Comparison of Beach Nourishment along the U.S. Atlantic, Great Lakes, Gulf of Mexico, and New England Shorelines

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The U.S. national beach nourishment experience is summarized for the East Coast barrier islands, the Gulf of Mexico, New England, and the Great Lakes. A total of 1,305 nourishment episodes on 382 beaches are recorded at a total estimated cost of approximately $1.4 billion ($2.5 billion in 1996 dollars). In terms of both volume and costs, nourishment has been the most extensive by far on the East Coast barrier islands. Depending on the region, between 65% and 85% of all nourishment projects have a federal funding component. Annual expenditures and sand volumes for beach nourishment are increasing, especially on East Coast barriers. At present, total annual national beach nourishment costs (excluding the Pacific Coast) are on the order of $100 million per year. The cost per cubic yard of nourishment sand as expressed in 1996 dollars has remained more or less constant over time. Additionally, the volumes of sand needed for subsequent nourishment episodes on individual beaches do not decrease, despite contrary assumptions in the shoreface-profile-of-equilibrium concept that subsequent nourishment volumes should diminish. In light of the historical experience of beach nourishment identified in this study, individual state and local coastal communities should reevaluate their plans for future beach nourishment programs. The complete listing of all the data on nourished beaches from this survey is available at www.geo.duke.edu/Research/psds/psds.htm

Keywords beach replenishment, coastal erosion control, soft stabilization

INTRODUCTION

Beach nourishment has become our nation's most utilized tool to mitigate the effects of coastal erosion and storm hazards. Although its use is widespread, up-to-date studies documenting the extent to which the United States has turned to beach nourish-

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ment are lacking. Such information would be particularly useful as a baseline in establishing policies and programs concerning beach nourishment. For example, in the current debate over what the appropriate federal role is in beach nourishment and who should pay for it, it would be helpful to know what the federal role *has been* and who *has* paid for beach nourishment.

This article summarizes the findings of several surveys, generally ending in late 1996, which examine beach nourishment in four U.S. regions: New England, the East Coast barrier islands, the Gulf Coast, and the Great Lakes shorelines (Haddad & Pilkey, 1998; Valverde, Trembanis, & Pilkey, in press; Trembanis & Pilkey, 1998; O'Brien et al., 1999). All of the raw data, including sand volumes and beach lengths of individual projects and episodes, are available at www.geo.duke.edu/Research/psds/psds.htm. Records on many projects are poor, and the data for individual episodes are sometimes incomplete. Data on some of the smaller sized projects may not be included.

Previous studies (which did not incorporate New England and the Great Lakes) include those of Pilkey and Clayton (1989), which covered East Coast barriers, and Dixon and Pilkey (1991), which covered the Gulf of Mexico. Studies of Pacific Coast nourishment include Clayton (1991) and Wiegel (1994). The success of the design parameters used to measure the nourished beaches from the earlier studies is summarized in Leonard, Clayton, and Pilkey (1990) and discussed by Pilkey (1988), Pilkey (1990), Houston (1990), Pilkey and Leonard (1990a), Brunn (1990), Pilkey and Leonard (1990b, 1990c), Houston (1991a, 1991b), Pilkey (1991), Pilkey and Leonard (1991), and Pilkey and Thieler (1992).

A more recent survey of design success by the U.S. Army Corps of Engineers (USAGE, 1994) was restricted to federal projects. The validity of the USACE survey was questioned by Pilkey (1995) and debated in a series of discussions (Hillyer & Stakhiv, 1997; Pilkey, 1997).

Methods

For the purposes of this study, a nourishment *episode* is defined as an event in which new sand was artificially placed on a beach, thereby increasing its volume. An episode is distinguished from a nourishment *project*, which refers to a location where a series of nourishment episodes have occurred over time.

For each nourishment episode, we attempted to collect the following information: location, year, funding category, volume, disposal length, and cost. Table 1 contains a summary of the number of episodes, along with total volume and cost for each state. This information is not readily available and had to be obtained from a variety of sources: coastal engineering literature and conference proceedings, consultants' reports, USACE documents, state permits and files, libraries, and personal communications.

