A PRELIMINARY APPRAISAL OF SEDIMENT SOURCES AND TRANSPORT IN KINGS BAY AND VICINITY, GEORGIA AND FLORIDA

By James B. McConnell, Dean B. Radtke, Timothy W. Hale, and Gary R. Buell

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CONVERSION FACTORS

For those readers who may prefer to use inch-pound units rather than metric units, the conversion factors for the terms used in this report are listed below:

Multiply metric unit	By	To obtain inch-pound unit
cubic meter (m^3)	35.31	cubic foot (ft^3)
gram (g)	0.03527	ounce (oz)
hectare (h)	2.471	acres
kilogram (kg)	2.205	pound (lb)
kilometer (km)	0.6214	statute mile (mi)
liter (L)	0.03531	cubic foot (ft^3)
meter (m)	3.281	feet (ft)
metric ton (t)	1.102	ton (short)
millimeter (mm)	0.03937	inch (in.)
square kilometer (km^2)	0.3861	square mile (mi^2)

$°F = 9/5°C + 32$ or $°C = \frac{5}{9}(°F-32)$

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, called NGVD of 1929, is referred to as sea level in this report.

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ABSTRACT

Water-quality, bottom-material, suspended-sediment, and current velocity data were collected in Kings Bay and vicinity to provide information on the sources and transport of estuarine sediments. Kings Bay and Cumberland Sound, the site of the Poseidon Submarine Base in southeast Georgia, are experiencing high rates of sediment deposition and accumulation, which are causing serious navigational and operational problems. Data were collected between November 10-18, 1981, at cross sections in upper and lower Kings Bay, Cumberland Sound, and St. Marys Entrance. Additional water-quality data were collected at one consecutive low and high tide at 29 sites on November 15, 1981, to assess the potential suspended-sediment sources and to define salinity variation throughout the study area.

No appreciable vertical or lateral variation in salinity and temperature was detected at the measurement cross sections or at the 29 low- and high-tide measurement sites. With the exception of the upper St. Marys River sites, the waterways measured in Kings Bay and vicinity would be classified as vertically and laterally homogenous.

Sediments in bottom-material samples collected at the cross sections ranged from coarse-gravel size shell fragments to fine silt and clay-size inorganic particles. Silt and clay-size particles and organic detrital material, however, were dominant only in bottom materials at the lower Kings Bay cross section.

Approximately 50 percent of the silt and clay-size particles in the bottom material at lower Kings Bay consisted of planktonic and benthic diatom remains. Most diatom remains probably originated outside Kings Bay proper. At the other three cross sections, the percentage of remains in the silt and clay-sized fraction of the bottom sediments was 15 percent or less.

Velocity, bathymetry, turbidity, and bottom material data suggest that the area in the vicinity of lower Kings Bay is accumulating deposits of suspended sediment transported from Cumberland Sound on the floodtide and from upper Kings Bay and the tidal marsh drained by Marianna Creek on the ebbtide. Suspended-sediment discharges computed for consecutive 13-hour ebbtides and floodtides showed that a net quantity of 62 x 10^3 kilograms of suspended sediment was transported seaward from upper Kings Bay and Marianna Creek. A net landward transport of suspended materials did not occur at the lower Kings Bay cross section, even though velocity and turbidity data suggested that suspended material may have been lost landward of this cross section. A net landward transport of 1,260 x 10^3 kilograms was computed for the St. Marys Entrance cross section. Areas seaward of St. Marys Entrance may be supplying sediment to the shoaling areas of the estuary, including lower Kings Bay. The St. Marys River is the single major source of freshwater inflow to the estuary; however, the upland drainage of the St. Marys River does not supply significant quantities of suspended sediment to the estuary.

INTRODUCTION

High rates of sediment deposition and accumulation are causing serious navigational and operational problems in Kings Bay and Cumberland Sound, southeast Georgia. Kings Bay, formerly the site of the Kings Bay Army Terminal, is now the site of a Poseidon Submarine Base. The existing base will soon be enlarged to accommodate the larger Trident submarine.

Of particular concern to the U.S. Navy is the impact of sediment shoaling on naval operations in the area. Continued dredging is required to maintain navigational depths in the Kings Bay wharf area and the access channel to the open sea. Sediment deposition rates have been estimated to be 3.8×10^5 m^3/yr (5×10^5 cubic yards per year) in Kings Bay (Environmental Science and Engineering, Inc., 1977, p. C-210) and 0.83×10^5 m^3/yr (1.08×10^5 cubic yards per year) in the Cumberland Sound access channel (Jenkins and Skelly, 1981, p. 2). To accommodate the Trident submarine, Kings Bay and the access channel will be made deeper and wider. The impact of shoaling on the Trident Support Base is uncertain. One prediction is that channel alterations will cause current shoaling rates to increase slightly in the access channel and about 6-fold in the quiet water facilities around Kings Bay (Jenkins and Skelly, 1981, p. 2). Even at the current shoaling rates, expenditures of millions of dollars will be required to maintain navigational depths.

Alternative systems for the control of sediment are being pursued by the Navy. However, important information needed to design and to evaluate the systems is lacking. Needed information includes determination of shoaling rates for specific reaches, identification of the major sediment sources, and determination of rates and characteristics of sediment transport.

In November 1981, the U.S. Geological Survey conducted a preliminary investigation of the nature and magnitude of sediment transport in Kings Bay and vicinity for the U.S. Navy, OICC (Officer in Charge of Construction), Trident. The purpose of the investigation was to collect and to evaluate basic hydrologic data that are relevant to the determination of the sources and transport characteristics of sediments in the Kings Bay area.

This report reviews descriptive background information of the Kings Bay area and presents data on currents, salinity, temperature, turbidity, suspended sediment, phytoplankton, and on the chemical and physical characteristics of bottom sediments. Water, salt, and suspended-sediment discharges are computed for consecutive ebbtides and floodtides that occurred during the November investigation.

The information presented in this report is based primarily on data collected over a short period of time during extremely high tidal conditions that were influenced by local weather. Therefore, the interpretations of the data relevant to the sedimentation problems are limited by the fact that the data represent only a short time period. Nevertheless, the data provide important information that is needed to appraise sediment sources, to understand sediment transport characteristics, and to design meaningful data-collection programs.

Previous Studies

Review of the literature reveals that numerous studies of water and sediment movement have been conducted in estuaries and tidal embayments of the Atlantic Coastal Plain, including the Georgia coast. However, only a few studies have been conducted in the vicinity of Kings Bay and St. Marys estuary. Oertel and Howard (1972) considered the associated water circulation and sediment movement patterns in all major estuary inlets of the Georgia coast, including the St. Marys inlet. Howard and Frey (1975) reported on the characteristics of bottom materials collected from Cumberland Sound and St. Marys River. Olsen (1977) studied the effects of inlet stabilization at St. Marys Entrance. The most comprehensive investigation in Kings Bay and vicinity was the environmental impact assessment for the Poseidon Submarine Base conducted in 1976-77 by ES & E (Environmental Science & Engineering, 1977) for the U.S. Navy. As part of that investigation, water-quality and tidal-flow data were collected periodically for a year to assess the integrated characteristics of water circulation and patterns of sediment erosion, deposition, and accumulation.

Acknowledgments

We wish to acknowledge Lt. Commander Anderson, U.S. Navy, OICC, for his assistance with the logistics of this project and U.S. Navy personnel at the Kings Bay docking facility for recording wind data.

Our special thanks go to Wayne York of Tradewinds Charter who was extremely cooperative by providing boat support. We thank Bill Harris, the Superintendent of Cumberland Island National Seashore, for allowing a tide-stage recorder to be installed at a dock on Cumberland Island.

The authors also acknowledge the following U.S. Geological Survey personnel for their assistance: J. L. Glenn for providing helpful suggestions regarding the investigation and the report; Howard A. Perlman and David W. Parker for their outstanding effort in developing computer graphics software for this report; Myron H. Brooks who provided invaluable assistance in the field operation; Janet Groseclose who edited and typed the manuscript; and lastly, the field personnel who, during the process of data collection, had to frequently endure long working hours and severe weather conditions.

DESCRIPTION OF THE STUDY AREA

The project study area (fig. 1) was Kings Bay, Cumberland Sound, St. Marys River, Crooked River, Cumberland River, Amelia River, and several smaller tributaries. It did not include any area seaward of the St. Marys Entrance cross section (D) or northward of Cumberland Dividings.

Physiography and Topography

The estuarine system of Kings Bay and vicinity is a bar-built system in the sea island section of the lower Atlantic Coastal Plain physiographic province of Georgia. Bar-built estuaries are defined as shallow basins,

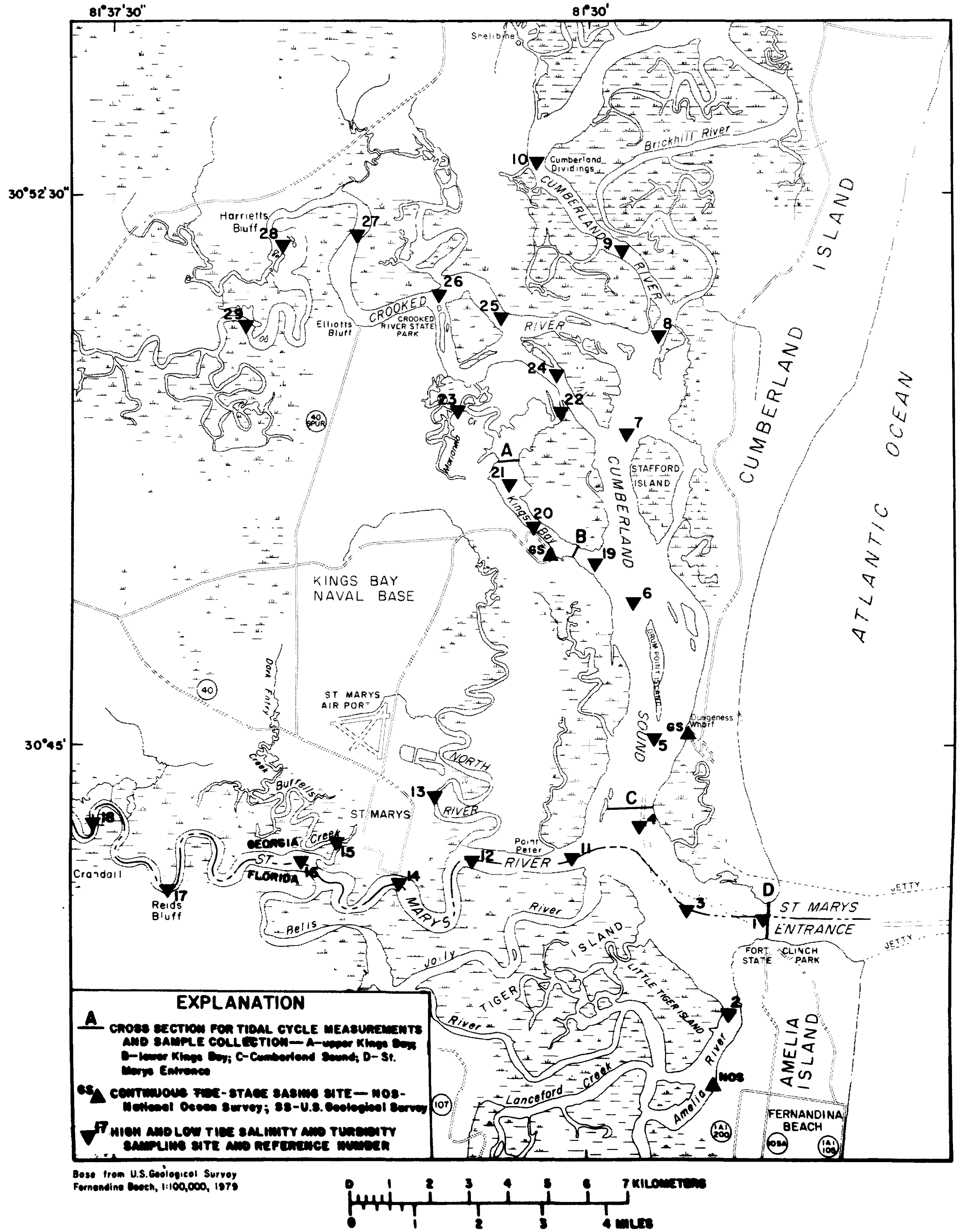


Figure 1.—Location of study area and data-collection sites.

often partially exposed at low tide, enclosed by offshore bars or barrier islands, and broken at intervals by tidal inlets (Pritchard, 1967). Cumberland Island and Little Cumberland Island (not shown in fig. 1) are low sandy islands which are separated from one another and the mainland by tidal creeks and inlets draining an extensive marsh-filled coastal lagoon. The mainland topography is characterized by broad depositional terraces alined in belts parallel to the present coastline. These terraces consist of Pleistocene coastal deposits that have a low gradient and subtle undulations of the surface.

Pleistocene sediments of these terraces are organized into topographically distinct geomorphic units. The two geomorphic units are linear sand ridges (former barrier islands) and broad clayey sand plains (former back-barrier tidal lagoons or marshes). These coastal terraces were formed during Pleistocene interglacial periods by erosional and depositional processes operating during transgressions and regressions of the Atlantic Ocean. Geologically, existing islands and marshes are unstable, being subject to migration due to natural forces (waves, tides, currents, and winds) and man-induced alterations (dredging, upstream dams, jetties, and other shoreline structures).

Ecology

The seaward margin of the mainland and the landward side of the barrier islands are bordered by extensive areas of salt marsh and limited areas of freshwater and brackish marsh. The salt marsh extends to the high-tide line and up tidal creeks and rivers, where its upper boundary is generally marked by black rush (Juncus roemerianus) (Wharton, 1978). Basically, the salt marsh is a grassland that includes zones of single species of salt-tolerant grasses, such as cordgrass (Spartina), salt grass (Distichlys), and rushes (Juncus). The marshes are watered and drained by an intricate network of tidal creeks and rivers.

Zones of vegetation in the salt marsh are determined by elevation, which controls the depth and duration of inundation by saline water. The harsh saltwater environment and water-level fluctuations in tidal marshes allow only a few species tolerant of salt stress and tidal fluctions to grow. Free from competition, extensive stands of smooth cordgrass (Spartina alterniflora) persist. Smooth cordgrass gives way to other species (Distichlys spicata, Borrichia frutescens, Salicornia virginica, and Linomium carolinianum) at higher marsh elevations where the marsh is flooded for only an hour a day (Wharton, 1978).

Productivity in a salt marsh may amount to 200 g carbon/m^2/yr and carbon production is due to mostly Spartina alterniflora (Wharton, 1978). Grosselink and others (1973) estimated that 42 percent of net primary production of Spartina alterniflora is flushed into the adjacent subtidal environments by tidal action, and Odum and de la Cruz (1967) estimated the net export of organic and mineral matter from 25 hectares of marsh to be 40 kg on neap tide and 140 kg on a spring tidal cycle. Odum (1961) has shown that the richest Georgia coastal marshes can produce up to 3.7 metric tons of plant material per hectare per year, which is a level of productivity more than six times the average world production of wheat per hectare.

Mud algae growing throughout the intertidal sediments also contribute a substantial amount (one-quarter to one-third) of the total primary productivity of the salt marsh ecosystem (Schelske and Odum, 1961). Tidal flushing enhances salt marsh productivity by replenishing nutrients and detritus and by circulating nutrients in estuarine waters. The high productivity of the tidal marshes is capable of supporting an extensive shellfish and fish resource important to the commercial seafood industry.

Climate

The climate of Kings Bay and vicinity is characterized by warm, humid summers and short, mild winters. Because the marine environment moderates the climate of this area, the winters are warmer and the summers are cooler than the inland areas. Rainfall averages about 1,270 mm per year, with spring being the driest season. Summer temperatures generally range from the 20's to the low 30's degrees Celsius, and the winter temperatures range from 4 to 15 degrees Celsius. The average relative humidity ranges from 45 percent in the spring to 60 percent in the fall.

The prevailing winds are generally from the southeast, but during the period from September to December the dominant winds are from the northeast. These "northeasters" generally are of high velocity and occasionally increase to moderate gale force. Tropical storms are common in the region; however, storms of hurricane strength have not occurred at Kings Bay as frequently as at most other locations along the Atlantic Coast. The most active hurricane period is from late June through mid-October. Hurricanes that move into the area are generally reduced to moderate winds and heavy rains after passing over land areas.

Streamflow

The St. Marys River is the major source of freshwater to the study area. The St. Marys River originates in the Okefenokee Swamp (53 km west of the study area) and empties into Cumberland Sound, about 7 km south of Kings Bay (fig. 1). The drainage area upstream from the mouth includes approximately 3,830 km^2 of swampland and coastal plain. Streamflow data have been collected at a station on the St. Marys River near Macclenny, Fla. (67 km southwest of the study area), since October 1926. This station is about 161 river kilometers upstream from the mouth; about half of the drainage area is upstream of this station. A flow-duration curve for the period of record (fig. 2) indicates that a daily flow of 7.0 m^3/s was exceeded 50 percent of the time. The mean daily flow for the same period was 19.2 m^3/s. Based on data gathered at this station and from nearby streams, the mean daily flow of the St. Marys River at its mouth is about 41 m^3/s.

Crooked River, a much smaller stream, drains into Cumberland Sound about 4 km north of Kings Bay. The drainage area above its mouth is approximately 231 km^2 and its estimated mean daily flow is 2.2 m^3/s.

Other streams within the project area are the Amelia and North Rivers and Marianna Creek. The surface-water runoff from these lowland streams is estimated to be less than the flow of Crooked River.

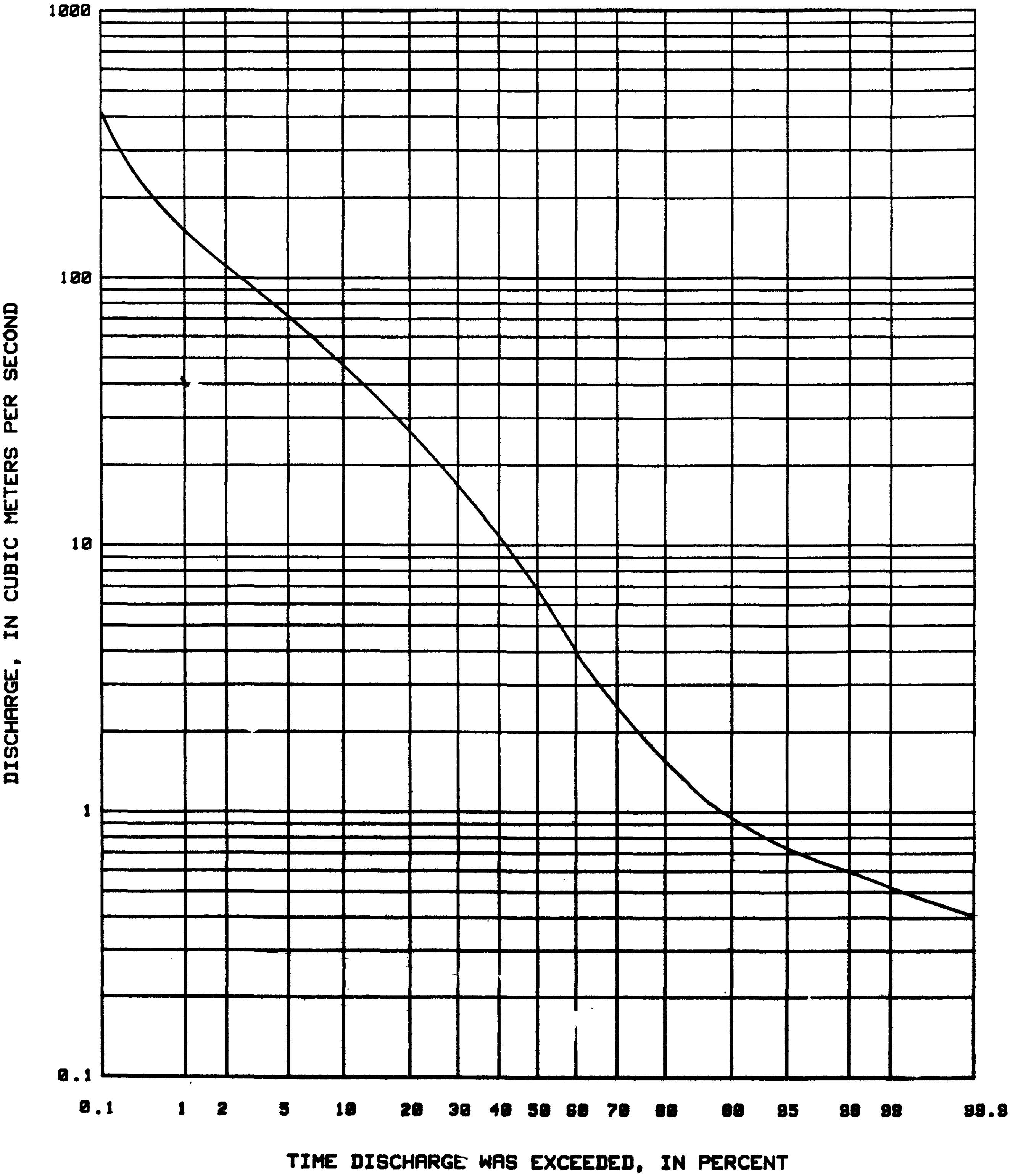


Figure 2.--Duration curve of daily flow, St. Marys River near Macclenny, Fla., 1927 - 80 water years.

Tides

Tides in Kings Bay and vicinity are semidiurnal and range from neap tides (minimum tidal range) generally exceeding 1.5 m to spring tides (maximum tidal range) which exceed 2.5 m. High- and low-water elevations follow the Moon's meridian passage by a nearly constant interval in the Cumberland Sound-St. Marys River estuary. The tide occurs 50 minutes later each day because the moon crosses the meridian 50 minutes later each day. During the floodtide (rising) and ebbtide (falling), strong tidal currents are generated. Over a tidal cycle, the ebbtidal current velocities tend to be greater than floodtidal current velocities because of the addition of freshwater to the ebbtide flow.

For this study the vertical reference datum is NGVD of 1929 which is based on, but not necessarily equivalent to, the mean sea level at 26 tide stations in the United States and Canada. NGVD of 1929 and local mean sea level cannot be used interchangeably because local mean sea level varies from place to place.

DATA COLLECTION

The methods of data collection used for this study are described in this section. When appropriate, reference has been made to specific methods that are described in the TWRI (Techniques of Water-Resources Investigations) series published by the U.S. Geological Survey. The field measurement techniques used are presented in table 1 and the sampling and laboratory methods used are presented in table 2.

Tide Stage, Wind Velocity, and Wind Direction

Tide-stage data were collected during the study period at continuous-stage recorder sites at Kings Bay, Cumberland Island, and Fernandina Beach. (See fig. 1.) The recorders at Kings Bay and Cumberland Island were installed by the U.S. Geological Survey at the beginning of this study. The recorder at Fernandina Beach, in operation since 1939, is maintained by the National Ocean Survey of the National Oceanic and Atmospheric Administration.

Wind velocity and direction data were recorded by Navy personnel from an anemometer located at Kings Bay Wharf. Readings were recorded hourly during the data-collection period.

Currents

Current velocity was measured at cross sections located in upper Kings Bay (A) and lower Kings Bay (B), Cumberland Sound (C), and the St. Marys Entrance (D) (fig. 1). The tides and the dates and time spans of the measurements are shown in figure 3. The measurements began near slack tide in the morning and continued until darkness. Measurements were made at three verticals in each cross section. The cross-sectional geometry and the locations of the verticals are shown in figures 4 and 5.

Table 1.--Field measurement techniques used at Kings Bay and vicinity

	Method of measurement	Frequency of measurement
Tide stage	Fisher-Porter digital recorder	15 minutes - Kings Bay Cumberland Island 6 minutes - Fernandina Beach
Wind speed and direction	Wind anemometer	60 minutes
Tidal current speed and direction	Price Type AA standard current meter	15 minutes
	Neal-Brown directional current meter	Do.
	McBirney directional current meter	Do.
	Ott current meter	About hourly during velocity measurement by moving boat
Cross-section bathymetry	Raytheon recording fathometer	Do.
Water temperature	YSI Model 33 S-C-T meter	5 vertical profiles during floodtide; 5 during ebbtide
Specific conductance	do.	Do.
Salinity	do.	Do.

