FINAL REPORT

Evaluation of Beach Renourishment Performance in South Carolina Using GIS Analysis

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ABSTRACT

Most coastlines throughout the world are suffering from erosion. Population growth and human development in the coastal zone, especially within the last 50 years, have created a situation in which coastal erosion can lead to severe economic consequences. As the interface and energy buffer between land and sea, beaches are particularly vulnerable to erosion. Two main methods of erosion control, hard and soft stabilization, have been employed in an attempt to alleviate problems associated with an eroding coastline. Hard stabilization, which involves the erection of a permanent structure such as a seawall, revetment or groin to protect private property and associated infrastructure, has fallen out of favor in recent years as a coastal management method. Hard stabilization does not protect the beach, and in most instances results in negatively impacting the shoreline. Beach renourishment, a form of soft stabilization, adds additional sand to the system thereby increasing the overall sediment budget. The advantages of beach nourishment over other options have led to widespread use of this erosion control technique to stabilize the shoreline.

Although beach renourishment has become the erosion control device of choice, knowledge of nourishment project performance is lacking. Several factors contribute to a poor understanding of project performance. Overall lack of monitoring data has prevented accurate evaluation of many prior nourishment efforts. In addition, coastal engineers, coastal zone managers, coastal geologists, and representatives from local, state, and federal government agencies have not agreed upon standard evaluation criteria. Often the objectives of a renourishment project are not clearly stated or communicated to the public leading to diverse perceptions of the success of a project.

This research examines three recently completed beach nourishment projects in South Carolina to determine project performance. Hunting, Edisto, and Hilton Head Islands were all renourished within the past nine years. Monitoring surveys were obtained for each project and incorporated into a geographic information system (GIS). Evaluation criteria consisting of changes in sediment volume and beach width were measured to determine the lifespan of each project.

Results indicate that the Hunting Island renourishment was short-lived and had a lifespan of less than 5 years when volumetric change was considered. Application of the beach width criteria resulted in greater predicted durability for this project. The Edisto Island renourishment project had favorable results when tested using both criteria, and had a greater sand volume at the end of the monitoring period. While monitoring data for the year following the Hilton Head Island renourishment was available, transect spacing was too great to generate realistic beach surfaces, however volumetric change was calculated using the interpolated grids. Volumetric change results indicate that the Hilton Head Island renourishment had a lifespan of less than one year. Beach width also decreased consistently over time but showed that the lifespan would be greater than one year using this criterion. For all three projects, additional monitoring data would have allowed a more comprehensive performance analysis.

INTRODUCTION

Beaches and Erosion

Beaches are one of the most unique landforms on earth. As the transition zone between land and sea, beaches are extremely dynamic environments. Coastal change can be more rapid than that found in almost any other geologic environment. The width, height, and slope as well as location of a beach may change abruptly in a very short period of time in response to both natural processes and human activities. Sand is moved onto and off of the shoreline by currents and waves. Annual seasonal patterns of sediment transport result in broad summer beaches followed by narrower winter beaches. Major storms and hurricanes, accompanied by huge waves and storm surges, can move large volumes of coastal sediments in a matter of hours.

As one component of the coastal zone, beaches reflect the dynamic nature of the entire coastline. On a larger scale, the coast moves towards equilibrium in response to forces acting on it (Williams *et al.*, 1990). Rivers transport sediments toward the ocean where they may add to the sediment budget and extend the coast. Headlands are eroded causing a landward shift of the coastline. Barrier islands and offshore sandbars migrate along the coast, propelled by longshore currents. Tidal currents transport sediments in and out of inlets, depositing sand on flood or ebb tidal deltas in tide-dominated regions. Simultaneously, barrier islands and offshore sandbars migrate landward in response to sea level rise and wave activity.

In addition to their unique morphodynamics, barrier islands found along the Atlantic Coast are part of a complex integrated system of beaches, dunes, salt marshes, estuaries, tidal creeks, and inlets. Sandy beaches play a critical role in forming and maintaining coastal wetlands and estuaries, which in turn are rich in nutrients and provide invaluable habitat to many fish and wildlife species (Williams *et al.*, 1990). Beaches absorb the brunt of wave energy along the margin of the sea and protect plants and organisms unable to withstand such forces. Beaches provide nesting sites for endangered sea turtles and many species of shorebirds (Dean and Yoo, 1992). Sand contained in the beach and dune system offers a buffer against storm surges and assists in flood control (Finkl, 1996).

Besides its role in the natural system, the beach environment also affords a variety of opportunities for humans. The main reasons for human occupation of the coast include residential and recreational, industrial and commercial, waste disposal, agriculture, aquaculture and fishing, nature reserves, and military and strategic (Carter, 1988). Perhaps the most apparent use of coastal resources falls under the residential and recreational category.

Most beaches are currently threatened with the persistent problem of sediment loss. Erosion is occurring along almost all coastlines on a global scale. In undeveloped coastal areas an eroding shoreline presents little threat to human activities. Erosion, however, is a critical problem along almost all developed coastlines. Increasing human population, coupled with erosion, serves to exacerbate the problems associated with coastal land loss (Williams *et al.*, 1990). Estimates indicate that 70% of sandy shorelines are eroding worldwide (Bird, 1985). Assessments in South Carolina indicate that approximately 50% of the 90 miles of developed shoreline is eroding or lacks a significant dry-sand beach (Kana, 1990).

Both natural and anthropogenic variables influence the erosion rate of a beach. Natural factors, including reduced sediment supply, storm frequency, sediment type, tidal range, wave energy, bathymetry, and global sea-level rise effect the rate of shoreline change (Kana, 1988). Impacts of human activities such as construction of harbor jetties, seawalls, revetments, groins, beach scraping, and shorefront development can also modify erosion rates (Kana, 1988).

Many coastal populations exhibit allometric growth, thus they are expanding faster than the average national population (Carter, 1988). Beach visitation has become synonymous with coastal recreation. Living on or near a sandy beach is highly prized (NRC, 1995). The result has been a rapid escalation in population and land values in many coastal regions (Houston, 1995). In 1990, 50% of the U.S. population lived within an hour's drive of a coast (Culliton *et al.*, 1990). Projections indicate that the number will increase to 75% by 2010 (Culliton *et al.*, 1990). Coastal areas along the United

States have population densities five times the national average (Williams *et al.*, 1990). Coincidentally, the most dynamic coastal environment, the beach, is under increasing pressure from development and recreational use.

As coastal populations grow, direct threats to coastal environments increase as pressure mounts from human occupation of the shoreline. Problems facing coastal regions stem in part from misconceptions about coastal processes and from human actions based on those misconceptions. People think of land as stable, and approach its use and management as if it were a permanent asset (Williams *et al.*, 1990). In general, this is a reasonable presumption because land loss normally occurs very slowly. Although tectonic and geologic processes, such as continental drift and sediment deposition, are ongoing, change is typically so gradual that it is barely noticeable within a human lifetime (Williams *et al.*, 1990).

Barrier islands and beaches are not static, rather, they are constantly on the move, eroding, accreting, and migrating in response to both human and natural forces. Because humans treat the coast just like any other parcel of land that is thought to be stable and safe to build upon, some activities conflict directly with the dynamic nature of the coast (Williams *et al.*, 1990).

Solutions to the Erosion Problem

Four basic responses have been suggested as options available to coastal communities faced with an eroding shoreline. Proposed alternatives include: 1) retreat, meaning the relocation of buildings and infrastructure in a landward direction; 2) accommodate, or raise buildings above the projected flood levels; 3) protect buildings and infrastructure by some physical alteration of the shoreline (hard or soft stabilization); and 4) the unplanned response or no action (IPCC, 1990, Pilkey and Clayton, 1989). Areas of dense population and highly developed infrastructure have chosen protection as the preferred alternative (NRC, 1995).

Several engineering approaches have been used to protect shorelines and counteract erosional effects. One approach is hard stabilization, which involves the installation of permanent structures such as seawalls, revetments, groins, or offshore breakwaters. While these structures can reduce flooding hazards, protect buildings, and stabilize the shoreline, they do not add additional sand to compensate for deficits in the sediment budget (NRC, 1995). Hard structures are costly and inflexible and often environmentally and aesthetically undesirable (Davison *et al.*, 1992). In addition, hard structures often create new problems, such as restricted beach access and enhanced erosion (NRC, 1995). On beaches with long-term erosion problems and where a seawall immobilizes the shoreline, erosion will continue unabated (Dean, 1985; Kraus and McDougal, 1996). In such cases, the subaerial beach fronting the seawall will eventually disappear (Kraus, 1988; Hall and Pilkey, 1991; Kraus and McDougal, 1996).

A second category of erosion control, termed soft stabilization, has gained popularity over the last several decades (NRC, 1995, Davison *et al.*, 1992, Leonard *et al.*, 1990a). Soft stabilization techniques include beach scraping, dune stabilization, and beach nourishment. Of these, beach nourishment is the only method that adds new sand to the beach, and thus restores the beach with sediment from outside the eroding system. Beach nourishment, renourishment, and replenishment are used here as interchangeable terms for the process of placing sand on an eroding shore in order to restore or form, and subsequently maintain, an adequate protective or desired recreational beach (USACE, 1984).

Advantages of beach nourishment over other options have made this alternative the coastal management tool of choice (NRC, 1987; Leatherman, 1991). Davison *et al.* (1992, p. 985) succinctly lists benefits of beach nourishment as follows:

(1) The widened berm and advanced beach profile, in some cases combined with protective dunes, dissipate wave energy, which in turn acts to reduce damages from storms (Dean, 1987).

(2) The widened berm is aesthetically pleasing, unlike hard structures, and promotes tourism by easing congestion during peak vacation season.

(3) The widened beach resets the long-term "erosion clock" and dispels the negative erosion-prone stigma of a coastal community.

(4) Beach nourishment does not appear to produce the negative downdrift effects commonly associated with rigid coastal engineering structures. In fact, the beach fill

adds to the coastal sediment budget and benefits downdrift beaches and adjacent communities.

(5) Costs are generally lower and more evenly spread over time compared to hard structures.

(6) Projects are inherently flexible as the profile can adjust to variable hydrodynamic conditions.

These benefits have led to wide acceptance and use of beach nourishment as a management tool for an eroding shoreline (NRC, 1995).

Beach Renourishment: Project Design and Implementation

The decision-making process, the first phase of a beach renourishment project, begins when a beachfront community perceives an erosion problem (NRC, 1995). The erosion problem may be chronic, in which case the decision process may take years of planning and discussion. In other cases, a severe storm or hurricane may force a quick decision to perform some type of shore protection to prevent additional damage to buildings and infrastructure. Once beach renourishment is selected as the method of erosion control, planning and design begin.

Early nourishment projects in the U.S. served primarily as repositories of dredged material associated with harbor and channel maintenance and were constructed without formal planning (Domurat, 1987). Within the last two decades, beach nourishment project design has evolved to a quantitative engineering endeavor that takes into account such parameters as grain size, volume of sand required, and wave energy (Davison *et al.*, 1992). The 1970s began the era of computer-aided project design and eased the integration of the many factors considered in project formulation.

Grain size and compatibility of the fill material with native sand is a major consideration in beach nourishment projects (USACE, 1984). Fill material containing large quantities of silts and clays will be winnowed and carried away from the beach more rapidly than native sediments causing a rapid erosion of the nourishment project (Davison *et al.*, 1992). Conversely, fill with a coarser grain size tends to be more stable but may result in undesirable changes in the profile configuration (Davison *et al.*, 1992).

Fill behavior is most predictable when the fill is compatible with the native sand (NRC, 1995).

Placement location and delivery method of the fill material are important design considerations. Possible fill placement locations include the dune, visible beach, swash and wave zone, nearshore zone and offshore storm bar (Smith and Jackson, 1990) or spread across the entire profile (Bruun, 1990). Placement location along the beach may be chosen to more efficiently address erosional hot spots (NRC, 1995). In the U.S., fill material is typically dredged from an offshore borrow site and hydraulically pumped to the placement site although some projects have employed inland sand sources and trucks to deliver the material (NRC, 1995). It is common practice in the U.S. to place fill material on the subaerial beach, the cheapest placement site given the type of equipment and shallow profile (Houston, 1998), and then allow hydrodynamic processes to redistribute the fill across the profile (Davison *et al.*, 1992). The technique of stacking the fill on the subaerial beach is also used to ensure that the material is spread alongshore according to design and allows volumetric measurement of the fill material.

Many different design methods are available today and fall into two general categories (Davison *et al.*, 1992). An empirical design approach based on practical experience with a particular shoreline is often used in Europe (Delft Hydraulics, 1987). For example, numerous renourishment projects have been constructed on the island of Sylt, Germany through the 1970s and 1980s (Delft Hydraulics, 1987). A consistent post-project monitoring regime conducted since 1972 has allowed further design refinement as knowledge is gained from experience (Delft Hydraulics, 1987). This approach is considered to work well in regions with sufficient historical shoreline trend data, although few countries have quality long-term data (Davison *et al.*, 1992). The second design approach is more theoretical and employs computer models such as one-line, two-line, longshore, and cross-shore designs (Davison *et al.*, 1992). Theoretical design methods are more commonly used in the U.S. than are empirical methods (Davison *et al.*, 1992).

The one-line model uses one contour line (usually the mean sea level water line) to represent shoreline changes, while the two-line model allows for consideration of beach stabilization structures and the resulting profile steepening and flattening updrift and downdrift respectively (Dean and Yoo, 1992). The longshore model assumes that all losses of fill material are caused by longshore transport and indicates that beach fill is most effective under low wave energy conditions or when the project length is long (Dean, 1987). Cross-shore design method takes into account the entire active beach profile to closure depth or the depth to which sand is molded by wave action (Dean, 1997). Since most of the active beach profile is submerged (Leatherman, 1991), the equilibrium profile concept suggests that the entire beach profile must be considered when designing a nourishment project (Bruun, 1990).

Summary of Beach Renourishment in South Carolina

More than 200 beaches in the United States have undergone some form of renourishment effort (Pilkey, 1995). Over 90 beaches along the Atlantic Coast have been renourished by over 270 individual efforts through 1987 (Leonard *et al.*, 1990a). To date, nine beaches in South Carolina have been replenished (Figure 1). Nearly 23 million cubic yards of sand have been pumped onto 52 miles of beach, which is over half of the developed shoreline. The most recent nourishment of the Myrtle Beach area accounts for about half of the 52 miles. A total of nearly 87 miles of shoreline have been renourished or restored when overlapping efforts are included (Table 1). A more detailed summary of historical beach renourishment parameters is located in Appendix A.

Edisto Island was the first beach to undergo renourishment in South Carolina. Between 1948 and 1954, 12 groins were installed by the South Carolina Highway Department. Approximately 850,000 cubic yards of sand were pumped onto the beach to protect Palmetto Boulevard (CSE, 1993a). No other beach was altered until 1968 when Hunting Island was nourished by the U.S. Army Corps of Engineers (USACE) as part of an on-going renourishment program lasting until 1980 (CSE, 1995). From 1979 through 1989 several more coastal communities joined the battle against an eroding shoreline.

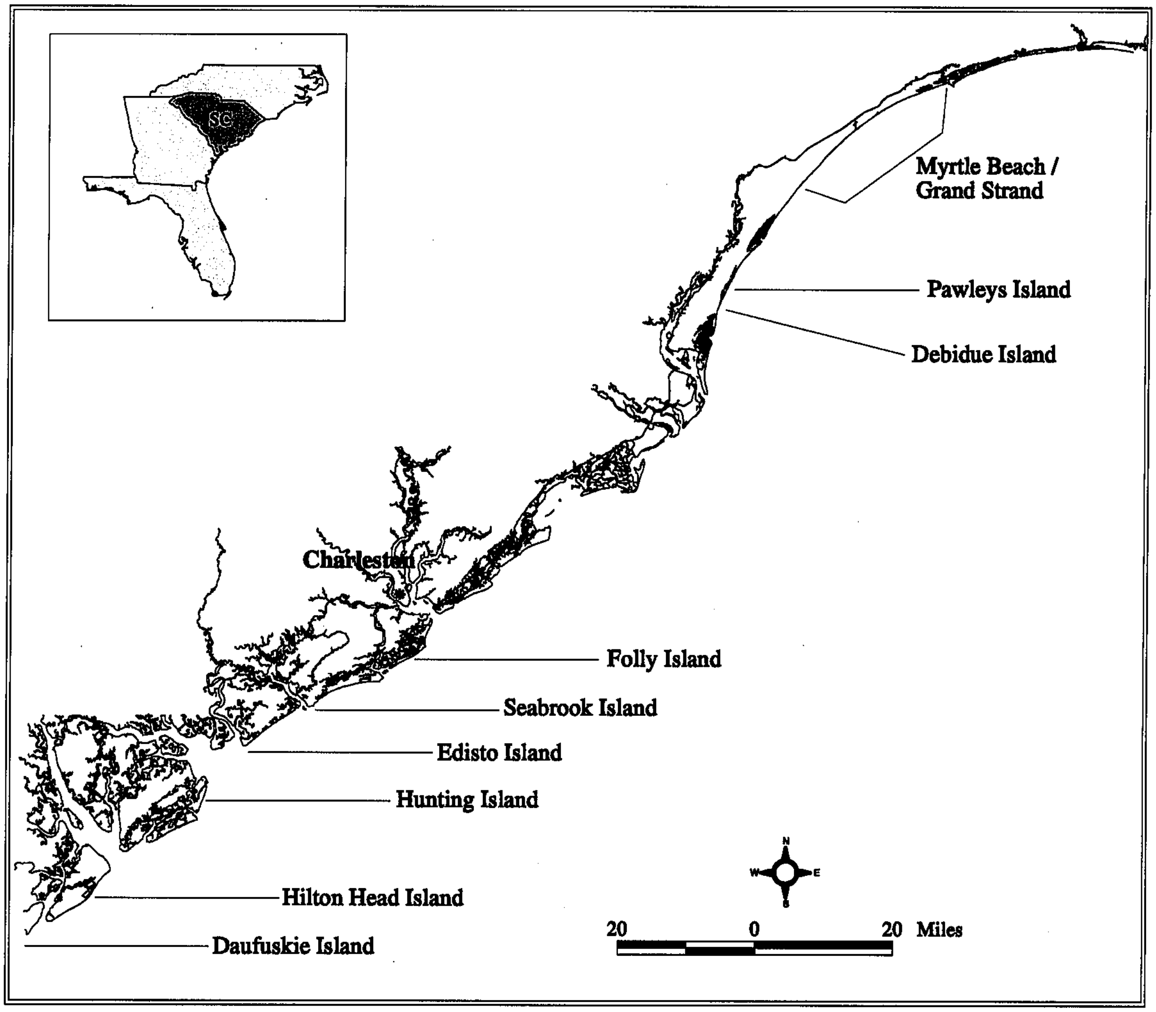


Figure 1. Index map of South Carolina nourishment projects.

