DRAFT

FEASIBILITY STUDY

EROSION ASSESSMENT AND BEACH RESTORATION ALTERNATIVES FOR HUNTING ISLAND, SOUTH CAROLINA

June 1990

Prepared for:

South Carolina Department of Parks, Recreation and Tourism

COASTAL SCIENCE & ENGINEERING, INC.

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Prepared for:

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INTRODUCTION

This report outlines findings and recommendations regarding beach restoration alternatives for Hunting Island, South Carolina. It is prepared in connection with an erosion assessment study of Hunting Island and Edisto Beach State Parks by Coastal Science & Engineering, Inc. (CSE), under contract to the South Carolina Department of Parks, Recreation and Tourism (PRT). Recommendations herein are limited to Hunting Island and are based on PRT review of draft findings and tailored to funding availability at this time.

The emphasis of this report is on alternatives rather than presentation of historical data. We outline key findings of previous studies, new surveys accomplished, and a conceptual model of erosion. While detailed station-by-station results and statistical analyses have been included in appendices, lengthy discussions of these data have been omitted. There are a considerable number of reports on Hunting Island's erosion problem available through the early 1980s, and reviewers of this report and its recommendations are directed to the original reports annotated in Table 1 for further background information.

Hunting Island has experienced severe erosion for over 100 years and is expected to continue eroding in the future, although the rate may change as a function of sea-level rise and other factors beyond manmade control. Four prior nourishment projects, constructed between 1968 and 1980 at a cost of $4.2 million, have demonstrated that the rate of shoreline recession can be reduced significantly. The question of whether continued nourishment is justified or if some other form of shoreline stabilization is preferable is a management decision. The present report is intended to address the technical and longevity requirements of shore protection and outlines several alternatives and levels of effort for Hunting Island. Costs of each alternative may then be weighed against recreational benefits (the anticipated primary impact), improved storm-damage reduction, and reduction of land loss.

PREVIOUS STUDIES & BEACH RESTORATION PROJECTS

The majority of erosion studies of Hunting Island were initiated by the U.S. Army Corps of Engineers (USACE). Others were prepared by the University of South Carolina, Clemson University, and South Carolina Sea Grant (Table 1). These reports all confirm a persistent trend and one of the highest rates of erosion along the South Carolina coast (Table 2). Unlike Fripp Island and Hilton Head Island where erosion along the center of the islands is approximately balanced by accretion at the ends (Kana et al., 1986; CSE, 1990), Hunting Island has experienced high net losses of sand throughout its length. With the exception of recent (20-year) spit growth at the south end and accretion around the terminal groin (1959) at the north end, most of the sand lost from the beach is believed to have shifted to the offshore shoals at Johnson Creek, St. Helena Sound, and Fripp Inlet. Volumetric erosion along the beach has been estimated from beach surveys at 250,000 cubic yards per year (cy/yr) prior to nourishment (USACE, 1964; 1977) and about 160,000 cy/yr for the period 1920-1973 from nearshore bathymetry (Stapor and May, 1981).

Four nourishment projects have been completed along Hunting Island since 1968 (Table 3). These projects have involved a total of over 3.5 million cubic yards of fill at a cost of $4.2 million (London et al., 1981). The most recent project in 1980 is most representative of present costs and volume requirements. At 1,412,692 cy, it was the largest nourishment project and cost $2,267,201 ($2.45/cy). Until the present Hilton Head beach nourishment project (≈2.5 million cubic yards at $9.7 million), the 1980 Hunting Island project was the largest ever in South Carolina in terms of sand volume. Total expenditures were second to Myrtle Beach's $4.7 million project (853,350 cy @ $5.55/cy).

TABLE 1. Annotated listing of reports on Hunting Island erosion.

CIT	= The Citadel	SCWMRD	= South Carolina Wildlife & Marine Resources Division
CLEM	= Clemson University	SCSG	= South Carolina Sea Grant Consortium
CSE	= Coastal Science & Engineering, Inc.	USC	= University of South Carolina
SCCC	= South Carolina Coastal Council	USACE	= U.S. Army Corps of Engineers

Date	Agency	Title of Report •Key Findings
1949	USACE	Cooperative Beach Erosion Study — State of South Carolina •First erosion report available describes exposed palmettos/oaks on the beach; 100 ft of recession between 1947 and 1949; 35,000 park users per year; lighthouse situated 1,200 ft inland; beach sand has median diameter of 0.2 mm (with shell) and 0.17 mm (without shell). •Hurricanes of record in 1893 and 1940 produced 75-100 ft of erosion at MHW; however, fall and winter northeasters "have a greater cumulative effect on damage than hurricanes." •Reports 1851-1948 shoreline recessions of 2,700 ft (north end), 500 ft (center), and 1,800 ft (south end). •Reports southerly longshore transport but "little new material reaches Hunting Island from St. Helena Sound." •Reports palmetto log groins authorized in 1948 by State Highway Department. •Report proposes 30 new groins for Hunting Island; average beach slope in December 1948 was ±0.022. •Recommends protective works.
1964	USACE	Hunting Island Beach, South Carolina (Letter to Congress from Secretary of the Army) •Second USACE report recommending periodic nourishment plus a terminal groin at north end. •Reports 100-500 ft of erosion for the period 1948-1964. •Reports median grain sizes of 0.15 to 0.17 mm diameter along various sections of the beach and offshore profile. •Reports 1959 hurricane surge of 11.1 ft MLW and 25 ft of dune erosion. •Reports 10-40 ft of erosion and damage to the bathhouse from the March 1962 northeasters. •Reports the following annual average erosion rates: Stations 0+00 to 73+00N — 24.5 ft/yr — 1859-1920 Stations 0+00 to 141+00S — 2.4 ft/yr — 1859-1920 Stations 0+00 to 73+00N — 17.7 ft/yr — 1933-1948 Stations 0+00 to 141+00S — 35.9 ft/yr — 1933-1948 Stations 73+00N to 141+00S — 14.1 ft/yr — 1859-1948 •Reports mean beach slopes for 31 profiles (1961-1962) at 1 on 44 (0.0227). •Reports volumetric erosion of backshore to -6.5 ft MLW as follows: Stations 73+00N to 112+00S — -16.8 cy/ft — 1961-1962 Stations 112+00S to 114+00S — +10.5 cy/ft — 1961-1962 Stations 24+00N to 24+00S — -17.5 cy/ft/yr — 1948-1962 Stations 24+00N to 24+00S — -24.4 cy/ft/yr — 1961-1962 •Recommended plan A for nourishment (50+00N to 50+00S) of 750,000 cy (over 3 years) plus renourishment at 250,000 cy/yr plus terminal groin near 70+00N; estimated costs of $455,000 (1964).

TABLE 1. (continued) Annotated listing of reports on Hunting Island erosion.

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Date	Agency	Title of Report •Key Findings
1965	USACE	**Hurricane Survey, Edisto and Hunting Island Beaches, South Carolina** •Most severe hurricane will produce damages estimated at $500,000 (1965) at Hunting Island but local interests have not expressed desire for hurricane protection works. •No additional erosion data after the 1964 letter to Congress report.
1977	USACE	**Hunting Island Beach, South Carolina: Project Evaluation and Proposals for FY 1977 Construction (manuscript)** •Most detailed analysis of Hunting Island erosion available. •Summarizes first three nourishment projects (1968, 1971, and 1974); $2,115,118 for 2,124,298 cy plus terminal groin. •Concludes volumetric losses around 255,000 cy/yr from nourished sections and ±197,200 cy/yr from southern unnourished section; sand transported to north into shoals of Johnson Creek, St. Helena Sound. •Reviews borrow sources (lagoon for projects 1 and 2, Fripp ebb-tidal delta for project 3). •Calculates time to complete loss of fill for each project as 2.6 to 4.2 years based on corrections for sand size (i.e., finer borrow material). •Computes overfill ratios of 1.4 to greater than 2.0 on the borrow material used with lagoon sand having higher overfill ratios. •Volumetric losses for project 3 were ±176,780 cy/yr for a 1.7-year period (June 1975 to February 1977). •Volume placed in 1975 on a unit-width basis ranged from ±38 cy/ft (60+00N) to 102.4 cy/ft (0+00). •Volumetric losses from June 1969 to June 1973 were 256,000 cy/yr or 25.6 cy/ft/yr. •Concludes borrow sand from Fripp Inlet more stable than lagoon sand. •Suggests improved performance if sand is pumped without retaining dikes (which artificially hold the beach face at a higher-than-natural slope); also recommends longer period between nourishment because loss rate diminishes over time.
1977	USC	**Beach Erosion Inventory of Horry, Georgetown, and Beaufort Counties, South Carolina** •Used aerial photos and historical charts to calculate erosion rates at six points along Hunting Island; rates were highest and most variable at the ends with a period of rapid accretion between 1940 and 1972 at the ends; shoreline change rates included:

Station	Trends (ft/yr) 25-yr	50-yr	100-yr
H-2 (vicinity of 30+00N)	-9	-22	-26
H-3 (vicinity of 0+00)	-22	-14	-11
H-4 (vicinity of 50+00S)	-13	-17	-6
H-5 (vicinity of 110+00S)	+6	-15	-10

TABLE 1. (continued) Annotated listing of reports on Hunting Island erosion.

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Date	Agency	Title of Report	•Key Findings

1981 SCSG A Study of Shore Erosion Management Issues and Options In South Carolina

- •Includes a case study on Hunting Island reviewing previous studies and restoration projects.
- •Results of a wave-refraction model (based on the outdated Dobson-Stanford University model from the early 1970s).
- •Presents profiles for the period, July 1974 to July 1976 (overlapping third nourishment project) and November 1979 to July 1980 (overlapping fourth nourishment project).
- •Volumetric changes therefore reflect the artificial condition of nourishment.
- •An economic analysis of beach nourishment is included for a low-cost and high-cost scenario yielding a B/C ratio of 1.167.
- •Report concludes that the federal/state distribution of costs for further nourishment cycles will be an important determining factor based on the relative equality of benefits and costs.

1981 CIT CLEM SCWMRD USC Hunting Island State Park, South Carolina

[Prepared for PRT, the study is in three parts and addresses: I. Hydraulic Model Studies (CLEM); II. Sediment Transport (SCWMRD/CIT); and III. Beach Erosional Shoreline Processes (USC)]

- •Findings include volumetric erosion of 170,000-180,000 cy/yr (1920-1978); average shoreline retreat of ±28 ft/yr; predominance of northerly transport at ±145,000 cy/yr; dominance of flood currents over the nearshore area directed into St. Helena Sound and possible influence on northerly transport; beach erosion contributes to observed buildup of Johnson Creek shoals, St. Helena shoals, and nearshore region of Harbor Island; St. Helena Sound hydrodynamics exert a strong control on Hunting Island and contribute to large-scale wave refraction; physical model predicted northerly transport.
- •Report concludes that erosion problem is related to tidal flows from St. Helena Sound.
- •Report recommends continued beach nourishment as the "most reasonable course of action" to maintain the beach; however, it recommends using both the north and south ends of the island for borrow sources and possibly raising the elevation of the terminal groin which was overpassing sediment at the time.

1981 (circa) USC Hunting Island (unpublished manuscript, not dated)

- •Appears to be an earlier draft of a section of the SCSG 1981 study
- •Includes essentially the same profile results and wave-refraction model.

TABLE 1. (continued) Annotated listing of reports on Hunting Island erosion.

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Date	Agency	Title of Report •Key Findings
1982	USC (McCreesh)	**A Beach Process Response Study at Hunting Island, South Carolina** •A USC Master's thesis with emphasis on measurement of short-term beach profiles and coastal processes (littoral environment observations or LEO). •Reports correlation between large, steep waves generated by northeasters and short-term erosion events especially during spring tides. •Reports short-term depositional trends associated with long-period swells particularly from the southeast during neap tides. •Most LEO measurements concentrated between 50+00S and 90+00S, covering the period February to June 1980. •Reports wave refraction producing a divergence of transport toward the ends of the island on one measurement day.
1987	PRT	**Letter Dated January 26, 1987, to USACE** •Formal request for emergency assistance following the 1987 New Year's Day northeaster; provides an estimate of 208,000 cy eroded during the storm. •Request was eventually denied in subsequent correspondence on the grounds that the state had not maintained the federal project as per previous agreements.
1988	SCCC CSE	**Analysis of Beach Survey Data Along the South Carolina Coast** •Initial profiles established by SCCC for periodic monitoring as part of a statewide network. •Results cover period January/February to May 1987; 11 stations with "healthy" beach volumes (+10 ft to -5 ft NGVD) of 120 cy/ft. •Short-term changes highly variable ranging from -35 cy/ft to +43 cy/ft for the period.
1989	SCCC CSE	**Analysis of Beach Survey Data Along the South Carolina Coast for October 1987 to August 1988** •Eleven SCCC profiles (1800-1895) show 11 cy/ft accretion from November 1987 to June 1988 and an average net loss of 9 cy/ft from May 1987 to June 1988. •Individual station results are highly variable; for example, station 1820 lost 12 cy/ft; 1830 gained 7 cy/ft; 1840 lost 18 cy/ft; 1850 gained 21 cy/ft; and 1860 lost 24 cy/ft. •Original SCCC monuments dating to January 1987 were replaced by 11 new monuments in the winter of 1988 but were not surveyed during the study period.

TABLE 1. (continued) Annotated listing of reports on Hunting Island erosion.

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Date	Agency	Title of Report •Key Findings
1989	SCCC CSE	**Analysis of Beach Survey Data Along the South Carolina Coast — Fall 1988** •Eleven new SCCC monuments (1800-1890) were profiled in October 1988. •No erosion comparisons were possible since this was the first survey at new monuments; however, unit-width volumes reported after the October 1988 survey were much lower than previous surveys (e.g., 60-80 cy/ft typical versus 80-120 cy/ft typical), indicating high rates of erosion had occurred since June 1987. •Report records 40-year average annual erosion rate of 22 ft/yr based on Hubbard et al. (1977) (USC) results of aerial photo analysis.
1989	PRT	**Beach Nourishment Proposal, Hunting Island State Park** •Formal request for nourishment funding under the $10 million Beach Management Trust Fund submitted by PRT to the SCCC. •Requests a project involving 829,944 cy between SCCC stations 1800 and 1850 (11,000 ft @ ≈75 cy/ft); this would encompass the northern two miles of Hunting Island; fill profile calls for 100-ft berm at +10 ft MSL and a 1:25 slope beach face to grade. •Estimates average erosion rate after nourishment at 9 cy/ft/yr; estimated cost is $3.3 million based on $4/cy; proposed borrow site is the lagoon near the cabin area. •Funding was approved around September 15, 1989, at $1.8 million level (state share), but temporarily withdrawn after *Hugo*; it was reinstated around January 1990 at a level of $1.75 million (state share).

TABLE 2. Representative 40-year shoreline change rates from various sources including Eiser and Jones (1989).

Locality	Change (ft/yr)	Locality	Change (ft/yr)
Dewees Island	-20.0	Pawleys Island	-1.3
Daufuskie Island (center)	-6.0 to -8.0	Myrtle Beach	-0.7
Hilton Head Island (center)	-5.0 to -6.0	North Myrtle Beach	-0.4
Folly Beach	-2.0 to -6.0	Kiawah Island	+2.0
DeBordieu Beach (center)	-2.0 to 6.0	Isle of Palms	+5.0 to 10.0
Edisto Beach	-0.4 to -2.7	Sullivans Island	Greater than +10.0
Surfside Beach	-1.5		

TABLE 3. USACE beach nourishment projects along Hunting Island. [Sources: USACE (1977); London et al. (1981)]

[*NOTE: USACE stations run north and south from the vicinity of the lighthouse (e.g., 50+00N is 5,000 ft north; 97+00S is 9,700 ft south of the lighthouse). Total length of Hunting Island is about 21,000 ft (±4 miles), ranging from ±70+00N to ±140+00S.]

Project*	Construction Dates	Volume (cy)	Limits of Placement	Net Unit Cost ($/cy)	Total Cost ($)
1968	Feb-Dec'68	750,000	50+00N to 50+00S*	0.58	435,178
1971	May-Dec'71	761,324	50+00N to 50+00S	0.70	534,000
1975	Apr-Jun'75	612,974	60+00N to 30+00S	1.58	971,540
1980	Jan-May'80	1,412,692	24+60N to 97+00S	1.60	2,267,201
	TOTALS	**3,536,990 cy**		**$1.19/cy**	**$4,207,919**

Related protective works along the Hunting Island beach include the 1948 construction of two palmetto log groins in the vicinity of the lighthouse (USACE stations 0+00 and 6+00S) and the 1949-1951 construction of timber groins at stations 6+00N, 12+00S, 54+00N and 60+00N. The latter two stations are situated about one mile north of the lighthouse. The palmetto log groins were replaced by timber structures in 1951. An experimental bulkhead 600 ft long was constructed in 1957 (presumably in the vicinity of the lighthouse). Its useful life according to the USACE (1964) was less than two years. In 1961, the South Carolina Highway Department removed the groins at 6+00N and 12+00S and strengthened the remaining ones at 0+00 and 6+00S to protect a bathhouse and picnic area. These two structures eventually were flanked and destroyed. In 1968, the USACE constructed a terminal groin at station 69+08N near the mouth of Johnson Creek. This is believed to be the only remaining functioning structure along the beach and has been reported as effective in trapping sand along a limited reach at the north end of the island (USACE, 1977).

Beach Nourishment

The initial USACE nourishment plan was based on estimated annual losses of 250,000 cy/yr (USACE, 1977). The first project authorized by the U.S. Congrèss in 1964 called for a 750,000 cy project (initial nourishment) and a schedule of renourishment at three-year intervals. It was successfully constructed by December 1968 using an interior lagoon as the sand source (Fig. 1). The second project, using the same sand source, was completed in August 1971 (761,324 cy). The third nourishment (612,974 cy) was completed in June 1975 using sand from the Fripp Inlet ebb-tidal delta. Because of delays, the 1980 project was increased in size and completed in May. Figure 1 shows the fill limits for each project. The majority of the fill has been placed along the northern two-thirds of the island, particularly between 50+00N and 50+00S (i.e., one mile north and south of the lighthouse). The 1980 project extended approximately one half mile north (to station 24+60N) and two miles south of the lighthouse (to station 97+00S). The 1977 USACE project evaluation concluded the majority of fill lost from the first three projects shifted north into the shoals of Johnson Creek and the south margin of St. Helena Sound (i.e., ebb-tidal delta shoals).

Detailed analyses by the USACE (1977) of the sand placed for nourishment indicated the first three projects involved finer grained material than existed on the native beach. High erosion rates in the fill were attributed partly to sand size differences. New analytical techniques developed around the time of the second project allowed estimates of the **overfill ratio** for the borrow material (CERC, 1984). From this analysis, the USACE concluded between 1.5 cy and 2.0 cy of borrow sand were required to produce the equivalent performance of 1 cy native sand. In simple terms, this means almost twice as much material would have to be pumped to keep up with the projected erosion rates surveyed before the projects.

The 1980 project, like the 1975 project, used the north shoal of Fripp Inlet as a borrow source. No postproject sediment compatibility analyses are available. However, Stapor and May (1981) reported general uniformity of sediments along the beach in the 0.14 mm to 0.20 mm size range (fine sand). The 1977 USACE study reported mean grain size on the beach and borrow areas as 0.16 mm (1963, native) and 0.18 mm (1971, beach fill). The dry-sand beach (berm) contained median sand sizes generally between 0.19 mm to 0.21 mm in March 1971 prior to the second nourishment project.

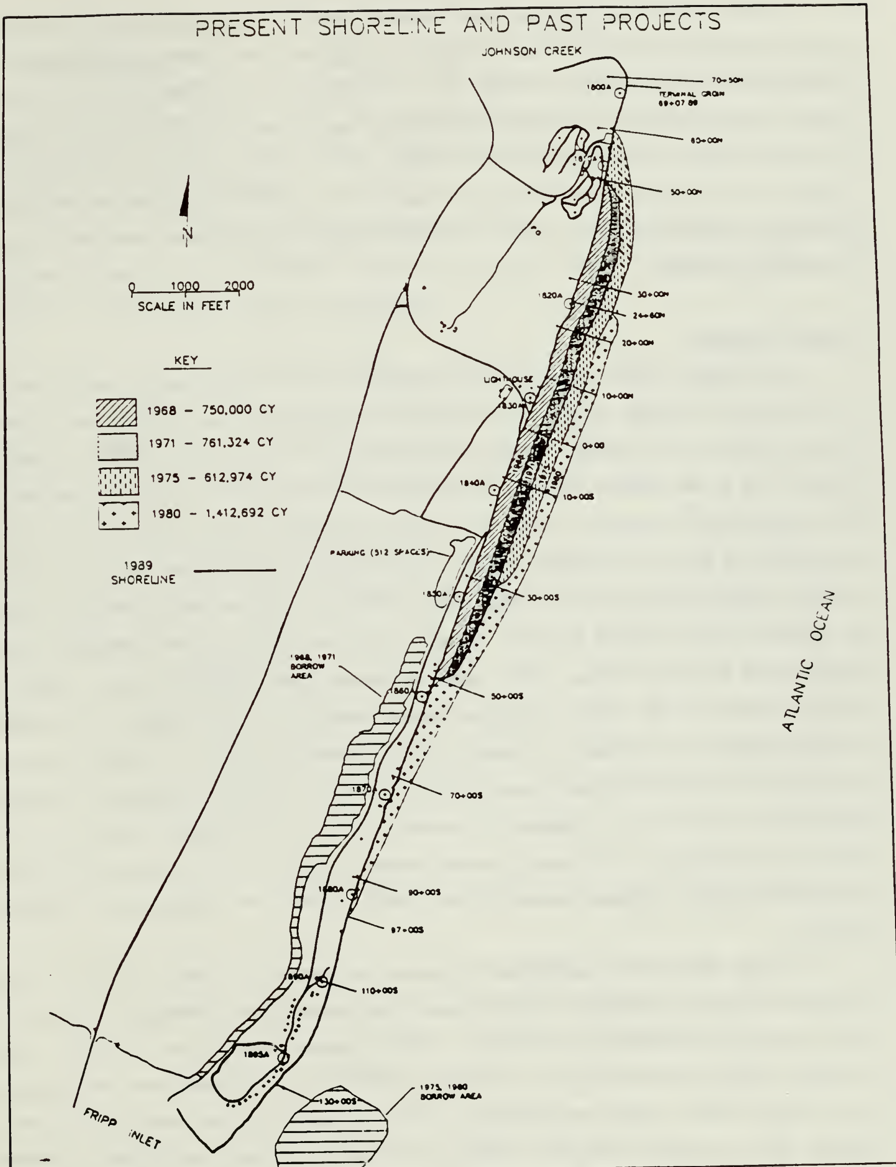


FIGURE 1. Prior nourishment projects along Hunting Island. Longshore boundaries are to scale: offshore boundaries are distorted to illustrate overlap of projects.

These results suggest that while borrow sand may have been finer on average than the native beach for the early projects, differences were small and the result after nourishment and winnowing of fines was a slightly coarser material left on the back beach. These changes are subtle, however, and by themselves, probably do not account for much of the accelerated erosion of the fill. A more important factor, in our opinion, is the length of each project whereby fill placed over a limited reach (e.g., 50+00N to 50+00S) will tend to unravel from the ends and feed the adjacent unnourished sections.

Recent Planning

The 1968 to 1980 projects were completed by the USACE with a state cost-share of 30 percent (USACE, 1977). The USACE authorization was initially for a ten-year period (through June 1979). It was extended to 15 years (through June 1984) by Section 156 of the Water Resource Development Act of 1976. With the expiration of the authorization more than five years ago, the federal government can no longer participate in beach restoration projects at Hunting Island without further feasibility analysis (USACE letter of 22 October 1986 to PRT). PRT requested federal assistance in January 1987 following the New Year's Day storm which caused extensive damage along South Carolina beaches. PRT staff estimated about 208,000 cy were eroded from Hunting Island by the storm, causing extensive damage to park facilities. The USACE acknowledged that without a demonstrated commitment by the local sponsor to maintain the nourished beach and lacking updated feasibility analyses, the federal government was not in a position to assist in further nourishment efforts. By July 1987, it appeared that "the next renourishment would probably require 100 percent nonfederal funding" [memo dated 31 July 1987 from Dr. H. Wayne Beam (SCCC) to PRT].

In July 1989, PRT submitted a request to the South Carolina Coastal Council (SCCC) for beach renourishment funds under the state's Beach Management Trust Fund authorized by the legislature that year. PRT's request was for an 11,000 ft project (northern half of the island) at an estimated •830,000 cy. Project cost was estimated at (•)$3.3 million based on $4.00/cy. The proposed borrow site was the interior lagoon near the cabin areas (PRT, 1989). Just prior to Hurricane *Hugo* in September 1989, the SCCC allocated $1.8 million toward construction of the project (SCCC memorandum dated September 15, 1989). These funds were temporarily withdrawn following *Hugo* because of emergency nourishment projects in the Grand Strand. After the legislature reconvened in 1990, funding for the Hunting Island project at approximately the previously approved level was restored. PRT officials have indicated that 40 percent matching funds are now available from department sources (W. McMeekin, pers. comm., May 1990). Thus, an estimated $2.92 million are presently available for beach restoration.

The present study was commissioned in February 1990 to develop an updated erosion assessment and feasibility study of alternative beach restoration plans. The following section outlines work accomplished.

SCOPE OF SERVICES & WORK ACCOMPLISHED

CSE's services and work accomplished through June 1990 include:

1) Data review.
2) Field surveys (topographic and geotechnical).
3) Engineering analysis.
4) Preparation of alternative plans.

Data Review

In addition to the reports annotated in Table 1, CSE used the data sources listed in Table 4 to analyze shoreline changes and volumetric erosion rates. These included original surveys by the USACE in connection with each nourishment project, recent surveys by the SCCC, and historical vertical photographs mainly from the U.S. Department of Agriculture. CSE supplemented these data with a resurvey of SCCC profiles in April. For purposes of comparison, USACE stations situated close to SCCC beach survey markers were emphasized in our analysis. The USACE had established at least two baselines from which their stationings were measured. Unfortunately, control was lost except for one starting point (0+00) near the lighthouse. Therefore, it was not possible to locate USACE surveys and relate them accurately to recent surveys. While other beach profiles were available (e.g., Zarillo et al., 1981), they lacked horizontal and vertical control and could not be recovered.

Those stations having comparative data from March 1969 to August 1983 (USACE) and located close to present SCCC survey monuments (Table 4) were entered into the computer from field notes and analyzed for volumetric change and contour movement.

Historical aerial photographs (approximately 1 in. = 400-ft scale) were analyzed using a 1979 PRT base map for control points and photo rectification. Vegetation lines and the dry-sand/wet-sand contact line (approximate high watermark) were digitized in AutoCad™ format for the years 1951 to 1989 (Table 4, Fig. 2). Shoreline change rates were computed from digitized shorelines at 11 points approximately corresponding to the present location of SCCC beach survey stations. For time periods not covered in the above analyses, we took the results of previous studies by the USACE and others at face value. These results extend the time period of interest back to 1859 for certain erosion rates.

TABLE 4. Data sources used in the present study to update shoreline changes and volumetric erosion rates.*

I. Vertical Aerial Photographs

Date	Source	Enlarged Scale
Feb'51	U.S. Department of Agriculture	1 in = 400 ft
Jan'55	U.S. Department of Agriculture	1 in = 400 ft
Nov'59	U.S. Department of Agriculture	1 in = 400 ft
Apr'72	U.S. Department of Agriculture	1 in = 800 ft
Mar'83	U.S. Department of Agriculture	1 in = 800 ft
Feb'89	U.S. Department of Agriculture	1 in = 400 ft

II. Beach Surveys — USACE Monitoring Stations

Mar'69	U.S. Army Corps of Engineers	Postproject 1
Mar'70	U.S. Army Corps of Engineers	Postproject 1
Mar'71	U.S. Army Corps of Engineers	Preproject 2
Mar'72	U.S. Army Corps of Engineers	Postproject 2
Jan'75	U.S. Army Corps of Engineers	Preproject 3
May'81	U.S. Army Corps of Engineers	Postproject 4
Aug'83	U.S. Army Corps of Engineers	Postproject 4

III. Beach Surveys — SCCC Monitoring Stations — April 1990 — CSE

Reach	SCCC Station	Corresponding USACE Station
Northern	1800	60+00N
	1810	50+00N
	1820	20+00N
Lighthouse	1830	10+00N
	1840	10+00S
Central	1850	30+00S
	1860	50+00S
	1870	70+00S
	1880	90+00S
Southern	1890	110+00S
	1895	130+00S

IV. Other Quantitative Erosion Surveys Referenced Include:

USACE (1949)	Hubbard et al. (1977)	Zarillo et al. (1981)
USACE (1964)	Stapor and May (1981)	Eiser et al. (1988)
USACE (1977)		

*The above-listed USACE beach surveys represent those that were recoverable for comparison with present surveys. Because of erosion, the control for USACE surveys prior to 1969 has been lost, and it was not possible to recover earlier data. However, the USACE 1977 study provides a detailed analysis of volumetric losses up through the 1975 nourishment project.