It is important to note that comparison of gross nourishment cost differences between states and between federal, state, and local projects does not tell the whole story. Many different methods for obtaining sand (dredge or truck), differing sand source sites, and the occasional inclusion of hard structures in project costs all make comparison difficult. Another approach to comparison of costs and volumes could be obtained by comparing similar types of projects, but the incompleteness of the data set makes this a difficult task as well. Our data set contains both designed and nondesigned projects. In spite of all these difficulties, it has remained our stated goal to give the most extensive assessment of the total amount of sediment placed on U.S. beaches.

Documented beach nourishment episodes were classified according to primary funding source into one of nine funding types, which are very briefly explained in what follows.

Table 1

State and regional summary of volume, cost, and number of beach nourishment episodes

State	Number of episodes[a]	Number of projects[b]	Total volume (cubic yards)	Total documented cost[c]	Total estimated cost[d]	Documented cost, adjusted ($1966)[e]	Total adjusted cost ($1966)[f]
New England							
Maine	15	6	650,000	$1,180,000	$3,640,000	$7,000,000	$6,780,000
New Hampshire	8	2	2,210,000	$3,180,000	$3,910,000	$18,000,000	$25,600,000
Massachusetts	81	65	3,650,000	$12,200,000	$18,100,000	$22,000,000	$56,400,000
Rhode Island	11	7	217,000	$1,350,000	$1,480,000	$1,500,000	$3,250,000
Connecticut	44	37	5,250,000	$12,400,000	$12,400,000	$12,400,000	$48,200,000
Regional Total	159	117	11,980,000	$30,300,000	$39,500,000	$60,900,000	$140,000,000
East Coast							
New York	73	23	98,200,000	$159,000,000	$183,000,000	$400,000,000	$523,000,000
New Jersey	124	37	57,400,000	$163,000,000	$188,000,000	$214,000,000	$313,000,000
Delaware	33	12	7,830,000	$15,600,000	$20,600,000	$22,000,000	$46,900,000
Maryland	6	1	10,300,000	$51,300,000	$51,300,000	$51,000,000	$66,000,000
Virginia	48	3	13,600,000	$18,200,000	$38,500,000	$58,000,000	$78,800,000
North Carolina	108	16	43,500,000	$60,100,000	$93,500,000	$106,000,000	$146,000,000
South Carolina	28	13	19,200,000	$43,700,000	$53,500,000	$65,000,000	$90,000,000
Georgia	8	2	8,460,000	$15,300,000	$25,700,000	$27,000,000	$34,000,000
Florida	144	40	86,300,000	$200,000,000	$287,000,000	$313,000,000	$443,000,000
Regional Total	572	147	345,000,000	$726,000,000	$941,000,000	$1,260,000,000	$1,740,000,000
Gulf Coast							
Florida	113	44	46,300,000	$143,000,000	$212,000,000	$238,000,000	$225,000,000
Alabama	2	2	680,000	NA	$1,460,000	$1,800,000	$1,870,000
Mississippi	13	3	12,100,000	$5,000,000	$19,700,000	$32,900,000	$56,000,000
Louisiana	16	4	12,100,000	$37,000,000	$39,700,000	$40,000,000	$54,500,000
Texas	14	7	4,630,000	$13,800,000	$19,800,000	$14,000,000	$24,600,000
Regional Total	158	60	75,800,000	$200,000,000	$293,000,000	$327,000,000	$362,000,000

(Table continues on next page)

Table 1

State and regional summary of volume, cost, and number of beach nourishment episodes (*Continued*)

State	Number of episodes[a]	Number of projects[b]	Total volume (cubic yards)	Total documented cost[c]	Total estimated cost[d]	Documented cost, adjusted ($1966)[e]	Total adjusted cost ($1966)[f]
Great Lakes							
Erie	54	9	9,420,000	$39,600,000	$40,500,000	$41,000,000	$77,900,000
Huron	26	7	786,000	$2,380,000	$3,880,000	$4,600,000	$5,170,000
Ontario	3	2	328,000	$1,280,000	$1,280,000	$1,280,000	$2,850,000
Superior	53	11	1,390,000	$7,150,000	$7,380,000	$7,530,000	$9,550,000
Michigan	280	29	13,000,000	$39,300,000	$65,800,000	$66,000,000	$101,000,000
Regional Total	416	58	24,900,000	$89,700,000	$119,000,000	$120,000,000	$196,000,000
Total	1305	382	458,000,000	$1,050,000,000	$1,390,000,000	$1,770,000,000	$2,438,000,000
Pacific[g]	143	36	190,000,000	$23,900,000			$950,000,000
Total w/Pacific	1448	418	648,000,000	$1,073,300,000			$3,388,000,000

