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An Analysis of Replenished Beach Design Parameters on U.S. East Coast Barrier Islands

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ABSTRACT

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Forty-three beach replenishment projects on the United States Atlantic Coast are divided into 3 categories based on time of fill retention: (1) less-than-1-year beaches (26%), (2) 1-to-5 year beaches (62%), and (3) greater-than-five-year beaches (12%). Filled or replenished beaches north of Florida generally have lifetimes of fewer than 5 years. Storm history is the most important factor in determining beach durability—so important that the effects of the other parameters, which may also play a role in artificial beach behavior, are overshadowed. Beach length, grain size, shoreface slope, shelf width and method of fill emplacement show no correlation to regional replenished beach lifetime. Inlet proximity and a combination of shoreline orientation and dominant angle of wave approach may exert minor influence on beach behavior. Initial density of fill (volume per unit length) exerts significant influence on the percentage of fill remaining after one year, but the effect becomes less well defined beyond the first year.

ADDITIONAL INDEX WORDS: *Artificial beach behavior, beach erosion, beach durability, beach replenishment, control erosion, coastal protection.*

INTRODUCTION

Our society has four alternatives available for the management of receding shorelines. Broadly stated, these alternatives are: (1) hard stabilization, (2) soft stabilization, (3) retreat or relocation and (4) no action. In recent years, because of the widely-held perception that hard stabilization is destructive to recreational beaches, beach replenishment, one type of soft stabilization, has become a more and more frequently chosen option.

"Beach replenishment" is the process of mechanically or hydraulically placing sand directly on an eroding shore to restore or form, and subsequently maintain, an adequate protective or desired recreational beach (U.S. ARMY CORPS OF ENGINEERS, 1984). Replenishment of sand, however, does not permanently solve an erosion problem; therefore, periodic re-replenishment, termed "beach nourishment", is necessary.

Over 90 beaches on the U.S. East Coast have been replenished in more than 270 individual pumping or trucking operations identified through 1987. This number does not include innumerable small replenishment operations involving a few dump-truck loads of sand. According to LEONARD *et al.* (1988), most material used in replenishment is derived from either offshore areas or from the ebb or flood tidal deltas of nearby inlets. Smaller quantities of sand may be hauled in from upland areas or taken from a nearby lagoon; the latter practice is now almost halted because of environmental concerns.

The relative success or failure (*i.e.*, longevity) of a beach replenishment project is attributed to a number of factors. LEONARD *et al.* (1988) report that the most commonly cited factor in unexpectedly rapid sand loss is "unusual" storm activity (cited 47% of the time). Next in frequency of citation are proximity to inlets (32%) and grain size (19%).

This paper reports on beach replenishment on barrier island beaches of the United States East Coast from New York to Florida. Monitoring data was collected in order to determine (1)

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"replenished beach success," (2) predictability of beach longevity and (3) the importance of various parameters in the design of beaches. The ultimate goal is to improve the predictability of replenished beach performance.

A similar summary of the beach replenishment experience on the Gulf of Mexico coast is reported by DIXON and PILKEY (1989). Beach replenishment on three U.S. coasts (Pacific, Gulf and Atlantic) is compared by LEONARD *et al.* (1989).

METHODS

The results of this study are based on three types of analyses: (1) testing of current models of beach behavior with what little data is available from the field; (2) simultaneous evaluation of multiple design parameters; and (3) evaluation of beach design parameters by comparing multiple replenishment operations on a single beach.

The records of more than 90 replenished barrier island beaches on the U.S. East Coast were examined for monitoring data. Forty-three replenishment operations with suitable data have been selected (Table 1, Figure 1). However, even for the 43 projects chosen, the type, quality, and extent of data vary. "Suitability," therefore, is primarily a function of completeness. For example, a beach for which grain size, length and volume data are available may be missing data on durability or storm history. As a result, the documentation for only 42 of 270 identified replenishment operations on the U.S. Atlantic Coast yielded information adequate for analysis of durability, 32 projects for grain size and fill density, 35 projects for beach length and 19 for storm history.

The data are an assortment of both qualitative and quantitative assessments of project behavior collected from published reports, papers and proceedings, archival materials, historical records, media reports and personal communications. The information about post-placement behavior of the beach is not standardized for quantitative comparisons (*e.g.*, some residence times are reported in the original documents as volumetric losses; in other instances, in terms of shoreline recession). The qualitative terms, "lost", "gone", *etc.*, fit no rigorous definition.

For this study, beach lifespans are expressed in terms of beach lifetime categories. "Beach lifetime" is defined as the period between the time of initial emplacement of the sand and the earliest documented loss of at least 50% of the fill material. The authors consider this definition of beach lifetime as conservative since, in most cases, more than 50% of the fill had been lost by the time of documentation of the "at least half" loss.

Beaches were then categorized according to their "lifetimes" as defined above. Most analyses in this study utilize a scheme of three categories: less-than-1-year, 1-to-5-years and greater-than-5-years. Most of the durability, density and length data were obtained from PILKEY and CLAYTON (1987), PILKEY (1988), PILKEY and CLAYTON (1989). Grain size data are from U.S. Army Corps of Engineers (USACE), Jacksonville District (1972), WALTON (1977), NORDSTROM *et al.* (1979), USACE (1984) and STAUBLE and HOEL (1986).

Durability of replenished beaches can also be expressed in terms of beach half-life and percentage of fill remaining after one year. Both expressions are based on a linear extrapolation of beach loss. In nature, however, fill loss for artificial beaches presumably occurs in a non-linear fashion (*e.g.* during storms). In addition, such reported loss rates are usually only rough approximations of volumetric losses obtained during a limited period of monitoring. We believe that "lumping" projects into beach lifetime categories offers a suitable representation of replenished beach durability given the often rather generalized nature of the data available for this study.

For present purposes, a storm is defined as an event which causes notable, documented erosion, has an associated storm surge and/or experiences sustained winds of at least 50 miles per hour. This definition of storms is based on that given by WINTON *et al.* (1981). The storm data are collected from several sources: (1) "Storm Activity and Unusual Weather Phenomenon" (National Oceanic and Atmospheric Administration); (2) newspaper clippings; and (3) beach monitoring reports. The wave data used in this report are from the USACE Hindcast Data for Shallow Water Significant Wave Information (JENSEN, 1983). These data have been trans-

Table 1. *List of beach replenishment projects with suitable monitoring data for purposes of the analyses in this paper. Project number is used in several of the data plots. Location of projects is shown in Figure 1*

Project Number	Project Initials	Location	Year
1	RB67	Rockaway Beach, NY	1967
2	SH77	Sandy Hook, NJ	1977
3	SH83	Sandy Hook, NJ	1983
4	LB79	Long Beach Island, NJ	1979
5	AC48	Atlantic City, NJ	1948
6	AC63	Atlantic City, NJ	1963
7	AC70	Atlantic City, NJ	1970
8	AC86	Atlantic City, NJ	1986
9	OC52	Ocean City, NJ	1952
10	OC82	Ocean City, NJ	1982
11	ST82	Strathmere, NJ	1982
12	WH80	Whale Beach, NJ	1980's
13	CH66	Cape Hatteras, NC	1966
14	CH72	Cape Hatteras, NC	1972
15	CH73	Cape Hatteras, NC	1973
16	WB66	Wrightsville Beach, NC	1966
17	WB70	Wrightsville Beach, NC	1970
18	CB65	Carolina Beach, NC	1965
19	CB67	Carolina Beach, NC	1967
20	CB82	Carolina Beach, NC	1982
21	HI68	Hunting Island, SC	1968
22	HI71	Hunting Island, SC	1971
23	EB54	Edisto Beach, SC	1954
24	HH82	Hilton Head, SC	1982
25	TI76	Tybee Island, GA	1976
26	JB81	Jacksonville Beach, FL	1981
27	CC74-75	Canaveral Beach, FL	1974-1975
28	IM80-81	Indialantic-Melbourne, FL	1980-1981
29	JI74	Jupiter Island, FL	1974
30	JI78	Jupiter Island, FL	1978
31	JI83	Jupiter Island, FL	1983
32	PB48	Palm Beach, FL	1948
33	PB49	Palm Beach, FL	1949
34	PB75	Palm Beach, FL	1975
35	DB73	Delray Beach, FL	1973
36	DB78	Delray Beach, FL	1978
37	DB84	Delray Beach, FL	1984
38	BR85	Boca Raton, FL	1985
39	BH75	Bal Harbour, FL	1975
40	MI76-82	Miami Beach, FL	1976-1982
41	VK69	Virginia Key, FL	1969
42	VK77	Virginia Key, FL	1977
43	KB69	Key Biscayne, FL	1969

formed from deep-water buoy readings to shallow-water wave heights for ten mile segments of shoreline. For this study, wave data are expressed as mean significant wave height (H_m) and maximum wave height (H_{max}). Mean significant wave height is the mean of the highest one-third of waves occurring at the location under consideration. The maximum wave height is the long-term mean of the highest wave measured in any given month.

