Second Annual Report

to the

John F. Kennedy Space Center, NASA

Cape Canaveral, Florida

A Study of Lagoonal and Estuarine Processes in the Area of Merritt Island Encompassing the Space Center

NGR 10-015-008

Covering the period 1 July 1973 to 31 August 1974

(NASA-CR-140601) A STUDY OF LAGOONAL AND ESTUARINE PROCESSES IN THE AREA OF MERRITT ISLAND ENCOMPASSING THE SPACE CENTER Annual Report, 1 Jul. (Florida Inst. of Tech.) 69 p HC $4.25 CSCL 08C

N75-10670

Unclas

G3/48 52752

Florida Institute of Technology

Melbourne, Florida

FOREWARD

This report on the work by the Florida Institute of Technology during the second year of the study of lagoonal and estuarine ecological processes in the area of Merritt Island encompassing the John F. Kennedy Space Center has been prepared in separate chapters. Each chapter covers the work of one principal investigator.

TABLE OF CONTENTS

Chapter I

A Summary Report

on the

Biological Sampling

of the

Lagoonal Complex Surrounding KSC

Presented to

NASA Kennedy Space Center

Grant No. NGR 10-015-008

Prepared by

K. B. Clark

J. Thomas

Taxonomic Studies

One of the major areas of concentration during F.Y. 1974 involved the compilation of a taxonomic list of marine animals in the Indian River. An important conclusion of this study is that diversity of the benthic community is substantially higher than expected. Though salinity eliminates certain major taxa (echinoids, asteroids, scaphopods), a total of 90 species was found in benthic grab samples (Table 1). About 45% of the invertebrate species in the Indian River have boreal or Carolinean geographic affinities, a surprising finding, since other Florida environments have predominantly Antillean affinities.

Larger invertebrates, those found on rock substrates, aufwuchs species, and those which are rare or otherwise not collected by grab sampler, are listed in Table 2. As aufwuchs species are highly seasonal, the total number of species on this list should increase significantly when seasonal investigations are completed.

Transect Analysis

The transectional analysis of the North Indian River benthic community has been completed, and is the basis of a masters' thesis (J. Thomas). As the manuscript is quite long, a copy will be forwarded separately to NASA. This report deals with the effect of major climatic factors on the diversity and structure of the benthic community. Depth, Eh (redox potential), organic carbon, the presence of rooted vegetation, and sediment characteristics have significant effects on diversity and community structure.

The redox potential (Eh) of sediments is a useful indicator of long-term oxygen availability relative to the availability of organic matter in marine sediments. During 24-hour sampling programs, we have found anaerobic conditions can occur nocturnally in shallow water areas (0.5 - 2m). As this condition may cause mortality of some invertebrates, low-oxygen conditions may limit species richness. If low oxygen conditions are common, Eh values tend to be low. As very low values (-900 mv) occur in some Indian River sediments, the relationship between Eh and diversity was analyzed (fig. 1). A highly significant statistical correlation of Eh and diversity was found for samples in grass-free areas.

Community Structure

A trellis diagram based on faunal similarity (Bray & Curtis, 1957) was constructed from benthic sample data collected in the transectional study (fig. 2). This diagram defines two discrete communities. The first, found at stations 1-4, is a shallow-water community dominated by Diplanthera and Cymodoceum. The second community, less well-defined, extends from stations 5 through 12. Stations 13-15 show little similarity among themselves or to the other stations, possibly indicating the effect of different environmental conditions than other stations, possibly the result of proximity to the city of Titusville and its attendant alterative influences.

Diversity Values

A variety of diversity indices are in general use for measurement of diversity in marine communities. One of the most widely used, the Shannon-Weaver index (H^1) quantifies diversity as number of species relative to the number of individuals in a population (Pielow, 1969). As sample diversity depends not only upon the number of species present but also upon how evenly the relative numbers of each species are distributed, we have calculated coefficients of evenness ($J^1 = \frac{H^1}{\log s}$) where s is the number of species and H^1 the diversity. These values are given in Table 4.

A less quantitative but more readily appreciated diversity index is Sanders' Rarefaction index (Sanders, 1968). Rarefaction values for the transect are

Figure 1. Relationship of diversity and sediment Eh

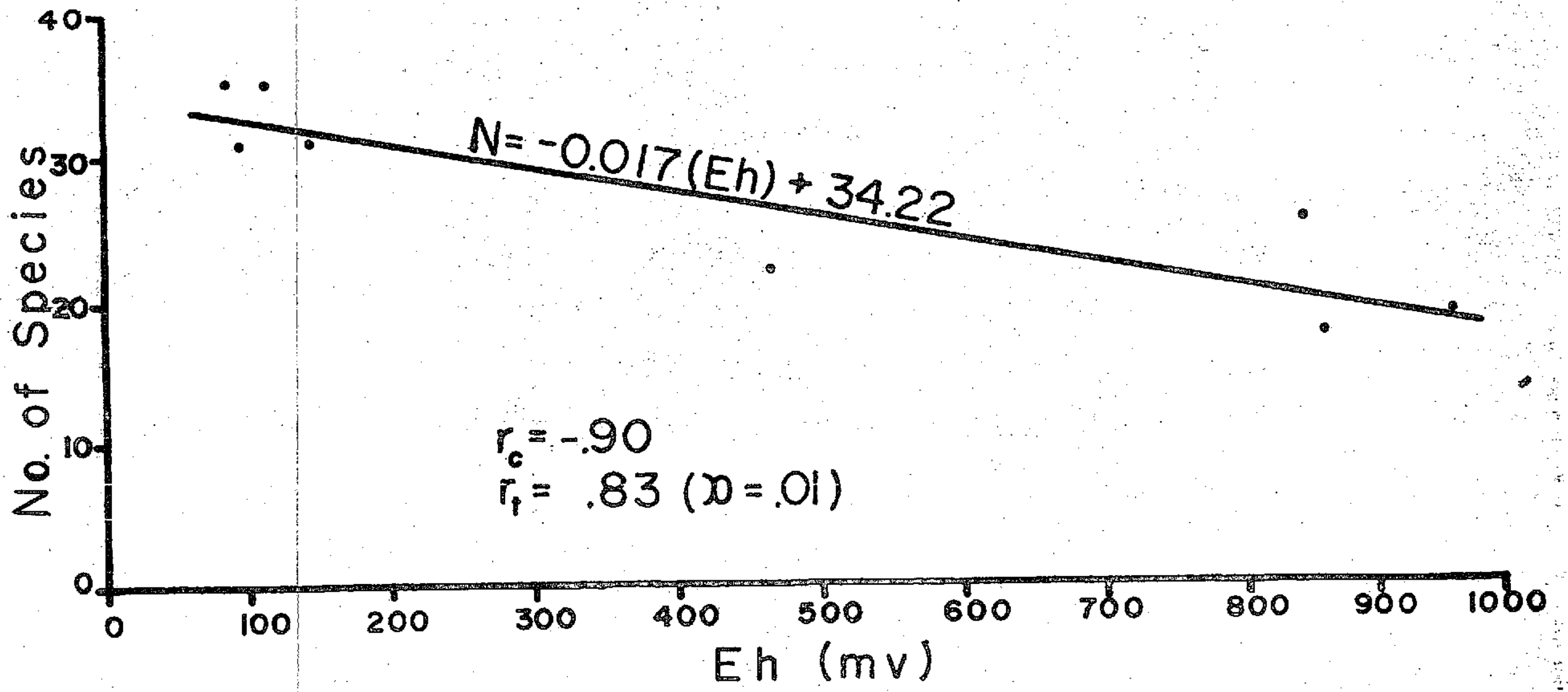
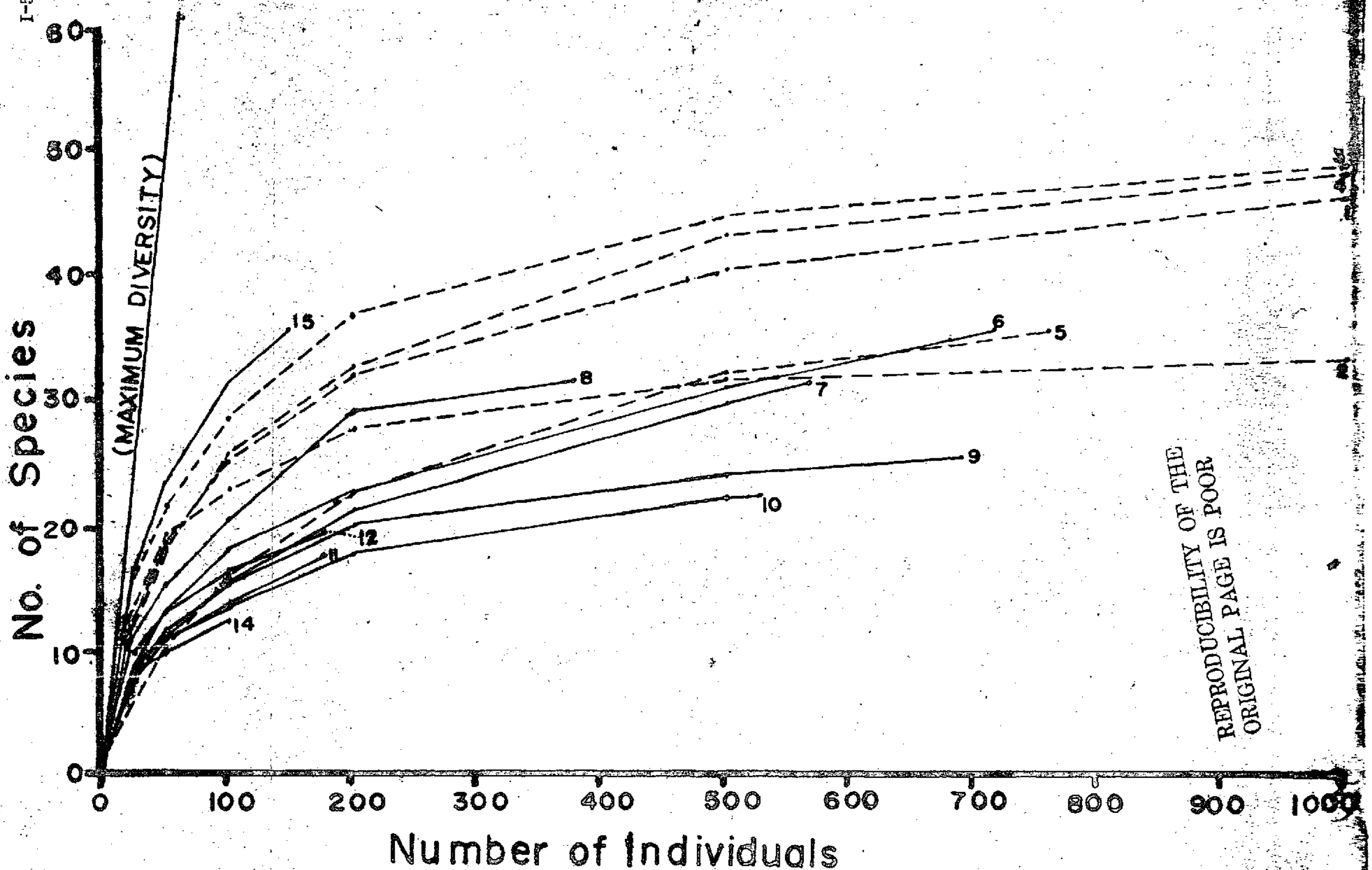


Figure 2. Trellis diagram of faunal affinity of transect stations TR-1 through TR-15

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1		77.1	83.3	72.9	55.1	52.8	52.3	45.4	48.4	47.5	37.7	41.4	0.2	31.4	37.1
2			72.2	68.5	59.6	53.3	56.6	44.4	56.0	51.1	43.9	47.8	0.3	30.5	[illegible]
3				80.5	59.2	54.0	53.7	50.0	53.1	52.5	40.0	43.3	0.3	34.0	58.3
4					68.3	53.3	47.1	46.4	52.3	48.4	35.7	46.8	0.3	22.2	[illegible]
5						74.6	69.2	67.9	53.1	60.9	45.0	49.9	0.5	31.6	53.1
6							65.9	64.3	57.7	57.1	51.2	54.2	0.6	34.2	[illegible]
7								69.4	62.2	57.1	50.0	58.5	0.7	38.3	66.6
8									65.2	55.8	58.5	52.4	1.1	34.3	[illegible]
9										71.8	60.6	52.6	0.6	33.7	54.0
10											60.0	62.9	0.8	36.7	58.6
11												62.1	2.2	34.8	43.9
12													2.2	37.0	47.8
13														3.8	2.6
14															41.0
15															

0 — 19.9 20-39.9 40-59.9 60-79.9 80-100

Figure 3. Rarefaction diversity curves, Stations TR 1-15



presented in figure 3. Greatly simplified, the higher the curve, the higher the species diversity of the sample. Highest diversity is found at stations with rooted vegetation (1-4), and somewhat lower diversity at deeper stations without rooted vegetation. The values of these curves approximate those of high-diversity tropical estuaries sampled by Sanders (1968), though climatic features would suggest that the Indian River should have somewhat lower values.