Table 2.—Sampling and laboratory methods for samples collected at Kings Bay and vicinity

[SL, left vertical facing seaward; C, center vertical; SR, right vertical facing seaward]

	Method of sample collection	Sample treatment/ preservation	Container type	Vertical sampled	Collection frequency	Method of analysis	Reference
Water column sampling							
Turbidity (at 22 sites)	Point (grab-type) sampler	None	250-mL plastic bottle	--	1 at each site at ebb and flood slack tide	Nephelometric, Hach turbidimeter Model 2100 or 2100A	Skougstad and others, 1979
Turbidity (at 4 cross sections)	Pump samples from drifting boat; periodic P61 point samples from anchored boat	do.	do.	C	5 samples during floodtide 5 samples during ebbtide	do.	Do.
Total suspended-sediment concentration	do.	do.	1-L glass bottle	1,2,3,4,5	do.	Filtration method, gravimetric	Guy, H. P., 1969
Sand plus silt concentration	do.	do.	do.	do.	do.	Wet sieve, gravimetric	Do.
Phytoplankton standing stock (at 11 sites)	do.	20 mL. Lugol's solution	1-L plastic bottle	C	1 at each site at ebb and flood slack tide	Inverted microscope method	Skougstad and others, 1979
Phytoplankton taxonomy	do.	do.	do.	do.	do.	Inverted microscope method to generic level	Do.
Bottom material sampling							
Bottom material particle size (at 12 sites)	Grab sample w. US BMH-54	Chill at 4°C	Plastic freezer carton	SL, C, SR	1 sample at either flood slack or ebb slack tide	Wet sieve, gravimetric	Guy, H. P., 1969
Total carbon in bottom material (at 12 sites)	do.	do.	do.	do.	do.	CO_2 conversion; thermal conductance	Goerlitz, D. F., and Brown, Eugene, 1972
Total inorganic carbon in bottom material	do.	do.	do.	do.	do.	Modified Van Slyke procedure	Do.
Total organic carbon in bottom material	Calculated as the difference between total carbon and total inorganic carbon.						
Algal remains in bottom material (at 14 sites)	Grab sample w. US BMH-54	Chill at 4°C	Plastic freezer carton	SL, C, SR	1 sample at either flood slack or ebb slack tide	H_2O_2 digestion; inverted microscope method	Greeson, P. E., 1979
Percent of algal remains in bottom material	do.	do.	do.	do.	do.	Inverted microscope method	Do.

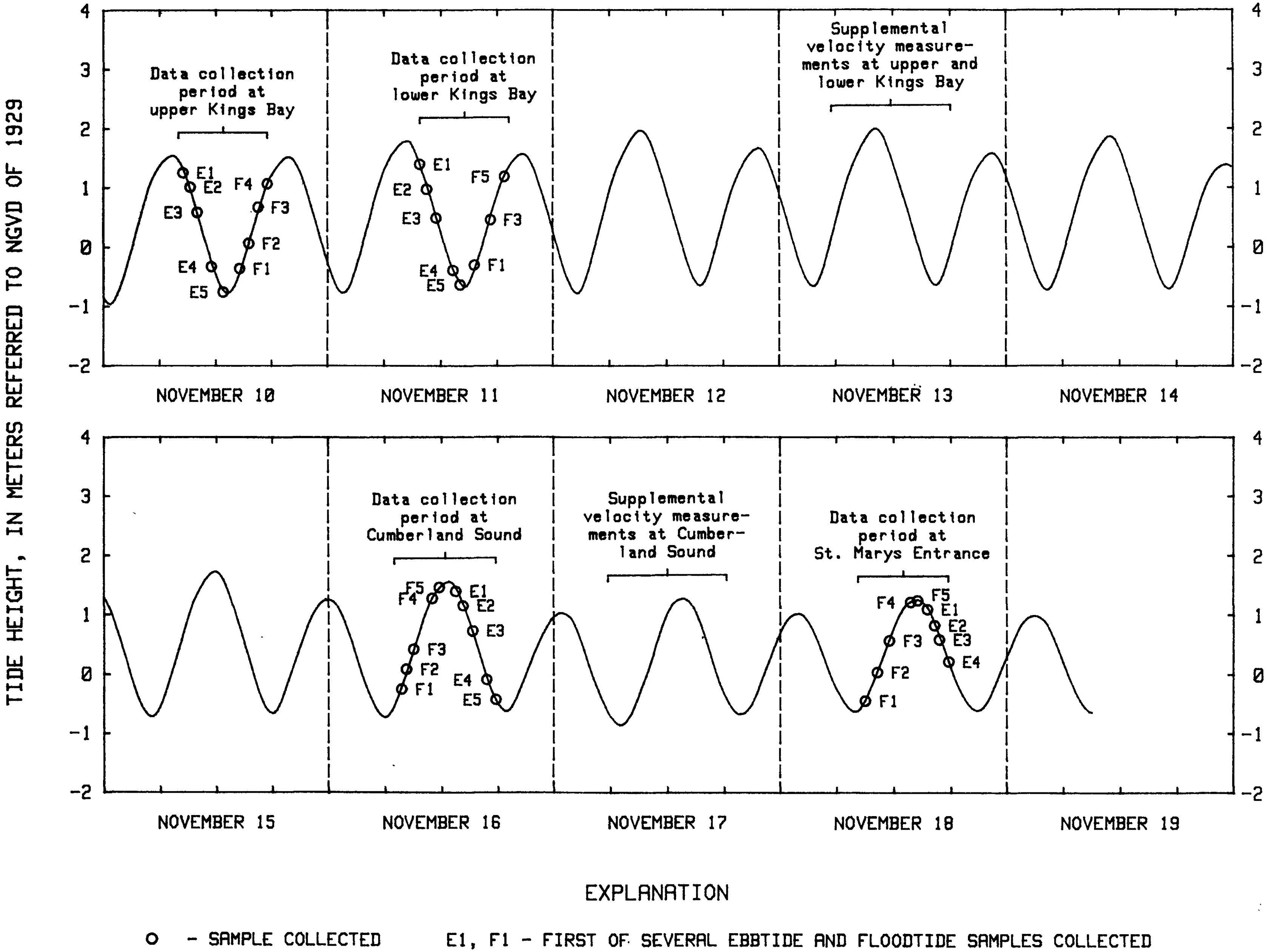


Figure 3.--Tidal conditions at Cumberland Island gage during the study period and data-collection times at the four measurement cross sections.

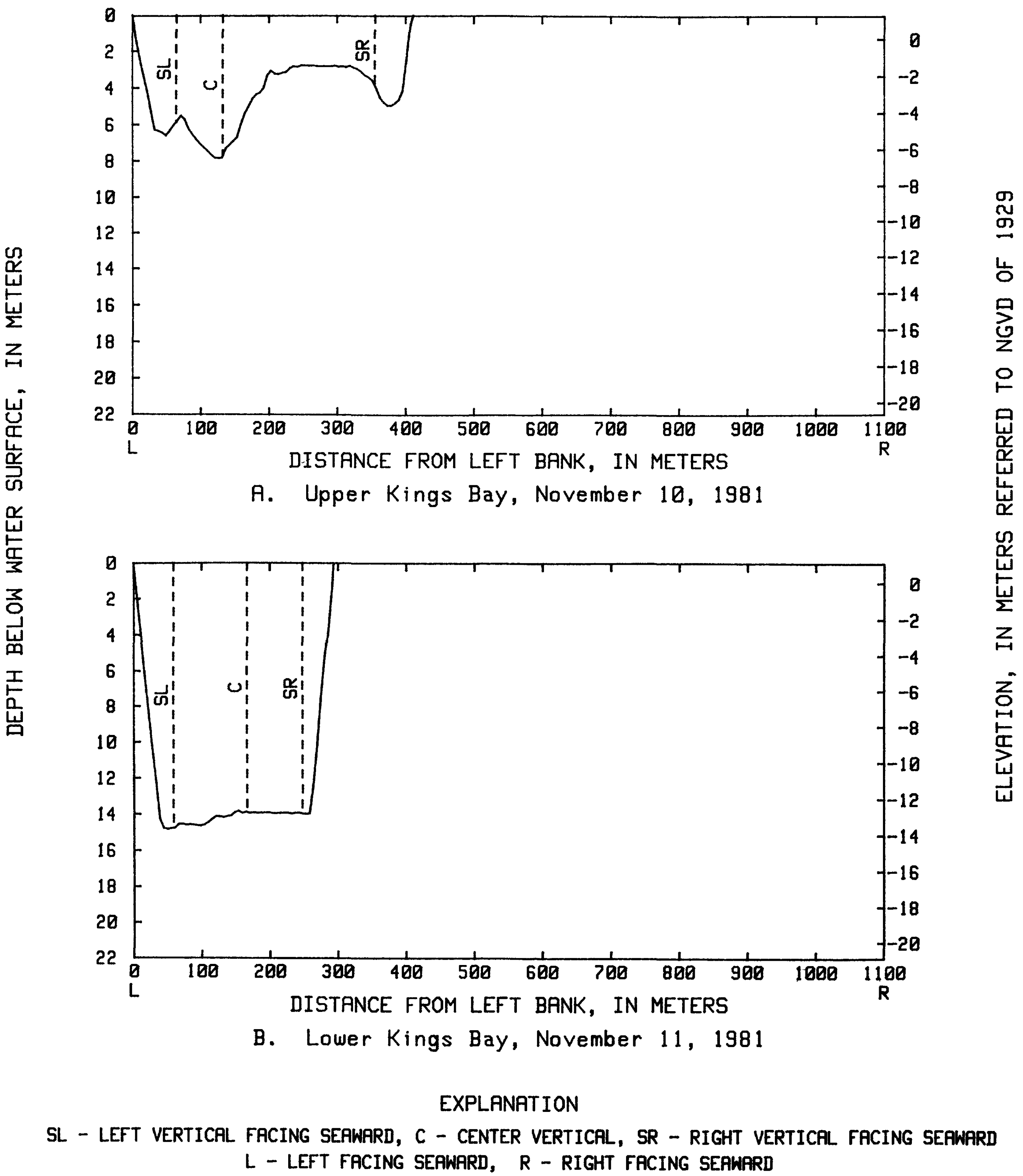
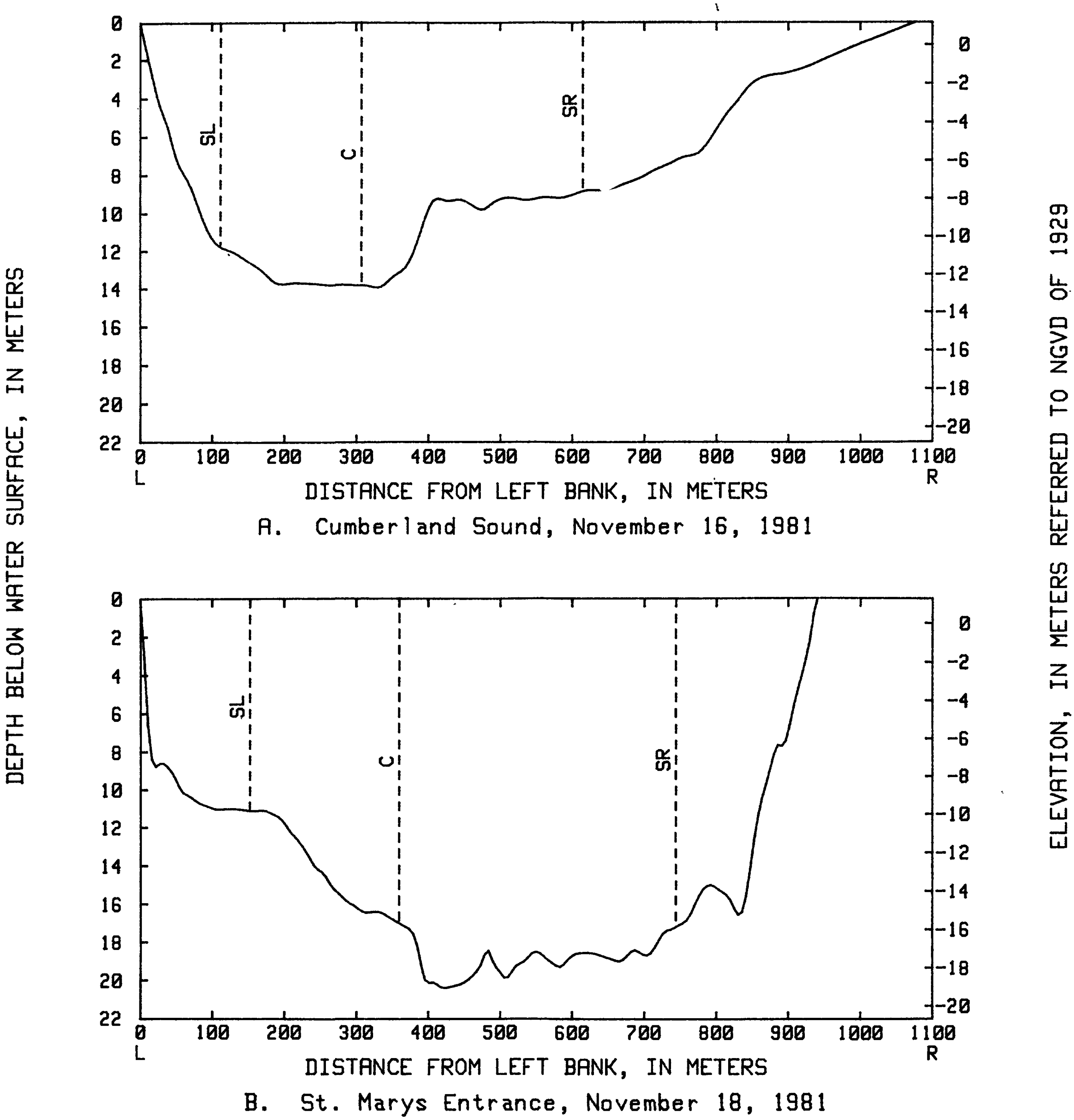


Figure 4.--Channel geometry and location of measurement verticals at upper Kings Bay and lower Kings Bay cross sections.



EXPLANATION

SL - LEFT VERTICAL FACING SEAWARD, C - CENTER VERTICAL, SR - RIGHT VERTICAL FACING SEAWARD
L - LEFT FACING SEAWARD, R - RIGHT FACING SEAWARD

Figure 5.--Channel geometry and location of measurement verticals at Cumberland Sound and St. Marys Entrance cross sections.

Current velocity was measured by two methods: the anchored-boat method and the moving-boat method. In the anchored-boat method, Price AA current meters and a Neal-Brown directional current meter were used to measure velocity.[1] Direction of flow was measured by a Neal-Brown and a McBirney directional current meter. These meters were suspended from depth-sounding reels mounted on boats anchored at three verticals in each cross section. The boats were positioned at the verticals by use of a transit located on shore near the cross section. Current velocity was measured at 15-minute intervals at 0.2, 0.4, 0.6, and 0.8 of the water depth and at 0.5 m above the bottom of the channel. The current meters and the depth-sounding equipment were used according to methods described in TWRI's by Buchanan and Somers (1976) and Smoot and Novak (1968). Two boats anchored in the cross sections were also equipped with meters which were used to measure the velocity and direction of flow simultaneously.

Additional current velocity data were collected at the upper and lower Kings Bay cross sections on November 13, and at the Cumberland Sound cross section on November 17. These data were used to supplement the velocity data collected on November 10, 11, 16, and 18. The anchored-boat technique described in the preceding paragraph was used for these measurements. Measurements were made at only one vertical in the cross sections, except at the lower Kings Bay cross section, where measurements were made at two verticals.

In the moving-boat method (Smoot and Novak, 1969), current velocity was measured approximately 1 m below the water surface by an Ott current meter. The meter was attached to a boat that traversed the cross section. About 20 to 40 near-surface measurements were made on each pass of the boat. Moving-boat measurements were made at the upper Kings Bay cross section on November 10 and 13, the lower Kings Bay cross section on November 11 and 13, the Cumberland Sound cross section on November 17, and the St. Marys Entrance cross section on November 18.

Bathymetry

Water depths were measured by a recording fathometer during the moving-boat current measurements. Cross-sectional widths were determined from fathometer data and from channel widths measured at each cross section by use of a transit.

Water Quality

Suspended-sediment and turbidity samples were collected and water temperature, specific-conductance, and salinity measurements were made at the same four cross sections where current measurements were made. An attempt was made to collect these data five times during both the floodtide and ebbtide. However, as figure 3 shows, the total number of samples and measurements obtained was less than 10 for all but the Cumberland Sound cross

1 The use of brand names in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

section. Data were collected approximately 1 m below the water surface, at middepth, and 1 m above the bottom at three verticals in each cross section. Times of data collection relative to the tide curve at the Cumberland Island gage are shown in figure 3. Phytoplankton samples were collected 1 m below the surface at the center vertical in each cross section at the beginning of ebbtide and floodtide. Water samples and measurements were taken while drifting through the cross section in a boat. Samples for the determination of suspended sediment, turbidity, and phytoplankton were collected with a pumping sampler. Measurements of temperature, specific conductance, and salinity were made on site with a field meter.

Pump sampling for suspended sediment is commonly used by the U.S. Geological Survey for sampling suspended sediment in streams, but has not been widely used for sampling suspended sediment in estuaries. For fixed-site stream sampling, strict design criteria concerning the type of pumping equipment used and its installation must be followed in order to maximize sampling efficiency. Also, the accuracy of the pumping-sample method must be checked against the conventional point-sample method for collecting suspended-sediment samples in streams.

Criteria for pumping suspended-sediment samples in estuaries with a portable pumping sampler are not as well defined as for streams. Criteria that were recommended (D. C. Hahl and C. F. Nordin, U.S. Geological Survey, oral commun., Sept. 1981) are: (1) samples should be pumped while drifting with the tidal current so that the supply hose and intake are approximately normal to the flow, (2) the intake end of the hose should be fitted with a funnel to reduce particle-size bias in the samples, and (3) the intake velocity and delivery rate should not be less than 1 m/s. Adherence to these criteria should improve sampling performance; however, it is not known whether the concentration and particle-size distribution in the sample accurately represents that in the water being sampled.

For this study, sample collection by the pump-sampling method was chosen over the conventional point-sampling method because pumped samples can be collected much more rapidly. Manpower and equipment constraints required that a few people collect many samples quickly in order to define the suspended-sediment conditions with time in the dynamic estuarine-flow system. A few samples were collected by the conventional point-sampling method to compare with the samples collected by pumping.

The pumping sampler consisted of a Kahlsico self-priming diaphragm pump that has an open-flow rating of 20.8 L/min. The pump was powered by a 12-volt marine battery. The delivery line was a 19 mm (ID), 20.5-m long, non-collapsible hose. At the intake end of the hose, a 150 mm-diameter funnel was fitted inside the hose bore. The water intake and delivery velocities through the hose were about 1.2 m/s. Pumped samples were collected while drifting with the tidal currents.

Conventional samples were taken with a cable-suspended US P-61 (Guy and Norman, 1970) point-integrating sampler fitted with a 4.8-mm diameter teflon nozzle. The sampler was operated from an anchored boat, and could be opened and closed at prescribed depths to collect about 400 mL of water.

Samples were collected at approximately the same location, depth, and time by each method at a vertical in the St. Marys Entrance and the lower

Kings Bay cross sections. At the St. Marys Entrance vertical, the pumping sampler undersampled the total suspended material and selectively sampled by particle size (table 3). At lower Kings Bay, the concentrations and particle-size distributions of suspended-sediment samples collected by each method compared well. Samples at the Kings Bay vertical had much higher percentages of silt plus clay (>90 percent) than did the samples at the St. Marys Entrance vertical.

Differences between the data collected by each method may be attributed to a factor other than methodology. That is, pumped samples, which were collected from a drifting boat, were not collected at precisely the same point and at the same time as samples collected from the anchored boat. This could result in significant differences when one considers the patchy distribution of suspended sand. The precision of each method seems to be good even though the loss of accuracy in the suspended-sediment data may be associated with an increase in percentage of sand in suspension.

Turbidity and salinity data also were collected at 29 sites in the study area (fig. 1) on November 15, 1981, near or at a consecutive low and high slack tide. To facilitate the data collection, the study area was divided into three reaches: St. Marys Entrance to the Cumberland Dividings (sites 1-10); St. Marys River and tributaries (sites 11-18); and Kings Bay, Marianna Creek, and Crooked River (sites 19-29). Each reach was sampled and measured by crews in separate boats. Data collection began near the St. Marys Entrance at high and low slack tide (zero velocity) and progressed landward. An attempt was made to arrive at each site prior to slack tide and wait until slack tide before sampling and measuring the water. Slack tide was estimated to occur when the line supporting the sampler from a stationary boat hung vertically in the water column. Salinity was measured on site at several points in the vertical with a salinity meter to define the salinity profile. Turbidity samples were collected at middepth with a point water sampler and analyzed later at the laboratory.

Bottom Material

Bottom-material samples were collected at the four measurement cross sections (fig. 1) by using a cable-suspended US BMH-54 grab-type sampler operated by a motor-driven B-series reel. To prevent contamination of the samples by trace metals from the sampler, the bucket of the US BMH-54 sampler and the equipment used for sample preparation and handling were coated with epoxy paint. Samples for particle-size analysis were taken at three verticals during maximum flood and ebb current velocity and at either a slack floodtide or slack ebbtide. Samples for the analysis of carbon and algal remains were collected one time at three verticals during slack tide, and samples for the analysis of organochlorine compounds and heavy metals were collected one time at the center vertical.

METHODS OF COMPUTATION

The methods used to compute mean current velocity and water, salt, and suspended-sediment discharges are discussed in this section. Most of the numerical computations were performed by a computer. The mean velocity and

Table 3.--Comparison of suspended-sediment samples collected by a pumping and US P-61 sampler at St. Marys Entrance and lower Kings Bay cross sections

[Pumping sampler, Kahlsico diaphragm pump with 19 mm i.d. reinforced rubber hose. Estimated velocities based upon comparison with measured velocities on November 11 (lower Kings Bay cross section) and November 18 (St. Marys Entrance cross section)]

Date	Tide cycle	Estimated velocity (m/s)	Time	Total suspended-sediment concentration (mg/L)		Percentage of silt-clay (percent finer than 0.062 mm)	
				Pumped sample	US P-61 sample	Pumped sample	US P-61 sample
St. Marys Entrance cross section							
Nov. 9, 1981	Ebb	0.30-.40	0810	13	33	62	39
			0815	16	43	69	35
			0820	14	35	79	46
			Mean	14	37	72	44
Do.	Ebb	1.10-1.20	1010	53	75	77	73
			1012	54	66	72	71
			1020	53	75	79	63
			Mean	53	72	76	69
Lower Kings Bay cross section							
Do.	Flood	0.20	1415	9	14	89	86
			1420	19	17	95	94
			1425	19	21	95	86
			Mean	16	17	92	90
Do.	Flood	0.35	1530	13	18	92	83
			1535	14	18	93	100
			1540	14	22	93	91
			Mean	14	19	90	93

discharge curves used in the computational procedures were smooth-fitted through the data points by hand. Generally, the last 2 or 3 hours of the mean velocity and discharge curves had to be estimated because of missing data.

Mean Current Velocity in the Vertical

Mean velocities at the three verticals in the measurement cross sections were computed for each series of anchored-boat velocity measurements by the equation:

$$V_m = (3V_{0.2} + 2V_{0.4} + 2V_{0.6} + 2V_{0.8} + V_B)/10,$$

where

V_m is the computed mean velocity in the vertical;

$V_{0.2}$, $V_{0.4}$, $V_{0.6}$, and $V_{0.8}$ are the velocities measured at 0.2, 0.4, 0.6, and 0.8 of the water depth, respectively;

and

V_B is the velocity measured 0.5 m above the channel bottom.

Smooth mean velocity-time curves for the 13-hour tidal cycle were constructed for each vertical in the measurement cross sections from the computed mean velocity data. The mean velocity curves for the last 2 to 3 hours of the tidal cycles had to be estimated because of missing data. These latter parts of the velocity curves were extrapolated to zero velocity based on the relation between tide stage (which was continuously measured) and current velocity that was determined from tide stage and velocity measurements of similar tidal conditions during the study period.

Water Discharge

Current velocity obtained by the moving-boat method (See page 14.) was used to determine water discharge at each measurement cross section. The discharge-measurement method is described by Smoot and Novak (1969). Smooth discharge-time curves for the 13-hour tidal cycle were constructed for each measurement cross section and subsections within the cross sections. Parts of the water-discharge curves had to be estimated because of missing data, as was done for the mean velocity curves. The last 2 to 3 hours of the water discharge curves were extrapolated to zero discharge based on the following information: (1) tide height, (2) velocities measured at the verticals from the anchored-boats, (3) the relation between mean moving-boat velocity and mean velocity in the verticals, (4) the relation between cross-section area and tide stage, (5) the discharge distribution in the cross sections, and (6) comparison of consecutive ebbtide and floodtide volumes. Further adjustments were made in the discharge-time curves for the subsections so that the sum of the areas under the subsection discharge curves equalled the area under the discharge curve for the entire cross section.

Water discharges defined by the water discharge-time curves should only be considered approximations of the true tidal discharges. Inaccuracies in the discharge measurement technique and the limited amount of velocity data could have resulted in large differences between the true and the measured discharges.

The volume of water exchanged during the ebbtide and floodtide periods at each cross section was determined by computing the area under the water discharge curves for each subsection of a cross section. The sum of the three subvolumes is the total volume exchanged. Integration of the area at 0.1-hour time intervals was done by computer.

Mean and Maximum Current Velocity in the Cross Sections

Mean current velocities for the measurement cross sections were computed by dividing the cross-section discharges by the cross-section areas. Mean velocity curves for each cross section (figs. 11 and 12) were constructed from mean velocities computed at 30-minute intervals. The cross-section discharges and the cross-section areas which were used in the computations were obtained from the cross-section discharge-time curves and from tide stage-area relations, respectively.

Maximum velocities for the measurement cross sections are point velocities measured at 0.2 of the water depth at the vertical where maximum velocities occurred during the tidal cycle. Maximum velocity-time curves for the 13-hour tidal cycles were constructed for each measurement cross section (figs. 11 and 12).