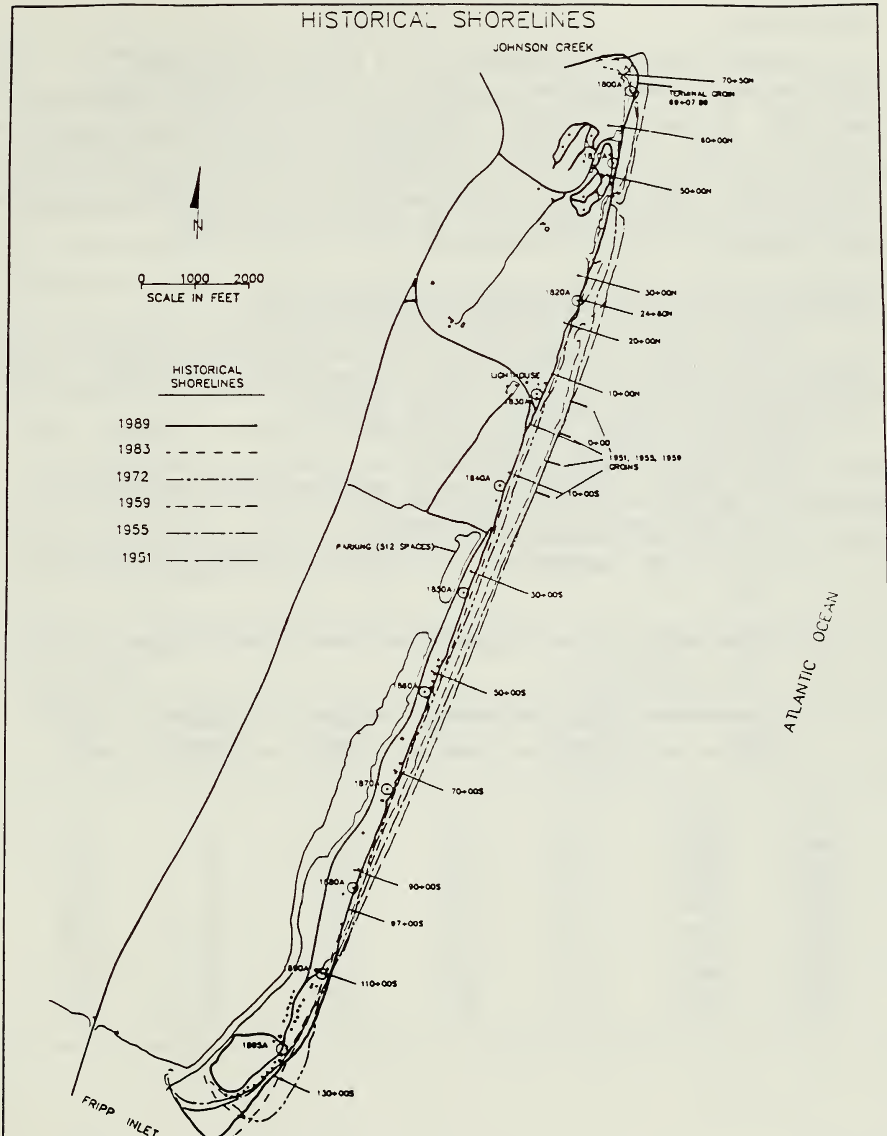


FIGURE 2. Historical shorelines (seaward vegetation line) between 1951 and 1989 developed by computer from USDA vertical aerial photos.

Field Surveys

In addition to general inspections of the site, CSE reoccupied the 11 existing SCCC stations and surveyed beach profiles to -5 ft NGVD (low-tide wading depth) in April 1990. In June, we mobilized a 45-ft catamaran survey vessel by subcontract and obtained ten cores at potential borrow sites offshore of Hunting Island and five sites off Edisto Beach. Cores off Hunting Island averaged 11.5 ft of penetration and covered representative areas directly offshore and over the nearby inlet deltas.

Engineering Analyses and Preparation of Alternative Plans

The above data were analyzed to compute sand budgets particularly for recent periods since completion of the 1980 project, evaluate sediment compatibility of selected core samples and develop alternative beach-fill sections.

The primary alternatives evaluated were:

1) **Do nothing** – Prediction of future trends in 10 years and 25 years if no remedial measures are implemented.
2) **Large-scale nourishment** – Predicated on a design life around ten years.
3) **Alternative small-scale nourishment plans** – Predicated on a budget limit of (±)$3 million.
4) **Nourishment with sand-retaining structures** – Predicated on a design life for the fill around ten years and for structures around 25 years.

GEOTECHNICAL DATA

Ten vibracores were obtained in June off Hunting Island (Fig. 3) to determine if there were any potential borrow areas immediately offshore. Some of the cores were also taken on the north shoal of Fripp Inlet to confirm sediment quality. Table 5 lists the cores. length recovered. Loran coordinates. and approximate water depth at the site when the cores were taken. Generally. the water depths indicated exceed mean lower low datum by 1 ft to 4 ft. Each two-inch-diameter core was opened. logged. photographed. and split for sampling and archiving. Sediment samples (composites) were taken from representative sections exhibiting similar lithologies (texture. sediment size. and type). Twenty sediment samples were processed by wet and dry sieving to determine size gradations and mud content. Table 6 includes summary grain-size results. Appendix I contains the entire set of core logs and grain-size statistics.

In general. fine sand with mean grain sizes of 0.14 mm to 0.24 mm predominates. Some of the cores had mud zones in the form of alternating sand and mud lenses (flaser bedding) which is indicative of cyclic sedimentation. A number exhibited uniform sand throughout their length.

TABLE 5. Offshore vibracores obtained off Hunting Island in June 1990. [*Water depth at the time core was taken.]

Core I.D.	Water Depth* (ft)	1990 Coring. Date	Time Cored	Recovered Core Length	Loran Coordinates	
HI-1	12	6-13	0615	11' 0"	60842.5	45585.0
HI-2	11	6-13	0740	12'10"	60959.4	45604.3
HI-3	13	6-13	0845	12' 4"	60952.8	45589.8
HI-4	17	6-13	1030	12' 0"	60945.2	45586.7
HI-5	17	6-13	1200	6' 6"	60972.1	45590.3
HI-6	12	6-13	1310	13' 4"	60977.6	45589.8
HI-7	8	6-14	0815	13' 2"	60944.6	45594.5
HI-8	14	6-14	0930	8' 3"	60964.0	45585.4
HI-9	12	6-14	1040	7' 3"	60983.1	45585.1
HI-10	15	6-14	1230	13' 9"	60982.4	45586.2

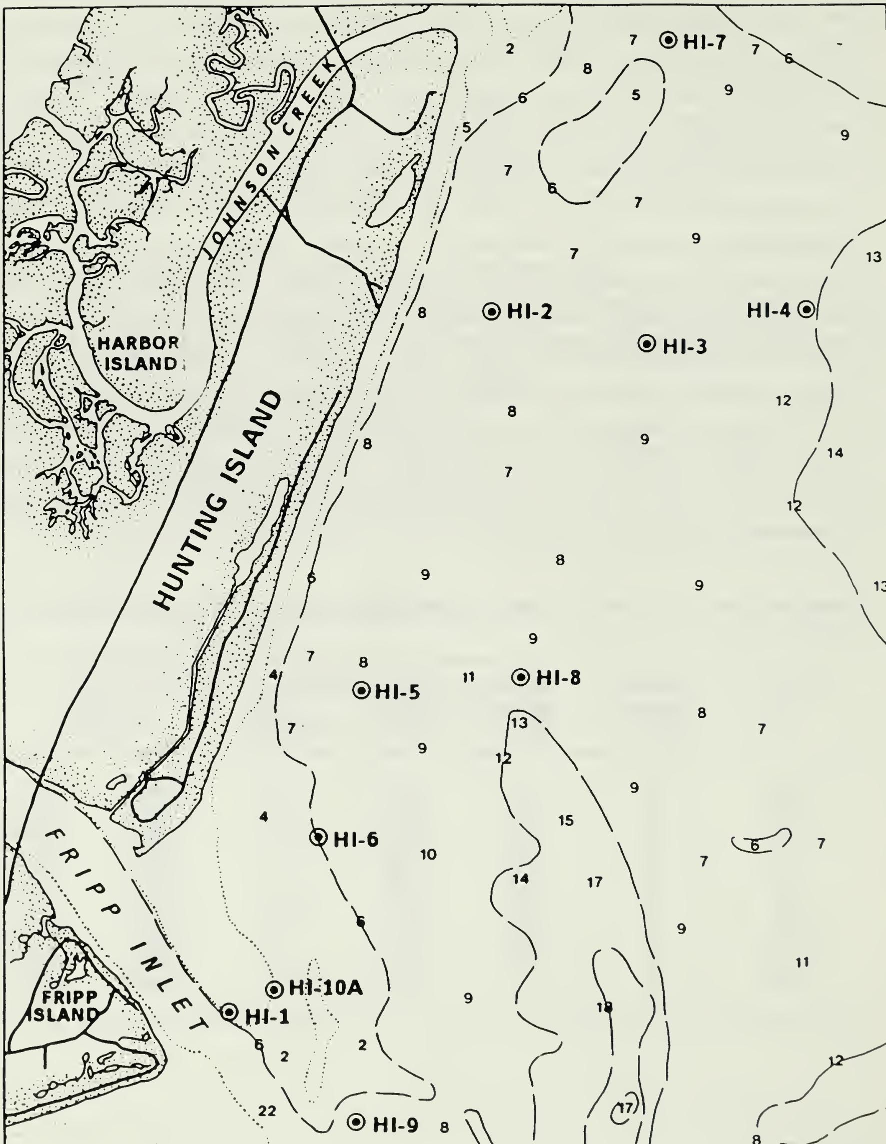


FIGURE 3. Location of ten vibracores offshore Hunting Island obtained in June 1990. See Table 5 for Loran coordinates. Soundings from NOS chart 11517; mean low water datum.

TABLE 6. Summary of graphic (Folk and Ward, 1957) grain-size statistics for sediment samples from Hunting Island, South Carolina. See Appendix I for detailed statistics and moment measures of grain size.

MS = moderately sorted
MWS = moderately well sorted
PS = poorly sorted
WS = well sorted
VWS = very well sorted
CS = coarse skewed
FS = fine skewed
NS = near symmetrical
SCS = strongly coarse skewed
SFS = strongly fine skewed

Sample ID	Core Depth Sampled (ft)	Mean Grain Size			Standard Deviation	Skewness
		Phi(ϕ)	mm	Class		
HI-2-1	0-6	2.46	0.18	Fine sand	0.89 (MS)	-0.48 (SCS)
HI-2-2	6-8.5	2.24	0.21	Fine sand	0.73 (MS)	-0.39 (SCS)
HI-2-3	8.5-bottom	2.54	0.18	Fine sand	0.52 (MWS)	-0.04 (NS)
HI-3-1	0-3	2.05	0.24	Fine sand	1.24 (PS)	-0.53 (SCS)
HI-3-2	3-8	2.80	0.14	Fine sand	0.62 (MWS)	-0.35 (SCS)
HI-4-1	0-5	2.35	0.20	Fine sand	0.95 (MS)	-0.51 (SCS)
HI-4-2	5-6.5	2.67	0.16	Fine sand	0.81 (MS)	-0.23 (CS)
HI-4-3	6.5-bottom	2.32	0.20	Fine sand	0.71 (MS)	-0.29 (CS)
HI-5-1	0-6.5	2.49	0.19	Fine sand	0.50 (WS)	-0.09 (NS)
HI-5-2	6.5-bottom	2.36	0.19	Fine sand	0.71 (MS)	-0.33 (SCS)
HI-6-1	0-6.5	2.60	0.16	Fine sand	0.47 (WS)	-0.09 (NS)
HI-6-2	6.5-bottom	2.39	0.19	Fine sand	0.72 (MS)	-0.29 (CS)
HI-7-1	0-3.5	2.40	0.19	Fine sand	0.56 (MWS)	-0.20 (CS)
HI-7-2	3.5-6	2.53	0.17	Fine sand	0.41 (WS)	+0.10 (NS)
HI-8-1	Entire	2.22	0.21	Fine sand	0.69 (MS)	-0.39 (SCS)
HI-9-1	0-3.5	2.42	0.19	Fine sand	0.43 (WS)	-0.06 (NS)
HI-9-2	3.5-4.5	2.28	0.21	Fine sand	0.47 (WS)	-0.12 (CS)
HI-9-3	4.5-bottom	2.48	0.18	Fine sand	0.26 (VWS)	+0.27 (FS)
HI-10-1	0-3.5	2.45	0.18	Fine sand	0.32 (VWS)	+0.12 (FS)
HI-10-2	3.5-bottom	2.54	0.17	Fine sand	0.30 (VWS)	+0.33 (SFS)

Most noteworthy were the results from cores HI-3 and HI-4. These were located 1.2 to 1.8 miles offshore of Hunting Island, relatively close to the area considered in most need of nourishment around the lighthouse. It is well established the cost of nourishment is a function of distance from borrow source to the beach. Therefore, any suitable material in close proximity will usually be favored over more remote borrow sites. Cores HI-3 and HI-4 contained 0.20-0.24 mm sand in the upper 3 ft and 12 ft of each core, respectively, indicating the area may be suitable for borrowing after more detailed surveys. Core HI-3 is located approximately 6,500 ft seaward of the lighthouse in about 10 ft of water (at low tide). The upper 3 ft were coarser than the lower 5 ft (0.24 mm versus 0.14 mm) and were not considered as suitable as core HI-4 which was located about 9,700 ft seaward of the lighthouse. Core HI-4 contained 0.2 mm sand from 0 ft to 5 ft and from 6.5 ft to 12 ft. An intermediate layer 1.5 ft thick was slightly finer (0.16 mm) and contained about 30 percent mud (Table 7). Nevertheless, as a whole, the deposit at HI-4 is a good prospect for nourishment with a mud content less than 5 percent through a thickness of 12 ft.

Overfill ratios were calculated using the James' method (CERC, 1984) for native sands and core HI-4. The results depend on the selection of "native" grain size from the data available. We used two "native" grain sizes as reported by the USACE (1977) for nourished (0.22 mm) versus unnourished (0.18 mm) sections. The overfill ratios fell in the range of 1.1 to 1.6 which at the least suggests the deposit should be investigated in more detail. [Note: An overfill ratio of 1.0 is the target match.] Promising results were also obtained for cores HI-5, HI-6, and HI-8, located off the southern one-third of Hunting Island, and HI-7 about 1 mile off the entrance to Johnson Creek.

These geotechnical results have important implications for nourishment at Hunting Island. They indicate suitable beach-quality sand exists relatively close to shore and an alternative borrow area may be developed which is more cost-effective than Fripp Inlet. In our opinion, these results are sufficiently promising to warrant a more detailed offshore sand search concentrated around the potential borrow area outlined herein.

TABLE 7. Percentages of mud in selected samples from Hunting Island. [*Weight of fraction with sizes greater than 63 μm. **Less than 63 μm sizes.]

Sample ID	Sample Weight (grams)	Sand Fraction*	Mud Fraction*	Percent Mud**
HI-2 (6-8.5 ft)	87.60	69.80	17.80	20
HI-4 (5-6.5 ft)	81.50	55.90	25.60	31
HI-9 (3.5-4.5 ft)	130.50	123.10	7.40	6
HI-10 (3.5-bottom)	161.50	153.90	7.60	5

SHORELINE CHANGES

The USACE (1964) reported "mean high water" changes for 22 stations using U.S. Coast and Geodetic Survey charts and various maps by their agency. The results have been grouped by series of stations in five reaches as given in Table 8 and are reported for selected time periods and stations. While mean high water (MHW) as surveyed in the 1800s and today is probably not the same point relative to the beach profile and is subject to wide seasonal fluctuations, it provides an approximation of trends. In the case of Hunting Island, rapid erosion was the dominant trend between 1859 and 1962 by any standard. However, as Table 8 shows, the annual rate of erosion varied by reach and period. The northern ±1 mile of shoreline was consistently erosional at a high rate (-15 ft/yr to -27 ft/yr) for all periods. The "lighthouse reach" eroded steadily, but at rates ranging from 7 ft/yr to 14 ft/yr. The central and southern reaches varied the most with certain prolonged periods of accretion interrupting the long-term erosion trend. These rates represent natural trends without the influence of nourishment.

Table 9 contains the results of CSE's aerial photo analysis covering the 38-year period from 1951 to 1989. Historical shorelines are also given in Figure 2. Appendix II includes statistics for individual stations. This analysis gives changes in the seawardmost vegetation line and a high watermark interpreted as the dry-sand/wet-sand contact on the aerial photos (i.e., not true MHW). The points of comparison approximately correspond to the existing SCCC beach survey stations. The results in Table 9 reflect the impact of nourishment after 1959. Note the average annual change was 20 ft/yr for the period 1951-1959, whereas the rate reduced to about 5 ft/yr after 1959. The southern one mile of shoreline fluctuated the most, alternating between erosion and accretion. The trend during most of the 1980s for the southern reach has been rapid accretion, probably due to nourishment in the central reach for the first time in 1980. USACE (1977) and other reports (Stapor and May, 1981) indicate the earlier projects lost sand to the north [compare erosion rates for the northern reach through 1962 (Table 8) with the rates after 1972 (Table 9)]. Shoreline change data prove the nourishment projects slowed the rate of erosion dramatically, but did not completely offset the trend and stabilize the shoreline.

TABLE 8. Historical shoreline change rates averaged by reach from USACE and U.S. Coast & Geodetic Surveys of mean high water (based on USACE, 1964). [(-) erosion; (+) accretion]

Reach	Applicable USACE Stations	Representative Shoreline Length (ft)	Average Annual Shoreline Change (ft/yr)			
			1859-1920	1920-1948	1948-1962	1859-1962
Northern	60+00N to 20+00N	5,000	-19.4	-15.4	-26.7	-19.3
Lighthouse	10+00N to 10+00S	3,000	-7.0	-13.9	-12.7	-9.6
Central	20+00S to 90+00S	8,500	+3.2	-25.6	-12.2	-6.8
Southern	100+00S to 141+00S	4,500	-10.0	-35.6	+15.6	-13.5
TOTALS/AVERAGES		21,000	-6.5	-23.6	-9.8	-11.6

TABLE 9. Historical shoreline change rates from USDA and other historical aerial photographs. Reaches are the same as Table 8. [(-) erosion; (+) accretion]

Reach	Applicable SCCC Stations	Representative Shoreline Length (ft)	Average Annual Vegetation Change (ft/yr)			
			1951-1959	1959-1972	1972-1983	1983-1989
Northern	1800,1810,1820	5,000	-32.8	-10.2	+4.0	-2.2
Lighthouse	1830,1840	3,000	-11.3	-25.5	-4.2	-14.0
Central	1850,1860 1870,1880	8,500	-22.8	-7.6	-4.4	-7.9
Southern	1890,1895	4,500	-7.2	+16.4	-17.2	+12.0
TOTALS/AVERAGES		21,000	-20.2	-5.6	-5.1	-3.2

Reach	Representative Shoreline Length (ft)	Average Annual Change (ft/yr)	
		High Water Line (1951-1989)	Vegetation Line (1951-1989)
Northern	5,000	-7.2	-9.6
Lighthouse	3,000	-14.6	-14.5
Central	8,500	-9.1	-9.9
Northern	4,500	+2.1	+1.0
TOTALS/AVERAGES	21,000	-7.0	-8.2

Volumetric Analysis

Beach profiles are available from numerous USACE surveys completed in conjunction with previous nourishment projects. Unfortunately, survey data prior to March 1969 could not be reproduced for direct comparison because of changes in the USACE baseline. However, detailed sand budgets were developed by the USACE in their 1977 project evaluation report and can be used to evaluate quantitative losses for the first three projects. The USACE concluded in 1974 that the nourishment section lost 255,000 cy/yr between January 1969 and June 1973 (encompassing the first two nourishments one mile north and one mile south of the lighthouse). During the same period, the south beach lost 197,200 cy/yr. These estimates were later revised slightly to a combined loss of 468,000 cy/yr for the period (USACE, 1977). This equates to approximately 25 cy/ft/yr losses, an exceedingly high rate for any beach. [Note: By comparison, Myrtle Beach's volumetric erosion rate is on the order of 1-2 cy/ft/yr (Kana et al., 1984a).] Based on these results, the USACE (1977) concluded there was no evidence that fill placed in sections 50+00N to 50+00S moved south.

Several intranourishment periods were analyzed for short-term volumetric losses. The selection of periods was limited because of the difficulty in confirming profile control between surveys. Table 10 presents the most relevant results; additional data are provided in Appendix II. It can be seen that annualized loss rates after the second and fourth nourishment projects ranged upwards of 20 cy/ft/yr. While the average erosion rates for all periods listed in Table 10 range from 11.5 cy/ft to 13.4 cy/ft, the results are generally higher along the nourished areas of the island. These rates apply to periods 1-3 years after completion of each project and, therefore, do not reflect initial loss rates immediately following placement which are generally higher. While the 1981-1983 period encompassed a season of strong northeasters during the winter of 1982-1983, the results from other postproject periods were similar. It is apparent from review of all volumetric survey data presented in earlier reports as well as the results herein that quantitative erosion rates have consistently reached 15-20 cy/ft/yr along most of Hunting Island. This provides a realistic range of measures of the fill quantity that must be replaced each year to maintain a stable beach.

TABLE 10. Unit-volume losses along beach profiles as surveyed from +10.0 ft NGVD (dunes/highland scarps) to -5 ft NGVD (low-tide wading depth). [*Through January 1975. **Based on rough juxtaposition of CSE surveys at SCCC monuments with USACE surveys; not considered reliable comparison. ***Surveyed stations only. ND = no data.]

Reach	USACE Station	Equivalent SCCC Station	Representative Shoreline Length (ft)	Unit-Volume Change (cy/ft/yr) Mar'72-Sep'74 (2.5 yrs)	May'81-Aug'83 (2.3 yrs)	Aug'83-Apr'90 (6.6 yrs)**
Northern	60+00N	1800	1,000	-8.9*	-10.9	-13.5
	50+00N	1810	2,000	-13.9	-6.6	-16.9
	20+00N	1820	2,000	-20.1	-13.5	-10.2
Lighthouse	10+00N	1830	1,500	-19.6	-19.0	-10.9
	10+00S	1840	1,500	-15.6	-14.6	-16.4
Central	30+00S	1850	2,500	-14.0	-15.9	-11.9
	50+00S	1860	2,000	-1.6	-13.5	-13.8
	70+00S	1870	2,000	ND	-10.8	-15.4
	90+00S	1880	2,000	ND	-10.4	-4.5
Southern	110+00S	1890	2,000	ND	+12.6	-10.2
	120+00S	1895	2,500	ND	-22.6	-9.5
	TOTALS/AVERAGES		21,000	-13.4***	-11.5	-11.9

CONCEPTUAL MODEL OF EROSION

Based on previous studies, analyses of shoreline changes, and the experience of prior nourishment projects, we believe the following factors are the primary causes of erosion along Hunting Island.

Wave Refraction and Diffraction

The southern shoals of St. Helena Sound reorient waves through the process of refraction and diffraction and cause sediment to shift north and south away from the center of the island. Two processes are at work here. First, refraction of waves which is a bending of wave rays (general direction of travel) around the St. Helena Sound ebb-tidal delta. This causes waves from the northeast, for example, to bend toward the west as they propagate over the shoals toward Hunting Island. By the time they strike the shoreline along the north end of the island, they often break toward the north. Waves from the south similarly bend toward shore around the shoals of Fripp Inlet. In either case, the tendency is for waves to arrive at a different direction with respect to the beach than they would without refraction. The second process is diffraction which is a spreading of wave energy along a wave crest. This occurs where waves have to propagate through a narrow opening. At the opening, waves will propagate as a "point" source much like the waves produced from a pebble dropped in a pond. Diffraction along the coast can occur wherever there are breaks in offshore shoals or exposed bars at inlets. The narrowest openings cause the most curvature in the diffracted wave. And because it is spreading energy parallel to each wave, the height will diminish away from the opening or point of propagation. Wider openings produce less curvature in diffracted wave crests but basically produce the same effect.

We believe both refraction and diffraction exert strong controls on the distribution of wave energy along the island. Waves fundamentally do most of the work of building or eroding beaches. Refraction around the St. Helena sand shoals offsets the influence of waves from the north and allows a sand transport reversal at Hunting Island from the southerly flow that predominates along the East Coast. Diffraction occurs as waves propagate through the large gap in shoals between Fripp Inlet and St. Helena Sound and smaller gaps within each shoal complex. This enhances the divergence of flow to the north and south and produces localized changes near the inlets (accounting possibly for alternate periods of accretion and erosion in the north and south reaches.

The sketch in Figure 4 illustrates our interpretation of the net effect of refraction/diffraction on wave approach along Hunting Island. Until wave crests align with the shoreline, the beach will remain out of equilibrium and will continue to erode at a high rate.

Shoreline Morphology

The morphology of the Hunting Island shoreline is basically out of equilibrium with the incident wave field. Its beach is not aligned with the incoming waves which form a broad arc between the inlets; rather it is straight to slightly convex seaward, similar to Hilton Head Island. Examples of shorelines in equilibrium are the Grand Strand and Kiawah Island, both of which are broad arcs bounded and anchored by the ebb-tidal deltas at either end. Pocket beaches between headlands are another example of shorelines in equilibrium, aligned with the incoming waves. Once equilibrium is achieved, the primary sand movement occurs in the onshore/offshore direction in the form of beach profile adjustment, rather than longshore transport. It appears that longshore transport is dominant along Hunting Island; otherwise, sand losses from the beach would have built up the nearshore zone just offshore. But the direction of transport splits, shifting sand to the north as well as to the south (Fig. 4). This process also occurs along Hilton Head Island and Fripp Island (Kana et al., 1986; CSE, 1990).

Tidal Currents

Flood currents associated with the marginal channels of St. Helena Sound provide additional energy to move sediment northward. While tidal currents seldom directly cause beach erosion (which is primarily a wave-generated process), they can scour underwater features such as bars which otherwise may hold the beach in place. During storms, waves erode sand from the beach and shift it to the nearshore zone. If tidal currents are present, they may redistribute this sand alongshore or sweep it from the area. Studies by Sill et al. (1981) and Stapor and May (1981) confirm the dominance of flood currents along Hunting Island directed north toward the shoals of St. Helena Sound. This current is analogous to the currents in flood channels (Hayes, 1980) which exist at the margins of ebb-tidal deltas. The difference in this case is simply one of scale.

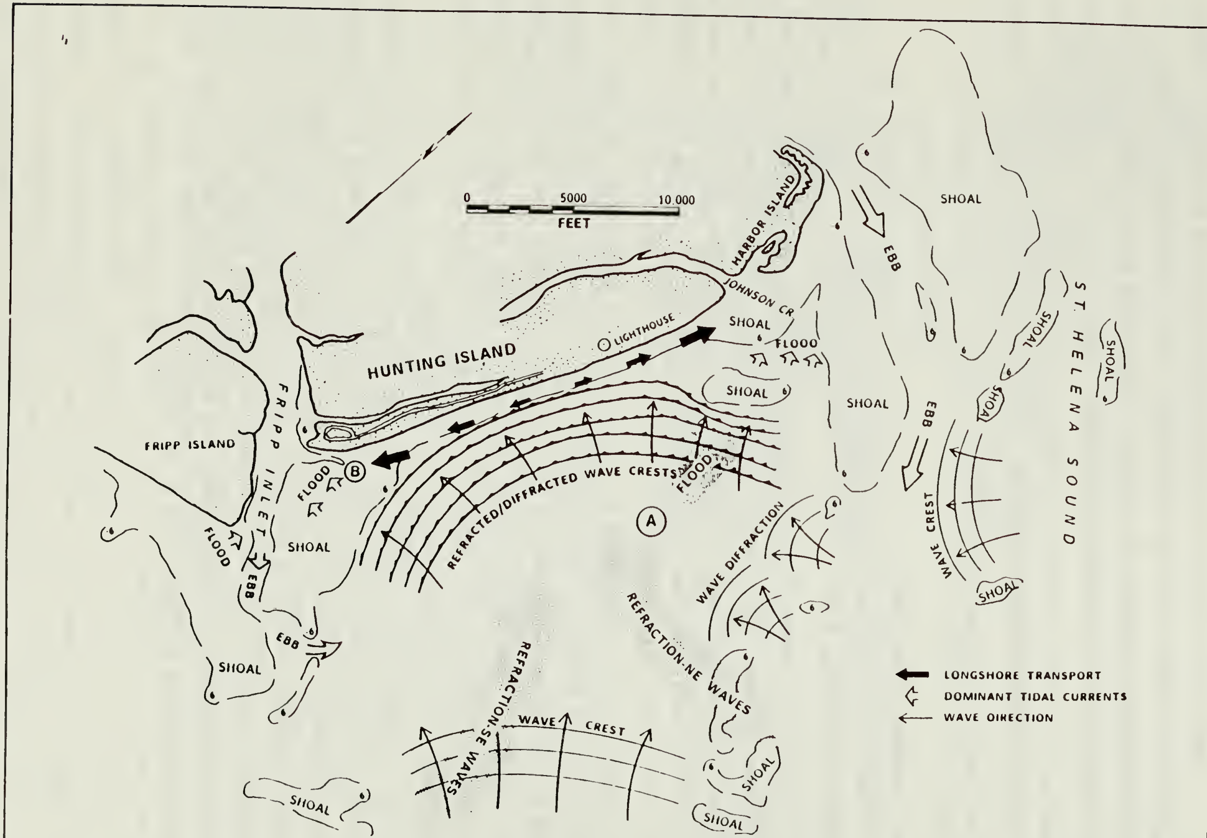


FIGURE 4. General model of coastal processes producing refraction and diffraction around shoals and sand transport away from the center of Hunting Island. Contours are based on NOS chart 11513; datum is mean low water.

St. Helena Sound has one of the largest deltas along the East Coast. Its south marginal flood channel is fed by water flowing over the broad shallow platform 0.5-2 miles off Hunting Island (Fig. 4, label A). Sand eroded from Hunting Island during storms would tend to shift north if exposed to these currents. A similar but lesser channel exists at the south end of Hunting Island and produces southerly directed currents into Fripp Inlet (Fig. 4, label B). Its influence and size, of course, are much smaller than its counterpart to the north.

