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The Effects of Houses and Sand Fences on the Eolian Sediment Budget at Fire Island, New York[1]

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ABSTRACT

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This study was conducted to identify the effects of houses and sand fences on dune dynamics on a moderately developed barrier island. Wind velocity data gathered beneath and around buildings built on pilings in the dunes revealed that isolated buildings considerably reduced the average velocity of winds. Cumulative sand surface elevation changes during the 102 day period were less than 7.6 cm.

A simulation of the sediment budget revealed that 1.9 m^3 of sediment per 10 linear meters of dune crest would be deposited landward of the dune crest under natural conditions. Houses constructed on pilings at a 25% linear density along the crest reduce the natural rate of deposition by 13.8%. If houses are constructed directly on the dune surface at a frontage density of 43% and protected using sand fences, the natural rate of eolian transport would be reduced by 67.5%. Structures built on or near the dune crest cause a local increase in the height of the dune and reduce the inland migration of the dune. Even a moderate level of development can strongly affect sediment transfers, and performance criteria should be developed for new shorefront buildings to insure maintenance of important characteristics of the natural system.

ADDITIONAL INDEX WORDS: *Barrier island, dune, eolian transport, Fire Island, sand fence, sediment budget.*

INTRODUCTION

Coastal scientists and planners have called attention to the paucity of data on developed shorelines and the need to study developed areas to devise more effective management plans for these hazardous environments (MEISBURGER *et al.*, 1980; FINKL, 1983; PEOPLES and GREGG, 1983). The need to assess human induced changes to coastal dunes is especially important because dunes provide protection to shorefront properties from the destructive effects of waves and high water generated by storms (CERC, 1977). Dunes are dynamic and fragile, however, and they are especially vulnerable to human modification (GODFREY *et al.*, 1978; VOGT, 1979; GARES, 1983). Appreciation of the value and sensitivity of coastal dunes has led some communities to institute legal restrictions on construction in the dune to control buildings which would interfere with the natural exchanges of sand which replenish the dunes (TOWN OF ISLIP, 1978; TOWN OF BROOKHAVEN, 1981). The implication of these restrictions is that buildings endanger the integrity of the dune to the point where the hazard potential is increased.

Coastal engineers, developers, and property owners have maintained that buildings can be constructed in the dunes without creating unwarranted hazards. Engineers have developed construction methods to improve the resistence of structures to the winds and waves of large coastal storms (MACHEMEHL, 1978; COLLIER *et al.*, 1977). These studies have documented the effects of the natural system on houses, but the effect of houses on the dune has not been demonstrated. This study was designed to identify the effects of shorefront houses on sand transfers by wind in order to pro-

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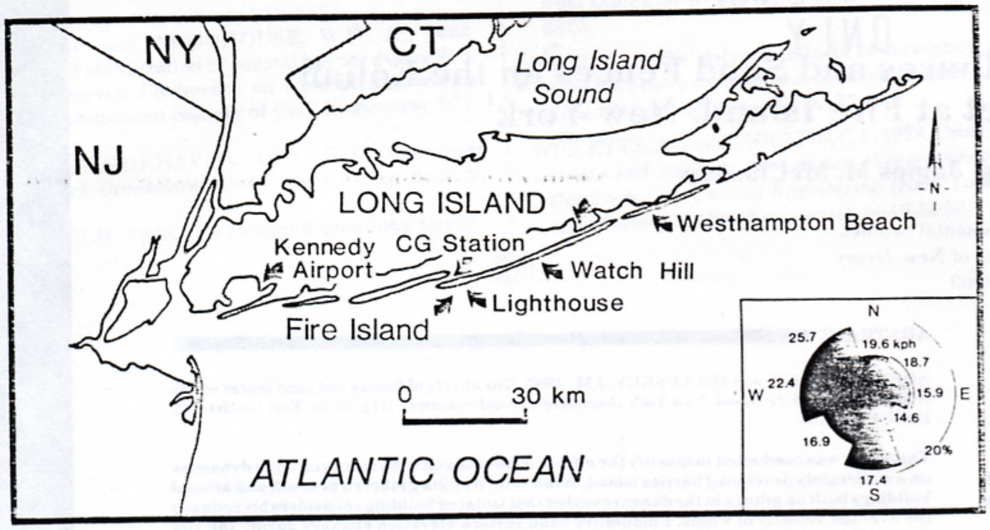

