Journal of Coastal Research | 8 | 1 | 88–98 | Fort Lauderdale, Florida | Winter 1992

Site Specific Controls on Wind and Wave Processes and Beach Mobility on Estuarine Beaches in New Jersey, U.S.A.

Nancy L. Jackson and Karl F. Nordstrom

Institute of Marine and Coastal Sciences
Rutgers University
New Brunswick, NJ 08903, U.S.A.

ABSTRACT

JACKSON, N.L., NORDSTROM, K.F., 1992. Site specific controls on wind and wave processes and beach mobility on estuarine beaches in New Jersey, U.S.A. *Journal of Coastal Research*, 8(1), 88–98. Fort Lauderdale (Florida). ISSN 0749-0208.

Data for eight low-energy meso-tidal sand beaches in developed communities on Raritan Bay and Delaware Bay estuaries in New Jersey, U.S.A., are compared to identify the influence of shoreline orientation, sheltering by adjacent headlands, slope and width of the low tide terrace, and human modification on beach processes and responses. Data on these controls, derived from charts and air photos, are used to explain statistically significant similarities and differences in wind and wave characteristics and beach mobility derived from field investigations.

Wind conditions were similar on both bays, but processes and responses differed between sites. Shoreline orientation affects the degree to which refracted ocean waves alter the incident wave field, and sites farther from the ocean may have more conspicuous ocean wave influences than sites closer to the ocean. Site specific differences in the width and slope of the low tide terrace have pronounced effects on wave height and mobility of the upper foreshore. Sheltering by natural headlands appears to be less effective than human controls. Compartmentalization of a beach by structures can increase or decrease beach mobility, depending on position relative to the ends of a longshore drift compartment. Localized human impacts can have conspicuous effects on low-energy estuarine beaches that undergo limited profile change under natural conditions.

ADDITIONAL INDEX WORDS: *Fetch distance, human modification, low tide terrace, wave refraction.*

INTRODUCTION

Sandy beaches in tidal estuaries are found in a wide range of settings, including small deposits within semi-enclosed embayments formed by resistant marsh, long transgressive barriers overlying marsh deposits, and beaches fronting eroding headlands. Attempts to understand susceptibility of estuarine beaches to long term erosion have focussed on determination of resistant formations within the beach profile, including vegetation on the foreshore, peat outcrops and clay layers (Rosen, 1980; Phillips, 1985). The magnitude of beach mobility in estuaries is a function of controls that increase or decrease susceptibility to erosion. Fetch distance, shoreline orientation and morphology, tidal range, and rates of submergence have been identified as the chief controls operative in tidal estuaries (Rosen, 1977, 1978, 1980; Phillips, 1985, 1986).

Human controls are also important on many estuarine sand beaches. Shore protection projects such as beach nourishment and implementation of protection structures are well documented (Anderson, 1987; Schmeltz and McCarthy, 1987; Kieslich and Brunt, 1989; U.S. Army Corps of Engineers, 1981; Wang *et al.*, 1982). More localized structures such as outfall pipes or shorefront buildings are also effective on estuarine shorelines but have not been well documented. The variability inherent in response of sandy beaches in developed areas is not dependent on resistant natural features in the beach profile but rather a function of resistant features outside the beach matrix. As a result, some of the controls governing process-response relationships on these beaches are different from their undeveloped counterparts.

The focus of this paper is on resistant factors outside the beach profile that alter local wave and wind processes and sediment mobility. We are comparing sites with similar morphologic characteristics in two bays that are of different sizes but have similar energy inputs in order to determine the influence of site specific controls in establishing similarities and differences in beach mobility. Controls previously determined to affect

---

90114 received 10 September 1990; accepted in revision 8 July 1991.

Financial assistance for this research was provided by the US Department of Commerce, National Oceanic and Atmospheric Administration, Office of Coastal Zone Management under provisions of Section 305 of the Federal Coastal Zone Management Act (P.L. 92-583) in cooperation with the State of New Jersey Department of Environmental Protection, Division of Coastal Resources.

This is contribution number 90-25 of the Rutgers University Institute of Marine and Coastal Sciences.

erosion rates are evaluated. These controls include: (1) shoreline orientation; (2) sheltering by adjacent morphology; and (3) slope and width of the low tide terrace. Human controls are also considered because many estuarine sand beaches have been altered by humans, affecting either the local processes or morphology.

METHODS

Study Sites

Data were gathered on shoreline characteristics, wind and wave processes, and beach change at four sites on Raritan Bay and four sites on Delaware Bay (Figure 1) between December 1, 1987 and December 19, 1988. These bays are funnel shaped estuaries, located at the north and south ends of the ocean shoreline of New Jersey and separated by a distance of 145 km. The tides are semi-diurnal with a mean range of 1.4 to 1.5 m on Raritan Bay and 1.6 to 1.8 m on Delaware Bay. Spring tidal ranges are 1.7 to 1.8 m on Raritan Bay and 1.9 to 2.1 on Delaware Bay (NOAA, 1990). Ocean waves enter the estuaries through openings to the Atlantic Ocean, but locally generated wind waves are dominant. The prevailing winds are from the southwest, but northeasterly storm winds and northwesterly winds are common and have higher velocities. The maximum fetch distance in Delaware Bay is approximately two times the fetch distance in Raritan Bay.

