GILLIAN
CAMBERS

COPING WITH BEACH EROSION

COASTAL MANAGEMENT SOURCEBOOKS

UNESCO
PUBLISHING

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Coping with Beach Erosion

With case studies from the Caribbean

By Gillian Cambers

With contributions from Malcolm Hendry

Environment and Development

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I would also like to express my gratitude to UNESCO and to the Sea Grant College Program of the University of Puerto Rico, in particular Manuel Valdes-Pizzini, for their joint sponsorship of the present manual and unfailing support of the Coast and Beach Stability in the Caribbean (COSALC) project.

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GILLIAN CAMBERS

Foreword

Coastline changes due to natural processes and human intervention represent a major concern of coastal planners the world over, and indeed of ordinary citizens who have real or potential interests in beaches and seaside property. While beaches may be the substance of vacation dreams for some, their disappearance through erosion can lead to nightmares for those who live, relax and build close to the shore.

The United Nations Educational, Scientific and Cultural Organization (UNESCO) has been involved in the search for answers to coastal problems for well over two decades. Under the auspices of its Coastal Marine programme, a project was developed and eventually entitled Coast and Beach Stability in the Caribbean (COSALC). Since 1993, the project has benefited from the co-sponsorship of the Sea Grant College Program of the University of Puerto Rico. More recently, UNESCO's support for the project's activities has been provided through the Organization's platform for cross-sectoral action: Environment and Development in Coastal Regions and in Small Islands (CSI).

The publication of *Coping with Beach Erosion* is one tangible output of the above-mentioned project. The information and advice contained herein are the fruit of scientific research findings since the mid-1980s. They are particularly relevant to the Caribbean, whose shores are subject to powerful, frequent hurricanes and where the loss of beaches, vital to the tourism-based economies, adversely affects the welfare of numerous coastal inhabitants.

Based on copious observations, the author describes practical steps to follow when contemplating an oceanside purchase — or when a favourite beach suddenly disappears overnight. The wise practices discussed herein, while initially directed towards Caribbean coastal managers, property owners and beach users, should prove useful for seaside dwellers elsewhere. Indeed, it is hoped that the text will help coastal planners and stakeholders around the world to establish their own specific measures and guidelines for dealing with coastline instability.

In addition to expressing appreciation for Dr Cambers' unflagging efforts to develop these invaluable guidelines, recognition is given to Dr Malcolm Hendry, who was instrumental in initiating the manuscript as part of his collaboration with UNESCO's Intergovernmental Oceanographic Commission via its subsidiary body in the Caribbean (IOCARIBE).

This volume launches a new UNESCO series entitled Coastal Management Sourcebooks. The series is to serve as a source of information, ideas and practical tools for environmentally sound, socially equitable and culturally appropriate management and development in coastal regions and small islands.

Dirk G. Troost, Alexei E. Suzyumov
UNESCO CSI, Paris, September 1998

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Introduction

The purpose of the present manual is to provide people with the knowledge necessary to make informed decisions about the problems resulting from coastal changes. While the manual focuses on the Caribbean, many of the conclusions and measures described could be relevant to beach systems elsewhere in the world.

THE ENVIRONMENTAL SETTING

Caribbean beaches are highly valued by residents for relaxation, sports and simple enjoyment. Most islanders are proud of their beaches and wish to conserve them for posterity. To others, Caribbean beaches evoke idyllic pictures of soft sand, clear waters, cool breezes and shady trees combined with the prospect of relaxed living and revitalization. The prospect of visiting such places or even living beside the beach is a dream for many people. With global travel having made remote places more accessible, such dreams are becoming reality. Yet all too often, Caribbean beaches are subject to natural disasters, inadequate planning and a lack of environmental sensitivity.

Shorelines are areas of continuous change where the natural forces of wind and water interact with the land.

Photograph 1. Sand beach, Pigeon Point, Antigua, 1995. An idyllic sand beach backed by sea grapes and palm trees.

These changes have been taking place for millennia. History provides the example of Cockburn Town in the Turks and Caicos Islands, where Back Street had to be renamed Front Street at the beginning of this century as erosion took its toll. Shoreline changes are the result of both natural forces and human activities, such as sand mining and beach construction.

These shifts between water and land have taken on paramount importance in the Caribbean islands since tourism became the major industry in the 1970s. Despite their economic value in a region where tourism is dependent for the most part on sun, sea and sand, beaches have unfortunately not been perceived as areas needing management, protection and funding, but rather as permanent features of the landscape.

Environmental awareness has been growing slowly. International events, such as the United Nations Conferences on Environment and Development (Rio de Janeiro, 1992) and on Sustainable Development of Small Island Developing States (Barbados, 1994), have helped to focus public attention on the need for environmental management. Yet it was the dramatic events of 1989 and 1995 that gave the region the most direct demonstration of the need for beach management; Hurricane Hugo in 1989 and the numerous hurricanes in 1995 brought home to everyone the impermanence and vulnerability of the region's beaches.

On the threshold of the third millenium, as the Caribbean enters a cycle of heightened hurricane activity against a

Photograph 2. Eroded beach, Runaway Bay, Antigua, 1997. Erosion of the sand has caused walls to collapse leaving concrete debris on the beach as the land edge retreats inland.

background of global sea level rise, all islanders – whether or not they live on the shore – should be concerned about the state and future of the region's beaches.

Taking informed action: some practical advice

The main part of the manual (Chapter 1) has been organized around the theme of beach disappearance and erosion. A total of eleven cases describing different situations have been developed. Readers may turn to whichever case relates most closely to their particular problem or alternatively may read all eleven cases to obtain the maximum information. Each opens with a description of the environmental conditions and their causes. This is followed by a section offering practical advice on appropriate actions and responses. Considerable cross-referencing between cases serves to combine several situations.

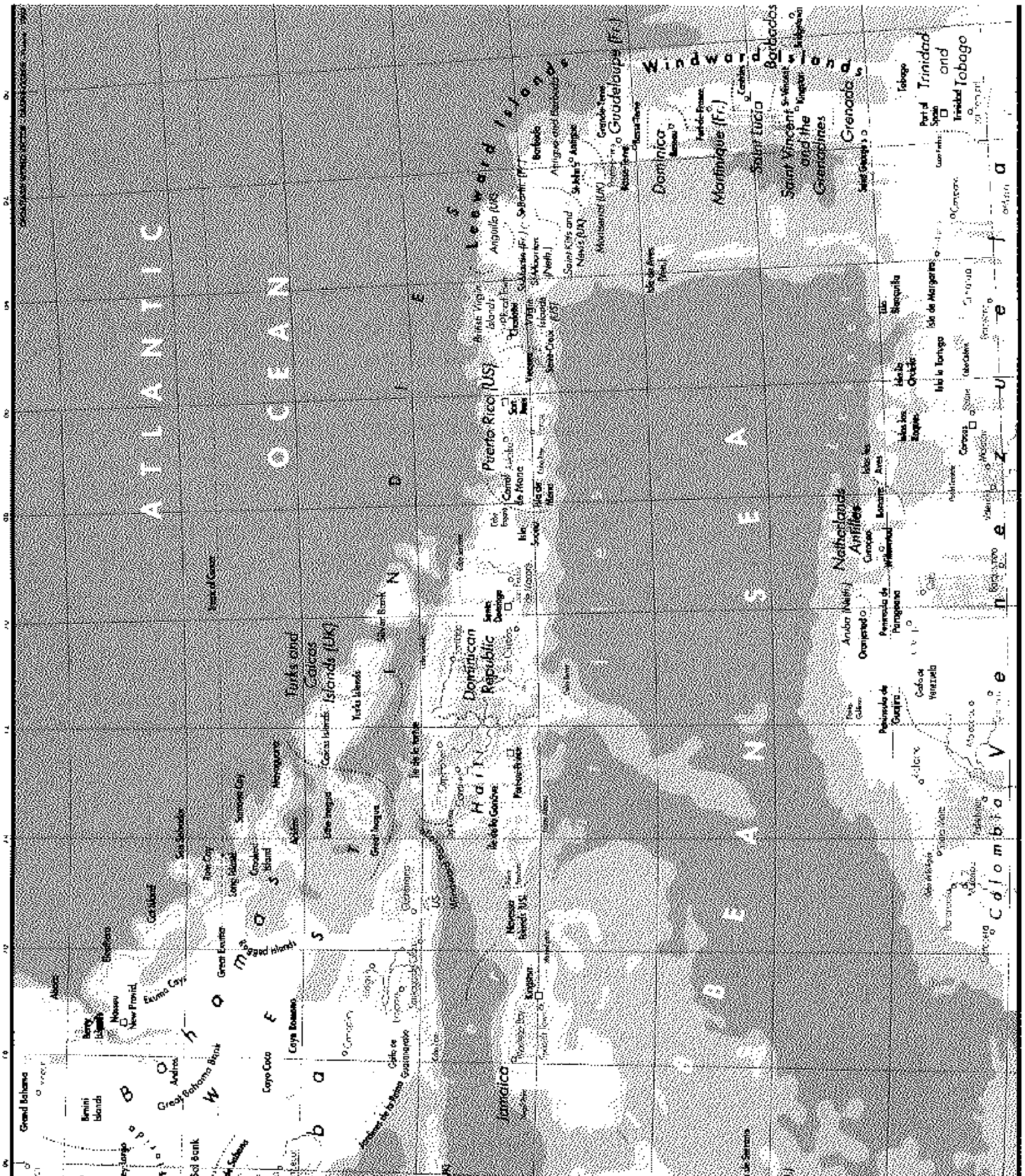
Chapter 2 centres around the theme. 'What to look for when investing in coastal land or property.' It provides guidelines for prospective buyers and a checklist to help evaluate the potential of a particular site.

