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GEOMORPHIC PROCESSES AND LAND USE PLANNING, SOUTH TEXAS BARRIER ISLANDS

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ABSTRACT

Barrier islands are active geomorphic areas that are also highly desirable development sites. Two basic classes of processes affect these areas: (a) hurricanes and storms, which are irregular, intermittent events; and (b) shoreline and aeolian processes, which are regular, daily processes. The intermittent events can drastically alter the island in a short time period, whereas the daily processes gradually modify the island. Land use planners and developers rarely consider the active processes or the impact of altering the geomorphology of the island. Studies conducted along separate areas of Padre Island, Texas, suggest that active geomorphic processes are different for each site. A study of the natural alteration of a part of the Padre Island Natural Seashore, using historical aerial photographs, shows that the island geomorphology follows a predictable cycle. The cycle is initiated when a hurricane breaches the foredune ridge. The resulting major foredune breach gradually heals as isolated dunes coalesce except at the downwind end where an aeolian chute forms. The chute funnels aeolian sand through the foredune ridge, forming an aeolian fan and back-island dune field. This aeolian transport system may exist for as long as 30 years. Eventually the chute closes and the island returns to pre-hurricane conditions. Land use decisions should contend with both irregular events and daily processes. It is impossible to predict where the next hurricane will strike, thus structures should either be designed to withstand the storm or as sacrifice structures. Once a hurricane breach forms, however, the location of the resulting aeolian fan can be predicted and the effect of aeolian transport can be incorporated into land use plans. Historical air photography of South Padre Island shows that hurricanes alter island geomorphology predictably and that daily processes do not effectively change this alteration. Hurricane hazard zones could easily be considered in land use plans to ensure responsible development of the area. To date, development on South Padre has disregarded the active coastal processes: residential zones have been built in washover channels, portions of the foredune ridge have been removed for hotel construction, construction siting has disregarded shoreline erosion, and aeolian sand is being removed for fill on the mainland. To maximize protection: from storm surge and scour, commercial structures should be founded on deep piles and located behind the foredune ridge; from washover channel erosion, channel sites should be maintained to relieve erosive pressure from the foredune ridge; from flooding, residential structures should be located on back-island areas away from washover channels. With low cost and little effort, geologic input can be incorporated into any plan and can make the barrier island a safer place to live.

INTRODUCTION

The physical environment, unlike either the socioeconomic or biological environments, is often considered by man to be static and stable, whereas in fact this environment is highly dynamic. The land existing today along the Texas coast was produced through a continuous process of erosion and sedimentation. These processes are still active and capable of significantly changing the coast many times in a person's life span.

The Texas coast is characterized by flatlands crossed by numerous rivers, a scene very similar to one that has persisted over thousands of years. The typical coastline of Texas is one having sandy barrier islands facing the open Gulf of Mexico with protected lagoons between these islands and the mainland (Fig. 1). This barrier island/lagoon complex extends from Trinity Bay along the coast to near Brownsville. These beautiful islands are the basic physical environment upon which the recreational potential of the Texas coast rests.

Padre Island is presently undergoing extensive land and recreational development. Barrier islands, especially, have been the focus of rapid development because of their proximity to the ocean and appeal to sun and sea enthusiasts. Unfortunately for both

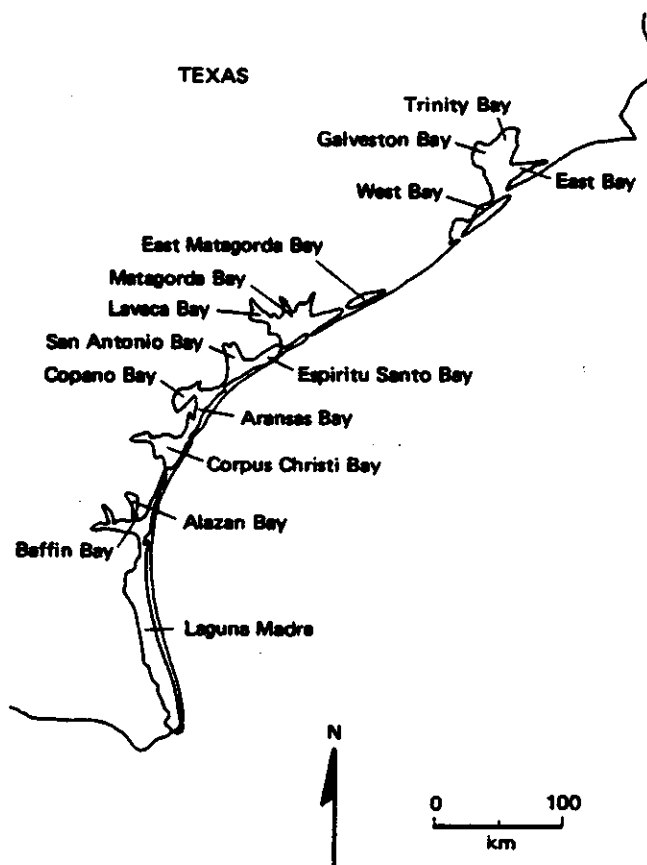


Figure 1 Map of the Texas coastal zone showing the estuaries and lagoons that make up the environment.

seasonal tourists and permanent residents, the dynamic processes that have formed and continue to modify the barrier island are not generally considered by land use planners and builders. The result has been for many unwary consumers an economic and physical loss for which there is no adequate compensation (McGowen et al. 1970; Mathewson 1976).

Padre Island is the southernmost member of the chain of barrier islands that make up the Texas Gulf Coast shoreline (Fig. 2). To the north it is separated from Mustang Island by Corpus Christi Pass; on the south it is separated from the Rio Grande Delta Complex by Brazos Santiago Pass. Padre Island is 177 km long and is a nearly continuous network of beaches, dunes, and marshes interrupted only by Mansfield Pass. The island varies in width from 3.2 km in the north to slightly more than 0.8 km in its southern extremity. Vertical relief is predominately determined by the height of the larger dunes, which rarely exceed 12 m. Much of the island lies within 2.4 m of sea level. The distance from the mainland varies from about 8 km at the north end to about 16 km at the southern part.

Between Padre Island and the mainland lies Laguna Madre, a body of water that varies in width from 3.2 km at the north to a maximum of 12.8 km at the south and rarely attains a depth of more than 3 m. The Intracoastal Waterway, dredged by the Corps of Engineers along the entire length of the Texas Gulf Coast, traces a path within the lagoon parallel to the mainland. The Intracoastal Waterway is 60 m wide, and averages about 2.7 m in depth.