The study sites were selected because they represent major shoreline compartments in each bay. All sites on Raritan Bay and one site (Villas) on Delaware Bay are backed by upland composed primarily of sand with some pebbles. Some of the beaches are composed of fill sediments. The three Delaware Bay sites north of Villas are on barriers fronting marshes. All sites are similar in that there are no resistant formations in the beach matrix that affect beach mobility. They are also similar in overall morphology, having a steep, reflective upper foreshore and flat low tide terrace (Figure 2). The sites are all located in human settlements, but they differ in terms of their proximity to buildings and the density of structures that are located behind the beach. They also differ in terms of distance to the nearest natural or cultural shore-perpendicular feature that affects longshore sediment transport (Figures 3 and 4).

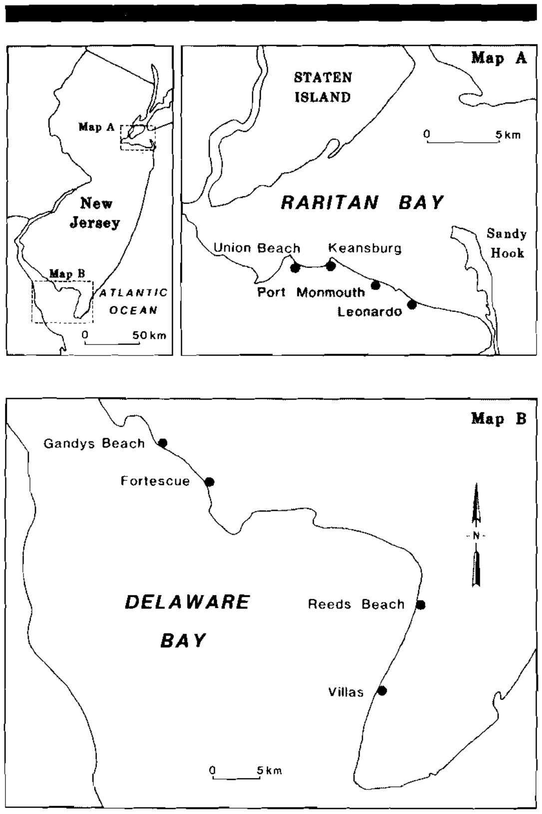

Figure 1. Study locations.

Data Collection and Analysis

The specific controls considered in this study are represented by the variables identified in Table 1. Data on beach processes and responses were gathered on the variables presented in Table 2. U.S. National Ocean Survey navigation charts were used to determine: (1) fetch distance in the three principal wind directions (an indication of exposure to locally generated waves), (2) distance to the ocean outlet at each bay (an indication of exposure to refracted ocean waves), and (3) distance between mean high water (MHW) and mean low water (MLW) out on the low tide terrace (an indication of the effectiveness of the low tide terrace as a wave energy filter). The navigation charts were used to determine the distance between MHW and MLW for Union Beach, Leonardo, Villas, and Reeds Beach. The distance was shorter on the other sites and was determined from survey profiles.

Beach orientation was measured with a compass in the field. Distance from the profile line at each site to the nearest shore perpendicular feature was measured from 1:9,600 scale vertical air photos. Only features that extended at least to