The third and final chapter deals with the theme 'Protecting beaches: how you can help.' It contains several suggestions for individuals or groups wishing to undertake projects to improve a particular beach on their island.

A glossary has been included to define potentially unfamiliar terms; for easy reference, the first mention of these in each case and in chapters two and three is highlighted in red. There is also a detailed subject index to assist the reader in locating additional information on specific items.

By adopting an action-oriented approach, the present manual is intended to help readers make informed decisions about suitable responses to beach changes on their particular island. Although beach erosion can be slowed down or the problems transferred to another section of shoreline, generally speaking, erosion is inevitable. It is hoped that use of this manual will reduce the impact of natural disasters and increase awareness of what individuals or small groups can do to preserve and protect their beaches.

Figure 1. Map of the Caribbean region (taken from Graphi-Ogre, 1998).



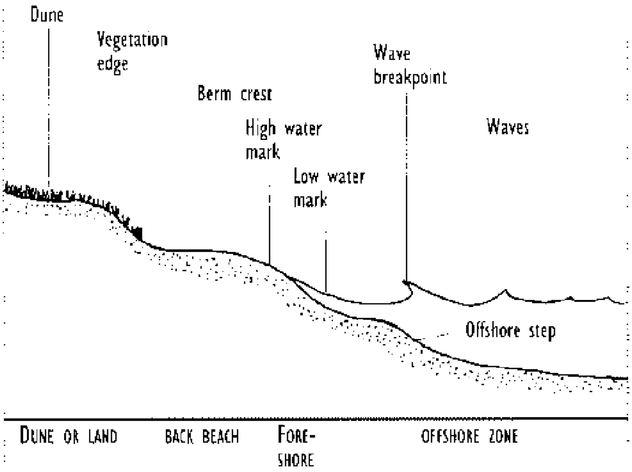
Chapter 1

The disappearing beach: what can be done?

This chapter looks at the many different circumstances that may cause a beach to disappear and suggests some possible responses in each situation.

Figure 2 shows a simple diagram naming the various parts of a beach. A beach can be defined as a zone of loose material extending from the low water mark to a point landward where either the topography abruptly changes or permanent vegetation first appears. Although beaches are often made up of sand particles, they may also consist of clay, silt, gravel, cobbles or boulders, or any combination of these.

Figure 2. Cross-section of a typical beach



SEDIMENT SIZES

Clay	Less than 0.004 mm	Less than 0.00015 inches
Silt	0.004–0.08 mm	0.00015–0.003 inches
Sand	0.08–4.6 mm	0.003–0.18 inches
Gravel	4.6–77 mm	0.18–3 inches
Cobbles	77–256 mm	3–10 inches
Boulders	Greater than 256 mm	Greater than 10 inches

Countering the effects of high seas in winter

Environmental background

Waves are the most significant force affecting beaches.

Ocean and tidal currents move sediment on the adjacent coastal shelf.

The Northeast Trade Winds approach with great constancy from the northeast, east and southeast. The speed and specific direction, however, vary throughout the year.

There are several natural forces that cause beach changes; these include: waves, tides and ocean currents. Waves are formed when the wind blows over the sea surface and the wind's energy is transferred to the water. As waves move towards the shoreline, they break and the turbulent energy stirs up and moves the beach sand. The higher the waves, the more energy is available for sand movement.

Tides are another factor influencing beaches. (Tides are the periodic rising and falling of large bodies of water resulting from the gravitational pull of the moon and sun on the rotating earth.) There are usually two high tides and two low tides every day in the Caribbean islands, with about six hours between high tide and low tide. The average tidal range is low, around 0.3 m (1 ft). Tides generate currents, which flow in one direction as the tide is rising and in the opposite direction as the tide is falling. These tidal currents can move sand. Tidal currents are particularly significant in the passages between islands and at river mouths. (See also Case 9.) Ocean currents also help to shape coastal areas. These continuous flows of water in the ocean are controlled by the prevailing wind patterns. The North Equatorial Current flows in a west-northwest direction through the eastern Caribbean islands.

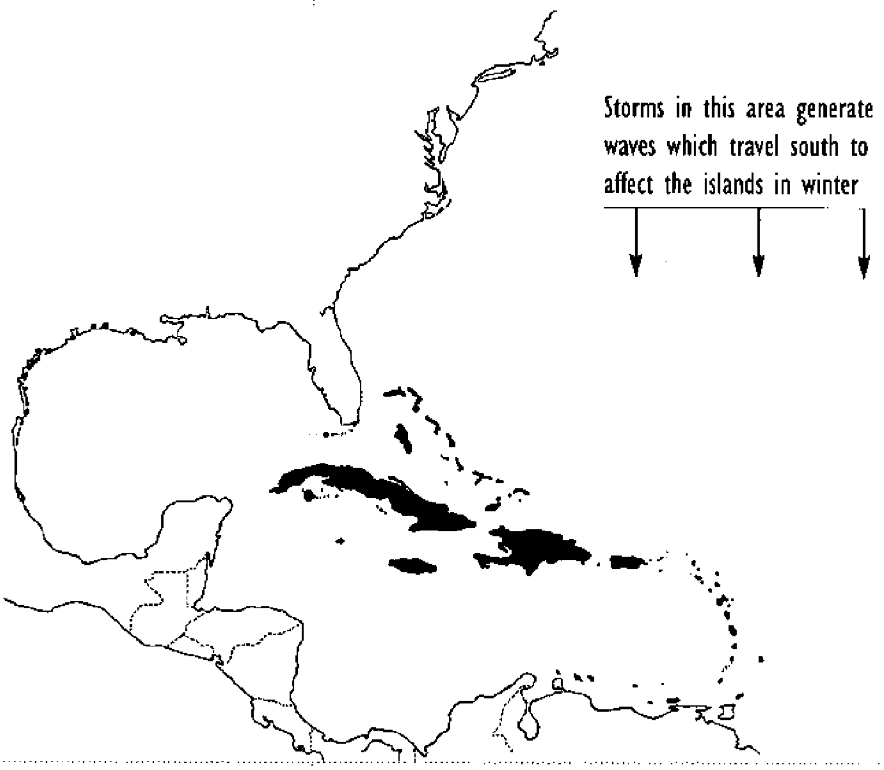
The Caribbean islands lie within the Northeast Trade Wind zone. Waves are generally highest from June to July and from December to March when the wind speeds are highest. Wave direction varies according to the time of year. In the eastern Caribbean islands, waves approach from a predominantly easterly direction. For this reason, the waves are highest on the east or windward coasts where average wave height is more than 1 m (3 ft). On the leeward coasts, average wave height is usually less than 0.3 m (1 ft). Wave energy is concentrated at headlands and spread out in bays.

