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Sedimentation Study
Environmental Monitoring and Operations Guidance System (EMOGS)
Kings Bay, Georgia and Florida
Phase III - FY 1989

by

D.G. Aubrey, T.R. McSherry, W.D. Spencer

August 1990

Funding was provided by the National Oceanic Atmospheric Administration
under Sea Grant No. NA860A-D-SG090.

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WOODS HOLE OCEANOGRAPHIC INSTITUTION COASTAL RESEARCH CENTER

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Woods Hole, Massachusetts 02543

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Technical Report

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David G. Aubrey, Director
Coastal Research Center

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SEDIMENTATION STUDY
ENVIRONMENTAL MONITORING AND OPERATIONS GUIDANCE SYSTEM (EMOGS)
KINGS BAY, GEORGIA AND FLORIDA
PHASE III--FY1989

DAVID G. AUBREY, DIRECTOR
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SUMMARY

Repeated side-scan sonar and multi-frequency bathymetric surveys, accompanied by accurate, high resolution, and repeatable navigation, were conducted in the vicinity of a tidal inlet to define the length and time scales associated with bedforms and channel shoaling in a structured tidal inlet. The study site, St. Mary's entrance channel along the Georgia/Florida border (Fig. 1), has a dredged channel approximately 46-52 feet in depth, bordered by a large ebb tidal delta. The tidal inlet serves Cumberland Sound, Kings Bay, and associated waterways, providing a large discharge of water from the inlet that creates bedforms and channel shoaling, given the abundance of sand-sized sediment in the vicinity. The jettied inlet produces flows that are predominantly tidally-driven, whereas farther offshore the driving forces consist predominantly of waves and storm-generated flows. In the channel reaches (Table 1) between these two areas, combined wave/steady flows are present, creating a myriad of scales of bedforms and shoaling patterns. This study was designed to elucidate the time and space scales of these variable bedforms and shoaling patterns, emphasizing the difference in these scales between the three different flow regimes. The results provide an important data base for quantifying shoaling processes and mechanisms in tidal inlet channels.

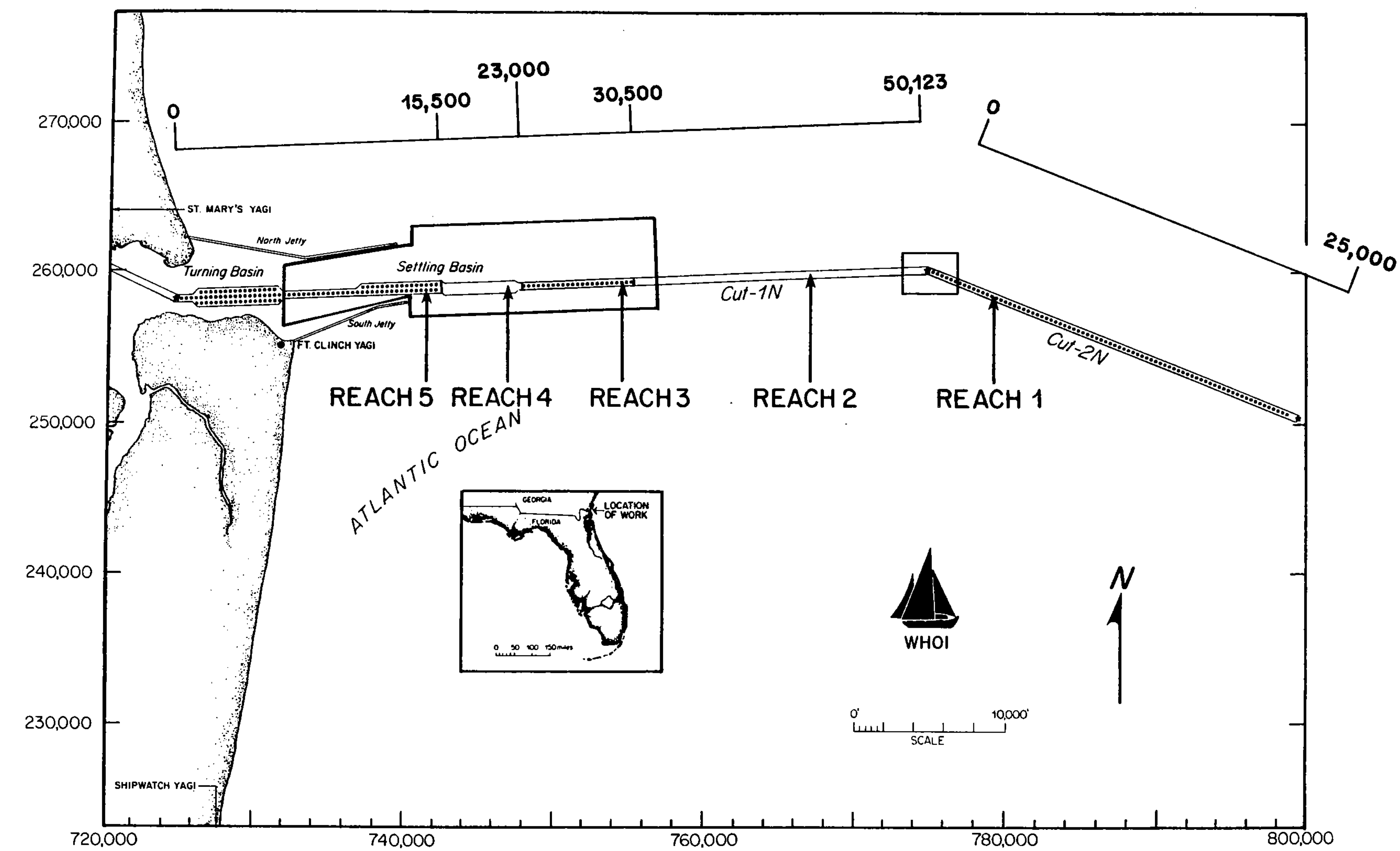

Figure 1. Survey area along the St. Mary's entrance channel

TABLE 1

DEFINED REACHES FOR ST. MARYS ENTRANCE CHANNEL

Reach	Start	End
1	Cut 2-N 000+00	Cut 2-N 250+00
2	Cut 1-N 305+00	Cut 1-N 501+23.68
3	Cut 1-N 230+00	Cut 1-N 305+00
4	Cut 1-N 155+00	Cut 1-N 230+00
5	Cut 1-N 7100	Cut 1-N 155+00

During phase III six bathymetric and side scan sonar surveys were accomplished. Not all data acquired during these surveys are directly comparable inside the channel. Dredging activity during the year created major changes to the channel, making comparison of differences in channel bathymetry ambiguous. Similarly, comparison of channel bedforms was difficult because many of the forms were not fully developed following dredging. Comparisons of bedforms in areas outside and adjacent to the channel over different surveys is less ambiguous.

Phase III data indicate the following tentative conclusions:

a) Changes in bathymetry occur within and outside the channel on various time and space scales.
b) Bedforms of various scales occur in and outside of the channel. Within the channel, bedforms occur commonly, having heights of 2-3 feet and possibly higher. Outside the channel, bedforms (shoals) reach more than 10 feet higher than the ambient delta depths.
c) Shoaling appears largest along the north margin of the channel.
d) The locations of shoals on the ebb tidal delta suggest little movement of these bedforms to the south, towards the dredged channel.
e) Hotspots where sedimentation rates appear highest are concentrated on the ebb-tidal delta (stations 255+00 to 265+00), just outside and just inside the jetties (from near station 135+00 to near station 230+00), and near navigation buoy #12 (stations 400+00 to 450+00). A sedimentation monitoring program emphasizing periodic hotspot surveys from a surface vessel is suggested to guarantee adequate information about channel depths for the EMOGS program.

INTRODUCTION

St. Mary's entrance channel connects the Atlantic Ocean with Cumberland Sound, and is located on the border between Georgia and Florida (Fig. 1). Previous work in this region has been done by Olsen (1977), Parchure (1982), Aubrey (1986), Aubrey *et al.* (1987), Marino (1986), and Vermulakonda *et al.* (1988). Marino (1986) has summarized earlier work, listing the important physical parameters of the system (Table 2). The large spring tidal prism creates strong flows within the inlet (up to 1.5 m/sec), which are ebb-dominated. Abundant sand-sized and smaller sediment within the estuary and nearshore contributes to the build-up of the large ebb tide delta, which has grown significantly since man's influence has increased over the past half-century, primarily through construction of the jetties protecting the inlet entrance (Olsen, 1977).

TABLE 2
PHYSICAL PARAMETERS FOR ST. MARY'S INLET
(from Marino, 1986)

PARAMETER	DESCRIPTION	VALUE
V	total volume of ebb tide delta	95×10^6 m^3
P	Spring tidal prism	154×10^6 m^3
A_c	Inlet cross-sectional area	12.4×10^3 m^2
W	Inlet width at throat	12.7×10^2 m
D	Inlet depth at throat	9.5 m
a_o	Ocean spring tidal amplitude	2.1 m
H_s	Significant wave height	0.55 m
T_w	weighted mean wave period	6.0 sec

Whereas steady currents dominate flows within the inlet itself, past work (Aubrey, 1986; Aubrey *et al.*, 1987) has shown that waves become more dominant on the margins of the ebb tide delta. The geometry of the system combined with its exposure to open waves and a spring tidal range of 2.1 m dictates the interesting flow patterns that will generate complex bedforms and shoaling patterns. With abundant sediment on the ebb delta margin, bedforms of various scales and sizes are formed.

METHODOLOGY

The present study addresses the definition of time and space scales of bedforms and shoaling at Kings Bay entrance channel. Study techniques include surveys from surface vessels using high resolution down-looking and side-scan sonars, tied to an accurate navigation system. Repetitive surveys from the surface using the multi-frequency sonar provide snapshots of the bottom configuration and texture. Overlays of the bathymetry using sophisticated software provide information on the shoaling in the channel and on the ebb-tide delta. Repetitive side-scan sonar data provide quantitative information on bedform scales throughout various parts of the survey region. Changes associated with storm or fair weather waves are documented by these repetitive side-scan surveys.

SURVEY TECHNIQUES

Data were acquired along electronically guided tracks over the 14-mile length of the entrance channel and along cross lines to the channel in selected areas. Each survey involved 43 transects 3000 feet long, 82 transects 5300 feet long, 21 transects 2600 feet long, and four transects 67,924 feet long, for a total shiptrack of 169 miles. Ship's speed along the survey lines was about 5 miles/hour giving an uninterrupted running time of about 33.8 hours. A survey can normally be accomplished in four, 12-hour days. A list of survey equipment is given in Table A1. All equipment were selected based on their demonstrated high accuracy and reliability (Aubrey *et al.*, 1988). The survey system has operated within specifications and expectations over the two year period since purchase.

All surveys have been conducted from the 29-foot long charter boat *Sis*, which is powered by an inboard diesel. It has a cuddy cabin in the forward section of the vessel, and a soft canvas top aft of the cuddy cabin that has been modified for the project with a hard aft bulkhead. This modification was necessary to protect the equipment from inclement weather since some was located just aft of the cuddy cabin.

The *Sis* was chosen for its capability to accomplish the surveys, its experienced skipper and crew, and reasonable charter costs. The *Sis* offers some advantages to the EMOGS surveys over other available larger boats. The *Sis* charters for $375 per 8 hour day verses the $1000 to $1500 per 8 hour day charged by larger boats. The crew of the *Sis* will work 12-hour days and on the weekends, thereby accomplishing the survey quickly. This reduction is critical in the winter when good weather and calm seas are often rare. Surveying is limited to sea conditions of three feet significant wave height or less. Some of the disadvantages to using the *Sis* are inherent to all small boats. A larger boat offers more comfort for the crew thereby increasing productivity, gives better vessel stability (increasing survey accuracy and maximum sea state limits), and provides greater safety.

EQUIPMENT

A listing of all major equipment is provided in Appendix A. The equipment was selected and procured during Phase II of EMOGS. The fathometer used in the surveys is an Odom model DF-3200 (manufactured by Odom Hydrographic, Baton Rouge, Louisiana). The Odom model DF-3200 was chosen for its dual frequency capabilities, high precision, digital based construction, and its demonstrated high reliability. The system has operated flawlessly since it was purchased. The company has provided excellent product support for the unit when needed. The model DF-3200 has a 24/200 kHz transducer with a narrow beam (3 db at 19/9 degrees beamwidth respectively) propagation pattern. One frequency (user selectable) can be output serially with an optional upgrade from Odom to include both frequencies. The Odom DF-3200 has an accuracy of 0.39 inches, but when error factors are considered (differences of water density, changes in transducer draft, calibration technique error, tidal correction errors, and sea state) an overall survey depth accuracy of one to two feet is estimated.

The Klein side scan sonar model 595 is a high resolution, dual frequency (100 and 500 kHz) side looking sonar that has digital and analog output. The system is used to typify the features over the surveyed bottom. The sidescan towfish is towed at 25 to 50 feet aft and center of the *Sis*, at a depth of about 10 feet. The system was chosen for its high resolution, its dual frequency capability, and the reputation of the manufacturer. Sand ripples, having a wavelength of 6 inches (amplitude of < 2") can be observed from an altitude of 30 feet above the bottom using the Klein system. Although hard to quantify, the data from the Klein side-looking sonar gives valuable and clear information about the shapes (acoustic reflectors) on the bottom. The Klein system was purchased with hands off tuning (HOT) to minimize the underway tuning required. A conventional side scan system requires almost constant tuning while being operated over a varying bottom. The HOT system has automatic gain control logic to keep the gain adjusted as a function of the returning signal strength.

The Del Norte model 547 trisponder navigation system has a specified accuracy of +/- 2 meters over a maximum transmission range of 80 kilometers. The system has worked well with some exceptions when the shore stations have been inoperative or poorly operative. The Del Norte system interrogates as many as four shore located transponders at a maximum rate of 10 Hz and outputs distance measurements to the survey management computer. The survey management computer uses these data to calculate state plane coordinates, latitude, longitude, and project specific coordinates (cut, station and range).

The survey management system is an integrated navigation and data acquisition system (INDAS) purchased from Science Applications International Corporation (Newport R.I.). INDAS comprises a Hewlett Packard (HP) 9000 series model 220 processor with an HP 9153C disk drive (10 MB hard drive and a 800 KB, 3.5 inch floppy drive), necessary peripheral components (plotters, printers, monochrome monitor, and keyboard), and survey management software. Data are directed to the floppy drive during the survey. The survey management system provides accurate guidance to the helmsman, reliable data logging and clear annotation to peripherals.

UNDERWAY CONSIDERATIONS

Many factors have to be considered during the field survey. Sea state is a key factor when trying to accomplish high quality bathymetric and side scan surveys. In our survey area sea state is a major limiting factor. The survey cannot be conducted if surface waves exceed three feet. High sea conditions translate into more boat use and higher costs. Some strategy can be used to minimize poor weather days. Knowing when in the tidal cycle to survey areas sensitive to wave and tidal flow interaction can save hours of boat use. Surveying in the direction of the tide flow instead of against it during times of high flow in the narrow parts of the channel can also save valuable hours. Working long days and on the weekend when conditions are good can be important in the winter. Carefully maintaining all gear and watching closely for weakening of mechanical components helps avoid time-consuming repairs.

RESULTS

All data were analyzed at Woods Hole. Tidal correction of bathymetry data was done with heights predicted by NOAA corrected to mean low water (MLW). Heights are predicted to the end of the north jetty (see Appendix A). Some cross channel lines were run twice (at different tidal stages) to check the accuracies of the tidal corrections to bathymetric data and the daily calibrations of the fathometer. Editing for horizontal and vertical wild points is accomplished automatically and checked manually. Plots and calculations are checked on hard copy before final plots and statistics are output. The output includes:

1. printing of depths (smoothsheets) versus position on state plane grided charts;
2. hard copies of contour and contour differences on state plane grided charts;
3. hard copy plots of bottom texture from side scan data on state plane grided charts;
4. archival of all digital bathymetric and side scan data, and
5. plots of statistical results (see probability results in this section).

BATHYMETRIC MAPS

During phase III in FY1989, six surveys were accomplished (Table 3). Bathymetric smoothsheets from these surveys produced a time series of data that indicates a general stability of the major shoals during the year. Although major shoals (Fig. 2) north and south of the channel move slowly, there is strong evidence that smaller bedforms are constantly changing and that the channel is a strong sink for sediment. The areas of concern for channel shoaling are near the mouth of the jetties, on the ebb tide delta outside the jetties in Reach 3 (Table 1). Accretion of 2.5 feet average depth occurred in Reach 3 (Tables D5 and D6) between the September and the October surveys (during which time Hurricane Hugo passed); this was the largest accretion in channel depth on a reach-by-reach basis during 1989. One way to monitor this hotspot is to install in-situ sand level monitors in the area. Other methods have been proposed and/or are in effect currently (see EMOGS operations plan).

