CHAPTER 152

BEACH PROFILE SPACING: PRACTICAL GUIDANCE FOR MONITORING NOURISHMENT PROJECTS

Timothy W. Kana, Ph.D., and Christopher J. Andrassy, P.E.[1]

ABSTRACT

A search of the literature shows there are no established standards for the spacing of profiles for postnourishment monitoring. One standard that appears to apply in the United States relates to construction surveys. Most recent nourishment projects use prefill and postfill profiles at 100-foot (ft) [~30 meter (m)] spacing for payment purposes. Rarely is this close spacing duplicated in subsequent monitoring surveys. How accurately does such spacing reflect the actual volume of fill remaining?

Four sets of closely spaced profile surveys to closure were performed over a two-year period following the 1991 Hunting Island, South Carolina, nourishment project. Fill volumes remaining within the project area were computed to closure depth using the average-end-area method. The complete dataset at 100-ft (30 m) spacing provided the basis of comparison. Volume calculations were performed for the possible combinations of profiles at greater spacings up to 1,200 ft (365 m). The normalized results show the expected increase in error as profile spacing increases. However, the variation was generally less than ±3 percent up to spacings of 500 ft (~150 m). At 1,000 ft (~365 m), the error band spanned 20 percent of the project volume. The Hunting Island dataset provides guidance for minimum profile spacing for nourishment projects with highly varying fill sections or irregular shoreline morphology. Spacings of 400-500 ft (120-150 m) provided a reasonably accurate result. Accuracy was greatly reduced at longer spacings. Longer nourishment projects, involving less variable fill volumes, likely can be evaluated at somewhat longer spacing with comparable accuracy. However, a disadvantage of surveying only the minimum number of profile lines is the error introduced if even one line has to be discarded from the dataset because of field survey errors.

[1]CSE Coastal Science & Engineering, Inc., PO Box 8056 Columbia SC 29202

INTRODUCTION

A critical aspect of beach nourishment is postproject monitoring. Periodic surveys are typically performed to determine the amount of fill remaining and establish quantitative loss rates. Beach and inshore profiles--shore-perpendicular transects from the backshore to depth of closure--are the principal database. There are no established standards for the spacing of profiles. A search of the literature shows a wide range of profile spacing, sometimes dictated by project length and economics, other times a function of the interest of the designers and owners. The more profiles obtained, the more detailed and, presumably, accurate the result. One standard that appears to apply in the United States relates to construction surveys. Most recent nourishment projects use prefill and postfill profiles at 100-foot (ft) [~30 meter (m)] spacing for payment purposes. Rarely is this close spacing duplicated in subsequent monitoring surveys.

Example profile spacings are given in Table 1. A typical spacing for routine beach monitoring or postproject evaluation appears to be 1,000 ft (~300 m), or greater. The State of Florida, for example, has one of the best established networks of profiles which are monitored at a frequency of less than once every three years (Bokuniewicz and Tanski, 1991). The State of South Carolina surveys wading depth profiles on ~1,500 ft (450 m) spacing twice per year. The 1986 Myrtle Beach (South Carolina) nourishment project (Williams and Kana, 1987) and the 1991 Ocean City (Maryland) project (Stauble and Grosskopf, 1993) have been monitored yearly or more frequently using profiles at 700-1,000 ft (215-300 m) spacing, respectively. How accurately does such spacing reflect the actual volume of fill remaining?

TABLE 1. Typical profile spacing for beach monitoring. [Sources: Bokuniewicz and Tanski (1991), Kana and Andrassy (1993), Stauble and Grosskopf (1993).]

• Pre and Post Construction:		100 ft (30 m)
• Project Monitoring:		>1,000 ft (300 m)
• Statewide Surveys:		
○ Florida		1,000 ft (300 m)
○ South Carolina		1,500 ft (450 m)
○ New Jersey		6,500 ft (2,000 m)
○ New York (proposed)		2,000 ft (600 m)
Example Projects		
Myrtle Beach (SC)	1986	750 ft (semiannual)
Ocean City (MD)	1988	1,000 ft (quarterly)

To investigate that question, the authors performed four sets of profile surveys over a two-year period following the 1991 Hunting Island, South Carolina, nourishment project. Hunting Island is a 4.2-mile (7-kilometer) long barrier island bounded by large tidal deltas (Fig. 1). Background erosion rates are exceedingly high at around 25 cubic yards per foot per year (cy/ft/yr) [62.5 cubic meters per meter per year