This is a result of wave refraction, a process which results in the wave fronts being 'bent' as they approach the shore. Most of the islands from Grenada to Saint Martin have longer east- and west-facing coastlines. The east is the windward coast and the west the leeward coast. However, the Greater Antilles (Cuba, Hispaniola, Jamaica and Puerto Rico), several of the Virgin Islands and the Bahamas have longer north- and south-facing coastlines. Here, the windward/leeward distinction is not so clear.

Swell waves cause serious beach erosion during the winter months.

Waves formed where the wind is blowing are often irregular and are called wind waves. As these waves move away from the area where the wind is blowing, they sort themselves out into groups with similar speeds and form a regular pattern known as swell. Swell waves are most often experienced in the Caribbean between the months of October and April. They are usually caused by intense mid-latitude storms in the North Atlantic Ocean. (See Figure 3.) Swell waves travel thousands of kilometres south to affect the west, north and east coasts of the islands. Thus, severe storms in the North Atlantic Ocean, like those off the coast of Canada and the eastern USA, may indirectly affect the Caribbean through these swell waves.

Figure 3. Origin of swell waves affecting the Caribbean islands. Waves travel south as swell to affect the Caribbean islands in the winter months and often cause serious beach erosion (Bacon, 1978).



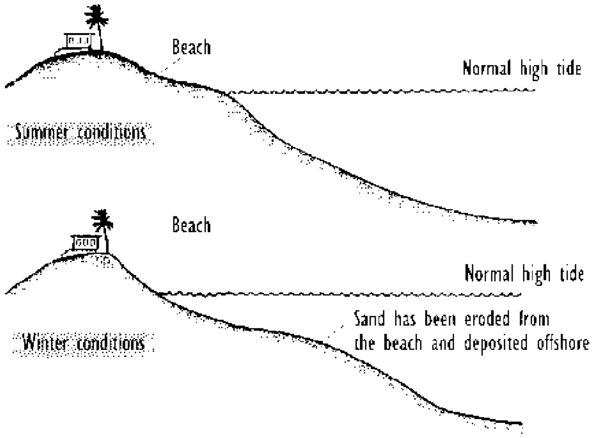


Figure 4. Seasonal beach changes. During the summer, there is a wide beach protecting the dune and the building. This is eroded during the winter leaving the dune and building vulnerable to direct wave action (adapted from Bush et al.*, 1995).*

As a result of swell, large waves may be seen breaking on the coast even on calm, sunny days in winter. (Swell waves are also generated by hurricanes; see also Case 2.) During each winter season, there may be from five to ten swell events, each lasting from one to eight days. Research has also shown that intense winter swell activity often runs in cycles, several active years being followed by several less active years (Deane *et al.*, 1973). These swells are known locally by a variety of names, for example as groundseas. The height of swell waves on a usually calm leeward coast may vary between 1 m and 3 m (3–10 ft), although occasionally they may be as high as 5 m (16 ft).

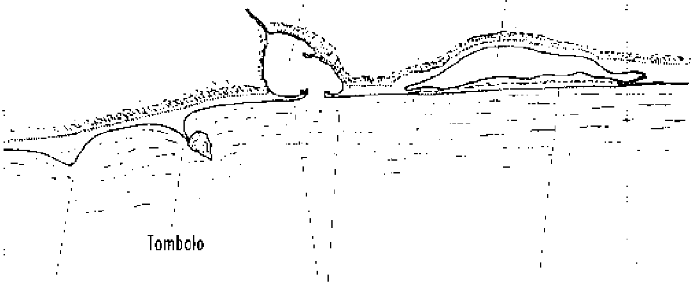
Together with Trade Wind waves, winter swells are responsible for most of the seasonal changes seen on Caribbean beaches

In the Greater Antilles, the Virgin Islands, the Bahamas chain and the northern Leeward Islands, swell waves may also be generated by frontal systems moving across the southern part of the USA during winter. These systems generate waves from a westerly, northwesterly and northerly direction.

During swell wave conditions, leeward coasts in particular experience considerable erosion. (These leeward coasts

Photograph 3. Winter beach conditions, Folkestone, Barbados, 1980. Following a severe winter swell, the waves have eroded the beach and cut into the edge of the land, leaving tree roots exposed. In the background, one large tree has fallen as a result of erosion.

Figure 5. Accretionary coastal features. These features are formed when sand is deposited by waves moving sand along the coast, a process known as longshore transport. See also Figure 16 (adapted from Komar, 1976).



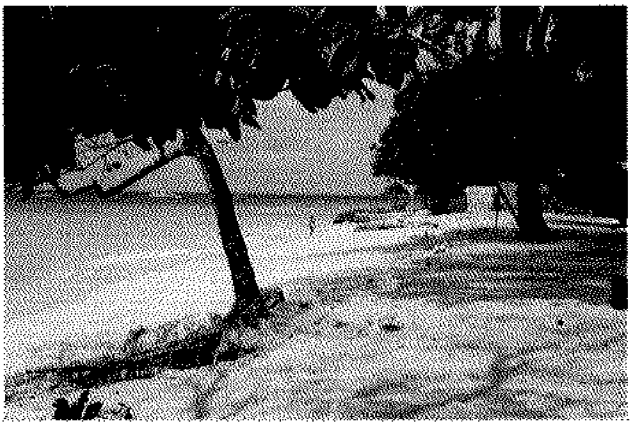
usually experience fairly calm conditions.) Sand is moved offshore and trees and walls are undermined, leaving their roots or foundations exposed. (See Figure 4.) Swell waves may also cause changes in the shape of a beach by moving sand from one end to the other.

Beaches tend to erode during the winter months and build up (or accrete) during the summer months, although this is not always the case.

During the summer months, when the seas are calmer and the waves smaller, beaches tend to build up. This process is known as accretion. Obviously, exceptions occur when a hurricane passes over or close to an island. The hurricane season lasts from June to November.

If the amount of winter erosion exceeds summer accretion, there is overall erosion with the land behind the beach being eroded as the beach retreats inland. The rate of retreat is called the erosion rate. Overall erosion may be due to one or more factors, for example: a particularly severe winter swell, a recent hurricane, the death of an adjacent coral reef or interference in the supply of sand.

Conversely, if accretion exceeds erosion, the beach gets wider over time and accretionary features, such as cuspate forelands, tombolos, spits and bars, may develop. (See Figure 5.)



Photograph 4. Summer beach conditions, Folkestone, Barbados, 1980. The dead trees have been removed and the beach has shown significant accretion. However, the exposed roots of the tree in the foreground indicate that the beach has not fully recovered from winter erosion.

PRACTICAL RESPONSES

Seasonal changes are inevitable, so human activities must be adapted accordingly.

Be aware that seasonal changes are natural occurrences. They cannot be prevented, so it is necessary to learn to live with them. Also, changes in one year may be much more severe than in the previous year.

View winter and summer beach conditions before contemplating the purchase of beachfront property.

If purchasing beachfront property, visit the site several times in both winter and summer before completing the purchase. If this is not possible, talk to neighbours about their observations of seasonal changes to the beach. Ask if they have photographs. Also consult local planning and environmental agencies, who may have information on beach changes.