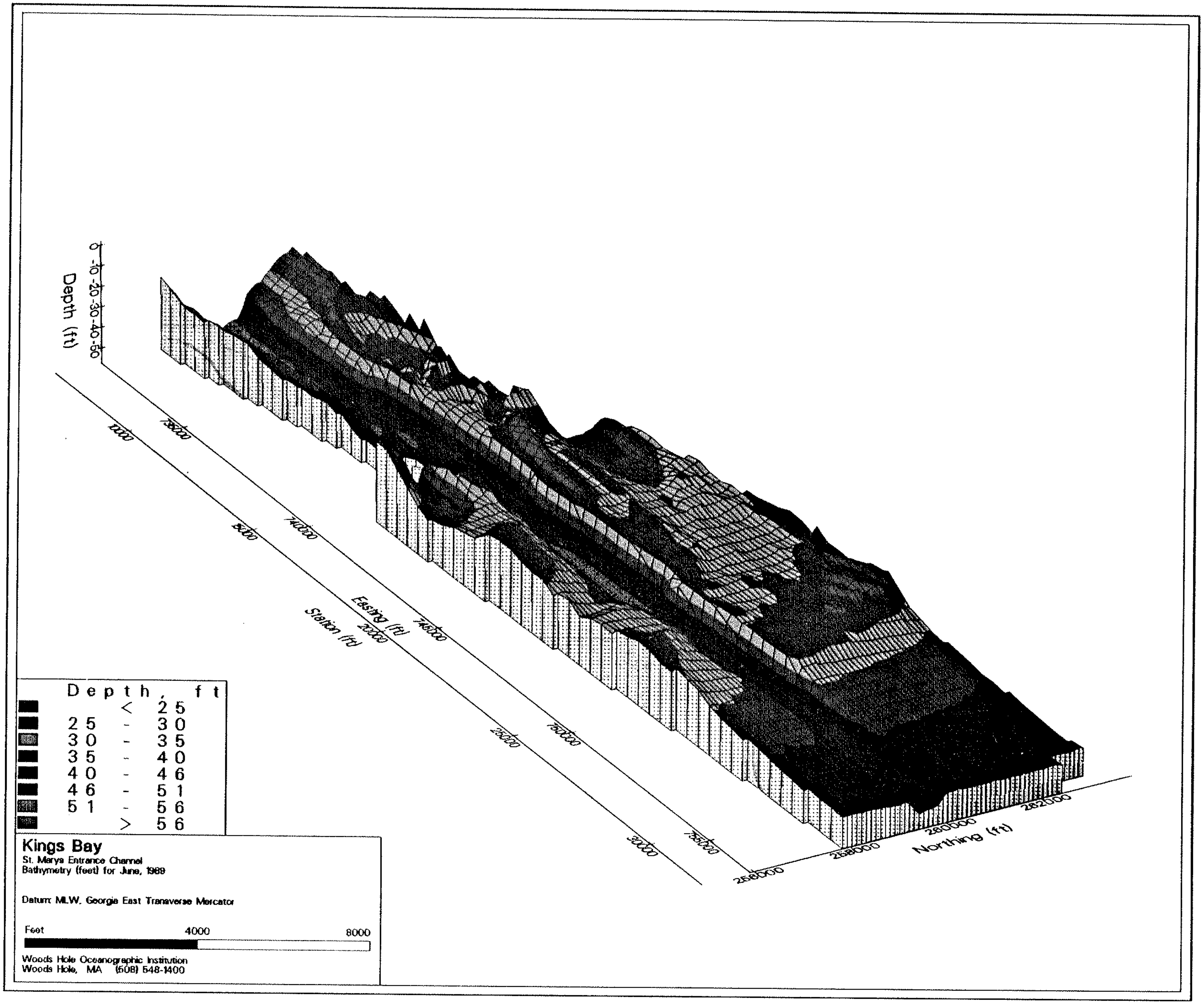

Figure 2. Bathymetry at St. Mary's entrance channel around end of jetties

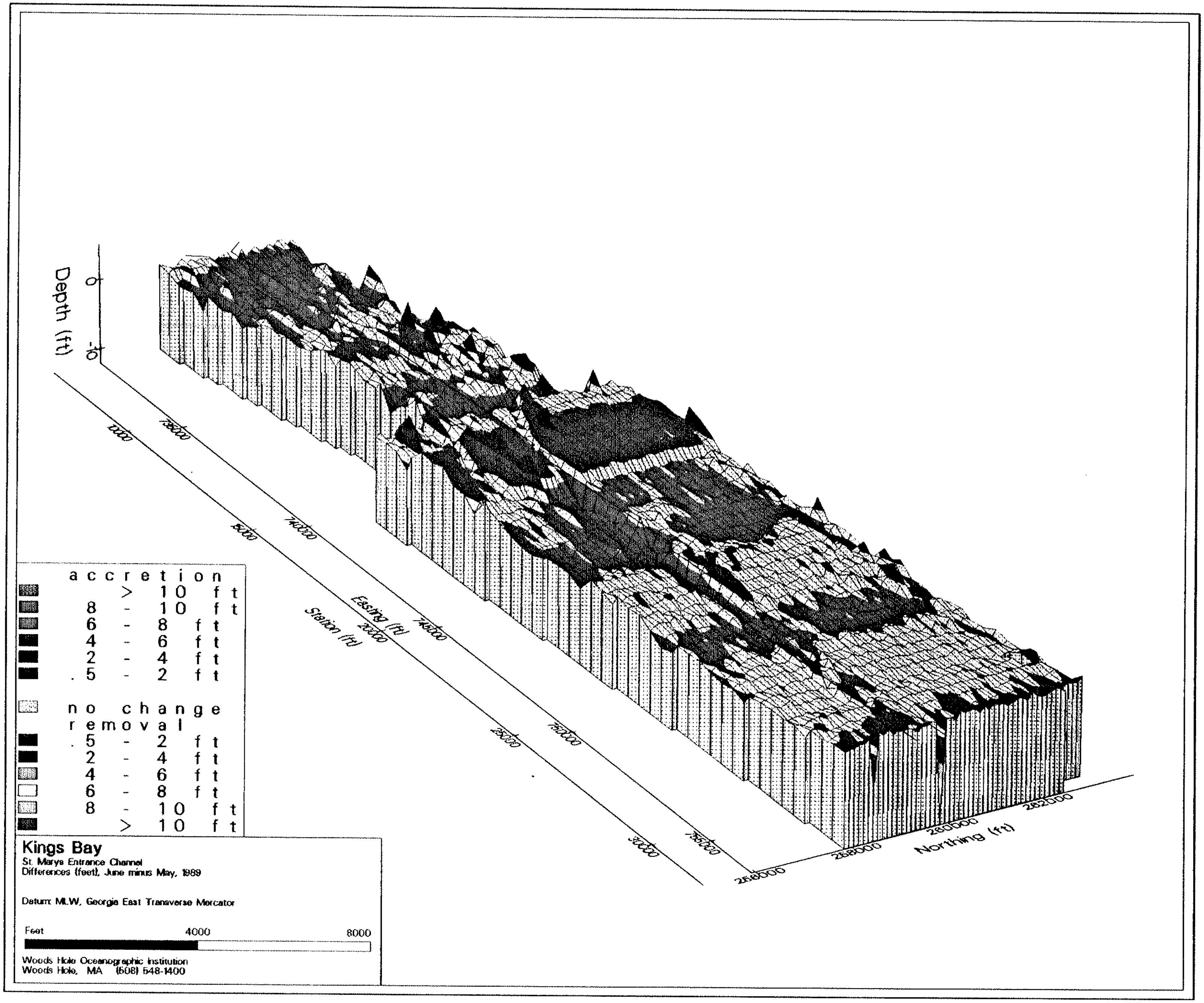

Figure 3. Contour differences around end of jetties

TABLE 3

CRUISE SCHEDULE

DATE	EXTENT & TYPE OF WORK	DREDGED SINCE LAST SURVEY?
18-26 January, 1989	complete survey	YES (696,000 cu. yds.) Oct. 1988
6-13 March, 1989	complete survey	NO
1-8 May, 1989	complete survey	NO
8-13 June, 1989	complete survey	YES (152,000 cu. yds.) 1-15 June 1989
10-16 September, 1989	complete survey	NO
28 September - 3 October, 1989	located sunken buoy # 17	
4-16 October, 1989	complete survey	NO

TABLE 4

AVERAGES CALCULATED FROM CHANNEL BATHYMETRY DATA FOR THE SIX 1989 SURVEYS

Reach	Average Depth (ft - MLW)	Minimum Depth (ft - MLW)	Standard Deviation (ft)
1	51.8	48.0	1.5
2	51.5	46.1	1.4
3	50.2	41.2	1.6
4	51.3	41.5	1.7
5	51.4	33.4	2.5

SIDE-SCAN MAPS

During the six surveys in 1989, duAl frequency side-scan sonar data were recorded. The side-scan data were analyzed at WHOI to compile bottom texture maps. The bottom texture description is made up of 15 categories (Fig. 4) some of which are presented from original records in figures C1 through C6. Ripples are defined as small sandwaves having a wavelength less than 1 foot. S1 sandwaves are 1 to 3 feet in wavelength. S2 sandwaves are 3 to 6 feet in wavelength and S3 sandwaves are greater than 12 feet. "Shoals" are defined as large bedforms that rise higher than 5 feet above the surrounding bottom. "Mottled" is a bottom giving a return that indicates poorly defined to almost nonexistent bedforms. "No bedform" is a bottom indicating no distinct shapes on the bottom. "Dredge marks" are identified by long scars along the channel. The original data are translated into the 15 catagories and presented on a chart gridded in state plane coordinates to form a texture map. The texture map is then digitized to form separate files on a Vax 8800 that can be displayed using various plotting software. Figure 4 is a product of one plotting routine.

Sandwaves are an important features to observe with side scan sonar as they can give an estimate of sediment type and dynamics in the nearshore zone. Between the jetties within the Saint Marys Entrance Channel we observe S1,S2, and S3 sandwaves with more S3 waves than S1-S2 waves to the East beyond the jetties to station 21+400. Mottled bottom and no bedforms are less descriptive of sediment type and dynamics without knowledge of sediment type. Within the channel from station 21+400 outward to the start of the cut 2-N the dominant bedform is mottled bottom. Eastward along cut 2-N the dominant bedform is mottled with increasing amounts of no bedform.

Inside and outside the jetties and beyond the channel there are bedforms of various types. All 15 bedform types are found in the west portion of the survey area (Fig. 1). Starting at station 21+000 going eastward to the end of the channel, mottled bottom and no bedforms dominate.

PROBABILITY MODEL

A probabilistic description of the collected data was made that considered those data points inside the channel marging boundaries, including the channel slopes. We performed certain statistical tests on these data that would be useful to EMOGS in describing the bathymetry of the channel.

A program has been transferred to the Army Corps of Engineers in Jacksonville, Florida, to perform the following tasks:

1. filtering of bad data
2. application of tide correction

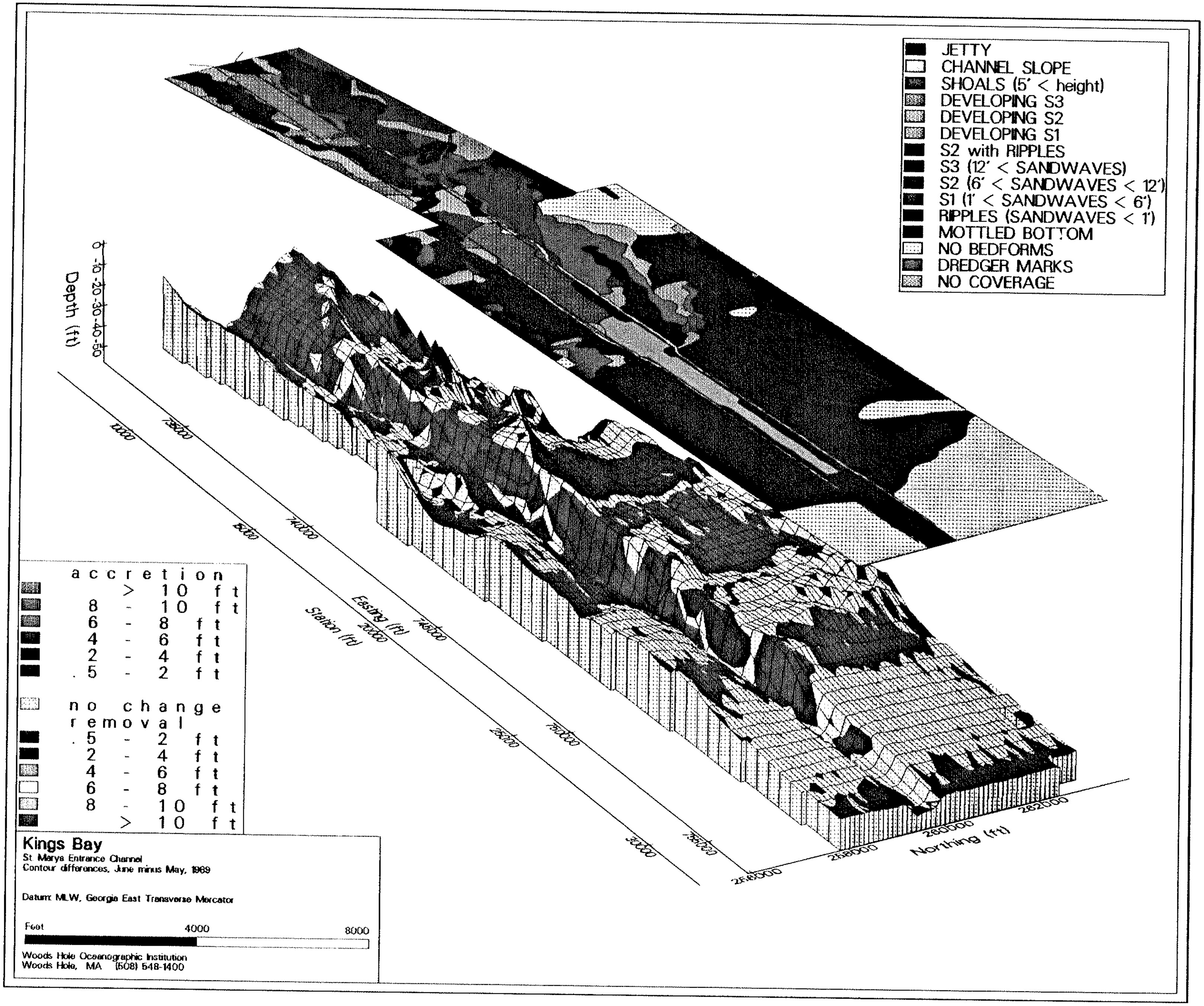

Figure 4. Bottom texture for settling basin region

3. separation of depth data into the samples lying within the channel slope margins
4. separation of channel depth samples into the five defined reaches, from inside the jetty to beyond the dogleg (see figure 1)
5. calculation of sample mean, standard deviation, skewness and kurtosis for each reach sample
6. calculation of sample 97.5% confidence intervals of skewness and kurtosis for a normal distribution
7. definition of the 99th percentile depth in each reach sample, that is, the depth which 99 percent of the sample exceeds
8. listing and location of depths shallower than the 99th percentile depth.
9. tabulation of frequency distributions for depths from 0 to 100 feet
10. tabulation of depth and location for samples occurring within 50 feet of stations 122+00, 180+00, 234+00, 238+00, 282+00, and 284+00

The data were filtered by eliminating depths less than 25 feet and greater than 100 feet. The second task was to apply an appropriate tide correction. The ACE in Jacksonville use telemeter data from onsite installations which inject the tide correction directly into the data acquisitioning, therefore providing a correction for each point. The tide values are predicted from real time tide observations made just south of the south jetty at about station 130+00. The popular opinion is that the predictions have a maximum error of $\pm$ 0.3 feet. Woods Hole uses hourly predicted data from National Ocean Services extrapolations from tide stations to the end of the north jetty at St. Mary's entrance channel. These data are exterior to the depth data, and must be inserted during the data analysis procedure. In the present algorithm the day, hour and minute for each point are read and the correction is interpolated using a straight line approximation of the hourly tide record.

With the corners of the channel template provided, each point's location is then read to determine whether the data fall within the channel margins. Separation into the five reaches finally yields five sets of depth data for further processing. Once the data samples have been defined for each reach, the mean and standard deviations are calculated:

$$\bar{z} = \frac{1}{N}\sum_{1}^{N} z$$

$$\sigma^2_z = \frac{1}{N-1}\sum_{N}^{1}(z - \bar{z})^2$$

where N is total number of samples. The skewness determines the bias of the sample about the mean, and was represented by a skewness coefficient defined as,

$$\gamma_z = \frac{1}{\sigma^3 N}\sum_{1}^{N}(z - \bar{z})^3$$

The kurtosis describes the shape of the frequency diagram in terms of its distribution about the mean value. If the sample is highly kurtotic, the frequency diagram is sharply peaked about the mean, with a low, flat slope. If the sample is slightly kurtotic, the depths are distributed more equally over the range of values. Kurtosis was determined by a kurtosis coefficient:

$$\beta = \frac{1}{\sigma^4 N}\sum_{1}^{N}(z - \bar{z})^4 - 3$$

It was of interest to compare the samples to a normal sample. The normal distribution sample would have confidence intervals on skewness and kurtosis, to evaluate normality. For a 2.5% confidence the skewness and kurtosis confidence intervals are, respectively,

$$\text{skew}_{\text{c.i.}} = \sqrt{\frac{6}{N}}$$

$$\text{kurtosis}_{\text{c.i.}} = \sqrt{\frac{24}{N}}$$

One important aspect of the EMOGS program is to determine a channel "controlling depth". This depth has been defined as the 99th percentile depth, or the depth that 99% of the other depths in the channel exceed. This is done in the model by calculating the frequency distribution for each reach, then summing the area under this function until the area equals or exceeds 1% of the total area. The depth corresponding to this 1% area is defined as the controlling depth. As part of the program, this controlling depth is output in a summary of the statistical characteristics of each reach sample. In addition, depths which fall short of this depth are listed along with their locations. The frequency distribution for depth from 0 to 100 feet are recorded to a separate file.

Finally, the program outputs depth and location along six selected stations, 122+00, 180+00, 234+00, 238+00, 282+00, and 284+00. These were chosen as representative stations in the survey, since they pass through historically determined accretion zones. These stations are all on Cut 1-N, where sediment accretion has been documented. The surveys east of the dogleg show that these depths have been stable during our analysis.

The results from the statistical algorithm are presented for each of the six surveys from 1989. Survey results consist of a summary of the pertinent statistical quantities on a reach-by-reach basis in Appendix D, frequency tables of depth for each reach in Appendix E, a plot of the frequency distributions for each reach (figures 8-15) and a superposition of all reach distributions for a given survey (Appendix E: figure E1-E5), the 99 percent depths with locations of depths shallower in Appendix F, and plots of range versus depth at selected staions for each survey in Appendix G. A short synopsis is given for each month's results below.

January 1989

For this survey, the average depths are consistently about 51 feet (Appendix D: Table D1), with the lowest average in Reach 3. Channel depths spread about this mean by roughly 1.5 feet, with the greatest spread in Reach 5. During the course of the investigations at St. Marys Inlet, we have discovered very active sediment movement in Reach 5 due to the high tidal flows. This trend will remain through the 1989 survey season. The skewness and kurtosis coefficients are defined as being zero for a normal distribution, and if they fall within the confidence intervals given, the sample distribution can still be considered normal. From Table D1, it is seen that the sample distributions are confirmed non-normal in skewness and kurtosis. A skewed distribution means the depths are biased about the mean to shallower or deeper depths, depending on the sign of the coefficient. A kurtotic distribution has depths either gathered about the mean in a peak, or spread fairly uniformly over all sampled depths. From the plots of Reach depth distributions (Figure 8), it is seen that all but Reach 2 and Reach 4 depths are skewed to shallower or deeper depths. Reach 1 is skewed towards deep water, which gives a safety factor for travel through the channel. Reach 3 is clearly skewed towards shallower depths, indicative from the skewness of -1.297, but Reach 5 looks as though it is skewed towards deep water, despite a skewness of -1.232. Looking at the table of depths for Reach 5 (Appendix E: Table E1) shows that there is a spread of depths into very shallow water, giving the negative skewness coefficient. This skewness is perhaps contaminated by the slumping channel margin at Station 122+00.

March 1989

The cruise from March, 1989, shows average depths again on the order of 51 feet (Appendix D: Table D2). An immediate comparison made with the January survey is that Reach 3 has again the minimum average depth. Another consistency is that Reach 5 shows the greatest variability in depths. From the coefficients all reaches except Reach 4 are non-normal. Reach 4 has a normal distribution type of skewness. Reaches 3 and 5 are again skewed towards shallow water from the mean. Note that Reach 1 has a low kurtosis, even though it exceeds the limits for normality. This can be seen in Figure 9 by the relatively flat distribution across depths of 50 to 55 feet. If this is compared with January Reach 1, the shape is fairly consistent. This would suggest that Reach 1 is inactive, at least between these two surveys. Station 284+00 (Appendix G: Figure G2) shows the local variations and the need for several sources of data when looking at channel bathymetry. The extreme hitch at range 1000 for Station 284+00 does not show up in the March 1989 smooth sheet, nor does it impact the contour map of the settling basin. What was discovered when interpreting the data was that those points making up the spike were part of a run along the longitudinal channel axis. With predominant wave propogation from the northeast on that day of surveying, an excessive ship roll could have given a fathometer return on the channel slope rather than the bottom. The mild winter during the year did not produce any major storm capable of moving large amounts of sediment, but the tidal dynamics have shifted Reach 5 towards a greater skewness in shallow samples, suggesting a need to dredge. Another indication for dangerous channel character would be a negative high kurtosis coupled with a negative skewness, meaning that there is a uniform spread of depths shallower than the sample mean, and these depths are occuring almost as often as the mean depth, making it difficult to navigate. This condition was not apparent in any of the March 1989 data.