The climate of the south Texas coastal area is predominately semiarid subtropical. Annual temperatures average from 22 to 24°C; freezing is rare, occurring about once each year. Annual precipitation is extremely variable, ranging from 30 to 121 cm with an

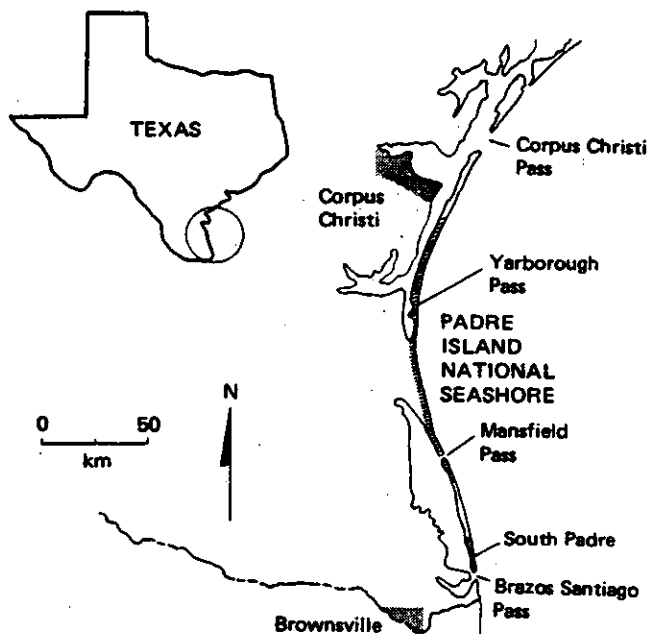


Figure 2 Location map of Padre Island study sites. The National Seashore site is near Yarborough Pass and the other site is in the community of South Padre.

annual average of 66 cm. Precipitation is greatly biased by the number and intensity of tropical storms in a given year. Prevailing winds are from the southeast, variably punctuated with north to northeast winds of greater intensity usually associated with winter storms.

The first historical reference of man's uses of Padre Island dates to 1519, when Alonso Alvarez de Pineda set foot on the island and established Spain's claim. However, no attempt to colonize the island was made. The next contact the Spanish had with Padre Island was in 1553, when a fleet of Spanish galleons were sunk or ran aground during a storm. The Spaniards returned the next year and undertook a salvage effort that recovered about half the sunken treasure.

There seems to be some confusion in early historical accounts concerning the proper name of the island. In the south it was called Isla de Los Malquitos and Isla Blanca (either name being acceptable); in the north it was referred to as Isla de Corpus Christi.

The island was not referred to again by any of its names until the early 1800s, when the Spanish King, Charles IV, granted the island to Padre Nicolas Balli. The Padre gave the island both its name and its first industry - cattle raising. The island soon became known as "the Padre's Island." In 1827, a survey by order of Governor Fernandez was conducted to determine the extent of the land acquired by the Padre, who at the time of his death was a very wealthy and powerful man. More than a hundred families, in south Texas and across the Rio Grande into Mexico, trace their lineage back to the good Padre - a mark of his influence although not a credit to his profession.

In 1840, after the rebellion and the independence of Texas from Mexico, the southern part of the island was occupied by John Singer of the Singer sewing machine family of Boston. He grazed a herd of some 1500 head of cattle on the island but was forced to leave with the outbreak of the Civil War.

Following the vacancy caused by the Singer expulsion, Padre Island was deserted except for the U.S. Army. Between 1864 and 1865 some 5000 to 6000 troops were drilled and trained there. As isolated as it was, news traveled slowly and training continued for 33 days after Lee's surrender at Appomattox.

In the latter half of the nineteenth century, the cattle business was booming and in 1879 an Irish-American, Patrick Dunn, settled the island. The "Duke of Padre" as he was called soon owned most of the island and grazed several thousand head of cattle. In 1926 he sold his vast surface rights but retained the mineral rights, a holding still owned by members of the Dunn family.

From the days of Padre Balli to well after Dunn sold out, the cattle business ruled the island. With the increased demand for hydrocarbons in the 1940s and 1950s, however, petroleum companies began exploring and drilling in the area. When some of Laguna Madre and a small amount of Padre Island were affected by this drilling, public interest began to call for the creation of a park.

In 1962 Congress enacted legislation to obtain land on Padre Island and to establish Padre Island National Seashore. The National Seashore stretches some 105 km along the coast and provides camping, swimming, and fishing for visitors. The National Park Service is charged with the responsibility of (a) managing a geologically dynamic environment, and providing for (b) the development of potential energy deposits, (c) increased recreational uses, (d) the protection of the environment, and (e) wildlife habitat.

The island is presently open to most park visitors only at North and South Beaches and in the Malquite Beach day-use area because no roads have been constructed down the

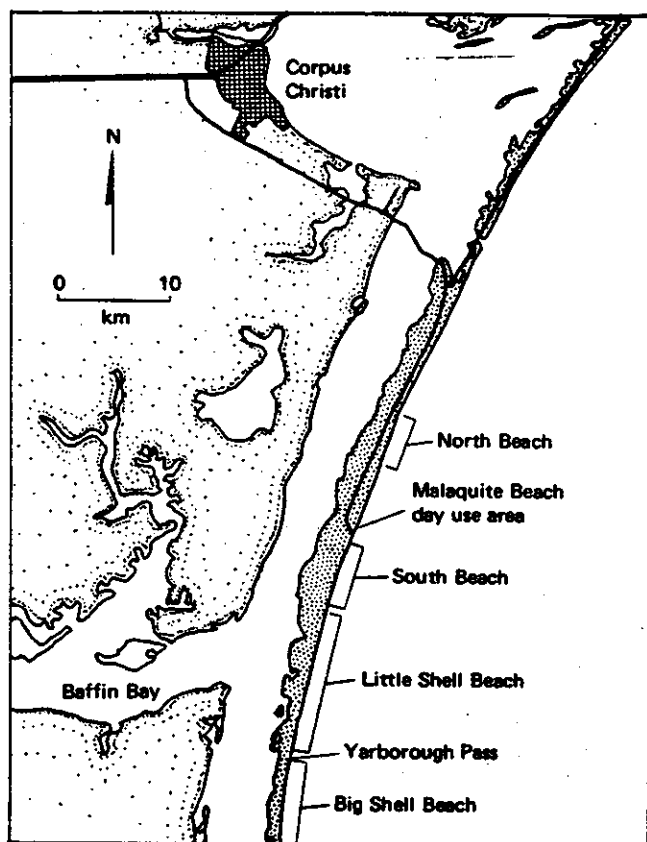


Figure 3 Padre Island National Seashore heavy-use areas. Conventional vehicles and the more than 1,000,000 annual visitors are confined to North and South Beaches and the Malaquite Beach day-use area.

island (Fig. 3). Thus traffic must move on the beach. Little Shell and Big Shell Beaches contain shell pockets that are impassable in conventional vehicles. As a result, a majority of the park visitors are confined to about 24 km of the entire 105 km of National Seashore. Since park visitation now exceeds 1 million per year, this heavy use must be distributed throughout more of the available island space to protect the existing barrier island environment. A proposed master plan calls for the closure of beach access and construction of a shell road behind the foredunes as far south as Yarborough Pass.

