Beach Fill at Fenwick Island, Delaware

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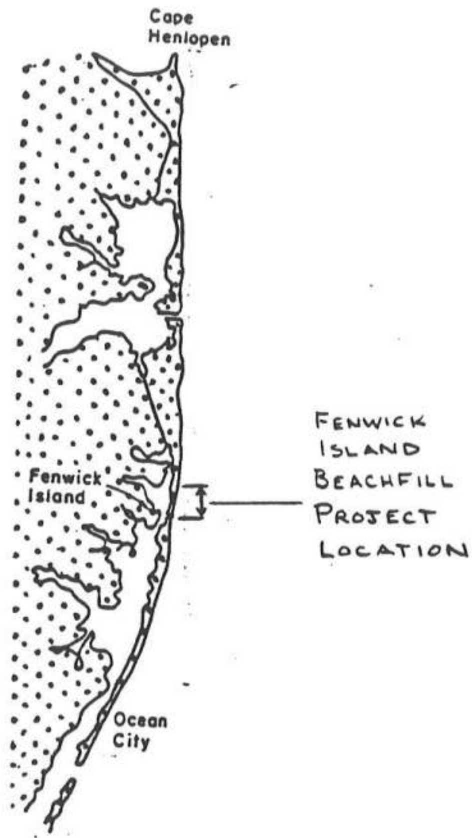

Figure 1: Delaware Coast and Beachfill Location

Introduction

The purpose of this study was to determine the behavior and lifetime of the beachfill placed at Fenwick Island, Delaware in the Fall of 1988. This beach has been an area of high erosion (Dalrymple and Mann, 1985; Dick and Dalrymple, 1983) and the beach fill project was designed to restore the bathing beach. The beachfill location is shown in Figure 1 and Figure 2. The Fenwick Island beachfill was a northward extension of the Ocean City, Maryland beachfill project which took place throughout most of 1988. The total length of the combined beachfills, extending from the Ocean City Inlet north to Fenwick Island, was approximately 9.4 miles, containing about 2.9 million yd^3 of fill sand. However, this study only concerns the approximately 325,000 yd^3 of sand placed on 6000 ft of beach extending northward from the Delaware/Maryland state line.

This report is presented in three parts. In Part I, several factors which can influence the lifetime of a beachfill have been examined. The report concentrates on factors which can be calculated and controlled in the design process. Part II examines several beachfill projects which have already been completed or are still in progress along the Atlantic Coast of the United States to determine if the factors in Part I were properly considered. Then the projects are evaluated to see if they are functioning properly, especially noting if these beachfill projects are "holding-up" and not eroding unexpectedly fast. Finally, in Part III, the actual calculations for estimating the lifetime for the Fenwick Island beachfill are presented. The lifetime was calculated several ways including recession rates and volumetric erosional rates. (All the computations are based on data obtained up to January, 1989).

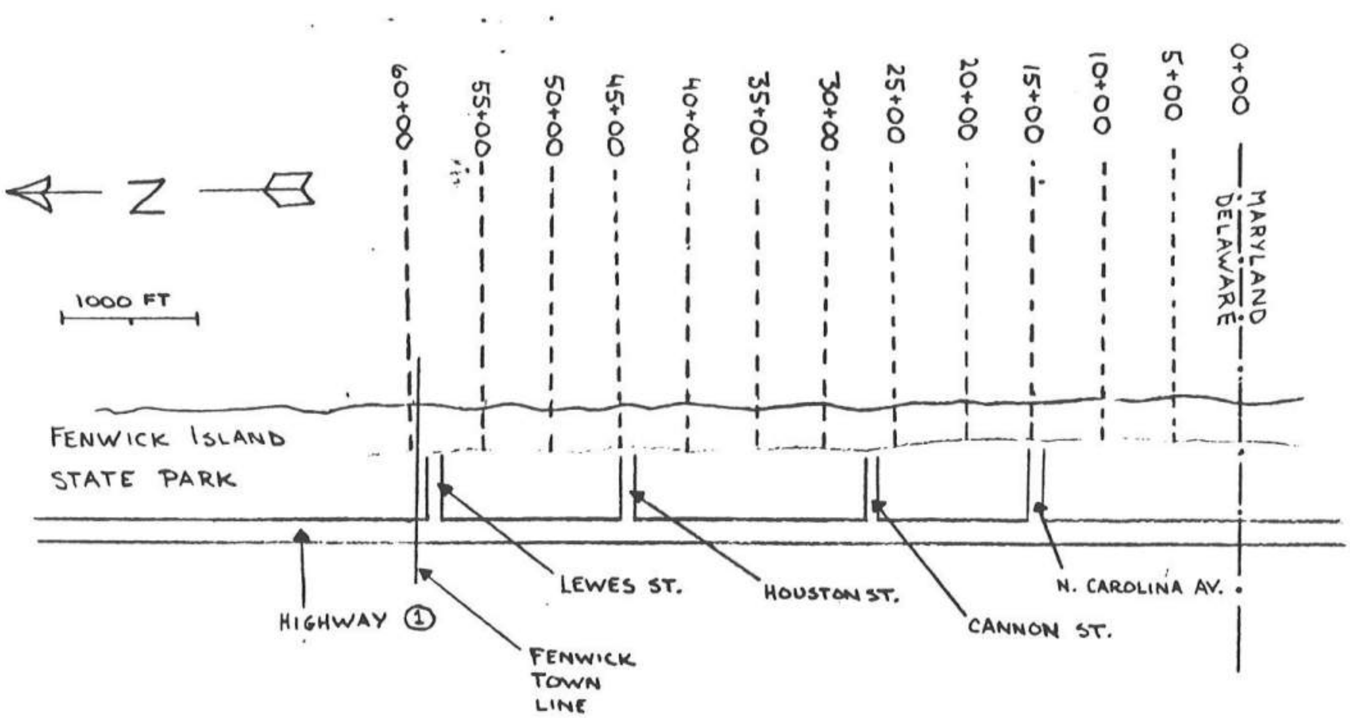

Figure 2: Close-up of Beachfill Location with Profile Lines

1 Factors Controlling the Lifetime of a Beach Fill

There are many factors which help determine the life time of a beachfill project. The emphasis here is on those factors which can be controlled in the design and placement of beachfill projects. Obviously, environmental factors, such as the wave climate (i.e., heights, frequencies and directions) and weather (i.e., storm frequency and severity) are important in determining how long a beachfill will last, but can not be controlled.

Beachfills are used to help replace the sand that for many years has been eroded away by waves and currents. However, the beachfill is not a cure to the erosional problem, but is only an "aspirin" to give temporary relief to the eroding beach. The placed beachfill does very little, if anything, to change the erosive conditions that caused the need for the beachfill in the first place. The environmental factors, such as the waves, storms and currents, remain the same. The beachfill is not an attempt to reverse the erosional processes, but an attempt to go back in time to a wider beach which existed before years of erosion took place. Because the erosional problems are not cured, the beachfill erodes as the original beach did. After many years of erosion, the beachfill will have eroded completely away, and the beach originally in place will once again exist. However, this beach will continue to erode unless another beachfill is placed. Thus, a cycle of placing beachfills is set in motion. The cycle cannot stop unless the beach is surrendered to the ocean or a better method of beach protection is used; one in which the erosional processes are altered.

Beach nourishment is presently thought to be one of the best solutions to an eroding beach, especially for beaches used as recreational areas, as structures are not used in the restoration. Further, in the case of Fenwick Island, which is not at the end of a littoral drift cell, but more of a source area for both the northerly littoral transport in Delaware and the southerly drift to Maryland, structures may not prove to be as helpful as they are in other Delaware sites, e.g., Rehoboth Beach and Bethany Beach, which have groin fields.

The lifetime of a beachfill is an important factor in the economics of beach restoration. It is necessary to provide a definition of the lifetime, as there are several possible definitions. In this report, the lifetime begins when the fill is placed and ends when the entire volume of fill sand is gone from the active beach system (i.e., when the beach returns to the state that existed before the beachfill was placed). Sand which moves downdrift along the coast to an area not originally part of the project area can be considered lost (especially by the community which financed the beachfill project for their beaches alone). The sand is not really lost, of course, but it no longer contributes to the length of beach for which it was meant. (There is a tangible benefit however to downdrift beaches, which should not be overlooked in the planning of beach fills.) Sand which is transported offshore is not considered lost either. Here it is important to remember that the beach does not only include the beach above the Mean Water Level (MWL). This part of the beach which is above water and visible makes up only a fraction of the total beach profile. The sand just offshore plays an active role in the evolution of the beach. This sand can be transported onshore during periods of beach accretion or be used to form bars which act as natural protection during winter storms. Further, the seasonal loss of the beach in the winter season is not considered a permanent loss of material. It is the net annual loss of material from the project area that is to be considered for the lifetime of the fill project.

In most cases, beaches are attacked by waves which approach the beach at an oblique angle, as shown in Figure 3 (Dalrymple and Mann, 1985), based on hindcast wave data (CERC WIS data). As shown, in the spring (April to June) the waves generally approach the Delaware coast from the southeast. Because of the obliquity of the wave approach, the

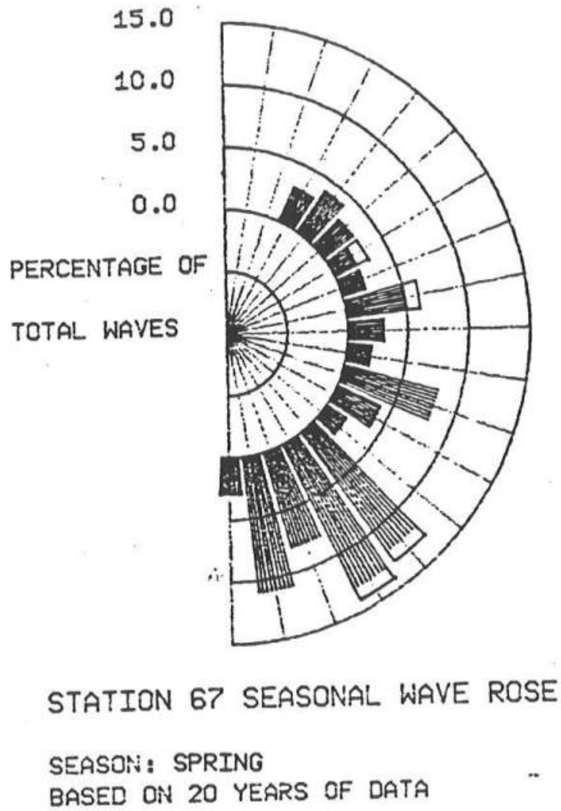

Figure 3: Hindcast Seasonal Wave Rose Showing Wave Directions (Dalrymple, Mann 1985)

net force due to the waves can be split into two components: cross-shore and longshore sediment transport. Cross-shore sediment transport involves moving sand on and offshore. It is believed that cross-shore transport of sand is basically temporary (during storms) and seasonal. The cross-shore sand transport is landward during the summer and fall, and seaward during the winter months along Delaware's coast (Dick, 1983). Thus sand moved in cross-shore transport is largely not lost from the beachfill area. Most sand lost from beachfills is due to the longshore sediment transport, which involves moving sand along the beach. Deguchi and Sawaragi (1986) found that the amount of sand moved in the longshore direction surpasses the amount of sand transported in the cross-shore direction regardless of the shapes of the shorelines. Because the sand is removed from the beachfill area, it is considered lost.

As an example of the longshore transport, the waves represented by the wave rose in Figure 3 would cause a net transport of sand northward of Fenwick Island during the spring. By including all of the seasons, Dalrymple and Mann (1985) predicted annual littoral drift values for three sections of coastline, Ocean City–Fenwick Island, Fenwick Island–Rehoboth Beach, Rehoboth Beach–Cape Henlopen. As shown in Table 1 from their results, the annual littoral drift varies greatly from year to year. In fact, for two of the sections, the standard deviation in the annual drift was greater than the 20 year mean transport rate. This shows that often the predicted historical littoral drift rate for an area may or may not be indicative of what will happen to a beach during any given year. The number of storms, their severity, and directions from which they come are all very important in determining the net littoral drift of an area for any given year. In fact, it is known that "northeasters", severe storms that are most prevalent during the winter months, are particularly damaging to Delaware's

Year	Station 65 Ocean City-Fenwick yd^3/yr	Station 66 Fenwick- Rehoboth yd^3/yr	Station 67 Rehoboth-Cape Henlopen yd^3/yr
1956	-63720	272426	1131544
1957	-113292	-40295	110485
1958	-176954	-450115	175900
1959	-172608	-175944	-43191
1960	-113479	67417	338391
1961	-96657	100242	245857
1962	-67646	584679	869985
1963	-130146	35547	153723
1964	-75295	230978	229643
1965	-88862	83786	167369
1966	-191221	-20213	83561
1967	-47625	79274	143494
1968	-188871	44609	76025
1969	-119023	396041	798964
1970	-149771	-65215	187657
1971	-225432	-72666	134313
1972	-201196	126919	272020
1973	-420150	-160474	-210039
1974	-175128	-36368	-48388
1975	-243095	136825	666079
Mean	-153000	56900	274200
Standard Deviation	84530	217610	336178

Note: The negative sign(-) denotes littoral drift to the south.

Table 1: Predicted Annual Sediment Transport for Delaware-Maryland Coast in Cubic Yards per Year (Dalrymple, Mann, 1985)

Atlantic coast. During such storms, large amounts of sand are transported southward into Maryland and very little of it ever returns to Delaware because of the existing sediment transport tendencies (south in Maryland and north in Delaware).

Although erosion will continue to take place after a beach is nourished, several factors can be controlled to extend the lifetime of a beachfill: beach profiles of the fill, the borrow sediment quality, and shape and size of the beachfill. These three factors, when determined properly, can optimize the lifetime of a beachfill.

1.1 Beach Equilibrium Profiles

The physical performance of beach nourishment projects can be split into two categories: cross-shore response and longshore response. The longshore response is considered to be the transport of sand out of the area in which it was placed. The cross-shore response is the natural adjustment of the initial profile, which is a result of the method of placement. The most basic assumption in cross-shore sediment transport is that the beach profile, evolving under persistent wave attack, will eventually reach a stable configuration, implying both an equilibrium form and equilibrium position of the beach profile (Swart, 1976). This equilibrium profile assumption is used later in Part III to help predict the lifetime of a beach fill.

Dean (1983) empirically developed a usable relation between beach sand sizes and the equilibrium profile shape. The equation for the variation of water depth with distance (y) offshore is:

$$h(y) = Ay^m \simeq By^{2/3}D^{1/3} \tag{1}$$

where $h(y)$ = water depth,
A = scale parameter related to the grain size, D
m = exponent (usually 2/3),
B = scale parameter.

Dean has shown that $h(y) = Ay^{2/3}$ does in fact represent the profiles of beaches along the eastern coast of the United States. Notice that the only variable in this equation is the scale parameter, A, which, as stated, is related to the diameter of the sand which makes up the beach. Thus, the sand size is responsible for the beach's equilibrium shape to a great extent. More discussion on the effects of sand size will be discussed in Section 1.2 of Part I.

Using the concept of equilibrium profiles, it can be deduced that sand, identical to the original beach sand, placed on a beach during a nourishment project will adjust to a profile identical to the equilibrium profile which existed before the renourishment. Ideally, if the beachfill sand is placed in a fashion as to exactly match the equilibrium profile, that is, onshore and offshore placement of the fill, no profile adjustment would take place. However, achieving this equilibrium profile during placement of the fill is just not very practical and it would be very difficult and expensive to place sand so as to form a profile exactly equal to the equilibrium profile predicted by Dean's equation. For most cases, the fill is placed on the dry beach. The technique used at Fenwick Island, for example, consisted basically of pumping the sand onshore from an offshore barge and then pushing the sand using heavy machinery, such as bulldozers, shaping the beach as best as possible. It is obvious that with these techniques, there is not much that can be done about how the sand shapes itself offshore.

In the general case, the onshore placement of the sand forms a very wide but very steep beach. Because the beach is made so artificially steep, the dry beach is made much wider than can be supported by the equilibrium planform and nature soon adjusts the profile to equilibrium, causing a loss of shore material to the offshore. This is what is meant by *profile adjustment*. The profile adjustment is shown in idealized form in Figure 4 and in actual profiles in Figure 5 taken at the Fenwick Island beachfill by the Department of Natural Resources and Environmental Control (DNREC). Notice how the fill placed at a steep angle has moved seaward thus forming a milder-sloped beach, ideally evolving to the ideal profile, $h = Ay^{2/3}$. So, while the initial placement of the fill resulted in an average of 91 ft of shoreline advancement, it is clear that a portion of the added beach width from the beachfill is lost during profile adjustment. Exact losses in beach width at the Fenwick Island project are given in Table 8 in Part III of this report. The average beach width loss at Fenwick during approximately the first 1-1/2 months was 28% with some profiles losing almost 60% of their added beach width. By accounting for profile readjustment in the original fill calculations and letting nature move the sand offshore, time and money are

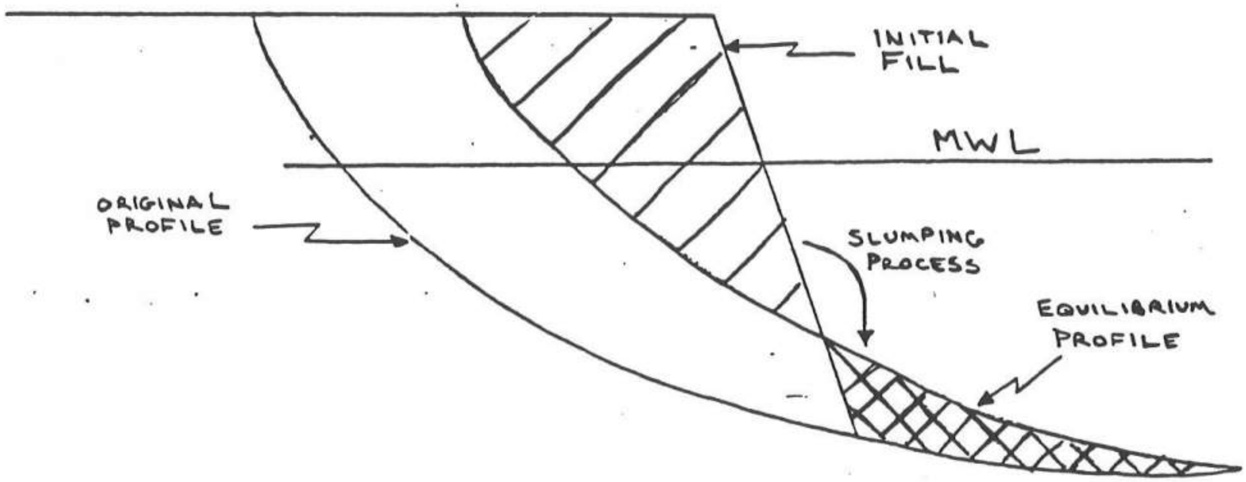

Figure 4: Profile Adjustment

saved. The sand which is transported offshore is not lost from the beachfill; it is adding to the stability of the beach. The beach is becoming less steep and the offshore waters are becoming shallower,h thus causing waves to break further offshore, which adds protection to the beach, and increases the recreational value of the beach.

An ideal situation would be to place the beachfill in the shape of its equilibrium profile. This would negate the need for the profile readjustment process. As mentioned, this is not easily done, but the sand should be placed in a way that is as close to the equilibrium profile as possible. This will shorten the readjustment process, diminishing any beach width losses that could be deemed as project failure by a pessimistic evaluation, and insure that the sand is placed on the offshore profile, rather than moved alongshore out of the project area before profile readjustment can take place. Figures 6 and 7 show the equilibrium profile for one section of beach 2500 feet north of the Delaware/Maryland line. Two surveys taken during two separate years, but at the same time of the year, were compared to ensure the beach was at its equilibrium profile. Notice the similar shapes of both profiles (Figure 6 was taken November 11, 1985 and Figure 7 taken November 26, 1988 both by the DNREC). Similar features include the flat bar approximately 50 feet long, located about 2.5 feet deep and 50 feet offshore, giving way to a steep slope which then becomes milder, eventually to form another bar approximately 250 feet offshore. The similar shapes suggest the two profiles are equilibrium profiles for this section of beach during that particular time of year. As shown in Figure 7, because the sand was placed similar in shape to the equilibrium profile, very little profile adjustment needed to take place, and there was minimal loss in beach width from the time of placement.

