A brief history of beach nourishment in South Carolina

By

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ABSTRACT

There were ~59 discrete beach-nourishment events along the South Carolina coast between 1954 and 2010. These projects encompassed 17 localities — 62.6 miles — which is ~65 percent of the developed or accessible-park oceanfront in the state (~33.5% of the ocean coast). The total volume of nourishment through 2010 was ~44.1 million cubic yards (mcy) for an average fill density of 133.3 cubic yards per foot (cy/ft) of shoreline. The adjusted cost of all projects in 2010 constant dollars (2010$$) was (~)$351 million for an average unit-volume cost of $7.96/cy (2010$$). Nourishment volumes by decade peaked in the 1990s at 20.7 mcy — 47 percent of the total. Between 2000 and 2010, nourishment volumes declined to ~12.7 mcy partly due to reduced need following initial restoration efforts at some sites. Six project areas (North Myrtle Beach, Myrtle Beach, Garden City-Surfside Beach, Folly Beach, Hunting Island, and Hilton Head Island), comprising 42.6 miles of coast, have received about 70% of the nourishment volume. Most of these sites have measurably wider beachfront area compared with pre-nourishment conditions. Hilton Head Island, with five events since 1969, has received 10.6 mcy. Three sites (Debidue Beach, Folly spit, and Hunting Island), comprising ~7% of the nourished shoreline in South Carolina, have not kept pace with erosion and have lost beachfront area. The volume and cost of nourishment applied over project lengths and time periods yield South Carolina expenditures averaging (~)$39 per foot of shoreline per year (2010$$) [range (~)$7–$107/ft/yr]. The present value of developed oceanfront shoreline in South Carolina is roughly in the range $5,000 to $50,000 per linear foot. Thus, annualized expenditures for areas nourished have averaged well under 1% of property values.

ADDITIONAL KEYWORDS: Beach nourishment, South Carolina, fill density, unit volumes, unit costs.

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The first beach nourishment project in South Carolina was at Edisto Beach in 1954 (Figure 1). That project involved 830,000 cubic yards (cy) of poor-quality material dredged from the back-barrier salt marsh and placed by hydraulic dredge along 1 mile of eroding shoreline (USACE 1969, Cubit 1987). The muddy sediments (visible as large plumes on historical aerial photographs) quickly winnowed from the beach, leaving in place a concentration of oyster shells, enhancing Edisto's reputation as the shelliest beach in South Carolina. Since 1954, nearly five dozen nourishment events have added over 44 million cubic yards (mcy) to 63 miles of beach at a present-day cost of (~)$350 million (Figure 2). Some projects, like Edisto's first, placed less-than-ideal sediments on the beach. However, over time, the quality of nourishment material has improved, the volume of projects has increased, and the condition of many South Carolina beaches is better.

South Carolina's nourishment history is as varied as its segmented coast. With numerous tidal inlets and large ebb-tidal deltas in this "mixed-energy" setting (Hayes 1994), the 187-mile ocean shoreline exhibits diverse signatures of erosion, development styles, and shore-protection measures (London *et al.* 2009, OCRM 2010). The northeast portion of the coast (the "Grand Strand") is a relatively stable 35-mile-long arcuate segment between two of South Carolina's four jettied inlets (Little River and Murrells). The central part of the coast around Charleston contains almost a dozen beach-ridge barrier islands, several of which have the classic drumstick morphology (e.g. Bull Island, Isle of Palms, Kiawah Island — Hayes 1979). Mean tide range (6.9 ft, NOAA-COOPS) and the size of inlets reaches a maximum near Hilton Head Island and Daufuskie Island at the southwest end of the state with nearly every foot of "ocean" shoreline influenced by ebb-tidal delta shoals (Hayes and Michel 2008).

About 53% (~98 miles) of the ocean coast is developed (or accessible park) land. The remainder (~89 miles) is largely inaccessible and undeveloped wilderness beaches. Of the developed beaches, fully 65% have received nourishment at some level during the past 55 years as detailed herein.

PURPOSE

As part of a larger effort to track regional sand volumes at decadal-to-century time scales for community planning, the author searched for nourishment records from numerous sources, particularly the agencies responsible for permitting and executing projects. It soon became clear that records are incomplete, inconsistent, or impossible to find for some older projects. Nevertheless, to track littoral volumes over time, quantities placed in nourishment events are an important component of sand budgets at mesoscales.

This paper is an attempt to compile best-available data on the volumes placed, lengths of shoreline directly nourished, and costs of each project. Source references should be checked for details on borrow area locations and sediment quality, particularly reports by South Carolina Department of Natural Resources (SCDNR) (e.g. Van Dolah *et al.* 1998).

METHODS

Nourishment projects selected for inclusion were implemented between 1954 and December 2010, nominally a "55-year" period. Each project was assigned to the decade completed, particularly those straddling different decades during construction. Primary data sources in order of importance include:

- Unpublished project records and final reports of quantities, costs, and placement limits.
- Interviews and correspondence with project engineers, particularly USACE officials.
- State permitting records.
- Pre-project planning documents.
- Third-party scientific publications.
- Media reports.

To keep the present paper brief, no more than two sources are listed for each project. Future researchers many uncover more precise archived records for some projects. In the detailed tabulations that follow, volumes that are considered imprecise are given in rounded amounts. The lengths and volumes given with greater precision are "in-place" measures as documented by post-nourishment surveys as reported by engineers and published in final reports or other unpublished project documents. Where pay volumes and "in-place" volumes are available from source documents, the volume listed is the best-available "in-place" volume since the goal is to account for actual quantities added to the beach. For example, several Hilton Head Island projects have involved considerably higher "in-place" volumes than the pay volumes for the benefit of the community (OA 1992, 1999).

Cost information was similarly compiled from project records to the extent possible. The "federal" projects executed by USACE generally include engineering, planning, and related "soft costs" whereas most of the locally-sponsored projects only include construction costs. Some of the

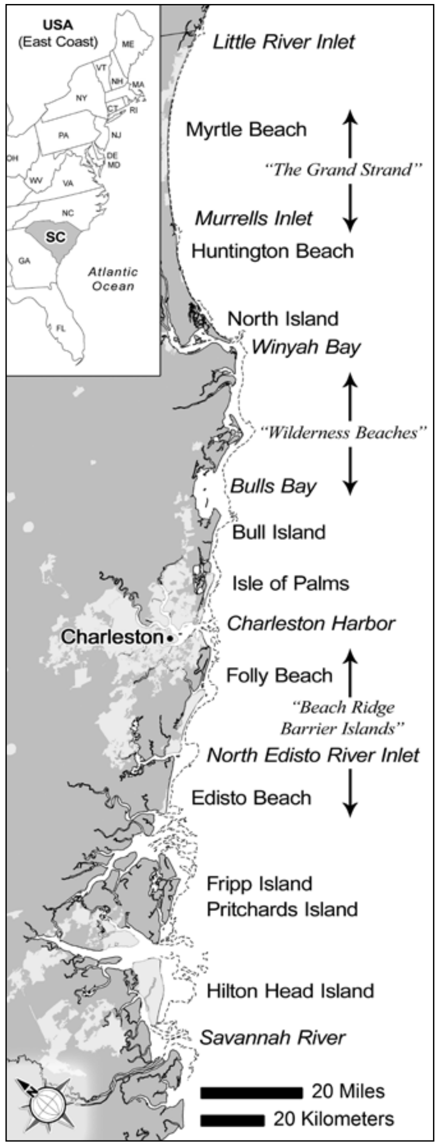


Figure 1. Vicinity map of the South Carolina coast.

bypassing projects associated with jetty construction at Murrells Inlet (1977) and Little River Inlet (1980) were rolled into all capital costs. The nourishment component had to be apportioned from the totals. In some cases (given in *italics*), a cost estimate is based on similar unit-pumping costs for the time period of execution. While these estimates are ripe for future revision, the author found that they constitute a small proportion of the overall expenditures. The large projects, accounting for the majority of nourishment volumes and costs, are generally well documented.

