CHAPTER 89

Cape Hatteras Beach Nourishment

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Abstract

The 1973 beach nourishment at Cape Hatteras placed approximately 465,000 m^3 on the subaerial beach. Eighteen months later, about 51 percent of this material remained on the beach. During this period there were relatively few major storms, and this mild wave climate is largely responsible for this high retention. At the end of this monitoring period the beach was stable and fully capable of providing shoreline protection and recreation.

A correlation is presented relating storm erosion with the complete storm wave climate, including a post-storm period. A new parameter is defined which includes a measure of wave steepness and longshore current velocity.

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Introduction

The placement of sand as beach nourishment is one of coastal engineering's most successful techniques for the short-term arresting of coastal erosion. This practice is particularly popular when the endangered beach is primarily valued for recreation, including motel sites, piers, etc.. In these situations the use of groins, seawalls, and other alternatives is often undesirable and to be avoided when possible. Of course, the suitability of a beach nourishment plan depends upon the availability of nearby sand, as well as several legal and economic considerations.

This paper describes a recently completed beach nourishment project at Cape Hatteras, North Carolina. During an eighteen month period ending in the fall of 1973, approximately 1.25 million cu yds (956,000 m^3) were placed along a 1.5 mile (2400 m) stretch of shoreline at Buxton, North Carolina, Figure 1. This particular beach at Cape Hatteras has experienced a relatively high erosion rate in recent years. As a consequence, several different coastal engineering schemes have been tried, including groins, sand bags, and two previous nourishment projects. Although some of these projects have had limited success, the beach has continued to erode, necessitating this latest project. This paper describes the scope of the project, and the condition of the beach eighteen months after its completion. We have included the beach volume changes, the observed wave climate and the frequency and dimensions of the severe storms during this period. Finally, we present some preliminary thoughts on how these data can be used in developing a rationale for the prediction of nourishment retention.