If you own beachfront property and are concerned, about seasonal changes occurring, you can take some simple measurements on a regular basis to assess whether a problem exists.

Measure the beach changes.

Measure the distance from a fixed point, such as a wall or tree, to the high water mark once a week with a tape measure.

Table 1 shows how measurements can be used to assess whether a problem exists. Take photographs of the beach

Photograph 5. Measuring beach changes. The observers are measuring the distance between the vegetation line and the high water mark.

Table 1

Sample measurements of beach width

A *Average the measured distances for each month and enter values in the table.*

Table of beach widths in 1993

Month	Distance to high water mark (metres)
January	15.5
February	10.2
March	13.7
April	14.0
May	14.2
June	15.0
July	16.0
August	18.5
September	17.0
October	16.0
November	14.4
December	13.2

B *Calculate the average winter and summer values.*

Average of the winter months October to April
(Add the values for October to April and divide the total by 7.)
= 13.9 m
Average of the summer months May to September
(Add the values for May to September and divide the total by 5.)
= 16.1 m

C *Compare the winter and summer values for successive years*

Year	Average Winter *Distance (m)*	Average Summer *Distance (m)*	Minimum Distance *(m)*	Maximum Distance *(m)*
1993	13.9	16.1	10.2	18.5
1994	13.5	17.0	9.0	21.0
1995	14.2	15.3	11.9	18.2
1996	8.2	16.4	6.0	15.8

In the example above, the variation was normal between 1993 and 1995; however, there was very significant erosion in 1996 with a very low winter average and a low minimum value. If similar figures are obtained for 1997, it may be necessary at this site to envisage possible sea defence options before the situation becomes an emergency.

It is important to consider the effects of your actions on neighbouring properties.

from a fixed point during good (summer) conditions and bad (winter) conditions and compare these photographs over the years.

Obtain advice and permission from planning agencies.
If, during seasonal erosion in winter, your land or property is being seriously eroded, you may wish to try to stabilize the shoreline or your property boundary.
The decision as to what to do is a difficult one and needs careful consideration. It may involve both your property and that of your neighbours.

Act before an emergency situation develops.

Implement measures during the summer when wave conditions are calmer.
The timing for suitable responses is also important. It is much harder and more expensive to build a structure when the waves are actually undermining the building. In other words, do not wait until the situation has turned into a dire emergency.

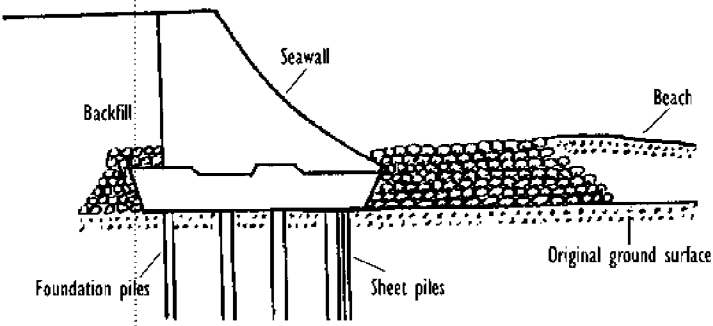
All shoreline protection measures must be carefully designed and permits obtained from the planning authorities before construction starts.

Set new buildings well back from the beach.
If your beachfront land has not yet been built on, you may wish to consider setting your buildings farther back from the sea than initially planned. You would thus help to conserve the beach in a natural state without having to build expensive, unsightly sea defences. The beach will also protect your property. Consult your planning agency for more information about recommended building setbacks. (See also Chapter 2 for more information on coastal development setbacks for buildings and how they may be calculated.)

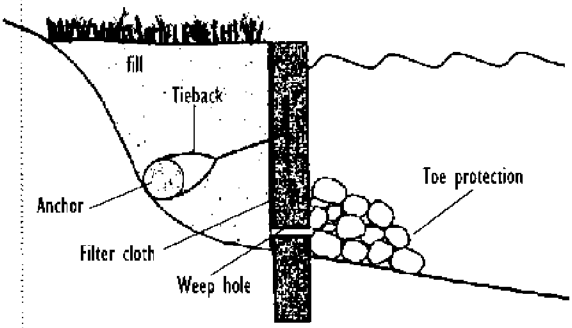
Consider the sea defence options.
If buildings are already in place and being threatened by erosion, you may wish to protect your property. The various options described on the following pages fall into two main categories:

- measures which protect the land but which do not promote beach build-up, such as seawalls, rock revetments and bulkheads. (See Figure 6.) Case 4 discusses these structures further;
- measures which protect the land by promoting beach build-up, such as groynes, offshore breakwaters (See also Case 4.) and beach nourishment. (See also Case 5.)

Seawalls



Bulkheads



Rock revetments

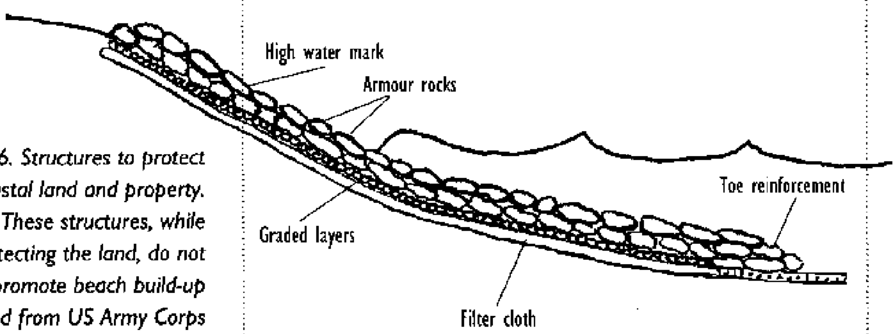


Figure 6. Structures to protect coastal land and property. These structures, while protecting the land, do not usually promote beach build-up (adapted from US Army Corps of Engineers, 1981 and Bush et al., 1995).

Consider measures which protect the land, but which do not promote beach build-up.

Seawalls are massive structures made of steel, rock or concrete. They have a curved or vertical seaward face and are designed to protect land and buildings from the impact of the waves.

Bulkheads are similar to seawalls. They have vertical seaward faces and are designed to protect land from

slumping and eroding into the sea. They are most suitable for quiet water areas like lagoons.
Rock revetments consist of armour rocks placed against a sloping face.
Structures with a vertical seaward face, such as seawalls and bulkheads, reflect wave energy and augment wave turbulence. This results in the water cutting downwards below the base of the structure and digging out the sand, a process known as wave scour. On the other hand, a sloping rock revetment absorbs much of the wave energy.
It is important to understand the consequences of building structures which protect the land or property only. While these structures may protect the land, they do not promote the deposition of sand.

As erosion continues, the beaches in front of seawalls or revetments become narrower and, in some cases, disappear altogether.

Seawalls, bulkheads, revetments and the like may also affect neighbouring properties, so often a community approach is recommended. (See also Case 4 and Figures 14 and 15.)
Gabions, which consist of stones in wire baskets, are often used as materials to construct walls, bulkheads, revetments and sometimes 'mattresses' extending under the beach in the Caribbean. (See Figure 7.)
The wire enclosing the gabion basket is coated with plastic. However, without regular maintenance, water action results in the stones rubbing against each other and wearing away the plastic-coated wire, leaving the stones to spill over the beach. Gabions are best for slope or channel stabilization where there is no danger of waves reaching them frequently.

Photograph 6. Deteriorated gabion groynes, Speightstown, Barbados, 1980. The gabion baskets have spilled open, spreading the stones over the beach.

Consider measures which protect the land by promoting beach build-up.

Groynes and offshore breakwaters are hard structures; the former is designed to trap sediment and the latter to protect the shore from wave action. These are described in greater detail in Case 4. As for beach nourishment, it consists of adding sand to the beach, usually from an offshore source. (See also Case 5.) Generally, such measures are not carried out by individuals working alone because they are very expensive and affect entire beaches. They require the co-operation of all land owners along a particular beach or coastal stretch.

