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Marsh, Mudflat and Tidal Creek Assessment Cumberland Island National Seashore

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CUMBERLAND ISLAND NATIONAL SEASHORE

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MARSH, MUDFLAT AND TIDAL CREEK ASSESSMENT

CUMBERLAND ISLAND NATIONAL SEASHORE

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PREFACE

Cumberland Island National Seashore was established in 1972 to preserve the scenic, scientific and historical values of the largest and most southerly island off the coast of Georgia. It is well-known for its marine turtles, abundant shorebirds, dune fields, maritime forests, fishing, marshes and tidal creeks and flats, and historic structures. The St. Marys Inlet, at the border between Florida and Georgia, is a Federally maintained entrance channel to the Intracoastal Waterway, ports at Fernandina, Florida, and St. Marys, Georgia, and the U.S. Naval Submarine Base at Kings Bay, Georgia. Construction of coastal engineering works and channel dredging over the past 100 years have had noticeable effects on the St. Marys Entrance, Cumberland Island, Georgia and Amelia Island, Florida. In the early 1960's, Kings Bay was selected as the Navy's home port for Poseidon-class submarines. In the mid-1970's, Kings Bay was selected to homeport the Navy's new class of Trident submarines. In upgrading the Kings Bay base from the smaller Poseidon submarines, it was necessary to deepen, widen, and lengthen the entrance channel to Kings Bay. The 5-year, Kings Bay Environmental Research Program was conceived in 1986 by the U.S. Departments of Interior and Navy. This Department of the Navy funded Program focuses on evaluating the potential effects on the natural resources of Cumberland Island and vicinity of the deepening of the Kings Bay Trident Submarine ship channel from 42 ft. (12.7 m) to 51 ft. (15.5 m). The channel is almost 22 miles (35.2 km) long and required the removal of approximately 35 million cubic yards (26.8 million cu m) of dredged material. The potential biophysical effects of dredging are being evaluated by the National Park Service through a series of biological and geological research projects. The Department of the Navy, through the U.S. Army Engineers, is monitoring the physical aspects of the ocean shoreline of Cumberland and Amelia Islands and the Cumberland Sound estuary. Technical direction and guidance during the study were provided by Dr. Albert Greene, Jr., National Park Service (NPS); Messrs. Thomas J. Peeling, Naval Facilities Engineering Command (NAVFAC); John Headland, NAVFAC; Darryll Molzan, NAVFAC; Dr. Robert Dean, University of Florida, Gainesville (NPS); Dr. Stephen Cofer-Shabica (NPS); and the late Dr. William Odum, University of Virginia, Charlottesville (NPS).

The ultimate goal of this research is to document the potential for short- and long-term changes on the resources of Cumberland Island and Cumberland Sound estuary related to channel dredging. The work described in this report is one of a series of National Park Service studies directed towards this goal.

Stephen Cofer-Shabica

TABLE OF CONTENTS

		Page Number
	Executive Summary	i
1.0	Introduction	1
2.0	Statement of Problem	3
	2.1 Physical Setting	3
	2.2 History	4
	2.3 Statistical Approach	6
3.0	Study Site Selection	8
	3.1 Site 1 - Beach Creek	9
	3.2 Site 2 - Grassy Knoll	9
	3.3 Site 3 - Old House	10
4.0	Methods	11
	4.1 Field Surveys	12
	4.2 Volumetric Change Data	13
	4.3 Sedimentation Pins	14
	4.4 Sedimentation Table	14
	4.5 Clay-Marker Horizons	16
	4.6 Stable Rare-Earth Element (REE) Tracer	17
	4.7 Cesium (^{137}Cs) Dating	18
	4.8 Laboratory Analyses	19
	4.9 Data Reduction and Interpretation	20
5.0	Results	21
	5.1 Field Surveys	21
	5.2 Sedimentation Pins	23
	5.3 Sedimentation Table	24
	5.4 Clay-Marker Layer and Stable Rare-Earth Element (REE) Tracer	25
	5.5 Cesium (^{137}Cs) Dating	27
6.0	Discussion of First-Year Results	29
	6.1 Natural Spatial Variability in Marsh Surface Elevation	29

6.2 Temporal Variability in Marsh Surface Elevation 30
6.3 Agreement Among Methods 30
6.4 Initial Ranking of Methods 33
7.0 Conclusions 35
8.0 References 37

LIST OF TABLES

Table Number

1 Summary Volumetric Changes for Each Profile Line
2 Summary Slope Changes per Profile Line
3 Bulk Density Profiles in Five Cores
4 Percent by Weight of Mineral and Organic Matter Profiles in Five Cores
5 Range of Marsh Surface Elevations Acquired by Various Techniques
6 Estimates of Marsh Accretion and Erosion Acquired by Various Techniques
7 Qualitative Method Evaluation

LIST OF FIGURES

Figure Number	
1	Location of Cumberland Island National Seashore, Georgia
2	Location of Site 1
3	Location of Sites 2 and 3
4	Plan View of Marsh/Mudflat Measurement Locations
5	Mudflat Walkway at Site 1
6	Electronic Distance Measuring (EDM) Unit Used to Tie-in Subdatums to Benchmarks
7	Siting with EDM to Prism Cluster
8	Sedimentation Pin Array and Clay/Feldspar Marker in Mudflat
9	Clay/Feldspar Marker in Marsh
10	Setting of Sedimentation Table in Mounting Post
11	Sedimentation Table Measurements of Marsh Surface
12	Sedimentation Table Measurements of Mudflat Surface
13	Spraying of Rare-Earth Element Marker
14	Site 1: Marsh (Sound) Profiles
15	Site 1: Mudflat (Creek) Profiles
16	Site 2: Marsh (Sound) Profiles
17	Site 2: Mudflat (Creek) Profiles
18	Site 3: Marsh (Sound) Profiles
19	Site 3: Mudflat (Creek) Profiles
20	Cumulative Sedimentation Pin Changes - Site 1 Marsh
21	Cumulative Sedimentation Pin Changes - Site 1 Mudflat
22	Cumulative Sedimentation Pin Changes - Site 2 Marsh
23	Cumulative Sedimentation Pin Changes - Site 3 Marsh
24	Cumulative Sedimentation Pin Changes - Site 3 Mudflat
25	Sedimentation Table Changes - Site 1 Marsh & Mudflat
26	Sedimentation Table Changes - Site 2 Marsh
27	Sedimentation Table Changes - Site 3 Marsh & Mudflat
28	Rare-Earth Element - Feldspar Marker Results
29	Bulk Density Determinations for Sites 1, 2, and 3
30	Cesium Profile - Site 1 Marsh
31	Cesium Profile - Site 1 Mudflat
32	Cesium Profile - Site 2 Marsh

LIST OF FIGURES (cont'd)

33 Cesium Profile - Site 3 Marsh
34 Cesium Profile - Site 3 Mudflat

LIST OF APPENDICES

Appendix

A Summary Elevation Data From Topographic Surveys
B Incremental Volumetric Changes

MARSH, MUDFLAT AND TIDAL CREEK ASSESSMENT
CUMBERLAND ISLAND NATIONAL SEASHORE, GEORGIA

EXECUTIVE SUMMARY

This project was designed to determine whether backbarrier dredging for the Kings Bay Naval Base is affecting marsh habitat sustainability on Cumberland Island. Research was predicated on the hypothesis that if this operation is indeed exerting an influence on Cumberland Island, it will most likely be first perceived in the effect it has on the rates of supply and delivery of sediments to the marshes and mudflats.

We accomplished three goals in the first year. First, we located three comparable sites, which experience a different levels of exposure to the effects of dredging. Second, we initiated a time-series of marsh/mudflat sedimentation measurements, which are expected to be continued in future years. Finally, we compared six different methods (field surveys, sedimentation pins, a sedimentation table, Cesium activity, Rare-Earth Element tracers, and clay-feldspar marker layers) for monitoring sedimentation, all of which are currently in practice. It is this last analysis of data that makes up the bulk of this report.

The field data contained in this report were collected during the first contract year and cover the 8-month period between December 1989 and August 1990, when the fourth field trip took place. Eight months of measurement do not constitute a sufficient monitoring period for resolution of annual or seasonal trends. That period is, however, long enough to provide initial assessments of (a) natural spatial variability in marsh/mudflat surface elevations, (b) the relative magnitude of vertical change to be expected, and (c) the amount of agreement between methods. It is anticipated that this monitoring effort and subsequent

process-related work will ultimately result in a predictive model characterizing local marsh sedimentation dynamics at Cumberland Island.

The three marsh sites appear in some ways to be grade from south to north, exhibiting an apparent increase in elevation and microtopographical roughness and a drop in the mineral or sand content. Net accretion and erosion estimates do not show any regional gradient, but are uniformly low, averaging between 0 and 15 mm for the eight-month monitoring record. It is not yet possible to draw any conclusions about the effects of dredging on sedimentation in the backbarrier marshes or mudflats.

An initial evaluation has been made of the strengths and weaknesses of the various sedimentation monitoring methods that were employed. The two marker-layer methods were found to be seriously deficient in that they do not have the capability to record erosion. The standard survey approach is too imprecise for measuring minute vertical change, but it does provide an accurate indicator of lateral changes in marsh width. The sedimentation pins provided useful results, although they are subject to disturbance from flotsam/jetsam and accidental contact. The sedimentation table was found to have the most advantages. This method, which has not yet been published in its current form, is described in detail.

Monitoring will continue for the next year, and an additional line of inquiry will be developed concerning short-term variability in sedimentation dynamics measured over single tidal cycles. Flumes have now been constructed at the three marsh sites and measurements will commence in early 1991.

1.0 INTRODUCTION

Coastal wetland loss has become recognized as a significant habitat destruction and degradation process. The causes of land loss in wetlands are complex, however, and the linkages to natural processes and cultural factors are poorly understood in most cases. Efforts to establish causal relationships have led a number of researchers to develop techniques for assessing changes in marsh environments. These analyses have been limited mostly to measurements of planimetric change or land loss itself.

It is recognized, however, that changes in rates of sedimentation, nutrient supply, and inundation may cause physiological stress to marsh vegetation, the ultimate result of which is plant death, disintegration of the root mat, and finally land loss. Fewer efforts have been directed toward measuring the early changes. The rate of change in marsh surface elevation -- if it could be measured reliably -- might serve as a diagnostic predictor of these more subtle impacts. Such knowledge might make possible a very focused countermeasure program that could reduce or stop land loss.

This project was designed to determine whether backbarrier dredging for the King's Bay Naval Base is affecting marsh habitat sustainability on Cumberland Island (Figure 1). Research was predicated on the hypothesis that if this operation is indeed exerting an influence on Cumberland Island, it will most likely be first perceived in the effect it has on the rates of supply and delivery of sediments to the marshes and mudflats.

Jettying of the St. Marys River Entrance and more recent dredging of its approaches have affected patterns of erosion and accretion along both seaward and backbarrier shorelines of Cumberland

Island, the largest of Georgia's "Sea Isles" (Nash 1977, Oertel 1977, Parchure 1982, Griffin and Henry 1983). Jetty construction began in the early 1880s, with sediment removal and dredging operations beginning in the early 1890s. Recent improvements have resulted in a widened (to 165 m) and deepened (to -14.5 m Mean Sea Level - MSL) channel at the St. Marys River Entrance and the Intracoastal Waterway (ICWW). These new modifications to the St. Marys River Entrance resulted in a significant enlargement of the ICWW through Cumberland Sound and were planned to improve navigation to the U.S. Navy submarine base at King's Bay.

The National Park Service (NPS) and the Navy have been tasked by Congress to determine the potential posed by the existing and proposed channel works for short- and long-term impacts on the backbarrier habitat of Cumberland Island National Seashore and Cumberland Sound. The Navy's effort is being directed by the U.S. Army Corps of Engineers Coastal Engineering Research Center (CERC) and is focused on monitoring beach, shoreline, and water level changes. The project described in this report was designed to meet NPS requirements for a quantitative assessment of marsh and mudflat sedimentation responses and to complement the CERC and other Cumberland Sound-related investigations. We have now completed year one of this investigation.

We accomplished three goals in the first year. First, we located three comparable sites (Figure 1) that experience a range of levels of exposure to the effects of dredging. Second, we initiated a relatively easily maintained time series of marsh/mudflat sedimentation measurements that will be continued for the next four years. Finally, we compared six different methods for monitoring sedimentation, all of which are currently in practice. It is this last analysis that makes up the bulk of this report.

The field data contained in this report were collected during the first contract year and cover the 8-month period between December 1989 -- when the field sites were selected and monitoring was initiated -- and August 1990, when the fourth field trip took place. A fifth trip took place in November 1990 under the second-year contract, but these data, which would extend coverage to 11 months, have not yet been reduced.

Eight months of measurement do not constitute a sufficient monitoring period for resolution of annual or seasonal trends. That period is, however, long enough to provide initial assessments of (a) natural spatial variability in marsh/mudflat surface elevations, (b) the relative magnitude of vertical change to be expected, and (c) the amount of agreement between methods.

In this report, we describe the monitoring methods, the first eight months of data, and our current strategy for statistically isolating sources of natural and man-induced variability. "Man-induced variability" in this context includes that attributable to both the management of the backbarrier lagoon system (dredging) and on another level, to that inherently associated with the measurement process or technique.

We anticipate that this monitoring effort and subsequent process-related work will ultimately result in a predictive model that will characterize local marsh sedimentation dynamics at Cumberland Island.

2.0 STATEMENT OF PROBLEM

2.1 Physical Setting

Cumberland Island is the southern terminus and the largest of Georgia's "Sea Isles" barrier island system. It is backed by

Cumberland Sound, which receives the limited freshwater input of the Crooked River and St. Marys River basins. The Sound is connected to the Atlantic via St. Marys River Entrance, an artificially stabilized inlet at the southern end of Cumberland Island. Littoral drift on the ocean side at Cumberland Island is toward the south (St. Marys River Entrance), and this drift has created a wide sandy beach that fronts relict dunes and modern foredune deposits. The Sound is in a mesotidal setting (Davies 1964) characterized by semi-diurnal tides, with a mean tidal range of 1.9 m and a spring range of 2.6 m.

Georgia's coastal salt marshes are built on sands and muds reworked from Pleistocene coastal outcrops, including those that form the core of each barrier island (Howard and Frey 1985). These features are a rich source of sediments that have been largely retained within individual barrier/sound/shoal complexes (BSSC), rather than exported offshore or downcoast (DePratter and Howard 1977). The St. Marys and Satilla Rivers carry very little sediment to the coast, and localized zones of land-building and land loss occur throughout the Cumberland BSSC (Griffin 1982, Griffin and Henry 1983). The total areas of upland, marsh, and mudflat within this system have, at least until very recently, remained relatively constant through historical time, despite the eustatic rise in sea level (Letzsch and Frey 1980a). This condition, in which a stable land area appears to reflect a balance between sediment supply and demand within the BSSC system, has been described as one of "dynamic equilibrium" (Bruun 1978).

2.2 History

The combined U. S. Navy and National Park Service (NPS) investigation of Cumberland Island is designed to determine whether the existing and proposed channel works will disrupt the sediment supply equilibrium in a way that results in measurable, predictable, or preventable habitat change and land loss. Olsen (1977) reported that while the jetties at the St. Marys Entrance have successfully stabilized the inlet over the past century, they have also displaced the ebb tidal delta (shoal) so far offshore that sediments deposited there are lost to the littoral transport system. Channel training has also given rise to a larger channel cross-section (Granant 1990). The St. Marys River Entrance now serves as a more efficient conduit to the offshore for sediments introduced on the seaward side through the permeable rubble jetties and through the throat itself from Cumberland Island Sound.

If the jettied channel depletes the finite Pleistocene sediment source by shunting it offshore, as Olsen (1977) suggests, the Cumberland Island BSSC is then faced with a new "demand" for sediment, in addition to that posed by sea level rise. This demand will necessarily be met through a reworking of existing marsh or barrier deposits but will not be offset by compensatory land-building elsewhere within the system. The enlarged ICWW section to King's Bay, if it cannot be stabilized and continually accumulates sediments, will similarly constitute a new sink or "demand" for sediments that will affect the present equilibrium.

Redfield (1972) suggested that tidal marshes are able to maintain the elevation of their substrate during rapid sea level rise by capturing and retaining additional sediments for below-ground macrophyte production. Letzsch and Frey (1980b) developed this concept further in proposing that vertical accretion, the primary mechanism of marsh maintenance, is actually enhanced by coastal submergence.

Recent evidence from the eastern shore of Maryland (Stevenson et al. 1985, Stevenson et al. 1988) and from Louisiana (DeLaune et al. 1983, Mendelssohn and McKee 1987) suggests that rates of vertical accretion are actually more directly affected by the rate of sediment supply than by sea level change and that the two factors are not always linked. In these two locations, at least, sea level rise has occurred at the same time as a reduction in sediment supply. In both cases, marshes develop an "aggradation deficit" and are unable to maintain an optimum substrate elevation. Marsh vegetation has been observed under these conditions to undergo physiological stress and death (Mendelssohn and McKee 1987).

If the existing and proposed channel works in the Cumberland Island BSSC result in a significant reduction in sediment supply, all marshes and mudflats will experience a reduced potential for vertical accretion. Such areas would be most likely to develop aggradation deficits and eventually convert from land to water as the vegetation dies back.

The marsh and mudflat monitoring program we have established has a good potential to resolve the effects of the jetties and other channel works on backbarrier sediment transport, deposition, and erosion during a multi-year investigation. The most challenging problem is that of defensibly isolating these effects from the background of other spatial and temporal variables that also influence marsh/mudflat morphodynamics.

2.3 Statistical Approach

The six techniques employed in monitoring the Cumberland Island backbarrier sites are described in detail in the Section 4. They can be conceptually divided into two categories. These are the Repeated Point Measures, or RPMs, where surface elevation is repeatedly measured at the same point in a nondestructive way, and the Marker Layer Methods, or MLMs, where accretion above a distinctive soil horizon marker is measured through destructive sampling by coring.

The three RPMs used include a field survey technique developed by Nakashima et al. (1983), a sedimentation pin method, and a sedimentation table method. These methods provide accretion and erosion data as a function of distance to the sediment surface measured from a fixed datum. The methods have a range of different spatial scales as well as differing levels of precision and accuracy.

Three MLMs were also employed. Two involved placement of marker layers, a visible white feldspar clay in one case, and a mixture of rare earth elements that tag the existing surface sediments in the other. The last MLM investigated was designed to measure accretion above a Cesium (^{137}Cs) marker assumed already to be in place as a result of atmospheric testing of nuclear weapons in the 1950s and early 1960s.

Our working hypothesis is that all of these methods, if deployed at the same location, should yield comparable results within limits of precision and accuracy that could be assessed for each. We are in the process of testing this hypothesis rigorously with 11 months of data and a sufficient number of paired datasets.

All data are expressed in units of length (mm or cm), which are manipulated in the form of differences (positive or negative) over one or more monitoring intervals. We are using a multivariate analysis of variance (MANOVA) scheme to determine significant differences:

- among repeated measurements made over the same time interval, site and type of station (mudflat or marsh) using the same method;

- among measurements made over the same time interval, site and type of station using different methods;

- among different time intervals, sites, and types of stations.

Where significant differences are identified, a discriminant analysis will be performed to describe clusters of like methods.

3.0 STUDY SITE SELECTION

Three permanent marsh study sites were selected in the southern half of Cumberland Island during early December, 1989 (Figure 1). The sites consisted of marsh, mudflat, and tidal creek systems that were comparable in morphology but exhibited a spectrum of different exposures to Cumberland Sound, the St. Marys Entrance, and the ICWW.

3.1 Site 1 - Beach Creek

Site 1, the southernmost site, is located 3 kilometers (km) northwest of St. Marys Entrance inlet (see Figure 1). Cumberland Sound reaches its maximum width at this point, adjacent to the mouth of St. Marys River, and has a fetch of about 8 km due west up the river. The monitoring station is on the southern bank of Beach Creek, as shown in Figure 2. The station is at the crossing of two survey lines running east-west and north-south and extending 60 and 35 meters (m), respectively, to the Sound and to the creek (Figure 4). Both marsh and mudflat monitoring stations were established at Site 1 in December 1989.

Beach Creek is about 40 m wide at the terminus of the north-south transect; the southern bank appears to be predominantly a depositional point-bar feature. Unvegetated mudflats were not found along the Sound shoreline in this area but do occur as depositional features along the margins of the tidal creek. The mudflat monitoring station was thus located adjacent to Beach Creek near the end of the north-south transect, as shown in Figure 4.

Wave energy, tidal currents and exposure to both inlet and tidal creek processes are greater here than at the other two sites. This location was chosen to provide an indication of the upper limits for sediment erosion and deposition dynamics.

3.2 Site 2 - Grassy Knoll

Site 2, the middle site, is located near the Greyfield Inn dock, 6 km north of Site 1 and immediately across the Sound from Kings Bay Naval Base (Figure 1). Cumberland Sound has a width at this point of approximately 1.5 km. The monitoring station is on the southern bank of a small, unnamed marsh creek, as shown in Figure

3. The station is at the crossing of two survey lines running east-west and north-south and extending 40 and 35 m respectively to the sound and to the creek (see Figure 4). The marsh monitoring station was set up in December 1989, but the mudflat station was not established until November 1990.

The unnamed creek at Site 2 is about 10 m wide at the terminus of the north-south transect and the southern bank appears to be relatively stable, neither obviously depositional nor erosional. Unvegetated mudflats were found along the sound shoreline in this area, but not along the bank of the creek. The mudflat monitoring location was, therefore located near the Sound end of the east-west transect, as shown in Figure 4.

Exposure to inlet and tidal creek processes is greatly reduced relative to Site 1, but this site is closest of the three to the channel dredging operation and is exposed to waves generated by boat wakes. This location was selected to provide a benchmark for normal backbarrier marsh sedimentation rates away from the influence of the inlet, but near the Kings Bay Naval facility. One indication of the effects of channel dredging would be unusually high or low deposition/erosion rates at this intermediate location.

3.3 Site 3 - Old House

Site 3, the northernmost station, is located 1.5 km north of Site 2 in the lee of Stafford Island (see Figure 1). Cumberland Sound between Cumberland and Stafford Islands is really itself a tidal river approximately 0.5 km across. The monitoring station is on the southern bank of the first small, unnamed marsh creek north of Old House Creek, as shown in Figure 3. The station is at the crossing of two survey lines running east-west and north-south and extending 40 and 20 m respectively to the Sound and to the creek (see Figure 4). The marsh and mudflat stations were established in December 1989.

The unnamed creek is about 10 m wide at the terminus of the north-south transect and the southern bank appears to be relatively stable, neither obviously depositional nor erosional. Unvegetated mudflats were not found along the Sound shoreline in this area, but occurred along the bank of the creek. The mudflat monitoring station was therefore located near the creek end of the north-south transect, as shown in Figure 4.

Exposure to inlet and tidal creek processes at Site 3 is greatly reduced even when compared to Site 2, and this location is expected to be insulated from the influences of both inlet processes and the effects of the dredging. This location was chosen as the control site to provide an indication of the lower limits for sediment erosion and deposition dynamics.

4.0 METHODS

Six field techniques were employed to monitor the areal and vertical extent of erosion and accretion at the selected sites in the backbarrier marshes and mudflats of Cumberland Island. These techniques included field surveys, sedimentation pins, clay-marker horizons, a sedimentation table, stable rare-earth tracers, and Cesium (^{137}Cs) dating. The areas sampled for each method were nested in close proximity to one another in order to provide a good basis for comparison (see Figure 4).

Wooden walkways were constructed to provide undisturbed access to the sampling areas. At each site, the walkways were constructed of treated boards (5 cm x 30 cm x 2.4 m) placed on wooden supports and cross-members. To limit disturbance during construction, the supports were constructed at a staging area prior to installation in the marsh or mudflat subenvironment. A typical marsh/mudflat walkway is shown in Figure 5. Site 1 required further construction of an exclosure to prevent horses from entering the sampling area. Upon sampling, each site was approached carefully via the same corner of the walkway and all measurements were made from the elevated platforms. The layout of the walkways, sedimentation table mounts, sedimentation pins, survey transects, Cesium cores, and clay feldspar markers is shown in Figure 4.