Figure 1. Long Island, New York showing location of study area from Fire Island to Westhampton Beach and field site at Watch Hill. Wind rose data are from Kennedy Airport for five year period 1975-79 (NOAA, 1980).

vide a scientific basis for decisions on the suitability of constructing buildings in the dune. The effect of sand fences was also investigated because the use of this strategy to protect houses is so common in coastal communities.

The procedure includes measurement of alterations to wind patterns, sediment movement, and topographic changes resulting from shorefront development at field sites on Fire Island, a barrier island on the south shore of Long Island (Figure 1). The field data are then used to calculate an eolian sediment budget to determine the effects of buildings of different characteristics on the kind of barrier island that characterizes the northeast coast of the United States. An assessment is then made of the implications of the sediment budget to the development of performance criteria for new buildings.

The focus of this study is on houses elevated on pilings because it is assumed that they have the least impact on the form of the dune. It is also likely that most future buildings will be constructed on pilings as awareness of the value of this mode of construction increases and because this method of construction will be required in most communities in the Federal Insurance Administration Flood Insurance Program (FEMA, 1980).

ALTERATIONS IN WIND PATTERNS AROUND ISOLATED STRUCTURES

Field work was conducted in two phases which corresponded to two separate studies conducted for the US National Park Service. Both studies were conducted in the winter to obtain data when winds were high and vegetation density was at a mininum. This was done to identify eolian effects under conditions of maximum transport potential. The first field study was conducted at the Watch Hill Unit of Fire Island National Seashore from December 1979 to March 1980 to identify the effects of isolated structures on changes in wind velocity and direction. The second field study was conducted near the Fire island Lighthouse in March and April 1982 and was designed to determine the role of the wind in the eolian sediment budget of Fire Island. The data from the first field study (Table 1) provide the basis for the assessement of the effects of isolated buildings. The data from the second field study are combined with the data from the first study to identify the cumulative effects of buildings and sand fences (Table 2).

Three house sites at Watch Hill (Figure 2) were selected for intensive study. The houses had been

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Table 1. *Averaged modal wind speeds for sampling locations.*

		Northerly and Northwesterly Winds		Southerly and Southwesterly Winds	
Site	Location	Number of cases	A.M.W.S. (kph)*	Number of cases	A.M.W.S.(kph)*
Site A	15m upwind	16	13.0	6	15.7
	0 (center)	16	10.8	6	7.0
	6m downwind	16	2.2	6	2.6
	15m downwind	16	4.6	6	0.9
Site B	15m upwind	13	10.1	6	9.4
	0 (center)	13	13.6	6	5.2
	6m downwind	13	16.8	6	2.0
	15m downwind	13	20.0	6	3.0
Site C (pre-removal)	15m upwind	12	9.4	3	20.9
	0 (center)	12	8.4	3	0.4
	6m downwind	12	5.7	3	8.0
	15m downwind	12	8.1	3	5.0
Site C (post-removal)	15m upwind	4	13.7	3	12.4
	0 (center)	4	11.3	3	3.3
	6m downwind	4	17.9	3	1.8
	15m downwind	4	17.6	3	0.4
Site D	15m upwind	16	11.8	6	3.3
	0 (center)	16	8.7	6	4.1
	6m downwind	16	10.4	6	8.1
	15m downwind	16	13.7	6	10.2
Site E	15m upwind	16	10.4	6	11.7
	0 (center)	16	7.5	6	8.9
	6m downwind	16	10.8	6	12.2
	15m downwind	16	13.7	6	17.6

*Average Modal Wind Speed, kilometers per hour.

previously condemned and one of them (Site B) was removed at the beginning of the data collection period. Another house (Site C) was removed during the sampling period. This allowed before/after comparisons to be made. Data from the house sites were compared with data from two undeveloped areas (Sites D and E).