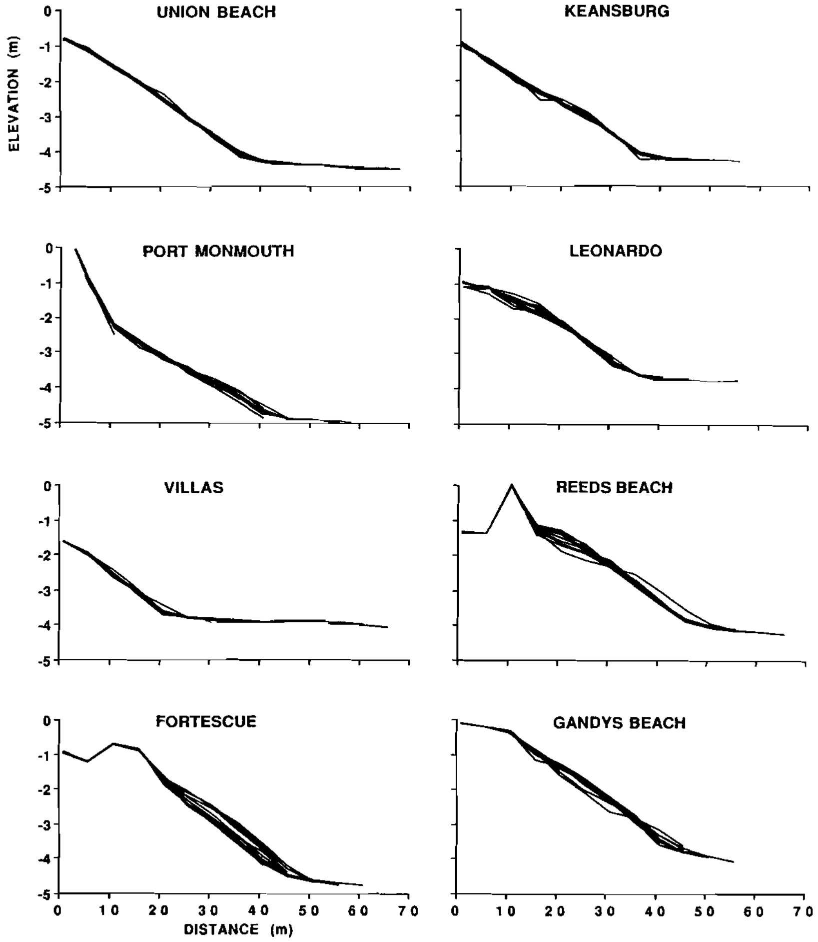

Figure 2. Sweep zone profiles for selected sites, from monthly field surveys.

the break in slope between the upper foreshore and the low tide terrace were used because these features could be considered effective traps to longshore transport. An indication of the amount of shorefront development was provided by determining the number of buildings per 100 m length of shoreline landward of each field site using the vertical air photos. A second indication of exposure (orientation) to ocean wave influences was provided by measuring the angle between two straight lines drawn on the navigation charts from the site to the spits or capes bordering the outlet to the ocean. This angle was considered to be zero if the two lines intersected land in the bay before encountering the outlet. The variable is complementary to the distance to the ocean outlet, which is not based on line of sight.

Visual wind and wave data were gathered at the eight sites on a minimum of 21 days during the one year period. Wind direction was measured with a compass by sighting along the fall paths of dry sand grains. Wind speed was measured on the crest of the beach berm using a hand-held digital anemometer. Wave heights were measured visually with reference to a graduated staff held in the breaking waves. Breaker periods were determined by averaging the time taken for 30 wave crests to pass a given point. Breaker angle was determined by taking the difference between the azimuth of the beach along the waterline and the

Figure 3. Union Beach, New Jersey, in Raritan Bay, facing southeast, showing the nature of bulkhead tiebacks that isolate the shoreline into compartments.

Table 1. *Site characteristics controlling wind and wave processes and beach mobility.*

	Slope of Low Tide Terrace	Fetch Distance (km) to				Distance MHW-MLW	Nearest Shore-perpendicular Feature (m)				Shorefront Development	Relationship to Ocean Outlet	
							Updrift		Downdrift				
	(deg)	NW	NE	SW	Beach Orientation	(m)	Distance (m)	Feature	Distance (m)	Feature	Units/ 100 m	Distance (km)	Orientation (deg)
Union Beach	0.7	7.7	19.2	0	NNW/SSE	117	73	bulkhead	53	bulkhead	5	13.2	15
Keansburg	0.3	8.3	18.1	0	WSW/ENE	40	284	headland	802	stream	0	10.9	0
Port Monmouth	0.6	11.7	17.6	0	WNW/ESE	45	271	groin	956	jetty	0	7.6	7
Leonardo	0.1	15.1	5.7	0	WNW/ESE	178	348	groin	74	groin	3	7.1	0
Villas	0.5	23.6	0	33.0	SSW/NNE	254	>1,000	N/A	>1,000	N/A	3	11.2	<1**
Reeds Beach	1.0	11.0	0	42.3	SSW/NNE	81	300	bulkhead	761	jetty	0	21.6	<1**
Fortescue	0.6	0*	0	27.0	WNW/SSE	29	223	bulkhead	57	jetty	0.4	37.5	<1**
Gandys Beach	1.6	0*	0	21.6	NNW/ESE	32	448	stream	730	bulkhead	5	42.7	18

*The northwest direction is nearly parallel to the shoreline orientation at these sites and the wave generating area is in the river channel rather than the bay. Northwesterly winds have some effect but the meaning of a discrete distance would be obscure.

**The window to the ocean for these sites falls outside the cape south of Delaware Bay, but intersects the ocean shoreline south of the cape.

Figure 4. Gandys Beach, New Jersey, in Delaware Bay, facing northwest, showing buildings behind the beach that alter wind flow and lack of shore-perpendicular obstructions to transport.

average azimuth of the breakers by sighting along these features with a compass in the surf zone. Longshore current velocity was measured in the surf using a Marsh McBirney Model 201 electromagnetic current meter.

Beach surveys were conducted at the 8 sites to characterize beach slope, profile shape and beach mobility. The slope of the low tide terrace did not change during the study period. This variable affects wave energy and thus beach mobility and is considered an independent variable at the time scale of this study. Beach elevations were measured using a transit and stadia rod placed at 5 m intervals starting at a location landward of the limit of normal wave influence and extending into the bay below the break in slope between the upper foreshore and the low tide terrace. The surveys were conducted on a monthly basis during the one year period and after three small storms, two on Raritan Bay and one on Delaware Bay. Beach mobility represents the maximum vertical elevation change at any survey point in the zone of wave action between any two successive profiles.

A *t*-test was performed on the process variables identified in Table 2, both between bays and between sites to determine whether the samples were from the same populations. Those found to be statistically significant at the 0.05 level were then analyzed to determine the degree of linear association between the two sample populations. Mobility rates were derived from the profile data by comparing the maximum monthly elevation changes at any of the five meter intervals. A Mann-Whitney test was applied to the data to determine significant differences. Correlation coefficients were then calculated on these data.