Folly, Hilton Head, and Seabrook Islands and Myrtle Beach were renourished during the 1980s. The south end of Folly Island was renourished repeatedly as part of a federal navigation project to maintain the Folly River channel. During the 1990s, all beaches with past nourishment histories were renourished once again and some beaches underwent their first shoreline stabilization project. Folly underwent its first large renourishment in 1993 when 2.5 million cubic yards of sand were placed along the central portion of the island. In 1990 Hilton Head Island also completed a major nourishment project with the application of over 2 million cubic yards of sediment along a 6-mile stretch of beach. Erosion on Debidue, Pawleys and Daufuskie Islands became problematic and all three were renourished for the first time during the 1990s.

Table 1. Summary table of beach nourishment projects along the South Carolina coast. Funding Source refers to the principle source(s) of funding for the project. Federal funding is divided into several categories depending on the goal of the project.

Beach	Year	Volume (cubic yards)	Length (miles)	Cost ($)	Funding Source
Myrtle Beach	1986-1987	853,350	8.6	4,700,000	State/Local
	1990	395,960	8.4	2,400,000	Federal Emergency
	1991	28,000	0.23	165,000	No data
	1996-1998	5,135,000	25.4	50,515,470	Federal/State/Local - Storm and Erosion
Pawleys Island	1998-1999	250,000	2.5	1,200,000	State
Debidue	1990	191,693	1.53	855,000	Private
	1998	250,000	1.5	1,500,000	Private
Folly Beach	1979	20,022	0.19	No data	Federal Navigation
	1982	18,526	0.19	No data	Federal Navigation
	1984	51,965	0.19	No data	Federal Navigation
	1985	57,858	0.19	No data	Federal Navigation
	1986	70,181	0.19	No data	Federal Navigation
	1987	56,696	0.19	No data	Federal Navigation
	1988	50,336	0.19	No data	Federal Navigation
	1993	2,500,000	5.34	12,520,000	Federal/State - Storm and Erosion
Seabrook Island	1982	75,000	No data	No data	Private
	1983	250,000	No data	300,000	Private
	1990	685,000	1.12	1,660,000	Private
Edisto Island	1954	850,000	1.01	No data	Federal/State - Storm and Erosion
	1995	148,404	2.27	1,500,000	State/Local
(State Park)	1999	25,000	0.57	100,000	State
Hunting Island	1968	750,000	1.89	435,178	Federal - Storm and Erosion
	1971	761,324	1.89	534,000	Federal - Storm and Erosion
	1975	612,974	1.7	971,540	Federal - Storm and Erosion
	1980	1,412,692	2.27	2,267,201	Federal - Storm and Erosion
	1991	715,766	1.42	2,920,000	State
Hilton Head Island	1981	800,000	No data	No data	By-product of construction at Palmetto Dunes
	1990	2,338,000	6.63	9,700,000	State/Local
	1997	2,000,000	7	11,000,000	State/Local
(Sea Pines)	1999	200,000	0.8	1,200,000	Local
Daufuskie Island	1998	1,400,000	3.5	6,000,000	Private
Totals	**45 years**	**22,703,747 cubic yards**	**86.9 miles***	**$112,443,389**	

* Note: When overlapping projects are taken into account, the total equals 52.5 miles.

The use of beach renourishment as an erosion control management tool has increased during the last decade (Figure 2). In particular, a rapid increase in the total volume of sand emplaced along the South Carolina coast can be seen in the last 20 years. In the last decade alone 16.3 million cubic yards of sand, 70.9% of the total, have been placed on eroding beaches. When the 1980s are also considered, 87.0% of the volume of nourishment sand has been added within the last 18 years.

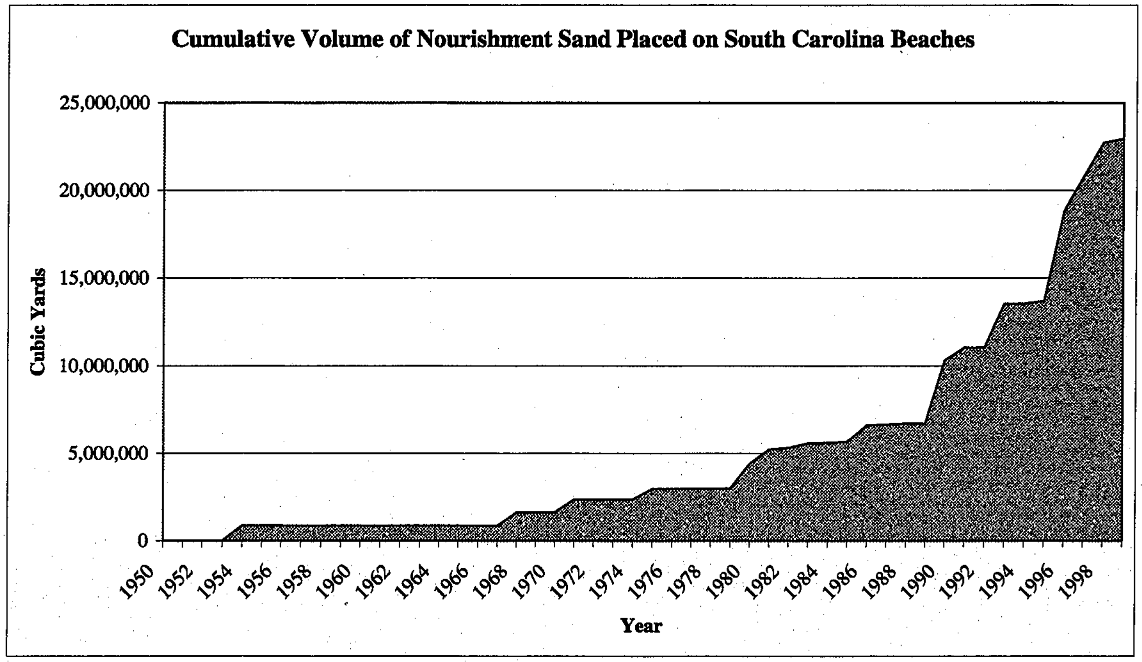


Figure 2. Cumulative volume of sand placed on South Carolina beaches from 1954 to 1999.

As one would expect, the cost of beach nourishment projects has followed a similar trend. An even more dramatic increase in cumulative dollars spent has occurred as the cost has gone up simultaneously with the rate of emplacing sand (Figure 3). Thirty years ago, sand cost approximately $1.00 per cubic yard while today the average cost ranges from $5.00 to $10.00 per cubic yard (Eiser, 1999b). The most recent Myrtle Beach nourishment cost over $50 million for just over 5 million cubic yards of sand. Since 1968, over $112 million has been spent on beach nourishment in South Carolina. Because costs were not known for all projects and dollar figures were not adjusted for inflation, the exact dollar figure can be expected to be even higher.

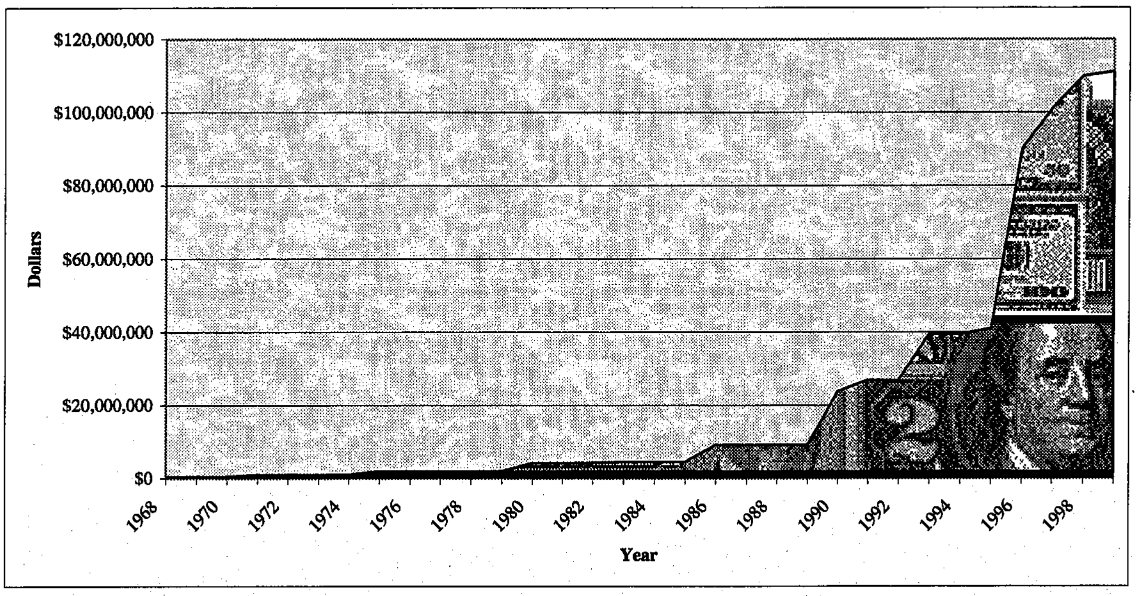


Figure 3. Cumulative dollars spent in South Carolina since 1968.

State and local sources have made up 45.8% of the funding with a contribution of about $51 million. Federal funding has provided for 45.0% of all nourishment costs in this state. Privately funded projects constitute the remaining 9.2% (Figure 4).

In the future, if the current trends of erosion and coastal population growth continue, the rate at which beaches are renourished may be expected to increase. It is possible that the distribution of funding will change over time depending on the political climate. In response to citizens' objections against paying to protect wealthy individuals' beach vacation homes, the Clinton administration considered pulling federal support out of beach renourishment projects altogether (The Daily Times, 1999). However, most recently the White House supported a congressional bill requiring coastal communities to pay 50% of the cost of nourishment (The Daily Times, 1999). Regardless of this support, the current administration has cut the availability of federal funds supporting beach nourishment so that a greater burden rests on state and local funding sources (Trembanis and Pilkey, 1998). Clinton's budget request for fiscal 2000 provided only $35 million for shore protection research and projects nationwide (The Daily Times, 1999). It appears that coastal states with erosion problems will need to allocate more funds toward beach stabilization than in the past. In South Carolina, a bill has been introduced in the state legislature to allocate $3 million annually for beach restoration purposes (Eiser, 1999b).

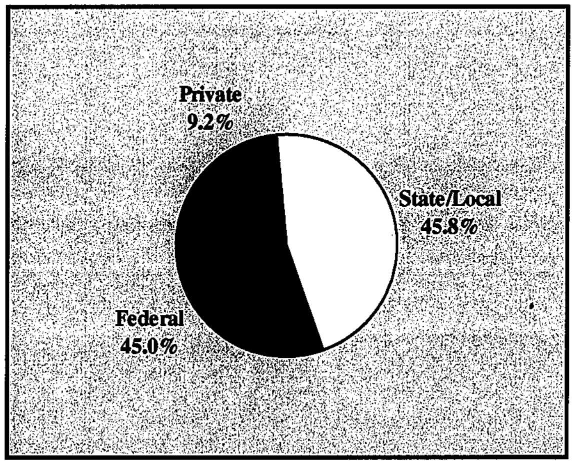


Figure 4. Funding sources of South Carolina nourishment projects based on percent of total dollars spent since 1954.

Beach Nourishment Project Evaluation

Although the use of beach nourishment has become widespread, considerable controversy surrounds this method of erosion control (NRC, 1995). Opinions range from vehement opposition to fervent support (NRC, 1995). Proponents view nourishment as a technically and economically sound alternative for managing an eroding shoreline when projects are well designed and implemented (NRC, 1995). Opponents consider nourishment a losing battle against the unbeatable force of the advancing sea (NRC, 1995). Often contenders see nourishment as throwing money into the ocean (Dean, 1989). Critics of beach renourishment have attacked design methodology, modeling techniques, performance prediction, monitoring, economic analyses, and construction procedures (Davison *et al.*, 1992). They argue that complex coastal processes are not well understood, hence models used to design projects are lacking vital information (NRC, 1995).

A contributing factor to this debate is a relatively poor understanding of project performance (Cooper, 1998). The lack of high quality monitoring data that includes the multiple parameters believed to influence beach fill performance has made it impossible to accurately gauge the relative success of most nourishment efforts in the U.S. (NRC, 1995). Most completed projects do not include sufficient pre- and post-nourishment monitoring to allow for objective project evaluation (Davison *et al.*, 1992). Many nourishment efforts lack any type of post-project monitoring, often there is only anecdotal or vague qualitative follow up (Clayton, 1989). For example, Leonard *et al.* (1990a,b) found that less than half of the 90 renourished beaches on the East Coast had enough monitoring data to be included in their evaluation of nourishment performance.

Those nourishment projects that do include post-project monitoring do not employ standardized monitoring, data analysis, presentation, procedures, or reporting periods (Stauble and Hoel, 1986). Some monitoring regimes have very closely spaced profile measurements; others may use an order of magnitude greater spacing (CSE, 1991, Olsen Associates, 1992). Some monitoring programs include profiles to wading depth, others may measure the profile to closure depth (depth beyond which sand is no longer available to the system). Some projects may only include monitoring within the project bounds, even if the nourishment is designed to spread over a greater length and "feed" other portions of the beach (CSE, 1991). In addition, other important parameters such as wave climate, grain size of fill material, and placement design may not be recorded at all (Leonard *et al.*, 1990a). Basic reputable data, such as time-series profile surveys are often difficult or impossible to obtain for evaluation purposes (Dixon and Pilkey, 1989). Without sufficient monitoring data, specifically, the same type and quality of monitoring data available for analysis, it is virtually impossible to accurately compare performance of beach nourishment projects.

Evaluation of project performance is made more difficult because objective criteria for measuring performance have not been established or accepted (NRC, 1995). The large number of interested parties makes discussion of, and agreement on appropriate evaluation criteria even more difficult (NRC, 1995). The purpose of a given beach nourishment project varies at each location and for each nourishment episode. Evaluation criteria appropriate at one site may not apply at another site (NRC, 1995). The NRC (1995) summarized a list of objectives, criteria for success, and measures of performance (Table 2). The list illustrates the subjective nature of project evaluation

(NRC, 1995). Although this list is a starting point, generic, quantitative criteria, have not been standardized even for those listed objectives (NRC, 1995).

Despite the lack of comprehensive monitoring data and agreed upon evaluation criteria, several summaries and analyses have been published that examine performance of nourishment projects on a regional and national scale (Pilkey and Clayton, 1989; Dixon and Pilkey, 1989; Leonard *et al.*, 1990a, b; Trembanis and Pilkey, 1998). The databases compiled for these research efforts established a relatively complete overview of the extent of beach nourishment as an erosion control device along the U.S. East and West Coasts and the Gulf of Mexico. Pilkey and Clayton (1989) summarized the U.S. East Coast replenishment experience. Leonard, *et al.* (1990a) analyzed performance of 43 of the 90 renourishment projects on East Coast barrier islands that had sufficient data to determine longevity or durability of the beach fill. Trembanis and Pilkey (1998) updated a previous summary (Dixon and Pilkey, 1989) of beach nourishment along the Gulf of Mexico. A similar comparison was made of nourishment projects on all three coastlines (Leonard, *et al.*, 1990b).

Databases for the U.S. Atlantic and Pacific Coasts, and Gulf of Mexico compiled information on the date, volume, length, cost, and funding source of each nourishment episode. In particular, Leonard *et al.* (1990b) assessed the success of 43 beach nourishment projects along the U.S. East Coast, the accuracy of predictions of fill retention time, and the effect of design parameters on project longevity. Using evaluation criteria criticized by others in the scientific and engineering communities, the researchers found that most beach nourishment projects have short lifespans, lasting less than five years (Leonard, *et al.*, 1990b; Davison *et al.*, 1992). In general, they surmised that with few exceptions, beach nourishment performance predictions were inaccurate and overestimated the longevity of the beach fill (Leonard *et al.*, 1990b). Parameters such as fill length, grain size, and emplacement method were found to have little impact on beach durability (Leonard *et al.*, 1990b). They found that the most important factor influencing the longevity of beach nourishment was storm activity (Leonard *et al.*, 1990b).

Table 2. Major objectives, criteria and approaches for evaluating beach nourishment projects and programs (NRC, 1995, p. 42).

Objective	Criteria for Success	Measures of Performance
Provide, enhance or maintain a recreational beach	A viable (acceptable width and carrying capacity) recreational asset during the beach-going season, usually expressed as dry berm width.	Period survey of beach width using quantifiable observation techniques. Assessment of a number of beach visits. Aerial photography useful.
Protect facilities from wave attack	Sufficient sand, gravel, or cobbles remaining in a configuration suitable to block or dissipate wave energy prior to its striking facilities. Protection possibly including hard structures in the solution.	Evaluation of structural and flooding damage following storms that do not exceed the limit for which the project was designed.
Maintain an intact dune or seawall system	No overtopping during a storm that does not exceed design and water-level and wave-height limits.	Verification of stabilization of the shoreline position.
Create, restore, or maintain beach habitat	Seasonal extremes in erosion not exceeding the design profile. Structures, if allowed, remaining intact. Post-fill erosion rates comparable to historical values.	Profile surveys to establish that the amount and configuration of the sediment meet or exceed the design profile.
Protect the environment	Sediment extent and condition and the vegetation of the back beach or dune meeting environmental needs.	Observations of habitat characteristics and condition.
Avoid long-term ecological changes in affected habitats	Return to pre-nourishment conditions within an acceptable time period.	Periodic monitoring of faunal assemblages of great concern.

The controversial conclusions of poor performance assessments are in direct conflict with design principles applied to most beach nourishment efforts in the past 20 years (Davison *et al.*, 1992). Members of the scientific and engineering community vigorously rebutted the findings of Leonard and others (Davison *et al.*, 1992). Primarily, Houston (1990) questioned the methodology and evaluation criteria of Leonard. Further, he argued that the definition of beach fill durability (loss of 50% of the fill) is actually a measurement of project half-life rather than total life (Houston, 1991). Profile measurements taken during the equilibration period led to erroneous calculations of pre- and post-nourishment erosion rates in the Leonard *et al.* study, hence conclusions drawn from their research were flawed (Houston, 1990). Houston (1991) also pointed out that some projects are designed with an initial, large-volume beach restoration to be followed by smaller nourishments at 3 to 4 year intervals. As such, those projects were assigned a lifespan of less than 5 years (Leonard *et al.*, 1990a) when in reality the beaches were designed to be renourished frequently (Houston, 1991).