Note: This database and a complete listing of sources may be found on the Web at the following address: http://www.geo.duke.edu/Research/psds/psds.htm

Sources: Data for New England from Haddad and Pilkey (1998); data for East Coast from Valverde, Trembanis, and Pilkey (in press); data for Gulf Coast from Trembanis and Pilkey (1998); data for Great Lakes from O'Brien et al. (1999).

[a]Episodes refer to individual nourishment events in which sand was placed on a given beach.

[b]Project refers to a given beach location with one or multiple nourishment episodes.

[c]Total documented cost includes only projects with known costs (in project year dollars).

[d]Total estimated cost includes all projects, with both known and unknown costs (in project year dollars). Unknown costs are estimated from the average cost per cubic yard of projects in the same region and/or funding category. Estimates were not made for projects with unknown volume.

[e]Documented cost, adjusted, is the adjusted cost only for projects with known costs, in 1996 dollars.

[f]Total adjusted cost includes all projects, with the costs being adjusted to 1996 dollars.

[g]Data from the Pacific is valid only up to 1988 based on the study of Clayton (1991). Cost estimate based on assumption of $5/cubic yard cost estimate.

Federal Storm and Erosion. These are nourishment episodes performed as part of a federally sponsored beach erosion control, shore protection, or hurricane protection project. Up to 65% of the total costs of these projects are federally authorized by Congress. The remaining share is paid for by state and local governments.

Federal Navigation. This funding category encompasses those nourishment episodes that occurred as a result of beach disposal of dredged material associated with federal navigation channel maintenance. Compared to disposing of dredged material offshore or on upland disposal sites, sometimes it is less expensive and more beneficial to dispose of the sand on an adjacent beach, at no cost to the local community. If beach disposal is not cost effective, in some cases the local communities will pay the extra costs incurred to have the dredge spoil placed on their beaches.

Federal Emergency. These are federally funded nourishment episodes, which restore a beach nourishment project to its design dimensions after it suffers damage from a large storm.

Federal Mitigation (Section 111). This is nourishment undertaken to mitigate the impact of federal navigation activities and structures (e.g., jetties). They are known as Section 111 projects, referring to authorization provided by Section 111 of the Rivers and Harbors Act of 1968.

Federal Small Scope Specifically Authorized (SST). This category includes federally sponsored nourishment episodes authorized before the enactment of Section 102 of the Rivers and Harbors Act of 1962. Such nourishment episodes are exclusively within the New England region.

Federal Unknown. This includes nourishment episodes that are known to be federally funded, but whose specific funding category is unknown.

State. These are nourishment episodes paid for entirely with state funds.

State/Local. This classification includes beach nourishment episodes that were sponsored under a state and local government cost-sharing agreement.

Local/Private. These are nourishment episodes carried out and funded at the local level, either by a municipality or local homeowners.

Detailed descriptions of each funding type may be found in the specific summary of each region (Haddad & Pilkey, 1998; Valverde, Trembanis, & Pilkey, in press; Trembanis & Pilkey, 1998; O'Brien et al., 1999). For a summary of the Pacific nourishment experience up through 1988, please see Clayton (1991).

