Geologists, Engineers, and a Rising Sea Level

Orrin H. Pilkey (b. 1934) is the James B. Duke Professor of Geology and director of the Program for the Study of Developed Shorelines at Duke University. He also serves on the Committee on Beach Nourishment and Protection of the National Academy of Sciences' National Research Council. A winner of both the Society for Sedimentary Geology's Francis Shepard Medal for excellence in marine geology (1987) and the American Geological Institute's award for outstanding contributions to public understanding of geology (1993), Pilkey has earned a reputation as one of the most outspoken critics of efforts to manage erosion along America's coastline.

In the following selection taken from "Geologists, Engineers, and a Rising Sea Level," *Northeastern Geology,* (vol. 3, nos. 3/4, 1981), Pilkey focuses on attempts to stabilize rapidly eroding barrier beaches, although he maintains that his analysis applies to any sandy shoreline. Pilkey's sardonic, but serious review of the methods employed by the U.S. Army Corps of Engineers leads him to conclude that shoreline engineering is not only ineffective in the long run, but that in the short run it is a contributing factor to beach destruction. In his view, much of the Corps' work involves the use of taxpayers' money to offer temporary protection to coastal property owners at a price that is far in excess of the worth of the property, and at the additional environmental cost of promoting the destruction of public beachfront. He suggests that if the American public were properly educated they would keep engineers away from ocean shoreline.

Pilkey, along with coastal policy reform activist Katharine L. Dixon, has expanded on these arguments and analyses in their recently published book *The Corps and the Shore* (Island Press, 1996).

Key Concept: most engineering efforts to stabilize coastal beaches are ecologically counterproductive

If an engineer is asked for his opinion on an open ocean shoreline erosion problem, he will suggest a solution with alacrity. With equal alacrity, a geologist will point out that there is no solution. Both are right. The engineer is right in a 20 to 30 year sense, and the geologist in a 50 to 150 year sense. No wonder that most pragmatic politicians' responses to a shoreline geologist's suggestion, is, "Who needs geologists?"

Most stretches of the American shoreline are eroding. Erosion is particularly widespread along our barrier island coasts. Many natural factors are involved in causing erosion, among which are sand supply, storms, changes in wave regime, and changes in bottom topography. Along developed shores man often becomes the principal cause of erosion. Sea walls, jetties, and groins all reduce shoreline flexibility and ultimately cause problems.

Underlying and reinforcing all causes of shoreline erosion is the sea level rise. Both the present rapid rates of shoreline retreat and the wide occurrence of such retreat can be laid at the doorstep of the sea level rise. Unfortunately none of the various shoreline stabilization schemes used by engineers responds to the sea level rise, the major cause of the problem they seek to alleviate. The long range result of treating the symptoms instead of the cause is destruction of the beach.

Understanding the disagreement between geologists and engineers is important because the future of the American recreational shoreline is at stake.

In the following discussion emphasis is placed on the effect of engineering on open ocean barrier island beaches. This is because most of the U.S. Gulf and Atlantic open ocean shoreline is on barrier islands and also because these systems, compared to rocky mainland shores, are more uniform and perhaps less complex. Nonetheless, most of the principles developed apply to any type of sandy shoreline.

THE SEA LEVEL RISE AND BARRIER ISLANDS AND BEACHES

Evidence from the continental shelf developed by Swift (1975) and Duane and Field (1976) indicates that barrier islands fronting all of the American coastal plain coasts probably formed at the shelf edge. After formation the islands migrated to their present position in response to the Holocene sea level rise. During their period of cross shelf migration the barrier islands must have been skinny (Table 1), judging from the fact that barrier islands today that are migrating rapidly are very skinny (e.g., Capes Island, South Carolina). It does not follow, however, that all skinny islands are migrating rapidly.