Wind velocity data (Table 1) were gathered either once or twice daily on 16 days using a hand-held anemometer. The days were selected to obtain a variety of wind conditions which were representative of a longer term wind record for the area (Figure 1). On most days, wind conditions did not change significantly during daylight hours. On 6 of the 16 days, conditions were sufficiently different to justify a second set of readings. The data in Table 1 thus represent 22 separate sampling periods. Readings were taken for one minute at each of four locations within each site. The sampling locations were at the center of the site, 15 m upwind of the center, and 6 m and 15 m downwind of the center along the azimuth that the wind was blowing at the sampling time. The houses at Sites A and C were elevated on pilings, so the center measurement was taken underneath the structures.

Offshore (Northerly and Northwesterly) Winds

The house at Site A is located on the crest of the dune. The effect of the house there is considerable, as wind velocities are much reduced to the lee of the house (Table 1). The velocity of the wind below the house is not much less than the velocity on the windward side. This occurs because the air flow is canalized under the elevated structure which maintains its velocity.

Data from Site C also document the significance of a house in reducing wind velocity to its lee. Comparison of the wind data before and after removal reveals that there is little difference in the average velocities at the center relative to the velocity measured 15 m upwind under both situations, but the velocities to the lee of the center location are considerably higher in the absence of a house. The wind velocity increases downwind of the center because the dune is higher there.

The increase in wind velocity downwind of Site B

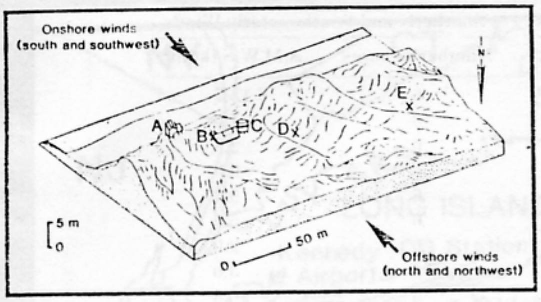

Figure 2. Topographic setting of Watch Hill study area showing conditions after removal of the house at Site B and prior to the removal of the house at Site C. The structure linking the house at Sites B and C is a 1 m high deck with a swimming pool in it.

results from greater exposure to the wind in the air column due to increases in the elevation of the sampling locations on the dune in the downwind direction. A comparison of the data for offshore winds at the three developed sites indicates that there can be a substantial difference in the degree of interference with wind velocity by houses located at different elevations with respect to the dune crest and in different topographic configurations.

Wind velocities in undeveloped Sites D and E were lowest at the centers of these sites, presumably because that location was the lowest, most sheltered part of the profile. The wind velocity varied little between the other sampling stations. This appears to be due to the lack of cultural or natural obstructions to winds from the north and northwest.

Onshore (Southerly and Southwesterly) Winds

Wind velocities are high at Site E during onshore winds (Table 1) because the dune crest has been breached here, and there is no high ground nor building to interfere with wind flow from the beach. There is a greater difference in wind velocities in the downwind direction at the other natural area (Site D), and the wind speeds are lower than at Site E due to the sheltering effect of the high, wide dune ridge to the south. Velocities increase downwind of the dune crest away from this wind shelter.