References Cited

Bray, J.R. and J. T. Curtis, 1957. Ecol. Monogr. 27:325.

Pielow, E.C., 1969. An Introduction to Mathematical Ecology. Wiley, N.Y. 286 pp.

Sanders, H. L., 1968. Amer. Natur. 102:243.

Sanders, H. L., and R. R. Hessler, 1969. Science 163:1419.

TABLE 1

Species Occurring in Indian River Benthic Samples

Cnidaria

Actinothoe gracillima

Nemertinea

Sp. 1

Nematoda

Sp. 1

Sp. 2

Polychaeta

Aglaophamus verrilli

Aricidia jeffreysi

Armandia agilis

Diopatra cuprea

Eteone heteropoda

Exogone hebes

Fabricia sabella

Glycera americana

Glycinde solitarea

Hydroides dianthus

Hypaniola grayi

Leiochone dispar

Lepidonotus sp.

Maldane sarsi

Marphysa sanguinea

Nereis succinea

Odontosyllis fulgurans

Pectinaria gouldii

Pista palmata

Platynereis dumerlii

Podarke obscura

Polydora ligni

Potamilla sp.

Prionospio sp.

Sabella crassicornis

Sabella microphthalmus

Scoloplos rubra

Stauronereis rudolphi

Syllis gracilis

Tharyx sp.

Sipuncula

Phascolion strombi

Mollusca

Bivalvia

Anadara transversa

Anomalocardia cuneimeris

Amygdalum papyria

Brachidontes exustus

Chione cancellata

Gemma sp.

Laevicardium sp.

Lyonsia hyalina

Mercenaria campechiensis

Mulinia lateralis

Nucula proxima

Tagelus divisus

Tellina sp.

Gastropoda: Prosobranchia

Caecum pulchellum

Cerithiopsis emersonii

Cerithium muscarum

Crepidula convexa

Crepidula plana

Eupleura sp.

Mitrella lunata

Nassarius vibex

Prunum apicinum

Turbonilla interrupta

Urosalpinx sp.

Gastropoda: Opisthobranchia

Acteocina candei

Bulla striata

Cylichna (Cylichnella) alba

Haminoea antillarum

Odostomia sp. 1

Odostomia sp. 2

Polycera aurisula

Anthropoda

Pycnogonida

Callipallene brevirostris

Crustacea

Amphipoda

Ampeliscidae sp. 1

Caprella equilibra

Corophiidae sp. 1

Cystosomidae sp. 1

Lysianopsis alba

Microdeutopus sp.

Cirripedia

Balanus sp.

Cumacea

Oxyurostylis smithi

Decapoda

Alpheus heterochelis

Pagurus annulipes

Panopeus herbstii

Isopoda

Cyathura sp.

Erichsoniella attenuata

Sphaeroma quadridentatum

Ostracoda

Cylindroleberis mariae

Cythereis sp.

Sarsiella americana

Tanaidacea

Tanais sp.

Echinodermata

Ophiuroidea

Ophiophragmus filograneus

Holothuroidea

Holothuria sp.

Synapta inhaerens

Phoronida

Phoronis architecta

TABLE 2

Invertebrates Collected other than by Ponar Grab Samples

Cnidaria

Aurelia aurita

Edwardsia sp.

Eudendrium aff. *ramosum*

Leptogorgia virgulata

Obelia aff. *dichotoma*

Pennaria tiarella

Bryozoa

Amathia convoluta

Bugula sp.

Zoobotryon verticillatum

Mollusca

Bivalvia

Atrina rigida

Gastropoda: Prosobranchia

Fasciolaria tulipa

Gastropoda: Opisthobranchia

Aplysia wilcoxi

Cratena pilata

Godiva sp. nov.

Phidiana lynceus

Stiliger funereus

Stiliger fuscatus

Stiliger sp. 3

Tenellia fuscata

Arthropoda

<u>Callinectes sapidus</u>

<u>Limulus polyphemus</u>

<u>Menippe mercenaria</u>

<u>Penaeus</u> sp.

TABLE 3

Vertebrates Observed in Marine Areas of Kennedy Space Center

Pisces	
Archosargus probatocephalus	Sheepshead
Bagre marinus	Sail catfish
Brevoortia tyrannus	Menhaden
Centropomis undecimalis	Snook
Chilomycterus schoepfi	
Cynoscion regalis	Speckled trout
Dasyatus americanus	Stingray
Elops saurus	Ten-pounder
Haemulon sp. 1	
Haemulon sp. 2	
Hippocampus sp.	Sea horse
Mugil cephalus	Mullet
Opsanus tau	Toadfish
Paralichthys lethostigmus	Southern flounder
Prionotus sp. 1	
Prionotus sp. 2	
Scomberomorus sp.	
Spheroides spengleri	Spiny puffer
Tarpon atlanticus	
Reptilia	
Malaclemys terrapin	Diamondback terrapin
Mammalia	
Trichechus manatus	Manatee
Tursiops truncatus	Bottle-nosed Dolphin

TABLE 4

Summary of Diversity Values at Transect Stations

Sta.	Depth(m)	Sample size	Total Species	Diversity (H^1)	Evenness (J^1)	% Carbon	Sediment Eh(mv)
1	0.22	2008	49	4.53	.81	2.11	-320
2	0.47	1463	34	4.99	.98	1.21	+192
3	0.54	1361	50	5.54	.98	1.23	-460
4	0.85	1314	49	4.24	.75	0.91	-130
5	1.40	759	35	1.66	.32	0.72	-110
6	1.90	716	35	3.50	.68	0.93	- 82
7	2.00	568	31	3.45	.70	0.96	- 93
8	2.00	376	31	2.93	.62	0.62	-142
9	2.25	689	25	3.73	.80	0.82	-835
10	2.25	527	22	3.95	.88	0.72	-462
11	2.00	175	17	2.14	.56	0.74	-850
12	2.20	177	19	2.35	.59	0.86	-940
13	3.25	4	3	0.90	1.00	2.18	-915
14	2.25	100	12	2.28	.70	0.98	-790
15	2.50	148	35	3.70	.81	0.34	-700

Chapter II

A Summary Report

on the

Microbiological Studies

of the

Lagoonal Complex Surrounding KSC

Presented to

NASA Kennedy Space Center

Grant No. NGR 10-015-008

Prepared by

T. A. Nevin

W. L. Blevins

C. Noble

Microbiological Studies

Introduction

As a result of the first year's efforts two avenues of research opened. The first of these stemmed from the characterization of the bacterial flora in sulfide mud beds under the waters adjacent to the Kennedy Space Center.(1) The second from repeated observations of the vanishingly small amounts of dissolved nitrogen compounds available in the area waters.(2)

Present endeavors were directed to the activities of the more nearly marine type of salt dependent microorganisms, indigenous to, or adventitiously present in the area waters.

The primary method used for eliciting bacterial response was the well recognized enrichment culture technique. In practice test compounds were dissolved in suitable quantities of lagoonal water which had been prefiltered through a coarse filter to remove suspensions of large particles. The solutions were then sterilized, and aliquots added to specimens of lagoonal water which had been collected in presterilized containers.

Sulfur Metabolism

The production of what seemed to be hydrogen sulfide during aerobic incubation of lagoonal water enriched with small amounts of nutrient broth (Difco) was noted during preliminary experiments. Therefore, quantitative experiments were conducted to aid in explaining this unexpected observation.

Sulfide, sulfite and sulfate levels were determined in freshly prepared enrichments, and again in parallel enrichments after 48 hours incubation under aerobic and anaerobic conditions. Sulfide (3) was determined by iodometric titration of acid liberated H_2S gas which had been trapped in cadmium chloride at pH 1-2. Sulfite (4) was determined by iodometric titration of the "cell free" menstruum, and corrected for $S^{=}$ content by difference. Sulfate (4) was determined by barium precipitation. The data are presented in Table I.

Under aerobic conditions, remarkably large amounts of sulfate disappeared, as did also occur to a lesser extent under anaerobic conditions. This probably represents the utilization of sulfate as a hydrogen acceptor by various members of the mixed flora which grew. This aspect of the data was held for later pursual.

The amounts of iodometrically titratable materials which had been thought to be sulfite were increased markedly under both conditions of incubation, but was three times greater in surface water samples incubated under anaerobic conditions than those incubated under aerobic conditions. The bottom water samples (collected 3 to 6 inches above the sediments) yielded similar differences. Both yielded greater

Table I

Changes in sulfide, sulfite and sulfate (mg/l) levels in samples of lagoonal water enriched with nutrient broth after 48 hours incubation under aerobic and anaerobic conditions.

	$S^{=}$	$SO_3^{=}$	$SO_4^{=}$
Aerobic			
Surface Water	+0.004	+5.00	440
Bottom Water	-0.016	+7.25	540
Anaerobic			
Surface Water	+0.02	+16.75	350
Bottom Water	+0.002	+18.30	240

amounts than did the surface water samples, however the anaerobic culture yielded about 2.5 times more than the aerobic culture.

Sulfide production was not greatly evident under aerobic conditions, but did occur under anaerobic conditions although the amounts recovered were not large. These data did, in fact, establish that production of hydrogen sulfide under aerobic conditions continues to be unusual, in fact, sulfide can serve as a substrate for the production of the reactive substance. Further studies of "sulfite" production were then undertaken.

A suspension of bacterial cells was obtained by enriching several liters of lagoonal water, incubating anaerobically for 48 hours, then harvesting by centrifugation. The cells were washed once in sterile lagoonal water, then suspended in 50 ml of sterile lagoonal water. The suspension was divided between two dialysis bags, one of which was then heated at 100°C. for 15 minutes to kill the cells. Each bag was then placed into a container of sterile lagoonal water to which a measured amount of sodium sulfite had been added. Sulfite and sulfate levels were determined immediately after introduction of the dialysis bags, and again after four hours incubation. Thereupon the bags were opened, the cells separated by centrifugation and sulfate and sulfite levels determined in the supernatant.

Table II

Changes in sulfite (mg/l) levels as effected by "resting" bacterial suspensions(1) in dialysis sacs

	Initial (tank)	Final tank	Final sac	Net change in sac
Live cells				
$SO_3^{=}$	7.50	2.20	12.20	+6.90
Killed cells				
$SO_3^{=}$	9.5	3.80	6.70	+1.00 (2)

(1) in sterile river water with added Na_2SO_3

(2) initial (tank) - final (tank) + final (sac)

The initial level of sulfate, 2.5 gms per liter was about that which is usually encountered in lagoonal water samples. About the same amount of sulfate disappeared from both containers, thus in the present context no immediately useful purposes were served by this ion. Sulfite ions, however, migrated into the dialysis bags and seemed to remain there. The numbers, however, indicate much greater amounts of sulfite in the bag containing live cells; an increase of 6.9 mg/l over that which could be explained by the amount added. A small increase is also evident in the bag containing killed cells, but may only reflect a residue of inactivated enzymes. The sulfite data are summarized in Table II.

These data did not support the possibility that the intermediate formed was sulfite, therefore a series of qualitative tests were carried out in order to gain some idea of its nature.

The "cell free" supernatants of freshly grown enrichments were known to react with iodine, and also reacted positively with sodium azide in the presence of iodine, which is a highly sensitive test for sulfur present as sulfhydryl, disulfide, or thiosulfate groups [5]. Dithionates and polythionates do not react with iodine[5]. The malachite green test for sulfite, bisulfite and metabisulfite [5] and the mercuric chloride test for thiosulfate [5] were negative.