In order to estimate the total amount spent on beach nourishment, it was necessary to estimate missing cost figures. First, all documented costs were updated to 1996 dollars using the Construction Cost Index factors provided by USACE (1994). The update factors provided by USACE only update costs to 1993 dollars, therefore, a steady 3% annual inflation was assumed to update project costs from 1993 to 1996. The second step in determining missing costs called for establishing an estimated cost for every project type in each region. All nourishment episodes with a documented volume and cost were sorted according to funding type. For each funding type, we calculated an average cost per cubic yard (total cost of each episode divided by total volume; see

Table 2

Average cost per cubic yard of every project type within each region

Funding type	East Coast	Gulf Coast	New England	Great Lakes
Federal storm and erosion	$5.08	$6.49	$14.51	$13.51
Federal navigation	$4.99	$2.74	$10.26	$5.84
Federal emergency	$5.76	$5.68	$21.90	NA
Federal mitigation	NA	NA	NA	$6.48
Federal SSSA	NA	NA	$9.61	NA
State	$5.34	NA	NA	NA
State/local	$5.08	$4.67	$15.28	$5.45
Local/private	$3.98	$5.17	NA	NA
Mean	$4.99	$5.94	$12.96	$7.17

Sources: Data for East Coast from Valverde, Trembanis, and Pilkey (in press); data for Gulf Coast from Trembanis and Pilkey (1998); data for New England from Haddad and Pilkey (1998); data for Great Lakes from O'Brien et al. (1999).

Table 2). In calculating the average cost per cubic yard, we discarded "outliers" (values greater or less than one standard deviation from the mean). In addition to calculating an average cost per cubic yard for each funding type, an overall average value was also calculated for each region.

In order to estimate missing costs for episodes with a known funding type, the episode volume was simply multiplied by the corresponding average cost per cubic yard taken from Table 2. For nourishment episodes with an unknown funding type, we multiplied volume by the overall average cost per cubic yard value for the corresponding region. Through this calculation we arrived at a total cost estimate for all nourishment episodes in 1996 dollars (see the last column of Table 1). For an historical estimate of what was spent on all beach nourishment activity, we simply calculated costs back into project-year dollars by using the Construction Cost Index factors in reverse (see Table 1, column labeled "Total Estimated Cost").

Our collection of nourishment data is by no means complete and needs to be continually updated. To facilitate this, our beach nourishment database is available for examination at our Website, http://www.geo.duke.edu/Research/psds/psds.htm. Comments, corrections, and additions to our data table will be accepted gladly.

Findings

Sand Volumes of Nourished Beaches

The East Coast barrier island shoreline is where most U.S. beach nourishment activity occurs (Valverde, Trembanis & Pilkey, in press). The total volume of 345 million cubic yards placed on 147 East Coast barrier beaches dwarfs the amount placed on other coastlines (Figure 1). In part this is because the East Coast barrier island shoreline is the greatest in continuous length of developed sandy coastline. The large nourishment effort also reflects the great economic importance of recreational beaches in this region. Following the East Coast in volume of sand placed on beaches are the Pacific Coast, with approximately 190 million cubic yards on 36 beaches (Clayton, 1991); the Gulf Coast, with approximately 75 million cubic yards on 60 beaches (Trembanis & Pilkey, 1998); the Great Lakes shoreline, with approximately 25 million cubic yards on 58 beaches (O'Brien et al., 1999); and the New England shoreline, with approximately 12 million

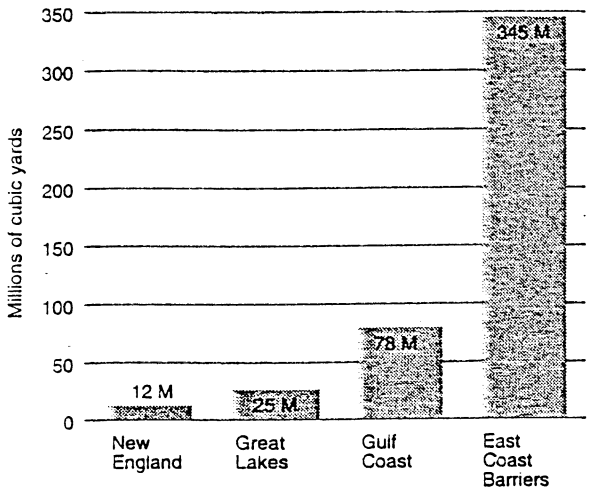

Figure 1. Total documented nourishment volume for each region.

cubic yards on 117 beaches (Haddad & Pilkey, 1998). The large difference in scale between the East Coast and New England is illustrated by the fact that the total nourishment sand volume placed on New England's beaches (about 12 million cubic yards) is less than the single 1981 nourishment episode in Miami Beach, Florida.