In contrast to the National Seashore, South Padre Island, lying south of Mansfield Pass, has become a major coastal area development with beachfront hotels and condominiums, second houses, and other related recreational and community facilities. Development of South Padre Island as of August 1978 has disregarded the geological processes acting upon the island. Hotels and condominiums line the beach and, in many cases, the foredune ridge has been removed to make room for beachfront construction. Residential zones have been developed behind the hotel complexes. Many houses and resort cottages have little or no foredune protection; others are built in proven washover channels.

Although Padre Island is only one barrier island complex, two fundamental land use planning and public safety requirements exist. Along the Island, land use decisions and engineering construction must consider the diverse interactions between man and the geologic environment. The interrelationships between irregular, intermittent events (hurricanes and storms) and uniform, recurrent events (daily winds, tides, and tidal currents) must be understood to improve park management decisions and to provide adequate public safety along South Padre Island. The significant land use planning contrast between the National Seashore and South Padre Island is that one of these is intended for temporary camping (primitive) habitation at limited sites, whereas the other is designed for permanent (civilized) habitation throughout the area.

ACTIVE GEOMORPHIC PROCESSES

In general, active geomorphic processes can be divided into two basic categories: (a) those related to hurricanes and other irregular, intermittent events and (b) those caused by daily winds and other regular, recurrent events. Hurricanes and storms are irregular in intensity and occur on an intermittent schedule, making them difficult to predict. Wind, on the other hand, is more regular in intensity and occurs more frequently, often having a cycle of a day or so.

Hurricanes have a significant impact on the geologic environment of Padre Island (Hayes 1967; McGowen et al. 1970). In general, a surge of high water washes through low places on the island, cuts passes, erodes the beach and dunes, and floods the back-island flats. These processes drastically alter the morphology of the island. The foredune ridge may be breached, new washover sands will cover parts of the vegetated flats, and washover channels may sever the island into a chain of islands. Once the storm passes, however, the uniform recurrent events once again become the significant geologic processes.

To identify the rate and magnitude of geomorphic changes occurring on Padre Island, historical geomorphic maps were constructed from aerial photographs. The island was divided into six geomorphic provinces: the beach, the foredune ridge, vegetated flats, wind-tidal flats, washover channels, and back-island dunes. Comparison of the maps reveals that daily shoreline processes alter island physiography rather slowly, but that large-scale, intermittent events produce rapid and drastic changes. These changes are described next.

Padre Island National Seashore

A study of historical aerial photographs of the Yarbrough Pass area suggests that uniform, recurrent events active on Padre Island are the significant processes to be considered in park management decisions and in the design and construction of engineering works (Mathewson et al. 1975; Mathewson 1977). In 1933 a hurricane formed both a major hurricane channel and a major foredune breach; another hurricane in 1936 probably reopened the breach in the foredune ridge. The 1937 aerial photogeologic map (Fig. 4) shows that the washover fan and the major hurricane breach have not revegetated. By 1943 the hurricane washover fan sediments were stabilized by grasses, the foredune ridge was discontinuous and partially vegetated, and the hurricane beach ridge had become an active dune field (Fig. 4). By 1953 the foredune ridge had reformed except for the southern end, where an aeolian chute had developed (Fig. 4). Between

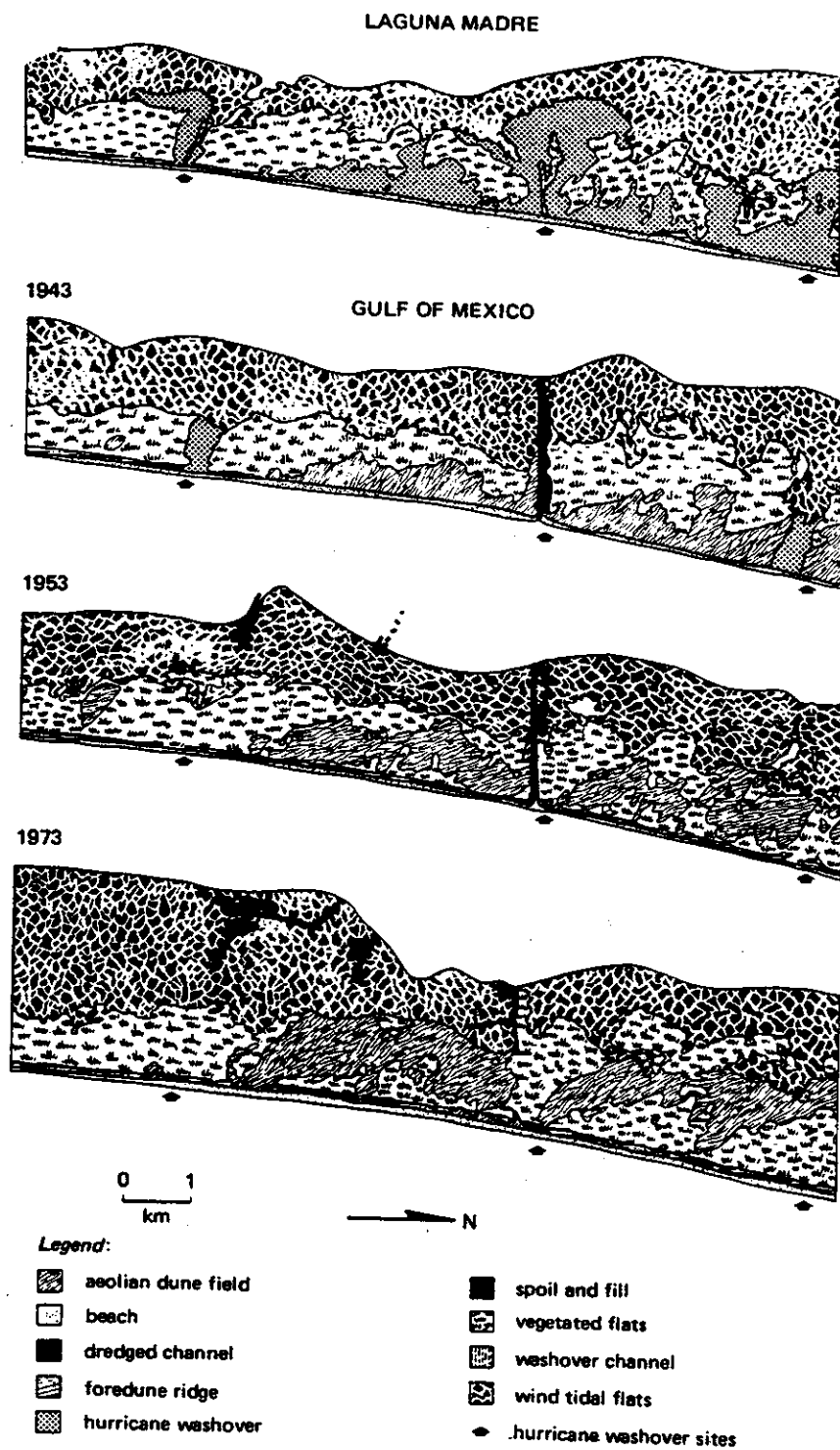


Figure 4 Physical environment maps of the area around Yarbrough Pass Padre Island National Seashore, showing the island environment in 1937, 1943, 1953, and 1973.