Other conflicting assessments of project performance further highlight the problems inherent in nourishment evaluation (Davison *et al.*, 1992). The National Research Council (NRC, 1990) found that the 1980 Indialantic beach nourishment in Florida was unsuccessful because over half of the fill material was lost alongshore in the first three months. In contrast, Stauble and Holem (1991) conducted detailed monitoring over a seven-year period. The long-term performance evaluation found the project a success when a large storm in 1984 caused no dune scarping (Stauble and Holem, 1991). Clearly, the objective assessment of project performance is only possible if high quality monitoring data are available and evaluated using commonly agreed upon criteria of success and failure (Stauble and Hoel, 1986; Davison *et al.*, 1992; NRC, 1995).

There is considerable controversy surrounding the practice of beach nourishment due in large part to a lack of understanding of project performance. Performance is not well understood because projects have not been carefully monitored. Lack of data has made objective, quantitative assessment of many projects impossible. Secondly, there are no standardized criteria with which to measure project success or failure. Quantitative criteria such as a loss of 50% of fill material are disputed or unclear. Qualitative criteria such as those presented by the NRC (1995) are subjective in nature. To apply these criteria, a clear statement of objectives must be made in advance of the project, then the nourishment must be carefully monitored to determine if and for how long the objective(s) were met. Lastly, performance predictions have become intertwined with performance evaluation. Although models are used to design projects, predicted performance does not always match actual performance.

Overview of Predictive Models

A second issue of mounting concern has been actual versus predicted performance (Morris, 1991). Predictive models attempt to forecast beach fill behavior in response to complex hydrodynamic forces (Cooper, 1998). Performance predictions have not always been accurate (Pilkey and Clayton, 1989; Leonard *et al.*, 1990a,b). Failure of actual performance to match predicted performance has generated a lack of confidence in nourishment design procedures and an overall perception of project failure (Davison *et al.*, 1992).

Numerous attempts have been made to model and predict nourishment performance. The use of numerical models in the design and implementation of beach nourishment projects has become standard practice for the USACE (NRC, 1995). Application of computer models that simulate processes of longshore transport incorporate equations relating sediment movement to nearshore waves and currents. The generalized model for simulating shoreline change, known as GENESIS, was developed by the USACE for use in the design and performance predictions of beach nourishment projects. GENESIS calculates wave and alongshore sediment transport patterns, then determines the resulting shoreline changes (NRC, 1995).

Dean and Yoo (1992) present two numerical methods, one simple and one detailed, for calculating shoreline evolution following nourishment. Both methods fall within the category of one-line shoreline models in which the active profile is displaced seaward or landward without change in form. Their model represents wave refraction and shoaling in the vicinity of the nourished area and can include influences of beach stabilization structures such as groins. Their test cases showed that results derived by the simple method correspond well with those of the detailed method and required a fraction of the computing time. However, most of their test cases did not take into account historic background erosion rates, which can be a significant site-specific factor in the longevity and performance of individual nourishment projects (Dean and Yoo, 1992).

Führböter (1991) and Verhagen (1996) have derived formulae to express volumetric decay of a nourished beach with respect to time. Führböter's model results in an exponential decay in fill volume and assumes a stable coastline with sediment losses occurring only in the longshore direction and "adaptation losses" in the cross-shore direction. In this model the erosion rate may be assumed to be a linear function of fill material migrating seaward. Verhagen's model incorporates an additional component relating to the linear background erosion rate of the coastline. Verhagen applied his model to eight nourishment projects in Germany and the Netherlands. He found that the mathematical description fit well with the observed decay of those nourishment projects. He also noted that loss in the first year varied from 1–25%, and depended on the method of construction as well as the closure depth for volumetric analysis.

Cooper (1998) pointed out that data sets used by Verhagen for model verification only ranged from 3 to 6 years in duration. As an additional test of the models, Cooper applied both the Führböter and Verhagen formulae to nourishments in Poole Bay, England. He found that the Verhagen model provided better representation of the slower rates of decline than the Führböter model because it incorporated the linear background erosion rate. Cooper (1998) suggested a two-phase linear decay rate with rapid loss occurring during profile adjustment and slower loss occurring after the adjustment period. The two-phase model prediction was found to fit the actual erosion rate better than either the Führböter or Verhagen models (Cooper, 1998).

Work and Dean (1995) developed and tested numerical models for planform and profile evolution of the 1989-90 nourishment of Perdido Key, Florida. This approach investigated longshore and cross-shore sediment transport processes separately then addressed the relative importance of each over time and space. Their results indicated that beach planform evolution was influenced by longshore gradients of longshore sediment transport, especially at the "shoulders" or ends of the project, but verification was limited by a lack of detailed wave data (Work and Dean, 1995). Cross-shore sediment transport was found to be important at water depths greater than those influenced by longshore sediment transport. Their modified profile-response model yielded good results immediately following nourishment but poorer results as the beach profile adjusted to a more natural configuration. They concluded that the coupling of longshore sediment transport and cross-shore processes is necessary for assessment of three-dimensional changes in the littoral zone.

Objectives of this Study

The objectives of this research were to review historical nourishment activities in South Carolina; to identify selected projects that had sufficient data available to perform analyses using Geographic Information System (GIS) methodologies; to analyze change in shoreline volume and width within each project area using the GIS system; and to compare the results derived from the GIS analysis with more traditional measures of shoreline change.

METHODS

Study Area

The central and southern South Carolina coast is characterized as a mesotidal shoreline (6 – 12 foot tidal range) with broad wet-sand beaches and narrow dry-sand beaches (Kana, 1993). Short, drumstick shaped islands, numerous tidal inlets, extensive salt marshes, and ebb-tidal deltas characterize this segment of the South Carolina shoreline.

Three renourished beaches along the South Carolina coast comprise the study area: Hunting Island, Edisto Island, and Hilton Head Island (Figure 5). These three islands were chosen for study because they have undergone renourishment at least once since 1990 and sufficient field monitoring data are available following nourishment to provide a time series of profile measurements. In addition, monitoring of these nourishment projects often included a high density of profiles which is conducive to digital elevation modeling. Although other beaches (Folly Island, Debidue Island, Seabrook Island, and Myrtle Beach) were nourished and monitored within this time frame, these data were not available for this study. Each of the study locations is described in more detail below.

Data Acquisition

Published and unpublished beach surveys for each island were obtained in order to measure volumetric change following nourishment. Where possible, monitoring surveys conducted by the contractor specifically for performance evaluation were acquired. Historical profile surveys were provided by the South Carolina Department of Health and Environmental Control, Office of Ocean and Coastal Resource Management (OCRM) and Coastal Carolina University (CCU). Digital planimetric base maps were also provided for each island by OCRM. Base maps were digitized by Westinghouse from 1993 orthophotographs for OCRM and included such features as building footprints, roads, seawalls, groins, revetments, baseline, setback line, and the water line at the time the aerial photograph was taken. Coordinates and elevations of beach monitoring (base) stations were provided by OCRM. Monitoring reports were obtained from OCRM to confirm nourishment boundaries and survey limits. Coastal Science and Engineering (CSE)-Baird, Inc. provided monitoring data for the Hunting Island and Edisto Island nourishment projects on 3½-inch floppy disks. Olsen Associates, Inc. provided monitoring surveys for the Hilton Head Island nourishment via email attachment. Data from each contractor included base station coordinates. The NOAA Coastal Services Center (CSC) provided 1997 laser topographic altimetry (LIDAR) data as reference elevations to aid in interpolation.

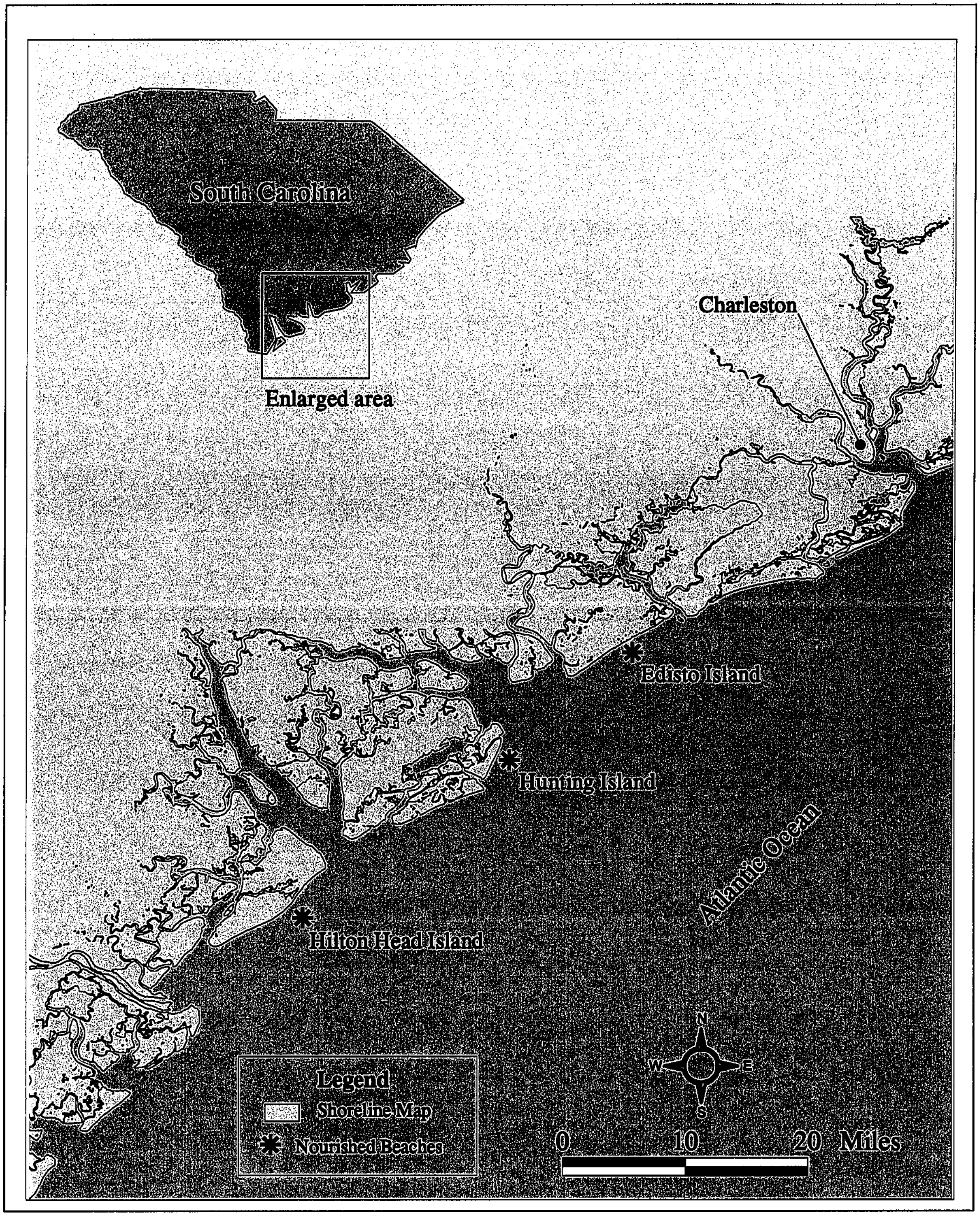


Figure 5. Map of study area with location of three renourished beaches.

General Data Processing

All beach profile data were processed using ARC/INFO (Environmental Systems Research Institute, Version 7.2) on a SUN SPARC 5 and SUN Ultra60. ArcView® versions 3.0b and 3.1 were used to enter data and create spatially referenced graphic displays. Survey profiles were provided for each station with distance measurements from the base station and elevation at that location. Elevation data were first organized in an Excel spreadsheet by date and station. All profiles for a given survey date were concatenated to one file and saved in Dbase-IV format. ARC/INFO command <DBASEINFO> was used to convert the Dbase-IV file to an INFO file.

Dynamic segmentation, a linear data model provided in ARC/INFO, was used to convert profile elevation measurements to geographically referenced point coverages (ESRI, 1998). Dynamic segmentation uses linear measure values to define locations along linear features (ESRI, 1998). Beginning with a digitized base map constructed from 1993 orthophotographs as a reference, shore-normal lines originating from each station were created in ArcView as a shapefile. The line shapefile was converted to a line coverage in ARC/INFO. Lines served as routes in the dynamic segmentation process. Each line was snapped to its corresponding base station to ensure a direct match. Data provided in the surveys consisted of distance from a specified station and elevation at that point. In this case, elevation measurements served as point events. Point events were referenced to a location on the route using a single measure value, the distance from the station following the method outlined by ESRI (1998).

Point coverages for each survey date were used to create an estimated beach surface. A Triangulated Irregular Network (TIN) was generated for each survey date (Figure 6). A TIN consists of a set of adjacent non-overlapping triangles computed from irregularly spaced points (ESRI, 1991). The TIN triangulation method ensures that all sample points are connected with their two nearest neighbors to form triangles. This data structure allows generation of continuous surface models for the analysis and display of topography. The command <DESCRIBETIN> was used to verify each TIN model.

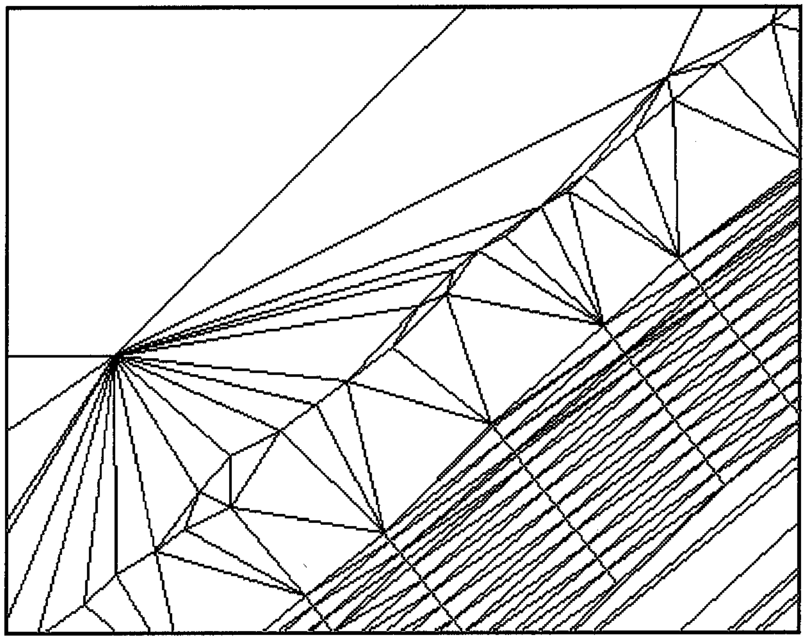


Figure 6. Sample portion of a TIN.

The <TINLATTICE> {linear} command was used to interpolate z values from the TIN. Each TIN surface was converted to a floating point GRID, a data model that allows accurate representation of continuous surfaces (ESRI, 1991). A GRID stores data, (i.e. elevation measurements) in a raster, or cell-based format where each cell represents the elevation within that area. A cell size of 2 feet by 2 feet was used for analysis of the Hunting Island renourishment project in order to achieve high resolution. This cell size was possible due to the relatively small project area. . For the Edisto and Hilton Head projects a cell size of 5 feet by 5 feet was applied. This cell size maintained the resolution while conserving computer disk space. Boundary coordinates of each GRID were compared. GRIDs were resampled to the smallest area's bounding coordinates using the <LATTICERESAMPLE> command so that all GRIDs were coincident.

The general steps outlined above were followed to create digital elevation models (DEMs) of the beach and nearshore surfaces within the project boundaries for each subsequent survey period. Project boundaries were provided in survey reports prepared by CSE for the Hunting Island and Edisto Island projects (CSE, 1991, 1995). Project boundaries for the Hilton Head Island project were obtained from survey reports compiled by Olsen Associates (1992). Using the resampled GRIDs, the command <CUTFILL> was applied to each survey and to subsequent surveys. The CUTFILL operation produces a summary file including the cut volume (loss), fill volume (gain), balance volume (loss - gain), total area cut, filled, graded, not graded, and total area used in the analysis. Analysis of the volumetric change between immediate pre- and post-construction surveys indicated volume of sediment placed on the beach during nourishment efforts. This calculation was compared to the volume of nourishment sand added to the beach as reported by the contractor. Subsequent surveys were used to calculate changes in sediment volume from survey to survey.

Beach Renourishment Project Performance Evaluation

As mentioned previously, there are no standard criteria for performance evaluation (NRC, 1995). Therefore, for the purpose of this study two performance criteria were determined and applied. The first criterion was longevity of beach fill as defined by Leonard *et al.* (1990b). Specifically, the time required for 50% or more volumetric loss of fill material was used as a conservative measure of the durability of each project (Leonard *et al.*, 1990b). Volumetric change was calculated between subsequent surveys. The pre-nourishment beach surface was considered zero so that the difference between pre- and post-nourishment calculated the fill volume. The difference between post-nourishment and survey 1 (time 0-time 1), survey 1 and survey 2 (time 1-time 2), and so on, allowed calculations of volume change from survey to survey. Cumulative volume over time was also calculated by adding gain or subtracting loss to the previous balance. Cumulative percent change was calculated for each survey date. Project lifespan was then categorized in one of three groups: lifespan of 1 year or less; lifespan of 1 to 5 years; or greater than 5 years (Leonard *et al.*, 1990b).

The second criterion used to assess the performance of each nourishment project was longevity of beach fill as defined by Houston (1998). Life of a fill is defined as the length of time until the beach width is such that it will not provide a sufficient level of flood protection or has reached a width deemed too short for the desired recreation (Houston, 1998). This definition was standardized to incorporate OCRM's definition of a "healthy" beach. A healthy beach has a width of 25 feet or more seaward of the dune at an elevation of 7 feet above mean sea level (Eiser, 1999b). Each survey DEM was queried to find the 7-foot contour. Beach width was measured from the 7-foot contour landward to the edge of the data set or monitoring station, which ever came first. Beach width at each monitoring station was measured along the entire project length and the average calculated. When the average beach width reached 25 feet or less, the life of the project was considered complete.

HUNTING ISLAND

Background

Hunting Island is located in Beaufort County. The beach is 4.3 miles long and bounded to the north by Johnson Creek and to the south by Fripp Inlet. The island is preserved as a state park and is undeveloped aside from a few private cabins and the park's visitor center and facilities.

Hunting Island has a long history of rapid erosion. In 1872, the Hunting Island lighthouse, designed to be portable, was moved a mile inland to its current location when a storm washed away the sand from around its base (News and Courier, 1989). In tandem with a rapid erosion rate, the island has a long history of nourishment (Table 1). The first effort was conducted in 1968 followed by subsequent nourishments in 1971, 1975, and 1980 (CSE, 1995). Collectively, over 3.5 million cubic yards of sand were placed on the beach at a cost of $4.2 million (CSE, 1995). The four projects were completed by the USACE under federal authorization that dated back to 1964 and expired in 1984 (CSE, 1991).