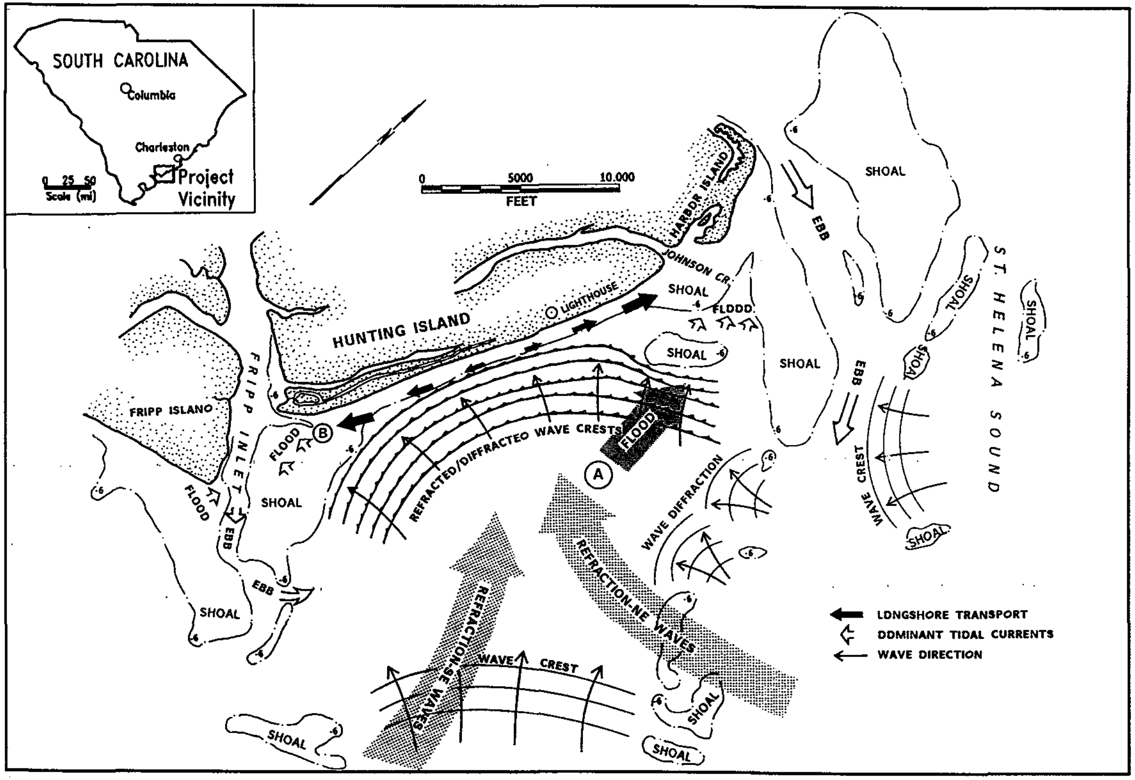

FIGURE 1. General model of coastal processes producing refraction and diffraction around shoals and sand transport away from the center of Hunting Island. Shoals are defined by the -6 ft (-1.8 m) mean low water contour as depicted on U.S. National Ocean Survey Chart No. 11513 (after CSE, 1990).

(m^3/m)] (USACE, 1977; CSE, 1990). Historical surveys in connection with earlier nourishment projects indicate that as the center of the island erodes, sediment is transported toward both ends of the island. This pattern of sediment transport appears to be controlled by wave refraction and diffraction around and through ebb-tidal delta shoals associated with St. Helena Sound, Johnson Creek, and Fripp Inlet.

Hunting Island has been nourished five times since 1968. The first four projects were engineered by the U.S. Army Corps of Engineers and were completed in 1968, 1971, 1975, and 1980 (Table 2). The 1991 project was sponsored by the South Carolina Department of Parks, Recreation and Tourism with all funding by the state. The project involved excavation of sediment from an offshore borrow area by hydraulic dredge and placement along an ~8,500 ft (2,600 m) reach in the center of Hunting Island. Mean grain size on the beach averaged 0.20 millimeter (mm) diameter before the 1991 project. Grain size in the borrow area averaged 0.22 mm diameter. The contractor (Great Lakes Dredge & Dock Company) mobilized equipment the first week of February 1991 and completed the project on 24 March 1991, 44 days after pumping began. The pay volume was based on surveys in the borrow area with a total pay volume not to exceed 755,000 cy as per terms of the contract.

TABLE 2. Beach nourishment projects along Hunting Island. [Sources: USACE (1977); CSE (1991).]

[*NOTE: USACE stations for the 1968-1980 projects run north and south from the vicinity of the lighthouse (e.g., 50+00N is 5,000 ft north; 97+00S is 9,700 ft south of the lighthouse). Total length of Hunting Island is about 21,0000 ft (±4 miles), ranging from ±70+00N to ±140+00S.]