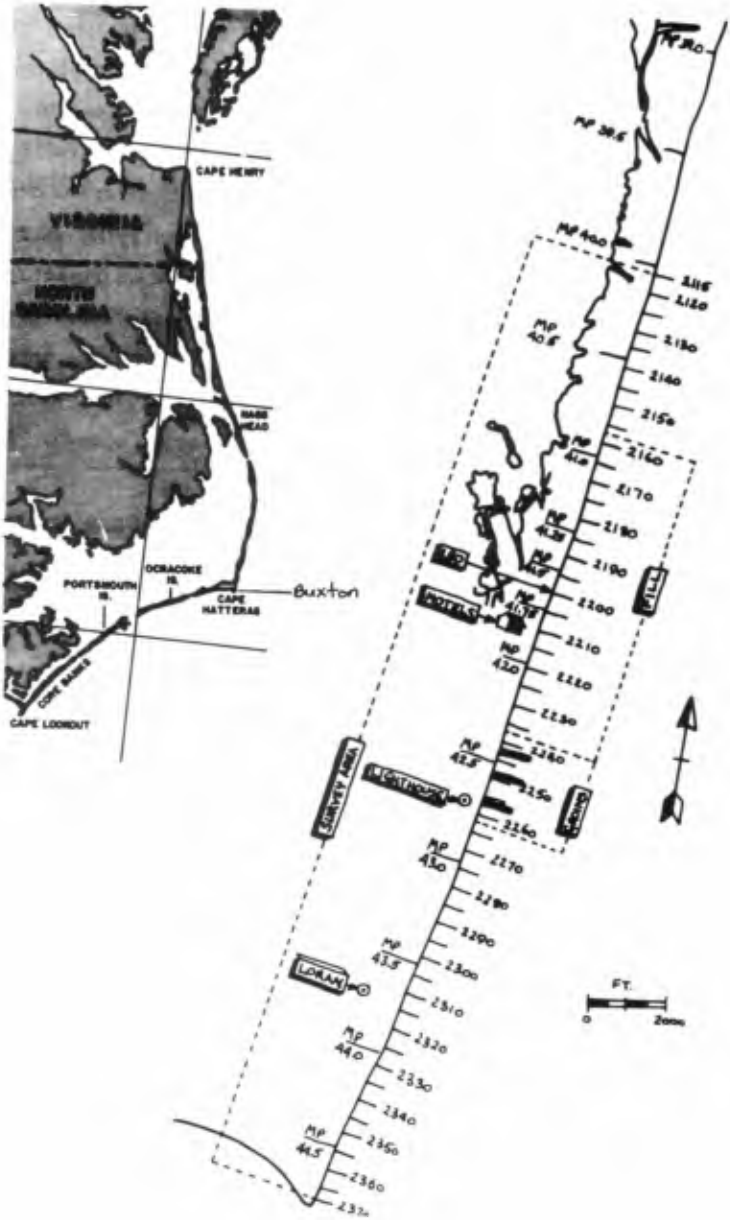

Figure 1 Location map and project dimensions

Project Description

Cape Hatteras is well known for its dramatic series of barrier islands and their beaches, as well as the large waves and severe storms which frequent them. Most of this shoreline is included in the Cape Hatteras National Seashore, as is the beach nourishment site at Buxton, on Cape Point. The fill area is located on the northern side of Cape Point, where Hatteras Island makes an abrupt change in orientation, turning to the west, Figure 1. The predominant longshore drift on the northern side of the point is to the south, in part forming this classic spit feature. This spit provided an excellent source of fill material, being both nearby and similar in texture to the beach sand. The nourishment sand had a mean diameter of .37 mm, and the area to be filled a diameter of .38 mm.

A borrow pit was excavated at the spit and the material was pumped 4 miles (6400 m) to the north. At the completion of the dredging and pumping, the borrow pit was approximately 2500 ft (762 m) by 1000 ft (304 m) with an average depth of 15 ft (4.6 m). There was no connection with the ocean initially, but an inlet cut into the southwest side at a later date and has remained open.

The fill material was placed along a 1.5 mile (2400 m) segment of shoreline. The dredge pipe was located so that the discharge was immediately above the mean high water line, with no effort made to shape or bulldoze the sand into a designed profile. In general, the nourishment resulted in an increase in subaerial beach width of roughly 250 feet (76 m) along the 1.5 mile (2400 m) beach, Figure 1. This material was intended to provide some immediate shoreline protection to the lighthouse, Naval Station, and public and private property. To a limited extent, this goal was accomplished, and the previously eroded and narrowed beach at Buxton was restored to a width providing more shoreline protection and increased recreation.

In order to assess the impact and performance of the nourishment project, a program of field studies was initiated by the National Park Service. This monitoring program included frequent surveys of the beach, portions of the nearshore bathymetry, the borrow pit, as well as daily wave climate observations. Dolan, et al. (1) summarize this data for the period from the project beginning to completion of pumping. Fisher, et al. (2) report on the survey results for the succeeding 18 month period. In addition to the measurement of volume changes, an analysis of the ecological impact of the fill material on the native beach was undertaken, Hayden and Dolan (3). Their study suggests that there is no significant damage to the beach ecology as a result of the fill activities.

As with many coastal engineering projects, the measurement of the wave environment proved to be one of the most difficult problems in the monitoring program. The nearest wave gage is 60 miles (97 km) north of the fill area at Nags Head. The wave conditions at the site were estimated according to the LEO, Littoral Environment Observation Program, as developed by the Coastal Engineering Research Center, CERC, Bruno and Hipakka (4). The LEO program includes the daily observation of wave period, angle and height of breaking, as well as a simple estimate of the longshore current velocity. These wave observations suffer from the usual symptoms of non-instrumentated data collection, nonetheless, they did provide an important reference in documenting significant changes in the wave climate. In particular, they enabled us to observe the change in wave conditions associated with storm systems.

The survey program included the borrow pit, the beach and the offshore. The latter two areas included the immediate fill area as well as adjacent areas to the north and south, for a total of 4.5 miles (7200 m). The entire borrow pit was surveyed once during the study period, and the southern end was surveyed five additional times, when possible change was suggested. The offshore was profiled with a Raytheon Fathometer a total of five times during the 12-month period discussed here. Unfortunately, the survey vessel was unable to cross the inner bar, and therefore the beach profile could not be extended out to the Fathometer profiles. The data for both the borrow pit and offshore are not presented here.