RESULTS

Site Characteristics and Controls

Union Beach, on Raritan Bay (Figure 3), is partially exposed to ocean swell waves that enter the bay north of Sandy Hook (Table 1, last column).

Table 2. *Summary statistics for process data measured in the field.*

	Union Beach	Keansburg	Port Monmouth	Leonardo
Wind speed (ms^{-1})				
Mean	2.1	3.8	3.4	1.8
Standard deviation	1.4	2.0	2.2	1.7
Cases	23	23	23	23
Breaker height (m)				
Mean	0.10	0.11	0.14	0.09
Standard deviation	0.11	0.09	0.11	0.08
Cases	26	23	26	25
Breaker period (s)				
Mean	3.0	2.4	2.8	2.5
Standard deviation	1.3	0.9	0.8	0.9
Cases	25	23	26	25
Breaker angle (deg)				
Mean	5	14	13	8
Standard deviation	5	9	10	7
Cases	23	23	24	24
Longshore velocity (ms^{-1})				
Mean	0.05	0.14	0.11	0.07
Standard deviation	0.04	0.10	0.13	0.06
Cases	21	21	21	20

	Villas	Reeds Beach	Fortescue	Gandys Beach
Wind speed (ms^{-1})				
Mean	3.7	3.9	3.8	3.0
Standard deviation	3.0	2.5	1.9	1.8
Cases	21	22	21	21
Breaker height (m)				
Mean	0.13	0.19	0.19	0.21
Standard deviation	0.09	0.11	0.08	0.10
Cases	20	21	20	21
Breaker period (s)				
Mean	2.9	2.7	2.8	3.0
Standard deviation	1.0	1.0	0.6	1.0
Cases	19	21	20	21
Breaker angle (deg)				
Mean	7	10	9	9
Standard deviation	4	8	8	8
Cases	18	20	20	20
Longshore velocity (ms^{-1})				
Mean	0.11	0.13	0.11	0.12
Standard deviation	0.09	0.09	0.08	0.08
Cases	20	20	20	21

Table 3. *Summary of statistical tests performed on NOAA local climatological data.*

	$t_{observed}$	Mean	Standard Deviation	Correlation Coefficient (r)
Wind speed				
Raritan Bay	−0.04	8.13	3.63	0.53
Delaware Bay		8.16	4.0	
Wind direction				
Raritan Bay	−0.10	220.66	94.73	0.95
Delaware Bay		222.46	97.09	

$t_{critical}$: 2 tailed test, 0.05, 120 DF = 1.980
$r_{critical}$: 0.05, 60 DF = 0.2542

The beach has a broad low tide terrace that helps dissipate waves at low water levels, and the beach is partially enclosed between adjacent bulkheads nearby (Table 1) that extend across the upper foreshore to the low tide terrace. The site offers the opportunity to examine change in a beach enclave within a protected area and provides a contrast with the more exposed northeast-facing undeveloped site at Port Monmouth. The Keansburg site is not directly exposed to ocean waves and bay waves generated by northeast winds because of the orientation of the shoreline. There are no buildings or protection structures located close to the field site (Table 1), so differences between this site and the others are believed to be attributable primarily to beach orientation. The Port Monmouth site is exposed to bay waves generated by easterly and westerly winds as well as ocean swell. Human structures are less conspicuous here than at Union Beach and Leonardo, and the site was expected to undergo the greatest amount of beach profile change of the Raritan Bay sites that can be related to natural processes. The Leonardo site is backed by a bulkhead, but storm water levels during the year of study were not high enough for the structure to play a role in beach change. The site is sheltered from refracted ocean swell waves and bay waves generated by northeast storms because of its position near the east side of the bay. The profile line is located near a storm drain that empties directly onto the backbeach 5 m downdrift (east) of the profile line, and storm runoff periodically reworks the beach.

The sites in Delaware Bay are exposed to the effects of waves generated by winds from the westerly quadrants (Figure 1, Table 1), but they differ in degree of exposure to the dominant northwesterly winds. These sites are not exposed to waves generated by northeasterly winds. Except for Villas, they are farther from the ocean than

Table 4. *Correlation coefficients for process and response data gathered in Raritan and Delaware Bays, New Jersey.*