English units and original project costs at time of construction are listed herein for consistency with the source documents. This is to facilitate cross-referencing of quantities in the future. The original cost of each project was converted to 2010 constant dollars (2010$$) using the USACE Civil Works Construction Cost Index System — Base Year 1967 (CWCCIS 2012). The tabulations give the index normalized to the Year 2010 (i.e. = 1.0), which yields an adjusted cost in 2010 dollars for each project.

Applicable lengths and project durations

Project lengths (in feet) are as documented in the original sources. In cases of multiple nourishment events and overlapping areas within a particular locality, the maximum length of shoreline nourished over time was used as the "project length." For example, Hunting Island has been nourished eight times since 1968 with individual projects ranging from 2,484 to 12,160 linear feet. Upon review of the stationing and limits of these projects, it was determined that ~15,700 linear feet (~75% of the Hunting Island ocean shoreline) have received nourishment. This "impact" length was adopted for calculation of unit rates.

The applicable years of project impacts were assumed to begin around the time of the first nourishment at a site and to extend through 2010. These periods were arbitrarily rounded in nearest five-year increments so as to provide measures of annualized unit volumes and costs. The longest duration project is, therefore, Edisto Beach, at 55 years while the shortest duration project is Daufuskie Island (ATM unpublished data), which was constructed in 1999.

The annualized expenditures for projects are highly sensitive to the applicable duration, of course, but some time period must be assumed. In the case of Edisto Beach, the second and third projects did not occur until 40-50 years later (1995

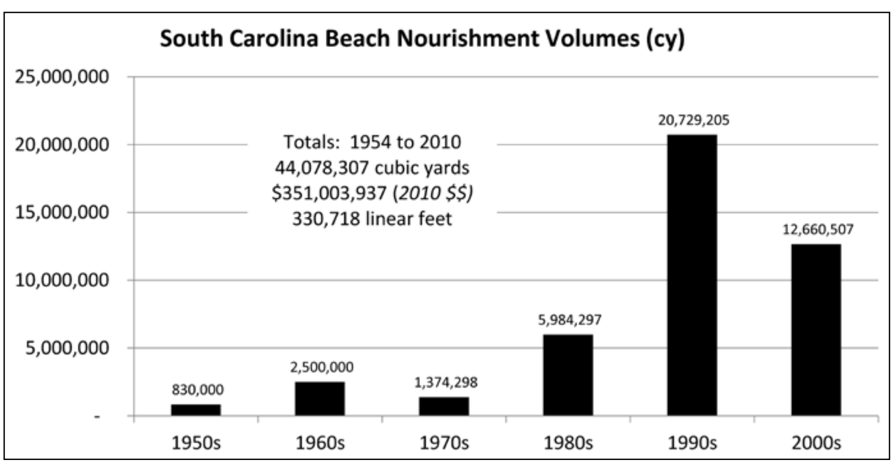


Figure 2. Beach nourishment volumes (in cubic yards [cy]) by decade. Sources listed in Tables 1-2.

and 2006), so the annualized expenditure is relatively low compared with Daufuskie Island. Omission of the 1954 project brings Edisto's expenditures more in line with statewide averages.

Unit measures

The fundamental unit of littoral sediment budgets is a volume per unit length of shoreline within defined cross-shore boundaries (Kraus and Rosati 1998, Rosati 2005). In English units, the standard measure is cubic yards per linear foot of shoreline (cy/ft). Also referred to as "fill density" (Dean 2002), *average* unit volumes were computed for each nourishment event using the reported volume and project length irrespective of variations in fill density common for most projects. Results of individual projects show this value to range from under 10 cy/ft to over 200 cy/ft, with obvious implications for performance, project impacts, and public perceptions. When annualized over applicable project periods, the unit fill volumes can be compared with unit volume changes and background erosion rates as a first-cut determination of whether nourishment is keeping pace.

Aggregate project costs were similarly apportioned over distance and time to derive annualized unit costs. This is, perhaps, the most interesting result of nourishment compilations because it offers community planners a measure of relative expenditures from site to site, particularly in relation to property values. The results herein show a range of annual expenditures (2010$$) between (~)$10/ft/yr to (~)$100/ft/yr [average (~)$40/ft/yr]. South Carolina oceanfront property values today are roughly in the range $5,000-$50,000 per foot of shoreline[1] (source: www.zillow.com). The ratio of unit nourishment cost to unit property value is an objective measure of maintenance-cost efficiency. In nearly all cases, the annual expenditures for nourishment have averaged well below 1% of property values at the project sites.

1)This assumes a typical oceanfront property spans ~100 ft of shoreline. Therefore, the low end of the range would be a property worth (~)$500,000 whereas the high end of the range would be property worth (~)$5 million. The author is personally familiar with a number of hotels in Myrtle Beach as well as beachfront homes in high-end resorts, such as Kiawah Island and Hilton Head Island, with ~100-ft frontage that would exceed the high end of the range in today's market. Similarly, there may be some undeveloped oceanfront lots that can be purchased for less than the low end of the range, although the author is not aware of any.

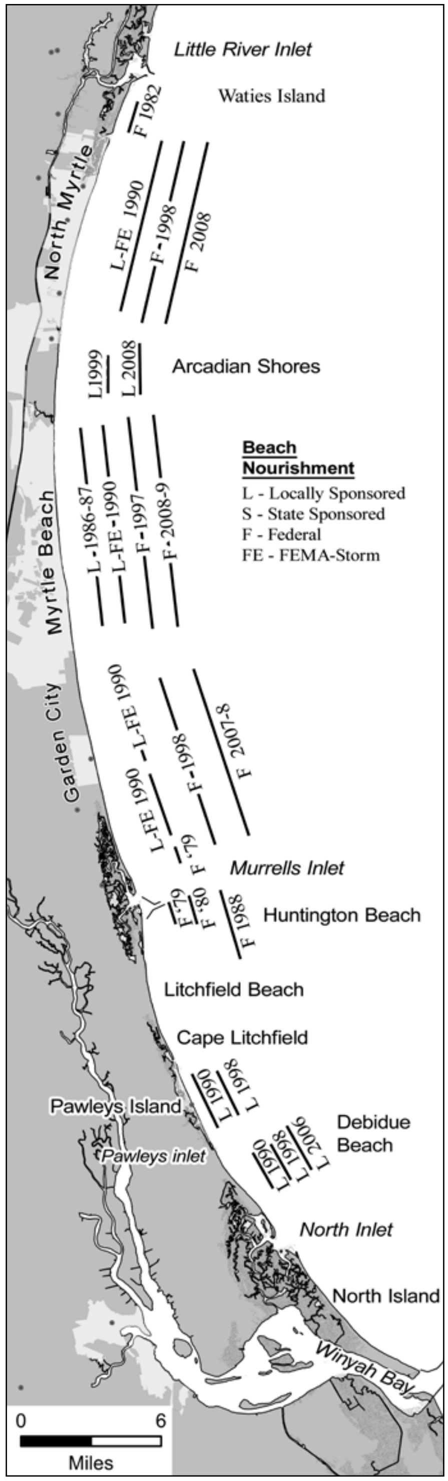


Figure 3 (above). General locations of nourishment events along the north coast of South Carolina. See Table 1 for details of each project.

Figure 4 (right). General locations of nourishment events along the south coast of South Carolina. Note "a-f" at Folly Beach correspond to Folly spit events. Letters "a–b" at Hilton Head Island are "Sea Pines" events. Hunting Island events (#1-8) are detailed in Table 2.