Above, it was critical to compare profiles that were made about the same time of the year. The reason is that Delaware's coast undergoes seasonal profile adjustments, as the wave climate changes seasonally . Such adjustments are shown in Figure 8 (Dick and Dalrymple, 1983). The summer (or swell) profile is characterized by a wide berm, relatively steep foreshore, and a smooth offshore profile. The winter (or storm) profile, in contrast, has almost no berm. The sand moves offshore to form one or a series of sand bars parallel to the shoreline. The winter profile is developed by large storm waves that erode the berm

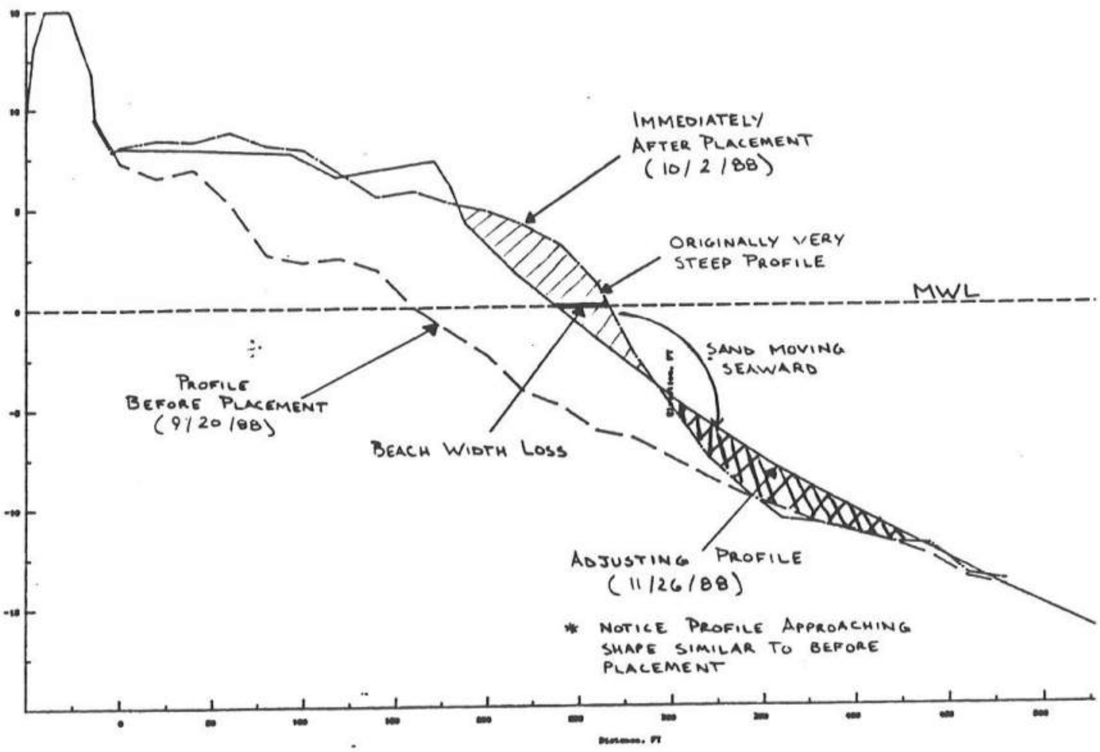

Figure 5: Example of Profile Adjustment (DNREC)

and deposit the material offshore into sand bars, which then act as a type of natural storm protection. The gentle swell waves transport the sand back onshore, reshaping the berm into the summer profile. In the cross-shore direction, the sediment shifts seasonally from berm to bar so the volume of sand involved remains relatively constant over the profile. Thus, even though the beach width is greatly reduced during the winter, very little sand is actually lost, except that due to longshore transport, which will be discussed later. The seasonal profile adjustments, therefore, are of little concern when dealing with beachfills because they will occur whether the fill is there or not. This seasonal adjustment can cause alarm, particularly if the performance of the profile is evaluated after the winter season. It is best to compare the performance of the beach fill at the same season from year to year.

1.2 Beachfill Sediment Quality

The response of beachfills to sediment quality is perhaps one of the most studied and therefore most understood area of beach nourishment planning. The main concern when choosing a fill sediment is the sand size. More specifically, how compatible is the borrow material with the native beach sand. Presumably, if the fill material placed on the eroded beach is compatible with the energy of the coastal processes, it will be resorted along the profile, but be retained within acceptable limits in the vicinity of the project area (Stauble, 1984).

The size of the beach sediment is intimately connected to the equilibrium profile of the beach calculated from $h(y) = Ay^{2/3}$. The parameter A is approximately proportional to $D^{1/3}$, where D is the median sand grain diameter. Figure 9 (Dean, 1983) shows that, as the sediment size increases, A also increases, and as A increases, the equilibrium profile

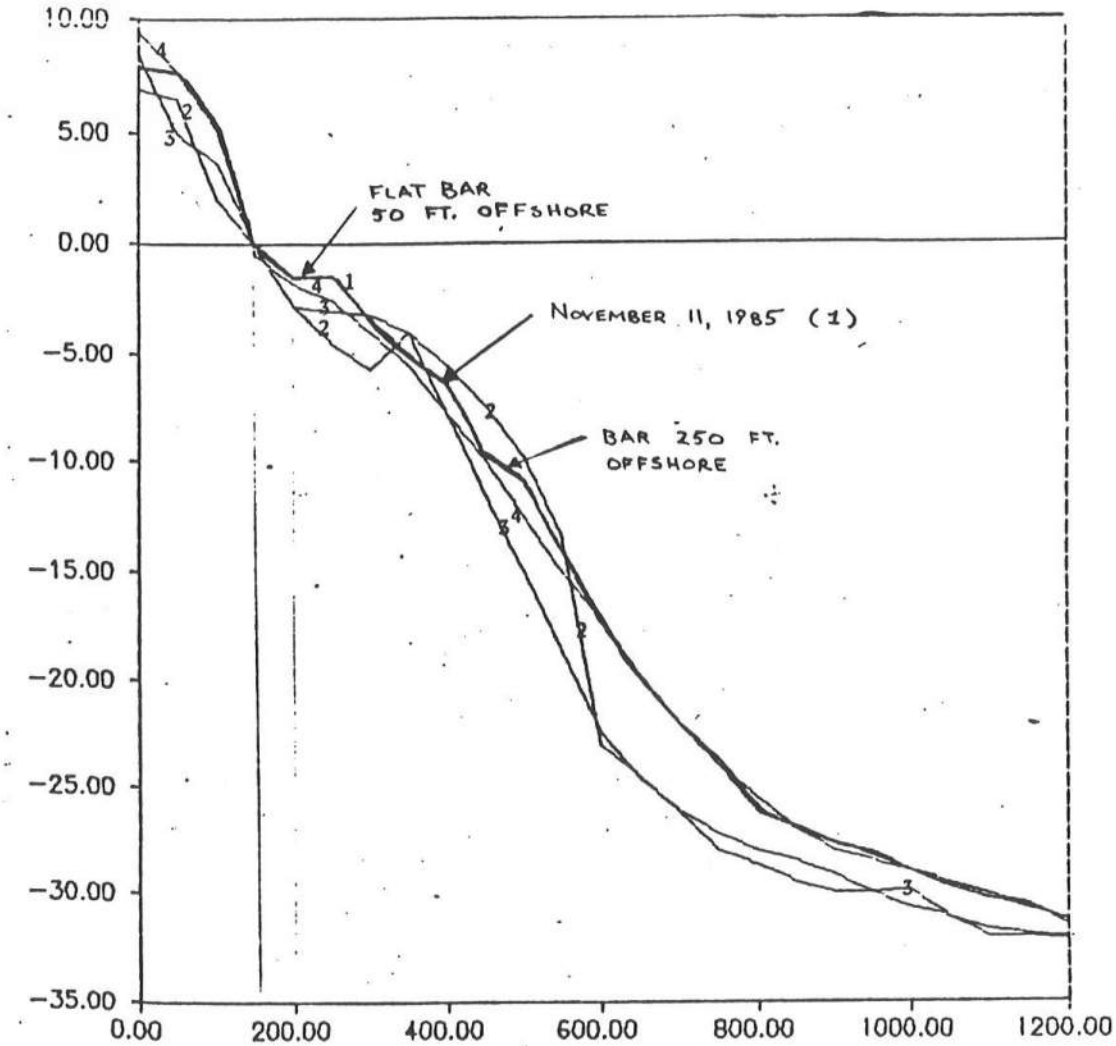

Figure 6: Profile 2500 ft. North of Stateline 11/11/85 (DNREC, in Dalrymple, Mann, 1985)

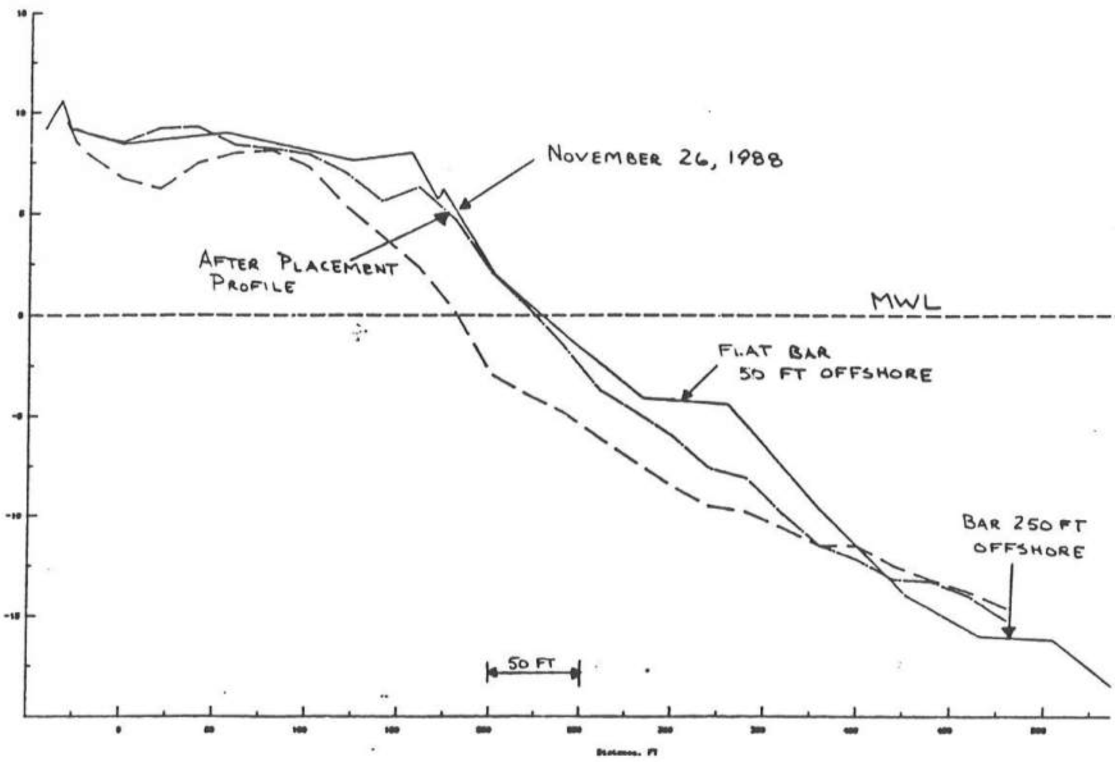

Figure 7: Profile 2500 ft. North of Stateline 11/26/88 (DNREC)

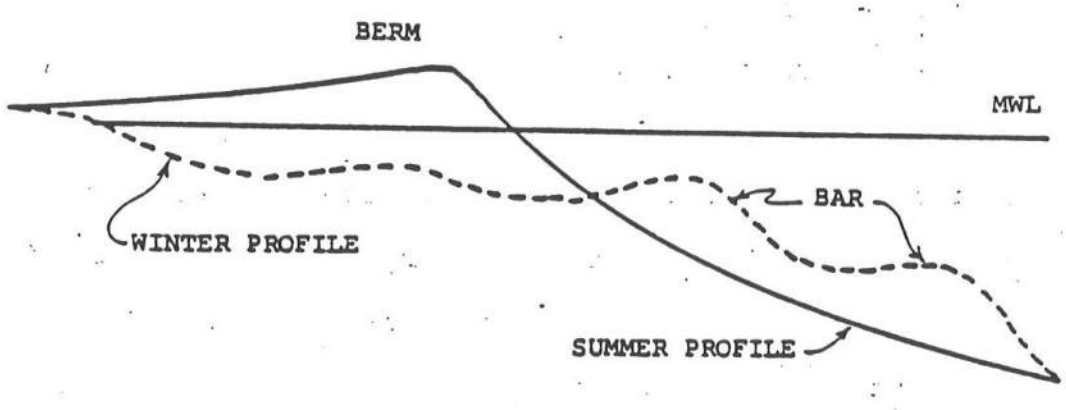

Figure 8: Seasonal Profile Adjustments (Dick and Dalrymple, 1983)

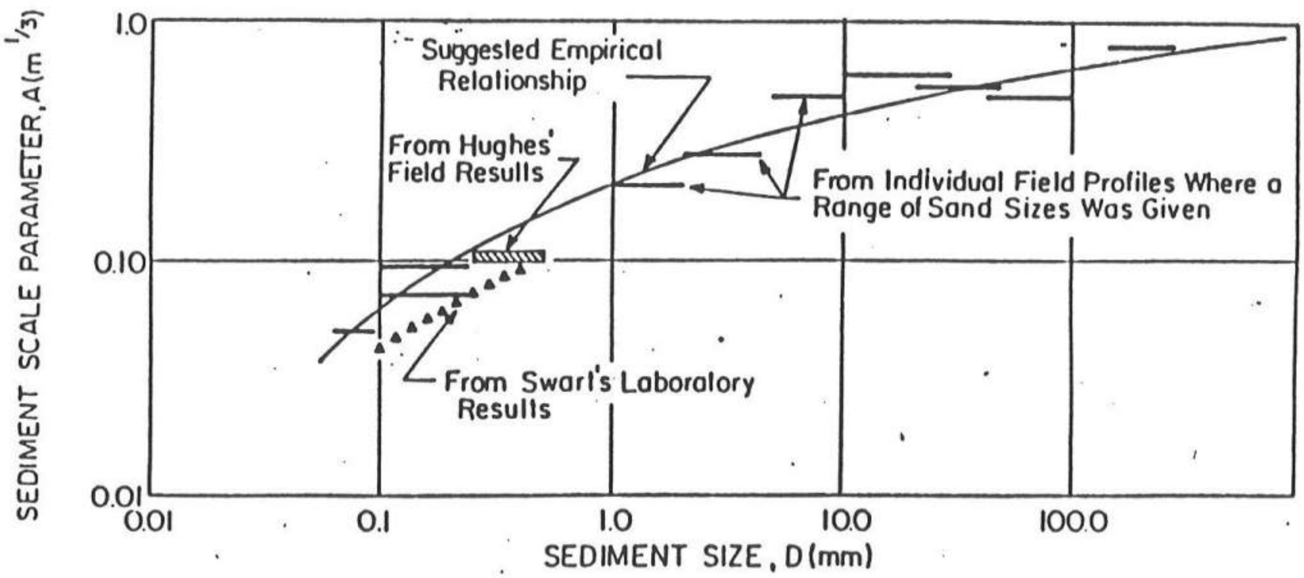

Figure 9: Beach Profile Factor, A, vs. Sediment Diameter, D (Dean, 1983; Modified from Moore, 1982)

becomes steeper. Thus a finer sediment will be associated with a milder-sloped profile than one composed of coarse sediment. An example of this is shown in Figure 10 (Dean, 1983).

The stability of various sand sizes is different; coarser sediment is more stable and it is able to withstand stronger erosional forces than a finer sand. Fine, well-sorted borrow material, such as that commonly found in bays, backshore dunes, or on the bottom of the offshore zone, will generally respond rapidly to wave and current conditions, moving alongshore and offshore out of the project area. Thus, material that is finer than the native beach sediment is generally not suitable for use as beach fill. The erosional rate of finer material will always be greater than that of the native material. On the other hand, coarse, more poorly-sorted material, such as that found in alluvial channels, glacial outwash, and sometimes in offshore shoals, tends to provide more stable beach fills, although the resulting beach is not always ideal for recreational purposes (James, 1974). Therefore, it seems best to choose a borrow material which is at least as coarse as the native beach sand or somewhat coarser.

In past studies, it has been found that the percentage of the borrow material which is very fine in comparison to the native material will migrate offshore to form a wide shoal (Silvester 1978). Therefore, shortly after beachfill placement (one or two months), it is found that a percentage of the material, sometimes up to 20%, is lost. However, after sampling the sediment, it is discovered that much of this lost sediment are fines. Table 2 shows the volume losses for the Fenwick Island beachfill project over approximately the first 6 weeks of the project. Volumes were computed by DNREC using the Corps of Engineers Interactive Survey Reduction Program (ISRP). As shown in Figure 11, the difference in

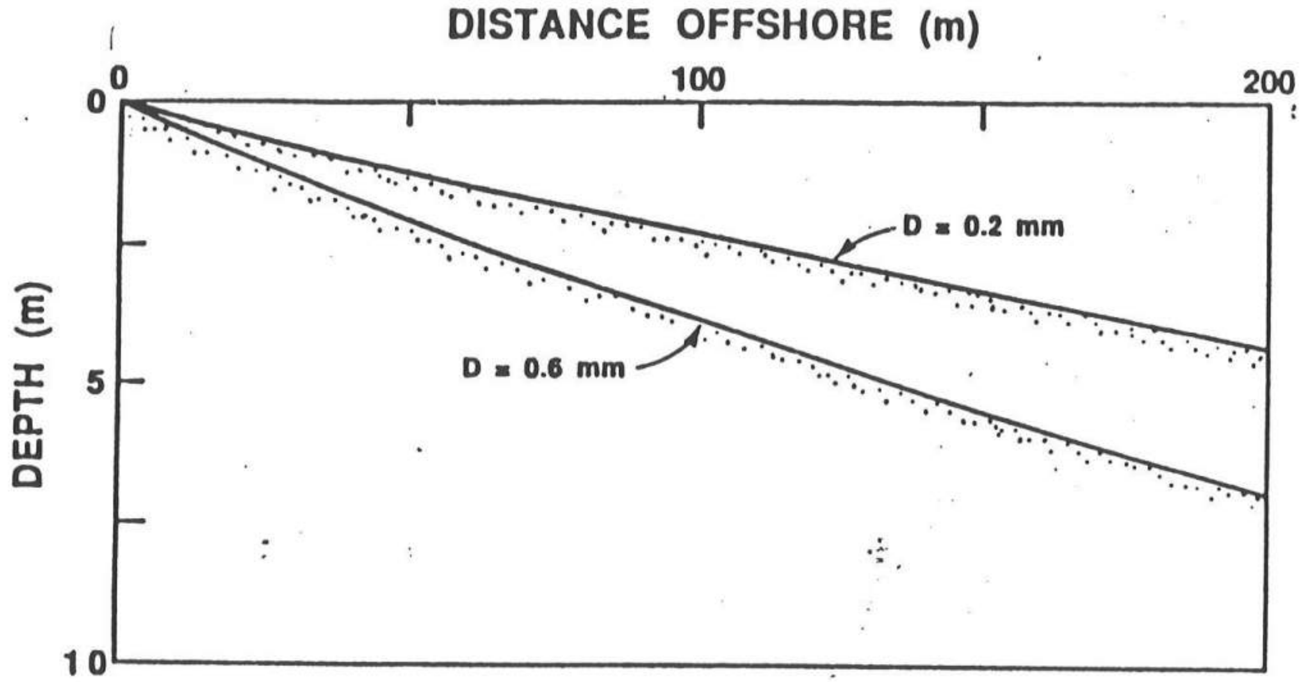

Figure 10: Equilibrium Beach Profiles for Sand Sizes of 0.2 mm and 0.6 mm A(D=0.2mm) = 0.1m$^{1/3}$ A(D=0.6mm) = 0.2m$^{1/3}$ (Dean 1983)

area lost and area gained gives the net change in area that took place during the first 1-1/2 months. As shown in Part III of the report, this amount of erosion is much higher (by a factor of two) than historical erosion rates for this area. Again, most of the sand being lost is very fine in texture, and as the fill becomes properly sorted the erosion rate will decrease to a more appropriate level. The ISRP analysis also determined that 27,178 yd^3 were lost from the portion of the profile above the mean sea level (MSL) and 14,560 yd^3 was gained below MSL, further proof of the profile readjustment.

A final factor, which is not as obvious, is how the sediment size affects the width of the fill. Dean (1983) has shown that the coarser the nourishment material, the greater the dry beach width per unit volume of fill placed, due to the steeper profile for the coaser material. This is illustrated in Figure 12 (Dean, 1983). In this figure, A_N and A_F denote the native and fill profile sediment scale parameters, respectively, and h_* is the breaking depth which is not important to this discussion. Figure 12 shows the effect of placing the same volume of three different sized sands. In Figure 12a, sand coarser than the native is used and a relatively wide beach Δy is obtained. In Figure 12b, the same volume of sand of the same size as the native is used and the dry beach width gained is less. In Figure 12c, the placed sand is finer than the native and much of the sand is utilized in satisfying the milder sloped underwater profile requirements. In a limiting case, shown in Figure 12d, no dry beach is created, with all the fill sand being used to satisfy the underwater profile requirements. These results are quantified in Dean (1983).