Project*	Construction Dates	Volume (cy)	Limits of Placement	Net Unit Cost ($/cy)	Total Cost ($)
1968	Feb-Dec'68	750,000	50+00N to 50+00S*	0.58	435,178
1971	May-Dec'71	761,324	50+00N to 50+00S	0.70	534,000
1975	Apr-Jun'75	612,974	60+00N to 30+00S	1.58	971,540
1980	Jan-May'80	1,412,692	24+60N to 97+00S	1.60	2,267,201
	Subtotal	3,536,990		$1.19/cy	$4,207,919
1991	**Feb-Mar'91**	**757,644**	**7+00 to 85+00**	**$3.80/cy**	**$2,876,250**
	GRAND TOTAL	**4,294,634**		**$1.65/cy**	**$7,084,169**

The 1991 project concentrated the fill at two localities (Fig. 2). One bulge in the fill was constructed along a recreational beach access ~1.4 miles (2.3 km) from the north end of the island. The second bulge was centered at the midpoint of the island. Unit fill volumes ranged from a low of 40 cy/ft (100 m^3/m) between the two "bulges" to highs of about 140 cy/ft (350 m^3/m) and 110 cy/ft (275 m^3/m) at the north and south ends of the project, respectively.

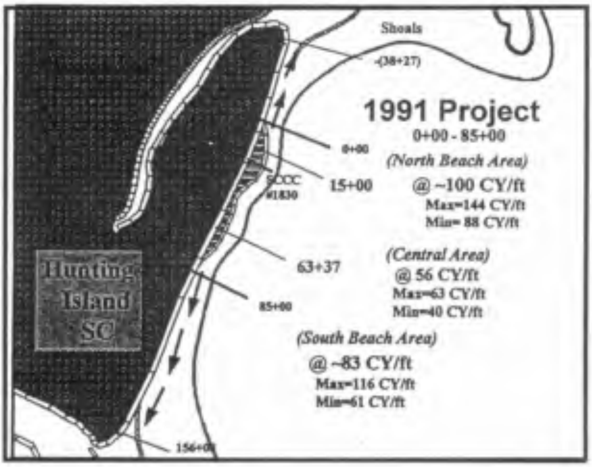

FIGURE 2. Vicinity map of the 1991 Hunting Island nourishment project fill limits between station 0+00 and 85+00 (stationing in feet divided by 100).

Profile Surveys

Profiles at 100-ft (30-m) spacing were surveyed to the estimated depth of closure along the Hunting Island project area. Closure depth was defined based on negligible profile change for available surveys, as well as morphological evidence of nearly flat slopes with distance from shore and the initial presence of mud at the surface of the substrate (Fig. 3). Closure depths range from 11 ft to 12 ft (3.3 m to 3.7 m) below mean sea level in this mesotidal setting [mean tide range equals 6.7 ft (2.05 m)]. Profiles were analyzed for unit-volume change. Fill volumes remaining within the project area were computed the traditional way by extrapolating unit volumes after each survey over representative shore lengths using the average-end-area method. Four reference lenses were developed as follows:

1) *Backshore to mean high water* — At Hunting Island, this is represented by the +10 ft to +3.2 ft (+3 m to +1 m) NGVD* contour and corresponds to the dry beach. *NGVD — National Geodetic Vertical Datum of 1929 which in South Carolina is approximately 0.5 ft (0.15 m) below present mean sea level.

2) *Intertidal beach* — From mean high water (MHW) to mean low water (MLW) [-2.2 ft -0.67 m) NGVD].

3) *Wading zone* — From MLW to -5.0 ft (-1.5 m) NGVD.

4) *Lower foreshore* — From -5.0 ft NGVD to -12.0 ft (-3.65 m) NGVD.