THE EAST COAST BARRIER ISLAND BEACH REPLENISHMENT EXPERIENCE

Predictability

Volume. In general, prediction of long-term volumetric requirements, durabilities and costs of beach maintenance have been poor (PILKEY and CLAYTON, 1987; 1989). Long-term volu-

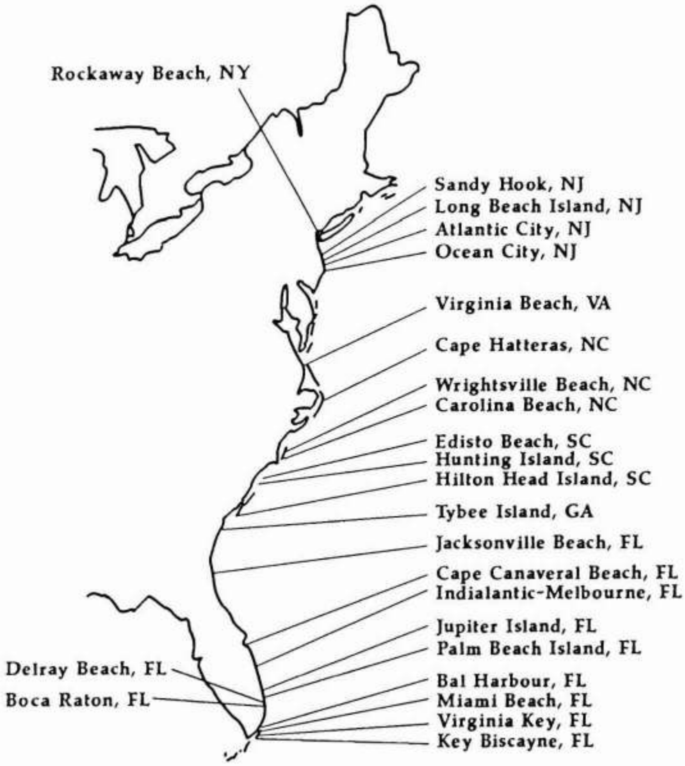

Figure 1. Location of the 24 projects (43 pumpings in all) which provide the bulk of the data used in the analyses shown in this paper.

metric requirements for beach maintenance tend to be underestimated. These predictions are usually based on the assumption that the volume required annually for periodic nourishment will be equal to the historic average annual erosion losses from the natural beach (USACE, 1984). Artificial beaches, however, have experienced loss rates significantly higher than historical rates for the natural beach (WALTON and PURPURA, 1977; DEAN, 1983; PILKEY and CLAYTON, 1987) even when differences in grain size and sorting have been taken into account (*e.g.* FISHER *et al.* 1975; JARRETT, 1977). ASHLEY *et al.* (1987) and EVERTS *et al.* (1974) cite examples of erosion rates for replenished beaches which are greater than the erosion rates of adjacent unreplenished beaches. LEONARD *et al.* (1988) suggest that this is the general case.

When post-replenishment loss rates are compared to pre-replenishment (*i.e.* natural) loss rates, the post-replenishment rates are found to be one and a half to twelve times greater; the lone exception is Miami Beach (Figure 2; the post-emplacement rates illustrated by the figure do not include measurements made during the beaches' initial "equilibration" period). These results suggest that future beach design models should not base volumetric predictions on the assumption that annual renourishment volume requirements will be equal to historical average annual erosional losses on the natural beach.

Longevity. The majority of replenished barrier island beaches on the U.S. East Coast have suffered at least 50% volumetric losses in under five years (Figure 3). Twenty-six percent of the study projects fall into the less-than-1-year beach lifetime category. Sixty-two percent of the beaches fall into the 1-to-5-year category. Only 12% of the projects examined fall into the

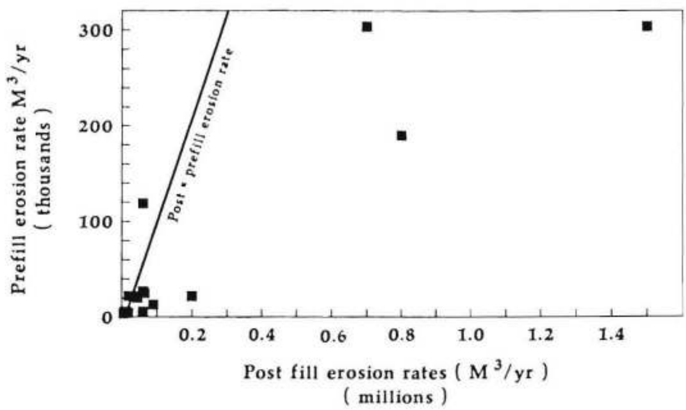

Figure 2. Comparison of the pre- and post-fill erosion rates of replenished beaches. The rate of fill loss is taken *after* the initial equilibration period when a replenished beach is said to adjust its profile to a new equilibrium slope.

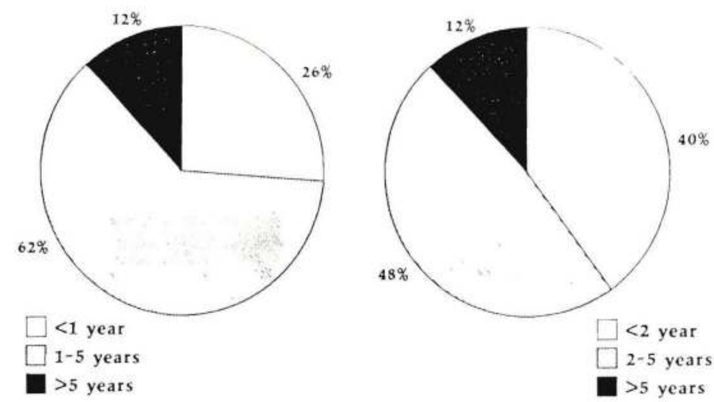

Figure 3. Durability or longetivity of replenished beaches in U.S. East Coast barrier islands. See text for explanation.

greater-than-5-year category. Most of these are located in Florida. As noted previously, the use of these categories is a conservative approach to estimating longevity as the categories are based on a reported loss of at least 50% of the fill material. In most cases, actual losses were considerably in excess of 50%.

In current engineering practice, several theoretical models are used for predicting the durability of an artificial beach (*e.g.* JAMES, 1975; DEAN, 1983; 1988). JAMES (1975) introduced the renourishment factor (R_j), the ratio of the predicted erosion rate for the borrow material relative to the existing erosion rate of natural beach material (Equation 1). In theory, the renourishment factor predicts how long after initial replenishment a subsequent nourishment will be required. For example, an R_j value of 1.0 predicts identical loss rate of native and replenishment material. If $R_j = 1.4$, nourishment with the borrow material in question must be emplaced 1.4 times as often as materials considered identical to the native beach material (USACE, 1984, p. 5–13).

$$R_j = e\left[\Delta\left(\frac{\mu_b - \mu_n}{\sigma_n}\right) - \frac{\Delta^2}{2}\left(\frac{\sigma_b^2}{\sigma_n^2} - 1\right)\right] \quad (1)$$

where: μ_b = borrow mean grain size in ϕ units;
μ_n = native mean grain size in ϕ units;
σ_b = borrow sorting in ϕ units;

Table 2. *Comparison of predicted and actual renourishment factors (R_j)* (James, 1975).

Project Location	R_j	R_j using actual loss rate of borrow material
Ocean City, NJ 1982	1.5	0.25
Indialantic-Melbourne, FL 1980-81	0.13	1.2
Delray Beach, FL 1978	7.4	5
Carolina Beach, NC 1967	0.25	1.75
Sandy Hook, NJ 1977	0.045	0.25

σ_n = native sorting in ϕ units;
Δ is a winnowing function.

Application of the R_j model to six East Coast barrier island projects fails to accurately predict the time interval between the initial replenishment of an artificial beach and the first necessary nourishment of that beach. "Necessary" for this study is defined as a 100% volumetric loss of fill material, or the point at which a subsequent nourishment actually occurred, whichever occurred earlier (Table 2).