It is obvious that each size of sand chosen as the fill material has its advantages and disadvantages. From a totally engineering point of view, it makes sense to use as coarse a

Profile	Profile Volume yd^3	Total Volume (ft^3)
100	-4.0	
		-3100
105	-8.4	
		-6720
110	-18.5	
		-6585
115	-7.8	
		-5495
120	-14.1	
		470
125	12.3	
		4633
130	6.3	
		1317
135	-1.0	
		-278
140	-0.1	
		2260
145	9.1	
		5803
150	14.1	
		598
155	-11.7	
		-4575
160	-6.6	
Total (yds^3)		-11672

Table 2: Volume Change Profiles 100–160 AD(10/88)–AD(11/26/88)

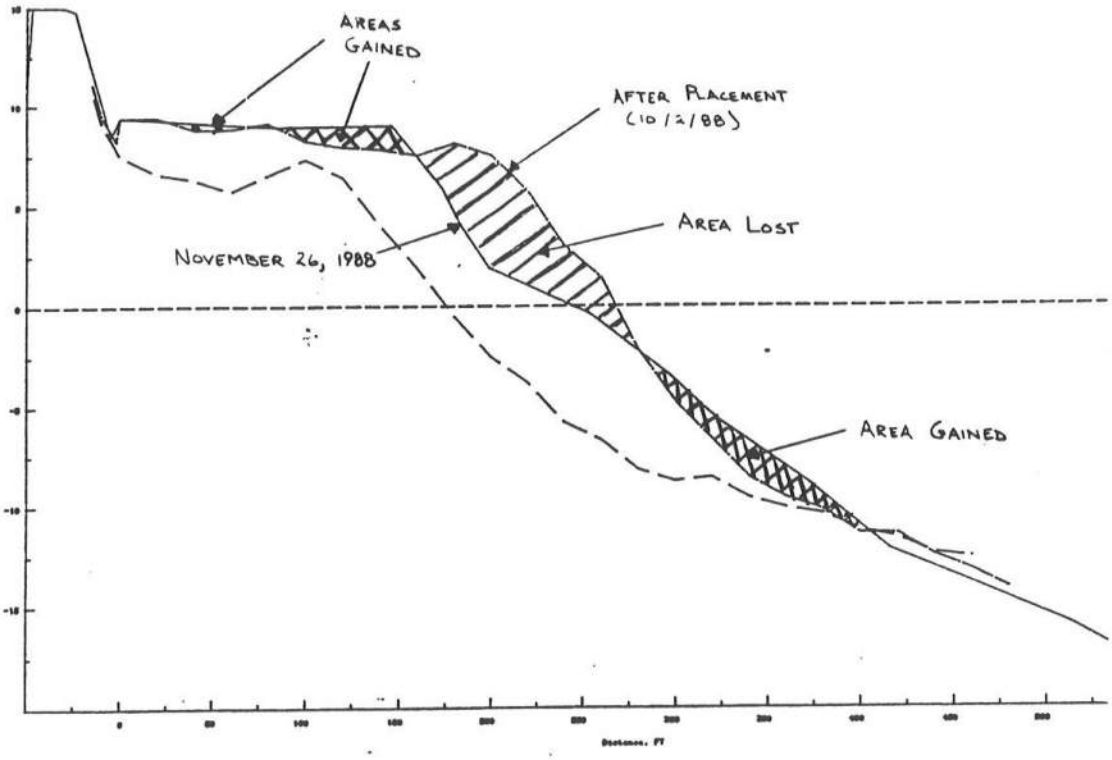

Figure 11: Initial Volume Losses Due to Loss of Fines

fill material as possible. The coarse material is more stable, and produces a wider beach for a given volume of sand. However, the sand is rough and the beach is steep. What is generally done is to choose a middle course, selecting a fill material that is as similar as possible to the native material. By choosing similar sand, the original equilibrium profile of the beach is retained. Further, it becomes much easier to predict the future behavior of the beachfill (i.e., lifetime, profile readjustment, etc.). The nourished beach can be expected to behave in a manner similar to the original beach. Thus, historical data, such as recession and erosion rates can be used in calculations involving this beach, as is done in Part III. However, it is not always possible to find a borrow area where it is economically feasible to pump sand with similar characteristics to the native material. In this case, the nourished material should be coarser than the native material and much finer material should not be considered for stability reasons.

Sediment data for three of the profiles at the Fenwick Island fill are given in Table 3, which lists mean sediment size along certain profiles prior to and after the beach nourishment (Delaware Geological Survey). Notice that the fill is coarser than the native material. On the average the fill sand is 0.13 mm larger in diameter than the native sand; an increase in size of about 30%. Station N25+00 also shows that the coarser fill sand has not yet spread offshore very far. At a depth of 12 feet, the sand size has remained relatively unchanged the first two months after the fill was placed. This will change as the sand is transported seaward to establish an equilibrium shape. The table also shows that the sand is coarser at the waterline, indicating that the fines are being transported from that region.

Since the beach fill is coarser than the native sand, the new equilibrium beach profile will be steeper. Figure 13 (Dalrymple and Thompson, 1976) can be used to develop a

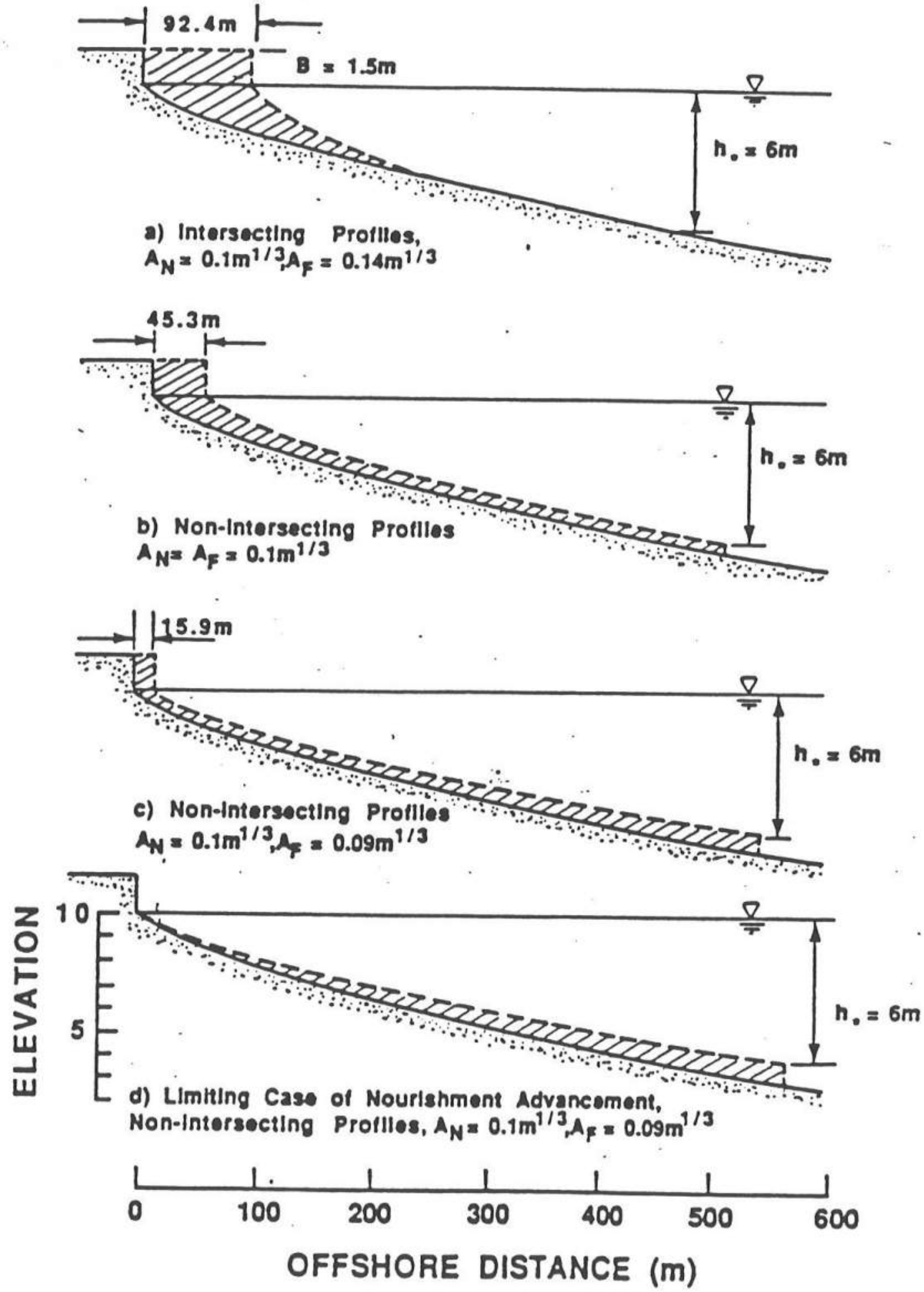

Figure 12: Effect of Nourishment Material Scale Parameter, A_F, on Width of Resulting Dry Beach. Four Examples of Decreasing A_F. (Dean 1983)

Station	Location	Mean Sand Grain Diameter (mm)	
		Prior to Nourishment (9/20/88)	After Nourishment (12/1/88)
N5+00	base dune	.358	.454
	mid-beach	.344	.578
	berm crest	.346	420
	MHW	.368	.633
	MSL	.412	
	MLW	.463	.669
	-6	.518	
	-12	.824	
N25+00	base dune	.349	.507
	mid-beach	.420	.578
	berm crest	.432	.415
	MHW	.438	.511
	MSL	.480	
	MLW	.551	.712
	-6	.253	
	-12	.179	.186
N45+00	base dune	.415	.473
	mid-beach	.371	.599
	berm crest	.395	.418
	MHW	.435	.525
	MSL	.467	
	MLW	.507	.660
	-6	.660	
	-12	.182	

Table 3: Sediment Data Prior and After Beach Nourishment (DNREC)

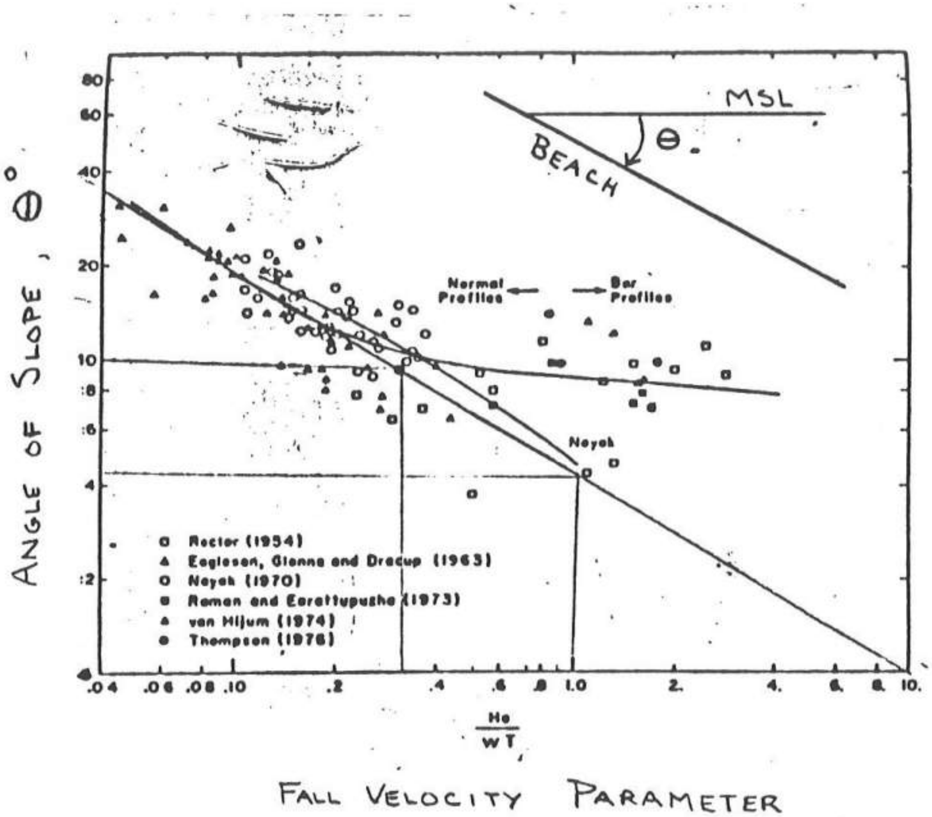

Figure 13: Beach Slope vs. Dimensionless Fall Velocity (Dalrymple, Thompson, 1976)

relationship between the relative change in sand size and the effect it has on the foreshore slope, as it shows the foreshore slope as a function of the dimensionless fall velocity of the sediment, $\Omega = H_o/wT$, where H_o is a representative wave height, T, a representative period and w, the fall velocity of the sediment. If we assume that the wave characteristics remain the same (before and after the fill), then the influence of the coarser fill is to increase the fall velocity of the sediment, w (the fall velocity is directly related to the grain size of the sediment, although empirically). Assuming that a straight line can be fit through the data in Figure 13, we have the beach face slope, θ, defined as the acute angle formed by the beach profile and the water line, related to the fall velocity by

$$\theta = c\Omega^a \tag{2}$$

Differentiating both sides and dividing by θ gives us an equation relating the change in θ, $d\theta$ to the change in the fall velocity, dw.

$$\frac{d\theta}{\theta} = -a\frac{dw}{w} \tag{3}$$

Table 4 shows the calculated relative change in beach slope for a given wave climate, due to the placement of the coarser fill sand. The sand size shown in the table was an average of the beach locations (berm crest, MHW, MSL, and MLW). The constant, a, in the above equation was found to be -0.725. Along profiles N5+00, N25+00, and N45+00, the average sand size was increased by 55, 18 and 21% respectively. The corresponding increase in equilibrium foreshore slope is 40, 13 and 15% respectively. The large change at N5+00 is due to the relatively small grain size initially in place.

STATION	Mean Beachface Sand Diameter, d (mm)		Corresponding Fall Velocity, w (cm/s)		Relative Change in Sand Size	Relative Change in Beach Slope
	BP	AP	BP	AP	dw/w	$d\theta/\theta$
N5+00	.397	.574	5.8	9.0	0.55	0.40
N25+00	.475	.546	7.2	8.5	0.18	0.13
N45+00	.451	.534	6.6	8.0	0.21	0.15

BP before placement 9/20/88
AP after placement 12/1/88
H_o, T = constants
a =-0.725

Table 4: Relative Changes in Beach Slope Due to Changing Sand Size

1.3 Size and Shape of the Beachfill

The size and shape of a beachfill also help determine its lifetime. The size of the beachfill is determined by the quantity of fill material. The term shape refers to the shoreline planform configuration of the fill. Both of these factors influence longshore sand losses, due to the longshore transport.

It is easy to see how the size of a beachfill will affect its lifetime. The greater volume of sand placed, the longer it will last. However, the greater the volume placed, the higher the costs. Therefore, determining an ideal volume of sand to place per foot of beach is more a matter of economics than engineering.

How the alongshore shape of a beachfill affects its lifetime is not so obvious. The planform evolution of a beach nourishment project is very important in determining just how much of the sand tends to stay in the nourished area and how much leaves via longshore transport. A method for examining the influence of the planform shape is to examine analytical models of the shoreline. The linearized equation of beach planform evolution was first developed and applied by Pelnard–Consideré in 1956. This equation is developed by combining two equations: the sediment transport equation and the equation of sediment conservation which are listed below.

Sediment Transport Equation:

$$Q = \frac{K}{8} \frac{H_b^{5/2} \sqrt{g/\kappa}}{(1-p)(s-1)} \frac{\sin 2(\beta - \alpha_b)}{2} \tag{4}$$

where

Q = volumetric flow rate of sand
K = factor proportional to sediment size (shown in Figure 14)
H_b = breaking wave height
g = gravity
κ = spilling breaking wave proportionality factor (0.78)
p = sediment porosity ($\sim$ 0.35 - 0.40)
s = sediment specific gravity (=2.65)
β = azimuth of an outward normal to the shoreline

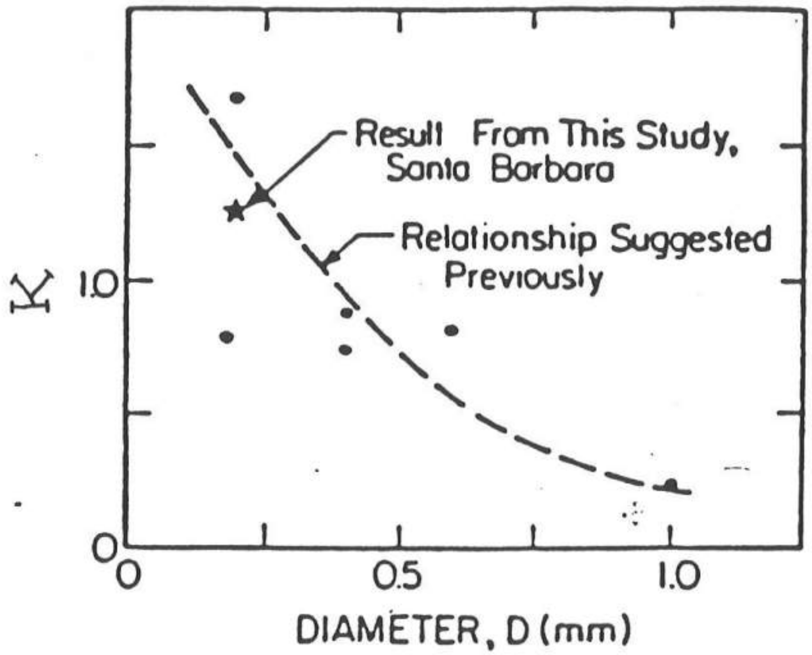

Figure 14: Plot of K vs. D (Dean 1983; modified from Dean, 1978)

α_b = azimuth of the direction from which the breaking wave originates.
Figure 15 is a definition sketch of selected terms.

Equation of Sediment Conservation:

$$\frac{\partial y}{\partial t} + \frac{1}{h_* + B}\frac{dQ}{dx} = 0 \tag{5}$$

where

- y = location of the shoreline measured from a given baseline
- t = time
- h_* = breaking depth (proportional to wave height)
- B = berm height
- Q = volumetric sediment transport
- x = distance alongshore

Figure 15 is a defining sketch of selected terms.

Pelnard–Considerè (1956) then combined these two equations to come up with the basic tool used in determining planform evolutions of beachfill projects:

$$\frac{\partial y}{\partial t} = G\,\frac{\partial^2 y}{\partial x^2} \tag{6}$$

where

$$G = \frac{K H_b^{5/2}\sqrt{g/\kappa}}{8(s-1)(1-p)(h_* + B)} \tag{7}$$

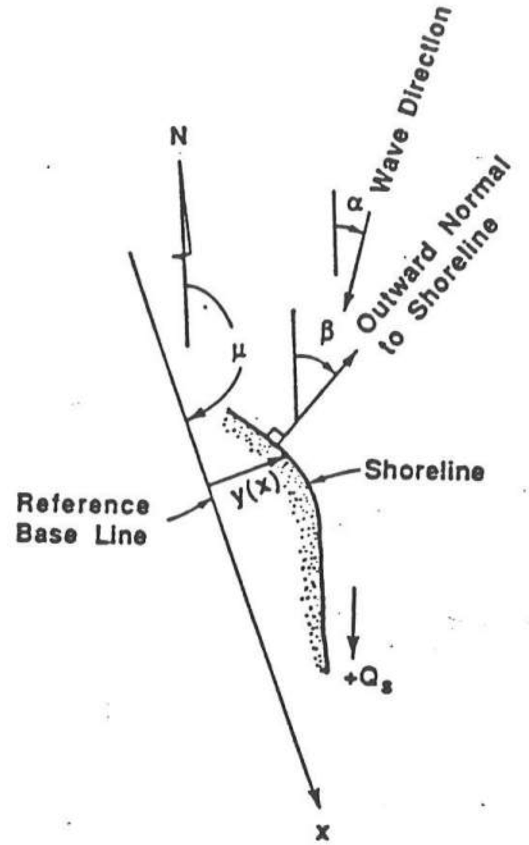

Figure 15: Definition Sketch (Dean, 1983)

which is a single equation describing the planform evolution for a shoreline which is initially out of equilibrium. The parameter G may be considered as a "shoreline diffusivity" with dimensions of $(\text{length})^2/\text{time}$, the combined equation is in the form of the heat or diffusion equation for which a number of analytical solutions are available, some of which will be explored later in this section.

Dean (1983) has developed a table giving approximate values of the shoreline diffusivity, G. These values are given in Table 5 (Dean, 1983). It is seen that G depends strongly on H_b, and secondarily on $(h_* + B)$ and K.

To use the equation for beach planform evolution, assume the initial beachfill planform, presented in Figure 16 (Dean, 1983), to be rectangular with a longshore length, ℓ, and extending into the ocean a distance, y. This planform is an appropriate idealized configuration for the beachfill at Fenwick Island when considered as an extension to the project in Ocean City.