Sand Trapping by the Inlets

This is an important factor controlling sand budgets throughout the South Carolina coast (Hubbard et al., 1979). The volume of sand in Fripp Inlet and the south shoals of St. Helena Sound are large in comparison to the volume contained in the adjacent beaches (Fig. 4; note 6-ft MLW contours delineating extensive shoals). Sand lost from the previous nourishment projects has shifted both to the attached shoals off Johnson Creek and the spit at the south end of Hunting Island (USACE, 1977). We estimate 150,000-250,000 cy have accreted at the south spit since 1980 from losses along the ocean beach (see Fig. 2, historical shorelines). But gains at the ends of Hunting Island are not sufficient to account for the net sand loss along the island or the general retreat of the ends of the island along with the central portion since the 1800s. This means sand is being shifted further offshore into the detached inlet shoals. USACE (1977) theorizes much of the fill from the first two projects shifted north to the southern shoals of St. Helena Sound.

At the south end of Hunting Island, rapid recovery of the Fripp Inlet borrow area after the 1975 and 1980 projects may have been due to some beach fill shifting back offshore although we believe the primary source for infilling was offshore sand from shoals immediately seaward of the borrow areas. Regardless of the details which are impossible to quantify, it is well established that once sand reaches the ebb-tidal delta, it will be trapped there for long periods until shoals detach and accrete to the adjacent beach (FitzGerald et al., 1976; Kana et al., 1985).

Other Factors

There are numerous factors contributing to beach erosion not listed above including sea-level rise, frequency of storms, and sediment incompatibility after nourishment. But we have listed those factors believed to be most important for Hunting Island in particular order:

1) **Wave refraction and diffraction** producing longshore transport at the shoreline away from the center of the island.
2) Existing **shoreline morphology** which is out of equilibrium with normal wave approach directions.
3) **Flood-tide currents** associated with St. Helena Sound ebb-tidal delta (and to a lesser extent Fripp Inlet) which have the tendency to shift sediment toward the deltas.
4) **Sand trapping by the ebb-tidal deltas** of St. Helena Sound and Fripp Inlet which have both enlarged over the past 70 years (Stapor and May, 1981), but have not released shoals to the adjacent beaches as is the case along other South Carolina beaches.

A final factor that may influence erosion along Hunting Island is the difference between normal and storm wave energy. Where there is little difference between net fair-weather (i.e., beach-building) energy and erosion-causing wave energy, offshore transport by storms is balanced by onshore transport during normal conditions and the beach remains more stable. We believe this is the case along central Kiawah Island and the Grand Strand where the coast is more exposed to ocean waves. In contrast, where the ocean shoreline is protected by inlet shoals (e.g., Dewees Island and Daufuskie Island), storm wave energy is much higher than normal energy. Thus, erosion during storms may not be offset by onshore transport between storms. The normal waves along Dewees Island and Daufuskie Island, for example, average less than one foot. Low waves such as this have less energy to push eroded sand back to the beach. With the added influence of nearby tidal inlets to capture this sand, the result is a net shoreline retreat of 20 ft/yr and 8 ft/yr, respectively, in these two cases (Kana et al., 1984b; 1984c). A similar situation may occur along Hunting Island. However, we do not consider this to be the primary factor based on the detailed littoral environment observation (LEO) measurements of waves by McCreesh (1982). That study reported average waves along the center of the island of about 2 ft which is higher than Dewees and Daufuskie and is comparable to other South Carolina beaches (Brown, 1977).

While the conceptual model of erosion is not quantitative, we use it as a basis for predicting trends and formulating alternatives. Fortunately, quantitative beach survey data are available to estimate nourishment needs; the conceptual model is used to refine the plan in a manner which produces a cost-effective result and works with the natural processes as much as possible. The next section discusses several beach restoration alternatives for Hunting Island based on the findings herein.

BEACH RESTORATION ALTERNATIVES

I. DO NOTHING

The **do-nothing** alternative assumes a continuation of erosion if no nourishment or shore-protection structures are added along Hunting Island. Our best estimate of future erosion is 15 ft/yr along most of the oceanfront where present park or private facilities exist. This erosion estimate is based on the following:

1) Prenourishment long-term erosion rates of *13.4 ft/yr (1920-1962), *12.6 ft/yr (1859-1962), and *20.4 ft/yr (1951-1959).
2) Assumption that erosion of past nourishment projects was faster than the natural rate because they were limited to approximately one-half the island length and therefore served as a feeder beach to unnourished sections.
3) Future erosion from the present shoreline position will involve vegetated highland versus unvegetated beach sand. Roots, stumps, and vegetation have some binding capacity although it is small.

While erosion along the northern reach has been higher than the center of the island prior to nourishment, we do not believe the natural trend is significantly different from the rest of the island after construction of the terminal groin in 1959. And while accretion has occurred recently along the southern reach (100+00 to 141+00), the long-term trend is also erosional. In consideration of these factors, we estimate a somewhat lower erosion rate will prevail along the ends of the island in the future. No imminently threatened structures exist along the ends of the island.

Using the estimate of 15 ft/yr erosion over most of the island, we have projected 10-year and 25-year future shorelines (vegetation line) at 150 ft and 375 ft landward of the present scarp. These projections are shown in Figure 5. We assumed the rate will be uniform between stations 40+00N and 90+00S (13,000 ft) and taper to zero at 60+00N (about 1,000 ft updrift of the groin) and 130+00S. The lessening of erosion at the ends of the island is predicated on the supply of eroded sand from the center shifting to the ends. Under the 25-year scenario (in actuality sooner if a major storm impacts the area), the beach would be breached near the north end of the lagoon and a new inlet formed between stations 40+00S and 80+00S. There is also the possibility of a breach forming between stations 20+00N and 30+00N into a freshwater wetland behind the beach at that locality. A breach at the north end of the island

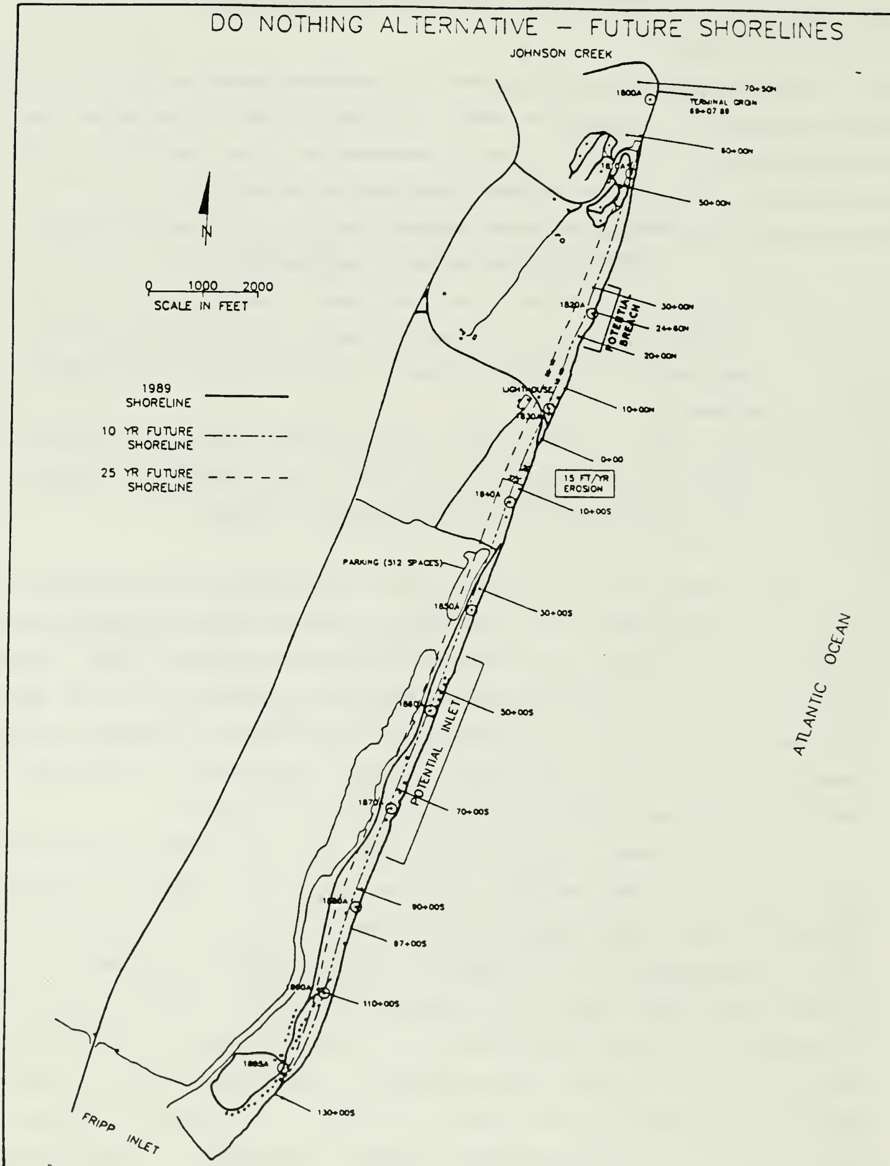


FIGURE 5. Predicted 10-year and 25-year future shorelines assuming no beach restoration attempts and average annual erosion of 15 ft/yr. The erosion rate is assumed to taper to zero at stations 60+00N (near groin) and 130+00S (recurved spit).

would be much smaller than an inlet into the lagoon because the volume of the basin is small.

Under the **do-nothing** alternative, we estimate the following losses will occur:

Impact	10-Year Scenario	25-Year Scenario
Shoreline retreat (40+00N to 90+00N)	150 ft	375 ft
Highland acreage lost (60+00N to 140+00S)	58.5	146.3
Dry-sand beach (40+00N to 90+00N) (negligible at present)	Negligible	Negligible
Wet-sand beach	0	0
Cottages	20	28
Other infrastructures	Yes	Yes
Inlet formation	Possible	Yes

It can be seen that even with erosion, the wet-sand beach may be maintained with little change in area. It will simply shift landward as erosion progresses. The area of dry-sand beach is presently negligible except at the ends of the island and is not expected to change much under either scenario compared to its degraded condition. The quality of the beach for recreation however will be degraded further if eroded trees and stumps are not removed along the principal recreation areas. Beaches such as this (e.g., Capers Island) become impassable at all but the lowest tides, reducing opportunities for common public recreation activities at the beach. Of course, these recreation losses are offset by creation of wildlife habitat and introduction of alternative recreation activities. But sunbathing and swimming, the two activities that drive most of the demand at the park, would undoubtedly decline.

We have not placed any values on land and structure loss or substitution of alternative habitats for a high-use recreation beach. But clearly, the overall impact will be negative from the standpoint of accommodating many people at the beach. Under the do-nothing alternative, the dry-sand beach could be maintained if the oceanfront highland were cleared in advance of erosion and existing structures abandoned or relocated. A rough estimate of such costs is as follows:

Item	Unit Cost	Number of Units (10-Year Scenario)	Total Cost
Cottage relocation	$25,000*/cottage	20	$500,000
Land clearing/grading	$2,500/acre	±60	150,000
Debris disposal	$2,000/acre	±60	120,000
Relocation of infrastructure	$50,000(?)	1	50,000
Emergency closure of inlets	$100,000	1	100,000
		Total	$920,000

*Assuming some economies if all done under one contract. NOTE: FEMA pays up to 40 percent of structure value in some cases where property is federally insured.

Based on the above findings, the do-nothing alternative will not be without costs. PRT officials are in the best position to refine these costs and determine if they are compatible with the mission of the park. While CSE offers no opinion regarding the suitability of this alternative for the state, we believe the erosion scenarios are realistic based on review of all available data.

II. LARGE-SCALE NOURISHMENT ALTERNATIVE

For purposes of developing nourishment alternatives, we assumed a design life of ten years which is equivalent to the period since the last nourishment project. Design life as defined here is the estimated time for a nourishment project to erode back to existing conditions. As such, it differs from designs intended to withstand certain storm occurrences without damage to backshore facilities. This is an important difference because even a large volume of sand placed on the beach will not prevent rare surges from inundating the land, as we saw after Hurricane *Hugo*. Surge protection requires both a stable beach and foredunes well above the expected storm tide.

The ten-year nourishment requirement for Hunting Island is based on an estimated erosion rate of 20 cy/ft/yr over most of the island. Volumetric surveys indicate erosion of past projects occurred at 14-20 cy/ft/yr (1-3 years after the 1971 project) and 10-16 cy/ft/yr (1-3 years after the 1980 project). Reported preproject erosion rates range from ±12 cy/ft/yr to 25 cy/ft/yr (USACE, 1977). The volumetric loss rate from 1981-1990 (see Table 10) has been estimated at ±12 cy/ft/yr (to -5 ft NGVD). While most of these rates are lower than the 20 cy/ft/yr rate estimated for the ten-year nourishment requirement, the higher rate is used because the present condition of the beach is worse than it was prior to each nourishment project.

In other words, past projects have not kept pace with erosion, whereas a large-scale project envisioned here should at least stabilize the shoreline for the period of the design life. This may be accomplished through a series of small projects or with a large project sufficient to withstand the high annual sand losses expected along Hunting Island. We have also assumed a ten-year project to introduce economies of scale during construction. Larger projects generally have lower unit costs, all other factors being equal. The large-scale nourishment alternative is illustrated in Figure 6 and would involve the following design criteria:

DESCRIPTION — LARGE-SCALE NOURISHMENT ALTERNATIVE

Length / limits	16,500 ft / 55+00N to 110+00S
Unit volume (average)	200 cy/ft
Total volume	3,300,000 cy
Berm elevation	+7.5 ft NGVD
Adjusted beach slope	1:40
Initial berm width after adjustment	±250 ft
Initial width to mean high water	±450 ft
Distance to fill intercept with existing ocean bottom	±1,000 ft
Ratios — Proposed:1980 project	2.35X

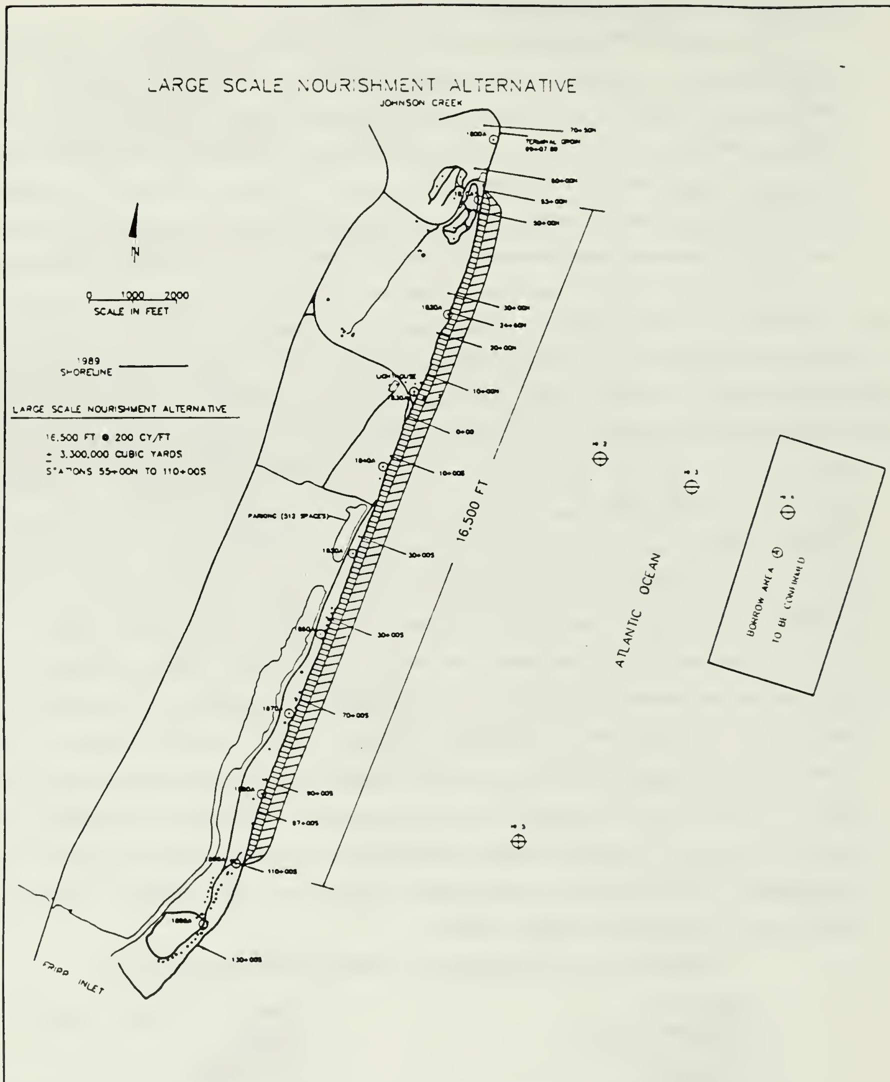


FIGURE 6. Large-scale beach nourishment plan for a 10-year design life (time to erode back to present conditions).

The above criteria assume erosion of the fill will nourish the north and south ends of the islands, and therefore, the project length can be reduced to approximately 80 percent of the island's length. The assumed beach slope of 1:40 is slightly steeper than the natural beach face (1:45) but is offset by construction of a flat berm along the backshore and steeper slopes that will occur underwater below the -6 ft NGVD contour (unpublished data from Seabrook Island and Hilton Head Island nourishment projects by Great Lakes Dredge & Dock Company and CSE, March-June 1990). The fill sections (Fig. 7) would involve 200 cy/ft, a quantity that is ten times higher per foot than the 1986-1987 Myrtle Beach nourishment project and about three times higher than the Hilton Head Island project, which is presently under construction.

Borrow Source

Preliminary surveys of sand deposits offshore of Hunting Island confirm that several sites contain beach-quality sand. The 1975 and 1980 projects used the north shoal of Fripp Inlet (see Fig. 1). Cores taken for this study over the Fripp ebb-tidal delta confirm good material is abundantly available. However, the distance to the area of greatest need will be 3-5 miles from Fripp Inlet. Costs of dredging increase as a function of distance from the source to the beach. Cores HI-3 and HI-4 (Table 11) were taken 1.2 mile and 1.8 miles offshore of the lighthouse; HI-5 was taken about 1.1 miles seaward of station 80+00S. Sand tests indicate the latter two cores contain beach-quality sand with relatively low mud content (less than 5 percent) in the upper part of the deposit (Table 11). Because the area ±1.5 miles offshore of the lighthouse would be closer to the nourishment area, unit-dredging costs would be less. This suggests more detailed evaluation of the sand deposits directly offshore are warranted before finalizing alternatives. Our results of core HI-3 showed good quality sand in the upper 3 ft but material considered too fine below that layer (Table 11). However, core HI-4 contained beach-quality material to at least 12 ft below the bottom. Assuming an average of 10 ft could be excavated in this offshore region, a borrow area 1 mile long by 0.5 mile wide could provide the necessary quantity of fill for the large-scale nourishment alternative.

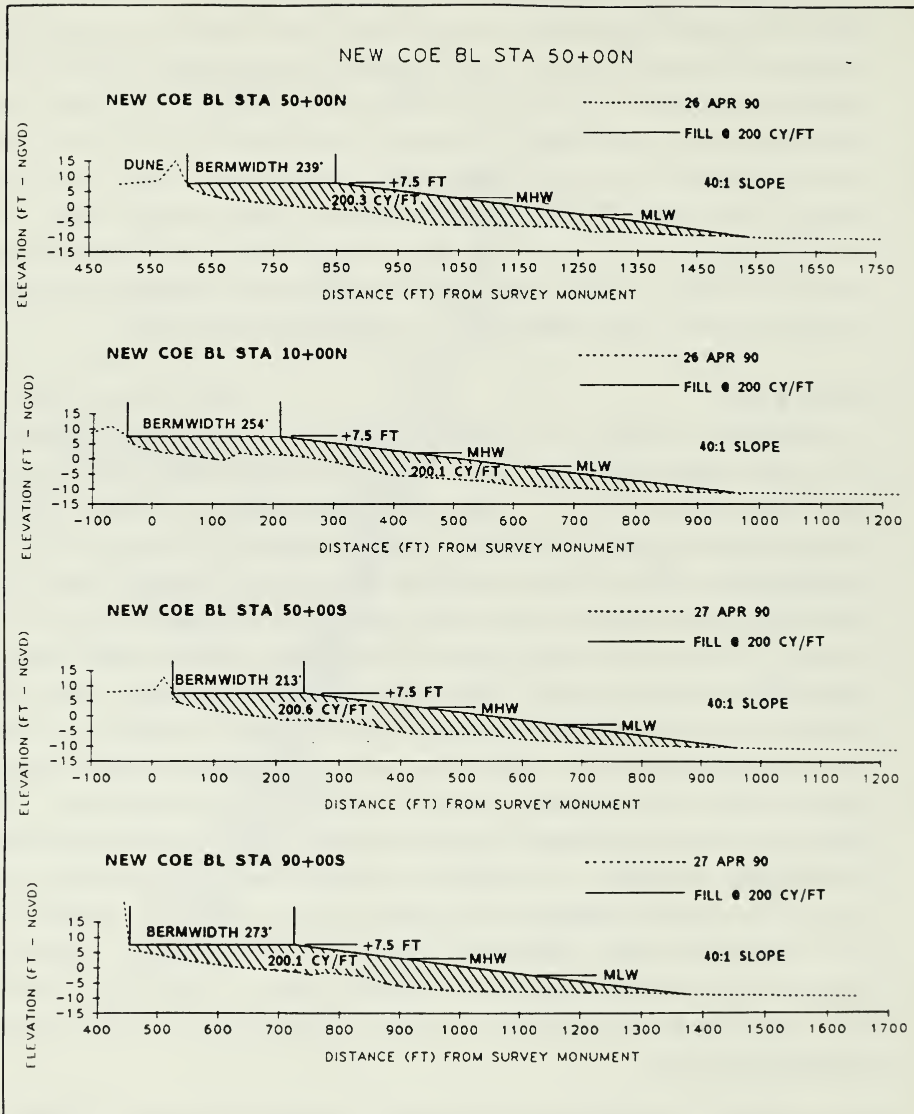


FIGURE 7. Representative fill sections for the large-scale nourishment project (3,300,000 cy). Note: While sections would average 200 cy/ft, final design would likely vary these somewhat to improve the distribution of fill and improve longevity around primary recreation areas.

TABLE 11. Representative sediment quality data (graphic statistics) from vibracores taken during this study off Hunting Island in June 1990. Native beach samples are given at the bottom. [M_z = mean size in phi (ϕ) units and millimeters (mm).]

Core	Depth (ft)	M_z (ϕ)	M_z (mm)	Description
HI-3	0-3	2.05	0.24	Fine sand, coarse skewed, poorly sorted
	3-8	2.80	0.14	Fine sand, coarse skewed, well sorted
HI-4	0-5	2.35	0.20	Fine sand, coarse skewed, moderately sorted
	6.5-12	2.32	0.20	Fine sand, coarse skewed, moderately sorted
HI-5	0-6.5	2.49	0.19	Fine sand, symmetrical, well sorted
	6.5-12	2.36	0.19	Fine sand, coarse skewed, moderately sorted
HI-6	0-6.5	2.60	0.16	Fine sand, symmetrical, well sorted
	6.5-13.5	2.39	0.19	Fine sand, coarse skewed, moderately sorted
HI-8	0-8.3	2.22	0.21	Fine sand, coarse skewed, well sorted
Native Beach (USACE, 1977)				
1963	Berm	2.58	0.17	Fine sand, well sorted
	Beach face	2.68	0.16	Fine sand, well sorted
1971 @ 10+00N				
	Berm	2.33	0.20	Fine sand, well sorted
	Beach face	2.31	0.20	Fine sand, well sorted
	-3 ft MLW	2.33	0.20	Fine sand, well sorted
1975 @ nourished section				
	Beach face	2.19	0.22	Fine sand, well sorted
1975 @ unnourished section				
	Beach face	2.49	0.18	Fine sand, well sorted

Based on the dimensions of the fill and proposed borrow area between 1-2 miles offshore of the delivery point, we estimate the costs of this alternative as follows:

LARGE-SCALE NOURISHMENT ALTERNATIVE
CONSTRUCTION METHOD — HYDRAULIC DREDGE

Mobilization/demobilization — ocean-certified dredge	$350,000
Pumping/placement costs (3,300,000 cy @ $2.25/cy)	$7,425,000
Engineering/surveys/construction management @ *7 percent	$ 545,000
Total Costs	**$8,320,000**

The above costs are based on recent bids for Seabrook (*685,000 cy @ $1,550,000 including mobilization, engineering, and construction) and Hilton Head Island (*2,500,000 cy @ $9,700,000). The Seabrook project (March 1990) involved lower unit pumping costs ($1.90/cy) because distances from borrow site to the beach were less than one mile. Hilton Head (under construction April-July 1990) involves pumping distances of up to five miles. Unit costs for Hunting Island should also be lower than Hilton Head because the fill sections would be fatter. This reduces the amount of down time for movement of pipe along the beach.

A project of the scale outlined under this alternative would provide increased dry-beach area (*95 acres upon initial fill adjustment plus additional acreage seaward of the berm crest) and could sustain losses of ten acres per year before erosion reverts to the present shoreline. It would also provide a relatively long time before renourishment is required, therefore minimizing disruption to recreation over the next decade. However, to achieve success under the design criteria above, the project has to be longer than previous projects to account for losses at the ends of the island. And like previous nourishment projects, it will not be a permanent solution much beyond ten years.

III. SMALL-SCALE NOURISHMENT ALTERNATIVE

The second nourishment alternative is formulated around the budget limit of (*)$3 million. In simple terms, this budget would provide for a project approximately one-third the size of the large-scale nourishment alternative although unit costs would be higher because the mobilization charge is apportioned over fewer yards of sand. A smaller project constructed similar as the large-scale project would also last proportionately less, perhaps three years. Therefore, we investigated alternative nourishment schemes which may increase the design life under the present budget limitations and focus nourishment along the area of greatest need.

Erosion and volumetric loss rates for this alternative are assumed to be 25 percent higher than the large-scale nourishment alternative, 25 cy/ft/yr, because the project would likely have to be shorter and function as a feeder beach to adjacent sections. The area of greatest need is considered to be the high-use recreation areas around the lighthouse and stations 20+00S to 40+00S. Other areas of PRT concern are the park cottage area around 50+00S and the campground around 50+00N. Private cottages between 60+00S and 100+00S are also vulnerable to erosion. Unfortunately, the separation of these sites makes selective nourishment more difficult and would increase unit costs because of the extra mobilization and shifting of pipes. For this reason, we recommend the small-scale project concentrate on nourishment around the primary public recreation areas, particularly from stations 15+00N to 50+00S. This 6,500-ft reach has the highest day use and best access. It is also at the center of the island which has historically provided sand to the northern and southern reaches along Hunting Island.

We developed a specific plan for small-scale nourishment under the given budget limit, using the following goals and criteria:

1) Increase the design life in the high-use recreation area.
2) Formulate a plan that is relatively easy to construct by hydraulic dredge using a nearby borrow area and involves relatively short pumping distances and fat sections.
3) Plan for natural processes to help redistribute fill, thereby potentially lowering unit costs.
4) Overfill the critical sections to accommodate accelerated erosion after project completion.

5) Provide fill to additional areas where structures are imminently threatened.

6) Develop a plan whereby smaller scale maintenance nourishment is possible without mobilizing a hydraulic dredge.

A small-scale nourishment alternative that meets these criteria is shown in Figure 8. It includes the following:

DESCRIPTION – SMALL-SCALE NOURISHMENT ALTERNATIVE

Length/limits	9,500 ft	15+00N to 80+00S
Unit volume A	100 cy/ft	15+00N to 50+00S
Unit volume B	50 cy/ft	50+00S to 80+00S
Beach fill volume A	*650,000 cy	
Beach fill volume B	*150,000 cy	
Berm elevation	+7.5 ft NGVD	
Adjusted beach slope	1:40	
Initial berm width after adjustment	A) *100 ft	B) *25 ft
Initial width to MHW	A) *225 ft	B) *100 ft
Distance to fill intercept with existing ocean bottom	A) *750 ft	B) 550 ft

Sand breakwaters (2) @ 0+00 and 30+00S
- Dimensions: *400 ft x 800 ft to mean sea level (average fill thickness = 8 ft)
- Initial distance offshore: *750 ft @ centerline
- Initial intertidal area: *1.5 acres each
- Fill volume: *100,000 cy each

Total Project Volume: *1,000,000 cy

The small-scale nourishment alternative has three parts, beginning with a 6,500-ft-long recreational beach involving unit fill of 100 cy/ft. This part of the project calls for a unit fill quantity that is approximately 50 percent greater than the recent Hilton Head project. Assuming historic erosion rates, such a quantity alone (650,000 cy) would only last about three years. The second part extends the project 3,000 ft south at a lower unit volume of 50 cy/ft. This will provide limited erosion relief for 2-3 years to structures in the vicinity and provide a feeder beach for the south end of the island.