The apparent inaccuracy of the model may be the result of (1) poor (*i.e.* inaccurate) grain size information, or (2) the lack of the relation of grain size and sorting to durability as postulated by the model.

DEAN (1983) examines the effect of fill length on longevity and derives a relationship (Equation 2) by which the longevity of a subsequent nourishment may be predicted, based on the longevity of a prior replenishment or nourishment operation.

$$(t_p)_2 = (t_p)_1 \frac{L_2^2}{L_1^2}\frac{K_1}{K_2} \qquad (2)$$

$(t_p)_1$ = time to lose a given percentage of fill from an initial fill operation;
$(t_p)_2$ = time to lose a given percentage of fill in a subsequent fill operation;
L_1 = length of initially replenished beach;
L_2 = length of subsequently replenished beach;
K = rate constant expressed in terms of breaking wave height, H_b, as:
$K = GH_b^{5/2}$
G is a factor incorporating beach and sediment characteristics (see Dean, 1983).

By comparing repeated pumpings of similar fill material on the same beach, K_1 is approximately equal to K_2 and Equation 2 becomes:

$$(t_p)_2 = (t_p)_1 \frac{L_2^2}{L_1^2} \qquad (3)$$

Table 3. *Actual and predicted longevity of 5 replenished projects using equation 3. Longevity is expressed as time to lose 50% of the fill material*

Project Location	Years	Predicted Months	Actual Months
Hunting Island, SC	1968–1971	9	3
Delray Beach, FL	1973–1978	54	60
Jupiter Island, FL	1974–1983	99	40
Wrightsville Beach, NC	1966–1970	171	24
Carolina Beach, NC	1965–1967	66	28

Table 3 tallies application of the model to repeated pumpings on five beach replenishment projects. Fill characteristics and wave height are assumed constant (never entirely true assumptions). The actual time to lose 50% of the fill material is, in almost every case, less than the amount of time predicted by this model.

DEAN (1988) has also derived a model for predicting the time necessary to lose a given percentage of fill material from a replenished beach. This model applies the principles of heat conduction or diffusion to a planform beach in order to describe the two ends of the planform as they begin to spread out (*i.e.*, experience end losses). Presumably, as the effects of sand loss from the ends move toward the center of the nourished beach, the planform shape approaches that of a curve describing a normal distribution. The analytical expression for the fraction of sand remaining in the placement area as this "smoothing" occurs is defined by Equation 4. This model assumes that all losses occur due to longshore transport and that offshore losses are negligible.

$$t_{50} = 8.7 \frac{L^2}{H_b^{5/2}} \qquad (4)$$

where t_{50} = time to lose 50% of the fill;
L = length of the nourished beach;
H_b = breaking wave height.

Applied to 34 East Coast projects, the "beach half-life" equation fails to predict accurately beach behavior, as measured by beach lifetime categories, approximately 80% of the time (Table 4).

STAUBLE and HOEL (1986) suggest that a

Table 4. *Success of the Dean (1988) model for predicting the time necessary to lose 50% of beach fill using "beach lifetime" categories.*

Replenishment Project	Beach Lifetime Category Predicted	Actual
	—OVERESTIMATED—	
Rockaway Beach, NY 1967	1 - 5	< 1
Long Beach Is., NJ 1979	> 5	1 - 5
Atlantic City, NJ 1948	1 - 5	< 1
Ocean City, NJ 1982	> 5	< 1
Wrightsville Beach, NC 1970	> 5	1 - 5
Carolina Beach, NC 1965	> 5	1 - 5
Carolina Beach, NC 1967	1 - 5	< 1
Carolina Beach, NC 1982	> 5	< 1
Hunting Island, SC 1968	> 5	< 1
Hunting Island, SC 1971	> 5	< 1
Tybee Island, GA 1976	> 5	1 - 5
Indialantic-Melbourne, FL 1981	1 - 5	< 1
Jupiter Island, FL 1974	> 5	1 - 5
Jupiter Island, FL 1978	> 5	1 - 5
Jupiter Island, FL 1983	> 5	1 - 5
Delray Beach, FL 1973	> 5	1 - 5
	—UNDERESTIMATED—	
Atlantic City, NJ 1963	< 1	1 - 5
Ocean City, NJ 1952	< 1	1 - 5
Edisto Beach, SC 1954	1 5	> 5
Canaveral Beach, FL 1975	1 - 5	> 5
Palm Beach, FL 1975	< 1	1 - 5
Bal Harbour, FL 1975	1 - 5	> 5
Virginia Key, FL 1977	1 - 5	> 5
	—ACCURATE—	
Sandy Hook, NJ 1977	< 1	< 1
Sandy Hook, NJ 1983	< 1	< 1
Atlantic City, NJ 1970	1 - 5	1 - 5
Cape Hatteras, NC 1973	1 - 5	1 - 5
Wrightsville Beach, NC 1966	1 - 5	1 - 5
Jacksonville Beach, FL 1981	> 5	> 5
Delray Beach, FL 1978	1 - 5	1 - 5
Boca Raton, FL 1985	< 1	< 1
Miami Beach, FL 1978–82	> 5	> 5
Key Biscayne, FL 1969	1 - 5	1 - 5

best fit curve generated from the density and durability data of previous beach replenishment projects may be used to predict the percentage of fill that should remain on a replenished beach after one year. Figure 4 shows the STAUBLE and HOEL data points with the addition of eleven data points from this study. A logarithmic curve, defined by Equation 5, describes the relationship between fill density and the percentage of fill material remaining on the beach after one year.

Although the correlation coefficient (0.83) indicates the relationship between density and durability is a significant one, the large scatter of data points (Figure 4) limits the practical application of the relationship.

$$Y = 20.012 \ln(X) - 34.4 \qquad (5)$$

where: Y is the estimated percentage of fill remaining after one year and X is the volume of fill placed per unit length of project (m^3/m).

Since other parameters, such as length, grain size and wave climate may also affect durability, STAUBLE and HOEL (1986) suggest the use of a factor, Z, which combines these parameters:

$$Z = \frac{\mu_b - \mu_n}{\sigma_n}\left[\frac{L}{H}\right] \qquad (6)$$

where: μ_b = borrow mean grain size in ϕ units;

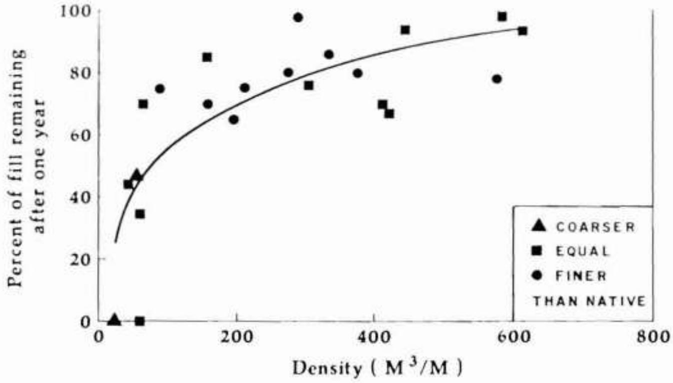

Figure 4. Relationship between the percent fill remaining after one year and density. STAUBLE and HOEL (1986) suggest use of such a relationship to predict durability of a replenished beach. Also shown in this figure is grain size of replenishment sand relative to original grain size.

μ_n = borrow mean grain size in ϕ units;
L = project length in meters;
H = mean significant wave height in meters;
σ_n = native sorting in ϕ units.

The Z factor, in theory, accounts for the combined effects of grain size, beach length, and breaking wave height and expresses the uncertainty associated with any portion of the density/durability curve. Based on four data points, Stauble and Hoel show a linear relationship between durability and the Z factor. When data from Sandy Hook (1977), Carolina Beach (1967), Wrightsville Beach (1970) and Delray Beach (1978) are added to the data set, the relationship between the Z factor and the percent difference between predicted and actual sand loss after one year becomes exponential (Figure 5).

By plotting the difference in calculated and actual percentages of fill remaining from Figure 4 against the Z factor, the following curve is obtained (Equation 7 and Figure 5).

$$Y = \exp(-0.001118\, Z)\, 2.0633 \qquad (7)$$

As the value of Z becomes increasingly negative, the difference between the calculated percent of fill remaining after one year (Equation 5) and the measured percent of fill remaining after one year increases (Figure 5). That is, the predictions made from the density/durability curve become less accurate.