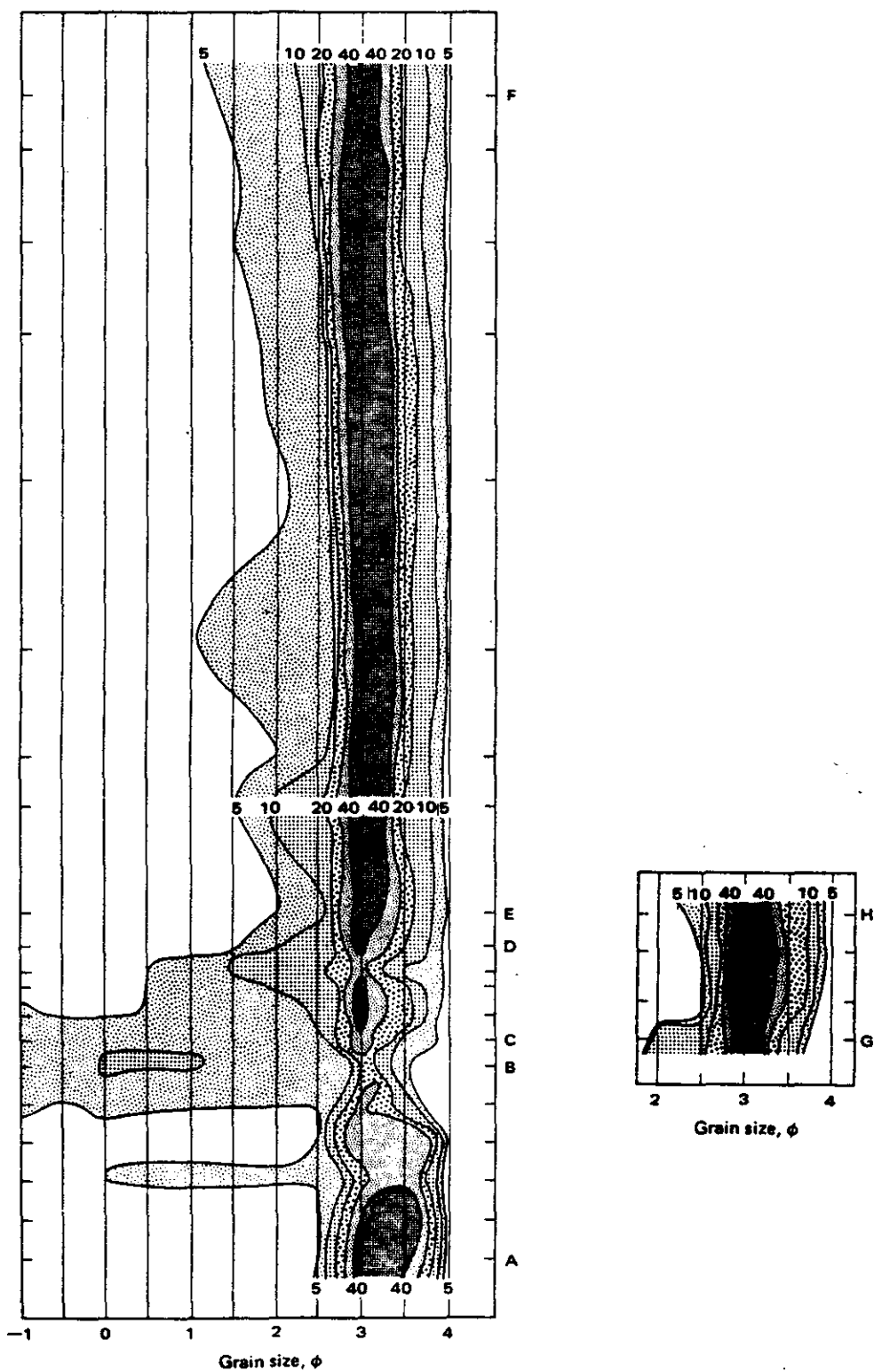


Figure 5 Dowling diagram of the distribution of sediment size along a transect from the first bar offshore to the wind tidal flats. Note the influence of aeolian sorting. Figure 6 shows the map location.

1953 and 1973, sand was continually added to the aeolian fan through the chute, lengthening it in the downwind direction. By 1973 the chute had effectively closed and the aeolian fan had crossed the vegetated flats and encroached onto the wind tidal flats (Fig. 4). Vegetation is now slowly stabilizing the head of the aeolian fan. As the sand in the aeolian fan continues to move lagoonward, it apparently will migrate onto the wind tidal flats and eventually form the back island dunes. With a storm of the intensity of that in 1933, the chute may be reopened or the dune wall breached, initiating the cycle again.

Sediment data collected from the aeolian fan at Yarborough Pass further support the process described in the photogeologic analysis. Figure 5 is a Dowling (1977) diagram of the grain size distribution along a series of profiles starting at the first offshore bar,