Hunting Island 1991 Nourishment Project

The fifth Hunting Island beach renourishment project was completed on 24 March 1991 after 44 days of pumping sand from an offshore borrow site (CSE, 1992a). The consulting firm, Coastal Science and Engineering, Inc. (CSE) designed, implemented, and monitored the project. Sediment was placed by the contractor, Great Lakes Dredge and Dock Company, by hydraulic dredge along a 7,500-foot reach in the center of

Hunting Island (CSE, 1992a). Placement of the fill was concentrated on North Beach and South Beach, the two primary recreational areas on Hunting Island (Figure 7) (CSE, 1995). Beach fill produced a 100- to 200-foot-wide berm at about the +7 foot NGVD elevation with a slope similar to the pre-nourishment beach slope (CSE, 1993b). Following nourishment, final surveys of the beach and foreshore determined the in-place volume of sediment was 715,766 cubic yards (CSE, 1995).

CSE monitored the project performance for four years. Profile data were available for February 1991 (pre-nourishment), March 1991 (post-nourishment), November 1992, April 1993, and 1994, and May 1995. Profile spacing was at approximately 200-foot intervals within the project area. Shore-perpendicular surveys were made using conventional rod-and-level techniques, and measured from known points (stations) along the beach (CSE, 1992a). CSE established horizontal control for each profile using temporary baselines related to OCRM monuments and CSE nourishment project markers spaced at 500-foot intervals (CSE, 1995). Permanent OCRM monuments (1800 series) are spaced at approximately 2,000-foot intervals. Horizontal coordinates for all survey stations were established in the North American Datum of 1983 (NAD83). Surveys extended approximately 1,000 feet offshore to -10 to -12 feet mean sea level (M.S.L.) and the estimated closure depth was determined by the presence of mud accumulations at the seaward terminus of the transects (CSE, 1991). Elevation measurements were established in the National Geodetic Vertical Datum of 1929 (NGVD29).

CSE computed volumetric changes using CSE's beach profile analysis system (BPAS). Changes in the area under sequential profiles at each station were computed, then converted to an equivalent volume per foot of shoreline. Results for each station were then extrapolated over a representative shore length by the average end area method (CSE, 1991). Standard limits for computing volume change after nourishment were the uppermost beach contour or backshore scarp (typically at elevation 7 to 8 feet NGVD) and the -11.5 feet NGVD contour. The design called for extra sand to be placed along North Beach and South Beach to serve as feeders to adjacent areas and to extend the life of the project in these two prime recreation regions.

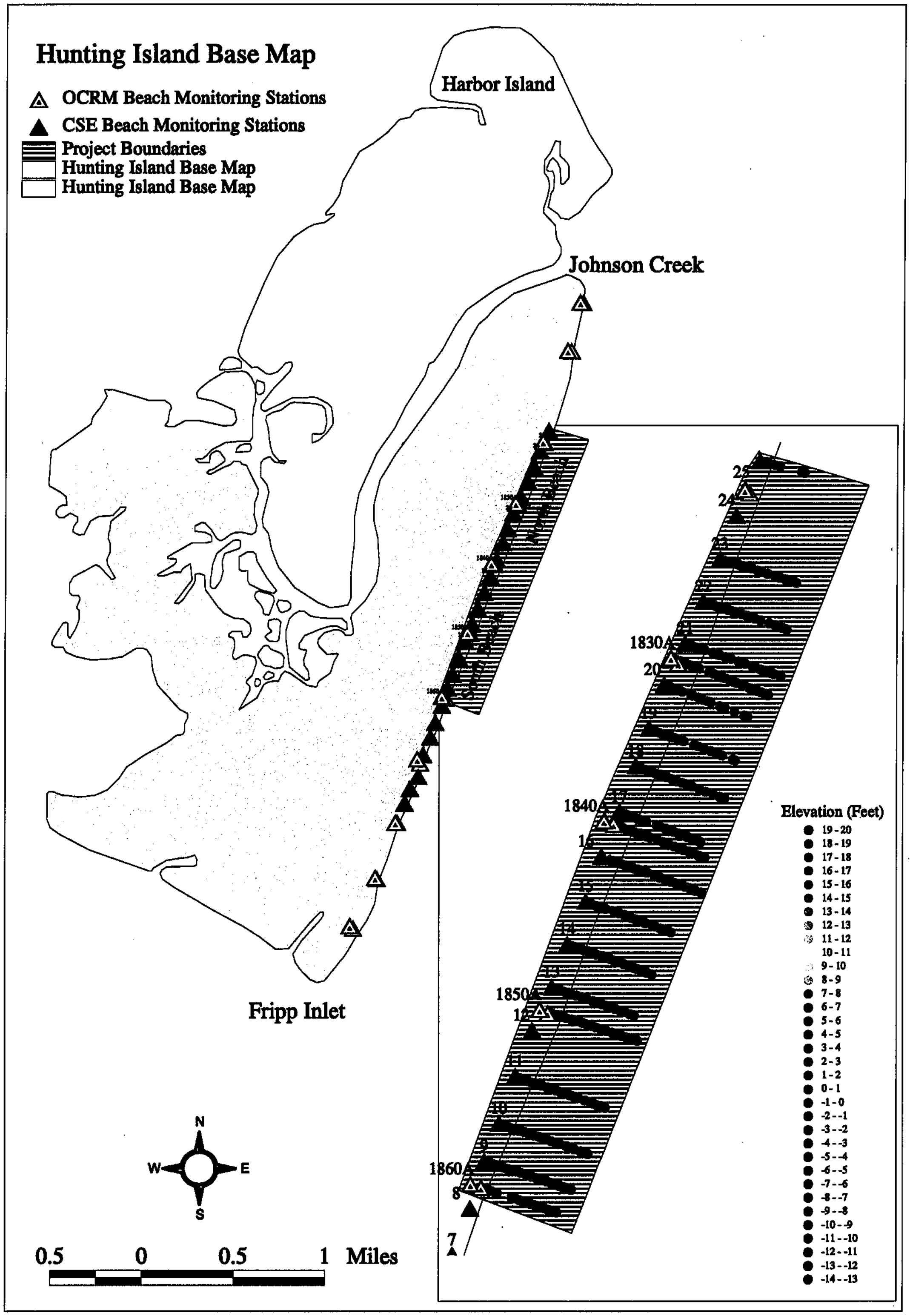


Figure 7. Hunting Island base map.

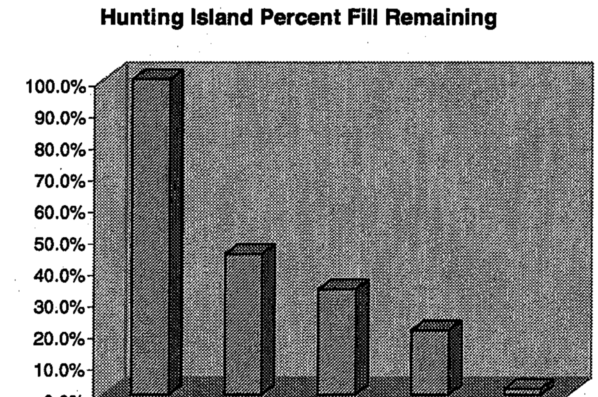
Hunting Island 1991 Nourishment: Results

Comparison of pre- and post-construction surveys indicates a net gain of 677,672 cubic yards within the project area (Table 3). This estimate was slightly lower than the estimate of 681,974 cubic yards in-place volume on the beach and foreshore made by CSE (CSE, 1995). There are several possible explanations for the difference. Following the February 1991 survey some sand may have been lost prior to, or during, the nourishment process. This volume would have been unaccounted for in the pre-nourishment survey. The GIS method involves an interpolated rather than extrapolated surface and may more closely reflect the surface of the beach and nearshore topography. The area interpolated in the GIS model may vary slightly from that analyzed by CSE. Although there is a difference of 4,302 cubic yards between the two estimates, this amounts to only 0.6% of the total volume added in the nourishment effort using either estimate (Table 4).

Table 3. Volumetric change calculations for the 1991 Hunting Island beach nourishment.

Survey Dates	02/91-03/91	04/91-11/92	11/92-04/93	04/93-04/94	04/94-05/95
Time from Previous	Pre- & Post-Surveys	19 months	5 months	12 months	13 months
Net Gain/Loss (cy)	677,672	-375,761	-75,031	-88,614	-125,089
	Mar-91	Nov-92	Apr-93	Apr-94	May-95
Volume Remaining (cy)	677,672	301,911	226,880	138,266	13,176
Percent Remaining	100.0%	44.6%	33.5%	20.4%	1.9%
Percent Rate of Change	100.0%	-55.4%	-11.1%	-13.1%	-18.5%
Percent Cumulative Change	100.0%	-55.4%	-66.5%	-79.6%	-98.1%

By November 1992, 19 months after the nourishment was completed, a total of 375,761 cubic yards of sand had been lost within the project limits which accounts for a loss of over 55% of the original fill volume. CSE estimated a loss of 319,968 cubic yards or 47% loss for the same time period (CSE, 1995). Explanations for the difference in the results are similar to those previously stated. The greatest rate of erosion occurred in those areas that had received an increased volume of sediment during the nourishment. For example, examination of the difference grid (Figure 9) shows an average loss of 6 feet in elevation where 7 feet had been gained during the nourishment. It appears that some fill migrated to, and filled in, a topographic low in the nearshore zone along North Beach (Figure 9). CSE's 1992 survey report indicated that all the fill material within the project area would be eroded in 2 to 3 years (CSE, 1992a).



	Mar-91	Nov-92	Apr-93	Apr-94	May-95
Percent	100.0%	44.6%	33.5%	20.4%	1.9%

Figure 8. Percent fill material remaining within the project area. March 1991 corresponds to the completion of the nourishment project

By April 1993, two years after nourishment, the project area had lost 66.5% of the original volume of sand added to the beach, an additional net loss of 75,031 cubic yards (Table 3). Material within the project area appeared to have been transported offshore as the beach profile reached equilibrium. This trend in sand depletion continued for the next two years. By spring 1995, 98.1% of the fill material had been lost from the project area (Figure 8).

Subsequent estimates of fill volume remaining within the project area were compared (Table 4). Percent fill remaining was calculated based on both the contractor's volume estimates and estimates derived using the GIS method. Results of the two calculation methods were similar. The greatest difference between the estimated percent remaining was 8.5%. As mentioned earlier, a possible explanation for these differences is that the GIS method used a consistent area for each calculation while the contractor may have adjusted the calculation area based on variable profile lengths. Since the exact analysis bounds used by CSE are not known, it is not possible to reproduce the contractor's results exactly. Regardless of the absolute differences, both calculation methods show the same pattern of loss of the fill material.

Table 4. Comparison of volumetric change results using two calculation methods.

	Traditional method used by contractor (CSE, 1995)		GIS method			
Date	Volume Remaining (cy)	% Remaining	Volume Remaining (cy)	% Remaining	Difference (cy)	% Difference
March 1991	681,974	100.0%	677,672	100.0%	4,302	N/A
November 1992	362,006	53.1%	301,911	44.6%	60,095	8.5%
April 1993	279,326	41.0%	226,880	33.5%	52,446	7.5%
April 1994	180,040	26.4%	138,266	20.4%	41,774	6.0%
May 1995	47,234	6.9%	13,176	1.9%	34,058	5.0%

Average beach width at or above the 7-foot contour was examined. The average initial beach width was 31 feet prior to nourishment as compared to a post-nourishment beach width of 69 feet (Table 5). Subsequent surveys show a systematic decrease in average beach width. By May 1995 the average beach width had returned to its pre-nourishment condition. Note that along several surveys (Stations 13, 14, 15, 17, and 18) the beach width reaches zero by April 1993. These areas may be an indication of erosional hot spots.

Hunting Island 1991 Nourishment: Discussion

Performance was evaluated using criteria mentioned earlier. The first criterion, measurement of longevity based on volumetric change, indicates that the Hunting Island nourishment had a lifespan of 19 months. By this time, over 50% of the fill material had been lost from the project area. Under this criterion, the longevity of the project fell into the second category of 1 to 5 years.

Table 5. Beach width in feet at the 7-foot contour and above within the project limits on Hunting Island.

STATION	Feb-91	Mar-91	Nov-92	Apr-93	Apr-94	May-95
1860A	4	0	81	77	78	71
9	2	0	0	0	0	0
10	2	0	10	0	0	0
11	7	0	15	0	0	0
12	38	46	48	47	41	34
1850A	40	60	101	80	78	56
13	21	22	44	0	0	0
14	39	15	1	0	0	0
15	44	51	25	0	0	0
16	110	104	136	116	122	112
1840A	50	49	70	112	119	105
17	62	66	24	0	0	0
18	48	60	48	0	22	0
19	29	126	70	44	35	13
20	12	170	64	70	60	22
1830A	72	211	115	170	182	114
21	0	155	80	54	64	34
22	0	112	69	83	65	33
23	0	65	50	54	41	0
Average Beach Width (feet)	31	69	55	48	48	31

Evaluation using the second criterion, measurement of average beach width, indicates that the Hunting Island project was still viable by the last survey in May 1995. Although the average width was greater than OCRM's definition of a healthy beach, the beach had essentially returned to its pre-nourishment condition. At several monitoring stations the beach width had decreased to zero feet, and attained a condition worse than existed prior to nourishment.

Difference grids or change maps illustrate movement of fill material. The change from February 1991 to March 1991 clearly shows a substantial gain in elevation, particularly along the landward edge of the project limits where fill material was deposited (Figure 9). Two sediment lobes of higher elevation can be detected in darker green along the landward edge of the project limits which corresponds to the project design plan (CSE, 1992a). In addition, an area of sediment loss appeared as a depression on the seaward side (seen in yellow). This loss occurred at some time during the emplacement of the fill material and may be the result of initial scouring due to the presence of a steeper beachface created by the emplacement of the artificial berm.

The next difference grid (Figure 9) depicts the change occurring from the immediate post-nourishment survey to November 1992, a time lapse of 19 months. It is clear that the greatest loss in elevation occurred between the two fill lobes with in-filling of the depression in the nearshore zone. This change may be indicative of profile equilibration as the waves redistribute the sediment (fill) to fill in the low tide erosional profile.

The following two change maps (Figure 10) generally portray continued loss of fill material on the landward side and deposition along the seaward side of the project area. The April 1993 to April 1994 difference grid does show some slight gain in elevation along the landward edge of the project area, but the gain is on the order of ½ foot.

The last difference grid (Figure 11) shows the change from April 1994 to May 1995 and follows a similar pattern as previous change maps. However, it appears that fill material may have been dispersed alongshore as indicated by two elevated areas at either end of the grid. This gain in elevation may be the result of sediment transport by longshore currents.

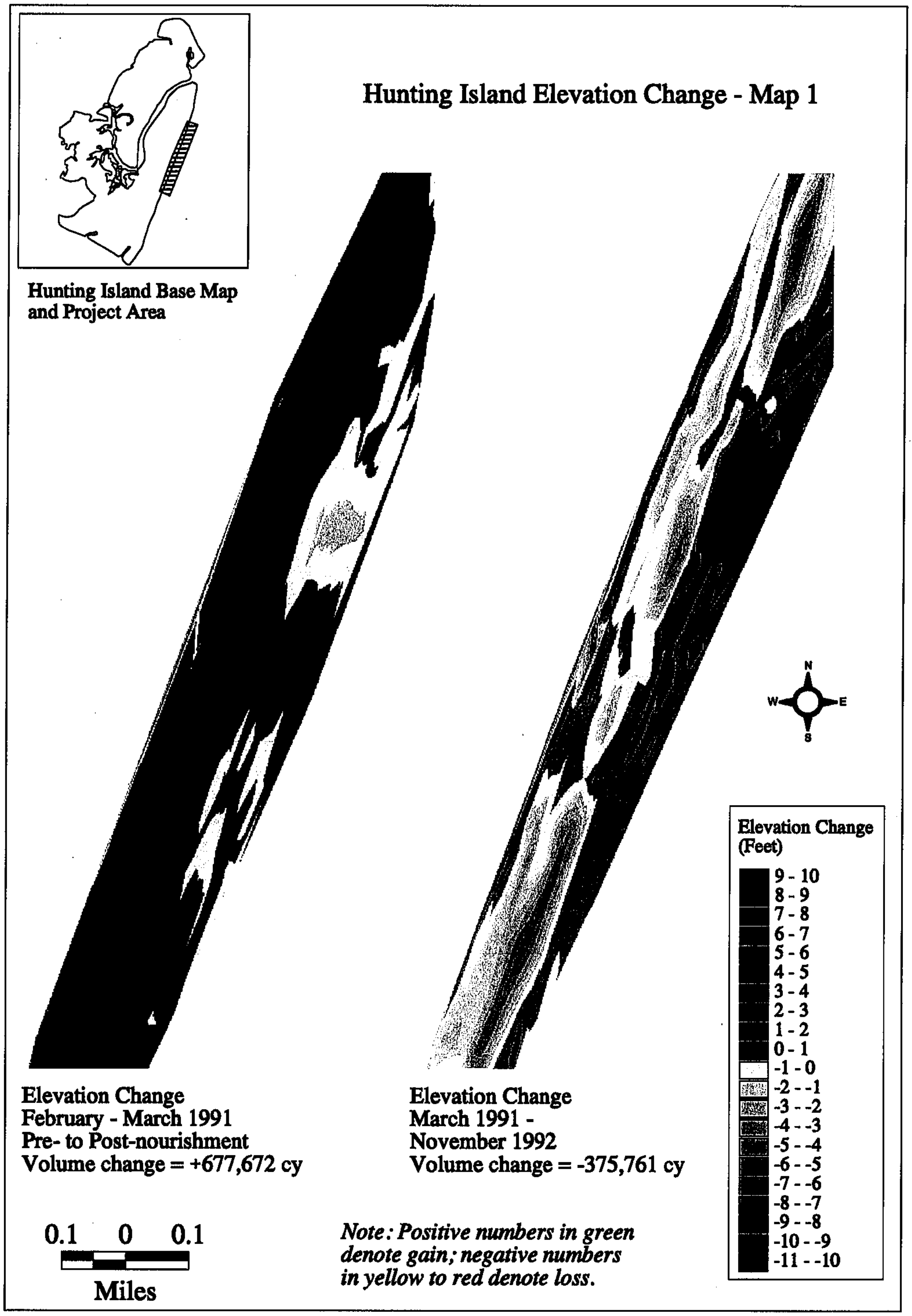


Figure 9. Elevation change (1) and volumetric calculations for Hunting Island.