May 1989

The Spring cruise shows the same tendencies as the first two, with the characteristic low average depth in Reach 3 and high spread in Reach 5 (Appendix D: Table D3). An immediate note is that Reach 3 has an average depth that has dropped below 50 feet. Another is that kurtosis in Reach 2 shifted from 11.474 in March to 2.331 in May. Looking at Figures 6 and 7, the May distribution appears more kurtotic then in March, but the coefficient has dropped significantly between the two months. This shows that the distribution of depths about the mean and the accompanying standard deviation are important when the kurtosis coefficient is calculated. Although the March depth distribution appears flatter than that in May, the samples grouped at 51 and 52 feet comprise 60% of the total sample. The May distribution has a 37% sample volume at 51 feet, with 25% of the sample at 52 feet. Evidently the high grouping of samples in the March distribution was responsible for the high kurtosis coefficient.

June 1989

A dredging was done in June during the survey, between stations 21+800 to 32+900. This would contaminate direct comparison between May and June, but should show up in the statistical results. As seen (Appendix D: Table D4), the dredging lowered the skewness in Reach 5, also lowering the kurtosis. This is a result of the removal of material that had collected at Station 122+00. Note that Reach 4 has increased to a high kurtosis; looking at the histogram values in Appendix E: Table E4, the new behavior in June is a grouping of fairly level depths about the mean from depths of 50 to 55 feet. The peak is not as pronounced as in May, which has a sharply increasing sample count towards the peak. From this example and the one mentioned above for

Reach 2 kurtosis levels, a high kurtosis makes itself evident by grouping of uniform depths distributed within the standard deviation of average depth. This type of channel character would be safely navigable as long as average depths were acceptable and spreads were within safe bounds.

September 1989

The survey results show a decrease in average depth of 1.4 feet between the June and September surveys in Reach 5 (Appendix D: Table D5). This again shows the high dependence in this stretch on tidal flows, and independence from storm events. Kurtosis is high again in Reach 5, but has dropped in Reach 4. This behavior of erratic kurtosis in a sample region through time would suggest that the channel slopes might be encroaching on the margins. This has been seen in the smooth sheet printouts for Reach 4 with a large shoal on the north side of the channel that appears to feed the channel with sediment continually. Note the minimum depth in Reach 4 is 25.6 feet for June, at Station 19+237 on the north side. There is no such "spillage" in September. These differences are also mildly displayed in standard deviation, where June's exceeds September's by one-half foot. When interpreting this data, it is important not only to look at statistical quantities, but the distributions, dredging information, and smooth sheets.

October 1989

Hurricane Hugo passed through the area in late September, 1989. The modal period for this major event was 10 seconds, not very large but sufficient to move sediment. As shown in Appendix D: Table D6, the largest change for September is that all Reaches have shallower average depths by roughly a foot. In Reach 1, there is little difference in depth. Standard deviations give no hint of storm effect, but the skewness and kurtosis coefficients in Reach 3 are within normal bounds. Figures 10 and 11 for the depth distributions between September and October show Reaches 3 and 5 have gone through some changes. Reach 3 has a flatter distribution over shallow depths in October, with 12% of the samples occurring at the 46 foot depth. An appreciable amount of the channel is barely above the control depth limit. Reach 5 has experienced similar spreading, which is probably due to the high energy within the jetties during a storm. With the decreased average depth, and evidence that sediment has been placed at shallower depths in Reaches 3 and 5, the question is whether this was a simple transfer of sediment within each reach due to higher waves, or an intrusion from an outside source. The survey smooth sheets from October show a general accretion in the northern part of the survey area outside of the channel. Since Hugo passed to the north of St. Marys Inlet, waves would have been travelling from the northeast, and a longshore current could have been established from that direction. Thus large amounts of sediment could have been transported from the north into the survey area, then trapped by the channel.