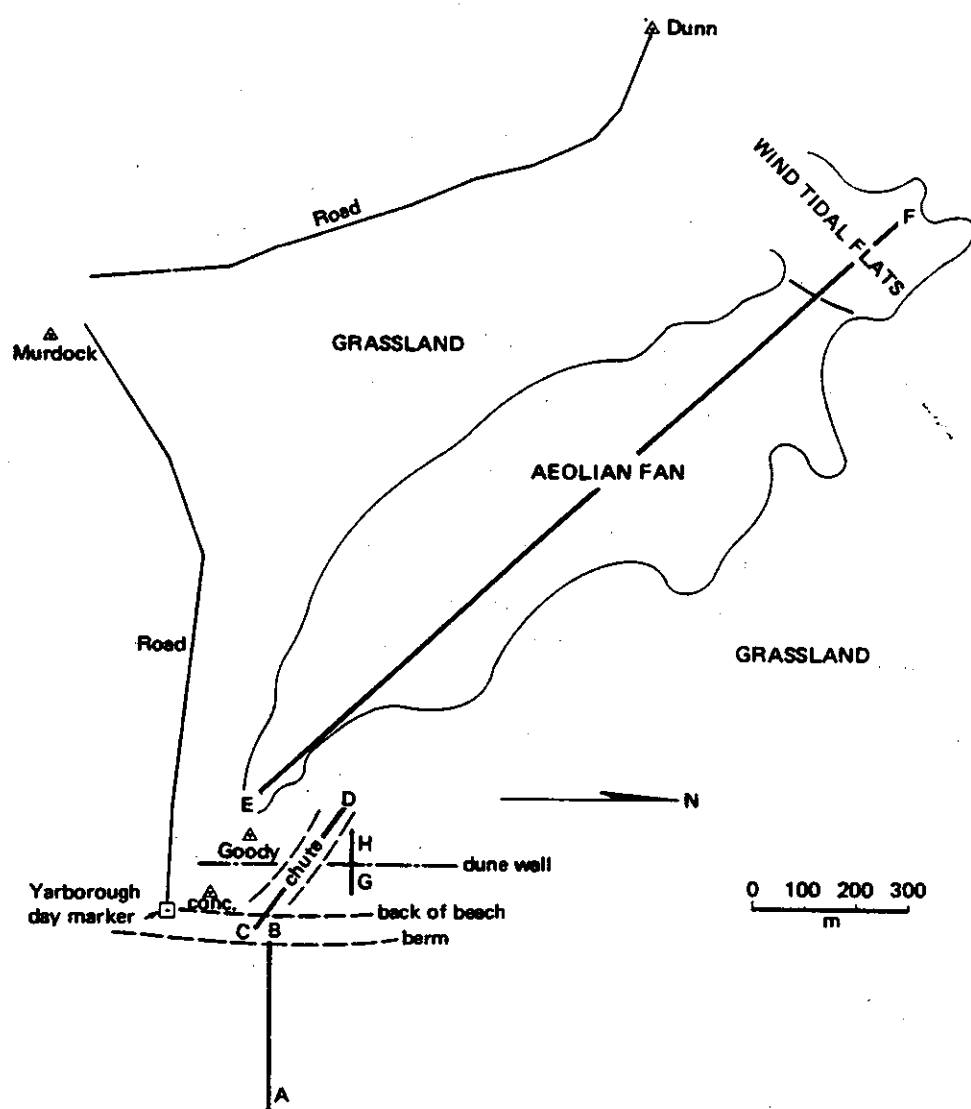


Figure 6 Map of transects along which samples were collected to construct the Dowling diagram in Figure 5.

crossing the beach and extending through the aeolian chute to the wind tidal flats at the back of the island (Fig. 6).

These results show that the sand in the aeolian fan and wind tidal flats is usually distributed and transported by aeolian processes. Note the similarity in the characteristics of the sand in the foredune ridge (profile G-H) to that in the aeolian fan. The sharp shift

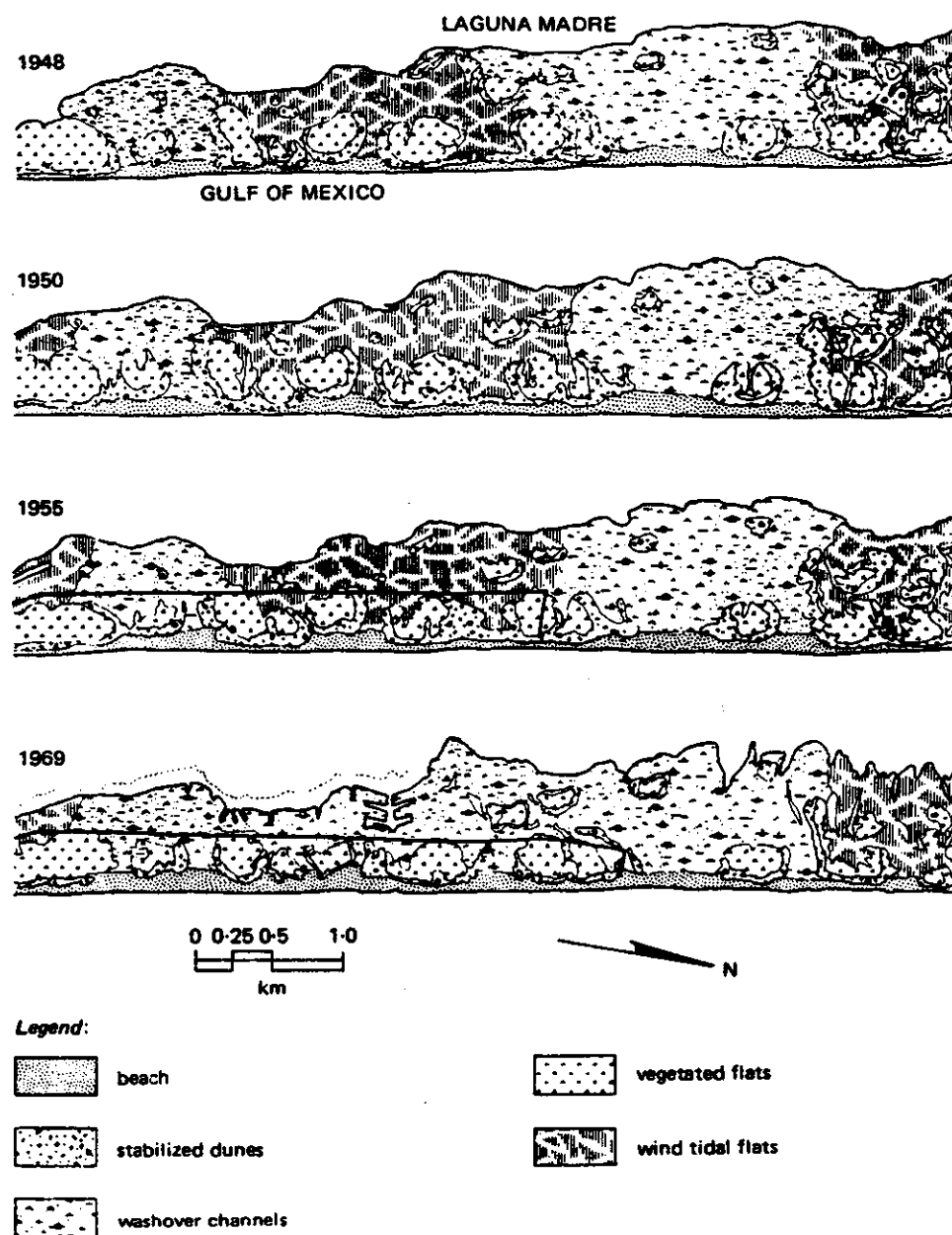


Figure 7 Historical geomorphic maps of South Padre Island (1948, 1969—NOAA photography; 1950, 1955—USDA photography).