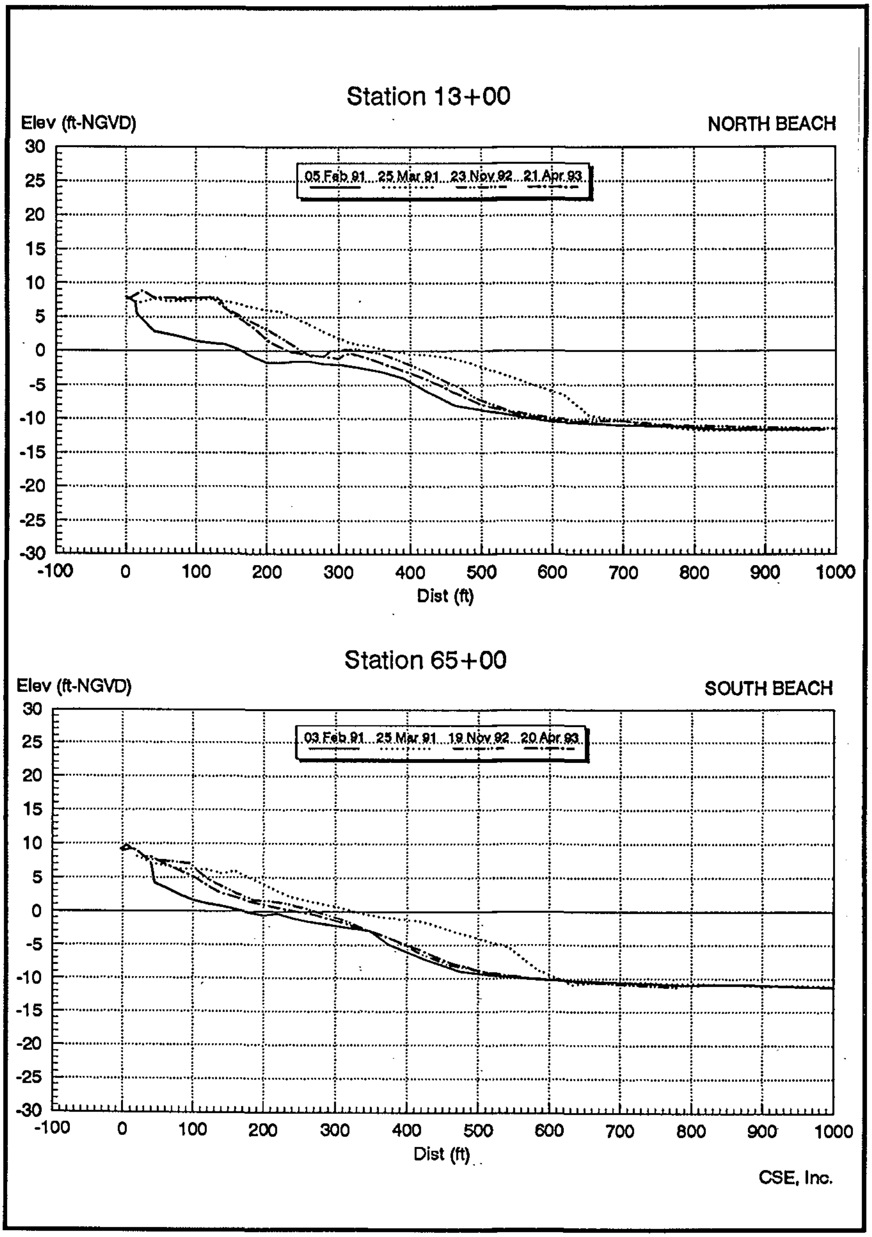

FIGURE 3. Representative profiles to closure along North Beach and South Beach before and after the March 1991 nourishment (after Kana and Andrassy, 1993).

In addition to the above contour boundaries, certain cross-shore boundaries were prescribed in the analysis. In general, the starting distance for volume calculations is at the prenourishment scarp in the backshore. The seaward limit is generally prescribed at a point within 100 ft seaward of the base of the fill.

Unit volumes (quantity of sand per unit length of shoreline between given contour intervals) and unit-volume changes between prenourishment and postnourishment surveys were computed for all profiles. The variation in unit volumes before and after nourishment within the Hunting Island project area is given in Figure 4. With minor exceptions, the quantity of sand in the profile was less than 200 cy/ft (500 m^3/m) [to -12.0 ft (-3.65 m) NGVD] before nourishment (February 1991) and ranged from 250 cy/ft (625 m^3/m) to 350 cy/ft (875 m^3/m) after nourishment (April 1991). North Beach and South Beach, by design, received the most fill. Erosion rates for the 1991 project as well as earlier projects have been exceedingly high. North Beach, in general, retained the most sand. Higher loss rates are evident at the ends of the project, particularly south of station 73+00. The average trend in unit sand volume by contour interval, retained within the project area since nourishment, is illustrated in Figure 5. These loss rates have averaged 20-25 cy/ft/yr (50-62.5 m^3/m/yr) and are nearly the same as loss rates reported after the 1971 and 1975 beach fills (USACE, 1977).

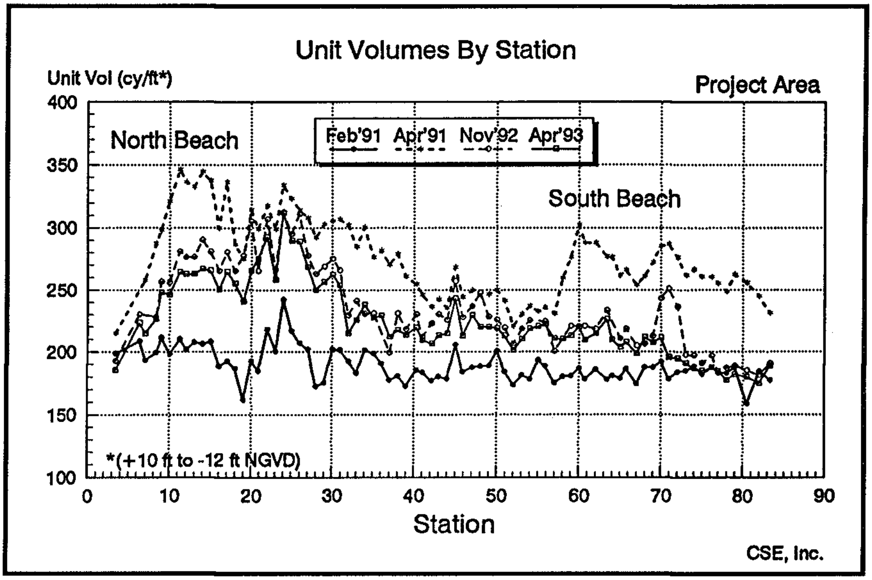

FIGURE 4. Variation in sand volume per foot of shoreline by profile station and date within the project area. Computation boundaries are from the foredune-scarp to -12.0 ft (-3.65 m) NGVD.