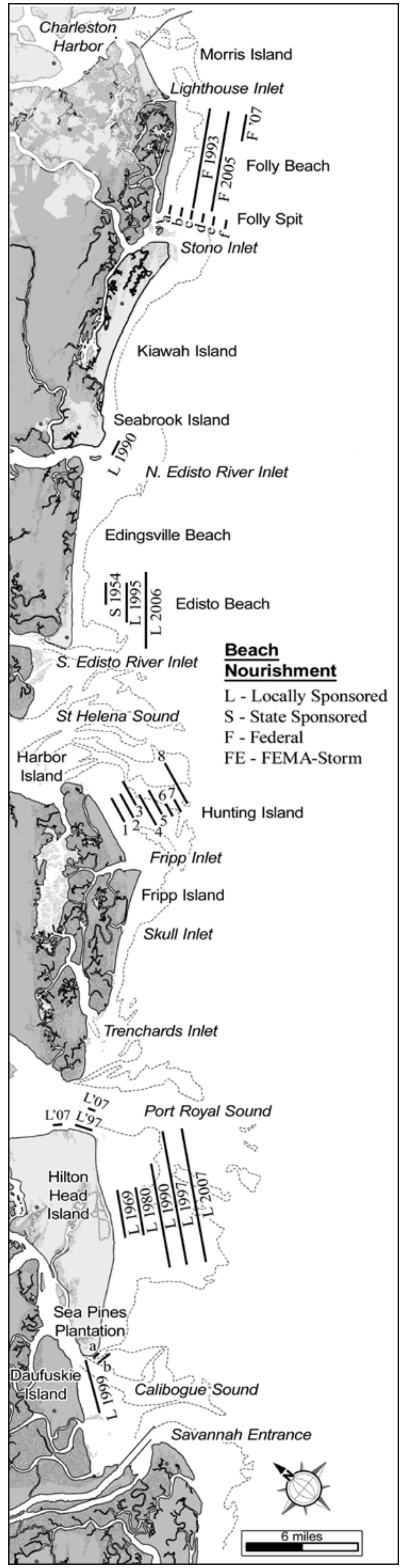


Table 1.

South Carolina beach nourishment projects generally involving non-beach sand sources in geographic and chronological order from north to south (see Figs. 3 and 4).

Locality north to south (fund[1])	Year completed	Length (ft)	Volume (cy)	Unit vol. (cy/ft)	Orig. cost (*estimate*)	Means[2] borrow[3]	Const.[4] index (USACE)	Adjusted cost 2010$$	Adjusted unit vol. cost ($/cy)
Waties Island F-N	1982	6,500	513,000	78.9	*$850,000*	Nav-By	0.432	$1,967,655	$3.84
North Myrtle Beach(1) L-FE	1990	42,360	376,920	8.9	$1,937,000	Tr-Sh	0.547	$3,542,488	$9.40
North Myrtle Beach (2) F	1997	45,400	2,622,904	57.8	$20,154,213	D-Off	0.644	$31,318,277	$11.94
North Myrtle Beach (3) F	2008	45,400	902,725	19.9	$9,554,008	DH-Off	0.937	$10,198,484	$11.30
Arcadian Shores (1) L	1999	4,780	446,000	93.3	$4,093,218	D-Off	0.689	$5,938,770	$13.32
Arcadian Shores (2) L	2008	6,400	331,574	51.8	$4,097,223	DH-Off	0.937	$4,373,606	$13.19
Myrtle Beach (1) L	1987	45,100	853,350	18.9	$4,736,000	Tr-In	0.482	$9,824,391	$11.51
Myrtle Beach (2) FE	1990	44,900	395,960	8.8	$2,667,600	Tr-In	0.547	$4,878,648	$12.32
Myrtle Beach (3) F	1997	48,780	2,249,916	46.1	$16,870,194	D-Off	0.654	$25,777,643	$11.46
Myrtle Beach (4) F	2009	48,780	1,497,975	30.7	$17,612,822	DH-Off	0.937	$18,800,915	$12.55
Garden City Beach F-N	1979	4,000	633,497	158.4	*$950,000*	Nav-By	0.330	$2,881,163	$4.55
Surfside Beach L-FE	1990	5,000	70,000	14.0	$581,250	Tr-In	0.547	$1,063,021	$15.19
Garden City Beach L-FE	1990	13,500	163,500	12.1	$1,640,000	Tr-In	0.547	$2,999,319	$18.34
Garden City Beach F	1998	30,000	1,517,494	50.6	$14,294,614	DH-Off	0.670	$21,345,090	$14.07
Garden City/ Surfside F	2008	40,650	857,633	21.1	$10,448,954	D-Off	0.937	$11,153,800	$13.01
Huntington Beach (1) F-N	1979	2,800	353,232	126.2	*$530,000*	Nav-By	0.330	$1,607,386	$4.55
Huntington Beach (2) F-N	1980	4,000	542,944	135.7	*$815,000*	Nav-By	0.361	$2,260,174	$4.16
Huntington Beach (3) F-N	1988	10,000	450,000	45.0	$900,000	Nav-By	0.506	$1,776,955	$3.95
Pawleys Island (1) L	1990	16,200	220,000	13.6	$612,000	Tr-Sh	0.689	$887,939	$4.04
Pawleys Island (2) L	1999	13,200	270,000	20.5	$800,000	Tr-Sh	0.547	$1,463,082	$5.42
Debidue Beach (1) L	1990	8,030	191,693	23.9	$862,600	Tr-In	0.547	$1,577,569	$8.23
Debidue Beach (2) L	1998	7,980	262,386	32.9	$950,000	Tr-In	0.670	$1,418,565	$5.41
Debidue Beach (3) L	2006	8,500	590,000	69.4	$6,000,000	DH-Off	0.872	$6,884,367	$11.67
Isle of Palms (1) L	1984	5,000	350,000	70.0	$1,000,000	D-Lag	0.464	$2,154,871	$6.16
Isle of Palms (2) L	2008	10,200	933,895	91.6	$8,402,090	D-Off	0.937	$8,968,862	$9.60

Notes/key:

1) Principal funding by: F=Federal (USACE); FE-FEMA Post-storm; L=Local (state, county, municipal, homeowners associations); N=Federal navigation/disposal/bypassing.

2) Means of construction: D=hydraulic pipeline dredge; DH=hopper dredge; Tr=trucks; Nav-By=Dredging and bypassing at Inlets; Nav-Dis=Disposal of harbor dredging.

3) Borrow area type: Sh=Attached shoals at inlets; Off=Offshore generally beyond littoral zone; In=Inland deposits; Lag=Lagoon, marsh, tidal creek.

4) On 2010 Transformed from USACE Civil Works Construction Cost Index System (CWCCIS-1967 Base Year), USACE Engineering and Design Manual, EM 1110-2-1304, dated 31 March 2012.

5) "Unpub" includes memoranda, correspondence and pers. comm. from USACE-Charleston District, Olsen Associates, Horry County Public Works, and Applied Technology & Management Inc.

Adjusted unit length cost ($/ft)	Notes sources[5]
$302.72	Chasten 1992
$83.63	CSE 1990a
$689.83	USACE unpub.
$224.64	USACE unpub.; McCoy *et al.* 2010
$1,242.42	Horry County unpub.
$683.38	Horry County unpub.; CSE 2008a
$217.84	Eiser & Jones 1989; Kana *et al.* 1997
$108.66	Kana & Andrassy 1993
$528.45	USACE unpub.; CSE 2005
$385.42	USACE unpub.; McCoy *et al.* 2010
$720.29	Douglass 1987
$212.60	Kana *et al.* 1990
$222.17	Kana *et al.* 1990
$711.50	USACE unpub.
$274.39	USACE unpub.; McCoy *et al.* 2010
$574.07	Douglass 1987; USACE unpub.
$565.04	Douglass 1987; USACE unpub.
$177.70	USACE unpub.; Kana 1990
$54.81	Kana 1990
$110.84	Kana *et al.* 2004
$196.46	CSE Baird 1996
$177.77	CSE Baird 1999
$809.93	ATM unpub.
$430.97	Williams & Kana 1987
$879.30	CSE 2008b