As the sea level rise slowed down, 4 to 5,000 years ago, many barrier islands began to fatten or grow seaward, e.g., Bogue Banks, North Carolina; Galveston Island, Texas. Fattening occurred on islands with large sand supplies. With few exceptions, the fattening of American barriers halted a few

From Notable selections in Environmental Studies
Dushkin/McGraw Hill
Edited by Theodore Goldfarb
2000 — 395 p.

TABLE 1

A Sketch History of Barrier Islands

Origin–15,000 years ago–
Islands formed at shelf edge.

Skinny island phase–15,000–4,000 years ago–
Islands migrated or hopped across the shelf in response to the Holocene sea level rise.

Fat island phase–4,000–300 years ago–
Many islands grew seaward in response to the slowdown in the sea level rise.

Slimming down phase–300 years ago to present–
Islands are slimming down in response to a sea level rise. The rise has accelerated within the last 50 years. Slimming prepares islands to migrate once more.

hundred years ago to be replaced by frontside retreat, probably in response to an increased rate of sea level rise once again.

Tide gauge studies by Hicks (1972) indicate that 50 or so years ago sea level rise rate took a major leap. It is now eustatically rising at a rate of close to one foot per century. Whether this sea level rise is a momentary "blip" on the sea level curve or the start of a major long-continued rise is unknown. Even the cause of the 50-year jump in rise rate remains a mystery; is the ice melting, is the melting due to the greenhouse effect or is a mid ocean ridge bulging?

The net result of the recent sea level rise is to cause erosion on both sides of many American islands. From a broad viewpoint this erosion can be seen as a "slimming down" of the islands, preparatory to continued landward migration, assuming that the sea level rise continues unabated. Rapidly migrating islands must widen themselves on their backsides over a broad front (Leatherman, 1979). The only way to do this is to allow complete cross-island overwash along a broad front; hence the need to slim down.

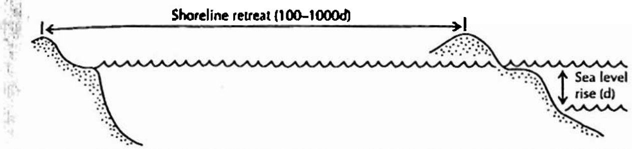
The evidence (other than tide gauge records) of a eustatic sea level rise is best seen on barrier islands. The most pertinent evidence is the fact that almost every "old" community on the front side of a barrier island is in trouble. If an "old" town has no frontside problems, it inevitably means that no one built on the frontside or more likely that a block or two of houses has been allowed to peacefully fall in when their time came. In other words, the community kept engineers off their beaches.

Other lines of evidence pointing to a eustatic sea level rise are the widespread direct (aerial photos, charts) and indirect (stumps, saltmarsh peat on beaches) indicators of frontside erosion. Recently on Whale Beach, New Jersey, marsh mud containing cow hooves and colonial implements appeared after a northeaster (Norbert Psuty, pers. comm.). This indicated a migration of

FIGURE 1

The Effect of Sea Level Rise on Shoreline Retreat

How a Shoreline Responds to a Rising Sea Level



at least one island width since a colonist dumped his garbage in the salt marsh. In North Carolina widespread killing of certain tree species with low salt tolerance along the fringes of Pamlico and Albemarle Sounds reflects flooding by a rising sea.

Because of all the factors involved, it is difficult to directly relate sea level rise with shoreline erosion rate over a time span of a few years. However, Rosen (1978) states that the sea level rise accounts for all shore retreat in the Virginia Chesapeake Bay shoreline. Morton (1979) finds a very general correspondence between Texas shoreline movement and sea level change.