4.1 Field Surveys

Field surveys are the standard ground-truth method for determining rates of shoreline change (Tanner 1978). Numerous beach survey approaches have been developed (Williams 1947, Saville and Caldwell 1953, Inman and Rasnak 1956, Emery 1961, Zwamborn et al. 1972, Birkemeier 1981, Zacks 1982, Dackombe and Gardiner 1983). A method developed by Nakashima et al. (1983) was utilized in our surveys.

At each site, a permanent working subdatum was established from which repeated surveys could be made. Then, 2.5-m-long metal stakes were placed at 5-m intervals, following a line-of-sight established with an engineer's level.

Distances above the survey line were determined with standard field survey methods out to the maximum limit of wading. The subdatums were then tied into permanent U. S. Army Corps of Engineers (USACE) benchmarks positioned at bayside and streamside locations throughout the study area, by means of an electronic distance measuring (EDM) unit with a triple prism cluster (Figures 6 and 7). Upon reoccupation, elevations relative to the subdatums were obtained with a standard optical level or laser device.

Two survey transects were established at each of the three field sites, producing a total of six transects. Monitoring of the marshes and tidal creeks began on December 7, 1989 with subsequent resurveys on February 2, 1990, March 30, 1990, July 27, 1990, and November 2, 1990. The survey data were transcribed, reduced, and plotted with a computer program (Birkemeier 1984).

Reduced field survey data are presented as summary tables (Appendix A). Information is provided for each shoreline, including a two-letter locality code (CI), a profile number, a survey date, the number of surveys per locality, the units of measurement (m), and the maximum number of points in the set of surveys. Elevations were set to the National Geodetic Vertical Datum (NGVD). The even spacing of readings every 5 m along the transect was selected to simplify further statistical analysis (Appendix A). Net between-stake elevation changes are provided in Appendix B for each survey pair.

4.2 Volumetric Change Data

Volumetric changes were computed in cubic meters per meter (m^3m^{-1}) for a hypothetical strip or "sweep zone" extending 0.5 m to each side of the survey line for each 5-m horizontal distance along the transect for each time interval between measurements. These results are reported in Appendix B both as incremental and gross volume changes. The incremental change may be positive or negative for any one time interval and, when summed, may give a result that is a poor representation of total activity or dynamics over two or more time intervals. Gross volume change, which is a sum of the absolute value of changes over two or more time intervals, is a better indication of overall dynamics but a poor measure of net effect on elevation.

Erosion and deposition are also addressed in summary cut (negative values) and fill (positive values) tables that correspond to digitized stadia intervals (see Appendix B). Thickness values in these tables differ from those of the digitized pairs because they are direct measurements of vertical changes obtained from the cross-sectional area of each profile cell. The net volumetric change is described according to the cumulative volume in the cut-and-fill computation.

<u>4.3</u> <u>Sedimentation Pins</u>

Sedimentation pins are used to obtain detailed local information on erosion and accretion in wetland environments (Letzsch and Frey 1980a, Pethick and Reed 1987). For this project, 50-centimeter-long stainless steel pins were pushed into the marsh and mudflat surfaces to a 27.1-cm depth. Six pins were placed in the arrays shown in Figure 8 to monitor both lateral and vertical patterns of erosion and deposition near the marsh shoreline and tidal creek mudflats. Net erosion, accretion, or stability of the marsh-mudflat surface was determined by measuring the distance from the top of the sedimentation pin to the sediment surface (outside of any local scour hole) with a steel rule graduated in millimeters. The sedimentation pins were used primarily to monitor erosion near the marker plots and to provide more frequent estimates of accretion that were compared with marker-layer results obtained from examination of cores. The use of sedimentation pins is a necessary complement to all marker-horizon techniques in areas where erosion is a possibility.

<u>4.4</u> <u>Sedimentation Table</u>

The sedimentation table (Schoot and de Jong 1982) complements sedimentation pins and clay marker plots in its capability to obtain many detailed measurements of net change in sedimentation without the need to leave any marker or pins in place. The sedimentation table is designed to repeatedly measure elevation of the sediment surface of vegetated and unvegetated intertidal and shallow subtidal areas to an accuracy of a few millimeters. The procedure causes no disturbance to the surface being measured, and the many measurements provided over small areas give a measure of spatial variability associated with microtopography.

Before installation of the sedimentation table, the supports were constructed at a staging area and transported to the chosen location. The site was approached carefully and platforms constructed so as to avoid disturbance to the area to be measured. For all subsequent installation and measurement activities, the site was approached at the same corner of the platform and all work was carried out from the platforms.

The sedimentation table required the installation of a stable mounting post that also served as the field survey subdatum at each site. The mounting post was an aluminum irrigation pipe (7.5 cm diameter x 6.1 m length) that was vibracored into the marsh or mudflat substrate until refusal. The pipe was filled with cement and fitted with a machined aluminum mounting pin to accommodate the sedimentation table, which was constructed of stainless steel and machined aluminum (Figure 10). Two mounting posts were installed in each of Sites 1 and 3 (marsh and mudflat) and one post was installed in the marsh at Site 2 in December 1989. An additional sedimentation table location was established in the mudflat subenvironment at Site 2 in November 1990.

The upper part of the sedimentation table has four components: a vertical arm, a horizontal arm that can be leveled in two planes, a flat plate or table, and nine pins. The vertical arm slides 25 cm into notches in the mounting post, such that measurements can be made in four quadrants with precise repeatability. The horizontal arm of the sedimentation table attaches to the vertical arm with a pin at the pivot point. This pivot point allows the arm to be leveled up or down with the double-threaded adjustment screw. The horizontal arm can also be leveled from side-to-side and locked in place when a bubble level indicates that leveling in both planes is complete.

When leveled, the table on the end of the horizontal arm provides a constant plane in space from which the distance to the sediment surface is measured. This distance is measured with nine pins that pass through holes in the table. The table is made up of three separate plates, the upper and lower being fixed and the middle one movable. A thumb screw attached by a rod to the middle plate allows it to be moved back and forth or locked. There are nine holes in each plate and these can be lined up by moving the middle plate so that the pins can be inserted. By moving the middle plate slightly, and then locking it in place, the pins are held in position by pressure from rubber o-rings.

When the table was level, the nine pins were placed in the holes and locked in place. By loosening the screw slightly, the pins could be lowered manually if the sediment surface was visible or lowered slowly with the hand screw until the pins rested on the bottom in shallow turbid water. After the pins were on the sediment surface, they were locked in place, the length of each pin above the table was measured to the nearest millimeter, and the distance to the sediment surface was calculated by difference. This procedure was repeated for each of the four directions to yield 27 elevation measurements (Figures 11 and 12).

<u>4.5 Clay-Marker Horizons</u>

Visual monitoring of sediment accumulation above artificial soil horizons of white feldspar-clay has been found to be an effective and inexpensive technique for monitoring accretion in Louisiana marshes (Cahoon and Turner 1987). For the purposes of this project, a layer of feldspar-clay was emplaced in two 30-cm^2 plots at each of the three marsh sites on December 1989 (Figure 9). A total of nine shallow cores were taken from these marker plots on June 4, 1990, providing a single, 6-month estimate of accretion.

4.6 Stable Rare-Earth Element (REE) Tracer

The method of using stable, rare-earth tracers as nonobtrusive soil horizon markers was recently tested on a large scale in Louisiana marshes and was found to offer some advantages to techniques depending on a visual marker, such as feldspar (Knaus and Van Gent 1987). The two rare-earth elements used in the Louisiana work were dysprosium (Dy) and samarium (Sm), which were determined to be biologically nonessential and chemically inert. These were also found to be appropriate for use in Georgia. When samples containing these nonradioactive elements are bombarded with neutrons in a reactor, using Instrumental Neutron-Activation Analysis (INAA), a relatively low-cost detection method, radionuclides are produced. These radionuclides have a gamma ray emission that is sufficiently intense and energetic such that the presence of these elements can be quantified at concentrations as low as 0.1 microgram per sample. For marker layer preparation, measured amounts of a slightly acidified Dy-Sm nitrate ($Dy\text{-}Sm_2NO_3$) mixture diluted with water from the marsh are applied to the exposed sediment surface using a sprayer (Figure 13). The tracer then rapidly precipitates onto all surfaces contacted, forming a permanent, insoluble tracer that moves only when the sediment particle itself moves.

The rare-earth tracer can be applied more easily to larger areas than to the small plots used for other markers and is therefore easier to locate in the field. Because it bonds with the sediment particles in place, it is believed to provide a better indicator of processes actually affecting those particles than other introduced materials that result in some environmental modification. In Louisiana marshes, use of the INAA technique resulted in meaningful measurements made on sediment slices as thin as 3 mm.

The ability to evaluate very thin accumulations is more important in Georgia than was true in Louisiana because it permits accretion estimates to be made at shorter time intervals. We are interested in evaluating this method for use in the Cumberland Island marshes not only for use in marker horizons but for future work in which we can actually trace sediment movement within the marsh, between creek and marsh, and on mudflat surfaces.

Two areas in each of the three Cumberland Island marsh sites were targeted for application of either Dy, Sm, or dysprosium oxide (Dy_2O_3). Sixteen cores were taken from these sites, including nine from the feldspar marker plots.

4.7 Cesium (^{137}Cs) Dating

Cesium (^{137}Cs) is a product of atmospheric nuclear weapons testing that does not occur naturally. Significant levels first appeared in the atmosphere in the early 1950s, with peak quantities detected in 1963 and 1964 (Pennington et al. 1973). This radionuclide was introduced to surface soils from the atmosphere and accumulated. In the sediments, it decays exponentially to Barium (^{137}Ba), with a 30-year half-life.

The distribution of ^{137}Cs in wetland soils has been used throughout the world to measure relatively recent accretion (DeLaune et al. 1978, DeLaune et al. 1983). Typically, the profile of ^{137}Cs with depth shows a maximum corresponding to the 1963 peak in atmospheric testing. Although there appears to be some migration of ^{137}Cs in sediments, peak concentrations do not shift substantially, since ^{137}Cs is rapidly absorbed onto the clay components of the soil (Robbins and Edington 1975).

The evaluation work for the first year of this project involved the collection and analysis of ^{137}Cs profiles in five cores. Two cores were taken in each of Sites 1 and 3 and one core was taken from Site 2, yielding five cores that represented either marsh or mudflat subenvironments. The core locations are shown in Figure 4.

4.8 Laboratory Analyses

All laboratory work for ^{137}Cs accretion analysis was conducted by the Laboratory for Wetland Soils and Sediments (LWSS), a research unit within the Center for Wetland Resources and Department of Marine Sciences at Louisiana State University (LSU). The LWSS is fully equipped to determine ^{137}Cs profiles in soil cores and does so on a routine basis.

For ^{137}Cs, up to eight 1- to 3-cm-thick core sections were analyzed for each site (Delaune et al. 1983). The core section sample was dried, and the ^{137}Cs activity was counted without further treatment using a lithium-drifted germanium detector (GeLi) and multichannel analyzer. Bulk density and organic matter content were analyzed on the same samples to provide information about the nature of the accretion process and to serve as a control for variation in ^{137}Cs adsorption onto mineral and organic soil particles (DeLaune et al. 1978).

The Nuclear Science Center (NSC) is another research unit at LSU that has worked closely with the LWSS in the development of wetland accretion monitoring techniques for more than a decade. Neutron activation and instrumental neutron activation analysis (INAA) of the wetland soil samples was carried out at the research reactor at Texas A&M University, which was made available to the NSC under the U. S. Department of Energy Reactor Sharing Programs.

The INAA marker technique used small push cores of marsh substrate, sections of which were dried out and encapsulated for neutron irradiation. These samples were then transported to the reactor facility. At the reactor site, samples and standards were activated by neutron bombardment. The type and quantity of activated rare-earth radionuclides were then determined by analyzing the spectrum of gamma ray emissions using a GeLi-detector interfaced with a multichannel analyzer.

4.9 Data Reduction and Interpretation

The project was designed to put most emphasis on field activities such that little office data reduction would be required for the initial year of data. The data are stored in dBase III files, which have been provided on diskettes along with this report. Text material is retained in WordPerfect 5.0 files. Two complete sets of 35-mm color transparencies containing 30 annotated slides have also been provided.

5.0 RESULTS

5.1 Field Surveys

Sweep-zone profiles evolving from December 1989 through July 1990 for the marsh and mudflat transects at the three sites are shown in Figures 14 through 19. Elevation characteristics of the profiles are provided in Appendix A, volumetric changes are summarized in Table 1, and slope changes are provided in Table 2.

The average apparent vertical change at all the monitoring locations (5-m spacing) on the sound profile at Site 1 (SOUND 1) over the 8-month interval was on the order of 4 cm (Figure 14). The edge of vegetation on the Sound end of this profile showed an apparent shoreward retreat of 20 cm and was found at an elevation of approximately 1.3 m National Geodetic Vertical Datum (NGVD). The elevation of the marker plot at the landward end of the profile was 1.85 m NGVD. The average slope of the marsh surface was tan 0.008 and on the sound beach face, tan 0.185. Incremental volumetric changes for the SOUND 1 profile revealed losses in marsh volume ranging from 0.08 to 0.47 m^3m^{-1}, with a net change of -0.85 m^3m^{-1}.

Results from the Site 1 Creek profile (CREEK 1) also showed an apparent mean vertical change of about 4 cm (Figure 15). The marsh/mudflat interface on the creek bank advanced approximately 30 cm toward the creek and was at approximately the same elevation as at SOUND 1 (1.3 m NGVD). The slope of the marsh surface at CREEK 1 was similar to that at SOUND 1 (tan 0.010), but the mudflat surface was intermediate in slope between the marsh and the sound beach face, averaging tan 0.080. Incremental volumetric changes on this profile indicated loss during the winter, with a small amount of accretion during the spring and summer. The net change in the CREEK 1 profile for the 8-month period was somewhat less than for the SOUND 1 profile, averaging -0.57 m^3m^{-1}.

Very little apparent vertical change was observed on either profile at Site 2 -- SOUND 2 or CREEK 2 -- with minor sediment losses during the winter replaced during the spring and summer (Figures 16 and 17). The elevation of the marsh marker plot was 1.96 m NGVD, about 10 cm higher than at Site 1, but the slope of the marsh surface was less, averaging tan 0.007 for the SOUND 2 profile and tan 0.001 for CREEK 2. The edge of marsh vegetation was also found at a higher elevation on both the Sound and mudflat transects, but in this case nearly 40 cm higher, at about 1.8 m NGVD. The beach face and mudflat which form the ends of the two transects were both much steeper than at Site 1, averaging tan 0.500 and tan 0.208, respectively. Locations of the edge of marsh vegetation on the sound end of SOUND 1 and on the mudflat end of CREEK 2 did not show detectable change over the 8 months of record. Net volumetric changes for the SOUND 2 and CREEK 2 profiles amounted to +0.03 and +0.08 m^3m^{-1}, respectively.

Apparent mean vertical change at all the monitoring locations (5-m spacing) on the Sound profile at Site 3 (SOUND 3) over the 8-month interval was on the order of 10 cm and was more dynamic than any other profile monitored (Figure 18), a result that was not expected. The edge of vegetation on the sound end of this profile showed no detectable change but was found at an elevation of approximately 2.0 m NGVD, higher than at Sites 1 and 2. The elevation of the marker plot at the landward end of the profile was also higher, at 2.24 m NGVD. The slope of the marsh surface averaged tan 0.005 and on the Sound beach face, tan 0.120. The pattern of incremental volumetric changes for the SOUND 3 profile was counter to that found at the other two sites in that accretion took place during the winter and spring (+0.41 m^3m^{-1}) and nearly equivalent losses occurred during the summer (-0.41 m^3m^{-1}), for an insignificant net change of +0.01 m^3m^{-1}.

The apparent mean vertical change on the creek profile at Site 3 (CREEK 3) over the 8-month interval was on the order of 5 cm (Figure 19). The edge of vegetation on the Sound end of this profile showed no detectable change. The slope of the marsh surface averaged tan 0.004 and on the creek mudflat surface, tan 0.070, very similar to that of the Site 1 mudflat. Incremental volumetric changes for the CREEK 3 profile showed little deposition occurring at any time, but a substantial loss in winter (-0.35 m^3m^{-1}). Net change for CREEK 3 averaged -0.40 m^3m^{-1} for the 8 months of record.

In summary, the initial survey results presented in Table 2 show that Sites 1, 2, and 3 are characterized by a gradient of increasing marsh elevation from south to north. The slopes of the marsh surfaces at all sites are similar and of extremely low angle. The slopes of the creekbank-mudflat surfaces are steeper and more variable. If the net changes in all profiles are considered, three profiles show mean losses of -0.40 m^3m^{-1} or more (1 SOUND and 2 CREEK), while the other three profiles show virtually no change over the 8-month initial monitoring period (2 SOUND and 1 CREEK).

5.2 Sedimentation Pins

Sedimentation pins were installed in five subenvironments at the three sites (Figure 4). The Site 1 marsh showed a net gain of approximately 10 mm over the three seasons monitored (Figure 20). Results from only four of six pins are reported because two of the pins had been pushed into the ground. The Site 1 mudflat underwent a larger amount of deposition, with the greatest gains occurring during the spring between the second and third sampling intervals and overall sedimentation approaching 20 cm (Figure 21). Mudflat sedimentation pin heights were not obtained in July 1990 because of a storm in Cumberland Sound.

Marsh sedimentation at Site 2 was inconsistent over the three seasons monitored (Figure 22). A 26-mm range in vertical change was recorded at this site. Three of the sedimentation pins exhibited a maximum accretion of 8 mm, whereas three other pins showed losses up to 18 mm. Although the pins were located in close proximity to one another, localized areas of erosion and deposition were apparent. Two of the pins (3 and 4) appear to be in the lee of the walkway supports and were possibly recording local deposition associated with scour adjacent to the structure (Figure 4). A mudflat station was not established at this location until November 1990.

Both marsh and mudflat subenvironments at Site 3 experienced net sediment accretion. While pin-to-pin variation in accretion was from 0 to 20 mm, most estimates were in the 8-to-20 millimeter range. Most sedimentation occurred during the summer (Figure 23). The mudflat exhibited a net vertical accretion at all but one of the pins during the winter and spring intervals (Figure 24). Sediment gains on the mudflat were in the 4-to-8-mm range. Again, mudflat sedimentation rates during the summer could not be assessed, as pin data were not obtained from the mudflats in July 1990.

5.3 Sedimentation Table

Changes in marsh/mudflat elevations recorded by the sedimentation table are shown in Figures 25 to 27. A net loss in elevation was measured for all subenvironments except the Site 1 mudflat and the Site 3 marsh. Changes in elevation were generally greater on the mudflats than on the marsh surfaces. Although the marsh values did not change very much, they exceeded the mudflat values on two occasions. Both of these occurrences were recorded at the Site 3 marsh, at the NW and NE corners during sampling interval 3. The least elevation change recorded on the mudflat was 1.0 cm.

The four corners at a station generally showed similar rates of elevation change. Rates that were significantly different at the 95% confidence level were observed between the NE and SE corners at the Site 2 marsh during the first measurement period. Significantly different rates during the second measurement period were also recorded between the NE and SE corners at the Site 3 marsh, between the NE and other corners at the Site 1 mudflat, between the NE and other quadrants at the Site 1 marsh, and between two of four corners at the Site 3 marsh during the third sampling period.

The five sites showed different rates of elevation change during the same intervals, but these changes for the most part did not differ significantly at the 95% confidence level.
The Site 3 mudflat and the marsh showed more variability in elevation measurements than other subenvironments. The Site 3 mudflat features a considerable slope to the channel and a great deal of reworking of the surface by fiddler crabs.

5.4 Clay Marker Layer and Stable Rare Earth Element (REE) Tracer

Six cores were taken at Site 1 on June 12, 1990 at the locations shown in Figure 4. Cores were taken in pairs (1-2, 3-4, and 5-6) with the second core serving as a replicate. Cores 1, 2, 5, and 6 were taken where feldspar had been placed previously (December 9, 1989). Feldspar was found in all four of these cores, although at only 1-to-15 mm thicknesses (Figure 28). Cores 3 and 4 were assessed for depth of REE soil-horizon marker alone. Cores 2 and 6 were assessed for REE as well as feldspar. The REE marker was found in all four cores (Figure 28). Bulk density and organic/inorganic determinations for the top 3 cm of soil adjacent to cores 1 and 6 appear in Figure 29. Clay segments taken along cores 1 to 6 were 5 mm thick, and those along cores 7, 9 to 12, and 14 to 16 were 3 mm thick. Depth of the REE marker was reported as occurring at the middle of the segment, where the highest concentration of the REE marker occurred. Therefore, accretion was calculated by dividing the depth of the segment by 2. Thus, the accretion in cores 1-6 is 2.5 mm (5 mm divided by 2) and of the other cores is 1.5 mm (3 mm divided by 2).

Five cores were taken at Site 2, with two pairs of cores (7-8 and 9-10) having replicates. The ground was extremely hard in the vicinity of core 11 and no replicate core was taken there. Cores 7, 8, and 11 were taken where feldspar had been placed previously. Feldspar was found in all three of these cores and was conspicuous on the ground surface in the vicinity of the cores (Figure 28). Cores 9 and 10 were assessed for the depth of REE soil horizon markers, along with feldspar cores of 8 and 11. The REE marker was found in all four cores (Figure 28). Bulk density determinations for Site 2 also appear in Figure 29.

Six cores, including two pairs with replicates (12-13, 14-16, and 17) were taken at Site 3. Cores 12, 13, 14, and 17 were taken where feldspar had been placed previously. Feldspar was found or clearly seen in all four of these cores. The feldspar marker at core 17 was on hard ground, showing clearly at the surface. No accretion appeared to have taken place, but this could not be confirmed because core 17 was lost (inverted). Core 14 was a Dy_2O_3 "powder plot"; that is, the powder of the rare earth oxide was used in a thick, visible (0.25-cm) layer. Cores 15 and 16 were taken 5 m from core 14 in an attempt to assess washout or dispersal of a concentrated source of Dy. The REE marker was found in all four cores analyzed (Figure 28). Bulk density determinations for Site 3 appear in Figure 29.

5.5 Cesium (^{137}Cs) Dating

Bulk density of the sediment profiles ranged from approximately 0.3 g cm^{-3} for cores collected from a marsh location to over 1.0 g cm^{-3} for a core taken from a mudflat at site 1 (Table 3). The bulk density values for the marsh subenvironments were similar to values reported for streamside salt marshes located along the Louisiana Gulf Coast (Hatton et al. 1983).

Organic carbon and bulk density analyses of the cores used for ^{137}Cs dating showed that the marsh and mudflats vertically accrete through the accumulation of mineral sediment and organic matter (Table 4). The two cores from the mudflats contained between 81 and 97% mineral sediment (sand) in the profile, with the highest organic matter content in the Site 3 mudflat. The marsh cores contained less mineral sediment, between 62 and 84%, than cores taken from an adjacent mudflat.

Profile distributions of ^{137}Cs in cores are shown in Figures 30 to 34. The ^{137}Cs profile at Site 1 did not show a distinct trend that could be used to access sedimentation rates at either the marsh or the mudflat (Figures 30 and 31, respectively). The mudflat core contained too much sand, which does not effectively bind ^{137}Cs. The ^{137}Cs profile distribution of the core taken from the marsh at Site 1 was not deep enough to identify the point in the profile at which ^{137}Cs was absent, a marker representative of 1954, the year ^{137}Cs first entered the environment. Likewise, a ^{137}Cs maximum representing 1963, the year of maximum fallout, was not present in the marsh core taken from Site 1 (Figure 30), but this could also be caused by extensive reworking.

The core taken from the marsh at Site 2 showed a reduction in ^{137}Cs activity at an approximate depth of 20 cm that depth representing the early 1950s when ^{137}Cs first entered the environment (Figure 33). Using the marker, vertical accretion of the Site 2 marsh was estimated to be 0.57 cm yr^{-1} when integrated over the past 3 decades.