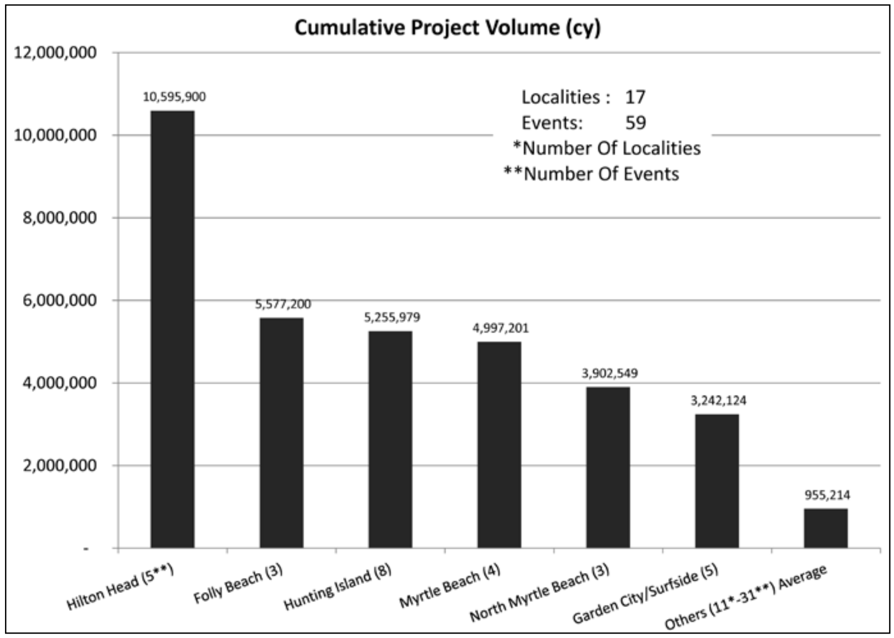


Figure 5. Nourishment volume for six projects accounts for 70% of the statewide total through 2010.

Qualitative performance

Detailed performance measures, such as the percent or absolute volume of nourishment remaining, are available for some projects in the various source documents and should be consulted for details. London *et al.* (2009) used aerial photography to compile estimates of "beachfront lands" gained or lost between 1987 and 2006. Because this ~20-year period coincides with a majority of the beach nourishment events in South Carolina, the London *et al.* data provide an independent measure of whether nourishment has had a sustained positive impact at a particular locality.

It can be shown that, for many U.S. East Coast sites, 1 cy of nourishment adds the equivalent of roughly 1 square foot (ft^2) of beach area (CERC 1984). The ratio for South Carolina beaches is actually more generous because of shallower limits of the active littoral zone (i.e. zone of annual cross-shore sediment transport). In some localities, such as Hunting Island where the normal limit of measurable volume change is ~12 ft

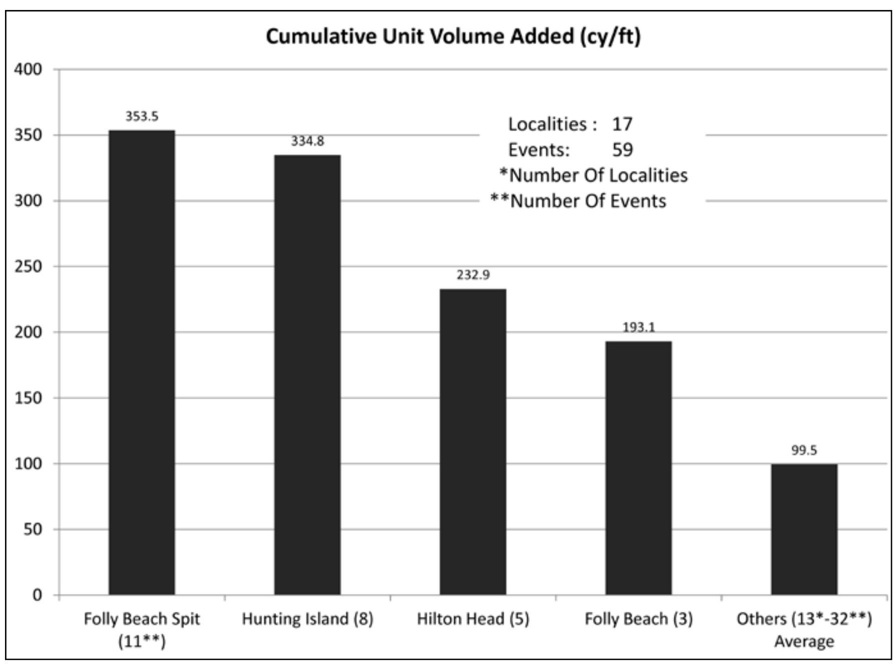


Figure 6. Average total fill density for four project areas. Statewide average for 17 nourishment sites is 133.3 cy/ft.

Table 2.

South Carolina beach nourishment projects generally involving non-beach sand sources in geographic and chronological order from north to south (see Figs. 3 and 4). See Table 1 for key.

Locality north to south (fund[1])	Year completed	Length (ft)	Volume (cy)	Unit vol. (cy/ft)	Orig cost (*estimate*)	Means[2] borrow[3]	Const.[4] index (USACE)	Adjusted cost 2010$$	Adjusted unit vol cost ($/cy)	Adjusted unit length cost ($/ft)
Folly Beach (1) F	1993	28,200	2,695,900	95.6	$12,538,693	D-Lag	0.596	$21,039,064	$7.80	$746.07
Folly Beach (2) F	2005	28,880	2,395,200	82.9	$14,227,825	D-Off	0.832	$17,093,165	$7.14	$591.87
Folly Beach (3) F	2007	10,140	486,100	47.9	$8,185,024	D-Off	0.910	$8,989,992	$18.49	$886.59
Folly Beach Spit (1) F-N	1979	1,500	20,022	13.3	*$33,000*	Nav-Dis	0.330	$100,083	$5.00	$66.72
Folly Beach Spit (2-7) F-N	1982-88	1,500	305,560	203.7	*$500,000*	Nav-Dis	0.464	$1,077,435	$3.53	$718.29
Folly Beach Spit (8) F-N	1990	1,500	*200,000*	133.3	*$500,000*	Nav-Dis	0.547	$914,426	$4.57	$609.62
Folly Beach Spit (9) F-N	1990	1,500	*40,000*	26.7	*$100,000*	Nav-Dis	0.547	$182,885	$4.57	$121.92
Folly Beach Spit (10) F-N	1998	2,000	*40,000*	20.0	*$120,000*	Nav-Dis	0.670	$179,187	$4.48	$89.59
Folly Beach Spit (11) F-N	2000	2,000	101,513	50.8	$307,610	Nav-Dis	0.704	$437,240	$4.31	$218.62
Seabrook Isl.	1990	5,850	684,474	117.0	$1,660,000	D-Off	0.547	$3,035,896	$4.44	$518.96
Edisto Beach (1) L	1954	5,400	830,000	153.7	*$400,000*	D-Lag	0.080	$5,000,000	$6.02	$925.93
Edisto Beach (2) L	1995	10,371	148,414	14.3	*$1,100,000*	D-Off; Tr	0.626	$1,756,882	$11.84	$169.40
Edisto Beach State Park L	2006	3,200	181,728	56.8	$1,593,866	D-Off	0.872	$1,828,792	$10.06	$571.50
Edisto Beach (3) L	2006	15,058	695,919	46.2	$6,103,634	D-Off	0.872	$7,003,276	$10.06	$465.09
Hunting Isl. (1) F	1968	10,000	750,000	75.0	$435,178	D-Lag	0.140	$3,105,134	$4.14	$310.51
Hunting Isl. (2) F	1971	10,000	761,324	76.1	$534,000	D-Lag	0.168	$3,184,570	$4.18	$318.46
Hunting Isl. (3) F	1975	8,860	612,974	69.2	$971,540	D-Sh.	0.249	$3,904,517	$6.37	$440.69
Hunting Isl. (4) F	1980	12,160	1,412,692	116.2	$1,267,201	D-Sh.	0.361	$3,514,227	$2.49	$289.00
Hunting Isl. (5) L	1991	7,800	757,644	97.1	$2,876,250	D-Off	0.562	$5,116,397	$6.75	$655.95
Hunting Isl. (6) F	2003	2,484	230,031	92.6	$2,480,250	D-Sh.	0.772	$3,212,146	$13.96	$1,293.13
Hunting Isl. (7) F	2005	2,484	87,092	35.1	$1,666,326	D-Sh.	0.832	$2,001,907	$22.99	$805.92
Hunting Isl. (8) L	2006	7,985	644,222	80.7	$4,379,300	D-Off	0.872	$5,024,784	$7.80	$629.28
Hilton Head Island (1) L	1969	14,600	*1,600,000*	109.6	*$1,000,000*	Tr-In	0.150	$6,680,783	$4.18	$457.59
Hilton Head Island (2) L	1980	14,600	*550,000*	37.7	*$1,100,000*	Tr-In	0.361	$3,050,542	$5.55	$208.94
Hilton Head Island (3) L	1990	35,000	2,338,000	66.8	$9,044,760	D-Off	0.547	$16,541,536	$7.08	$472.62
Hilton Head Island (4) L	1997	43,500	3,383,000	77.8	$8,711,342	D-Off	0.654	$13,310,924	$3.93	$306.00
Hilton Head Island (5) L	2007	45,500	2,724,900	59.9	$16,709,831	D-Off	0.910	$18,353,183	$6.74	$403.37
Hilton Head-Sea Pines (1) L	1969	1,200	*150,000*	125.0	*$100,000*	Tr-In	0.150	$668,078	$4.45	$556.73
Hilton Head-Sea Pines (2) L	1999	3,400	245,000	72.1	$1,140,000	D-Off	0.689	$1,654,004	$6.75	$486.47
Daufuskie L	1999	18,500	1,410,000	76.2	$5,500,000	D-Off	0.689	$7,979,842	$5.66	$431.34