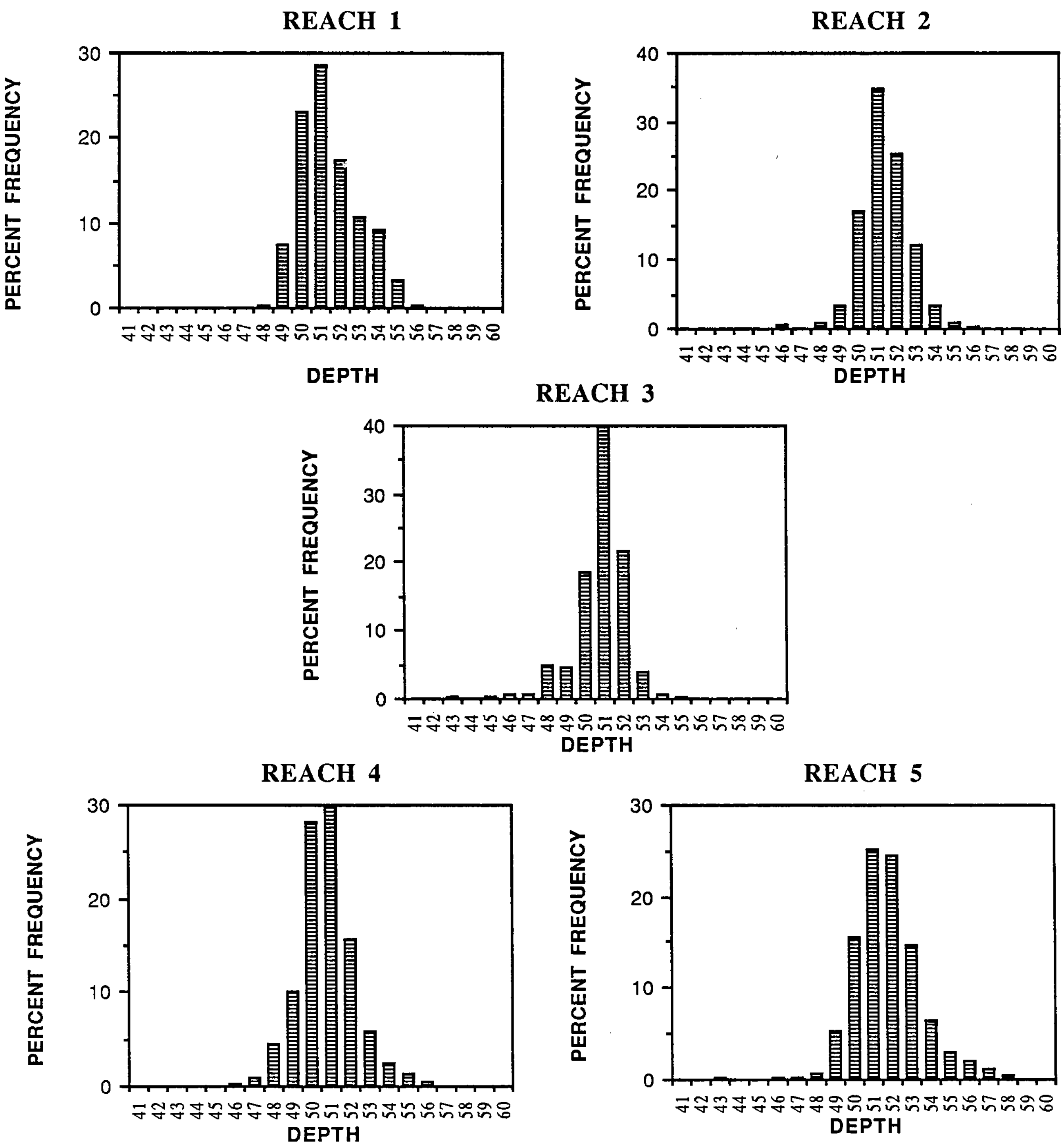

Figure 5. Histograms of Depth (ft) for January, 1989

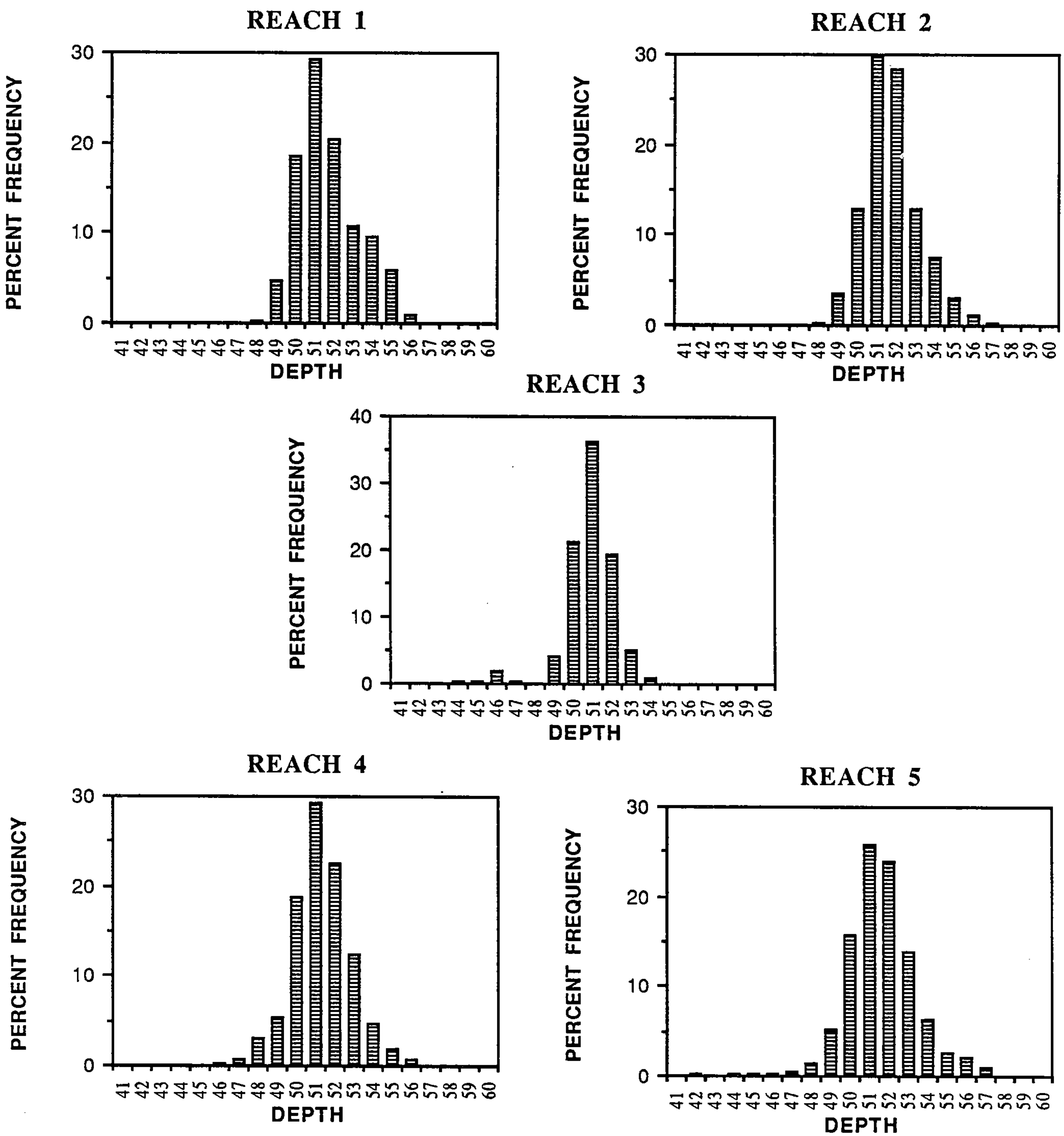

Figure 6. Histograms of Depth (ft) for March, 1989

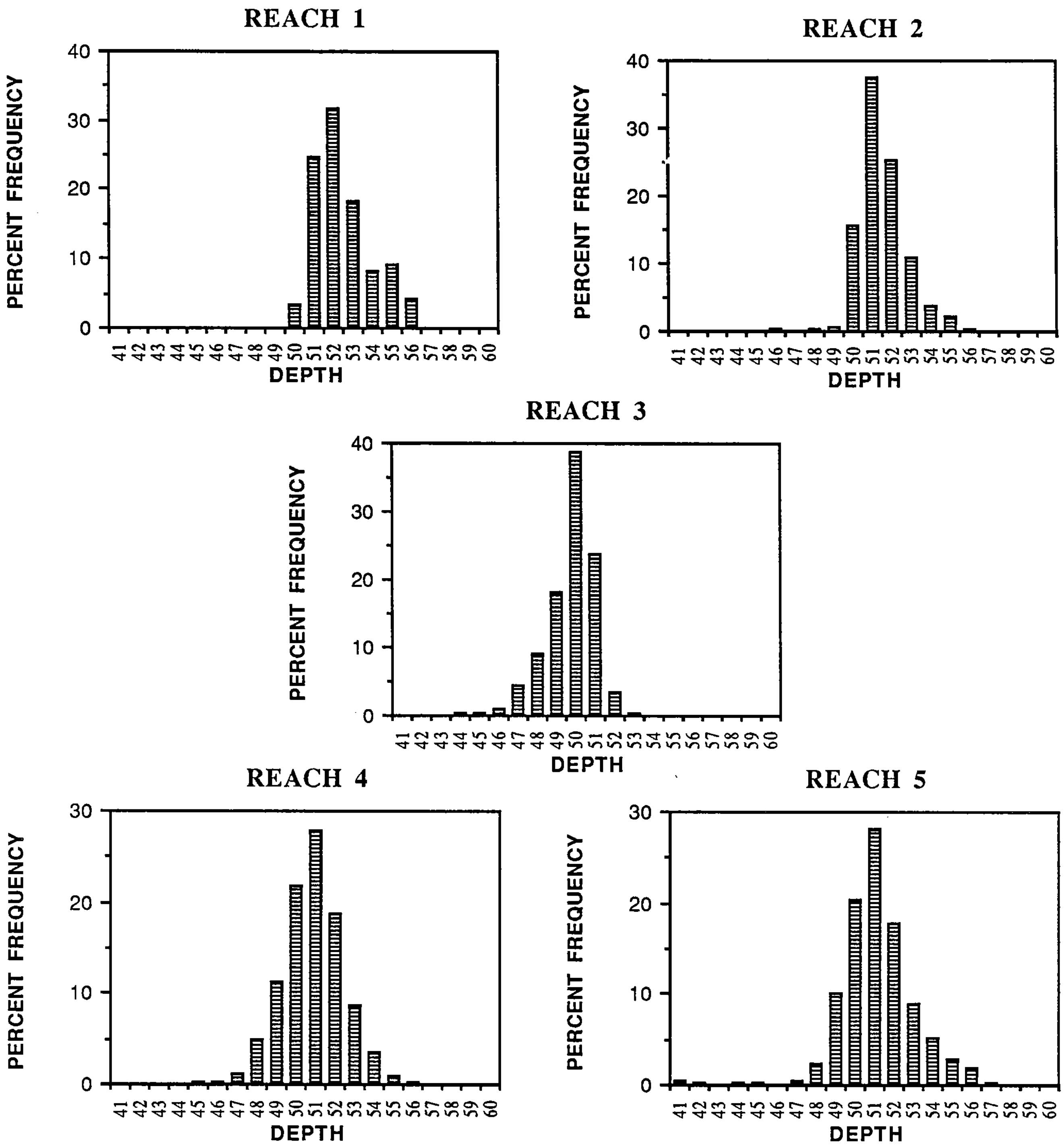

Figure 7. Histograms of Depth (ft) for May, 1989

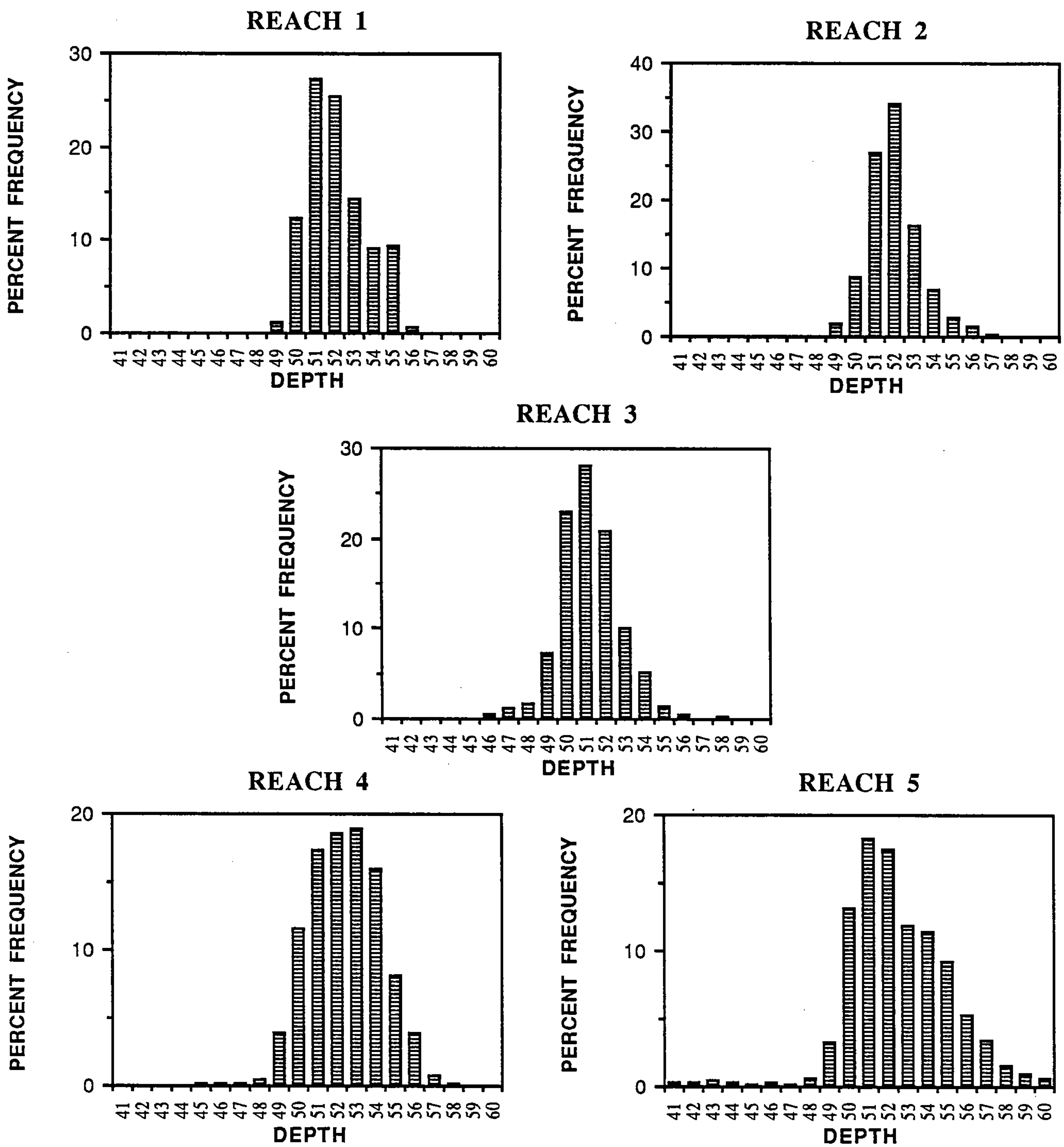

Figure 8. Histograms of Depth (ft) for June, 1989

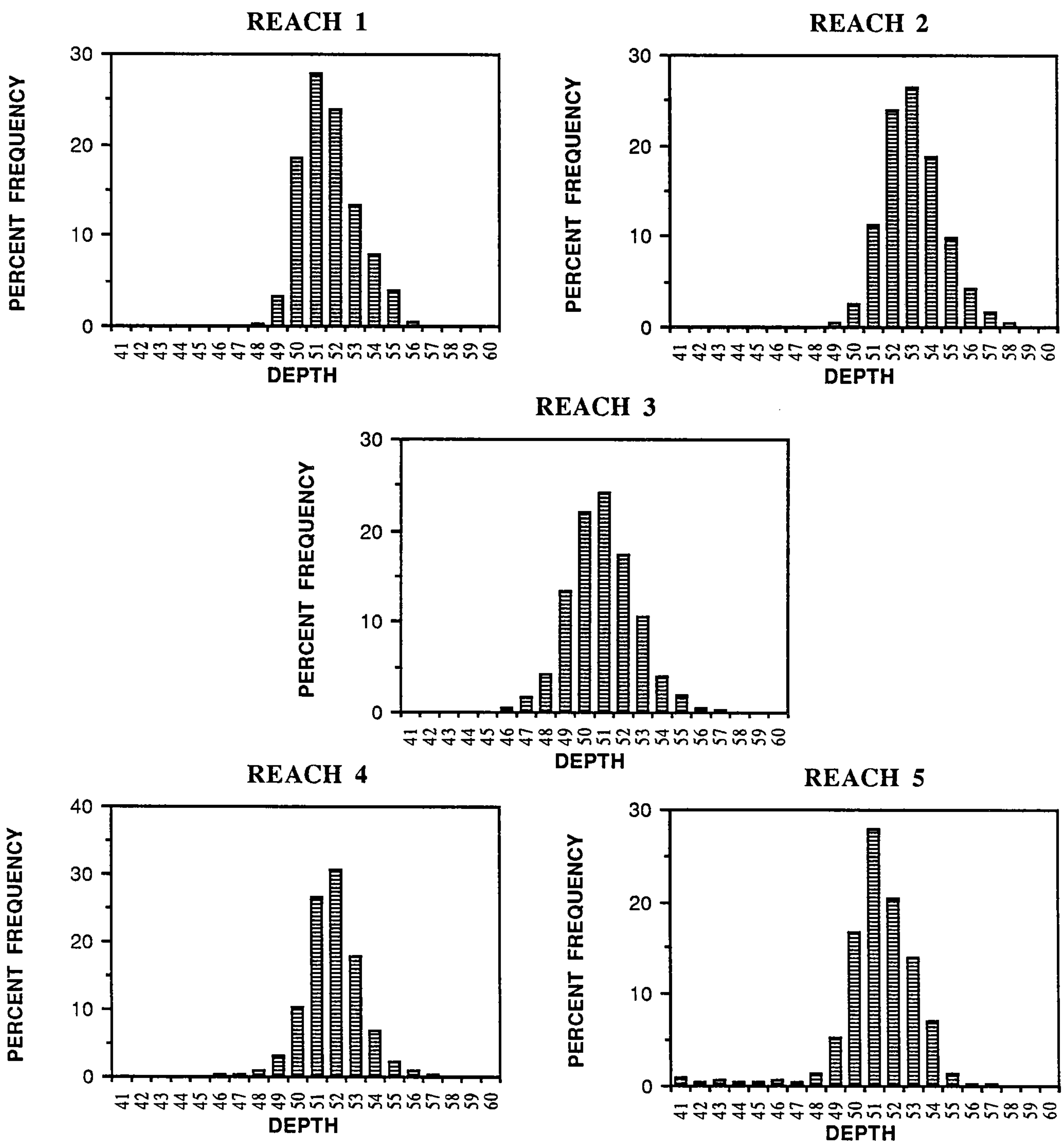

Figure 9. Histograms of Depth (ft) for September, 1989

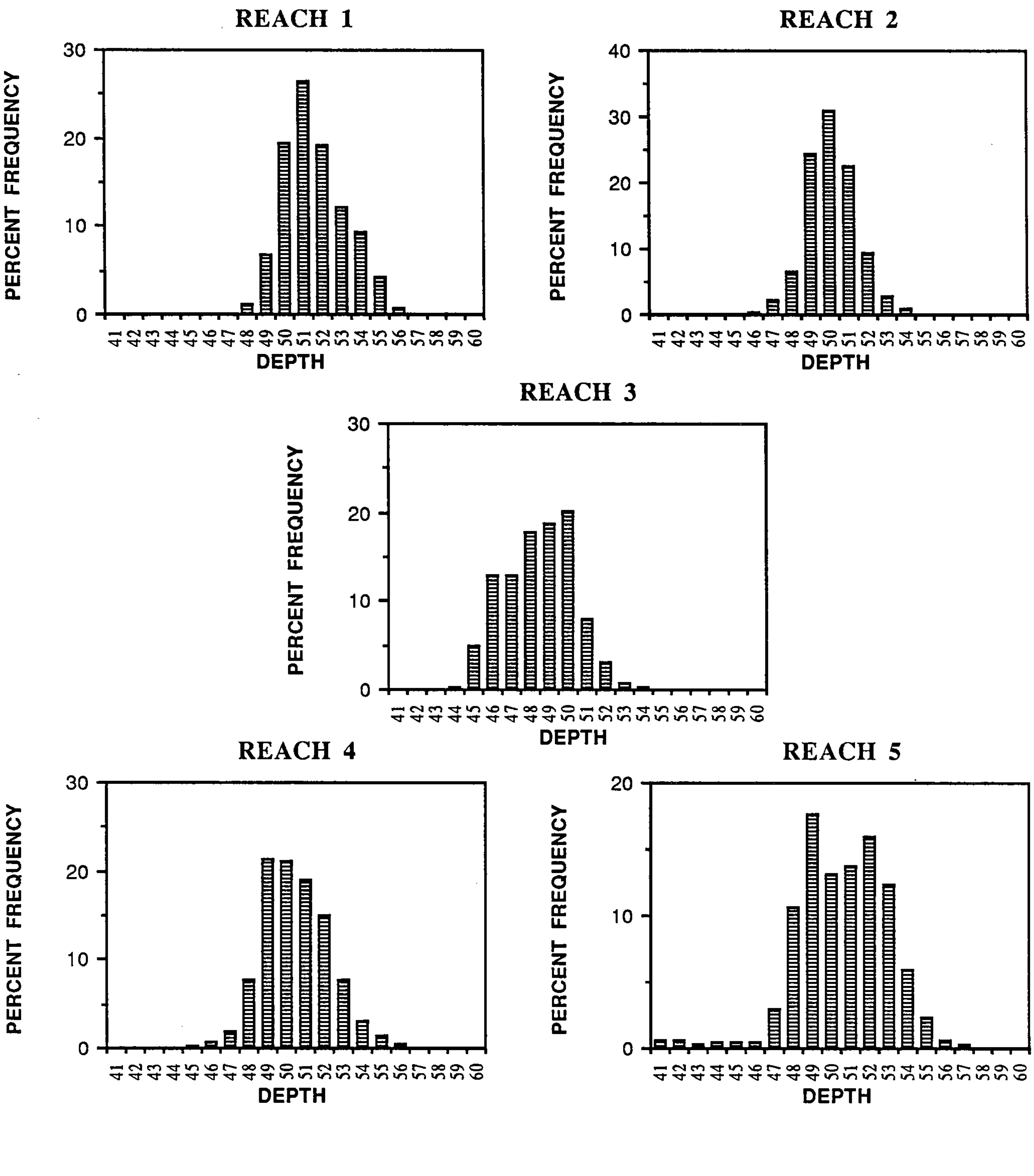

Figure 10. Histograms of Depth (ft) for October, 1989

DISCUSSION

During phase III of the 1989 EMOGS sediment component six precision bathymetric surveys were conducted in areas outlined in Figure 1. Charts of depth values, contours, and contour differences (differences relative to the previous survey) were created of all surveyed areas. These data also were analyzed by determining the probability density of depth values from edited data taken from only the channel. The average depth in all reaches for the six surveys varied from 48.4 to 52.5 feet (Appendix D: Tables D1-D6). The skewness and kurtosis varied widely over the reaches and the surveys. The differences in skewness and kurtosis indicate that channel depths varied significantly between surveys. In 1989 the largest average channel depth change occurred in Reach 3 which accreted 2.5 feet following the passage of hurricane Hugo (from September to October survey) indicating that during a relatively small storm event (significant wave heights of about 8 feet with a modal period of 10 seconds) a significant depth change can occur. During larger storms (certainly during a 100-year event) a much larger average depth change would be expected. Of the 5 channel reaches, Reach 3 had the lowest average channel depth of 50.2 feet calculated from the 1989 surveys and a standard deviation of 1.6 feet (Appendix D: Tables D1-D6). Reach 3 should be checked closely after storms as this is a hotspot for sedimentation activity. Reach 5 had the lowest minimum depth and the largest average standard deviation. The low minimum depth is from a small hotspot at the northwest corner of the settling basin. This small hotspot could be of significance during a large storm and should be monitored closely.

Two dredge operations were conducted in Saint Mary's entrance channel for the Kings Bay Naval Submarine Base during 1989 (telephone conversation with Mr. Joe Hyatt, Kings Bay Submarine Base Pubic Works Office). During October 1988, 696,000 cubic yards were dredged from the channel. From 1-15 June 1989 152,000 cubic yards of sediment were removed between stations 21+800 and 32+900, and from 20 November 1989 to 15 December 1989, 795,000 cubic yards were removed from between the same stations. The volume calculations for dredge operations are valuable as they give an accurate measure of sediment transport into the channel. These volume calculations should be included in the future to interpret transport trends along the channel.

The entrance channel to Kings Bay has been surveyed extensively since it was deepened to 46 feet channel depth. The results show that the channel is an effective sink for the sediment that transits the area. Reach 3 seems to be the area along the channel that is most affected by this sediment transport, and Reach 5 also has areas of extensive shoaling. The Final Report in September, 1990, will examine relationships between channel shoaling and transport processes.

PHASE III (1990): PROPOSED WORK FOR SEDIMENT COMPONENT

During 1990 the sediment component will acquire two surveys. The thrust of these surveys will be to document the post-dredge condition of the channel and the subsequent build-up of bedforms in and around the St. Mary's entrance channel to Kings Bay Naval Submarine Base. The comparison of data from these two surveys coupled with the observed wave data will provide valuable input into the EMOGS operator guidance model. In the absence of a significant storm we have planned our second survey to coincide with the NOARL experiment in June (Ed Mosely, Stennis Space Center , MS).

A major focus for 1990 will be the analysis of the data collected during the other phases of EMOGS. An emphasis will be placed on the predictive capabilities for EMOGS.

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APPENDIX A
SURVEY SYSTEM
EMOGS SEDIMENTATION STUDY
WOODS HOLE OCEANOGRAPHIC INSTITUTION

Four major components make up the EMOGS bathymetric survey system (Table A1):

1) Navigation: A UHF navigation system that was installed and is maintained by the USACE forms the basis for all navigation for the surveys. A UHF master transponder and DDMU (Digital Distance Measuring Unit) are the sea-borne components. Range accuracies for each remote transponder are approximately 0.5 to 1 m. However, positional accuracy depends strongly on the geometry of the stations, and on how well the network is maintained (tuning of the transmitters, integrity of the sites, etc.).

2) Fathometer: A dual-frequency, survey-quality, echosounder operating at 24 and 200 kHz was selected for the bathymetric surveys. One or both of the frequencies can be activated at any time; the use of dual frequency provides a means for evaluating the presence of soft sediments on the bottom. These data are digitized and fed into the survey computer hardware and software. A two-way communication allows the computer to control the time base of the fathometer, and to annotate the fathometer with time, position, and other information.

3) Side-scan sonar: A state-of-the-art, dual frequency, side-scan sonar was purchased to provide textural information and swath mapping of the channel off Kings Bay. The side-scan operates 100 and 500 kHz signals simultaneously, recording both on magnetic tape (FM recorder) and on thermal paper for a high resolution, broad bandwidth record of bottom backscatter. These data indicate the length scales of bedforms present in various parts of the entrance channel, and show other changes in bottom texture (grain size, sorting, etc.). This is the primary tool for mapping bedforms in the channel.

4) Data acquisition system: The hardware and software system selected for data acquisition is the SAIC INDAS system, consisting of HP computers and plotters and a specialized survey software system. The data acquisition system software includes synchronization capabilities for side-scan and echo-sounder while surveying in the field, as well as the storage of time, depth, and position information. The post-processing software contains numerous options, including the output of standard, tide-corrected bathymetric plots, three-dimensional bathymetry plots, contour maps, and volume-difference calculations for between-survey comparisons.

In addition to the four primary components listed above, a number of other smaller components are required, including generator, power supplies, etc. which support the above components. All surveys to date have been conducted on the vessel *Sis,* owned by Bill Kavanagh and operated out of Fernandina Beach, Florida.

TABLE A1

EMOGS NAVIGATION SYSTEM COMPONENTS

SEDIMENTATION STUDY

Del Norte Navigation System

- Del Norte model 547 DDMU
- Del Norte Model 547 Master Transponder
- Del Norte model 547 Antenna

ODOM Hydrographic Systems Fathometer

- ODOM Echotrac Model DF-3200 Control Unit
- Dual Frequency (24 kHz, 200 kHz) transducer, model 210-33/9-19

Side Scan Sonar System

- Klein Digital Side Scan Recorder: Model 595
- Klein Dual Frequency (100 kHz, 500 kHz) towfish, model 4225-101HF
- Hewlett-Packard 1/4" magnetic tape recorder, model HP396YA

SAIC Integrated Navigation and Data Acquisition System (INDAS)

Computer Hardware	Computer Software
HP 9920S Computer	INDAS Real time navigation software
HP 98256A RAM	INDAS post-survey processing software
HP 9153C-010 Disk	
HP 82913 Monitor	
HP 93526A Serial	
HP 2225A ThinkJet Printer	
HP 7475A Plotter	
HP 7596A Plotter	
HP 10833C HPIB	

APPENDIX B
ST. MARY'S ENTRANCE CHANNEL
TIDAL DATA

Enclosed is an explanation of the method we have employed in obtaining tidal data for St. Mary's Entrance Channel at King's Bay, Georgia. This method has proven most expedient in our previous bathymetric surveying operations and therefore we plan to continue with this method in our future work, unless an improved method is tested and proven.

From personnel under the supervision of Elmo E. Long, the Acting Chief of the Tide and Current Prediction Section at the National Ocean Service in Rockville, Maryland, we obtain tables, in ten days or less, with hourly tide predictions for all the days in any month at a service charge of ten dollars. The tide predictions are based on harmonic constants for a station nearby on the Amelia River in Fernandina Beach. The harmonic constants enable tide predictions for the Amelia River station to be calculated. Then, with known (previously measured) time differences and height ratios for high and low water, the times and tide levels at high and low water can be calculated for the North Jetty at St. Mary's Entrance Channel. Tide levels between high and low water at the North Jetty are then calculated by interpolation along a cosine curve.

This procedure yields hourly tide predictions for the North Jetty location in St. Mary's Entrance Channel at King's Bay, Georgia. We have compared this output with tidal output acquired by *in situ* tide gauges provided by the Army Corps of Engineers from two locations in St. Mary's Entrance Channel (Stilling Well, Telemetry Station). The results of this comparison were satisfactory with a ten-day test period showing maximum differences of only one foot between the calculated tidal predictions and both physical measurements of the tide at the two different locations.

Previously, there had been concerns regarding tidal data for St. Mary's Entrance Channel. One concern had been that *in situ* physical measurements would be required for accurate tidal information. A second concern involved whether tidal characteristics varied significantly between the area inside the jetties and the area outside the jetties at St. Mary's Entrance Channel. The results of the comparison discussed above addressed both these issues since one of the physical tide sensors (Stilling Well location) operated by the Army Corps of Engineers is located inside the jetties and the other (Telemetry Station location) is located outside the jetties at St. Mary's Entrance Channel. The comparison indicated tidal characteristics are similar, and vary less than one foot the vast majority of time.

Based upon information available to us up to this time, we have selected the method of tidal correction based on the predictions from harmonic constants at Amelia River provided by the National Ocean Service. Although such predictions are not able to account for local meteorological effects on the tide, such as set-up, we assume that survey work will not be undertaken during times (e.g., storm conditions) when meteorological events are expected to have a *significant* effect on the tide. During the early period of our research involvement, we found that the tide-gauge operation of the Army Corps of Engineers was not a feasible means to obtain consistent tidal data due to unpredictable periods of both instrumentation inaccuracy and instrumentation down-time. As this condition has changed, we have begun to modify our operations accordingly.

The National Ocean Service has made available to us both the harmonic constants at the Amelia River station and the offsets to the North Jetty at St. Mary's Entrance Channel. With existing software developed at WHOI, we have the capability to generate the tidal predictions ourselves in the future, for inclusion in EMOGS.

APPENDIX C
SIDE-SCAN DATA INTERPRETATION

Side-scan sonar data must be interpreted in a descriptive fashion to document textural differences along the bottom. Factors affecting this interpretation include variability in the manual tuning of the side-scan hardware, variability in the water quality due to the effect of the tide on suspension of particulate matter, variability in towing dimensions of the fish (side-scan transducer body) due to the restrictions of water depth, and finally the subjective nature of classifying the continuum of bedform textures into distinct categories. As we gained more experience from working with the side-scan data from King's Bay, we refined our classification scheme of the bedform textures to meet both the difficulties of interpretation and the overall goals of our analysis. This accounts for the more detailed legends on the more recent texture maps from our side-scan work. To distinguish textures from side-scan records, bedforms were scaled by their lengths, since bedform height is more difficult to measure from a side-scan image. Fathometer traces over bedforms are contaminated by wave motion and ship motions, so they are not useful to show bedform height. The classification to be discussed below includes the following elements:

a) Developing bedforms: These bedforms are not well-formed, or are not imaged well by side-scan. In general, these bedforms show less coherence than developed bedforms.

b) Developed bedforms: These forms show spatial homogeneity and coherence (wavelengths of 0.5 - 12 feet and greater). Bedforms with wavelengths of one to six feet are shown in Figure C1, with a 15 meter distance between scale lines. Bedforms having lengths between six and twelve feet are exemplified by Figure C2, where the distance between scale lines is 15 meters. Bedforms having wavelengths greater than 12 feet are shown in Figure C3, where scale lines again are separated by 15 m. Note that the fidelity of the bedform image is affected by look angle (one image is always better than the opposite image).

c) Dredge marks: The many dredges operating in the area left large scars, particularly where the hopper dredges worked. These are imaged well by the side-scan (Fig. C4). Their distinctive geometry make them easily recognizable by side-scan sonar.

d) Mottled bed: Often, bedforms cannot be distinguished because of lack of coherence, fineness of sediments, or because bedforms are not present. Figure C5 shows a mottled bed, consisting of several different types of reflectors, none of which is regular.

e) Specific features: Occasionally, specific features such as the end of the jetties are distinguished in the side-scan images. These features are marked on the texture maps. The anchor and chain to a buoy are indicated on Figure C6, as imaged by side-scan.

f) Dredge interference: Suspended sediment from the dredging operations (particularly the hopper dredges) degraded signal quality on the early surveys in particular, but in all surveys to some extent. Suspended sediment near a hopper dredge can block all returns within the channel.