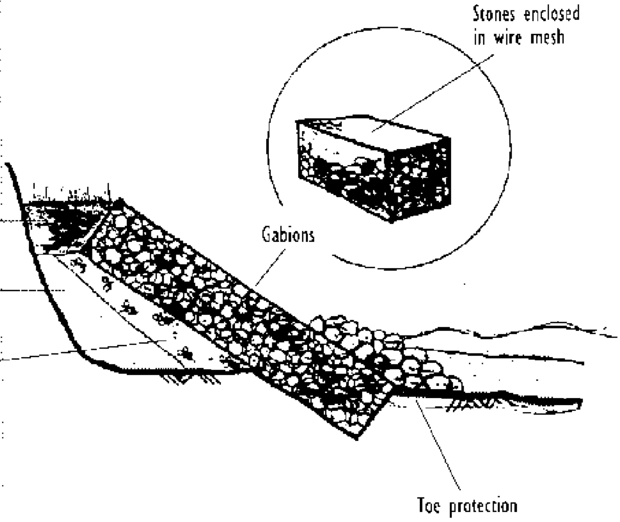
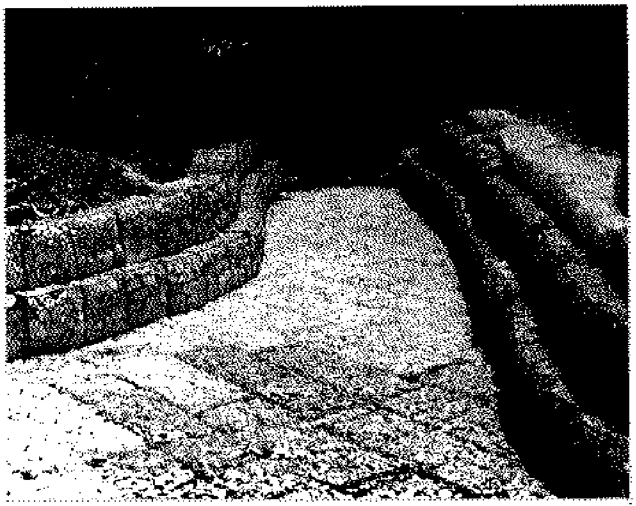


Figure 7. Slope stabilization using gabions. The stones have to be closely packed in the wire baskets so as to reduce their movement (adapted from US Army Corps of Engineers, 1981b).



Photograph 7. Gabion channel stabilization, Tent Bay, Barbados, 1987. Gabions are most successful in slope and river channel stabilization where they are not affected by wave action.

When a hurricane occurs

ENVIRONMENTAL BACKGROUND

Hurricanes are intense weather systems which affect the Caribbean every year from June to November.

Most hurricanes are experienced in September in the Caribbean. Many hurricanes originate as tropical waves off the west coast of Africa and travel across the Atlantic Ocean gaining strength from the warm ocean waters. As tropical waves strengthen, they pass through several stages, including tropical depression and tropical storm before reaching hurricane strength. Once a system reaches tropical storm strength, it is named. Hurricanes are further classified into five categories based on wind speed. (See Table 2.)

TABLE 2
Hurricane categories

CATEGORY	WIND SPEED (KM/HR)	WIND SPEED (MPH)
1	118 - 152	74 - 95
2	153 - 176	96 - 110
3	177 - 208	111 - 130
4	209 - 248	131 - 155
5	249 +	156 +

All tropical storms and hurricanes should be considered as potentially dangerous storms. They have the potential to inflict serious damage to a beach system.

The wind speeds in categories one to five refer to sustained wind speeds. Actual gusts may be much higher. While the higher category storms cause the most damage, even a tropical storm or category one hurricane may do considerable damage depending on its particular characteristics. For example, Tropical Storm Debbie resulted in significant flooding of Saint Lucia in September 1994. Indeed, lesser storms also have the potential to cause serious beach erosion, especially when the waves approach from an unusual direction, such as from the west.

Based on a study of weather patterns and climate records over the past century, it appears that hurricane generation

An active hurricane cycle is expected to continue for the next two decades.

in the North Atlantic Ocean occurs in 20–25-year alternating cycles of activity and relative inactivity. The evidence indicates that we are now entering an active cycle. The years 1995 and 1996 were especially active, 1995 registering as the second-most active year on record with 19 named storms. However, even within an active cycle, there are years with below-average hurricane activity, such as 1997.

Hurricanes that miss a particular island may still cause beach erosion there as a result of swell waves.

Tropical storms and hurricanes are such intense, well-organized systems that they generate waves which move out of the immediate vicinity of the hurricane to affect other islands as swell waves. (See also Case 1.) For example, Hurricane Erika in September 1997 did not directly affect any of the Caribbean islands as it followed a track north of the Leeward Islands. (See Figure 8.) However, swells from this hurricane affected islands as far south as Grenada and as far west as Hispaniola. Thus, waves from a particular hurricane can affect islands several hundred kilometres distant from its immediate path.

Tropical storms and hurricanes may cause catastrophic damage to beach systems as a result of: high seas, raised water level (known as a storm surge), high winds and heavy rainfall.

Strong winds generate high seas. Hurricane waves erode the beaches and penetrate farther into the land behind the beach causing flooding, erosion of sand dunes and destruction of coastal highways and buildings. (See Figure 9.)

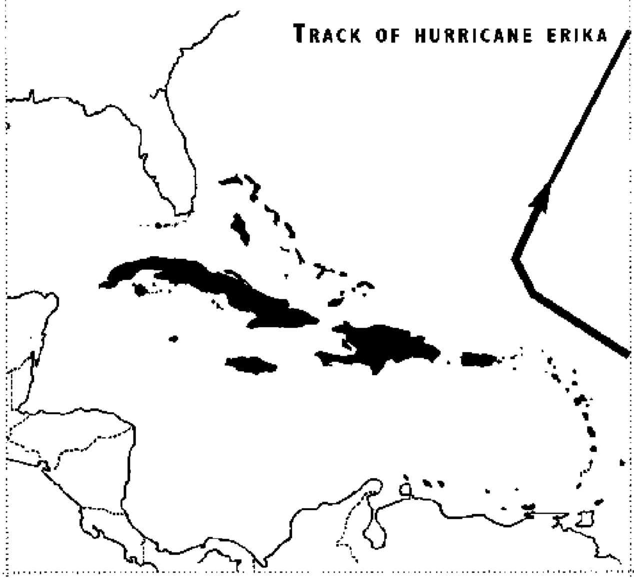


Figure 8. Track of Hurricane Erika, 4–10 September 1997. Islands as far south as Grenada and as far west as Hispaniola experienced high swell waves from this hurricane (adapted from Bacon, 1978).