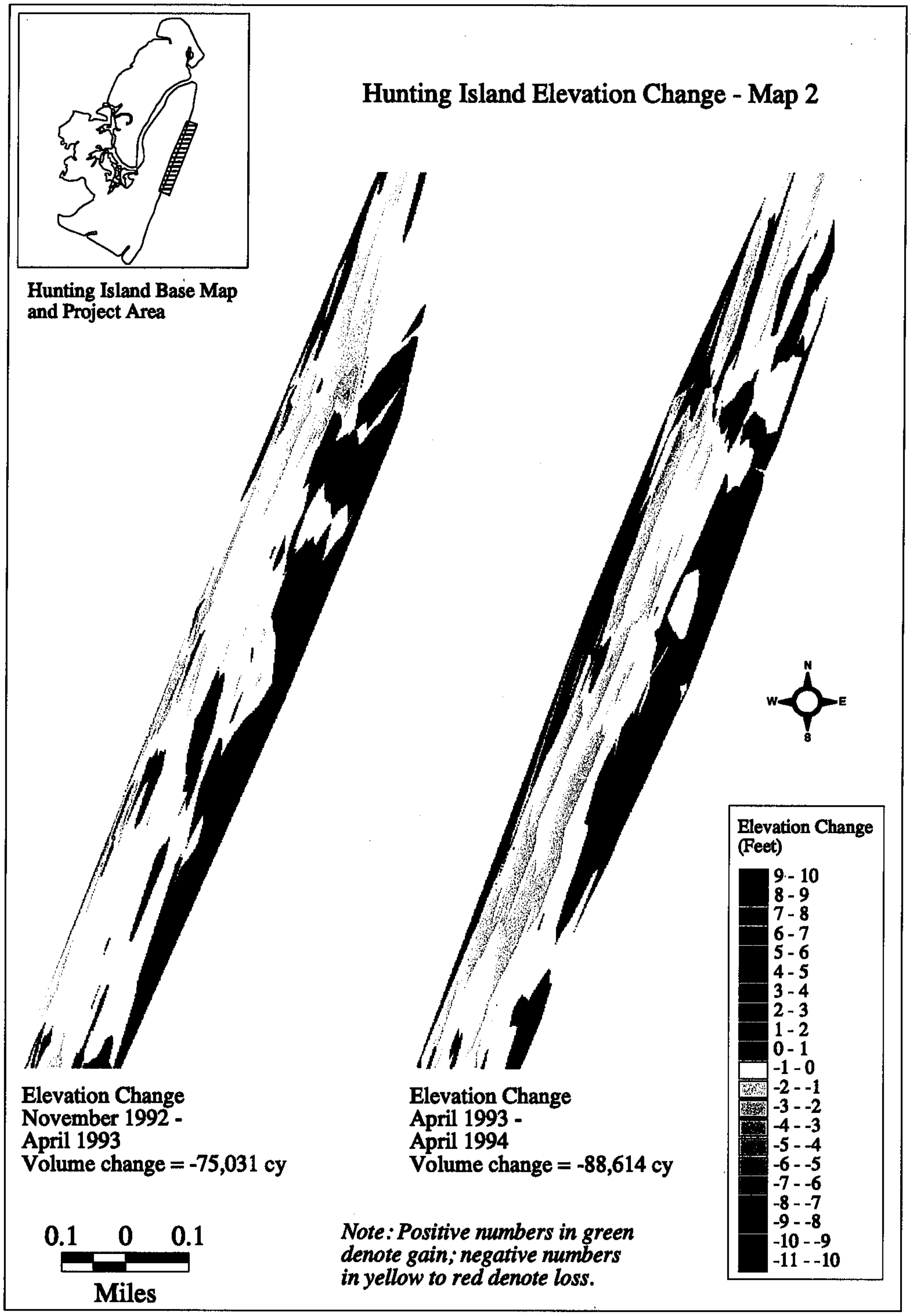


Figure 10. Elevation change (2) and volumetric calculations for Hunting Island.

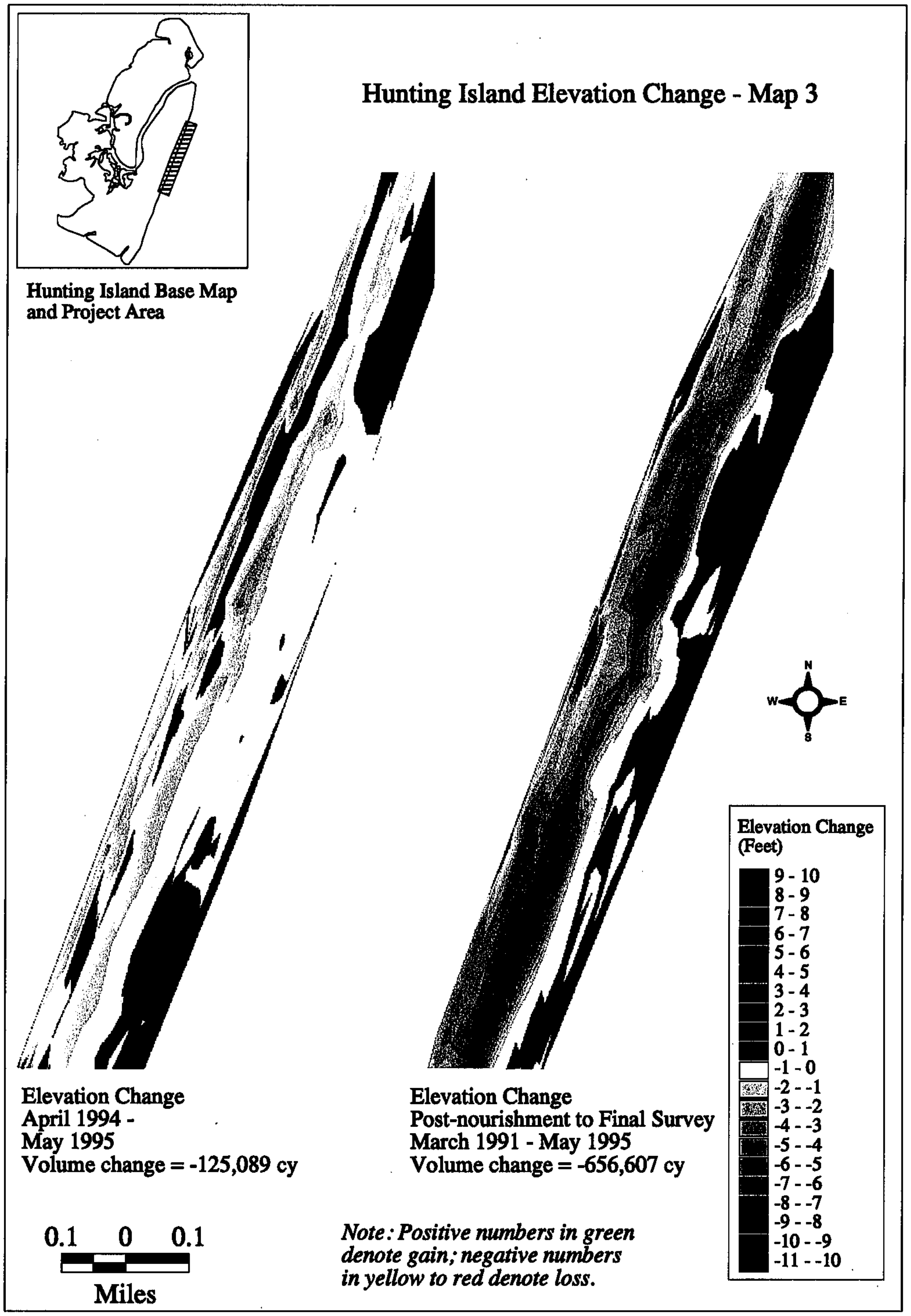


Figure 11. Elevation change (3) and volumetric calculations for Hunting Island.

EDISTO ISLAND

Background

Edisto Island is located in Colleton County. The barrier island is 4.4 miles long and is separated from the mainland by Scott Creek and bounded to the north by Jeremy Inlet and to the south by the South Edisto River. The northern 1.3 miles of shoreline is a state park and undeveloped; the rest of the shoreline is part of the Town of Edisto beach.

Available shoreline change data dating back to the 1800s reveals a long history of shoreline erosion (CSE, 1993a). Erosion became so severe in the late 1940s, that portions of the coastal road had been undermined (CSE, 1993a). In 1948, in response to the problem, the South Carolina Department of Highways and Public Transportation began constructing a groin field in an attempt to curtail erosion. Over the course of the next 30 years, additional groins were added. The first 23 groins were made of timber and sheet-pile. Later groins were constructed of quarry stone. Thirty-four groins were in place by February 1993. As the groins have aged, the sediment trapping capability of the groins have changed due to the deterioration of timber sections and displacement or settling of quarry stones. Ongoing processes continue to modify the effects of the groins as the effective lengths and permeability changes (CSE, 1993a).

In 1954 Edisto Island was the first beach to be renourished in the state of South Carolina. Approximately 830,000 cubic yards of fill material was dredged from Scott Creek and placed between groins 3 through 12, a distance of 5,350 feet (CSE, 1993a). It is estimated that the beach retained a small portion of the sand added in 1954 for as long as 26 years (Cubit, 1981).

Edisto Beach 1995 Nourishment Project

CSE designed, conducted, and monitored the most recent 1995 renourishment project. Weeks Marine, Inc. completed the project with assistance from Great Lakes Dredge and Dock Co., Inc., and WestBank Construction, Inc. (CSE-Baird, 1996a). Original plans called for 112,000 cubic yards of sand to be pumped by hydraulic dredge from an ebb-tidal shoal off the south end of Edisto Island. This amount was later reduced to 101,000 cubic yards to remain within the town's budget. Sand pumping began on April 24 and ended on April 30. Fill was stockpiled between groins 13 and 15, at the southern end of the large nourished area, then hauled by truck to fill individual groin compartments along 12,000 feet of beach. Distribution of the fill material proceeded from south to north. In some cases, northern groin compartments were filled concurrently with southerly cells to accelerate construction. Sand hauling was completed on May 14 and final grading was finished on May 15. The project consisted of three reaches; Reach 1 included groin cells 1 through 10; Reach 2, groin cells 11 through 16; and Reach 3, at the southern tip of the island, included groin cells 24 to 28. Reaches 1 and 2 were treated as one continuous stretch (Figure 12).

Weeks Marine, Inc. conducted pre- and post-nourishment surveys and determined that nearly 150,000 cubic yards of sand had been placed in the designated cells (CSE-Baird, 1996a). This amount was substantially more than the volume (~49,000 cubic yards) called for in the contract. CSE-Baird was contracted to monitor performance of the nourishment effort. Surveys were available for April 1995 (pre-nourishment), May 1995 (post-nourishment), July 1995, January 1996, May 1996, and July 1997. Permanent OCRM survey monuments (2100 series) were supplemented with additional monuments and control points (Figure 11 - base map with labeled benchmarks). Three survey transects were established in each groin cell (Weeks Marine used 5 transect lines per groin cell for the pre- and post-nourishment surveys) at a spacing of approximately 200 feet (CSE-Baird, 1996a).

Surveys were performed by traditional rod and level methods and extended from the backshore (or road) to approximately –7 feet NGVD or deeper (CSE-Baird, 1996b). Comparative volume changes were calculated using the average area end method. Volume changes at each profile line were extrapolated to the next transect line to determine net volume change for each groin cell (CSE-Baird, 1996a). Horizontal coordinates were established in NAD83; vertical elevation measurements were established in NGVD29.

Edisto Beach 1995 Nourishment: Elevation Data Processing

All Edisto Island profile data provided by CSE-Baird were processed in the same manner as the Hunting Island data with several exceptions. Additional steps were required to generate realistic beach surfaces for Edisto Island. Initial TIN creation resulted in anomalous triangular features along the landward side of the project boundary. The triangles were coincident with the profiles. Several factors contributed to poor interpolation. Because there were no data landward of the first measurement, the triangulation routine made erroneous "assumptions" about the progression of the elevation trends. In addition the total span of data encompassed the entire beachfront. The TIN process attempted to fill in the area between and landward of the extreme endpoints of the survey points.

Several methods were tested in an attempt to correct the problem. The final solution made use of 1997 LIDAR data provided by the NOAA Coastal Services Center. Elevation measurements located inland on the shore parallel road were assumed to be of constant elevation through time. These elevation measurements contributed reference points and the interpolation was able to produce realistic beach surfaces.

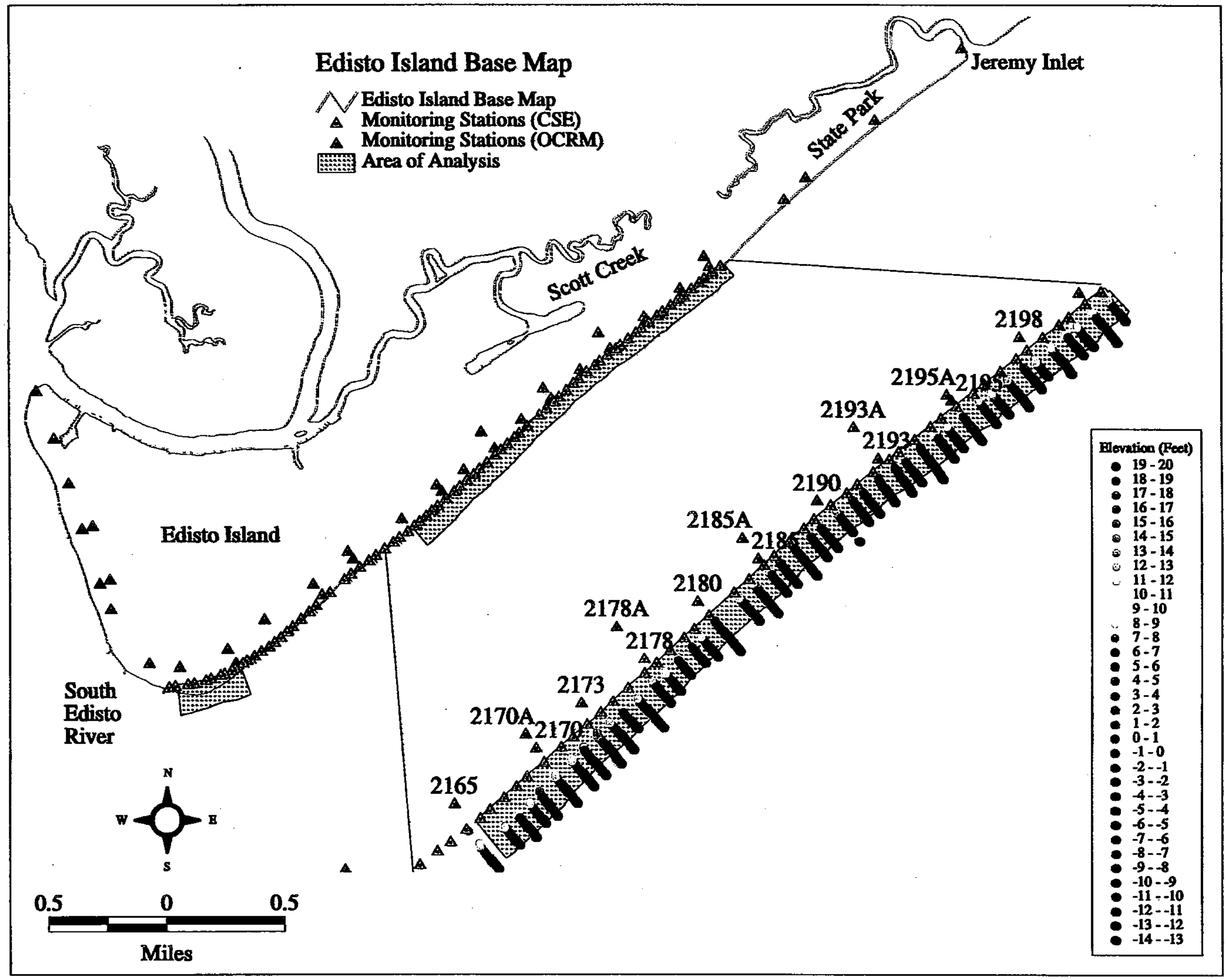


Figure 12. Edisto Island base map. Shaded areas indicate project boundaries.

It was necessary to generate boundaries to clip the final grids so that extraneous interpolation *behind* or landward of the benchmarks was not included in the analysis. This step was not required for the Hunting Island data because the extent of the project was small and relatively straight while on Edisto the project extent spanned the entire island. Reach 3, located at the south end, encompassed the tip of the island and led to incidental interpolation. A boundary polygon was created in ArcView and converted to an ARC/INFO coverage. Project boundaries were determined from monitoring reports. DEMs were examined to locate the –7 feet contour to establish the seaward boundary. The landward boundary was delineated using the monitoring stations as a guide. The polygons were assumed to represent the nourished area project limits.

The <LATTICERESAMPLE> command was not required since clipping each beach surface with the boundary polygons created coincident DEMs.

Cell size was increased to 5 feet (Hunting Island DEMs have a cell size of 2 feet) to reduce disk storage space and speed processing time while maintaining good resolution.

1995 Edisto Beach Nourishment Project: Results

Comparison of the pre- and post-nourishment surveys revealed that approximately 142,791 cubic yards of sand were placed on the beach within the project boundaries (Table 6). This estimate was slightly lower than the estimate of 148,404 cubic yards made by CSE-Baird (CSE-Baird, 1996a). The difference between the two estimations is only 5,613 cubic yards, or 3.8% of the total volume added in the nourishment effort.

There are several possible explanations for the difference. The region interpolated in the GIS model may include a different area than that analyzed by CSE-Baird. The seaward boundary was generated by selecting the -7-foot contour for all DEMs and approximating an average

Table 6. Volumetric change calculations for 1995 Edisto Island beach nourishment.

Survey Dates	04/95-05/95	05/95-07/95	07/95-01/96	01/96-05/96	05/96-07/97
Time from Previous	Pre- & Post-Surveys	2 months	6 months	5 months	14 months
Net Gain/Loss (cy)	142,791	50,642	-17,152	-71,000	63,167
	May-95	Jul-95	Jan-96	May-96	Jul-97
Volume Remaining (cy)	142,791	193,433	176,281	105,281	168,448
Percent Remaining	100.0%	135.5%	123.5%	73.7%	118.0%
Percent Rate of Change	100.0%	35.5%	-12.0%	-49.7%	44.2%
Percent Cumulative Change	100.0%	35.5%	23.5%	-26.3%	18.0%

location. The landward boundary was interpreted as the shore parallel line connecting the monitoring stations. A second explanation for the difference is that the GIS method of volume calculation interpolates rather than extrapolates a surface and may more closely reflect the surface of the beach and nearshore topography. The presence of groins and associated variations in beach morphology are difficult to account for and may have affected one or both of the calculated results.