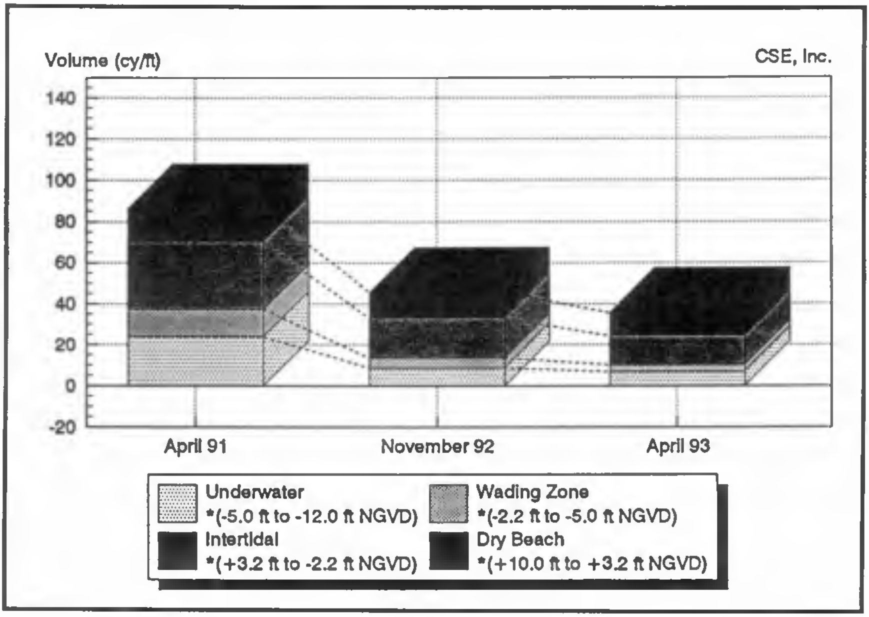

FIGURE 5. Average unit-volume beach change since nourishment (February 1991) as a function of contour interval* within the Hunting Island project area (stations 3+42 to 83+31). Note: Higher loss rate for lower beach lenses is thought to be related to variations in grain size along the profile. After Kana and Andrassy (1993).

Interestingly, the loss rate for the upper beach lenses was much lower than the underwater lenses. The dry beach to MHW (lens 1) within the project area retained 70 percent of the fill through April 1993. The intertidal beach (MHW to MLW) retained about 45 percent of the fill two years later. These two zones comprise the primary recreational zone of the beach. In contrast, the underwater lenses (mean low water to closure) retained only 27 percent by April 1993. These cross-shore variations in the rate of beach fill losses produced a steepening of the mean profile slope along the intertidal beach (see Fig. 3). Krishnamohan et al. (1993) theorize this results from the presence of a minor coarse fraction in the borrow sediments which was selectively deposited along the backshore during construction.

Profile Spacing Criteria

It is apparent profile spacing can increase for a given accuracy as the variance of individual profile volumes approaches the mean profile volume of a dataset. This is illustrated conceptually in Figure 6. The ideal case is where standard deviation of unit volume change is zero and all profiles in the dataset yield the exact mean volume change. In this case, one profile line can accurately define the performance of the nourishment project. For this to occur in the field is nearly impossible, however, given the uncertainty in placement of underwater volumes, variations in sediment quality, discharge rates, and the inherent natural variation in profile geometry. More commonly, the initial condition after nourishment will show considerable variations in actual volumes, even where fill volumes are designed to be uniform.

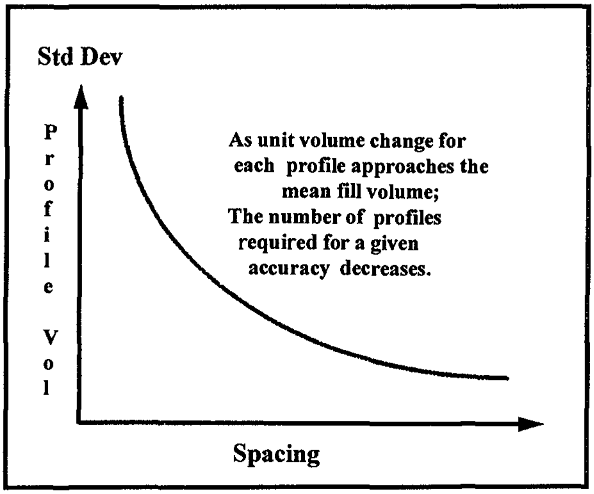

FIGURE 6. Conceptual model of the relationship of profile volume variance to profile spacing. For projects where the variance of profiles is high, more closely spaced are required to yield the "true" volume change.