The marsh core taken from Site 3 showed a distinct 1963 marker at the 12-to 15-cm depth, which is interpreted as signifying an accretion rate of 0.54 cm yr^{-1}. There appeared to be tailing, with no well-defined 1954 marker in this core (Figure 33). The mudflat at Site 3 showed significant ^{137}Cs activity throughout the sampled profile, suggesting very rapid sedimentation or extensive reworking (Figure 34).

It should be pointed out that some compaction occurred during collection of several of the cores; however, the amount would represent compaction only at the lower portion of the marsh sediment profile. Compaction is generally minimal in the surface 30 to 40 cm, which is the portion of the profile containing the ^{137}Cs markers. The ^{137}Cs measurements overall provide a unique indication of how the relatively instantaneous rate measurements from the other methods compare with the long-term measurements.

6.0 DISCUSSION OF FIRST-YEAR RESULTS

Six different methods for measuring sedimentation and erosion rates on marsh and mudflat surfaces are being applied for comparison at three backbarrier study sites on Cumberland Island in an effort to determine whether channel dredging is affecting marsh/mudflat habitat sustainability. Preceding sections of this report have detailed activities undertaken during the first year of a 5-year project. Specifically, these activities have included site selection, methods development, and data reduction. The data provided in this report date from the initiation of field activities in December 1989 through July 1990.

We do not attempt a detailed analysis of the limited number of repeated measures available at this time, particularly with respect to the few measurements made at mudflat locations. The following discussion is therefore confined to the measurements made on the marsh surface. This database allows initial estimates to be made of (a) the natural spatial variability of marsh surface elevations, (b) the magnitude of short-term vertical changes, and (c) the amount of agreement among the six methods under evaluation. This discussion deals with these subjects and closes with an initial ranking of the methods.

6.1 Natural Spatial Variability in Marsh Surface Elevation

The survey data suggest that the interior marsh surface exhibits an apparently regional trend of increasing elevation from south to north with a range of 40 cm between Sites 1 and 3. This apparent regional trend will be investigated further during future surveys by use of more USACE benchmarks.

The marsh surface also shows variability within individual sites. The survey shows that the surface typically slopes at a low angle toward the Sound and creeks. The other methods record the effects on elevation of elements of microtopography, which range from high-tide debris deposits to footprints and fiddler crab burrows. The range data collected in Table 5 permit an initial assessment of the extent of spatial variability encountered during the first 8 months of the field effort. A presently unknown portion of this variability is assumed to derive from error associated with the precision of each method.

The survey results show that over a distance of tens of meters, the vegetated marsh surface elevation at any one site at any single time varies within a range of 10 to 50 cm. Over smaller distances of a single meter or less, results obtained from the other methods show that the marsh mud surface exhibits a range in elevation or roughness of 1 to 6 cm, an order of magnitude lower.

6.2 Temporal Variability in Marsh-Surface Elevation

Accretion and erosion of the marsh surface is assumed to be manifested in apparent changes in the elevation of this surface relative to a benchmark (repeated point measure) or to a tagged soil layer (marker layer method). A summary of the record of accretion (+) and erosion (-) for each site is provided in Table 6, with the net change over the first 8 months (7 months for MLM's) given at the right margin. The signs and numbers vary with method even at the same site. Looking only at the scale of change, however, fluctuations over individual 3-month intervals are of about the same magnitude as the 8-month net. Furthermore, all methods suggest that changes are in the range of 5 to 20 mm.

6.3 Agreement Among Methods

The first year's results show that in assessing significant regional differences in sedimentation rates, or their change over a period of 5 years or less, we will be dealing with projected annual changes of 1 to 2 cm on surfaces that have a natural, short-range spatial variability on the order of 1 to 5 cm, and a natural, longer-range spatial variability of 20 to 50 cm. This is a daunting proposition, even if it can be assumed that measurements can be taken with sufficient accuracy and precision to resolve such small changes.

A summary of results of first-year accretion and erosion data is presented in Table 6. The long-term results from the cesium cores are not comparable to the other short-term measures, but are provided for comparative purposes. These figures do not inspire confidence. For example, results of three methods suggest that the marsh at Site 1 experienced accretion of 11 to 20 mm, while one method shows no change and another suggests net erosion and removal of 12 mm. Similarly, three of five methods report net accretion, although minor (1 to 4 mm), at the Site 2 marsh, while two methods indicate erosion (3 to 13 mm). Finally, at Site 3, agreement is no better, with three methods indicating net accretion (4 to 15 mm), one showing no change, and another showing net erosion (-12 mm). Some variability was expected, as measurements for each method are not taken in exactly the same locations at each site, but the span of results produced by the different techniques exceeded expectations.

It is clear that more investigation is warranted, first, into what each method is actually measuring, and second, into each method's precision. Results are quite comparable among the MLM's, but this is not unexpected, as these methods can report only positive or zero values. If erosion occurs, these methods will give a misleading result. We must assume that where MLM results are close to zero, erosion may actually have taken place.

The visible clay layer recovered from the feldspar marker plots was found to be present in all cores obtained but at thicknesses ranging from 1 to 12 mm. While the thickness of the feldspar layer that was initially applied probably varied somewhat across the surface of the marker plot, it is likely that some of the measured variation is due to erosion and removal of some of the clay. Indeed, at Site 3, the clay was clearly exposed and had been visibly dispersed across the marsh surface outside of the plot. In addition, the cores collected from the marker layers for analysis were obtained over a month earlier than the last measurements made using the other methods. At Site 3, where the MLMs suggest a lower accretion rate than either the sedimentation table or the pins, most of the accretion was reported by these other methods in the period between April and July. Thus, it is possible that most of the accretion actually occurred between June 11 and July 27, after the MLM cores were collected.

At Sites 1 and 3, however, the results of the standard survey suggest that substantial erosion has occurred, while all of the other methods report accretion or no change (Table 6). The precision of this method is estimated at +/- 15 mm because the stadia rod is calibrated in tenths of feet (3 cm). This level of precision is similar to the maximum level of change expected over a period of a year or more. While this method is useful in determining larger-scale spatial trends and lateral changes, it has too coarse a resolution to be useful in tracking the vertical changes expected over periods of a year or less.

Discounting the results of the survey and cesium methods, we would interpret the data presented in Table 6 to indicate that Sites 1 and 3 experienced accretion of 5 to 15 mm during the 8-month period of record, while Site 2 experienced erosion at a similar rate. Many of the questions about precision and accuracy will be answered as the database grows.

6.4 Initial Ranking of Methods

The scattered results that are plotted in Figure 6 throw doubt on the comparability of various methods that are currently being used to evaluate detailed patterns of vertical change on marsh surfaces. The analysis in the preceding section suggests that all methods are not inherently equal. This analysis is broadened in Table 7 into a first qualitative, side-by-side evaluation on the basis of six criteria.

The first of these criteria is listed in Table 7 as "Datum." The question here is whether the method by which accretion and erosion measurements are obtained allows relatively accurate reduction to an absolute datum (NGVD, for example). Given that relative measurements accumulate error over time, it is preferable to make all measurements from the same stable benchmark throughout the entire course of study. The survey and sedimentation table methods offer this advantage.

The second criterion is whether the method can monitor erosion. If not, then it will not provide useful information in a subenvironment in which erosion occurs at a rate similar to or greater than deposition. All marker layer methods suffer to a greater or lesser degree from this limitation. Unlike marshes in Louisiana and other areas experiencing more rapid subsidence and deposition, Cumberland Island marshes appear to experience erosion as well as deposition. Even for the cesium method, one or both of the activity peaks was commonly absent, suggesting that erosion and reworking have been characteristic of the Cumberland Island marsh surface for some time.

The third criterion is "data loss probability." All methods that require placement of equipment in the marsh for long periods of time are susceptible to loss of data either because the equipment cannot be relocated or because it is damaged in some way by natural and human activities. The sedimentation pins are most susceptible in this regard, in that they are easily lost and prone to disturbance by processes and activities to be expected in any marsh. If pins are disturbed without being pushed over entirely, they will provide inaccurate and misleading results. The survey and sedimentation table methods are less susceptible, as each requires placement of only a benchmark monument that can be made both easy to find and indestructible.

"Precision," the fourth criterion, can be evaluated only qualitatively at this time. It is clear, however, that a method useful for discriminating real changes of 5 mm or less must have a precision that allows resolution of such change. The survey method as it has been employed to date does not have this level of precision. The marker-layer methods also suffer from uncertainty because determination of the position of top of the marker and that of the sediment surface both introduce error that is cumulative in the difference interpreted as accretion. The sedimentation table initially appears to offer the highest precision of the methods tested.

"Cost" is always an important criterion in that it can limit the number of measurements that can be obtained. This is certainly a factor in the rare-earth and cesium methods, which require extensive laboratory analysis. The feldspar marker can actually be analyzed in the field and is a very low-cost approach, as is the sedimentation-pin method. Construction of a well-machined sedimentation table, by contrast, can cost as much as $1,000, but that is a one-time capital investment that should last indefinitely.

Finally, like cost, the "logistical difficulty" of deploying a method in the field may greatly affect project effectiveness by limiting the number of measurements obtainable by a fixed number of workers in the time allotted. The sedimentation pin method places first in this category since a single worker, if he can find the pins readily, can make a large number of measurements in a very short time carrying only a small calibrated ruler. The marker-layer methods each require collection of a short core, which is not always easy in a densely vegetated marsh. The sedimentation table itself is fairly heavy and cumbersome but can be handled by a single person with about the same level of effort as that required to carry a survey instrument and tripod.

7.0 CONCLUSIONS

Three goals were accomplished in the first year. First, we established and characterized three comparable backbarrier marsh/mudflat sites that experience a range of levels of exposure to potential impacts that are associated with channel dredging. Second, we initiated sedimentation monitoring at these locations and reported here the first 8 months of data collected, between December 1989 and July 1990. Finally, we compared six different methods for measuring accretion and erosion, including all that currently exist in the scientific literature.

The three marsh sites appear in some ways to be gradational from south to north, exhibiting an apparent increase in elevation and microtopographical roughness and a drop in the mineral or sand content. Net accretion and erosion estimates do not show any regional gradient, but are uniformly low, averaging between 0 and 15 mm for the 8-month monitoring record. It is not yet possible to draw any conclusions about the effects dredging has on sedimentation in the backbarrier marshes or mudflats.

An initial evaluation has been made of the strengths and weaknesses of the various sedimentation monitoring methods employed. The two marker layer methods were found to be seriously deficient in that they do not have the capability to record erosion. The standard survey approach is too imprecise. The sedimentation pins provided useful results, although they are subject to disturbance from flotsam/jetsam and accidental contact. The sedimentation table was found to have the most advantages. This method, which has not yet been published in its current form, is described in detail.

Monitoring will continue for the next year, and an additional line of inquiry will be developed concerning short-term variability in sedimentation dynamics that can be measured over single tidal cycles. Flumes have now been constructed at the three marsh sites and will be sampled in early 1991.

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TABLES

TABLE 1

SUMMARY VOLUMETRIC CHANGES (m^3 m^{-1}) FOR EACH PROFILE LINE

Profile Line	Type	Survey Interval 1-2 (Winter)	2-3 (Spring)	3 - 4 (Summer)	Net Change (m^3 m^{-1})
1 (Site 1)	Sound	-0.47	-0.08	-0.30	-0.85
2 (Site 1)	Creek	-0.77	+0.07	-0.13	-0.57
3 (Site 2)	Sound	+0.10	+0.10	-0.17	+0.03
4 (Site 2)	Creek	+0.10	-0.05	+0.05	+0.01
5 (Site 3)	Sound	+0.38	+0.03	-0.40	-0.07
6 (Site 3)	Creek	-0.35	0.00	-0.05	-0.40

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TABLE 2

SUMMARY SLOPE CHANGES (TAN) PER PROFILE LINE

Profile Line	Profile Location Marsh Top	Slope-Crest	Marsh-Sound Intercept
1 (Site 1)	0.008	0.032	0.185
2 (Site 1)	0.010	0.080	0.080
3 (Site 2)	0.007	0.500	0.045
4 (Site 2)	0.005	0.167	0.208
5 (Site 3)	0.005	0.020	0.120
6 (Site 3)	0.004	0.020	0.070
Mean	0.006	0.136	0.135

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TABLE 3

BULK DENSITY PROFILES (GR/CC) IN 5 CORES

Depth (cm)	Site 1 Marsh	Site 1 Mudflat	Site 2 Marsh	Site 3 Marsh	Site 3 Mudflat
0 - 3	0.472	1.004	0.309	0.272	0.466
3 - 6	0.312	1.004	0.408	0.333	0.398
6 - 9	0.423	1.142	0.423	0.367	0.360
9 - 12	0.339	0.823	0.332	0.349	0.408
12 - 15	0.405	0.760	0.235	0.284	0.300
15 - 18	0.355	0.878	0.278	0.323	0.447
18 - 21	0.311	0.850	0.249	0.361	0.334
21 - 24	0.294	1.174	0.338	0.380	0.314
24 - 27	0.282	0.927	0.280	0.316	0.365
27 - 30	0.339	0.825	0.310	0.376	0.306
30 - 33	0.372	1.043	0.322	0.371	0.325
33 - 36	0.425	0.895	0.384	0.337[c]	0.376
42 - 45	0.492[a]	1.070	0.337[b]		0.365
45 - 48		0.952			0.625
48 - 51		1.180			
51 - 53		0.866			

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[a] actual depth range was 42-46 cm

[b] actual depth range was 42-44.5 cm

[c] actual depth range was 36-38 cm

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TABLE 4

PERCENT BY WEIGHT OF MINERAL AND ORGANIC MATTER PROFILES IN 5 CORES

Depth (cm)	Site 1 Marsh	Site 1 Mudflat	Site 2 Marsh	Site 3 Marsh	Site 3 Mudflat
	(% Mineral, % Organic)				
0 - 3	76.4, 23.6	97.0, 3.0	77.7, 22.3	64.8, 35.2	84.1, 15.9
6 - 9	79.9, 20.1	96.0, 4.0	62.3, 37.7	70.1, 29.9	81.3, 18.7
12 - 15	80.0,20.0	93.8, 6.2	76.8,23.2	73.5,26.5	83.5,16.5
18 - 21	81.9,18.1	96.4, 3.6	76.5,23.5	78.1,21.9	82.7,17.3
24 - 27	80.4,19.6	96.3, 3.7	81.3,18.7	80.4,19.6	82.3,17.7
30 - 33	81.6,18.5	95.7, 4.3	80.2,19.8	82.1,17.9	82.2,17.8
36 - 39	80.8,19.2	95.6, 4.4		82.4,17.6[b]	83.0,17.0
42 - 45	83.6,16.4[a]	95.8, 4.1			82.3,17.7
48 - 51		97.3, 2.7			

[a] 42-46 cm depth

[b] 36-38 cm depth

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TABLE 5

RANGE OF MARSH SURFACE ELEVATIONS ACQUIRED BY VARIOUS TECHNIQUES (MILLIMETERS)

		DATE					
METHOD	SITE	7 Dec.	2 Feb.	30 Mar.	11 Jun.	27 Jul.	Mean
Survey	1	550	550	550	--	550	550
Survey	2	160	160	160	--	160	160
Survey	3	240	240	240	--	240	240
SedPin	1	--	10	12	--	4	9
SedPin	2	--	--	15	--	22	19
SedPin	3	--	--	22	--	21	22
SedTab	1	34	17	20	--	50	30
SedTab	2	16	24	13	--	100	38
SedTab	3	53	68	53	--	74	62
FelMrkr	1	--	--	--	13(5)[a]	--	13
FelMrkr	2	--	--	--	1(2)[a]	--	1
FelMrkr	3	--	--	--	0(11)[a]	--	0
REEMrkr	1	--	--	--	5	--	5
REEMrkr	2	--	--	--	3	--	3
REEMrkr	3	--	--	--	6	--	6
CesMrKr	1,2,3	--	--	--	--	--	--

a = range of thickness of feldspar marker layers

TABLE 6

ESTIMATES OF MARSH ACCRETION AND EROSION ACQUIRED BY VARIOUS TECHNIQUES (MILLIMETERS)

		DATE					
METHOD	SITE	7 Dec.	2 Feb.	30 Mar.	11 Jun.	27 Jul.	Net
Survey	1	S	-17	+2	--	+3	-12
Survey	2	S	+3	0	--	-2	+1
Survey	3	S	-7	0	--	-5	-12
SedPin	1	S	+1	0	--	+10	+11
SedPin	2	S	--	+2	--	-5	-3
SedPin	3	S	--	+6	--	+7	+13
SedTab	1	S	-7	+9	--	-2	0
SedTab	2	S	-5	+1	--	-9	-13
SedTab	3	S	-5	+4	--	+16	+15
FelMrkr	1	S	--	--	+16	--	+16
FelMrkr	2	S	--	--	+1	--	+1
FelMrkr	3	S	--	--	0	--	0
REEMrkr	1	S	--	--	+20	--	+20
REEMrkr	2	S	--	--	+3	--	+3
REEMrkr	3	S	--	--	+4	--	+4
CesMrkr	1	--	--	--	--	--	--
CesMrkr	2	--	--	--	--	--	+4
CesMrkr	3	--	--	--	--	--	+4

TABLE 7

QUALITATIVE METHOD EVALUATION

Criteria	Survey	SedPin	SedTab	FelMrkr	REEMrkr	CesMrkr
Datum (+Real/-Relative)	+	-	+	-	-	-
Monitor Erosion (+Yes/-No)	+	+	+	-	-	-
Data Loss Prob. (+Low/-High)	+	-	+	-	-	-
Precision (+High/oMed/-Low)	-	o	+	o	-	-
Cost (+Low/oMed/-High)	o	+	o	+	-	-
Logistics (+Easy/oMed/-Hard)	o	+	-	o	o	o