Notes sources[5]
Edge *et al.* 1994;
Ebersole *et al.* 1996
Bergquist *et al.* 2007;
USACE unpub.
USACE unpub.
Jones 1989; USACE unpub.
Jones 1989; USACE unpub.
Kana 1990; CCPRC unpub.
USACE unpub.
USACE unpub.
USACE unpub.
CSE 1990b; Kana 1990
USACE 1969; Cubit 1987
CSE Baird 1996
Kana *et al.* 2004
CSE 2006
CSE 2006
USACE 1977; Traynum *et al.* 2010
USACE 1977; Traynum *et al.* 2010
USACE 1977; Traynum *et al.* 2010
London *et al.* 1981;
Traynum *et al.* 2010
Kana & Andrassy 1993
USACE unpub.;
Traynum *et al.* 2010
USACE unpub.;
Traynum *et al.* 2010
CSE 2007; Traynum *et al.* 2010
USACE 1974
Kana 1990; Palmetto Dunes unpub.
OA 1992; Bodge *et al.* 1993
OA 1999; OA unpub.
OA 2008; OA unpub.
USACE 1974
OA 2006; OA, unpub.
ATM unpub.; London *et al.* 2009

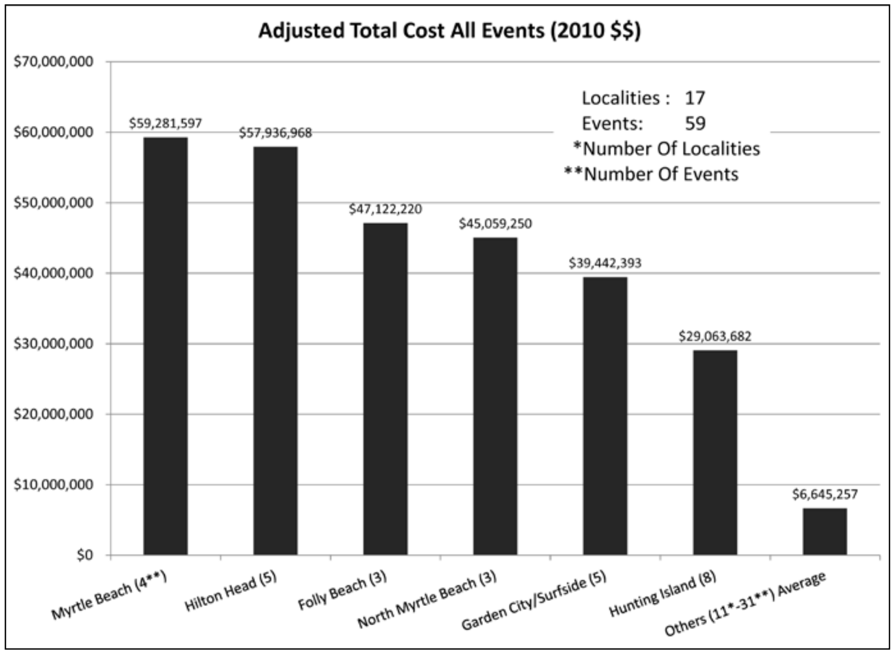


Figure 7. Total expenditures to date for six project sites in 2010 constant dollars.

NAVD, 1 cy adds ~1.5 ft² to the beach (Traynum *et al.* 2010).

Other tangible indicators of performance include burial of seawalls, growth of dunes, or lack of property abandonment to erosion, which are visible and obvious in the event. No attempt is made herein to rigorously quantify performance of each project, and any opinions expressed are based largely on the author's first-hand experience at a site.

RESULTS

A total of 59 discrete nourishment events placed at ~17 localities were identified for the period 1954-2010 (Tables 1 and 2). Projects involving sand scraping from nearby attached shoals are generally excluded in favor of projects that introduce a new sand volume (at decadal scales) from non-beach sources. Possible exceptions to this are two events at Pawleys Island (south of Murrells Inlet — Figure 3) in which the downcoast spit and shoals of Pawleys Inlet were excavated and "recycled" updrift along the Pawleys Island littoral cell. Similarly, inlet dredging and bypassing projects at Little River at the North Carolina border (Chasten 1992) and Murrells Inlet (Douglass 1987) are included under the assumption those volumes would not likely have been available to the adjacent beaches due to the presence of jetties.

Projects are sorted in north-to-south geographic and chronological order in Tables 1 and 2, with localities shown on Figures 3 and 4. Figure 3 covers projects north of Winyah Bay while Figure 4 shows areas south of Charleston Harbor. The ~60-mile-long segment of coast between Winyah Bay and Charleston (see Figure 1) is mainly wilderness area with only one site at the northeast end of Isle of Palms receiving nourishment to date. The graphics include shore-parallel lines roughly corresponding to the alongshore placement limits. Dates for each event and the primary funding source are given without further breakdown. Tables 1 and 2 also list the means of construction and types of borrow sources.

In South Carolina, some "offshore" borrow areas (e.g. Gaskin Banks off Hilton Head Island, OA 1992) are more accurately portions of ebb-tidal deltas. Nevertheless, they are referenced as offshore here because of the scale of many deltas. Port Royal Sound at Hilton Head Island (Figure 4, bottom of map), for example, contains over 200 mcy with shoals extending miles offshore. Borrow areas within the delta complex, while in relatively shallow water depths, are generally removed from the active beach zone and are not expected to feed the adjacent beach by natural bypassing at decadal scales (Gaudiano and Kana 2001).

Table 3 consolidates the results into 17 nourishment areas, indicating the total number of events per area and the applicable years. False precision is retained for the totals for purposes of

Table 3.

Total nourishment applied to 17 project areas in South Carolina. Applicable years are to the nearest five years starting with the first event at a site. Length is the total ocean frontage receiving direct nourishment in at least one event. See text for further explanation.