Sites	Wind Speed	Wind Direction	Breaker Height	Breaker Angle	Breaker Period	Longshore Velocity	Beach Mobility
Raritan Bay							
Leonardo/Union Beach	*0.52	*0.77	*0.75	*	*	*	
Leonardo/Keansburg		*0.43	*		*		**
Leonardo/Port Monmouth		*0.99	*0.92		*	*0.83	
Port Monmouth/Union Beach		*0.77	*0.75		*0.47		
Port Monmouth/Keansburg	*	*	*	*	*	*	
Keansburg/Union Beach		*0.57	*		*		
Delaware Bay							
Villas/Fortescue	*	*		*	*	*	
Villas/Reeds Beach	*0.74	*0.90		*	*0.89	*	
Villas/Gandys Beach	*	*		*	*	*	
Fortescue/Reeds Beach	*0.48	*0.55	*	*	*	*0.53	
Fortescue/Gandys Beach	*0.75	*0.91	*0.79	*0.52	*0.46	*0.75	**
Reeds Beach/Gandys Beach	*	*0.47	*	*	*	*0.51	
Raritan & Delaware Bays							
Leonardo/Villas		*	*	*	*	*0.58	
Leonardo/Reeds		*		*	*		
Leonardo/Fortescue							
Leonardo/Gandys Beach		*		*	*		**
Port Monmouth/Villas	*	*	*		*	*	
Port Monmouth/Reeds Beach	*	*	*	*	*	*	
Port Monmouth/Fortescue	*	*	*0.50	*	*	*	**
Port Monmouth/Gandys Beach	*	*		*0.44	*0.58	*	**
Keansburg/Villas	*	*	*		*	*	
Keansburg/Fortescue	*	*			*	*	
Keansburg/Reeds Beach	*	*		*	*	*	**
Keansburg/Gandys Beach	*	*			*	*	**0.63
Union Beach/Villas		*	*	*	*	*	**
Union Beach/Reeds Beach		*			*		**
Union Beach/Fortescue		*		*	*		
Union Beach/Gandys Beach	*	*		*	*		

Correlation coefficients significant at 0.05 confidence level
*t-test performed; significant at 0.05 confidence level
**Mann-Whitney U test performed; significant at 0.05 confidence level

the Raritan Bay sites; this reduces the effectiveness of ocean swell relative to bay waves. Villas has a low, narrow upper foreshore (Figure 2) with a broad low tide terrace. The low tide terrace is wider than it is at all other sites (revealed by the distance to MLW in Table 1), and is the only one consistently exposed at low water. The low tide terrace at Reeds Beach is much narrower and steeper (Table 1), and comparison of data from this site and Villas provides perspective on the effect of offshore characteristics on wave processes and beach change. Fortescue is bounded by a large stone jetty and a shore-perpendicular bulkhead that extends bayward to the low tide terrace. Gandys Beach is roughly comparable to Fortescue in orientation and fetch distance, but there are no shore protection structures to alter longshore sediment exchanges (Figure 4). Data from these two sites thus provide insight into some of the effects of human structures. Offshore slope is greater at Gandys Beach than at all other field sites and waves that break on the upper foreshore undergo less modification by shoaling on the low tide terrace.

Wind and Wave Data

A test for normality on local climatological data (NOAA, 1987, 1988) for Raritan Bay and Delaware Bay showed that wind speed and wind direction are normally distributed. A t-test showed that these two variables are similar between bays, and wind direction is highly correlated (Table 3).

Average wind speeds at the Delaware Bay sites are similar to average wind speeds on the most exposed Raritan Bay sites (Table 2). Wind speeds at Union Beach, Leonardo and Gandys Beach are lower than at the other sites on their respective bays because of the reduction in offshore wind velocities caused by houses behind the beach (Figures 3 and 4, Table 1). This sheltering is a local phenomenon that does not affect wave generation. Breaker heights are greater on Delaware Bay than on Raritan Bay, presumably due to greater fetch distances (Table 1).

Keansburg is exposed to waves generated by winds from the northwest, but the fetch distance for these winds is less than the fetch distance at Port Monmouth (Table 1). Relatively high waves at Port Monmouth result from its exposure to both northwesterly and northeasterly waves. Breaker angles are higher at Keansburg (Table 2) because of the extreme refraction that the northeasterly waves undergo. Average breaker height is low at Leonardo (Table 2), despite the relatively long fetch to the northwest. Breaker heights are low here and at Union Beach because the high elevation and great width of the low tide terrace (Table 1) cause it to act as a wave energy filter.

Relatively high waves at Gandys Beach may be a function of the deeper offshore water depth, indicated by the slope and width of the low tide terrace (Table 1). Another explanation is the frequent occurrence of southwesterly winds (7 out of the 20 days monitored) that blow nearly directly onshore. Low breaker heights at Villas appear to be related to wave attenuation on the flat, wide, low tide terrace.

Long wave periods at Union Beach are due to the dominance of ocean waves that come through the mouth of Raritan Bay. The site is farther from the ocean outlet than the other Raritan Bay sites but is more exposed to direct wave approach (Table 1). Villas is located closer to the mouth of the bay than the other Delaware Bay sites, and refracted ocean swell waves appear to be responsible for the slightly greater average wave period. Breaker angles are lower at Union Beach and Villas because the crests of the long period ocean waves are more readily refracted on the broad low tide terraces, and they break more nearly parallel to the shoreline. Longshore current velocities are low at these two sites because wave heights and breaker angles are low.

Process data were compared for Raritan Bay and Delaware Bay for the variables identified in Table 2. Wave height was the only variable that did not show similarity between the two bays at the 95% confidence level. Differences in the size and configuration of each bay thus appear to affect the generation and growth of waves. Statistical analysis of the other variables revealed that the processes operating within both bays are from the same population.

A *t*-test performed on the process variables at the eight sites (Table 4) shows site specific differences in the populations both between bays and within the same bay. Union Beach and Leonardo are similar to each other in terms of wind speed, as are Union Beach and Gandys Beach. The similarity may be attributed to the similarity in building density at all three sites (Table 1).

