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REPLY

Reply To: Houston Discussion of Pilkey (1990) and Leonard *et al.* (1990) [This issue, pp. 1023–1036]

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ABSTRACT

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This paper replies to Houston's analysis which falls short of his promise to discuss "the editorial PILKEY (1990) and the paper LEONARD *et al.*, (1990)." Actually, Houston's discussion is limited to one figure (Figure 2, LEONARD *et al.*, 1990). His discussion, an extremely flawed analysis, is a contrived attempt to discredit our studies. Houston incorrectly asserts that essentially all of the pre- and post-fill erosion rates in our analysis are wrong. With three exceptions, we note sources for and successfully defend the values used to construct the figure in question. Houston concludes that eleven of the twelve beaches discussed have post-fill erosion rates roughly equal to their pre-fill erosion rates. We demonstrate that this conclusion is wrong. Our study (LEONARD *et al.*, 1990) remains an important contribution to the science of beach replenishment.

INTRODUCTION

In his discussion of Figure 2 (LEONARD *et al.*, 1990), James R. Houston makes two major points: our work in the pre-fill/post-fill behavior analysis is extremely flawed; and his analysis finds that pre- and post-erosion rates of replenished beaches are about the same. In this reply we will examine both of Houston's points.

Houston's entire discussion focuses on a single figure (Figure 2) in LEONARD *et al.* (1990). Figure 2 consists of 11 data points and is discussed in four sentences. Nonetheless, Figure 2 provides a partial basis for one of our most important conclusions; therefore, discussion of this figure is appropriate.

INDIVIDUAL PROJECT ANALYSES

Sandy Hook, New Jersey

Houston asserts that the 1977 beach replenishment project at Sandy Hook was not a designed beachfill because the fill was emplaced under emergency conditions. Houston's assertion is inaccurate. Although the project was deemed an emergency action in an effort to protect coastal roads, the fill was placed according to a design.

Houston further attempts to characterize the Sandy Hook 1977 replenishment as a "feeder" beach. Consequently, we are given a picture of

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a "tiny finger of sand" projecting 40 m into the surf zone. Houston's Figure 1 shows that the fill was emplaced in a substantial end-around embayment. The finger of sand description seems overstated when, in fact, the beach fill was intended to smooth out the bend in the shoreline.

The fill was emplaced to prevent frequent overwash of the highway leading to Sandy Hook (NORDSTROM *et al.*, 1979). It was called "access protection" by the U.S. National Park Service. This fill was not intended as a feeder beach expected to erode rapidly and supply sand to the remainder of the 1400 m recreational beach at Sandy Hook. The fill was designed to prevent or reduce a flooding problem at a particular point.

Houston claims that the pre-fill erosion rate used in Figure 2 (LEONARD *et al.*, 1990) is flawed because "the pre-fill erosion rate should be {calculated} for the entire 1400 m," not just the 250 m stretch of the designed project. We disagree. The 1400 m figure has nothing to do with the length of this project nor subsequent projects at Sandy Hook. The 1400 m is the length proposed in a design document for a more extensive (2.3 million cu m) replenishment project. The actual length of the fill finally emplaced 5 years later was 700 m, not 1400 m.

Houston's pre-fill erosion rate of 235,000 cu m per year is too large as it applies to a stretch of shoreline more than five times the length of the 1977 project beach. Our pre-fill erosion rate calculated from data included in NORDSTROM and ALLAN (1979), agrees with the average retreat of 8 m per year (NORDSTROM *et al.*, 1979) for the South Recreation Beach.

Houston criticizes the post-fill erosion rate used in Figure 2 (LEONARD *et al.*, 1990), because storm season data were extrapolated resulting in a rate that he considers too high. Because of the rapid rate of erosion LEONARD *et al.* (1990) considered the time of emplacement to be part of the beach life, a conservative approach that will yield a relatively low loss rate. Loss rates on other beaches are generally calculated from the time sand emplacement is completed. If we calculate Sandy Hook loss rates as we did the others, we start by using NORDSTROM *et al.*'s (1979) statement: "More than ⅔ of the fill was removed in less than two months after the termination of the fill operation." Hence, about 100,000 cu m of sand disappeared from this very short beach in two months. On a per meter basis, this rate (400 m^3/m/2 months, *i.e.* 100,000 cu m in 2 months) is a startling figure, and is one of the highest loss rates (pre- or post-fill) that we have seen on a U.S. East Coast beach. Considering the conditions at the time of emplacement, our post-fill estimate of 270,000 cu m annual loss is neither unreasonable nor too high.