The importance of federal sponsorship in beach nourishment efforts is illustrated in Table 3, which expresses funding type as a percentage of the total emplaced nourishment sand volume. Between 65% and 95% of the total historical nourishment sand volume was placed as a result of federally sponsored nourishment projects in the regions studied.

Beach nourishment has seen a marked increase in all of the regions studied, except in New England, where no increase is apparent over the last three decades. For example, over 50% of the total historical nourishment volume placed on the East, Gulf, and Great Lakes coasts has been placed only within the last 16 years. Figure 2 presents the increase

Table 3

Distribution of funding sources for each region based on volume (note the importance of federal sponsorship in all regions)

Funding type	New England, % of total volume	East Coast, % of total volume	Gulf Coast, % of total volume	Great Lakes, % of total volume
Federal emergency	1	6	12	
Federal mitigation				30
Federal navigation	10	13	33	14
Federal SSSA[a]	12			
Federal storm/erosion	7	44	38	40
Federal unknown	38			11
State/local	28	20	16	2
Local/private	1	9	1	1
Unknown	2	8		2

Sources: Data for New England from Haddad and Pilkey (1998); data for East Coast from Valverde, Trembanis, and Pilkey (in press); data for Gulf Coast from Trembanis and Pilkey (1998); data for Great Lakes from O'Brien et al. (1999).

[a]SSSA: small scale specifically authorized.