Locality (number of events)	Applicable years	Length (ft)	Volume (cy)	Unit vol. (cy/ft)	Orig. cost (estimate)	Adjusted cost (2010$$)	Adjusted unit vol cost ($/cy)	Adjusted unit lngth cost ($/ft)	~Yrs since since 1st nourish	Annualized unit vol. (cy/ft/yr)	Annualized unit lngth cost ($/ft/yr)
Waties Island (1)	1980-2010	6,500	513,000	78.9	*$850,000*	$1,967,655	$3.84	$302.72	30	2.63	$10.09
North Myrtle Beach (3)	1990-2010	45,400	3,902,549	86.0	$31,645,221	$45,059,250	$11.55	$992.49	20	4.30	$49.62
Arcadian Shores (2)	1995-2010	6,400	777,574	121.5	$8,190,441	$10,312,376	$13.26	$1,611.31	15	8.10	$107.42
Myrtle Beach (4)	1985-2010	48,780	4,997,201	102.4	$41,886,616	$59,281,597	$11.86	$1,215.28	25	4.10	$48.61
Garden City/ Surfside (5)	1990-2010	40,650	3,242,124	79.8	$27,914,818	$39,442,393	$12.17	$970.29	20	3.99	$48.51
Huntington Beach (3)	1980-2010	10,000	1,346,176	134.6	*$2,245,000*	$5,644,515	$4.19	$564.45	30	4.49	$18.82
Pawleys Island (2)	1990-2010	16,200	490,000	30.2	$1,412,000	$2,351,021	$4.80	$145.12	20	1.51	$7.26
Debidue Beach (3)	1990-2010	8,500	1,044,079	122.8	$7,812,600	$9,880,500	$9.46	$1,162.41	20	6.14	$58.12
Isle of Palms (2)	1985-2010	10,200	1,283,895	125.9	$9,402,090	$11,123,733	$8.66	$1,090.56	25	5.03	$43.62
Folly Beach (3)	1990-2010	28,880	5,577,200	193.1	$34,951,542	$47,122,220	$8.45	$1,631.66	20	9.66	$81.58
Folly Beach Spit (11)	1980-2010	2,000	707,095	353.5	*$1,560,610*	$2,891,257	$4.09	$1,445.63	30	11.78	$48.19
Seabrook Island (1)	1990-2010	5,850	684,474	117.0	$1,660,000	$3,035,896	$4.44	$518.96	20	5.85	$25.95
Edisto Beach (3)	1955-2010	18,258	1,856,061	101.7	$9,197,500	$15,588,950	$8.40	$853.81	55	1.85	$15.52
Hunting Island (8)	1970-2010	15,700	5,255,979	334.8	$14,610,045	$29,063,682	$5.53	$1,851.19	40	8.37	$46.28
Hilton Head (5)	1970-2010	45,500	10,595,900	232.9	$36,565,933	$57,936,968	$5.47	$1,273.34	40	5.82	$31.83
Hilton Head- Sea Pines (2)	1970-2010	3,400	395,000	116.2	*$1,240,000*	$2,322,082	$5.88	$682.97	40	2.90	$17.07
Daufuskie (1)	2000-2010	18,500	1,410,000	76.2	$5,500,000	$7,979,842	$5.66	$431.34	10	7.62	$43.13
Statewide (59)	1954-2010	330,718	44,078,307	133.3	$236,644,416	$351,003,937	$7.96	$1,061.34	27.06	4.93	$39.22

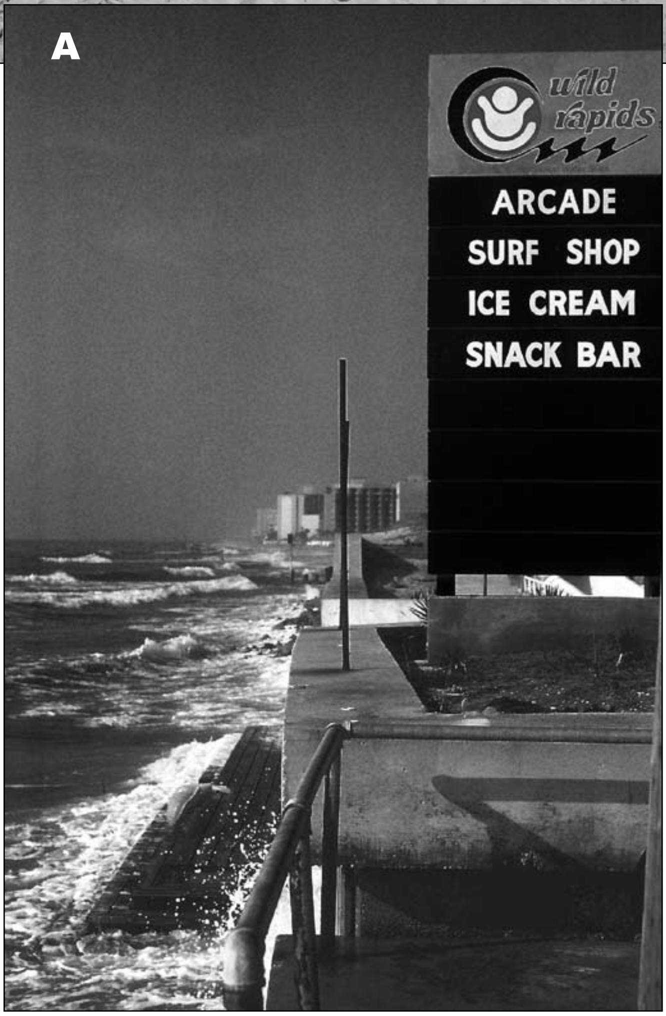


Figure 8. High-tide conditions in Myrtle Beach (2nd Avenue South) prior to nourishment (A — 1986) and after four events (B — 2012). The concrete seawall protecting "Wild Rapids" Water Park in 1985 is now buried and fronted by ~75 ft of vegetated dunes and dry-sand beach.

future cross-referencing. Table 3 shows six project areas (listed north to south) receiving over 3 mcy to date — North Myrtle Beach, Myrtle Beach, Garden City-Surfside Beach, Folly Beach, Hunting Island, and Hilton Head Island (Figure 5). These ~42.6 miles of coast have received over 35.5 mcy or about 70% of total volume placed. Five nourishments at Hilton Head Island since 1969 have added about 10.6 mcy to the oceanfront (USACE 1974, OA 2008). Nourishment rates there are much higher than Grand Strand beaches because of much higher underlying erosion rates (Kana 1990).

Based on the methods applied herein, the average cumulative fill density has been 133.3 cy/ft. Hunting Island (Figure 4, middle of map), with eight events over a relatively short length of ~3 miles, has received 335 cy/ft since 1968 (Traynum *et al.* 2010). Despite nourishment rates >8 cy/ft/yr, Hunting Island has receded nearly 1,000 ft in the past 50 years. Historical erosion rates along Hunting Island, upward of 25 ft/yr (Anders *et al.* 1990), are among the highest on the coast. Figure 6 shows the fill densities for four localities receiving the greatest concentration of nourishment.