We are criticized for our methods because we extrapolate a rate measured during the winter to an annual rate. Our manipulation of the data is the same as that of other workers including Houston. Houston goes to great length, using an Atlantic City example, to criticize us for using extrapolation, a method he later employed to obtain his Atlantic City numbers (see discussion of Atlantic City in this reply). PHILLIPS *et al.* (1984, p. 5) uses a similar approach for Sandy Hook, although extrapolation was through only 4 months. PHILLIPS *et al.* (1984) reflect local knowledge. We believe that local coastal scientists use approaches reasonable for their areas. That is, they would know if they have blundered because they are on the scene.

In summary, Houston has put up some smoke screens (emergency project; Atlantic City), changed the rules of the game (1400 m) and then declared himself the winner. Take whatever pre-fill numbers you wish, this short, highly unstable beach fill eroded more rapidly than its natural predecessor.

Atlantic City, New Jersey

Houston makes some valid points in his criticism of our analyses of Atlantic City. Yet, on the whole, his analysis is equally open to criticism. Houston's Atlantic City/Ocean City analysis further complicates an already complex issue by careless reporting on his part. Our numbers are as follows:

(1) Pre-project erosion rate—1963 replenishment—is taken directly from U.S. ARMY CORPS OF ENGINEERS (1962). Houston goes through a complicated and inaccurate summary of his incorrect assumptions of how we obtained the rate, attributing a number of major mistakes to us along the way; mistakes we did not make. It's unfortunate that despite lengthy correspondence between Houston's office and ours,

he never requested specific information about the values we reported.

(2) Pre-project Erosion Rate—1986 replenishment—is from U.S. ARMY CORPS OF ENGINEERS (1962). The data are admittedly old, but we did not locate in the published literature a more reliable figure.

(3) Post-Project Erosion rate—1963 replenishment. We are wrong. We, incorrectly, use a number from the 1970 project which is a lower loss rate than the 1963 project.

(4) Post-project Erosion rate—1986 replenishment. Our projection was premature. This project was completed just before we completed our study. We extrapolated the early loss data and obtained an erosion rate than was greater than the actual case. The mistake was not due to the source of the loss rate information. Houston chastises us for using a city engineer's estimation of beach loss. We have found that some city engineers, including the one in question, are better informed about their beaches than the local Corps Districts and can be excellent sources of data. We did not use media sources for loss rates as stated by Houston.

Houston's numbers are as follows:

(1) Pre-project erosion rate—1963 replenishment. Houston estimates this rate from values reported in MCCANN (1981), but, upon review, we cannot follow Houston's logic to the final numbers he presents. Houston's pre-project erosion rates for the 1963 and 1986 fills are based on erosion rates obtained between 1936 and 1947. This value ignores perturbations to the system caused by the construction of hard structures and emplacement of one nourishment project since 1947. Furthermore, by using these rates, Houston neglects the high erosion losses incurred after the 1962 Ash Wednesday storm, the same losses which were the justification for the 1963 project. Thus, Houston follows a procedure (overlooking immediate pre-project increases in erosion rate) for which he finds us in error in determining pre-project rates for other projects (*e.g.* Sandy Hook, Indialantic, Canaveral).

(2) Pre-project erosion rate—1986 replenishment. Our comments on the 1963 project apply here.

(3) Post-project erosion rate—1963 project. Houston's 75,000 cu m per year loss is attributed to EVERTS *et al.* (1974). The number presented by Houston was extrapolated from an 8 month loss (EVERTS *et al.,* 1974) which did not include losses from the stormy months of February and March. Again, Houston follows a procedure (extrapolation) for which he finds us in error in determining pre-project erosion rates, specifically for Sandy Hook. Ironically, in his Sandy Hook discussion, Houston employs an example from Atlantic City to make his criticism. This inconsistency marked by inaccurate and selective criticism of our methods pervades Houston's analysis and sets a distastefull tone for his discussion.