Having eliminated the most probable inorganic sulfur compounds, attention was directed toward the more common organic sulfur compounds. Cystine and cysteine both react in the iodide-azide test, but methionine does not. Thus, the field was reduced to either an -SH group or a -S-S group.

Qualitative tests of the samples for thiols using an alkaline solution of cupric chloride and hydroxylamine [5] were strongly positive, as was the alkaline decomposition test for primary and secondary thiols [5]. That the sulfur was present as an -SH group or thiol was established by reaction with mercuric nitrate [6].

Thiols are generally soluble in diethyl ether, and can be extracted from aqueous solutions with this solvent. So too was the iodometrically reactive substance formed during incubation of the enrichment cultures. Solubility of the reactive substance in ether automatically eliminated the amino acids cysteine, cystine, methionine and the peptide glutathione since none of these are soluble therein.

The reactive substance, having been extracted from the supernatant medium, was made ether-free by evaporation. The resulting deposit was dissolved in a small amount of water. A 50% solution of mercuric nitrate was added, and a yellow-white precipitate formed. This substance was strongly reactive in the azide-iodine test, and is considered to be a thiol (mercaptan). Final identification is in progress.

Nitrogen Metabolism

In continuing studies of the lagoonal system of the Central East Coast of Florida (2), it has been a usual observation that combined nitrogen could not be detected in the waters by the methods employed. The noted deficiency may be explained plausibly by any of a number of arguments. Few of these, however, admit of ready experimental evaluation.

An approach to the problem employs the indigenous heterotrophic, moderately halophilic bacteria. These creatures are expected to have relatively simple but somewhat exacting requirements for nitrogenous nutrilites (7, 8, 9). They should, therefore, assimilate rapidly, any soluble nitrogenous compounds available.

Methods and Materials

Samples of lagoonal waters 6 to 10 liters each were collected by immersing clean, sterile bottles 3 to 6 inches below the surface, removing the cap and allowing the bottle to fill. After filling and still below the surface the cap was replaced, and the collected samples were stored in the cold. They were ordinarily used within 24 hours. The temperature, pH and salinity of the water were determined at the sample site.

Several one hundred milliliter aliquots of the sample were dispersed into sterile amber glass bottles, and each was enriched with 10 mgs. of a single amino acid (NBCo.). In all, 20 amino acids were so used. The enrichment cultures were then incubated at room temperature (25 degrees C) in the dark for 72 hours. Infrequently, the incubation was continued for an additional 24 hours in the hope that a greater cell crop would be obtained. The appearance of visible turbidity indicated a successful enrichment, and relative amounts of growth were estimated by percent transmittance at 600mu in a Spectronic 20 colorimeter. Gram stained preparations of each enrichment culture were examined microscopically. Those amino acids which proved to be growth supporting enrichments were then studied in all available combinations to determine any growth enhancing effect of multiple additions.

Four control cultures were carried in parallel. These were 100 ml amounts of lagoonal water enriched with: 5 ml of sterile reconstituted nutrient broth (Difco) which was replaced by a peptone solution in later experiments; or 0.05 mgs. of yeast extract (NBCo.); or 7.6 mgs. of NH_4Cl; or unenriched as a control on indigenously supported growth.

The MPN of organisms which would grow upon enrichment with amino acids was estimated using raw lagoonal water serially diluted from 10^{-2} through 10^{-6} with sterilized lagoonal water. Aliquots of each dilution were then inoculated into each of 5 tubes containing a sterile solution of the best growth producing combination of amino acids in lagoonal water. Eight isolates were obtained in pure culture from this experimentation and have been tentatively identified at the genus level.

A mixture of vitamins including thiamine, pyridoxine, p-aminobenzoic acid, pantothenic acid, niacinamide, biotin and folic acid were used as enrichments of the lagoonal water and were also added to single amino acid enrichments to establish their effect if any. So too were an ethanol-, ether-chloroform soluble fraction of yeast extract, the insoluble residue, and an acid hydrohysate of the residue.

Results

Visible evidence of the bacterial growth (cloudiness) occurred when any one of the amino acids: tyrosine, histidine, proline, serine, cystine, methionine or glycine was used as an enrichment for lagoonal water. Several varieties of gram negative rod shaped organisms, both motile and non-motile, as well as cocci and spirilla were always found. The nutrient broth enriched and yeast extract enriched controls, although yielding denser growth did not support a broader variety of organisms.

Of the possible combinations of the 7 amino acids, the following groups produced 5% or greater reduction in light transmission at 600mu: serine, methionine, proline; cystine, proline, histidine, glycine; serine, histidine, cystine, glycine, methionine. Glycine seemed to inhibit growth where either, or both, cystine and tyrosine were present, but the inhibition was not apparent when serine and histidine were also present. The addition of either cystine or methionine to any other non-inhibiting combination of amino acids always seemed to enhance growth, thus suggesting a need for supplemental organic sulfur.

The most probable number of organisms which could be grown by amino acid enrichments of water samples taken from 6 different sample sites are presented in Table III.

Table III

MPN[1] (100 mls) of organisms in river water enriched with 6 [2] amino acids

Sample #	MPN x 10^3
S - 25	2.8
S - 26	9.2
S - 27	0.8
S - 28	22.0
S - 29	35.0
S - 30	35.0

[1] Previous data also indicate 10^3 to 10^4 organisms when MPN's were determined in thioglycollate medium prepared with distilled water, but these were gram (+) spore formers.

[2] Glycine, methionine, proline, histidine, cystine, serine.

extract was also carried out. The "lipid" fraction, so obtained, was then added to several combinations of enrichments of sterile lagoonal water. The resulting media were inoculated with pure cultures of 6 of the 8 isolates with only slight enhancement of growth.

The extracted residue however, yielded excellent growth. This effect was obviated when the residue was hydrolyzed at 100C with 12 N HCl for 4 hours. The Biuret (for peptides) and Molisch tests (for carbohydrates) which were rather strong before hydrolysis, were greatly diminished in intensity. Upon the addition of glucose to each of two products of the acid hydrolysate exceptionally good growth was obtained using the solid residue, but no significant effect was noted when the acid soluble fraction was used. These data are presented in Table V.

Table V

Influence of Y.E. derived enrichments on the growth of lagoonal halophils

Enrichment	Probable Major Component			
	Peptide(Biuret)	C H_2O (Molisch)	Lipid(Sudan IV)	Growth % Trans.
EEC[1] soluble	trace	trace	strong	93
EEC insoluble	strong[3]	strong	not done	61
Acid hydrolyzed[2] EEC insoluble				
a) Acid soluble	negative	negative	not done	100
Glucose + soluble	"	(glucose=trace)	"	95
b) Solid	trace	negative	not done	86.5
Glucose + solid	"	(glucose=trace)	"	39

1) Ethanol-diethylether-chloroform(3,1,1,)
2) 12 N HCl, 100°C, 4 hrs.
3) equivalent to that of an 8 mg/ml soln. of crystalline Bovine albumin. A trace was equivalent to 0.5 mg. of CBA.

Table IV

Substitutions for amino acids as lagoonal water enrichments

Substituent	Growth as % transmission at 600mu
Peptone	86
Peptone + NH_4^+	93
Glucose	98
Glucose + NH_4^+	98
6 Amino acids	95
6 Amino acids + yeast extract	70
Yeast extract	60
Yeast extract + NH_4^+	80
Unenriched control	100

That they are present in appreciable numbers is evident, however, only 4 genera were tentatively distinguished; Vibrio, Benecka, Agarbacterium, and Pseudomonas according to criteria in Bergeys' Manual (ref.).

The cell crop was improved by substituting for the amino acids more complex materials. The results of these experiments are presented in Table IV. At this point, a commercial peptone was substituted for the more complex nutrient broth hitherto used as a control. Yeast extract also proved an excellent growth enhancing substance. Further, the indigenous organisms do not use NH_4^+ even when supplied with glucose as a source of organic carbon. It is, in fact, evident that NH_4^+ is distinctly inhibitory to these organisms since their growth is greatly diminished when the ion is added to an otherwise good enrichment.

In order to gain some insight into the growth enhancing effect of yeast extract, a mixture of known water soluble vitamins was added to the amino acid enrichment, but this had no demonstrable effect. An ethanol-ether-chloroform extraction of the yeast

Definition of the probable requirements for carbohydrates, as indicated in Table V, should enable publication of this material.

References

1. Beazley, R. W. T. A. Nevin, & J. A. Lasater. Haloduric Anaerobes in the Sulfide Muds of a Saline Lagoon. Bull. Environ. Contam. and Toxicology 12, 346-354, 1974.
2. Study of Lagoonal and Estuarine Ecological Processes in the Area of Merritt Island encompassing the Kennedy Space Center. Second Semi-Annual Report to the National Aeronautics and Space Administration, Kennedy Space Center, Fla. under Grant No. 10-015-008, 1973.
3. Akimoto, D., Survey of the Benthos at Two Sites in the Indian River for Sulfide Ions. M.S. Thesis, Florida Institute of Technology, June, 1971.
4. Standard Methods for the Examination of Water and Waste Water. 13th Ed. New York, American Public Health Assoc. 1971.
5. Fiegl, F., V. Anger and R.E. Oesper Volume I, Spot Tests in Inorganic Analysis, Volume II, Spot Tests in Organic Analysis, Elsevier Publishing Co., New York, 1966.
6. Karchmer, J.H. The Analytical Chemistry of Sulfur and its Compounds. Wiley Inter-science, New York, 1970, Part I.
7. Waksman and Selmen, "Marine Bacteria -- Recollections and Problems," Woods Hole Oceanographic Institution. Papers in Marine Biology and Oceanography. New York: Pergamon Press, 1955, III.
8. Dundas and Halverson, "Arginine Metabolism in Halobacterium salinarium, An Obligately Halophilic Bacteria," Journal of Bacteriology, 1966.
9. Kayamure, Yoshihiko and Takada. "Effect of Sodium Ions on the Nitrogen Utilization in a Halophilic Strain," Translated:Mycological Society of Japan, 1974.

Chapter III
A Summary Report

on the

Physical Aspects

of the

Lagoonal Complex Surrounding KSC

Presented to

NASA Kennedy Space Center

Grant No. NGR 10-015-008

Prepared by

P. S. Dubbelday

Physical Aspects

Introduction

The water movement in the lagoonal system presents an important aspect in the understanding of the chemical and biological processes. The currents transport chemical constituents, nutrients and biological organisms, and thus are a necessary link in the dynamics of the system. They carry pollutants through the system, and a predictive capability on their behavior may reduce potential damage, or indicate corrective measures.

In simplified one-dimensional modeling the details of the current structure are sometimes replaced by an effective (longitudinal) dispersion coefficient. As a matter of scaling it is clear that this approach may be useful for long duration processes, in the order of years or decades. For short term understanding and prediction a much finer sampling is needed.

Both the a priori opinion on the system, and experience gained by observation asserted that the lagoonal systems under study are essentially wind driven. Therefore it was decided to measure surface currents by current crosses in conjunction with local winds. To assess the overall effect of global wind on the expanse of the lagoons, the transport through Haulover Canal was measured as a function of the water level difference at its extreme ends, and correlated with the overall wind pattern.

The details of these studies are contained in two theses;

1) "A study of the circulation in the lagoons encompassing the Kennedy Space Center," by R. E. Dill, Florida Institute of Technology 1974

2) "A study of the transport of water through the Haulover Canal," by D. R. Browne, Florida Institute of Technology 1974

These theses are added as an appendix to the report, and references to the literature are found there .

The substance of these theses is adapted for submission to be published respectively in "Limnology and Oceanography", and "Estuarine and Coastal Marine Science."

The main results are summarized in the following sections.

2. Transport through Haulover Canal

The surface current was measured by a current cross; the transport per unit width by a velocity averaging free falling instrument. The level difference along the canal was determined by stilling well type gauges, the movements of the float were recorded by a self contained recorder. Wind vectors were provided by the Canaveral Weather Station.

The results for average velocity as a function of level height difference show a satisfactory fit by the Chè formula

$$V = \frac{R^{2/3} S^{1/2}}{n},$$

where R is the hydraulic radius, (= 3.74 m here) S the surface slope, and n the Manning roughness coefficient. By least squares fit n was determined to be 0.0215 $sm^{-1/3}$.