The Hunting Island 1991 profile dataset, in addition to yielding a certain but unknown variance due to normal problems in controlling fill placement, included a planned variation in fill volumes. Thinnest sections designed for the center reach of the project area involved an average of only 56 cy/ft (140 m^3/m). In contrast, the north and south bulges involved average sections of 100 cy/ft (250 m^3/m) and ~83 cy/ft (207 m^3/m), respectively, as shown in Figure 2. This yielded a standard deviation in profile volume change for pre and postconstruction surveys (all profiles) of approximately ±25 cy/ft (62 m^3/m). Profile variance is also reflected in the unit volumes from station to station (see Fig. 4).

Postproject Surveys and Profile Analysis

Pre and postnourishment surveys at 100 ft (30 m) spacing provided the basis for the initial fill volume calculation. For the 1991 Hunting Island project, payment was based on borrow area surveys rather than beach surveys. Results in the borrow area confirmed an excavation volume of 757,644 cy (579,219 m^3). The initial postconstruction beach surveys confirmed an in-place volume of 715,766 cy (547,209 m^3) (CSE, 1991a). This latter volume represents 94.5 percent of the excavated quantity and is considered a satisfactory result based on the confirmed mud content of 5 percent in the borrow area (CSE, 1991b).

For purposes of evaluating project performance using various profile spacings, it was assumed the entire set of profiles at 100 ft (30 m) spacing for each of three postproject surveys yielded the true sand volume change on the beach compared to prenourishment conditions. Volume calculations were then performed for the possible combinations of profiles at greater spacings up to 1,200 ft (365 m). There are two possible combinations using profiles at 200-ft (61-m) spacing (i.e., odd-numbered stations and even-numbered stations). At 300-ft (91-m) spacing, there are three combinations and so on up to 1,200-ft (365-m) spacing. Adjacent unnourished areas were also surveyed but at a minimum profile spacing of 500 ft (152 m). By convention, the end surveys within the project area were applied in each analysis to provide a uniform shoreline length for comparison. Thus, the two profiles at each end of the project will not necessarily be spaced the same distance as the chosen profile spacing. Because of earlier surveys at variable spacing and a desire to match profile lines, certain stations were offset slightly from 100 ft (30 m) spacing. In practice, this is common because of obstructions which prevent backshore monuments from being placed at uniform distances along the shoreline.

Table 3 and Figures 7 and 8 provide results of the analysis. It can be seen that as the profile spacing increases, the range of computed sand volume changes also increases. As Table 3 shows, the normalized volume change (as a percentage of the result for all profiles in April 1991) varied by only ±3 percent up to spacings of 500 ft. At 800 ft, the error band increased to about ±5 percent; at 1,000 ft, the error band spanned about ±10 percent.

It can also be seen the percentage error reduces by April 1993 (two years postproject) when compared to the original fill volume. However, this also reflects the smaller volume being compared. If the April 1993 data are normalized against the result for all profiles in April 1993, the percent difference at 1,000-ft spacing is on the order of ±12 percent. For a project involving about one-half million cubic yards (cubic meters), this equates to a possible range from 440,000 cy (cm) to 560,000 cy (cm), computed from various profile spacings.

TABLE 3. Sand volume change as a function of the number of profiles for the Hunting Island project area (stations 3+42 to 83+31). Transition profiles 0+00 to 3+42 and 83+31 to 85+00 are excluded in profile spacing analysis, but are included in references to the initial fill volume in this paper. [*Compared to Feb'91 prenourishment; volumes in cy.]

Profile Spacing (ft)	Change in Sand Volume*			% Apr'91 — All Data		
	Apr'91	Nov'92	Apr'93	Apr'91	Nov'92	Apr'93
100	688,044	364,310	283,684	100.0	52.9	41.2
200	687,984	370,606	282,083	100.0	53.9	41.0
200	686,356	356,774	285,632	99.8	51.9	41.5
300	676,274	360,192	280,030	98.3	52.4	40.7
300	674,053	367,858	290,556	98.0	53.5	42.2
300	704,369	369,914	279,689	102.4	53.8	40.6
400	684,518	382,628	282,995	99.5	55.6	41.1
400	678,568	368,531	276,713	98.6	53.6	40.2
400	683,294	334,328	282,873	99.3	48.6	41.1
400	689,316	365,819	282,873	100.2	53.2	41.1
500	690,362	380,933	279,081	100.3	55.4	40.6
500	692,609	362,730	292,520	100.7	52.7	42.5
500	681,282	342,794	276,787	99.0	49.8	40.2
500	671,701	355,069	284,679	97.6	51.6	41.4
500	692,414	364,361	279,572	100.6	53.0	40.6
600	692,291	366,586	273,499	100.6	53.3	39.8
600	673,749	345,906	298,219	97.9	50.3	43.3
600	678,468	366,565	276,200	98.6	53.3	40.1
600	703,348	372,565	283,572	102.2	54.1	41.2
600	666,795	393,747	283,185	96.9	57.2	41.2
600	666,339	356,257	276,462	96.8	51.8	40.2
800	663,282	371,372	260,967	96.4	54.0	37.9
800	669,662	335,324	283,120	97.3	48.7	41.1
800	649,346	321,921	255,955	94.4	46.8	37.2
800	671,164	368,586	277,771	97.5	53.6	40.4
800	696,087	389,739	298,181	101.2	56.6	43.3
800	703,751	343,752	311,129	102.3	50.0	45.2
800	688,300	392,952	285,210	100.0	57.1	41.5
800	681,566	395,918	284,233	99.1	57.5	41.3

[continued . . .]