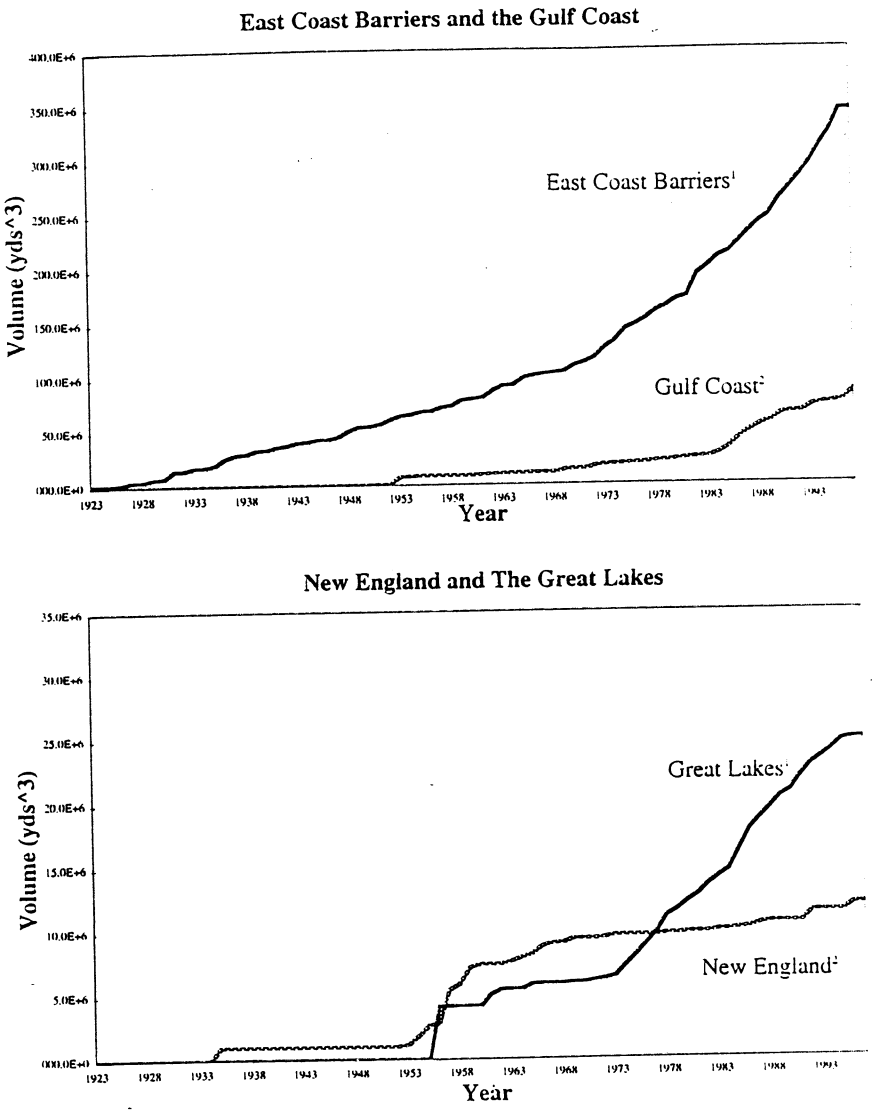

Figure 2. Total cumulative nourishment volume for each region. Note the scale difference between the East/Gulf coast and New England/Great Lakes graphs. *Sources*: Data for East Coast from Valverde, Trembanis, and Pilkey (in press); data for Gulf Coast from Trembanis and Pilkey (1998); data for Great Lakes from O'Brien et al. (1999); data for New England from Haddad and Pilkey (1998).

in total nourishment over time for each region. The increase in nourishment volume follows the increasing trend of federal involvement in beach property protection.

Nourishment Needs

An explicit consequence of the shoreface-profile-of-equilibrium concept is that sand volume requirements for a beach nourishment should decrease with time (Dean, 1984). The assumption is that subaqueous sand will pile up on the shoreface and not extend beyond the *closure depth*. The concept of closure depth has been questioned (Pilkey et al.,

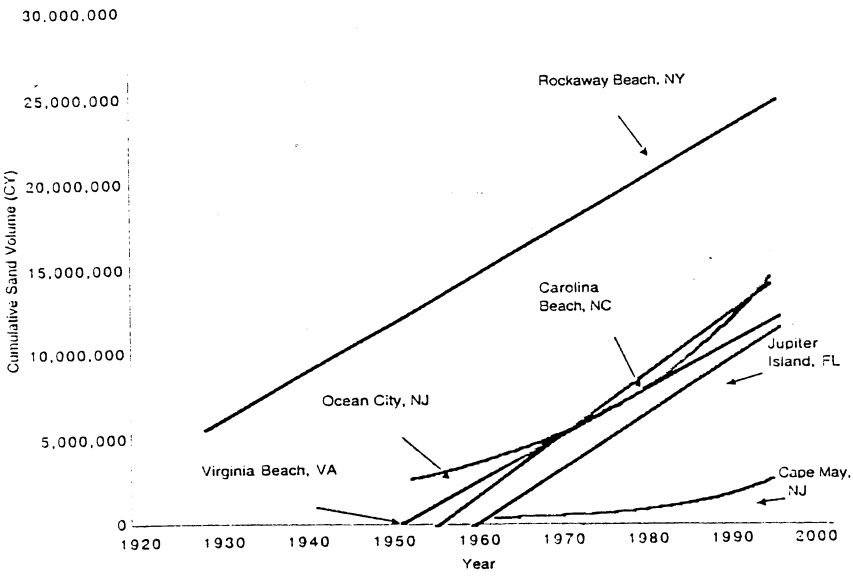

Figure 3. Cumulative nourishment volume trend for numerous East Coast beaches, showing no long-term decrease in nourishment volume needs.

1993), and evidence exists that sand from nourishment projects extends well beyond closure depth (Thieler et al., 1995). Figure 3 presents plots of cumulative sand volume for a number of projects with long-term nourishment records, which indicate no such reduction in sand needs over time. Therefore, despite previous indications, coastal communities should not expect any long-term reduction in nourishment sand needs.

Costs of Nourished Beaches

The average cost per cubic yard was found to be lower on East Coast barrier beaches ($5/yd^3) than on the Gulf ($6/yd^3), the Great Lakes ($7/yd^3), and New England ($13/yd^3) beaches; see Table 2. In all of the regions studied, we found no significant increase in the average cost per cubic yard of nourishment sand (approximately $5/yd^3 expressed in 1996 dollars) to have occurred over time.

In general, the average cost per cubic yard of sand for local and privately funded nourishment episodes ($4/yd^3) is lower than federally funded episodes ($5/yd^3). Beach nourishment appears to be carried out more efficiently on a local level.