Wave angle is a function of refraction and is dependent on the orientation of the shoreline relative to the direction of deep water wave approach, water depth, and wave length. In Keansburg, many of the sharp breaker angles are associated with waves locally generated by strong easterly winds that must undergo a 130 degree change in direction to approach normal to the beach. High wave angles at Port Monmouth are often associated with westerly winds that blow nearly parallel to the shore. Keansburg, Port Monmouth, and Reeds Beach show no difference in wave angle populations. Exposure of Port Monmouth and Reeds Beach in the central portion of each bay, far from shore-perpendicular human structures, results in a wave regime that falls within the spectrum of both bays.

Beach Mobility

Principal net surface changes on the eight beaches (Figure 2) are on the upper foreshore. Wave energy dissipation on the low tide terrace restricts sediment reworking at low water levels. Sediment reworking on the low tide terrace is restricted at high water levels because this zone is seaward of the breakers. Differences in energy levels between the upper foreshore and low tide terrace restrict sediment exchanges between these two components of the beach profile, and most of the mobility of the beaches is associated with sediment exchanges between the upper and lower portions of the upper foreshore. The overall slope of the upper foreshores changed little throughout the 1 year period. The greatest changes were at Reeds Beach, where the range in values was only 1.53 degrees.

Processes at two sites may be similar but not show any similarity in beach mobility (Table 4). Alternatively, the processes may be similar and highly correlated, and sediment mobility may be similar (revealed by the Mann-Whitney test), but the degree of linear trend between the beach mobility populations (revealed by the correlation coefficient) may not be highly correlated. The greatest insight is provided by comparing the site pairings from the same bay where: (1) breaker heights are highly correlated but beach mobility is not from the same population; and (2) beach mobility is from the same population.

Differences in beach mobility are conspicuous in the profiles (Figure 2). Human development at Union Beach helps compartmentalize the beach, and this factor may restrict mobility. Sand is transported to the southeast end of the compartment when transport is influenced by waves generated by northwest winds and is transported to the northwest end when northeasterly winds are dominant. The field site is near the middle of the compartment (Table 1), close to the antinode of shoreline fluctuations resulting from trapping and removal of sediments at the structures caused by reversals of sediment transport. The central location would make the site less susceptible to erosion and accretion than a location closer to the structures. Stability of the beach is aided by low longshore current velocities, due to lower breaking wave heights and breaker angles (Table 2). Lack of human development at Port Monmouth allows the waves to work the beach more effectively. Beach mobility at Port Monmouth is sufficiently greater to be statistically different from Union Beach.

The great mobility of the upper foreshore at Leonardo (Figure 2) despite low wave energies (Table 2) is a function of migration of the storm runoff channel across the upper foreshore. Data from Leonardo and Union Beach reveal that human development can increase or reduce mobility to the extent that sites highly correlated in terms of breaker height may not be similar in terms of beach mobility and that breaker height may not be related directly to beach mobility.

Beach mobility at Leonardo is similar to Keansburg, despite lower breaker heights and longshore current velocities. The relatively high rate of mobility on the beach at Leonardo is a function of human activities. The result is a degree of beach mobility that is associated with a more energetic site.

Comparison of processes and beach mobility at Fortescue and Gandys Beach (Figure 2, Tables 2 and 4) reveals the effects of human activities (in this case, shore protection structures) on beach change. Process variables are more highly correlated for these sites than any other site pairings. Analysis of beach mobility reveals similar populations at the two sites but no significant correlations between them. Greater mobility of the Fortescue profile is believed to be attributed to the greater effect of local reversals of longshore transport within the confined shoreline compartment. The jetty and the bulkhead create sediment traps that change the nature of beach mobility at this site compared to the site at Gandys Beach where there is no artificial obstruction in the longshore direction. Sediment removed from the Fortescue site by longshore current reversals (approaching from the west-northwest) is not replaced from sources on the other side of the jetty. The effect of sediment removal is pronounced at Fortescue because the profile line is located close to the jetty at the end of the drift compartment, accentuating the temporary accretion and erosion. Reversals in transport direction result from reversals in wind direction in environments that are dominated by locally generated waves (DAVIDSON-ARNOTT and MCDONALD, 1989). Thus, shoreline change may be attributed to fluctuations in wind direction rather than net sediment loss.

DISCUSSION AND CONCLUSIONS

Processes that are similar at the regional level express themselves differently at the local level because of site specific controls. The estuaries are statistically similar in terms of energy inputs, but they are characterized by different sizes and configurations. These differences determine the degree to which energy is transformed at each site. Analysis of process data for each site shows the influence of orientation, sheltering, slope and width of the low tide terrace, and human development on the magnitude and effectiveness of energy in mobilizing sediments.

