96	37.76	12.54
2	1.88	3.52	31.13	25.31	16.21
3	6.55	8.79	26.82	12.49	21.68
4	0.37	0.37	2.48	0.85	3.09
5		6.02	0.54	0.77	3.37
6	10.64	1.70	1.19	0.23	3.24
7	6.42	9.07	5.24	0.76	13.15
8	3.01	4.46	1.91		5.22
9	70.26	63.78	28.76	12.29	18.56
M	7.39	6.89	4.22	1.42	3.98
σ	1.63	2.03	2.65	1.95	2.96
Sk	-0.82	-0.87	0.68	0.51	0.42
K	1.62	1.43	0.56	2.08	0.62
LOI	18.13	20.94	9.61	2.57	4.71

Key:
*Sediment samples that were analyzed for pesticides, PCBs and heavy metals

M = Mean Phi
σ = Inclusive graphic standard deviation
Sk = Inclusive graphic skewness
K = Kurtosis
LOI = % Weight lost on ignition

Appendix E

Cluster Analysis for St. Lucie Estuary Sediment Samples

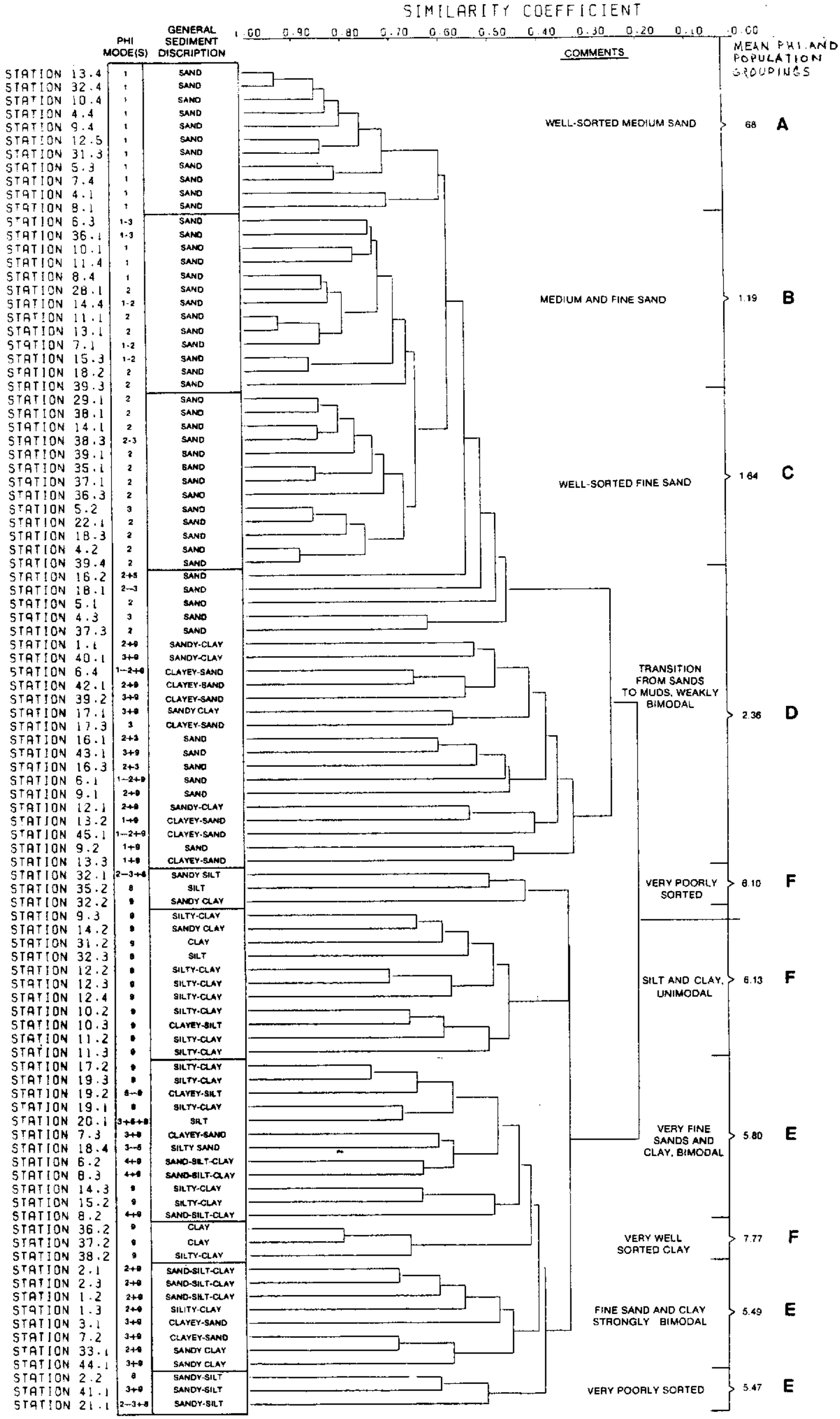

SIMILARITY COEFFICIENT
1.00 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.00
PHI MODE(S)
GENERAL SEDIMENT DISCRIPTION
COMMENTS
MEAN PHI AND POPULATION GROUPINGS
STATION 13.4 1 SAND
STATION 32.4 1 SAND
STATION 10.4 1 SAND
STATION 4.4 1 SAND
STATION 9.4 1 SAND
STATION 12.5 1 SAND
STATION 31.3 1 SAND
STATION 5.3 1 SAND
STATION 7.4 1 SAND
STATION 4.1 1 SAND
STATION 8.1 1 SAND
STATION 6.3 1-3 SAND
STATION 36.1 1-3 SAND
STATION 10.1 1 SAND
STATION 11.4 1 SAND
STATION 8.4 1 SAND
STATION 28.1 2 SAND
STATION 14.4 1-2 SAND
STATION 11.1 2 SAND
STATION 13.1 2 SAND
STATION 7.1 1-2 SAND
STATION 15.3 1-2 SAND
STATION 18.2 2 SAND
STATION 39.3 2 SAND
STATION 29.1 2 SAND
STATION 38.1 2 SAND
STATION 14.1 2 SAND
STATION 38.3 2-3 SAND
STATION 39.1 2 SAND
STATION 35.1 2 SAND
STATION 37.1 2 SAND
STATION 36.3 2 SAND
STATION 5.2 3 SAND
STATION 22.1 2 SAND
STATION 18.3 2 SAND
STATION 4.2 2 SAND
STATION 39.4 2 SAND
STATION 16.2 2+5 SAND
STATION 18.1 2-3 SAND
STATION 5.1 2 SAND
STATION 4.3 3 SAND
STATION 37.3 2 SAND
STATION 1.1 2+9 SANDY-CLAY
STATION 40.1 3+9 SANDY-CLAY