There is a sizable reduction in the velocity of the wind in the downdrift direction at Site C. This is attributed to sheltering by both the dune ridge and the house. The reduction in wind speed below the house during onshore winds is greater than the reduction in wind speed during offshore winds because of the extra shelter provided by the dune. The wind velocity under the house at Site A at the top of the dune crest is considerably greater than the velocity under the house at Site C which is to the lee of the dune. This provides further documentation of the significance of the dune in reducing wind velocity to the lee. These data, and evidence for the reduction in wind velocity to the lee of the house at Site A, confirm that there can be considerable modification of wind speeds by both structures and topography.

TOPOGRAPHIC CHANGES AT ISOLATED STRUCTURES

Changes in ground surface elevation were determined at sample Sites A, D, and E using depth of disturbance stakes. Twelve wooden stakes (2.5 cm x 5 cm) were emplaced under and around the house at Site A out to a distance of 16 m. They were arranged in four lines of three stakes each, oriented northeast, southeast, southwest, and northwest. A similar array was emplaced at the two natural areas. Elevation changes were monitored at these stakes

Table 2. *Calculated rates of onshore sand transport by wind and quantities of sand trapped at obstructions across a 1 km length of dune crest under different conditions of development.*

Development status	Rate[a]	Amount[b]
Without sand fences		
Natural area (100% vacant)	195.6	0.0
Elevated houses, 25% density	168.6	27.0
Elevated houses, 43% density	149.2	46.4
Houses on ground, 25% density	146.7	48.9
Houses on ground, 43% density	111.5	84.1
With sand fences along 100% of crest		
Fences only	111.5	84.1
Fences with elevated houses, 25% density	96.1	99.5
Fences with elevated houses, 43% density	84.9	110.7
Fences, houses on ground, 25% density	83.6	112.0
Fences, houses on ground, 43% density	63.6	132.0

[a]Rate of transport across dune crest, cubic kilimeters per year.

[b]Quantity of sand trapped at man-made obstructions, cubic kilometers per year.

from December 9, 1979 to March 20, 1980. The greatest amount of cumulative change over the 102 day period was 7.9 cm of erosion at a stake emplaced on a bare sand surface at Site E. There was erosion and deposition at stakes at all three sites but all other changes were less than 5 cm. The amount of change due to eolian processes on the landward side of the dune crest is thus quite low when compared to the rapid changes which occur at the contact between the beach and dune seaward of the dune crest on coastal barriers (ROSEN, 1979).

There was less change in the elevation of the ground surface than could have occurred given the wind velocities monitored during the study period. Neither the houses nor the natural dunes were complete sediment traps. The location of the bulk of the houses above the sand surface and the low vegetation density under winter conditions allowed for movement of sediment onshore and offshore as a result of wind reversals. Sediment deposited as a result of wind from one direction could thus be removed by winds from the other direction. Sand fences and houses built directly on the ground are more complete obstructions to sediment transport, and they could be expected to have greater effect on changes in dune morphology. These structures were not monitored in the field, but their effects on the sediment budget were calculated and compared with changes which would occur under natural conditions and with elevated houses.

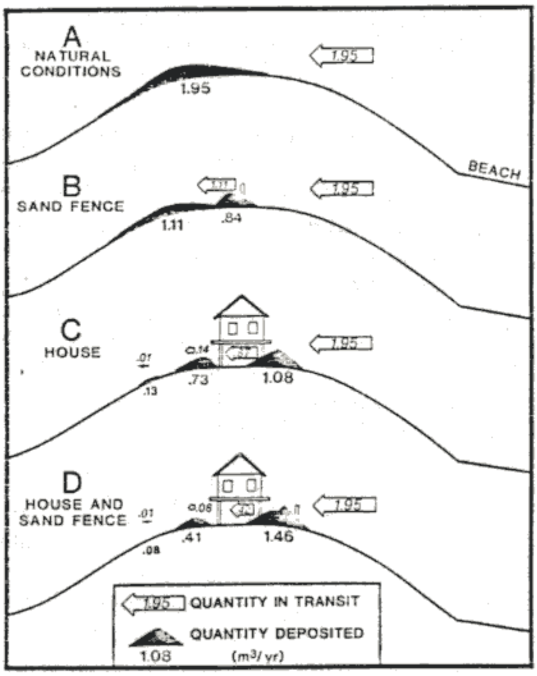

Figure 3. Calculated annual net eolian sediment budget (m^3/yr) for sand crossing a 10 m length of dune crest of a representative dune at Fire Island, New York, under different conditions of development.