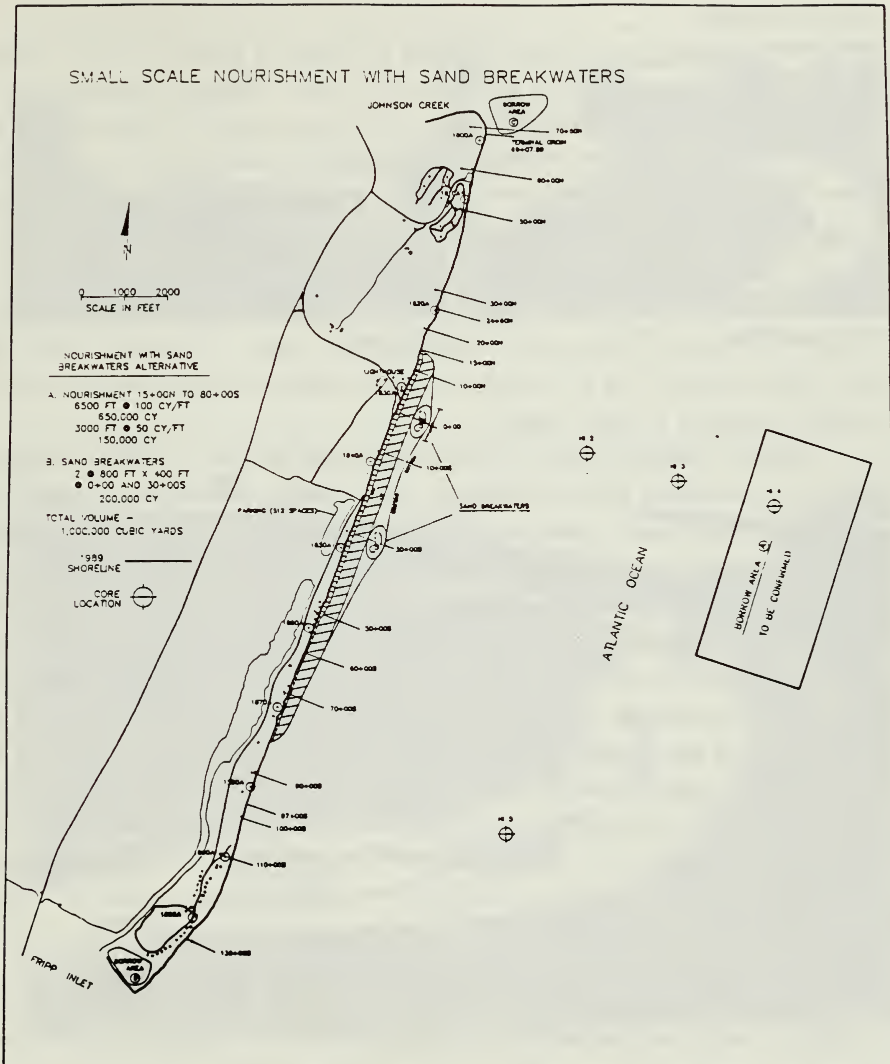


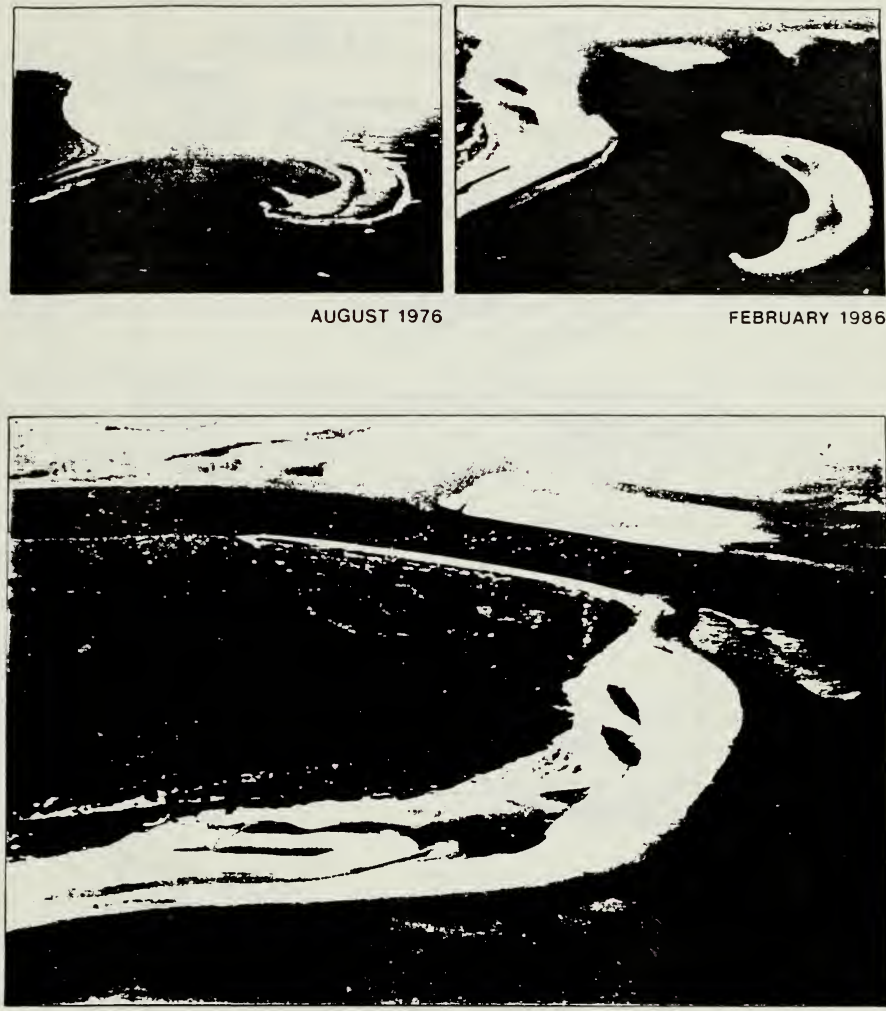
FIGURE 8. **Small-scale nourishment alternative with sand breakwaters positioned at the primary beach accesses near stations 0+00 and 30+00S.**

Sand Breakwater

The third part is an innovation intended to extend the design life in the primary recreation areas and result in an extra quantity of sand placed at the lowest price. Referred to here as **sand breakwaters**, two such features would be constructed in the vicinity of the primary beach accesses. Sand would be pumped to the toe of the new beach and built up to the approximate mid-tide level. The mounds would have rough dimensions of 800 ft alongshore and 400 ft across shore (Fig. 8). Placement in this fashion would extend the toe of the fill approximately 400 ft further seaward than the initial nourishment. At high tide immediately after construction, the sand breakwaters would be underwater, forming a bar where large waves break. At low water, each sand bar, shaped somewhat like a hot dog that curves seaward along the center, would be exposed seaward of a shallow trough.

Artificial breakwaters have been used along many beaches to stabilize shorelines and their general effect is fairly well known (CERC, 1984). The degree to which they stabilize a beach, however, varies and depends on how much wave energy they intercept and whether there is a natural sand supply coming into the area. This same function is produced by natural breakwaters which, in South Carolina, include sand bars around inlets. While bars at inlets are often trapped in the ebb-tidal delta for years, if a channel shifts, some sand may be released at once to migrate and attach to the beach. This process has occurred several times at Isle of Palms, Sullivans Island, Kiawah, and Seabrook in the past decade. Figures 9 and 10 illustrate the process. First, the bar coalesces just offshore where it is pushed shoreward by waves. If ebb-tidal currents are weak because the bar is close to shore or an inlet channel has moved, sand will migrate up the profile and eventually weld to the lower beach. This provides natural nourishment as high as 500,000 cy, such as the examples in Figures 9 and 10. Figure 11 illustrates the 20 ft/month rate of onshore movement of the 1983 bar at Isle of Palms.

The tendency for bars to move onshore is related to the breaker type, slope of a particular beach, and the imbalance between onshore and offshore sand transport. Where the beach and inshore profile have a gentle slope, breakers spill gradually toward shore, producing a translational wave that pushes sand up the beach. As sand accumulates further up the beach, the slope increases and this eventually changes the character of waves to a more plunging form. Plunging-type waves have a tendency to erode the profile and shift sand back offshore (Kana, 1979). By placing a sand



AUGUST 1976

FEBRUARY 1986

APRIL 1983

FIGURE 9. Shoal formation, migration, and attachment to the beach around a tidal inlet. Two examples from the east end of Kiawah Island between 1976 and 1986. [Photos courtesy of CSE]

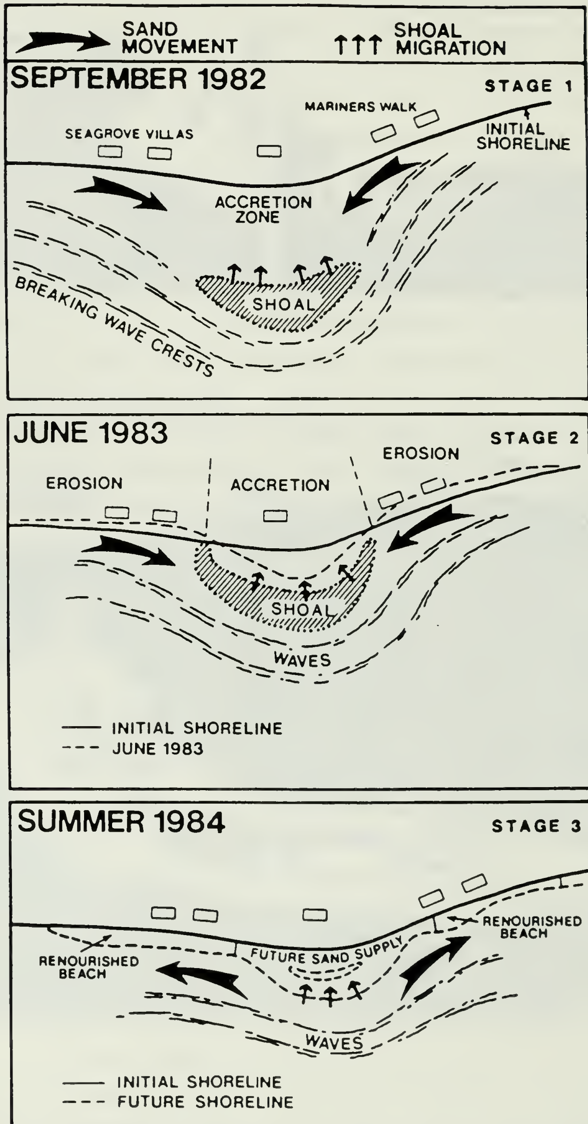


FIGURE 10. Model for shoal bypassing and natural nourishment at South Carolina barrier islands, based on examples from Isle of Palms and Kiawah (after Kana et al., 1985).

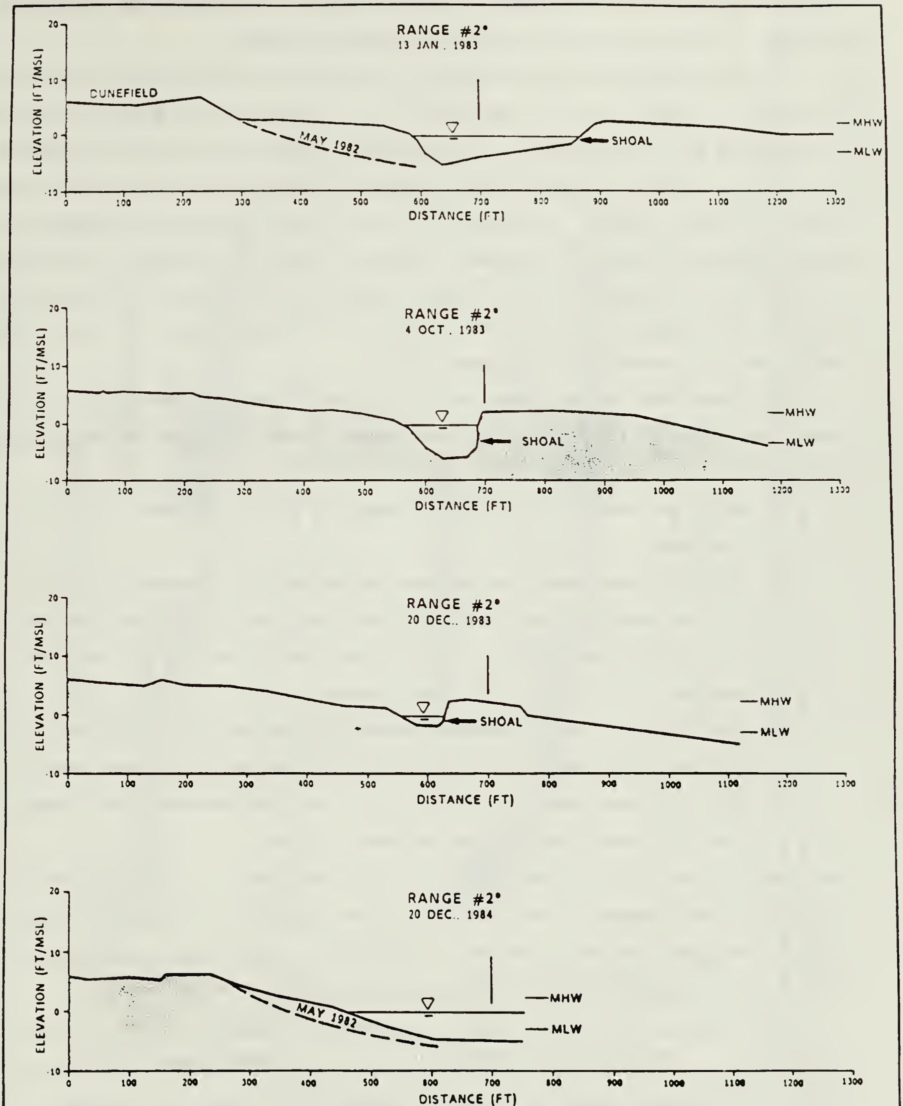


FIGURE 11. Sequential profiles in the direct lee of a migrating inlet shoal at the northeast end of Isle of Palms between January 1983 and December 1984 showing the rate of migration. Note associated buildup of the beach. [After Kana et al., 1985]

breakwater at the toe of the beach, the beach slope is reduced below its equilibrium for the area. In the short term, this promotes onshore transport.

As bar migration occurs, the beach will undergo accretion in the area protected and erosion to either end of the bar (see Fig. 10). The extent of erosion and accretion are related to the size of the bar. For the Isle of Palms case, accretion exceeded 300 ft in the lee of the bar before shoal attachment (Fig. 11), while erosion reached upwards of 150 ft adjacent to the ends of the bar during the same time period. Once attached, however, the bar introduces a new sand supply to the beach. This natural nourishment is then spread in both directions away from the center of the bar (Fig. 10, stage 3). The scale of erosion and accretion for a smaller bar, of course, will be smaller and the process will occur more rapidly.

We believe the natural process of bar migration and attachment can be used to extend the design life of the Hunting Island project in the vicinity of the beach accesses as follows:

1) Initial nourishment of 100 cy/ft along the beach will restore the dry-sand beach.
2) The sand breakwaters just offshore will be pushed shoreward during the first two years, gradually adding to the beach width at their locations. This will delay erosion of the fill at the critical points and help maintain a wide beach a few years longer.
3) Similar to the natural process, erosion will initially occur adjacent to the bars. The intent is for this to occur along lower-use areas nearby.
4) After bar attachment in 1-2 years, sand from the breakwater will spread north and south, and feed the adjacent beaches.

The time for this cycle of bar migration and attachment to occur depends on the quantity of sand involved. Small volumes under 50,000 cy will be distributed in a matter of months, whereas a volume of 500,000 cy could require upwards of three years as was the case at Isle of Palms in 1982-1985 (Kana et al., 1985).

The plan for the small-scale nourishment alternative calls for two sand breakwaters at 100,000 cy each (Fig. 12). This size will require about one year for complete attachment based on rates for natural bars under the influence of South Carolina's wave climate. The size of each breakwater has been established based on construction estimates. This plan offers flexibility to modify their size depending on the budget remaining after the beach nourishment is accomplished. The size also allows for

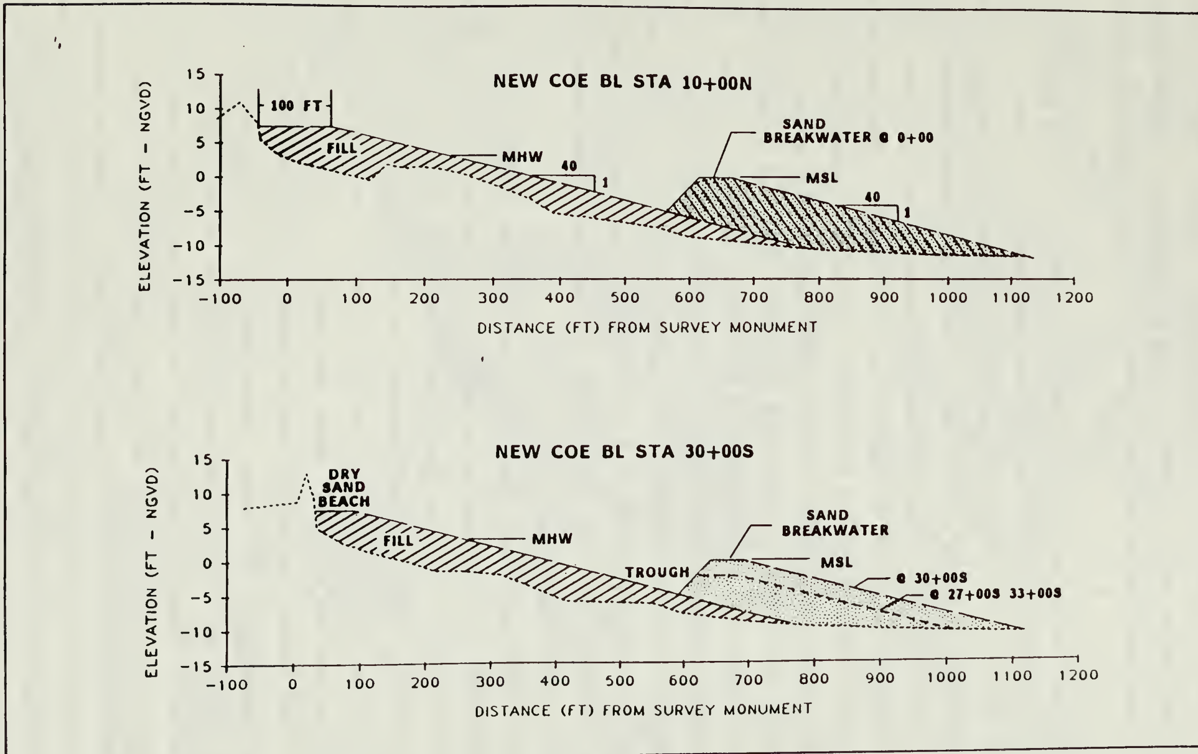


FIGURE 12. Design cross-sections for the small-scale nourishment with sand breakwater alternative. Compare with the upper two diagrams in Figure 11. The initial trough would be temporary and eventually fill in as the sand breakwater migrates onshore.

short-term erosion adjacent to the sand breakwaters at about 50-75 ft. This accelerated erosion will be short term and centered around stations 20+00N. 15+00S. and 45+00S. areas which are not believed to have any imminently threatened structures (see Fig. 8).

The proposed borrow source for the small-scale alternative is the same as the large-scale project. pending confirmation with additional borings. As can be seen in Figure 8. the borrow area is situated about 9.000 ft offshore and would be relatively cost-effective compared to shoals at Fripp Inlet or those further into St. Helena Sound.

Other criteria considered in the designation of the borrow area were water depth. proximity to existing channels of St. Helena Sound. and logistics. The area around core HI-4 is at the landward edge of the southern channel of the sound and close to the end of the Harbor Island shoal complex. Being close to the channel. it would allow easy access for a dredge to move inland to safety in the event of storms. NOS charts and our survey at HI-4 indicate 12-14 ft depths occur at mean low water. This is approximately the depth limit for navigation by large ocean-certified dredges such as the one used in the Seabrook and Hilton Head nourishment projects. Support vessels would be able to access the area by way of several channels through the shoals into Harbor River or Morgan River (Fig. 13). A final consideration is environmental which is discussed in a later section of this report.

The small-scale nourishment alternative is not expected to last as long as the large-scale alternative and is not designed to address erosion in the campground section at the north end of the island or the cottage area at the south end (south of 80+00S). However. to address these limitations. we have designated two "onshore" borrow areas at the ends of the island (see Fig. 8. areas B and C). Each area is accreted land or attached intertidal shoals that could be accessed by landbased equipment. These borrow areas could be used for periodic maintenance nourishment or for emergency renourishment after storms. Borrow area B at the south end of Hunting Island is an accreted spit containing upwards of 200.000 cy in the upper 10 ft of the section. The sand is assumed compatible with the beach and free of mud because of its recent origin (see Fig 3. historical shorelines). Borrow area C is situated at the mouth of Johnson Creek and consists of beach-quality sand. It could be accessed by landbased equipment during approximately half the tidal cycle and contains several hundred thousand yards of sand in the upper 6 ft. Emergency nourishment on the order of 250.000 cy or less would be more cost-effective using landbased equipment

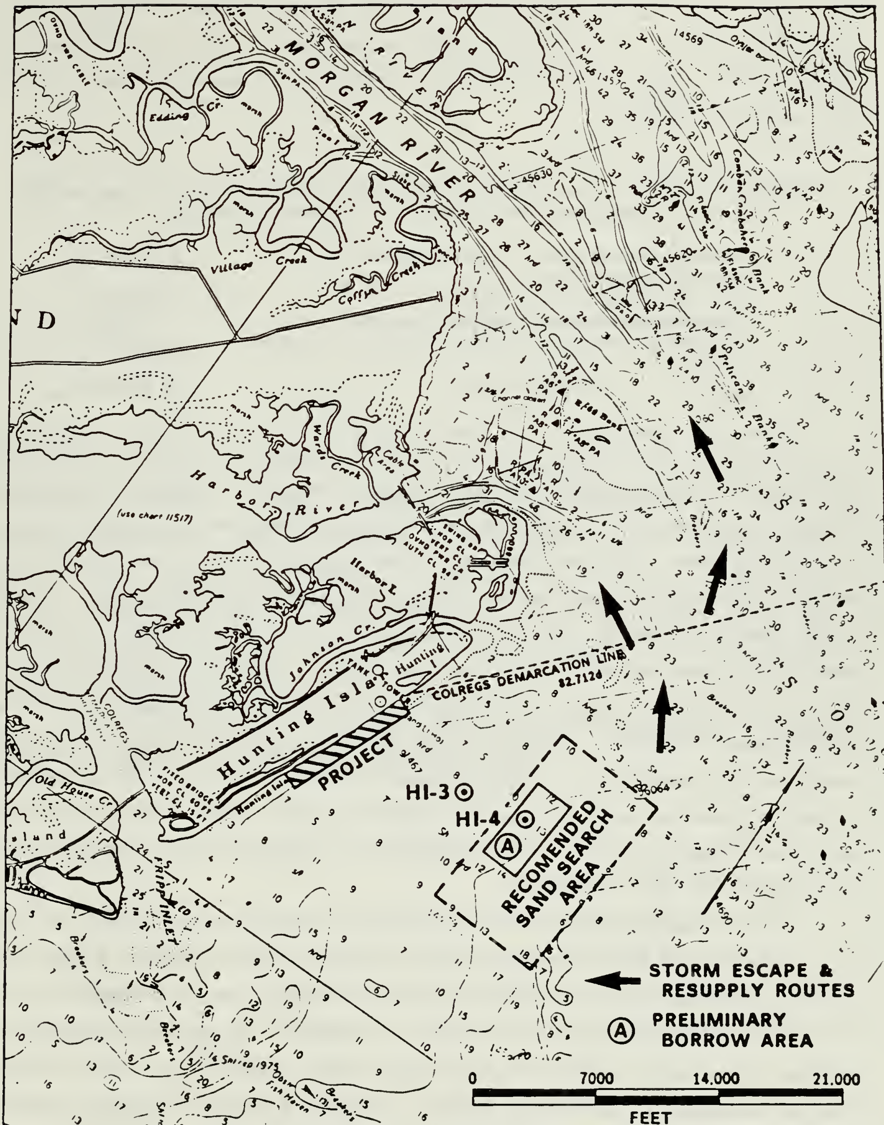


FIGURE 13. NOS bathymetry of St. Helena Sound showing location of project, preliminary borrow area, area recommended for additional sand search, and storm escape and resupply channels. Small survey vessels under 25 ft may be able to base out of Fripp Inlet Marina up Old House Creek, but navigation through Fripp Inlet is marginal.

from these sites because mobilization costs would be relatively low compared with ocean-going dredges. A small dredge could also be used over the Johnson Creek shoals inside the U.S. Coast Guard COLREGS line (demarcation between inland and ocean rules for vessels: Fig. 13).

ESTIMATED COSTS — SMALL-SCALE NOURISHMENT WITH SAND BREAKWATERS
CONSTRUCTION METHOD — HYDRAULIC DREDGE

Mobilization/demobilization — ocean-certified dredge	$ 350,000
Pumping/placement costs	
A. Beach 800,000 cy @ $2.65/cy	2,120,000
B. Sand breakwaters 200,000 cy @ $1.50/cy	300,000
Engineering/surveys/construction management @ 7.2 percent	200,000
Estimated Costs	**$2,970,000**

The total nourishment volume under this alternative would be 1,000,000 cy (including sand breakwaters), based on the above unit costs. Without the breakwaters at the beach access areas, design life as previously defined for this quantity would be around three years. With the breakwaters, the design life for the two recreation areas would be increased by about two more years. Remaining unnourished areas of Hunting Island would continue to erode although the rate would lessen during the first two years as the beach is fed from the nourished section. The most vulnerable section in terms of potential damage to structures appears to be the cottage area between 50+00S and 100+00S. Cottages around 50+00S to 60+00S would receive direct benefit of the nourishment. Cottages around 70+00S (see Fig. 8) would possibly be subject to erosion as soon as one year after the project. This would result from the extra sand trapping around the south breakwater. This effect would diminish after the bar attaches and shifts southward.

The cost estimate differs from the large-scale project in two ways. We assume unit pumping and placement costs will be $0.40/cy higher because of the smaller volume. However, we also assume the sand breakwaters can be pumped in at lower unit costs ($1.50/cy) because little shaping is specified. As the sand breakwaters are pumped, wave action will rework the features into a natural slope. Also included in the cost estimate is $200,000 for surveys, additional borings, engineering, permitting, and construction management (≈7.2 percent of construction costs).

Under the proposed plan, the design can be modified several ways if bids vary substantially from the above estimates. Unit volumes of beach fill can be revised upward (with lower unit costs), or the project can be shortened from the south end to save yardage. Generally, the bid prices increase if projects such as this are lengthened using lower unit volumes, so it is more cost-effective to thin the fill sections or shorten the project in response to high bid prices. The sand breakwaters offer another opportunity to tailor the final design to the bid. Each breakwater can be enlarged or reduced in size and still improve design life around the recreational beaches. The impact on fill longevity will remain a function of the size of the breakwaters.

The small-scale nourishment project outlined here is considered to be the most cost-effective alternative, considering a budget limitation of around $3 million. It is not a perfect solution and, like all nourishment projects along eroding beaches, will not be permanent. However, given past experience with nourishment at Hunting Island, some innovation is in order, in our opinion. While we believe South Carolina beaches that are highly erosional may ultimately have to resort to a combination of nourishment and permanent sand-retaining structures (groins and breakwaters), the present budget is considered inadequate for such a solution. The sand breakwaters are a soft solution which can be used to test the effect of a fixed breakwater over the short term. As such, it would provide new information regarding the movement of sand along the beach. Any disadvantage including short-term erosion to either side of the sand breakwaters structure would be tempered by their eventual erosion and spreading of sand to other sections of the beach.

The next section outlines a fourth alternative considered more permanent that incorporates sand-retaining structures with nourishment.

IV. NOURISHMENT WITH GROINS ALTERNATIVE

The fourth alternative considered involves a combination of nourishment with groins to reduce the rate of sand loss. The focus of this solution would be on the center of the island at the high-use access points. Groins have been used at Edisto Beach, Folly Beach, and Pawleys Island since the 1950s and 1960s to retard erosion along those areas. While erosion remains a problem at all three beaches, experience shows the groins have substantially reduced the rate of sand loss in comparison to the unprotected beach.

As a rule, groins are most effective when used over a length of shoreline extending to natural boundaries, such as tidal inlets or headlands, at either end of the groin field. Where sand transport is predominantly in one direction, their effect is reasonably predictable with accretion occurring on the updrift side and erosion on the downdrift side. But in areas where transport reverses from season to season or where natural transport splits in either direction, their effect is less predictable.

The erosion model for Hunting Island predicts a divergence of sand transport from the center of the island. Therefore, groins placed around the primary beach accesses have the potential to trap sand moving in either direction. If they are high enough and extend seaward some distance beyond the beach, they will create mini beach compartments. Groins will trap sand between adjacent structures in relation to their size and length, and retain sand in the profile indefinitely if there is no "leakage" around the ends. For groins to totally eliminate sand exchange in the longshore direction, they would have to extend well offshore beyond the zone of active sand movement, perhaps 1,000-2,000 ft from the beach at Hunting Island. Since the cost of such structures is proportional to length, such total littoral barriers would be expensive due to size alone.

A compromise alternative would involve shorter structures and periodic nourishment. The optimal configuration will depend on cost of each element. Shorter or smaller groins cost less but will reduce sand retention. Periodic nourishment can be used to replenish the losses from each groin compartment. A complete analysis of this option is beyond the scope of work for the present study. However, we developed a representative plan based on experience in other areas including Westhampton Beach (Long Island, New York) and Pawleys Island (DeWall, 1979; Cubit Engineering, 1981; RPI, 1985).

Assumptions for the fourth alternative include:

1) Protection priority along primary beach accesses.
2) No additional protection for cottage area or campground.
3) Initial nourishment to produce a 150-ft. dry-sand beach between structures.
4) Length of groins based on approximate mid-tide mark after initial nourishment.
5) Estimate erosion rate in groin field reduces to 10 cy/ft/yr with eroded sand bypassing groins to areas north and south.
6) Approximate design life of nourished beach is ten years.
7) Design life of groins is ±25 years.