The subaerial beach was surveyed bi-weekly as well as immediately after a storm. Fifty-three survey stations were established on 500 ft (152 m) intervals from Mile Post 40.0 to Cape Point, Figure 1. Nine of these stations were north of the fill area, 16 in the fill area, and 28 to the south. The profiles were made with level and rod, and extended from a project baseline on the backshore into the swash to the mean low water level.

Figure 2 illustrates the changes at three of these stations, one in the fill area, and one both north and south of the fill. Station 2200 is located approximately in the middle of the nourishment area, it also is the site of the LEO wave observations. The post pumping profile, September 1973, clearly shows the increase in beach width with the additional material, at this site, over 300 ft (91 m). The depression landward of the beach crest is a result of the decision not to shape the fill material or otherwise attempt to develop a predetermined beach profile. At this particular site, this depression was within the National Seashore boundaries. Further to the south, the resulting depression was within private property, and

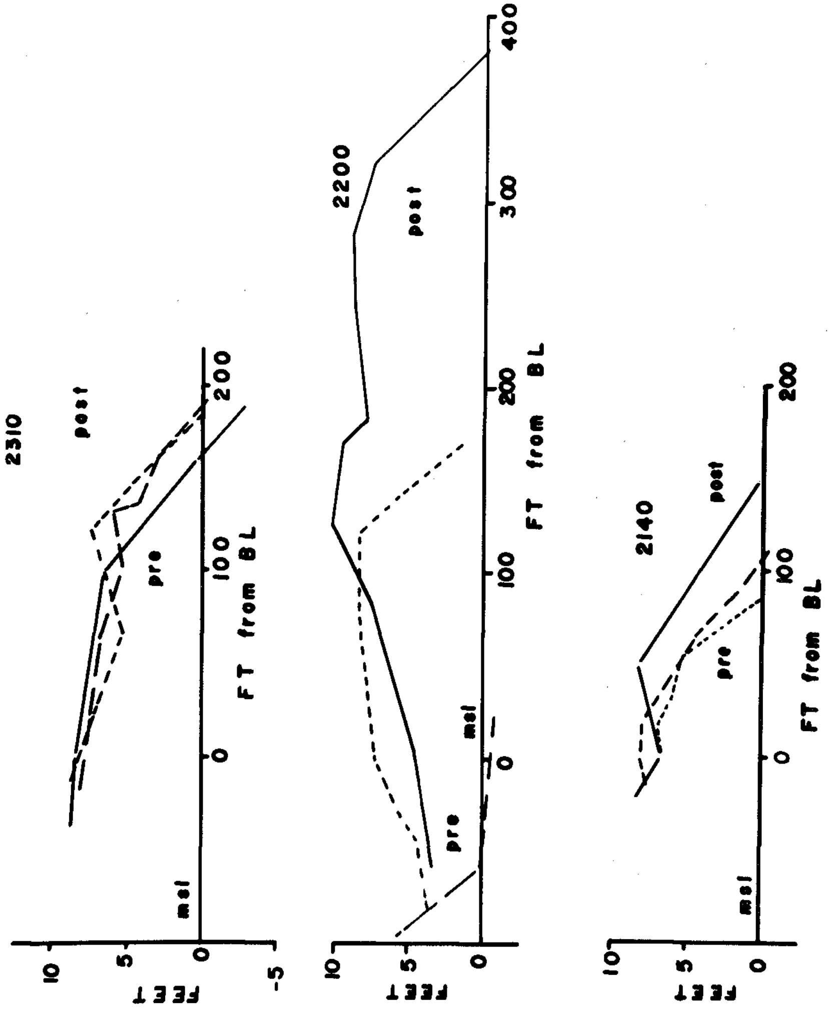

Figure 2 Subaerial beach profiles

thus there was no intentional placement of fill outside of the National Seashore. The profile for February 1975 at this same station illustrates the extent of subaerial beach erosion during this period. The 50 per cent decrease in beach width is typical of the fill area, with the bulk of the material transported offshore, as evidenced by the relatively small change in the dimensions of the landward depression.