SIMULATIONS OF STRUCTURE EFFECT ON SEDIMENT EXCHANGES

Figure 3 contains the calculated net volumes of sand which pass the crest of a 3 m high vegetated dune under different conditions of development. The data were determined using a sediment budget calculation procedure modified from KADIB (1964) and ROSEN (1979). The procedure is described in greater detail in McCLUSKEY *et al.* (1983). The data in Figure 3 are based on sediment trap data and wind records gathered in 1982, calibrated by the wind data gathered at Watch Hill in 1979-1980. Trap data were obtained from multidirectional eolian sediment samplers of the LEATHERMAN (1978) design emplaced on the beach, foredune crest, and backdune of a representative 3 m high, 60 m wide dune near Fire Island Lighthouse (Figure 1). The traps were in place March 9 to April 20, 1982. Measurements were taken daily except for 8 days when snow was on the ground and traps were clogged. Rates of sediment transport which occurred during the sampling interval were extended to represent an annual net sediment budget using the meteorologic data for 1980 from the Fire Island Coast Guard Station (Figure 1).

The arrows on the right side of Figure 3 represent the resultant vectors of annual sediment transport delivered to the dune crest. The calculated net sand movement is onshore, despite the occurrence of strong offshore winds (Figure 1) because vegetation landward of the dune crest in the field site reduced the rate of transport offshore from that source. The data are expressed in m^3 per year per 10 m of dune crest measured in the longshore direction. The 10 m crest length was selected because this dimension approximates the width of a representative house in the study area. The data for rates of sand movement through a sand fence (Figure 3b) were derived by reducing the natural sediment transport rate to correspond to a straight fence with a porosity of 50% as recommended by SAVAGE and WOODHOUSE (1968). The natural rate of transport was reduced to

57% according to the ratios given in WILLETS and PHILLIPS (1978). The data for movement of sand through the house site (Figure 3C) were determined by calibrating the natural values with the ratios of wind reduction passing the house at Site A at Watch Hill.

Under natural conditions (Figure 3A) 1.95 m^3 of sediment pass the crest of the dune. This figure was calculated using data from the sand traps emplaced on the dune crest. Data from traps placed on the backdune showed that the sediment is deposited to the lee of the crest. This occurs as a result of diminished wind velocity and increased density of vegetation. A sand fence emplaced on the crest of the dune would trap 43% of this value, increasing the volume of the dune crest by 0.84% m^3 per year for each 10 m of dune crest length (Figure 3B). When a house with the characteristics of the house at Site A is placed on the dune crest, the simulated rate of sand transport under the house will be reduced to .87 m^3 per year (Figure 3C). This will result in deposition at a rate of 1.08 m^3 of sand per year near the structure on the ocean side. The reduction in wind velocity landward of the structure results in further deposition. These deposits form a ridge of higher ground around the house.

When sand fences are used in combination with a house, the deposition increases, which creates a higher dune. In most communities, the fences are placed well in front of the houses which displaces the crest farther seaward (Figure 3D). Both houses and sand fences thus contribute to increased crest height and reduce the rate of inland migration of the dune. The rate at which these calculated changes take place is not particularly rapid. The volume of sand in the prototype dune is 943 m^3 per 10 m length, and the volume of sand added to the dune each year is less than 1% of the bulk of the dune. This value is low because net sediment transport rates were used. If gross transport rates (representing the absolute values of onshore and offshore transport) were used, the calculated amounts of sediment deposited would be greater. Gross transport rates are more significant when assessing the effect of impenetrable structures such as houses placed on the ground or the effect of erosional scarps in the dune which function as complete sand traps. The main purpose of this study is to demonstrate that there are important differences in the eolian sediment budget due to different methods of house construction and to the use of sand fences. Net transport rates are considered appropriate for this purpose. Gross transport rates will be of greater value in the development of the actual design criteria for new structures.