Two additional important points must be made regarding the relationship between the sea level rise and shoreline erosion. First of all, the rate of retreat should be roughly a function of the slope of the land surface over which the sea is flooding. Steep slopes produce slow migration rates; gentle coastal plain surfaces should produce a shoreline retreat 100 to 1000 times the sea level rise (Fig. 1). A one foot rise should cause a retreat of 100 to 1000 feet. The second point is that the retreat of a beach is not just a surf zone retreat. Instead the entire shoreface probably moves landward as suggested in Swift's model of continental shelf evolution. Bruun (1962) proposed that a beach moves up and back and retains its same surf zone profile as the sea level rises. This is not in conflict with Swift's ideas. Swift has simply looked at shoreline movement on a larger scale (Fig. 2).

WHAT ENGINEERS DO

To begin with, engineers respond to a perceived public need. They respond to a public outcry to "save the beach" or "save our cottages." Frequently the former phrase is used when the latter is really meant. In the long run abundant evidence indicates that engineering destroys open ocean beaches. However,

FIGURE 2

Comparison of the Bruun Rule and the Swift Model of Shoreface Response Elements to the Sea Level Rise

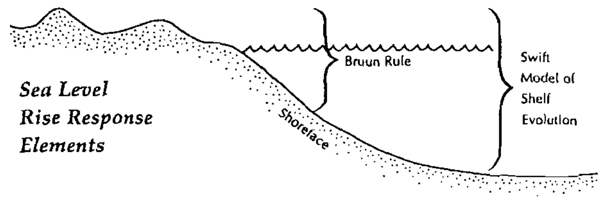


TABLE 2

The Truths of the Shoreline

I.	There is no shoreline erosion problem until someone builds something on the beach to measure it by.
II.	Construction on the beach reduces flexibility and in itself causes erosion.
III.	The interests of beach property owners should not be confused with the national interest.
IV.	Once you start stabilization, you can't stop.
V.	The cost of saving beach property is, in the long run, greater than the value of the property to be saved.
VI.	In order to save the beach, you destroy it.

Source: Pilkey *et al.*, 1980.

if short run preservation of beach front buildings is deemed the purpose of shoreline engineering, then engineers are much more successful.

It is important to point out that not all shoreline engineering structures that one sees on beaches were placed there by trained engineers. However, on the open ocean, high energy shoreline, few structures have been built without some expert design help. It is also important to note that sometimes engineers are forced for economic and political reasons to carry out projects that they know full well will cause serious environmental damage.

Table 2 is a summary of the truths of the shoreline; a set of carefully researched, incontrovertible, unassailable, precise generalizations. What engineers basically do to the shoreline in order to stabilize it is shown in Table 3. None of these approaches in any way addresses the sea level rise.

The gentlest thing that can be done by an engineer to a beach is replenishment. Replenished sands disappear faster than natural beaches as a rule for

TABLE 3

What Engineers Do to Beaches

I	Replace sand	replenishment
II	Trap sand	groins, jetties breakwaters
III	Block wave energy	sea walls, bulkheads, revetments

Note: I is a nonstructural "solution," II and III are structural "solutions."

two reasons. The most obvious problem is that, for good economic reasons, sand is only pumped onto the upper shoreface. Thus the beach is steepened and in order to come to a natural equilibrium the sand is soon scattered across the shoreface, most of which is below the tide line. Perhaps a more fundamental problem is that because of the sea level rise the "equilibrium island" or equilibrium profile should continue to be displaced landward of the stabilized shoreline and each successive replenished beach should be more unstable (and disappear more quickly). The replenished beach at Wrightsville Beach, North Carolina, disappeared 10 times faster than the natural erosion rate. It remains to be seen how rapidly the second replenishment project (1980) disappears.

Since replenishment is a relatively gentle thing to do to a beach, it is not unreasonable to ask, "Why replenish all of our problem areas?" The first and most obvious reason is cost. *Fifteen* miles of Miami Beach were replenished at a cost of 65 million dollars. A second factor is the effect of replenishment on development. The initial replenishment often takes place when development is relatively light. The new beach, however, adds time which is used by developers to increase density of development. The increased density and building size provides an increasing political power base which fosters additional replenishment projects but ultimately (in 50 years?) eliminates all alternatives to shoreline management except the inevitable sea wall.