TABLE 3. (continued)

Profile Spacing (ft)	Change in Sand Volume*			% Apr'91 — All Data		
	Apr'91	Nov'92	Apr'93	Apr'91	Nov'92	Apr'93
1,000	605,373	390,369	276,788	88.0	56.7	40.2
1,000	662,836	306,811	292,476	96.3	44.6	42.5
1,000	660,298	363,351	284,311	96.0	52.8	41.3
1,000	704,117	396,662	307,580	102.3	57.7	44.7
1,000	736,092	412,425	290,777	107.0	59.9	42.3
1,000	729,360	387,250	283,878	106.0	56.3	41.3
1,000	680,873	356,546	241,304	99.0	51.8	35.1
1,000	646,969	352,494	271,981	94.0	51.2	39.5
1,000	654,105	321,139	271,866	95.1	46.7	39.5
1,000	613,281	329,670	259,566	89.1	47.9	37.7
1,200	684,896	352,287	290,984	99.5	51.2	42.3
1,200	637,199	339,229	281,853	92.6	49.3	41.0
1,200	606,005	381,766	270,707	88.1	55.5	39.3
1,200	651,454	345,424	263,448	94.7	50.2	38.3
1,200	659,058	347,853	316,214	95.8	50.6	46.0
1,200	680,001	377,555	277,574	98.8	54.9	40.3
1,200	704,075	388,157	268,647	102.3	56.4	39.0
1,200	710,351	445,059	284,561	103.2	64.7	41.4
1,200	697,919	311,538	271,016	101.4	45.3	39.4
1,200	701,185	362,156	265,173	101.9	52.6	38.5
1,200	664,103	347,339	288,246	96.5	50.5	41.9
1,200	579,424	353,125	271,109	84.2	51.3	39.4