Although Houston uses information from EVERTS *et al.* (1974), he apparently chose to ignore a statement highly pertinent to the question of relative fill loss rates. "Loss rates for fill materials were much larger than loss rates of adjacent natural materials. When averaged over the fill area, the loss rates were 65 and 47 m^3/m/year respectively (1963 and 1970) or twelve and nine times the mean annual loss from the entire subaerial Atlantic City Beach." On a long stabilized and many times replenished beach such as Atlantic City, there could be no better measure of the relative behavior of fill and "natural" beach. There is no indication that the pre-1963 erosion rates on the project areas were so dramatically greater than the remainder of the island. EVERTS *et al.* (1974, p. 1383) also notes storm "losses on the nourished profile were 2 to 5 times greater than on other profile lines." We believe these points make a very strong case for rapid loss of fill relative to the natural beach. They deserve, but do not receive, mention by Houston.

(4) Post fill erosion rate—1986 replenishment. Houston's number is from a publication that came out after our work was completed. Furthermore, it is a number obtained through extrapolation. Again, Houston follows a procedure for which he finds us in error.

Ocean City, New Jersey

The source of our pre-fill erosion rate for Ocean City, 1952 is HALL (1952). It is the net rate of annual littoral transport. Discussion in HALL (1952) suggests that he considers this rate to be indicative of the erosion rate. Perhaps Houston is correct in criticizing the use of littoral drift estimates as equivalent to erosion. But his 38,000 cu m per year seems ridiculously low in light of the huge losses sustained by both the 1952 and 1982 projects. Houston finds our post-fill loss rate to be too high for this project. Yet, the rate was obtained from the same source he references for his pre-project loss rate (WATTS, 1956). WATTS (1956) cites a volumetric loss of about fifty percent of the Ocean City 1952 fill (total fill volume: 1,938,000 cu m) in only seven months. We extrapolated this value to obtain our loss rate. Similarly, large rates were observed for the 1982 fill which lost between 50 and 91% of its volume along various profiles in 5 months (FARRELL and INGLIN, 1988).

We are in agreement with Houston that the pre-project fill loss rate is less than the post-project rate.

Hunting Island, South Carolina

First the big picture. The Hunting Island beach replenishment project began in December, 1968 (WALTON and PURPURA, 1977). By the time the last beach replenishment disappeared in 1983, the beach had been replenished 4 times. A total of 2,688,000 cu m of sand was emplaced (PILKEY and CLAYTON, 1989) averaging out to 179,000 cu m of sand per year. This is very close to the estimated pre-fill erosion rate of 190,000 cu m (US ARMY CORPS OF ENGINEERS, 1964) and might indicate that pre- and post-fill erosion rates are the same. Hunting Island, however, has proved to be one of the most unstable replenished beaches on the U.S. East Coast and during the 15-year time span, the beach was completely gone for perhaps half the time between 1968 and 1983. Since we do not have information on the loss rate of the 1975 beach, we can only estimate the amount of time Hunting Island was without a nourished beach.

We do agree, however, that our 820,000 cu m per year estimate is too high for the 1969 fill. We do not agree that it is unreasonable. The 1971 fill was completely lost from the fill area in 6 months (520,000 cu m) (WALTON and PURPURA, 1977), yielding a rate close to our estimate.

Houston is incorrect in his assertion that after emplacement of the fill, "the erosion rate for the natural beach was greater than for the fill beach." According to WALTON (1977), 380,000 cu m was placed in 1969 along the 3,050 meters of feeder beach and the remainder of the sand was placed evenly along the rest of the beach. Houston may have confused the 1969 and 1971 fills. In 1971 sand was placed solely on the so-called feeder beach. Thus, at least some of the sand eroded on Houston's "natural" beach was not "natural" sand and Houston's assertion quoted above is inaccurate. In addition, Houston's accusation of a "significant error" made on our part by including "natural" beach in fill loss figures is undeserved. The erosion rate of the "natural" shoreline adjacent to a replenished beach may be significantly affected one way or the other by the groin effect of the fill sand.

On a beside-the-point note... The document reporting this project to the Congress (US ARMYCORPS OF ENGINEERS, 1964) noted (in Appendix D) that the proposed Hunting Island project "would be adequate to sustain the various erosional forces, including the long term normal wave attack and the short term wave actions and high tides associated with storms." The beach was emplaced; it disappeared very quickly and storms are blamed for the loss.