Pilkey (1988) suggests a "Thumbnail" method for a rough estimation of length of life of replenishment projects on previously unreplenished beaches. The method was devised, based on regional behavior of replenished beaches, because of the poor record of beach durability predictions on East Coast barrier islands, using standard design assumptions. For Florida beaches, assumption of a nourishment interval of 9 years is suggested, compared to 3 years for New Jersey and 5 years for the remaining East Coast barrier island states. The results of the present study, however, indicate that PILKEY'S (1988) assumptions may be too optimistic and that assumption of renourishment intervals of seven, one and three years for Florida, New Jersey and the other east coast barrier states respectively, may be more accurate.

In summary, present predictive abilities inadequately measure actual volume requirements and durability. Yet, the successful design of beach replenishment projects, at least from the public's viewpoint, depends on accurate predictions. In an attempt to determine the best predictive use of parameters affecting beach durability and to improve our predictive capabilities, this study isolates and discusses the beach design parameters.

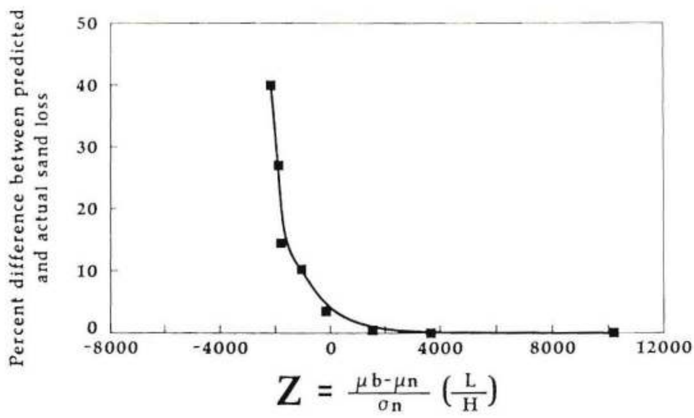

Figure 5. Plot of the Z factor (STAUBLE and HOEL, 1986) versus the percent difference between predicted and actual loss of beach fill.

Analysis of Beach Design Parameters

Grain size. One of the most widely accepted tenets of beach design is that the sorting and grain size of fill material exert fundamental control on the longevity of a replenished beach (*e.g.* DEAN, 1974; and JAMES, 1975—see U.S. ARMY CORPS OF ENGINEERS, 1984). Presumably, borrow material containing an excess of fines will lose a large percentage of its initial volume rapidly due to the sorting process. WIEGEL (1964) and DEAN (1983) have shown theoretically that coarser fill material yields longer-lived beaches than finer fill material. BERG and DUANE (1968) have observed this relationship in the field.

The effect of grain size on replenished beach lifespan can be observed by several means. The regional approach used here is not the ideal method. In any case, if grain size is important in control of beach durability, it should be apparent on an East Coast-wide scale. In a later section of this paper, analyses of repetitive nourishments of different grain sizes on the same beach are presented.

Figure 6 shows the relationship between relative grain size (finer than, coarser than or comparable to native) and longevity. There is no obvious correlation between relative grain size and replenished beach durability on an East Coast scale. Both coarse and fine beaches have experienced 50% volumetric losses in less than one year.

Figure 7 is a matrix diagram showing the distribution of relative fill grain sizes with respect to the maximum wave height and beach lifetime category. Intuitively, one might expect durability to increase with an increase in grain size for a given wave climate. These limited data do not suggest that such a relationship exists.

Length. An increase in the longevity of a replenished beach with an increase in the length of the replenished beach is another widely accepted principle (DEAN, 1983, 1988; FLORIDA STATE DEPARTMENT OF NATURAL RESOURCES, 1986). For example, DEAN (1983) states that doubling the length of a replenished beach will increase its longevity by a factor of four.

Underlying this length-durability relationship is the assumption that most losses occur in the longshore direction as the result of littoral drift and that offshore losses are negligible. Clearly, some beaches are dominated by longshore drift. Offshore losses, however, do occur, particularly during storm activity (SWIFT, 1976). PEARSON and RIGGS (1981), while collecting vibracores for an unrelated study of the inner continental shelf of North Carolina, inadvertently documented that more than four million cubic yards of replenishment sand from Wrightsville Beach had moved directly offshore. The replenishment sand was distinguished by its gray coloration, in contrast to the

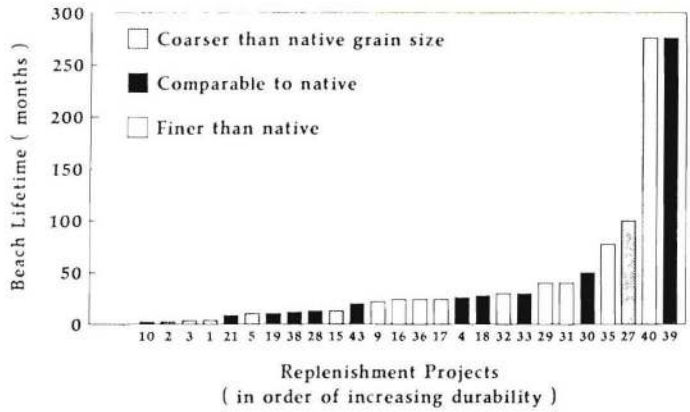

Figure 6. Bar graph showing the relationship between fill grain size and durability of the replenished beach. Numbers on the abscissa refer to specific beach localities listed in Table 1.

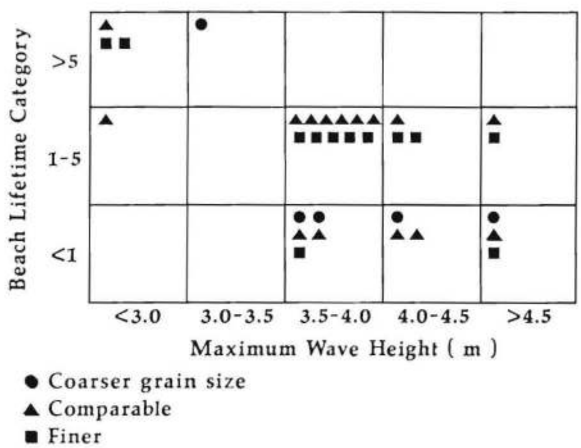

Figure 7. A matrix showing the relationship between grain size, wave activity and beach lifetime categories (years).

natural, brown-colored surficial shelf sand. Although profiling studies of replenished beaches do exist (*e.g.* WINTON *et al.*, 1981), these studies generally do not extend far enough offshore to monitor the offshore movement of sand.

Figure 8 illustrates the length/longevity relationship based on the study data. All beaches in the less than one-year category are shorter than four kilometers; however, the overall behavior of beaches less than four kilometers is variable. Short (< 4 km) as well as long beaches have been long-lived. No clear cut and strong relationship exists between the length of East Coast replenished beaches and durability.

Density. Another widely accepted principle is that the density (m^3/m) of material placed on the replenished beach exerts a major effect on the durability of the replenished beach: the greater the density of fill, the longer the life of the beach. For example, NORDSTROM, *et al.* (1979) conclude that the low-density projects on Sandy Hook, New Jersey, were "too small" to be of lasting value. STAUBLE and HOEL (1986) find that density controls the percentage of ini-

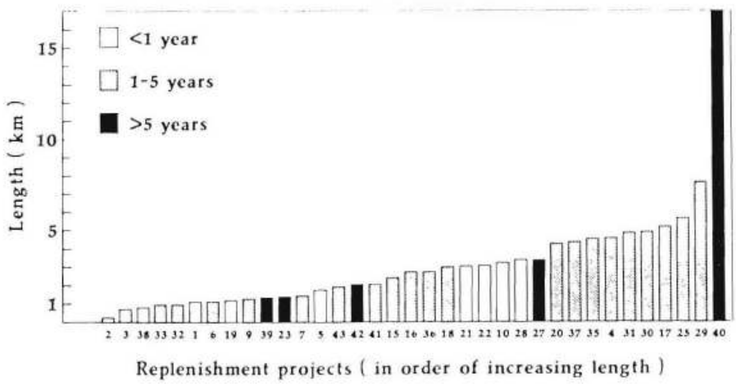

Figure 8. Bar graph showing the relationship between replenished beach length and replenished beach longevity. Numbers on the abscissa refer to specific beach localities listed in Table 1.

tial fill remaining after one year on several replenished beaches in Florida. They conclude that at least 150 m^3/m of material is necessary to achieve 60% retention after the first year.