Groins and jetties and other structures emplaced perpendicular to the beach hold sand in place by reducing longshore currents. Breakwaters work in the same way. The problem here is that the long range and long distance effect of sand trapping is impossible to predict. Morton (1979) estimates that sand trapping structures on the relatively undeveloped Texas shoreline have already tied up 50 percent of the longshore drift sand supply from eroding headlands. One would suspect that every grain of sand has been trapped on the much more heavily developed and heavily engineered New Jersey shore. Seasonal effects are often poorly understood. Engineers have proposed to place groins off Ocean City, Maryland. Statements have been made to the effect that no damage should accrue to the Delaware shoreline since it is "upstream" and net sand movement is to the south, away from Delaware. However, during the winter large amounts of sand travel north from Maryland to Delaware and hence the groins are likely to cause damage to Delaware beaches by cutting off their winter supply.

Designing groins and evaluating their potential effects on the basis of known net transportation rates is a common engineering error. Consider, for example, the part played in the shoreline longshore drift equilibrium picture by the 5 year, 10 year, 20 year, etc. storm. Storms that move sand in strange directions and quantities can't be plugged into formulas and hence are considered to be natural disasters by engineers. Geologists consider storms to be part of the system to be worked with even if we can't predict their role. Paul Komar (pers. comm.) points out that jetties caused severe beach erosion and loss of the town of Bay Ocean, Oregon, even though there is no net transport of sand on Tillamook Spit. The jetties caused the inner shelf to change shape, the changed shape refracted waves, refracted waves caused erosion, and buildings fell in.

The worst thing that can be done to a natural shoreline system is construction of a sea wall. As pointed out in the Corps' Shoreline Protection Manual (Corps of Engineers, 1975), wave reflection and other effects eventually remove beaches from the front of sea walls.

Discussing the effect of sea walls is a good time to bring in the concept of New Jerseyization, the end point of the walled open ocean shoreline in a rising sea level. New Jerseyization, a 50 to 150 year phenomena, can be viewed in any number of "old" New Jersey islands or shore communities such as Sea Bright, Monmouth Beach, Long Branch, Cape May, and many others. New Jerseyization is a phenomenon not restricted to New Jersey, however. Other American beach communities such as Ocean City, Maryland; Wrightsville Beach, North Carolina; Folly Beach, South Carolina; much of south Florida; Holly Beach, Louisiana; and South Padre Island, Texas (to name a few) are well on their way.

The classical New Jerseyized beach is no longer a beach except perhaps at low tide. The upper foreshore is scattered with debris from destroyed sea walls and groins of an earlier generation. Swimming is dangerous, but fishing is probably improved because of the multitude of habitats. The present sea wall is a massive and impressive structure. However, winds of 25 mph are capable of producing sea wall topping waves and during genuine storms, the volume of water pouring over and through the wall is impressive. The problem is that the shoreface has steepened considerably and all waves, big or small, break directly on the wall. By the time a developed shoreline has matured to the point of New Jerseyization, the equilibrium profile (where the beach wants to be) is 10's or hundreds of meters landward, the shoreface has steepened to the point where replenishment is no longer an economically viable alternative, and the island or beach has become a fortress. All the community can do hereafter is build bigger and better seawalls.

In spite of the massive evidence that New Jerseyization is the long range inevitable endpoint of open beach stabilization, sea walls are sprouting like dandelions. In 1979 David fathered new ones on at least three islands in Georgia. The attitude of the cottage owner is: I can't just let my house fall in, can I? But it is shortsighted in the extreme to respond to the few individuals whose homes are endangered when one considers that the long range effect will be to destroy a resource that is used by a much larger public.