Canaveral Beach, Florida

Houston criticizes our pre-project erosion rate because he assumes that we do not take into account the increase in erosion rate due to jetty construction. The reference that we used in our analysis, STAUBLE and HOEL (1986), notes a shoreline retreat rate of 3.04 m per year, and discusses the accretion and erosion patterns as well as jetty-related changes to this shoreline reach. Clearly, STAUBLE and HOEL (1986) are aware of the effect of jetties on shoreline retreat rates. Using the *Shore Protection Manual* (US ARMY CORPS OF ENGINEERS, 1984a) conversion factor of 1 linear ft. retreat = 1 cu yd., we derived our 25,000 cu m per year. If we use Houston's factor of 1 linear m of retreat = 8.2 cu m, we obtain a pre-project rate of 84,000 cu m per year. Both of these numbers are well below Houston's post-fill loss rate.

Our post-fill erosion rate is wrong, apparently due to a typographical error. The 27,868 cu m per year value that we cited has nothing to do with Canaveral Beach. In our notes, we have a post-fill erosion rate of 124,000 cu m per year for Canaveral Beach based on a loss of 30% of the fill in 5 years.

Indialantic, Florida

This beach was replenished in 1981 with 413,000 cu m of sand emplaced by dump trucks along 2.1 miles of shoreline. Profiles taken immediately after emplacement revealed that only 195,000 cu m remained (STAUBLE and HOEL, 1986).

Houston considers our pre-project erosion rate to be in the realm of possibility but significantly too low. We believe a low number is a reasonable choice in this instance (and there are a number of possible erosion rates to choose from). STAUBLE and HOEL (1986) note that the shoreline was retreating at 1.5 m per year before 1960 and had been stable since then. HUNT's (1980) figure of 50,000 cu m per year, cited by Houston, comes from profiles taken prior to 1965; therefore HUNT's (1980) rate is higher than the actual one at the time of beach emplacement.

Houston (citing PHLEGAR and DEAN (1989) which became available as our paper was in press) discusses the highly variable nature of shoreline erosion rates for this beach. It is common knowledge that many reaches of barrier island shorelines have highly variable rates of erosion, creating an all too frequent problem for those who are planning beach replenishment.

We find Houston's discussion of the history of the Indialantic fill misleading. STAUBLE (1990), which is currently in press, is the apparent basis of this discussion. STAUBLE (1986) notes that the 1984 Thanksgiving Day storm removed the last of the replenished beach, 3 years after its emplacement. Now we are told (on the basis of a single profile) that 18% of the volume remains (STAUBLE, 1990). We would like to see this profile and its location. Is it south (downdrift) of the study area? How does one accurately determine volumes with one profile? How does one know that this material is the original replenishment sand? On the basis of this description of the beach history, Houston assumes a loss rate of 25,000 cu m per year.

We have a different interpretation of the beach's history. We accept that this fill was lost within 12 to 14 months as reported by STAUBLE and HOEL (1986). By that time, with a density of less than 26,000 cu m per km, and much of that to the south, the profile had essentially returned to the normal, more stable beach profile. Losses and gains became smaller and basically indistinguishable from the changes of the natural beach. Thus, Houston's 25,000 cu m per year is probably quite inaccurate. The actual loss rate is much higher; on the order of 90,000 cu m per year. Our post fill loss rate for this small replenished beach is probably much closer to the mark.

If one considers that 50% of the fill volume was reported to have been lost during emplacement, the fill loss rate becomes even greater. From the standpoint of those who have paid for the fill, a loss of 50% of their purchase is hardly negligible. Thus, emplacement losses should be added to post-placement losses yielding a much higher figure than that cited by Houston (or us).

Delray Beach, Florida

Houston cites PHLEGAR and DEAN, (1989), a paper published after our manuscript was in press, to show an increase in erosion rates during the 1960's as proof our number is too low. We have no argument with new information. The reference we used was a 1972 Corps of Engineers document.

Does Houston once again ignore pertinent information when he says that the pre-fill erosion rate is unknown (his Table II)? We cannot say. As for most of the other beaches discussed for the LEONARD *et al.*, (1990) Figure 2, a range of numbers is available and a choice must be made based on the best understanding possible of the natural system and of the method used to obtain the numbers. This is no more difficult for Delray Beach than for any of the other beaches.

The LEONARD *et al.* (1990) post-fill loss rate, taken from STROCK AND ASSOCIATES (1983) and STROCK AND ASSOCIATES (1984), is 90,200 cu yds per year or roughly 69,000 cu m per year. This rate or one close to it is used repeatedly by Strock in his follow-up reports on Delray Beach. Review of the sources used by LEONARD *et al.* (1990) found post-fill erosion rates ranging from 69,000 cu m per year to 84,000 cu m per year.