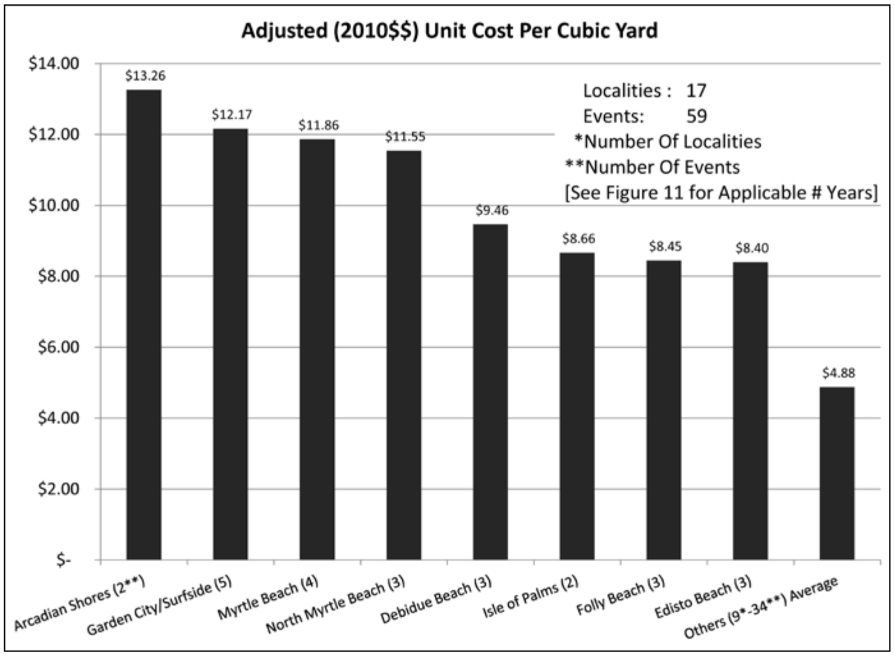
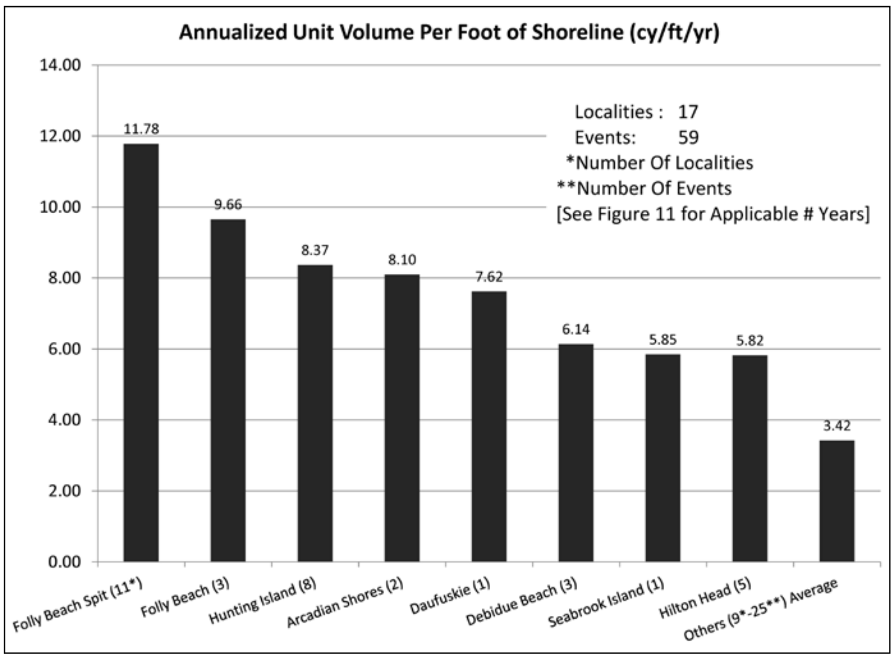


Figure 9. Net cost per cy (2010$$) for eight project areas inclusive of mobilization, pumping costs, and (as applicable) associated project planning and engineering costs.

Figure 10. Average annual rate of nourishment at eight project areas.



Folly spit (Figure 4, top of map), a short 2,000-ft segment at the downcoast end of Folly Beach received 11 additions of sand in connection with disposal of Folly River navigation project sediments between 1979 and 2000 (USACE unpublished data, Jones 1989). This was equivalent to ~40 cy/ft/yr over a 20-year period. Since 2000, only one project has occurred, reducing the rate of nourishment for this area to ~10 cy/ft/yr (CSE 2012). Erosion has accelerated in the past few years along Folly spit, site of one of Charleston's most popular public parks, and has forced closure of the facility. Meanwhile, a 50-year project (the other listing in Table 3 and Figure 6), encompassing nearly the entire 6-mile-long oceanfront of Folly Beach, has generally improved the beach well beyond its pre-nourishment condition (Ebersole *et al.* 1996).

The original cost of all noted South Carolina projects was approximately $236.6 million, which is equivalent to (~)$351 million in 2010 constant dollars. As a check on these amounts, London *et al.* (2009) estimated total nourishment expenditures of (~)$325.2 million in 2008 constant dollars. Expenditures to date along Myrtle Beach and Hilton Head Island each approaches $60 million (2010$$) (Figure 7). The average cost for 11 remaining sites is (~)$6.6 million (2010$$) each.

Beach improvements

Arguably, the most successful application of nourishment is South Carolina's Grand Strand, where widened beaches were needed to accommodate millions of visitors each year. The ~35-mile-long shoreline, bounded by Little River Inlet and Murrells Inlet with only minor intervening inlets, is considered an equilibrium coast with low rates of change (Brown 1977, Hayes and Michel 2008). Despite the shoreline's general stability, encroaching development in the 1960s and 1970s led to extensive armoring. By 1980, well over 50% of the Grand Strand was protected by seawalls, bulkheads, and revetments. Little or no dry beach existed at high tide (Figure 8). The first beach fills (~1979–1982) occurred near the inlets in conjunction with jetty construction and artificial bypassing.

Myrtle Beach completed a locally-sponsored project between 1986 and 1987 in which more than 60,000 truckloads of sand from inland pits were hauled and placed along 8.5 miles of beach (Kana *et al.* 1997). Hurricane Hugo (September 1989) led to additional emergency fills in 1990 with funding from both FEMA and state-local sources. During this time, a federal 50-year project was in planning (USACE 1993) culminating with the initial nourishment in 1997-1998 at North Myrtle Beach, Myrtle Beach, and Garden City-Surfside Beach (McCoy *et al.* 2010). Each nourishment event advanced the shoreline further, buried virtually all seawalls, and led to an increase of over 250 acres between 1987 and 2006 (London *et al.* 2009). This is equivalent to an average beach widening of ~100 ft between Little River Inlet and Murrells Inlet. Another indication of stability (and probably low longshore transport rates) within the Grand Strand is the lack of artificial bypassing at Little River Inlet and Murrells Inlet since 1988.

At the opposite end of the state, five nourishments at Hilton Head Island have more than compensated for average annual losses of the order 5-8 cy/ft/yr (USACE 1974, Jones *et al.* 1988, OA 1999, 2008). London *et al.* (2009) reported a net gain of 152 acres (~105-ft width over 12 miles) of beach area between 1987 and 2006. Note that reported gains in beach area by island may reflect spreading of nourishment sand to unnourished areas as well as possible natural additions associated with "shoal-bypassing" events near inlets (Gaudiano and Kana 2001).

Chronic Problem Areas

Within the Grand Strand (Figure 3), two areas tend to be chronic "hot spots" of erosion—(1) "Cherry Grove," an ~1-mile reach within the North Myrtle Beach segment ~5 miles south of Little River Inlet where a former inlet existed, and (2) a one-half-mile reach at the south end of Garden City, about 1 mile north of Murrells Inlet and also the site of a former inlet (McCoy *et al.* 2010, CSE unpublished).

Debidue Beach (Figure 3, bottom of map) is a ~1.6-mile-long developed section of Debidue Island where there is a large gradient in erosion from north to south. The highly eroding south end is anchored by a bulkhead which has encroached on the active beach since the 1980s. Three nourishment events have failed to keep pace with erosion at the south end of the development, largely because of high erosion rates (i.e. >15 ft/yr — Jones *et al.* 1988) in the wilderness area to the south. A prominent shoreline salient formed in connection with a prior inlet south of the development. After that inlet closed and flows diverted to North Inlet, the salient became a focus of erosion (CSE Baird 1999). Nourishment has been problematic along Debidue because of the short length of each project and lack of containment of the material. It is one of the few defensible sites in the state for a terminal groin.