There was little difference between surface current and average current indicating an almost uniform profile.

The cross sectional area of the canal is about 203 m^2. To give a typical value, a water level difference of 10 cm gave a surface current of 0.75 m/s (1.5 knots), and a total transport of 150 m^3/s through the canal.

By maximizing the correlation coefficient and current it was determined what direction of wind is optimal in driving the current through the canal. For current from the Indian River to Mosquito Lagoon this optimal wind direction was about 225^o, or SW; from Mosquito Lagoon to the Indian River the optimal wind direction was close to 360^o or due N.

The data were not sufficient to establish time constants, and as a consequence it was not attempted to fit wind versus transport data by an empirical curve.

3. Surface currents in lagoonal areas

The results from this study show in general a close relation between local wind and surface current, to the extent that other driving forces (astronomic tide, runoff) can be excluded as important to the circulation.

Details of the relation, though, are dependent on the history of the wind vector, and the details of the bathymetry.

As a consequence, it is not appropos to establish a supposedly direct relation between surface current and local wind, as some authors attempt to do. In this study the current varied all the way from 0.3 % of the wind speed to 1.8 % of the wind speed (at 10m height).

The history of the wind enters into the picture through the establishment of slope current. If the wind starts blowing over the quiescent lagoon, a stationary vertical velocity profile is established in about 5 minutes (order of magnitude only). The ensuing transport will cause a pile up of water against the shores, and a "slope current" will build up forced by this water level difference. The pertinent time constant depends on the length measure of the water surface in the direction of the flow: for a crosswind therefore stationarity may be established in about one hour, for a lengthwise wind stationarity might not be achieved in the time of permanence of the given wind pattern.

Evidence of the time constants involved are shown by some examples in the thesis by Dill (p.47 ff).

The wind set-up does not only influence the vertical current profile as to strength, but also may produce a direction variation of the current with depth.

The graphs of current vectors show also that wind driven currents can exist in fairly shallow water ($\sim$ 50 cm deep). Further, the effect of causeways is apparent: the openings in the causeways act as "leaks" in the almost closed lagoons, and the current is forced by the wind set up to much larger values than would be possible by direct action of the wind stress.

Chapter IV

A Summary Report

on the

Sediment Analysis

of the

Lagoonal Complex Surrounding KSC

Presented to

NASA Kennedy Space Center

Grant No. NGR 10-015-008

Prepared by

E. H. Kalajian

Sediment Analysis

The texture of the bottom sediments in the Indian River (Area 1 and 2) and Mosquito Lagoon (Area 3) has been compiled from data taken at the sampling stations. These are shown on Figures 1, 2 & 3. Where available, data on organic carbon in percent of dry weight has also been presented.

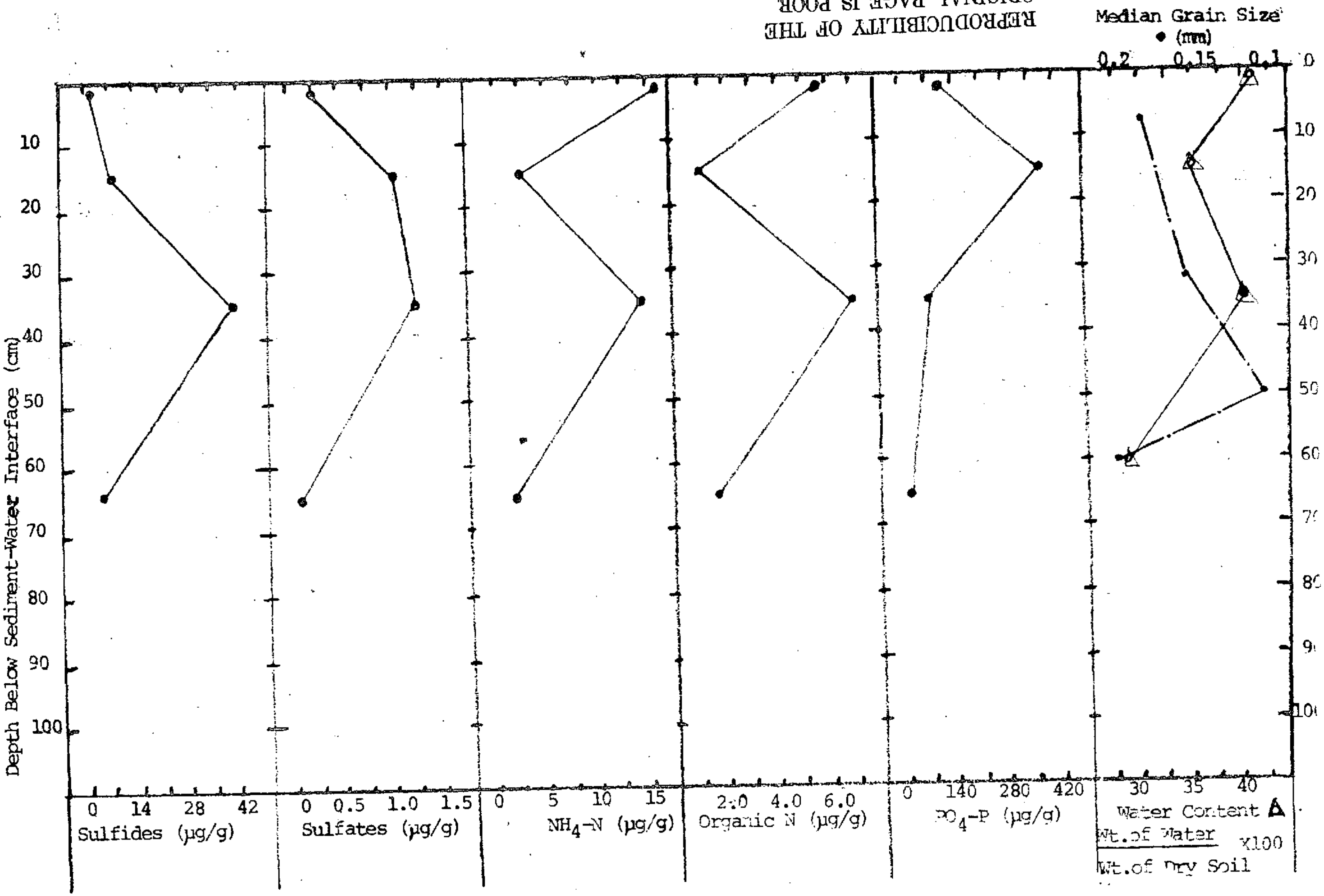
The sediments are predominately a fine sand with shell or trace of shell material. Variations occur with depth for the cores and shell layering or bonding frequently occurs in many of the cores. The effect of burrowing of benthic organisms has been observed in many of the cores.

Silt and silty sand appear at certain locations with the silt occuring at deeper water depths such as near Titusville (water depth 10') or south of the railroad bridge (water depth 21'). Color of the wet sediments were compared with the Munsell color chart. Colors ranged from 2.5Y3/1 (very dark gray) to 5Y4/5 (olive).

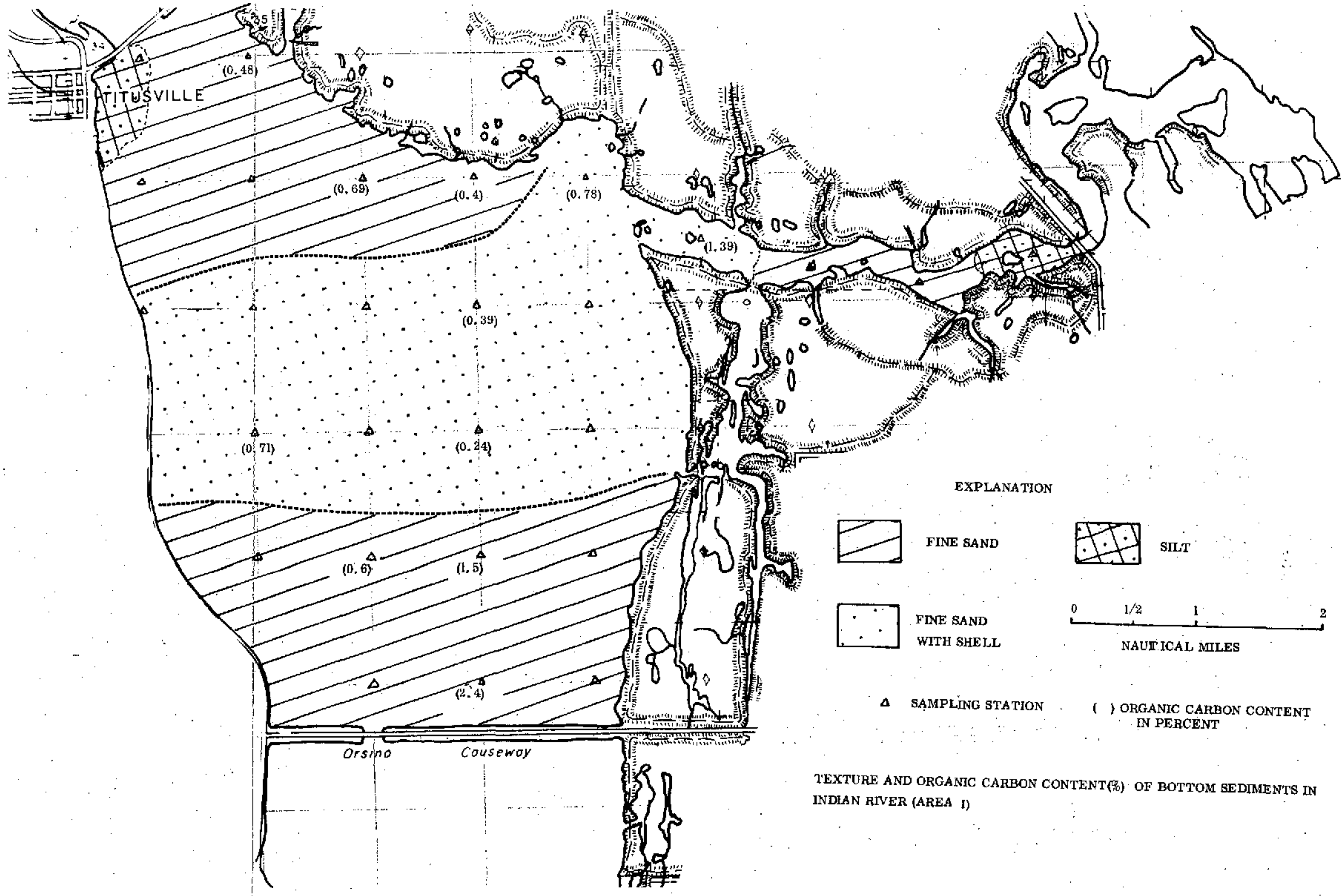
Organic carbon contents of bottom sediments ranged from 0 to 2.4% with the majority of the sediments having values of less than 1%. These values compare well with other coastal locations for sediments of similar texture. Additional effort in this phase of the work will take place during the next contract year with emphasis on using Environmental Protection Agency criteria, for chemical analysis of the sediments.

One core from Banana Creek has extensively been analyzed using wet chemistry methods and the results on chemical stratigraphy on Core 1-17 are given in Figure 4. No conclusions can be drawn from this work at present.