STATION 6.4 1-2+9 CLAYEY-SAND
STATION 42.1 2+9 CLAYEY-SAND
STATION 39.2 3+9 CLAYEY-SAND
STATION 17.1 3+9 SANDY CLAY
STATION 17.3 3 CLAYEY-SAND
STATION 16.1 2+3 SAND
STATION 43.1 3+9 SAND
STATION 16.3 2+3 SAND
STATION 6.1 1-2+9 SAND
STATION 9.1 2+9 SAND
STATION 12.1 2+9 SANDY-CLAY
STATION 13.2 1+9 CLAYEY-SAND
STATION 45.1 1-2+9 CLAYEY-SAND
STATION 9.2 1+9 SAND
STATION 13.3 1+9 CLAYEY-SAND
STATION 32.1 2-3+8 SANDY SILT
STATION 35.2 8 SILT
STATION 32.2 9 SANDY CLAY
STATION 9.3 9 SILTY-CLAY
STATION 14.2 9 SANDY CLAY
STATION 31.2 9 CLAY
STATION 32.3 9 SILT
STATION 12.2 9 SILTY-CLAY
STATION 12.3 9 SILTY-CLAY
STATION 12.4 9 SILTY-CLAY
STATION 10.2 9 SILTY-CLAY
STATION 10.3 9 CLAYEY-SILT
STATION 11.2 9 SILTY-CLAY
STATION 11.3 9 SILTY-CLAY
STATION 17.2 9 SILTY-CLAY
STATION 19.3 9 SILTY-CLAY
STATION 19.2 6-9 CLAYEY-SILT
STATION 19.1 9 SILTY-CLAY
STATION 20.1 3+6+9 SILT
STATION 7.3 3+9 CLAYEY-SAND
STATION 18.4 3-5 SILTY SAND
STATION 6.2 4+9 SAND-SILT-CLAY
STATION 8.3 4+9 SAND-SILT-CLAY
STATION 14.3 9 SILTY-CLAY
STATION 15.2 9 SILTY-CLAY
STATION 8.2 4+9 SAND-SILT-CLAY
STATION 36.2 9 CLAY
STATION 37.2 9 CLAY
STATION 38.2 9 SILTY-CLAY
STATION 2.1 2+9 SAND-SILT-CLAY
STATION 2.3 2+9 SAND-SILT-CLAY
STATION 1.2 2+9 SAND-SILT-CLAY
STATION 1.3 2+9 SILITY-CLAY
STATION 3.1 3+9 CLAYEY-SAND
STATION 7.2 3+9 CLAYEY-SAND
STATION 33.1 2+9 SANDY CLAY
STATION 44.1 3+9 SANDY CLAY
STATION 2.2 8 SANDY-SILT
STATION 41.1 3+9 SANDY-SILT
STATION 21.1 2-3+8 SANDY-SILT
WELL-SORTED MEDIUM SAND 68 A
MEDIUM AND FINE SAND 1.19 B
WELL-SORTED FINE SAND 1.64 C
TRANSITION FROM SANDS TO MUDS, WEAKLY BIMODAL 2.36 D
VERY POORLY SORTED 8.10 F
SILT AND CLAY, UNIMODAL 6.13 F
VERY FINE SANDS AND CLAY, BIMODAL 5.80 E
VERY WELL SORTED CLAY 7.77 F
FINE SAND AND CLAY STRONGLY BIMODAL 5.49 E
VERY POORLY SORTED 5.47 E