The vertical axis could be considered the Ocean City Inlet jetty and the extreme right end of the rectangular fill could be considered to be 6000 ft. north of the Delaware/Maryland line. The analytic solution for this initial planform can be expressed in terms of two error functions as

$$y(x,t) = \frac{Y}{2}\left\{\text{erf}\left[\frac{\ell}{4\sqrt{Gt}}\left(\frac{2x}{\ell}+1\right)\right] - \text{erf}\left[\frac{l}{4\sqrt{Gt}}\left(\frac{2x}{l}-1\right)\right]\right\} \tag{8}$$

where the error function "erf()" is defined as

$$\text{erf}(z) = \frac{2}{\sqrt{\pi}}\int_0^z e^{-u^2}\,du \tag{9}$$

H_b	Value of G in			
(ft)	ft^2/s	mi^2/yr	m^2/s	Km^2/yr
1	0.0214	0.0242	0.00199	0.0626
2	2.121	0.137	0.0112	0.354
5	1.194	1.350	0.111	3.50
10	6.753	7.638	0.628	19.79
20	38.2	43.2	3.55	111.9

Note: In this table the following values have been employed: $K = 0.77$, $\kappa = 0.78$,. $g = 32.2$ ft/s^2, $s = 2.65$, $p = 0.35$, $h_* + B = 27$ ft.

Table 5: Values of G for Representative Wave Heights (Dean, 1983)

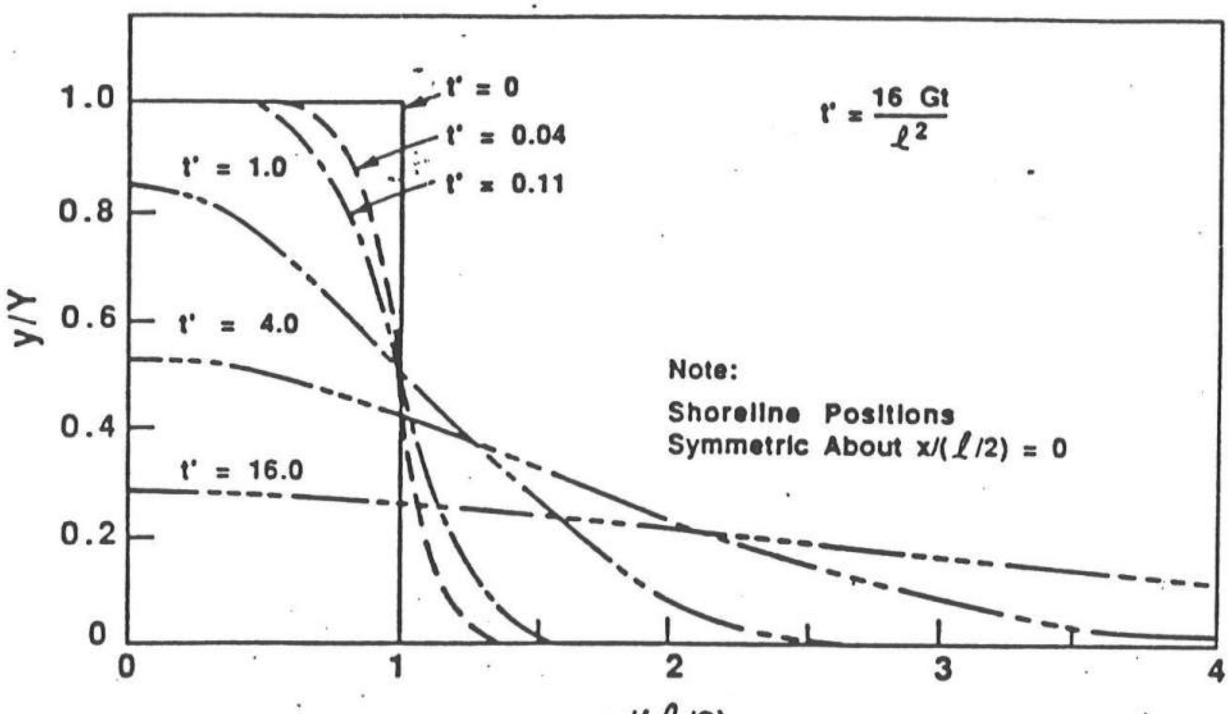

Figure 16: Evolution of an Initially Rectangular Beach Planform on an Otherwise Straight Beach (Dean, 1983)

and u is a dummy variable of integration. The solution is examined in Figure 16 where it is seen that initially the ends of the beach fill spread out and as the end effects move toward the center, the planform shape becomes more like a normal probability distribution. Therefore, just from planform evolution, since Fenwick Island is at the end of a beachfill, sand will be lost from the fill area and be transported northward along the Delaware Coast, benefitting adjacent beaches at the expense of Fenwick Island. So the location along the beachfill concerned also plays an important role in lifetime determination. The ends of beachfill erode more quickly at first due to planform adjustment, but this effect diminishes with time as the originally rectangular beachfill "flattens" and "smooths" out. On the other hand, Fenwick Island benefits from sand being transported longshore from the Ocean City beachfill. This is shown by examining Figure 17 and Figure 18, which show the August 22 and September 19 N1+00 profiles (located on the stateline), respectively, both of which were taken before placement. By examining the southern portion of the Fenwick Island project, the DNREC has shown that even the earliest pre- project surveys show the effect of northerly transport of fill from Ocean City. In some cases, a three foot vertical accretion in the berm area can be seen in the figures. (One drawback of the Pelnard–Consideré solution is that it is unable to predict the migration of the entire fill project along the coast nor is it able to predict an asymmetric transport of sand, thus the solution does not predict the southward transport of sand that is known to occur during winter months.)

In examining the solution to the Pelnard–Consideré equation, it is seen that the important parameter is

$$\eta \equiv \frac{\ell}{\sqrt{Gt}} \tag{10}$$

where ℓ is the length of the rectangular planform and G is the parameter defined earlier, Eq. 7. Two beach planforms with the same dimensionless ($\ell/\sqrt{Gt}$) quantity also have the same planform evolution. Examining this further, if two nourishment projects are exposed to the same wave climate, which determines the shoreline diffusivity, G, but have different lengths, then the project with the greater length would tend to last longer. In fact, the longevity of a project varies as the square of the length; thus if Project A with a shoreline length of one mile "loses" 50% of its material in 2 years, Project B subjected to the same wave climate but with a length of 4 miles would be expected to lose 50% of its material from the region where it was placed in a period of 32 years. Thus the project length is very significant to its performance. This makes sense since if a beachfill is very long, it would take a relatively long time for sand located at the updrift end of the project to be transported longshore out of the project area, which would be at the downdrift end of the project. In a sense, the lifetime of the project is determined, as far as longshore transport goes, by how long it takes sand to travel from one end of the project (the updrift end) to the other (the downdrift end). The basis for this is that sand moving from one area of the project to another stretch of beach still in the project area is not yet lost to the designated beachfill.

As far as the Fenwick Island project is concerned, the 6000 ft length of the project is not really relevant, as the Fenwick beachfill is an extension of the Ocean City beachfill. In this calculation, the combined length of the project in Fenwick and Ocean City have to be used and then the lifetime would be for this entire area. So as far as Fenwick Island is concerned, sand leaves Fenwick by spreading out northward along the Delaware coast, but enters Fenwick from Ocean City. The difficulty in this calculation is that the littoral drift nodal point, which on the Delaware/Maryland shoreline denotes the dividing line between northward and southward longshore transport, is sometimes located in this area (and is

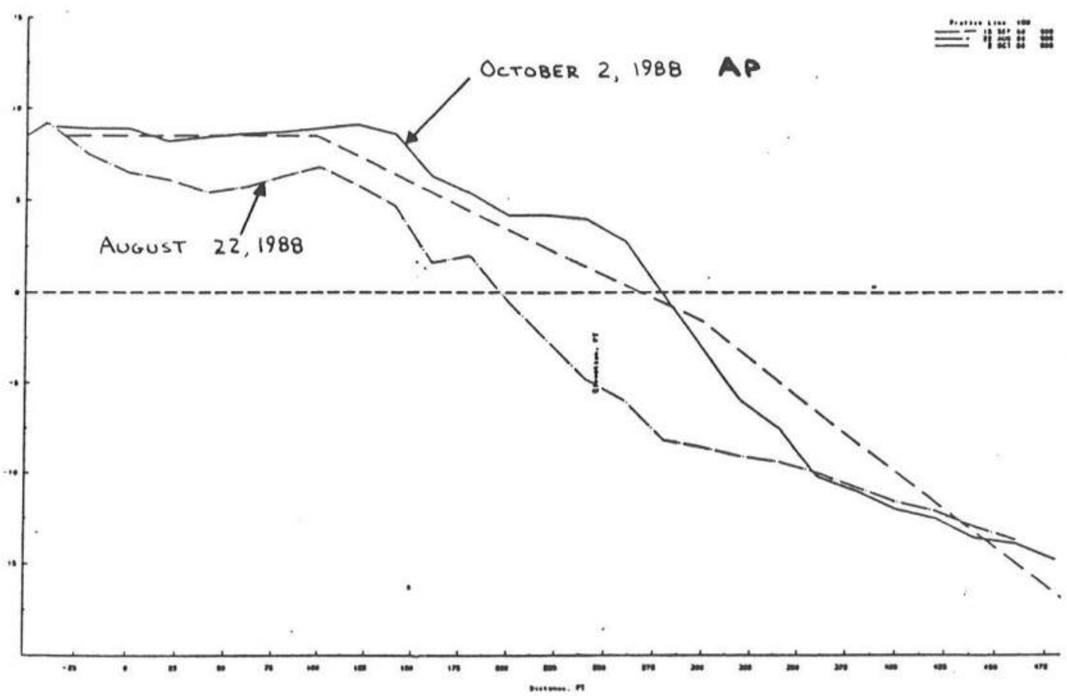

Figure 17: Profile N1+00 August 22, 1988 (DNREC)

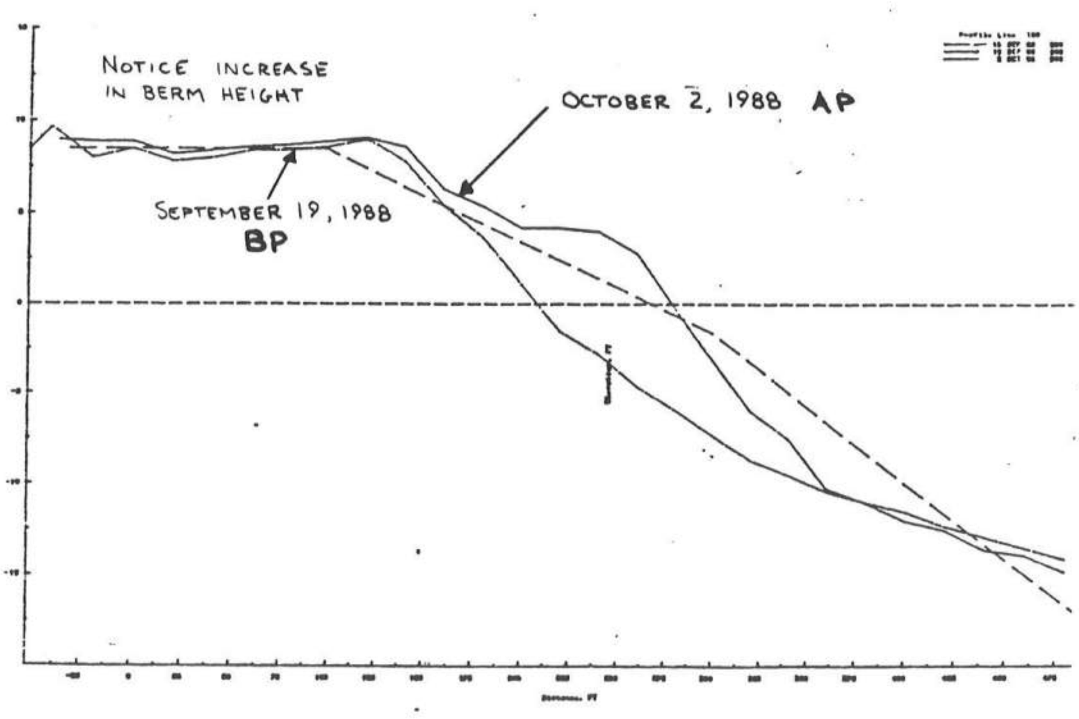

Figure 18: Profile N1+00 September 19, 1988 Showing Transport of Sand Northward from Ocean City Due to Planform Evolution (DNREC)

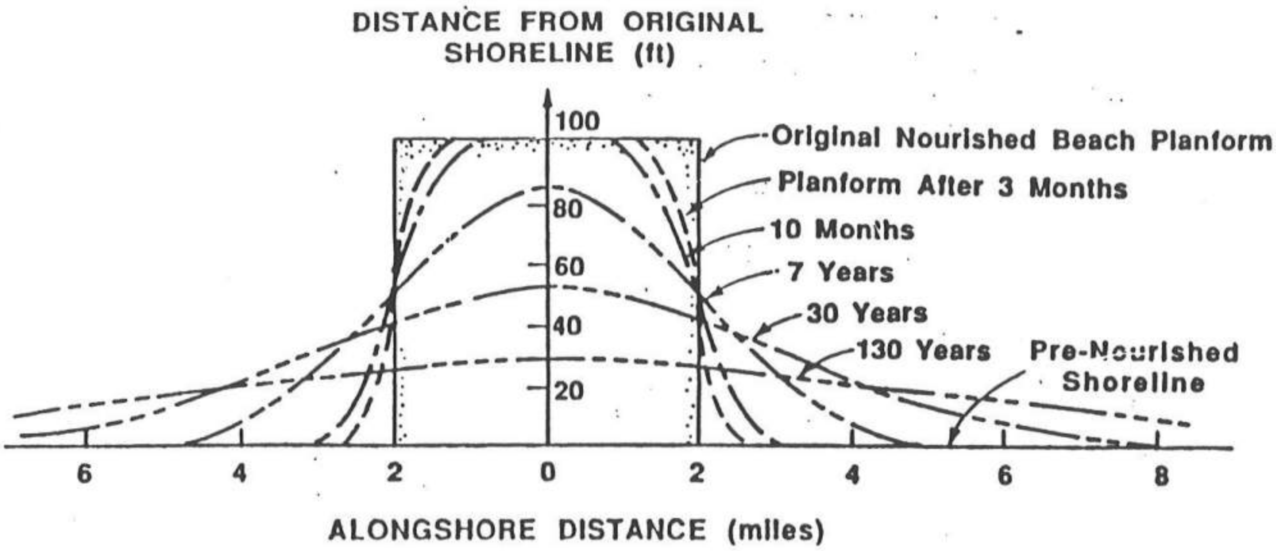

Figure 19: Example of Evolution of Initially Rectangular Nourished Beach Planform. Example for Project Length, ℓ, of 4 miles and Effective Wave Height, H, of 2 feet and Initial Nourished Beach Width of 100 ft (Dean, 1983)

considered most often to be north of Fenwick Island, Dalrymple and Mann, 1985), so the net sand transport may be north or south in any given year.

The next obvious case to consider is when two projects of the same length but located in different wave climates are compared. It is seen that the "activity", G, varies with the wave height to the 5/2 power. Thus if Project A is located where the wave height is 4 feet and loses 50% of its material in a period of 2 years, then Project B with a similarly configured beach planform located where the wave height is 1 foot would be expected to last a period of 64 years. Thus, the life of a beachfill project is even more dependent on the wave climate than its length. As far as beachfill projects along the Delaware Coast, or even much of the U.S. Atlantic coast, for that matter, are concerned, variations in wave climate are not important. The wave climate along Delaware's coast can be considered basically a constant for any given time of year. From October to March, wave height off the coast of Delaware averages 1.2 meters (3.9 feet), and 0.3 meters (1.0 feet) for the remainder of the year (Polis and Kupferman, 1973). Ocean waves under severe storm conditions have been estimated to be nine meters high in the surf zone (USACE, 1956). However, since the wave climate is basically constant over the entire Delaware coast, a beachfill placed on an Atlantic beach in southern Delaware would be expected to last just as long as one placed on an Atlantic beach in northern Delaware, keeping all other factors constant. It is also likely that the wave climate for Delaware will remain unchanged with time in the near future, barring any unforeseen consequences such as those from the rising sea level due to the "Greenhouse" effect. Therefore, the present beachfill project should provide a representative behavior from which other beachfill projects in the state could be modeled.

Figure 19 presents a specific example of beach evolution and Figure 20 presents results in terms of the proportion of sediment remaining in front of the beach segment where it was

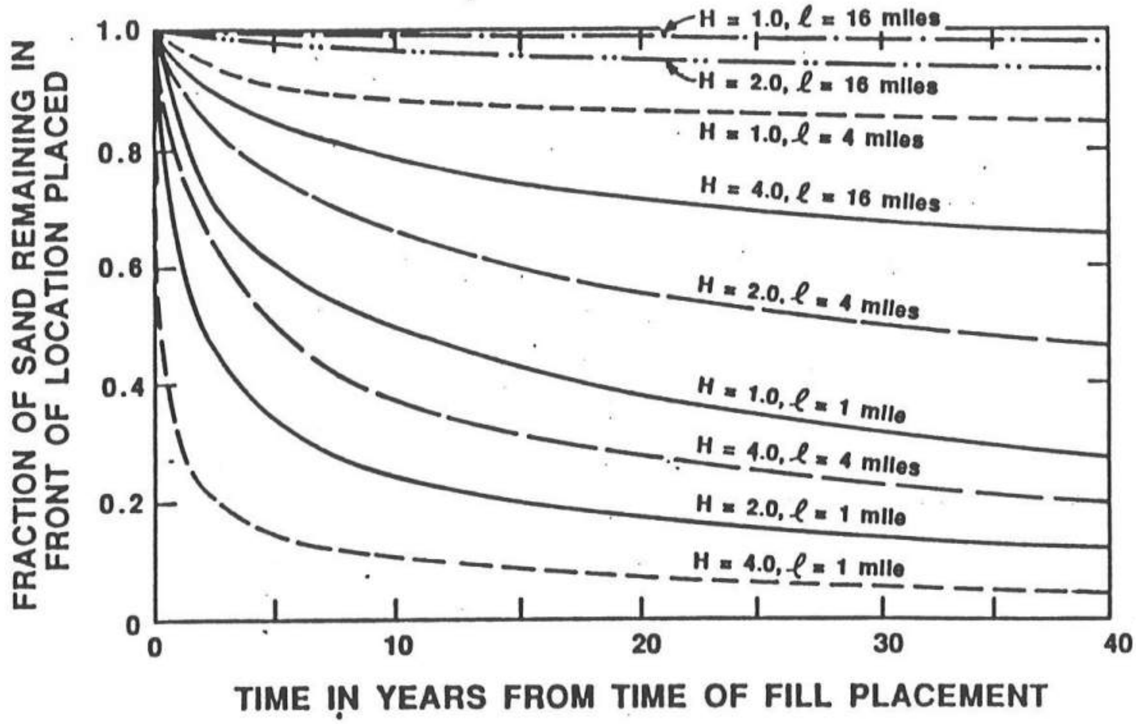

Figure 20: Fraction of Material Remaining in Front of Location Placed for Several Wave Heights, H, and Project Lengths, ℓ. Effect of Longshore Transport (Dean, 1983)

placed as a function of time (Dean, 1983). These results are presented for several examples of combinations of wave height and project length. The analytical expressions for these figures are developed in Dean (1983). Figure 19 shows that since Fenwick Island is at the end of a beachfill project, it loses much of the added width (about 50%) almost immediately to evolution. However, after the initial adjustments, the ends of projects become stabilized, with little change in beach width from year to year. Figure 20 does not really pertain to the Fenwick Island beachfill because it is just an extension of a larger project. However, the figure could be used for future projects in Delaware using a representative wave height found to be between 1-4 feet (depending on the season). Figure 21 shows a similar correlation of percentage of material remaining versus the parameter $1/\eta \equiv \sqrt{Gt}/\ell$ (Dean, 1983).

One final factor associated with the beachfill's shape that may affect the projects lifetime is the effects of the ends of the fill. One approach to retain the sand within the project boundaries as long as practical is to install retaining or stabilization structures near the end of the fill. This, however, is expensive and is known to induce erosion on the downdrift sides of such structures. A second approach is to simply set-back the limits of the fill from the project boundaries with the understanding that the sand would soon "spread out". So initially, some areas of the project would not receive any sand, knowing they would be "naturally" nourished due to the beach planform evolution (i.e., spreading out). Figure 22 (Dean, 1983) presents results for relative end set-backs $\Delta/\ell = 0,\ 0.2,\ 0.5$. As shown, the effects of set-back are greatest early in the project life ($1/\eta = \sqrt{Gt}/\ell = 0.6 - 0.8$) when the sand would redistribute itself to an area still within the project limits.