Houston's post-fill loss rate number is probably based on reports of 4 years of beach loss rather than 5 years as stated. At the end of the fourth year an additional fill had been emplaced.

On another beside-the-point note, Houston claims that the Delray Beach high loss rate was expected because of the fine grain size. He does not mention similarly rapid losses of beachfill at Sandy Hook and Hunting Island where the grain size was about the same as the native sand size. We have found the question of grain size in need of further examination and would refer the reader to STAUBLE and HOEL (1986) and LEONARD *et al.* (1990).

Bal Harbor, Florida

Again, Houston makes an inappropriate assumption in his discussion of LEONARD *et al.* (1990) Figure 2. Houston cites us for a too high pre-fill erosion rate; a rate not included in our analysis. A pre-fill erosion rate for Bal Harbor is listed in the appendix of LEONARD (1988), an unpublished master's thesis. Due to its questionable status, the value along with some other unused numbers has remained in the thesis appendix, despite Houston's attempts to extricate it. Bal Harbor was not included in Figure 2.

Again, Houston's analysis is contrived to discredit us. His discussion of Bal Harbor attributes numbers to us that we chose to confine to a master's thesis appendix. Houston, by relating this never-used appendix number to the Miami Beach project assumes a very large post-fill erosion rate for Bal Harbor. Now we are criticized for both a pre-fill number and post-fill number that we never used. Houston's assertion that "our" Bal Harbor post-fill erosion rate is 15 times greater than the measured rate is quite a surprise to us, because we do not have an opinion regarding the post-fill rate of loss.

Miami Beach, Florida

Houston further criticizes us for considering the Bal Harbor fill both as a separate fill and as part of the Miami Beach fill. Bal Harbour received separate nourishment in 1960, 1961, 1963–73 and 1974–75. In 1979–81, Bal Harbour and Baker Haulover Park joined with Miami Beach in the Dade County beach replenishment project (U.S. ARMY CORPS OF ENGINEERS, 1975) and became the Miami Beach replenishment project. It is, therefore, appropriate that Bal Harbor be considered both separately and together with Miami Beach.

Under the pre-fill discussion, we are again assaulted with our Bal Harbor number which, as discussed (see Bal Harbour discussion in this reply), is a number from a thesis appendix not used in Figure 2 (LEONARD *et al.*, 1990). We regret his continued attack on one, unused value. Using this number, Houston decries the fact that LEONARD *et al.* (1990) failed to recognize any inconsistency in a pre-fill erosion rate of 74.2 cu m/m per year at Bal Harbour and 1.4 cu m/m per year on either side of Bal Harbor. Even if such a contrast in rates were the case on adjacent beaches, Houston's criticism would be unjustified. In response, let us tell the story of Tybee Island, Georgia, to explain why we would not be startled by such a contrast in erosion rates (remember, though, that the 74.2 cu m/m/year is imaginary from our view).

The beach on Tybee Island, Georgia, was replenished in 1976 and quickly experienced "unexpected rapid erosion" (POSEY and SEYLE, 1980). At the end of the first year, roughly 50% of the fill material had disappeared. Prior to replenishment, the island had serious erosion problems at its northern and southern ends from which, subsequently, the replenished sand disappeared. The artificial beach remained for more than 10 years in the central area of the beach where no erosion problem existed prior to the project. Hence, the erosion rate of the Tybee Beach project varied dramatically over short distances. Examples abound of selective rapid loss of replenished beaches. Houston's implied criticism of our acceptance of dramatically different erosion rates over short distances is off-base.

The pre-project erosion rate that we used for Miami Beach is taken from U.S. ARMY CORPS OF ENGINEERS (1968), and is based on actual profile surveys taken between 1919 and 1961. Houston's pre-project rates are higher than ours, and are based on historical changes in topography, *i.e.* charts and dredging surveys, and a wave energy flux model. The beach profile technique seems a more accurate representation of pre-project behavior.