FIGURE 5 MEAN PARTICLE SIZE DISTRIBUTION OF SURFACE SEDIMENTS FOR THE ST. LUCIE ESTUARY

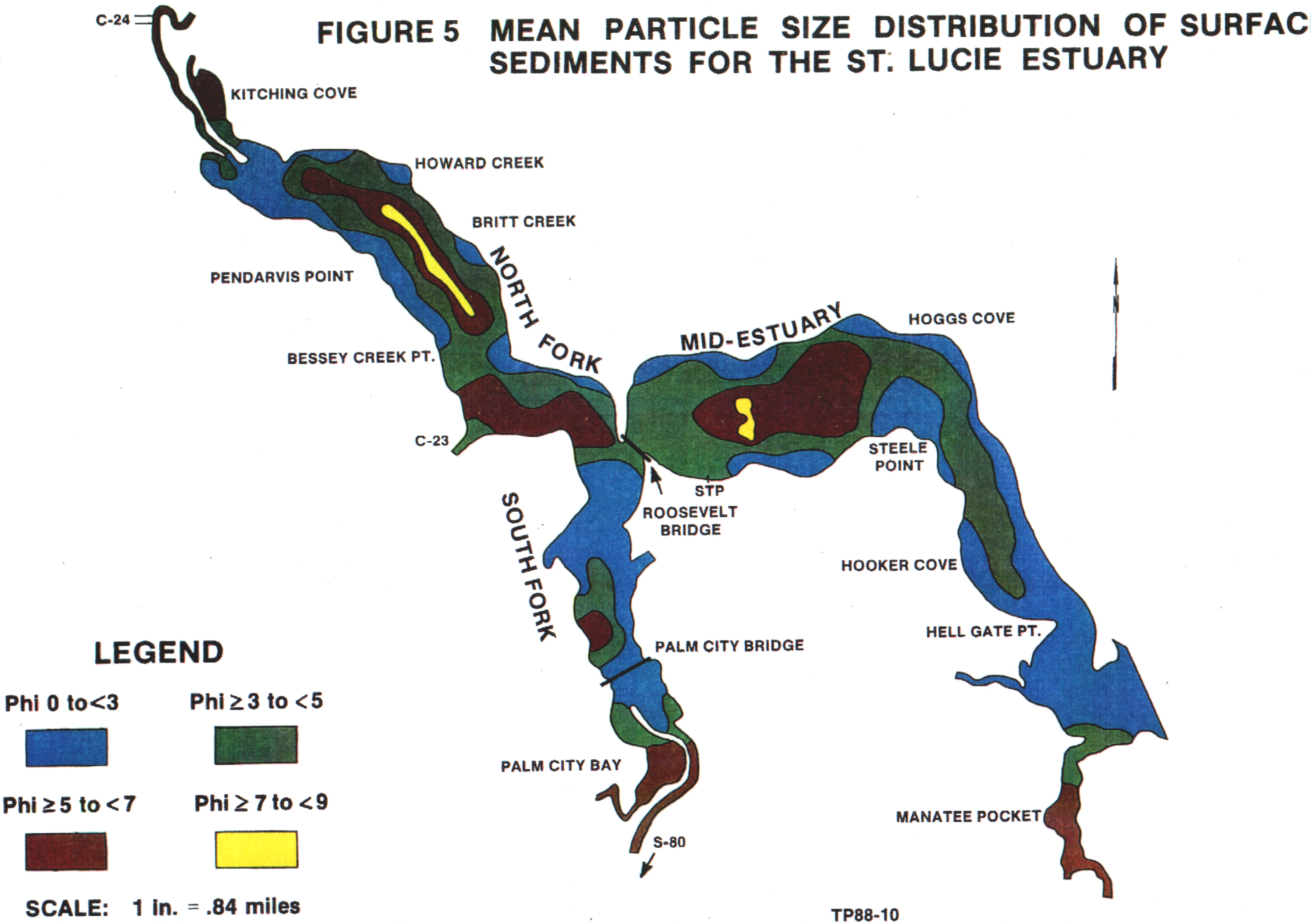