A third approach is to taper the ends of the beachfill, as shown in Figure 23 (Dean,

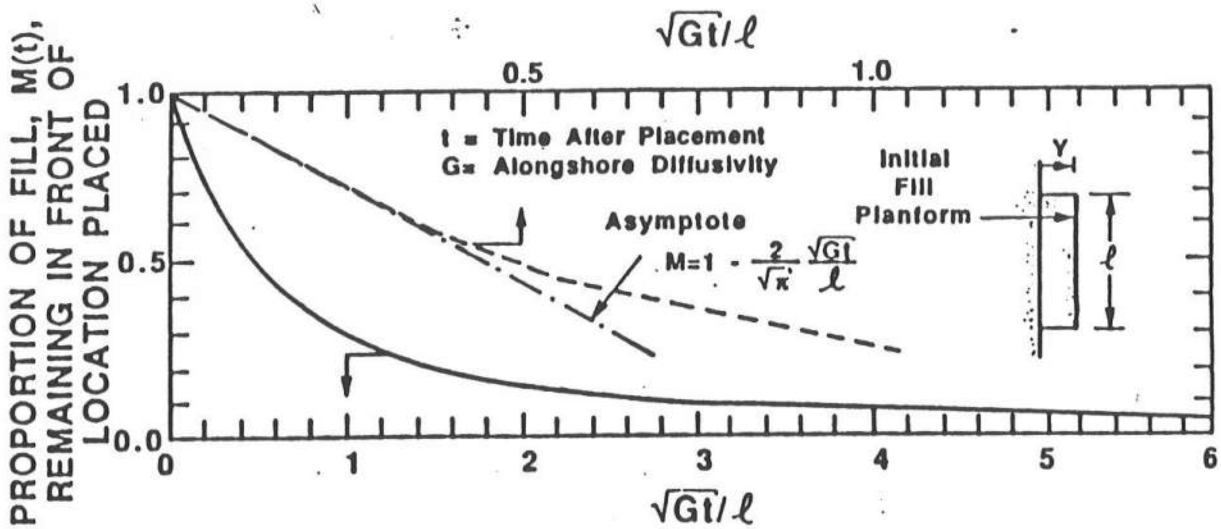

Figure 21: Percentage of Material Remaining in Region Placed vs. the Parameter $1/\eta$ (Dean, 1983)

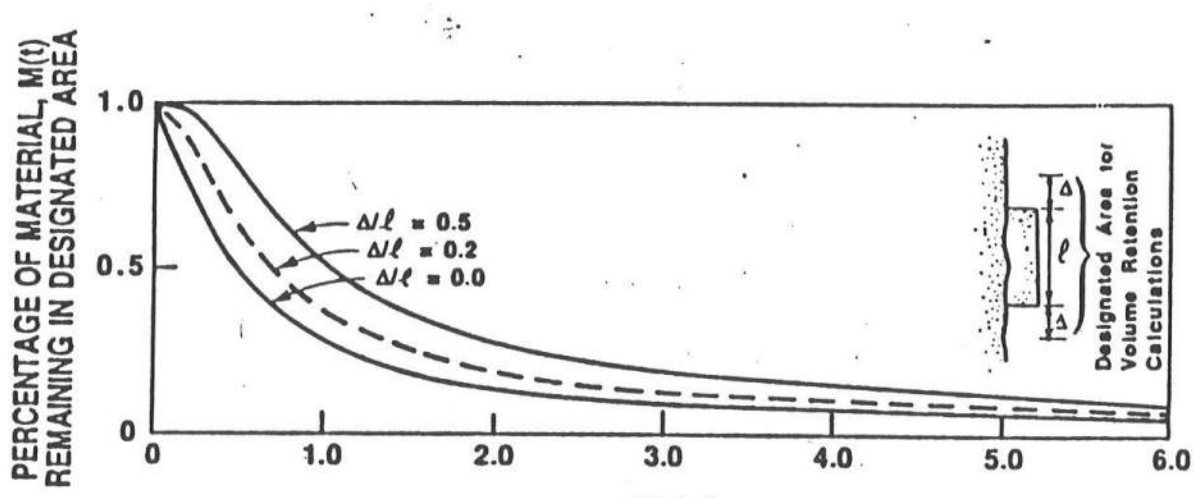

Figure 22: % of Material Remaining in Designated Area of Length, $\ell + 2\Delta$. Rectangular Beach Fill of Length, ℓ (Dean, 1983)

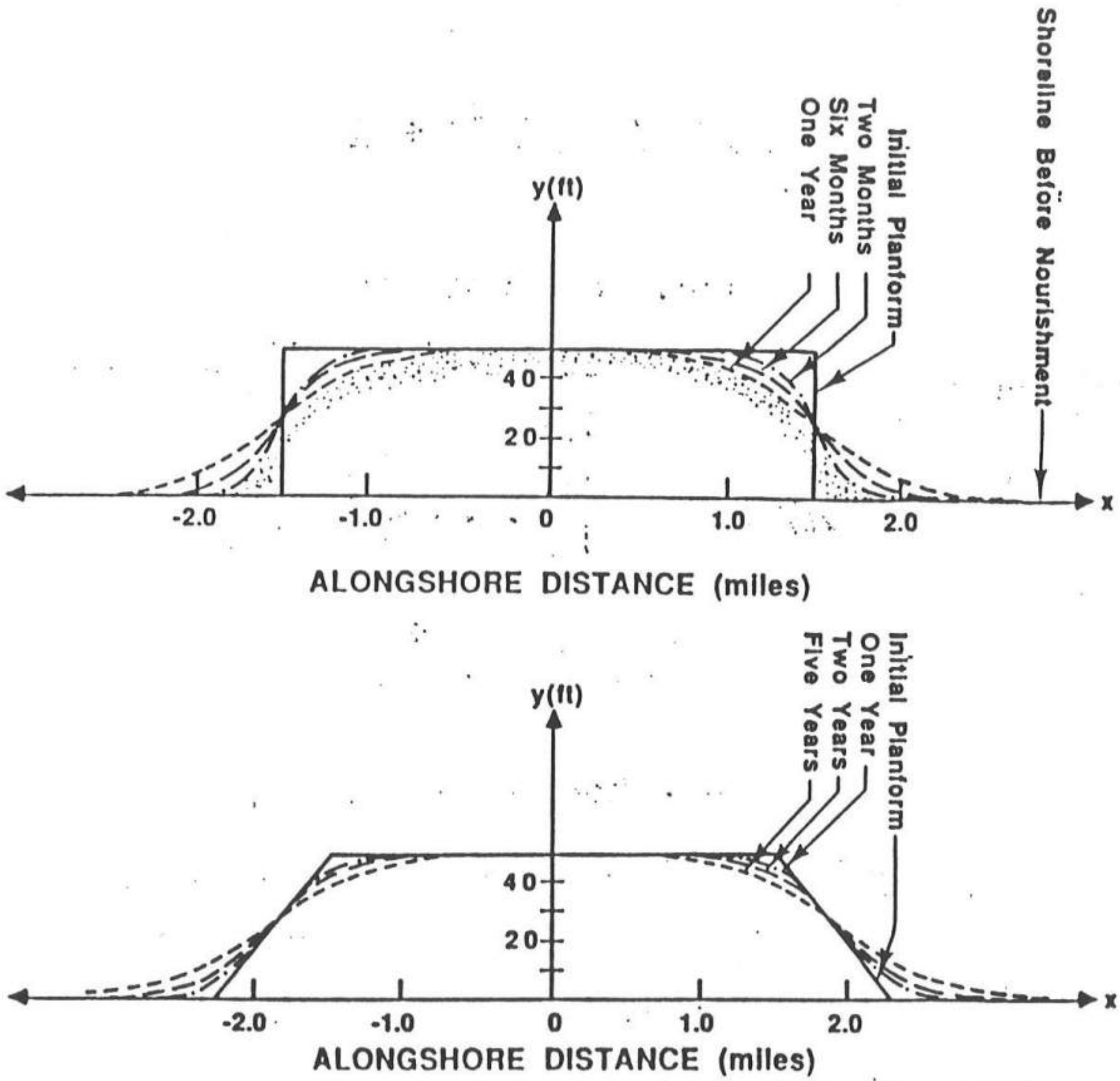

Figure 23: Calculated Evolution of a Beach Nourishment Project (Dean, 1983)

1983). Basing the longevity on the retention of sand within the placed planform, tapered-end planforms have a substantially greater longevity than rectangular planforms. As shown, the evolution of the planform is such that the early changes are the most extreme. The tapered end planform, which approximates the evolved rectangular planform at a later stage, has early evolution stages approximate to that of the later (and less dramatically changing) stages of a rectangular fill. Table 6, compiled by Dean (1983), summarizes the cumulative losses from the region placed over the first five years. It is seen that tapered end-fills have reduced the end losses by about 33%.

Years After Placement	Cumulative % Losses With	
	Rectangular Planform	Rectangular Planform with Triangular Fillets
1	5.7	2.4
2	9.5	4.6
3	11.8	6.6
4	13.8	8.3
5	15.5	9.8

(G=0.02 ft^2/sec, ℓ=3 miles, Y=55 ft)

Table 6: Comparison of Cumulative Percentage Losses from Rectangular and Tapered Fill Planforms (Dean, 1983)

2 Past Beachfill Projects

Here we examine several beachfill projects which have already been completed or are still in progress. More specifically, those projects found in Pilkey (1988) were examined. This group of projects was chosen for two reasons. First, all projects in this article were for barrier-type beaches located along the eastern coast of the United States. Since Fenwick Island falls in this category, it is believed that these beachfills would behave similarly to the one placed at Fenwick Island. The wave environment, weather severity, currents, and seasonal effects felt by the Fenwick beachfill would be comparable to these same effects felt by these other beachfills, particularly those located along the New York, New Jersey, and Virginia coasts. The second reason to examine this particular group of beachfills was the extremely bleak picture Pilkey presented of these projects. Pilkey suggests that beachfills are basically futile projects that are useless in trying to overcome the erosional processes of nature. Pilkey states that for most beaches along the U.S. east coast, beachfills only last five years before major restoration must take place. He states New Jersey beachfills will last only three years. A re-examination of the data used by Pilkey was deemed worthwhile.

2.1 Problems in Evaluating Beachfills

The major problem with evaluating the performance of a beachfill is that often conclusions are based upon observed changes of only a restricted section of the profile above a certain elevation. This is often because only rarely are comprehensive bathymetric surveys made through out the life of a fill project. However, volumetric evaluations of fill project performance based on dry beach or wading surveys lead to errors as profile readjustment certainly extends to greater depths than generally are surveyed as mentioned in Part I. In fact, the sand still forms part of the overall active beach system and is not really lost. Therefore, in cases where the performance of the beachfill is expressed in terms of sand losses, which Pilkey does, the limits of the beach considered should be well defined.

In his article, Pilkey states that some "residence times" were measured in terms of volumetric losses; in other instances, in terms of shoreline recessions. However, in presenting the performance evaluations of the various beachfill projects, he neglects to specify what his data represents. Does "30% lost" mean 30% of the added beach width was lost, or 30% of the added volume of sand was lost? And he admittedly states in his article that the terms "lost", "gone", etc. fit no rigorous definition. These facts make it very difficult to draw any conclusions from the data he presents. To make a rational engineering decision about how a beachfill is performing, many factors, as discussed in this report, must be considered. Any valid evaluation should consider not only how much and how fast sand is being lost, but also how the sand is being lost and where the sand is going.

In "An Assessment of Beach Replenishment Parameters," Pilkey *et al.* define beachfill lifetime as the time required for the loss of at least 50% of the fill material. This is an unduly stringent requirement, since 50% of the fill remains. The definition we are using here is 100% loss. Further their calculations for lifetime are determined by extrapolating loss rates, often determined shortly after fill placement when they are the highest. At a minimum, the Pilkey *et al.* lifetimes can be safely multiplied by two, and there are factors (such as the slowing of fill erosion rates with time) which would indicate that much longer lifetimes are more realistic.

Findings such as "lost 90% in 8 months" and "80% of fill lost in 17 months", seem extremely unrealistic. As stated earlier in the report, nourishment sand, if similar to the

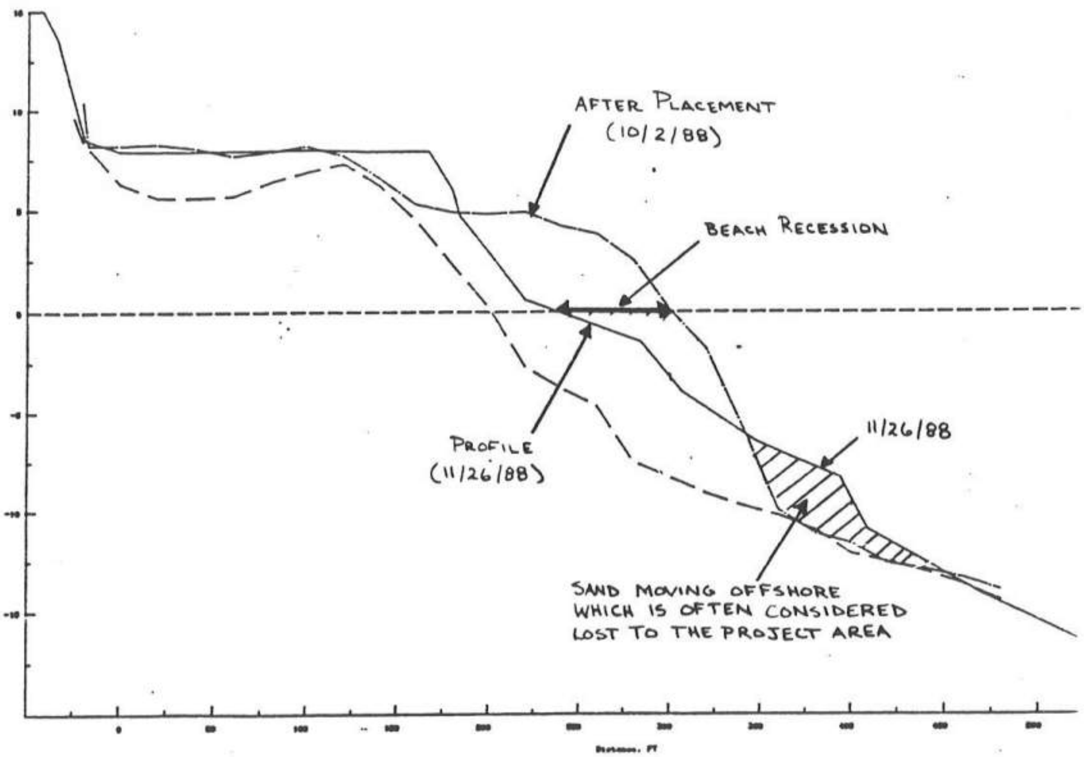

Figure 24: Profile Showing Sand Neglected in Evaluations Using Recession Rates

native sand, erodes at a rate similar to the native sand. With this in mind, it seems reasonable to disregard such high erosion rates as possible volumetric losses. Values as large as these are more likely to be beach recessional rates. Higher than average recession rates are much more easily explained than increased volumetric erosion rates. High beach recession rates, especially shortly after the fill is placed (within one or two years) can often be explained by profile adjustments or end effects.

As mentioned above, very high percentage losses of beachfills in relatively short periods of time are probably referring to beach recessions (i.e., losses in added width). This is often due to profile readjustments and not loss of sand from the area. Thus, by referring to a beachfill as only the sand left above the water line is an oversimplification, and will lead to rather dismal life expectancies for a nourishment project, especially during the profile adjustment stage. Figure 24 identifies the problem associated with evaluating a beachfill using initial beach recessions. These initial recessions, which are often very significant (in the case of the Fenwick Island project an average of almost 30% of the added beach width lost in approximately 1-1/2 months), are misleading as far as sand loss is concerned. It should come as no surprise if 40-50% of the added width from the beachfill project is lost in the first year; in fact, it is often expected.

It was found that some of the "losses" listed in the project evaluations done by Pilkey could be primarily attributed to profile adjustments. During a state of "erosion" of the beach face, an opposite condition of accretion resulted in the offshore reaches of the beach, thus suggesting profile readjustment. Initial high "erosion" rates, followed by an extended period of relative stabilization, also tends to point to the concept of profile readjustment. Profile readjustment was thought to be a major cause for initial "losses" in projects such as Atlantic City, N.J., Virginia Beach, Va., Cape Hatteras, N.C., and Tybee Island, Ga. In these projects, the sand was found not to be lost almost immediately after placement, but to be transported slightly offshore to remain active in the dynamic beach system. In fact, any project whose performance is based on recession rates taken shortly after the nourishment is completed, such as Jupiter Island, Fl., is overlooking the need for profile adjustments to take place. The life of the project will be greatly underestimated.

Failing to recognize that seasonal changes in a beach's profile take place has similar consequences. The season can be crucial to how a beach adjusts. As found at the Atlantic City beachfill, on-offshore movement of the sand is seasonal and mostly non- permanent and may be 2-1/2 times the volume moved longshore (Everts, 1974). For example, when Pilkey states that beaches such as Rockaway Beach, N.Y. and Myrtle Beach, S.C. experienced great loss of the berm during the winter months, when a significant portion of sand moved to the nearshore, he is telling only half the story. He is qualifying this sand as lost to the beachfill area, but as explained in Part I of the report, the berm of many beaches is lost temporarily during the winter to form offshore bars, only to return again in the summer. So seasonal adjustments should not be categorized as "losses". Thus, considering both profile and seasonal adjustments of the beach, recession rates are useful only when the equilibrium profiles of a beach are compared at similar times of the year.

Evaluating the performance of beachfill projects on volumetric erosional rates, while less error prone than using recession rates, can still be misleading. Volumes of beachfills are often calculated by measuring the sand prism. This is done by multiplying the cross-sectional area of the beach by a longshore distance, thus arriving at a volume. The problem which arises is the surveying errors included in the area calculations, which are then magnified by the multiplication procedure used to obtain volume. The surveys should be extended to a depth of closure, which is the depth at which no active sand transport takes place. The depth of closure is discussed in greater detail in Part III of this report. Stopping the surveys at any distance short of depth of closure is sure to cause errors. Figure 25, a survey which is not extended to depth of closure, shows what error may occur. Significant error could arise if for instance a bar formed offshore at a distance further than the survey was extended. The sand comprising the bar would be incorrectly qualified as lost.

A second problem with using volumetric erosional rates is planform evolution. Many times sand is considered lost when it actually just moved down the beach to another area of the project. Pilkey often states erosion takes place along certain stretches of the project without mentioning what took place anywhere else. As mentioned in Part I, beachfills tend to spread out along the beach, and if the sand moves, but still remains within the project limits, it should not be considered lost. An argument could easily be raised that sand displaced outside the limits is still not really "lost" in that it is nourishing nearby beaches, but this report will stick to its original definition of "lost". Erosion in one area of the project (often the ends or updrift areas) is usually accompanied by an equal amount of accretion in another area of the project (often downdrift areas). For example, Pilkey states that the Atlantic City project in 1963 "lost 90% in 6 months" and in 1970 "lost 90% in 8 months". But what he failed to mention was that these losses were for only one profile. Total losses incurred for the entire Atlantic city project were actually less than 12%

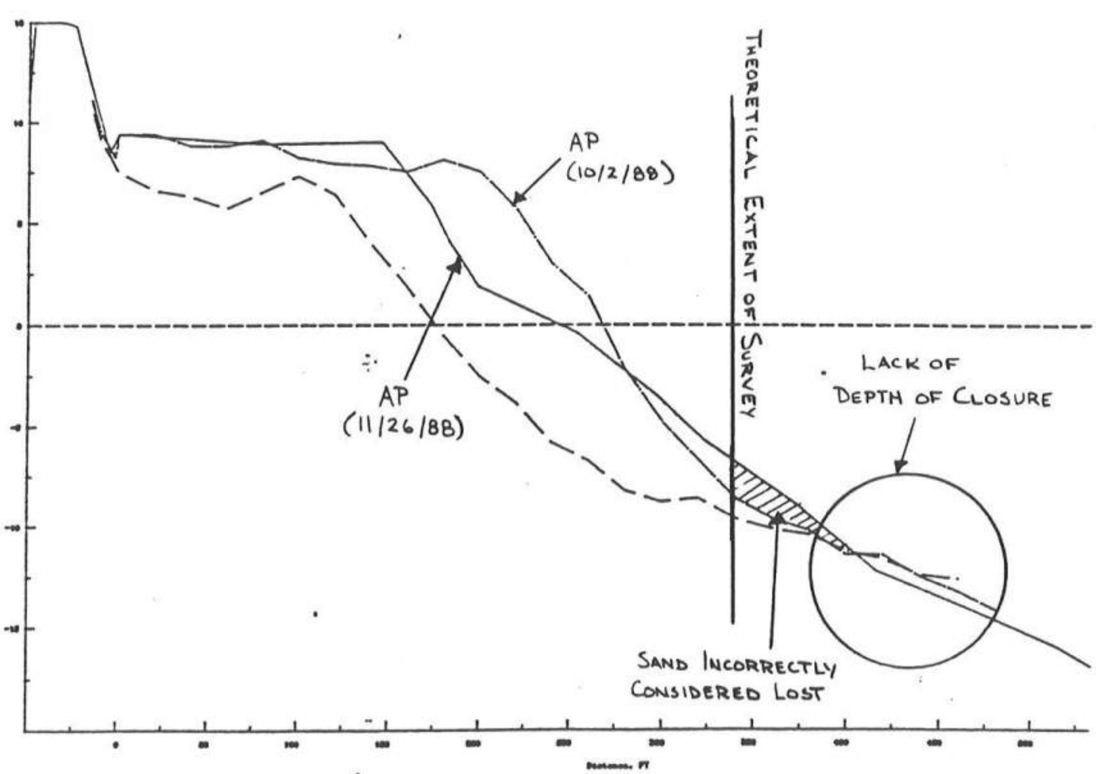

Figure 25: Survey Showing Error Incurred by Lack of Depth of Closure

lost in 8 months in 1963, and only 13.7% lost in 15 months in 1970. In fact, many of the projects examined experienced simultaneous erosion and accretion profiles, thus supporting the concept of longshore transport (i.e., planform evolution) and not sand loss. Besides Atlantic City, other beachfills whose longshore movement was incorrectly diagnosed as sand loss include Rockaway Beach, N.Y., Long Beach Island, N.J., and Tybee Island, Ga. In these projects, the location of the "lost" sand was known. End losses which occur rather rapidly, as happened at Tybee Island, can be considered real losses. However, sand migration, as happened at Atlantic City, where the sand is transported downdrift to other profiles of the project area, should not be considered lost.