Salt Discharge

Ebbtide and floodtide salt discharges were determined at each cross section from the water-discharge and salinity data. Salinity-time curves were constructed from salinity data collected at each of the three measurement verticals. Each point in time used to define the salinity curve was an arithmetic average of the vertical measurements. Generally, 8 to 10 measurements were made during the measurement period: 5 on the first tide and the remainder on the following tide. By use of a computer, the product of salinity (density adjusted) and the corresponding water discharge was computed at 0.1-hour time increments, which resulted in a salt-discharge time curve for each subsection. The incremented areas under the salt-discharge curves were simultaneously computed and summed to give the total salt discharges for the ebbtide and floodtide.

Suspended-Sediment Discharge

Ebbtide and floodtide total suspended-sediment discharge, sand discharge, and silt plus clay discharge were determined at each cross section from the water discharge and the suspended-sediment concentrations. The procedure was similar to the salt-discharge computation. The average suspended-sediment concentrations used in the sediment-discharge computations were arithmetic averages of the three concentrations in the verticals. Arithmetic averages were used rather than depth-weighted averages because arithmetic averages were simpler to compute, and because comparison of averages computed from selected data indicated that the differences between arithmetic and depth-weighted averages were small.

RESULTS OF STUDY

Tide and Wind Conditions

Reconnaissance sampling at Kings Bay and vicinity was conducted during a period of high spring tides. Tide conditions measured at the three tide-stage recorders at Kings Bay, Cumberland Island, and Fernandina Beach are summarized in table 4. From November 9 to November 12, the tide range generally increased due primarily to increasing high tides rather than decreasing low tides. On November 12, the tide range reached a maximum of 2.82 m at the Kings Bay gage, 2.75 m at the Cumberland Island gage, and 2.69 m at the Fernandina Beach gage. From November 12 to November 18, the tide range decreased due primarily to a decreasing high tide. On November 18, the lowest tide range was 1.70 m at the Kings Bay gage, 1.64 m at the Cumberland Island gage, and 1.64 m at the Fernandina Beach gage. The tide heights at the Kings Bay and Cumberland Island gages and the differences among the tide heights at the three gages may be subject to some error because of uncertain elevation datums at the Cumberland Island and Kings Bay gages. The times of high and low tides at the Kings Bay recorder lagged the times at the Cumberland Island gage by about 15 minutes except for a few occasions when the times were the same, and lagged those at the Fernandina Beach recorder by 5 to 25 minutes.

Wind-velocity data recorded at Kings Bay are presented in table 5. When upper Kings Bay was sampled on November 10, wind velocities averaged 5 km/h out of the north until about 1600 hours, after which they shifted to a northeasterly direction, averaging 17 km/h. Lower Kings Bay was sampled the next day. Until about 1600 hours, the wind velocity averaged 28 km/h from the north. After 1600 hours, the wind velocity dropped sharply and the wind direction shifted to the northwest. The average wind velocity for the remainder of the 24-hour day was 16 km/h. When Cumberland Sound was sampled on November 16, winds had shifted to the south-southwest, averaging about 8 km/h till 1745 hours and then increasing to 14 km/h average for the remainder of the day. When the St. Marys Entrance was sampled on November 18, winds were from the southwest at about 7 km/h.

Temperature and Salinity

Water temperatures at the measurement cross sections ranged from 16 to 20.5°C (figs. 6 and 7). Slight variations in water temperature occurred with stage changes in lower cross sections (C and D, fig. 1). At any one measurement cross section, the maximum temperature variation from top to bottom or among verticals was less than 1.5°C, which indicates that the cross sections were thermally well mixed (homogeneous).

Salinities ranged from 31.0 to 33.0 g/kg (grams of salts per 1 kilogram of water) among the measurement cross sections. Seawater typically has a salinity of 32 to 35 g/kg, whereas freshwater generally has a salinity of less than 0.5 g/kg. Higher salinities, which varied only slightly with changes in stage, occurred at the lower cross sections (C and D, fig. 1). Salinity did not vary appreciably within and among the measurement verticals. At any one cross section, the maximum salinity variation from top to bottom or between verticals was less than 1.5 g/kg (figs. 8 and 9).

Table 4.--Tide conditions measured at three tide-stage recorder sites at Kings Bay, Cumberland Island, and Fernandina Beach for November 9-18, 1981

[Datum is NGVD of 1929. Tide heights and ranges in meters. Eastern Standard Time]

Date	Kings Bay			Cumberland Island			Fernandina Beach		
	Time	Tide height	Tide range	Time	Tide height	Tide range	Time	Tide height	Tide range
1981									
Nov. 9	0630	1.29		0630	1.34		0620	1.26	
			2.21			2.14			2.09
	1230	-.92		1215	-.80		1205	-.83	
			2.20			2.13			2.09
	1900	1.28		1845	1.33		1850	1.26	
			2.36			2.29			2.24
Nov. 10	0045	-1.08		0045	-.96		0030	-.98	
			2.57			2.50			2.43
	0730	1.49		0715	1.54		0710	1.45	
			2.39			2.33			2.25
	1315	-.90		1315	-.79		1300	-.80	
			2.36			2.30			2.24
	2000	1.46		1945	1.51		1935	1.44	
			2.36			2.28			2.24
Nov. 11	0145	-.90		0130	-.77		0125	-.80	
			2.63			2.56			2.51
	0830	1.73		0830	1.79		0820	1.71	
			2.53			2.46			2.40
	1445	-.80		1430	-.67		1420	-.69	
			2.31			2.23			2.17
	2100	1.51		2045	1.56		2035	1.48	
			2.42			2.34			2.29
Nov. 12	0245	-.91		0230	-.78		0225	-.81	
			2.82			2.75			2.69
	0930	1.91		0915	1.97		0910	1.88	
			2.68			2.62			2.56
	1545	-.77		1530	-.65		1520	-.68	
			2.39			2.32			2.27
	2200	1.62		2145	1.67		2140	1.59	
			2.40			2.32			2.27
Nov. 13	0345	-.78		0330	-.65		0325	-.68	
			2.72			2.64			2.59
	1015	1.94		1015	1.99		1000	1.91	
			2.71			2.64			2.59
	1645	-.77		1630	-.65		1620	-.68	
			2.39			2.23			2.18
	2245	1.52		2230	1.58		2225	1.50	
			2.37			2.31			2.26

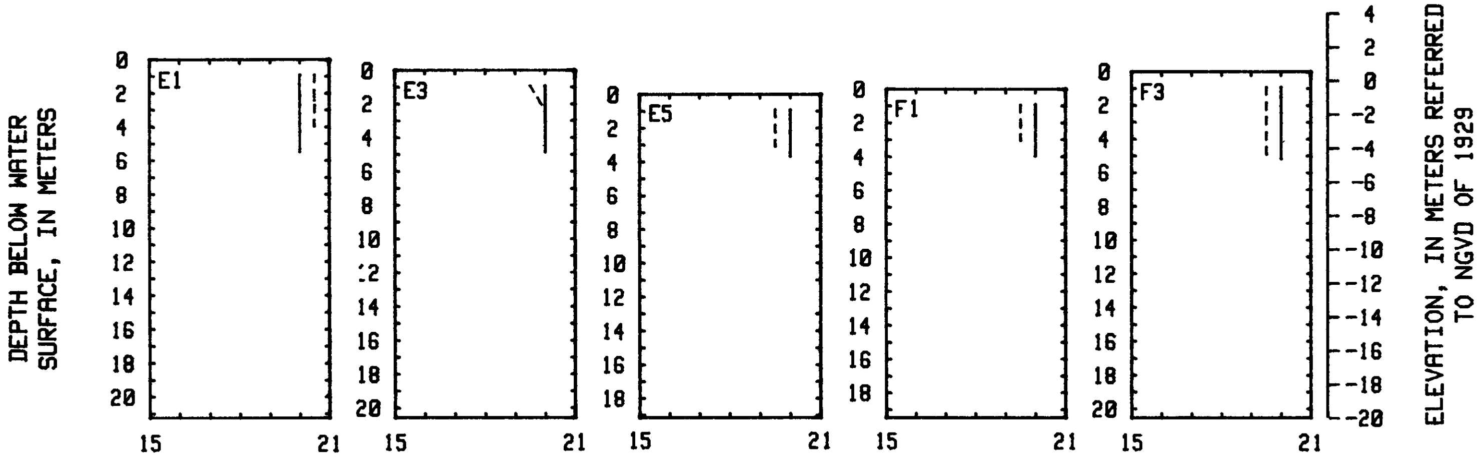
Table 4.--Tide conditions measured at three tide-stage recorder sites at Kings Bay, Cumberland Island, and Fernandina Beach for November 9-18, 1981--Continued

Date	Kings Bay			Cumberland Island			Fernandina Beach		
	Time	Tide height	Tide range	Time	Tide height	Tide range	Time	Tide height	Tide range
1981 Nov. 14	0430	-0.85		0415	-0.73		0410	-0.76	
			2.66			2.59			2.54
	1115	1.81		1100	1.86		1055	1.78	
			2.64			2.57			2.53
	1715	-.83		1715	-.71		1700	-.75	
			2.15			2.04			2.05
	2330	1.32		2315	1.33		2310	1.30	
			2.16			2.05			2.05
Nov. 15	0515	-.84		0500	-.72		0455	-.75	
			2.52			2.45			2.39
	1200	1.68		1145	1.73		1150	1.64	
			2.46			2.39			2.30
	1815	-.78		1800	-.66		1750	-.66	
			1.98			1.92			1.86
	--	--		2400	1.26		--	--	
			--			1.98			--
Nov. 16	0015	1.20		--	--		0000	1.20	
			2.03			--			1.95
	0615	-.83		0600	-.72		0555	-.75	
			2.34			2.28			2.19
	1300	1.51		1245	1.56		1240	1.44	
			2.26			2.18			2.10
	1900	-.75		1845	-.62		1850	-.66	
			1.71			1.65			1.58
Nov. 17	0100	.96		0045	1.03		0050	.92	
			1.94			1.89			1.79
	0715	-.98		0700	-.86		0705	-.87	
			2.19			2.13			2.07
	1345	1.21		1330	1.27		1335	1.20	
			2.00			2.00			1.92
	1945	-.79		1930	-.73		1940	-.72	
			1.75			1.75			1.64
Nov. 18	0200	.96		0200	1.02		0150	.92	
			1.70			1.64			1.68
	0800	-.74		0745	-.62		0750	-.76	
			1.93			1.87			1.93
	1430	1.19		1430	1.25		1420	1.17	
			1.92			1.86			1.81
	2100	-.73		2045	-.61		2040	-.64	
Mean			2.30			2.33			2.17
Minimum			1.70			1.64			1.58
Maximum			2.82			2.75			2.69

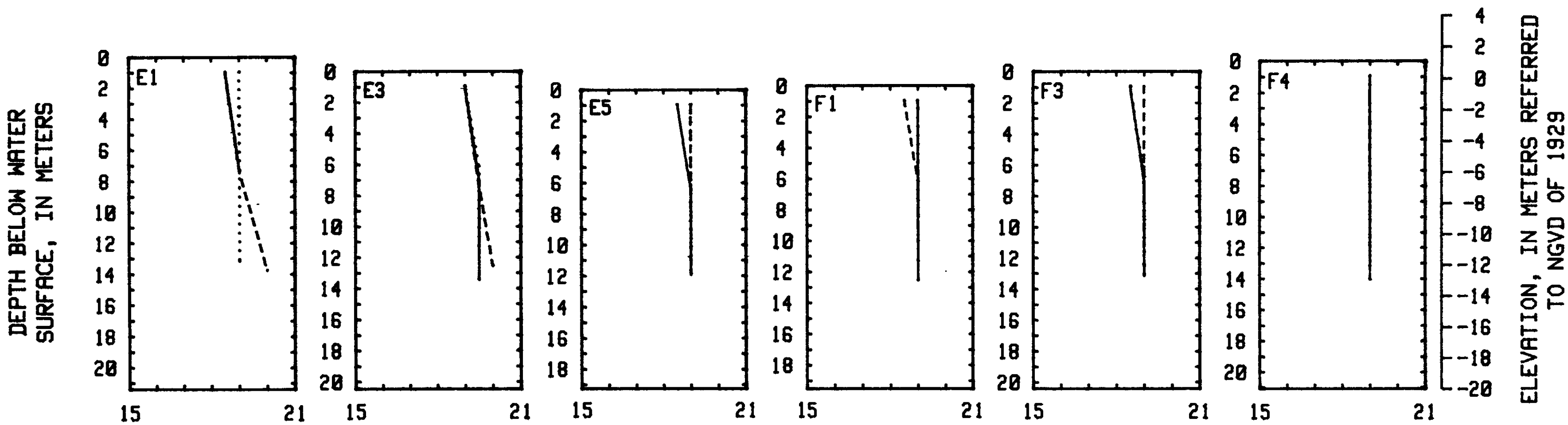
Table 5.--Wind velocity and direction at Kings Bay, November 10-18, 1981

[Wind speed in kilometers per hour (knots in parentheses)]

Date	Time period	Number of measurements	Wind velocity statistics						Wind direction
			Mean		Minimum		Maximum		
1981									
Nov. 10	0055-1600	13	5	(3)	1	(0.5)	20	(11)	N
	1600-2400	7	17	(9)	11	(6)	26	(14)	NE
Nov. 11	0000-1600	16	28	(15)	19	(10)	37	(20)	N
	1600-2400	18	16	(9)	11	(6)	28	(15)	NW
Nov. 12	0000-2400	20	17	(9)	9	(5)	28	(15)	N
Nov. 13	0000-2130	19	18	(10)	9	(5)	33	(18)	N
	2130-2400	2	10	(6)	9	(5)	11	(6)	NW
Nov. 14	0000-0445	5	7	(4)	6	(3)	11	(6)	NW
	0445-1515	10	18	(10)	11	(6)	30	(16)	N
	1515-2400	8	9	(5)	4	(2)	15	(8)	NW
Nov. 15	0000-0730	8	4	(2)	2	(1)	7	(4)	NW
	0730-1230	5	6	(3)	4	(2)	7	(4)	N
	1230-2400	10	5	(3)	0	(0)	18	(10)	SW
Nov. 16	0000-1500	13	9	(5)	4	(2)	15	(8)	SW
	1500-1745	2	7	(4)	4	(2)	11	(6)	S
	1745-2400	5	14	(8)	7	(4)	18	(10)	SW
Nov. 17	0000-2400	19	12	(6)	7	(4)	18	(10)	SW
Nov. 18	0000-0715	8	7	(4)	6	(3)	9	(5)	SW
	0715-1000	2	7	(4)	4	(2)	7	(4)	SW
	1000-2400	9	6	(3)	4	(2)	7	(4)	SW



A. Upper Kings Bay, November 10, 1981



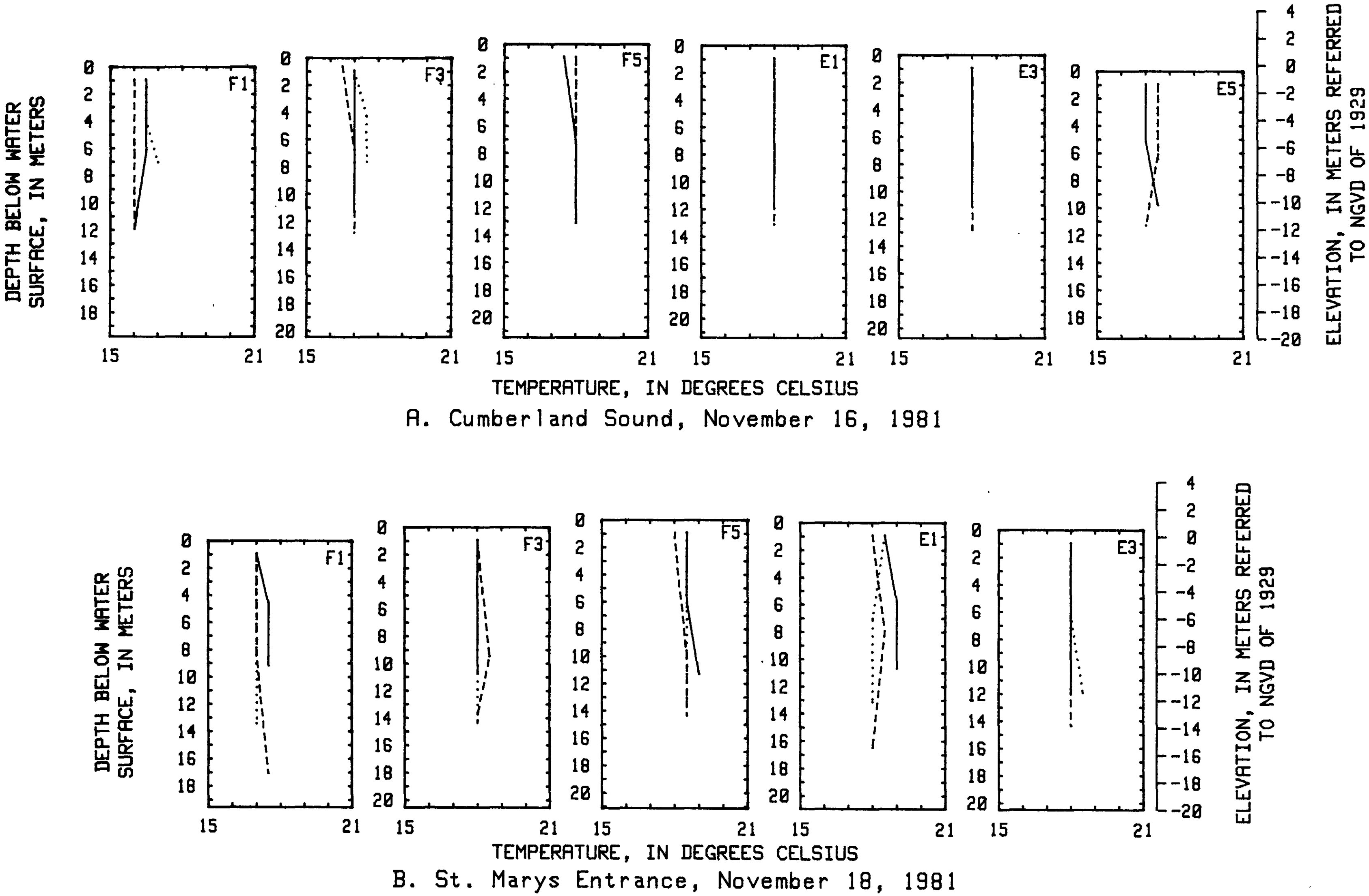
B. Lower Kings Bay, November 11, 1981

EXPLANATION

—— LEFT VERTICAL FACING SEAWARD - - - CENTER VERTICAL ····· RIGHT VERTICAL FACING SEAWARD

E1, F1 - FIRST OF SEVERAL EBBTIDE OR FLOODTIDE DATA-COLLECTION TIMES

Figure 6.--Temperature profiles at the measurement verticals at upper Kings Bay and lower Kings Bay cross sections.

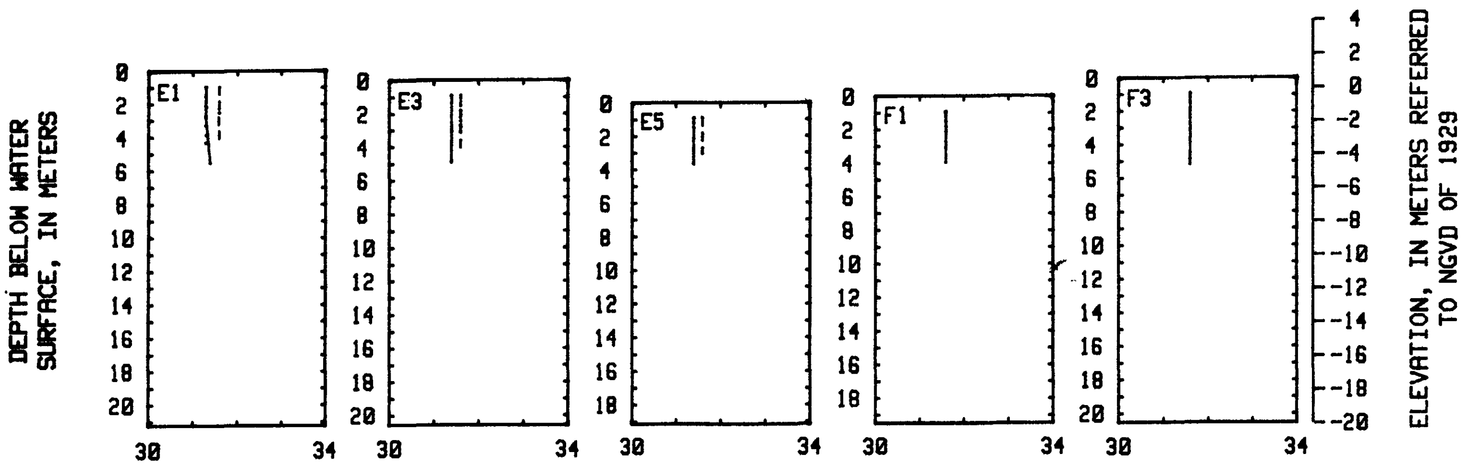


EXPLANATION

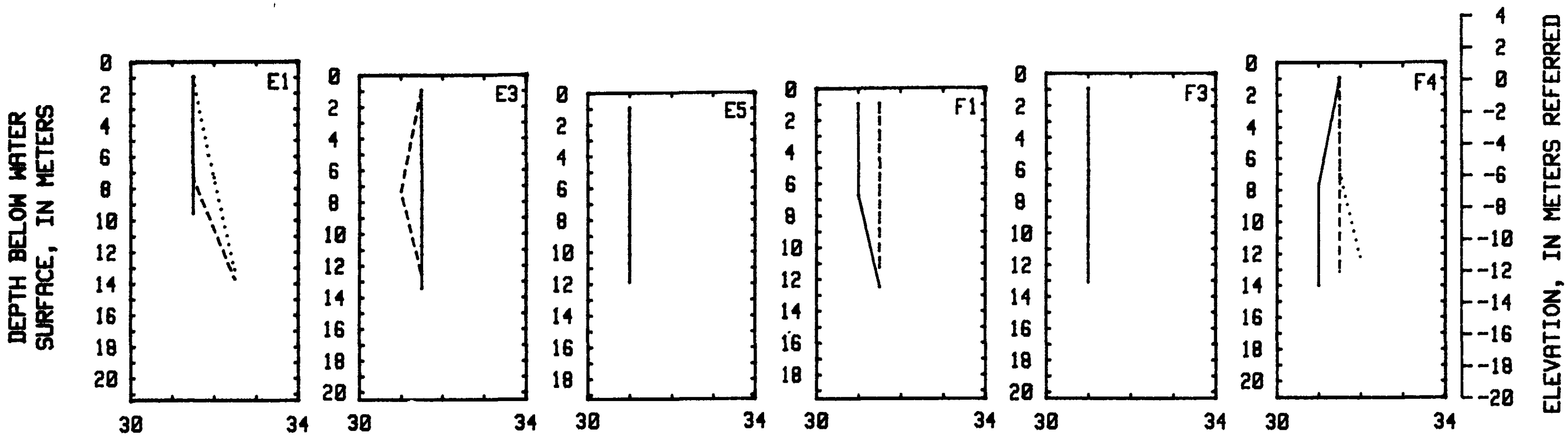
—— LEFT VERTICAL FACING SEAWARD - - - CENTER VERTICAL ····· RIGHT VERTICAL FACING SEAWARD

E1, F1 - FIRST OF SEVERAL EBBTIDE OR FLOODTIDE DATA-COLLECTION TIMES

Figure 7.--Temperature profiles at the measurement verticals at Cumberland Sound and St. Marys Entrance cross sections.