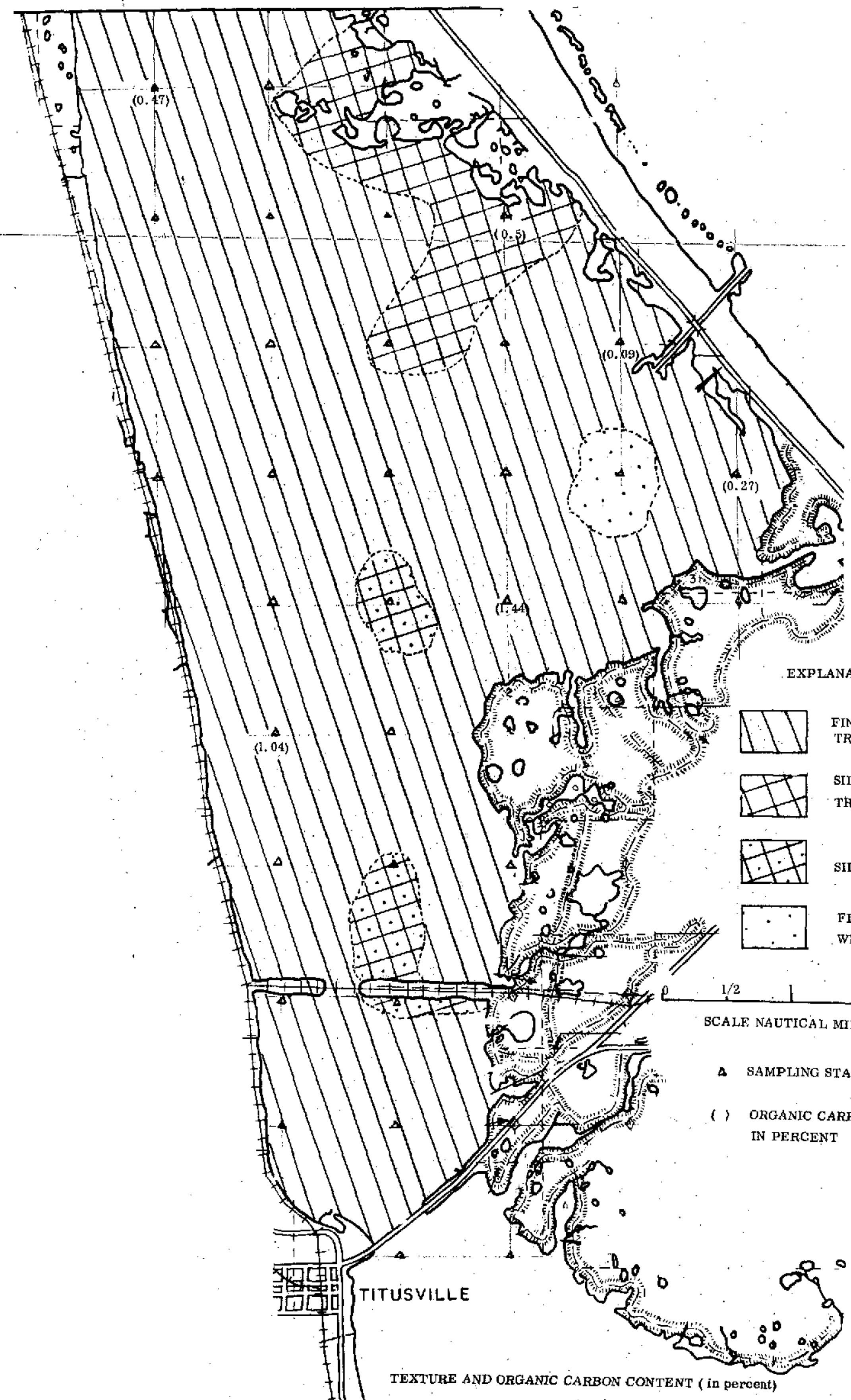
Equipment for testing the filtering aspects of sediments on hypergolic fuels has been set up in the laboratory by an undergraduate student. Permeability tests on the sediments have been conducted and safety procedures for handling the fuels have been reviewed. Testing will begin shortly and will be concluded this fall.



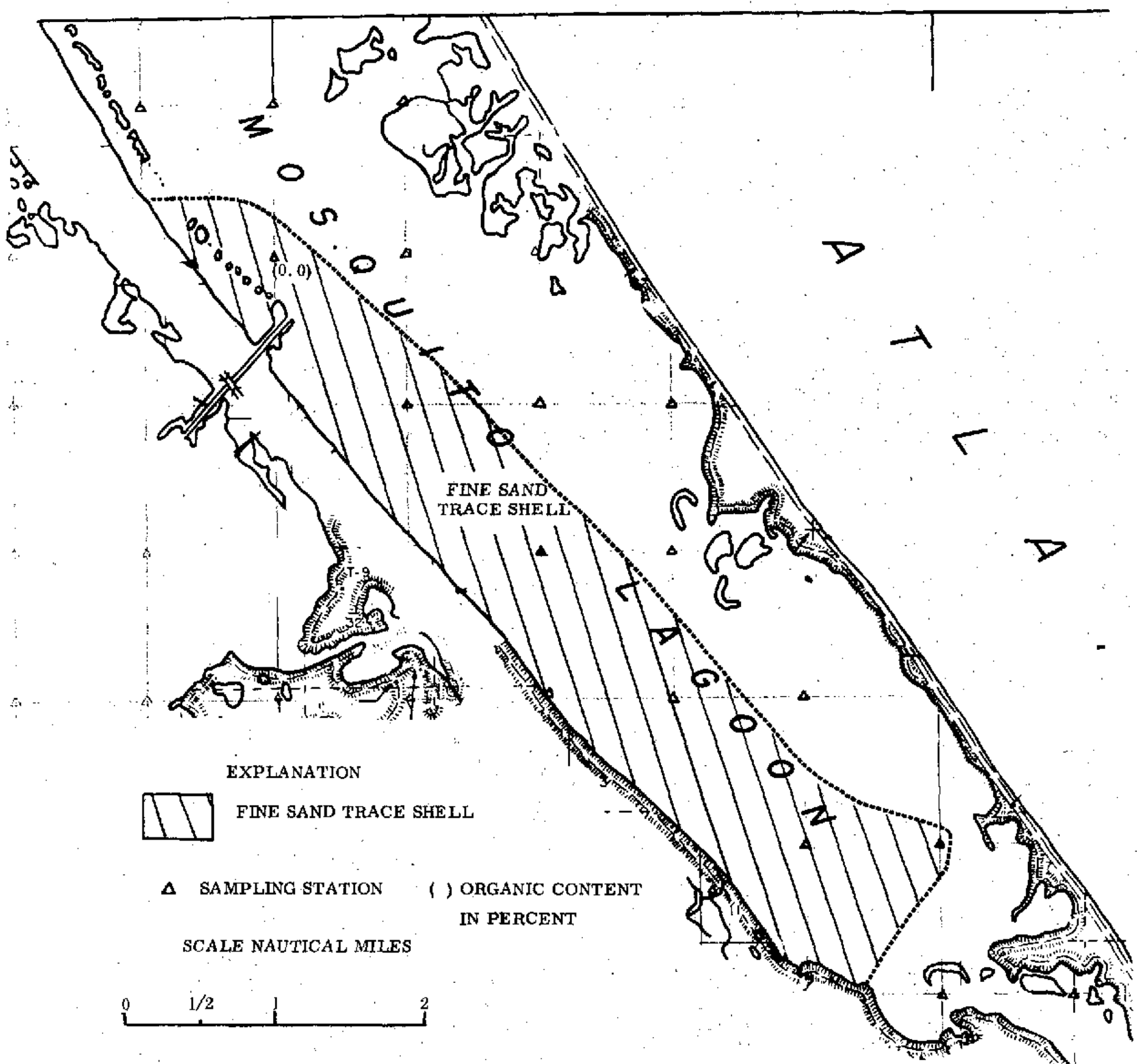
Chemical Stratigraphy of Banana Creek Sediment, Site 1-17



TEXTURE AND ORGANIC CARBON CONTENT(%) OF BOTTOM SEDIMENTS IN INDIAN RIVER (AREA I)



TEXTURE AND ORGANIC CARBON CONTENT (in percent)
OF BOTTOM SEDIMENTS IN INDIAN RIVER (AREA 2)



NOTE: MANY OF THESE CORES 3-3, 3-4, 3-9 HAVE STRONG OUTHOUSE OR INDUSTRIAL WASTE ODOR. STATIONS 3-7, 3-9, and 3-12 HAD POCKETS OR LAYERS OF SILT AND CLAY.

TEXTURE AND ORGANIC CARBON CONTENT (in percent) OF BOTTOM SEDIMENTS IN MOSQUITO LAGOON (AREA 3)

Chapter V

A Summary Report

on the

Water Quality Parameters

of the

Lagoonal Complex Surrounding KSC

Presented to

NASA Kennedy Space Center

Grant No. NGR 10-015-008

Prepared by

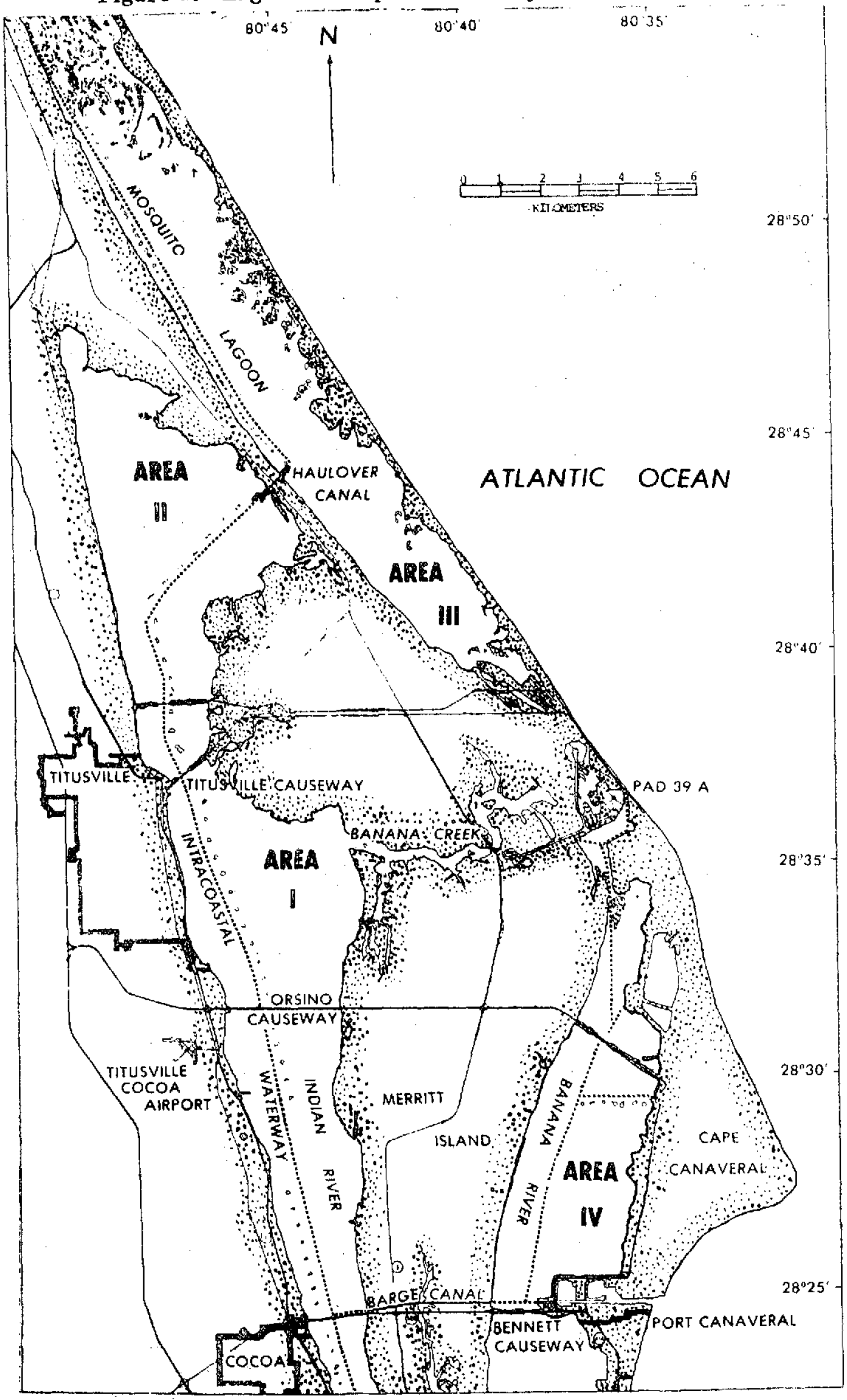
J. A. Lasater

1.0 Introduction

Kennedy Space Center (KSC) situated on Merritt Island is located at the apex of the three principal components of the lagoonal complex of East Central Florida comprised of Indian River Lagoon (formerly Mosquito Lagoon), the Indian River, and the Banana River (Figure 1). The latter two segments are misnomers since all of these waters are saline and are near classical examples of lagoons; however, there are areas of these waters where there is significant influx of fresh waters and the lagoons have estuarine character.