Station 2140 is one mile (1600 m) north of station 2200, and is about .5 mile (800 m) north of the limits of the nourishment area. There was a relatively small increase in beach width just after the completion of nourishment, and a more recent erosion, with only a modest net increase in width by February 1975. The beach to the south of the fill area, is illustrated by station 2310, about one mile (1600 m) south of the fill area. Again, there is only a small net change in beach dimensions outside of the fill area.

Wave and Storm Climate

According to the record from the CERC wave gage, the annual mean wave height along Cape Hatteras is the largest for the mid-Atlantic coast. The gage at Nags Head, 60 miles (97 km) north of Buxton has a mean value of 3.0 ft (.9 m), CERC (4). Our LEO observations covered the period from April 1974 to February 1975, and were made at station 2200, 3.4 miles (5.4 km) north of Cape Point, Figure 1. The mean wave height from this data is 2.2 ft (.67 m), the mean period is 7.9 sec, and the mean longshore current is approximately zero. This latter parameter does not accurately reflect the net longshore drift, which is clearly from the north, towards the point. This low net current magnitude does suggest that large wave conditions, i.e., during storm periods transport the bulk of the littoral material. This observation is consistent with the literature, including the discussion presented in the Shore Protection Manual, CERC (5).

Figure 3 illustrates a portion of the LEO data, including the wave period, longshore current velocity squared, and the square of the wave height. Of particular interest in this data are the episodes of high waves and large currents, both from the north and the south. These dates are associated with storms, although the correlations are not as high as one might expect for this coastline. It is difficult to assemble a reasonable model for wave observations and storm intensity when the available data is this limited. However, by simply using a hindcast deep water wave height, one can gain a limited feeling for this system.

The bottom graph on Figure 3 is the SMB hindcast deep water wave height H_o for all storms with H_o greater than 5 feet (1.5 m). This technique, Bretschneider (6), depends upon the available meteorological observations for the estimation of the storm fetch and duration, as determined from the synoptic weather charts. Figure 3 shows the storms to be generating the larger waves and currents, although there is some noise in the data. A notable exception occurs during the period from October 19th to the 21st. In fact, a small low pressure did move rapidly up the coast during this period, but its deep water waves were only hindcast to be 4 ft (1.2 m). This event helps to dramatize the weakness of this simple model. Although the storm's deep water waves were relatively small, its LEO waves were the same magnitude as some of the larger events.

As stated above, the mean net longshore current is almost zero, although the shoreline geometry indicates significant longshore sediment transport to the south. Of the larger storms, all but one had a longshore current towards the south, the exception being the early December storm.