The greatest sea wall in America's Atlantic or Gulf Coasts is the massive Galveston wall. It was built in response to the Hurricane of 1900 that killed 6,000 people in Galveston. Since the flooding that killed most of the people probably came from the backside, the structure was built on the front side. Over the years what was once a wide beach in front of the wall has largely disappeared. At the base of one end of the wall, a row of boulder rip rap was placed to protect the wall from undermining. A while later a second row of rip rap was emplaced to protect the first row of rip rap. Now a third row of rip rap is planned to protect the second row of rip rap which was emplaced to protect the first row of rip rap which protects the base of the sea wall. The sequence of riprapping is a vivid demonstration of the shoreface steepening effect of a stabilized shoreline in a rising sea level....

The Final Word: Open ocean shoreline stabilization in the long range results in loss of the taxpayer's beach in order to protect the property of a very few at a cost in taxpayers' dollars greater than the property is worth and, of course, the very few whose property is being saved cause the problem to begin with just by being there!

DO ENGINEERS EVER DO ANYTHING USEFUL?

Thousands of houses along miles and miles of stabilized American shorelines owe their very existence to engineering structures. The rising sea level and the migrating barrier island would have long since caught up with them had it not been for the sea walls and revetments fronting the beach. On the other hand many of these communities have been New Jerseyized; all that's left of their original *raison d'être* is the sea breeze.

What would have happened if the shorelines had not been stabilized or engineered? The answer is that the front row or two of houses would no longer exist; third avenue would now be front street, and a thriving beach and beautiful sea view would be there for all to enjoy. No private or public funds would have been wasted on engineering schemes and the future would not require a heavy tax burden to build bigger and better seawalls. Big storms striking non-engineered beach communities will destroy houses, but the same storm on an engineered beach will also destroy houses.

What are we to do with the beaches of New York City such as Coney Island where a hundred thousand or more people may frolic on a sunny day? Should we allow them to respond to the sea level rise and watch as ferris wheels, roller coasters, and apartment buildings fall in? Of course not. Costly beach preservation procedures are fully justifiable to preserve and even enhance these critical natural resources. The question is, where does one draw the tax money line between 100,000 swimmers a day on Coney Island, New York, and 100 beach cottage owners on Wrightsville Beach, North Carolina?

The Corps of Engineers carries out demonstration projects along "quiet" water shorelines to experiment with new ideas on shoreline stabilization. Although conceived by some of the best brains in shoreline engineering and in spite of the fact that a great deal of ingenuity is exhibited in increasing effectiveness at lower costs, the structures still block wave energy, replace sand, or trap sand (Table 3). No one seems to sit back and ask the perfectly logical question: "How can we respond to the sea level rise?"

One unique approach that *would* take into account the rising sea was conceived by some National Park Service bureaucrats from Fire Island National Seashore. They have suggested that instead of pumping sand on the front side of the island, in the future it should be pumped on the backside. The sand would come from maintenance dredging of the intracoastal waterway. *This would migrate the island artificially.* There are, of course, some political problems with this. Home owners on front sides will be required to be good sports as their houses fall in, but their sportsmanship will be greatly aided by tax-supported federal flood insurance which will pay for their lost houses. Engineers have proposed alternative schemes for Fire Island management involving, you guessed it, sea walls, groins, jetties, and beach replenishment at a great cost to the taxpayers.

What other approaches can be taken as alternatives to stabilization? How about moving houses back as the shoreline retreats? The wrecking ball may have to be used on big structures, an approach actually suggested by some New Jersey officials. How about declaring front row conservation easements after the next hurricane; i.e., don't allow reconstruction next to the beach? How about establishing minimum construction standards for seawalls and groins (an idea given to me by engineer Jay Langfelder)? This would allow people to stabilize their beach with structures that would withstand the 5-year storm but not the 10-year storm. The homeowner thus will gamble on when the 10-year storm will occur while hopefully such temporary stabilization will not wipe out the beach. Care must be taken not to allow the temporary structures simply to be replaced. Stabilization schemes billed as temporary or stop gap have a consistent history of not only becoming permanent but also "bigger and better."