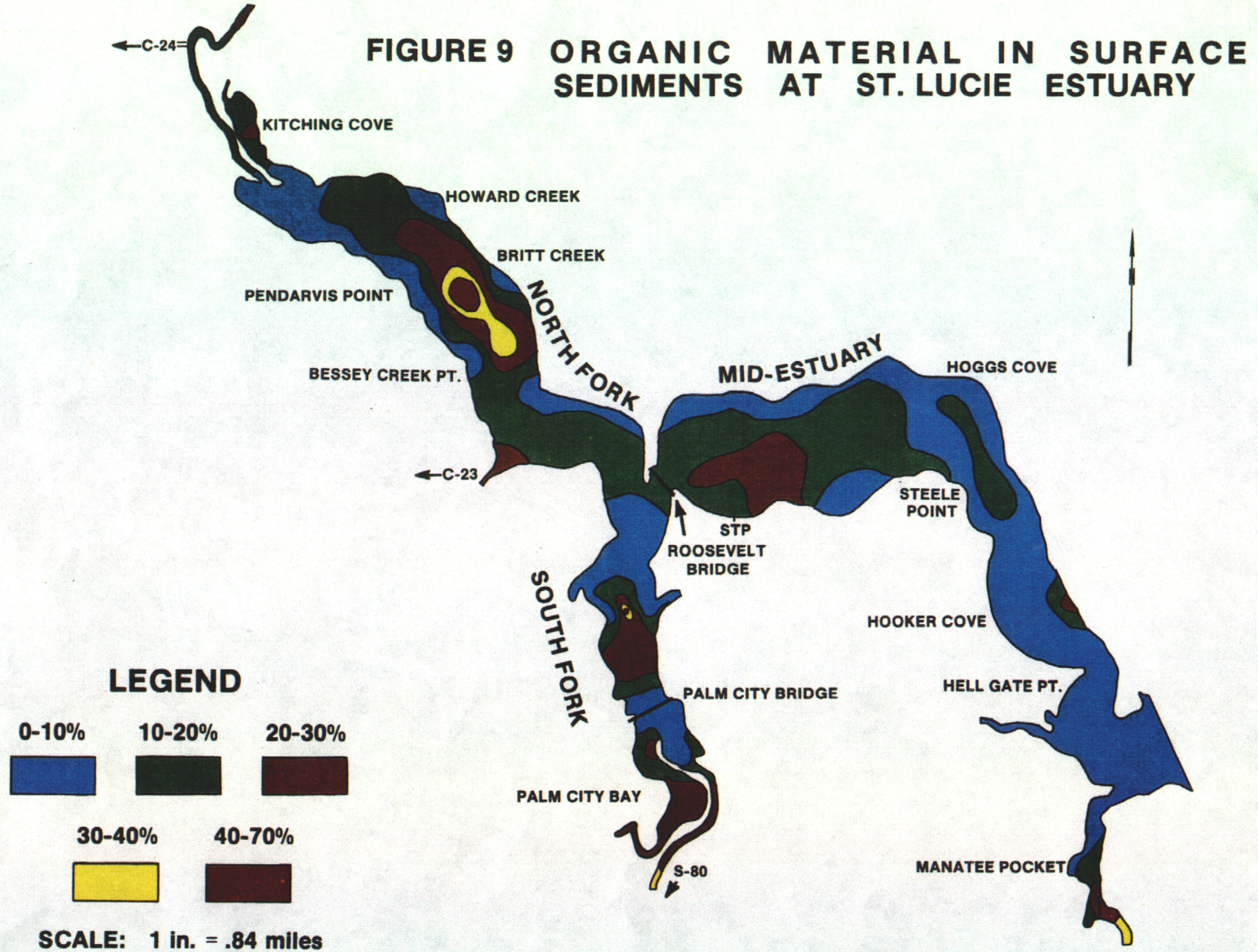


FIGURE 9 ORGANIC MATERIAL IN SURFACE SEDIMENTS AT ST. LUCIE ESTUARY



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