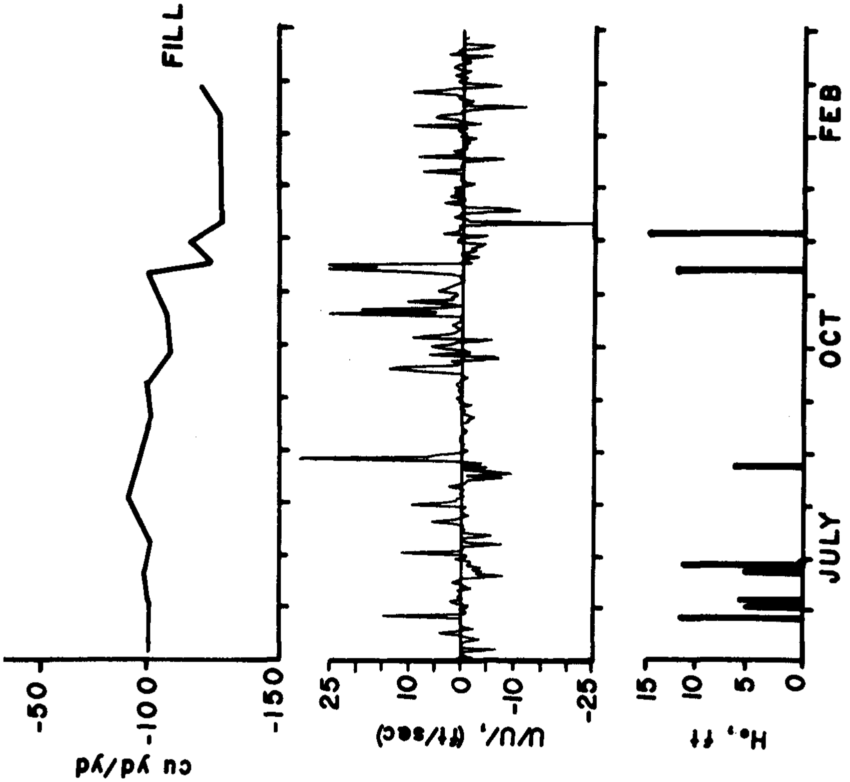

Figure 3 Wave and storm climate

This storm developed off of the South Carolina coast and maintained its strongest winds while still south of Cape Hatteras, hence the south to north current direction. This direction, although followed for approximately one half of the LEO observations, is unusual during periods of high wave energy. It is probable that this strong northerly flow was in part responsible for the overall impact this storm had on the subaerial beach volume change.

For the observation period from April 1974 to February 1975, there were ten storms with deep water waves hindcast greater than 5 ft (1.5 m). As will be discussed in the following section, only a few of these storms had any significant impact on the nourished beach. In terms of storm frequency, 1974 was a relatively mild year for Cape Hatteras. According to Dolan and Hayden (1) this section of the mid-Atlantic coast averages about 34 storms per year, whereas 1974 had a total of only twenty.

Nourishment Retention

From June to September 1973, approximately 1.25 million cu yd (956,000 m^3) of fill were pumped. Using surveys made immediately preceding and following the completion of pumping, the volume of fill which contributed to the accretion of the subaerial beach has been calculated. This data fails to account for the material which was washed into the inshore zone, which must have been a large percentage of the original fill volume. The lack of data in this zone because of the difficulty of surveying in the breakers, is an obvious handicap to our computations of fill retention and overall project performance. The following discussion and analysis, limited to the beach above the mean low water level, must be recognized as only a portion of the complete sand budget.

Table 1 presents the net volume of sand accumulated at each of the 16 stations within the fill area. The total for this area was 646,667 cu yd (494,442 m^3), an average gain of 243 cu yd/yd (203 m^3/m). During this same period, stations to the north and south of the fill area accreted an average of 14 cu yd/yd (12 m^3/m). Using this mean value outside the fill area as an estimate of natural deposition throughout the study area, we have assumed the mean gain due to fill was 229 cu yd/yd (191 m^3/m) between stations 2165 and 2240, and the total deposition above MSL of 608,480 cu yd (465,243 m^3), or 49 percent of the material pumped. The remaining material was deposited below sea level at each station.

In terms of beach restoration and protection, the volume accumulated below MSL is an important component of the overall nourishment project. This material, the bulk of which was presumably retained within the nearshore zone, provides a source of material to the beach, and helps maintain the inner bar system and hence wave energy dissipation. Because of the inability to accurately survey the nearshore, no data is available to analyse the volume changes in this zone.

The remainder of this retention discussion deals with the volume of nourishment sand on the beach itself, above MSL. Figure 4 shows the volume changes along the entire project, both for before and after pumping, and from completion of pumping to 18 months later. The significant area of change is within the fill area itself. Eighteen months after the completion of the pumping, 51 percent of the nourishment sand remained in place in this area, or 307,343 cu yd (235,000 m^3).

Outside of the fill area the changes have been relatively small. To the north, there has been no significant erosion or accretion. South of the nourishment area there has been a small amount of accretion.