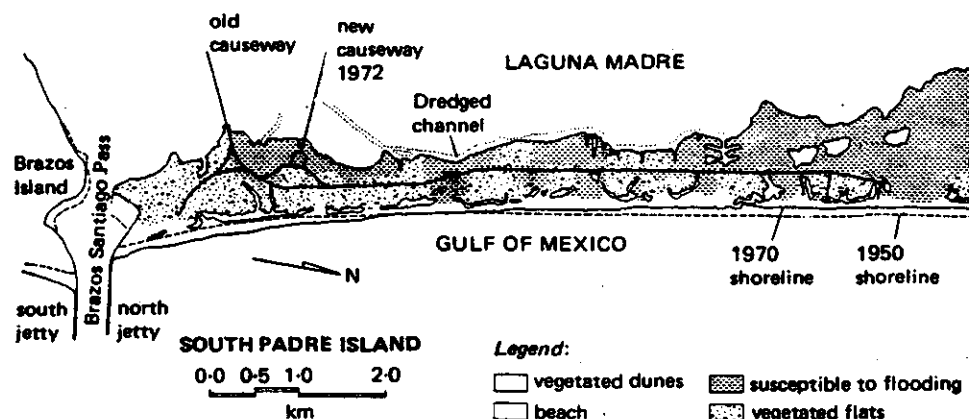


Figure 8 Shoreline changes along South Padre Island between 1950 and 1970.

to a coarser grain size in the head of the aeolian chute is indicative of higher wind shear caused by the funnel shape of the chute. This evidence is compatible with measured wind velocities at the head of the chute, which are 2 to 5 m/s higher than on the crest of the neighboring foredune. Mathewson (1977) suggested that the back-island dunes and aeolian fans on North Padre Island are the result of the same process: aeolian transport initiated by hurricane formation of a major foredune breach.

South Padre Island

Studies of historical aerial photographs of a portion of South Padre Island suggest that irregular, intermittent events are the significant geomorphic process to be considered in land use planning. Figure 7 shows that the various geomorphic provinces exist in approximately the same position for the years 1948, 1950, and 1955, whereas the 1969 map is dominated by a large washover channel and many openings in the foredune ridge. The 1969 map reflects the amount of alteration that the island experienced during Hurricane Beulah, an intermittent event, which struck South Padre Island in the fall of 1967.

Geomorphic data suggest that active aeolian processes that would act to alter the island morphology are inhibited by a lack of a sediment supply. The foredune ridge is not reconstructed and large dune fields do not exist. The 1948, 1950, and 1955 aerial photographs show only minor accretion of the existing vegetated foredunes.

A comparison of 1950 aerial photographs with 1970 aerial photographs demonstrates that the significant daily process is shoreline erosion or accretion (Fig. 8). This geomorphic process, however, is limited to high-value beachfront developments and does not represent a general risk to the entire island as does the hurricane.

LAND USE PLANNING

It is interesting to note that the analysis of historical aerial photographs near Yarbrough Pass, Padre Island National Seashore, and on South Padre Island suggest that these two sites are significantly different. Geomorphic changes in the National Seashore are due predominately to aeolian transport of sand, whereas those at South Padre are due pre-

dominately to hurricane and storm waves. As a result, land use planning decisions must not only consider the intended land uses but also the various geologic processes.

Padre Island National Seashore

The rapid reconstruction of the continuous foredune ridge, except at the aeolian chute, makes it impossible to predict where the next hurricane will breach the dunes. It is therefore not possible to establish high-hurricane-risk zones for the back island areas since no obvious washover site is preserved. The hurricane must be considered as a "rare" event that provides limited design alternatives for any park improvements. Structures should be designed and built to withstand scour, flooding, wave attack, and high winds or be sacrificed to the storm. Management choices should be based on economic considerations, cost-risk analyses, potential environmental hazards, and the goals of the park plan.

Aeolian processes, however, are preserved and can be evaluated through the use of historical aerial photographs. Once a hurricane has formed a major foredune breach, it is possible to predict where back-island areas will be affected by aeolian transport. The development of dune fields in the area progress through five stages (Fig. 9). The initial morphologic features include the beach, the foredune ridge, and vegetated flats which grade lagoonward into wind tidal flats. Sediment is deposited on the beach by wave action, sorted and transported by the prevailing southeast winds, and finally, deflected northward by the foredune ridge.

Aeolian transport across the island is inhibited when the foredune ridge and back-island flats are stabilized by vegetation. However, hurricane attack of the foredune ridge strips away the stabilizing vegetation and forms a hurricane beach, allowing aeolian processes to become highly effective (Fig. 9, stage 2). In the case of major and minor hurricane channels, the breach is narrow and such channels heal quickly when compared to a major foredune breach. In the area of a major breach, hurricane waves form a hurricane beach.

The hurricane beach is topographically higher than the surrounding flats and above the capillary fringe of the island freshwater lens. This higher elevation allows the sand to drain; thus, revegetation is slower and aeolian processes become the major transport mechanism. Reconstruction of the foredune ridge by aeolian processes, as described by Bagnold (1941) and Fisk (1959), closes the major foredune breach by forming scattered dunes which eventually coalesce. At the south end of the breach, high sediment transport and high wind shear apparently keep sand from being deposited (Fig. 9, stage 3), and an aerodynamically stable chute forms. The aeolian chute continues to serve as a conduit for sand that is transported to the back-island areas, producing the aeolian fan (Fig. 9, stage 4). At Yarbrough Pass, the chute is aligned with the prevailing wind and remained a transport route for windblown sand for more than 30 years.

Eventually the chute becomes inefficient because of encroachment of the vegetated foredune ridge and closes (Fig. 9, stage 5). Following the closing of the chute, the source of sediment for the aeolian fan is lost and the sand migrates across the islands as a dune field and eventually becomes the back-island dunes. This study suggests that the large active dune fields in the National Seashore were formed through long-term aeolian processes rather than through hurricane processes alone, as proposed by Boker (1953), Blankenship (1953), and Hayes (1967).