Figure 9 is a plot of density versus longevity. The density data in Figure 9 conveniently fall into clusters. These groups may be assigned to three categories: (1) low density (0–100 m^3/m), (2) intermediate density (100–450 m^3/m) and (3) high density (>450 m^3/m). Beaches in the low-density category generally experience lifetimes of less than two years, whereas beaches in the high-density category generally exhibit lifetimes in excess of five years. Eighty percent of the beaches in the intermediate- and high-density categories experience lifetimes greater than two years. Clearly, density plays a role in determining replenished beach durability, but it is obvious that other factors are at work as well. Figure 4 and equation 5, discussed in a previous section, indicate that a density of 70 m^3/m should be used to achieve at least 50% retention after one year. As pointed out earlier, the large scatter of data points (Figure 4) limits the precision in the application of this relationship.

To explore the combined effects of density and wave climate on durability, density is plotted against maximum wave height (Figure 10). The data suggest that a relationship exists between wave climate and beach durability with respect to density. Durability tends to increase for a

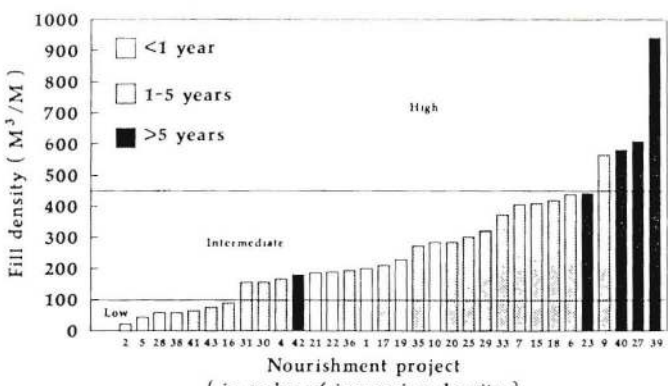

Figure 9. Bar graph showing the relationship between replenished beach density and replenished beach longevity. Numbers on the abscissa refer to specific beach localities listed in Table 1.

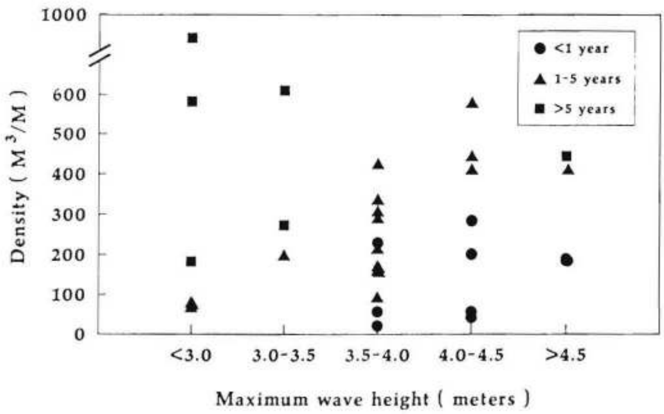

Figure 10. Plot showing the interrelationship of maximum wave height, density and replenished beach durability.

given wave-height class as the density of the nourished beach increases. That is, as density increases, there is a tendency for the beach lifetime category to gradually shift from the less durable to the more durable categories.

Beaches having low maximum wave heights (< 3.0 m) are, for the most part, more durable than beaches with greater wave heights, regardless of density (Figure 10). For comparable densities, durability decreases with an increase in maximum wave height. For example, the beach lifetime categories of replenished beaches with densities in the range of 150 m^3/m to 250 m^3/m gradually shift from greater-than-5-years, to 1-to-5-years and then to less-than-1-year as the maximum wave height increases from less than three meters to greater than four and a half meters.

Method of Emplacement. Method of emplacement has also been cited as an influential factor in artificial beach longevity. The hydraulic dredge and pipeline is the most widely used method of sand emplacement on the U.S. East Coast, although land hauling techniques are also employed. NORDSTROM *et al.* (1979) suggest that dump-trucked sand was lost more quickly on Sandy Hook, New Jersey, than it would have been if the sediments had been emplaced by hydraulic dredge and pipeline. Presumably, this difference is due to differences in initial packing and its effect on sand grain entrainment in the surf zone.

Three projects in which the entire fill was emplaced by dump-truck are included in this study. These are: Sandy Hook, NJ (1977), Indialantic-Melbourne and Virginia Key, FL (1989); all three exhibited rapid losses of sand. These projects, however, also had low fill densities relative to other projects.

Virginia Beach, VA, is an example of a continuously maintained, nourished beach. Each year, sand is emplaced by both hydraulic dredging adjacent to an inlet and by dump-truck along the central sections of the beach. If dump-trucked sand is lost more readily than hydraulically pumped material, the percentage of fill lost should perhaps increase with an increase in the percentage of fill trucked. The data in Figure 11 indicate that this is not the case.

Inlet Proximity. It is well established that barrier island inlets and their associated tidal deltas may act as both sand sources and sinks. It is also well established that inlet dynamics strongly affect shoreline position and changes in shoreline position adjacent to inlets. It has been suggested that inlets act as sinks for sand from replenished beaches (FLORIDA DIVISION OF BEACHES AND SHORES, 1985; STAUBLE and HOEL 1986) and, as such, may affect the durability of a nourished beach. Figure 12 is a plot of the proximity of inlets to nourished beaches versus beach longevity. There is a clear difference in the beach lifetime of those replenishment projects 10 km or more away from unstabilized inlets and those 6 km or closer to inlets. The projects at greater dis-

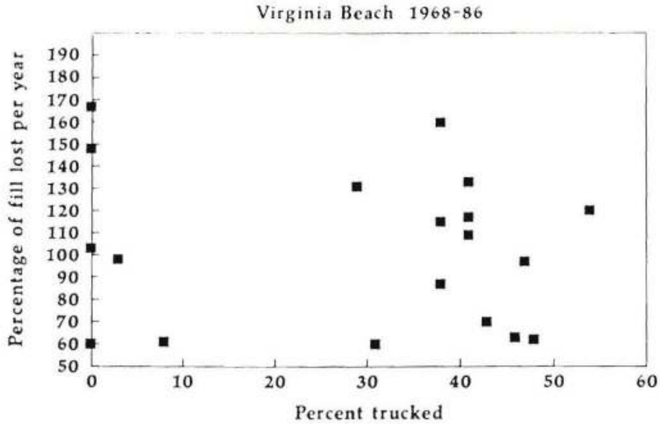

Figure 11. Percentage of fill lost each year (between 1968 and 1986) at Virginia Beach versus the percent of sand trucked in (as opposed to pumping).

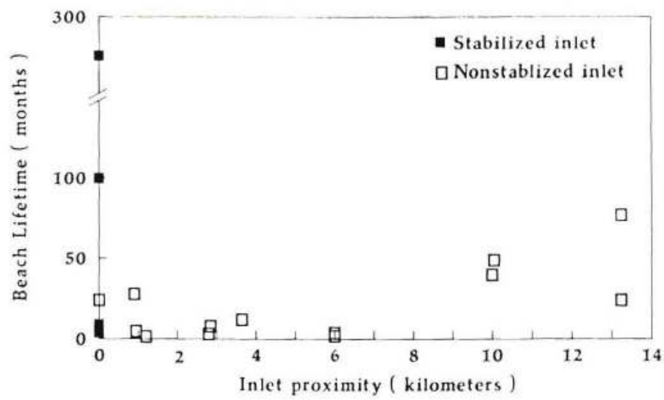

Figure 12. Replenished beach durability as related to inlet proximity.

tance from an inlet exhibit greater durability. We conclude that distance away from an unstabilized inlet is a factor, albeit ill-defined, controlling beach life. The six replenished beaches adjacent to jetties illustrated in Figure 12 exhibit a wide range of durability. Two beach replenishment projects at Atlantic City, NJ, in 1963 and in 1970 exhibited overall lifetimes of 1-to-5 years. For both projects, however, the section of beach immediately downdrift and adjacent to the jetty was less durable than the remainder of the beach. The jetty-adjacent sections lost 90% of their original fill volume within one year.

Groins. Hard stabilization structures may also affect beach longevity. These effects would be related to the position of the structure, parallel or perpendicular, with respect to the shoreline. Shore-parallel structures such as seawalls are believed to have a detrimental effect on the natural beach profile (WALTON and SENSABAUGH, 1983; PILKEY and WRIGHT, 1988) although the specific dynamics of this phenomenon/process remain uncertain.

Beach bulldozing has been referred to as "poor man's replenishment." Since, however, no new sand is added to the beach, it is not, technically, actual replenishment. KANA and

SVETLICHNY (1982) noted that sand bulldozed up seaward of seawalls experienced higher loss rates than did sand which was bulldozed up seaward of adjacent unstabilized dunes. On Myrtle Beach, SC, the bulldozed sand in front of shore protection structures eroded in several weeks to four months, whereas virtually no loss was noted adjacent to natural dunes in the fourteen month study period. In addition, these authors noticed slower recovery after storms at armored stations.