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FIGURES

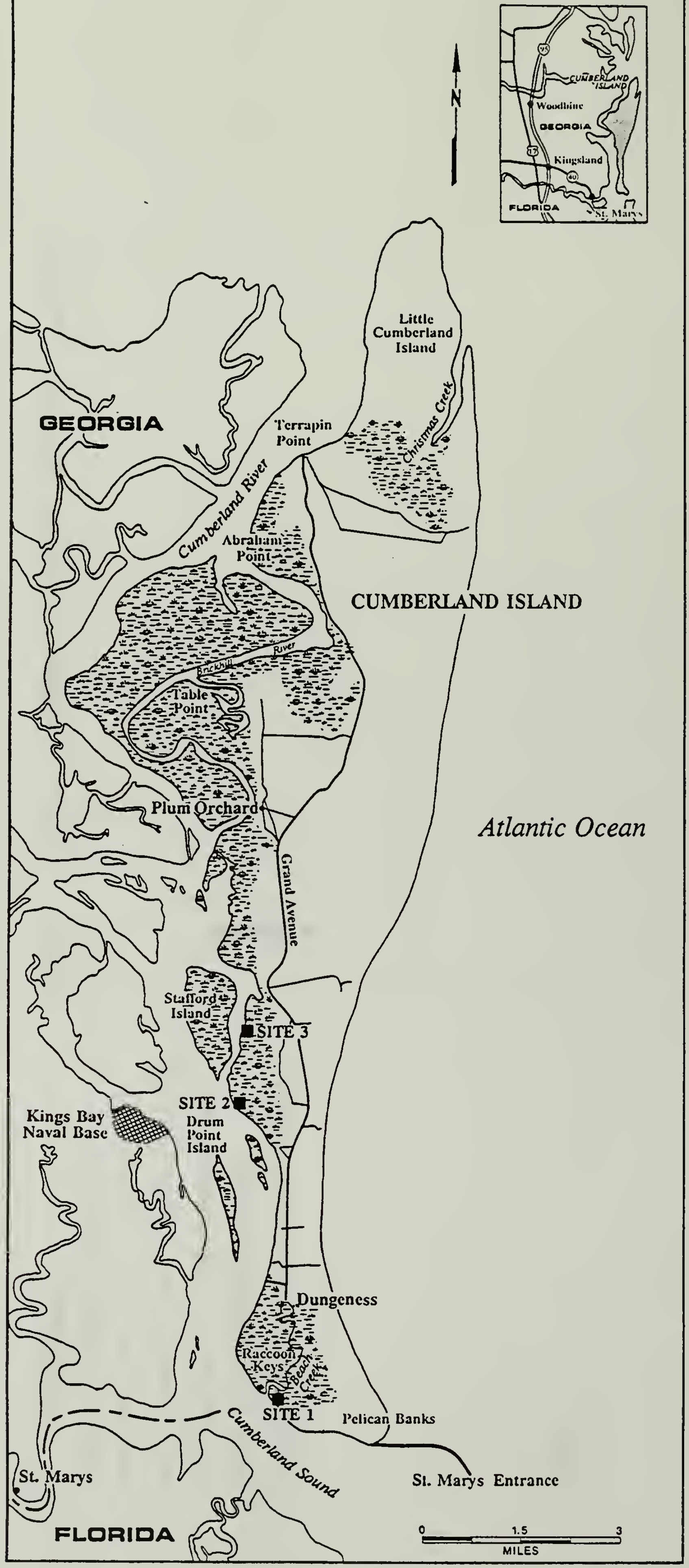


Figure 1: Location of Cumberland Island, Georgia

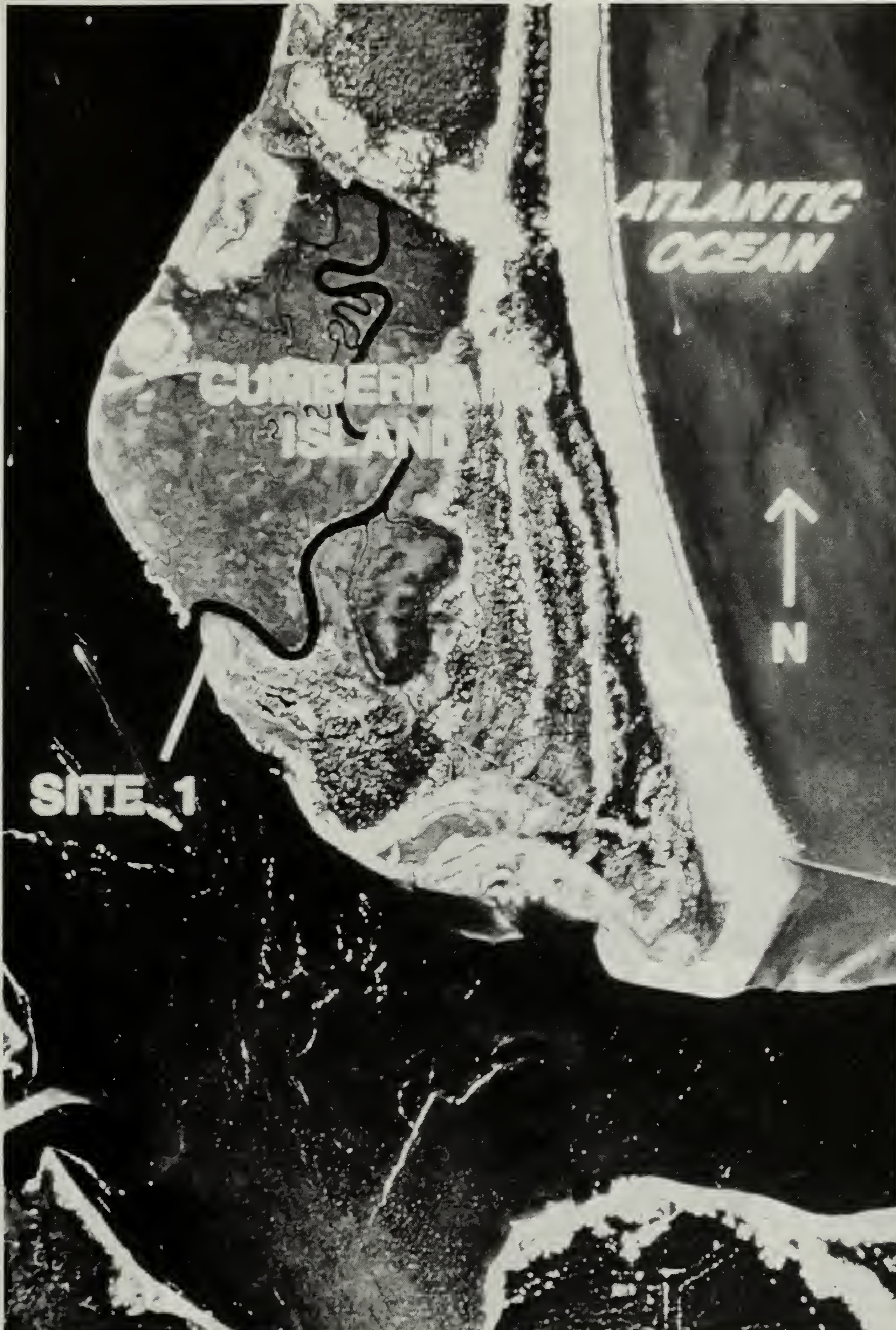


Figure 2. Location of Site 1

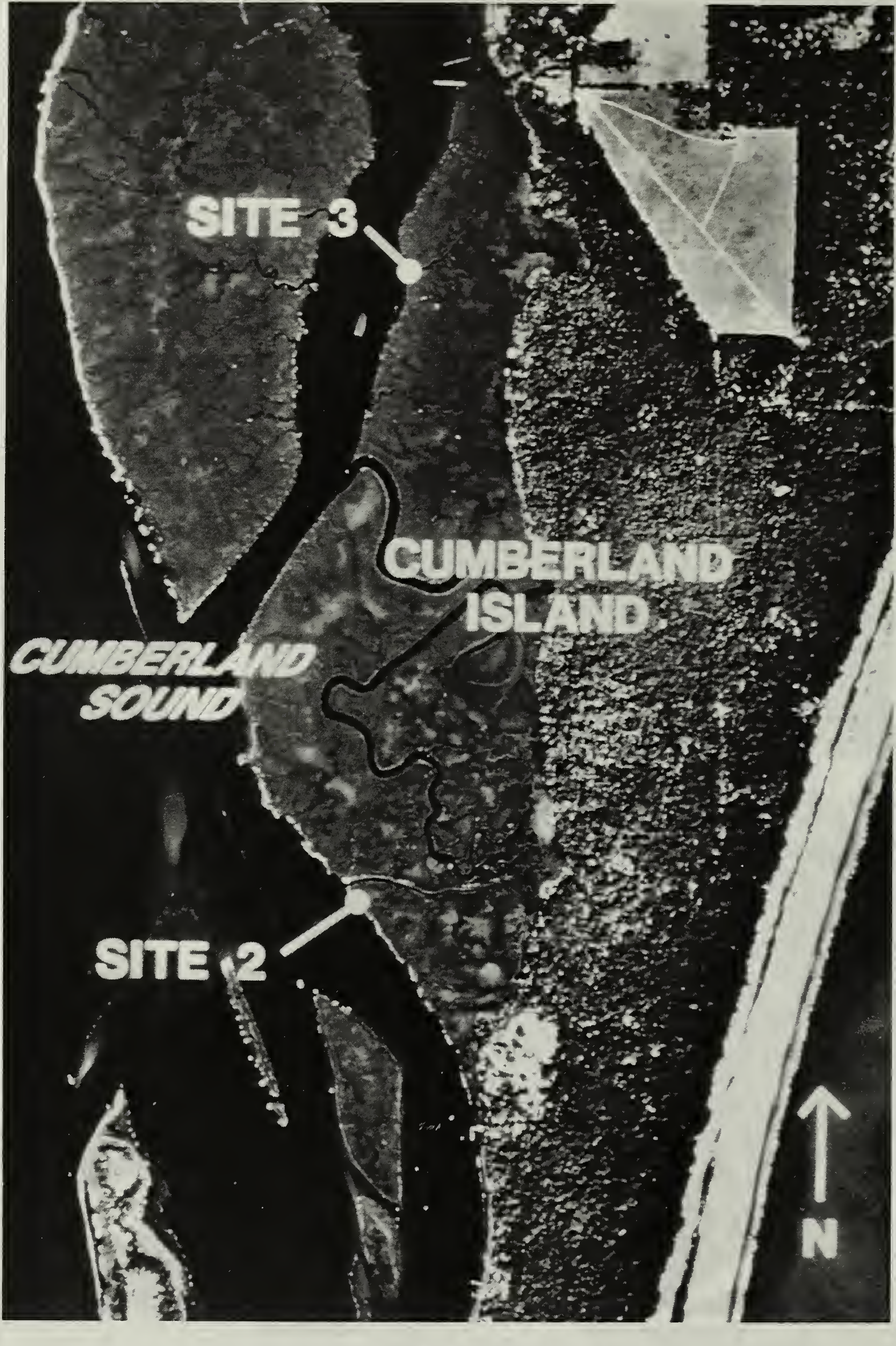


Figure 3. Locations of Sites 2 and 3

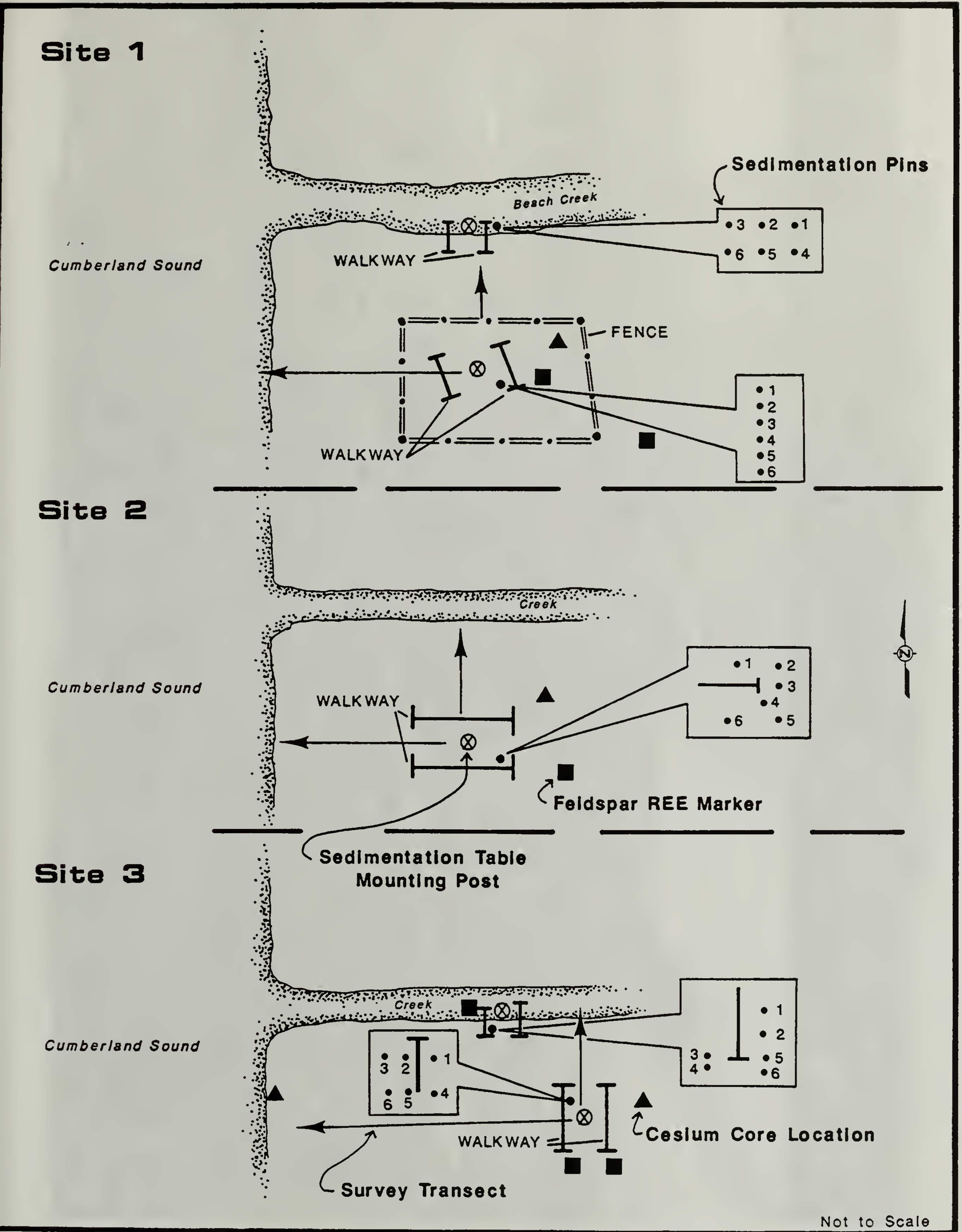


FIGURE 4: PLAN VIEW OF MARSH/MUDFLAT MEASUREMENT LOCATIONS

Figure 5. Mudflat Walkway at Site 1

Figure 6. Electronic Distance Meter Unit used to tie-in Subdatums to Benchmarks

Figure 7. Sighting with Electronic Distance Meter to Prism Cluster

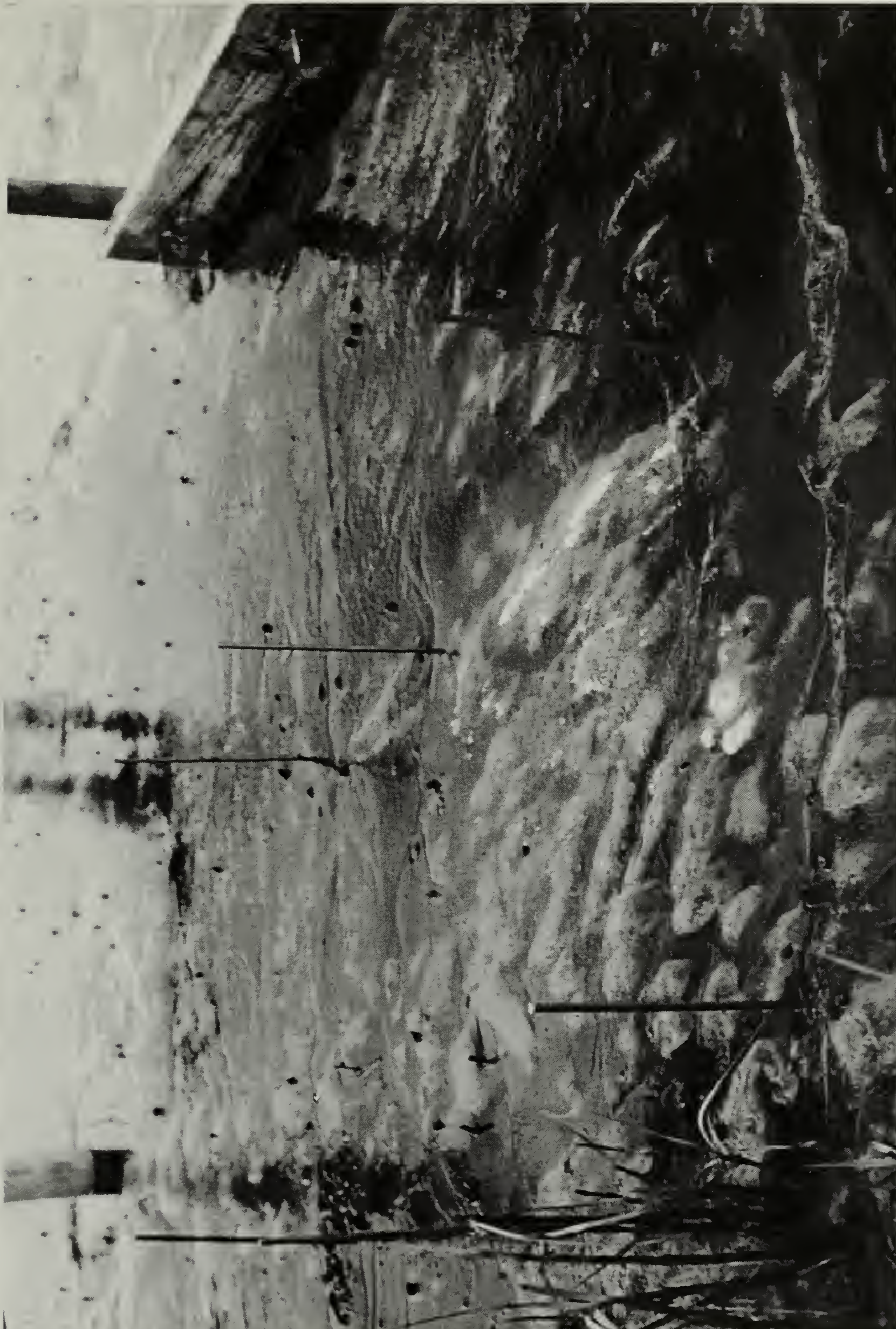


Figure 8. Sedimentation Pin Array and Clay/Feldspar Marker in Mudflat

Figure 9. Clay/Feldspar Marker in Marsh

Figure 10. Setting of Sedimentation Table in Mounting Post

Figure 11. Sedimentation Table Measurements of Marsh Surface

Figure 12. Sedimentation Table Measurements of Mudflat Surface

Figure 13. Spraying of Rare-earth element Marker Surface

SITE 1: MARSH (SOUND) PROFILE