TABLE 1

VOLUME OF MATERIAL REMAINING ON THE

SUBAERIAL BEACH UPON COMPLETION OF PUMPING

Station	Cu Yds/Yd
2165	63
2170	160
2175	270
2180	250
2185	250
2190	210
2195	330
2200	350
2205	230
2210	280
2215	270
2220	300
2225	240
2230	290
2235	260
2240	27

Mean accretion in fill area:	243 cu yds/yd
Mean accretion outside fill area:	14 cu yds/yd
Net accretion of fill:	229 cu yds/yd
Total accretion:	608,480 cubic yards
Total pumped:	1,250,000 cubic yards
Net percent of fill material retained on subaerial beach:	49 percent

Inasmuch as the longshore drift during high wave conditions is towards the south, we can reasonably assume that this accretion is derived in part from the nourishment area. There are three short groins just south of the fill area. The volume change within the groin field both during and after nourishment has been rather small. The impression one gets from Figure 4 is that this groin field is behaving like a filter in that it appears to have dampened the volume changes immediately downdrift from the fill area.

Figure 5 shows the post-fill volume changes over the 18 month period of our surveying. The shoreline is divided into four increments, north, fill, groins, and south, and the combined changes are also shown in this figure. Again, it is clear that the only section undergoing significant change during this period is the fill area itself. And in fact, even the fill area appears relatively stable with the exception of the loss in early November. This large loss of sand occurred at all four of the project areas, although it was most severe within the nourished beach. From Figure 3 we can relate this large volume of erosion to a single November storm, with H_o of about 10 ft (3 m). This figure presents the volume change for the combined project area as well as the hindcast wave height and longshore current. It is apparent that this relatively large November storm, with its strong north to south current is responsible for the erosion. However, there are two other events illustrated on this figure which tend to confuse the correlation. During mid-October, a smaller storm generated longshore currents just as strong as the November event, but the beach accreted. And in early December, an even larger storm, H_o > 15 ft (4.6m) caused considerably less erosion than the November storm. Thus, from this series of events, we are presented with a rather