Folly Beach, downcoast of the Charleston Harbor jetties (Figure 4, top of map), has been an area of chronic erosion for decades (Hansen *et al.* 1987). A Section 111 study led to a 50-year federal project with the initial nourishment in 1993 (Ebersole *et al.* 1996). Renourishments[2] occurred in 2005 and 2007, and are planned for 2014 (USACE unpublished). Folly Beach sustained rapid spreading losses to the adjacent inlets (CSE 2012). Nevertheless, as London *et al.* (2009) reported, Folly Beach gained an extra

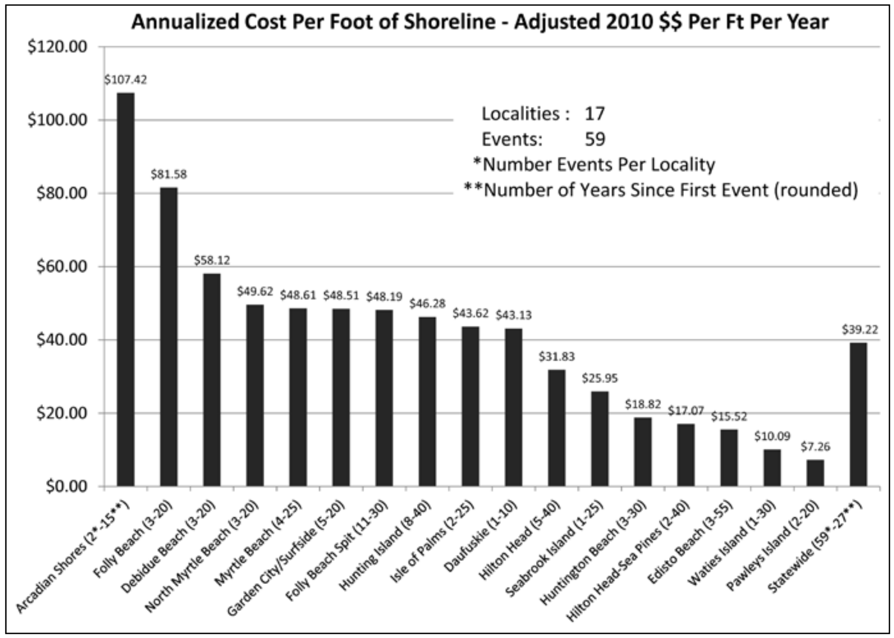


Figure 11. Average annual expenditures (2010$$) per foot of shoreline receiving nourishment for 17 project areas.

77.6 acres between 1987 and 2006. The principal hot-spot areas are the "washout" situated near Lighthouse Inlet at the north end and Folly spit at the south end.

Other chronic erosion areas include a one-half-mile reach of nourished shoreline along the south end of Seabrook Island (Figure 4, near top of map), which is subject to encroachment of a marginal channel of North Edisto River Inlet. Others are the "Pavilion" area near the north end of Edisto Beach (approximate north limit of the 1954 nourishment bar for Edisto Beach shown near the middle of Figure 4) and Hunting Island (CSE 2007), particularly the south 1-mile end of the island which has never been directly nourished.

Unit rates

The expenditures for beach nourishment reduce to the net unit cost of sand placement (i.e. $/cy) and the unit rate of fill (i.e. cy/ft). Figures 9 and 10 show annualized results for selected localities. Four sites (all in the Grand Strand) had net costs (>)$10/cy — Arcadian Shores, Garden City–Surfside Beach, Myrtle Beach, and North Myrtle Beach. Arcadian Shores involved two locally-funded projects totaling ~780,000 cy. Both events were completed via ocean-certified, trailing-suction hopper dredges using offshore borrow areas. Dredge mobilization "piggy-backed" with adjacent federal projects, but still accounted for 10-16% of construction costs (CSE 2008a). The other Grand Strand events include considerable soft costs (e.g. 15–20 percent) associated with federal projects in South Carolina (USACE unpublished).

While total expenditures and nourishment volumes have been highest for Hilton Head Island, the proximity of the borrow areas to the island and economies of scale (C Creed, OA, pers comm, September 2012) have reduced the average net costs of sand placement to (~)$5.50/cy (Table 3). The state-wide average in 2010$$ was $7.96/cy.

Annualized fill densities are given in Table 3 and Figure 10. The highest fill densities have been placed on Folly spit with ~11 discrete events over a ~2,000-linear-foot segment, adding the equivalent of nearly 12 cy/ft/yr. Other high rates of fill (>8 cy/ft/yr) include

2) The term "renourishment" (where used herein) refers to subsequent events along a segment of shoreline scheduled for periodic nourishment under a particular authorization such as a 50-year federal project. For example, Hunting Island received an initial "federal" nourishment in 1968 and three renourishments under the same authority in 1971, 1975, and 1980. Subsequently, under state sponsorship, Hunting Island was nourished in 1991. Next, a small section of Hunting Island was nourished under a new federal authority in 2003 and renourished under the same authority (and approximate same area) in 2005. Finally, under a state plan separate from authorities for all preceding events, Hunting Island was again nourished in 2006. Notwithstanding the particular usages of nourishment and renourishment herein, the author recognizes that the two words are often interchanged in the literature.

Folly Beach, Hunting Island, and Arcadian Shores. The state-wide average for nourished areas has been just under 5 cy/ft/yr.

Combining the annualized rate of nourishment and unit cost of sand yields an estimate of the unit expenditures for beach restoration per foot of shoreline (Figure 11). Arcadian Shores, due to the short applicable time frame of 15 years and high sand cost, was the only site exceeding $100/ft/yr. Like other Grand Strand beaches, Arcadian Shores is significantly wider than pre-nourishment conditions (CSE 2008a). Seven of 17 sites had expenditures between $40/ft/yr and $50/ft/yr (2010$$). Of these sites, five are in measurably better condition (North Myrtle Beach, Myrtle Beach, Garden City-Surfside Beach, Isle of Palms, Daufuskie Island — see source references), and two have not kept pace with erosion (Folly spit and Hunting Island, both of which are important public-access parks). At the low end of the cost (and improvement) range, Pawleys Island moved ~30 cy/ft by trucks in two events (1990 and 1998 — Kana *et al.* 2004) at an adjusted unit cost of (~)$4.80/cy for annualized expenditures of (~)$7/ft/yr over a 20-year period (Table 3). The average expenditure for 62.6 miles of nourished beaches over an average of ~27 years has been (~)$39/ft/yr (2010$$) (Table 3).

SUMMARY AND FINDINGS

South Carolina beach-nourishment projects peaked in number of events (23), volumes (20.7 mcy), and expenditures [(~)$173.8 million (2010 $$)] in the 1990s. The volume of nourishment declined to ~60 percent of the 1990s rate between 2000 and 2010. In the case of the Grand Strand beaches, which are now maintained under a 50-year federal project, renourishment volumes have been lower because of sustained improvements after earlier projects. Therefore, it is useful to distinguish between projects that have measurably improved South Carolina beaches in a sustained manner from those that have simply attempted to keep pace with erosion. Using the data from London *et al.* (2009), which reports changes in beachfront area between 1987 and 2006, the following nourished beaches are significantly wider than they were in the 1980s:

- North Myrtle Beach
- Myrtle Beach
- Garden City-Surfside Beach
- Edisto Beach
- Arcadian Shores
- Folly Beach
- Seabrook Island
- Hilton Head Island
- Daufuskie Island

The cost of simply maintaining a fixed shoreline position in these localities is lower than the expenditures per foot per year shown in Figure 11. These localities represent ~48.9 miles (78 percent) of the nourished beachfront in South Carolina. An estimated 9.4 miles (15%) of nourished beachfront remains in similar condition today after one or more events (e.g. Waties Island, Huntington Beach, Pawleys Island).

Project areas that are not significantly better today compared with the beach condition in 1980 include.

- Debidue Beach
- Folly spit
- Hunting Island

These localities represent ~4.6 miles (7%) of the nourished beaches in the state. Clearly, to effect improvements beyond existing conditions, a greater sustained effort will be necessary at these places. Coincidently, all three sites have considered incorporation of groins in their projects to reduce the end losses of beach fills. Terminal groins at Debidue Beach and Folly spit are pending. Six groins at Hunting Island (installed in 2007 — CSE 2007), have stabilized much of the northern half of the 4-mile-long island where net transport is directed north. The southern end of the island, which has never been nourished, remains highly erosional.

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