Terminal structures (*e.g.*, jetties or groins located at the ends of a replenishment project) are sometimes constructed with the aim of increasing durability of the artificial beach. DEAN (1983) concludes that terminal groins may be most effective where the dominant waves approach the shoreline with small obliquity, and that groin fields may be most effective where dominant waves approach the beach at a high angle.

The results of this investigation suggest that groins in conjunction with beach replenishment can help stabilize a beach. For example, Edisto Beach, SC, is reported to have retained at least a small part of its 1954 fill material for as long as 26 years (CUBIT ENGINEERING, 1981). This high degree of retention is attributed to the 34 groins spaced every 500 to 600 feet along the shoreline.

Sea Isle City, NJ, pumped 535,500 m^3 of sand onto the beach in a 1984 project. The northern half of the project included a groin field and the southern half was nonstabilized. Losses in the groined area, following the 1984 fill, were much less rapid than those in the non-groined area, which suffered substantial volumetric losses and was renourished (120,870 m^3/m) in 1987 (PREVITTI, *pers. comm.*). Inlet proximity and storm occurrence may also have influenced fill retention on the nonstabilized portion of the project (HALSEY and FARRELL, 1988).

Lastly, repeated pumpings on Virginia Key, FL, clearly exhibit an increase in beach fill retention as the result of nourishment in conjunction with groin construction. Virginia Key was first replenished in 1969. Retention was low, however, with a 50% volumetric loss in under two years. When Virginia Key was renourished in 1977, rubble groins were added to the shoreline. Apparently, the groins have increased the durability of this beach (CAMPBELL, *pers. comm.*). As of 1988, local engineers report that a "significant" amount of fill material remains on the beach.

EGENSE and SONU (1987) conclude that the degree of beach fill retention may be related to the degree of compartmentalization of the beach. Presumably, highly compartmented beaches, such as beaches having a groin field are more durable than other beaches. The data in Figure 13, which summarizes beach longevity and project boundary conditions, support this relationship. The few examples of replenished groined beaches exhibit durabilities in excess of five years.

The durabilities of replenished beaches that have an updrift terminal structure or nonstabilized inlet vary. For the most part, however, these beaches have been short-lived (*e.g.* Rockaway Beach, Boca Raton, Hunting Island). In some cases such as Atlantic City, Tybee Island, and Carolina Beach, the degree of retention of the fill is locally much lower near the updrift boundary than the overall durability categories indicate. This is because the durability categories reflect overall beach behavior, which masks localized behavior adjacent to structures.

Oceanographic Parameters

Storm Frequency. The oceanographic parameter chosen to best express wave climate in this study is storm frequency. Shelf width and shoreface slope, which may indirectly influence wave climate, do not markedly affect replenished beach durability (LEONARD *et al.*, 1988).

One cannot overemphasize the importance of storms as sediment movers (HAYES, 1967). Although partial recovery of the beach usually occurs, in many cases, substantial amounts of material can be permanently lost to the offshore (WIEBEL, 1964; SWIFT, 1976; U.S. ARMY CORPS OF ENGINEERS, 1984; BRUUN, 1985). Unfortunately, few published studies quantify the impact of storm events on artificial beach behavior (ASHLEY *et al.*, 1987).

Wave climate, reflected by storm frequency, is expressed in two ways: (1) the number of storms occurring in the first year of the project life and (2) the number of months after beach emplacement until the first storm event occurs (Table 5). These data are from *Storm Data*

DOWNDRIFT			UPDRIFT: ADJACENT — GROIN FIELD within project limits	UPDRIFT: ADJACENT — TERMINAL STRUCTURE	UPDRIFT: ADJACENT — NON-STABILIZED INLET	UPDRIFT: NON-ADJACENT — WITHIN 5 KM — GROIN FIELD	UPDRIFT: NON-ADJACENT — WITHIN 5 KM — TERMINAL STRUCTURE	UPDRIFT: NON-ADJACENT — OUTSIDE 5 KM
ADJACENT		GROIN FIELD	VK77 / > 5 EB54 / > 5	RB67 / < 1				
ADJACENT		TERMINAL STRUCTURE			TI76 / 1-5		MI82 / > 5	CH73 / 1-5 WB66 / 1-5 WB70 / 1-5 LB79 / 1-5
NON-ADJACENT	WITHIN 5 KM	NON STABILIZED INLET						VK69 / 1-5
NON-ADJACENT	WITHIN 5 KM	GROIN FIELD		AC63 / 1-5 AC70 / 1 5				
NON-ADJACENT	WITHIN 5 KM	TERMINAL STRUCTURE			HI68 / < 1 HI71 / < 1			
NON-ADJACENT	OUTSIDE 5 KM	NO STRUCTURE	OC82 / < 1	JB81 / 1-5 CC75-76/ >5 BR85 / < 1 BH75 / > 5	CB82 / 1-5 CB65 / 1-5	SH77 / < 1		IM80-81/ <1 DB73 / 1-5 DB78 / 1-5 JI74 / 1-5 JI78 / 1-5 JI83 / 1-5

Figure 13. Replenished beach longevity and project boundary conditions for 28 beach replenishment projects. Given inside the boxes are beach name (see Table 1 for addreviation) and beach durability class.

Table 5. *Storm and durability data for selected East Coast replenished beaches.*

Project	Number of storms in the first year	Time until first storm (Months)	Durability Category
Rockaway Beach	2 +	—	1 year
Indialantic-Melbourne, 1980–81	4 +	3	< 1 year
Sandy Hook, 1977	5	2	< 1 year
Sandy Hook, 1983	5 +	1	< 1 year
Ocean City, 1982	17	0.25	< 1 year
Carolina Beach, 1967	2	2	< 1 year
Cape Hatteras, 1973	4	4	1 year
Carolina Beach, 1982	7	—	1–5 years
Carolina Beach, 1965	1	< 1	1–5 years
Wrightsville Beach, 1966	1	11	1–5 years
Wrightsville Beach, 1970	3	3	1–5 years
Tybee Island, 1976	1	1	1–5 years
Long Beach Island, 1979	1	1	1–5 years
Delray Beach, 1978	1	12	1–5 years
Delray Beach, 1984	1	1	1–5 years
Jacksonville Beach, 1979–81	0	39	1–5 years
Canaveral Beach, 1974–75	0	53	> 5 years
Bal Harbour, 1975	0	48	> 5 years
Miami Beach, 1976–82	0	> 15	> 5 years

(NOAA) 1975–1986, WINTON *et al.*, (1981) and media accounts.

Beaches in the less-than-one-year beach lifetime category (Table 5) experienced two to seventeen storms during the first year of the project life. Beaches in the 1-to-5-year category experienced one to four storms during the same period. Beaches in the greater-than-5-year category experienced no storms during the first year.

Figure 14 illustrates the relationship between the number of storms occurring in the first year of project life and beach longevity. The data indicate that all less-than-2-year beaches experienced at least two storms during the first year of project life. Two-to-five-year beaches experienced no more than one storm and greater-than-5-year beaches generally experienced no storms during the same period.

There may also be a relationship between the length of time between project completion, the first storm event, and beach longevity. Table 5 indicates that beaches in the less-than-one-year category were subjected to their first storm within 0.25 to four months time. One-to-five-year beaches were struck by their first storm within less than one to 39 months. Greater-than-5-year beaches were in place for times ranging from 20 to 53 months before the first storm. Overall, beaches in the greater-than-5-year category exhibit significantly longer periods (more than twelve months) between pumping and storm occurrence than the beaches in the shorter-lived beach lifetime categories with one exception (Table 5). Clearly, storm frequency and timing are important factors influencing replenished beach longevity.

The influence of storm activity on replenished beach durability is also illustrated by relating the time of year when the sand was emplaced and the durability of the beach (Figure 15). Beaches emplaced during the autumn and winter months (*i.e.* September through February) are less-than-one-year beaches. It is likely that these low durabilities are due to the increased storm activity during these seasons. The performance of beaches emplaced during less stormy seasons (*i.e.* spring and summer) varies; however, spring and summer beaches tend to exhibit beach lifetimes of 1-to-5 or greater-than-5 years.

The implication here is that, with time, some sort of stabilizing process occurs on beaches and those with more time to consolidate, before onset of the storm season, will be more durable. There is no direct evidence to support this consolidation hypothesis, but it should be an area of fruitful future research.