Beach orientation affects the degree to which ocean swell alters the wave regime and affects beach mobility. Results of previous studies indicate that the effectiveness of swell decreases with distance from the opening to the ocean (NORDSTROM, 1977; CARTER, 1980). Data from Union Beach indicate that shoreline orientation can offset the significance of distance. Beach orientation in relation to dominant winds influences the degree to which wave approach is oblique to the shoreline, and it affects both wave angle and longshore current velocity. Longshore current velocity generated by a given wind condition is a function of basin size and configuration as well. Differences in wave characteristics were observed between sites with similar fetch distances for northeasterly winds and similar distances from ocean outlets but having different orientations (Keansburg and Port Monmouth). Keansburg has a west-southwest/east-northeast orientation that results in the refraction of ocean swell and waves generated by easterly winds around the headland to the north. The angle of wave approach is larger than the angle of approach at Port Monmouth.

Sheltering refers to the effectiveness of headlands in providing protection from wave attack. The irregular configuration of many estuarine shorelines can be a major control in accounting for differences in erosion rates (Phillips, 1986). Sheltering does not play a major role at 7 of the 8 sites because there are no local headlands in the three principal wind directions. Leonardo is sheltered by Sandy Hook (a natural feature), contributing to low wave energies at this site. Beach mobility was high, but this was attributed to human development rather than shoreline orientation.

Site specific differences in width and slope of the low tide terrace affect wave height and thus beach mobility. The effect is pronounced on estuarine beaches, where the broad low tide terraces provide a wave energy filter. Comparison of data from Reeds Beach and Villas reveals that differences in the width of the upper portion of the low tide terrace may have a pronounced effect on wave energy, even where shoreline orientation, exposure, and human influences are similar.

Human controls have the effect of altering wind and wave processes, influencing the longshore sediment budget, and (as at Leonardo) directly affecting beach mobility. Buildings reduce wind speed, but this has a negligible effect on wave generation in estuaries that have large fetch distances. The increased mobility at Leonardo is a special case of a highly localized human impact that can have a conspicuous effect on a low-energy estuarine beach that would undergo rather limited beach change under natural conditions. This local impact caused Leonardo to be grouped statistically with sites with higher energy regimes when sediment mobility was the basis for comparison.

Division of a shoreline into compartments does not categorically lead to either increased or decreased mobility. Reduced mobility appears to occur if the site is in the center of a compartment or the longshore current velocity is weak, as at Union Beach. Thus human structures can have a pronounced effect. It is not possible to say that one type of human adjustment will result in either increased or decreased mobility, but it is possible to identify the conditions under which increased or decreased mobility will occur.

LITERATURE CITED

Anderson, M.E., 1987. An examination of the history and political processes involved in the reclamation of Alameda Beach, Alameda, California. *Proceedings, Coastal Zone 87* (American Society of Civil Engineers), pp. 1420–1431.

Carter, R.W.G., 1980. Longshore variations in nearshore wave processes at Magilligan Point, Northern Ireland. *Earth Surface Processes*, 5, 81–89.

Davidson-Arnott, R.G.D. and McDonald, R.A., 1989. Nearshore water motion and mean flows in a multiple parallel bar system. *Marine Geology*, 86, 321–338.

Kieslich, J.M. and Brunt, D.H., III, 1989. Assessment of a two-layer beach fill at Corpus Christi Beach, TX. *Proceedings, Coastal Zone 87* (American Society of Civil Engineers), pp. 3975–3984.

National Oceanic and Atmospheric Administration (NOAA), 1987, 1988. *Local Climatological Data. Monthly Summary: Newark Airport, NJ and Wilmington, DE.* Rockville, Maryland.

National Oceanic and Atmospheric Administration (NOAA), 1990. *Tide Tables: East Coast of North and South America.* Rockville, Maryland.

Nordstrom, K.F., 1977. Bayside beach dynamics: Implications for simulation modeling on eroding, sheltered, tidal beaches. *Marine Geology*, 25, 333–342.

Phillips, J.P., 1985. A spatial analysis of shoreline erosion, Delaware Bay, New Jersey. New Brunswick, New Jersey: Rutgers University Department of Geography, unpublished Ph.D. dissertation, 195p.

Phillips, J.P., 1986. Spatial anslysis of shoreline erosion, Delaware Bay, New Jersey. *Annals of the Association of American Geographers*, 76, 50–62.

Rosen, P.S., 1977. Increasing shoreline erosion rates with decreasing tidal range in the Virginia Chesapeake Bay. *Chesapeake Science*, 13, 383–386.

Rosen, P.S., 1978. A regional test of the Bruun Rule on shoreline erosion. *Marine Geology*, 34, M7–M16.

Rosen, P.S., 1980. Erosion susceptibility of the Virginia Chesapeake Bay shoreline. *Marine Geology*, 34, 45–59.

Schmeltz, E.J. and McCarthy, M.J., 1987. Design of a sand recycling system. *Proceedings, Coastal Sediments 87* (American Society of Civil Engineers), pp. 1274–1288.

U.S. Army Corps of Engineers, 1981. *Low-Cost Shore Protection,* Final report on the Shoreline Erosion Control Demonstration Program (Section 54). Washington, DC: Office of the Chief of Engineers.

Wang, H.; Dean, R.; Dalrymple, R.; Biggs, R.; Perlin, M., and Klemas, V., 1982. *An Assessment of Shore*

Erosion in Northern Chesapeake Bay and the Performance of Erosion Control Structures. Annapolis, Maryland: Department of Natural Resources Tidewater Administration.