2.2 Summary of Project Evaluation

Table 7 gives a brief summary of the performance of the beachfill projects that were previously evaluated in Pilkey's article. More specifically, the table lists facts, data and extenuating circumstances overlooked in Pilkey's evaluations. This report was concentrating on if "real" losses occurred and if so in what manner was the sand lost. Questions were asked such as: Was the beach merely adjusting to an equilibrium profile? Was the sand lost or simply transported down the beach? Were the losses at an expected rate? Were there any outstanding reasons for unusually rapid erosion?

In general, this report found that the communities were pleased with the performance of their beachfills. They recognized their beachfill for what it is: a temporary relief for an ongoing erosion problem. They realized that with present technology, beach nourishment is the best solution to coastline erosion. Hard structures, such as groins and seawalls, though effective for property protection, only add to the erosional problem. Though expensive to replenish, these seaside towns and cities realized the importance of the beach to their economy. In New Jersey, the beach provides a $9 billion/year tourism industry (Alsop, 1983). To these towns, the ideas of Pilkey to surrender to nature and for their communities to retreat from the approaching ocean are ludicrous. As put by Stephen Gabriel, a Coastal Management Specialist in Strathmere, N.J., "buying out all businesses and houses and moving the boardwalk back from the ocean makes $5.4 million spent for sand look like peanuts" (Alsop, 1983). Seaside communities tend to look at beach nourishment as a public works responsibility similar to maintaining public roads, buildings, and parks. They realize that the government cannot turn its back on the beach erosion problem since they have already allowed the oceanside development to take place.

In viewing these past projects, it would seem important that a community planning to undertake a beach nourishment project becomes at least generally educated on what to expect of their beachfill. They should be briefed on the ideas of profile adjustment, seasonal beach adjustments, planform evolutions, etc. This would eliminate drawing any hasty conclusions about the beachfill based on data such as initial recession rates (due mostly to profile adjustment) or end losses (due to planform evolution). A community familiar with beachfill dynamics would know more about what to expect of their beachfill, and be able to take the changes (especially initial adjustments) in stride. Perhaps most importantly, the community would realize that the beachfill is not some type of magical cure to the erosion problem. The nourished beach will not last forever; it will erode just as the original beach did. Beachfills are placed knowing that the beach will have to be renourished in the future.

Table 7: Project Performance Evaluations

Rockaway Beach, N.Y.

Inlet (Jamaica Bay); Available borrow material for nourishment finer than native material → so expected 20% loss of fill during initial textural adjustments; 10% handling losses (rehandling and placement). 1975: 2,804,082 m^3 placed. Much of sand migrated westward to other parts of the beach. Berm lost due to seasonal adjustments.

Sandy Hook, N.J.

Inlet (Lower New York Bay)

Long Beach Island, N.J.

Barnegat Inlet; Beach fills in 1963 and 1970 effectively stabilized any net volume change; August 1979: 1,000,000 m^3; both nourished and unnourished beaches have comparable erosion- accretion response to low intensity storms; Sand moved northward (not lost) and formed shoal which welded to the beach; placed in naturally eroding stretch of shoreline but had positive effect of reducing the impact of storms and Hurricane David; although more sand lost from nourished beaches clear beachfill was buffer during Hurricane between storm waves, dunes and shore property; Southern part lost in a year moved northward to other parts of beach; After 3-1/2 yrs sand gone from only 3 most southerly profiles and most moved northward to two most northern profiles; From Jan 79 → Aug 86 3 or 4 nourished beach profiles had a positive net volume change (+158, +86, +1, D90 m^3/m of beach); sand should have been placed further south to act as feeder beach by longshore currents.

Atlantic City, N.J.

Absecon Inlet; Much sand moved longshore to Ludlam Island; Feb- May 1963: 430,000 m^3; July 1970: 610,000 m^3; Volume loss rate greatest immediately following placement due to profile adjustment; Only Profile 1 lost 90% in 6 mos. (1963) and 90% in 8 mos. (1970); These were mostly storm changes; Profile 3 fill loss rates uniformly low and large natural recoveries of material were observed; Sand volumes on beaches SW of nourished areas increased w/time; After 1963 50,000 m^3 (12%) lost in 8 mos. After 1970, 84,000 m^3 (13.7%) lost in 15 mos. (Total losses not just individual profiles); Alongshore movement in waves: 2m/day (1963), 3m/day (1970); On- offshore movement is cyclic and mostly non-permanent and 2 1/2 times volume moved longshore (seasonal adjustments only).

Strathmere, N.J.

Beaches = \$9 billion/year tourism industry; only \$90,000 spent to haul sand as line of defense for three beach-front homes; Elizabeth Berens, VP of Strathmere Improvement Association, "all sand washed out within a week"; Coastal Management Specialist, Stephen Gabriel, buying out all businesses and houses, moving boardwalk back from ocean "make \$5.4 million spent for sand look like peanuts"; should maintain beach just like maintain roads and public buildings since development has already been allowed to take place.

Indian River Beach, De.

Inlet; is a starved beach (no sand coming in).

Virginia Beach, Va.

Annual nourishment required to maintain present beach dimensions = 141,000 yd^3; dredged pleasure craft channel offshore prevents sand from being carried onshore; Rudee Inlet; state of erosion in any given year → opposite condition results in offshore reaches (so, just profile adjustment to changing wave conditions); have been pumping only 130,000 yd^3/yr less than the required 141,000 yd^3 for the given erosional conditions so it can't keep pace; USACE suggests one time 2.5 million yd^3 and 300,000 yd^3/yr thereafter, to accommodate growing tourism; USACE → reduce storm damage, annual benefits of increased recreational space (spending); property protection would be \$2.7 mill/yr over 50 yrs compared to cost \$1.3 mill/yr.

Cape Hatteras, N.C.

Initial beach lost actually only profile adjustments.

Wrightsville Beach, N.C.

Artificial opening of Carolina Beach Inlet and north jetty at Masonboro Inlet which substantially reduced rate material movement onto beach; Carolina Beach Inlet responsible for majority of erosion problem being experienced at north end; North Jetty → net deficit of 155,000 yd^3/yr (by passing); Carolina Beach Inlet → erosion 269,000 yd^3/yr; shoreline's recessions probably due to profile adjustment.

Carolina Beach, N.C.

Known erosion accelerated by seawall.

Myrtle Beach, S.C.

Seasonal adjustments cause of winter losses to nearshore areas.

Tybee Island, Ga.

Inlet Savannah River; Early rapid erosion due to profile adjustment reached equilibrium in 5-6 mos.; 1976: 2.26 million yd^3; since initiation 100% increase in prism of sand stored between seawall and mean low water baseline; erosion in south due to inlet where sand migrated to develop a spit near borrow pit; Minor beach erosion (12% volumetric loss occurred along northern shoreline probably just rapid adjustment toward equilibrium) in 1st 5-6 mos.; only minor losses and gains in ensuing 6 mos.; same pattern of rapid erosion and relative stabilization along much of Tybee shoreline (profile adjustment); Most stabilized at 40% of original volume of exposed beach; Two areas do not follow trend: 10th St. retained 100% of nourishment material, extreme southern end 18th St. sand $\rightarrow$ form spit where w/in 9 mos of nourishment the volume of sediment in prism increased by 100%; At extreme north end out of project a relatively continuous rate of accretion; After 3 mos. prism increase by 90% volume, 6 mos. increase 190%, 12 mos. 220%; 50- 75% of initial losses related to accumulations of upper shoreface (1000 ft offshore); Historically experiences severe beach erosion anyway; of the 20% lost in 1st 43 mos., 74% can be observed on beach north of project limits, rest settled in shoal area at south end of Tybee Island, shifted to accreting area in middle of beach or carried off; By 1978 South = 2133' 62% erosion, Middle = 5225' 46% accretion, North = 5422' 44% erosion, S. Jetty = 630' 20% accretion, N. Jetty = 87' 9% erosion; Southern erosion due mainly to nearshore flood channel in Tybee Creek; Initial beach nourishment and groin construction functioned well over last 4 yrs; although erosion rate unpredicted beach has remained relatively stable despite the southern regions; Navigational improvements in the Savannah River (jetties, deepened channel) have eliminated sediment supply from north causing erosive stress on Tybee Island; considering sea level rise of 40 cm the shoreline has not eroded as much as might be expected and erosion control efforts have been moderately successful to date; loss of projection at NE island $\approx$ deposition near north island; beach nourishment contributed to formation of recreational beaches still present after 10 yrs; near central portion sand has accumulated resulting in fairly substantial dune field up to 70 m wide.

Miami Beach, Fl.

1976 - 80: 14 million yd^3; Average 300 ft wider beach; North: retreated 100 ft first 5 yrs then stabilized over next 4 (readjustment of profile); has withstood moderate Hurricanes (David 1979); clearly met needs of coastal cities behind fill (recreation beach, flood and storm buffer for expensive property and rejuvenated beach).

In the projects investigated here, the communities did seem to be aware of such factors, and thus were satisfied with their beachfill's performance. The fills enabled the beach to continue both as a recreational facility and as protection from the rising ocean. However, several of the projects were found to be "failures" for various reasons. In retrospect, it seems as if Pilkey selected to evaluate beachfill projects which did in fact have reason to fail.

Such projects often were designed without taking into account all factors which were deemed important to a fill's lifetime in Part I. Perhaps these projects were completed before the correlation of such factors to the lifetime were established.

First, it was noticed that many of the projects were locations of known high erosion. Such locations include beaches near inlets, which was the case for all the projects except Miami Beach, Fl., which has remained relatively stable for almost 10 years (NRC, 1987). Inlets, especially those man-made, such as the Carolina Beach Inlet, are known to cause unusually high erosion rates. Thus, the beachfills would be expected to be exposed to these same conditions, and therefore also erode relatively quickly when compared to nearby beaches which are not adjacent to an inlet. The Indian River Beach, DE, beachfill was placed on a starved beach (i.e., no sand coming in), as part of a dredging project, and therefore was expected to erode rapidly. Beachfills placed near other structures such as in front of a seawall at Carolina Beach, N.C. and adjacent to a jetty at Wrightsville Beach, N.C. are also now known to experience accelerated erosion rates.

Other projects, such as Long Beach Island, N.Y. and Miami Beach, Fl. were hit by hurricanes shortly after the fills were placed. This gave the appearance that the fills eroded unusually fast. However, both projects stood up well. The fill at Long Beach Island was noted as having a positive effect of reducing the impact of the storms felt by the protective dunes and shore property.

Several other mistakes were made in other projects that can now be looked back on as experience. The Rockaway Beach, N.Y. fill consisted of sand finer than the native material (USACE, NY). Finer sand, as explained, is less stable and therefore expected to erode faster. The Long Beach Island, N.J. fill was placed without considering the planform evolution. It was determined, after the fact, that the fill should have been placed further south to act as a feeder beach by longshore currents (Ashley, 1987). Two projects, Strathmere, N.J. and Virginia Beach, Va., were bound to be too small for their needs. Strathmere only spent \$90,000 to haul sand as a line of defense for three beach-front homes. A fill so small could not possibly be expected to function properly. Profile adjustments and planform evolution would use up a very high percentage of the sand placed. Virginia Beach was pumping only 130,000 yd^3/yr, while it was determined the area was losing 141,000 yd^3/yr to erosion (Bunch, 1970). Obviously, they were in a losing battle. While trying to minimize costs, a community must be sure that their fill project will be able to serve its purpose, whether recreation, protection, or both.

In conclusion, evaluating the performance of a beach nourishment project is no easy matter. Many factors enter into the picture. As of now, there is no standard way of determining the effectiveness of such projects. In fact, there is not even a universal definition of "lost" sand. It does, however, make sense to not classify sand as lost until it passes out of the project limits. It is also desired to evaluate beachfills on volumetric erosion rates and not recession rates because of the problems caused by profile adjustments.

In determining volumetric losses of a fill, surveys should be taken, if at all possible, to a depth of closure to include all the sand involved in the beach system. As stated, all factors (profile adjustments, grain compatibility, planform evolution, etc.) should be worked into an evaluation.

Oversimplifying the design and evaluation process is not the answer. Pilkey's equation shown below is grossly simplistic:

$$V_1 = (X/n)V \tag{11}$$

where V_1 = total volume of sand required to maintain a design beach of a given length n = assumed interval of required major restoration

For Florida, $n = 9$ years

For New Jersey, $n = 3$ years

For remaining East Coast barriers, $n = 5$ years

X = desired project life or design life

V = Volume of initial fill placed along beach of given length

Estimating long-term sand requirements as only the volume of fill placed and the state where the sand is placed could not possibly have any engineering backing. What if the statelines were changed? Presently, it seems best to study the past beach activity of a proposed project area and use this historical data to estimate the fills performance. The fill should then be evaluated only after years of monitoring; and not after only a few months in which the beachfill has not had time to stabilize, leading to erroneous conclusions.

3 Beach Fill Lifetime Calculations

Several methods for calculating lifetimes for the Fenwick Island beachfill are carried out in this section. In these calculations, it was necessary to use data from historical records. Much of these data came from three past reports: *A Coastal Engineering Assessment of Fenwick Island, Delaware* (Dalrymple and Mann, 1985), *Coastal Engineering Study of Bethany Beach, Delaware* (Dick and Dalrymple, 1983), and *Sediment Budget and Sand Bypassing System Parameters for Delaware's Atlantic Coast* (Coastal and Offshore Engineering and Research, Inc. (COER), 1983). Some of the data in these reports was in turn compiled by the U.S. Army Corps of Engineers. The only recent data (within the past 3 years) came from the DNREC. They supplied beach profiles for every 100 ft of the 6000 ft beachfill for times immediately before the sand placement and immediately after. The DNREC also obtained profiles on November 26, 1988. The recent data from the DNREC, thus, only contains information for the first months of the life of the beachfill. Therefore, it can be assumed that some of this data would not be indicative of the beachfill's entire lifespan, as the beachfill was still undergoing profile readjustment. Additional surveys will be taken in the future by DNREC on a bimonthly basis.

Using historical records is very convenient, especially when dealing with values such as recession and volumetric erosion rates. Values like these, when averaged over many years, take into account many factors which could be overlooked or omitted when values are only calculated for one specific time, say the most recent. Historical records take into account factors such as storm frequency and varying longshore littoral drift rates and wave data. By averaging historical data for, say, beach recession rates, all of these other factors are also "averaged-in", and the averaged quantities become better representative of what will happen to this beach in the future, than would values from only the most recent year. For instance, if only the most recent recession rate is used so that only the most up-to-date data is used, then the calculation is done assuming that every year in the future will be identical to the one used. It would be assumed that the severity and frequency of storms remained the same, the wave magnitude and direction remained the same, etc. It would be possible to use only the most recent recession rate and not make all of these assumptions, but this would involve many more calculations. More specifically, calculations of the effects of all these factors, such as littoral drift and wave data, would have to be incorporated. For this study, it was determined that historical data will in fact be relatively accurate in determining the beachfill's lifetime when compared with any other available methods.

Even though historical records were used, only the most recent data was chosen. Records that were very old, say over 50 years, were avoided, as it is believed that the erosion rate along the Delaware coast is presently higher than it has been in the past (COER 1983). Averaging very old data into our calculations would produce an erosion rate that is too low in reality, thus causing the lifetime calculations to be too high.

3.1 Lifetime Based on Recession Rates

In this section, the lifetime of the beachfill is estimated using the beach recession rates (i.e., how fast the width of the beach decreases with time). As stated above, the beach recession immediately after placement is ignored. The recession at this time is for the most part related to the beach changing shape towards its equilibrium profile. This initial recession is generally not due to sand losses. These initial beach recessions are shown in Table 8,which shows how far the beach accreted (widened) when the fill was first placed (BP-AP), how far

Profile	Beach Accretion Due to Sand Placement (BP-AP) (ft)	Beach Recession Due to Initial Profile Adjustment (AP - Nov. 26) (ft)	Net Change (BP - Nov 16) ft	% Width Loss Due to Adjustment (AP - Nov 26)
100	70.21	-39.2	31.0	-55.9%
105	99.67	-62.8	36.9	-63.0%
110	102.16	-50.1	52.1	-47.4%
115	91.94	-23.3	68.6	-23.8%
120	98.67	-35.5	63.2	-34.8%
125	42.92	3.8	46.8	7.3%
130	96.57	-31.2	65.3	-32.4%
135	112.00	-37.8	74.2	-33.5%
140	106.29	-28.4	77.9	-26.5%
145	67.33	13.6	80.9	18.6%
150	107.00	-16.7	90.3	-16.1%
155	114.53	-44.3	70.2	-38.2%
160	83.25	-20.0	63.2	-22.5%
AVG	91.33	-28.6	63.1	-28.2%

BP = before placement of fill Sept-Oct 1988
AP = immediately after placement of fill Oct 1988
Nov. 26, 1988 = first survey of the fill.

Table 8: Initial Beach Recessions for the Profiles of the Beachfill at Fenwick Island, 1988

the beach receded in the first month after placement (AP- Nov. 26), how much wider the beach was as of November 26 than before the beach fill was placed (BP-Nov 26) and, finally, the percentage of the added beach width that was lost in the first month (AP-Nov 26). The profile numbers are for the beach profiles every 500 ft, with Profile 100 at the DE/MD line, Profile 105 500 ft north of the DE/MD line, ..., up to Profile 160 which is the beach profile 6000 ft north of the DE/MD line. The changes in beach width were measured from the profiles provided by the DNREC. Example distances are shown in Fig. 26 . Note that on the average, the 325,000$yd^3$of fill added 91.33 ft to the width of the beach. This is in very good accordance with Dalrymple and Mann (1985) which approximates that 341,000 yd^3 placed on this 6000 ft of beach would widen the beach 100 ft.

Also note that Table 8 shows that on the average, the beach narrowed by 28.6 ft the first 1 1/2 months, or 28.5% of the added width from the beachfill. This number, corresponding to a recession rate of 19 ft/month (or 229 ft/yr), is obviously not a value that is indicative of the transformation of the beach throughout its life. Most calculations of the recession rate for Fenwick Island tend to be between 1.5-3.0 ft/yr. This shows that historical data must be used. Using the recession rate of the first 1 1/2 months would produce a beachfill lifetime of only a few months which is definitely not the case. The fact that the large recession rates are due to profile readjustment is also shown in Fig. 26. Note that the sand is not lost but has been transported by the waves from the beach berm to a position slightly offshore. Volumetric calculations in fact show that only 3% of the fill left the nourishment area during this time.

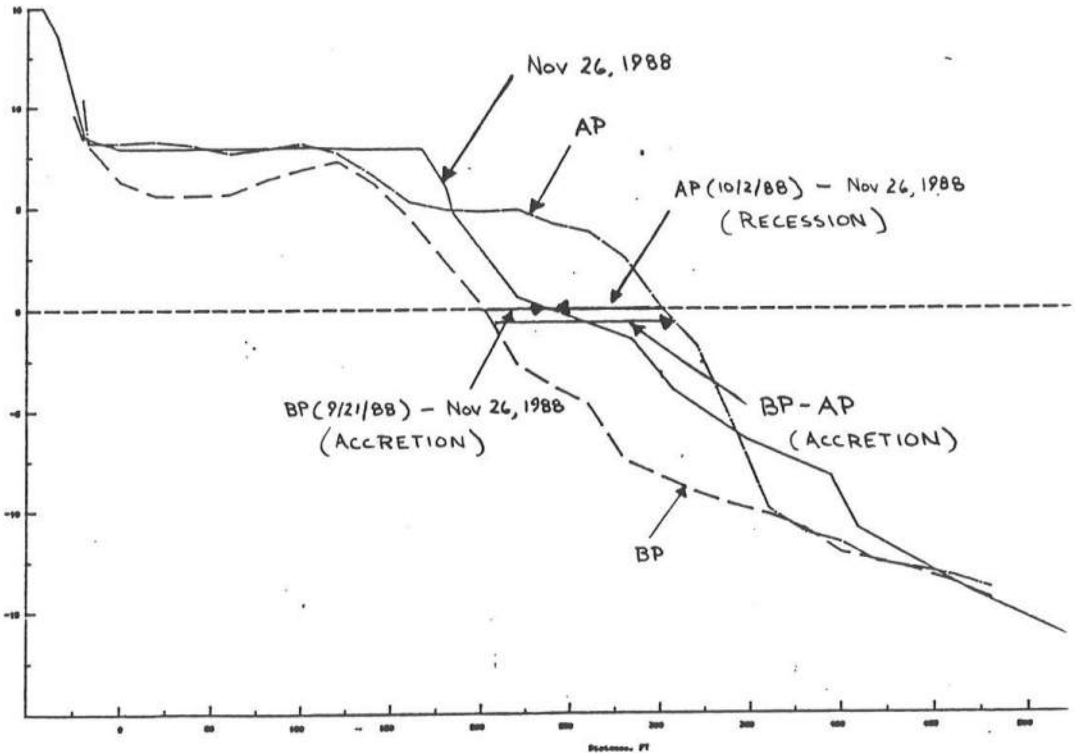

Figure 26: Profile Showing Beach Recession and Accretion During First 1 1/2 Months

Table 9 lists historian recession rates determined in past studies. Notice that the recession rates from the various studies vary greatly. Some values are almost three times the value found in other studies. In fact, notice that the standard deviation is greater then the value itself in some of the studies. Dalrymple and Mann (1985) found that between May 1977 and June 1979 the shoreline was eroding at 31.5 ft/yr (standard deviation = 18.6 ft/yr)! However, most values seem to be in the neighborhood of a recession rate between 1.5 and 4.0 ft/yr. An average value of 2.36 ft/yr seems reasonable. It may be more realistic, however, to use a slightly larger number say, 2.75-3.0 ft/yr, since it is known that the erosion rate of Delaware's coast has accelerated recently (approximately the last 27 years) (Dalrymple and Mann 1983).