Virginia Key, Florida

The 23,000 cu m pre-fill erosion rate we used in Figure 2 (LEONARD *et al.*, 1990 is based on the "inner profiles" extending 230 m seaward to a depth of 2.4 m. Houston suggests that the long profiles extending to 5.5 m depth and giving an erosion rate of 61,000 cu m per year yield a more useful erosion rate. We chose the inner and shallow profiles because the U.S. ARMY CORPS OF ENGINEERS (1961) considered them representative. Furthermore, WALTON (1977) believes that the sand movement from the Virginia Key replenished beach occurs entirely in the shallow-water zone. He states (WALTON, 1977, p. 26), "It was thus concluded that most of the sand movement took place well within the 5 foot contour as longshore movement. On Virginia Key, this movement was believed to be south into Bear Cut which accounts for the loss of sand in the survey area."

The long profiles, employed by Houston, measure shape change in two zones of littoral sand movement, yet only the inner zone involves the beach at Virginia Key. Offshore of Virginia Key is a wide shallow platform, more than a mile wide over most of its length and typically fewer than 5 ft deep. Wave activity, hence sand movement, is concentrated on the inner beach and at the rim of the offshore platform. According to Hal Wanless (*personal communication*), events at the rim of the platform may affect downstream areas to the south of Virginia Key, but should not affect the inner surf zone. Thus, Houston's choice of the long profiles actually measures changes in two surf zones! Houston's assumed 61,000 cu m maximum annual loss rate is inaccurate.

According to WALTON (1977, p. 26), "annual losses in the monitoring period were thus 57% higher than the long term average annual losses presented above", *i.e.* post-fill losses are 57% higher than pre-fill losses. Houston omits note of this conclusion, and again uses the literature in selective fashion (see discussion of Atlantic City in this reply).

Key Biscayne, Florida

Our number, 6536 cu m per year, is the pre-fill erosion rate estimate (1960–1969) found in U.S. ARMY CORPS OF ENGINEERS (1984b). Houston suggests that this number is wrong because pre-fill erosion rates from the period 1960–1969 were determined from short profiles extending to a depth of only 1.5 m. He is mistaken on two counts.

First, Key Biscayne like Virginia Key has a broad, submerged, shallow platform adjacent to it. The long profiles which Houston prefers, measure changes in two zones of sand transport (Hal Wanless, *personal communication*). As in Virginia Key, changes in the outer zone have little bearing on beach behavior. U.S. ARMY CORPS OF ENGINEERS (1961), as quoted in UNIVERSITY OF FLORIDA (1972), also find inner profiles relevant for study of Key Biscayne beach changes.

Second, the use of the 1960–1969 short profiles for estimation of pre-loss rates provides a relatively accurate estimation of the actual erosion problem which precipitated the perceived need for beach replenishment. According to Hal Wanless (*personal communication*), Key Biscayne's major erosion problem was a long ditch that had been dug close to the shore in the mid-50's, apparently to obtain fill for a parking lot. Thus, the time span of 1919–1960 for pre-fill erosion rates used by Houston does not accurately measure the impact of ditch construction.

Houston further criticizes LEONARD (1988) for inconsistency in using different time period and depth profiles for Virginia Key and Key Biscayne. As discussed above, the timing of ditch excavation in front of Key Biscayne provides one compelling reason for use of different time period profiles. Yet, Houston's criticism is more amazing than it may first appear. Why should we use the same time/depth profiles on two different islands? The two islands are separate and different natural systems with separate and different histories of development and separate and different types of erosion problems.

To understand post-fill numbers for the 1969 project off Key Biscayne, one must closely observe the natural system's response. The borrow area for the project was on the outer rim of the offshore platform. According to Hal Wanless (*personal communication*) borrow-pit construction initiated a large kill-off of seagrass which in turn, unstabilized and released large volumes of relatively fine sediment which moved landward and to the south. This sediment was measured by some of the post-fill profiles (UNIVERSITY OF FLORIDA, 1972). Thus, the post-fill change measurements for Key Biscayne have been strongly affected, at least short term, by events other than actual beach loss.

According to the U.S. ARMY CORPS OF ENGINEERS (1984a), "the estimated annual losses from the project as determined from historical shoreline losses are 22,000 cubic yards a year for the project area." The same paragraph refers to an annual average erosion rate of 18,000 cubic yards. Whether this rate is a pre-project projection or an actual post-fill measurement is unclear. From the range of values given, LEONARD (1988) took the round figure of 20,000 cubic yards per year (15,200 cu m per yr) as the post-fill erosion rate. Houston's zero post fill rate is unrealistic, if for no other reason than the shoreline retreat immediately after beach emplacement.