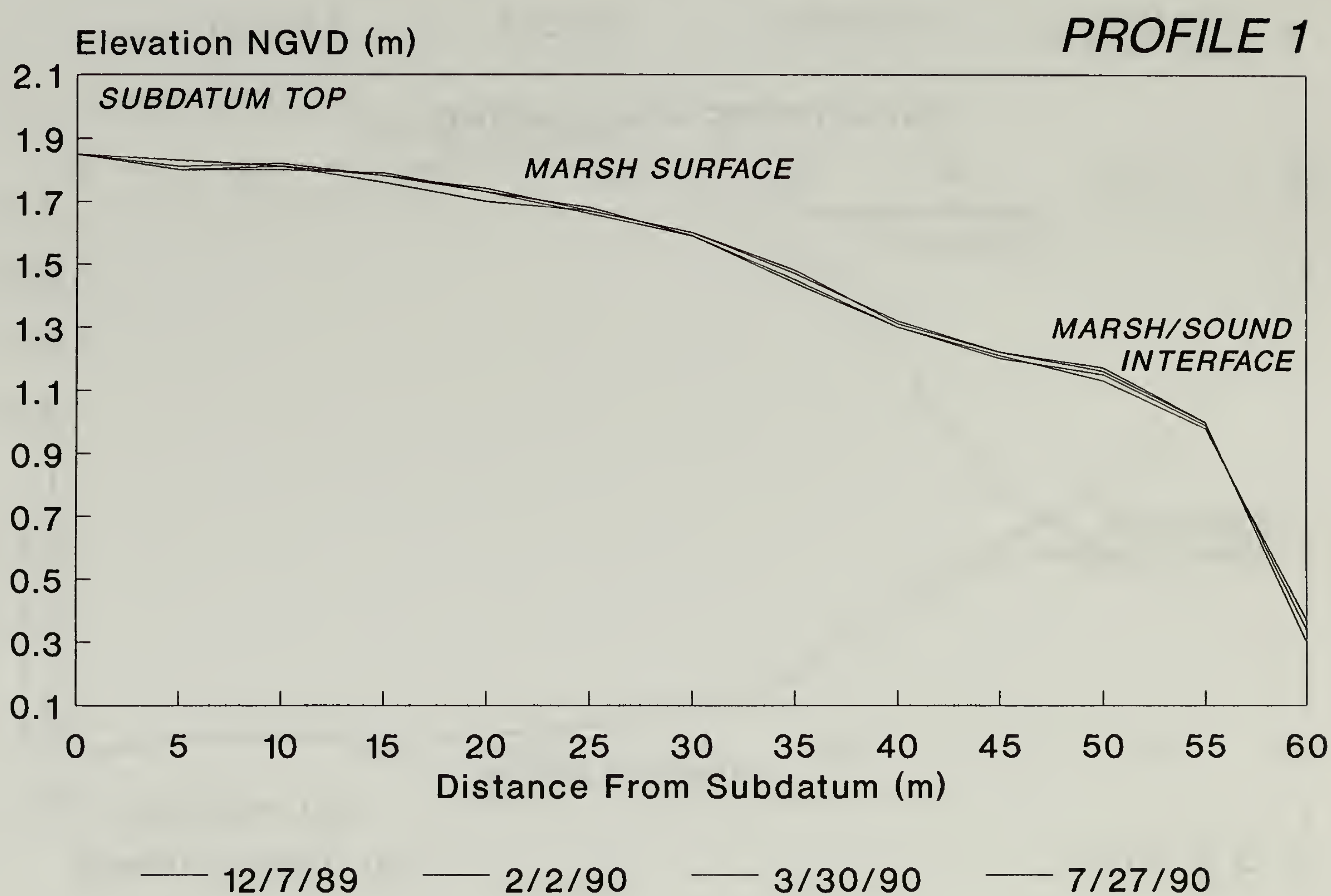


Figure 14

SITE 1: MUDFLAT (CREEK) PROFILES

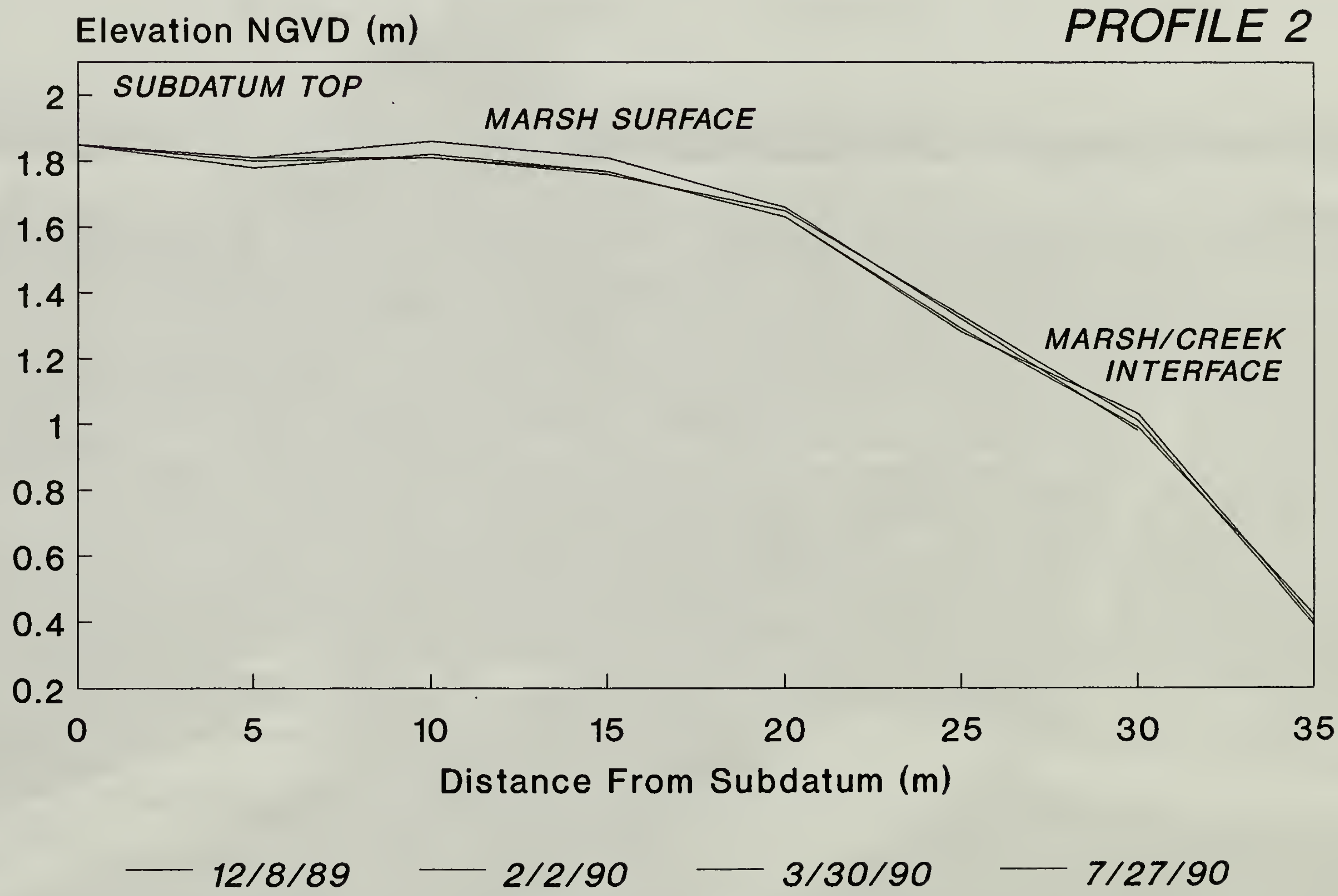


Figure 15

SITE 2: MARSH (SOUND) PROFILES

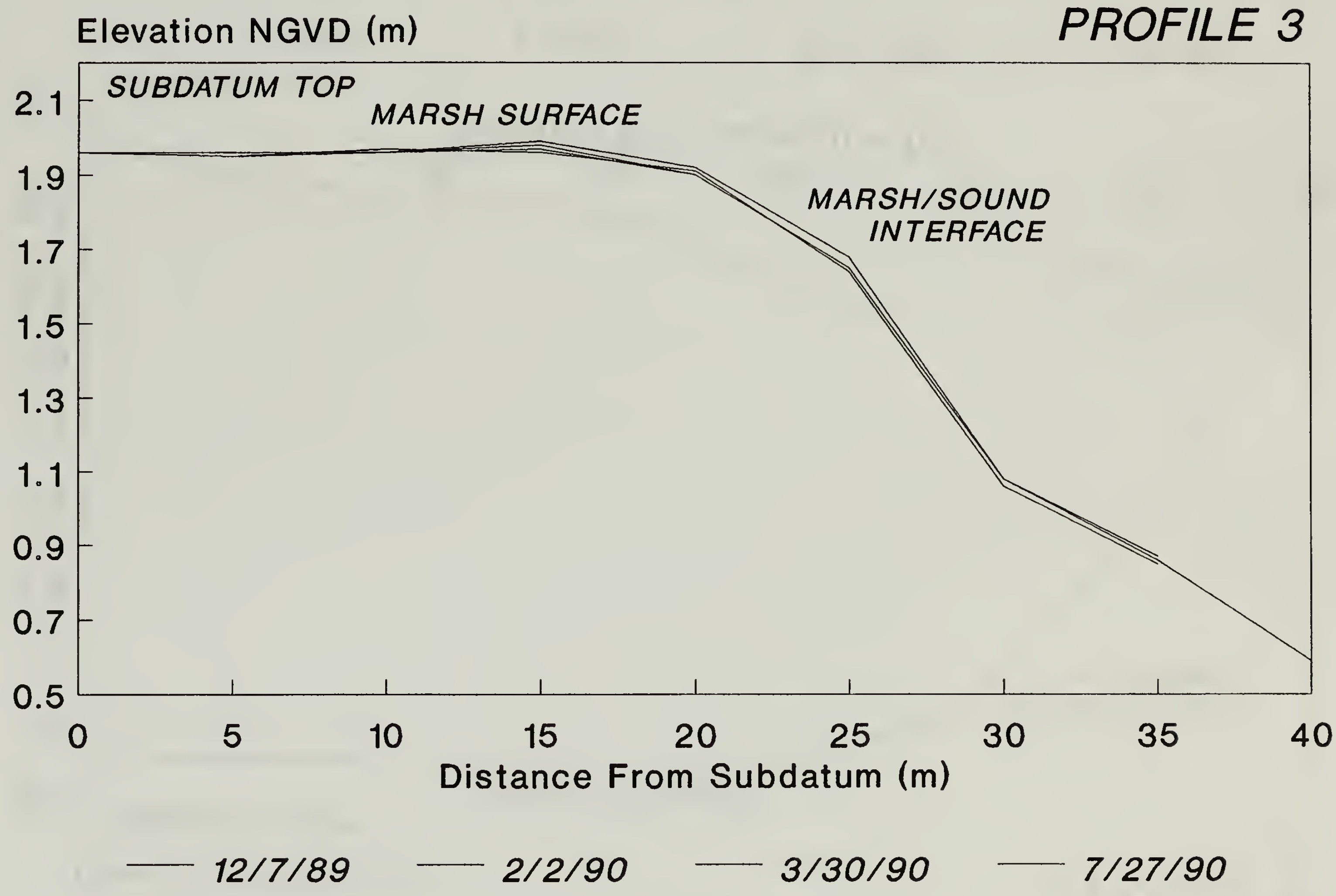


Figure 16

SITE 2: MUDFLAT (CREEK) PROFILES

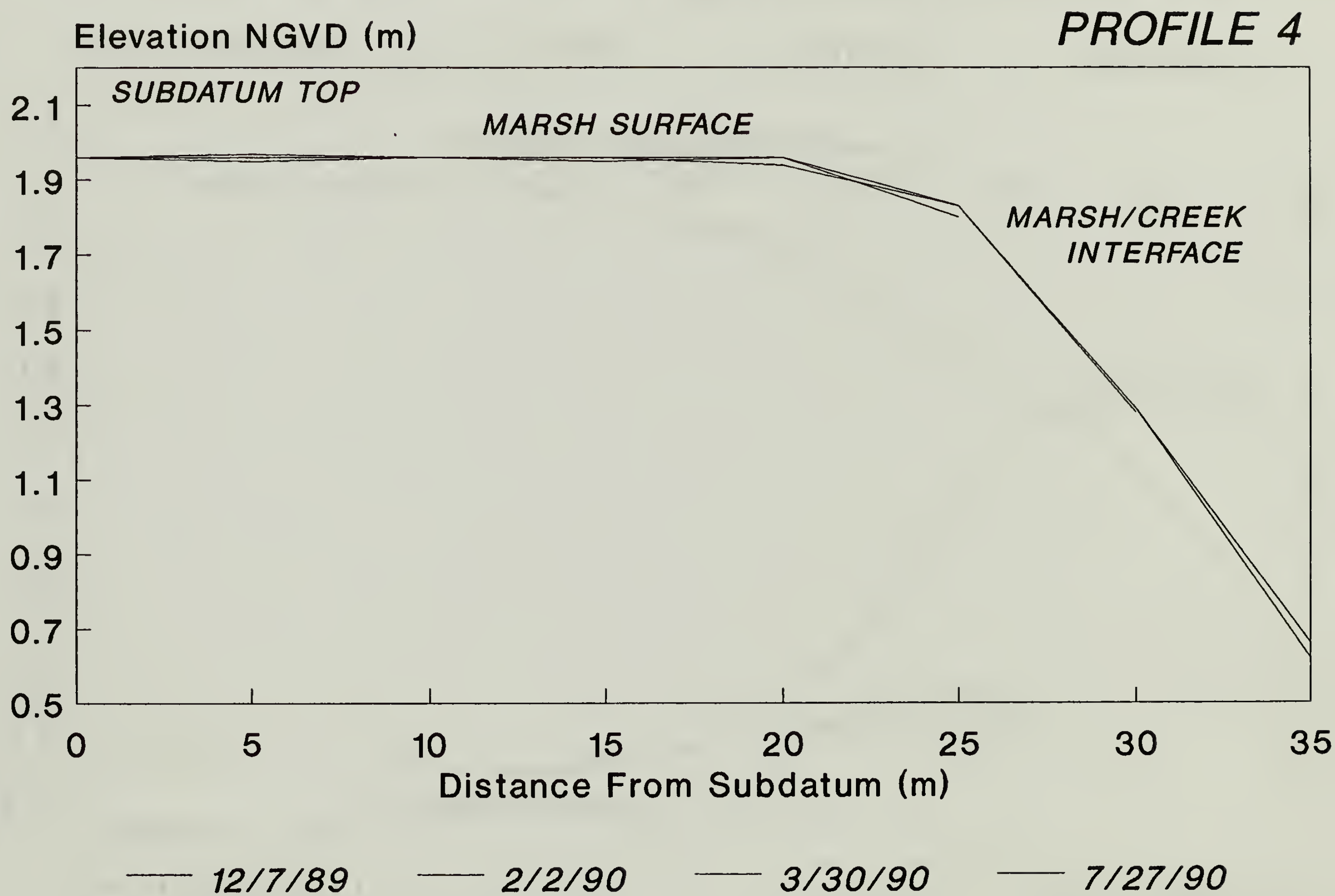


Figure 17

SITE 3: MARSH (SOUND) PROFILES

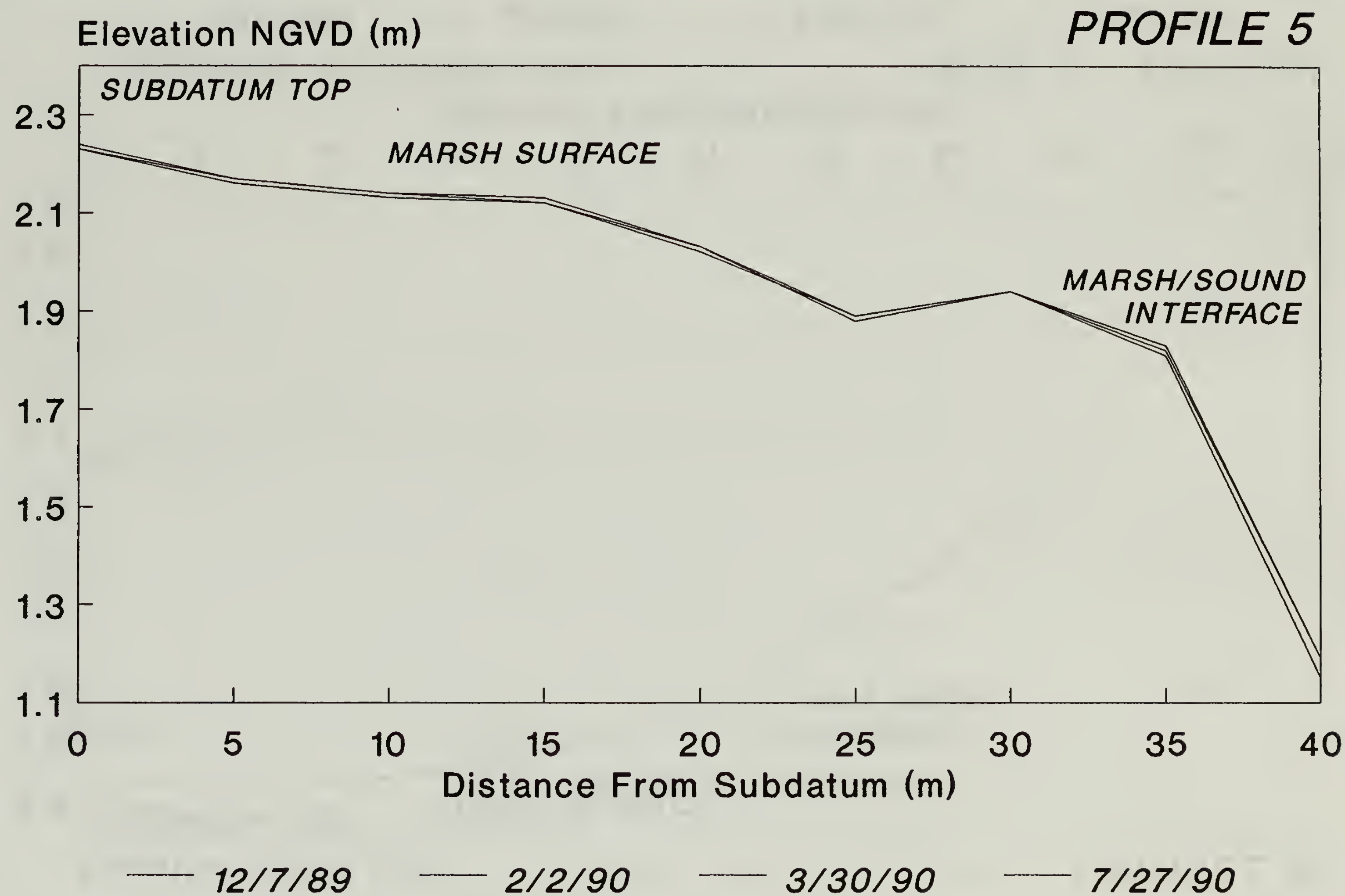


Figure 18

SITE 3: MUDFLAT (CREEK) PROFILES

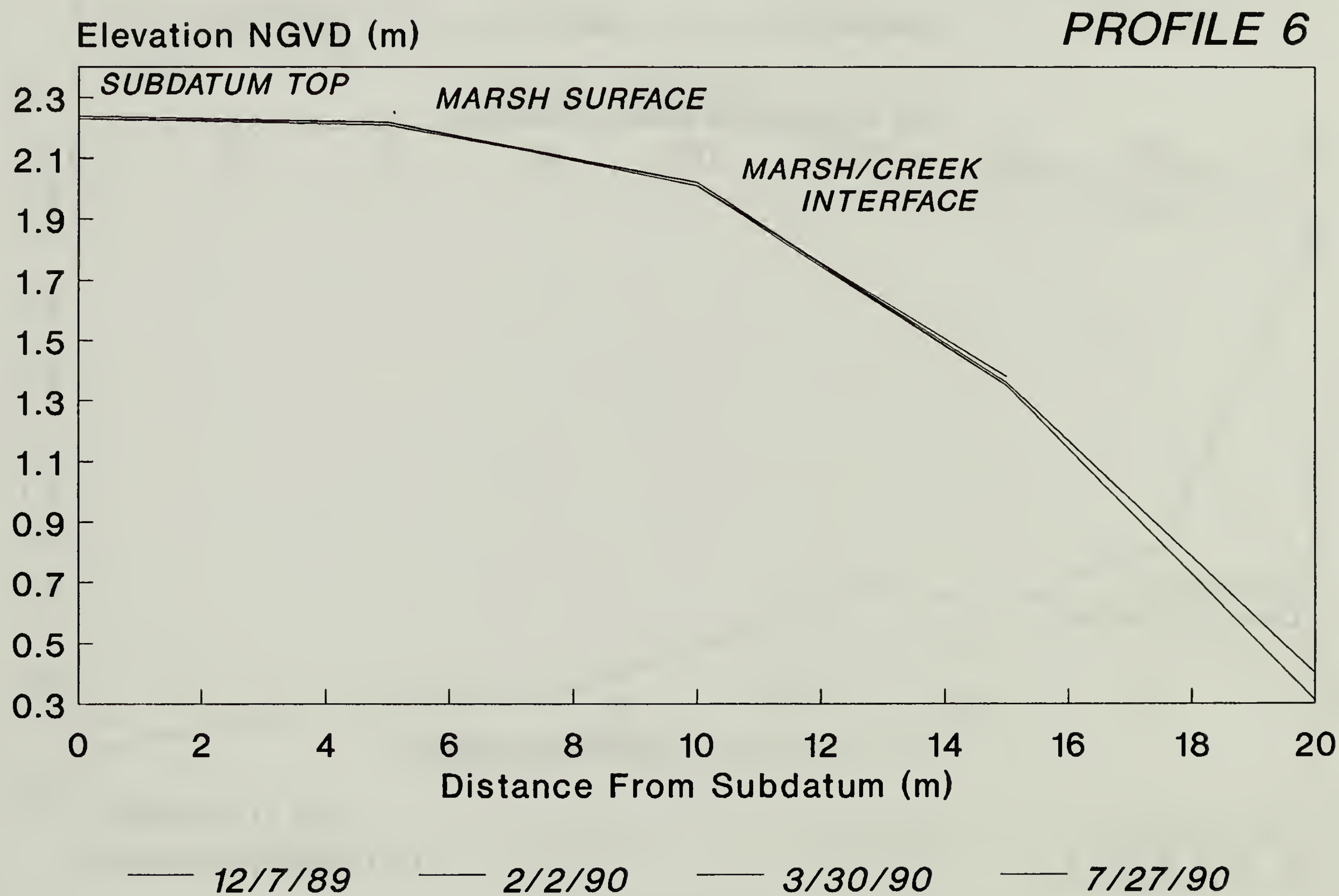


Figure 19

CUMULATIVE SEDIMENTATION PIN CHANGES

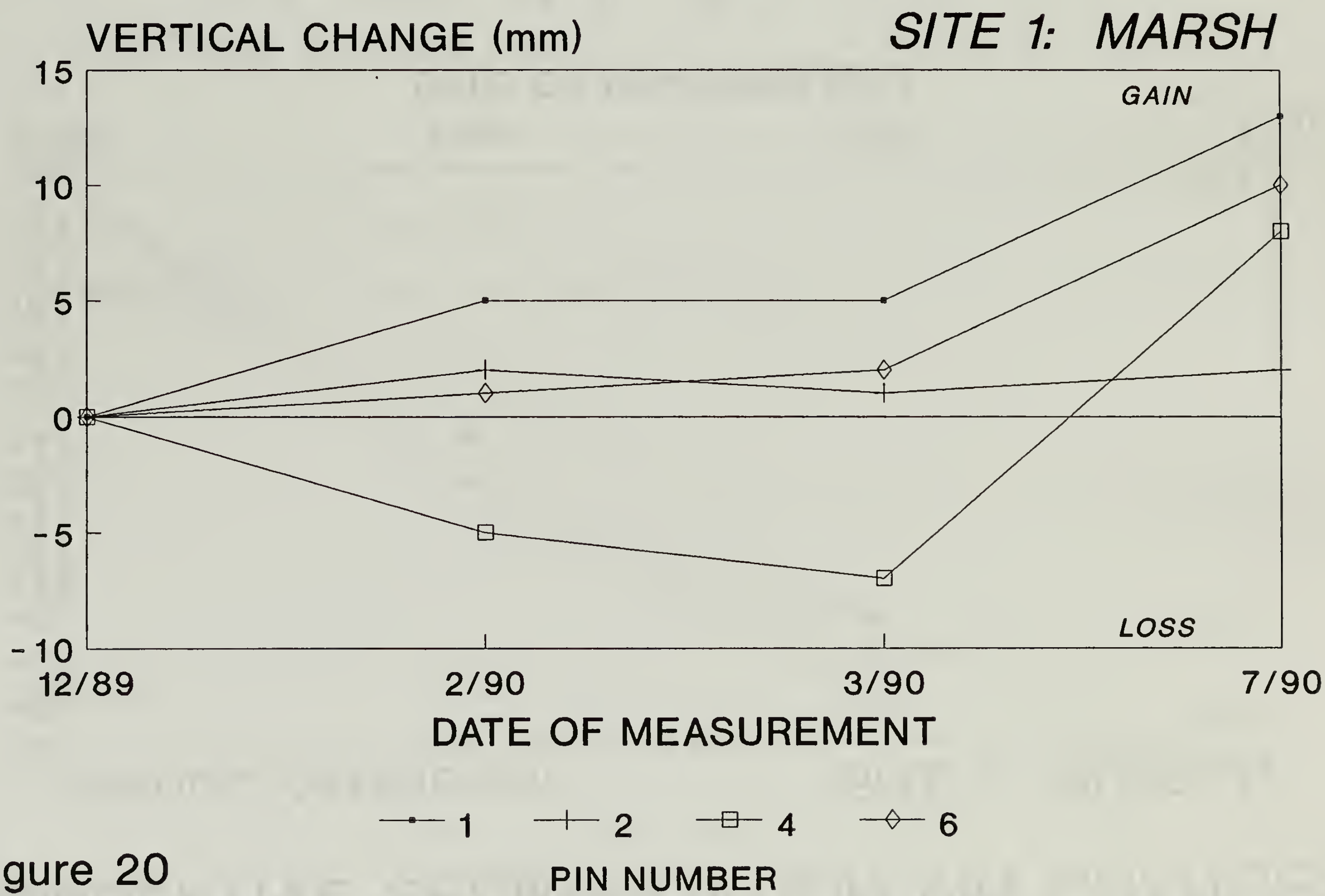


Figure 20

NATIONAL PARK SERVICE — WOODWARD-CLYDE CONSULTANTS

CUMULATIVE SEDIMENTATION PIN CHANGES

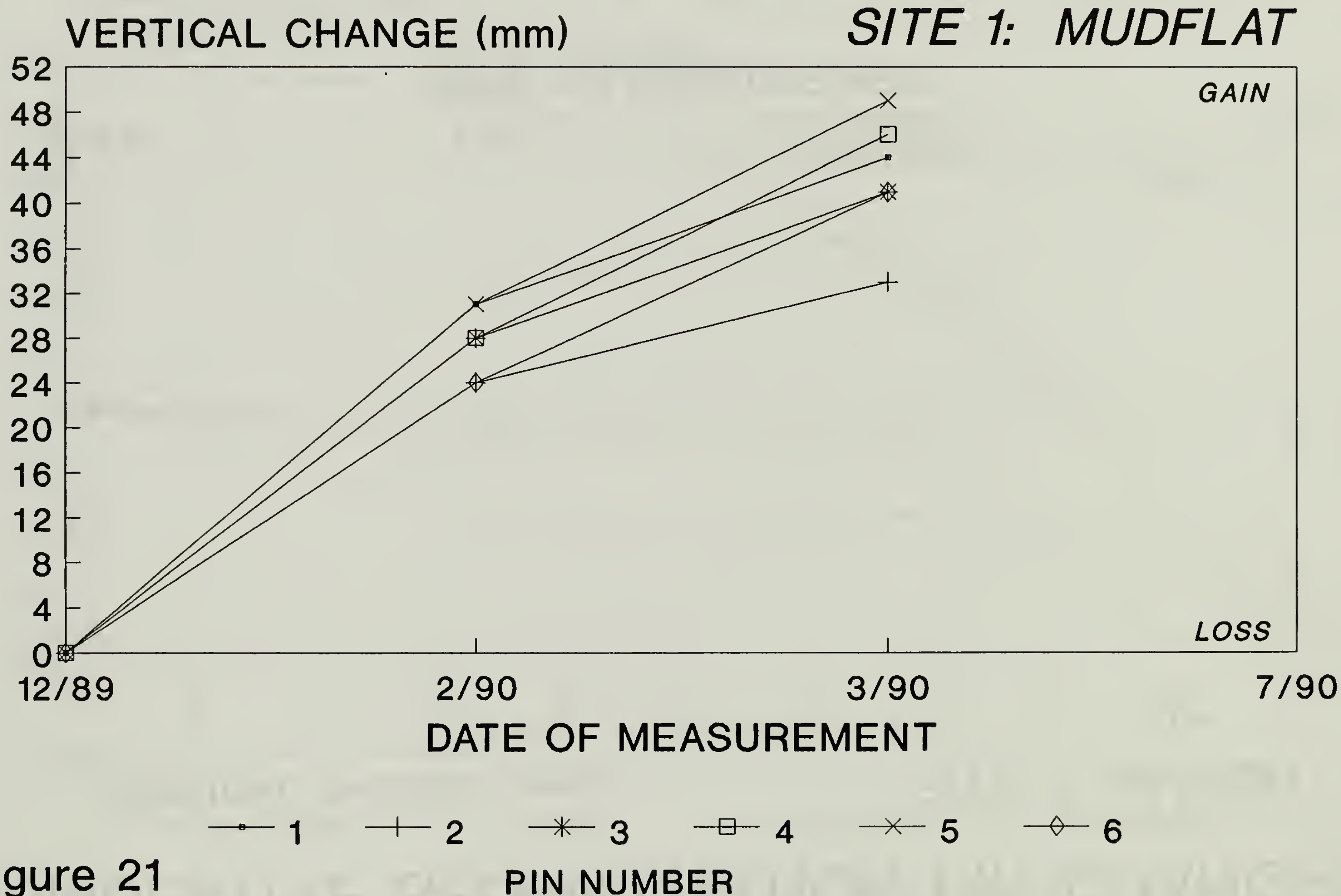


Figure 21

NATIONAL PARK SERVICE — WOODWARD-CLYDE CONSULTANTS

CUMULATIVE SEDIMENTATION PIN CHANGES

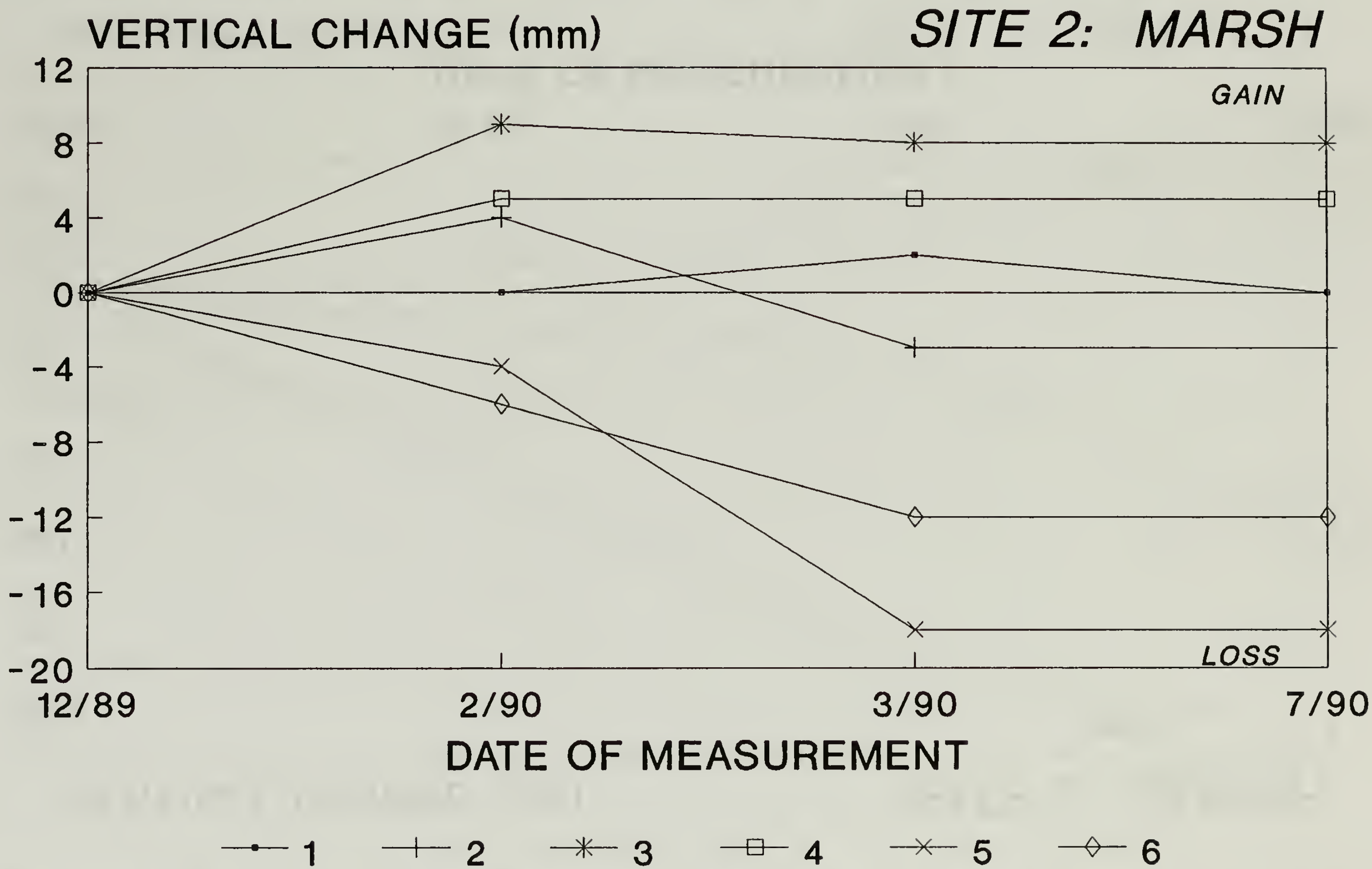


Figure 22

NATIONAL PARK SERVICE — WOODWARD-CLYDE CONSULTANTS

CUMULATIVE SEDIMENTATION PIN CHANGES

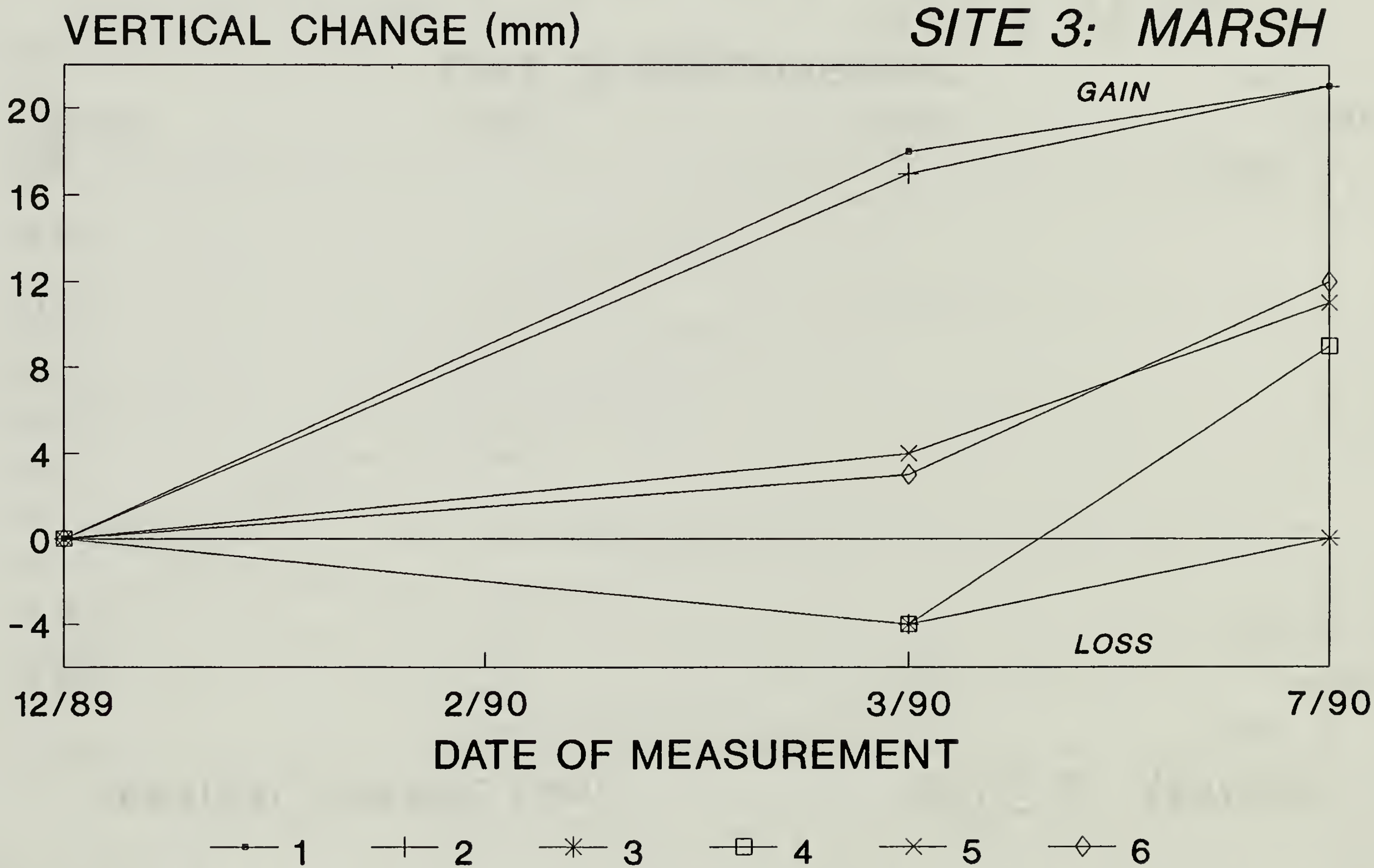


Figure 23