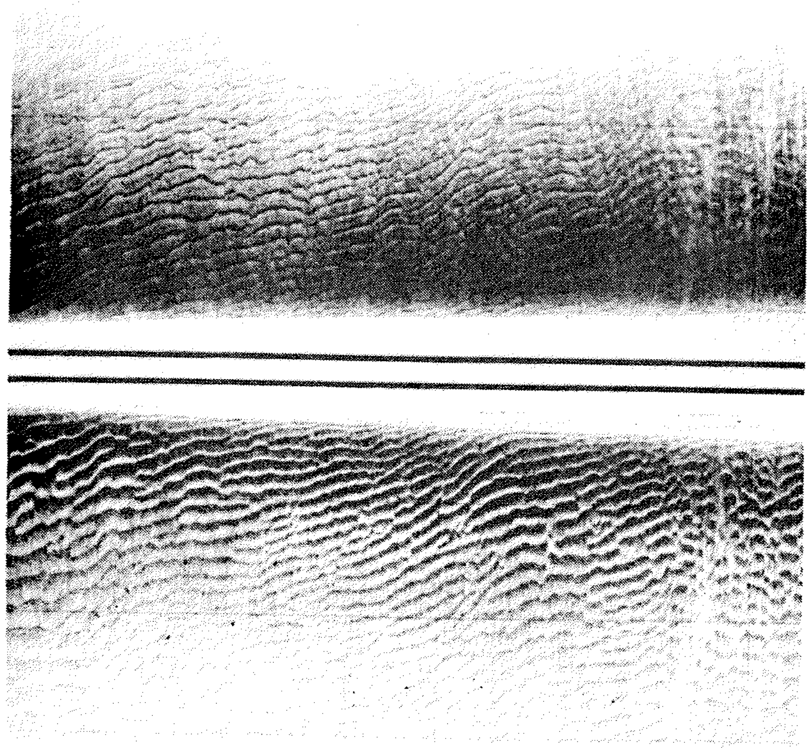

Figure C1. Side-scan return of S1 sand waves with wavelengths of one to six feet

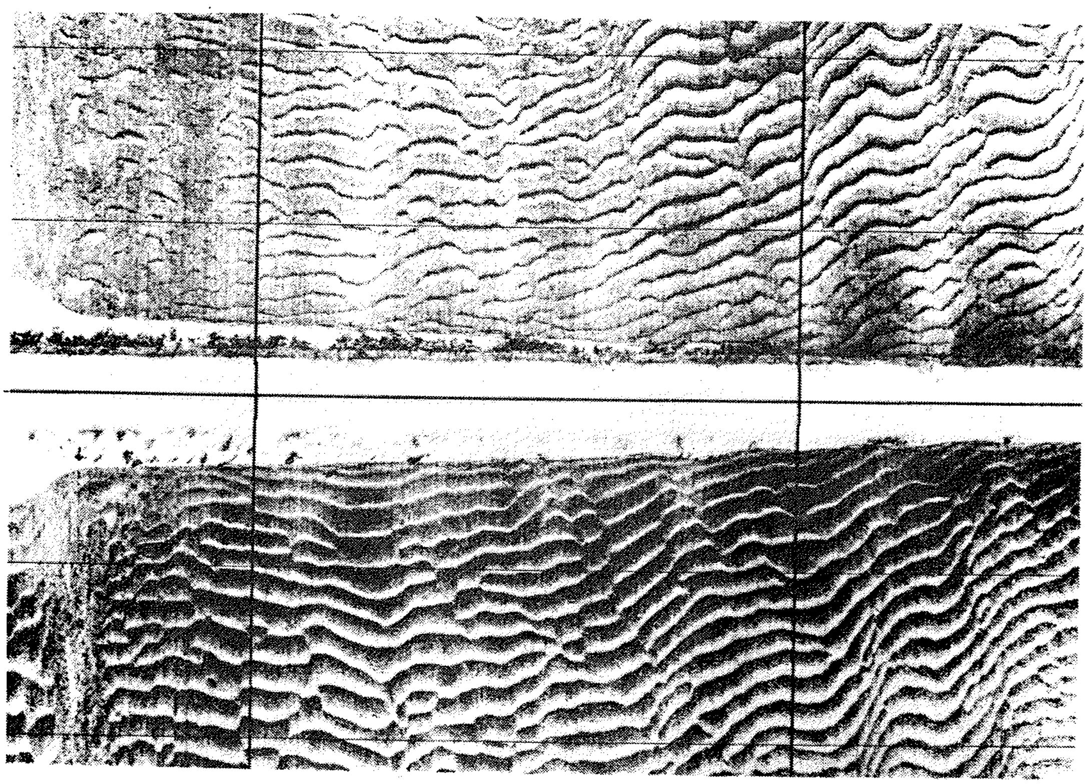

Figure C2. Side-scan return of S2 sand waves with wavelengths of six to twelve feet

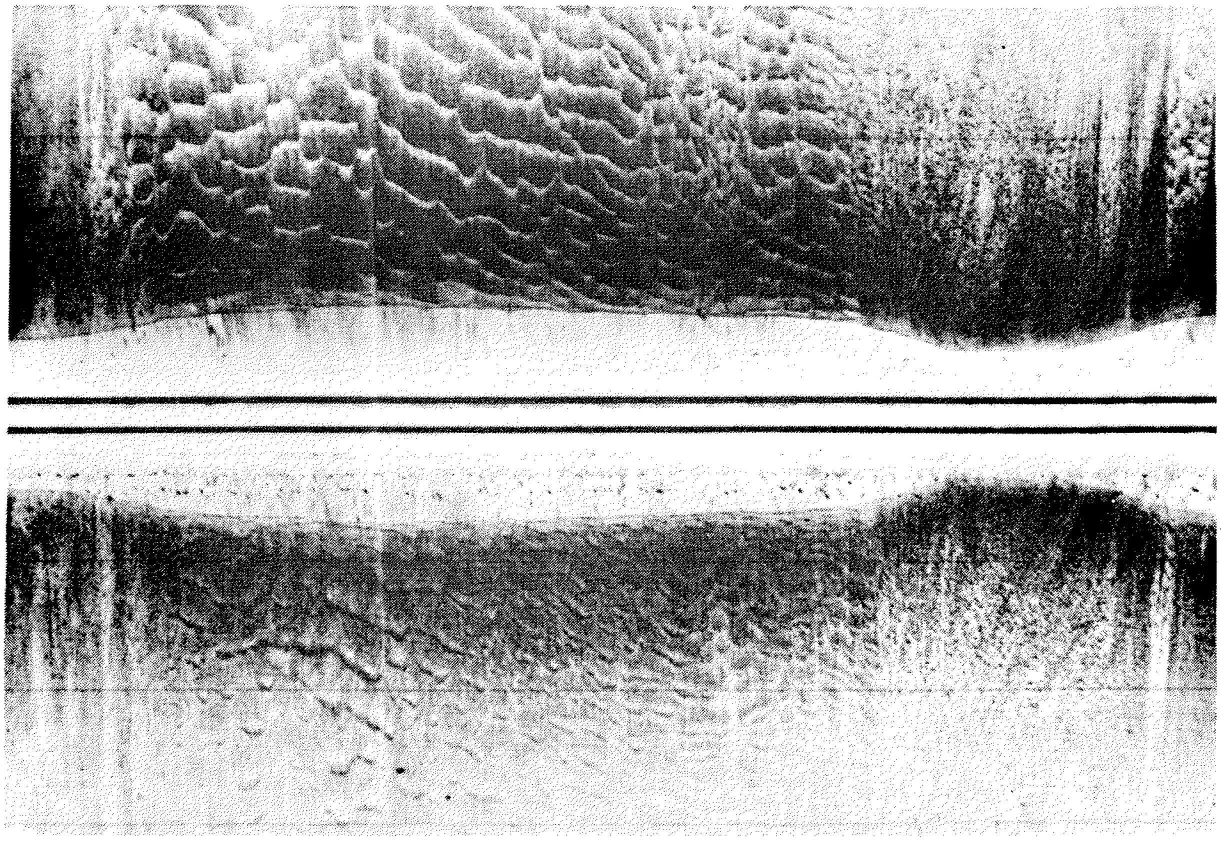

Figure C3. Side-scan return of S3 sand waves with wavelengths over twelve feet

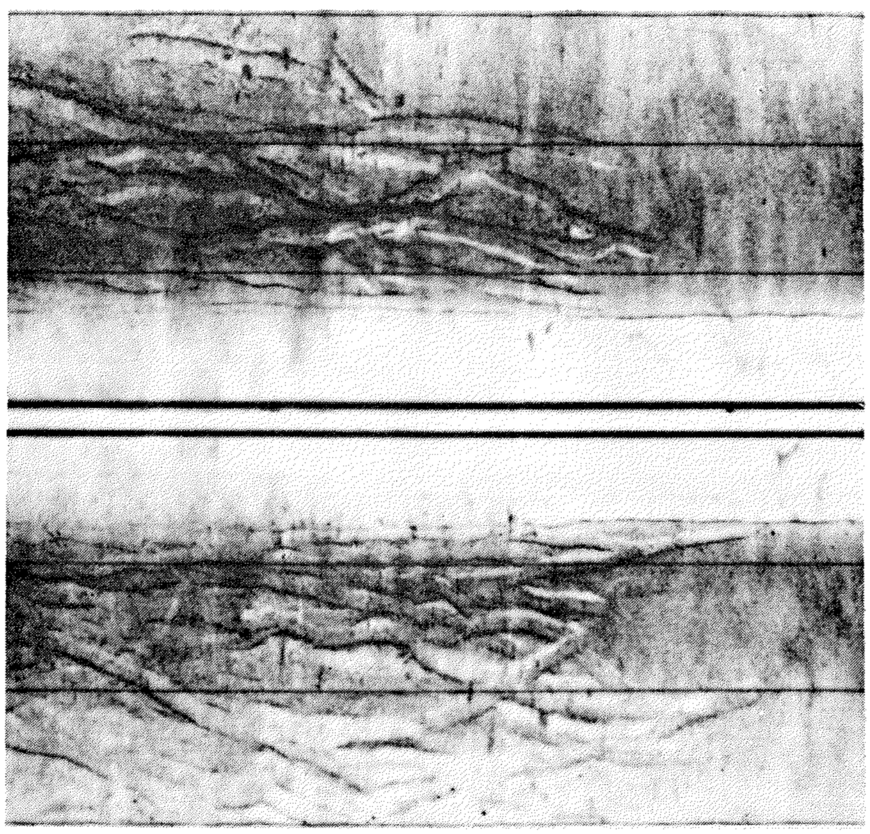

Figure C4. Side-scan return of dredger marks

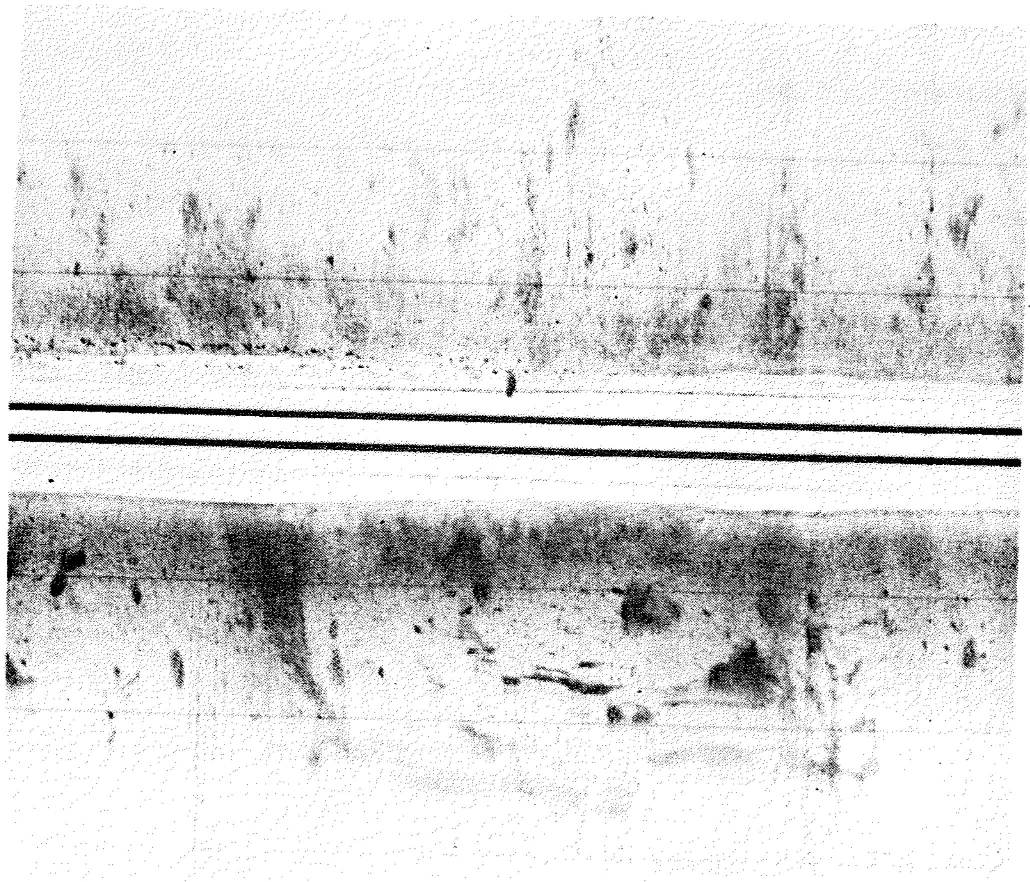

Figure C5. Side-scan return of mottled bottom

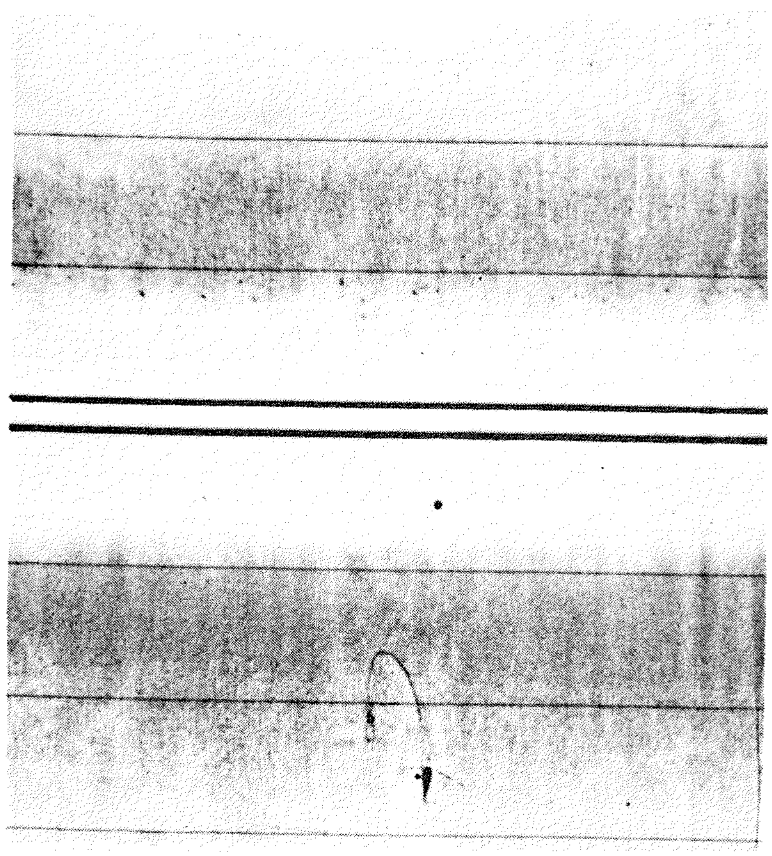

Figure C6. Side-scan return of buoy and anchor line

APPENDIX D
RESULTS OF PROBABILITY ANALYSIS FOR CHANNEL DEPTHS

TABLE D1
STATISTICAL QUANTITIES FOR JANUARY 1989

	REACH				
Quantity	1	2	3	4	5
Sample Size	3988	3364	2575	3754	3505
Average (ft)	51.4	51.4	50.6	50.8	51.7
St. Dev. (ft)	1.51	1.34	1.51	1.50	1.99
Skewness	0.555	0.183	-1.297	0.00996	-1.232
Kurtosis	-0.392	4.971	3.602	2.429	11.404
Skewness .025 confidence interval	0.00775	0.00845	0.00965	0.00800	0.00827
Kurtosis .025 confidence interval	0.155	0.169	0.193	0.160	0.165
Min. Depth	48.1	45.2	40.9	39.3	35.9
Station	6343	36365	26643	20036	12241
Range	1128	960	769	613	1427
Max. Depth	55.7	63.1	58.6	56.8	58.5
Station	22630	41374	24651	17574	8645
Range	755	1121	786	1320	991

TABLE D2
STATISTICAL QUANTITIES FOR MARCH 1989

	REACH				
Quantity	1	2	3	4	5
Sample Size	3220	2765	2035	3554	2623
Average (ft)	51.7	51.8	50.5	51.3	51.5
St. Dev. (ft)	1.56	1.53	1.68	1.55	2.16
Skewness	0.581	1.756	-1.393	-0.00776	-2.194
Kurtosis	-.303	11.474	3.352	1.550	17.730
Skewness .025 confidence interval	0.00863	0.00932	0.108	0.00822	0.00956
Kurtosis .025 confidence interval	0.172	0.186	0.217	0.164	0.191
Min. Depth	48.3	46.3	40.4	40.8	31.2
Station	6912	30728	28425	18242	12192
Range	921	776	990	1395	1522
Max. Depth	56.8	68.9	55.8	57.1	58.4
Station	24978	41310	29155	16531	8630
Range	787	1122	898	1124	987

TABLE D3
STATISTICAL QUANTITIES FOR MAY 1989

Quantity	REACH 1	2	3	4	5
Sample Size	4391	3120	1991	3915	4220
Average (ft)	52.5	51.4	49.7	50.8	51.1
St. Dev. (ft)	1.45	1.29	1.27	1.57	2.17
Skewness	0.720	0.680	-1.019	-0.103	-1.778
Kurtosis	-0.246	2.331	2.286	1.083	12.081
Skewness .025 confidence interval	0.00739	0.00877	0.110	0.00783	0.00754
Kurtosis .025 confidence interval	0.148	0.175	0.220	0.156	0.151
Min. Depth	49.2	45.9	42.5	41.4	33.0
Station	1680	38011	24633	18228	12226
Range	921	754	754	1392	1528
Max. Depth	56.8	59.1	54.6	56.9	57.4
Station	24882	41327	28856	17631	8330
Range	1162	904	967	1294	1109

TABLE D4
STATISTICAL QUANTITIES FOR JUNE 1989

Quantity	REACH 1	2	3	4	5
Sample Size	3336	2813	1850	3228	3061
Average (ft)	52.1	52.0	51.2	52.4	52.4
St. Dev. (ft)	1.50	1.38	1.59	1.95	2.90
Skewness	0.506	1.095	0.150	-1.487	-0.959
Kurtosis	-0.520	4.418	1.911	20.087	5.696
Skewness .025 confidence interval	0.00848	0.00924	0.114	0.00862	0.00885
Kurtosis .025 confidence interval	0.170	0.185	0.228	0.172	0.177
Min. Depth Station Range	48.6 7473 923	48.0 31021 752	42.8 23441 1246	25.6 19237 1197	33.7 12249 1547
Max. Depth Station Range	56.2 24924 940	64.8 41357 1107	58.4 23154 904	58.2 16636 1197	61.9 8620 978