Engineering works and park management decisions on Padre Island must contend with both categories of active processes. With respect to hurricanes, management

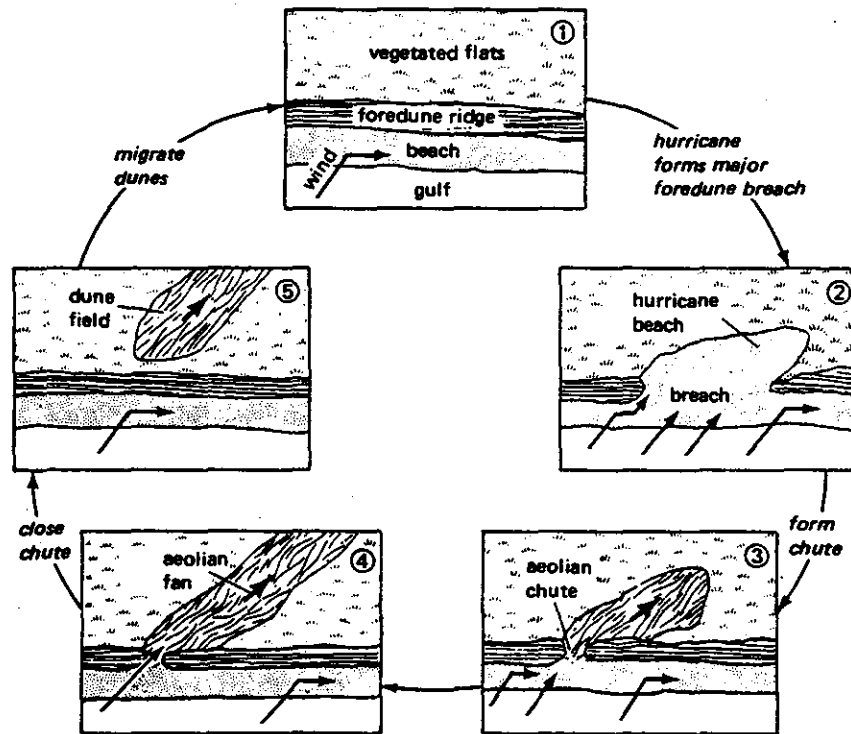


Figure 9 Schematic diagram showing the cycle of development of an aeolian fan and fields, based on studies of historical aerial photographs near Yarbrough Pass, Padre Island National Seashore. Initially, a hurricane breaches the foredune ridge and forms a hurricane beach. The breach gradually heals until the chute forms. Continuous sand transport through the chute forms the aeolian fan. Once the chute closes, the dune field migrates downwind.

decisions are usually limited to evacuation of personnel and visitors and to the closing down of operations. In terms of the engineering impact of hurricanes, structures can either be designed and built to withstand the storm or as sacrifice structures, depending upon economic and environmental considerations. Roads actually fit both categories, in that they are washed out in areas of high erosion and simply drowned by flooding in other areas. The net result of a hurricane is the cost of repair once the storm has passed, costs that should be incorporated into the design of the structure.

Rebuilding and repair after major storms should consider the post-storm island morphology with respect to the potential of modification by aeolian processes. It is impossible to predict the site of the next major hurricane breach in the foredune ridge; however, once the breach occurs the location of the related aeolian chute and fan can be predicted if it should develop. Thus post-storm reconstruction should consider the effect of aeolian transport as an economic parameter in the management decision.

South Padre Island

South Padre receives the full fury of the storm surge during the passage of hurricanes. Using the classification of the *Model Minimum Hurricane-Resistant Building Standards*

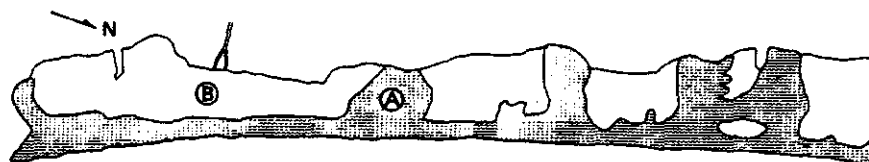


Figure 10 Hurricane hazard zones on South Padre. Zone A is susceptible to scour, battering with debris, flooding, and high winds. Zone B is protected from scour by the foredune but is susceptible to battering, flooding, and high winds.

for the Texas Gulf Coast (Texas Coastal and Marine Council 1976), the barrier island can be divided into two hurricane zones (Fig. 10). Zone A consists of areas open to the full impact of the storm surge, which includes the beach, the foredune ridge, and back-island areas directly exposed to the sea by washover channels. Structures built in zone A are subject to high-velocity winds, battering with debris, flooding, and scour. Areas protected by a continuous foredune ridge are not open to the high-velocity flow that causes scour, but they are still subjected to high winds, battering with debris, and flooding. Zone B would include back-island areas protected by a foredune ridge and not directly exposed to washover channels.

Low elevations combined with bulldozed openings in the foredune ridge on South Padre Island greatly increase the probability of back-island flooding and scour. The maximum elevation of the foredune ridge along South Padre Island is only 2.1 m above mean sea level, whereas the maximum storm surge height of hurricanes Carla and Beulah exceeded 4 m. The practice of bulldozing down the foredune ridge for hotel construction creates potential washover channels for future storms. This endangers back-island areas normally protected by a foredune ridge. In August 1978 tropical storm Amelia backed up sewer lines and caused flooding even though this was only a moderate storm. Although the entire island may be inundated when a hurricane strikes, the destructive force of the storm surge may be diminished by the establishment of a stable, continuous foredune ridge and vegetative cover on dunes and flats.

Although not as catastrophic as hurricanes, daily processes also have a lasting impact on the coastal regime. Shoreline changes result from the interaction of tides, sediment supply, storms, and sea-level fluctuations. The predominant southeasterly winds along the South Texas coast control the direction of the longshore currents as well as the angle at which waves attack the beach. LANDSAT photography indicates that the southern portion of the Texas coastline receives its sediment from longshore currents flowing northward from the Rio Grande delta.

Shoreline erosion cannot be prevented by man-made structures if there is not enough sediment in the system to allow deposition. To alleviate the problems of shoreline erosion and a low foredune ridge, the sediment supply should be renourished. Sand should be placed along the beach and allowed to be reworked by waves, and sand should also be placed in low spots in the foredune ridge and then stabilized by vegetation. There are several sources for sand on South Padre Island:

- (a) Presently, maintenance crews are removing sand dunes that are blowing across Park Road 100 north of the town and using the material as fill in construction sites on the mainland. This sand should be redistributed along the receding shoreline.

(b) Sand accumulating on the south side of the Brazos Santiago Pass or Mansfield Pass jetties could be used to renourish the beach.

In addition to renourishing the sediment supply, other methods of stabilizing the island and preventing back-island erosion and scour during hurricanes include prohibiting building and traffic along the beach, preventing foredune destruction for construction purposes, and establishing a dense vegetative cover where possible.