DISCUSSION

About Houston's Analysis

Table 1 is a brief summary of our analysis of Houston's specific pre-fill/post-fill rates and his conclusions regarding the relative overall rates of pre-fill and post-fill losses conclusions. We believe his conclusions are incorrect in 8 out of 11 analyses for the pre-fill versus post-fill erosion rate data points used in Figure 2 (LEONARD *et al.*, 1990).

We are at loss to understand Houston's statement that "only one of the 12 fills has post-fill erosion rates significantly greater than pre-fill rates." His Table 2 compares pre- and post-fill rates for 9 fill locations, not 12 (and one of those 9, Bal Harbour, is not included in our study). Of those 9, four cannot yield relative rates because they have pre-fill loss rates expressed as wide ranges of values. And then, of course, the statistical question remains: what is "significantly greater"?

If coastal engineers believe what Houston and his staff claim that they have demonstrated, that pre-fill and post-fill rates are essentially the same, then American beach replenishment design will probably continue on as it has, with large underestimations of cost and sand volumes. We are greatly disappointed.

Our Table 2 is a brief summary of our major criticisms of Houston's analyses of the beaches that he claims have nearly equal pre- and post-fill loss rates.

Houston is correct that we did not adequately consider an initial adjustment period for our post-fill loss numbers. We state in LEONARD *et al.* (1990 p. 18) that our numbers do not include initial profile adjustment losses. We should have made our reasoning clear. Such numbers are not included because they are impossible to obtain from available data sources. As a part of our analysis of beach replenishment, our intention has been to try to obtain post-fill loss rates taken over as long a time period as possible, in order to minimize the effect (if any) of initial fill adjustment. We have been successful in finding fairly long-term rates for Key Biscayne, Miami Beach, Delray Beach and Canaveral Beach. Sandy Hook, Ocean City, Hunting Island and Indialantic beaches lost more of their fill quickly; hence, the concept of initial profile adjustment does not apply.

Houston notes at least a dozen times that LEONARD (1988) and LEONARD *et al.* (1990) do not indicate the references used to obtain

Table 1. *Summary of our evaluation of the pre- and post-fill erosion rates cited by Leonard et al. (1990) and Houston (1991) analyses. The right-hand column shows our view of the correctness of Houston's opinion of relative rates of pre- and post-fill losses. For all beaches except Ocean City, Houston concludes that pre- and post-fill erosion rates are roughly the same.*

	Leonard et al. (1990)		Houston		Correctness of Houston's Conclusion
	Pre-fill	Post-fill	Pre-Fill	Post-Fill	
Sandy Hook	√	√	X	§	WRONG
Atlantic City (1963)	?	X	?	X	WRONG
Atlantic City (1986)	?	X	?	√	RIGHT
Ocean City	√	√	?	√	RIGHT
Hunting Island	√	?	√	?	WRONG
Canaveral Beach	√	X	?	√	WRONG
Indialantic	√	√	?	X	WRONG
Delray Beach	√	√	§	√	WRONG
Miami Beach	√	√	√	§	RIGHT
Virginia Key	√	√	X	√	WRONG
Key Biscayne	√	√	X	X	WRONG

√ = reasonable; X = wrong; ? = who knows; § = declared unknown by Houston.

Table 2. *Summary of our main criticism of Houston's pre-fill and post-fill loss rates in instances where we believe he is wrong (see Table 1). In all cases listed here, we found that post-fill loss rates exceeded pre-fill loss rates, while Houston concludes the opposite.*

Beach	Critique
Sandy Hook	Houston uses beach length five times the actual beach length, and obtains to high a pre-fill loss rate.
Atlantic City (1963)	Everts *et al.* (1974) find the nourished beach loss rate to be 12 times the mean annual erosion rate from the entire subaerial Atlantic City beach.
Hunting Island	Houston's own figures domonstrate higher post-fill loss rate. A fifteen year history of four replenishments shows post-fill loss rate to be larger than pre-fill loss rate.
Canaveral Beach	No fundamental criticism, but our numbers show greater post- than pre-fill loss rate.
Indialantic	The replenished beach disappeared in a little over a year. Houston's assumption that the beach lasted at least six years is wrong.
Delray Beach	Houston declares pre-project loss rate unknown. Our post-fill rate is 2.5 times the pre-fill rate of loss.
Virginia Key	Houston uses overly long profiles for pre-fill loss rate estimation. His rates include volume changes at the edge of a broad nearshore shallow platform which are not beach-related. Also, Walton (1977) notes post-fill loss rate is 57% greater than pre-fill rate.
Key Biscayne	Houston uses overly long profiles as on Virginia Key. Houston's post-fill loss rate of zero is unrealistic, because shoreline retreat was observed.