TABLE D5
STATISTICAL QUANTITIES FOR SEPTEMBER 1989

Quantity	REACH 1	2	3	4	5
Sample Size	3392	4526	2690	4900	1986
Average (ft)	51.7	52.1	50.9	51.8	50.7
St. Dev. (ft)	1.44	1.56	1.71	1.45	2.68
Skewness	0.515	0.766	0.148	-0.247	-2.795
Kurtosis	-0.145	3.040	0.613	2.956	11.735
Skewness .025 confidence interval	0.00841	0.00728	0.00944	0.00700	0.110
Kurtosis .025 confidence interval	0.168	0.145	0.189	0.140	0.220
Min. Depth	47.1	45.1	43.2	41.2	32.1
Station	10833	30964	26446	18430	12250
Range	754	760	756	1384	1531
Max. Depth	56.6	65.3	58.4	58.8	56.9
Station	23823	41450	23833	16622	12681
Range	922	1116	1047	1297	1311

TABLE D6
STATISTICAL QUANTITIES FOR OCTOBER 1989

	REACH				
Quantity	1	2	3	4	5
Sample Size	2782	3173	2345	3570	1714
Average (ft)	51.6	50.1	48.4	50.5	50.4
St. Dev. (ft)	1.62	1.31	1.85	1.79	2.76
Skewness	0.415	0.315	-0.00702	0.247	-1.435
Kurtosis	-0.267	1.134	-0.00599	0.631	5.015
Skewness .025 confidence interval	0.00929	0.00870	0.101	0.00820	0.118
Kurtosis .025 confidence interval	0.186	0.174	0.202	0.164	0.237
Min. Depth	46.8	46.0	37.6	42.5	34.6
Station	8718	32444	23449	18231	12226
Range	935	1206	1245	1398	1524
Max. Depth	57.2	58.6	54.6	58.3	57.2
Station	23810	48831	24454	16650	13060
Range	1126	1099	1037	1319	1024

APPENDIX E
HISTOGRAMS OF DEPTH FOR EACH SURVEY

TABLE E1
HISTOGRAM OF DEPTHS FOR JANUARY 1989

DEPTH (ft)	REACH 1	REACH 2	REACH 3	REACH 4	REACH 5
36	0	0	0	0	8
37	0	0	0	0	1
38	0	0	0	0	1
39	0	0	0	1	1
40	0	0	0	0	1
41	0	0	2	0	1
42	0	0	1	1	3
43	0	0	4	0	6
44	0	0	0	2	4
45	0	4	7	3	0
46	0	23	15	10	8
47	0	4	118	36	8
48	13	32	126	166	28
49	294	109	119	375	181
50	921	576	476	1057	549
51	1140	1176	1029	1125	880
52	695	857	558	590	856
53	422	414	101	221	514
54	369	118	13	96	227
55	127	35	4	52	104
56	7	12	1	17	69
57	0	1	0	2	40
58	0	1	0	0	14
59	0	0	1	0	1

TABLE E2
HISTOGRAM OF DEPTHS FOR MARCH 1989

DEPTH (ft)	REACH 1	REACH 2	REACH 3	REACH 4	REACH 5
31	0	0	0	0	1
32	0	0	0	0	1
33	0	0	0	0	4
34	0	0	0	0	0
35	0	0	0	0	0
36	0	0	0	0	2
37	0	0	0	0	0
38	0	0	0	0	0
39	0	0	0	0	0
40	0	0	1	0	3
41	0	0	2	1	3
42	0	0	3	0	5
43	0	0	2	1	2
44	0	0	4	0	8
45	0	0	5	3	6
46	0	1	40	8	7
47	0	1	109	26	10
48	6	4	102	107	34
49	148	100	85	190	136
50	593	357	435	667	410
51	945	822	737	1045	675
52	657	783	393	803	630
53	346	358	100	443	365
54	306	206	16	164	167
55	187	82	0	70	67
56	31	33	1	23	57
57	1	9	0	3	27
58	0	0	0	0	3
59	0	2	0	0	0
60	0	2	0	0	0
61	0	1	0	0	0
62	0	1	0	0	0
63	0	1	0	0	0
64	0	0	0	0	0
65	0	0	0	0	0
66	0	0	0	0	0
67	0	1	0	0	0
68	0	0	0	0	0
69	0	1	0	0	0

TABLE E3
HISTOGRAM OF DEPTHS FOR MAY 1989

DEPTH (ft)	REACH 1	REACH 2	REACH 3	REACH 4	REACH 5
33	0	0	0	0	3
34	0	0	0	0	3
35	0	0	0	0	1
36	0	0	0	0	1
37	0	0	0	0	1
38	0	0	0	0	2
39	0	0	0	0	5
40	0	0	0	0	9
41	0	0	0	1	18
42	0	0	1	0	5
43	0	0	1	2	4
44	0	0	5	1	8
45	0	0	6	6	5
46	0	5	20	9	3
47	0	1	90	46	19
48	0	13	183	193	100
49	3	117	363	443	423
50	152	486	769	857	863
51	1081	1169	475	1092	1185
52	1397	791	69	736	751
53	798	337	7	342	372
54	368	113	1	136	222
55	400	68	1	37	120
56	191	13	0	11	83
57	1	3	0	3	14
58	0	1	0	0	0
59	0	3	0	0	0

TABLE E4
HISTOGRAM OF DEPTHS FOR JUNE 1989

DEPTH (ft)	REACH 1	REACH 2	REACH 3	REACH 4	REACH 5
26	0	0	0	2	0
27	0	0	0	0	0
28	0	0	0	0	0
29	0	0	0	0	0
30	0	0	0	0	0
31	0	0	0	0	0
32	0	0	0	0	0
33	0	0	0	0	0
34	0	0	0	0	2
35	0	0	0	0	5
36	0	0	0	0	0
37	0	0	0	0	1
38	0	0	0	0	0
39	0	0	0	0	5
40	0	0	0	0	5
41	0	0	0	0	9
42	0	0	0	0	11
43	0	0	1	0	15
44	0	0	2	0	8
45	0	0	0	3	3
46	0	0	7	3	8
47	0	0	22	7	3
48	0	3	30	13	17
49	41	55	136	124	102
50	415	250	424	373	403
51	911	758	520	559	559
52	851	959	386	599	537
53	478	454	186	611	362
54	307	192	94	512	347
55	313	83	27	264	282
56	20	46	8	128	164
57	0	7	2	25	104
58	0	3	5	5	49
59	0	0	0	0	30
60	0	2	0	0	21
61	0	0	0	0	6
62	0	0	0	0	3
63	0	0	0	0	0
64	0	0	0	0	0
65	0	1	0	0	0

TABLE E5
HISTOGRAM OF DEPTHS FOR SEPTEMBER 1989

DEPTH (ft)	REACH 1	REACH 2	REACH 3	REACH 4	REACH 5
32	0	0	0	0	3
33	0	0	0	0	1
34	0	0	0	0	0
35	0	0	0	0	3
36	0	0	0	0	1
37	0	0	0	0	1
38	0	0	0	0	1
39	0	0	0	0	8
40	0	0	0	0	10
41	0	0	0	2	17
42	0	0	0	0	9
43	0	0	1	1	15
44	0	0	1	1	10
45	0	1	3	3	11
46	0	1	15	11	13
47	1	0	43	17	9
48	7	21	111	43	26
49	114	115	360	155	103
50	629	511	591	505	333
51	946	1085	649	1294	555
52	814	1203	465	1496	404
53	452	845	281	873	276
54	273	443	104	334	143
55	137	196	48	109	28
56	18	77	12	41	3
57	1	17	5	14	3
58	0	3	1	0	0
59	0	0	0	1	0
60	0	4	0	0	0
61	0	0	0	0	0
62	0	1	0	0	0
63	0	1	0	0	0
64	0	1	0	0	0
65	0	1	0	0	0

TABLE E6
HISTOGRAM OF DEPTHS FOR OCTOBER 1989

DEPTH (ft)	REACH 1	REACH 2	REACH 3	REACH 4	REACH 5
36	0	0	0	0	1
37	0	0	0	0	1
38	0	0	1	0	3
39	0	0	0	0	5
40	0	0	0	0	7
41	0	0	0	0	10
42	0	0	1	0	11
43	0	0	0	4	6
44	0	0	6	3	7
45	0	0	118	7	9
46	0	9	302	25	8
47	3	68	300	69	52
48	31	211	418	276	181
49	189	769	439	759	303
50	541	981	473	753	226
51	739	717	188	675	236
52	534	300	71	533	274
53	342	87	19	279	212
54	259	25	8	112	102
55	120	2	1	52	39
56	21	3	0	18	12
57	3	0	0	4	5
58	0	0	0	1	0
59	0	1	0	0	0