A conceptual plan meeting these criteria is given in Figure 14. It would consist of the following:

DESCRIPTION — NOURISHMENT AND GROIN FIELD ALTERNATIVE

Groins — (8) @ 1,000-ft centers from stations 15+00N to 55+00S
Primary beach accesses @ stations 0+00 and 30+00S would be positioned midway between groins
Typical dimensions: 400 ft long: crest @ +9 ft NGVD (trunk): crest @ +5 ft NGVD (head)
Structure type: rubble mound — 0.5-3.0 ton stone variable according to position and exposure along structures: side slopes of 1:2: crest width of 15 ft
Estimated tonnage per structure: 6,000

Nourishment — normal volume averaging 130 cy/ft: length @ 9,000 ft (25+00N to 65+00S): berm crest @ 150 ft: adjusted slope of 1:40

Total Estimated Volume 1,170,000 cy

The project would be constructed in phases, first placing groins along the existing profile, then pumping in the beach fill. Estimated costs are as follows:

Groins — Unit costs/groin	
Rock (0.5-3.0 ton range) delivered and placed 6,000 tons @ $100/ton	$ 600,000
Filter material	10,000
Site preparation	10,000
Contingency (5%)	30,000
Subtotal (1)	$650,000
Subtotal Groins (8)	$5,200,000

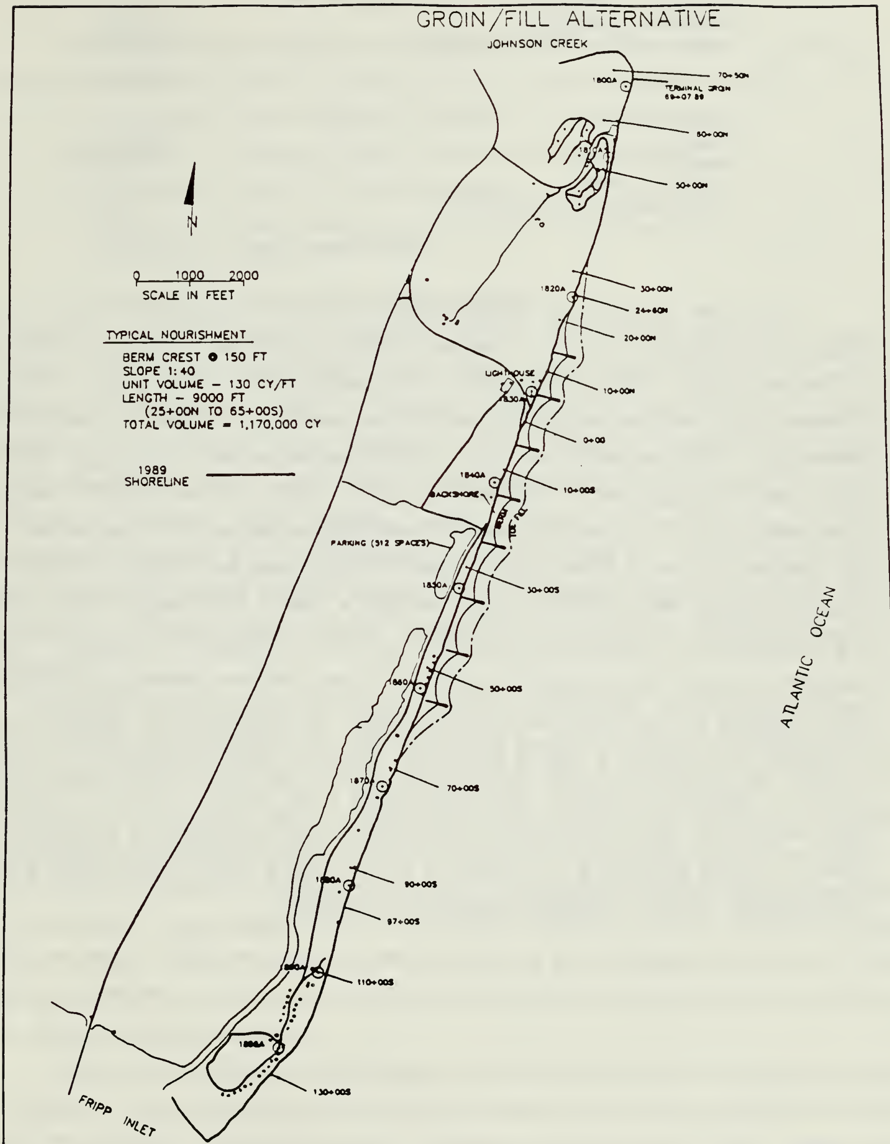


FIGURE 14. Nourishment-with-groins alternative designed to reduce the rate of sand loss from the center of the island.

Nourishment	
Mobilization/demobilization	$ 350,000
Sand pumping (1,170,000 cy @ $2.65/cy)	3,100,500
Subtotal	3,450,500
Total Project	
Groins	$5,200,000
Beach fill	3,450,500
Engineering/surveys/ construction management (*7%)	599,500
Total Estimated Costs	$9,250,000

The fourth alternative as outlined herein would be comparable in cost to the large-scale nourishment project. However, it would have greater longevity along the recreational beach accesses because of the "permanency" of the groins. Savings compared with the other alternatives would accrue over time because of a reduction in erosion rate. Unfortunately, initial cost of this alternative exceeds the budget available. But future investigations of the Hunting Island erosion problem should investigate alternatives such as this which combine sand-retaining structures with nourishment. In our opinion, failure of earlier groins near the lighthouse were more a function of inadequate design and capacity to trap sand than a flaw in the concept. The palmetto log structures were ineffectual because they leak sand through the structure. Timber sheetpile structures were probably too short or lacked sufficient anchorage to withstand rapid lowering of the beach face and also failed. By upgrading and lengthening the structures and extending a field of groins over the most important section of the island (from a recreational standpoint), their effectiveness would improve. We also recommend that future beach restoration plans investigate permanent breakwaters as a substitute for groins. Careful monitoring of alternative III (if it were constructed) would provide useful criteria on wave attenuation around such structures.

ENVIRONMENTAL CONCERNS

Beach nourishment projects are not without environmental impacts. But impacts should be minimized as much as possible. General impacts include the following:

1) Disruption of bottom-dwelling communities at the borrow site.
2) Smothering of bottom-dwelling communities along the beach.
3) Temporary increases in suspended solids.
4) Disruption of nests along the upper beach or spawning habitat around the borrow area.
5) Disruption of commercial shrimping activities.

The key to minimizing impacts is timing of projects. It has been shown that warmer months of the year produce higher impacts than winter months because (1) species density and diversity are higher, (2) certain species may be nesting, and (3) warmer waters have less capacity to hold dissolved oxygen. Therefore, if nourishment projects can be constructed in the winter months, certain specific environmental impacts can be reduced to a minimum, if not altogether avoided. Among them are turtle nesting along the backshore between May and November in South Carolina and bird nesting by least terns (threatened species) or other species in open supratidal areas during March-June. Construction in winter also avoids the commercial shrimping season between June and December.

Previous studies have shown that populations of benthic fauna (species living in the sediments) are upwards of ten times higher in summer than in winter (Knott et al., 1983; Reilly and Bellis, 1983; Nelson and Gorzelany, 1987; Lankford et al., 1988). If projects are constructed in winter, biological recovery of the borrow areas or beach will proceed more rapidly and in phase with the summer season (Lankford and Baca, 1989). Because of these generally accepted findings, we recommend the Hunting Island project be constructed in the winter months, preferably during the months of January and February, with a total construction window extending from December to March. Such timing would then avoid the turtle nesting season, the bird nesting season, and most of the shrimping season altogether.

The months of January and February are also favored because the weather is less changeable, being dominated by high-pressure systems and westerly (offshore) winds from the mainland. Northeasters occur in January and February but such systems are generally forecasted in sufficient detail to facilitate decisions regarding movement of offshore equipment to safe waters. Spring and fall tend to produce more variable and extreme weather patterns that can impact dredge operations. For all these reasons, a winter construction window is more favorable, in our opinion.

Environmental impacts of the Hunting Island project will be assessed by state and federal regulatory agencies including the U.S. Fish and Wildlife Service, National Marine Fisheries Service, U.S. Environmental Protection Agency, South Carolina Wildlife and Marine Resources Division, South Carolina Department of Health and Environmental Control, and the South Carolina Coastal Council. Assuming the project is planned for construction in winter, the following concerns may be raised by these agencies:

1) **Impacts to bottom communities in the borrow areas.** Baseline benthic samples should be taken before construction to insure there are no hard bottom (i.e., rocky substrate) communities in the area and to quantify the species densities and diversity. Sandy subtidal borrow areas (such as the preliminary borrow area identified for further investigation) recover more rapidly than hard bottom (Saloman et al., 1982).

2) **Impacts to bottom communities along the beach.** Because Hunting Island has been nourished four times since 1968 and is eroding at high rates, the existing community has already experienced a lot of stress. Previous South Carolina projects show that biological recovery along nourished beaches can be relatively rapid (e.g., Lankford et al., 1988; Baca and Lankford, 1988). Preproject baseline samples should be collected at several intertidal localities to verify existing faunal populations.

3) **Increased turbidity during construction.** This impact affects primary productivity (photosynthesis) but can be minimized by careful selection of a borrow area with low mud content and clean sand. Sand settles quickly and does not produce significant increases in turbidity the way mud does in suspension. The proposed borrow area consists of find sand with less than 5 percent mud in the upper 8-12 ft of section. Additional borings have been recommended to confirm the quality and extent of the deposit. We believe additional tests will confirm its suitability because it is situated within the ebb-tidal delta complex of St. Helena Sound, a feature which tends to be dominated by sand bodies rather than muddy deposits.

4) **Impacts to ghost crabs and vegetation that live and grow along the backshore.** Because Hunting Island is highly erosional, both vegetation and fauna such as ghost crabs have had to adapt already. Little dry-sand beach exists along the island. Without dry sand, the habitat for shoreline vegetation and ghost crabs is already limited.

5) **Impacts from sedimentation in the borrow area after dredging.** Where a deep pit (relative to the surrounding bottom) is dredged, silt and clay may be the primary sediment for infilling. This could adversely impact shrimping activity which is common in the area, or change the substrate from hard bottom to soft bottom. The effect of fine-grained sedimentation is lessened if current flow through the pit is maintained, preventing fine-grained material from settling. The proposed borrow area is adjacent to one of the principal ebb channels of St. Helena Sound. We believe current flow over the borrow area can be maintained by careful orientation of the dredge cuts with the ebb and flood flow, and by maintaining a shallow broad cut. This should be investigated before finalizing the design during the next stage of the project.

DRAFT

RECOMMENDED PLAN

The results of a feasibility study of beach restoration alternatives for Hunting Island show long-term (i.e., ≥10 years) solutions considerably exceed the available budget of (±)$3 million. The performance of past nourishment projects is sufficiently documented to support this conclusion unequivocally. At the other extreme, the do-nothing alternative is estimated to entail ten-year costs upwards of $1 million (not counting land loss) if the primary asset of the park (high-use recreational beaches) is to be maintained. A compromise plan having a shorter design life has been developed around a fixed budget of (±)$3 million and is recommended for implementation. It consists of nourishment along the areas of Hunting Island where beach access is greatest. The plan would take advantage of the natural tendency of sand to shift from the center of the island toward each end. Therefore by "overfilling" the center section, a dry-sand beach can be maintained longer where it is most needed. By comparison, a project involving the same nourishment quantity placed over the length of the island would not last as long in the high-use recreation areas.

The recommended alternative would involve three parts:

1) Nourishment with a ±3 year design life along a 6,500 ft reach encompassing the primary beach accesses.
2) Nourishment with a ±2 year design life in the park cottage section.
3) Two sand breakwaters positioned just offshore of the primary beach accesses designed to extend the life of the fill by 1-2 years at those two points.

Provision is made for emergency nourishment by landbased equipment using borrow sites at the ends of Hunting Island. However, the initial project will be most cost-effective if constructed by dredge.

A preliminary borrow site containing beach-quality sand with less than 5 percent fines in the deposit (upper 10 ft of section) has been located 9,000 ft offshore of the lighthouse. This site is deemed the most cost-effective for use by an ocean-certified dredge because of its proximity to the beach and accessible water depths. Borrow sites at Johnson Creek and Fripp Inlet contain good deposits but are less accessible by ocean-going equipment and would be further from the project area. Before designating the borrow site, however, additional borings are required. These will be used to confirm quantities and qualities of the material. Detailed geotechnical data reduces the uncertainty of projects such as this and can impact favorably on construction costs.

We recommend the final plan be implemented as an interim erosion plan with an expected design life of five years at the primary beach accesses. The project should be monitored by surveys on a quarterly basis during the first two years, then semiannually for succeeding years. Results of these surveys should be developed into sand budgets and used to refine future designs. Concurrent with the postproject surveys should be a reassessment of funding alternatives and development of a longer term plan for Hunting Island's beach that involves a combination of periodic nourishment with sand-retaining structures.

ACKNOWLEDGMENTS

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APPENDIX I

Geotechnical data obtained during the present study including ten core logs from offshore vibracores and 20 sediment analyses for selected core sections.

Well Depth From Ground Surface	Well ID HI-1	WELL LOG FORM
	Lithologic Description	Well Construction

Feet (MSL Elevation) Ft.

Date

0 — well sorted fine sand mud filled burrows mostly clean sand — mud~10%

2 — fine s. well sorted abundant flaser beds moderate to light bioturbation - flaser beds are mud/black reduced, mud to sand

ratio 50/50

4

6

8

10

bottom of core 11'

12

14

16

18

Well Development

Date

Comments -

Water Samples

Date

Sample ID

Location Spillover lobe Fripp Inlet (NE side)

Date Drilled 13 June 1990

Client CSE

Geologist Walter J. Sexton

ATHENA TECHNOLOGIES INC

600 South Holly St., Columbia, S.C. 29205

(803) 771-6764

Well Depth From Ground Surface	Well ID HI-2	WELL LOG FORM
	Lithologic Description	Well Construction

Feet (MSL Elevation) Ft.________

Date________

0
well sorted fine sand
clean

2 (thin shell lag mixed w/ f.s.
well sorted fine sand
clean slight increase in mud

4

thin shell lag mixed with f.s.
fine sand well sorted
6 random flaser bed (mud)

mixed sand & mud 50/50
abundant flaser beds
some mixed shell rich zones
8

clean fine sand (light grey)
mud filled burrows not common

10 abundant bioturbated flaser
beds - mud content 50/50 to
fine sand

12

Bottom of core 12'10"

14

16

18

Well Development

Date ________

Comments -

Water Samples

Date ________

Sample ID ________

Location Seaward of lighthouse Hunting Is.

Date Drilled 13 June 1990

Client CSE

Geologist Walter J. Sexton

ATHENA TECHNOLOGIES INC
600 South Holly St., Columbia, SC 29205
(803) 771-6714

WELL LOG FORM

Well ID HI-3

Well Depth From Ground Surface	Lithologic Description	Well Construction
Feet	(MSL Elevation) Ft.	Date
0	well sorted f. sand, clean almost no mud	
2	shell rich zone, some intact flaser beds mixed w/ fine sand	
4	mostly fine sand, occasional mud filled burrows and faint flaser beds. <5%, well sorted sands	
6		
8	well sorted f. sand flaser beds (mud) now more common and better preserved	
10	mud increasing w/ depth	
12	Bottom of core 12'4"	
14		
16		
18		

Well Development

Date

Comments -

Water Samples

Date

Sample ID

Location Seaward of lighthouse Hunting Island

Date Drilled 13 June 1990

Client CSE

Geologist Walter J. Sexton

ATHENA TECHNOLOGIES INC

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Well Depth From Ground Surface	Well ID HI-4	WELL LOG FOR
	Lithologic Description	Well Construction

Feet (MSL Elevation) Ft.

Date

Feet	Lithologic Description
0	thin shell lag 3" well sorted f. sand clean nearly no mud, very little shell
2	↓
4	occasional flaser (mud) bioturbated f. sand 90% s. 10% m.
6	thick flasers 2 to 3" mud - better preserved than above mixed with f. sand & shell
	slightly coarser sand - f. to m. sand clean <5% mud
8	↓
10	bioturbated sand, color of sand changes in burrows. occasional flaser bed (mud)
12	bottom of core 12'
14	
16	
18	

Well Development

Date

Comments -

Water Samples

Date

Sample ID

Location Seaward of lighthouse Hunting Island

Date Drilled 13 June 1990

Client CSE

Geologist Walter J. Sexton

ATHENA TECHNOLOGIES INC

600 South Holly St., Columbia, S.C. 292

(803) 771-6764

WELL LOG FORM

Well ID HI-5

Well Depth From Ground Surface	Lithologic Description	Well Construction
Feet	(MSL Elevation) Ft.	Date
0	fine sand ~, 5% mud found mostly at 1 to 1.6' some shell	
	found in mud rich zone	
2	well sorted very clean sand, f. grained - low shell content	
4		
6	core wash out	
	Bag sample to	base of full core barrel 6'6"
8	fine grained well sorted sand - some shell content	
10		
12	base of core barrel	
14		
16		
18		

Well Development

Date

Comments -

Water Samples

Date

Sample ID

Location Seaward of houses, S. end Hunting Is.

Date Drilled 13 June 1990

Client CSE

Geologist Walter J. Sexton

ATHENA TECHNOLOGIES INC

600 South Holly St., Columbia, S.C. 29205

(803) 771-6764

Well Depth From Ground Surface	Well ID Hi-6	WELL LOG FORM
	Lithologic Description	Well Construction

Feet (MSL Elevation) Ft.__________

Date__________

Feet	Lithologic Description
0	well sorted fine sand small mud filled burrows occasional intact flaser bed ~ 5 to 10% mud probably closer to
2	5%
4	slight increase in number of flaser beds & mud content w/ depth
6	well sorted fine sand, some shell <5% mud top of moderate washout zone
8	well sorted fine sand mixed with shells clean - no evidence of mud!
10	
12	
14	13'4" base of core barrel
16	
18	

Well Development

Date __________

Comments -

Water Samples

Date __________

Sample ID __________

Location N.E. Side of Fripp Inlet

Date Drilled 13 June 1990

Client CSE

Geologist Walter J. Sexton

ATHENA TECHNOLOGIES INC
600 South Holly St., Columbia, SC 29205
(803) 771-67[illegible]

WELL LOG FORM

Well ID HI-7

Well Depth From Ground Surface	Lithologic Description	Well Construction
Feet	(MSL Elevation) Ft.	Date
0	mixed f. sand & shell - occasional bioturbated flaser beds ~5 to 10% mud	
2	flaser beds (mud) are more intact than above	
4	clean well sorted sand. low mud content. flaser beds (mud) increasing with depth	
6	clean sand interbedded with well preserved flaser beds 90% s. 10% m.	
8	abundant flaser beds interbedded with sand 70% m. 30% s.	
10	mud increasing w/ depth	
12		
14	bottom of core 13'2"	
16		
18		

Well Development

Date

Comments

Water Samples

Date

Sample ID

Location S. side of Johnson Creek Delta

Date Drilled 14 June 1990

Client CSE

Geologist Walter J. Sexton

ATHENA TECHNOLOGIES INC

600 South Holly St., Columbia, S.C. 29205

(803) 771-6764

Well Depth From Ground Surface	Well ID HI-8	WELL LOG FORM
	Lithologic Description	Well Construction

Feet (MSL Elevation) Ft.________

Date________

Feet	Lithologic Description
0	clean well sorted f. sand very low mud content bioturbated - low shell content
2	clean well sorted f. sand slight increase in shell content - some bioturbation
4	
	one iron concretion nodule and one or two mud rip up clasts tan at top to grey.
6	slight change w/ depth still clean well sorted f. sand
8	8'3" bottom of core
10	
12	
14	
16	
18	

Well Development

Date ________

Comments -

Water Samples

Date ________

Sample ID ________

Location Seaward of houses S. end of Hunting Is.

Date Drilled 14 June 1990

Client CSE

Geologist Walter J. Sexton

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Well Depth From Ground Surface	Well ID HI-9	WELL LOG FORM
	Lithologic Description	Well Construction

Feet (MSL Elevation) Ft.________

Date________

0

clean moderately well sorted - very low shell content & mud

2

4

several thick mud flasers mixed w/ well sorted f. sand

clean moderately well sorted - very low shell content

6

8

bottom of core 7'3"

10

12

14

16

18

Well Development

Date ________

Comments -

Water Samples

Date ________

Sample ID ________

Location Channel on Fripp Delta, NE side

Date Drilled 14 June 1990

Client CSE

Geologist Walter J. Sexton

ATHENA TECHNOLOGIES INC
600 South Holly St., Columbia, SC 29205
(803) 771-6764

WELL LOG FORM

Well ID HI-10A

Well Depth From Ground Surface	Lithologic Description	Well Construction
Feet	(MSL Elevation) Ft.	Date
0	clean well sorted f. sand low shell } <5% low mud }	
2		
4	occasional mud flasers mixed/interbedded with clean well sorted f. sand	
6		
8		
10	slight increase in mud content w/ depth 5 to 7% entire core lacks shell conteat	
12		
14	13'9" bottom of core	
16		
18		

Well Development

Date

Comments -

Water Samples

Date

Sample ID

Location NE edge of Spillover.lobe

Date Drilled 14 June 1990

Client CSE

Geologist Walter J. Sexton

ATHENA TECHNOLOGIES INC
600 South Holly St., Columbia, S.C. 29205
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SAMPLE NO.	DATE	MIDPOINT (PHI)	WEIGHT (GRAM)	WEIGHT PERCENT	CLASS LIMITS (PHI)	CUM PERCENT
HI2-1	061290					
Hunting Island Core 2, 0-6'						
		-1.125	.600	.823	-1.000	.823
		-.875	.400	.549	-.750	1.372
		-.625	1.100	1.509	-.500	2.881
		-.375	1.000	1.372	-.250	4.252
		-.125	1.100	1.509	.000	5.761
		.125	1.500	2.058	.250	7.819
		.375	1.200	1.646	.500	9.465
		.625	.800	1.097	.750	10.562
		.875	1.200	1.646	1.000	12.209
		1.125	.900	1.235	1.250	13.443
		1.375	1.300	1.783	1.500	15.226
		1.625	.900	1.235	1.750	16.461
		1.875	2.200	3.018	2.000	19.479
		2.125	4.100	5.624	2.250	25.103
		2.375	10.700	14.678	2.500	39.781
		2.625	13.500	18.519	2.750	58.299
		2.875	15.400	21.125	3.000	79.424
		3.125	9.400	12.894	3.250	92.318
		3.375	4.300	5.898	3.500	98.217
		3.625	1.200	1.646	3.750	99.863
		3.875	.100	.137	4.000	100.000

TOTAL WEIGHT (GRAMS) = 72.900

PERCENT FINER THAN 4.00 PHI = .53 PERCENT COARSER THAN -1.00 PHI = 3.66

MOMENT MEASURES:

MEAN = 2.343 STANDARD DEVIATION = 1.006 SKEWNESS = -.847 KURTOSIS = 2.280

DISPERSION = .439 STANDARD DEVIATION = .664 DEVIATION FROM NORMAL DISTR. = -33.98%

PERCENTILES:

1.	5.	16.	25.	50.	75.	84.	95.	99.
-.919	-.126	1.657	2.245	2.638	2.948	3.089	3.364	3.619

GRAPHIC PHI PARAMETER	INMAN (1952)	FOLK AND WARD (1957)	
MEAN	2.373	2.461	FINE SAND
STANDARD DEVIATION	.716	.887	MODERATELY SORTED
SKEWNESS(1)	-.370	-.477	STRONGLY COARSE-SKEWED
SKEWNESS(2)	-1.423		
KURTOSIS	1.437	2.037	VERY LEPTOKURTIC

SAMPLE NO. DATE	MIDPOINT (PHI)	WEIGHT (GRAM)	WEIGHT PERCENT	CLASS LIMITS (PHI)	CUM PERCENT
B12-2 061390					
Hunting Island Core 2. 8.5'- bottom					
	-1.125	.100	.101	-1.000	.101
	-.875	.100	.101	-.750	.202
	-.625	.200	.202	-.500	.404
	-.375	.200	.202	-.250	.607
	-.125	.300	.303	.000	.910
	.125	.600	.607	.250	1.517
	.375	.600	.607	.500	2.123
	.625	.500	.506	.750	2.629
	.875	1.000	1.011	1.000	3.640
	1.125	.700	.708	1.250	4.348
	1.375	1.400	1.416	1.500	5.763
	1.625	1.400	1.416	1.750	7.179
	1.875	4.100	4.146	2.000	11.325
	2.125	10.700	10.819	2.250	22.144
	2.375	26.800	27.098	2.500	49.242
	2.625	18.500	18.706	2.750	67.947
	2.875	16.000	16.178	3.000	84.125
	3.125	9.900	10.010	3.250	94.135
	3.375	4.300	4.348	3.500	98.483
	3.625	1.400	1.416	3.750	99.899
	3.875	.100	.101	4.000	100.000

TOTAL WEIGHT (GRAMS) = 98.900

PERCENT FINER THAN 4.00 PHI = .80 PERCENT COARSER THAN -1.00 PHI = .20

MOMENT MEASURES:

MEAN = 2.483 STANDARD DEVIATION = .619 SKEWNESS = -.900 KURTOSIS = 6.079

DISPERSION = .317 STANDARD DEVIATION = .502 DEVIATION FROM NORMAL DISTR. = -18.96%

PERCENTILES:

1.	5.	16.	25.	50.	75.	84.	95.	99.
.037	1.365	2.108	2.276	2.510	2.859	2.998	3.300	3.591

GRAPHIC PHI PARAMETER	INMAN (1952)	FOLK AND WARD (1957)	
MEAN	2.553	2.539	FINE SAND
STANDARD DEVIATION	.445	.516	MODERATELY WELL SORTED
SKEWNESS(1)	.096	-.044	NEAR SYMMETRICAL
SKEWNESS(2)	-.399		
KURTOSIS	1.174	1.361	LEPTOKURTIC

SAMPLE NO. DATE	MIDPOINT (PHI)	(GRAM) WEIGHT	WEIGHT PERCENT	CLASS LIMITS (PHI)	CUM PERCENT
HI2-3 061390					
Hunting Island Core 2, 6"-8.5"					
	-1.125	.400	.613	-1.000	.613
	-.875	.500	.767	-.750	1.380
	-.625	.700	1.074	-.500	2.454
	-.375	.700	1.074	-.250	3.528
	-.125	.800	1.227	.000	4.755
	.125	1.000	1.534	.250	6.288
	.375	.900	1.380	.500	7.669
	.625	.700	1.074	.750	8.742
	.875	1.200	1.840	1.000	10.583
	1.125	.900	1.380	1.250	11.963
	1.375	1.600	2.454	1.500	14.417
	1.625	1.600	2.454	1.750	16.871
	1.875	4.500	6.902	2.000	23.773
	2.125	9.900	15.184	2.250	38.957
	2.375	19.900	30.521	2.500	69.479
	2.625	10.800	16.564	2.750	86.043
	2.875	4.900	7.515	3.000	93.558
	3.125	2.400	3.681	3.250	97.239
	3.375	1.200	1.840	3.500	99.080
	3.625	.500	.767	3.750	99.847
	3.875	.100	.153	4.000	100.000

TOTAL WEIGHT (GRAMS) = 65.200

PERCENT FINER THAN 4.00 PHI = .86 PERCENT COARSER THAN -1.00 PHI = 5.73

MOMENT MEASURES:

MEAN = 2.132 STANDARD DEVIATION = .854 SKEWNESS = -.881 KURTOSIS = 3.305

DISPERSION = .386 STANDARD DEVIATION = .586 DEVIATION FROM NORMAL DISTR. = -31.154

PERCENTILES:

1.	5.	16.	25.	50.	75.	84.	95.	99.
-.874	.040	1.661	2.020	2.340	2.583	2.719	3.098	3.489

GRAPHIC PHI PARAMETER	INMAN (1952)	FOLK AND WARD (1957)	
MEAN	2.190	2.240	FINE SAND
STANDARD DEVIATION	.529	.728	MODERATELY SORTED
SKEWNESS(1)	-.284	-.394	STRONGLY COARSE-SKEWED
SKEWNESS(2)	-1.459		
KURTOSIS	1.891	2.225	VERY LEPTOKURTIC

SAMPLE NO.	DATE	MIDPOINT (PHI)	WEIGHT (GRAM)	WEIGHT PERCENT	CLASS LIMITS (PHI)	CUM PERCENT
HI 3-1	061290					
Hunting Island Core 3, 0-3'						
		-1.125	.700	.896	-1.000	.896
		-.875	.900	1.152	-.750	2.049
		-.625	1.700	2.177	-.500	4.225
		-.375	1.100	1.408	-.250	5.634
		-.125	1.800	2.305	.000	7.939
		.125	3.100	3.969	.250	11.908
		.375	3.500	4.481	.500	16.389
		.625	2.600	3.329	.750	19.718
		.875	4.600	5.890	1.000	25.608
		1.125	2.400	3.073	1.250	28.681
		1.375	3.000	3.841	1.500	32.522
		1.625	1.700	2.177	1.750	34.699
		1.875	2.600	3.329	2.000	38.028
		2.125	3.000	3.841	2.250	41.869
		2.375	5.700	7.298	2.500	49.168
		2.625	7.600	9.731	2.750	58.899
		2.875	13.400	17.157	3.000	76.056
		3.125	11.000	14.085	3.250	90.141
		3.375	5.700	7.298	3.500	97.439
		3.625	1.800	2.305	3.750	99.744
		3.875	.200	.256	4.000	100.000

TOTAL WEIGHT (GRAMS) = 78.100

PERCENT FINER THAN 4.00 PHI = 1.10   PERCENT COARSER THAN -1.00 PHI = 3.54

MOMENT MEASURES:

MEAN = 2.021   STANDARD DEVIATION = 1.233   SKEWNESS = -.388   KURTOSIS = -.598

DISPERSION = .577   STANDARD DEVIATION = .913   DEVIATION FROM NORMAL DISTR. = -25.904

PERCENTILES:

1.	5.	16.	25.	50.	75.	84.	95.	99.
-.978	-.363	.478	.974	2.521	2.985	3.141	3.416	3.669

GRAPHIC PHI PARAMETER	INMAN (1952)	FOLK AND WARD (1957)	
MEAN	1.810	2.047	FINE SAND
STANDARD DEVIATION	1.331	1.238	POORLY SORTED
SKEWNESS(1)	-.535	-.530	STRONGLY COARSE-SKEWED
SKEWNESS(2)	-.747		
KURTOSIS	.419	.770	PLATYKURTIC