□ ZUSAMMENFASSUNG □

Die Daten für 8 Sandstrände in erschlossenen Gemeinden der Raritan-Bucht und der Delaware-Bucht in New Jersey/USA, welche in einem Milieu mit geringer Energie und mittlerem Tidenhub liegen, wurden verglichen, um den Einfluß der Orientierung der Küstenlinie, des Schutzes angrenzender Küstenvorsprünge, der Böschung und Breite der Niedrigwasserterrasse und des menschlichen Eingriffs in die Strandprozesse und seine Auswirkungen zu vergleichen. Die Ergebnisse daraus, zusammen mit solchen von Seekarten und Luftbildern, wurden verwendet, um statistisch signifikante Ähnlichkeiten und Unterschiede in der Wind- und Wellencharakteristik und den Strandbewegungen aus den Feldbeobachtungen zu entwickeln. Die Windbedingungen sind in beiden Buchten ähnlich, aber die Prozesse und ihre Auswirkungen unterscheiden sich dennoch. Die Orientierung der Küstenlinie bestimmt z.B. das Ausmaß der Veränderung und Refraktion der einlaufenden Wellen, und Lokalitäten in größerer Ozeanferne haben einen eher auffallenden Welleneinfluß als jene, die näher am Ozean liegen. Lokalitätsspezifische Unterschiede in der Breite und Böschung der Niedrigwasserterrasse haben merkliche Effekte auf die Wellenhöhe und die Beweglichkeit der oberen Partien des nassen Strandes. Die Schutzwirkung natürlicher Vorsprünge scheint weniger wirksam als menschliche Eingriffe. Die Aufteilung der Strände durch Baumaßnahmen kann die Strandmobilität erhöhen oder vermindern, je nachdem, wie weit ein Abschnitt von einer Sektion mit Longshoredrift entfernt liegt. Lokale menschliche Einflüsse können deutliche Effekte auf Estuarstrände mit geringer Energie haben, welche unter natürlichen Bedingungen nur sehr geringe Veränderungen aufweisen würden.—*Dieter Kelletat, Universität Essen, Germany.*

□ RESUMEN □

Datos correspondientes a ocho playas de arena situadas en zonas de baja energía y marea media en las bahías de Raritan y Delaware en New Jersey, USA, son utilizadas para identificar la influencia de la orientación de la costa, protección debida a promontorios, pendiente y anchura de la terraza mareal y modificaciones humanas sobre los procesos que ocurren en las playas. En ambas bahías, la acción del viento es similar, pero los procesos y respuestas son diferentes. La orientación de la costa afecta al grado en el cual las olas refractadas del mar abierto alteran el oleaje incidente, de modo tal que localidades más alejadas del océano pueden tener una influencia del oleaje más visible que lugares cercanos al mar abierto. Las diferencias en la anchura y pendiente de la terraza mareal tienen un pronunciado efecto en la altura de ola y la movilidad del sedimento. La protección debida a promontorios naturales parece ser menos efectiva que la causada por actuaciones humanas. La compartimentación de una playa por medio de estructuras puede aumentar o disminuir la movilidad de la misma dependiendo de su posición relativa a la de las celdas de deriva longitudinal. Las actuaciones humanas localizadas pueden tener notables efectos en playas de escasa energía que experimentan pocos cambios en condiciones naturales.—*Department of Water Sciences, University of Cantabria, Santander, Spain.*

□ RÉSUMÉ □

On a recueilli des données sur 8 plages sableuses de type méso-tidal des estuaires des baies de Raritan et de Delaware, au New Jersey. Ces données ont été conparées entre elles pour identifier l'influence de l'orientation de la plage, de la situation d'abri derrière des promontoires, de la pente et de la largeur de la plateforme de basse mer et des modifications anthropiques sur les processus d'actions dynamiques et les réponses sédimentaires. Les données sont tirés des cartes marines et des photos aériennes, et sont utilisées pour expliquer de manière statistiquement significative, similitudes et différences des caractéristiques de la houle et du vent, ou de la mobilité de la plage telles qu'elles ont été déduites sur le terrain. Les conditions de vent étaient semblables dans les deux baies, nais les processus d'actions dynamiques et les réponses sédimentaires différentes. L'orientation du rivage affecte l'altération du champ de vagues incidentes par le houle océanique réfractée. Les sites éloignés de l'océan peuvent subir des influences de la houle océanique plus visibles que d'autres plus proches de l'océan. Les différences spécifiques de largeur et de pente des plateformes de basse mer ont de grands effets sur la hauteur et la mobilité du haut de plage. La position d'abri derrière des promontoires semble mois efficace que les aménagements. Le compartimentage d'une plage par des structures peut augmenter ou diminuer la mobilité des plages, selon la position par rapport aux terminaisons du compartiment de dérive littorale. Des impacts anthropiques localisés peuvent avoir des effets visibles sur les plages estuariennes à faible énergie, ce qui implique des modifications limitées de leur profil par les conditions naturelles.—*Catherine Bousquet-Bressolier, Géomorphologie EPHE, Montrouge, France.*