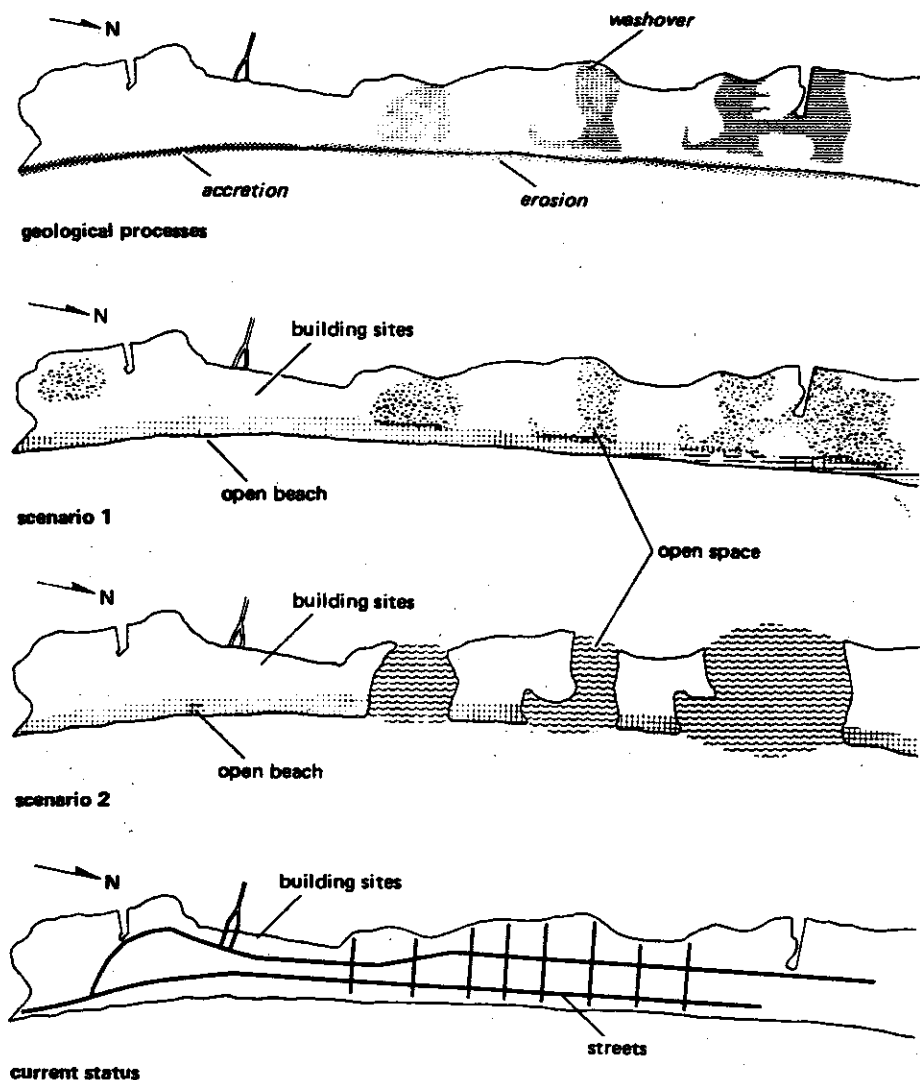


Figure 11 South Padre land use planning scenarios based on the geologic processes. The beach and washover areas are maintained as open spaces in order to minimize losses due to storms. The open washover channels act to relieve storm surge pressures and thereby help protect the foredunes. Note that the current status of land use on South Padre does not recognize the geologic processes.

Based on an understanding of the geological processes affecting South Padre Island, two planning scenarios are suggested that would greatly enhance public safety (Fig. 11). Scenario 1 identifies the hazards of shoreline erosion, destruction of structures in wash-over channels, inundation of the island in the event of a severe hurricane, sewer backup and water shortages, and temporary halt of vehicular movement. Under this scenario washover areas are designed as open spaces and residential development is confined to the stable portions of the island (i.e., back-island areas protected by a foredune ridge). It is recommended that performance standards for building construction and programs for renourishment of the depleted sediment supply be adopted by the city. Scenario 2 includes the conditions of scenario 1 but also considers potential separation of the island areas between washover channels, which may occur in the event of a particularly disastrous hurricane. Emergency facilities, residential zones, and high-cost commercial buildings are confined to the most stable portions of the island. A comparison of the current status and the geologic processes maps reveals that geology has not been considered in the development and land use planning on South Padre Island.

CONCLUSIONS

The application of geologic and geomorphic process information into land use decision making involves more than simply identifying hazardous areas. Any scenario that proposes restrictive land use, such as open space in washover areas or downwind of aeolian fans, must consider the constitutional rights of private land ownership. The site best suited to the direct application of geologic design is a site under single ownership, such as the case in the National Seashore. In South Padre, where multiple ownership exists, the concept of a "joint land corporation" or a "Padre Island Development District" in which landowners' shares are based on the value of their land could allow the same design flexibility afforded a single owner.

In addition to the problem of land ownership is the problem of defining land use zones rather than total density zones. It is impossible to recover any investment if density decreases caused by establishing open spaces are not compensated by allowing higher-density uses in other areas. Classical approaches to urban planning must also respond to the availability of geologic information.

REFERENCES

- Bagnold, R.A. 1941. *The physics of blown sand and desert dunes*. New York: William Morrow, 265 p.
- Blankenship, W.R. 1953. Sedimentology of the outer Texas coast. Master's thesis, Univ. Texas, 72 p.
- Boker, T.A. 1953. Sand dunes on northern Padre Island. Master's thesis, Univ. Kansas.
- Dowling, J.J. 1977. A grain size spectra map. *Jour. Sed. Petrologists* 47(1), 281-84.
- Fisk, H.N. 1959. Padre Island and the Laguna Madre flats, coastal south Texas. 2nd Coastal Geol. Conf., La. State Univ., Baton Rouge, 103-51.
- Hayes, M.O. 1967. *Hurricanes as geological agents: case studies of hurricanes Carla, 1961, and Cindy, 1963*. Univ. Texas, Bur. Econ. Geology Rept. Invest.

- Mathewson, C.C. 1976. Active geologic processes on Padre Island National Seashore - impact on park management. Abs., First Conf. Sci. Research in the National Parks, New Orleans, La., Nov.
- Mathewson, C.C. 1977. Beach washouts, an adverse effect of artificial dune construction. *Assoc. Eng. Geologists Bull.* 14(1).
- Mathewson, C.C., J.H. Clary and J.E. Stinson II 1975. Dynamic physical processes on a south Texas barrier island - impact on maintenance. Ocean 1975, Conf. of Engineering in the Ocean Environment and 11th Ann. Mtg. of the Marine Technol. Soc., San Diego, Calif., Sept. IEEE Pub. 75 CHO 995-1 OEC, 327-30.
- McGowen, J.H., C.G. Groat, L.F. Brown, Jr., W.L. Fisher and A.J. Scott 1970. *Effects of hurricane Celia - a focus on environmental geological problems of the Texas coastal zone*. Univ. Texas at Austin, Bur. Econ. Geology, Geol. Circ. 8-3, 35 p.
- Texas Coastal and Marine Council 1976. *Model minimum hurricane-resistant building standards for the Texas Gulf Coast*. General Land Office of Texas, Austin, Tex.