SAMPLE NO. DATE	MIDPOINT (PHI)	WEIGHT (GRAM)	WEIGHT PERCENT	CLASS LIMITS (PHI)	CUM PERCENT
hunt3- 061290					
Hunting Island Core 3. 3'-8'					
	-1.125	.100	.110	-1.000	.110
	-.875	.100	.110	-.750	.220
	-.625	.200	.220	-.500	.440
	-.375	.300	.330	-.250	.769
	-.125	.500	.549	.000	1.319
	.125	.900	.989	.250	2.308
	.375	1.000	1.099	.500	3.407
	.625	.800	.879	.750	4.286
	.875	1.000	1.099	1.000	5.385
	1.125	.500	.549	1.250	5.934
	1.375	.600	.659	1.500	6.593
	1.625	.500	.549	1.750	7.143
	1.875	1.700	1.868	2.000	9.011
	2.125	4.000	4.396	2.250	13.407
	2.375	10.300	11.319	2.500	24.725
	2.625	12.900	14.176	2.750	38.901
	2.875	24.200	26.593	3.000	65.494
	3.125	18.200	20.000	3.250	85.494
	3.375	9.800	10.769	3.500	96.264
	3.625	3.100	3.407	3.750	99.670
	3.875	.300	.330	4.000	100.000

TOTAL WEIGHT (GRAMS) = 91.000

PERCENT FINER THAN 4.00 PHI = 1.30 PERCENT COARSER THAN -1.00 PHI = .22

MOMENT MEASURES:

MEAN = 2.698 STANDARD DEVIATION = .726 SKEWNESS = -1.103 KURTOSIS = 5.979

DISPERSION = .326 STANDARD DEVIATION = .512 DEVIATION FROM NORMAL DISTR. = -29.50%

PERCENTILES:

1.	5.	16.	25.	50.	75.	84.	95.	99.
-.145	.913	2.307	2.505	2.854	3.119	3.231	3.471	3.701

GRAPHIC PHI PARAMETER	INMAN (1952)	FOLK AND WARD (1957)	
MEAN	2.769	2.798	FINE SAND
STANDARD DEVIATION	.462	.619	MODERATELY WELL SORTED
SKEWNESS(1)	-.184	-.351	STRONGLY COARSE-SKEWED
SKEWNESS(2)	-1.434		
KURTOSIS	1.768	1.708	VERY LEPTOKURTIC

SAMPLE NO.	DATE	MIDPOINT (PHI)	WEIGHT (GRAM)	WEIGHT PERCENT	CLASS LIMITS (PHI)	CUM PERCENT
hunt4-	061290					
Hunting Island Core4, 0-5'						
		-1.125	.700	1.178	-1.000	1.178
		-.875	.700	1.178	-.750	2.357
		-.625	1.100	1.852	-.500	4.209
		-.375	.700	1.178	-.250	5.387
		-.125	1.000	1.684	.000	7.071
		.125	1.200	2.020	.250	9.091
		.375	1.000	1.684	.500	10.774
		.625	.700	1.178	.750	11.953
		.875	1.000	1.684	1.000	13.636
		1.125	.600	1.010	1.250	14.646
		1.375	1.100	1.852	1.500	16.498
		1.625	1.000	1.684	1.750	18.182
		1.875	2.300	3.872	2.000	22.054
		2.125	4.300	7.239	2.250	29.293
		2.375	9.200	15.488	2.500	44.781
		2.625	11.200	18.855	2.750	63.636
		2.875	11.200	18.855	3.000	82.492
		3.125	6.700	11.279	3.250	93.771
		3.375	2.800	4.714	3.500	98.485
		3.625	.800	1.347	3.750	99.832
		3.875	.100	.168	4.000	100.000

TOTAL WEIGHT (GRAMS) = 59.400

PERCENT FINER THAN 4.00 PHI = .47 PERCENT COARSER THAN -1.00 PHI = 5.98

MOMENT MEASURES:

MEAN = 2.252 STANDARD DEVIATION = 1.054 SKEWNESS = -.807 KURTOSIS = 1.906

DISPERSION = .462 STANDARD DEVIATION = .701 DEVIATION FROM NORMAL DISTR. = -33.46%

PERCENTILES:

1.	5.	16.	25.	50.	75.	84.	95.	99.
-1.038	-.332	1.433	2.102	2.569	2.901	3.033	3.315	3.596

GRAPHIC PHI PARAMETER	INMAN (1952)	FOLK AND WARD (1957)	
MEAN	2.233	2.345	FINE SAND
STANDARD DEVIATION	.800	.953	MODERATELY SORTED
SKEWNESS(1)	-.420	-.505	STRONGLY COARSE-SKEWED
SKEWNESS(2)	-1.347		
KURTOSIS	1.279	1.871	VERY LEPTOKURTIC

SAMPLE NO. DATE	MIDPOINT (PHI)	WEIGHT (GRAM)	WEIGHT PERCENT	CLASS LIMITS (PHI)	CUM PERCENT
HI4-2 061390					
Hunting Island Core 4. 5'-6.5'					
	-1.125	.300	.564	-1.000	.564
	-.875	.200	.376	-.750	.940
	-.625	.400	.752	-.500	1.692
	-.375	.400	.752	-.250	2.444
	-.125	.500	.940	.000	3.383
	.125	.800	1.504	.250	4.887
	.375	.600	1.128	.500	6.015
	.625	.400	.752	.750	6.767
	.875	.800	1.504	1.000	8.271
	1.125	.500	.940	1.250	9.211
	1.375	.700	1.316	1.500	10.526
	1.625	.600	1.128	1.750	11.654
	1.875	1.500	2.820	2.000	14.474
	2.125	4.200	7.895	2.250	22.368
	2.375	9.300	17.481	2.500	39.850
	2.625	7.900	14.850	2.750	54.699
	2.875	7.300	13.722	3.000	68.421
	3.125	7.400	13.910	3.250	82.331
	3.375	5.800	10.902	3.500	93.233
	3.625	3.100	5.827	3.750	99.060
	3.875	.500	.940	4.000	100.000

TOTAL WEIGHT (GRAMS) = 53.200

PERCENT FINER THAN 4.00 PHI = 3.89 PERCENT COARSER THAN -1.00 PHI = 1.95

MOMENT MEASURES:

MEAN = 2.523 STANDARD DEVIATION = .915 SKEWNESS = -.857 KURTOSIS = 3.338

DISPERSION = .449 STANDARD DEVIATION = .680 DEVIATION FROM NORMAL DISTR. = -25.684

PERCENTILES:

1.	5.	16.	25.	50.	75.	84.	95.	99.
-.730	.275	2.048	2.288	2.671	3.118	3.288	3.576	3.747

GRAPHIC PHI PARAMETER	INMAN (1952)	FOLK AND WARD (1957)	
MEAN	2.668	2.669	FINE SAND
STANDARD DEVIATION	.620	.610	MODERATELY SORTED
SKEWNESS(1)	-.004	-.226	COARSE-SKEWED
SKEWNESS(2)	-1.202		
KURTOSIS	1.662	1.629	VERY LEPTOKURTIC

SAMPLE NO. DATE	MIDPOINT (PHI)	(GRAM)	WEIGHT	WEIGHT PERCENT	CLASS LIMITS (PHI)	CUM PERCENT
bunt4- 061290						
Hunting Island Core 4, 6.5-bot						
	-1.125	.600		.628	-1.000	.628
	-.875	.600		.628	-.750	1.257
	-.625	1.000		1.047	-.500	2.304
	-.375	.800		.838	-.250	3.141
	-.125	1.100		1.152	.000	4.293
	.125	1.500		1.571	.250	5.864
	.375	1.300		1.361	.500	7.225
	.625	.800		.838	.750	8.063
	.875	1.600		1.675	1.000	9.738
	1.125	1.100		1.152	1.250	10.890
	1.375	2.000		2.094	1.500	12.984
	1.625	1.800		1.885	1.750	14.869
	1.875	5.600		5.864	2.000	20.733
	2.125	16.600		17.382	2.250	38.115
	2.375	26.900		28.168	2.500	66.283
	2.625	14.600		15.288	2.750	81.571
	2.875	10.100		10.576	3.000	92.147
	3.125	5.000		5.236	3.250	97.382
	3.375	1.900		1.990	3.500	99.372
	3.625	.600		.628	3.750	100.000
	3.875	.000		.000	4.000	100.000

TOTAL WEIGHT (GRAMS) = 95.500

PERCENT FINER THAN 4.00 PHI = .30 PERCENT COARSER THAN -1.00 PHI = 4.10

MOMENT MEASURES:

MEAN = 2.183 STANDARD DEVIATION = .839 SKEWNESS = -.924 KURTOSIS = 3.724

DISPERSION = .379 STANDARD DEVIATION = .579 DEVIATION FROM NORMAL DISTR. = -30.97%

PERCENTILES:

1.	5.	16.	25.	50.	75.	84.	95.	99.
-.852	.112	1.798	2.061	2.355	2.643	2.807	3.136	3.453

GRAPHIC PHI PARAMETER	INMAN (1952)	FOLK AND WARD (1957)	
MEAN	2.303	2.320	FINE SAND
STANDARD DEVIATION	.505	.710	MODERATELY SORTED
SKEWNESS(1)	-.104	-.294	COARSE-SKEWED
SKEWNESS(2)	-1.449		
KURTOSIS	1.996	2.132	VERY LEPTOKURTIC

SAMPLE NO.	DATE	MIDPOINT (PHI)	WEIGHT (GRAM)	WEIGHT PERCENT	CLASS LIMITS (PHI)	CUM PERCENT
hunt5-	061290					
Hunting Island Core 5, 0-6.5'						
		-1.125	.100	.102	-1.000	.102
		-.875	.200	.204	-.750	.305
		-.625	.400	.407	-.500	.713
		-.375	.200	.204	-.250	.916
		-.125	.500	.509	.000	1.426
		.125	.800	.815	.250	2.240
		.375	.600	.611	.500	2.851
		.625	.500	.509	.750	3.360
		.875	.900	.916	1.000	4.277
		1.125	.600	.611	1.250	4.888
		1.375	1.400	1.426	1.500	6.314
		1.625	1.400	1.426	1.750	7.739
		1.875	4.300	4.379	2.000	12.118
		2.125	10.500	10.692	2.250	22.811
		2.375	30.500	31.059	2.500	53.870
		2.625	21.800	22.200	2.750	76.069
		2.875	12.900	13.136	3.000	89.206
		3.125	6.900	7.026	3.250	96.232
		3.375	2.800	2.851	3.500	99.084
		3.625	.800	.815	3.750	99.898
		3.875	.100	.102	4.000	100.000

TOTAL WEIGHT (GRAMS) = 98.200

PERCENT FINER THAN 4.00 PHI = .30 PERCENT COARSER THAN -1.00 PHI = 1.30

MOMENT MEASURES:

MEAN = 2.414 STANDARD DEVIATION = .630 SKEWNESS = -1.065 KURTOSIS = 7.300

DISPERSION = .288 STANDARD DEVIATION = .469 DEVIATION FROM NORMAL DISTR. = -25.594

PERCENTILES:

1.	5.	16.	25.	50.	75.	84.	95.	99.
-.209	1.270	2.091	2.268	2.469	2.738	2.901	3.206	3.493

GRAPHIC PHI PARAMETER	INMAN (1952)	FOLK AND WARD (1957)	
MEAN	2.496	2.487	FINE SAND
STANDARD DEVIATION	.405	.496	WELL SORTED
SKEWNESS(1)	.067	-.086	NEAR SYMMETRICAL
SKEWNESS(2)	-.570		
KURTOSIS	1.390	1.687	VERY LEPTOKURTIC

SAMPLE NO.	DATE	MIDPOINT (PHI)	WEIGHT (GRAM)	WEIGHT PERCENT	CLASS LIMITS (PHI)	CUM PERCENT
bunt5-	061290					
Hunting Island Core 5, 6.5'-bot						
		-1.125	.400	.504	-1.000	.504
		-.875	.500	.630	-.750	1.134
		-.625	.700	.882	-.500	2.015
		-.375	.700	.882	-.250	2.897
		-.125	.900	1.134	.000	4.030
		.125	1.500	1.889	.250	5.919
		.375	1.200	1.511	.500	7.431
		.625	.800	1.008	.750	8.438
		.875	1.300	1.637	1.000	10.076
		1.125	.800	1.008	1.250	11.083
		1.375	1.400	1.763	1.500	12.846
		1.625	1.300	1.637	1.750	14.484
		1.875	3.700	4.660	2.000	19.144
		2.125	8.900	11.209	2.250	30.353
		2.375	23.900	30.101	2.500	60.453
		2.625	15.300	19.270	2.750	79.723
		2.875	9.200	11.587	3.000	91.310
		3.125	4.600	5.793	3.250	97.103
		3.375	1.700	2.141	3.500	99.244
		3.625	.500	.630	3.750	99.874
		3.875	.100	.126	4.000	100.000

TOTAL WEIGHT (GRAMS) = 79.400

PERCENT FINER THAN 4.00 PHI = .12 PERCENT COARSER THAN -1.00 PHI = 4.33

MOMENT MEASURES:

MEAN = 2.230 STANDARD DEVIATION = .847 SKEWNESS = -.933 KURTOSIS = 3.606

DISPERSION = .368 STANDARD DEVIATION = .565 DEVIATION FROM NORMAL DISTR. = -33.29%

PERCENTILES:

1.	5.	16.	25.	50.	75.	84.	95.	99.
-.803	.126	1.831	2.131	2.413	2.689	2.842	3.159	3.471

GRAPHIC PHI PARAMETER	INMAN (1952)	FOLK AND WARD (1957)	
MEAN	2.337	2.362	FINE SAND
STANDARD DEVIATION	.505	.712	MODERATELY SORTED
SKEWNESS(1)	-.151	-.329	STRONGLY COARSE-SKEWED
SKEWNESS(2)	-1.522		
KURTOSIS	1.998	2.226	VERY LEPTOKURTIC

SAMPLE NO. DATE	MIDPOINT (PHI)	(GRAM)	WEIGHT	WEIGHT PERCENT CLASS LIMITS (PHI)	CUM PERCENT
buot6- 061290					
Hunting Island Core 6. 0-6.5'					
	-1.125	.100	.099	-1.000	.099
	-.875	.100	.099	-.750	.197
	-.625	.300	.296	-.500	.493
	-.375	.200	.197	-.250	.690
	-.125	.400	.394	.000	1.085
	.125	.600	.592	.250	1.677
	.375	.500	.493	.500	2.170
	.625	.400	.394	.750	2.564
	.875	.700	.690	1.000	3.254
	1.125	.500	.493	1.250	3.748
	1.375	1.100	1.085	1.500	4.832
	1.625	1.300	1.282	1.750	6.114
	1.875	3.900	3.846	2.000	9.961
	2.125	8.000	7.890	2.250	17.850
	2.375	24.000	23.669	2.500	41.519
	2.625	23.300	22.978	2.750	64.497
	2.875	19.700	19.428	3.000	83.925
	3.125	10.100	9.961	3.250	93.886
	3.375	4.600	4.536	3.500	98.422
	3.625	1.400	1.381	3.750	99.803
	3.875	.200	.197	4.000	100.000

TOTAL WEIGHT (GRAMS) = 101.400

PERCENT FINER THAN 4.00 PHI = .39 PERCENT COARSER THAN -1.00 PHI = 1.26

MOMENT MEASURES:

MEAN = 2.533 STANDARD DEVIATION = .610 SKEWNESS = -1.044 KURTOSIS = 7.665

DISPERSION = .298 STANDARD DEVIATION = .481 DEVIATION FROM NORMAL DISTR. = -21.104

PERCENTILES:

1.	5.	16.	25.	50.	75.	84.	95.	99.
-.054	1.533	2.191	2.326	2.592	2.885	3.002	3.311	3.605

GRAPHIC PHI PARAMETER	INMAN (1952)	FOLK AND WARD (1957)	
MEAN	2.597	2.595	FINE SAND
STANDARD DEVIATION	.405	.472	WELL SORTED
SKEWNESS(1)	.011	-.090	NEAR SYMMETRICAL
SKEWNESS(2)	-.420		
KURTOSIS	1.195	1.303	LEPTOKURTIC

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SAMPLE NO. DATE	MIDPOINT (PHI)	(GRAM)	WEIGHT	WEIGHT PERCENT	CLASS LIMITS (PHI)	CUM PERCENT
hunt6- 061290						
Hunting Island Core 6. 6.5'-bot						
	-1.125	.600		.623	-1.000	.623
	-.875	.600		.623	-.750	1.246
	-.625	.700		.727	-.500	1.973
	-.375	.900		.935	-.250	2.908
	-.125	1.100		1.142	.000	4.050
	.125	1.600		1.661	.250	5.711
	.375	1.400		1.454	.500	7.165
	.625	.900		.935	.750	8.100
	.875	1.400		1.454	1.000	9.553
	1.125	.900		.935	1.250	10.488
	1.375	1.600		1.661	1.500	12.150
	1.625	1.600		1.661	1.750	13.811
	1.875	4.400		4.569	2.000	18.380
	2.125	10.100		10.488	2.250	28.868
	2.375	28.600		29.699	2.500	58.567
	2.625	18.200		18.899	2.750	77.466
	2.875	11.600		12.046	3.000	89.512
	3.125	6.300		6.542	3.250	96.054
	3.375	2.900		3.011	3.500	99.065
	3.625	.800		.831	3.750	99.896
	3.875	.100		.104	4.000	100.000

TOTAL WEIGHT (GRAMS) = 96.300

PERCENT FINER THAN 4.00 PHI = .29 PERCENT COARSER THAN -1.00 PHI = 5.48

MOMENT MEASURES:

MEAN = 2.261 STANDARD DEVIATION = .850 SKEWNESS = -.944 KURTOSIS = 3.824

DISPERSION = .374 STANDARD DEVIATION = .572 DEVIATION FROM NORMAL DISTR. = -32.696

PERCENTILES:

1.	5.	16.	25.	50.	75.	84.	95.	99.
-.849	.143	1.870	2.158	2.428	2.717	2.886	3.210	3.495

GRAPHIC PHI PARAMETER	INMAN (1952)	FOLK AND WARD (1957)	
MEAN	2.378	2.394	FINE SAND
STANDARD DEVIATION	.508	.719	MODERATELY SORTED
SKEWNESS(1)	-.099	-.294	COARSE-SKEWED
SKEWNESS(2)	-1.480		
KURTOSIS	2.019	2.245	VERY LEPTOKURTIC

SAMPLE NO.	DATE	MIDPOINT (PHI)	WEIGHT (GRAM)	WEIGHT PERCENT	CLASS LIMITS (PHI)	CUM PERCENT
HI7-1	061490					
Hunting Island Core 7, 0-3.5'						
		-1.125	.300	.325	-1.000	.325
		-.875	.100	.108	-.750	.433
		-.625	.400	.433	-.500	.866
		-.375	.400	.433	-.250	1.299
		-.125	.700	.758	.000	2.056
		.125	.900	.974	.250	3.030
		.375	.900	.974	.500	4.004
		.625	.700	.758	.750	4.762
		.875	1.400	1.515	1.000	6.277
		1.125	1.000	1.082	1.250	7.359
		1.375	1.900	2.056	1.500	9.416
		1.625	1.700	1.840	1.750	11.255
		1.875	4.800	5.195	2.000	16.450
		2.125	13.600	14.719	2.250	31.169
		2.375	29.000	31.385	2.500	62.554
		2.625	17.100	18.506	2.750	81.061
		2.875	10.900	11.797	3.000	92.857
		3.125	4.900	5.303	3.250	98.160
		3.375	1.400	1.515	3.500	99.675
		3.625	.300	.325	3.750	100.000
		3.875	.000	.000	4.000	100.000

TOTAL WEIGHT (GRAMS) = 92.400

PERCENT FINER THAN 4.00 PHI = .21   PERCENT COARSER THAN -1.00 PHI = 2.53

MOMENT MEASURES:

MEAN = 2.292   STANDARD DEVIATION = .686   SKEWNESS = -1.027   KURTOSIS = 5.697

DISPERSION = .312   STANDARD DEVIATION = .496   DEVIATION FROM NORMAL DISTR. = -27.616

PERCENTILES:

1.	5.	16.	25.	50.	75.	84.	95.	99.
-.422	.789	1.978	2.145	2.400	2.666	2.812	3.101	3.389

GRAPHIC PHI PARAMETER	INMAN (1952)	FOLK AND WARD (1957)	
MEAN	2.395	2.397	FINE SAND
STANDARD DEVIATION	.417	.559	MODERATELY WELL SORTED
SKEWNESS(1)	-.011	-.202	COARSE-SKEWED
SKEWNESS(2)	-1.091		
KURTOSIS	1.772	1.812	VERY LEPTOKURTIC

SAMPLE NO. DATE	MIDPOINT (PHI)	WEIGHT (GRAM)	WEIGHT PERCENT	CLASS LIMITS (PHI)	CUM PERCENT
HI7-2 061490					
Hunting Island Core 7, 3.5'-6'					
	-1.125	.000	.000	-1.000	.000
	-.875	.100	.090	-.750	.090
	-.625	.100	.090	-.500	.181
	-.375	.100	.090	-.250	.271
	-.125	.200	.181	.000	.452
	.125	.300	.271	.250	.724
	.375	.300	.271	.500	.995
	.625	.300	.271	.750	1.267
	.875	.600	.543	1.000	1.810
	1.125	.400	.362	1.250	2.172
	1.375	1.000	.905	1.500	3.077
	1.625	1.200	1.086	1.750	4.163
	1.875	4.100	3.710	2.000	7.873
	2.125	13.800	12.489	2.250	20.362
	2.375	34.300	31.041	2.500	51.403
	2.625	21.900	19.819	2.750	71.222
	2.875	18.400	16.652	3.000	87.873
	3.125	9.000	8.145	3.250	96.018
	3.375	3.600	3.258	3.500	99.276
	3.625	.700	.633	3.750	99.910
	3.875	.100	.090	4.000	100.000

TOTAL WEIGHT (GRAMS) = 110.500

PERCENT FINER THAN 4.00 PHI = .18   PERCENT COARSER THAN -1.00 PHI = .27

MOMENT MEASURES:

MEAN = 2.502   STANDARD DEVIATION = .497   SKEWNESS = -.836   KURTOSIS = 7.757

DISPERSION = .239   STANDARD DEVIATION = .420   DEVIATION FROM NORMAL DISTR. = -15.51%

PERCENTILES:

1.	5.	16.	25.	50.	75.	84.	95.	99.
.504	1.806	2.163	2.287	2.489	2.807	2.942	3.219	3.479

GRAPHIC PHI PARAMETER	INMAN (1952)	FOLK AND WARD (1957)	
MEAN	2.552	2.531	FINE SAND
STANDARD DEVIATION	.390	.409	WELL SORTED
SKEWNESS(1)	.163	.098	NEAR SYMMETRICAL
SKEWNESS(2)	.061		
KURTOSIS	.813	1.114	LEPTOKURTIC

SAMPLE NO. DATE	MIDPOINT (PHI)	(GRAM)	WEIGHT	WEIGHT PERCENT	CLASS LIMITS (PHI)	CUM PERCENT
hunt8- 061390						
Hunting Island Core 8, entire						
	-1.125	.400		.411	-1.000	.411
	-.875	.500		.513	-.750	.924
	-.625	.900		.924	-.500	1.848
	-.375	.800		.821	-.250	2.669
	-.125	1.100		1.129	.000	3.799
	.125	1.600		1.643	.250	5.441
	.375	1.600		1.643	.500	7.084
	.625	1.200		1.232	.750	8.316
	.875	2.000		2.053	1.000	10.370
	1.125	1.400		1.437	1.250	11.807
	1.375	2.600		2.669	1.500	14.476
	1.625	2.600		2.669	1.750	17.146
	1.875	6.400		6.571	2.000	23.717
	2.125	18.900		19.405	2.250	43.121
	2.375	28.400		29.158	2.500	72.279
	2.625	14.400		14.784	2.750	87.064
	2.875	7.800		8.008	3.000	95.072
	3.125	3.500		3.593	3.250	98.665
	3.375	1.100		1.129	3.500	99.795
	3.625	.200		.205	3.750	100.000
	3.875	.000		.000	4.000	100.000

TOTAL WEIGHT (GRAMS) = 97.400

PERCENT FINER THAN 4.00 PHI = .10 PERCENT COARSER THAN -1.00 PHI = 2.89

MOMENT MEASURES:

MEAN = 2.115 STANDARD DEVIATION = .801 SKEWNESS = -.893 KURTOSIS = 3.398

DISPERSION = .367 STANDARD DEVIATION = .563 DEVIATION FROM NORMAL DISTR. = -29.77%

PERCENTILES:

1.	5.	16.	25.	50.	75.	84.	95.	99.
-.729	.183	1.643	2.017	2.309	2.546	2.698	2.998	3.324

GRAPHIC PHI PARAMETER	INMAN (1952)	FOLK AND WARD (1957)	
MEAN	2.170	2.217	FINE SAND
STANDARD DEVIATION	.528	.690	MODERATELY WELL SORTED
SKEWNESS(1)	-.263	-.387	STRONGLY COARSE-SKEWED
SKEWNESS(2)	-1.362		
KURTOSIS	1.667	2.179	VERY LEPTOKURTIC

SAMPLE NO.	DATE	MIDPOINT (PHI)	(GRAM) WEIGHT	WEIGHT PERCENT	CLASS LIMITS (PHI)	CUM PERCENT
H19-1	061490					
Hunting Island Core 9, 0-3.5"						
		-1.125	.000	.000	-1.000	.000
		-.875	.000	.000	-.750	.000
		-.625	.000	.000	-.500	.000
		-.375	.100	.090	-.250	.090
		-.125	.100	.090	.000	.179
		.125	.100	.090	.250	.269
		.375	.100	.090	.500	.359
		.625	.200	.179	.750	.538
		.875	.500	.448	1.000	.987
		1.125	.600	.538	1.250	1.525
		1.375	2.700	2.422	1.500	3.946
		1.625	3.800	3.408	1.750	7.354
		1.875	8.800	7.892	2.000	15.247
		2.125	12.200	10.942	2.250	26.188
		2.375	38.600	34.619	2.500	60.807
		2.625	22.700	20.359	2.750	81.166
		2.875	12.800	11.480	3.000	92.646
		3.125	5.500	4.933	3.250	97.578
		3.375	2.100	1.883	3.500	99.462
		3.625	.500	.448	3.750	99.910
		3.875	.100	.090	4.000	100.000

TOTAL WEIGHT (GRAMS) = 111.500

PERCENT FINER THAN 4.00 PHI = .18 PERCENT COARSER THAN -1.00 PHI = .18

MOMENT MEASURES:

MEAN = 2.404 STANDARD DEVIATION = .459 SKEWNESS = -.440 KURTOSIS = 3.390

DISPERSION = .236 STANDARD DEVIATION = -.417 DEVIATION FROM NORMAL DISTR. = -9.17%

PERCENTILES:

1.	5.	16.	25.	50.	75.	84.	95.	99.
1.006	1.577	2.017	2.223	2.422	2.674	2.812	3.119	3.439

GRAPHIC PHI PARAMETER	INMAN (1952)	FOLK AND WARD (1957)	
MEAN	2.414	2.417	FINE SAND
STANDARD DEVIATION	.397	.432	WELL SORTED
SKEWNESS(1)	-.019	-.057	NEAR SYMMETRICAL
SKEWNESS(2)	-.185		
KURTOSIS	.941	1.400	LEPTOKURTIC

SAMPLE NO. DATE	MIDPOINT (PHI)	WEIGHT (GRAM)	WEIGHT PERCENT	CLASS LIMITS (PHI)	CUM PERCENT
H19-2 061490					
Hunting Island Core 9, 3.5-4.5'					
	-1.125	.100	.096	-1.000	.096
	-.875	.100	.096	-.750	.193
	-.625	.200	.193	-.500	.385
	-.375	.200	.193	-.250	.578
	-.125	.200	.193	.000	.771
	.125	.400	.385	.250	1.156
	.375	.400	.385	.500	1.541
	.625	.400	.385	.750	1.927
	.875	.900	.867	1.000	2.794
	1.125	1.100	1.060	1.250	3.854
	1.375	3.300	3.179	1.500	7.033
	1.625	5.100	4.913	1.750	11.946
	1.875	12.600	12.139	2.000	24.085
	2.125	19.500	18.786	2.250	42.871
	2.375	29.800	28.709	2.500	71.580
	2.625	16.000	15.414	2.750	86.994
	2.875	7.800	7.514	3.000	94.509
	3.125	3.500	3.372	3.250	97.881
	3.375	1.500	1.445	3.500	99.326
	3.625	.600	.578	3.750	99.904
	3.875	.100	.096	4.000	100.000

TOTAL WEIGHT (GRAMS) = 103.800

PERCENT FINER THAN 4.00 PHI = .38 PERCENT COARSER THAN -1.00 PHI = .38

MOMENT MEASURES:

MEAN = 2.251 STANDARD DEVIATION = .555 SKEWNESS = -.706 KURTOSIS = 5.618

DISPERSION = .303 STANDARD DEVIATION = .486 DEVIATION FROM NORMAL DISTR. = -12.41%

PERCENTILES:

1.	5.	16.	25.	50.	75.	84.	95.	99.
.149	1.340	1.833	2.012	2.312	2.555	2.701	3.036	3.444

GRAPHIC PHI PARAMETER	INMAN (1952)	FOLK AND WARD (1957)	
MEAN	2.267	2.282	FINE SAND
STANDARD DEVIATION	.434	.474	WELL SORTED
SKEWNESS(1)	-.103	-.124	COARSE-SKEWED
SKEWNESS(2)	-.285		
KURTOSIS	.954	1.280	LEPTOKURTIC