To determine the lifetime of a beachfill the concept of an equilibrium profile will be used. The general idea is to assume that the beach will maintain its equilibrium profile, throughout the lifetime of the fill, no matter how much erosion or accretion takes place. With the equilibrium profile of the beach established, the beach recession rate is related to the volumetric loss of sand as shown in Figure 27 .

The definitions of the three terms are as follows:

B =average berm height after the fill has been placed
d_c = depth of closure
R = beach recession rate

If the beach maintains its equilibrium profile throughout the erosion process, which is a fairly good assumption, the two shaded regions in Figure 27 are equal in area. Therefore, if the entire beach of average berm height, B, and depth of closure, d_c, recedes a uniform

Source	Means of Deriving Rate	Years Averaged	Area Averaged	Recession Rate (ft/yr)
Mann	Aerial photography	1938-1979	1880 ft south of DE/MD line to 8695 ft North of DE/MD Line	1.7 Standard Deviation (S.D.) 0.8
Hayden				1.9 (S.D. = 3.9)
Mann	Profiles (Depth of Closure = 30 ft)			3.2 (S.D. = 3.3)
Mann	Profiles (Depth of Closure = 25 ft)			3.8
Mann	Conservative			3.0
Mann	Average of Methods			2.0
Dick		1954-1964	Indian River Inlet to DE/MD Line	2.0
COER	Profiles (d_c=35 ft)	1964-1983	1 1/4 mi north of DE/MD Line	1.43
USACE		1853-1983	South Delaware	1.64-2.95
			AVG =	2.36

Table 9: Historical recession Rates for Fenwick Island, Delaware

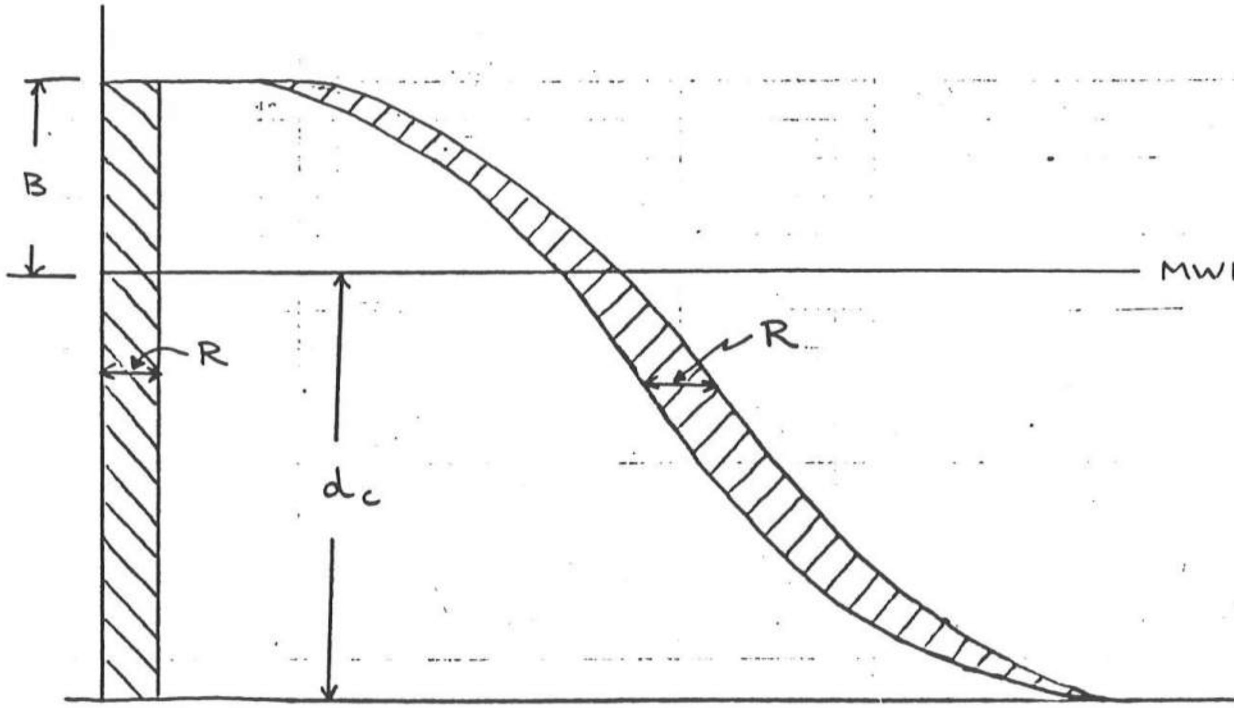

Figure 27: Relating Recession Rates to Volumetric Erosional Rates

amount, R, then each two- dimensional profile, as shown in Figure 27 , is in essence losing area equal to either one of the two shaded regions. Then by multiplying this average area loss by the length of the beachfill, a volume is attained, which represents the amount of sand lost over the entire beachfill.

Now an outline of the calculation procedure will be presented:

Step (1): Determine: V = total volume of fill placed (yd^3)
L = length of beachfill (ft)

Step (2): Calculate: $A_F = V/L$, area of fill per unit length of beach (yd^3/ft)

Step (3): Calculate: $A_E = (B + d_c)$
= area of fill lost due to 1 foot recession (ft^2)

Step (4): Calculate: $R_T = A_F/A_E$
= total possible shoreline advancement due to the fill, assuming total profile readjustment (ft)

Step (5): Calculate: Lifetime of Beachfill = R_T/R_H (yr)
where R_H is the annual shoreline recession

The values for Step (1) were supplied by the DNREC. The total volume of sand placed was calculated by comparing the profiles immediately before and immediately after placement of the beachfill. The net area added to each profile by the beachfill was calculated using an ISRP format computer program. The program basically calculated the areas of all the cut/fill cells along the length of the profile. Then all the cut/fill cell areas are added

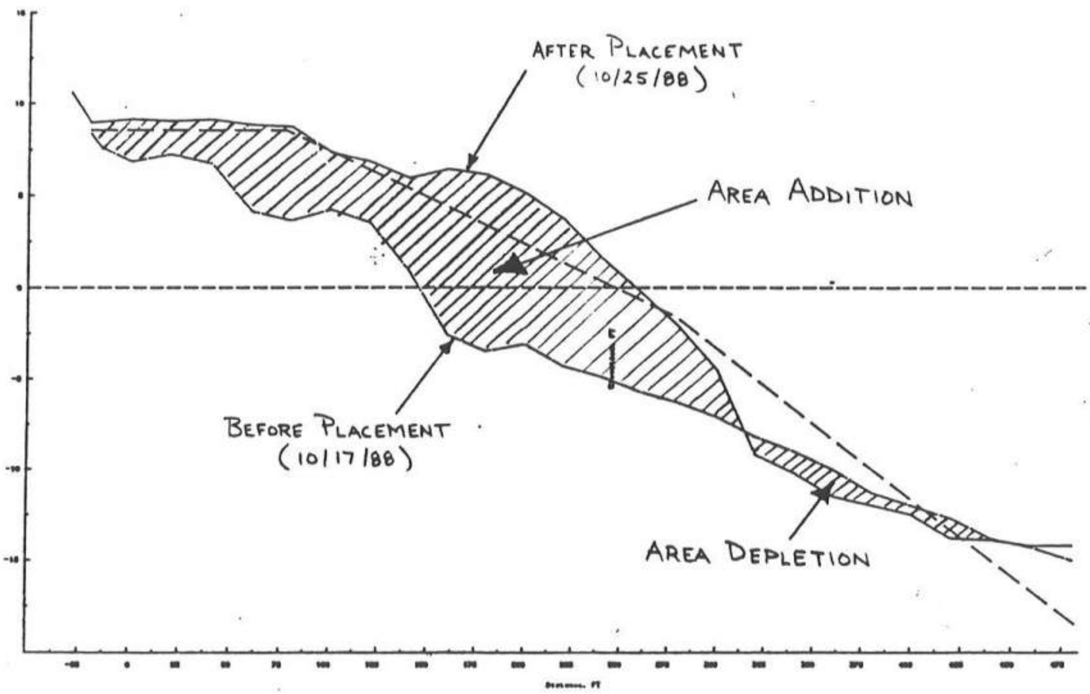

Figure 28: Cut/Fill Cell Areas Along a Profile

to obtain a net area change for that profile. Figure 28 shows an example of the cut/fill cells, of which the areas were computed. Actually, the areas are thought of as volume of sand placed per foot of beach, i.e., yd^3/ft, which has units identical to that of an area. The volume of sand placed between two adjacent profiles is then computed by averaging the two net changes of area due to the beachfill of the two profiles and multiplying it by the total distance between them. Finally, the volumes of sand placed between all adjacent profiles are summed to obtain the total volume of fill placed. Tables 10 and 10 show the net change of area along each profile, the average net change of area between adjacent profiles, the volume of sand placed between profiles, and the total volume of fill placed, V. The data in the tables were provided by the DNREC.

Now: L = 6000 ft
V = 325,573 yd^3 = 8,790,471 ft^3

In Step (2), A_F, the area of fill was computed. A_F is the volume of sand placed by the beachfill per foot of beach.

Now: $A_F = V/L = 325,573\ yd^3/6000ft = 1465\ ft^3/ft$ of beach
$= 54.26\ yd^3/ft$ of beach

So for every foot of beach in the beachfill area, an average of 54.26 yd^3 of sand was placed.

-1

In Step (3), A_E, the area of fill lost due to one foot of beach recession, was calculated. This calculation makes use of the assumption that the beach maintains its equilibrium

Profile	Net Area Change (yd^3/ft)	Avg. End Area (yd^3/ft)	X 100 ft (yd^3)
100	31.08		
		38.19	3,819
101	45.31		
		48.92	4,892
102	52.54		
		53.31	5,331
103	54.09		
		54.85	5,485
104	55.62		
		55.86	5,586
105	56.11		
		54.06	5,406
106	52.01		
		54.43	5,443
107	56.86		
		60.69	6.068
108	64.51		
		60.81	6,081
109	57.11		
		65.03	6,503
110	72.95		
		63.81	6,381
111	54.67		
		54.47	5,447
112	54.27		
		52.25	5,225
113	50.23		
		56.47	5,647
114	62.71		
		61.86	6,186
115	61.01		
		59.98	5,998
116	58.96		
		61.76	6,176
117	64.57		
		67.04	6,704
118	69.52		
		66.06 (X 50)	3,303
119 (18+50)	62.60		
		63.22 (X 150)	9,483
120	63.84		
		66.67	6,667
121	69.51		
		68.67	6,867
122	67.84		
		55.90	5,590
123	43.46		
		41.18	4,118
124	38.41		
		35.12	3,512

Profile	Net Area Change (yd^3/ft)	Avg. End Area (yd^3/ft)	X 100 ft (yd^3)
125	31.48		
		45.05	4,505
126	58.62		
		54.74	5,474
127	50.86		
		49.57	4,957
128	48.29		
		44.95	4,495
129	41.62		
		44.86	4,486
130	48.11		
		46.39	4,639
131	44.68		
		49.90	4,990
132	55.12		
		53.20	5,320
133	51.28		
		52.58	5,258
134	53.88		
		53.28	5,328
135	52.68		
		50.14	5,014
136	47.60		
		53.03	5,303
137	58.47		
		55.22	5,522
138	51.98		
		54.89	5,489
139	57.81		
		57.60	5,760
140	57.39		
		51.21	5,121
141	45.04		
		47.14	4,714
142	49.24		
		50.09	5,009
143	50.94		
		48.71	4,871
144	46.49		
		42.36	4,236
145	38.24		
		45.57	4,557
146	52.91		

Table 10: Volume Change Profiles 100-160 : BP (9-20-88) - AP (10-11-88) (DNREC)

Source	Equation	Depth of Closure d_e (ft)
Hallermeier (1978)	$d_c = 2.28H_e(H_e^2/gT_e^2)$ H_e= extreme wave height T_e = period of extreme wave	19.8
Hallermeier (1983)	$d_c = 2.9H(Sl - 1)^{-0.5}$ H= wave height of representative wave S = specific gravity of the sand	23.0 (H=10 ft, s=2.58) 35.0 (H=15 ft S=2.58)
Weggel (1979)	$d_c e^{-\alpha x} = (h - h_o)$ x = horizontal coordinate h = vertical coordinate h_o = datum adjustment factor α= empirical constant	40-50
Ocean City Project (Corps of Engineers)		21.0

Table 11: Depth of Closure Values for the Delaware Coast

profile, as stated before. This assumption greatly simplifies the calculations, since the area of beach lost due to erosion, which actually looks something like the curved shaded region in Figure 27 , is now equal to the much more easily computed rectangular region shown also in the figure. With this assumption, one can think of one foot of recession as picking the entire beach up, while retaining its shape, and moving it landward one foot. Therefore, A_E is the amount of area lost along a profile when the beach retreats one foot.

Note that A_E is dependent on the depth of closure d_c of the beach. The depth of closure is the depth at which there is no active sediment transport. At this depth, all beach profiles taken at different times at a site should coalesce. Looking at Figure 29 it is obvious that the DNREC did not extend its profiles to the depth of closure. The separate profile lines, which as shown extend to a depth of approximately 15 feet, do not join and become one. Therefore, in determining the volume of sand between the two profile lines (i.e., areas), the best that can be done is to estimate the profile lines out to a predicted depth of closure. The DNREC calculations did not do this but simply cut off the profiles at a point 480 feet from a predetermined reference point. Noting that on most of the profiles, the lines are only slightly separated at this distance, and will probably only get closer the deeper the surveys go. These calculations are probably within a reasonable error of the actual values. Later profiles will extend further offshore.

The problem with taking surveys out to the depth of closure is determining exactly what the depth of closure is. In Dalrymple and Mann (1985), several depths of closure for the Delaware Coast are computed using various methods. Several of these values are listed in Table 11. As shown, the values of d_c are quite varied. However, both of the Hallermeier equations suggest that d_c could not be 35 feet. Also, Weggel's formula is dismissed since the profile data does not seem to be described by an exponential fit. Therefore, Dalrymple and Mann (1985) suggest using a depth of closure of 28 feet. This is somewhat deeper than the 21 feet being used by the Corps of Engineers for the Ocean City Project, but provides a more conservative estimate of lifetime.

In Step (4), R_T is calculated, which represents the total possible shoreline advancement,

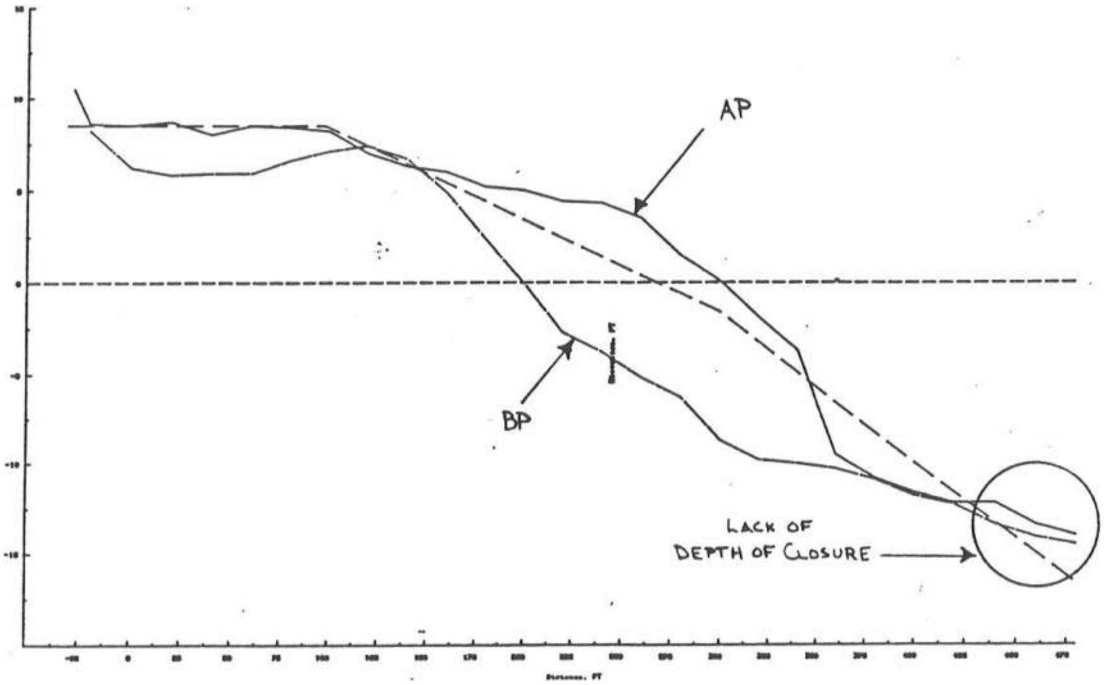

Figure 29: Profile Showing Lack of Depth of Closure

assuming total profile readjustment to the equilibrium profile. In other words, this step determines how far the beach will be expected to widen given a certain volume of fill. So once at equilibrium, the nourished beach will be expected to have a width increase of R_T. In this calculation, R is treated as an accretion and not a recession. In a sense, the reverse of Step (3), where area/volume losses were estimated from beach recession, is carried out. Here, beach widening is estimated from area/volume gains (i.e., beachfill). At this step, a check can be made to determine if the beach profiles have reached equilibrium. It is expected that after only 1-1/2 months since the beachfill was placed, the profiles would not yet have reached their equilibrium state. Therefore, all of the net changes in beach width from before placement on November 26 listed in Table 8 should be greater than the R_T values listed in Table 12, if the calculations are accurate. By examining these two tables, it is found that this is indeed the case except for the first two profiles where the net change is only slightly under the R_T values. It then can be assumed that as of November 26 the beachfill had not yet reached its equilibrium profile.

Step (5), the final step, is where the actual lifetime of the beachfill is computed. The lifetime is estimated by simply dividing the total width added by the beachfill, which was calculated in Step (4), by the expected recession rate for the beach. Table 12 lists the lifetimes of beachfills for various recession rates and depths of closure. This data is also plotted in Figure 30. These calculations were done using the following values which were calculated earlier:

$$V = 325,573 \text{ yd}^3$$
$$L = 6000\text{ft}$$

R_H	d_c = 20 ft			d_c = 25 ft			d_c = 30 ft			d_c = 35 ft		
(ft/yr)	A_E (yd^3/ft)	R_T (ft)	Life (yrs)	A_E (yd^3/ft)	R_T (ft)	Life (yrs)	A_E (yd^3/ft)	R_T (ft)	Life (yrs)	A_E (yd^3/ft)	R_T (ft)	Life (yrs)
1.0	1.06	50.96	50.96	1.25	43.41	43.41	1.44	37.81	37.81	1.62	33.49	33.49
1.43	1.06	50.96	35.64	1.25	43.41	30.36	1.44	37.82	267.44	1.62	33.49	23.42
1.64	1.06	50.96	31.07	1.25	43.41	26.47	1.44	37.81	23.05	1.62	33.49	10.42
1.7	1.06	50.96	29.98	1.25	43.41	25.53	1.44	37.81	22.24	1.62	33.49	19.70
1.9	1.06	50.96	26.82	1.25	43.41	22.85	1.44	37.81	19.90	1.62	33.49	17.63
2.0	1.06	50.96	25.48	1.25	43.41	21.71	1.44	37.81	18.91	1.62	33.49	16.75
2.95	1.06	50.96	17.27	1.25	43.41	14.72	1.44	37.81	12.82	1.62	33.49	11.35
3.0	1.06	50.96	16.99	1.25	43.41	14.47	1.44	37.81	12.60	1.62	33.49	11.16
3.2	1.06	50.96	15.93	1.25	43.41	13.57	1.44	37.81	11.82	1.62	33.49	10.47
3.8	1.06	50.96	13.41	1.25	43.41	11.42	1.44	37.81	9.95	1.62	33.49	8.81
4.0	1.06	50.96	12.74	1.25	43.41	10.85	1.44	37.81	9.45	1.62	33.49	8.37
5.0	1.06	50.96	10.19	1.25	43.41	8.68	1.44	37.81	7.56	1.62	33.49	6.70
6.0	1.06	50.96	8.49	1.25	43.41	7.24	1.44	37.81	6.30	1.62	33.49	5.58

Table 12: Lifetime of Beachfills for Various Recession Rates and Depths of Closure

$$A_F = 54.26\text{yd}^3/\text{ft}$$
$$B_{avg} = 8.75\text{ft}$$

Using Figure 30, the lifetime of the beachfill, using any of several estimates of the recession rate and depth of closure, can be determined. Using the d_c values obtained by studies listed in Table 11 andR_H values obtained in Table 9, lifetimes could vary anywhere between 8.81 - 35.64 years.