Man-made structures have significantly altered the geophysical nature of these lagoonal waters. Historically man-made influences began with the construction of the Intracoastal Waterway, in the late 1920's and early 1930's since this project resulted in the breaching of a narrow, low-lying land bridge between the northern reaches of the Indian River and the southern extremes of the Indian River Lagoon by the structure known as Haulover Canal. Haulover Canal allows a significant exchange of water between the norther part of the Indian River and the southern portion of the Indian River Lagoon. Subsequent man-made modifications include numerous (21 throughout the complex) land-filled causeways, canals (e.g. Canaveral Barge Canal), and other structures (e.g., Saturn V Crawlerway). Thus, man's activities have, on one hand, caused an increased interaction (e.g., Haulover Canal & Canaveral Barge Canal) between the various segments of the lagoonal complex and a diminution of the interaction (e.g., land-filled causeways, and Saturn V Crawlerway). Therefore, the lagoonal complex consists of a series of distinct basins which slowly but measurably interactivate one another. Consequently, the entire complex must be treated as a single entity with the segments which are remote from a given locale exercising a minimal influence. It follows that the portions of the Indian River south of Sebastian Inlet and the lagoonal complex north of Ponce de Leon Inlet may be considered of secondary importance with respect to their influence on the

Figure 1. Lagoonal complex in vicinity of KSC



lagoonal waters in the vicinity of KSC (Figure 2).

1.1 Climatological/Geophysical Aspects

East Central Florida has a subtropical climate with short, mild winters and hot humid summers. In general the weather pattern of the lagoonal complex is dominated from April to October by east to southeast winds generated by the Bermuda anticyclone. In the fall, usually the latter part of October, the prevailing winds shift to the north and/or northwest. Since the bulk of the circulation and mixing process are winddriven, the prevailing winds and the immediately preceding meteorological conditions are of the utmost significance in developing an understanding the observed chemical constituents concentrations. Although over one-quarter of the lagoonal waters have a depth of two feet or less, dredged portions (i.e., Intracoastal Waterway) have depths of 12 feet or more. A wind speed of 15 knots produces a well-mixed water column (i.e., uniform chemical parameter values) to a depth of 12 feet.

Annual rainfall (Cape Canaveral) is of the order of 48 inches per year. Summer precipitation is usually associated with thunderstorm activity and can be highly localized; whereas, the winter rains are generally associated with frontal activity and the distribution is reasonably uniform. However, the bulk of the rain usually falls during the period from mid-June through October. Although rainfall is the primary source of fresh water entering the lagoons, the amount of fresh water derived from the St. Johns River and subsurface aquifers is insignificant. It should be noted that all of the urban centers abutting the lagoonal complex utilize them as a sump for both sanitary and storm sewer effluents. In addition vast volumes of water derived from land drainage projects are ultimately shunted into Indian River, but lesser amounts find their way into the Indian River Lagoon and the Banana River.

Although the mean depth of the lagoons is five (5) feet, the extensive areas of shallow waters combined with the warm climate,generally yellow to grey bottoms, and relatively high light intensity results in high evaporational rates especially during the warm but low precipitation periods (e.g. drought periods). Consequently, there are areas of the lagoons where the evaporation/influx (from land run-off) are approximately in balance over a yearly cycle. Although these areas evaporation/influx have natural origins, mans-activities have increased the tendency (e.g., the northern reaches of the Banana River).

Since the prevailing winds are seasonally almost bidirectional (i.e., east/southeast spring to fall and north/northwest fall to spring), there is a net transport of water (winddriven) along the longitudinal axis (SE to NW) of the lagoons. The basinal characteristics of the lagoon tend to reduce the net transport, but observed motions in unrestricted portions of the lagoons show water motions ranging from one (1) to four (4) cm/sec (water motion of 1 cm/sec corresponds to a lineal transport of 1/2 mile/day). Therefore, there is slow transport of water from one basin into an adjacent one depending upon the direction of the wind. It follows then, that a sustained meteorological pattern can result in water from a relatively remote basin being transported into an area of interest.

1.2 Program Objectives and Sampling Procedures

Prior to the initiation of the existing water quality evaluation program, extensive discussions were conducted with NASA personnel as to the nature of the program. It was generally agreed that it should be consistent with the State of Florida requirements (e.g. Chapter 17-3 of the Administrative Code of Florida) and those of the Environmental Protection Agency (EPA) of the federal government. Consequently, most of the particular measured parameters were essentially predetermined; however, a degree of flexibility in the program was reserved by the participating members of the F.I.T. staff.

It is patently evident that no program of the scope of the project in question could be accomplished without a certain number of indigenous problems becoming apparent. One of the first problems was with respect to sampling scheduling. It is obvious from an idealistic standpoint, for all of the data to be acquired within a relatively short period of time, but realities must prevail. Thus, the data was assembled by progressive sampling of the pertinent areas over a time span of three (3) to five (5) days. At first glance, the time interval appears excessive from a synoptic standpoint, but if one considers the time rate of change of the parameters especially during meteorologically quiescent periods, it is evident that the approach used is the only practical option available. Thus, it must be accepted that the several day interval required to assemble the data for the various portions of the lagoonal complex become minimal on a long term basis since statistical treatment is the only rational one which can be employed.

Statistical evaluation of an area generally requires prodigenous amounts of data in order for the evaluation to be a sound one. It was on the basis of extensive amounts of data which led to the sampling pattern ultimately designated. That is, a sampling pattern was sought which would have the following attributes:

1) As uniform density as possible
2) Unbiased as to location, and
3) Readily transferable from one map to another

A sampling pattern which was adjudged to meet the above criteria was to utilize the latitudinal-longitudinal coordinates of the area in question and to establish a sample station at the intersection of each minute of arc of latitude and longitude. Admittedly, this approach yielded a rather close spacing of sites, but it did fulfill the basic criteria noted above, but it also provided sufficient data to be amenable to statistical evaluation.

2.0 Data and Results

All experimentally observed values were assembled and treated statistically. This analysis included on a yearly basis for the total area, each of the four (4) subareas on a yearly basis, total area and subareas on a quarterly and monthly basis. The results of the analysis of the total area for the year 1972 is illustrated in Table I and the subareas in figures 3 through 6.

Similar evaluations were made on the data collected in 1973, and a comparison of the statistical results showed that 1973 was somewhat more moist than 1972, but the average values remained within the standard deviation for 1972.

Shorter time intervals yielded similar average values to those observed for the yearly basis, but the variations were not as large. Differences observed for the same calendar periods for different years reflect the prevailing meteorological conditions.

Due to the general consistency of the statistical evaluations, it is believed that an adequate basis has been established to define the "lease-line" conditions. In addition further mathematical processing will permit a selection of a limited number of sampling stations which reflect the characteristic behavior of the lagoonal complex on a long-term basis.

Statistical evaluations are of importance in establishing the "expected values" for particular parameters; however, analysis of the statistically derived values in conjunction with numerous other observations and studies give every reason to believe that the fundamental process can now be identified. Past efforts in this direction are being continued and the development of an overall evaluation of the lagoonal complex appears highly promising.

TABLE I

Total Area Data for Year 1972

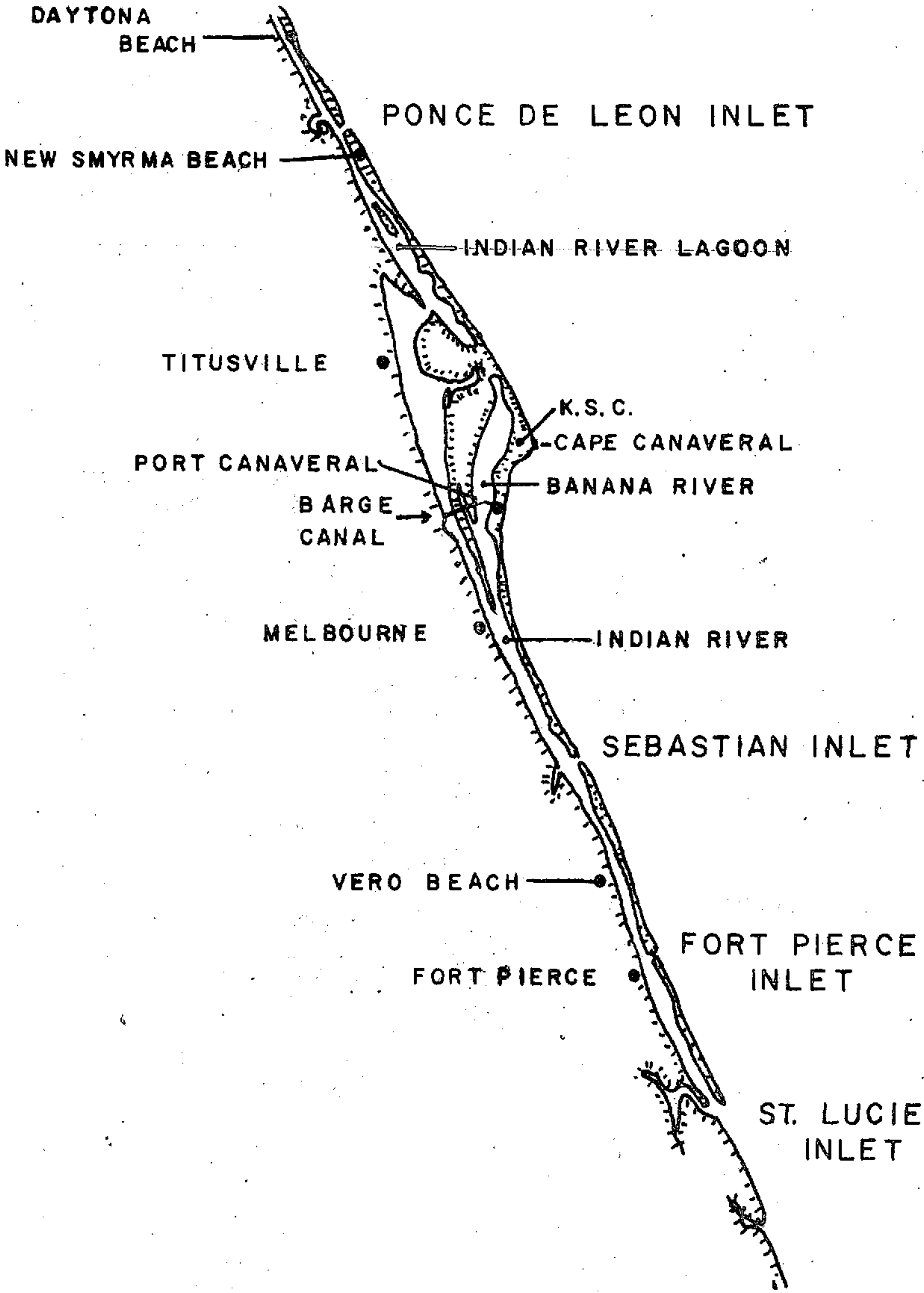
	Ave.	St. Dev.	Min.	Max.
Temperature °C	28.6	1.8	23.5	33.0
Salinity °/oo	27.8	3.78	10.0	39.0
pH	8.0	0.4	6.7	8.9
Dissolved oxygen ppm	5.2	0.8	3.2	7.0
Nitrate ppm	0.08	0.03	0.02	0.21
Phosphate ppm	0.08	0.08	0.0	0.66
Turbidity J.U.	28.0	21.0	10.0	206.0