NATIONAL PARK SERVICE — WOODWARD-CLYDE CONSULTANTS

CUMULATIVE SEDIMENTATION PIN CHANGES

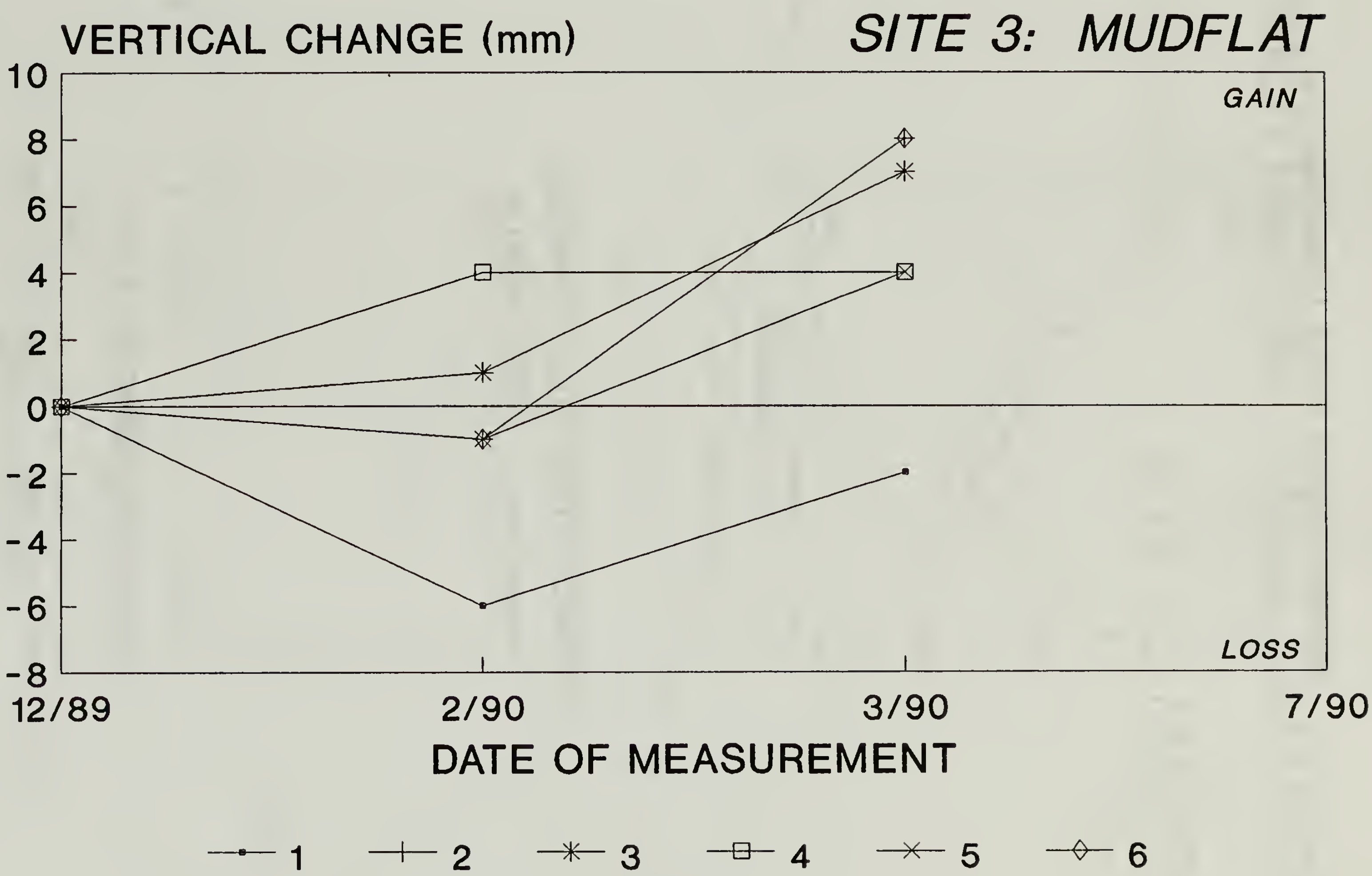
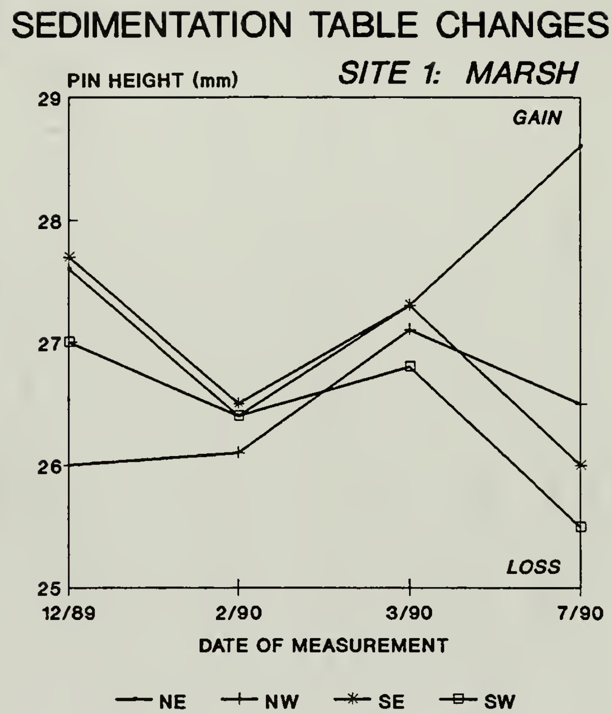
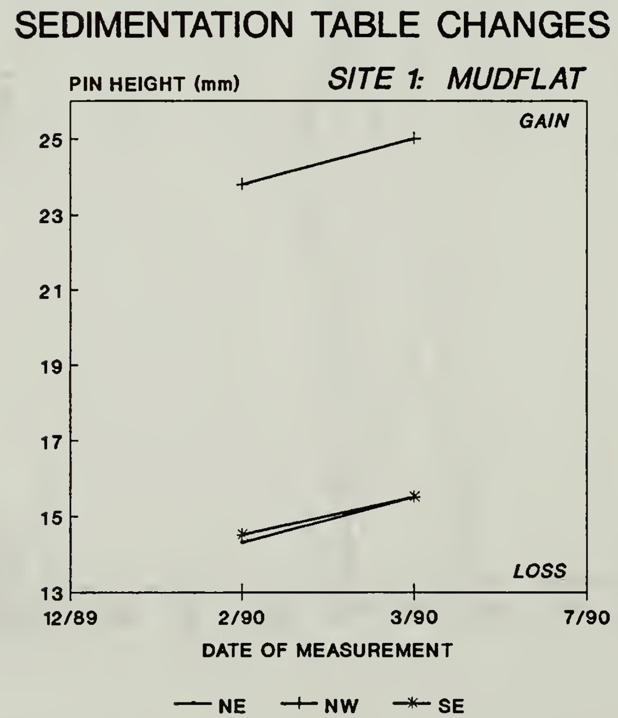


Figure 24

NATIONAL PARK SERVICE — WOODWARD-CLYDE CONSULTANTS



SEDIMENTATION TABLE CHANGES
PIN HEIGHT (mm)
SITE 1: MARSH
GAIN
LOSS
29
28
27
26
25
12/89
2/90
3/90
7/90
DATE OF MEASUREMENT
NE
NW
SE
SW



SEDIMENTATION TABLE CHANGES
PIN HEIGHT (mm)
SITE 1: MUDFLAT
GAIN
LOSS
25
23
21
19
17
15
13
12/89
2/90
3/90
7/90
DATE OF MEASUREMENT
NE
NW
SE

Figure 25

SEDIMENTATION TABLE CHANGES

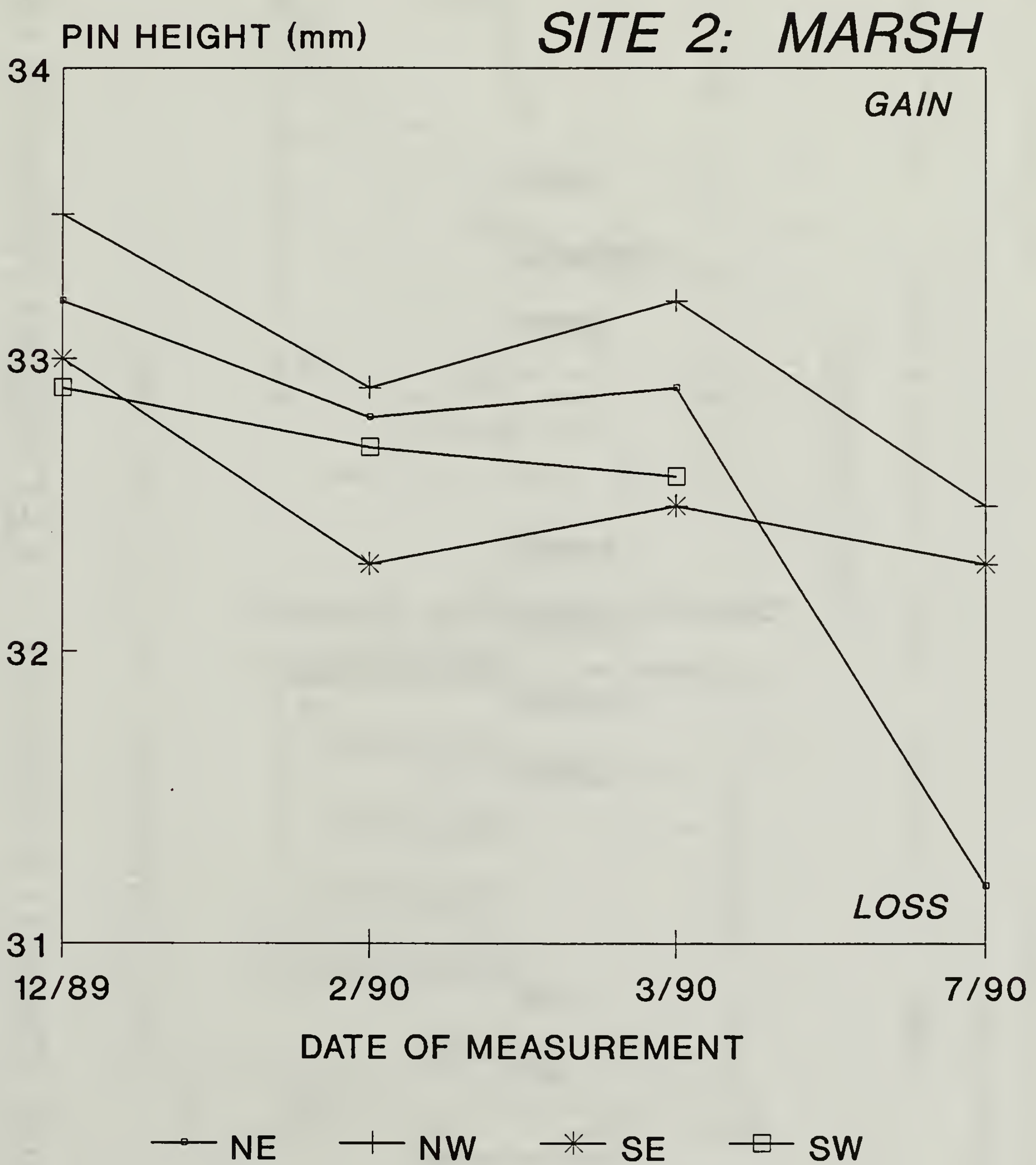
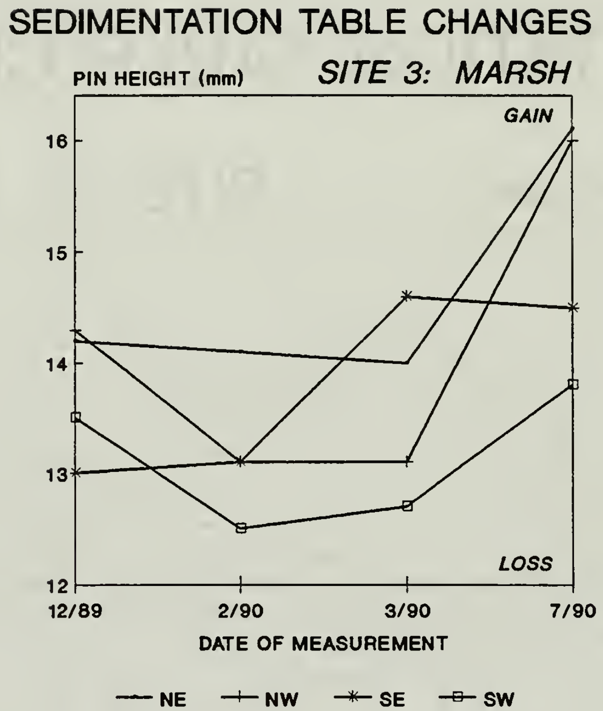


Figure 26


SEDIMENTATION TABLE CHANGES
PIN HEIGHT (mm)
SITE 3: MARSH
GAIN
LOSS
16
15
14
13
12
12/89
2/90
3/90
7/90
DATE OF MEASUREMENT
NE
NW
SE
SW

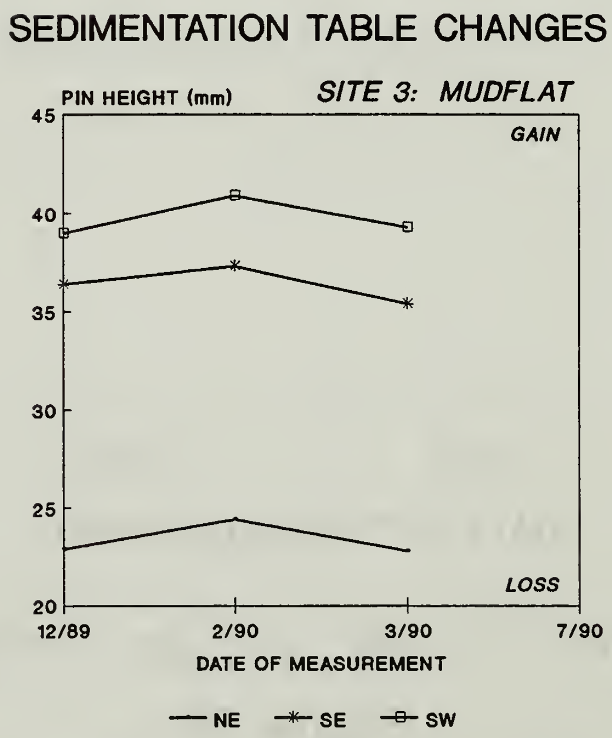

SEDIMENTATION TABLE CHANGES
PIN HEIGHT (mm)
SITE 3: MUDFLAT
GAIN
LOSS
45
40
35
30
25
20
12/89
2/90
3/90
7/90
DATE OF MEASUREMENT
NE
SE
SW