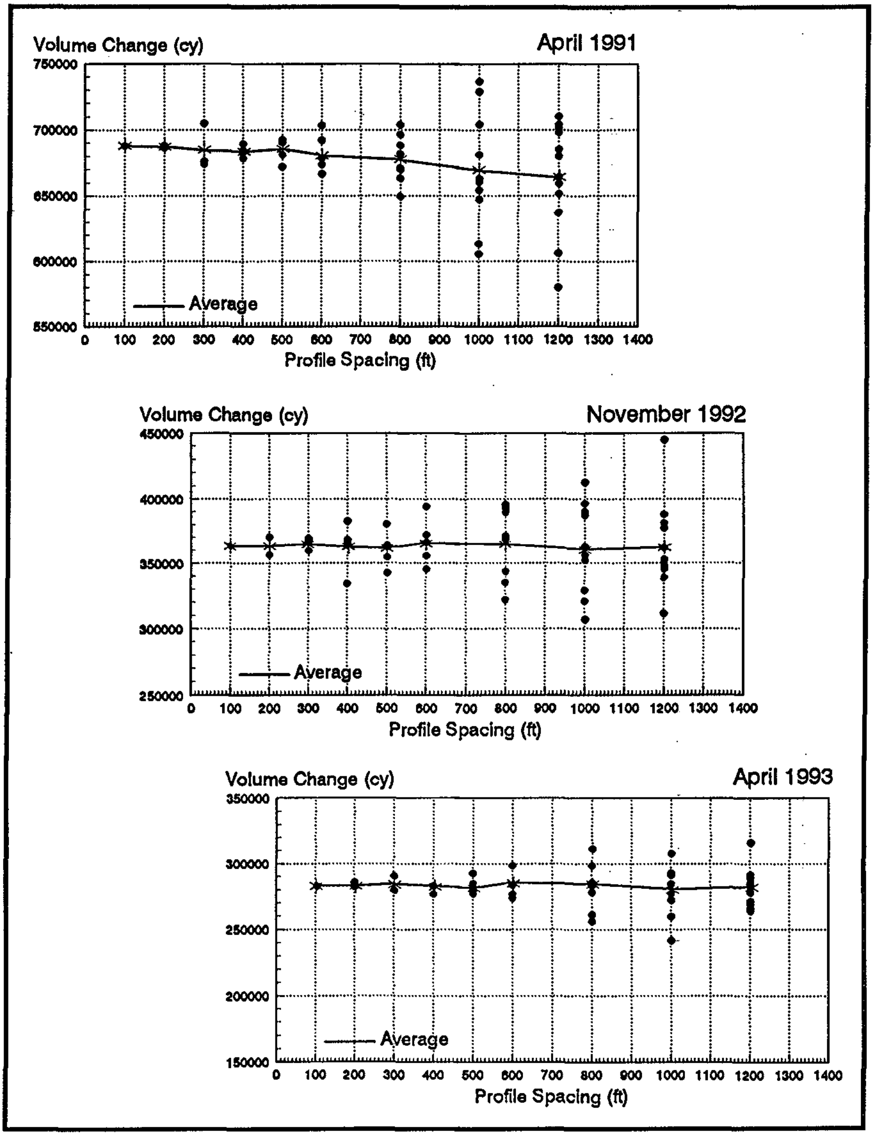

FIGURE 7. Computed sand volume changes since nourishment as a function of profile spacing for April 1991 (upper), November 1992 (middle), and April 1993 (lower) in the project area (stations 3+42 to 83+31). Averages are arithmetic and are not weighted for minor variations in profile spacing or for the fact that the ends of most profile pairs will not equal the nominal spacing, as explained in the text. After Kana and Andrassy (1993).

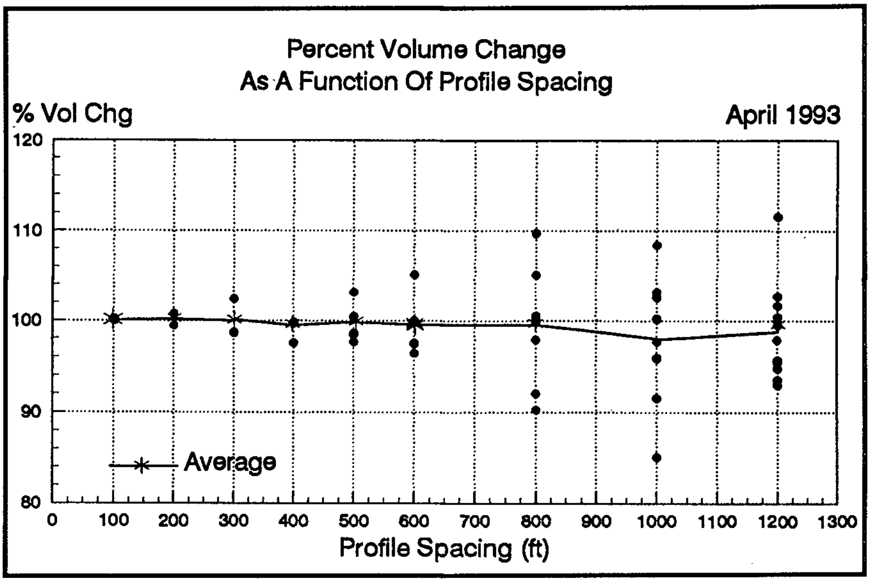

FIGURE 8. Normalized volume changes as a function of profile spacing for a post-nourishment survey of 90+ lines to closure at Hunting Island, South Carolina.

DISCUSSION

The Hunting Island dataset is somewhat unusual because of the project's short length and highly variable fill volumes (by design). A longer project with uniform fill volumes could probably be monitored at longer spacings. But in areas where rhythmic features are common along the shoreline (e.g., shoreline salients and offshore bars) or fill volumes are variable, the Hunting Island results provide some rules of thumb. In this case, profile spacings of 400-500 ft (120-150 m) appear to represent the practical limit for accurate results. Given the common uncertainty in performance because of no or few previous projects at most nourishment sites, initial monitoring should be performed in as much detail as possible. Errors of a few percentage points or less should be a requirement for all postproject surveys. Consider that a common goal of nourishment is restoration of a dry sand beach. The authors' experience suggests the upper portion of the profile which should contain the visible high-tide beach represents a small part of the profile volume. Variations in sand volume of 20-30 percent (the possible result from surveys involving large profile spacings) could mean the difference between a project yielding a viable high-tide beach and one that is not viable. With considerable debate regarding nourishment project performance, detailed profiling is one of the few means for objective analysis. Monitoring should favor as detailed a profile survey as possible.

Few datasets are available to develop any firm guidelines for profile spacing yet, but based on results of the recent Hunting Island nourishment project, it would appear profile spacings of less than 500 ft are required for a confident analysis of performance. The authors believe this will hold true for most large nourishment projects.

The suggested rule of thumb should be tested with additional datasets as they become available, but it provides a reasonable guide for most projects. Obviously, the main advantage of minimizing the number of profiles is lower expense of surveys. However, a disadvantage of surveying the fewest lines possible is the error due to profile spacing introduced if even one transect has to be discarded from the dataset because of field survey error.

ACKNOWLEDGMENTS

This study was sponsored by the South Carolina Coastal Council, South Carolina Department of Parks, Recreation and Tourism, and the U.S. Army Corps of Engineers, Coastal Engineering Research Center (CERC) (contract DACW39-92-C-0110). Field surveys in 1991 were performed by Great Lakes Dredge & Dock Company.

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