A. Upper Kings Bay, November 10, 1981



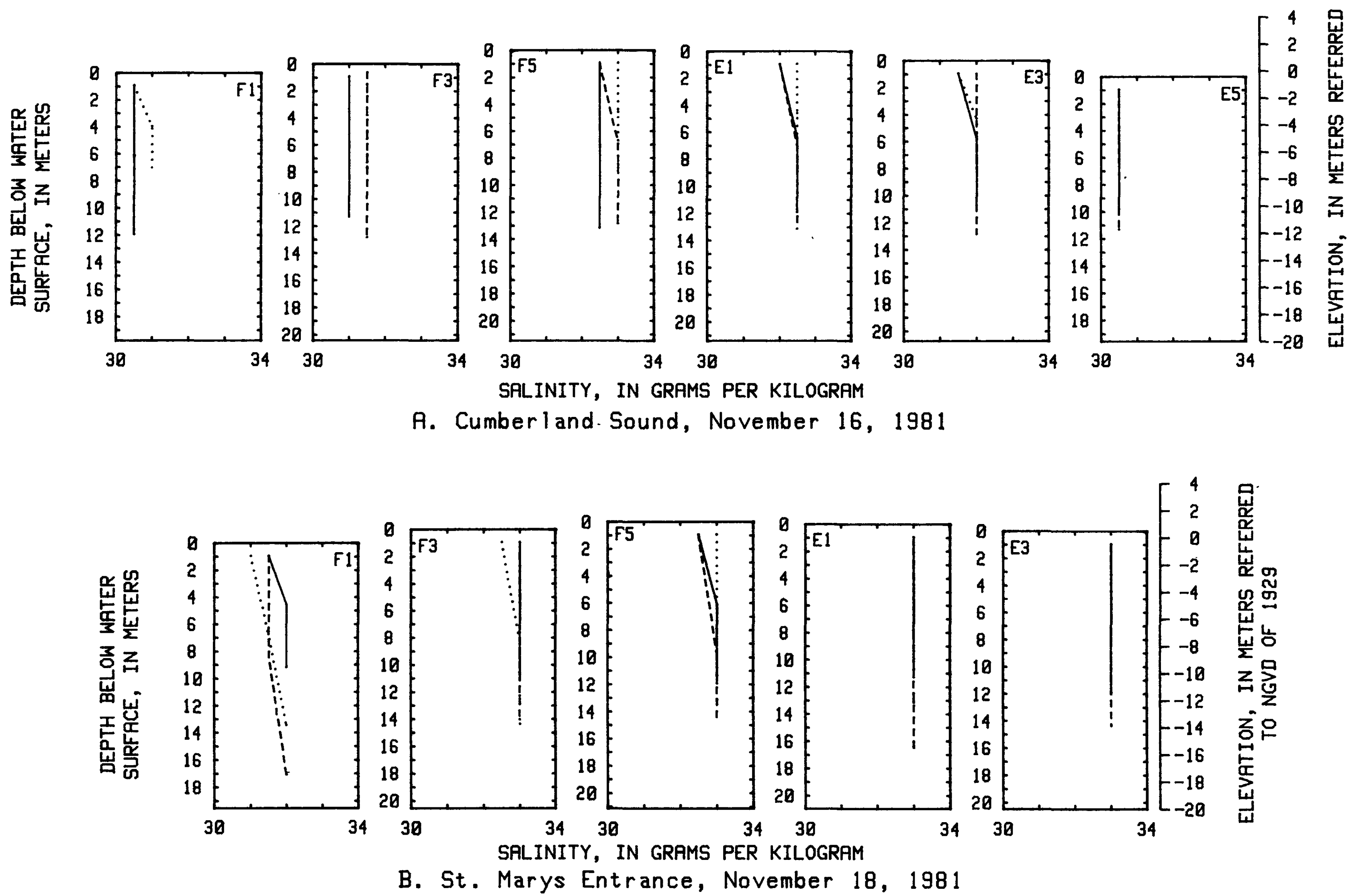
B. Lower Kings Bay, November 11, 1981

EXPLANATION

—— LEFT VERTICAL FACING SEAWARD - - - CENTER VERTICAL ····· RIGHT VERTICAL FACING SEAWARD

E1, F1 - FIRST OF SEVERAL EBBTIDE OR FLOODTIDE DATA-COLLECTION TIMES

Figure 8.--Salinity profiles at the measurement verticals at upper Kings Bay and lower Kings Bay cross sections.



EXPLANATION

—— LEFT VERTICAL FACING SEAWARD - - - CENTER VERTICAL ····· RIGHT VERTICAL FACING SEAWARD

E1, F1 - FIRST OF SEVERAL EBBTIDE OR FLOODTIDE DATA-COLLECTION TIMES

Figure 9.--Salinity profiles at the measurement verticals at Cumberland Sound and St. Marys Entrance cross sections.

Generally, the high- and low-tide salinity differences were small throughout the project area (fig. 10). Exceptions are sites 11-18 on the St. Marys River where the greater influx of freshwater from the St. Marys River accounts for a comparatively large spatial and tidal variation in salinity. Salinities at most sites were lower at low tide than at high tide due to the greater dilution of seawater during the low tide. However, at sites 7, 8, and 9, salinites were higher at low tide. The reach where these sites are located (See fig. 1.) could be responding to tidal inflows from St. Andrews Sound (not shown in fig. 10), which is northeast of site 10.

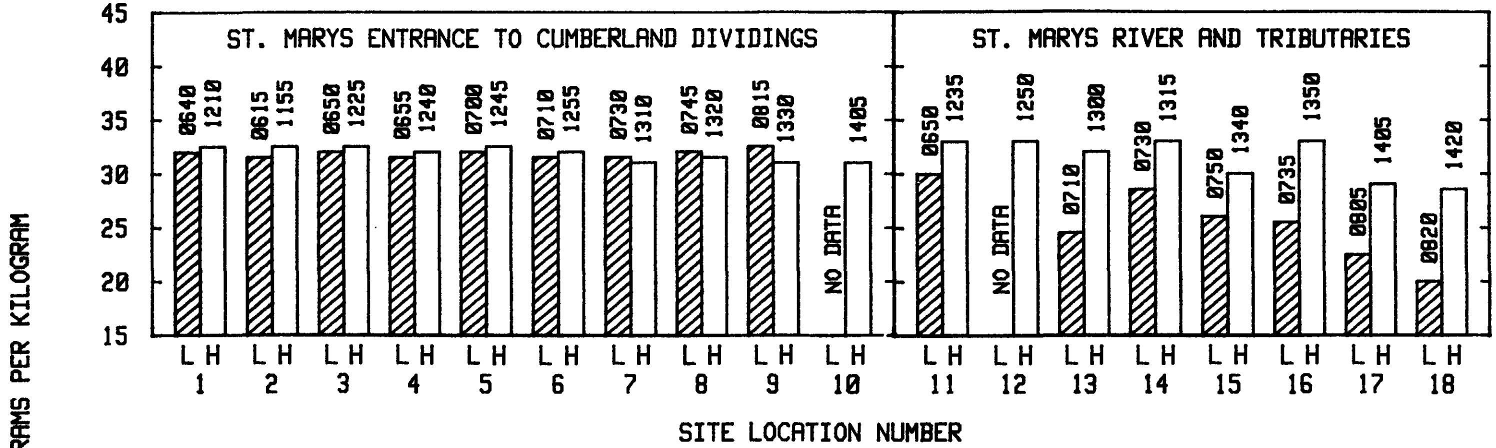
Current Velocity and Flow

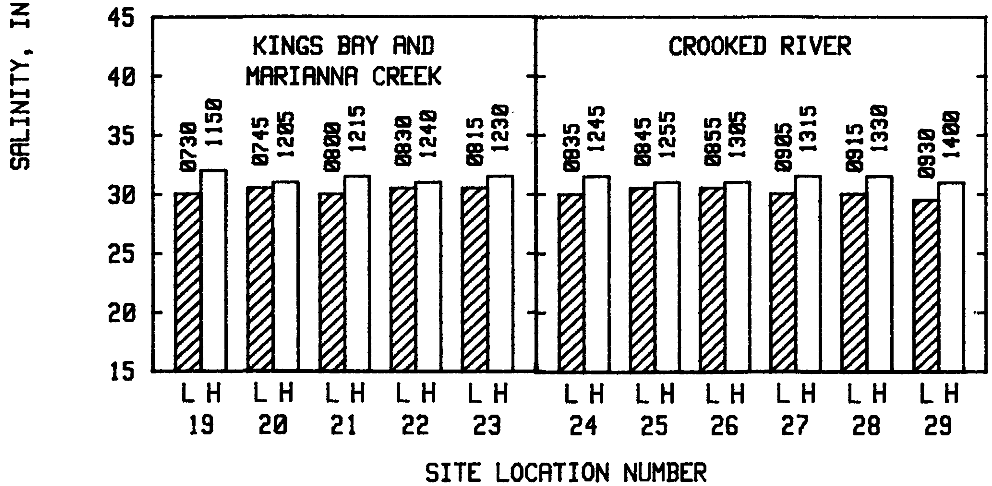
Current velocity and flow characteristics at the four cross sections in the study area are presented in figures 11-16. The data presented in these figures were not collected during similar tide and wind conditions and, therefore, do not present a synoptic picture of the current velocity and flow characteristics.

At the upper and lower Kings Bay cross sections (fig. 11), current velocities were measured during a period when predicted maximums for the year should have occurred (U.S. Department of Commerce, 1981a). Mean and maximum current velocities near midtide were higher during ebbtide than during floodtide. Peak mean and maximum current velocities at the upper Kings Bay cross section were 0.64 and 1.01 m/s, respectively, for the ebbtide and 0.51 and 0.69 m/s, respectively, for the floodtide (fig. 11-A). Peak mean and maximum current velocities at the lower Kings Bay cross section were 0.39 and 0.50 m/s, respectively, for the ebbtide and 0.38 and 0.58 m/s, respectively for the floodtide (fig. 11-B).

The decrease in current velocity at the lower Kings Bay cross section relative to the upper Kings Bay cross section was the result of a decrease in the ratio of tidal flow to the cross-section area at the lower Kings Bay cross section. The cross-section area at the lower Kings Bay cross section is about 2.5 times larger than the cross-section area at the upper Kings Bay cross section. The lower Kings Bay channel, where the lower cross section is located, extends roughly 1.1 km landward (northwest) from the lower Kings Bay measurement cross section. This channel has been dredged to a nearly uniform depth. The channel width increases immediately landward of the lower measurement cross section and then narrows somewhat about midway along this reach where the docking facilities begin. (See fig. 1.)

The upper Kings Bay cross section consists of a left and a right channel. The deeper and wider channel exists in the left part of the cross section. (See fig. 4-A.) This channel becomes more shallow and narrow as it extends northeastward and joins Cumberland Sound. On the right side of the cross section, a smaller channel becomes Marianna Creek as it extends into the tidal marsh. On the ebbtide, the current velocity near midtide was greater in the deeper left channel (left and center verticals) than in the right channel. On the floodtide, the current velocity near midtide was greater in the shallower right channel (fig. 13-A, E3, F3). This lateral shift of current velocity is reflected in the ebbflow and floodflow distribution near the time of maximum ebbflow and floodflow shown in figure 15-A.





EXPLANATION

L-LOW TIDE, H-HIGH TIDE, 0640-SAMPLING TIME

TIME	TIDE HEIGHT, IN METERS REFERRED TO NGVD		
	KINGS BAY	CUMBERLAND ISLAND	FERNANDINA BEACH
0400	-0.57	-0.52	-.59
0500	-.83	-.72*	-.75*
0515	-.84*	-.72	-.71
0600	-.71	-.56	-.54
0700	.24	-.10	-.11
0800	.30	.42	.40
0900	.84	.98	.93
1000	1.24	1.37	1.30
1100	1.53	1.63	1.56
1145	1.73*	1.73*	1.64*
1200	1.68	1.73	1.63
1300	1.51	1.50	1.39
1400	1.05	1.03	.94
1500	.54	.51	.43
1600	.02	.02	-.12

*-MINIMUM AND MAXIMUM TIDE HEIGHT RECORDED

TIDE HEIGHTS BEFORE, DURING, AND AFTER SYNOPTIC SURVEY PERIOD

Figure 10.--Spatial distribution of salinity at low and high tide, Kings Bay and vicinity, November 15, 1981.

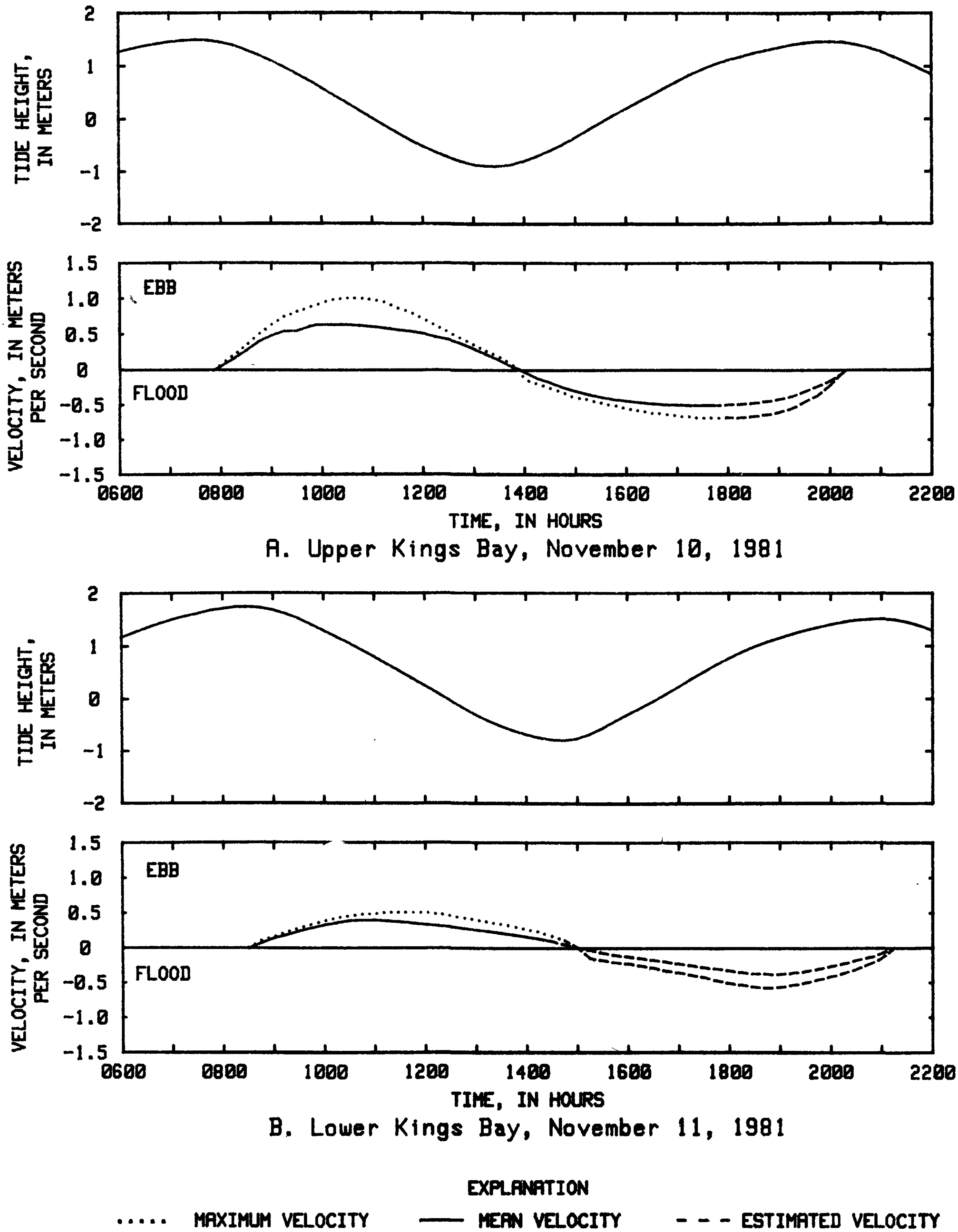


Figure 11.--Tide height and mean and maximum velocity distributions at upper Kings Bay and lower Kings Bay cross sections.

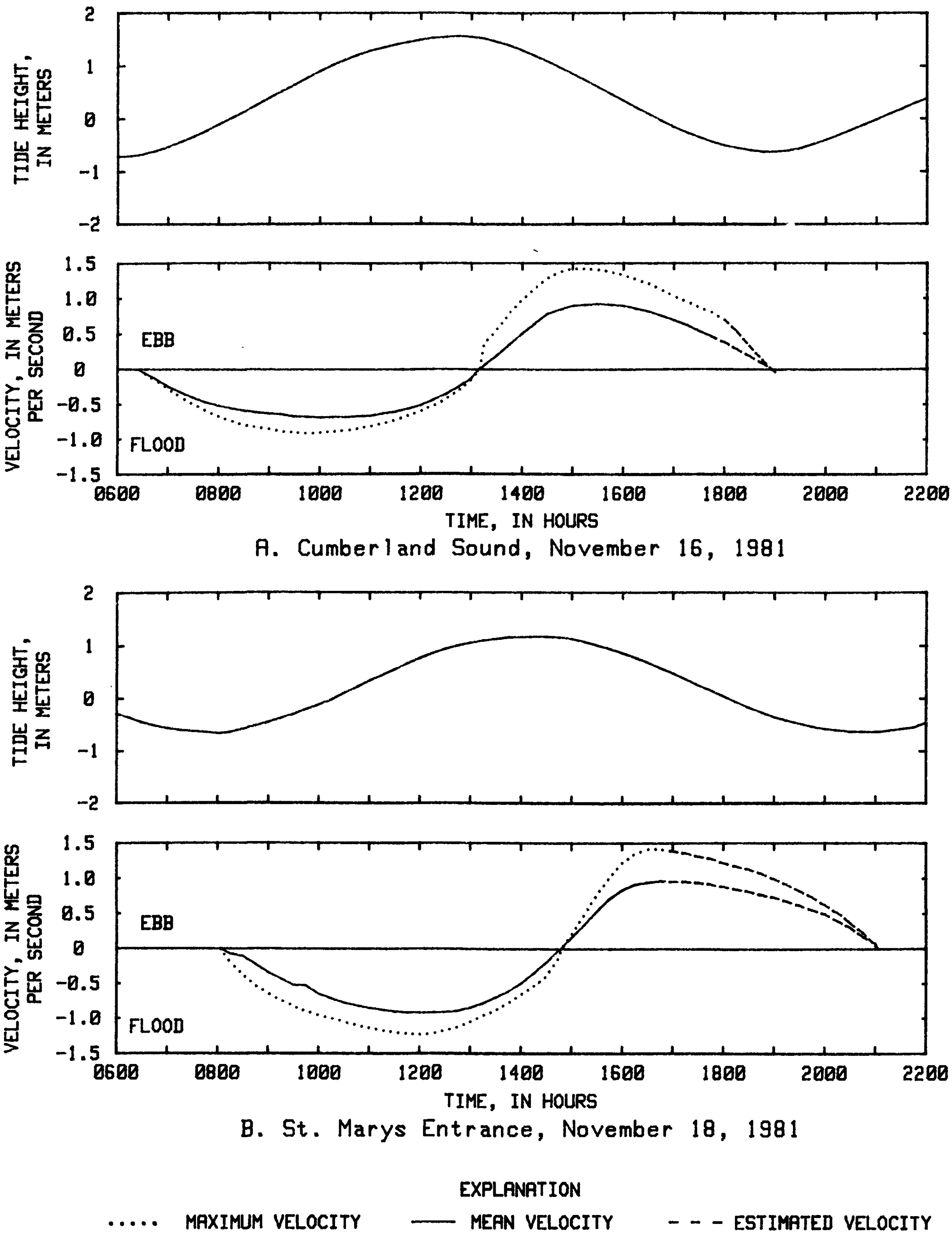


Figure 12.--Tide height and mean and maximum velocity distributions at Cumberland Sound and St. Marys Entrance cross sections.

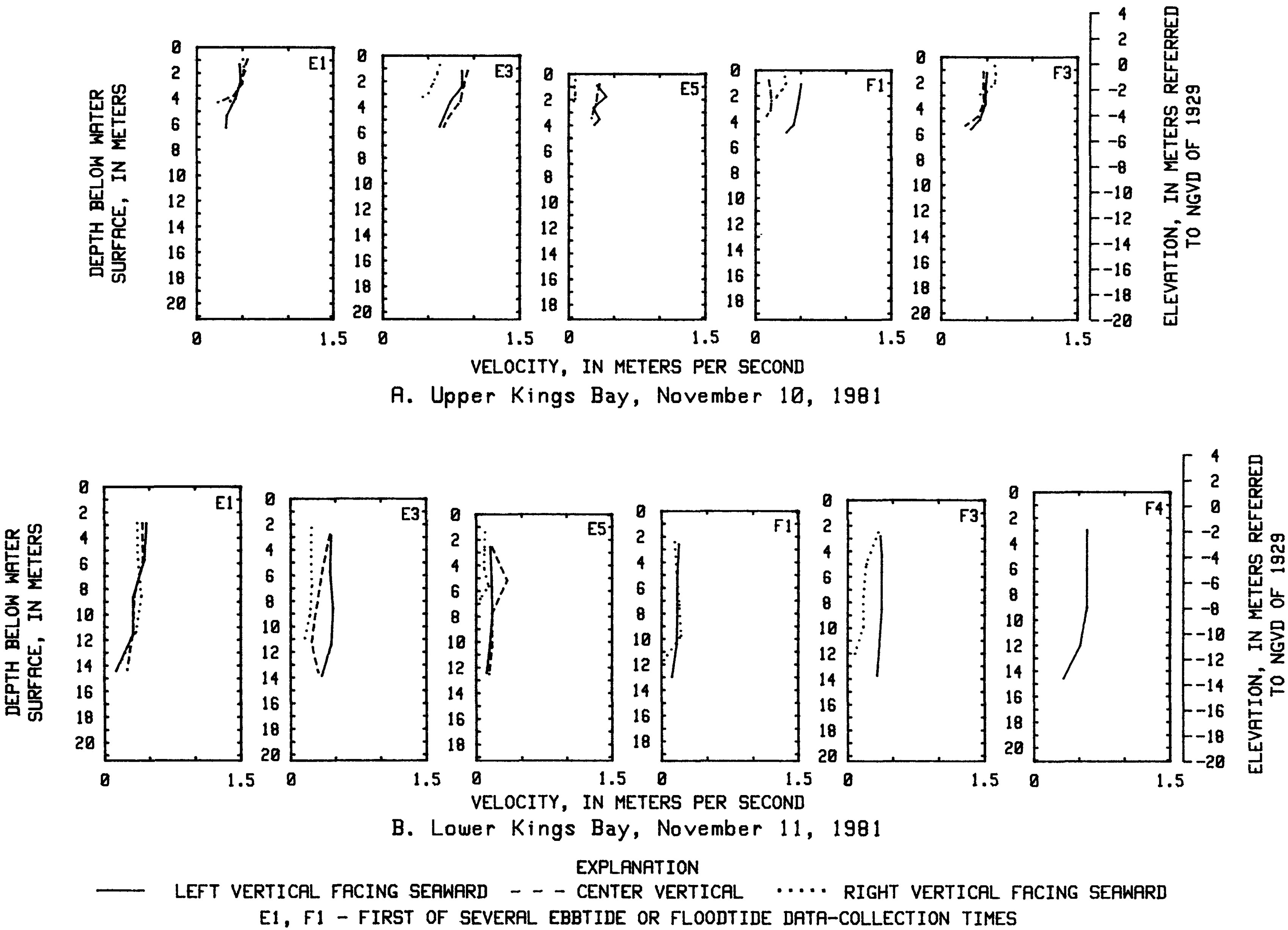
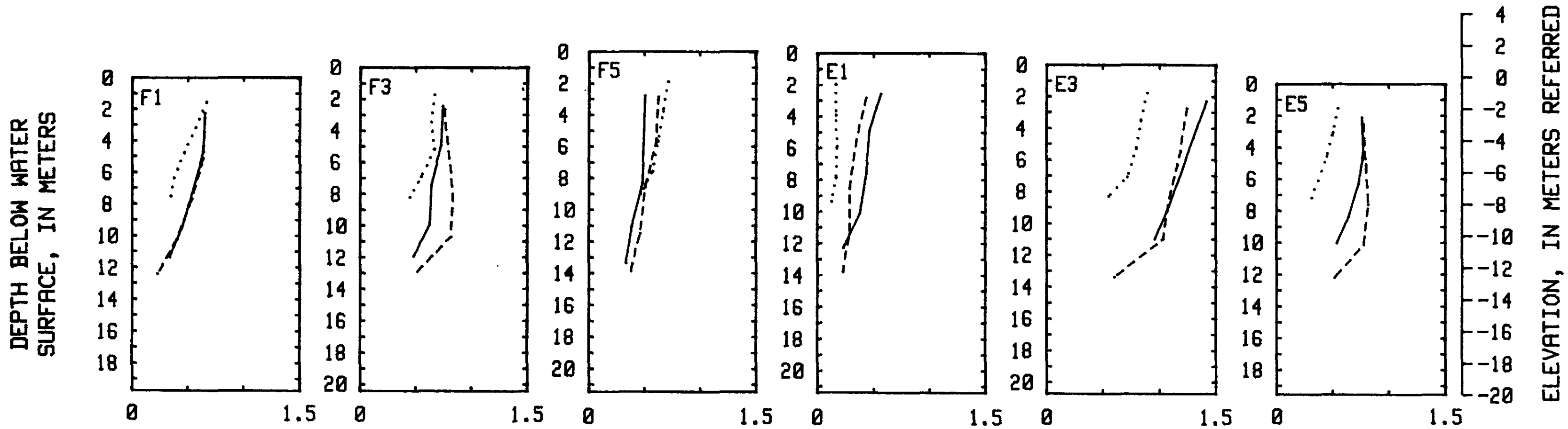
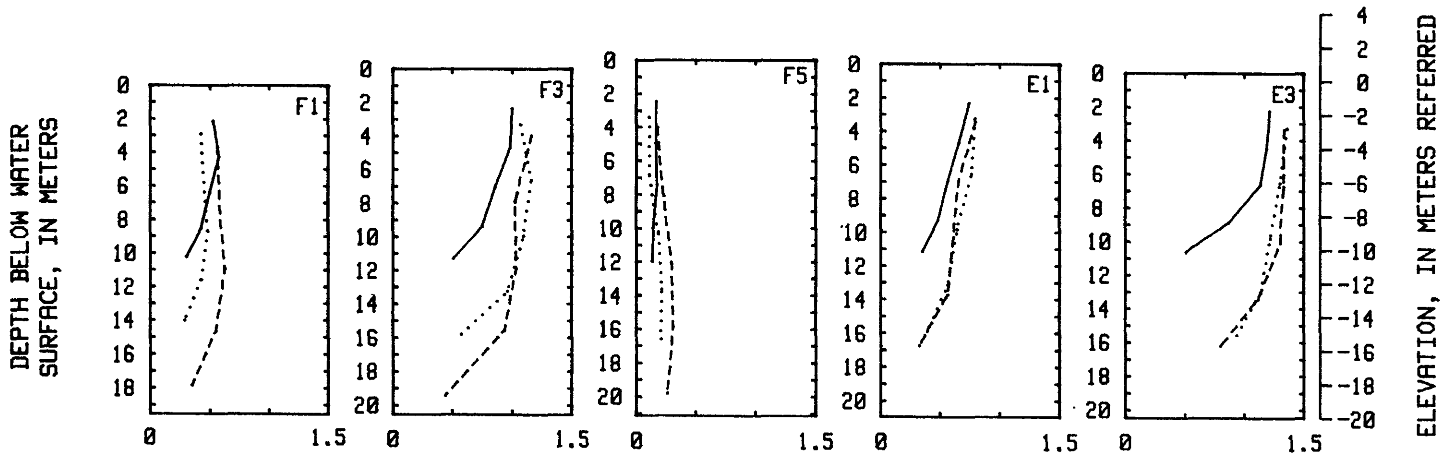


Figure 13.--Velocity profiles at the measurement verticals at upper Kings Bay and lower Kings Bay cross sections.