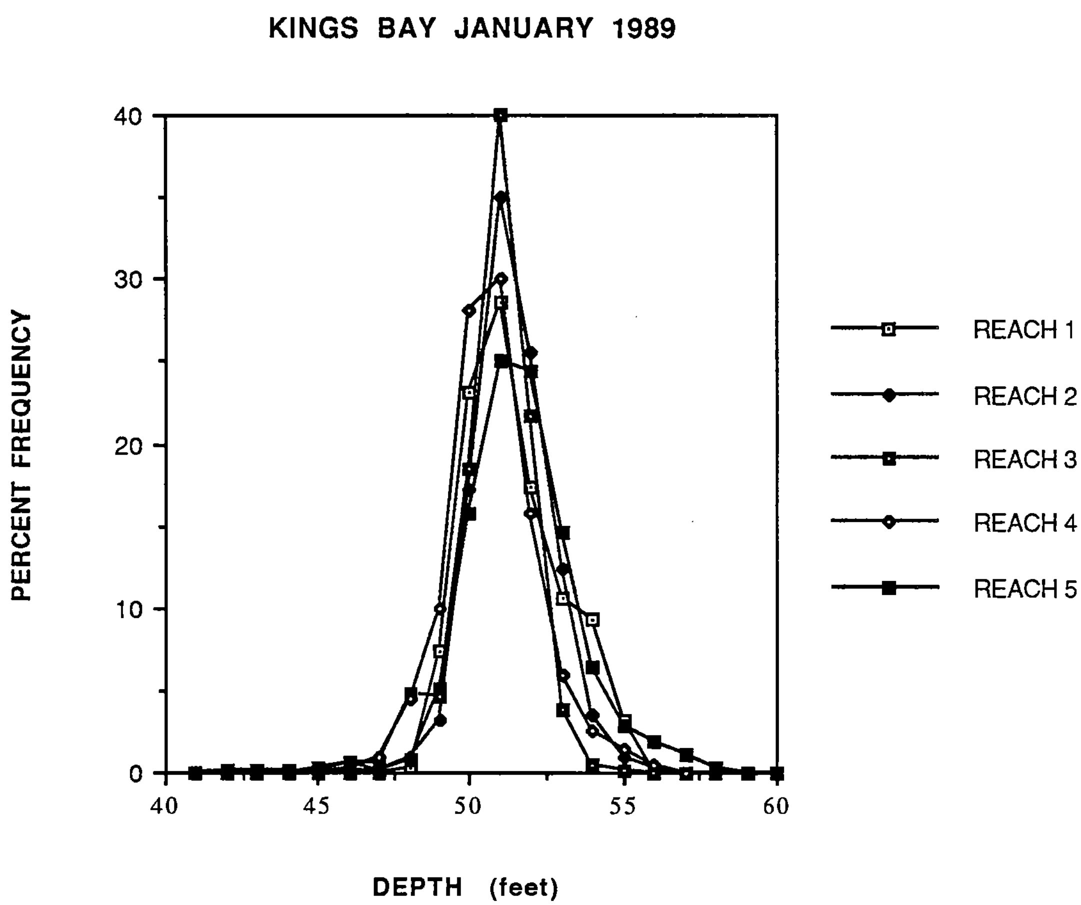

Figure E1. Depth Histograms for January, 1989

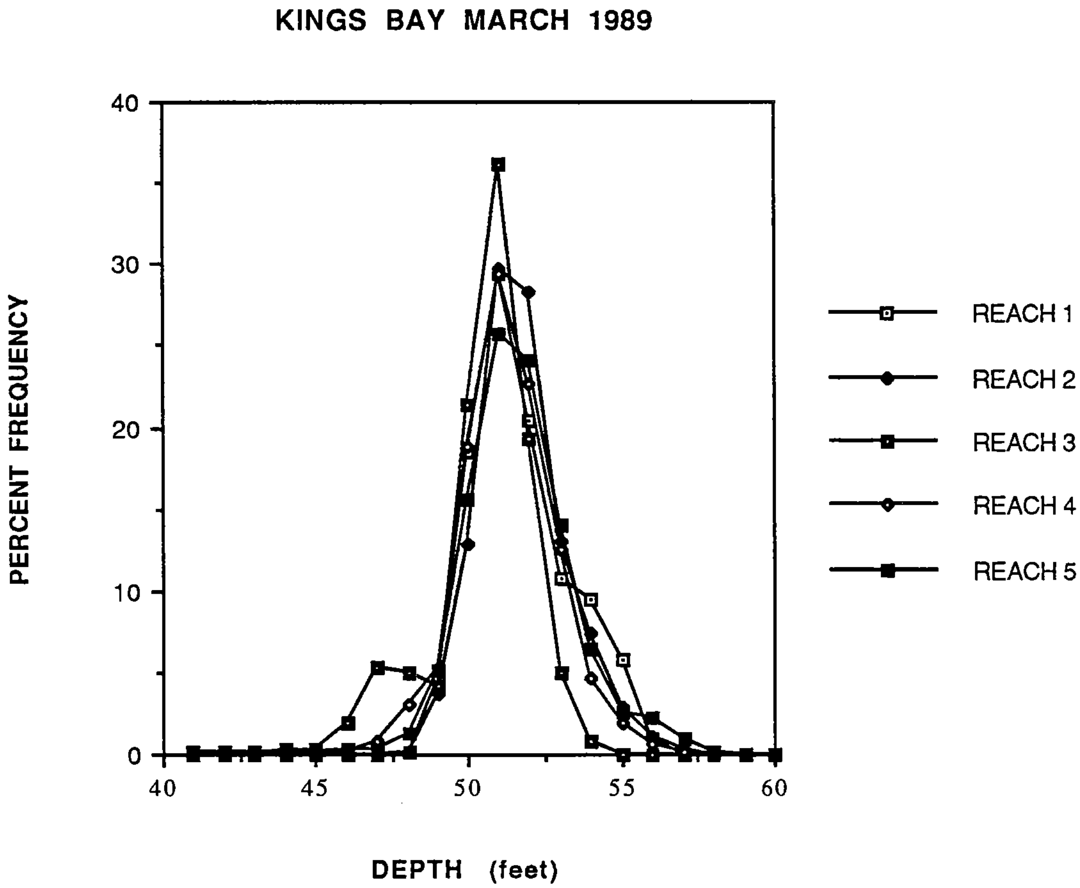

Figure E2. Depth Histograms for March, 1989

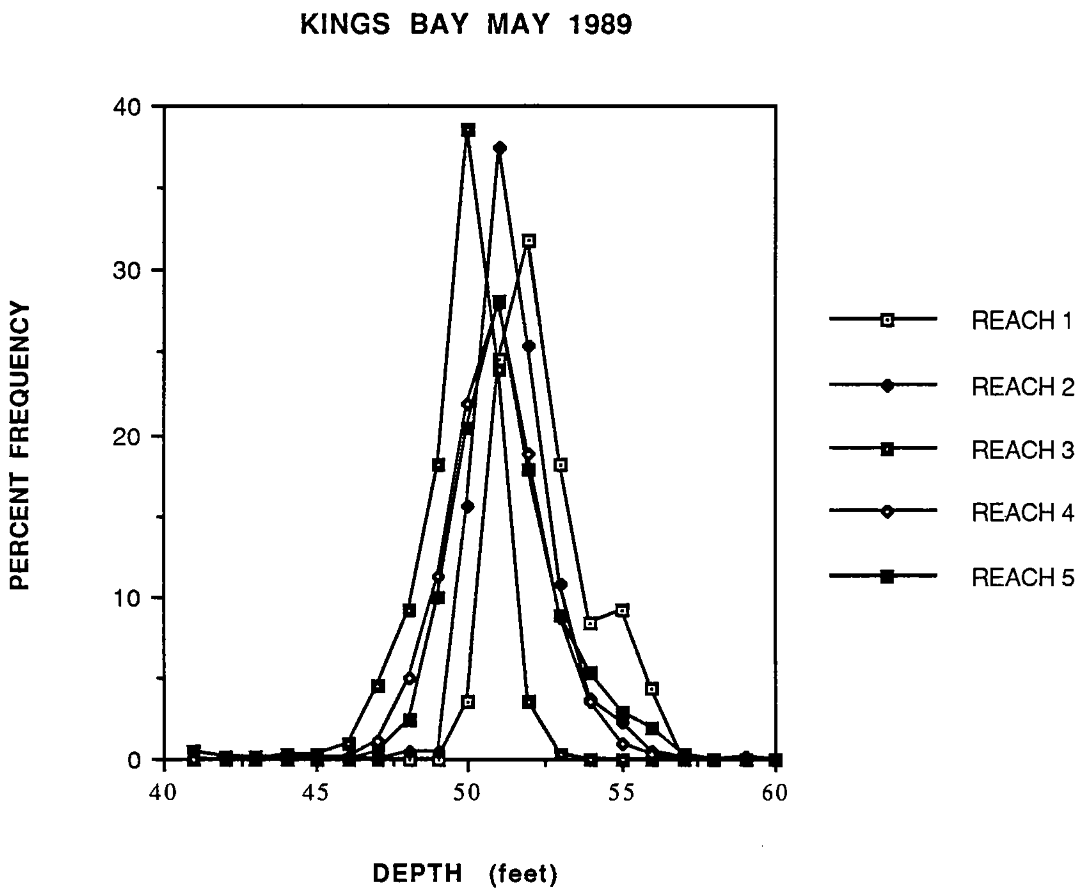

Figure E3. Depth Histograms for May, 1989

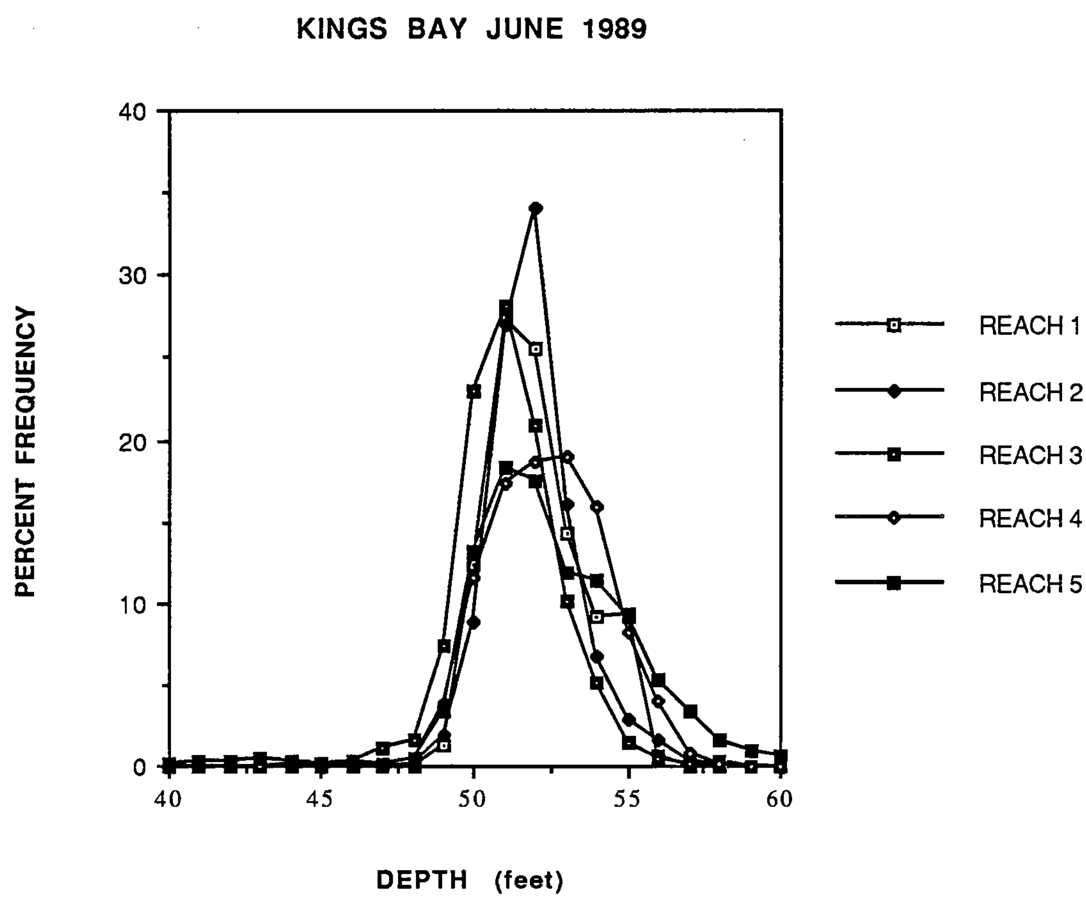

Figure E4. Depth Histograms for June, 1989

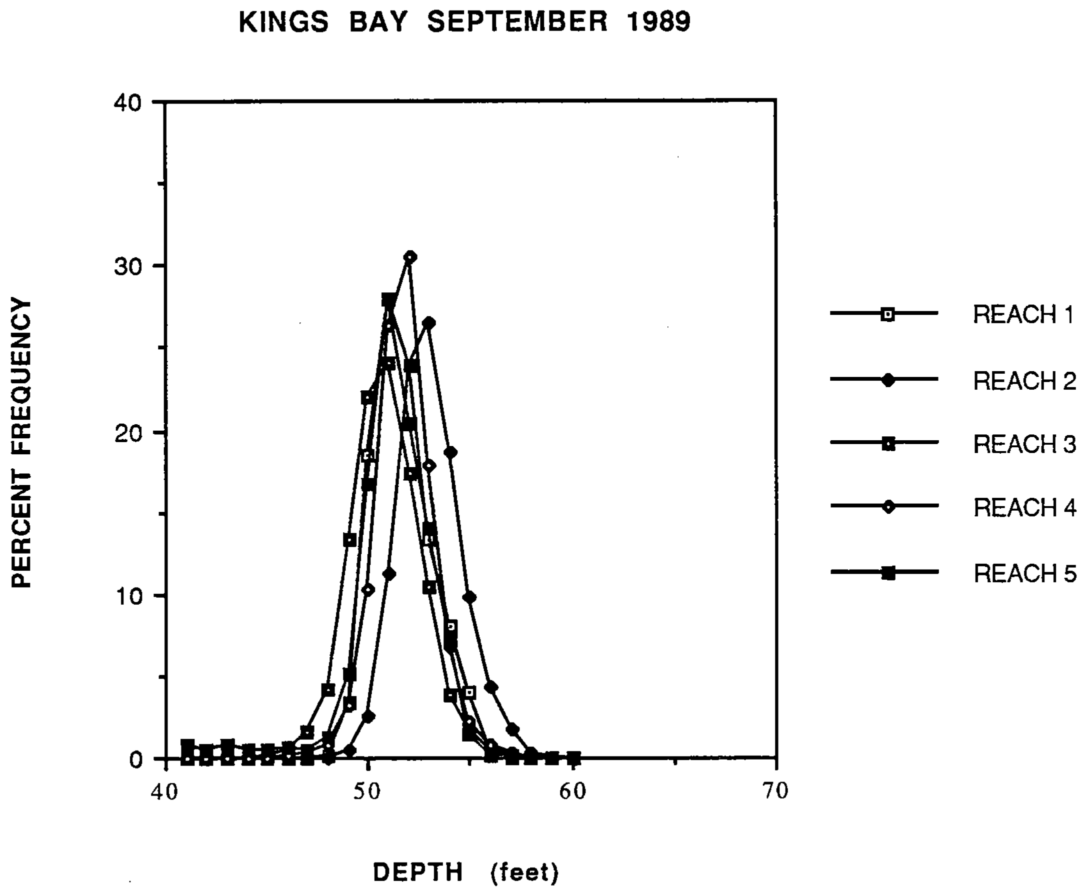

Figure E5. Depth Histograms for September, 1989

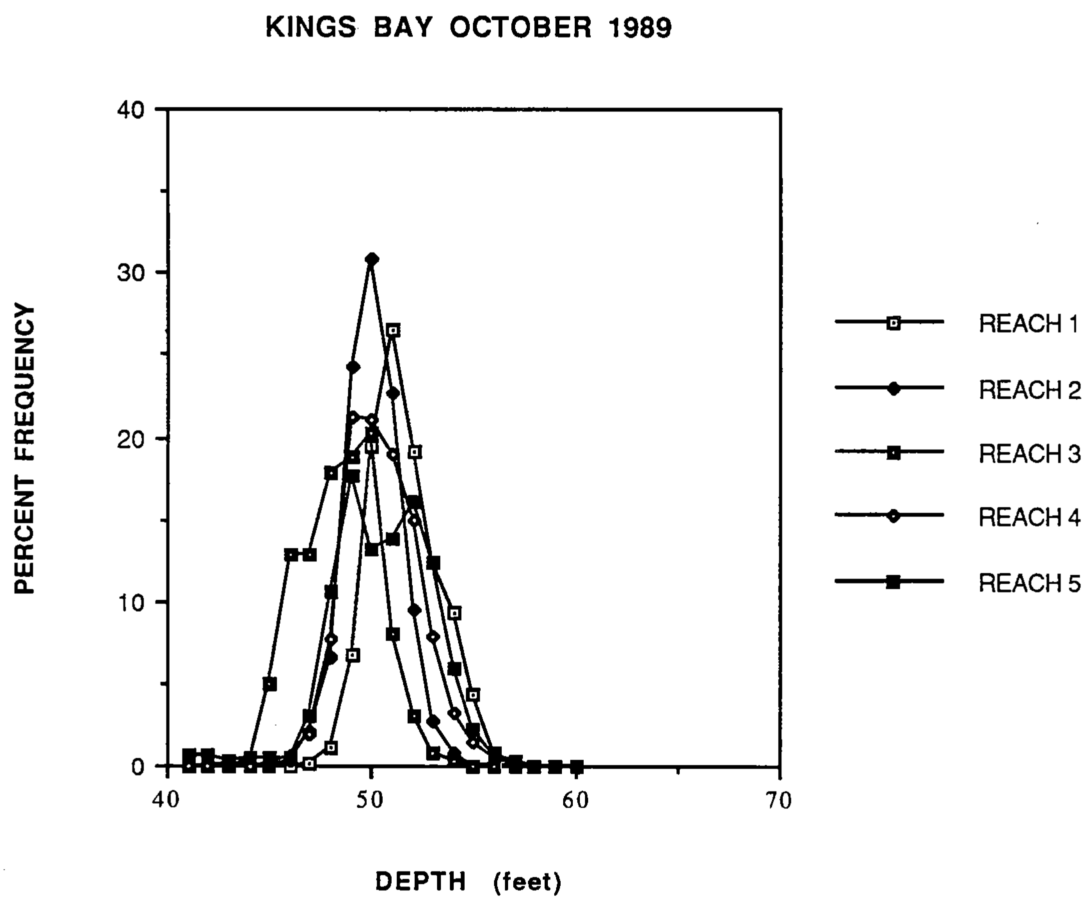

Figure E6. Depth Histograms for October, 1989

APPENDIX F
99 PERCENT CONTROLLING DEPTHS
REACH-BY-REACH

TABLE F1
99 PERCENT CONTROL DEPTHS FOR SEPTEMBER, 1989

REACH 1

99TH PERCENTILE DEPTH 48.3 feet

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
48.2	8901	1131
48.2	6201	1126
48.3	3458	937
48.1	5940	932
47.9	6062	926
48.3	6075	924
47.1	6138	921
48.1	6256	909
47.8	6583	911
47.7	6594	912
47.1	7071	914
48.0	8376	935
46.8	8719	936
48.3	8981	940
48.1	9897	933
48.0	14411	923
48.2	14884	926
48.1	15160	930
47.6	15656	927

REACH 2

99TH PERCENTILE DEPTH 46.8 feet

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
46.8	32701	1192
46.8	32687	1194
46.8	32679	1196
46.8	32658	1198
46.5	32626	1198
46.4	32612	1199
46.5	32599	1200
46.7	32548	1204
46.3	32536	1204
46.4	32524	1204
46.8	32511	1205
46.8	32482	1208

DEPTH	STATION	RANGE
46.4	32461	1207
46.0	32444	1207
46.7	32422	1210
46.8	32408	1211
46.6	32395	1214
46.6	32381	1213
46.4	32358	1217
46.2	32344	1216
46.5	32329	1218
46.7	32305	1217
46.6	32257	1217
46.6	32229	1218
46.7	32224	1218
46.7	30567	1102
46.5	30555	1101
46.8	30544	1103
46.7	30501	1108

REACH 3

99TH PERCENTILE DEPTH 44.6 feet

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
44.3	28340	1246
44.4	28336	1233
44.6	28418	1225
44.1	28417	1244
41.8	23858	753
44.0	23652	1248
37.6	23449	1246
43.6	28237	1223
44.4	28237	1113

REACH 4

99TH PERCENTILE DEPTH 46.4 feet

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
45.2	17412	1527
45.1	17409	1538
45.9	18238	1363
42.5	18232	1399
43.3	18424	1394
44.1	18423	1383
44.6	18627	1390
45.0	19055	1384
44.8	19053	1397
45.5	20634	1397
44.1	21064	1392
45.4	21239	1386

DEPTH	STATION	RANGE
46.3	21250	610
46.2	21447	610
45.4	21429	1376
46.3	21854	601
45.6	21837	1371
45.7	21838	1379
42.6	21835	1398
46.3	22016	1399
43.0	22476	602
44.3	22854	751
46.2	18381	1305
45.9	18394	1300
46.3	18408	1302
46.1	18425	1307
46.3	18438	1307
46.3	18456	1305
46.1	18472	1306
46.1	18509	1309
46.2	18538	1305

REACH 5

99TH PERCENTILE DEPTH 39.9 feet

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
38.8	12029	1366
38.6	12237	1438
38.8	12235	1447
36.3	12232	1458
35.0	12230	1487
35.3	12227	1497
34.8	12227	1516
34.6	12226	1524
39.9	12427	1414
39.5	12429	1393
38.0	11998	1337
37.5	12014	1334
38.3	12033	1334
38.1	12050	1336
38.7	12062	1335
39.1	12078	1334
39.9	12417	1307

TABLE F2

99 PERCENT CONTROL DEPTH FOR OCTOBER, 1989

REACH 1

99TH PERCENTILE DEPTH 48.3 feet

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
48.2	8901	1130
48.2	6201	1126
48.3	3458	937
48.1	5939	931
47.9	6061	926
48.3	6075	923
47.1	6138	921
48.1	6256	909
47.8	6583	911
47.7	6594	911
47.1	7071	914
47.9	8376	935
46.8	8718	936
48.3	8980	940
48.1	9896	933
48.0	14411	923
48.2	14884	925
48.1	15160	930
47.6	15656	926

REACH 2

99TH PERCENTILE DEPTH 46.8 feet

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
46.8	32701	1192
46.8	32687	1194
46.8	32678	1196
46.8	32626	1198
46.4	32612	1199
46.5	32599	1200
46.7	32548	1204
46.3	32535	1204
46.4	32524	1204
46.8	32511	1205
46.8	32481	1208
46.4	32461	1207
46.0	32444	1207
46.4	32434	1209
46.7	32422	1210
46.8	32408	1211

DEPTH	STATION	RANGE
46.6	32395	1213
46.6	32381	1213
46.2	32344	1215
46.5	32329	1218
46.7	32305	1217
46.6	32257	1217
46.5	32240	1217
46.6	32229	1218
46.7	32224	1218
46.7	30567	1101
46.5	30555	1101
46.8	30544	1101
46.7	30501	1108

REACH 3

99TH PERCENTILE DEPTH 44.6 feet

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
44.3	28340	1246
44.4	28336	1233
44.6	28418	1225
44.1	28417	1244
41.8	23858	754
44.0	23652	1248
43.6	28237	1223
44.4	28237	1113

REACH 4

99TH PERCENTILE DEPTH 46.4 feet

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
45.3	17412	1527
45.2	17409	1538
45.9	18238	1363
42.5	18231	1399
43.3	18424	1394
44.1	18423	1383
44.6	18627	1390
45.0	19055	1384
44.8	19053	1397
45.6	20634	1397
44.1	21064	1392
45.4	21239	1386
46.3	21250	610
46.2	21447	610
45.4	21429	1376
46.3	21854	601
45.6	21837	1371
45.7	21838	1379

DEPTH	STATION	RANGE
42.6	21836	1398
46.3	22016	1399
43.0	22476	602
44.3	22854	751
45.9	18394	1301
46.3	18408	1302
46.1	18425	1307
46.3	18438	1307
46.3	18456	1305
46.1	18472	1306
46.1	18509	1309
46.2	18538	1305

REACH 5

99TH PERCENTILE DEPTH 39.9 feet

DEPTHS SHALLOWER THAN THIS DEPTH:

DEPTH	STATION	RANGE
38.8	12029	1366
38.6	12237	1439
38.8	12235	1447
36.3	12232	1459
35.0	12230	1487
35.3	12227	1497
34.8	12227	1516
34.6	12226	1524
39.9	12427	1414
39.5	12429	1393
38.0	11998	1337
38.3	12033	1334
38.1	12050	1336
38.7	12062	1335
39.1	12078	1334
39.9	12416	1307