MULTIPLE NOURISHMENTS

The best way to assess the relative importance of the various replenishment design parameters is to evaluate them for repeated nourishments on the same beach. This approach should hold a number of variables constant, or relatively so. Unfortunately, appropriate data for this type of analysis is very limited for U.S. East Coast beaches.

Table 6 shows the parameters for nine beaches which have had multiple replenishment projects. In general, the "repeated pump-

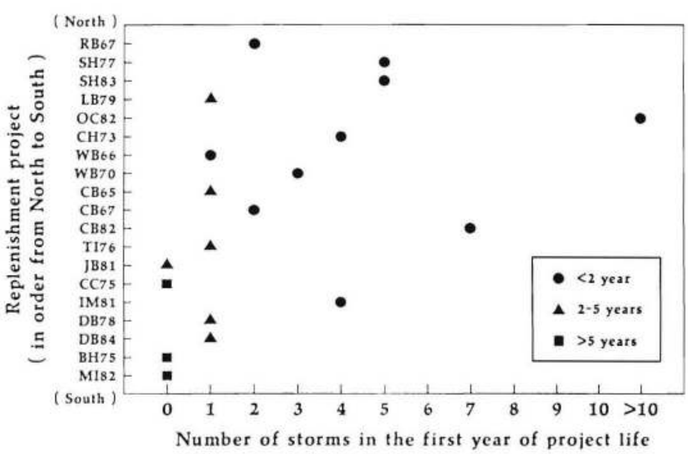

Figure 14. The effect of the number of storms in the first year of project life on replenished beach durability. See Table 1 for specific beach localities plotted on the ordinate.

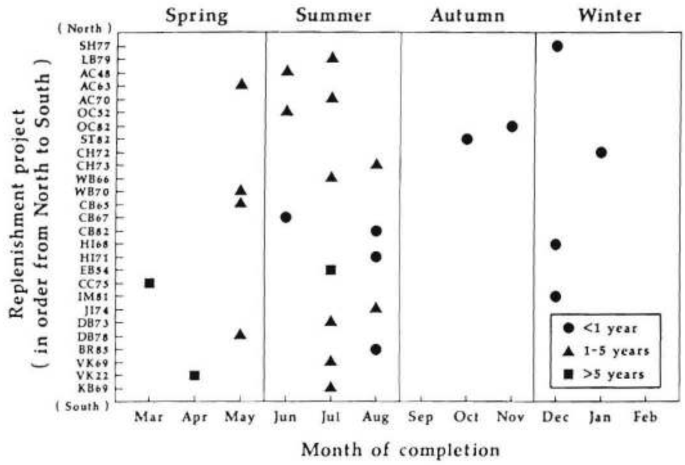

Figure 15. The role of the month of project completion in replenished beach durability. See Table 1 for specific beach localities plotted on the ordinate.

Table 6. *Length, density, grain size and durability for selected repeatedly nourished East Coast beaches.*

Project	Length (m)	Density (m^3/m)	Grain Size relative to native	Durability Category
Sandy Hook, '77	250	22.4	COARSER	< 1 year
Sandy Hook, '83	720	2517.3	COARSER	< 1 year
Atlantic City, '48	4570	43.12	SAME	< 1 year
Atlantic City, '63	1174	444.0	SAME	1 – 5 years
Atlantic City, '70	1160	407.6	SAME	1 – 5 years
Ocean City, '52	1290	575.0	FINER	1 – 5 years
Ocean City, '82	3220	285.0	SAME	< 1 year
Wrightsville, '66	2740	89.0	FINER	1 – 5 years
Wrightsville, '70	5780	211.6	FINER	1 – 5 years
Carolina Beach, '65	3000	421.0	SAME	1 – 5 years
Carolina Beach, '71	1200	287.7	SAME	1 – 5 years
Carolina Beach, '82	4270	229.2	COARSER	< 1 year
Hunting Island, '68	3050	186.9	SAME	< 1 year
Hunting Island, '71	3060	189.0	SAME	< 1 year
Jupiter Island, '74	7620	333.0	FINER	1 – 5 years
Jupiter Island, '78	4900	157.4	SAME	1 – 5 years
Delray Beach, '73	4520	274.8	FINER	1 – 5 years
Delray Beach, '78	2740	194.4	FINER	1 – 5 years
Delray Beach, '84	4350	194.4	—	> 3 years
Virginia Key, '69	2090	64.4	SAME	< 1 year
Virginia Key, '77	2080	184.0	FINER	> 5 years

ing" data suggest that the effects of density, hard stabilization and storm activity exert greater control on the durability of artificial beaches than do the effects of grain size and length.

For example, Ocean City, NJ, was replenished in 1952 and 1982. The 1952 project was shorter and had fill material that was finer than the native material (U.S. ARMY CORPS OF ENGINEERS, 1963; 1985, FARRELL, *pers.*

comm.); however, this project was longer-lived than the 1982 project. The 1982 project was more than twice as long as the earlier project and consisted of fill material of the same size as the native sand (BISHOP, 1986).

The increased longevity of the 1952 project is probably the result of the greater density and/or the difference in storm histories for the two projects. The 1982 project was reportedly subjected to a sequence of seventeen northeast storms in the first two and a half months after project completion (HALSEY and FARRELL, 1988).

For repeated pumpings at Atlantic City, NJ, the length of the nourished beach once again appears as a relatively unimportant control on beach retention. The Atlantic City 1948 project was almost four times as long as the two subsequent projects, however, it experienced much lower rates of retention (HALL, 1952; EVERTS *et al.*, 1974; SORENSEN and WEGGEL, 1985). By comparing the densities of the projects, it becomes evident that the poor retention of the 1948 project may have been the result of the low project density. In all three Atlantic City projects, the fill material had a grain size comparable to the native material.

The 1969 and 1977 replenishment projects on Virginia Key, FL, had approximately the same length (DEAN, 1983), however, the density of the more durable 1977 project was more than two times that of the 1969 project and included the construction of a groin field (WALTON, 1977). In addition, the 1977 fill material was finer than both the native and the 1969 fill material. Because the 1977 project experienced greater rates of retention, it appears that either grain size was unimportant in this instance or that the density of the fill and the groins masked the effects of grain size.

Repeated projects on Jupiter Island, FL, have generally experienced durabilities in the 1-to-5-year beach lifetime category. The earliest project, 1974, was longer and denser than the subsequent 1978 project (STAUBLE and HOEL, 1986). The fill material used in the 1974 project was finer than the native material whereas the borrow used in the 1978 project was comparable to the native material (WALTON, 1977; CAMPBELL, *pers. comm.*). Still, both projects experienced similar degrees of retention. This may indicate that length and/or density mask the effects of grain size on beach longevity or that grain size is not a controlling factor of beach retention.

Repeated nourishments at Delray Beach, FL, (1973 and 1978) have had differing lengths and volumes (WALTON, 1977; STROCK and ASSOC., 1984a, 1984b), although fill material of grain size finer than native was used in both cases. The 1973 project was slightly more durable than the 1978 project in addition to being of greater length and greater density.

Two pumpings on Wrightsville Beach, 1966 and 1970, have experienced similar durabilities (JARRETT, 1977). Both projects consisted of fill material finer than the native material. The 1970 project, however, was almost twice as long and had a density almost two and a half times the 1966 project (U.S. ARMY CORPS OF ENGINEERS, 1966; 1967; JARRETT, 1977). The similar durabilities may be the result of the storm histories of the two projects. The 1970 project was subjected to three significant erosional storms in the first year, whereas the 1966 project was subjected to only one (WINTON *et al.*, 1981). Increasing the density of the 1970 project probably enabled the 1970 beach to be as durable as the 1966 project, even though it was subjected to more storms.

In summary, this analysis of a small number of repeated pumpings indicates the same relationships (or lack thereof) between the numerous replenishment parameters and replenished beach durability as those determined by study of individual beaches on an East Coast scale. That is, grain size and length are relatively unimportant factors while storm activity, the presence of groins, and fill density are important factors.

SUMMARY AND CONCLUSIONS

The results of this study indicate that most U.S. East Coast replenished barrier island beaches experience durabilities of less than five years. Specifically, 26% of the replenished beaches lasted less than one year, 62% lasted one to five years, and 12% lasted longer than five years. It is important to re-emphasize that beach life is defined as the time required for a 50% or more volumetric loss of fill material. Use of this measure is a conservative approach because, in most cases, the volumetric loss of the beach within its stated lifetime interval is closer to 100%.