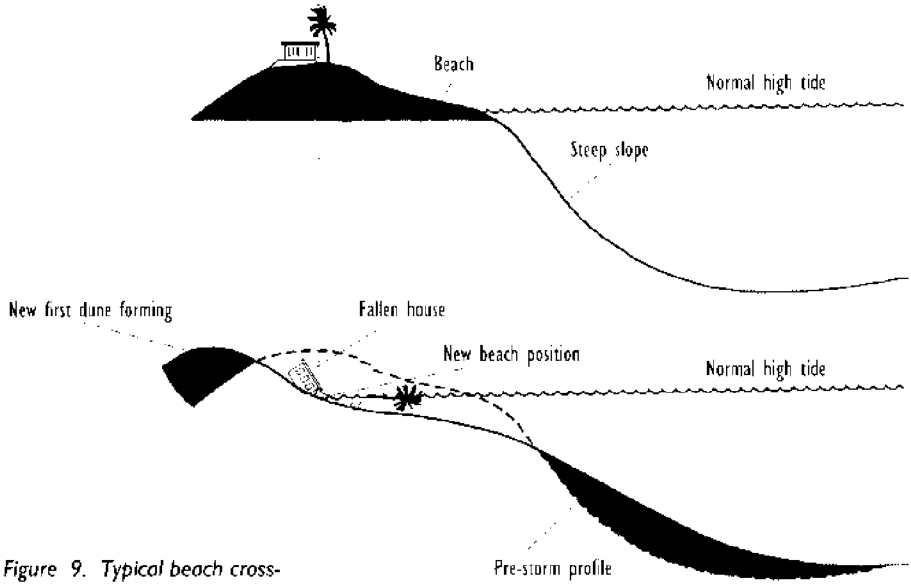


Figure 9. Typical beach cross-section before and after a hurricane. The hurricane waves overtopped the seaward dune and the building on the dune collapsed. Sand was moved offshore and inland (adapted from Bush et al., *1995).*

Within a hurricane, wind circulates counter-clockwise around a central eye. (See Figure 10.) Most hurricanes affecting the Caribbean islands move in a westerly to northwesterly direction. (See Figure 11.) As the hurricane approaches, winds usually blow from the east and north. Once the centre, or eye, of the hurricane has passed, the wind direction reverses and the wind blows from the west and south.

The high winds associated with hurricanes cause considerable damage to infrastructure and vegetation in both coastal and inland areas. The heavy rainfall often associated with these systems causes flooding of low-lying areas.

Beaches on all coasts of an island may be exposed to hurricane-generated waves.

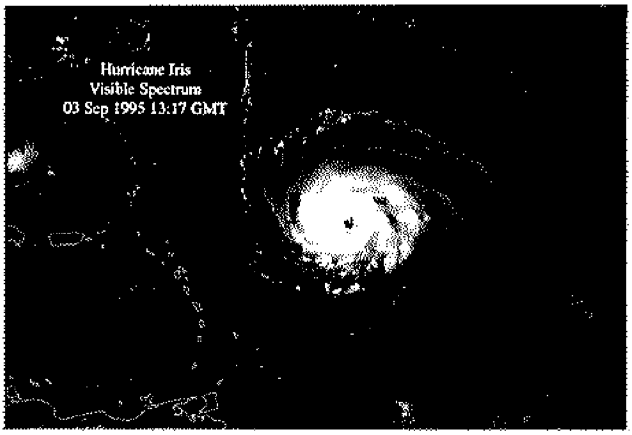


Figure 10. Satellite view of Hurricane Iris, 1995. The winds blow counter-clockwise around the central eye (shown in black). In the eye the winds are calm (from National Geophysical Data Center, 1996).

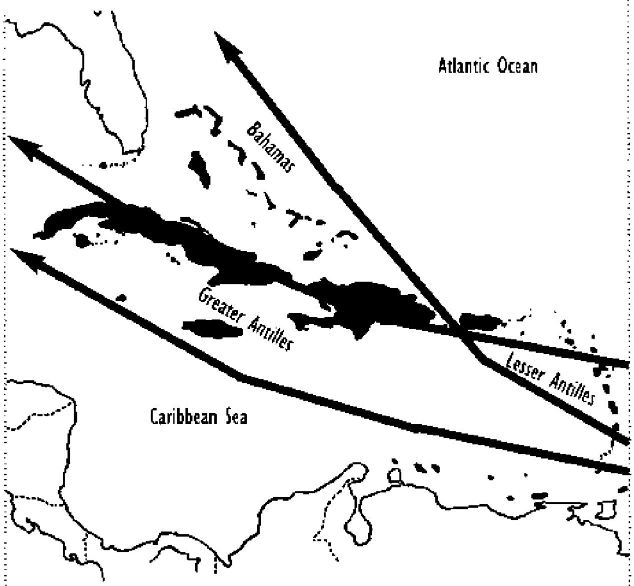


Figure 11. Main hurricane tracks in the Caribbean islands. Most hurricanes follow a westerly to northwesterly direction in the Caribbean region (adapted from Bacon, 1978).

The most serious damage to beaches is caused by hurricane waves and the storm surge.

High rainfall often results in rivers cutting new channels through the beach. After a hurricane, beaches are littered with debris, which may include mounds of dead seagrass, rubble torn from the coral reefs and huge tree trunks which sometimes originate in other islands. After Hurricane Luis in 1995, a new species of iguana arrived in Anguilla from neighbouring islands, presumably via rafts of logs (Dudley, 1996).

Beaches have been measured on a regular basis in many of the Caribbean islands over the past ten years as part of the Coast and Beach Stability in the Caribbean (COSALC) project. Monitoring has provided considerable information about the effects of hurricanes on beaches. Information collected has shown several major types of beach changes resulting from hurricanes. One or more of these changes may affect a particular beach.

Following a hurricane, beaches are usually lower and narrower. In the aftermath of Hurricane Luis in 1995, the average beach size shrank by 28 per cent on seven islands (Cambers, 1996c). Thus, waves may be able to reach roads or buildings that were tens of metres away from the active wave impact zone before the hurricane. Some beaches may be totally stripped of their sand leaving rock outcrops exposed. Rocky ledges often consisting of beachrock may become exposed where they were not evident before. (See also Case 10.) Considerable quantities of beach sand will

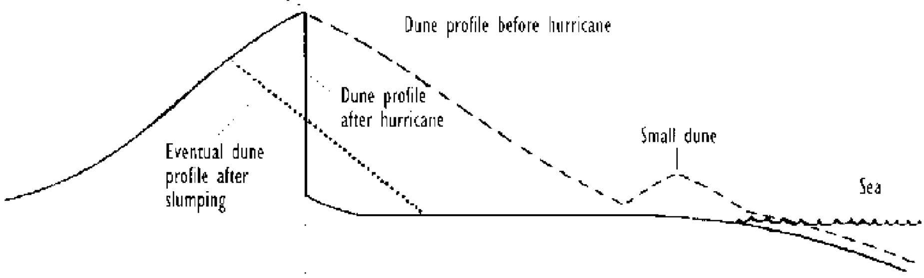


Figure 12. Dune retreat after a hurricane. The dune face has been eroded leaving a near vertical slope. In the months following the hurricane, the sand will slump to form a more stable slope (adapted from Cambers, 1995).

have been moved inland and deposited on coastal highways, in swimming pools and on beachfront properties. Large volumes of sand will have moved offshore. The water depth in the offshore zone may be much shallower than before the hurricane. Sand dunes which were previously gently sloping and covered with vegetation will now stand at a near-vertical angle bereft of vegetation. (See Figure 12.) In small sandy bays, sometimes all the sand will have been transported to one end of the beach. The material composing the beach may have changed from sand to stones and boulders. (See also Case 3.)

The normal picture after a hurricane is for beach erosion that may vary from slight to severe.

The preceding list of effects of hurricanes on beaches is by no means exhaustive. Indeed, on rare occasions, there may be no change or even accretion at a particular beach. For instance, two islands impacted by Hurricane Luis in 1995, Antigua and Anguilla, each showed accretion at only one beach.

The land behind the beach is also impacted by the hurricane waves and storm surge. The maximum dune

Photograph 8. Pre-hurricane beach conditions, Barnes Bay, Anguilla, 1994. There is a wide sand beach backed by palm trees.

Beachfront property owners should expect some loss of land after a major hurricane.

retreat recorded during Hurricane Luis in 1995 was 30 m (98 ft).

Dune or land retreat is important because features like sand dunes take decades to form. Thus, such changes may be regarded as semi-permanent.