°C = degrees centigrade

°/oo = parts per thousand

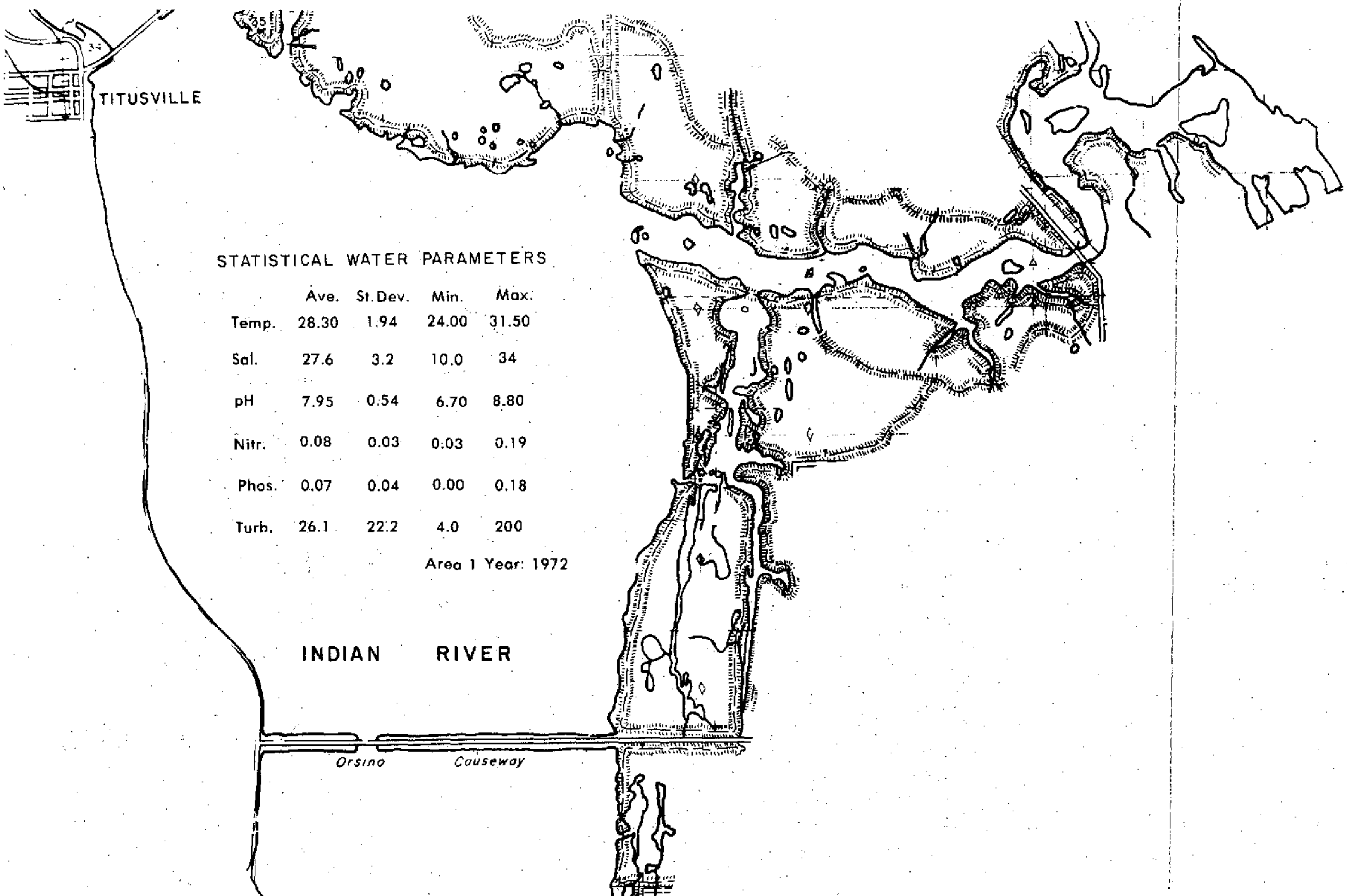
ppm = parts per million

J.U. = Jackson units



LAGOONS OF EAST CENTRAL FLORIDA

FIG. 2



STATISTICAL WATER PARAMETERS

	Ave.	St.Dev.	Min.	Max.
Temp.	28.30	1.94	24.00	31.50
Sal.	27.6	3.2	10.0	34
pH	7.95	0.54	6.70	8.80
Nitr.	0.08	0.03	0.03	0.19
Phos.	0.07	0.04	0.00	0.18
Turb.	26.1	22.2	4.0	200

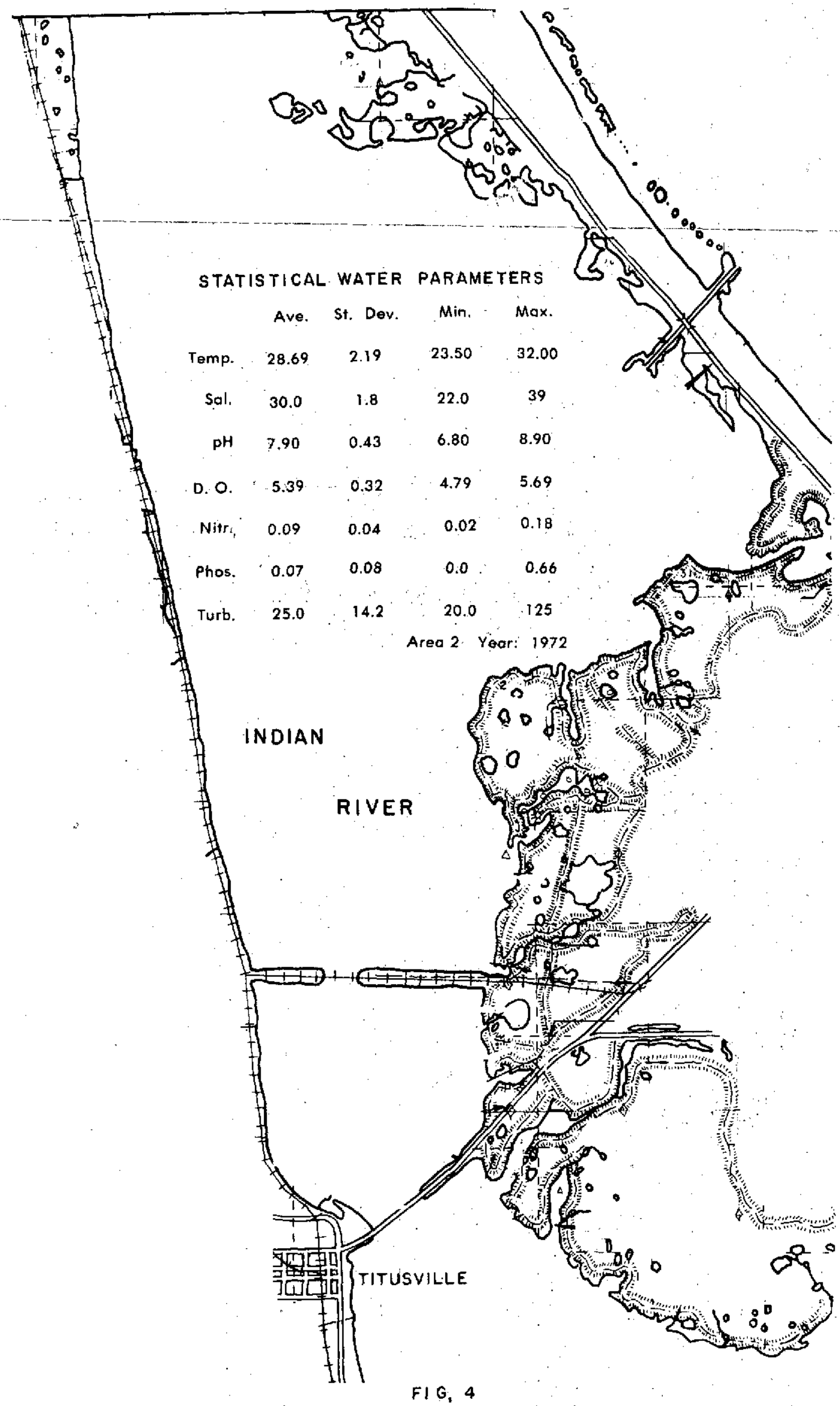
Area 1 Year: 1972

FIG. 3

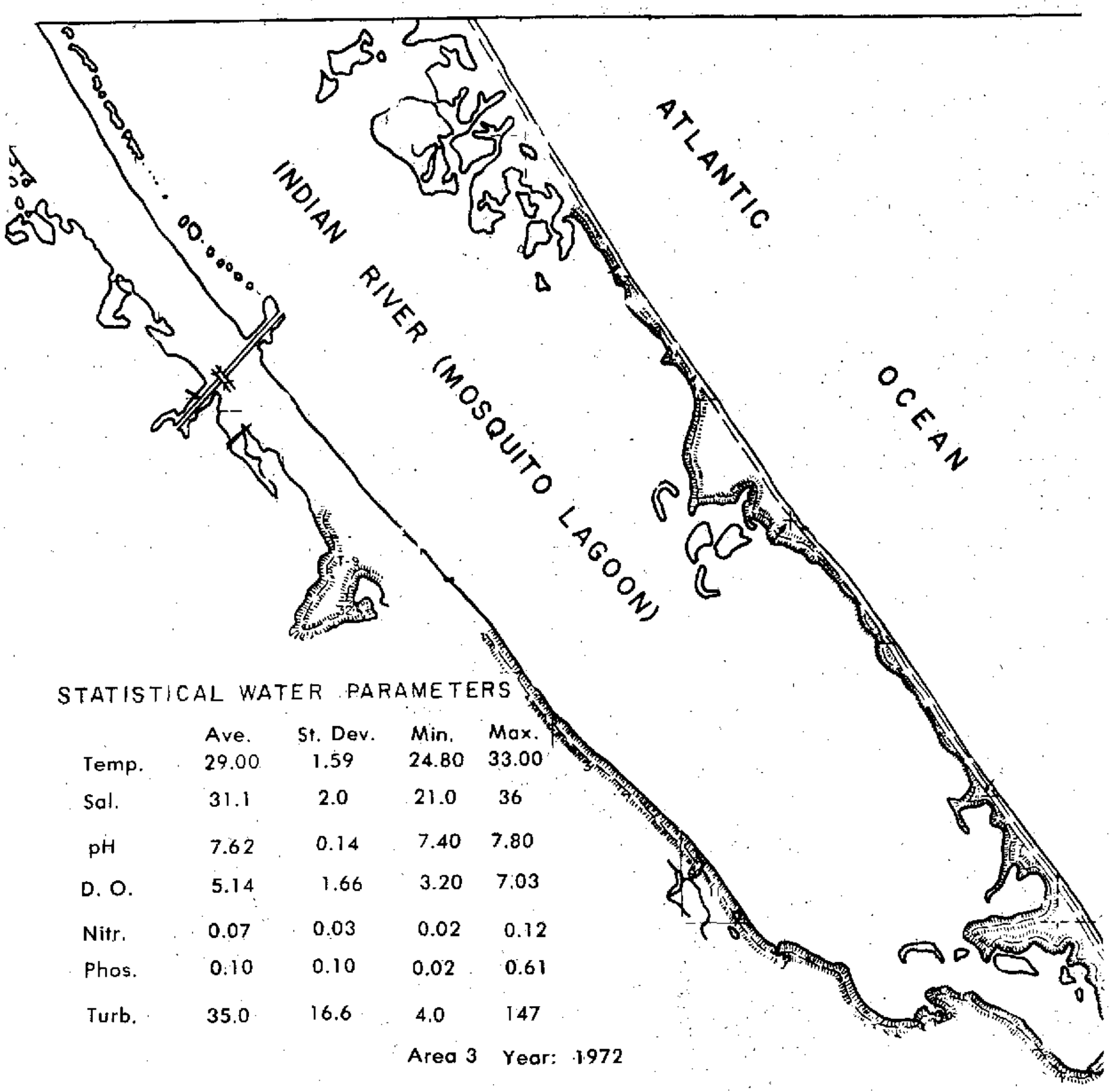
STATISTICAL WATER PARAMETERS

	Ave.	St. Dev.	Min.	Max.
Temp.	28.69	2.19	23.50	32.00
Sal.	30.0	1.8	22.0	39
pH	7.90	0.43	6.80	8.90
D. O.	5.39	0.32	4.79	5.69
Nitr.	0.09	0.04	0.02	0.18
Phos.	0.07	0.08	0.0	0.66
Turb.	25.0	14.2	20.0	125