The post-project erosion rates for most U.S. East Coast barrier island replenished beaches are one and a half to twelve times higher than pre-project (*i.e.* native) erosion rates. Miami Beach is the single exception. Clearly, and this is one of the most important conclusions of this study, replenished beaches are much more unstable than their natural predecessors. Present design strategies that assume nearly equal pre- and post-project erosion rates should not be considered valid.

The conclusion concerning the relative instability of replenished beaches is a straightforward and simple one based on a large amount of information. Besides the 42 beaches noted in Table 4 and Figure 1, a lot of "gray" and anecdotal information indicates that short lifespans, or at least shorter lifespans than normally predicted, are a fact of life on the East Coast.

Conclusions concerning design parameters, while statistically valid, are generally based on a smaller data base. The results of analysis of design parameters suggest that factors such as beach length, fill grain size, method of fill emplacement, shoreface slope and shelf width exert little influence on replenished beach durability when examined on this broad East Coast scale.

Other parameters have a greater effect on replenished beach longevity. The presence of groins, fill density and inlet proximity all impact on replenished beach longevity. Apparently, construction of groins on an artificially nourished beach aids in the retention of some beach fill, and an increase in fill density yields an increase in the percentage of fill remaining after one year. On an East Coast scale, at least 70 m^3/m of fill material should be used to achieve 50% retention after one year. Beyond the first year, however, density exerts less control over beach durability.

The most important control on replenished beach longevity is wave climate, particularly storm activity. For present purposes, storm activity is measured by the number of storms occurring in the first year of project life and the time elapsed between fill emplacement and the occurrence of the first storm. In general, the beaches with the greater longevities (*i.e.* greater than five years) experience fewer storms (usually none) during their first year of project life than the less durable beaches. Similarly, the longer-lived beaches have experienced longer time intervals between project completion and the first storm event than have the shorter-lived beaches. Beaches pumped in the spring generally exhibit greater longevities than beaches replenished during the autumn or winter, most likely due to the increased storm activity associated with the fall and winter months.

The observation that grain size does not significantly impact beach durability is both surprising and significant. Surprising, because it is "common sense" and is a widely held principle of replenished beach design. Significant, because all three models used to determine beach fill volumes assume that grain size characteristics are important in predicting replenished beach behavior. Significant also because, if it is true, considerable expense may be saved in future beach replenishment projects if grain size matching is no longer deemed necessary, or some threshold beyond which grain size variations are important can be established.

There are several possible explanations for the lack of observed grain size effect. For one, the range of grain sizes used on East Coast beach replenishment projects is small. For another, there is considerable question as to whether techniques used to characterize grain size of the huge volumes of potential fill material accurately characterize what actually arrives on the beach. STAUBLE and HOEL (1986) discuss this problem. Another strong possibility is that grain size does play a role, but that its importance is completely overshadowed by the importance of storm impact.

Perhaps, if more data and, particularly, better data on both beach longevity and grain size were available, a grain size relationship might become apparent. Future studies, specifically beach monitoring, should be designed to determine the role of sediment grain size in replenished beach behavior.

A direct relationship between beach length and beach durability is another widely accepted principle which is not supported by the data of this investigation. This principle, also, may be affected by the overwhelming importance of storms in determining beach longevity. But, another more important factor may be at work: beaches do not necessarily "disappear" in a downdrift longshore direction. Offshore transport may be important, too. If so, the basic assumption behind the length/durability relationship is incorrect. Only one study has documented the offshore fate of a replenished beach (PEARSON and RIGGS, 1981), and, in this case (Wrightsville Beach, N.C.), almost the entire project disappeared offshore.

The principle that longer replenished beaches exhibit greater longevity thus fails broad application on East Coast barrier beaches, because the basic underlying assumptions concerning shoreline processes are incorrect. Offshore transport may be much more important than has been assumed in the past beach replenishment literature.

Undoubtedly, in situations where longshore transport is dominant, beach length will make a difference in beach durability. Apparently such is the case in the Gulf of Mexico where a fairly close relationship exists between replenished beach durability and length of beach life (DIXON and PILKEY, 1989). A single storm event, however, may change the picture dramatically since steep waves tend to carry materials offshore. Thus, the relative importance of offshore and longshore transport may vary in both time and space.

Reading the literature on beach replenishment reveals how concepts such as the grain size and beach length/durability relationship are maintained and even strengthened by improper observations. Studies of single beach replenishment projects, although useful, are not the best approach to evaluation of the beach design parameters which affect beach durability. Too often, such studies can reinforce long held ideas by allowing the investigator to choose among several parameters to explain beach durability. For example, there is a tendency in the literature to readily attribute rapid loss of a beach to too fine grain size, but if a coarse beach disappears, its loss may be attributed to storms.

An urgent need exists for a national and perhaps international program in replenished beach monitoring. Only through a coordinated program of widespread, continuous, and standardized monitoring will we learn more about the design parameters of such beaches. In a time of rising sea level and accelerating shoreline erosion, such an effort should have high priority.

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□ ZUSAMMENFASSUNG □

Dreiundvierzig Strandaufspülungs-Projekte an der Atlantik-Küste der USA wurden aufgrund der Verweildauer des Materials in 3 Kategorien geteilt: (1) Erhaltung von weniger als 1 Jahr (26 %); (2) 1-5-jährige Strandverweilung (62 %) und (3) längere Stranderhaltung als 5 Jahre (12 %).

Aufgefüllte Stände nördlich von Florida haben generell nur eine Lebensdauer von weniger als 5 Jahren.

Das Sturmgeschehen ist der bedeutendste Faktor bei der Bestimmung der Stranderhaltung. Es ist so bedeutend, daß andere, welche ebenfalls eine Rolle bei dem Verhalten künstlicher Strande spielen, uberschattet werden. Strandlänge, Korngröße, Strandgefälle, Schelfbreite und Art der Verfüllung weisen jeweils keine Korrelation zur Erhaltung aller künstlichen Strände auf. Geringe Einflüsse haben dagegen die Nähe des Küstendruchlasses und eine Kombination zwischen Strandrichtung und dominierendem Winkel des Wellenauflaufs. Die ursprüngliche Dichte der Verfüllung hat signifikanten Einfluß auf die verbleibende Füllmenge nach 1 Jahr, später wird ihr Effekt aber weniger deutlich. —*Dieter Kelletat, Essen/FRG.*

□ RESUMEN □

Se ha dividido cuarenta y tres proyectos de regeneración de playa en la Costa Atlántica de los Estados Unidos en tres categorias, basadas en el tiempo de retención del relleno: (1) Playas de menos de 1 año (26%), (2) Playas de 1 a 5 años (62%), y (3) Playas de más de 5 años (12%). Las playas generadas o regeneradas del Norte de Florida tienen generalmente vidas útiles menores de 5 años. El régimen de temporales es el factor más importante para la determinacion de la durabilidad de la playa; tan importante que los efectos de otros parametros que también juegan un papel en el comportamiento de la playa artificial quedan enmascarados. La longitud de la playa, tamaño del grano, pendiente de la costa, anchura de la plataforma y método de colocacion del relleno no muestran correlación con el tiempo de retención del relleno. Las proximidades a una desembocadura y una combinación de la orientación de la linea de costa y del ángulo de aproximación dominante del oleaje pueden ejercer una influencia pequeña en el comportamiento de la playa. La densidad incial del relleno (volumen por unidad de longitud) ejerce una influencia significativa en el porcentaje del relleno que queda al cabo de un año, pero se vuelve menos importante a partir de este primer año.—*Department of Water Sciences, University of Cantabria, Santander, Spain*

□ RESUME □

Les quarante trois projets de remplissage de plage sur la côte atlantique des Etats Unis sont divisés en trois catégories, selon la durée de la rétention du remplissage: 1) moins d'un an (26%), 2) de 1 à 5 ans (62%), 3) plus de 5 ans (12%). Le remplissage des plages du Nord de la Floride a une durée de moins de 5 ans. Les tempêtes sont le facteur le plus important pour le maintien du remplissage, au point d'éclipser les autres paramètres qui peuvent jouer un rôle dans le comportement de la plage artificielle. Taille de grain, pente de la plage, largeur du plateau continental, technique utilisee ne sont pas correllés avec la durée de remplissage à l'échelle régionale. La proximité d'un goulet et la combinaison de l'angle d'orientation de la plage avec celui de l'approche des vagues dominant, exercent une influence mineure. La densité initiale du remplissage (volume par unité de longueur) ont une influence significative sur le pourcentage restant après un an, mais cet effet n'est plus aussi net apreés la première annèe.—*Catherine Bressolier (Géomorphologie E.P.H.E., Montrouge, France)*