data points for Figure 2. True enough. But we ask the reader to peruse our paper (LEONARD *et al.*, 1990) and note the large amount of data that would have to be referenced. We deemed it impractical to do so. Our most important information, beach durability (PILKEY, 1988) and a compilation of U.S. East Coast beach replenishment projects (PILKEY and CLAYTON, 1989) is referenced point by point. We have been willing to provide information to those analyzing our data. In fact, we have answered queries by Houston as he and his staff were analyzing our data in Figure 2. We supplied copies of the thesis and the *JCR* manuscript before its publication and asked for their comments. We twice offered members of Houston's staff the use of our raw data files, and we announced publicly at a U.S. Army Corps of Engineers Coastal Engineering Research Board meeting that we would share data and sources. All Houston had to do was telephone.

We feel that Houston's analysis is marked by inconsistencies with selective and inaccurate criticism of our methods. Some of the general problems are:

(1) Houston incorrectly assumes the derivation of some of our numbers and, consequently, attributes mistakes to us that we have not made.

(2) We are all constrained by the lack of consistent, high quality monitoring data but Houston often makes the same "errors" that he accuses us of making.

(3) Twice, Houston ignores critical conclusions evident in the literature that did not support his conclusions. In these cases, the conclusions were on the same page from which he obtained other data.

(4) Several times, Houston criticizes our work using references published after our paper was in press. New data should be used to update our paper, not to discredit it.

(5) Houston frequently, fundamentally and inappropriately criticizes LEONARD (1988), an unpublished masters thesis. He would do better to have limited his comments to the *JCR* papers.

Are We "Extremely Flawed"...

We think not, although we were distressed to discover three incorrect post-fill numbers. Two (Atlantic City 1963 fill; Canaveral Beach) were paper-shuffling errors. One (Atlantic City 1986 fill) was a premature call on a beach that was put in as we were finishing our study. Although these numbers are incorrect, our conclusion that pre-fill erosion rates are generally lower than post-fill erosion rates is correct.

Do Replenished Beaches Erode More Rapidly Than Their Natural Predecessors?

Yes. From our study, Houston's flawed analysis, and this reply, the conclusion based on Figure 2 of LEONARD *et al.* (1990) stands: replenished beaches erode more rapidly than their natural predecessors. Above all, this discussion has revealed the softness of the data, and demonstrates that much more work and much more data are needed for the final answer to this important question. The assumption that pre- and post-fill loss rates are the same is the mainstay of American beach replenishment design. Nourishment requirements are determined on the basis of erosion rates, then adjusted for a variety of other factors.

The most compelling evidence that replenished beaches disappear more quickly than natural beaches is the consistent under-estimation of beach durability by those who design U.S. East Coast barrier island replenished beaches (PILKEY and CLAYTON, 1987). If pre- and post-fill loss rates are truly similar, then we should be able to estimate beach fill durability far more accurately than has been the case. Another explanation for this consistent lack of predictive success is that perhaps designers of beachfills have consistently underestimated pre-fill erosion rates.

Is It True That Our Paper "Cannot Be Used To Reach Valid Conclusions About Beach Fill Performance"?

No! It is not true. Figure 2 is one of few of its type in this paper, *i.e.* comparison of precise quantities. Wherever possible we used categories instead of numbers. For example, for the all-important replenished beach durability analysis we used "<1," "1–5," and ">5" year categories. To make our numbers even more conservative (but, at the same time, less precise), the durability categories were defined on the basis of loss of 50% of the fill, noting (LEONARD *et al.*, 1990) that most of the beaches pigeonholed into categories had actually lost more than 50% of the fill. Instead of using quantitative grain size values, we used "coarser than," "comparable to," or "finer than" native categories.

In summary, we believe that our conclusions are valid. We are disappointed that Houston treats all of our conclusions with such contempt because of disagreement with one figure. The data are complex as this exchange with Houston so vividly demonstrates. But where applied with a broad brush, the conclusions are very worthy of consideration in beach design.

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