Two months following nourishment, from May 1995 to July 1995, results of the volumetric change analysis indicate a net gain of 50,642 cubic yards of sand to the project area (Figure 13). This represents a gain of 35.5% of the initial fill volume. It is highly unusual for a newly nourished beach to experience an additional volumetric gain, especially as the artificial profile begins to equilibrate (Katuna, 1998).

There are several possible explanations for the gain in volume following the nourishment effort. The project included repair and lengthening of existing groins (CSE-Baird, 1996a). Additional sand may have been trapped and held within the groin cells following nourishment particularly since the groins were grouted and extended vertically. There may have been errors in one or more of the surveys. More sand may have been added than initially accounted for in the pre- and post- nourishment surveys. The sand could have been added outside the bounds of analysis and consequently migrated into the project limits.

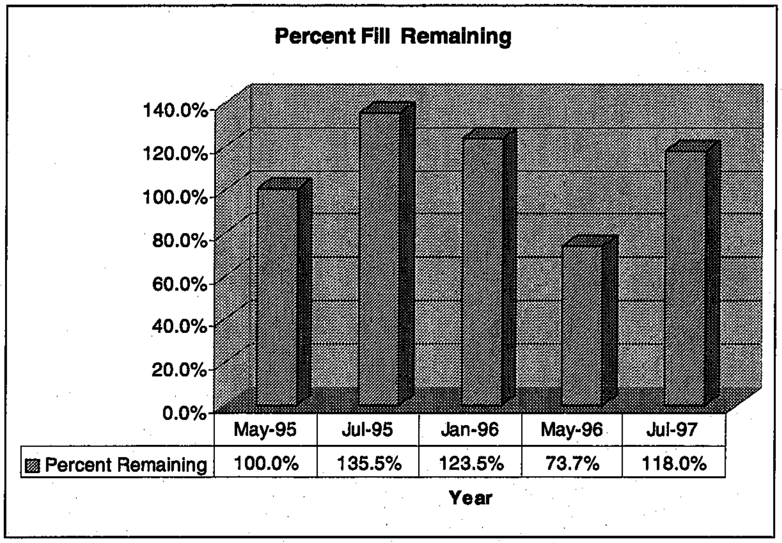


Figure 13. Percent fill material remaining within the nourishment project area on Edisto Island.

CSE-Baird (1996a) noted the passage of hurricanes *Barry* and *Chantal* in July and *Erin* in early August. The hurricanes were well offshore and generated long-period, large swells that overtopped the new berm and washed onto Palmetto Boulevard in the Town of Edisto Beach (CSE-Baird, 1996a). Such swell can result in beach accretion and may have transported additional sand landward into the project area (CSE-Baird, 1996a). In addition, the beach was scraped at the northern end of the project bounds to prevent further overwashing (CSE-Baird, 1996a). The redistribution of sand may have confounded the results of interpolation, or may have introduced more sand into the project area.

In the following survey period, from July 1995 to January 1996, the project area experienced a net loss of -17,152 cubic yards of sand. The greatest loss occurred in the stockpile area, which included cells 12, 13, and 14 (Figure 15). This loss amounted to 12.0% of the fill volume.

Losses continued during the spring. For the next survey period (January 1996 to May 1996), calculations show that an additional –71,000 cubic yards were lost from the project area, which accounts for approximately 49.7% of the initial fill volume (Figure 15).

The last monitoring survey was made in July 1997. Volumetric change from May 1996 to July 1997 indicates a gain of 63,176 cubic yards from the project area. By this time, two years and two months after nourishment, 118% of the fill material remained within the project bounds, a total of 18% more sand (24,540 cubic yards) than existed on the beach following nourishment.

Comparison of the volumetric change calculations using the contractor's method versus the GIS method shows a close correlation (3.8%) in the initial assessment of volume of fill added to the beach (Table 7). Subsequent calculations of percent fill remaining did not correlate as well and ranged from 16.5% to 28.5% difference. The differences between the results may be due to analysis of different spatial extents of the project area. The GIS method used one consistent analysis area for each calculation (Figure 12) while the contractor may have analyzed variable areas based on the length of each profile survey.

Table 7. Comparison of volumetric change results using two calculation methods.

	Traditional method used by contractor (CSE, 1997)		GIS method			
Date	Volume Remaining (cy)	% Remaining	Volume Remaining (cy)	% Remaining	Difference (cy)	% Difference
May 1995	148,404	100.0%	142,791	100.0%	5,613	N/A
July 1995	157,349	106.0%	193,433	135.5%	-36,084	29.4%
January 1996	138,340	93.2%	176,281	123.5%	-37,941	30.2%
May 1996	147,161	99.2%	105,281	73.7%	41,880	25.4%
July 1997	150,572	101.5%	168,448	118.0%	-17,876	16.5%

Beach width measurements indicate a wide beach within the project limits. Average beach width for Reaches 1 and 2 ranged between 145 and 177 feet following nourishment. Within Reach 3 the beach was even wider (364 to 447 feet) at the 7-foot contour. Overall beach width remained relatively stable in both sections of the project area. The width never approached 25 feet in either area. The width was measured from the 7-foot contour to the landward edge of the data or the monitoring station, whichever came first. The monitoring stations may have been set inland somewhat accounting for the increased width of the beach.

1995 Edisto Beach Nourishment Project: Discussion

Performance was evaluated using the two criteria. The first criteria, measurement of longevity as the amount of time required for loss of 50% or more of the fill material, indicates that as of July 1997, the Edisto Beach nourishment was still viable. At this time the project area had gained an additional 18% over the original fill volume. At the lowest point the project area maintained 73.7% of the initial fill volume. The total monitoring period encompassed a relatively short time span, only 2 years and 2 months. Given the variability of change, especially the loss of 71,000 cubic yards between January and May 1996 and the following episode of gain (63,167 cubic yards), it is difficult to predict future trends. Further monitoring and analysis will be necessary to establish the long-term trends of the project.

Beach width also indicates that the project was not changing significantly over time (Appendix B, Table 11 and Table 12). In both reaches, the width at the time of the final survey is greater than the width measured prior to nourishment. In general, analysis of 26 months of monitoring data indicate that this project may have a lifespan of 5 years or more.

The Edisto Island difference grids depict the pattern of gain and loss within the project area. From April to May 1995, the difference between the pre- and post-nourishment surveys illustrates considerable gain in sediment at the southern end of Reaches 1 and 2. This area was used as a temporary repository for the fill material. From there sand was hauled by truck to fill in the other groin compartments (CSE, 1996a). A clearly defined ridge of fill sand (greater elevation in dark green) can be detected along the center of the project area and probably represents the crest of the artificial berm (Figure 14).

The May to July 1995 difference grid indicates sediment losses primarily in the stockpile area and along the artificial berm ridge down the center of Reaches 1 and 2 (Figure 14). Some of the blocky appearance of the difference grid may be attributed to the division of the groin compartments.

Sediment losses continued for the next two monitoring periods with substantial losses apparent in the stockpile area (Figure 15). Also notice the gain of a shore parallel feature at the northern end of Reach 2. Beach scraping was necessary in this area after several summer hurricanes washed over the new berm onto Palmetto Boulevard (CSE, 1996a). Figure 15 depicts the largest volumetric change experienced by the nourishment project during the entire survey period. Considerable beach height was lost along the landward edge of Reaches 1 and 2 from January to May 1996, while some in-filling on the seaward edge occurred. This may reflect a similar pattern seen on Hunting Island due to offshore sediment transport.

The May 1996 to July 1997 change calculation shows a net gain of sand over much of the entire project area with isolated losses visible in places (Figure 16).

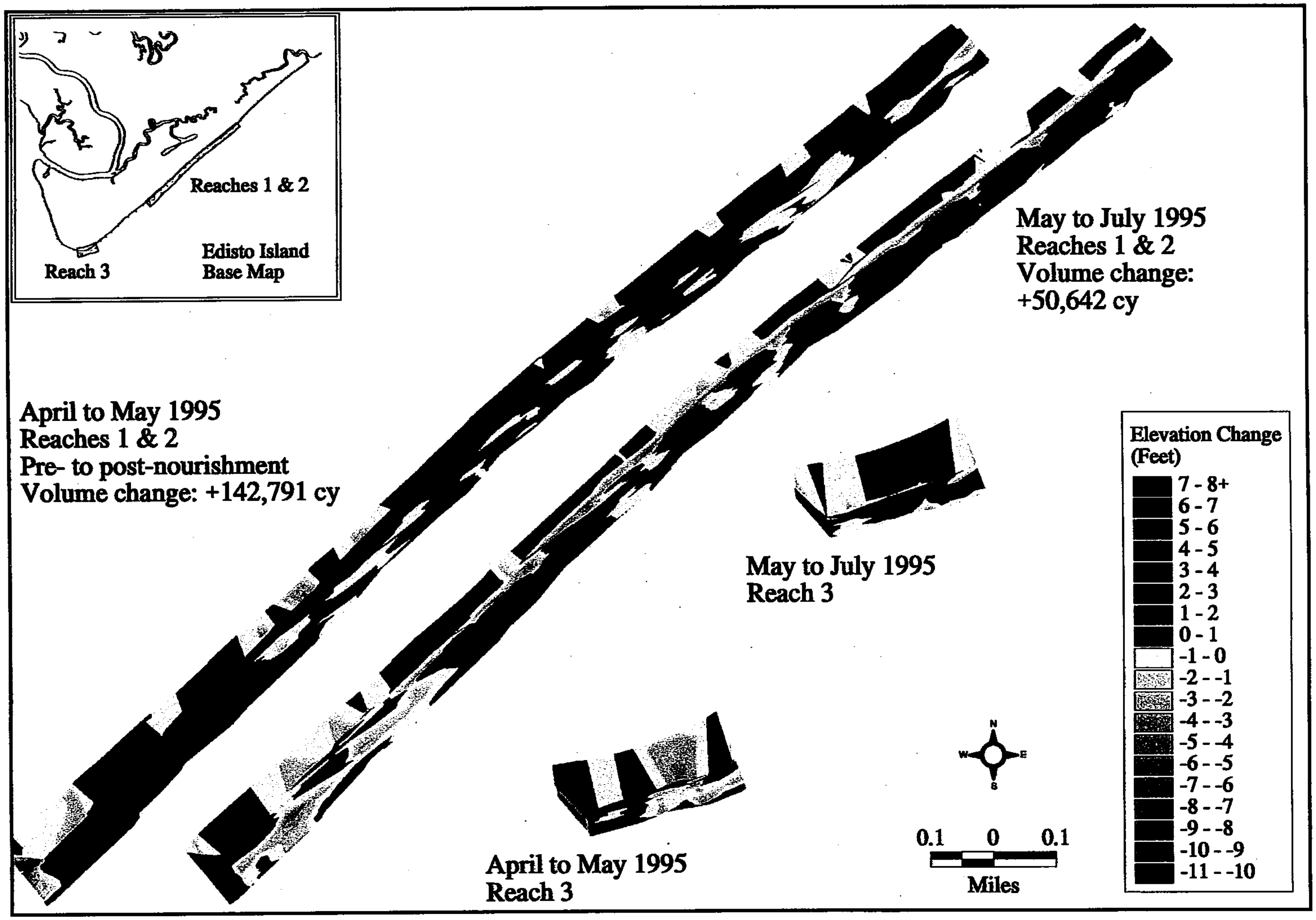


Figure 14. Edisto Island elevation change (1). Greens denote gain; yellows to red denote loss in elevation.

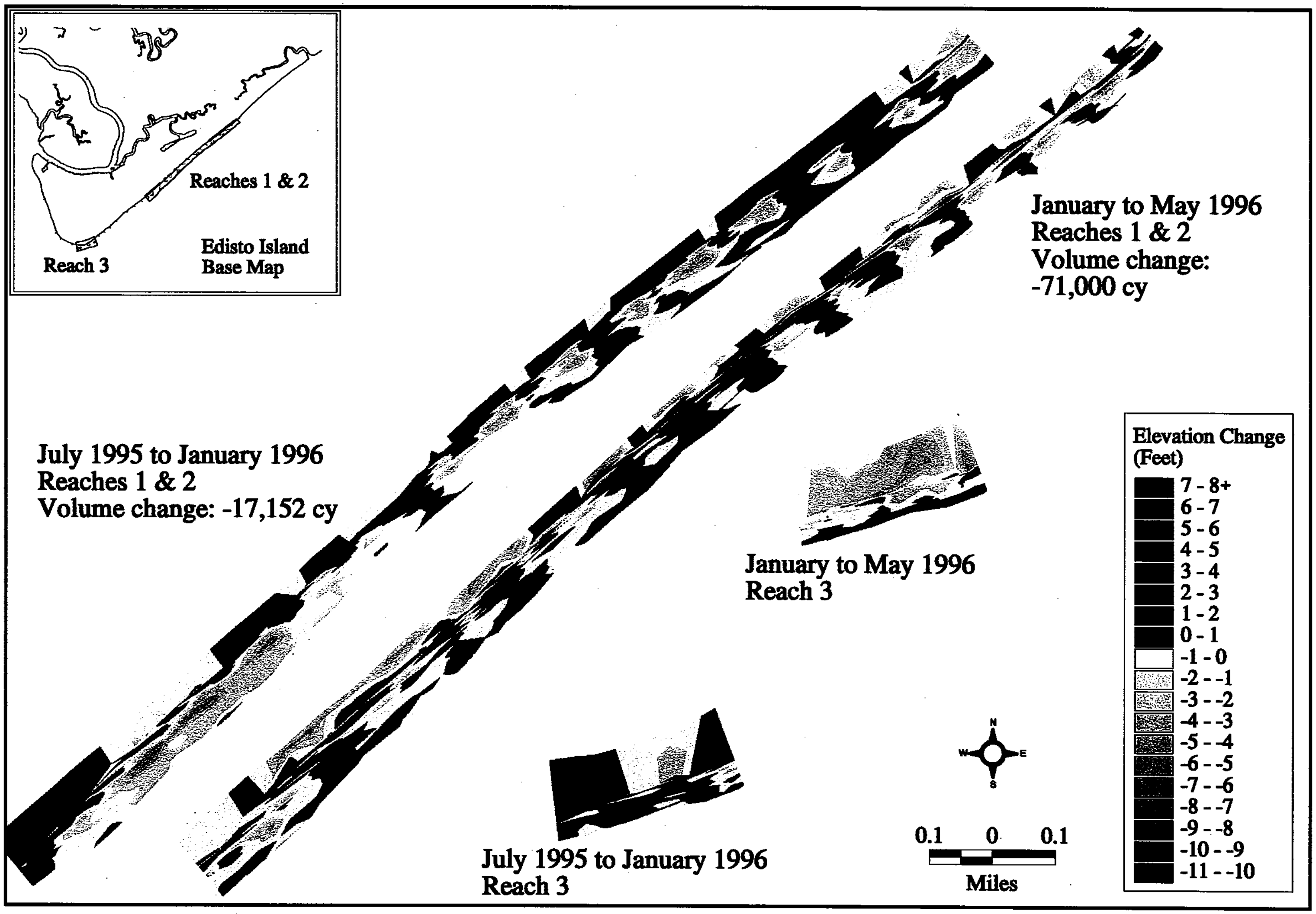


Figure 15. Edisto Island elevation change (2).

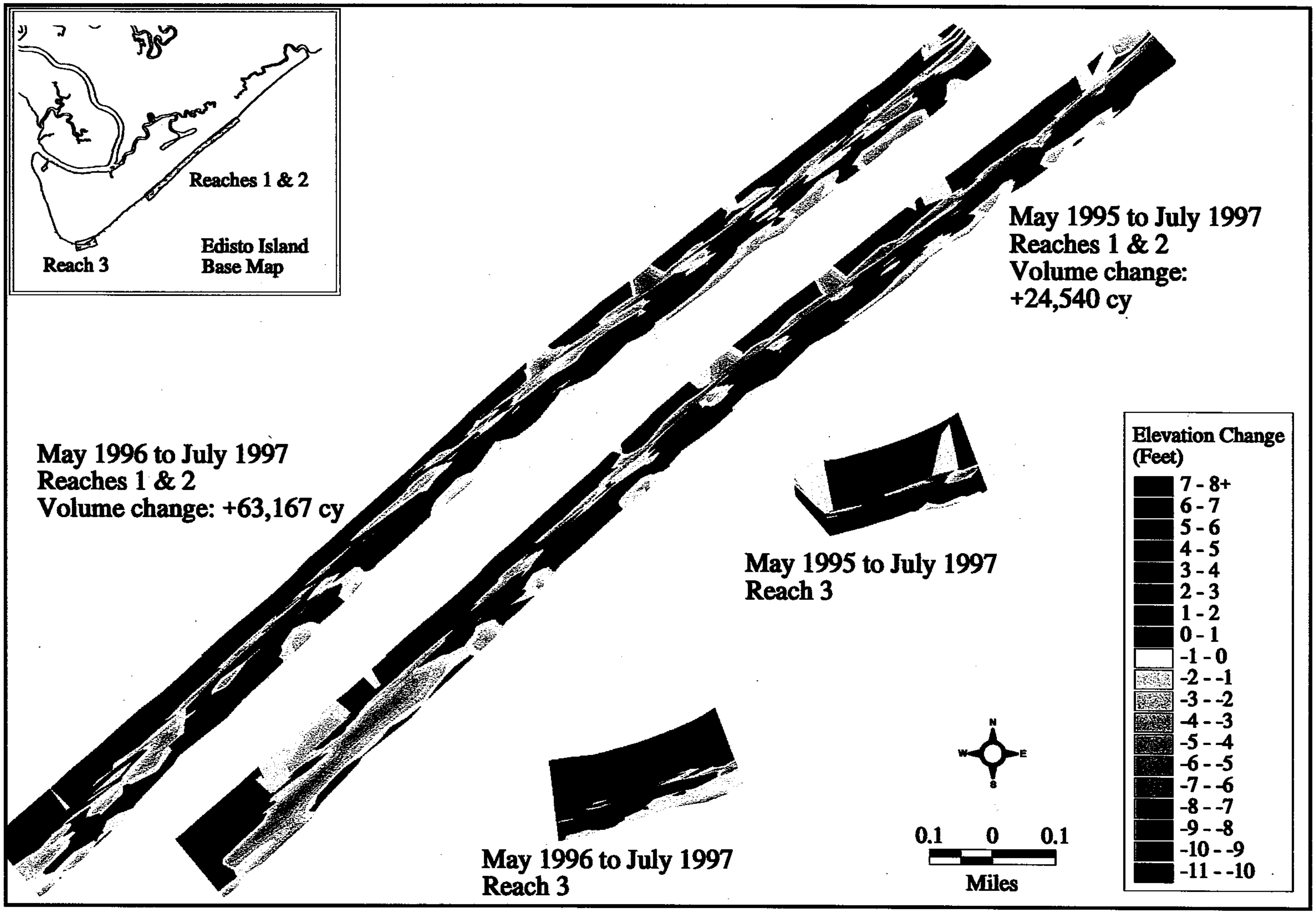


Figure 16. Edisto Island elevation change (3).