APPENDIX G

RANGE VERSUS DEPTH (feet) FOR

SELECTED CHANNEL LOCATIONS

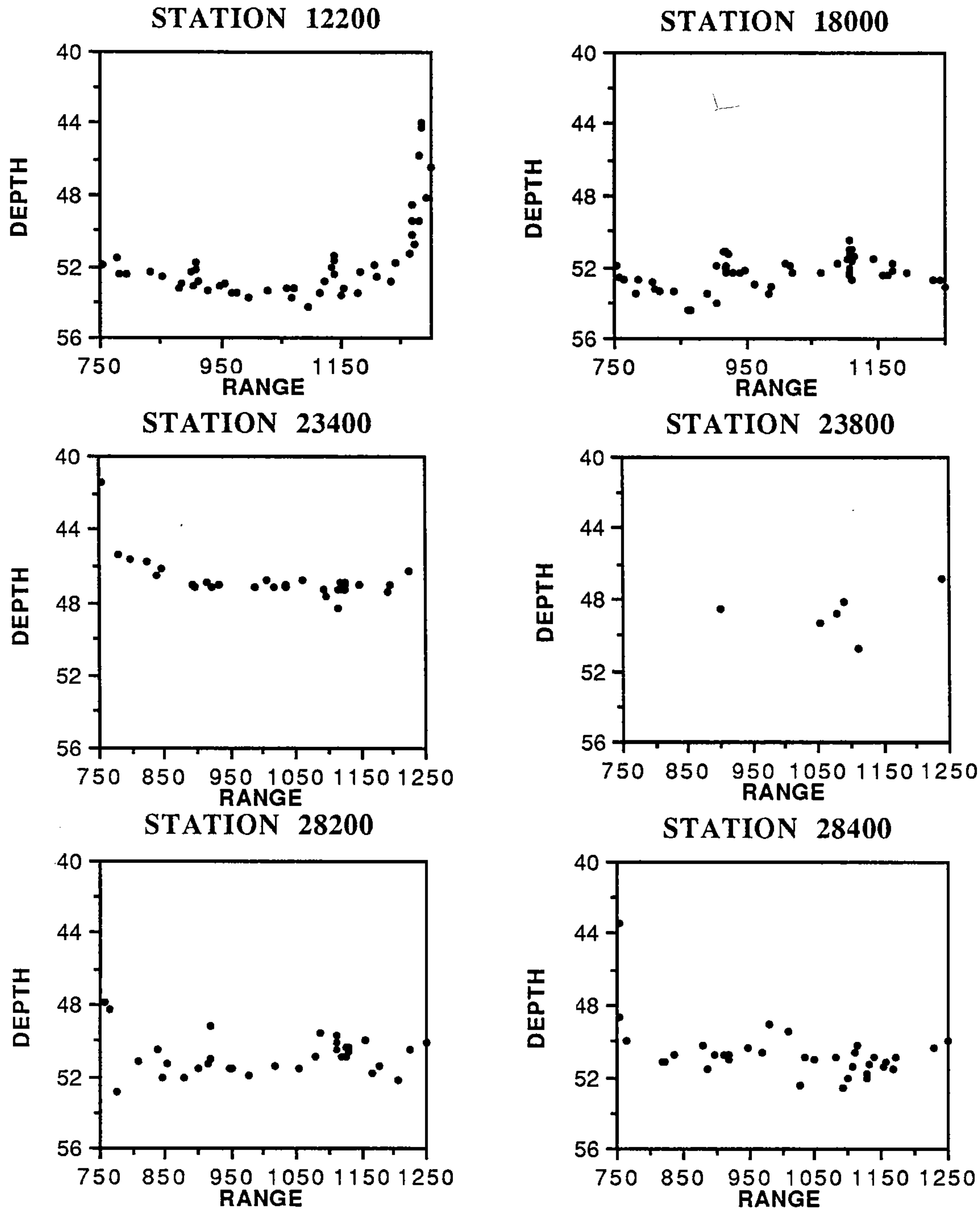

Figure G1. Range versus Depth (feet) for January, 1989

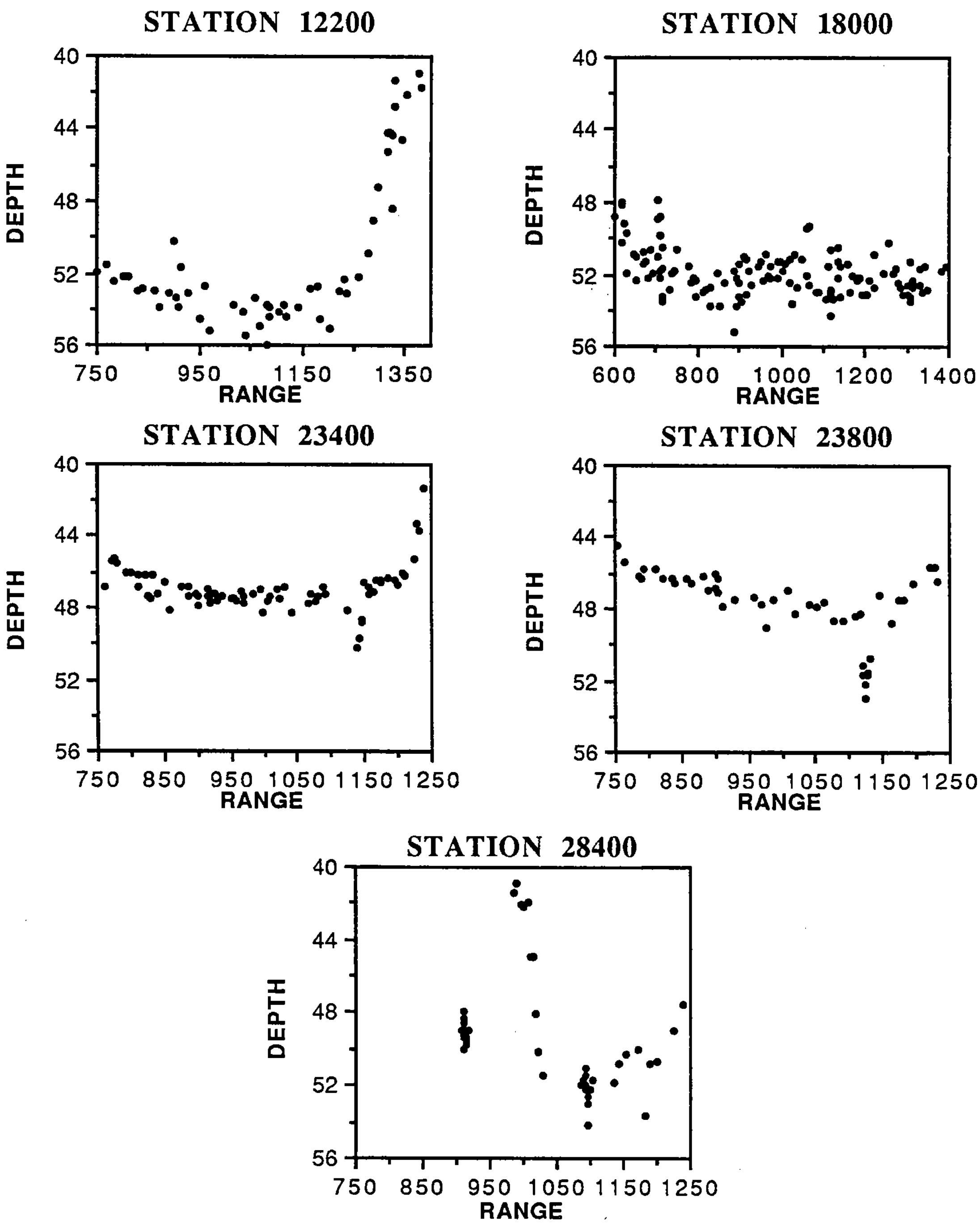

Figure G2. Range versus Depth (feet) for March, 1989

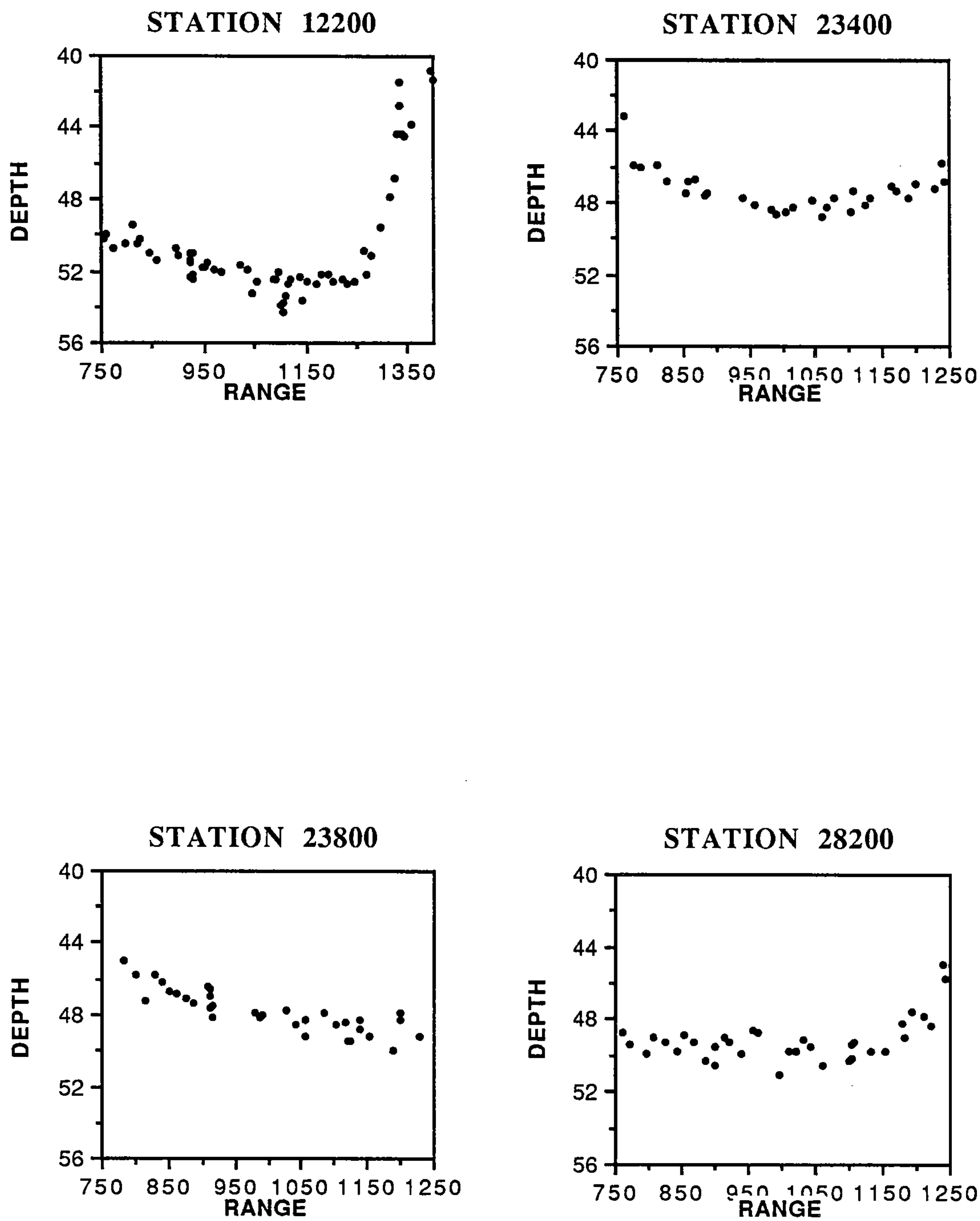

Figure G3. Range versus Depth (feet) for May, 1989

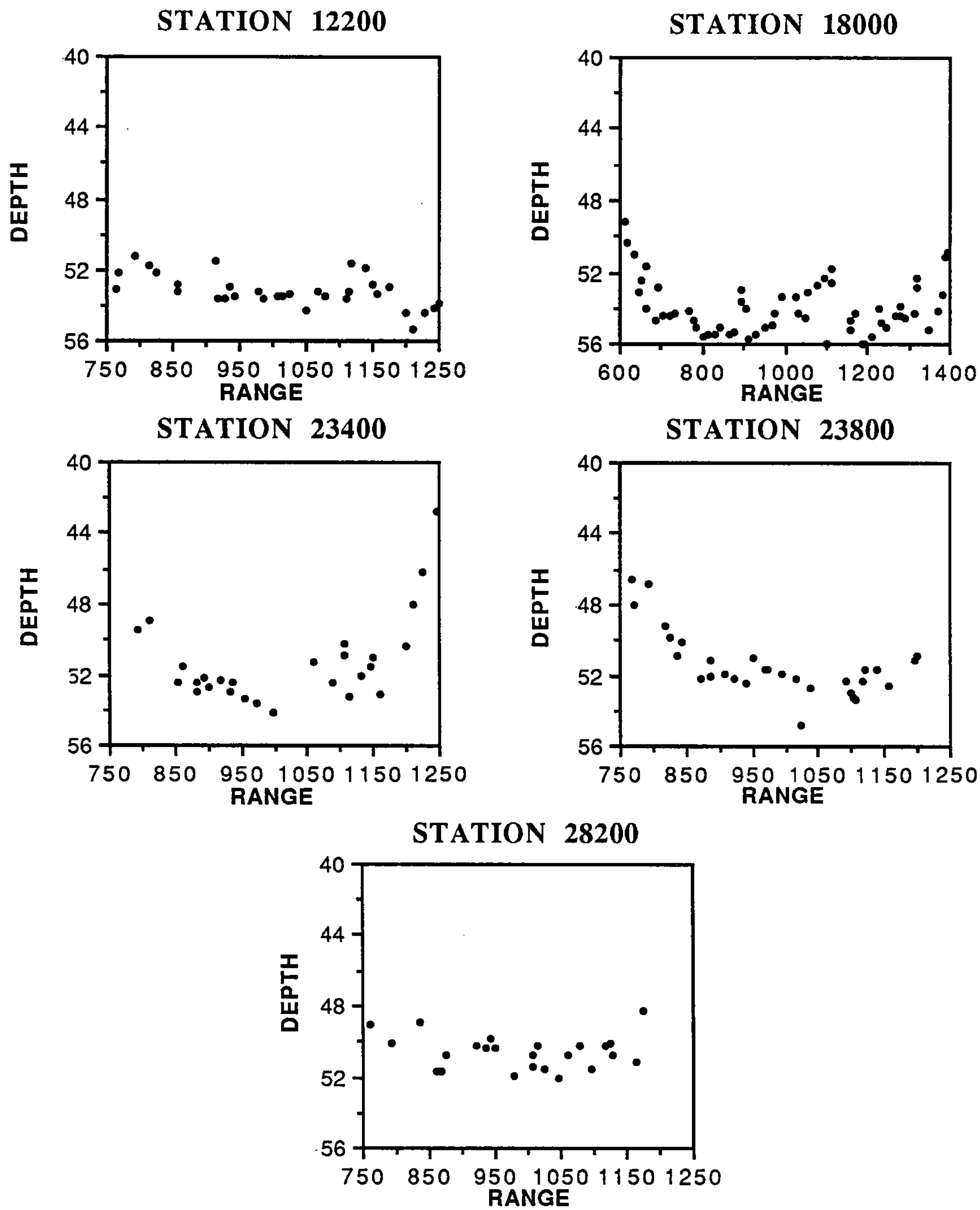

Figure G4. Range versus Depth (feet) for June, 1989

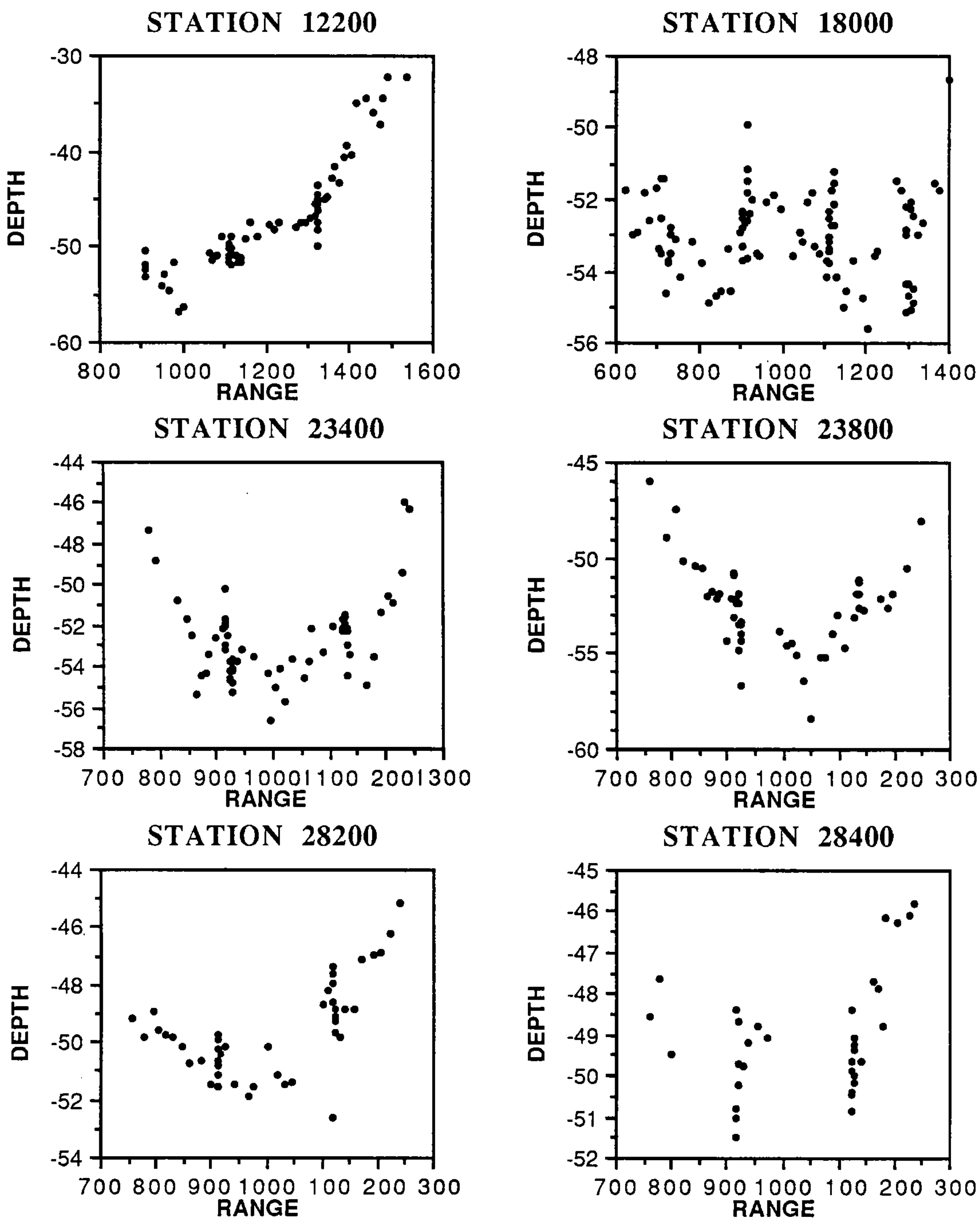

Figure G5. Range versus Depth (feet) for September, 1989

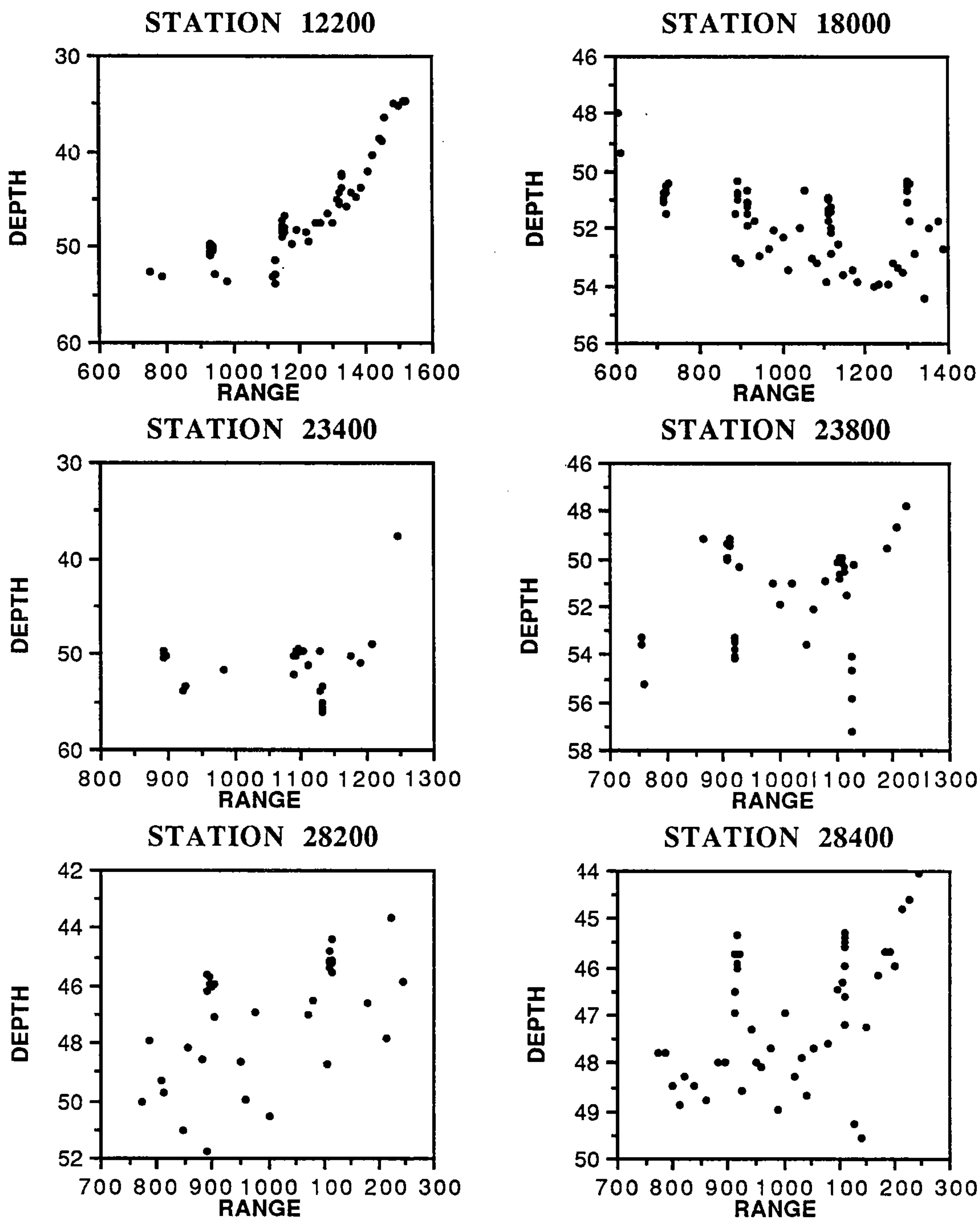

Figure G6. Range versus Depth (feet) for October, 1989

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16. Abstract (Limit: 200 words)

Repeated side-scan sonar and multi-frequency bathymetric surveys, accompanied by accurate, high resolution, and repeatable navigation, were conducted in the vicinity of a tidal inlet to define the length and time scales associated with bedforms and channel shoaling in a structured tidal inlet. The study site, St. Mary's entrance channel along the Georgia/Florida border (Fig. 1), has a dredged channel approximately 46-52 feet in depth, bordered by a large ebb tidal delta. The tidal inlet serves Cumberland Sound, Kings Bay, and associated waterways, providing a large discharge of water from the inlet that creates bedforms and channel shoaling, given the abundance of sand-sized sediment in the vicinity. The jettied inlet produces flows that are predominately tidally-driven, whereas farther offshore the driving forces consist predominantly of waves and storm-generated flows. In the channel reaches (Table 1) between these two areas, combined wave-steady flows are present, creating a myriad of scales of bedforms and shoaling patterns. This study was designed to elucidate the time and space scales of these variable bedforms and shoaling patterns, emphasizing the difference in these scales between the three different flow regimes. The results provide an important data base for quantifying shoaling processes and mechanisms in tidal inlet channels.

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5. controlling depth

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