Beaches, on the other hand, usually recover to a large extent after the hurricane. For instance, within eight months of Hurricane Luis in 1995, an 80 per cent average recovery was recorded (Cambers, 1996c). However, not all beaches show complete recovery after a hurricane. This was evident in Prince Rupert Bay in Dominica after Hurricane Hugo in 1989. Several beaches did not recover to pre-hurricane levels over a three year period (Cambers and James, 1994). In addition, accretionary features such as spits and tombolos, when impacted by successive hurricanes, show major changes. In the two decades since Hurricane David struck in 1979, the Scotts Head tombolo in Dominica has shown continuous lowering to the point where it is now easily breached by a small storm. Similarly, in Saint Kitts, since Hurricanes David and Frederick in 1979 and subsequent hurricanes, Dieppe Bay spit has virtually disappeared.

Beach recovery starts immediately after the hurricane and continues during the following months.

Hurricanes also affect offshore systems, such as seagrass beds and coral reefs. In these environments, damage often goes unseen and its effects may not become apparent for several years. Coral reefs provide protection for beaches by acting as natural breakwaters. They also produce sand for many beaches. Thus, hurricane damage to a coral reef may result in beach erosion several years after the actual hurricane. (See also Case 10.)

Photograph 9. Post-hurricane beach conditions, Barnes Bay, Anguilla, 1995. The sand had been stripped from the beach during Hurricane Luis leaving rocky outcrops exposed and just a few pockets of sand. The palm trees were lost.

Practical Responses

Hurricanes are natural, inescapable events. Recent predictions indicate that each Caribbean island can expect to be impacted by at least one category three hurricane within the next two decades.

The greater the distance between the buildings and the active wave impact zone, the higher the margin of safety from hurricane - generated waves.

Before the hurricane:

Hurricanes are inevitable and Caribbean islanders must plan for their impact.
A hurricane may not pass directly over a particular island but may pass close enough to cause a severe impact. People living in the Caribbean islands should know about these predictions and plan for their consequences.

Maintain a wide and stable beach.
A wide beach is the best protection against the high waves and storm surge generated by a hurricane. A beach is a flexible barrier which will be eroded during the storm but rebuilt quickly afterwards. Any measures which help to protect a beach or dune area, such as setting new buildings well back from the active wave impact zone, conserving natural beach and dune vegetation, dune stabilization practices and preventing beach sand mining, will help to conserve the beach as a natural storm barrier.

Establish maximum setbacks for new buildings, roads and other infrastructure.
If you are planning a beachfront property, obtain information from local planning and environmental authorities about beach changes during recent hurricanes and advice concerning safe setback distances for your property. (See also Chapter 2.) A coastal setback is a prescribed distance between a coastal feature, like the vegetation line, and a building. The depth of the land parcel permitting, the greater the setback, the safer the property.

Consult local insurance agencies regarding coverage for coastal property.
It is always best to obtain this information before investing in coastal land and starting to build, since insurance rates are increasing at a significant rate. On some islands,

insurance – particularly for beachfront properties – has been difficult to obtain because of recent hurricanes.

After the hurricane:

Beach damage after a hurricane is impressive, but should not be cause for panic.

Allow time for the beach to recover naturally. Do not rush out and build walls or other hard structures, since these may actually impede recovery.

As soon as the hurricane has passed out of the region, waves will usually begin to bring the sand back onto the beach. Most of the beach recovery will have occurred within six months of the hurricane. Most beaches do recover about 80 per cent of their pre-hurricane size. There are always exceptions. If a beach has not shown significant recovery within twelve months of the hurricane, it may be necessary to take some direct action along the lines of that described in Cases 1, 4, 5 and 7.

Consider the soft engineering option of beach nourishment.

Beach nourishment may speed up natural recovery in some instances.

In some instances, it may not be feasible to wait for natural beach recovery. Since hurricanes usually occur in September in the Caribbean, the start of the important winter tourist season is often less than three months away. A particular hotel owner may consider it essential to try to get a beach back in time for the start of the winter tourist season. In such instances, it is certainly advisable to consider replenishing the beach with sand dredged from the offshore zone. During the hurricane, much of the beach sand may have been deposited just offshore. However, such measures are expensive and require detailed preliminary studies. (See also Case 5.)

Wait until the end of the hurricane season before implementing remedial measures to restore the beach.

Before starting any beach nourishment, it is advisable to wait until the end of the most active hurricane period. For instance, if the hurricane that caused the damage occurred in late August, wait until the end of October before implementing any remedial measures. In particularly active hurricane years, a second hurricane may well bring some of the eroded sand back to the beach system naturally. This happened in Saint Lucia in 1995.

Consider other soft engineering options like dune rehabilitation.

While the best recommendation for beaches is to allow them to recover naturally, dunes are another matter, since they often take decades to form. If the dunes have been eroded leaving vertical cliffs of sand, then it may be appropriate to regrade the slope to a stable angle (around 20 degrees) and to replant with natural grasses and vines. Alternatively, sand accretion may be promoted by the use of sand fences. (See also Case 7.)

Hurricanes usually result in the permanent loss of beachfront land and dunes.

Reposition hurricane-damaged structures.
If a particular building adjacent to the beach has been structurally damaged by the hurricane, consider all options before reconstruction. Evidence has shown that hurricanes result in the permanent loss of beachfront land and/or dunes. The land edge may be several metres farther inland after the hurricane.
If you have lost a building or fixtures, obtain the advice of coastal professionals and planning authorities concerning if, where and how to rebuild. For instance, sometimes the building can be rebuilt farther back from the beach, behind or above existing buildings.

In most of the Caribbean, land below the mean high water mark belongs to the government. Beachfront land lost from erosion is the landowner's loss.

Have your property resurveyed after the hurricane.
It may be advisable to have the property resurveyed six months or so after the hurricane, so as to record permanently any changes in the size of the land parcel.

While cleaning up after the storm, replace any sand that has been moved inland on the beach.

Return sand to the beach after the hurricane.
Sand may have been washed onto beachfront property, into the swimming pool or into the building during the hurricane. Do not sell this sand for construction or other purposes. Returning this sand to the beach will help the beach recovery process and is the best way to conserve the beach.

Be aware that the full hurricane impacts may not be experienced until several years after the event.
When nearshore coral reefs have been damaged during hurricanes, the resultant impacts on beaches may not be experienced immediately. It may be several years before the beach starts to erode as a result of a sand deficit or a reduced reef breakwater effect, both of which may be caused by a past hurricane. It therefore pays to be vigilant and to use simple measurement methods and photography to record beach changes, as described in Case 1, Table 1.

When stones have replaced a sand beach

ENVIRONMENTAL BACKGROUND

Beaches can vary in size, shape, colour and composition. There are two main sources of beach material: land-based and offshore sources.

The size and colour of material on a beach depend on the types of materials available in the coastal area.

Land-based sources

Rivers and streams drain the land surface and carry with them particles of the underlying rock. The size of particles reaching the sea depends on the structure of the parent rocks and the extent to which the particles were worn or broken down during transport to the sea. The composition of the parent rocks determines the colour of these sediments. For example, volcanic rocks are typically dark grey to black. On the high volcanic islands of the Lesser Antilles, beach materials are commonly formed from these glistening dark minerals. Particles of rock may also be eroded from cliffs by wave action.

Offshore sources

Along tropical coasts, where the land extends offshore to form a shallow shelf and there are few land-based sediments to cloud the water, coral reefs and seagrasses grow in abundance. These environments play host to many species of plants and to many animal species with a skeleton formed from calcium. (See also Case 10.) When the organism dies, this material becomes sand and may be transported to the beach area by wave and current action. This material is predominantly white in colour.

In many Caribbean islands, both types of sand sources are found; beaches may be light, dark or a mixture of both mineral types. Once on a beach, particles are subjected to wave and current action which causes further breakdown in particle size. Longshore currents may move the sand far from its original sources. (See also Case 4.)