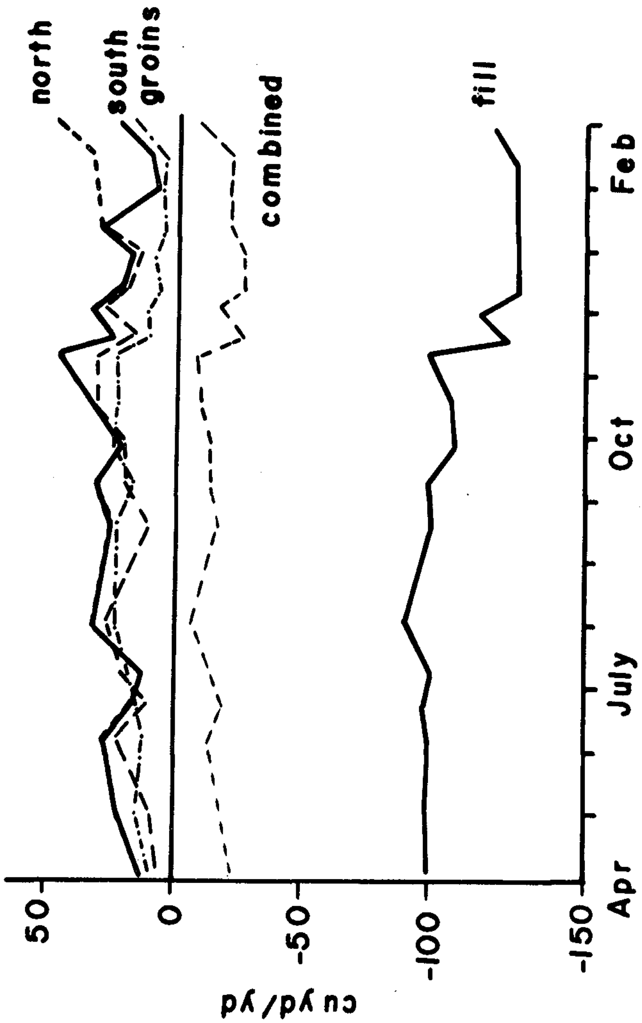

Figure 4 Volume changes for project period

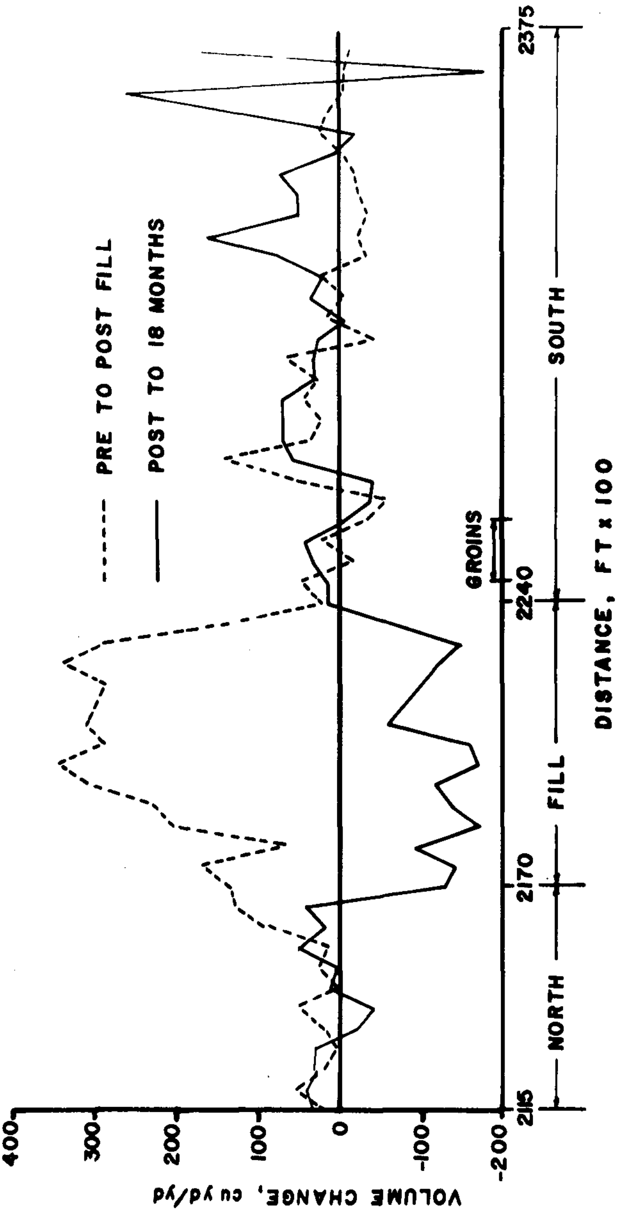

Figure 5 Pre and post fill volume changes

complex set of relationships regarding the impact of individual storms on the beach.

There is one interesting difference between these three storms and their associated beach changes which we feel is notable. The longshore drift immediately after the November storm was from the south whereas the post-October drift was from the north. If we consider the principle source of sand for this beach to be from the north, as suggested by its morphology, then it follows that a post-storm wave climate generating a drift to the south will be an ideal condition for beach recovery. Conversely, a post-storm drift from the south will not provide the beach with an equivalent quantity of sand. In addition the characteristics of the post-storm waves, i.e., their period, steepness, etc., should also play a role in this recovery process.

As a preliminary analysis of this hypothesis, we have made a simple correlation of the post-storm waves and drift. A dimensionless parameter, S, has been defined which includes the fall-time parameter $\frac{H}{V_f T}$ with the square of the longshore current normalized by the fall velocity,

$$S = \left(\frac{H}{V_f T}\right) \left(\frac{U}{V_f}\right)^2$$

As stated above, our assumption is that the impact of an individual storm is a function of the post-storm drift direction, i.e., from a source or sink of sand. To evaluate this assumption we have correlated the surveyed beach volume changes with this parameter S, assigning the sign of the post-storm drift.

$$\hat{S} = \overline{S} \text{ sgn } (U_{ps}),$$

where $\bar{S}$ is the mean of S over the survey period. Figure 6 shows the correlation of $\hat{S}$ with the mean volume change ΔV for the study period. The solid dots are for surveys which bracketed storms. There appears to be a high correlation, suggesting that we should take a serious look at this assumption and its implications for evaluating storm impact. We are presently analysing this data in this context, and will present our results in a forthcoming paper.