The budget calculation can be extended for greater distances alongshore to include the effects of housing density and the use of sand fences in front of houses and between houses. The data in Table 2 show the calculated rates of sand passing the dune crest along a 1 km reach of shoreline under different conditions of development. Housing density refers to the proportion of dune crest occupied by structures. The 43% figure represents the average proportion of shoreline length now devoted to houses in the developed communities along Fire Island and nearby Westhampton Beach. The 25% figure is arbitrary. It represents a lower density of development, presented for comparison.

The data in Table 2 indicate that elevated houses at low density do not have much effect on the natural transfers of sand. The effect of houses is not as great as the effect of a continuous sand fence placed along the crest, and houses and sand fences together can considerably reduce the volume of sand which passes the dune crest. It can also be seen that houses placed directly on the ground reduce the rate of sand transport inland. The net transport rate was used to determine these effects. A calculation of gross transport rates would show that the relative difference between houses placed on the ground and elevated houses is greater in terms of sediment trapped.

IMPLICATIONS FOR MANAGEMENT

Isolated houses which are elevated on pilings above the dune surface reduce the velocity of the wind to their lee and cause localized deposition. The interference with the eolian sediment budget and the rate of seaward displacement of the dune crest by a series of elevated structures placed along the crest of the dune is not particularly great relative to houses placed on the ground or to the effects of sand fences. The manner in which buildings are constructed is important in affecting the eolian sediment budget. The houses monitored in the study were not specifically designed to facilitate sand transfers. It is assumed that engineering design criteria can be applied which will further diminish interference with eolian processes. The conclusion is that houses should not be categorically excluded from the dunes on the grounds that they interfere with natural wind processes to the point where the structural integrity or equilibrium conditions of the dune are threatened.

Performance criteria for construction of new buildings may be required in some areas to ensure that the system functions according to management goals. In locations where it is desirable to retain a natural exchange of sediment across the dune crest, performance criteria should specify that buildings be elevated on pilings and have the practical minimum frontage density along the shorefront. Many shorelines are erosional, and the inevitable result of natural processes is the displacement of the location of beaches and dunes inland. Most houses built behind the dune crest have been built too low to allow for migration of the crest beneath them. New buildings constructed behind the dune should be built higher on their pilings at an elevation which will be compatible with a location on the crest of the dunes.

Sand fences have a much greater effect on the eolian sediment budget than houses built on pilings. In the past, shorefront residents have often been free to implement sand fencing programs as they wished. The implementation of controls on house construction and other uses of the dune without consideration of the changes induced by sand fences would be shortsighted, and planners should consider implementing stricter controls on the use of sand fences.

FUTURE RESEARCH

The present study should be viewed as the beginning of a comprehensive program designed to identify the effects of structures on shoreline processes. The focus of this investigation has been on the effects of houses constructed in dunes to performance criteria designed to minimize adverse effects of the natural system on the houses. Future studies should be directed toward determination of performance criteria for structures which will minimize interference with the natural system. Attention should also be given to how these structures will affect dunes which shift in position through time.

Methods of investigation used in this study are considered adequate to call attention to the way in which geomorphic data gathered on developed shorelines can be used to devise more effective management plans and to answer a basic question on the suitability of allowing houses in coastal dunes. The development of new performance criteria will require the identification of specific effects of turbulence caused by structures and the effects of currents caused by flow around the structures. This will require the use of a more sophisticated instrumentation and calculation procedure than was used here. These follow-up scientific studies can than be used to describe where and in what density houses should be located to provide the basis for legal restrictions on construction in coastal dunes.

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