A. Cumberland Sound, November 16, 1981



B. St. Marys Entrance, November 18, 1981

EXPLANATION

——— LEFT VERTICAL FACING SEAWARD - - - CENTER VERTICAL ····· RIGHT VERTICAL FACING SEAWARD

E1, F1 - FIRST OF SEVERAL EBBTIDE OR FLOODTIDE DATA-COLLECTION TIMES

Figure 14.--Velocity profiles at the measurement verticals at Cumberland Sound and St. Marys Entrance cross sections.

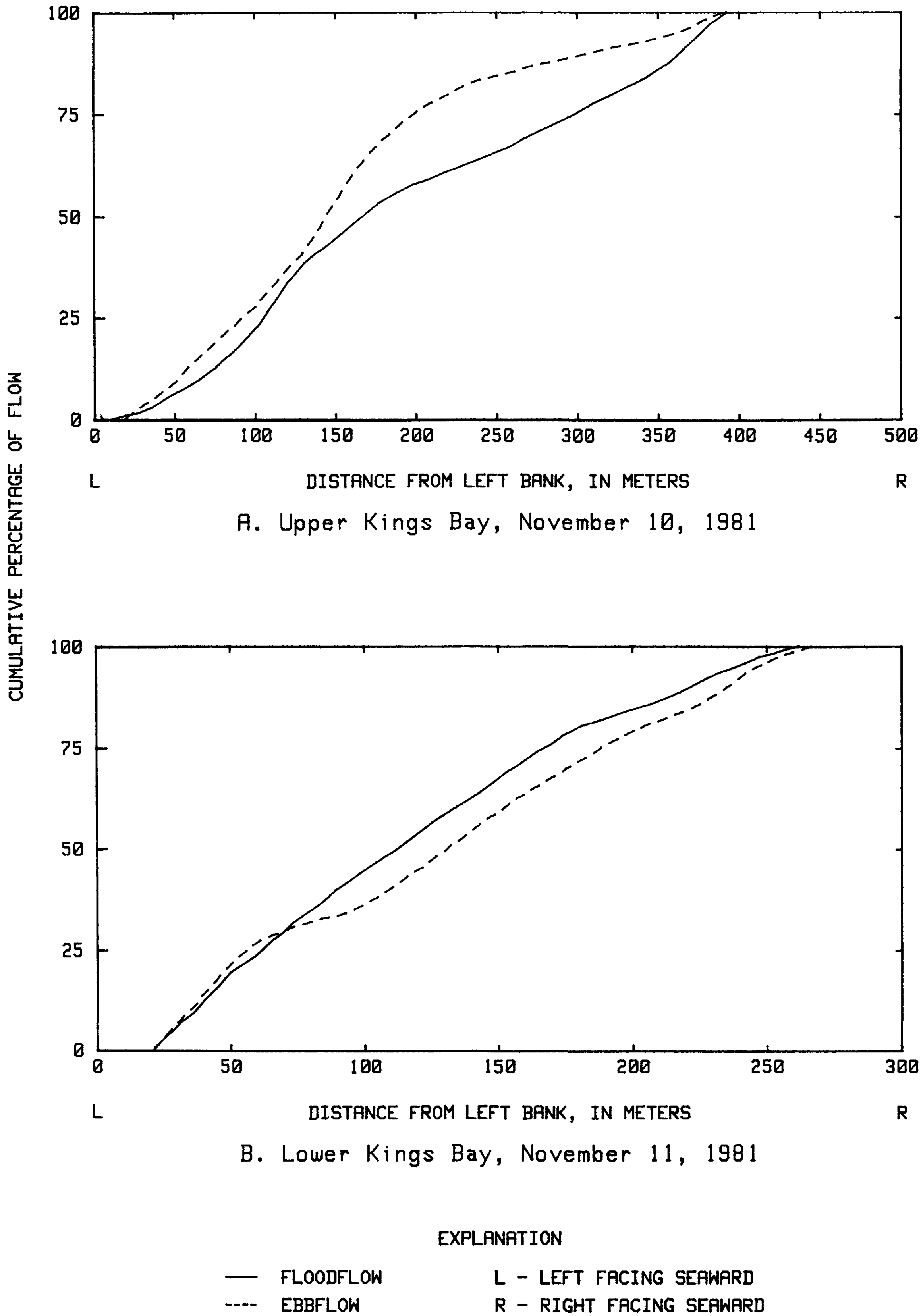


Figure 15.--Cumulative percentage of flow near maximum ebbflow and floodflow at upper Kings Bay and lower Kings Bay.

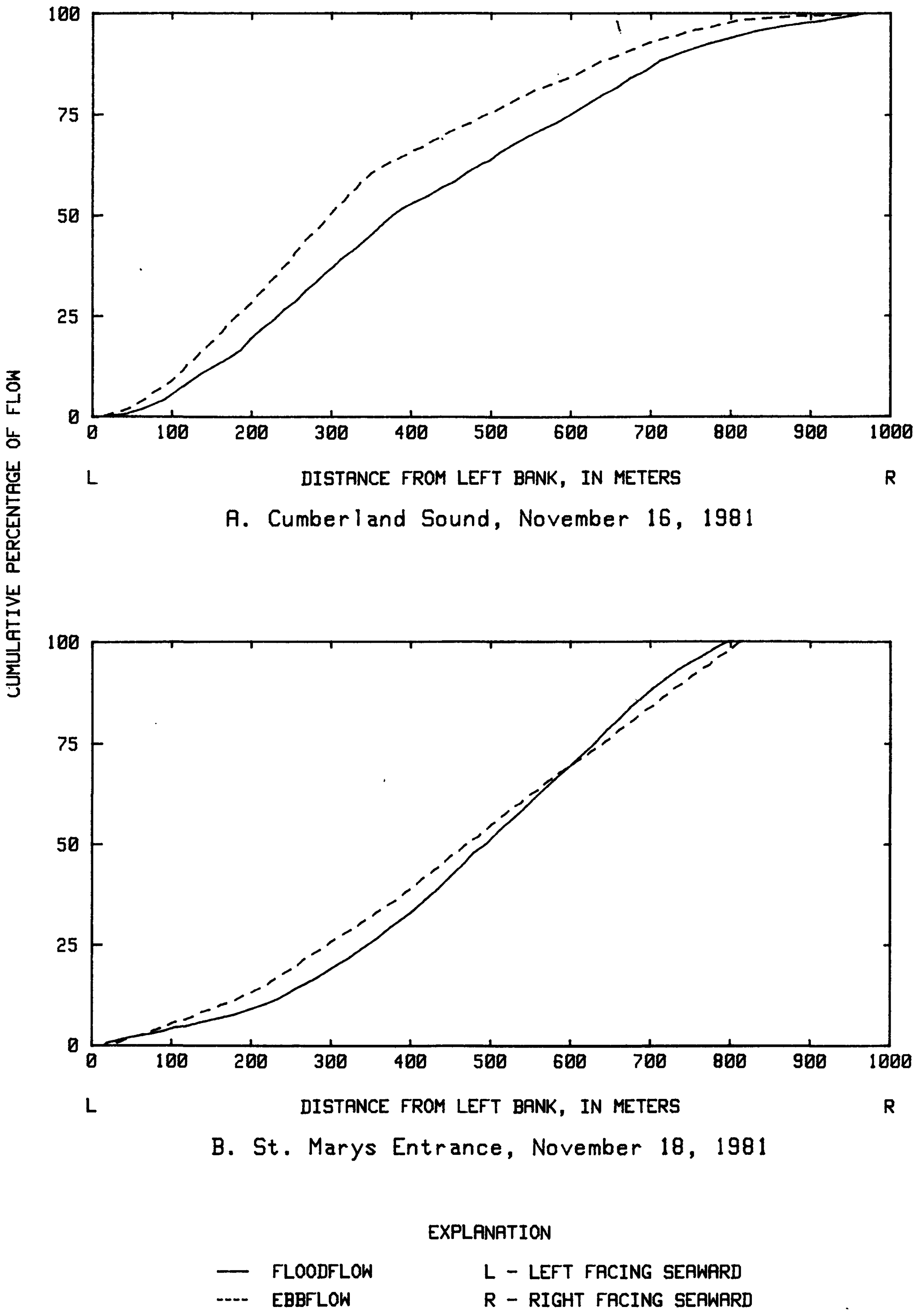


Figure 16.--Cumulative percentage of flow near maximum ebbflow and floodflow at Cumberland Sound and St. Marys Entrance.

At these times of similar ebbtide and floodtide heights, the left half of the cross section (250 m from L) carried about 87 percent of the ebbflow and about 69 percent of the floodflow.

The velocity profiles measured at the lower Kings Bay cross section indicate some tendency for higher current velocities to occur on the left side of the channel for both ebbtide and floodtide (fig. 13-B). Data were not collected during most of the floodtide because of boat and ship traffic. Differences in the flow distribution during ebbtide and floodtide appear to be small, as indicated in figure 15-B.

At the Cumberland Sound cross section, the current velocity curves in figure 12-A show that mean and maximum current velocities around mid-ebbtide were higher than during mid-floodtide. Peak mean and maximum current velocities were 0.69 and 0.91 m/s, respectively, for the floodtide and 0.91 and 1.42 m/s, respectively, for the ebbtide. The current velocities were greatest at the left and center vertical on the ebbtide and more uniform at each vertical on the floodtide (fig. 14-A). The lateral movement of the flood and ebb current velocity is reflected by a shift in the distribution of flow to the left near maximum floodflow and ebbflow (fig. 16-A).

The current velocity curves for the St. Marys Entrance site show greater mean and maximum current velocities on the ebbtide than the floodtide (fig. 12-B). Peak mean and maximum current velocities were 0.93 and 1.23 m/s, respectively, for the floodtide and 0.96 and 1.42 m/s for the ebbtide. The highest current velocities were maintained in the right and center vertical during both ebbtide and floodtide (fig. 14-B). The absence of a lateral shift in the current velocity between ebbtide and floodtide is reflected by little change in the flow distribution near maximum ebbflow and floodflow, shown in figure 16-B.

Suspended-Sediment Characteristics

The concentration of suspended sediment in samples collected during this study showed a high degree of variability among the measurement cross sections. The average concentration at each cross section was 17, 30, 48, and 18 mg/L at upper Kings Bay, lower Kings Bay, Cumberland Sound, and St. Marys Entrance, respectively (tables 6-9). These concentrations are considerably less than the seasonal range of 50 to 80 mg/L for Kings Bay and 58 to 94 mg/L for Cumberland Sound, reported by ES & E (1977, p. C-134). Higher average percentages of silt- and clay-size particles were contained in the upper and lower Kings Bay samples (91 and 86 percent, respectively) than in the Cumberland Sound (71 percent) and St. Marys Entrance (74 percent) samples. In the measurement verticals, the highest concentrations of suspended sediment commonly occurred in those samples collected at the deepest sampling depth. However, these samples did not consistently have the highest percentages of sand-size particles (tables 6-9).

The greatest suspended-sediment concentrations and largest percentages of suspended sand generally occurred around mid-ebbtide and mid-floodtide, when current velocities were greatest (figs. 17 and 18). Noticeably more sand was in suspension at the Cumberland Sound cross section than at the other three measurement cross sections. In each cross section, verticals

Table. 6.--Suspended-sediment data collected at upper Kings Bay cross section, November 10, 1981

[Tide heights from U.S. Geological Survey tide gage recorder at Kings Bay (NGVD of 1929). SL, left vertical facing seaward; C, center vertical; SR, right vertical facing seaward; E-1, F-1, first of several ebbtide or floodtide data collection times. Concentrations rather than the sample percentages listed were used to calculate the average percents of suspended silt plus clay and total suspended sediment lost on ignition for verticals and cross sections]

Sample time and code	Tide-height (m)	Sample depth (m below water surface)			Total suspended-sediment concentration (mg/L)			Percent of suspended silt plus clay (percent less than 0.062 mm)			Percent of total suspended sediment lost on ignition		
		Vertical			Vertical			Vertical			Vertical		
		SL	C	SR	SL	C	SR	SL	C	SR	SL	C	SR
0840		0.9	0.9	0.9	15	7	11	100	100	91	20	14	18
	1.24	2.7	2.4	2.1	8	19	18	100	95	94	13	21	22
E-1		5.5	4.0	4.3	28	29	19	96	96	95	21	17	21
0920		.9	.9	.9	22	21	16	95	90	88	--	--	--
	.94	3.7	2.4	1.8	22	22	17	91	91	88	--	--	--
E-2		6.7	4.0	2.7	33	23	19	88	91	84	--	--	--
1000		.9	.9	.9	23	19	16	96	79	88	17	16	19
	.59	3.7	2.4	1.8	22	21	16	91	81	88	18	19	19
E-3		4.9	4.0	2.7	21	--	20	90	--	80	14	--	15
1135		.9	.9	.9	16	7	20	88	57	90	--	--	--
	-.31	2.4	2.4	1.2	18	22	21	89	82	90	--	--	--
E-4		4.3	4.0	1.8	12	13	5	50	46	60	--	--	--
1255		.9	.9	.9	21	24	18	95	92	94	19	17	17
	-.85	2.1	2.1	1.2	24	24	16	92	92	94	19	17	19
E-5		3.7	3.0	1.5	27	28	18	93	89	94	19	18	17
Ebbtide average for verticals					21	22	17	91	86	89	18	18	18
Ebbtide average for cross section						19			89			18	
Standard deviation of ebbtide samples						5.9							
1440		0.9	0.9	0.9	7	13	13	86	92	92	29	23	23
	-.52	2.1	2.1	1.2	11	14	15	100	100	93	18	21	27
F-1		4.0	3.0	1.5	19	5	14	89	60	93	21	40	29
1530		.9	.9	.9	10	10	13	90	90	100	--	--	--
	-.07	2.4	2.4	1.2	14	16	14	93	94	93	--	--	--
F-2		4.3	4.0	1.8	15	17	5	93	94	80	--	--	--
1640		.9	.9	.9	16	17	13	94	94	92	25	24	23
	.54	3.0	2.7	1.5	18	18	18	94	94	94	28	28	22
F-3		5.2	4.9	2.4	20	21	18	90	90	94	25	24	22
1730		.9	.9	.9	15	16	14	93	94	93	--	--	--
	.95	3.0	3.0	1.8	15	17	11	93	94	91	--	--	--
F-4		5.5	5.2	2.7	16	17	20	94	94	75	--	--	--
Floodtide average for verticals					15	15	14	92	93	91	25	25	24
Floodtide average for cross section						15			92			25	
Standard deviation of floodtide samples						3.8							
Average of all samples						17			91			22	
Standard deviation of all samples						5.6							

Table. 7.--Suspended-sediment data collected at lower Kings Bay cross section, November 11, 1981

[Tide heights from U.S. Geological Survey tide gage recorder at Kings Bay (NGVD of 1929).SL, left vertical SL, left vertical facing seaward; C, center vertical; SR, right vertical facing seaward; E-1, F-1, first of several ebbtide or floodtide data collection times. Concentrations rather than the sample percentages listed were used to calculate the average percents of suspended silt plus clay and total suspended sediment lost on ignition for verticals and cross sections]

Sample time and code	Tide height (m)	Sample depth (m below water surface)			Total suspended-sediment concentration (mg/L)			Percent of suspended silt plus clay (percent less than 0.062 mm)			Percent of total suspended sediment lost on ignition		
		Vertical			Vertical			Vertical			Vertical		
		SL	C	SR	SL	C	SR	SL	C	SR	SL	C	SR
0945		0.9	0.9	0.9	15	15	14	87	93	93	20	20	14
	1.40	7.3	7.3	7.3	18	16	22	89	88	95	17	13	18
E-1		14.0	13.7	13.1	19	26	26	89	73	92	16	15	15
1040		.9	.9	.9	19	14	17	95	93	76	--	--	--
	.97	7.0	7.3	7.0	24	20	49	92	80	90	--	--	--
E-2		13.7	13.7	12.2	33	32	15	85	81	80	--	--	--
1135		.9	.9	.9	36	29	39	83	86	87	17	17	18
	.48	7.0	7.3	6.1	46	33	35	78	82	86	17	18	20
E-3		13.4	12.5	11.3	98	69	35	80	80	80	16	17	20
1320		.9	.9	.9	23	21	21	91	90	76	--	--	--
	-.46	6.7	6.7	5.2	34	20	27	76	90	85	--	--	--
E-4		12.2	12.2	9.4	40	32	31	78	84	84	--	--	--
1410		.9	.9	.9	18	18	16	94	89	94	22	17	19
	-.73	6.4	6.4	5.8	24	23	19	83	87	89	17	17	21
E-5		11.9	11.9	11.0	27	24	25	81	92	88	19	17	20
Ebbtide average for vertical					32	26	26	83	84	86	17	17	19
Ebbtide average for cross section						28			85			18	
Standard deviation of ebbtide samples						15.2							
1540		0.9	0.9	0.9	15	14	13	93	100	100	20	21	23
	-.47	6.7	6.1	4.9	36	14	14	94	86	100	14	21	21
F-1		12.5	11.3	8.8	91	39	22	95	85	95	15	15	23
1720		.9	.9	.9	7	15	20	71	80	95	--	--	--
	.42	7.0	6.1	6.7	26	26	27	92	92	85	--	--	--
F-3		13.1	11.6	12.5	39	64	15	82	92	67	--	--	--
1845		.9	.9	.9	24	25	19	88	84	74	21	20	21
	1.08	7.6	7.0	6.7	39	28	30	85	82	83	18	18	17
F-4		14.0	13.1	12.2	43	100	71	86	82	80	16	16	23
Floodtide average for vertical					36	36	26	89	86	85	17	17	21
Floodtide average for cross section						32			86			18	
Standard deviation of floodtide samples						23.5							
Average of all samples						30			86			18	
Standard deviation of all samples						18.7							

Table. 8.—Suspended-sediment data collected at Cumberland Sound cross section, November 16, 1981

[Tide heights from U.S. Geological Survey tide gage recorder at Cumberland Island (NGVD of 1929). SL, left vertical facing seaward; C, center vertical; SR, right vertical facing seaward; E-1, F-1, first of several ebbtide or floodtide data collection times. Concentrations rather than the sample percentages listed were used to calculate the average percents of suspended silt plus clay and total suspended sediment lost on ignition for verticals and cross sections]

Sample time and code	Tide height (m)	Sample depth (m below water surface)			Total suspended-sediment concentration (mg/L)			Percent of suspended silt plus clay (percent less than 0.062 mm)			Percent of total suspended sediment lost on ignition		
		Vertical			Vertical			Vertical			Vertical		
		SL	C	SR	SL	C	SR	SL	C	SR	SL	C	SR
0745		0.9	0.9	0.9	18	16	16	83	81	88	17	19	19
	-0.23	6.1	6.1	4.0	20	20	53	80	85	85	20	15	17
F-1		11.9	11.9	7.0	50	53	58	86	83	71	16	15	17
0825		.9	.9	.9	38	22	43	87	86	67	—	—	—
	.09	6.1	6.4	3.7	44	57	58	82	86	41	—	—	—
F-2		11.3	11.9	7.3	33	69	66	67	88	68	—	—	—
0905		.9	.9	.9	62	54	36	77	44	56	18	17	17
	.44	6.1	6.7	4.3	82	75	41	78	43	71	16	16	17
F-3		11.3	12.8	7.6	115	134	46	63	58	70	16	12	17
1100		.9	.9	.9	49	44	51	71	80	75	—	—	—
	1.28	7.0	7.0	4.6	53	26	49	79	69	61	—	—	—
F-4		13.1	13.4	8.2	58	59	54	81	75	76	—	—	—
1155		.9	.9	.9	39	37	37	72	73	70	18	19	19
	1.48	7.0	6.7	4.6	50	45	41	76	78	71	16	18	17
F-5		13.1	12.8	8.5	64	54	43	56	67	81	17	17	16
Floodtide average for verticals					52	51	46	74	70	69	17	15	17
Floodtide average for cross section						50			71			16	
Standard deviation of floodtide samples						22.5							
1340		0.9	0.9	0.9	21	3	18	71	100	83	19	33	17
	1.40	6.4	7.0	4.6	42	21	24	67	76	75	19	24	17
E-1		11.9	13.1	8.5	94	63	39	76	70	72	18	48	21
1420		.9	.9	.9	14	19	20	86	84	65	—	—	—
	1.15	5.8	7.0	4.6	50	32	38	74	91	71	—	—	—
E-2		11.0	13.1	8.2	85	45	48	71	73	65	—	—	—
1515		.9	.9	.9	39	32	31	79	75	90	18	19	16
	.73	5.8	6.7	4.3	54	39	31	76	69	81	17	18	16
E-3		11.0	12.8	7.9	72	94	37	56	39	59	14	9	14
1650		.9	.9	.9	75	59	37	80	83	81	—	—	—
	-.08	4.9	6.4	4.0	66	70	49	76	73	71	—	—	—
E-4		9.8	11.9	7.0	64	88	52	78	70	79	—	—	—
1745		.9	.9	.9	51	43	23	84	72	78	16	14	17
	-.44	5.2	6.1	3.7	54	45	34	74	69	82	17	13	18
E-5		9.8	11.3	6.4	61	62	38	79	52	76	16	13	16
Ebbtide average for verticals					56	48	35	74	68	75	17	14	17
Ebbtide average for cross section						46			72			16	
Standard deviation of ebbtide samples						21.7							
Average of all samples						48			71			16	
Standard deviation of all samples						22.0							

Table. 9.--Suspended-sediment data collected at St. Marys Entrance cross section, November 18, 1981

[Tide heights from National Ocean Survey tide gage recorder at Fernandina Beach (NGVD of 1929). SL, left vertical facing seaward; C, center vertical; SR, right vertical facing seaward; E-1, F-1, first of several ebbtide or floodtide data-collection times. Concentrations rather than the sample percentages listed were used to calculate the average percents of suspended silt plus clay and total suspended sediment lost on ignition for verticals and cross sections]

Sample time and code	Tide height (m)	Sample depth (m below water surface)			Total suspended-sediment concentration (mg/L)			Percent of suspended silt plus clay (percent less than 0.062 mm)			Percent of total suspended sediment lost on ignition		
		Vertical			Vertical			Vertical			Vertical		
		SL	C	SR	SL	C	SR	SL	C	SR	SL	C	SR
0900		0.9	0.9	0.9	10	10	13	70	80	92	20	20	23
	-0.46	4.6	8.2	6.7	16	14	14	75	64	86	13	14	14
F-1		9.1	17.1	13.4	23	28	34	78	79	71	13	18	18
1015		.9	.9	.9	32	17	27	81	65	78	--	--	--
	.02	5.5	9.1	7.0	33	29	37	64	86	84	--	--	--
F-2		10.1	14.3	13.4	38	25	68	68	76	87	--	--	--
1130		.9	.9	.9	17	22	20	82	77	70	12	14	15
	.55	4.9	9.4	8.2	17	24	10	76	67	50	12	13	10
F-3		10.7	13.7	14.3	20	25	11	70	76	82	10	16	9
1345		.9	.9	.9	20	16	19	85	81	63	--	--	--
	1.14	6.1	10.4	6.7	20	9	18	90	78	83	--	--	--
F-4		11.3	14.3	13.7	25	10	22	84	70	73	--	--	--
1440		.9	.9	.9	16	14	7	94	79	86	13	14	14
	1.13	6.1	9.8	6.4	16	8	13	81	62	85	13	13	15
F-5		11.3	14.3	13.1	18	7	13	67	71	77	11	0	15
Floodtide average for verticals					22	17	22	77	75	79	12	14	16
Floodtide average for cross section						20			77			14	
Standard deviation of floodtide samples						10.8							
1535		0.9	0.9	0.9	11	8	14	73	62	79	9	13	14
	.96	5.8	7.9	7.0	12	11	19	92	64	47	8	9	16
E-1		10.7	16.5	13.1	8	12	28	50	58	71	13	8	18
1620		.9	.9	.9	16	8	13	81	88	77	--	--	--
	.70	5.5	6.4	7.3	16	7	13	69	86	69	--	--	--
E-2		10.4	13.1	13.1	18	6	18	67	67	72	--	--	--
1655		.9	.9	.9	19	11	23	74	82	70	16	18	17
	.48	6.4	7.6	6.4	20	10	21	60	70	95	15	20	14
E-3		11.9	14.3	11.9	19	10	20	47	70	70	11	10	15
1745		.9	.9	.9	22	14	20	73	79	80	--	--	--
	.09	5.5	6.1	6.1	22	14	18	77	71	78	--	--	--
E-4		10.4	12.2	11.3	24	16	18	6	75	83	--	--	--
Ebbtide average for verticals					17	11	19	62	72	74	12	13	16
Ebbtide average for cross section						16			69			14	
Standard deviation of ebbtide samples						5.4							
Average of all samples						18			74			14	
Standard deviation of all samples						9.0							

having the highest current velocities had the largest individual and mean suspended-sediment concentrations (figs. 17 and 18, tables 6-9).