Best of all, why not do nothing? Is this really an unreasonable or irrational or irresponsible approach in view of the long range costs and effect of non-do-nothing engineering? The National Park Service came to the do-nothing alternative after long study. On Cape Cod National Seashore parking lots are being designed to be constructed with beach gravel so that when (not if) they fall in, no one except a harried bureaucrat will know.

Table 4 summarizes the good and bad points of the major approaches to shoreline management including doing nothing.

TABLE 4

Summary of the Long Range Economic and Environmental Effects of the Various Alternatives Open to Barrier Island Managers

	Preserves the beach?	Preserves houses?	Responds to Sea Level Rise?	Cost to Taxpayers?
Beach replenishment	Yes	Temporarily	No	Yes
Groins, jetties	Temporarily	Temporarily	No	Yes
Seawalls	No	Yes	No	Yes
Do-Nothing	Yes	No	Yes	No
Artificial Migration	Yes	No	Yes	Yes
Minimum construction standards	Probably	Temporarily	Yes	No

GEOLOGISTS AND ENGINEERS: DIFFERENT WAYS OF LIFE

A major problem in communication exists between engineers and geologists at the shoreline. Engineers faced with design criteria are forced to quantify the natural environment. Geologists tend to do a lot of arm waving instead, but nonetheless, have a better intuition for the long range view of shoreline processes. Table 5 is another carefully researched, incontrovertible summary of the differences between the engineering and the geological way of life.

The need to quantify is understandable. The mistake comes when the engineers actually believe their numbers. The complexities of a sandy shoreface are not about to be pinned down in equations that are meaningful in any long range sense.

Accepting numbers as "solid facts" tends to cause engineers to minimize potential damage caused by their structures. In fact, it is crucial to remember that anything and everything done to stabilize a beach is a long range (and perhaps short range) "environmental mistake." Perhaps the "environmental mistake" is acceptable in the equation relating human needs, politics, and economics. However, if the potential environmental damage of beach stabilization is simply brushed aside by confident engineers with impressive computer models, poor decisions will be made by beach community decision makers....

The following is a quote from the author of a prominent textbook on coastal engineering:

> "The subject of sea level hardly warrants a comment. [Problems caused by rising sea level] will be solved by future generations."

The first part of the quote probably represents a minority view among coastal engineers. Most believe that the sea level rise is an important cause of erosion. It is my opinion, however, that a good portion of the "old guard" of coastal engineering still does not accept a widespread sea level rise or even

TABLE 5

The Differences Between Coastal Engineers and Geologists

	Engineers	Geologists
Reason for shoreline study	Stabilization	Stabilization; understanding of depositional-erosional processes; ancient environmental interpretation
People versus environment	On the side of people	On the side of the environment
How quantitative?	Highly quantitative	Arm wavers
Belief in beach "numbers"	Highly confident	Totally skeptical
View of the beach	A beach is a beach	A beach is a component of the continental shelf and of a barrier island chain, etc.
View of nature	Something to be defeated	Something to be lived with
Time viewpoint	Very short	Very long
Confidence in ultimate success of shoreline stabilization	Over confident	Totally skeptical

the evidence of ubiquitous erosion. Solving erosion on a crisis by crisis basis without recognition of the overall problem can only result in a disaster for the American shoreline. The second part of the quote regarding future generations is the very essence of engineering mentality! Future technology will come to the rescue so damn the torpedoes! However, for miles and miles and miles of New Jerseyized shoreline there is no economically feasible solution. The future is here! We *are* the future generation and now what?

There is no question that given enough money an engineer would be able to solve *any* shoreline problem. If money were no object, even a geologist could solve the problems. With replenishment costs running at 1 to 5 million dollars per mile and climbing at a rate similar to the rate of shoreline development, the point of no return has been reached.