HILTON HEAD ISLAND

Background

Hilton Head Island is located in Beaufort County and bounded by Port Royal Sound to the north and Calibogue Sound to the south. The island is 11.5 miles long and 6.8 miles wide, and is the largest beach-ridge barrier island on the South Carolina coast (Neal *et al.,* 1984). Planned development began in 1956 and the island quickly transformed from a natural, rural area to a complex of coastal resorts and subdivisions (Neal *et al.,* 1984).

Historical shoreline analysis, using navigational maps and aerial photographs from 1859 to 1983, indicates erosion trends on the north and central sections of the island with lower rates of erosion or accretion at the southern end (Olsen, 1992). Two previous beach nourishment projects were conducted in 1969 and 1981 as a by-product of construction of the Palmetto Dunes development (Olsen, 1992).

Hilton Head 1990 Beach Nourishment Project

Hilton Head Island underwent renourishment in 1990. Sand was pumped from two offshore borrow areas, Joiner Bank shoal near the mouth of Port Royal Sound and Gaskin Banks shoal off the center of the island. The original design plan and fill volume were specified by Olsen Associates, Inc. in 1987. Pumping began in April 1990 by Great Lakes Dredge and Dock Company and was completed in August 1990. The design plan called for the placement of approximately 2 million cubic yards of sand along 30,000 feet of shoreline tapering at both ends to produce a project length of approximately 35,000 feet. Estimated total volume was 2,338,000 cubic yards. The initial construction berm was 150 to 180 feet wide with an average elevation of +8 feet NGVD. Engineering predictions indicated that after equilibration, the residual dry beach would be approximately 65 to 75 feet wide. The pre-nourishment condition was not characterized as natural hence the effects of numerous factors such as the 7,000 feet rock revetment, two groins, several sloping revetments, and erosional effects of the tidal creek were only estimated.

To calculate volumetric changes, the project area was divided into three shore-perpendicular reaches: the area above 0.0 feet NGVD, the area between 0.0 and –5 feet NGVD, and the area below –5 feet NGVD (typically to about –10 feet NGVD). The subcontractor, Sea Island Engineering, conducted beach profile surveys at 32 established stations with the exception of the pre- and post-nourishment surveys which were conducted by Great Lakes Dredge and Dock Company. Surveys were available for May 1990 (pre-nourishment), August 1990 (post-nourishment), January 1991, April 1991, July 1991, and October 1991. Profiles were measured using standard level (elevation) and chain (distance) survey techniques (Olsen, 1992) and extended from the landward dune or shorefront structure seaward to the –5 foot NGVD contour. Sediment volumes were calculated by multiplying the cross-sectional unit-area volume by a representative shoreline length between stations and summed to determine total volume within the study area.

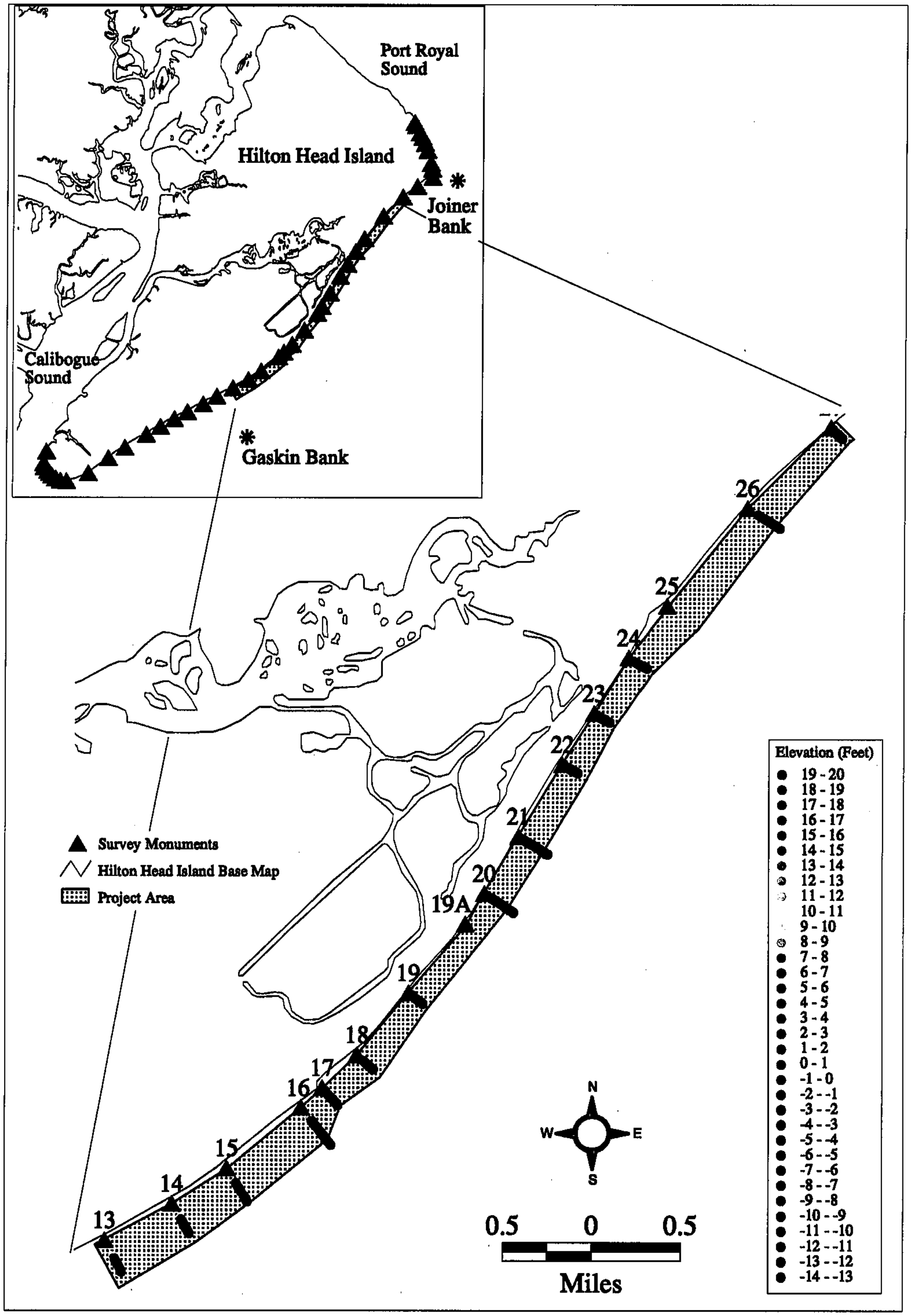


Figure 17. Hilton Head Island base map and survey monuments.

Hilton Head 1990 Beach Nourishment: Elevation Data Processing

Olsen Associates provided elevation data in the same format as the other monitoring data for the first year of monitoring. Survey data were available for May 1990 (pre-nourishment), August 1990 (post-nourishment), January 1991, April 1991, July 1991, and October 1991. Based on Olsen Associates (1992) monitoring report, a seaward limit of –5 feet NGVD was chosen. Stations 13 and 27 were used as the boundaries on either end of the project. A cell size of 5 feet was used to reduce disk storage space requirements and speed processing.

Initial interpolations of Hilton Head elevation data produced similar results to those seen with the Edisto Island interpolation. Hilton Head DEMs exhibited anomalous triangular shapes corresponding with profile transects (Figure 19). Corrections were attempted with the same method used on Edisto Island however, integration of landward data did not resolve the grid interpolation problem. Other correction methods were tested, for example interpolation with and without a bounding polygon, without success. Interpolation using the inverse distance weighted (IDW) algorithm was also attempted, but the resulting DEM did not represent a realistic beach surface. Although interpolation did not produce realistic beach surfaces, volumetric calculations were made using the original technique and compared to Olsen Associates' results.

It should be noted that the Hilton Head Island surveys had greater profile spacing than those conducted on Hunting and Edisto Islands. While profiles ranged in distance from approximately125 feet to 240 feet on Hunting and Edisto, profiles were spaced between 1,500 to 2,500 feet apart on Hilton Head. These distances may be too great for realistic DEM interpolation.

Due to the inconsistencies in the Hilton Head Island DEMs, beach width was measured using the point coverages rather than the interpolated grid. Each survey was queried to select elevations greater than or equal to 6.5 feet. The closest point to the +7 foot contour was estimated and the distance measured to the base station.

Hilton Head 1990 Beach Nourishment: Results

Volumetric change between the pre- and post-nourishment surveys was calculated as a gain of 2,015,377 cubic yards (Table 8). Despite the interpolation problems, this estimate was only slightly lower than the estimate of 2,043,285 cubic yards made by Olsen Associates (1992). The difference between the two estimations was 27,908 cubic yards or 1.4% of the total volume added in the nourishment project.

Table 8. Volumetric change calculations for 1990 Hilton Head Island beach nourishment.

Survey Dates	05/90-08/90	08/90-01/91	01/91-04/91	04/91-07/91	07/91-10/91
Time from Previous	Pre- & Post-Surveys	4 months	3 months	3 months	3 months
Net Gain/Loss (cy)	2,015,377	-660,421	4,022	-842,491	209,762
	Aug-90	Jan-91	Apr-91	Jul-91	Oct-91
Volume Remaining (cy)	2,015,377	1,354,956	1,358,978	516,487	726,249
Percent Remaining	100.0%	67.2%	67.4%	25.6%	36.0%
Percent Rate of Change	100.0%	-32.8%	0.2%	-41.8%	10.4%
Percent Cumulative Change	100.0%	-32.8%	-32.6%	-74.4%	-64.0%

Four months following nourishment, from August 1990 to January 1991, results of the volumetric change analysis indicate a loss of –660,421 cubic yards of fill material. This represents a loss of 32.8% of the initial fill volume. Three months later estimates show very little change with a small gain of 4,022 cubic yards, a change of only 0.2% of the total volume. By July 1991 the beach nourishment project had lost an additional – 842,491 cubic yards of sediment. At this time the GIS calculations indicate that only 25.6% of the fill material remained within the project area. The last survey in October 1991 showed a gain of 209,762 cubic yards. By the end of the first year of surveys the project area retained 36.0% of the initial fill volume.

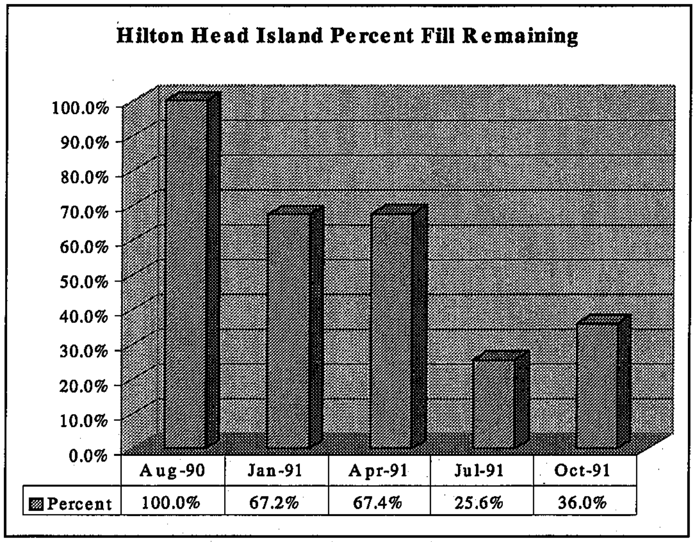


Figure 18. Percent fill material remaining within the nourishment project area on Hilton Head Island.

Comparison of the two volumetric calculation methods shows close results (1.4% difference) for the pre- and post-nourishment volume change. Differences between percent fill remaining range from 16.9% to 60.4%. The variation of the results derived from the two methods could be due to the application of different analysis areas. The GIS method uses a consistent area for volumetric change calculations while the contractor may have varied the analysis area based on transect length. In all cases the GIS calculation indicates greater volumetric losses than does the traditional calculation method.

Table 9. Comparison of volumetric change results using two calculation methods.

	Traditional method used by contractor (Olsen Associates, 1992)		GIS method			
Date	Volume Remaining (cy)	% Remaining	Volume Remaining (cy)	% Remaining	Difference (cy)	% Difference
August 1990	2,043,285	100.0%	2,015,377	100.0%	27,908	N/A
January 1991	1,921,755	94.1%	1,354,956	67.2%	566,799	26.8%
April 1991	1,722,533	84.3%	1,358,978	67.4%	363,555	16.9%
July 1991	1,758,248	86.1%	516,487	25.6%	1,241,761	60.4%
October 1991	1,736,126	85.0%	726,249	36.0%	1,009,877	48.9%

Beach width measurements show a wide beach within the project limits. Beach widths prior to nourishment ranged from 72 to 701 feet with an average width of 281 feet. This width is well above the 25-foot minimum to be considered a healthy beach, however, beach width was measured from the 7-foot contour to the base station to maintain consistency. Base stations may be located further inland than the edge of the active beach to avoid loss of benchmarks during erosional phases. This measurement, while providing an indication of *change* in width, may not accurately portray the width of the area considered to be active beach.

Table 10. Beach width in feet at the 7-foot contour and above within the project limits on Hilton Head Island.

STATION	May-90	Aug-90	Jan-91	Apr-91	Jul-91	Oct-91
12	701	784	765	810	769	784
13	600	778	707	702	714	689
14	531	691	613	599	626	598
15	518	670	588	581	590	558
16	494	653	594	589	582	552
17	83	289	232	216	177	180
18	225	380	326	334	327	283
19	88	216	173	164	143	139
20	94	258	205	191	192	188
21	94	227	191	184	195	174
22	93	233	189	175	191	173
23	91	235	199	194	182	181
24	177	270	287	277	270	270
25	No Data	No Data	397	394	419	412
26	359	470	481	472	466	464
27	72	159	137	141	135	129
Average Beach Width (feet)	281	421	380	376	374	361

Hilton Head 1990 Beach Nourishment: Discussion

Performance of this nourishment project was evaluated using two criteria. The first criterion, beach fill longevity based on volumetric change, indicates that the 1990 Hilton Head project had a lifespan of 11 months. By July 1991, 25.6% of the fill remained within the project limits. A slight increase was detected three months later bringing the remaining volume to 36.0% of the initial fill volume, still below the 50% volumetric loss criterion. Application of this standard indicates that the longevity of the Hilton Head project fell into the first category of less than 1 year. It should be noted that

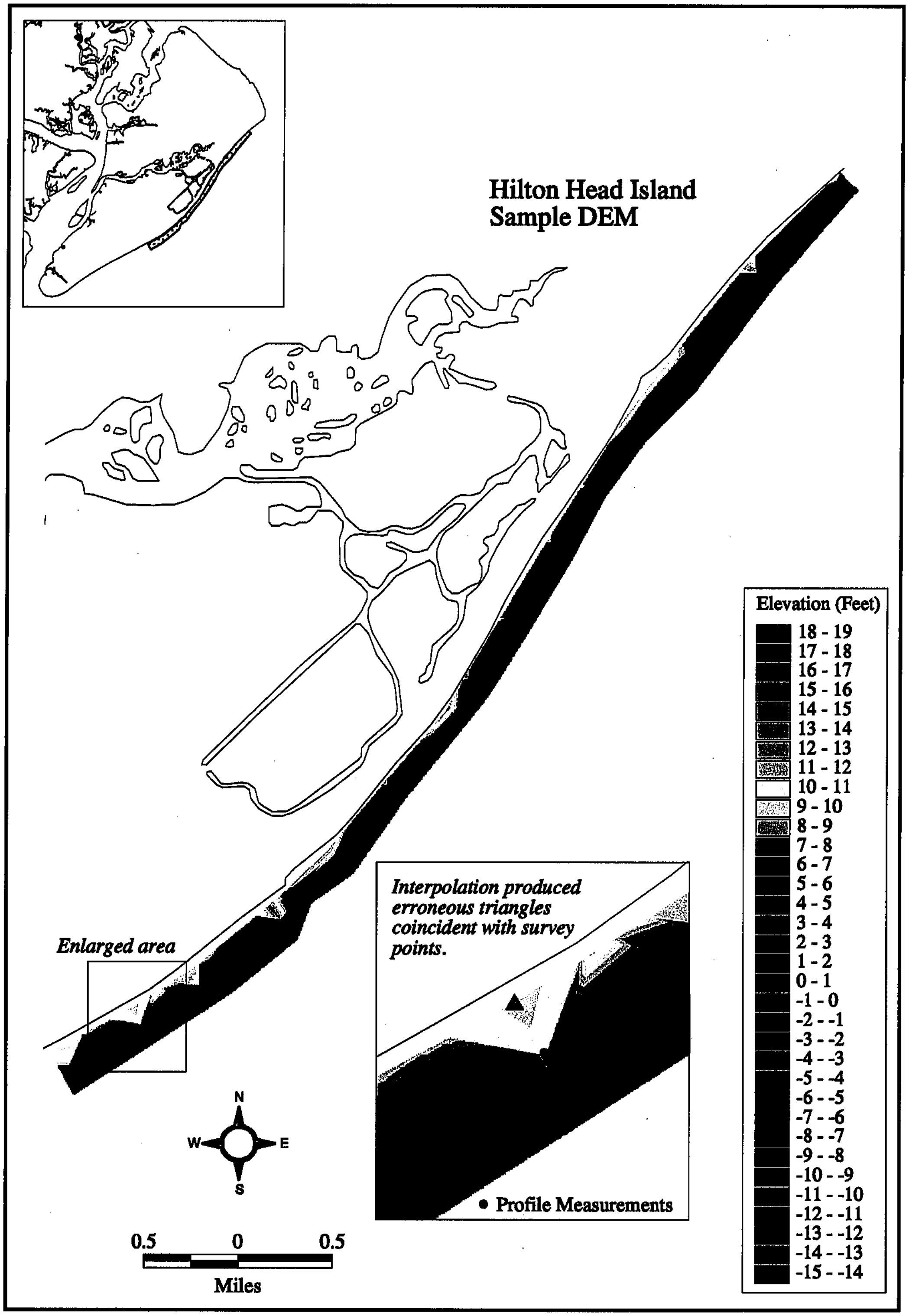


Figure 19. Hilton Head elevation data interpolation.

volumetric change calculations were made using DEMs which did not depict a realistic beach surface. Hence, volumes calculated using the GIS method could be inaccurate.