Figure 27

RARE-EARTH ELEMENT - FELDSPAR MARKER RESULTS

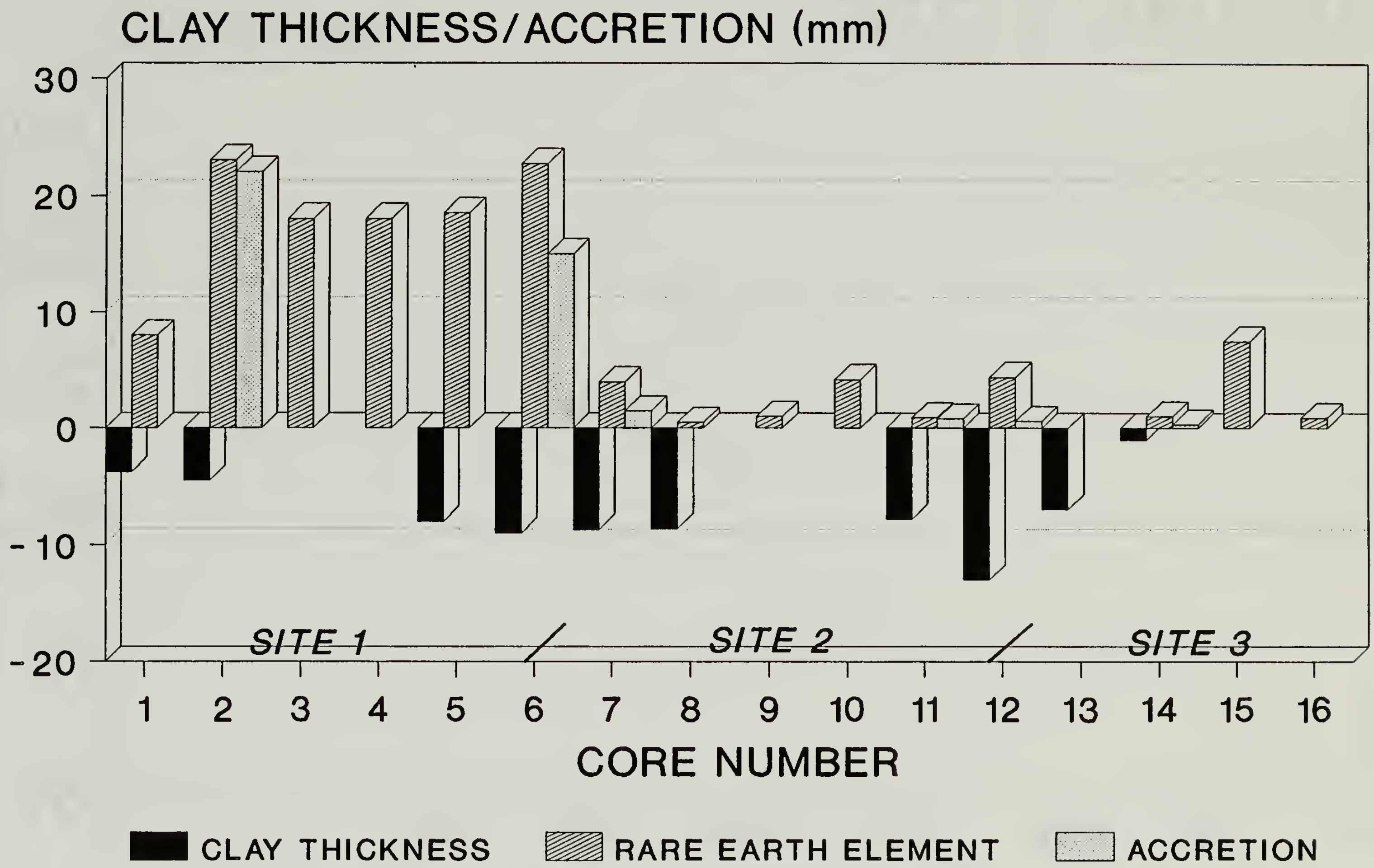


Figure 28

BULK DENSITY DETERMINATIONS FOR THREE SITES

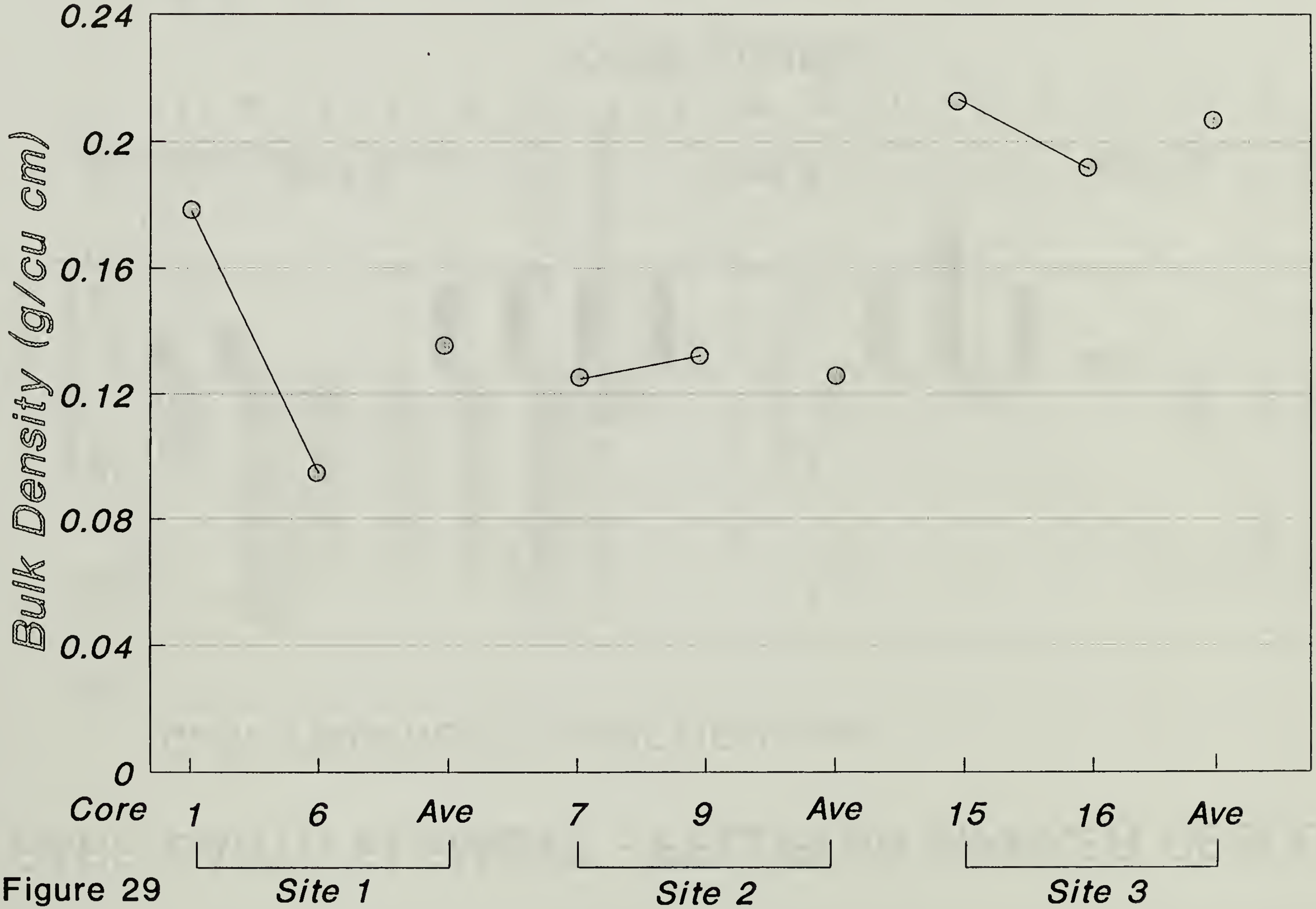


Figure 29

CESIUM PROFILE

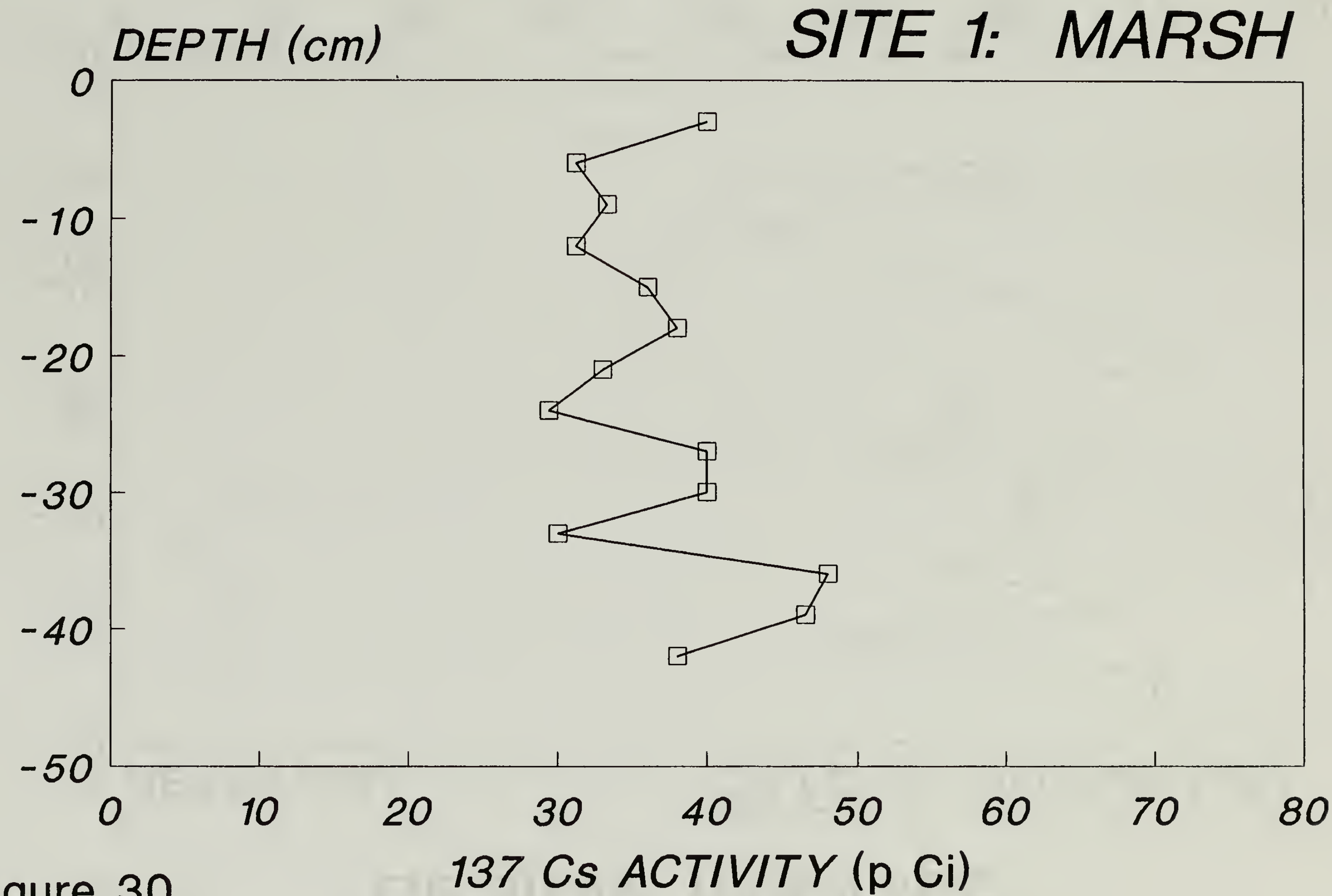


Figure 30

CESIUM PROFILE

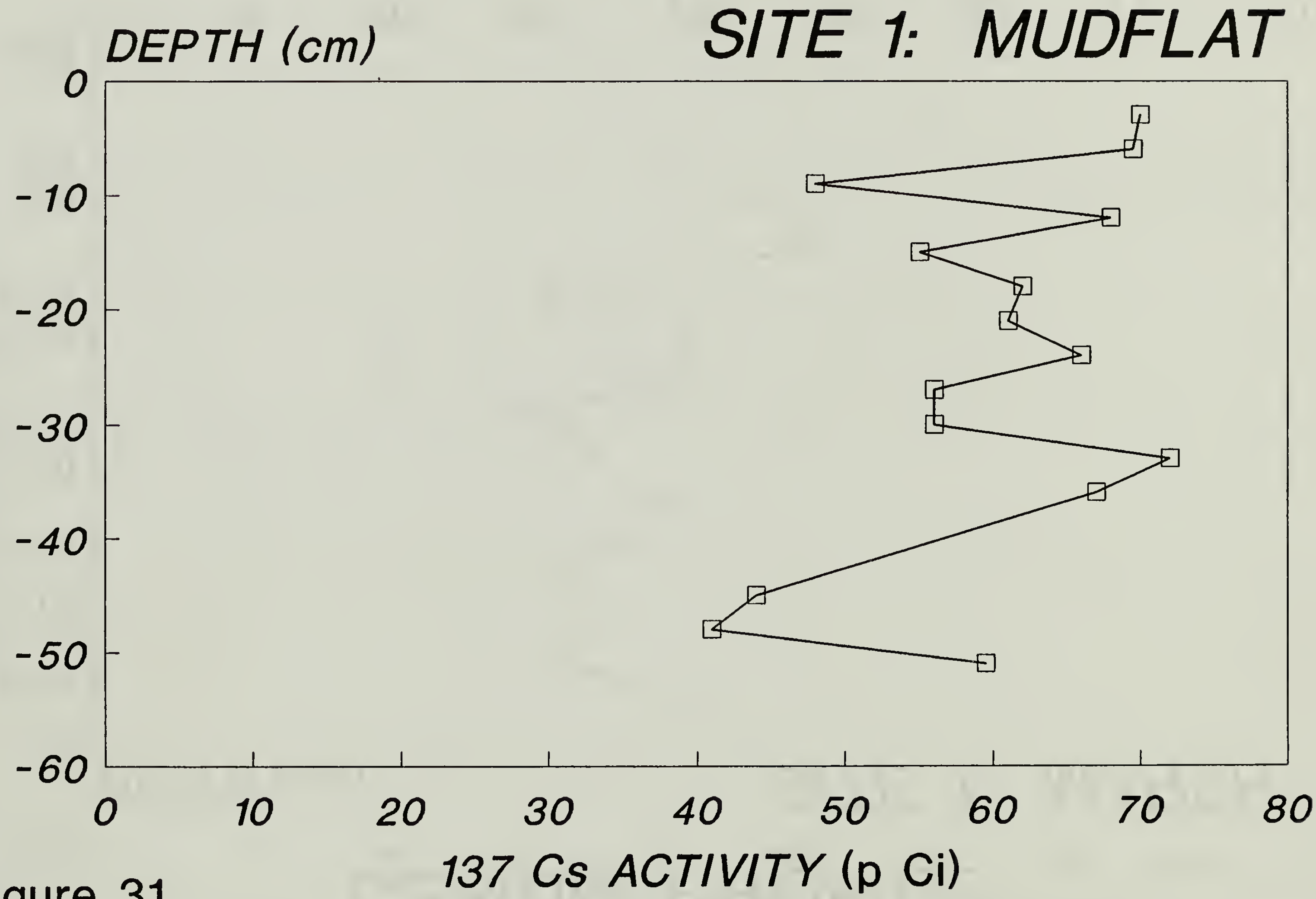


Figure 31

CESIUM PROFILE

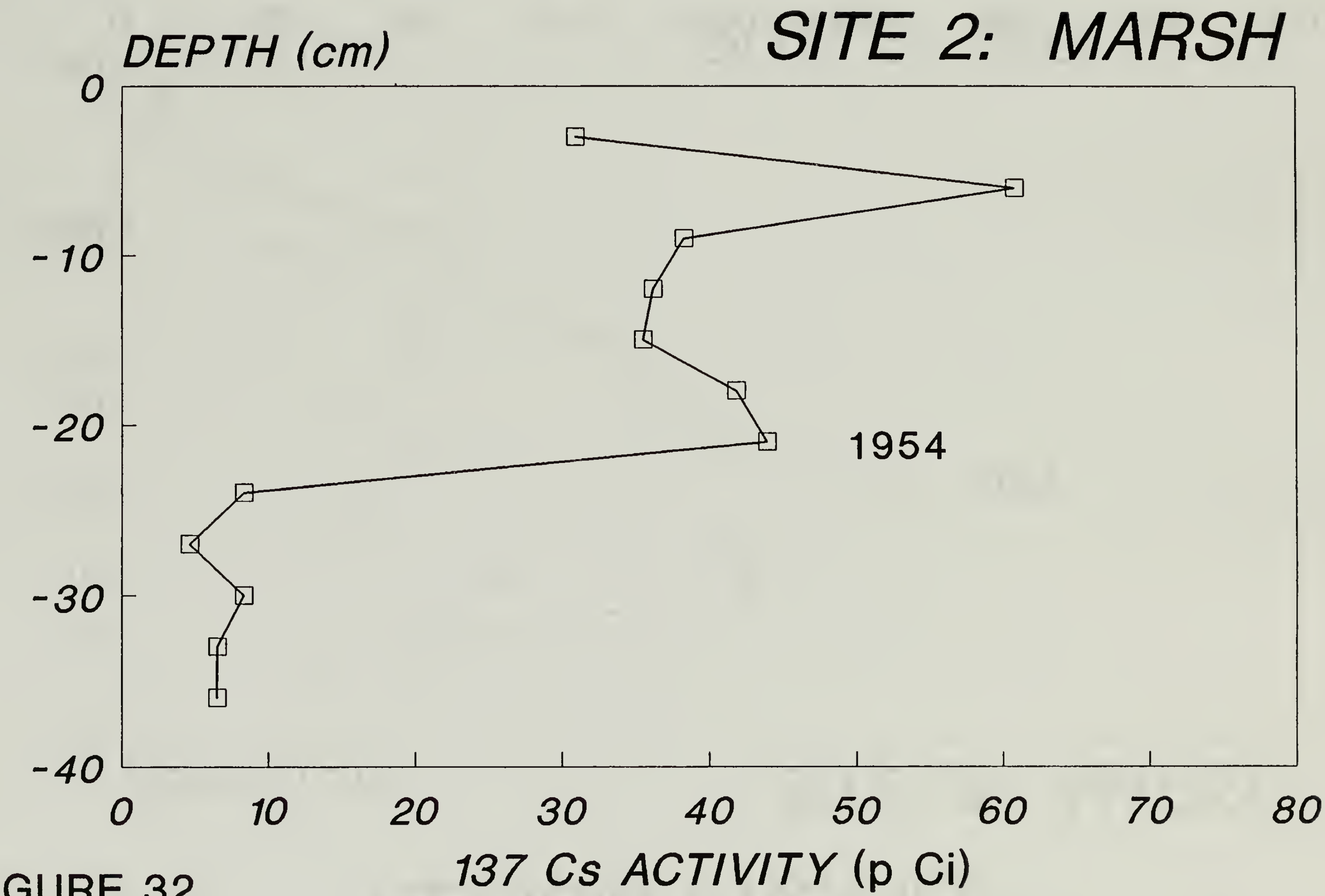


FIGURE 32

CESIUM PROFILE

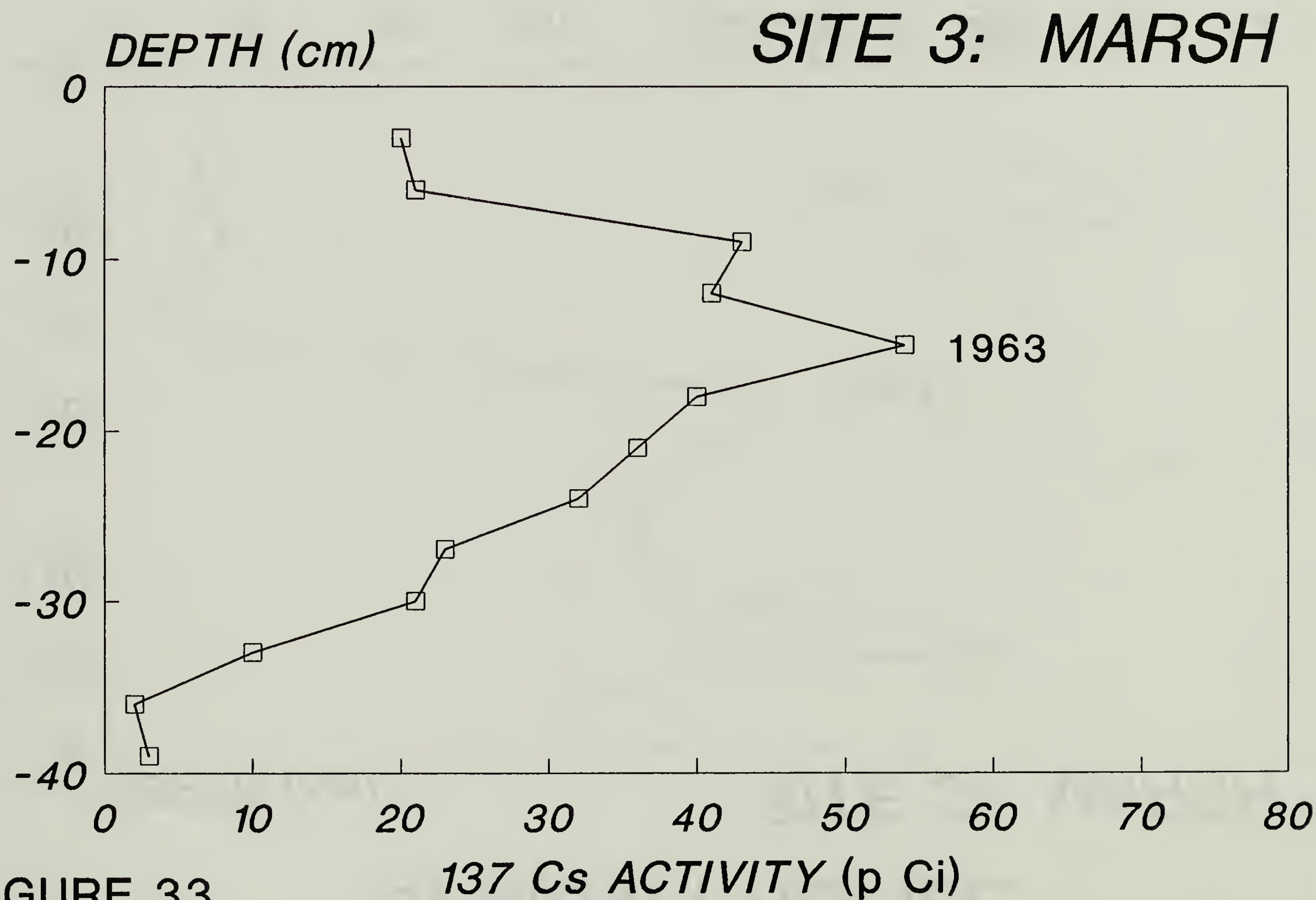


FIGURE 33

CESIUM PROFILE

SITE 3: MUDFLAT

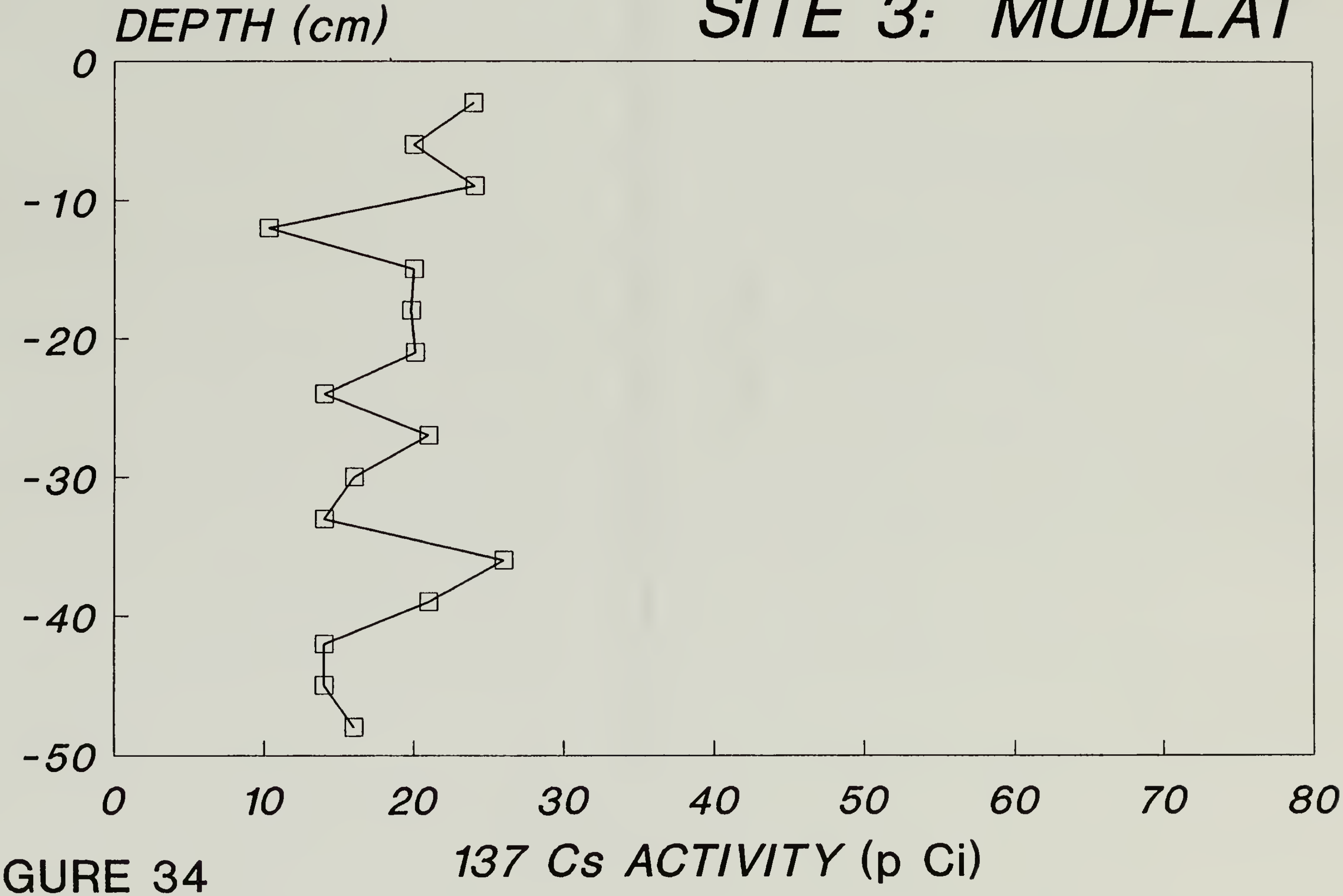


FIGURE 34

APPENDIX A

SUMMARY ELEVATION DATA FROM TOPOGRAPHIC SURVEYS

APPENDIX A: SUMMARY ELEVATION DATA

CUMBERLAND ISLAND

Elevations By Distance

Datum: NGVD

Profile Line 1

Locality - CI Total Surveys - 4 Units - M Total points - 13

Date	Survey	0	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0	60.0
891207	1	1.85	1.83	1.81	1.78	1.74	1.67	1.60	1.48	1.31	1.22	1.17	1.00	.00
900202	2	1.85	1.80	1.81	1.76	1.70	1.67	1.60	1.47	1.32	1.22	1.16	1.00	.50
900330	3	1.85	1.80	1.80	1.79	1.73	1.68	1.59	1.45	1.30	1.21	1.13	.98	.37
900727	4	1.85	1.81	1.82	1.78	1.73	1.66	1.54	1.44	1.30	1.20	1.15	.99	.34
Maximum		1.85	1.83	1.82	1.79	1.74	1.68	1.60	1.48	1.32	1.22	1.17	1.00	0.50
Minimum		1.85	1.80	1.80	1.76	1.70	1.66	1.54	1.44	1.30	1.20	1.13	0.98	0.34
Range		0.00	0.03	0.02	0.03	0.04	0.02	0.06	.04	.02	.02	.04	.02	.16
Mean		1.85	1.81	1.81	1.78	1.73	1.67	1.58	1.46	1.31	1.21	1.15	0.99	0.40
Std. Dev.		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09

CUMBERLAND ISLAND

Elevations By Distance

Datum: NGVD

Profile Line 2

Locality - CI Total Surveys - 4 Units - M Total points - 8

Date	Survey	0.0	5.0	10.0	15.0	20.0	25.0	30.0	35.0
891207	1	1.85	1.81	1.86	1.81	1.66	1.32	.98	.00
900202	2	1.85	1.78	1.82	1.77	1.63	1.29	.99	.42
900330	3	1.85	1.81	1.81	1.77	1.63	1.28	1.03	.40
900727	4	1.85	1.80	1.81	1.76	1.65	1.33	1.01	.39
Maximum		1.85	1.81	1.86	1.81	1.66	1.33	1.03	0.42
Minimum		1.85	1.78	1.81	1.76	1.63	1.28	0.98	0.39
Range		0.00	0.03	0.05	0.05	0.03	0.05	0.05	0.03
Mean		1.85	1.80	1.82	1.78	1.64	1.31	1.00	0.40
Std. Dev.		.00	.00	.00	.00	.00	.00	.00	0.00

CUMBERLAND ISLAND

Elevations By Distance

Datum: NGVD

Profile Line 3

Locality - CI Total Surveys - 4 Units - M Total points - 9

Date	Survey	0.0	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0
891207	1	1.96	1.95	1.96	1.97	1.90	1.65	0.00	0.00	0.00
900202	2	1.96	1.96	1.96	1.98	1.90	1.65	1.08	0.98	0.87
900330	3	1.96	1.96	1.96	1.99	1.92	1.68	1.08	0.86	0.59
900727	4	1.96	1.95	1.97	1.96	1.91	1.64	1.06	0.85	0.00
Maximum		1.96	1.96	1.97	1.99	1.92	1.68	1.08	0.98	0.87
Minimum		1.96	1.95	1.96	1.96	1.90	1.64	1.06	0.85	0.59
Range		0.00	0.01	0.01	0.03	0.02	0.04	0.02	0.13	0.28
Mean		1.96	1.95	1.96	1.98	1.91	1.65	1.07	0.89	0.73
Std. Dev.		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.20