The differences between the average suspended-sediment concentrations for a consecutive ebbtide and floodtide at the measurement cross sections were small. The two-sample _t_ test (two sided) (Dixon and Massey, 1969) established statistically significant differences (0.05 significance level) between the average ebbtide and floodtide concentrations at the upper Kings Bay and St. Marys Entrance cross sections. Differences in concentration were not statistically significant at the lower Kings Bay and Cumberland Sound cross sections. Average concentrations of samples were somewhat higher for the ebbtide than for the floodtide at the upper Kings Bay cross section and lower for the ebbtide than for the floodtide at the St. Marys Entrance cross sections.

The ignition loss at 550°C of suspended-sediment samples was determined to indicate the relative amounts and possibly the sources of particulate organic material present in the suspended sediment. The material lost on ignition includes organic carbon, hydration water of salts retained by the sediment particles, and residual amount of water retained by the clay-size particles after the sample has been dried at 110°C for the determination of suspended-sediment concentration. It is not certain, but perhaps half of the material lost on ignition may be particulate organic carbon (Dyer, 1979). At this time of year (Nov.), phytoplankton concentrations were low (See p. 45.) and, therefore, contributed little to the percentage lost on ignition.

The average percentage of total suspended sediment lost on ignition at each cross section for all samples collected over the 13-hour period ranged from 22 percent at the upper Kings Bay cross section to 14 percent at the St. Marys Entrance cross section. The percentages indicate a decreased ignition loss in a seaward direction.

Historic riverflow and sediment-concentration data collected by the U.S. Geological Survey at a station on the St. Marys River near Macclenny, Fla., were used to evaluate the importance of the river as a source of sediment to the study area. Because the station is 161 river kilometers upstream from the mouth, the data represent only the suspended sediment contributed to the estuary from upland sources. Contributions from erosion of the tidal channel and shoreline or from bedload transport were not investigated in this study.

The total suspended-sediment concentration at the St. Marys River near Macclenny station, based on monthly samples collected from 1974 to 1980, ranged from 1 to 15 mg/L and averaged 4 mg/L. Nearly all suspended-sediment particles were less than 0.062 mm in diameter. The relation between water and suspended-sediment discharges for the St. Marys River near Macclenny, Fla., is shown in figure 19. By using the flow-duration data for the St. Marys River station and the relation in figure 19, an annual suspended-sediment discharge of 3.1×10^6 kg/yr was computed. The annual sediment yield (computed as in Miller, 1951) for the drainage basin is 1.7×10^3 kg/km^2/yr.

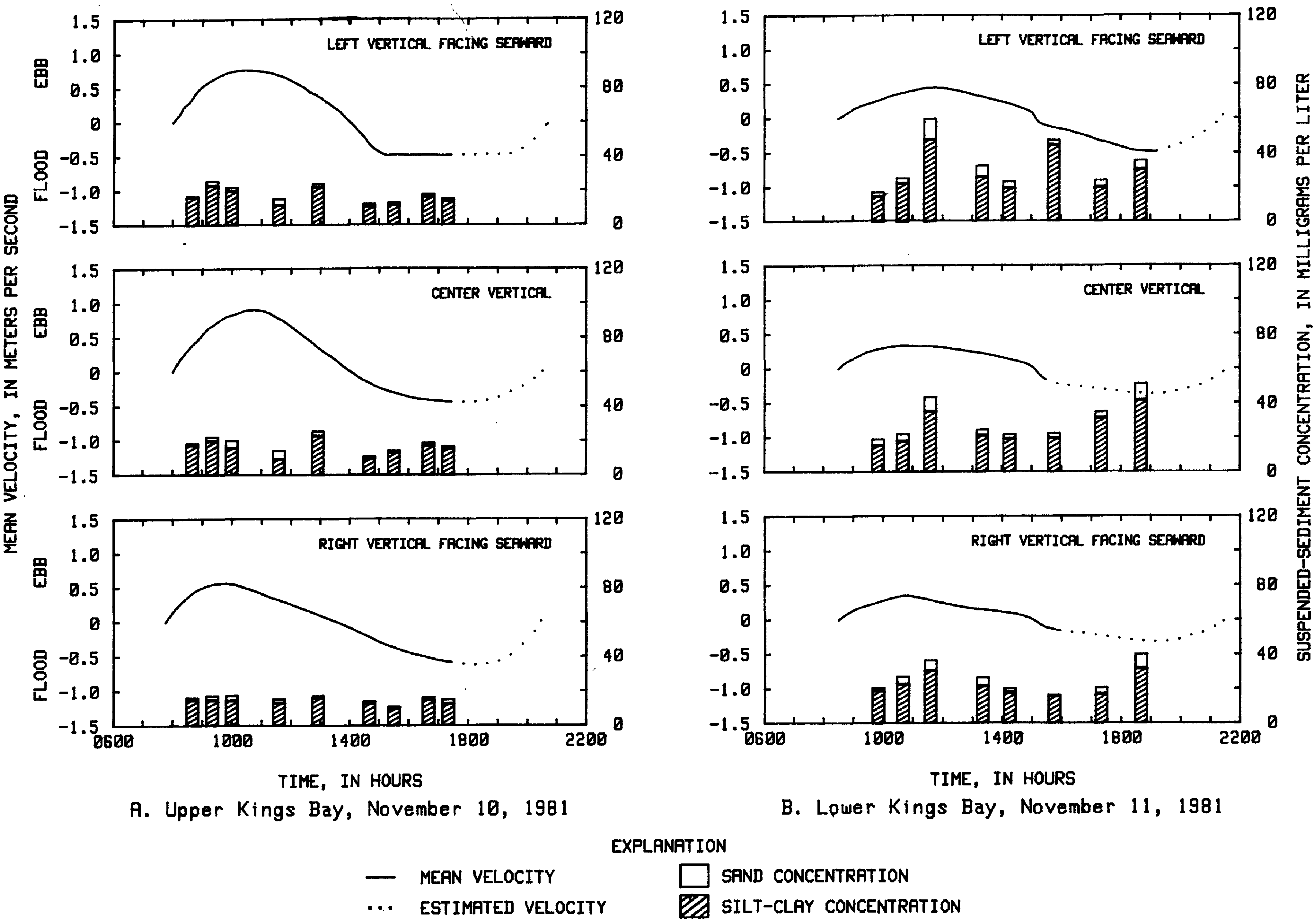


Figure 17.--Mean velocity and mean suspended-sediment concentration at the measurement verticals in upper Kings Bay and lower Kings Bay cross sections.

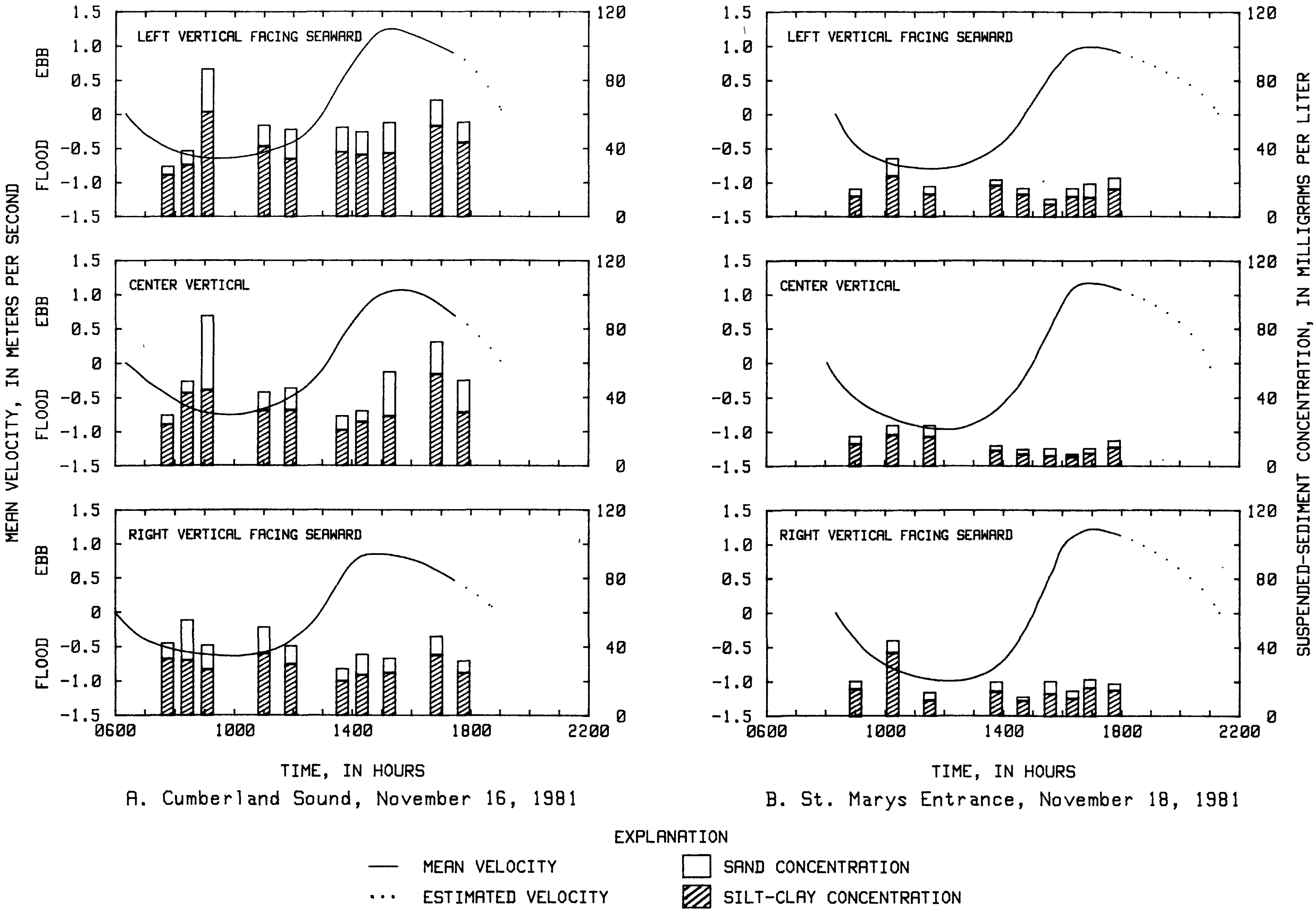


Figure 18.--Mean velocity and mean suspended-sediment concentration at the measurement verticals in Cumberland Sound and St. Marys Entrance cross sections.

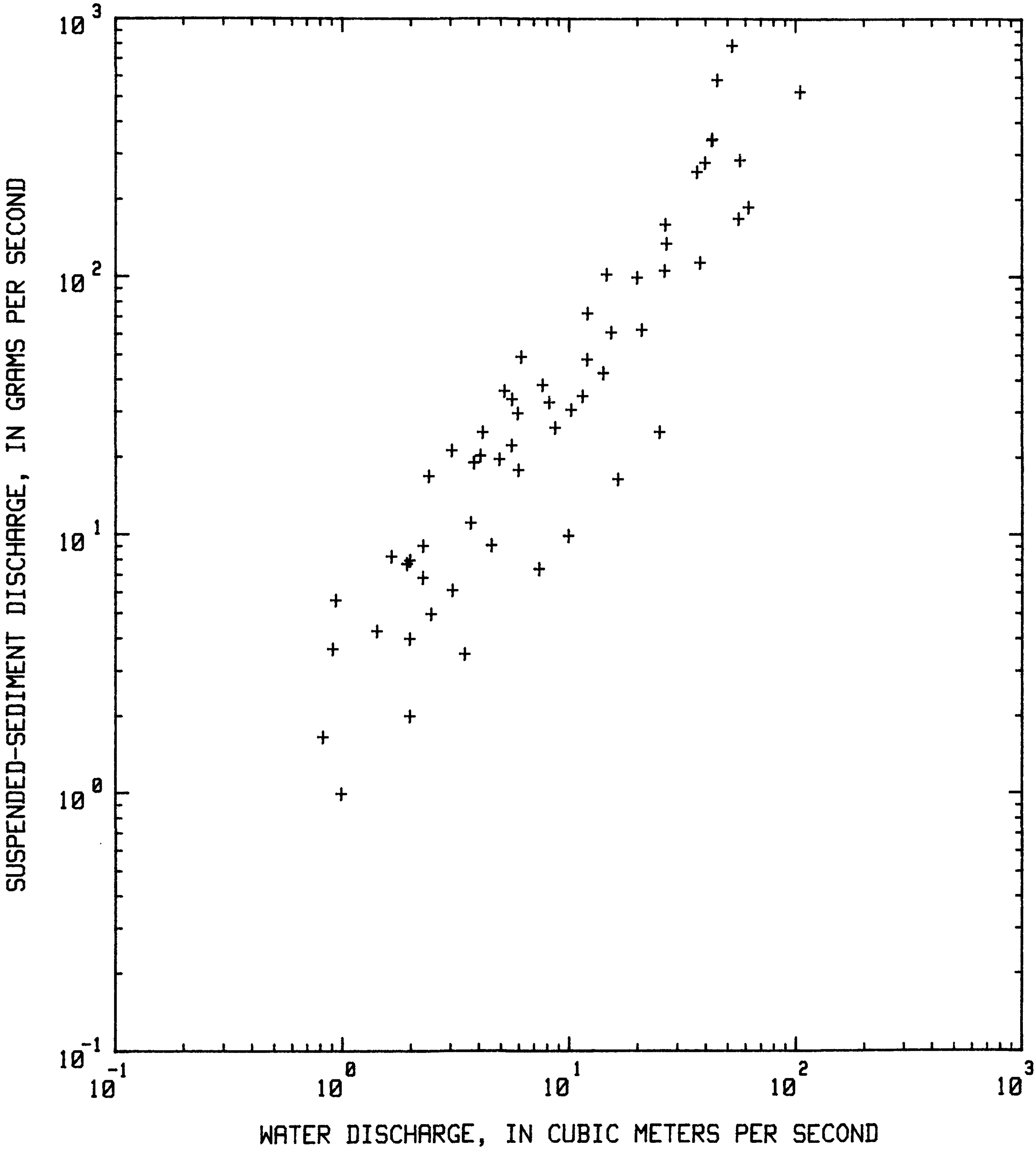


Figure 19.--Relation between water and suspended-sediment discharges, St. Marys River near Macclenny, Fla., 1974 - 80 water years.

The suspended-sediment loads and yields determined for the St. Marys River near Macclenny, Fla., indicate that the amount of suspended sediment transported from the upland to the estuary is small. For the purpose of comparison, table 10 lists the annual suspended-sediment discharge and yields from other streams that flow to the Atlantic coast in Georgia. The headwaters of the Altamaha and Ogeechee Rivers are in the Piedmont physiographic province and the headwaters of the remaining streams are in the Coastal Plain.

Phytoplankton

Phytoplankton standing stock data are presented in table 11. Phytoplankton primary productivity as indicated by standing stock was low at all sites during the study period, which was not unexpected for that time of year. Some observations can be made concerning the data in table 11: (1) the true plankters, Skletonema and Chaetoceros were the dominant organisms in terms of cells per milliliter; (2) within the plankton assemblage, species from planktonic (drifting), edaphic (marsh soils), and neritic (shallow water) origins were found; (3) with the exception of the upper Kings Bay site, ebbtide samples included a greater number of edaphic species and individuals derived from the tidal marsh. The highest standing stock (9,920 cells/mL) occurred during ebbtide at the lower Kings Bay site, and the lowest standing stock (952 cells/mL) occurred during ebbtide at upper Kings Bay; and (4) ebbtide samples had higher species richness (total number of species) values than floodtide samples.

Because the data were not collected synoptically, care must be exercised in interpreting these results. For example, the severe weather and the high tidal conditions that occurred during and between sampling periods could account for many of these observations.

Turbidity

The relation between turbidity and suspended-sediment concentration was investigated in Kings Bay and vicinity to determine if turbidity data could be used to indicate changes in suspended-sediment concentration during the November data-collection period. No universal relation exists between turbidity and suspended-sediment concentration because of the highly variable nature of the suspended material. A good association may exist, however, between these parameters at specific locations and times. A relation between these parameters could provide relatively inexpensive real-time estimates of suspended-sediment concentration to supplement data collected by direct sampling and later laboratory analyses.

The turbidity-suspended-sediment concentration curve for field data collected at the four measurement cross sections is presented in figure 20. A reasonable relation exists between the two parameters, at least for the November measurement period. The rather uniform distribution of ebbtide and floodtide data points illustrates that the relation is similar during both ebbtide and floodtide. The possibility of seasonal variability in the composition of the suspended sediment requires that the relation be established for each sampling period.

Table 10.--Flow and suspended-sediment transport characteristics for selected streams

Sample station (USGS station numbers)	Drainage area (km^2)	Median annual flow (m^3/s)	Record analyzed flow (yrs)	Record analyzed sediment (yrs)	Annual suspended-sediment discharge (kg x 10^6/yr)	Annual suspended-sediment yield (kg x $10^3/km^2$/yr)
Altamaha River at Doctortown, Ga. (02226000)	35,200	238	49	20	330	9.4
Canoochee River near Claxton, Ga. (02203000)	1,440	4.48	42	13	3.9	2.7
Ogeechee River near Eden, Ga. (02202500)	6,860	39.2	42	23	22	3.1
Satilla River at Atkinson, Ga. (02228000)	7,230	27.4	50	22	30	4.1
St. Marys River near Macclenny, Fla. (02231000)	1,810	6.44	53	6	3.1	1.7

Table 11.—Phytoplankton standing stock in Kings Bay and vicinity

[Standing stock in cells per milliliter. Samples taken 1 meter below water surface]

Station:	Upper Kings Bay				Lower Kings Bay				Cumberland Sound				St. Marys River Entrance			
Date:	Nov. 10, 1981				Nov. 11, 1981				Nov. 16, 1981				Nov. 17, 1981			
Vertical:	Center				Center				Center				Center			
Time:	0830		1432		0932		1533		0730		1348		0824		1540	
Tide:	Ebb		Flood		Ebb		Flood		Flood		Ebb		Flood		Ebb	
Taxa	Standing stock	Percent of total	Standing stock	Percent of total	Standing stock	Percent of total	Standing stock	Percent of total	Standing stock	Percent of total	Standing stock	Percent of total	Standing stock	Percent of total	Standing stock	Percent of total
Bacillariophyta Karsten																
Bacillariophyceae Hendey																
Eupodiscales																
Biddulphiaceae																
Biddulphia Gray & V.H.					140	1					28	1				
Chaetoceraceae																
Chaetoceros	14	2	380	23	980	10	56	5	56	7					14	1
Coscinodiscaceae																
Coscinodiscus Ehr.	70	7	42	3			14	1	14	2	42	2	28	2	14	1
Cyclotella Kutz.	630	66	490	30	6,000	61	610	59	340	38	360	19	460	28	110	7
Melosira Agardh.					280	3					98	5	42	3	110	7
Skeletonema Grev.	28	3	410	25	560	6	220	22	110	13	180	9	98	6	340	21
Thalassiosira									28	3	200	10	56	3	14	1
Rhizosoleniaceae																
Rhizosolenia									14	2	28	1	14	1	28	2
Fragillariales Silva																
Fragillariaceae Hustedt																
Asterionella Hass.	28	3									98	5	56	3	220	14
Fragillaria Lnygb.					420	4			42	5	350	18			310	20
Plagiogramma Grev.							70	7								
Striatella									14	2						
Thalassionema	28	3									42	2	70	4	70	4
Naviculales Bessey																
Naviculaceae Kutz.																
Diploneis Ehr.	28	3	14	1	140	1					14	1			14	1
Navicula Bory	42	4	28	2	700	7	28	3	56	7	200	10			70	4
Entomoneidaceae Rein.																
Entomoneis Ehr.													14	1		
Cymbellaceae Kutz.																
Amphora Ehr.Ex.Kutz.											28	1				
Gomphonemaceae																
Gomphonema Kutz.									28	3						
Bacillariales																
Nitzschiaceae																
Nitzschia Hass.	70	7	140	9	700	7			110	13	250	13	130	8	180	12
Surirellales																
Surirellaceae																
Surirella Turpin			14	1												
Cryptophyta																
Cryptophyceae																
Cryptomonadales																
Cryptochrysidaceae																
Chroomonas			98	6			28	3					28	2	42	3
Chrysophyta																
Chrysophyceae																
Chysomonadales																
Ochromonadaceae																
Ochromonas															28	2
Pyrrhophyta																
Dinophyceae																
Peridiniales																
Peridiniaceae																
Peridinium	14	1							42	5						
Cyanophyta																
Cyanophyceae																
Chroococcales																
Chroococcaceae Nageli																
Gomphosphaeria Kutz.													630	39		
Totals	952	100	1,616	100	9,920	100	1,026	100	854	100	1,918	100	1,626	100	1,564	100

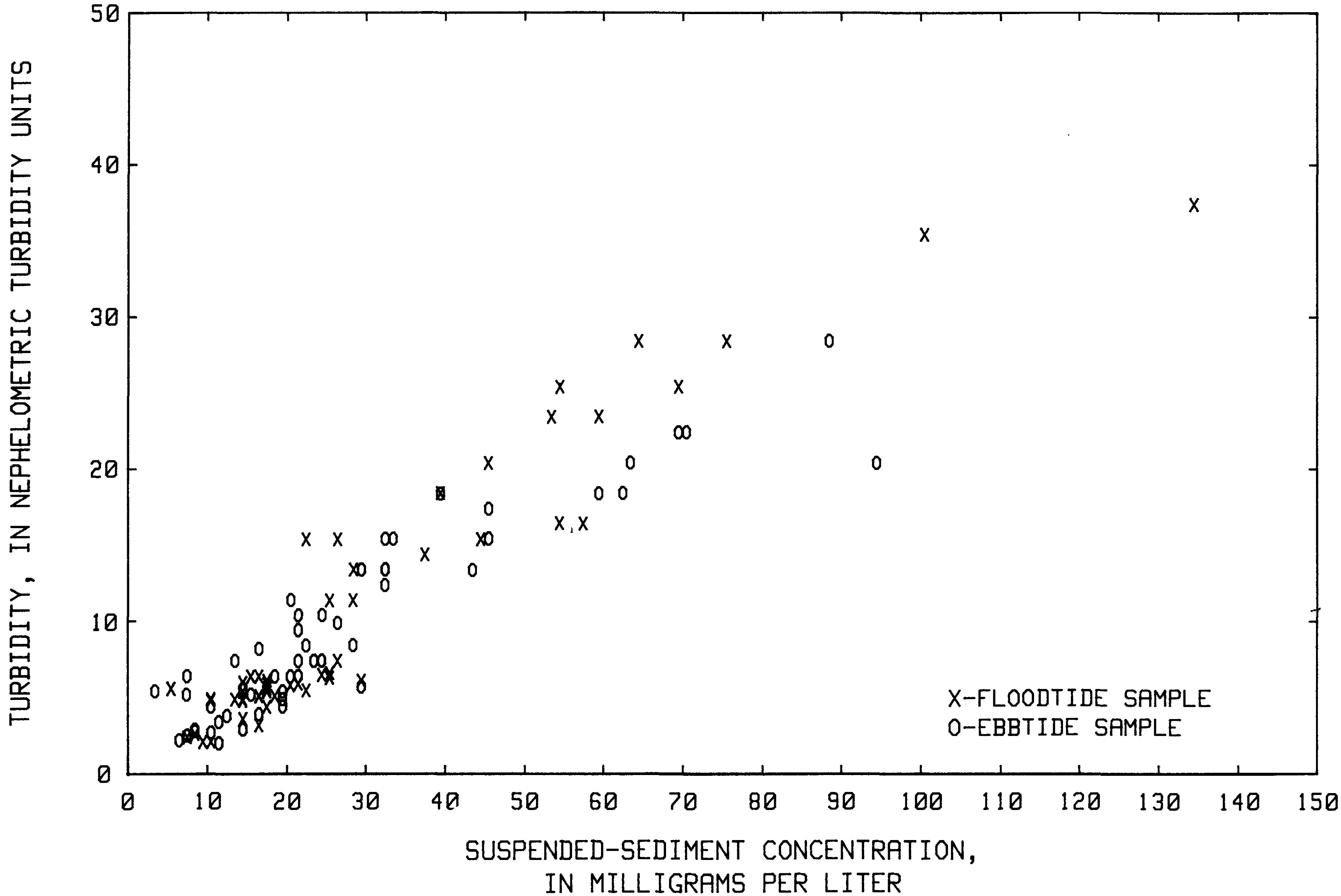


Figure 20.--Relation of suspended-sediment concentration to turbidity based on samples collected at the measurement cross sections, Kings Bay and vicinity, November 10-18, 1981.