Average beach width measured from the +7-foot contour to the base station indicates an increase of 140 feet from the pre- to the post-nourishment survey. This measurement correlates well with the project design of a 150- to 180-foot wide construction berm at an elevation of +8 feet NGVD (Olsen Associates, 1996). Subsequent measurements indicate that the beach width was gradually decreasing, but during the first year following nourishment it did not decrease below the 25-foot standard. Since data were available for only one year it is difficult to predict project longevity based on the beach width criterion.

CONCLUSIONS

Clearly the three nourishment projects examined in this study are each unique and highly variable. Hunting Island has undergone multiple nourishment episodes beginning in 1968. In each case, the project has performed in a manner similar to the 1991 effort and exhibited low retention times (CSE, 1995). Edisto was the first beach to be renourished in this state and had a severe erosion problem at that time. This beach has not required renourishment for 41 years. The 1995 Edisto nourishment may be an example of a more durable nourishment project. Available monitoring data indicate that the Hilton Head Island project had a lifespan of less than one year based on volumetric changes. Conversely, after the monitoring period examined (14 months) the beach width decreased but still fulfilled the definition of a healthy beach.

In all three cases the same problems encountered by Leonard *et al.* were found with data availability for nourishment projects. More thorough analyses could be conducted if monitoring data were consistent in profile spacing along the entire length of the island, used consistent time scales, and reports included clear explanation of project boundaries. For example, the Hunting Island renourishment was designed specifically as a feeder beach with the intent that fill material would migrate to both ends of the island (CSE, 1991). This may or may not have occurred, however without monitoring of sufficient density outside the project limits volumetric analyses could not be made.

Results of the assessment may have indicated better performance of Hunting Island's nourishment project if a more complete data set existed.

Edisto Island's project performance analysis was hindered because the exact bounds of the nourishment were not known. If monitoring reports had clearly stated the landward limits of nourishment, a more accurate analysis would be possible. Also, Edisto was only monitored for a little more than two years. This does not provide a complete long-term picture of the performance of this project.

Project performance analysis on Hilton Head was also impaired because the landward bounds of the project area were not known. In addition, only one year of post-nourishment data were made available, therefore an understanding of long-term project performance could not be determined. Spacing of the profiles at 2,000-foot intervals resulted in interpolation problems and may have compromised volumetric changes calculated using the GIS technique.

RECOMMENDATIONS

In order to use the GIS method of analyzing shoreline volumes and widths described in this study, it appears necessary to have closely spaced survey transects. Ideally a spacing of 200 feet seems to work well. Larger intervals may be feasible, but it appears that distances as large as 2,000 feet between transects introduce unaccountable errors. Further studies should be completed to determine the maximum distance that would accommodate this type of analysis. For large renourishment projects, it may not be practical or affordable to increase the number of transects. A more feasible alternative to increase density of elevation measurements may be to conduct several shore parallel transects along the length of the project area to accompany the standard shore normal measurements.

A monitoring duration of at least 4 years following nourishment is recommended. Annual surveys are suitable, although quarterly surveys during the first year post-nourishment could provide insights to the equilibration period. Geomorphologic changes of the shoreline following storm events may also merit examination. In addition, a monitoring plan designed specifically to account for expected fill behavior could help to refine predictive models. For example, if fill material is placed at the center of the island and expected to be dispersed to unnourished areas, it would be useful to monitor those benefited areas outside the project limits.

If spatially referenced data are desired for GIS functionality, use of a global positioning system (GPS) unit could provide x and y coordinates for all elevation measurements and eliminate the dynamic segmentation steps applied in this study.

Finally, clear statements of project objectives made in advance and evaluation criteria chosen prior to construction of the project would allow qualitative evaluation. While quantitative analyses should not be eliminated, the addition of qualitative evaluation using those criteria suggested by the NRC (1995) might serve to rectify discrepancies in perceived project performance.

APPENDIX A

Beach	Construction Dates	Completion Date	Volume of Sand (Cubic Yards) (cy)	Average Unit Area Volume(cy/ft)	Source of Sediment
Myrtle Beach	Stage 1: January 1986 - April 1986 Stage 2: Winter 1987	05/1987	853,350	19	Inland sand hauled by truck from International Paper property along AICWW (59,539 truckloads)
Myrtle Beach	Post-Hugo Emergency; December 1989 - March 1990	03/1990	395,960	8.7	Inland sand hauled by truck
Myrtle Beach	February 1991	02/1991	28,000	23.3	Inland sand hauled by truck
Myrtle Beach	Reach 1: N. Myrtle Beach - 09/12/1996-05/13/1997; Reach 2: Myrtle Beach - 04/09/1997-12/31/1997; Reach 3: Surfside and Garden City Beach - 8/15/98 - 11/24/98	11/1998	5,135,000	Reach 1: 55 Reach 2: 45 Reach 3:	Four offshore borrow sites: Little River, Cane North, Cane South, and Surfside.
Debidue	Late Spring 1990	05/1990	191,693	Reach 1: 19.3 Reach 2: 33.4	Inland sand hauled by truck from DeBourdieu Colony
Folly Beach	January - May 1993	05/1993	2,500,000	88.6	Folly River (shoal #4)to rear of Charleston County Park; hydraulic pipeline dredge w/booster plant
Seabrook Island	1990	1990	685,000	117	North shoal of North Edisto Inlet; hydraulic dredge
Edisto Island	April 24 - May 15, 1995	05/1995	148,404	13.4	Offshore ebb-tidal shoal; 2,500 ft off "The Point" (south end of Edisto); hauled by truck to fill groin compartments
Hunting Island	First week of February - March 24, 1991 (44 days of pumping)	03/1991	715,766	North Beach=144; Project center=40; South Beach=128	Offshore (in front of Lighthouse) borrow area by hydraulic dredge
Hilton Head Island	April 1990 - August 1990 (pumping)	10/1990	2,338,000	66.8	Pipeline dredge from offshore source "Joiner and Gaskin Banks"

APPENDIX A (CONTINUED)

Beach	Grain Size Characteristics Native Sediment/Fill	Previous Nourishments	Length of project (Coverage)	% Sacrificial Fill	Total Cost (Millions)	Cost of Components	Cost per Unit ($/cy)	Funding
MB	Native:0.27 mm; Borrow=0.27 mm; R_A=1.1	1958 (3 1/2 years post Hazel) USACE determined nourishment not necessary; Sand scraping following 1986-1987 New Year's Day Storm	45,000 ft (8.6 miles)	40% to beyond 15 ft depth (NGVD)	$4.7	N/A	$5.50/cy	Based on 10-year bond paid annually by accommodations tax revenue
MB	N/D	1986/1987 nourishment	44,352 ft (8.4 miles)	N/D	$2.4	N/A	$6.31/cy	State and FEMA
MB	N/D	1958 (3 1/2 years post Hazel) USACE determined nourishment not necessary; Sand scraping following 1986-1987 New Year's Day Storm; 1986/1987 nourishment	1,200 ft (.23 miles)	N/D	$.165	N/A	$5.89/cy	N/D
MB	Reach 1: Native = 0.44 mm; Borrow = 0.35 Reach 2: Native = 0.44; Borrow = 0.38	1958 (3 1/2 years post Hazel) USACE determined nourishment not necessary; Sand scraping following 1986-1987 New Year's Day Storm; 1986/1987 nourishment	134,112 ft (25.4 miles)	1.15%	$50.515470	N/D	$9.84/cy	Federal/State/Local
Db	Native=0.26 mm (avg) Borrow=0.29 mm (avg)	1970s: Beach scraping and dune enhancement; 1990: Repaired 800 ft of seawall destroyed by Hugo; artificial dune restored	8,060 ft Reach 1: 5,145 ft Reach 2: 2,615 ft (1.53 miles)	40% beyond 5 ft depth (NGVD)	$.855	N/D	$4.50.cy	Private
FB	Native=0.12 mm - 0.21 mm Borrow=0.10 mm - 0.28 mm (both well sorted)	1979 construction of Folly River navigation project; material from shoal 4 ~305,562 cy - 325,000 cy spoiled on west end of Folly	28,200 ft (5.34 miles)	(1.15cy/1cy) 13%	$12.52	$9.893 M -Fill and groins $1.78 M - Engineering and design	$5.00/cy	$1.88M State, through City of Folly Beach (15%) $10.64M Federal (85%)
SI	Native= 2.43 mm (avg median) 2.51 mm (mean)	1982: 70,000-75,000 cy using land based equipment; 1983: Capt. Sam's Inlet relocated ($~300,000); 225,000-250,000 cy ($1.25/cy); 1996 relocation of Captain Sams Inlet	5,850 ft (1.12 miles)	20% immediate loss predicted	$1.66	N/A	$2.43/cy	Private Seabrook Property Owners Association (POA)
EI	Native=1.0 mm - 0.18 mm (vary coarse to fine from north to south)	1948-1975: 34 groins installed; 1954: ~850,000 cy sand from "Yacht Basin"	12,000 ft (2.27 miles) Reach 1: 5,387 ft Reach 2: 3,609 ft Reach 3: 1,375 ft	37%	$1.5	N/D	$10.83/cy (includes groin repair)	$1M State / $.5M Town
HI	Borrow=5% mud (mean grain size <0.0625 mm)	1968, 1971, 1975, 1980; >3,500,000 cy; $4.2M	7,500 ft (1.42 miles)	N/D	$2.92	N/A	$3.80/cy	Sponsored by SC PRT; 60% funding under SCCC Beach Management Trust Fund
HHI	Native=0.15 mm - 0.18 mm Gaskin Bank RA=1.25 Joiner Bank RA=1.08	1969, 1970/1971 renourishment in front of Palmetto Dunes; 1981: ~800,000 cy sand added	35,000 ft final (6.63 miles)	~40% expected initial loss	$9.7	$7.92 M Great Lakes Dredge and Dock Co.	$4.15/cy	$6.5M State / $3.2M Local

APPENDIX A (CONTINUED)

Beach	Significant Storms	Storm Results	Action Taken	Monitoring	Engineer and Contractor
MB	Hurricane Hugo September 21, 1989	Average loss of 10.7 cy/ft (Kana) Average loss 7.7 cy/ft (Berkemeier); ~ 2.5 cy/ft less than pre-nourishment conditions	Beach scraping following New Year's Day Storm/ Emergency nourishment	Coastal Science and Engineering, Inc.	Coastal Science and Engineering, Inc./ M. C. Anderson, Inc. Garden City, GA
MB	Northeaster, March 13, 1993 ("The Storm of the Century")	Dune scarps with minor backshore erosion; between 10/92 and 5/93, substantial erosion in intertidal zone, beach lowered by 1 to 3 feet.	N/A	Coastal Science and Engineering, Inc.	Coastal Science and Engineering, Inc.
MB	N/D	N/D	N/D	N/D	N/D
MB	N/A	N/A	N/A	South Carolina Marine Resources Division, (in prep); Coastal Carolina University (in prep)	US Army Corps of Engineers
Db	October 1994 Nor'easter	Failure of ~ 50 ft of seawall	Emergency repairs completed by early 1995	Cubit Engineering, Ltd., 1981; Applied Technology & Management, Inc.; Olsen & Associates, Inc., 1986; CSE, 1989	Coastal Science and Engineering (CSE)/ L.D. Weaver, Inc. (Pamplico)
FB	Northeaster, March 13, 1993 ("The Storm of the Century")	Storm occurred during the construction of the project; visual checks indicate that significant sand was lost	Additional sand was applied to the project so that at completion 2.5M cy were placed on the beach	US Army Corps of Engineers during project; SC Dept. of Natural Resources, Marine Resouces Divison; Coastal Carolina University	US Army Corps of Engineers / T.L. James
SI	N/D	N/D	N/D	Coastal Science and Engineering, Inc. 1983 - 1995	Coastal Science and Engineering, Inc.
EI	Offshore hurricanes Barry & Chantal, July 1995; Hurricane Erin, early August 1995	Long-period large swells overtopped new berm and washed into Palmetto Blvd.	August 1995: Beach scraping to form small dune between groins 1 and 13; May 1996: Dune sand scraped back to beach	Coastal Science and Engineering, Inc.	Coastal Science and Engineering - Baird (CSE-Baird)/ Weeks Marine, Inc.; Great Lakes Dredge & Dock Co., Inc.; WestBank Construction, Inc.
HI	Northeaster, March 13, 1993 ("The Storm of the Century")	Produced fresh dune scarps and washed-out monuments; in general, backshore erosion w/in project area minor with no recession of dunes	No Action	Coastal Science and Engineering (CSE) Yr.1 - quarterly, YR. 2 -semiannual, YR. 3, 4 annual	Coastal Science and Engineering, Inc. / Great Lakes Dredge and Dock Co.
HHI	N/D	N/D	N/D	Olsen Associates, Inc., S.C. Department of Natural Resources, Marine Resources Divison	Olsen, Assoc. / Great Lakes Dredge and Dock Co.

APPENDIX A (CONTINUED)

Beach	Projected/Actual Lifespan	Historic Erosion Rates	Beach Stabilization Structures	References
MB	10 years/10 years (including emergency renourishment following Hugo)	1.0 - 2.75 cy/ft/yr mid 1950s - mid 1980s -0.4 - -0.5 ft/yr	N/A	(CSE, 1987; 1992b; 1993d; USACE, 1993)
MB	N/A	1.0 - 2.75 cy/ft/yr mid 1950s - mid 1980s -0.4 - -0.5 ft/yr	N/A	(CSE, 1987; 1992b; 1993d; USACE, 1993)
MB	N/A	1.0 - 2.75 cy/ft/yr mid 1950s - mid 1980s -0.4 - -0.5 ft/yr	N/A	(CSE, 1987; 1992b; 1993d; USACE, 1993)
MB	Reach 1: 10 years; Reach 2: 8 years; Reach 3:	1 ft/yr	N/A	(CSE, 1987; 1992b; 1993d; USACE, 1993; Limbaker, 1998)
Db	5 years/4 - 5 years	3.75 cy/ft/yr entire island 9.00 cy/ft/yr on south end ~10- 15 ft/yr. since late 1930's	Existing seawall ~4,500 ft long, 14 ft high; installed 1981 by Cubit Engineering, Ltd.	(CSE, 1995a)
FB	8 years; designed for 5 year frequency storm event/N/D	1854-1977: -9 ft/yr. -east end; -15 ft/yr. west end; 57% attributed to federal navigation project	Between 1949-1970 48 groins installed; almost entire shoreline is armored; 9 groins restored in project	(USACE, 1979; CSE, 1989; USACE, 1991)
SI	10 years/ by 1993 80% fill still within project area but below mid-tide line	1963 - 1970: +13 ft/yr south end 1970 - 1984: -18 ft/yr center 1963 - 1984: +10 north end	~5,000 ft rock revetment installed 1974 -1979; 1982: 8,000 ft of rip rap added to shoreline	(CSE, 1993c; 1995c)
EI	N/D	1854-1956:Botany Island=-34 ft/yr; Jeremy Inlet=-9 ft/yr; Collins Pier=-2.6 ft/yr with accretion at south end=+14.3 ft/yr	Repaired and used existing groins	(CSE, 1993a; CSE-Baird, 1996a; 1996b; 1997; Cubit, 1981)
HI	Less than 10 years (1992 report predicted fill "eroded completely in 2-3 years)	~20-25 cy/ft/yr. historic rates; ~18.3 cy/ft/yr. since nourishment	None existing; in 1995 CSE recommended that groins be added	(CSE, 1990; 1991; 1992a; 1993b; 1995b)
HHI	7 - 8 years/7 - 8 years	~10.00 cy/ft/yr South to north: 1.1 - 9.6 ft/yr	Several thousand feet of shoreline armored with stone revetments	(CSE, 1986; Olsen Associates, 1987; 1992; 1996)

APPENDIX B

Table 11. Edisto Island beach widths within Reaches 1 and 2.

STATION (Reaches 1-2)	Apr-95	May-95	Jul-95	Jan-96	May-96	Jul-97
1075	123	151	175	144	136	143
1300	135	165	168	163	163	166
1525	159	184	173	189	170	172
2075	146	181	195	186	174	173
2300	154	181	202	189	192	182
2525	173	199	174	206	190	182
3075	130	173	180	173	156	172
3300	126	166	172	168	162	157
3525	146	172	161	190	179	177
4075	115	165	157	121	127	140
4300	121	160	147	128	135	137
4525	122	159	150	156	148	153
5075	119	150	151	109	123	120
5300	105	139	141	125	132	123
5525	121	159	142	144	135	120
6075	113	152	155	120	132	138
6300	93	133	134	133	139	128
6525	104	142	124	152	148	140
7075	98	136	130	103	114	116
7300	105	132	131	123	128	122
7525	114	139	130	144	140	128
8075	91	136	131	98	110	127
8300	87	131	134	116	124	112
8525	79	141	123	140	129	134
9075	81	133	120	94	112	121
9300	83	124	109	116	100	113
9525	100	132	108	135	129	123
ED10300	96	134	133	126	128	133
ED10525	126	159	132	149	144	153
ED11075	136	170	156	130	143	162
ED11300	133	175	162	157	164	170
ED11525	166	173	168	188	184	185
ED12075	131	181	194	155	178	178
ED12300	162	195	189	180	137	185
ED12525	175	210	197	205	134	193
ED13075	178	217	227	192	157	193
ED13300	179	220	235	198	178	197
ED13525	206	247	235	235	193	214
ED14100	198	247	292	217	182	242
ED14350	215	271	281	254	220	250
ED14600	255	314	288	289	278	271
ED15065	260	282	310	276	280	289
ED15245	252	259	304	293	292	282
ED15450	268	268	291	306	299	283
ED19955	251	111	284	282	288	277
Average Beach Width	145	177	180	171	165	171

APPENDIX B (CONTINUED)

Table 12. Edisto Island beach widths within Reach 3.

STATION (Reach 3)	Apr-95	May-95	Jul-95	Jan-96	May-96	Jul-97
ED24100	462	491	478	471	246	456
ED24190	450	479	468	462	461	448
ED25100	429	417	444	450	197	441
ED25200	386	413	417	422	263	407
ED26115	424	413	426	419	404	416
ED26235	391	411	422	415	421	433
ED27145	421	442	442	448	435	444
ED27290	477	483	491	485	484	497
Average Beach Width	430	444	449	447	364	443

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