Short sighted approaches to the open ocean shoreline continue to abound. Recently the Corps announced a *permanent* solution to Ocean City's severe erosion problem in the form of a massive steel bulkhead accompanied by replenishment. If a decade or two is "permanent," then the statement is not misleading. But citizens of Ocean City should have been told that the solution would mean they will be New Jerseyized at great cost to themselves. Engineers on Folly Beach, South Carolina, have proposed a small beach replenishment project by taking sand from the lower beach and putting it on the upper beach. This will very likely increase the erosion rate!

Another quotation from an engineer shown below illustrates another point of difference between geologists and engineers:

> "This project (the new Miami Beach) should last indefinitely providing a major storm doesn't come by."
>
> —Miami District Corps of Engineers Official

To a geologist the storm is a perfectly predictable and essential part of the natural system. Engineers know about storms too. But when they come, all bets are off on design life because of this tragic act of nature that's gone and messed things up.

Geologists also feel that most engineers have a narrow view of the shoreline systems. A beach is a beach, an inlet is an inlet, and they are not perceived to be part of a large and complex barrier island chain-continental shelf system. This results in a practice best described as "bandaid engineering." That is, the immediate problem is "solved" with minimum regard or understanding of the impact on other beaches, islands, lagoons, inlets, etc.

THE BOTTOM LINE

The time has come to bite the bullet and either do nothing at the shoreline or at least respond to what's causing the problem—the sea level rise. Suggestions to do nothing usually elicit comments such as this:

> "This do-nothing philosophy may have suited the times of King Canute in the 11th century when population was limited and few people had time or inclination to visit the coast, but it is unacceptable to the general public in 20th century America where the federal government has taken the responsibility to provide for the general public welfare."
>
> —Corps of Engineers (CERC) geologist

The do-nothing suggestion made to a beach cottage owner elicits far more colorful comments with even longer sentences.

Nonetheless, a strong case can be made that shoreline stabilization does not provide for the general public welfare. In fact, it has been a massive long range failure on American open ocean shorelines. The American public must be told what the long range costs and effects of stabilization will be. The net result of such education almost surely will be to keep the engineer off and away from the open ocean shoreline.

REFERENCES

BRUUN, P., 1962, Sea level rise as a cause of shore erosion: Jour. Waterways and Harbor Div. A.S.C.E. Proc. 88, p. 117–130.

CORPS OF ENGINEERS, 1975, Shore Protection Manual. Vols. I, II, III.

FIELD, M.E., and DUANE, D. B., 1976, Post Pleistocene history of the U.S. inner continental shelf: Significance to origin of barrier islands: Geol. Soc. America Bull., v. 88, p. 734–736.

HICKS, S. D., 1972, On the classification and trends of long period sea level series: Shore and Beach, v. 40, p. 20–23.

LEATHERMAN, S. P., 1979, Barrier Island Handbook: Privately published, 101 p.
MORTON, R. A., 1979, Temporal and spatial variations in shoreline changes and their implications, examples from the Texas Gulf coast: Jour. Sed. Petrology, v. 49, p. 1101–1112.
PILKEY, O. H., NEAL, W. J., and RIGGS, S., 1980, From Currituck to Calabash: Living with North Carolina's Barrier Islands (2nd ed.): N. C. Sci. and Tech. Res. Center, 370 p.
ROSEN, P. S., 1978, A regional test of the Bruun rule on shoreline erosion: Marine Geology, v. 20, p. M7–M16.
SWIFT, D. J. P., 1975, Barrier island genesis: Sed. Geology, v. 14, p. 1–45.
———, 1976, Continental shelf sedimentation, *in* Stanley, D. J., and Swift, D. J. P., eds., Marine Sediment Transport and Environmental Management: New York, John Wiley, p. 311–350.

PART TWO

Energy

Chapter 5 Energy and Ecosystems 105

Chapter 6 Renewable and Nonrenewable Energy 119