Turbidity data (fig. 21) also were collected at 29 locations in the Kings Bay study area at consecutive low and high tides. The site location numbers correspond to the site locations and numbers in figure 1. Tide data are listed in figure 21 so that "closeness" of the sampling time to low or high water can be ascertained. As sites increase in distance landward from the tide recorder sites, the times of low and high tide at the sites occur later than the times shown at the tide recorder sites. The approximate times of low and high tide for those sites landward can be estimated by assuming that about a 2-hour lag exists between time of low or high tide at site 1 and the most landward sites (sites 18, 29, and 10) (U.S. Department of Commerce, 1981b).

An attempt was made to collect the turbidity samples at the low and high slack tide (zero velocity) periods which occurred at nearly the same times as the minimum and maximum tide heights. (See figs. 11 and 12.) Sample collection at slack tide was not always successful, particularly for the low tide samples. In the upper sections of the St. Marys River, Kings Bay, and Crooked River channels (sites 17, 18, 22, 23, and 26 through 29), the tide had begun to flood about 1 to 2 hours before the low tide samples were collected.

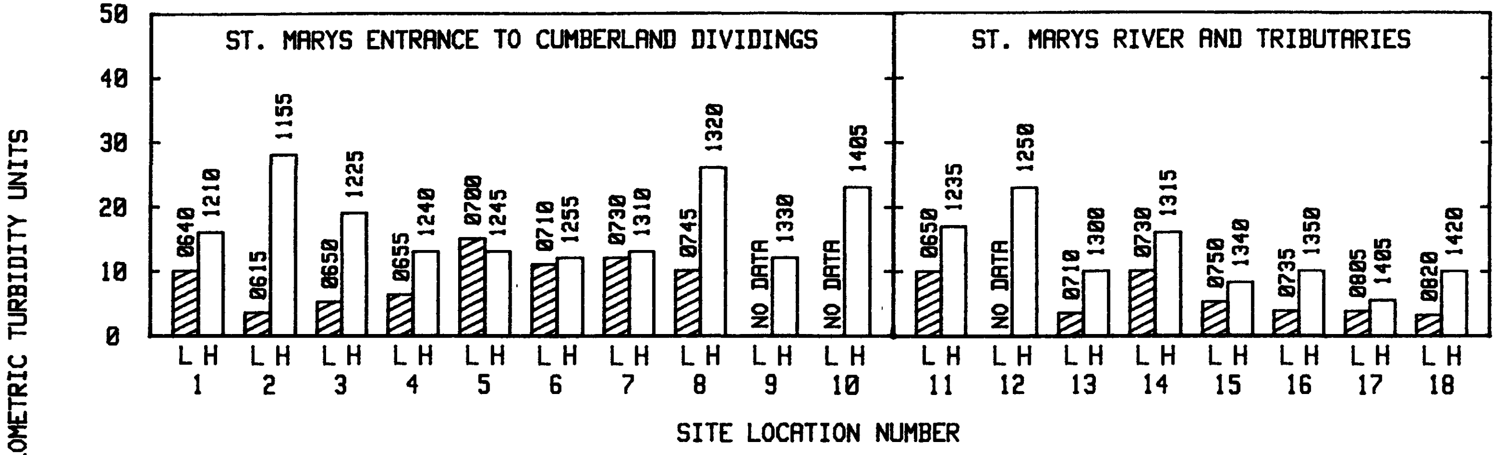
Observations and salient points concerning the low- and high-tide turbidity survey are:

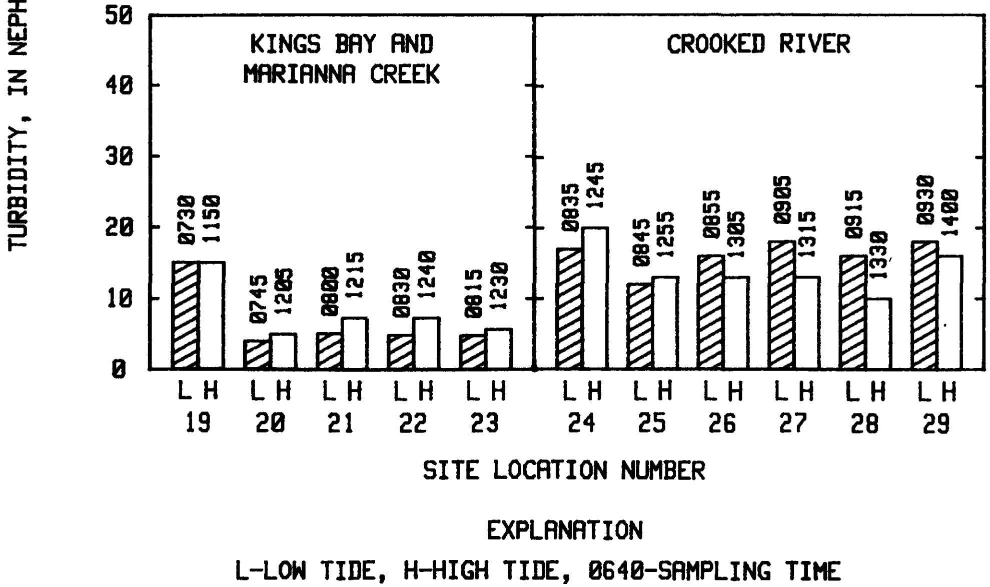
1. Generally, high-tide turbidity was greater than low-tide turbidity. The greater high-tide turbidities may be caused by the resuspension of materials from the marshes, shorelines, and exposed shoals by the tide or wind-generated currents. At low tide, the "wetted" surface area has decreased and progressively smaller deep-water areas are subject to erosion, primarily by the tidal currents. The result was a lesser low-tide turbidity. In the Crooked River reach, the opposite occurred. At sites 26-29, low-tide turbidity was greater than high-tide turbidity. However, the low-tide samples were collected well into the floodtide (about 2 hours after the estimated low tide), whereas the high-tide samples were obtained approximately at high slack tide. The turbulence associated with the rapidly increasing tidal currents could have resulted in higher turbidities than were measured during high-tide sampling.

2. Relatively high turbidities occurred near the entrance to Kings Bay (site 19) at high and low tide, compared to sites in Kings Bay. Apparently, local turbulence retained sediment in suspension for a longer period of time near the entrance to Kings Bay while lesser turbulence in Kings Bay permitted more rapid settling of sediment.

3. Turbidity data indicated that less suspended material was present in Kings Bay (sites 20, 21, and 22) and Marianna Creek (site 23) than in Cumberland Sound and the Crooked River reach.

4. Relatively high turbidities occurred in parts of the Cumberland River (sites 8 and 10). In the vicinity of the Cumberland Dividings (near site 10), flood waters from Cumberland Sound and St. Andrews Sound meet and mix, then flow in either direction on the ebbtide. Near the time of sampling, this reach was noticeably turbulent. The fate of the suspended material along this turbulent reach is not known, but it possibly may be a source of sediment to Cumberland Sound and Kings Bay.





TIME	TIDE HEIGHT, IN METERS REFERRED TO NGVD		
	KINGS BAY	CUMBERLAND ISLAND	FERNANDINA BEACH
0400	-0.57	-0.52	-.59
0500	-.83	-.72*	-.75*
0515	-.84*	-.72	-.71
0600	-.71	-.56	-.54
0700	.24	-.10	-.11
0800	.30	.42	.40
0900	.84	.98	.93
1000	1.24	1.37	1.30
1100	1.53	1.63	1.56
1145	1.73*	1.73*	1.64*
1200	1.68	1.73	1.63
1300	1.51	1.50	1.39
1400	1.05	1.03	.94
1500	.54	.51	.43
1600	.02	.02	-.12

*-MINIMUM AND MAXIMUM TIDE HEIGHT RECORDED

TIDE HEIGHTS BEFORE, DURING, AND AFTER SYNOPTIC SURVEY PERIOD

Figure 21.--Spatial distribution of turbidity at low and high tide, Kings Bay and vicinity, November 15, 1981.

The information obtained from the synoptic turbidity survey describes the distribution and the relative amounts of suspended sediment in the study area. The turbidity patterns observed may only represent the turbidity conditions at the time of the survey. However, the data support some of the findings from other parts of this study and provide an information base to compare with similar data collected at other times and tide conditions.

Bottom-Material Characteristics

Particle-size distribution and constituent concentrations of bottom materials from Kings Bay and vicinity provide information on the nature and distribution of bottom materials and on the concentrations of substances adsorbed on the bottom materials.

Particle Size

Bottom material was analyzed for particle sizes over a range that included silt plus clay (less than 0.062 mm) through very-coarse gravel (32 mm). Particle-size distributions at the cross sections are shown in table 12 and are summarized and displayed graphically in figures 22 and 23.

Bottom materials in the area ranged from coarse gravel-size shell fragments to fine silt and clay-size inorganic particles. Fine particles were predominant only in bottom materials at the lower Kings Bay cross section. At the upper Kings Bay cross section, bottom material consisted dominantly of fine and medium sand-size particles. Bottom materials at the Cumberland Sound cross section also were dominantly fine and medium sand particles, but had a greater percentage of gravel-size particles than the upper Kings Bay cross section. Bottom material from the St. Marys Entrance cross section consisted of medium to very-coarse sands and very-fine to coarse gravel-size shell fragments. The strong tidal currents at this cross section obviously have retarded the deposition of the fine sand and silt, clay particles.

Temporal and lateral variation in the particle size of bottom material collected at each cross section was minimal. Patterns that can be associated with current velocity, flow characteristics, or channel geometry (table 12 and figs. 22 and 23) are not evident.

Chlorinated Hydrocarbons

Chlorinated hydrocarbon concentrations (table 13) were less than the detection limits in most bottom-material samples from Kings Bay and vicinity. PCB and DDD were present in higher concentrations in fine sediments from the lower Kings Bay cross section. Many pesticides have a low water solubility that favors their sorption on fine-grained suspended or sedimented materials (U.S. Environmental Protection Agency, 1972).

Heavy Metals

Heavy metals (table 13) are present in low concentrations in most bottom-material samples. However, in fine sediments from the lower Kings

Table 12.—Particle-size distribution of bottom material in Kings Bay and vicinity

[SL, left vertical, facing seaward; C, center vertical; SR, right vertical, facing seaward.]

Range of particle size (mm)		Particle-size distribution, in percent									Particle-size distribution, in percent								
	Station:	Upper Kings Bay									Lower Kings Bay								
	Date:	Nov. 10, 1981									Nov. 11, 1981								
	Tide stage:	Slack			Ebb			Flood			Ebb			Slack			Flood		
	Time:	0740	0720	0700	0950	1000	1005	1640	1645	1635	1125	1110	1133	1441	1520	1454	1800	1805	1810
	Vertical:	SL	C	SR	SL	C	SR	SL	C	SR	SL	C	SR	SL	C	SR	SL	C	SR
Gravel fraction																			
16.00 - 32.00																			
8.00 - 16.00																			
4.00 - 8.00										3.0	1.5								
2.00 - 4.00		0.1	0.9		1.0			1.2	1.9	.5	5.9								
Sand fraction																			
1.00 - 2.00		.05	2.7	1.2	4.5	1.0	3.0	2.3	3.5	1.8	1.4								
.50 - 1.00		1.6	6.4	5.9	13.0	6.3	12.1	7.0	7.2	10.1	.5	0.1	0.5	0.1	0.1	0.2		0.1	
.25 - .50		20.4	9.8	22.4	29.0	24.1	44.5	26.7	14.9	26.4	.5	.3	2.5	.2	.2	.4	0.2	.1	0.1
.125 - .25		72.2	60.8	62.4	50.6	62.7	32.3	61.6	62.8	45.3	14.4	2.9	55.0	23.4	1.3	2.0	8.7	1.2	2.2
.062 - .125		3.2	11.5	7.1	1.1	2.8	1.3	1.7	5.2	3.5	24.5	12.8	15.8	31.5	3.9	1.8	20.3	4.0	3.6
Silt-clay fraction																			
.000 - .062		2.5	8.0	1.2	.7	3.1	6.9	0	4.6	8.2	51.4	83.9	26.1	44.8	94.4	95.6	70.8	94.5	94.1

Range of particle size (mm)		Particle-size distribution, in percent									Particle-size distribution, in percent								
	Station:	Cumberland Sound									St. Marys Entrance								
	Date:	Nov. 16, 1981									Nov. 18, 1981								
	Tide stage:	Flood			Slack			Ebb			Slack			Flood			Ebb		
	Time:	0923	0943	0926	1310	1330	1350	1700	1705	1736	0915	0836	0921	1200	1215	1230	1653	1700	1730
	Vertical:	SL	C	SR	SL	C	SR	SL	C	SR	SL	C	SR	SL	C	SR	SL	C	SR
Gravel fraction																			
16.00 - 32.00				5.4	7.4			6.8				3.7	4.6	2.0					24.8
8.00 - 16.00		12.4		.9	4.9			7.6		1.1		6.9	21.7	16.7					21.7
4.00 - 8.00		9.1		1.8	12.3			10.6	3.5	2.2	2 0	14.7	18.9	12.3	2.6		0.9	25.5	13.6
2.00 - 4.00		7.4		5.4	12.3	1.2	1.4	11.4	5.1	4.3	5.1	22.1	16.0	16.7	3.6	2.4	1.9	7.6	16.1
Sand fraction																			
1.00 - 2.00		5.0	2.2	3.6	12.3	1.2	1.4	9.1	5.0	6.5	13.1	25.8	17.1	21.6	2.1	6.0	5.6	5.8	9.4
.50 - 1.00		5.8	2.2	2.7	11.7	1.2	2.9	9.8	.6	7.6	41.4	23.5	14.9	20.6	3.0	37.3	37.4	9.3	5.9
.25 - .50		18.2	10.9	9.0	16.7	10.6	10.1	14.4	11.7	18.5	36.4	1.4	5.7	8.3	8.6	53.0	52.3	11.3	4.0
.125 - .25		38.8	80.4	63.1	18.5	81.2	79.7	25.8	61.8	55.4	2.0	1.4	.6	1.5	68.3	1.2	1.9	35.4	3.3
.062 - .125		2.5	4.3	6.3	2.5	4.7	2.9	3.8	5.9	3.3		.5	.6	.5	9.7			4.2	.7
Silt-clay fraction																			
.000 - .062		.8		1.8	1.2		1.4	.8	6.5	1.1					2.0			.9	.4

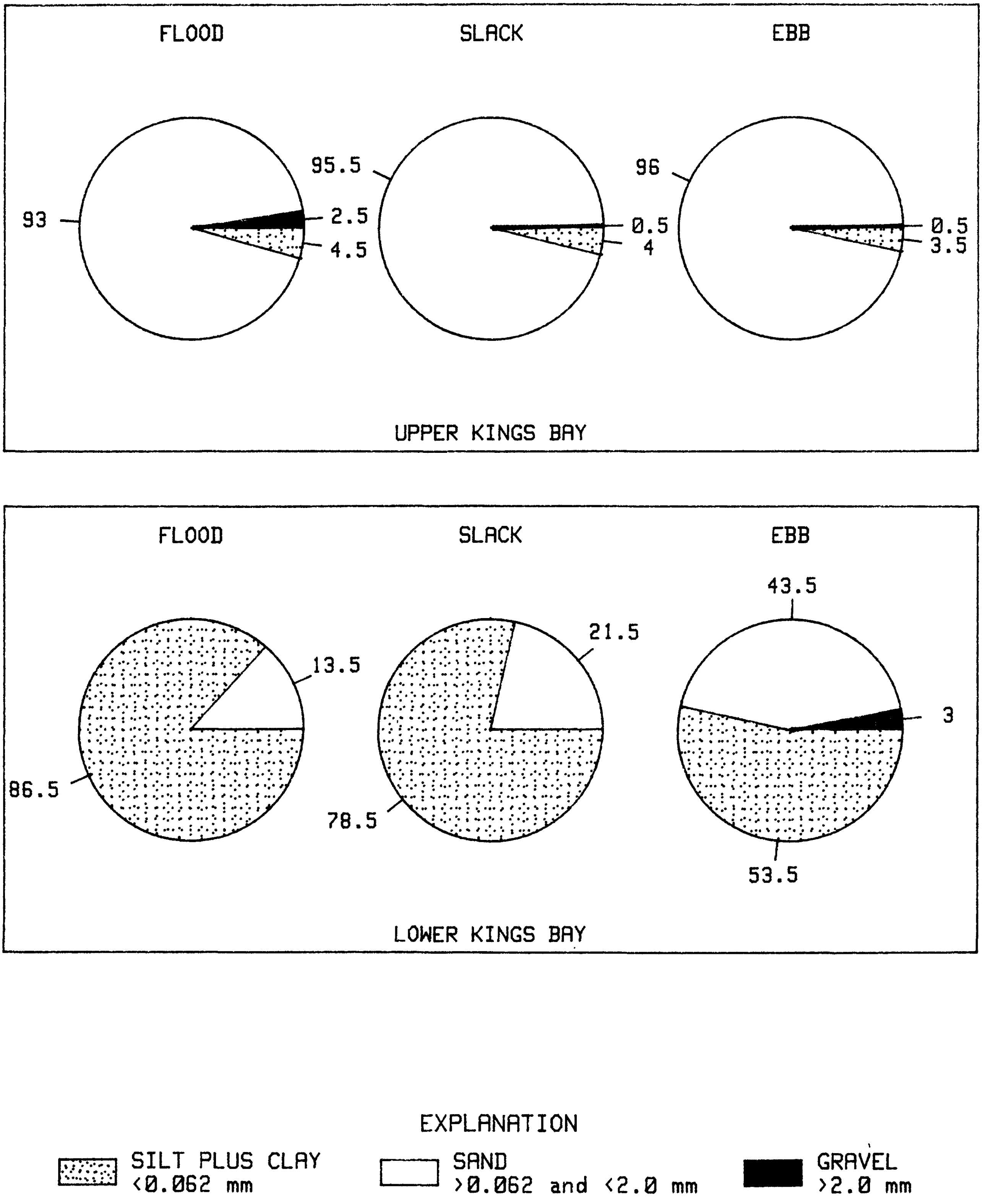


Figure 22.--Distribution of the major particle-size classes of bottom material at upper Kings Bay and lower Kings Bay cross sections, in percent.

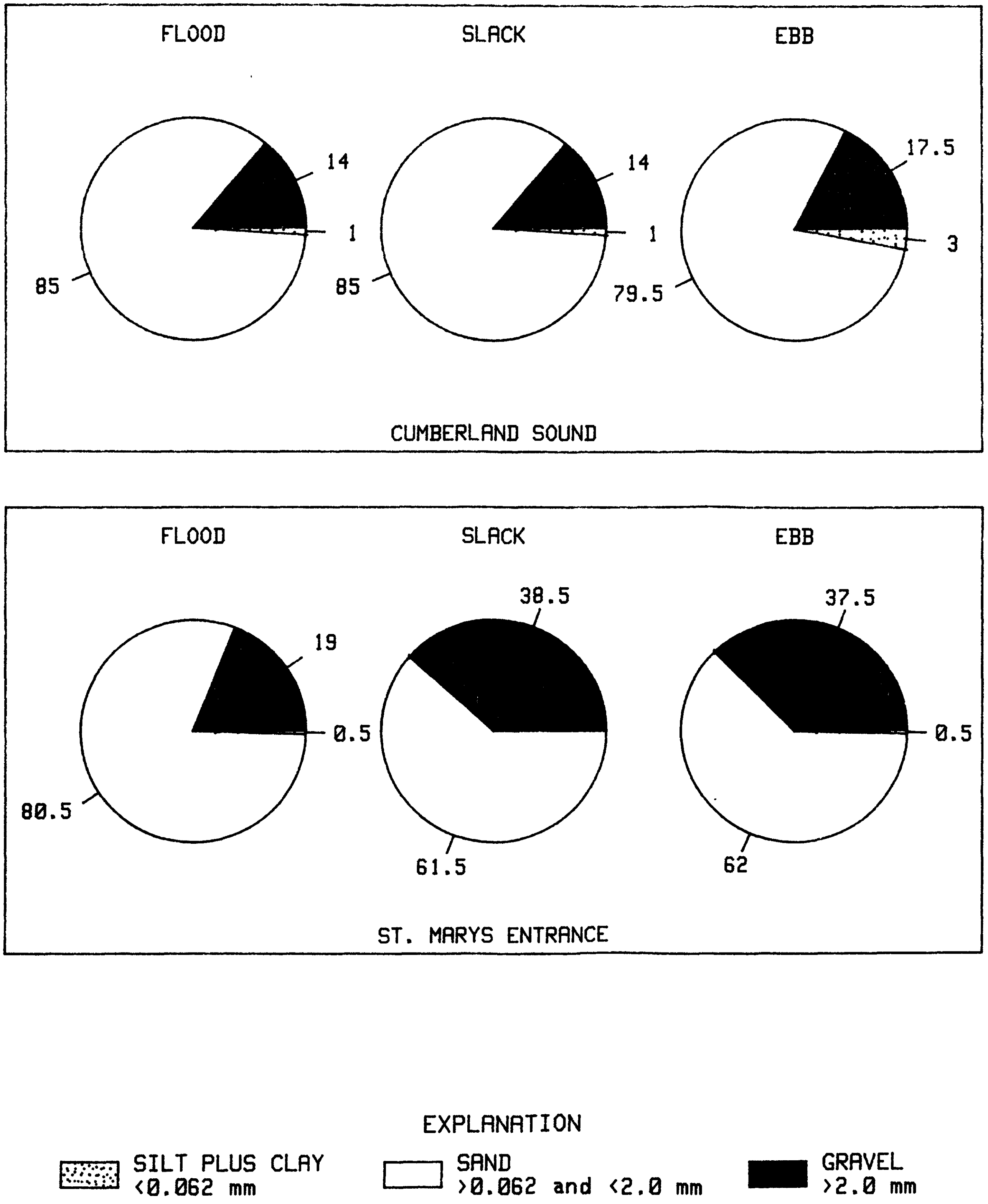


Figure 23.--Distribution of the major particle-size classes of bottom material at Cumberland Sound and St. Marys Entrance cross sections, in percent.

Bay cross section relatively high concentrations of chromium, copper, iron, lead, manganese, nickel, and zinc were detected. These constituents rapidly sorb on silts, clays, and organic detrital material (Feltz, 1980).

Carbon

Carbon data (total, organic, and inorganic) are presented in table 13. The highest concentration of total carbon (34-50 g/kg) occurred at lower Kings Bay cross section where organic carbon accounted for 91-96 percent of the total carbon. However, total carbon comprises a very small percentage of the total weight of bottom material. One obvious source of the organic carbon is the highly productive tidal marsh that is in close proximity to this cross section. However, significant amounts may also be transported from Cumberland Sound as finely divided particulate organic matter and as organic flotsam, specifically *Spartina*. Unlike the lower Kings Bay cross section, the upper Kings Bay cross section contained relatively low levels of organic carbon in the bottom sediments (1.4-4.7 g/kg). Even though upper Kings Bay is close to a tide marsh, shallower depths and higher velocities relative to lower Kings Bay cross section (p. 61) apparently do not permit the accumulation of finely divided particulate organic matter. The Cumberland Sound and St. Marys Entrance cross sections also had relatively low organic carbon concentrations. The highest inorganic carbon concentrations (3.2-25 g/kg) occurred at the St. Marys Entrance cross section where inorganic carbon from detrital shell fragments accounted for 46-93 percent of the total carbon in the bottom-material samples.

Algal Remains

Algal (diatom) remains (table 14) are present in substantial amounts in some bottom-material samples. Detrital diatom remains contribute substantial amounts (34,120,000 valves/cm^3, or roughly 50 percent) of silt-size particles (0.004 mm to 0.062 mm) to fine-grained bottom material at the lower Kings Bay cross section and to a lesser degree (1,944,000 valves/cm^3, or roughly 15 percent) to coarse sediments at the upper Kings Bay cross section. At the Cumberland Sound and St. Marys Entrance cross sections where bottom sediments are chiefly sand, the detrital diatom remains were negligible (216,600 and 89,150 valves/cm^3, roughly 10 and <5 percent, respectively) in bottom materials.

Diatom communities of planktonic, neritic, and edaphic origins are represented in all samples at all of the cross sections. *Cymatosira belgica*, *Cyclotella atomus*, *Fragilaria construens*, and *Fragilaria lapponica* are the dominant species found in bottom materials from the study area.

Transport and Sources of Suspended Sediment

The amount and rate of suspended material transported on a consecutive ebbtide and floodtide were computed at the four measurement cross sections. Prior to the computation of suspended-sediment discharges, water and salt discharges (based on salinity, a conservative parameter) were computed to evaluate the water and salt discharge balances for the ebbtide and floodtide. The discharges and pertinent tide data are presented in table 15.