Area 2 Year: 1972



FIG, 4

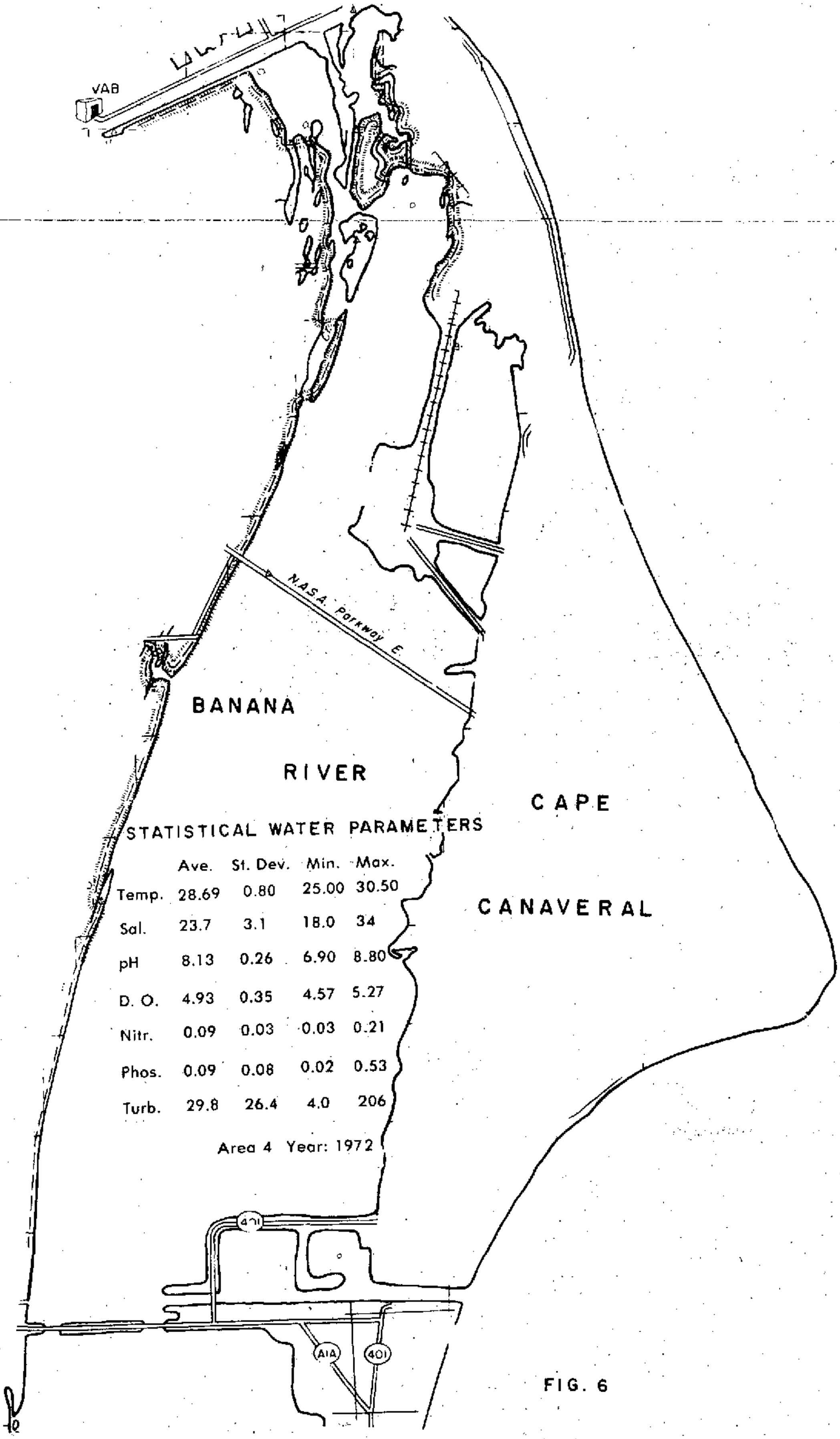


STATISTICAL WATER PARAMETERS

	Ave.	St. Dev.	Min.	Max.
Temp.	29.00	1.59	24.80	33.00
Sal.	31.1	2.0	21.0	36
pH	7.62	0.14	7.40	7.80
D. O.	5.14	1.66	3.20	7.03
Nitr.	0.07	0.03	0.02	0.12
Phos.	0.10	0.10	0.02	0.61
Turb.	35.0	16.6	4.0	147

Area 3 Year: 1972

FIG. 5



STATISTICAL WATER PARAMETERS

	Ave.	St. Dev.	Min.	Max.
Temp.	28.69	0.80	25.00	30.50
Sal.	23.7	3.1	18.0	34
pH	8.13	0.26	6.90	8.80
D. O.	4.93	0.35	4.57	5.27
Nitr.	0.09	0.03	0.03	0.21
Phos.	0.09	0.08	0.02	0.53
Turb.	29.8	26.4	4.0	206

Area 4 Year: 1972

FIG. 6

APPENDIX TO SECOND YEAR REPORT

A STUDY OF THE CIRCULATION IN THE LAGOONS ENCOMPASSING THE KENNEDY SPACE CENTER

by

Richard Evan Dill

B.S. in Engineering, United States Naval Academy, 1967

Submitted to the Graduate Faculty
in partial fulfillment of
the requirements for the degree of
Master of Science
in
Physical Oceanography

Florida Institute of Technology
1974

Richard E. Dill

ABSTRACT

Advisor Signature

A STUDY OF THE CIRCULATION IN THE LAGOONS ENCOMPASSING CAPE CANAVERAL, FLORIDA

Richard Dill, M.S.
Florida Institute of Technology, 1974

The hydrodynamics of the Indian and Banana Rivers and Mosquito Lagoon, surrounding the John F. Kennedy Space Center, Florida, is the object of this study. Data gathered from surface current measurements made with simple current crosses are compared with measurements of the wind field over each lagoon under varying meteorological conditions.

Steady-state and time dependent mathematical models are developed and predicted current velocities are compared with measured values. Extensive discussion is given to the previous work of other investigators in attempting to determine values for such ill-known quantities as eddy viscosity coefficients, dynamic roughness length, wind drag coefficient and bottom stress.

The circulation in these shallow lagoons appears to result from a combination of wind stress and slope currents. Tidal and Coriolis forces seem negligible. Calculations of theoretical surface current velocities under pure wind stress conditions compare reasonably well with measured current velocities. However, recommendations are made concerning specific areas of requisite future investigation.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

This study was supported by NASA Grant NGR 10-015-008, entitled "A Study of Lagoonal and Estuarine Ecological Processes in the Area of Merritt Island Encompassing the Space Center."

The author gratefully acknowledges the many valuable suggestions and comments made by Dr. Pieter S. Dubbelday.

INTRODUCTION

Man's interest in and use of estuaries has been well established in the past decades. With much of the world's transport done by ships and its many industrial complexes requiring access to coastal water bodies, population growth has thus increased tremendously near coastlines. More than forty-five per cent of the populace of the United States and seven of the world's ten largest urban areas are situated in coastal areas. With the increasing use of estuarine waters for a multitude of purposes, it has become vital for environmental protection and for the assessment of the proper use of these waters to understand more completely the physical and biological processes related to these nearshore waters.

In the past, the major interest in estuaries has been primarily biological, resulting in a notable lack of literature on specific estuary circulation processes. An even more apparent lack exists of synoptic field measurements in testing the accuracy of theoretical predictions of natural circulation phenomena. This disparity of field work has apparently been mainly due to a lack of proper funding because of various economic factors. The main factor is the high cost involved in obtaining an accurate, detailed description of such a large body of water, while another factor is the seemingly low, short-term return of such an expensive study. To date, there have only been a handful of detailed studies done on various estuaries; notably, the Chesapeake Bay and its tributaries (Pritchard (Lauff, 1967), Hansen and Rattray, 1966); Alaskan, Canadian and Norwegian fjords (Rattray and Saelen (Lauff, 1967)); the Columbia River, USA (Hansen, 1965); and the Mersey Estuary, England (Hansen and Bowden (Lauff, 1967)). It will later be seen that none of these estuaries exhibit the same characteristics as those under consideration in this paper.

A STUDY OF THE TRANSPORT OF WATER THROUGH THE HAULOVER CANAL

by

David Richard Browne

B.S., Physical Sciences

University of Maryland, 1970

Submitted to the Graduate Faculty

in partial fulfillment of

the requirements for the degree of

Master of Science

in

Physical Oceanography

Florida Institute of Technology

1974

ACKNOWLEDGEMENTS

This study was funded under the National Aeronautics and Space Agency grant number 10-015-008 and is part of a total research, under the title of "Study of Lagoonal and Estuarine Ecological Processes in the Area of Merritt Island Encompassing the Space Center," being carried out by both the Oceanography and Biology Departments of the Florida Institute of Technology. The author expresses his special thanks to Dr. P.S. Dubbelday for his assistance in preparing this thesis. Appreciation is also expressed to Dr. O. von Zweck of the Department of Oceanography and Dr. T.E. Bowman of the Department of Mechanical Engineering for their helpful assistance in this paper. The author thanks the General Electric Company, Orlando, Florida for their donation to this work. Special thanks is expressed to Andrew Nicholson for his assistance in construction of the water level gauges used in this work; and to Max Carey whose assistance and advice in all phases of data collection proved invaluable. The author expresses his gratitude to Miss Alison Slicker who helped bring this thesis to its final form through her typing skill and special talent as a layout artist.

CONTENTS

ABSTRACT

Haulover Canal is a prismatic channel connecting two large bodies of water, the Indian River and the Mosquito Lagoon. The Manning equation for uniform flow is found to be satisfactory in describing the relation between the transport through the canal and the slope of the water surface. The correlation between the suspected driving force, the prevailing winds, and the currents in the canal is established. Also a wind direction causing the maximum transport through the canal is found.

INTRODUCTION

This study is basically one of hydraulics, and to be more specific, one of open channel flow. Much of the literature reviewed has established theoretically and experimentally the same basic equations for both uniform and nonuniform flow in open channels. This has been done to such an extent that open channel flow has been made text book material.

Haulover Canal connects two large bodies of water. The water level of each, as a function of the wind field, undergoes slow changes affecting a flow in the canal in either direction. The rate of change of the water elevations at each end of the canal is believed to be so slow that the flow in the canal may be considered to be steady at any instant. This consideration is evident in the equations of motion developed for the flow through the Haulover Canal.

It will be discussed whether the equation of motion for varied flow or that of uniform flow (or gradually-varied flow) best describes the water transport through the canal as a function of the water level differences for the time period observed. When the flow is uniform, the boundary friction is in balance with the head loss; and therefore, controls the depth-velocity relation for a given flow rate. When the flow is nonuniform, it may be further classified as gradually-varied or rapidly-varied flow. In gradually-varied flow, the local time derivative of the velocity and the advective terms are of such small magnitude that the water surface slope changes slowly; and, therefore, boundary friction very nearly balances the head loss. In rapidly-varied flow, the momentum and inertial forces become more dominant in the role of establishing the water transport in a channel (Daily and Harleman, 1966).

A correlation between the wind field and the water surface slopes and resulting currents will be established. The preferred direction of the wind is practically defined as the direction from where the wind field approaches causing the maximum water surface slope in, and the consequent maximum current through the Haulover Canal; wind magnitude being held constant. The preferred direction of the wind causing this maximum piling of water at the mouths of Haulover Canal was found for the surface and average currents running through the canal and the water level differences between the canal ends. Correlating coefficients were also computed for the above three parameters with the east-west and north-south components of the wind.

LOCATION AND DESCRIPTION OF HAULOVER CANAL

Haulover Canal is part of the Merritt Island Wildlife Refuge in Brevard County, Florida. The canal is located east, across the Indian River, from Titusville on the mainland and is approximately 12 km north of the Vehicle Assembly Building at Kennedy Space Center. The canal connects the Indian River and the Mosquito Lagoon.

Haulover Canal is a prismatic channel (one that is uniform in cross-section and bed slope) running in the 045° and 225° directions. It was designed and excavated by the Army Corps of Engineers. The canal has a trapezoidal cross-section with side slopes of 1 on 1.5. The canal was designed to have a depth of 4.27 m but the average of actual readings indicate an actual depth of 4.53m. There is no bottom slope in the canal and the canal bed is considered parallel with the horizontal datum. The length of Haulover Canal is approximately 2.054 km. From these dimensions the cross-sectional area "A" is calculated to be $203.37 m^2$, the wetted perimeter "P" is calculated to be 54.43 m, and the hydraulic radius "R", which is the cross-sectional area divided by the wetted perimeter, is calculated to be 3.74 m.

As will be seen later, the hydraulic radius will be an important dimension in considering the flow through the canal.

Figure 1a

HAULOVER CANAL
AND SURROUNDING AREA