SAMPLE NO.	DATE	MIDPOINT (PHI)	WEIGHT (GRAM)	WEIGHT PERCENT	CLASS LIMITS (PHI)	CUM PERCENT
HI9S-3	061490					
Hunting Island Core 9, 4.5'- bottom						
		-1.125	.000	.000	-1.000	.000
		-.875	.000	.000	-.750	.000
		-.625	.000	.000	-.500	.000
		-.375	.100	.091	-.250	.091
		-.125	.000	.000	.000	.091
		.125	.000	.000	.250	.091
		.375	.100	.091	.500	.182
		.625	.000	.000	.750	.182
		.875	.100	.091	1.000	.273
		1.125	.000	.000	1.250	.273
		1.375	.100	.091	1.500	.364
		1.625	.300	.273	1.750	.636
		1.875	1.200	1.091	2.000	1.727
		2.125	13.100	11.909	2.250	13.636
		2.375	55.600	50.545	2.500	64.182
		2.625	21.900	19.909	2.750	84.091
		2.875	11.900	10.818	3.000	94.909
		3.125	4.300	3.909	3.250	98.818
		3.375	1.100	1.000	3.500	99.818
		3.625	.200	.182	3.750	100.000
		3.875	.000	.000	4.000	100.000

TOTAL WEIGHT (GRAMS) = 110.000

PERCENT FINER THAN 4.00 PHI = .09 PERCENT COARSER THAN -1.00 PHI = .00

MOMENT MEASURES:

MEAN = 2.477 STANDARD DEVIATION = .299 SKEWNESS = -.302 KURTOSIS = 10.747

DISPERSION = .021 STANDARD DEVIATION = .254 DEVIATION FROM NORMAL DISTR. = -14.90%

PERCENTILES:

1.	5.	16.	25.	50.	75.	84.	95.	99.
1.833	2.069	2.262	2.306	2.430	2.636	2.749	3.006	3.295

GRAPHIC PHI PARAMETER	INMAN (1952)	FOLK AND WARD (1957)	
MEAN	2.505	2.480	FINE SAND
STANDARD DEVIATION	.244	.264	VERY WELL SORTED
SKEWNESS(1)	.310	.269	FINE-SKEWED
SKEWNESS(2)	.441		
KURTOSIS	.924	1.165	LEPTOKURTIC

SAMPLE NO. DATE	MIDPOINT (PHI)	WEIGHT (GRAM)	WEIGHT PERCENT	CLASS LIMITS (PHI)	CUM PERCENT
HI10-1 061490					
Hunting Island Core 10, 0-3.5'					
	-1.125	.000	.000	-1.000	.000
	-.875	.200	.183	-.750	.183
	-.625	.200	.183	-.500	.366
	-.375	.200	.183	-.250	.549
	-.125	.200	.183	.000	.733
	.125	.300	.275	.250	1.007
	.375	.200	.183	.500	1.190
	.625	.200	.183	.750	1.374
	.875	.300	.275	1.000	1.648
	1.125	.200	.183	1.250	1.832
	1.375	.600	.549	1.500	2.381
	1.625	.800	.733	1.750	3.114
	1.875	3.300	3.022	2.000	6.136
	2.125	16.500	15.110	2.250	21.245
	2.375	46.900	42.949	2.500	64.194
	2.625	21.300	19.505	2.750	83.700
	2.875	11.500	10.531	3.000	94.231
	3.125	4.800	4.396	3.250	98.626
	3.375	1.200	1.099	3.500	99.725
	3.625	.300	.275	3.750	100.000
	3.875	.000	.000	4.000	100.000

TOTAL WEIGHT (GRAMS) = 109.200

PERCENT FINER THAN 4.00 PHI = .09 PERCENT COARSER THAN -1.00 PHI = .18

MOMENT MEASURES:

MEAN = 2.419 STANDARD DEVIATION = .447 SKEWNESS = -1.329 KURTOSIS = 15.801

DISPERSION = .132 STANDARD DEVIATION = .328 DEVIATION FROM NORMAL DISTR. = -26.65%

PERCENTILES:

1.	5.	16.	25.	50.	75.	84.	95.	99.
.243	1.906	2.163	2.272	2.417	2.636	2.757	3.044	3.335

GRAPHIC PHI PARAMETER	INMAN (1952)	FOLK AND WARD (1957)	
MEAN	2.460	2.446	FINE SAND
STANDARD DEVIATION	.297	.321	VERY WELL SORTED
SKEWNESS(1)	.144	.123	FINE-SKEWED
SKEWNESS(2)	.194		
KURTOSIS	.916	1.272	LEPTOKURTIC

SAMPLE NO. DATE	MIDPOINT (PHI)	WEIGHT (GRAM)	WEIGHT PERCENT	CLASS LIMITS (PHI)	CUM PERCENT
HI10-2 061490					
Hunting Island Core 10. 3.5'- bottom					
	-1.125	.000	.000	-1.000	.000
	-.875	.000	.000	-.750	.000
	-.625	.100	.088	-.500	.088
	-.375	.000	.000	-.250	.088
	-.125	.100	.088	.000	.176
	.125	.000	.000	.250	.176
	.375	.100	.088	.500	.264
	.625	.000	.000	.750	.264
	.875	.100	.088	1.000	.352
	1.125	.100	.088	1.250	.440
	1.375	.200	.176	1.500	.616
	1.625	.200	.176	1.750	.792
	1.875	1.200	1.056	2.000	1.849
	2.125	8.600	7.570	2.250	9.419
	2.375	52.800	46.479	2.500	55.898
	2.625	25.200	22.183	2.750	78.081
	2.875	15.300	13.468	3.000	91.549
	3.125	6.600	5.810	3.250	97.359
	3.375	2.200	1.937	3.500	99.296
	3.625	.700	.616	3.750	99.912
	3.875	.100	.088	4.000	100.000

TOTAL WEIGHT (GRAMS) = 113.600

PERCENT FINER THAN 4.00 PHI = .18 PERCENT COARSER THAN -1.00 PHI = .00

MOMENT MEASURES:

MEAN = 2.533 STANDARD DEVIATION = .341 SKEWNESS = -.433 KURTOSIS = 11.719

DISPERSION = .065 STANDARD DEVIATION = .281 DEVIATION FROM NORMAL DISTR. = -17.654

PERCENTILES:

1.	5.	16.	25.	50.	75.	84.	95.	99.
1.799	2.104	2.285	2.334	2.468	2.715	2.860	3.146	3.462

GRAPHIC PHI PARAMETER	INMAN (1952)	FOLK AND WARD (1957)	
MEAN	2.573	2.538	FINE SAND
STANDARD DEVIATION	.287	.302	VERY WELL SORTED
SKEWNESS(1)	.363	.333	STRONGLY FINE-SKEWED
SKEWNESS(2)	.550		
KURTOSIS	.818	1.122	LEPTOKURTIC

APPENDIX II

Beach erosion data covering the period 1951 to present including historical shoreline changes developed from vertical aerial photographs (U.S. Department of Agriculture), volumetric changes developed from USACE, SCCC, and CSE beach profiles, and representative beach profile plots.

APPENDIX II-1. Shoreline changes between 1951 and 1989 based on analysis of vertical aerial photographs. [*Dry-sand/wet-sand contact. **No high watermark (HWM) visible. photo at high tide. high watermark = vegetation line. (-) landward/erosion. (+) seaward/accretion compared to 1951 shoreline.]

Station	Distance to (ft)						Average Annual Shoreline Change for 1951-1989 (ft/yr)
	1951	1955	1959	1972	1983	1989	
SHORELINE CHANGE (VEGETATION LINE)							
60+00N	0	-333.2	-310.7	-426.9	-337.4	-332.1	-8.74
50+00N	0	-73.7	-82.8	-287.8	-279.7	-283.6	-7.46
20+00N	0	-187.8	-392.4	-470.7	-434.7	-483.9	-12.73
10+00N	0	-18.0	-124.0	-456.4	-470.5	-556.0	-14.63
10+00S	0	+10.1	-57.1	-386.9	-465.2	-548.2	-14.43
30+00S	0	-62.9	-166.9	-319.3	-399.2	-474.2	-12.48
50+00S	0	-102.1	-202.6	-342.9	-368.3	-428.9	-11.29
70+00S	0	-100.7	-199.8	-319.3	-319.3	-351.0	-9.24
90+00S	0	-80.5	-158.0	-145.2	-234.4	-255.4	-6.72
110+00S	0	-36.2	-88.4	-34.6	-115.1	-12.4	-0.33
130+00S	0	0	-26.8	+344.2	+46.3	+87.5	+2.30
SHORELINE CHANGE (HWM*)							
60+00N	0	-183.0	**	-190.2	-255.2	-165.9	-4.37
50+00N	0	-73.8	**	-230.7	-226.9	-242.8	-6.39
20+00N	0	-187.0	**	-300.8	-372.9	-408.9	-10.76
10+00N	0	-76.8	**	-399.8	-449.2	-582.5	-15.33
10+00S	0	-34.3	**	-346.3	-418.6	-526.1	-13.84
30+00S	0	-76.1	**	-290.7	-332.3	-472.0	-12.42
50+00S	0	-112.5	**	-293.4	-307.1	-411.7	-10.83
70+00S	0	-116.6	**	-215.7	-262.8	-314.0	-8.26
90+00S	0	-85.7	**	+11.4	-181.5	-185.7	-4.89
110+00S	0	-46.4	**	+212.2	-12.5	-5.2	-0.14
130+00S	0	-31.7	**	+439.7	+126.7	+168.9	+4.44

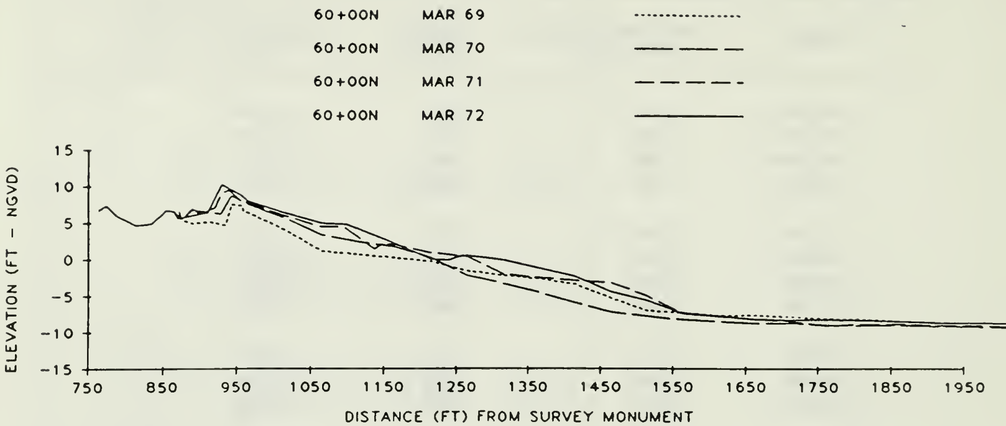
APPENDIX II-2. Beach volumes measured between the +10 ft to -5 ft NGVD contours for the period March 1969 to April 1990. [*Volume starts below +10 ft NGVD contour]

Station	+10 ft to -5 ft NGVD Unit Volume Changes (cy/ft)									(9 Years) 1981-1990 Difference (cy)
	Mar'69	Mar'70	Mar'71	Mar'72	Sep'74	Jan'75	May'81	Aug'83	Apr'90	
60+00N*	98.3	105.5	129.8	138.1	-	113.3	183.1	158.1	69.0	-114.1
50+00N	128.3	121.7	125.5	152.5	117.7	119.0	198.0	182.8	70.9	-127.1
20+00N*	126.9	107.6	104.9	159.4	109.1	102.9	159.0	128.0	60.6	-98.4
10+00N*	185.6	157.8	147.8	189.9	141.0	136.4	203.8	160.0	87.8	-116.0
10+00S*	192.1	188.2	149.8	176.4	137.4	139.9	199.7	166.0	58.1	-141.6
30+00S*	189.5	168.1	156.4	176.7	141.8	139.0	177.6	141.1	62.5	-115.1
50+00S	173.4	160.5	159.9	165.0	161.0	156.4	184.9	153.8	62.6	-122.3
70+00S	161.3	171.6	188.9	193.2	-	-	202.4	177.5	75.7	-126.7
90+00S	185.0	204.0	213.1	216.6	-	-	136.4	112.6	83.0	-53.4
110+00S	321.8	309.6	279.2	257.0	-	-	150.2	179.2	112.1	-38.1
130+00S*	479.2	428.1	372.9	310.2	-	-	248.0	196.0	133.5	-114.5

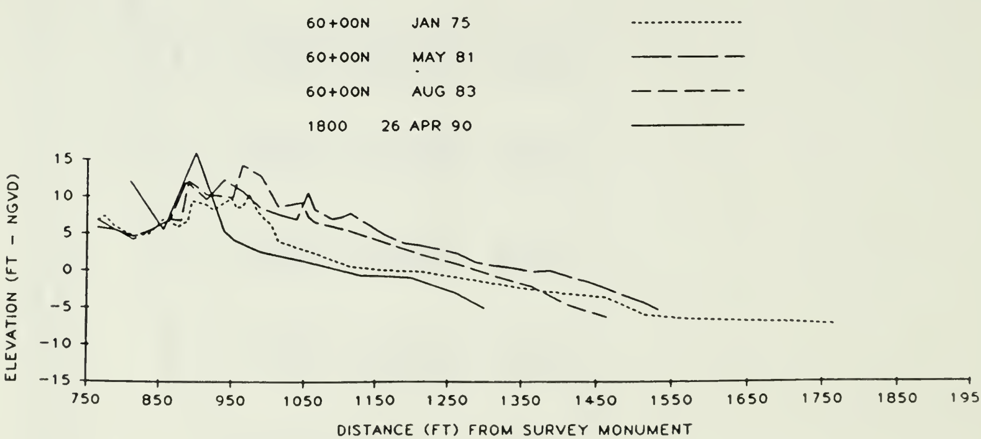
APPENDIX II-3. Sand budget 1981-1990 (+10 ft to -5 ft NGVD). [(-) erosion]

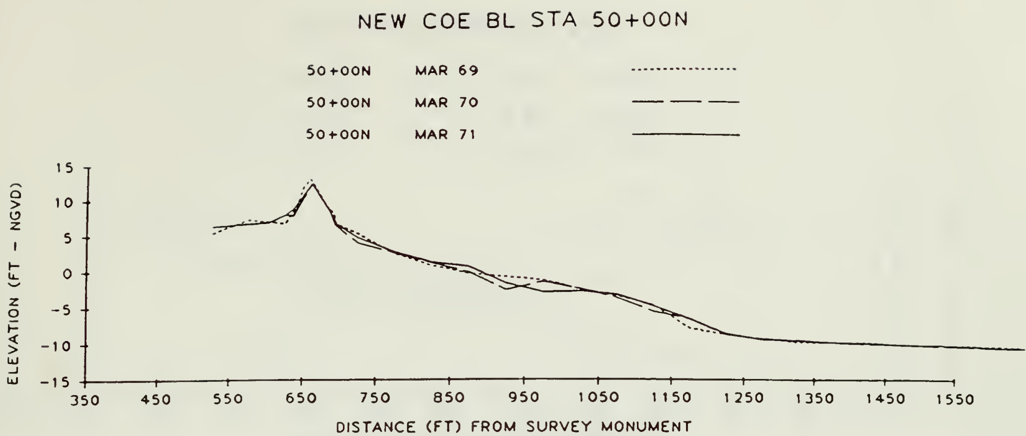
Station	Representative Length (ft)	Unit Change (cy/ft)	Net Change 9 Years (cy)
60+00N*	1,400	-114.1	-159,740
50+00N	2,000	-127.1	-254,200
20+00N*	2,000	-98.4	-196,800
10+00N*	1,500	-116.0	-174,000
10+00S*	2,000	-141.6	-283,200
30+00S*	2,000	-115.1	-230,200
50+00S	2,000	-122.3	-244,600
70+00S	2,000	-126.7	-253,400
90+00S	2,000	-53.4	-106,800
110+00S	1,500	-38.1	-57,150
130+00S*	2,600	-114.5	-297,700
	21,000		-2,257,790 = ~250,865 cy/yr

NEW COE BL STA 60+00N

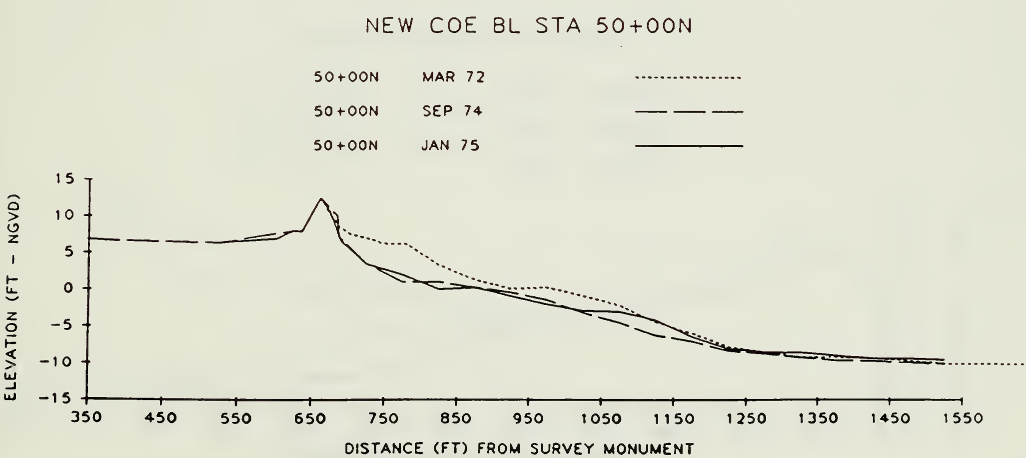


NEW COE BL STA 60+00N

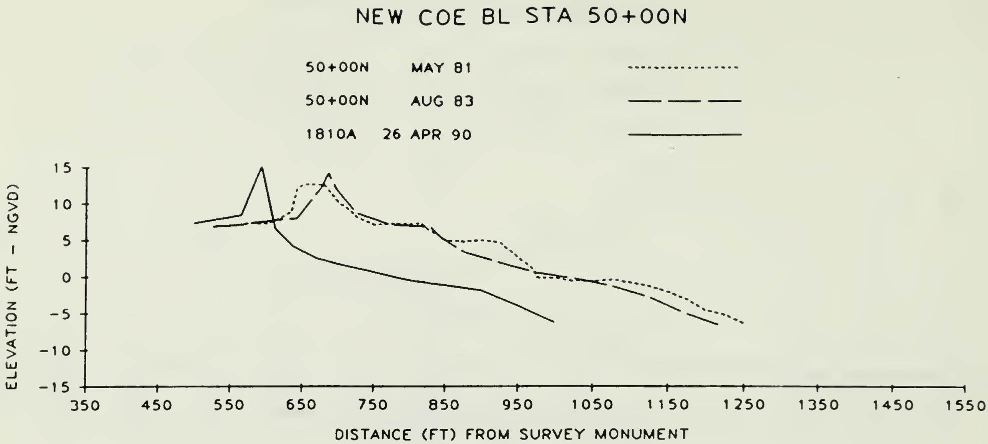




NEW COE BL STA 50+00N
50+00N MAR 69
50+00N MAR 70
50+00N MAR 71
ELEVATION (FT - NGVD)
15
10
5
0
-5
-10
-15
350
450
550
650
750
850
950
1050
1150
1250
1350
1450
1550
DISTANCE (FT) FROM SURVEY MONUMENT



NEW COE BL STA 50+00N
50+00N MAR 72
50+00N SEP 74
50+00N JAN 75
ELEVATION (FT - NGVD)
15
10
5
0
-5
-10
-15
350
450
550
650
750
850
950
1050
1150
1250
1350
1450
1550
DISTANCE (FT) FROM SURVEY MONUMENT



NEW COE BL STA 50+00N
50+00N MAY 81
50+00N AUG 83
1810A 26 APR 90
ELEVATION (FT - NGVD)
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10
5
0
-5
-10
-15
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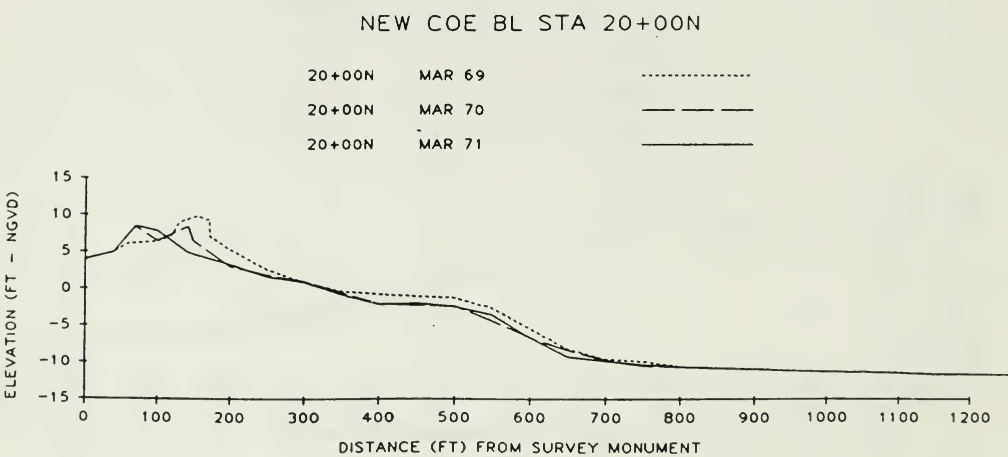
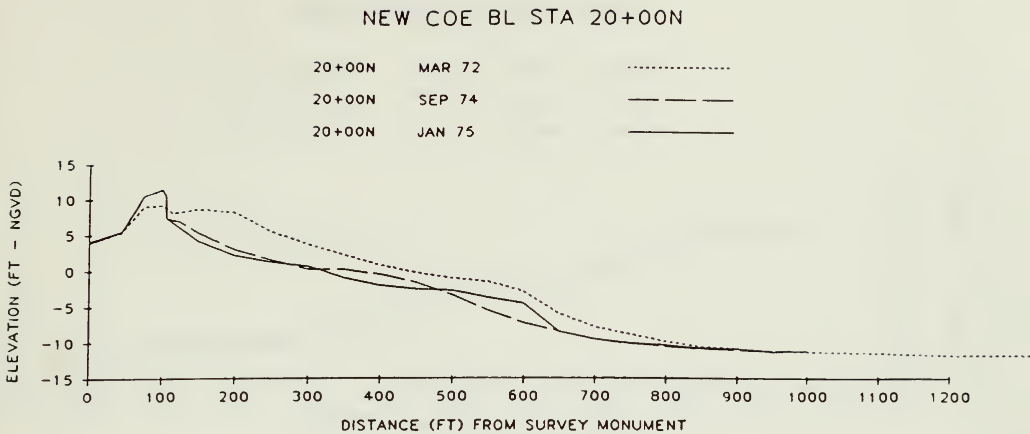
DISTANCE (FT) FROM SURVEY MONUMENT



NEW COE BL STA 20+00N
20+00N MAR 69
20+00N MAR 70
20+00N MAR 71
ELEVATION (FT - NGVD)
15
10
5
0
-5
-10
-15
0 100 200 300 400 500 600 700 800 900 1000 1100 1200
DISTANCE (FT) FROM SURVEY MONUMENT


NEW COE BL STA 20+00N
20+00N MAR 72
20+00N SEP 74
20+00N JAN 75
ELEVATION (FT - NGVD)
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10
5
0
-5
-10
-15
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100
200
300
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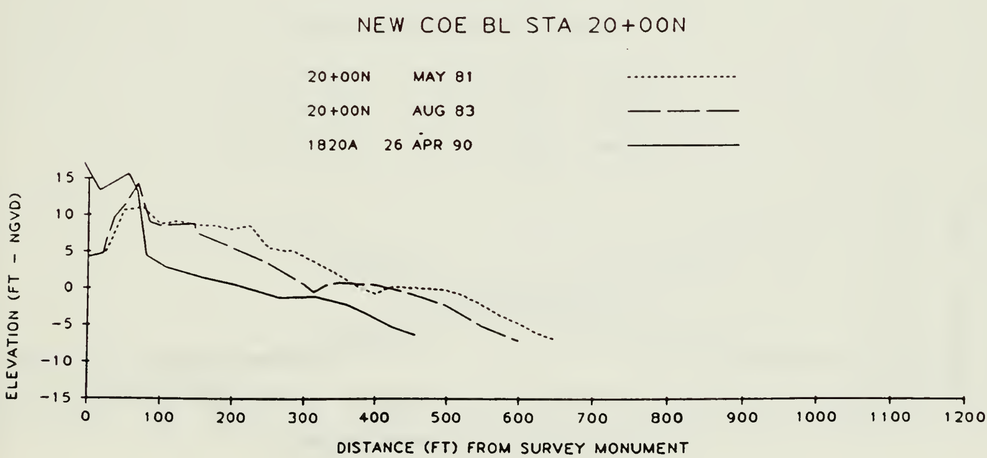
500
600
700
800
900
1000
1100
1200
DISTANCE (FT) FROM SURVEY MONUMENT


NEW COE BL STA 20+00N
20+00N MAY 81
20+00N AUG 83
1820A 26 APR 90
ELEVATION (FT - NGVD)
15
10
5
0
-5
-10
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300
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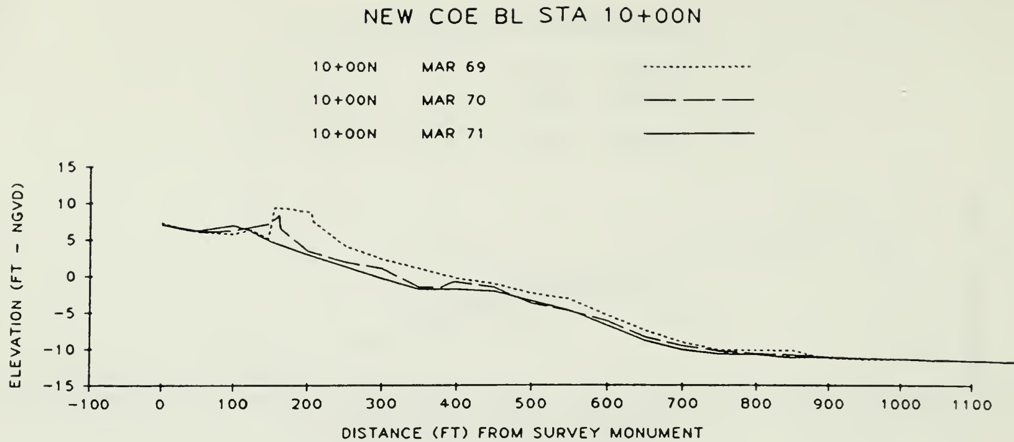
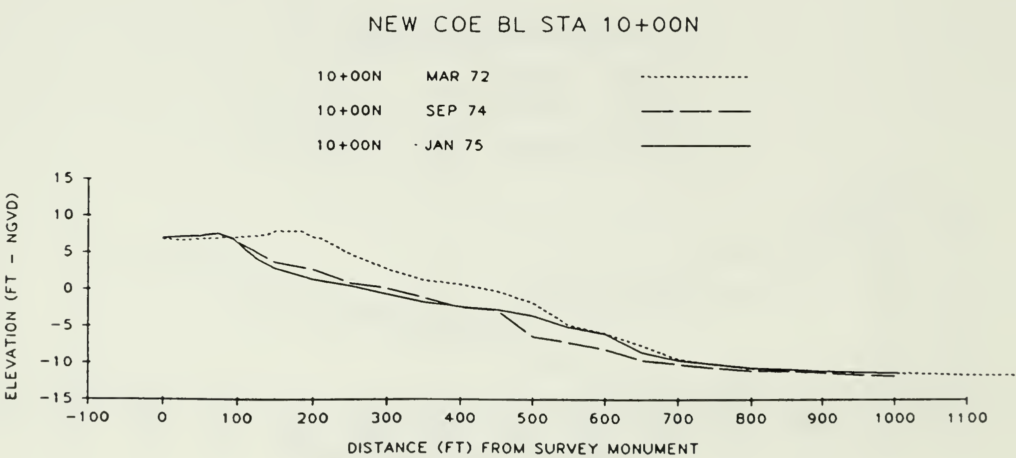
800
900
1000
1100
1200
DISTANCE (FT) FROM SURVEY MONUMENT


NEW COE BL STA 10+00N
10+00N MAR 69
10+00N MAR 70
10+00N MAR 71
ELEVATION (FT - NGVD)
15
10
5
0
-5
-10
-15
-100
0
100
200
300
400
500
600
700
800
900
1000
1100
DISTANCE (FT) FROM SURVEY MONUMENT


NEW COE BL STA 10+00N
10+00N MAR 72
10+00N SEP 74
10+00N JAN 75
ELEVATION (FT - NGVD)
15
10
5
0
-5
-10
-15
-100
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100
200
300
400
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600
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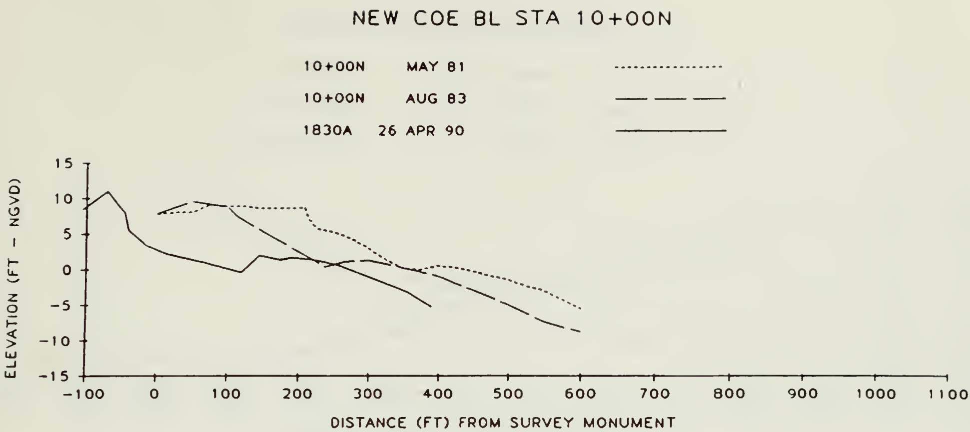
800
900
1000
1100
DISTANCE (FT) FROM SURVEY MONUMENT