Table 13.--Concentration of chlorinated hydrocarbons, heavy metals, and carbon in bottom materials from Kings Bay and vicinity

[Chlorinated hydrocarbons in micrograms per kilogram; heavy metal concentrations in milligrams per kilogram; and carbon concentrations in grams per kilogram. <, less than; SL, left vertical facing seaward; C, center vertical; SR, right vertical facing seaward]

	Constituent concentrations											
Station:	Upper Kings Bay			Lower Kings Bay			Cumberland Sound			St. Marys Entrance		
Date:	Nov. 10, 1981			Nov. 11, 1981			Nov. 16, 1981			Nov. 18, 1981		
Time:	0740	0720	0700	1441	1520	1445	1310	1330	1350	0905	0830	0921
Constituent Vertical:	SL	C	SR	SL	C	SR	SL	C	SR	SL	C	SR
Chlorinated hydrocarbons												
Aldrin			<0.1		<0.1			<0.1			<0.1	
Chlordane			<1		<1			<1			<1	
DDD			<.1		.2			<.1			<.1	
DDE			<.1		<.1			<.1			<.1	
DDT			<.1		<.1			<.1			<.1	
Dieldrin			<.1		<.1			<.1			<.1	
Endosulfan			<.1		<.1			<.1			<.1	
Endrin			<.1		<.1			<.1			<.1	
Heptaclor			<.1		<.1			<.1			<.1	
Heptaclor epoxide			<.1		<.1			<.1			<.1	
Lindane			<.1		<.1			<.1			<.1	
Mirex			<.1		<.1			<.1			<.1	
Methoxychlor			<.1		<.1			<.1			<.1	
PCB			<1		5			<1			<1	
PCN			<1		<1			<1			<1	
Perthane			<.1		<.1			<.1			<.1	
Toxaphene			<1		<1			<1			<1	
Heavy metals												
Antimony			<1		<1			<1			<1	
Arsenic			<1		1			<1			<1	
Cadmium			<1		2			<1			<1	
Chromium			1		40			2			2	
Cobalt			<10		10			<10			<10	
Copper			<1		140			<1			1	
Iron			500		26,000			740			1,000	
Lead			<10		40			<10			<10	
Manganese			10		790			19			31	
Mercury			<.01		<.01			<.01			<.01	
Nickel			<10		20			<10			10	
Selenium			<1		<1			<1			<1	
Silver			<1		<1			<1			<1	
Zinc			3		59			4			4	
Carbon												
Total carbon	2.0	4.8	1.4	34	50	46	3.7	10	1.8	8.6	7.0	27
Inorganic carbon	<0.1	0.1	<.1	3.5	2.7	1.9	2.2	.3	0.2	7.1	3.2	25
Organic carbon	2.0	4.7	1.4	31	47	44	1.5	9.7	1.6	1.5	3.8	2.0

Table 14.--Spatial variation in algal remains in bottom materials in Kings Bay and vicinity

[Algal remains in cells per cubic centimeter; *, present in insufficient densities to establish accurate count]

Taxa	Station: Upper Kings Bay	Lower Kings Bay	Cumberland Sound	St. Marys Entrance
Date:	Nov. 10, 1981	Nov. 11, 1981	Nov. 16, 1981	Nov. 18, 1981
Time:	0700	1520	1330	0905
Vertical:	Right, facing seaward	Center	Center	Left, facing seaward
Tide:	Flood slack	Ebb slack	Flood slack	Ebb slack
Bacillariophyta Karsten				
Bacillariophyceae Hendy				
Achnanthales Silva				
Achnanthaceae Kutz.				
Achnanthes Borg				
A. cuvirostrum Grun.		*		
A. hauckiana Grun.	160,000	660,000	*	4,000
Cocconeis Ehr.				
C. diminuta Pant.	31,000	330,000	3,400	900
C. discuius (Schum.)Cl.	*	*	*	
C. scutellum Ehr.	31,000			
Bacillarialles Silva				
Nitzschiaceae				
Bacillaria Gmelin				
B. paradoxa Gmelin	23,000			
Nitzschia Hassall				
N. amphibia Grun.	70,000	330,000		900
N. brittoni Hagelst.		*	*	1,300
N. clausii Hantz.	*	330,000		*
N. closterium (Ehr.)W.Sm.			*	
N. compressa Bail.	62,000	660,000	850	1,300
N. dissipata (Kutz.)Grun.	16,000	*	*	
N. fonticola Grun.	54,000	2,000,000	850	3,600
N. hungarica Grun.	31,000	160,000		
N. palea (Kutz.)W.Sm.	93,000	1,100,000	12,000	2,200
N. panduriformis v. minor Grun.				900
Eupodiscales				
Biddulphiaceae				
Biddulphia Gray & V.H.				
B. aurita (Lyng.)Breb. & Godey		*	9,300	*
B. favus (Ehr.)V.H.			*	
B. granulata Roper			*	
Eunotogramma Weisse				
E. laeva Grun.	39,000			
E. marinum (W.Sm.)Per.		490,000	*	900
Triceratium Ehr.			*	*
Coscinodiscaceae				
Actinoptychus Ehr. & V.H.				
A. undulatus (Kutz.)Ralfs		330,000	*	*
Coscinodiscus Ehr.				
C. excentricus Ehr.	70,000	820,000	6,800	4,500
C. lineatus Ehr.		160,000		
C. nitidulus Grun.		1,800,000		1,800
C. nitidus Greg.	23,000	1,600,000	2,500	450
Cyclotella Kutz.				
C. atomus Hust.	120,000	3,000,000	29,000	6,300
C. meneghiniana Kutz.	62,000	330,000		
C. striata (Kutz.)Grun.	39,000	660,000	1,700	3,100
Melosira Agardh.				
M. sulcata (Ehr.)Kutz.	*	490,000	19,000	450
Podosira Ehr.				
P. stelliger (Bailey)Mann			*	
Skeletonema Grev.				
S. costatum (Grev.)Cl		*	1,700	
Thalassiosira Cleve.				
T. decipiens (Grun.)Jorg.		2,500,000		
T. fluviatilis Hustedt	*		850	
Fragilariales Silva				
Fragilariaceae Hustedt				
Asterionella Hass.				
A. japonica Cleve.				900
Fragilaria Lyngb.				
F. construens v. venter (Ehr.)Grun.	150,000	3,100,000	26,000	14,000
F. lapponica Grun.	250,000	3,600,000	24,000	9,400
Opephora Petit				
O. martyi Herib.	78,000	330,000	*	1,300

Table 14.--Spatial variation in algal remains in bottom materials in Kings Bay and vicinity--Continued

Taxa	Station:	Upper Kings Bay	Lower Kings Bay	Cumberland Sound	St. Marys Entrance
	Date:	Nov. 10, 1981	Nov. 11, 1981	Nov. 16, 1981	Nov. 18, 1981
	Time:	0700	1520	1330	0905
	Vertical:	Right, facing seaward	Center	Center	Left, facing seaward
	Tidal:	Flood slack	Ebb slack	Flood slack	Ebb slack
Plagiogramma Grev.					
P. vanheurckii Grun.				850	
Rhaphoneis Ehr.					
R. amphiceros Ehr.		23,000	160,000	3,400	450
R. grossenpunctata Nov.spec.			160,000	*	900
Synedra Ehr.					
S. fasciculata					
v. truncata (Grev.)Patr.		*	660,000		
Cymatosira Grun.					
C. belgica Grun.		120,000	6,900,000	60,000	26,000
Naviculales Bessey					
Cymbellaceae Kutz.					
Amphora Ehr.Ex.Kutz.					
A. acutiuscula Kutz.		54,000	*		900
A. ovalis (Kutz.)Kutz.		47,000	160,000	7,600	900
Cymbella Agardh					
C. minuta Hilse Ex.Rahb.		39,000			
Entomoneidaceae Reim.					
Plagiotropis Pfitz.					
P. lepidoptera (Cl.)Reim.				*	
Naviculaceae Kutz.					
Diploneis Ehr.					
D. bombus Ehr.		16,000	*	5,100	450
D. didyma (Ehr.)Ehr.			*	*	450
D. gruendleri (A.S.)Cl.			*		
D. interrupta (Kutz.)Cl.			330,000		
D. puella (Schum.)Cl.		*	*	850	*
Gyrosigma Hass.					
G. exilis (Grun.)Reim.			*	*	
Navicula Bory		54,000	490,000		*
N. cryptocephala					
v. veneta (Kutz.)Rebh.			160,000		
N. formenterae Cleve.				*	*
N. ilopanoensis Hust.			160,000		
N. lyra Ehr.				*	
N. minima Grun.		110,000	160,000		
N. minuscula Grun.			*	850	*
N. mutica					
v. cohnii (Hilse)Grun.		16,000	*	*	*
N. pygmaea Kutz.		16,000	*		
N. radiosa (Breb.Ex.					
v. tenella Kutz.)Grun.		47,000	*		450
Pleurosigma W.Sm.					
P. angulatum (Quek.)W.Sm.				*	450
Surirellales					
Surirellaceae					
Surirella Turpin					
S. gemma (Ehr.)Kutz.				*	
S. ovata Kutz.		*	*	*	
Totals		1,944,000	34,120,000	216,600	89,150

Table 15.--Water, salt, and suspended-sediment discharges for consecutive ebbtides and floodtides at the measurement cross sections

[Start and end tides are based on the time of zero velocity which may differ from the time of maximum and minimum tide heights]

Cross section	Date (1981)	Tide	Tide height at start and end of measurement period (m - NGVD)	Duration of tide (hrs)	Water discharge ($m^3 \times 10^6$)	Salt discharge ($kg \times 10^6$)	Suspended-sediment discharge: Silt plus clay, $kg \times 10^3$	Suspended-sediment discharge: Silt plus clay, Percentage of total load	Suspended-sediment discharge: Sand, $kg \times 10^3$	Suspended-sediment discharge: Sand, Percentage of total load	Suspended-sediment discharge: Total, $kg \times 10^3$	Total, $kg \times 10^3$ per tidal cycle
Upper Kings Bay	Nov. 10	Ebb	1.44 (start)	6.0	12.7	413	209	85	35.8	15	245	62 (seaward)
		Flood	1.41 (end)	6.5	12.6	412	159	86	23.2	13	183	
Lower Kings Bay	Nov. 11	Ebb	1.73 (start)	6.5	19.4	628	499	82	108	18	607	17 (seaward)
		Flood	1.49 (end)	6.2	17.5	567	477	81	113	19	590	
Cumberland Sound	Nov. 16	Flood	-.67 (start)	6.7	105	3,480	3,640	67	1,770	33	5,420	360 (landward)
		Ebb	-.62 (end)	5.7	101	3,290	3,670	72	1,400	28	5,060	
St. Marys Entrance	Nov. 18	Flood	-.63 (start)	6.5	193	6,510	3,110	74	1,130	27	4,230	1,260 (landward)
		Ebb	-.65 (end)	6.3	185	6,330	2,160	73	805	27	2,970	

Tide heights and wind conditions should be similar within the estuary at the start and end of the tidal-cycle measurement period for the ebbtide and floodtide water discharge and salt discharge to balance. Adjustments in water volume due to water storage differences may be required if start and end tide heights are substantially different. At each measurement cross section, the tide heights at the start and end of the tidal cycle were reasonably close except at the lower Kings Bay cross section. Volume adjustments were not made at this cross section because it was judged that the difference in tide conditions would not by itself lead to a misinterpretation of the suspended-sediment discharge. The judgment was based primarily on the magnitude of difference between (1) starting and ending tide heights and (2) salt discharges, and the similarity between ebbtide and floodtide suspended-sediment concentrations.

The ebbtide and floodtide discharges for each cross section balanced reasonably well. The greatest difference occurred at the lower Kings Bay cross section because of a water storage difference at the beginning and end of the measurement period. As discussed in the computation section (p. 18), part of the tidal flow at the measurement cross sections was estimated for the last half of each measurement period (generally 2 to 3 hours). Adjustments due to freshwater inflow were not considered because the volumes of freshwater discharged to the estuary during the measurement periods were insignificant compared to the tidal volumes. For instance, the day that the St. Marys Entrance cross section was measured the estimated mean flow of the St. Marys River near the mouth was about 4 m^3/s. At this constant flow rate, the volume contributed to the estuary between the consecutive ebb slacktides was 184,000 m^3 (4 m^3/s for a 12.8-hour period). This volume was about 0.1 percent of the ebbtide volume.

The salt-discharge balance between the ebbtide and floodtide at each measurement site was good. The greatest difference in the salt discharges occurred at the lower Kings Bay cross section where the beginning and end tidal conditions for the measurement period were somewhat different. A balance of ebbtide and floodtide salt discharges suggests that the water volume computations are reasonable and that the water volumes can be used to compute the loads of suspended sediment, a nonconservative parameter.

Suspended-sediment discharge data for the November measurements suggest that there is: (1) a substantial net transport of suspended sediment seaward of the upper Kings Bay cross section and landward of the St. Marys Entrance cross section, (2) a small but probably insignificant net transport of suspended sediment landward of the Cumberland Sound cross section, and (3) no appreciable net transport at the lower Kings Bay cross section.

At each cross section, silt plus clay made up the largest percentage of the tidal discharges. The percentage of sand in the total discharge was greater at the St. Marys Entrance and Cumberland Sound cross sections than at the upper and lower Kings Bay cross sections.

DISCUSSION

Water circulation within the project area results from the interaction of numerous factors, including freshwater inflow, tidal conditions, wind regime, and bathymetry. ES & E (1977) found that the water of Cumberland

Sound and Kings Bay was generally vertically well-mixed because of the strong ocean breezes and strong tidal currents. Salinity stratification was detected infrequently by ES & E during measurements conducted seasonally at many sites in Kings Bay and Cumberland Sound. For the November 1981 U.S. Geological Survey study, minimal freshwater inflow, high tides, and strong winds resulted in vertically and laterally mixed water at the measurement cross sections. For these conditions, the water of Kings Bay and Cumberland Sound was classified as vertically and laterally homogeneous (Pritchard, 1955; Cameron and Pritchard, 1963). The water at all sampling sites measured in November 1981, with the exception of the St. Marys River, would be categorized as euhaline by the Venice System (Remane, 1971) for classifying salinity zones. The euhaline zone is defined as the zone bounded by salinities of 30 to 40 g/kg. This zone is indicative of negligible freshwater discharge. At sites in the St. Marys River, where salinities ranged from 18 to 30 g/kg, the waters are categorized as polyhaline, which indicates a small freshwater discharge.

Sedimentary processes in the estuary have resulted in characteristically different bottom sediments in lower Kings Bay (silt, clay, organic material) compared to the bottom sediments in upper Kings Bay (fine to medium sands), Cumberland Sound (fine to medium sands, gravel), and St. Marys Entrance (medium to coarse sands, shell fragments). Some of the fine-grained inorganic and organic bottom sediment in lower Kings Bay may have been transported from upper Kings Bay and Marianna Creek on the ebbtides, as suggested by the net seaward discharge of suspended sediment at the upper Kings Bay cross section. Cumberland Sound also may be supplying fine-grained sediment to lower Kings Bay on the floodtides. Suspended-sediment discharges at the lower Kings Bay cross section did not indicate a net sediment movement either landward or seaward. Several events associated with the tidal measurements at the lower Kings Bay cross section, however, may have resulted in suspended-sediment discharges that were not representative of the cross section during the tidal cycle measurement. Tide heights (water storage) at the beginning and end of the measurement period were not equal, ship and boat traffic in the area prevented the collection of much floodtide data, and dredging operations were being conducted in the area during part of the measurement period.

The relatively slow velocities in the deep channel of lower Kings Bay apparently permit much of the fine-grained suspended sediment to settle and to remain on the channel bottom, as indicated by the estimated accumulation rate of sediment in Kings Bay. (See p. 2.) It seems likely that part of the material set in motion by the relatively high ebb-current velocities in upper Kings Bay and Marianna Creek may be too heavy to remain in suspension or to be moved as bedload once the material reaches the slower velocity of the dredged lower Kings Bay channel. The same mechanism for the transport of fine-grained sediment may be occurring as the floodtide water moves into Kings Bay from Cumberland Sound. Current-velocity data collected in 1976 (ES & E, 1977, p. C-216) indicate that floodtide current velocity decreased appreciably between a measurement site at the north end of Drum Point Island and the entrance to Kings Bay. Apparently, the floodflow is deflected toward the northeast as it enters Kings Bay and a relatively slower velocity occurs on the inside of the arc (toward the southwest shore near the entrance to Kings Bay). Also, an enlargement of the cross-sectional area immediately landward (northwest) of the lower Kings Bay cross section would result in a reach of lower velocity. Turbidity measured at slack tide was much less in Kings Bay than in Cumberland Sound, which suggested lesser turbulence in Kings Bay. These areas of slow velocity and low turbulence are conducive to the deposition of fine-grained sediments. Areas seaward of the St. Marys Entrance also may be contributing sediment to Kings Bay and to other shoaling areas within the estuary, as indicated by the substantial net landward transport of suspended sediment at the St. Marys Entrance cross section. However, the fate and long-term transport trends of the sediment are unknown.

The silt and clay sediments of lower Kings Bay contained a large percentage of diatom remains which were much less abundant in the bottom samples collected at the upper Kings Bay, Cumberland Sound, and St. Marys Entrance cross sections. Phytoplankton biomass in the water column seems to be too low to contribute appreciable quantities of detrital material to the bottom sediments. The low phytoplankton concentrations measured during this study were probably normal for November, and the concentrations may not change greatly throughout the year. Chlorophyll a concentration in samples collected by ES & E (1977) at nine cross sections in Cumberland Sound and five cross sections in Kings Bay in 1976 (June, October) and 1977 (January-February, March-April) indicated phytoplankton concentrations were low and showed no seasonality. However, primary production continuously supplies some fine detrital material, including diatom remains, to the estuary annually. Movement and deposition of the detrital material to areas that are accumulating fine-grained sediments may account for the abundance of diatom remains in the bottom sediments of lower Kings Bay. The diatoms or their remains could have originated in the ocean or within the estuary, or both. By utilizing a similarity index (Stander, 1970), the lower Kings Bay diatom assemblage was found to be more similar (90 percent maximum similarity) to the Cumberland Sound and St. Marys Entrance assemblages than to the upper Kings Bay assemblage. This suggests that lower Kings Bay probably is receiving detrital material from Cumberland Sound. The diatom assemblage from lower Kings Bay, Cumberland Sound, and St. Marys Entrance had species more indicative of truly planktonic community assemblage. The upper Kings Bay cross section had more species representative of an edaphic community, which explains its dissimilarity to the other cross sections.

Sediment may be supplied to the shoaling areas in the estuary from places other than the marsh adjacent to upper Kings Bay or sources seaward of St. Marys Entrance. General areas of shoreline erosion in Kings Bay and Cumberland Sound that are potential sediment sources were delineated by ES & E (1977). Salt marshes in the area, in addition to the marsh area adjacent to Kings Bay, are sources of organic matter and possibly minerals as pointed out in the Ecology section of this report. Other obvious sediment sources are the tidal channels of Crooked River and St. Marys River, where large cut banks have been created along meanders by the tidal currents. Several of these cut banks occur along both tidal channels. One cut bank near Kings Bay is on a reach of Crooked River that borders Crooked River State Park. The Cumberland River (tidal channel), as noted in the Turbidity section, also may contribute sediment to Cumberland Sound and Kings Bay.

One source of sediment that is not a major contributor of suspended sediment to the estuary is the upland drainage of the St. Marys River. The transport rate of suspended sediment at the gaging station near Macclenny, Fla., is small, even at times of high flow. For example, at a floodflow of 70 m^3/s, which is exceeded only 5 percent of the time (fig. 2), the suspended-sediment discharge rate is about 0.4 kg/s. (See fig. 19.) The net landward transport of suspended sediment at the St. Marys Entrance cross section for the measurement period was 27.3 kg/s (net total load divided by the duration of time; table 15). Using these data for comparison purposes, the transport rate of the St. Marys River was about 1.4 percent of that at the St. Marys Entrance cross section. Note that the St. Marys River flow and suspended-sediment concentration data were collected at a station 161 river kilometers upstream of the mouth and, therefore, the suspended-sediment discharge is not a measure of the total suspended-sediment discharged to the estuary from the river system.

CONCLUSIONS

The conclusions that follow are based on the results of this study and, where possible, on other available data. Some statements are more strongly supported by the data base than others. Much of the data presented in this report may only represent conditions at the time of the data collection. Obviously, a broader (long term) data base is needed to confirm many conclusions.

The data indicate the following:

1. Lower Kings Bay and the area in the vicinity of Kings Bay entrance seem to be effective traps for sediment transported by both ebbtide and floodtide currents. Changes to channel geometry and shape probably caused a decrease in current velocities in these areas relative to current velocities in upper Kings Bay and Cumberland Sound. The result was a deposition of fine-grained sediments, including organic detrital material, in the areas having slower current velocity.

2. Substantial net quantities of suspended sediment were transported into Cumberland Sound through the St. Marys Entrance and possibly into Kings Bay. Suspended-sediment discharges computed for consecutive ebbtides and floodtides showed a large net landward transport of suspended sediment past the St. Marys Entrance cross section and a small, but probably insignificant net landward transport past the Cumberland Sound cross section. A net landward transport of suspended materials was not measured at the lower Kings Bay cross section, even though other data suggested that a loss of material may have occurred landward of this cross section.

3. Net quantities of suspended sediment are transported from upper Kings Bay and Marianna Creek and deposited in lower Kings Bay. New sediment may be delivered to upper Kings Bay from Cumberland Sound through a narrow connecting channel or from Crooked River via the intervening marsh.

4. Phytoplankton primary production was low at the time of sampling and phytoplankton biomass in the water column could not have contributed substantial quantities of detrital material to the estuary. However, annual primary production of planktonic and benthic algae over the entire estuary and surrounding environs could contribute significant quantities of detrital material to depositional areas within Kings Bay and vicinity. For example,

approximately 50 percent of the silt and clay-size particles in the bottom material sampled at lower Kings Bay consisted of a mixture of remains from planktonic and benthic diatoms. Most diatoms originated outside of Kings Bay proper, in Cumberland Sound, or the ocean.

5. Potential source areas of suspended sediment other than upper Kings Bay, the tidal marshes of Marianna Creek, and the area seaward of St. Marys Entrance cross section are: (a) parts of the shoreline surrounding Cumberland Sound, (b) the tidal channels of Crooked River and St. Marys River, (c) the tidal marshes in general, and (d) the Satilla River-St. Andrews Sound via the Cumberland River. Data are not available to evaluate the significance of the potential sediment sources as contributors to the sedimentation problems in Kings Bay and vicinity.

6. The upland drainage of the St. Marys River does not supply significant quantities of suspended sediment to the estuary. Long-term flow and sediment-discharge data from the St. Marys River station near Macclenny, Fla., reveal that even during flood periods the suspended-sediment delivery rate is small.

7. High concentrations of chromium, copper, iron, lead, manganese, nickel, and zinc are present in the bottom material of lower Kings Bay. These heavy metals readily adsorb to the silt, clay, and organic sediments present in lower Kings Bay.

8. Methods used to sample suspended sediment and to measure the current velocity in Kings Bay and vicinity are extremely important for the collection of data that accurately represent the conditions at the time of data collection. The dynamic flow characteristics of the estuary require that samples and measurements be taken quickly and frequently in order to define the flow and suspended-sediment transport characteristics with time. The methodology used in this study worked reasonably well. For future data collection of this nature, lateral and vertical definition of suspended sediment must be improved and all data must be collected as synoptically as possible. Flow-distribution data collected during this study provide information that will be useful for locating sampling and measurement verticals in the measurement cross sections.

FUTURE STUDIES

The processes of water and sediment movement and their relation to the sedimentation problems in Kings Bay and vicinity are not well understood. Because sediment-transport mechanisms are not well understood and sediment-transport models are not well developed for estuarine areas, future investigations that include both a measurement program and a research effort will provide the data needed to better manage sedimentation problems. The areas to include in future investigations are the estuary, the entrance channel seaward of the measurement cross section, the nearby offshore zone, and the Cumberland River north to St. Andrews Sound. These areas beyond the estuary likely play a very important role in the sedimentation that occurs in Kings Bay and Cumberland Sound. Within the estuary and particularly in Kings Bay and Cumberland Sound, samples and measurements in the channels, where the recent work was done, need to be supplemented by detailed studies in the adjacent intertidal environments. These environments alternately may be sources or sinks for sediments that are moving toward subtidal areas having sediment deposition problems. No studies are available in which the sedimentation coupling between subtidal and intertidal environments has been evaluated and quantified; thus, this effort would be classified as research.

Management of sedimentation problems could be greatly aided by a long-term data-collection program and by use of a hydrodynamic flow model for Kings Bay and vicinity. A model supported by appropriate flow and sediment data provides a means to compute water and sediment discharges, which are difficult and expensive to measure yet are needed to analyze sediment transport processes and mechanisms. Model evaluation for a wide range of tide and weather conditions that are experienced in Kings Bay and vicinity requires several years of periodic data collection. The data-collection program would consist of three parts:

(1) Intensive tidal cycle surveys that are keyed to specific tides. The surveys would be similar to the recent work that was done, but include more measurement and sampling verticals per cross section and cover the entire 13-hour tidal cycle. Also, measurement cross sections would be established in the St. Marys, Amelia, and Crooked Rivers channels. Data collected synoptically among the cross sections would have the greatest utility.

(2) Less intensive periodic sample collecting and measuring (probably at only one vertical) conducted between the intensive surveys at "index" stations. The data would be useful in analyzing transport processes and mechanisms and for the computation of discharges for model evaluation.

(3) Periodic bathymetric surveys of the study area to define changes in the bottom configuration. Bathymetric data would be required as an integral part of the modeling effort.

Equally important are studies that will clearly identify the major sources of sediment and quantify the amounts of sediment supplied by these sources. This information could be used to evaluate and develop methods of sedimentation control.

Bedload transport of sediment, which was not addressed in this study, is a consideration in future studies. A large percentage of the total sediment transported in the estuary, particularly in sand channels, may be transported as bedload.

Studies, such as these listed, can provide answers to fundamental questions regarding the sedimentary processes and the management of sedimentation problems in Kings Bay and vicinity.

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