Using the average values of d_c = 28 ft and R_H = 2.75 ft/yr, a probable lifetime of this beachfill using this method would be approximately 16 years.

Figure 30 shows, as is obvious, that higher recession rates create shorter beachfill lifetimes. Also notice that higher d_c values at a given recession rate decrease the calculated lifetime. In viewing Figure 27, this becomes clear since the rectangular shaded region, which corresponds to the eroded area, becomes taller when d_c is increased, thus increasing the area for a given R. Also note that increasing B would serve the same purpose. The effect of changing d_c (or B) on the calculated lifetime of the beachfill decreases with increasing R. Thus, as you increase the recession rate, R, you will reach a point where the $(B + d_c)$ term no longer dominates the lifetime expectancy of the beachfill, but instead is dominated by the recession rate approximation. Therefore, in using a relatively low recession rate approximation, say, less than 1.5 ft/yr, the lifetime expectancy is very critical of the d_c value chosen. On the other hand, if a relatively high recession rate is chosen, say greater than 4.0 ft/yr, the lifetime expectancy varies relatively little with changing d_c values. Therefore, the recession rate R dictates how accurate the d_c value used should be.

3.2 Lifetime Based on Volumetric Erosional Rates

In this section, the lifetime of the beachfill is estimated by using historical volumetric erosional rates for the Delaware coast. This method is a somewhat simplified version of the method using recession rates. The idea behind both ideas is essentially the same: estimate how long it will take the beachfill sand to leave the area using known recession rates of the past. The equation used in this section is as follows:

Beachfill Lifetime = V/EL

where V = total volume of fill (yd^3)
E = volumetric erosional rate per foot of beach (yd^3/ft/yr)
L = length of beachfill

Here, as shown, the idea is to simply calculate how much sand historically leaves the area and then determine how long the volume of sand in the fill can be expected to last. As shown

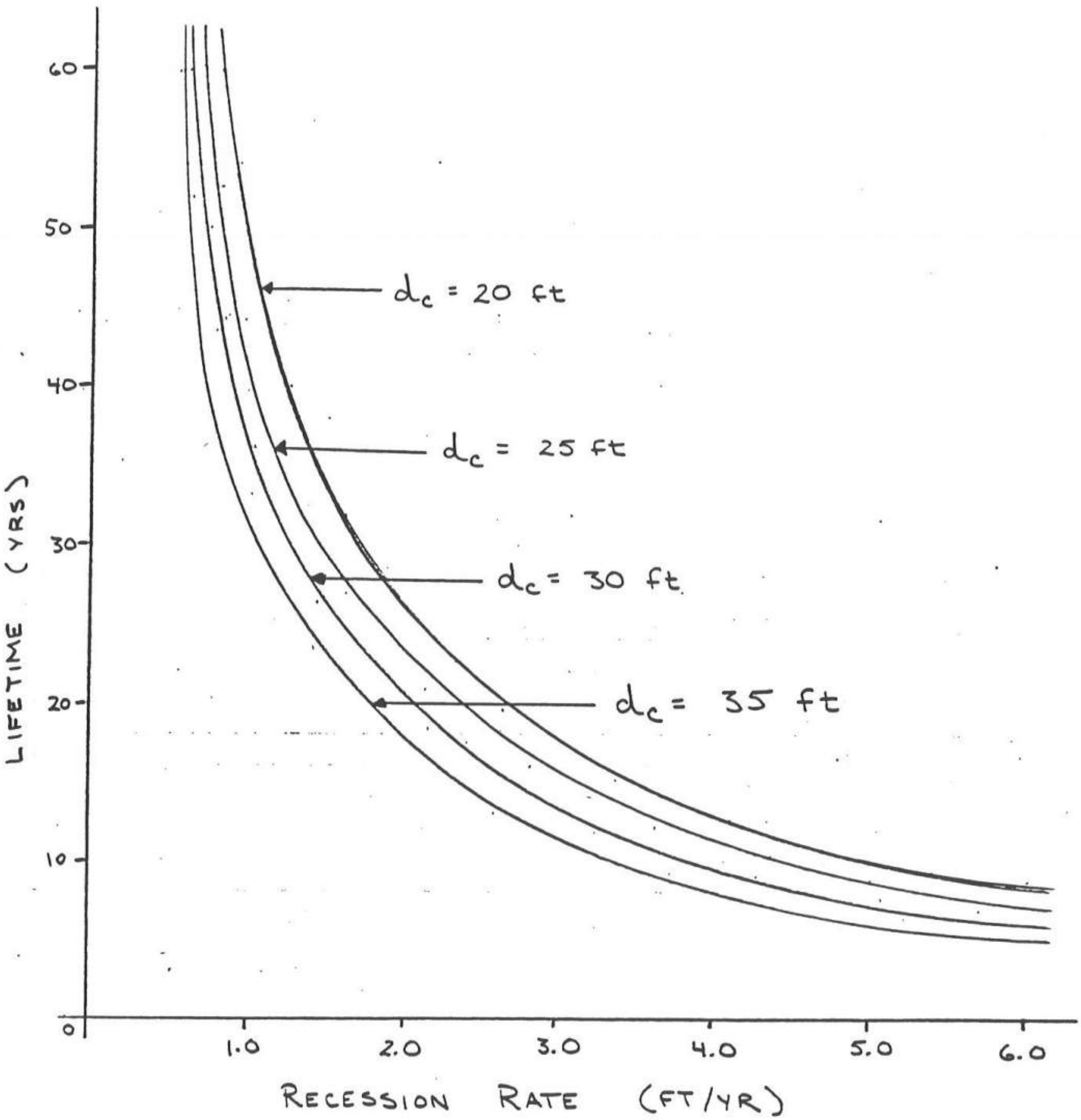

Figure 30: Beachfill Lifetime vs. Recession Rate ($d_c = 20, 25, 30, 35$ ft)

in the previous section V=325,573 yd^3 and L = 6000 ft. Historical volumetric erosional rates for the Delaware coast, especially in the Fenwick Island area, estimated in several past studies are listed in Table 13.

Many of these values listed in Table 13 can be discounted. The USACE study of 1929-1954 took place too far in the past. 1.77 yd^3/ft/yr is too low, remembering that it is believed that the erosional rate in Delaware's southern coast has accelerated in the past 10-15 years (Dalrymple, Mann 1985). The USACE study 1954-1964 which estimates the erosional rate at 8.21 yd^3/ft/yr is probably too high. The reason for this is that this study includes the entire area south of Bethany to the DE/MD line. Therefore, the York Beach area, which has a higher erosional rate than Fenwick Island would be averaged in (COER 1983). Because this value includes areas with higher erosional rates than those concerned, it would not be accurate to use this value.

The COER studies are more appropriate since erosional rates are given for more specific areas along the Delaware coast. From the COER study, erosional rates more indicative of the Fenwick Island area are available. The COER study is also very recent, 1964-1982, so these values are still relevant. COER felt that the values obtained using profile extensions were grossly too high, and that the erosion rates obtained using depth adjusted profiles were too low. The reason these two techniques were used in the first place was that the profiles provided to COER by the Corps of Engineers were not sufficiently accurate. COER suggests that the most accurate erosional rates are probably the values obtained without using either technique. Thus, considering all factors, such as time of the study, location of the study, and recommendations of the study groups, the 6.78 yd^3/ft/yr and 6.30 yd^3/ft/yr erosional rates determined by COER are probably the most accurate. Because both of these erosional rates were computed using neighboring profile lines in the vicinity of Fenwick Island, an appropriate volumetric erosional rate for Fenwick Island would be an average of the two equal to 6.54 yd^3/ft/yr.

The erosional rate estimated by Dalrymple and Mann (1985) of 3.6 yd^3/ft/yr may also be appropriate. In this study, the erosional rate was calculated using littoral drift values. The study is recent, 1985, and limited to the Fenwick Island area, and therefore should be considered as a possible value.

Table 14 lists several beachfill lifetimes along with their corresponding volumetric erosional rate estimates. A graph of these same values is shown in Figure 31. From this data, it is clear that as the volumetric erosional rate increases, the corresponding change in expected beachfill lifetime decreases. The lower the erosional rate estimate is, the more accurate it should be. Only slight differences in the erosional rate estimate below a certain value, say 2.5 yd^3/ft/yr, will cause large differences in the calculated lifetime. On the other hand, varying larger erosional rates cause relatively small variations in the calculated beachfill lifetime.

The erosional rates that were deemed most probable presently for the Fenwick Island area, of 6.54 yd^3/ft/yr and 3.6 yd^3/ft/yr, are both in the "safe region", i.e., where lifetime expectancies vary little with slight differences in erosion rate estimates. From Figure 31, it is seen that 3.6 yd^3/ft/yr and 6.54 yd^3/ft/yr correspond to beachfill lifetimes of approximately 15.2 years and 8.3 years, respectively. Note that the calculated 15.2 years lifetime calculation compares very favorably to the 16 years estimated previously using beach recession rates. Because of this fact, greater reliability may be assumed in using 3.6 yd^3/ft/yr as an erosional rate. However,the entire space 3.6 - 6.54 yd^3/ft/yr should be considered as possible. As stated before, 6.54 yd^3/ft/yr was obtained using profiles without reaching a depth of closure, and as shown in Table 13, by trying to compensate for this by depth adjusting the profiles,

Source	Years of Study	Area of Study	Erosional Rate ($yd^3/ft/yr$)
USACE	1929-1954	South of Bethany to DE/MD State line	1.77
USACE	1954-1964	South of Bethany to DE/MD line	8.21
COER*	1964-1982	DE/MD line to 1/2 mi north	6.78
COER*	1964-1982	1/2 mi north of line to $1\frac{1}{2}$ mi north of line	6.30
COER*	1964-1982	DE/MD line to 5.76 mi north of line	5.66 60.8 (using profile extensions) 1.91 (depth adjusted profiles)
COER*	1964-1982	DE/MD line to 1/2 mi north	1.18 (depth adjusted profiles)
COER*	1964-1982	1/2 mi north of line to 1-1/2 mi north of line	1.56 (depth adjusted profiles)
Dalrymple Mann	1983	Fenwick Island	3.6

* COER studies assume: MD/DE line is a nodal point
No sediment transport across the MD/DE line

Table 13: Historical Volumetric Erosional Rates for Fenwick Island, Delaware

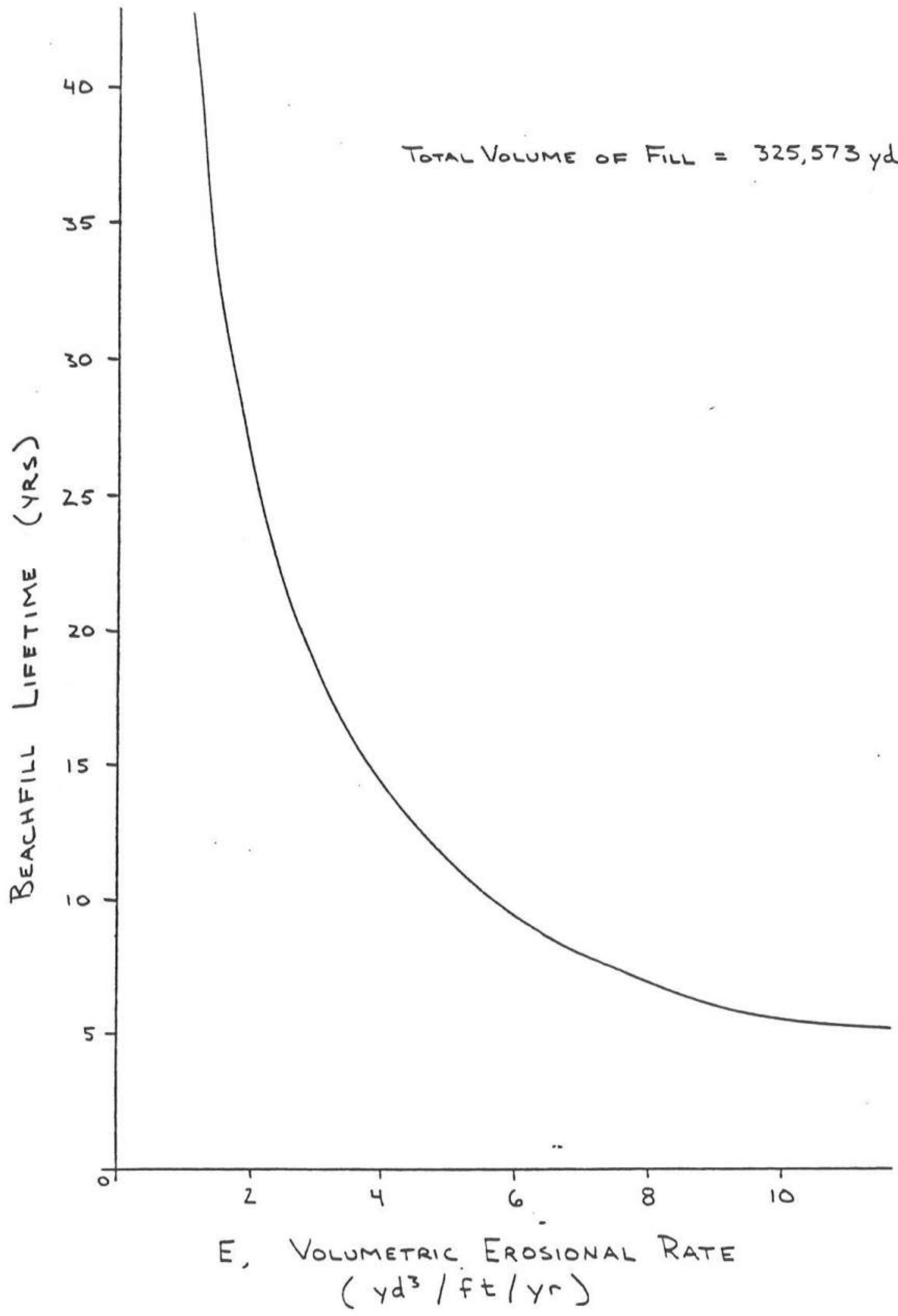

Figure 31: Beachfill Lifetime vs. Volumetric Erosional Rate

Volumetric Erosion Rate E ($yd^3/ft/yr$)	Beachfill Lifetime (yrs)	Volumetric Erosion Rate E ($yd^3/ft/yr$)	Beachfill Lifetime (yrs)
1.0	54.3	6.0	9.0
1.5	36.2	6.5	8.3
2.0	27.1	7.0	7.8
2.5	21.7	7.5	7.2
3.0	18.1	8.0	6.8
3.5	15.5	8.5	6.4
4.0	13.6	9.0	6.1
4.5	12.1	9.5	5.7
5.0	10.9	10.0	5.4

Beachfill Lifetime $= V/EL$

$V = 325{,}573\ yd^3$

$L = 6000$ ft

Table 14: Beachfill Lifetimes for Various Volumetric Erosional Rates

lower erosional rates were estimated. Therefore, the lower portion of this space, 3.6 - 5.0 $yd^3/ft/yr$, is probably most accurate, and the best estimate for this beachfill lifetime using this method is 10-15 years.

As calculated in Part II, the beachfill in its first 1-1/2 months (AD-11/26) lost 11,672 yd^3, or 3.6% of the entire volume of fill placed. But as stated, this corresponds to factors such as loss of fines and the transport of material away from the project site. This volumetric loss corresponds to an erosional rate of 12.72 $yd^3/ft/yr$, which is entirely too high to be considered as the actual long term erosional rate for Fenwick Island. Using this erosional rate, the beachfill would be expected to last only four or five years, which is much too short a time. This fact tends to support the idea the beachfill is obviously not yet at its equilibrium shape. The beach is still in a process of redistributing the sand in a manner to reach the equilibrium that existed before the fill was placed.

4 Conclusion

Many factors help determine the lifetime of a beach nourishment project. Four factors discussed in this report may be the most influential: beach equilibrium profiles, beach fill sediment quality, shape and quantity of the beachfill. Beach equilibrium profiles deal with on-offshore sand transport. The profile of a newly placed beachfill will adjust to reach its natural equilibrium profile. Generally, this is done by the transport of sand offshore, producing a milder–sloped beach. Beachfill sediment quality is concerned mostly with the sand size placed. The fill sand should be at least as coarse, if not coarser than, the native sand. Finer material is more unstable and erodes at an accelerated rate. Though more stable, the coarser the sand used, the steeper the nourished beach will be. The shape of a beach nourishment project affects the beach's planform evolution. A beachfill tends to spread–out along the coast with time. The planform, which often can be idealized by a rectangular shape, smooths out to somewhat of a bell-shape. Thus, the ends of a project tend to erode much more quickly at first. Finally, the longer and bigger the project is, the longer it would be expected to last.

There is no easy way to evaluate the performance of a beachfill. Any simple equation developed to perform such a task is over- simplifying the matter. There are too many environmental and engineering factors to be considered , which can not be contained in a short equation relating the volume of fill placed and the project's lifetime. Further, the evaluation of the performance of a beachfill can not be properly carried out until an extended period of time has elapsed after the fill was placed. This time span is on the order of five to ten years. Premature evaluations often lead to hasty conclusions, which with the proper knowledge can often be repudiated. Erroneous evaluations of performance often occur by not considering the adjustment of the fill material to its equilibrium state. Often sand is considered gone from the beach forever when it was never really "lost", but has moved offshore to fill the deeper parts of the equilibrium profile. A final consideration which does not benefit the area to be nourished is the fact that the nourished material is eventually moved along shore to other beaches. This alongshore transport does nourish the neighboring beaches, which should be considered in benefit/cost studies.

On January 27, 1989, we inspected the Fenwick Island beach nourishment project site, with DNREC representatives. At this time, it was expected that most changes would be related to equilibrium adjustments. The beachfill seems to be performing as expected. Some of the fill sand was being transported seaward to reach an equilibrium profile, thus accounting for the initial beach width losses. The new coarser fill sand also produced a somewhat steeper beach than existed before the project took place. The coarser fill sand, which can be identified by its reddish color, has spread northward of the project limits by several hundred feet. This northward transport of sand, due to the beach planform evolution and the predominant wave direction during this period of time, could prove beneficial to the Fenwick Island area since sand is now being eroded from the Ocean City project onto Delaware beaches. This sand from Ocean City could be the reason that the initial decrease in the nourished beach's width appeared less than expected. When finally reaching equilibrium, the beachfill should add approximately 43 feet to the pre-nourished beach. As of January, however, the added width , approximated using known markers of old water lines, appeared, in certain locations, to be still almost twice the expected 43 feet.

In predicting the lifetime of the Fenwick Island beach nourishment project, we relied on historical data recorded for this area. Too little time has passed since the completion of the project to enable us to draw any conclusions about the project's performance or expected lifetime based on the limited site-specific data available to us at this point. There is no evidence, however, that the lifetime expectancies calculated using historical data are not accurate. From our calculations, the Fenwick Island beachfill could ideally be expected to last approximately about 15 years. However, since historical data were used, several assumptions were made: (1) erosional and recessional rates for Fenwick Island will remain identical to those in the past (thus assuming the wave climate remains similar), (2) the fill sand is identical to the native sand (thus maintaining an identical equilibrium profile), and (3) the storms experienced by the project during its existence will be no more severe or more frequent than what would be expected for this area in a similar span of time. These are fairly big assumptions, but not unrealistic. One must also consider the fact that the fill sand is coarser and thus more stable than the native sand, and, at least at this time, it appears that sand is migrating northward from Ocean City into Fenwick Island, both of which would tend to extend the project's lifetime. However, in being conservative, the expected recessional and volumetric erosional rates used in the lifetime calculation are increased by 50% to 3.54 ft/yr and 5.4 yd^3/ft/yr, respectively. This produces a conservative estimate of the lifetime of the Fenwick Island beachfill project at 10-11 years.

On the other hand, should a major storm occur soon, such as the March, 1962 storm, then there could be a catastrophic loss of fill, with a resulting curtailed lifetime. (Despite the loss of the fill project in this worst case scenario, this "damage" has to be compared with that damage the storm-induced loss of sand would have caused in the absence of the fill project.) A storm of this magnitude, however, would be a major (hundreds of million dollars) disaster for the entire Atlantic coastline of Delaware.

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