NEW COE BL STA 10+00N
10+00N MAY 81
10+00N AUG 83
1830A 26 APR 90
ELEVATION (FT - NGVD)
15
10
5
0
-5
-10
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200
300
400
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600
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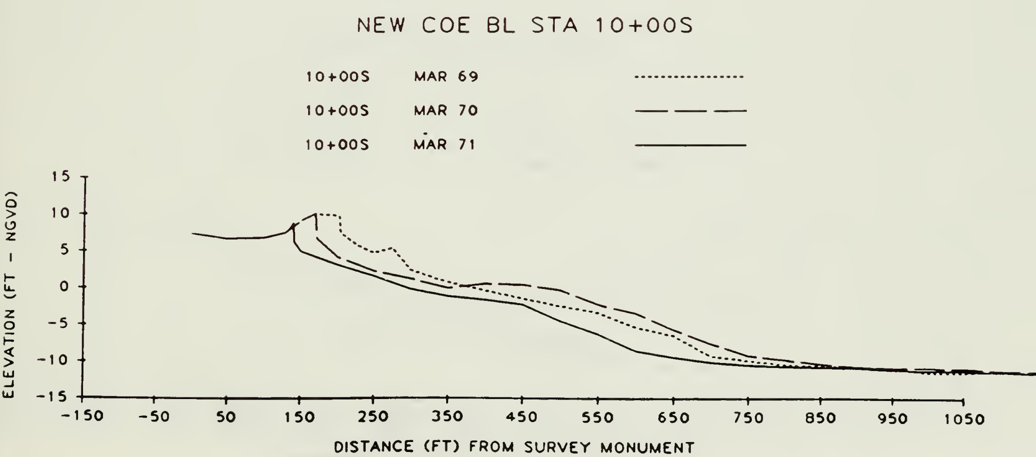
800
900
1000
1100
DISTANCE (FT) FROM SURVEY MONUMENT


NEW COE BL STA 10+00S
10+00S MAR 69
10+00S MAR 70
10+00S MAR 71
ELEVATION (FT - NGVD)
15
10
5
0
-5
-10
-15
-150
-50
50
150
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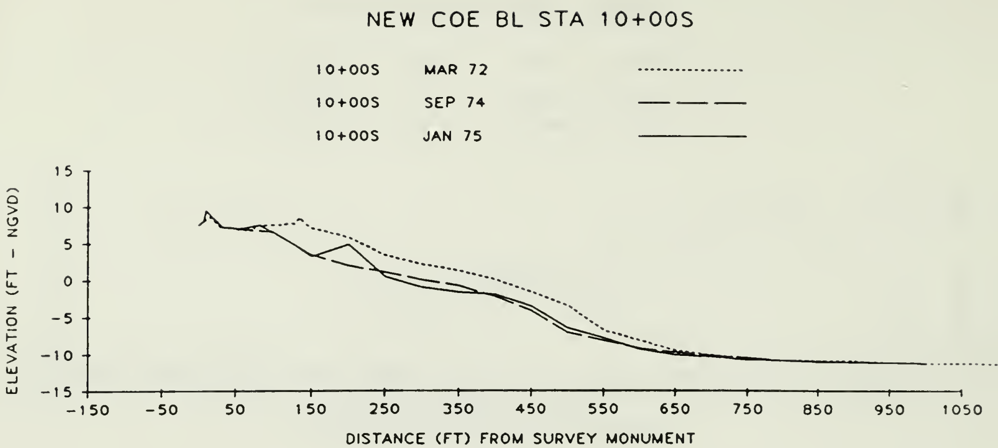
350
450
550
650
750
850
950
1050
DISTANCE (FT) FROM SURVEY MONUMENT


NEW COE BL STA 10+00S
10+00S MAR 72
10+00S SEP 74
10+00S JAN 75
ELEVATION (FT - NGVD)
15
10
5
0
-5
-10
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50
150
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550
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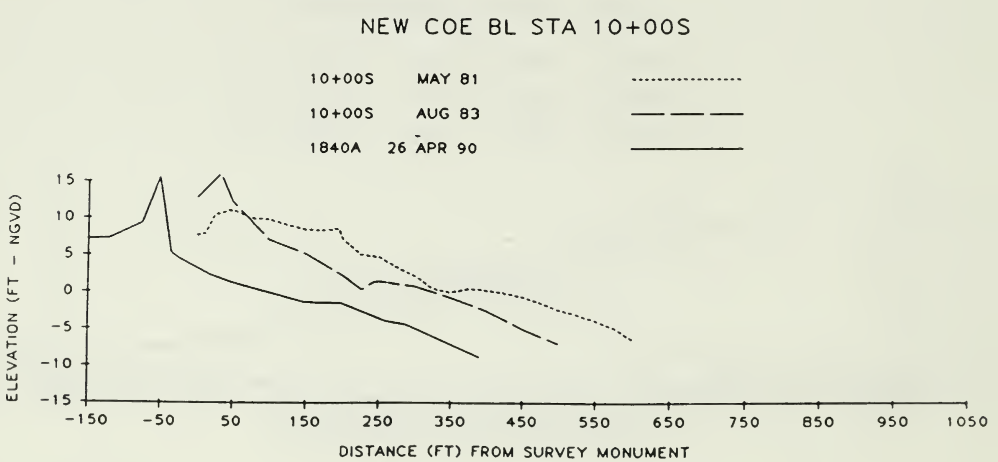
750
850
950
1050
DISTANCE (FT) FROM SURVEY MONUMENT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10+00S MAY 81
10+00S AUG 83
1840A 26 APR 90
ELEVATION (FT - NGVD)
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5
0
-5
-10
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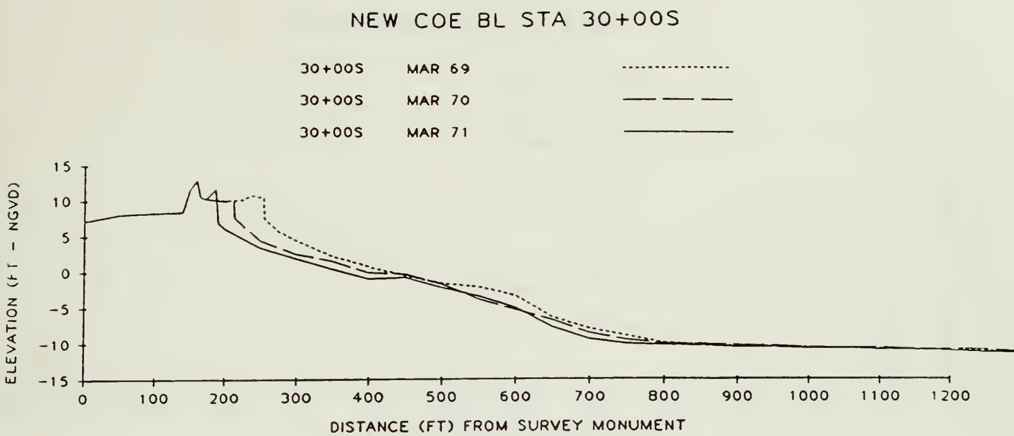
-150
-50
50
150
250
350
450
550
650
750
850
950
1050
DISTANCE (FT) FROM SURVEY MONUMENT


NEW COE BL STA 30+00S
30+00S MAR 69
30+00S MAR 70
30+00S MAR 71
ELEVATION (FT - NGVD)
15
10
5
0
-5
-10
-15
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100
200
300
400
500
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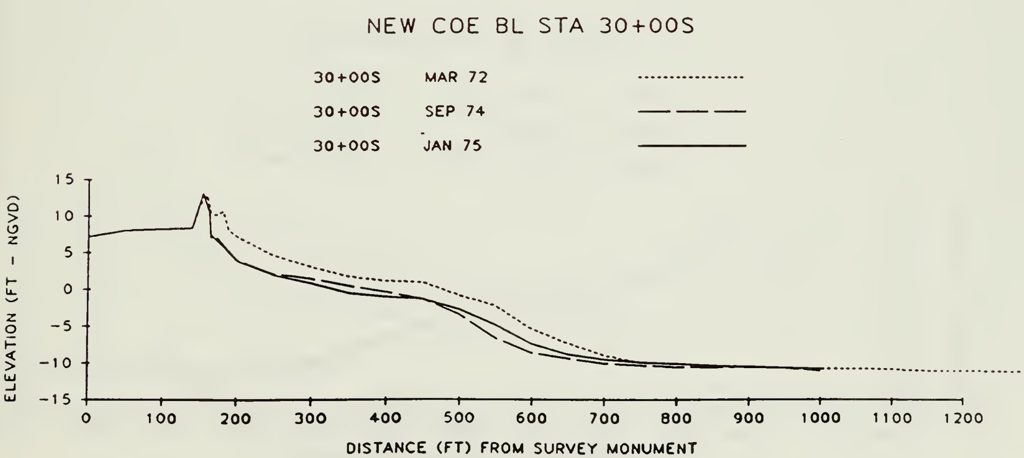
700
800
900
1000
1100
1200
DISTANCE (FT) FROM SURVEY MONUMENT


NEW COE BL STA 30+00S
30+00S MAR 72
30+00S SEP 74
30+00S JAN 75
ELEVATION (FT - NGVD)
15
10
5
0
-5
-10
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300
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500
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700
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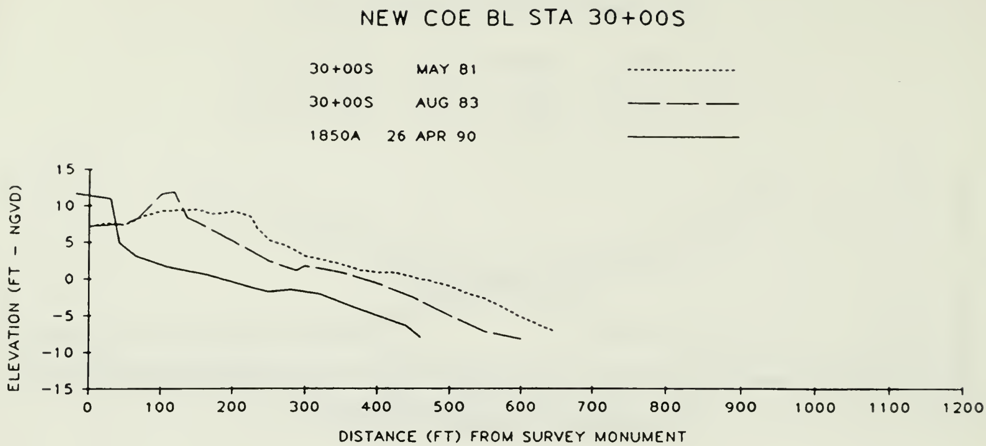
900
1000
1100
1200
DISTANCE (FT) FROM SURVEY MONUMENT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30+00S MAY 81
30+00S AUG 83
1850A 26 APR 90
ELEVATION (FT - NGVD)
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5
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-5
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300
400
500
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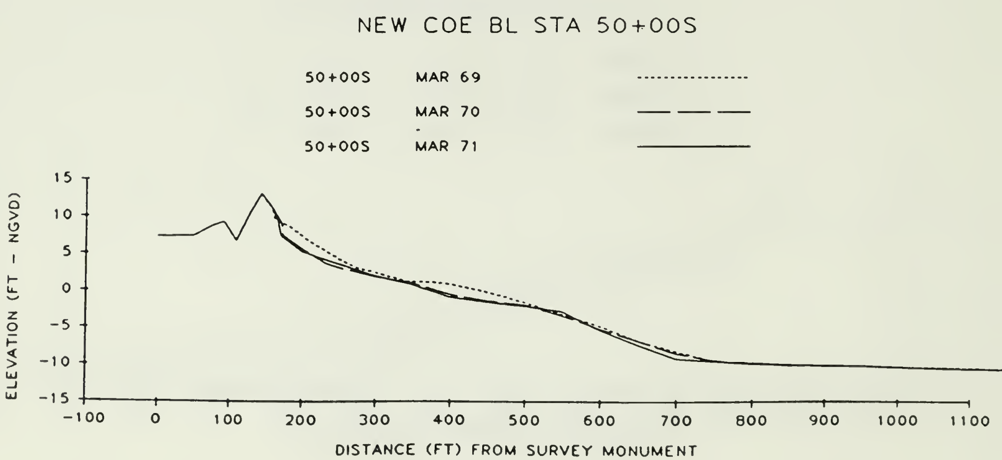
900
1000
1100
1200
DISTANCE (FT) FROM SURVEY MONUMENT


NEW COE BL STA 50+00S
50+00S MAR 69
50+00S MAR 70
50+00S MAR 71
ELEVATION (FT - NGVD)
15
10
5
0
-5
-10
-15
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0
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200
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800
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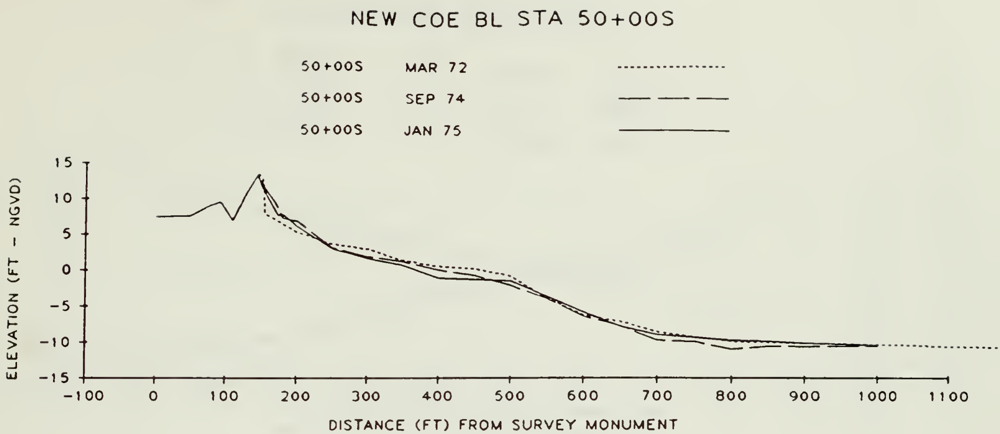
1100
DISTANCE (FT) FROM SURVEY MONUMENT


NEW COE BL STA 50+00S
50+00S MAR 72
50+00S SEP 74
50+00S JAN 75
ELEVATION (FT - NGVD)
15
10
5
0
-5
-10
-15
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200
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400
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600
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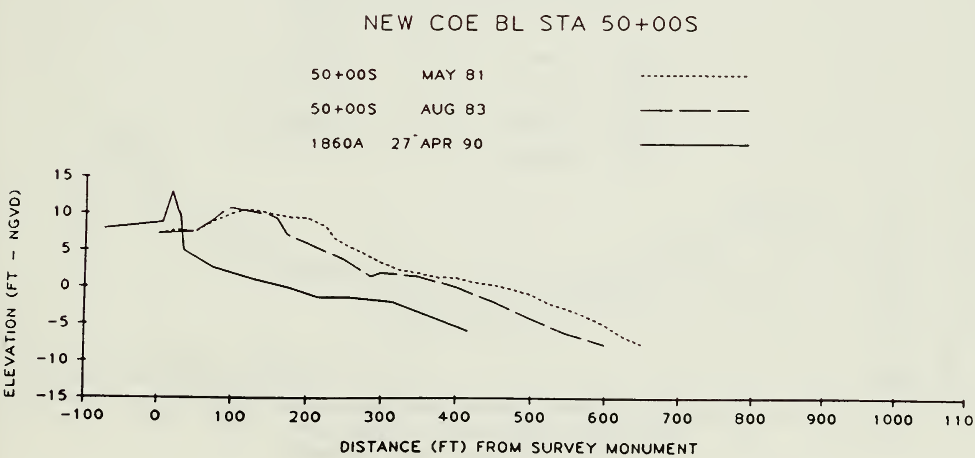
800
900
1000
1100
DISTANCE (FT) FROM SURVEY MONUMENT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50+00S MAY 81
50+00S AUG 83
1860A 27 APR 90
ELEVATION (FT - NGVD)
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0
-5
-10
-15
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200
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400
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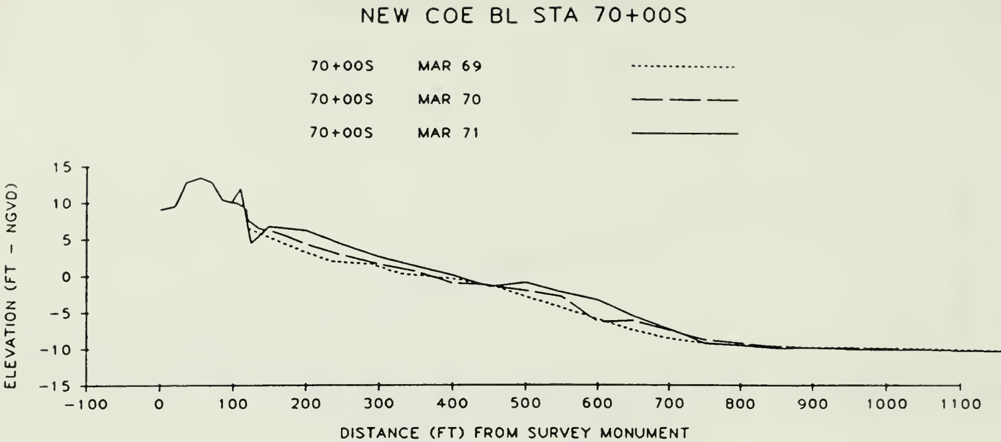
600
700
800
900
1000
1100
DISTANCE (FT) FROM SURVEY MONUMENT


NEW COE BL STA 70+00S
70+00S MAR 69
70+00S MAR 70
70+00S MAR 71
ELEVATION (FT - NGVD)
15
10
5
0
-5
-10
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200
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600
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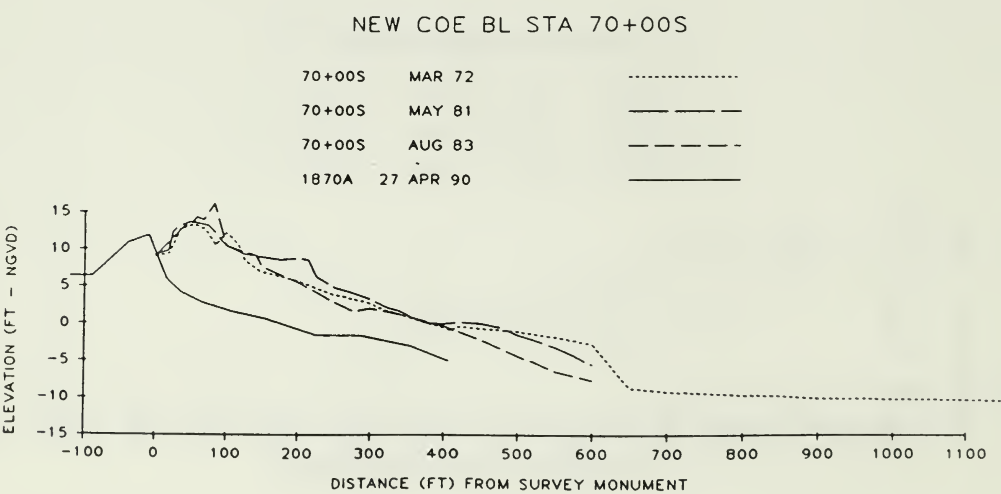
800
900
1000
1100
DISTANCE (FT) FROM SURVEY MONUMENT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70+00S MAY 81
70+00S AUG 83
1870A 27 APR 90
ELEVATION (FT - NGVD)
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10
5
0
-5
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200
300
400
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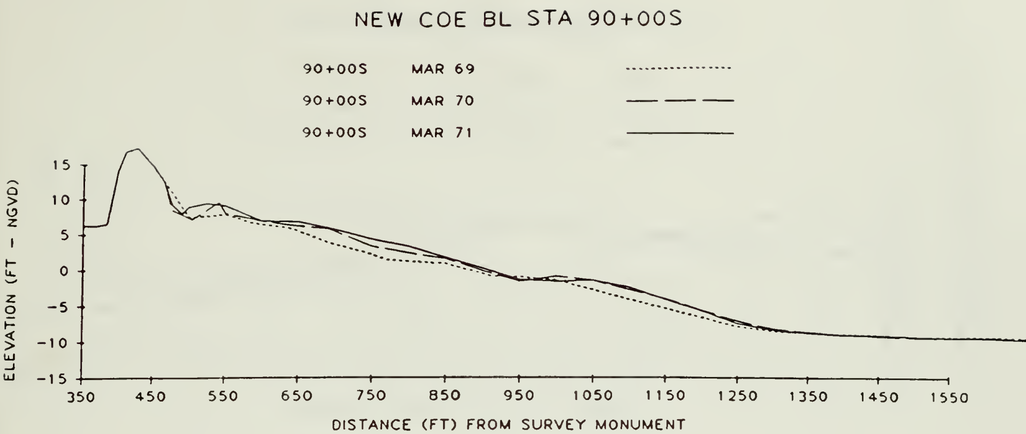
600
700
800
900
1000
1100
DISTANCE (FT) FROM SURVEY MONUMENT


NEW COE BL STA 90+00S
90+00S MAR 69
90+00S MAR 70
90+00S MAR 71
ELEVATION (FT - NGVD)
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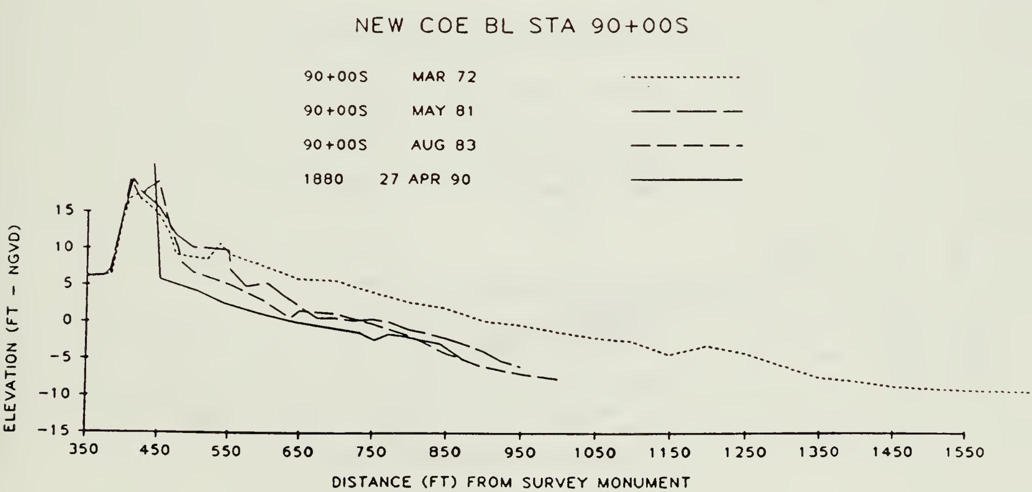
0
-5
-10
-15
350 450 550 650 750 850 950 1050 1150 1250 1350 1450 1550
DISTANCE (FT) FROM SURVEY MONUMENT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90+00S MAY 81
90+00S AUG 83
1880 27 APR 90
ELEVATION (FT - NGVD)
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-10
-15
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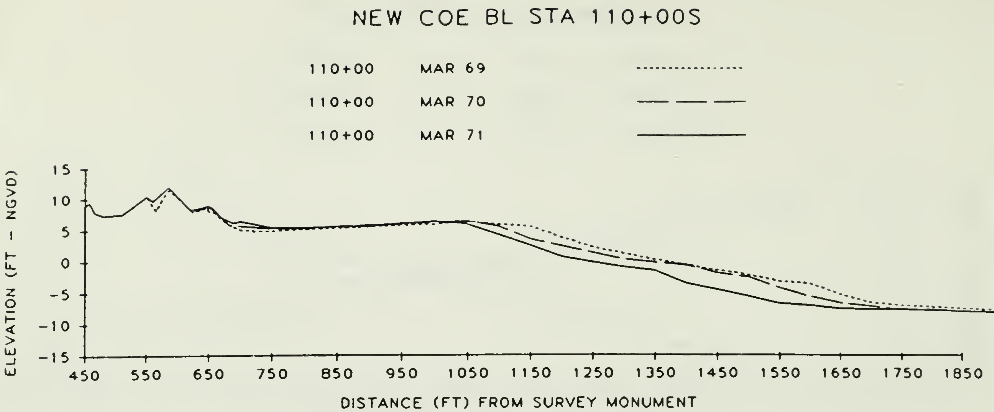
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110+00 MAR 69
110+00 MAR 70
110+00 MAR 71
ELEVATION (FT - NGVD)
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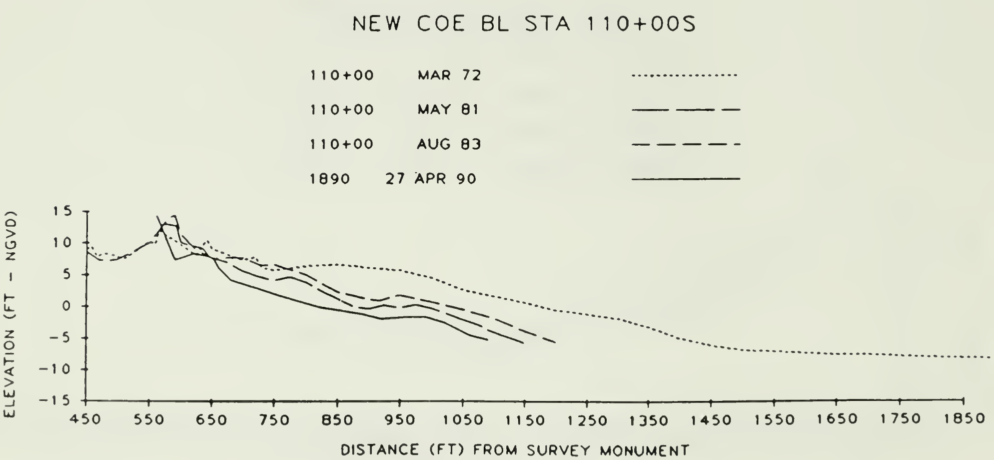
-15
450 550 650 750 850 950 1050 1150 1250 1350 1450 1550 1650 1750 1850
DISTANCE (FT) FROM SURVEY MONUMENT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110+00 MAR 72
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110+00 AUG 83
1890 27 APR 90
ELEVATION (FT - NGVD)
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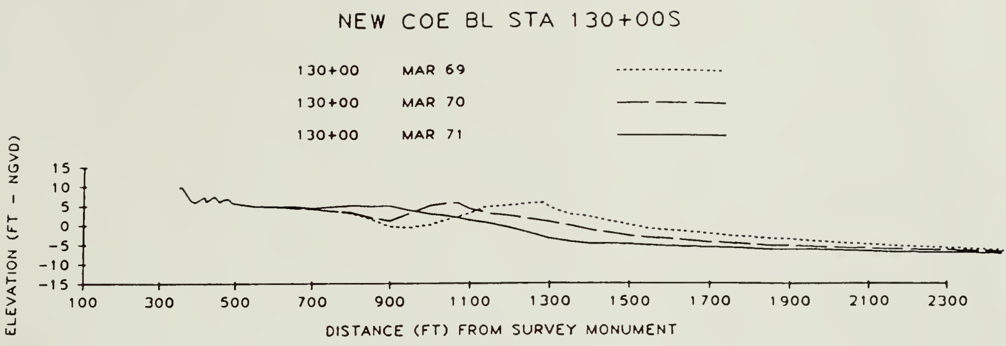
-15
450 550 650 750 850 950 1050 1150 1250 1350 1450 1550 1650 1750 1850
DISTANCE (FT) FROM SURVEY MONUMENT


NEW COE BL STA 130+00S
130+00 MAR 69
130+00 MAR 70
130+00 MAR 71
ELEVATION (FT - NGVD)
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10
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-5
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700
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1100
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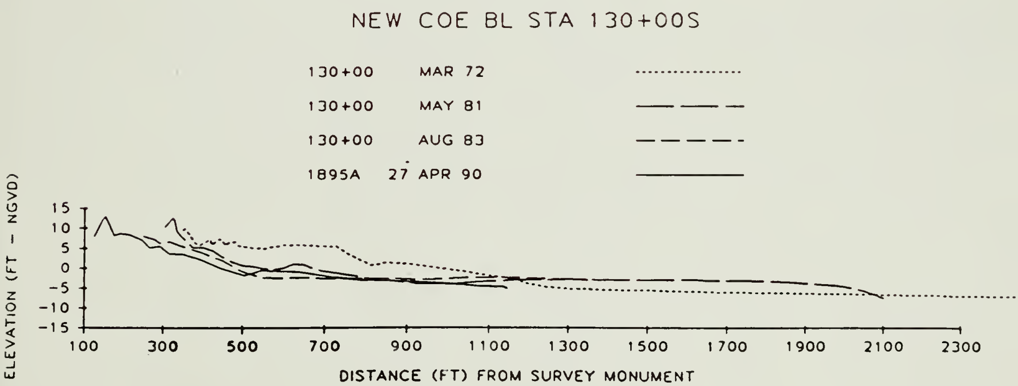
1500
1700
1900
2100
2300
DISTANCE (FT) FROM SURVEY MONUMENT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130+00 MAR 72
130+00 MAY 81
130+00 AUG 83
1895A 27 APR 90
ELEVATION (FT - NGVD)
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5
0
-5
-10
-15
100
300
500
700
900
1100
1300
1500
1700
1900
2100
2300
DISTANCE (FT) FROM SURVEY MONUMENT