Currently, the estimated annual amount that the United States is spending to nourish its beaches is over $100 million, using this study, and probably closer to $150 million, if one also considers the Pacific Coast using data from Clayton (1991). In contrast to these present findings, Houston (1995) estimated the national beach nourishment costs to be only a meager sum of $15 million annually. He used this number to compare U.S. costs with those of other countries and with U.S. farm subsidies. This number is low by an order of magnitude compared to the present study. The annual national expenditures in the 1990s are well in excess of $100 million. Houston's number was based mainly on large USACE projects, but $15 million annually is not an accurate reflection of the extent of our national beach nourishment effort.

In considering cost trends identified in this survey, coastal communities should expect to pay at least $5/yd^3 for nourishment sand and may wish to consider the price

differential between various project-sponsoring types. Additionally, in the national debate on the efficacy and future of the federal commitment to extensive beach nourishment programs, a new, more fully encompassing consideration of the true extent of past beach nourishment efforts must be utilized in lieu of narrowly construed past estimates.

Future Decadal Costs

We estimated the cost requirement for nourishing the entire length of developed shoreline for a few pivotal coastal states: New Jersey, North Carolina, South Carolina, and Florida. Costs (Table 4) were calculated using average 1996 costs per mile for each state, and rough regional estimates of likely nourished beach durability came from studies by Dixon and Pilkey (1991) and Clayton (1991). The costs shown in Table 4 are for the entire *developed* open ocean shorelines of each of these states, assuming that a nourished beach would be maintained continuously. Of course, political and economic factors often interfere, and many nourished beaches are not maintained continuously but rather only when convenient. For this "back of the envelope" calculation, we will follow the assumptions of these previous studies that in New Jersey, with an average life span of two years, a beach will need to be replenished five times within a decade, whereas a beach along the northeast coast of Florida would only need two episodes per decade. Total estimated decadal cost for New Jersey is therefore about $1.5 billion; for North Carolina, $690 million; for South Carolina, $200 million; and for Florida, $ 1.9 billion. In total, we estimate that over $4 billion in expenditures would be necessary to maintain the entire 736-mile length of developed shoreline in New Jersey, North Carolina, South Carolina, and Florida.

Although onetime costs vary from state to state, overall this would amount to an approximate 10-year upkeep cost of $6 million per mile for all four of the states. These numbers assume that sea-level rise will not accelerate erosion rates in future decades. Again, these sorts of estimates should be useful for coastal communities and managers in planning realistic long-range strategies for coastal property defense.

Conclusions

Clearly, in the societal debate about the appropriateness of the beach nourishment alternative, it is essential to have accurate cost and sand volume numbers. Nationally, the beach nourishment program has been far more extensive in both volume and cost than

Table 4

Estimated cost to nourish the entire length of developed shoreline along four states over a 10-year period based on assumptions of episode life span and average cost per mile of shoreline

Location	Miles	Cost/mile	Life span	10-Year cost
New Jersey	90	3.5 million	2 years	$1,575 million
North Carolina	138	2.0 million	4 years	$690 million
South Carolina	60	1.0 million	3 years	$200 million
Northeast Florida	113	2.5 million	5 years	$565 million
Southeast Florida	175	2.5 million	7 years	$625 million
Gulf Coast Florida	160	2.7 million	6 years	$720 million
Total Florida	448			$1,910 million
Total all locations	736			$4,375 million

Source: Data for life-span column from Leonard, Clayton, and Pilkey (1990).

some federal agencies have portrayed it (by as much as an order of magnitude). Beach nourishment activities have grown sharply over time, particularly within the last 15 to 20 years, and especially within the heavily developed regions of the East Coast and the Gulf of Mexico. Historically, federal projects have been slightly more expensive than local and privately funded projects, which may affect some future management decisions from all levels of government. Despite some regional variations, federal involvement dominates the funding efforts of beach nourishment programs nationally. Overall, it is estimated that over $3 billion dollars (1996 value) have been spent in placing nearly 650 million cubic yards of sand along developed reaches of our nation's beaches. Heavily developed states should expect to pay around $6 million every decade to sufficiently nourish every mile of developed coastline. In a time of rising sea level and intensifying coastal development, beach nourishment must not be viewed through rose-colored glasses. If beaches are to be preserved for future generations, restrictions to nourished beachfront population density and the relocation alternative must be fairly and realistically compared to the standard practices of hard stabilization and beach nourishment.

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