Conclusions

The success of a beach nourishment project cannot reasonably be measured in terms of the percent retention of material at a specified period after placement. There are too many political and social questions which must be included in the final appraisal. We have not looked at these problems, and will not comment on them. However, if we restrict our view to the impact of the fill on the subaerial beach, we can comment on the measured changes.

Eighteen months after pumping, about 50 percent of the subaerial nourishment was still in place. In as much as this period included a relatively mild storm climate, we consider this volume of sand to be greater than what might have been predicted. The remaining sand is providing a wide beach for recreation as well as some additional protection to the various public and private structures. The immediate threat of storm damage present prior to the nourishment has been, and continues to be alleviated.

The problem of designing future fill projects, and predicting their project life has been addressed in this paper in the context of identifying the impact of individual storms on the beach. We are presently able

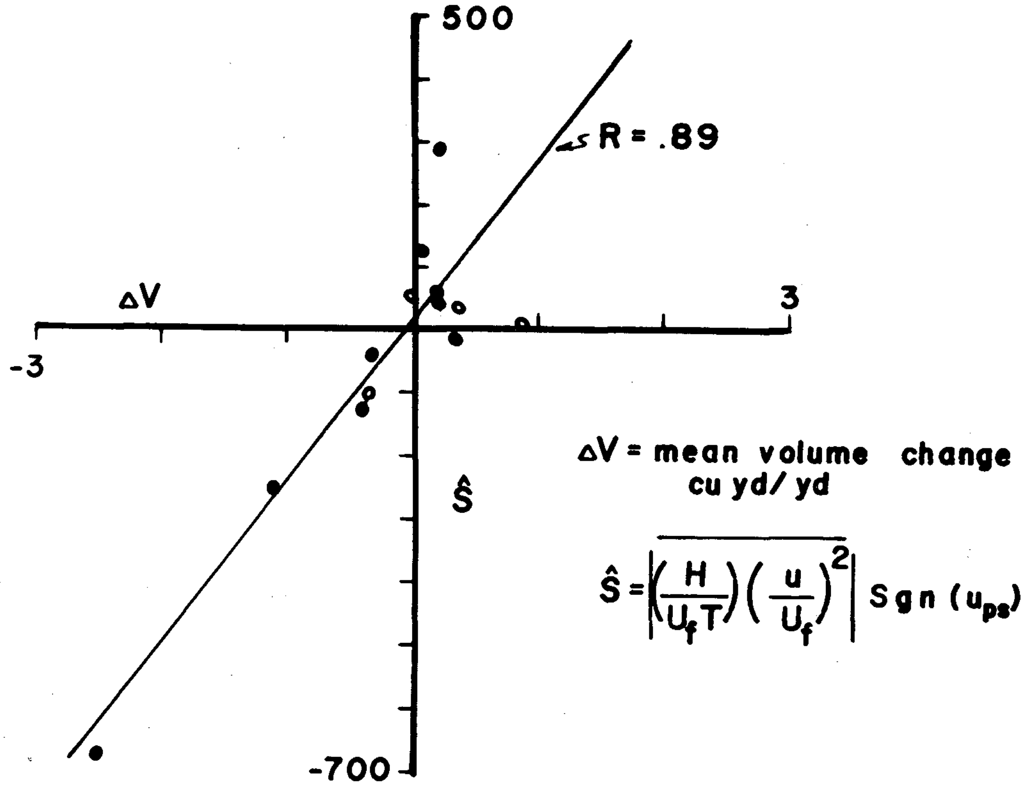

Figure 6 Correlation of volume change and wave conditions

to make crude predictions of storm and wave climates for a given stretch of shoreline. The problem is in estimating the erosion or accretion resulting from this simulated climate. Our analysis at Cape Hatteras suggests that in attempting to develop a relationship between storms and volume changes, that the post-storm wave conditions may be important. The preliminary results presented here indicate a strong correlation between volume change and direction of post-storm littoral drift.

Finally, we note that the analysis of aerial photography presented at the conference is being prepared for separate publication, as space limitations precluded its inclusion in this paper.

Acknowledgements

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