CUMBERLAND ISLAND

Elevations By Distance

Datum: NGVD

Profile Line 4

Locality – CI Total Surveys – 4 Units – M Total points – 8

Date	Survey	0.0	5.0	10.0	15.0	20.0	25.0	30.0	35.0
891207	1	1.96	1.95	1.96	1.96	1.94	1.83	1.28	0.00
900202	2	1.96	1.96	1.96	1.96	1.96	1.83	1.29	0.66
900330	3	1.96	1.96	1.96	1.95	1.96	1.83	1.29	0.62
900727	4	1.96	1.97	1.96	1.95	1.96	1.80	.00	0.00
Maximum		1.96	1.97	1.96	1.96	1.96	1.83	1.29	0.66
Minimum		1.96	1.95	1.96	1.95	1.94	1.80	1.28	0.62
Range		0.00	0.02	0.00	0.01	0.02	0.03	0.01	0.04
Mean		1.96	1.96	1.96	1.95	1.96	1.82	1.29	0.64
Std. Dev.		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

CUMBERLAND ISLAND

Elevations By Distance

Datum: NGVD

Profile Line 5

Locality – CI Total Surveys – 4 Units – M Total points – 9

Date	Survey	0.0	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0
891208	1	2.24	2.17	2.14	2.12	2.03	1.88	1.81	1.15	
900202	2	2.24	2.17	2.14	2.12	2.03	1.89	1.94	1.81	1.15
900330	3	2.23	2.17	2.14	2.13	2.03	1.89	1.94	1.82	1.19
900727	4	2.23	2.16	2.13	2.12	2.02	1.89	1.94	1.83	1.19
Maximum		2.24	2.17	2.14	2.13	2.03	1.89	1.94	1.83	1.19
Minimum		2.23	2.16	2.13	2.12	2.02	1.88	1.81	1.15	1.15
Range		0.01	0.01	0.01	0.01	0.01	0.00	0.13	0.68	0.04
Mean		2.24	2.17	2.14	2.12	2.03	1.89	1.91	1.65	1.18
Std. Dev.		0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.34	0.00

CUMBERLAND ISLAND

Elevations By Distance

Datum: NGVD

Profile Line 6

Locality - CI   Total Surveys - 4   Units - M   Total points - 5

Date	Survey	0.0	5.0	10.0	15.0	20.0
891208	1	2.24	2.26	2.01	1.38	0.00
900202	2	2.24	2.22	2.01	1.35	0.31
900330	3	2.23	2.22	2.02	1.35	0.31
900727	4	2.23	2.21	2.02	1.36	0.40
Maximum		2.24	2.26	2.02	1.38	0.40
Minimum		2.23	2.21	2.01	1.35	0.31
Range		0.01	0.05	0.01	0.03	0.09
Mean		2.24	2.23	2.01	1.36	0.34
Std. Dev.		0.00	0.00	0.00	0.00	0.05

APPENDIX B

INCREMENTAL VOLUMETRIC CHANGES

APPENDIX B: INCREMENTAL VOLUMETRIC CHANGES

CUMBERLAND ISLAND, GA

Volume Changes By Vertical Slices

Datum: NGVD
Volume computed every 5.00 m
Profile Line 1

Survey Numbers: 1 to 2

Starting distance = 0.00 m, Ending Distance = 50.00 m

Dist. m	891207 m	Elevation 900202 m	Change m	Elevation Change m3/m	Volume Net Volume m3/m	Cumulative Gross Volume m3/m	Cumulative Thickness (Net) m
0.0	1.85	1.85	0.00	0.000	0.000	0.000	0.000
5.0	1.83	1.80	-0.03	-0.075	-0.075	0.075	-0.015
10.0	1.81	1.81	0.00	-0.075	-0.150	0.150	-0.015
15.0	1.78	1.76	-0.02	-0.050	-0.200	0.200	-0.013
20.0	1.74	1.70	-0.04	-0.150	-0.350	0.350	-0.018
25.0	1.67	1.67	0.00	-0.100	-0.450	0.450	-0.018
30.0	1.60	1.60	0.00	0.000	-0.450	0.450	-0.015
35.0	1.48	1.47	-0.01	-0.025	-0.475	0.475	-0.014
40.0	1.31	1.32	0.01	0.000	-0.475	0.475	-0.012
45.0	1.22	1.22	0.00	0.025	-0.450	0.500	-0.010
50.0	1.17	1.16	-0.01	-0.025	-0.475	0.525	-0.009

Cut/Fill Computation from: 891207 to 900202

Point	Distance m	Elevation m	Volume m3/m	Thickness m	Cum.Vol. m3/m	Gross Vol m3/m
1	10.00	1.81	-0.15	-0.02	-0.15	0.15
2	25.00	1.67	-0.30	-0.02	-0.45	0.45
3	37.50	1.40	-0.04	-0.00	-0.49	0.49
END	50.00	1.16	-0.01	0.00	-0.47	0.50

Profile Line 1

Survey Numbers: 2 to 3
Starting distance = 0.00 m, Ending Distance = 50.00 m

Dist. m	Elevation 900202 m	900330 m	Elevation Change m	Volume Change m3/m	Cumulative Net Volume m3/m	Cumulative Gross Volume m3/m	Thickness (Net) m
0.0	1.85	1.85	0.00	0.000	0.000	0.000	0.000
5.0	1.80	1.80	0.00	0.000	0.000	0.000	0.000
10.0	1.81	1.80	-0.01	-0.025	-0.025	0.025	-0.002
15.0	1.76	1.79	0.03	0.050	0.025	0.075	0.002
20.0	1.70	1.73	0.03	0.150	0.175	0.225	0.009
25.0	1.67	1.68	0.01	0.100	0.275	0.325	0.011
30.0	1.60	1.59	-0.01	0.000	0.275	0.325	0.009
35.0	1.47	1.45	-0.02	-0.075	0.200	0.400	0.006
40.0	1.32	1.30	-0.02	-0.100	0.100	0.500	0.002
45.0	1.22	1.21	-0.01	-0.075	0.025	0.575	0.001
50.0	1.16	1.13	-0.03	-0.100	-0.075	0.675	-0.002

Cut/Fill Computation from: 900202 to 900330

Point	Distance m	Elevation m	Volume m3/m	Thickness m	Cum.Vol. m3/m	Gross Vol m3/m
1	11.25	1.80	-0.03	0.00	-0.03	0.03
2	27.50	1.63	0.32	0.02	0.29	0.35
END	50.00	1.14	-0.36	-0.02	-0.08	0.71

—————— Profile Line 1 ——————

Survey Numbers: 3 to 4

Starting distance = 0.00 m, Ending Distance = 50.00 m

Dist. m	Elevation 900330 m	Elevation 900727 m	Elevation Change m	Volume Change m3/m	Cumulative Net Volume m3/m	Cumulative Gross Volume m3/m	Thickness (Net) m
0.0	1.85	1.85	0.00	0.000	0.000	0.000	0.000
5.0	1.80	1.81	0.01	0.025	0.025	0.025	0.005
10.0	1.80	1.82	0.02	0.075	0.100	0.100	0.010
15.0	1.79	1.78	−0.01	0.025	0.125	0.125	0.008
20.0	1.73	1.73	0.00	−0.025	0.100	0.150	0.005
25.0	1.68	1.66	−0.02	−0.050	0.050	0.200	0.002
30.0	1.59	1.54	−0.05	−0.175	−0.125	0.375	−0.004
35.0	1.45	1.44	−0.01	−0.150	−0.275	0.525	−0.008
40.0	1.30	1.30	0.00	−0.025	−0.300	0.550	−0.007
45.0	1.21	1.20	−0.01	−0.025	−0.325	0.575	−0.007
50.0	1.13	1.15	0.02	0.025	−0.300	0.600	−0.006

Cut/Fill Computation from: 900330 to 900727

Point	Distance m	Elevation m	Volume m3/m	Thickness m	Cum.Vol. m3/m	Gross Vol m3/m
1	13.33	1.79	0.13	0.01	0.13	0.13
2	20.00	1.73	−0.03	−0.00	−0.10	0.17
3	40.00	1.30	−0.40	−0.02	−0.30	0.57
END	50.00	1.14	0.00	0.00	−0.30	0.57

CUMBERLAND ISLAND, GA

Volume Changes By Vertical Slices

Datum: NGVD
Volume computed every 5.00 m
Profile Line 2

Survey Numbers: 1 to 2
Starting distance = 0.00 m, Ending Distance = 25.00 m

Dist.	Elevation 891207	900202	Elevation Change	Volume Change	Cumulative Net Volume	Cumulative Gross Volume	Thickness (Net)
m	m	m	m	m3/m	m3/m	m3/m	m
0.0	1.85	1.85	0.00	0.000	0.000	0.000	0.000
5.0	1.81	1.78	-0.03	-0.075	-0.075	0.075	-0.015
10.0	1.86	1.82	-0.04	-0.175	-0.250	0.250	-0.025
15.0	1.81	1.77	-0.04	-0.200	-0.450	0.450	-0.030
20.0	1.66	1.63	-0.03	-0.175	-0.625	0.625	-0.031
25.0	1.32	1.29	-0.03	-0.150	-0.775	0.775	-0.031

Cut/Fill Computation from: 891207 to 900202

Point	Distance m	Elevation m	Volume m3/m	Thickness m	Cum.Vol. m3/m	Gross Vol m3/m
END	25.00	1.31	-0.77	-0.03	-0.77	0.77

Profile Line 2

Survey Numbers: 2 to 3
Starting distance = 0.00 m, Ending Distance = 25.00 m

Dist. m	Elevation 900202 m	Elevation 900330 m	Elevation Change m	Volume Change m3/m	Cumulative Net Volume m3/m	Cumulative Gross Volume m3/m	Thickness (Net) m
0.0	1.85	1.85	0.00	0.000	0.000	0.000	0.000
5.0	1.78	1.81	0.03	0.075	0.075	0.075	0.015
10.0	1.82	1.81	-0.01	0.050	0.125	0.125	0.012
15.0	1.77	1.77	0.00	-0.025	0.100	0.150	0.007
20.0	1.63	1.63	0.00	0.000	0.100	0.150	0.005
25.0	1.29	1.28	-0.01	-0.025	0.075	0.175	0.003

Cut/Fill Computation from: 900202 to 900330

Point	Distance m	Elevation m	Volume m3/m	Thickness m	Cum.Vol. m3/m	Gross Vol m3/m
1	8.75	1.81	0.13	0.01	0.13	0.13
2	15.00	1.77	-0.03	-0.01	0.10	0.16
END	25.00	1.28	-0.02	-0.00	0.07	0.19

Profile Line 2

Survey Numbers: 3 to 4
Starting distance = 0.00 m, Ending Distance = 25.00 m

Dist. m	Elevation 900330 m	Elevation 900727 m	Elevation Change m	Volume Change m3/m	Cumulative Net Volume m3/m	Cumulative Gross Volume m3/m	Thickness (Net) m
0.0	1.85	1.85	0.00	0.000	0.000	0.000	0.000
5.0	1.81	1.80	-0.01	-0.025	-0.025	0.025	-0.005
10.0	1.81	1.81	-0.00	-0.025	-0.050	0.050	-0.005
15.0	1.77	1.76	-0.01	-0.025	-0.075	0.075	-0.005
20.0	1.63	1.65	-0.02	-0.025	-0.050	0.100	-0.002
25.0	1.28	1.33	0.05	0.175	0.125	0.275	0.005

Cut/Fill Computation from: 900330 to 900727

Point	Distance m	Elevation m	Volume m3/m	Thickness m	Cum.Vol. m3/m	Gross Vol m3/m
1	10.00	1.81	-0.05	0.00	-0.05	0.05
2	16.67	1.72	-0.03	0.00	-0.08	0.08
END	25.00	1.31	0.21	0.03	0.13	0.29

CUMBERLAND ISLAND, GA

Volume Changes By Vertical Slices

Datum: NGVD
Volume computed every 5.00 m
Profile Line 3

Survey Numbers: 1 to 2
Starting distance = 0.00 m, Ending Distance = 20.00 m

Dist. m	Elevation 891207 m	Elevation 900202 m	Elevation Change m	Volume Change m3/m	Cumulative Net Volume m3/m	Cumulative Gross Volume m3/m	Thickness (Net) m
0.0	1.96	1.96	0.00	0.000	0.000	0.000	0.000
5.0	1.95	1.96	0.01	0.025	0.025	0.025	0.005
10.0	1.96	1.96	0.00	0.025	0.050	0.050	0.005
15.0	1.97	1.98	0.01	0.025	0.075	0.075	0.005
20.0	1.90	1.90	0.00	0.025	0.100	0.100	0.005

Cut/Fill Computation from: 891207 to 900202

Point	Distance m	Elevation m	Volume m3/m	Thickness m	Cum.Vol. m3/m	Gross Vol m3/m
END	20.00	1.90	0.10	0.00	0.10	0.10

Profile Line 3

Survey Numbers: 2 to 3
Starting distance = 0.00 m, Ending Distance = 20.00 m

Dist. m	Elevation 900202 m	Elevation 900330 m	Elevation Change m	Volume Change m3/m	Cumulative Net Volume m3/m	Cumulative Gross Volume m3/m	Thickness (Net) m
0.0	1.96	1.96	0.00	0.000	0.000	0.000	0.000
5.0	1.96	1.96	0.00	0.000	0.000	0.000	0.000
10.0	1.96	1.96	0.00	0.000	0.000	0.000	0.000
15.0	1.98	1.99	0.01	0.025	0.025	0.025	0.002
20.0	1.90	1.92	0.02	0.075	0.100	0.100	0.005

Cut/Fill Computation from: 900202 to 900330

Point	Distance m	Elevation m	Volume m3/m	Thickness m	Cum.Vol. m3/m	Gross Vol m3/m
END	20.00	1.91	0.10	0.00	0.10	0.10

Profile Line 3

Survey Numbers: 3 to 4
Starting distance = 0.00 m, Ending Distance = 20.00 m

Dist. m	Elevation 900330 m	Elevation 900727 m	Elevation Change m	Volume Change m3/m	Cumulative Net Volume m3/m	Cumulative Gross Volume m3/m	Thickness (Net) m
0.0	1.96	1.96	0.00	0.000	0.000	0.000	0.000
5.0	1.96	1.95	−0.01	−0.025	−0.025	0.025	−0.005
10.0	1.96	1.97	0.01	0.000	−0.025	0.025	−0.002
15.0	1.99	1.96	−0.03	−0.050	−0.075	0.075	−0.005
20.0	1.92	1.91	−0.01	−0.100	−0.175	0.175	−0.009

Cut/Fill Computation from: 900330 to 900727

Point	Distance m	Elevation m	Volume m3/m	Thickness m	Cum.Vol. m3/m	Gross Vol m3/m
1	7.50	1.96	−0.04	−0.00	−0.04	0.04
2	11.25	1.97	0.02	0.00	−0.02	0.06
END	20.00	1.91	−0.16	−0.02	−0.17	0.21

CUMBERLAND ISLAND, GA

Volume Changes By Vertical Slices

Datum: NGVD

Volume computed every 5.00 m

Profile Line 4

Survey Numbers: 1 to 2

Starting distance = 0.00 m, Ending Distance = 20.00 m

Dist. m	Elevation 891207 m	900202 m	Elevation Change m	Volume Change m3/m	Cumulative Net Volume m3/m	Cumulative Gross Volume m3/m	Thickness (Net) m
0.0	1.96	1.96	0.00	0.000	0.000	0.000	0.000
5.0	1.95	1.96	0.01	0.025	0.025	0.025	0.005
10.0	1.96	1.96	0.00	0.025	0.050	0.050	0.005
15.0	1.96	1.96	0.00	0.000	0.050	0.050	0.003
20.0	1.94	1.96	0.02	0.050	0.100	0.100	0.005

Cut/Fill Computation from: 891207 to 900202

Point	Distance m	Elevation m	Volume m3/m	Thickness m	Cum.Vol. m3/m	Gross Vol m3/m
END	20.00	1.95	0.10	0.00	0.10	0.10

Profile Line 4

Survey Numbers: 2 to 3
Starting distance = .00 m, Ending Distance = 20.00 m

Dist. m	Elevation 900202 m	Elevation 900330 m	Elevation Change m	Volume Change m3/m	Cumulative Net Volume m3/m	Cumulative Gross Volume m3/m	Thickness (Net) m
0.0	1.96	1.96	0.00	0.000	0.000	0.000	0.000
5.0	1.96	1.96	0.00	0.000	0.000	0.000	0.000
10.0	1.96	1.96	0.00	0.000	0.000	0.000	0.000
15.0	1.96	1.95	-0.01	-0.025	-0.025	0.025	-0.002
20.0	1.96	1.96	0.00	-0.025	-0.050	0.050	-0.002

Cut/Fill Computation from: 900202 to 900330

Point	Distance m	Elevation m	Volume m3/m	Thickness m	Cum.Vol. m3/m	Gross Vol m3/m
END	20.00	1.96	-0.05	-0.00	-0.05	0.05

Profile Line 4

Survey Numbers: 3 to 4
Starting distance = .00 m, Ending Distance = 20.00 m

Dist. m	Elevation 900330 m	Elevation 900727 m	Elevation Change m	Volume Change m3/m	Cumulative Net Volume m3/m	Cumulative Gross Volume m3/m	Thickness (Net) m
0.0	1.96	1.96	0.00	0.000	0.000	0.000	0.000
5.0	1.96	1.97	0.01	0.025	0.025	0.025	0.005
10.0	1.96	1.96	0.00	0.025	0.050	0.050	0.005
15.0	1.95	1.95	0.00	0.000	0.050	0.050	0.003
20.0	1.96	1.96	0.00	0.000	0.050	0.050	0.002

Cut/Fill Computation from: 900330 to 900727

Point	Distance m	Elevation m	Volume m3/m	Thickness m	Cum.Vol. m3/m	Gross Vol m3/m
END	20.00	1.96	0.05	0.00	0.05	0.05

CUMBERLAND ISLAND, GA

Volume Changes By Vertical Slices

Datum: NGVD
Volume computed every 5.00 m
Profile Line 5

Survey Numbers: 1 to 2
Starting distance = .00 m, Ending Distance = 30.00 m

Dist. m	Elevation 891208 m	900202 m	Elevation Change m	Volume Change m3/m	Cumulative Net Volume m3/m	Cumulative Gross Volume m3/m	Thickness (Net) m
0.0	2.24	2.24	0.00	0.000	0.000	0.000	0.000
5.0	2.17	2.17	0.00	0.000	0.000	0.000	0.000
10.0	2.14	2.14	0.00	0.000	0.000	0.000	0.000
15.0	2.12	2.12	0.00	0.000	0.000	0.000	0.000
20.0	2.03	2.03	0.00	0.000	0.000	0.000	0.000
25.0	1.88	1.89	0.01	0.025	0.025	0.025	0.001
30.0	1.81	1.94	0.13	0.350	0.375	0.375	0.013

Cut/Fill Computation from: 891208 to 900202

Point	Distance m	Elevation m	Volume m3/m	Thickness m	Cum.Vol. m3/m	Gross Vol m3/m
END	30.00	1.88	0.38	0.01	0.38	0.38

Profile Line 5

Survey Numbers: 2 to 3
Starting distance = 0.00 m, Ending Distance = 30.00 m

Dist. m	Elevation 900202 m	Elevation 900330 m	Elevation Change m	Volume Change m3/m	Cumulative Net Volume m3/m	Cumulative Gross Volume m3/m	Thickness (Net) m
0.0	2.24	2.23	-0.01	0.000	0.000	0.000	0.000
5.0	2.17	2.17	0.00	-0.025	-0.025	0.025	-0.005
10.0	2.14	2.14	0.00	0.000	-0.025	0.025	-0.002
15.0	2.12	2.13	0.01	0.025	0.000	0.050	0.000
20.0	2.03	2.03	0.00	0.025	0.025	0.075	0.001
25.0	1.89	1.89	0.00	0.000	0.025	0.075	0.001
30.0	1.94	1.94	0.00	0.000	0.025	0.075	0.001

Cut/Fill Computation from: 900202 to 900330

Point	Distance m	Elevation m	Volume m3/m	Thickness m	Cum.Vol. m3/m	Gross Vol m3/m
1	5.00	2.17	-0.02	0.00	-0.02	0.02
END	30.00	1.94	0.05	0.00	0.03	0.08

Profile Line 5

Survey Numbers: 3 to 4
Starting distance = 0.00 m, Ending Distance = 30.00 m

Dist. m	Elevation 900330 m	Elevation 900727 m	Elevation Change m	Volume Change m3/m	Cumulative Net Volume m3/m	Cumulative Gross Volume m3/m	Thickness (Net) m
.0	2.23	2.23	0.00	0.000	0.000	0.000	0.000
5.0	2.17	2.16	-0.01	-0.025	-0.025	0.025	-0.005
10.0	2.14	2.13	-0.01	-0.050	-0.075	0.075	-0.007
15.0	2.13	2.12	-0.01	-0.050	-0.125	0.125	-0.008
20.0	2.03	2.02	-0.01	-0.050	-0.175	0.175	-0.009
25.0	1.89	1.89	0.00	-0.025	-0.200	0.200	-0.008
30.0	1.94	1.94	0.00	0.000	-0.200	0.200	-0.007

Cut/Fill Computation from: 900330 to 900727

Point	Distance m	Elevation m	Volume m3/m	Thickness m	Cum.Vol. m3/m	Gross Vol m3/m
1	25.00	1.89	-0.20	-0.01	-0.20	0.20
END	30.00	1.94	0.00	-0.00	-0.20	0.20

CUMBERLAND ISLAND, GA

Volume Changes By Vertical Slices

Datum: NGVD
Volume computed every 5.00 m

——— Profile Line 6 ———

Survey Numbers: 1 to 2
Starting distance = .00 m, Ending Distance = 10.00 m

Dist.	Elevation 891208	900202	Elevation Change	Volume Change	Cumulative Net Volume	Cumulative Gross Volume	Thickness (Net)
m	m	m	m	m3/m	m3/m	m3/m	m
0.0	2.24	2.24	0.00	0.000	0.000	0.000	0.000
5.0	2.26	2.22	-0.04	-0.100	-0.100	0.100	-0.020
10.0	2.01	2.01	0.00	-0.100	-0.200	0.200	-0.020

Cut/Fill Computation from: 891208 to 900202

Point	Distance m	Elevation m	Volume m3/m	Thickness m	Cum.Vol. m3/m	Gross Vol m3/m
END	10.00	2.01	-0.20	-0.02	-0.20	0.20

Profile Line 6

Survey Numbers: 2 to 3
Starting distance = 0.00 m, Ending Distance = 10.00 m

Dist. m	Elevation 900202 m	Elevation 900330 m	Elevation Change m	Volume Change m3/m	Cumulative Net Volume m3/m	Cumulative Gross Volume m3/m	Thickness (Net) m
0.0	2.24	2.23	-0.01	0.000	0.000	0.000	0.000
5.0	2.22	2.22	-0.00	-0.025	-0.025	0.025	-0.005
10.0	2.01	2.02	0.01	0.025	0.000	0.050	0.000

Cut/Fill Computation from: 900202 to 900330

Point	Distance m	Elevation m	Volume m3/m	Thickness m	Cum.Vol. m3/m	Gross Vol m3/m
1	5.00	2.22	-0.02	0.00	-0.02	0.02
END	10.00	2.01	0.02	0.00	0.00	0.05

Profile Line 6

Survey Numbers: 3 to 4
Starting distance = .00 m, Ending Distance = 10.00 m

Dist. m	Elevation 900330 m	Elevation 900727 m	Elevation Change m	Volume Change m3/m	Cumulative Net Volume m3/m	Cumulative Gross Volume m3/m	Thickness (Net) m
0.0	2.23	2.23	0.00	0.000	0.000	0.000	-0.000
5.0	2.22	2.21	-0.01	-0.025	-0.025	0.025	-0.005
10.0	2.02	2.02	-0.00	-0.025	-0.050	0.050	-0.005

Cut/Fill Computation from: 900330 to 900727

Point	Distance m	Elevation m	Volume m3/m	Thickness m	Cum.Vol. m3/m	Gross Vol m3/m
END	10.00	2.02	-0.05	0.00	-0.05	0.05

As the nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people. The department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for American Indian reservation communities and for the people who live in island territories under U.S. administration.

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