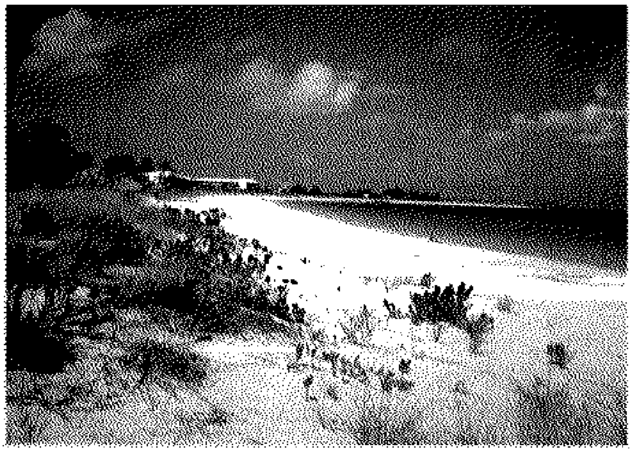
Photograph 10. Black sand beach, Byera, Saint Vincent, 1995. The sand particles on this beach are derived from the land and carried to the coast by rivers. Once at the coast, the material is reworked by wave action.

A beach may be covered with large rock particles. These may be chunks of coral derived from the breakdown of a coral reef or boulders and stones from a river or cliff. Other sources for coarse sediment may be man-made. They can include material derived from: ships' ballast, coastal quarrying activities, offshore dredging or boulders and stones from broken gabion baskets (See also Case 1.) or other sea defence structures.

A beach covered by coarse sediments year-round may be one which is only supplied with coarse sediment to start with or it may be going through an extended erosive cycle.

Sediments are deposited in layers on the beach. Size may vary between layers, reflecting the energy of the conditions at the time of deposition, as well as natural variation in the size of particles available in the particular beach system. These layers can be easily observed by scooping or digging a small trench through the beach.

A beach may be covered with stones at one time of the



Photograph 11. White sand beach, Grace Bay, Providenciales, Turks and Caicos Islands, 1995. This sand is derived from the offshore reefs and moved to the beach by wave action.

Photograph 12. Stone beach, Iles Bay, Montserrat, winter 1990. The beach is covered in stones thrown up by winter swells and by Hurricane Hugo (September, 1989).

year and with sand at another time. Such changes in grain size will most likely reflect one of two causes: seasonal erosion or seasonal deposition.

Seasonal erosion

During winter swells or hurricanes, finer grained sediments are often moved offshore or to the back beach area. The larger, heavier sediments are left as a residual layer on the beach.

Seasonal deposition

Coarse sediments may also be thrown up onto the beach from offshore during a winter swell or hurricane. Coarse sediments may be covered up when calmer wave conditions return sand to the beach.

Photograph 13. Sand and stone beach, Rockaway Beach, Dominica, June 1994. In the foreground, a layer of black sand can be seen partially covering the stones beneath. The stones which were deposited during the high energy winter swells have been partially covered by sand during the low wave energy of the summer months.

PRACTICAL RESPONSES

Obtain information on the beach before purchasing.
Observe the nature of the beach material on initial inspection of a beachfront property. Whether the beach consists of sand, stones or a mixture of sediment sizes, establish if this is a seasonal phenomenon or the normal condition for this location. Planning authorities, research organizations, local area residents and coastal landowners may all have useful information.

Some Caribbean beaches may consist predominantly of stones in the winter months and sand in the summer months.

Avoid hasty reactive responses.
Before considering what action to take on a beach that has changed from sand to stones, determine the possible cause of these changes. Establish whether there was a seasonal swell. If so, there is a very strong possibility that the sand will begin to come back to the beach within a few days. Natural sand replenishment is also likely to follow a tropical storm or hurricane, although this may take several months. (See also Case 2.)
Be aware that, on many Caribbean beaches, material size varies seasonally. For example, a stony beach in the winter months may be replaced by a sandy beach in the summer months. This is a response to seasonal changes in the wave conditions. Little can be done to alter these natural variations. Unfortunately, the stony periods often correspond to the winter months, the peak tourist season.

The removal of stones from a particular beach is rarely successful because more stones will be moved in from adjacent areas when the high energy waves return.

Consider whether any response is necessary.
After assessing the short- or long-term nature of the beach changes, determine whether to proceed with corrective measures, or whether to leave the beach to restore itself naturally. Any intervention must be carefully designed and involve consultation with the planning authorities.

Consider the engineering options.
Firstly, it is important to determine that the absence of sand is not a short-lived seasonal phenomenon. Only once

The artificial supply of beach sand must be carefully designed by experienced professionals.

this has been determined should consideration be given to engineering options. The most likely option will be to supply the beach with sand from an offshore or inland source. This option is called beach nourishment and is discussed in Case 5.

Sometimes a combination of engineering solutions is required at a particular site. Examples include nourishing the beach with sand and constructing groynes to prevent the newly placed sand from being moved to other coastal stretches.

Unplanned dumping of sand is unlikely to provide a lasting solution. The absence or loss of sand in the first place indicates that any sand added to the beach is also likely to be washed away.

Consult with the planning authorities.

In the Caribbean, the seabed belongs to the government. Any action involving alteration of the seabed, such as dredging it to provide sand for beach nourishment, will require planning permission. In approaching the authorities, be aware that they will want the following information:

- analysis as to the cause of the observed beach condition;
- design specifications for the proposed intervention;
- environmental impacts of the proposed intervention on neighbouring shorelines both during construction and during operation.

Assessing the impact of coastal structures

Environmental background

Any solid sea defence structure built on or near the beach will interfere with natural changes in the beach.

Beaches are constantly changing formations. They change over hourly, daily and yearly time-periods. Any sea defences built on or near the beach will influence the natural processes. Sea defences may result in beach accretion or erosion, or both of these on different parts of the beach. Sometimes, the changes may be seen just months after the structure is built. At other times, it may take years.

There are three main groups of solid structures which protect land and/or beaches: structures built parallel to the shore (seawalls, bulkheads, revetments); structures built at right angles to the shore (groynes and jetties); and offshore structures like offshore breakwaters.

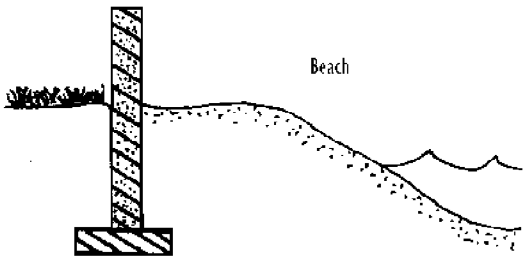
Seawalls and related structures only protect the land and property behind the beach. They do not promote beach build-up.

Structures built parallel to the shore

Generally, such structures are made of steel, concrete, rock or wood and are designed to protect land and buildings from erosion by the sea. They are the most common means of protection found on island beaches. They come in all shapes and sizes. The main types have already been described in Case 1. (See also Figure 6.) It is important to remember that these structures only protect the land. They do not promote beach accretion. In this sense, they can only be regarded as a means of 'buying time', since erosion will continue in front of the seawall and the beach will narrow or even eventually disappear. New, stronger structures may then be required to withstand the increased wave impact, making maintenance costs higher.

In the Caribbean, a retaining wall is often built adjacent to the beach to define property boundaries and to provide privacy for hotels and residential property. When beach erosion takes place, these retaining walls come under wave

Retaining wall



Bulkhead

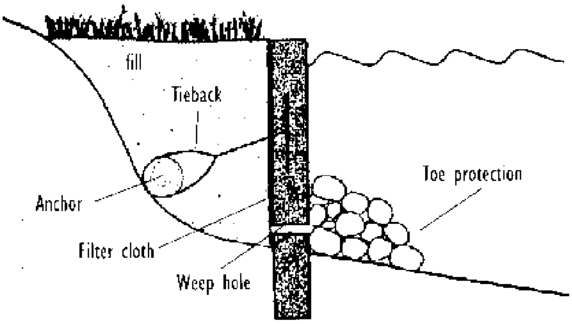
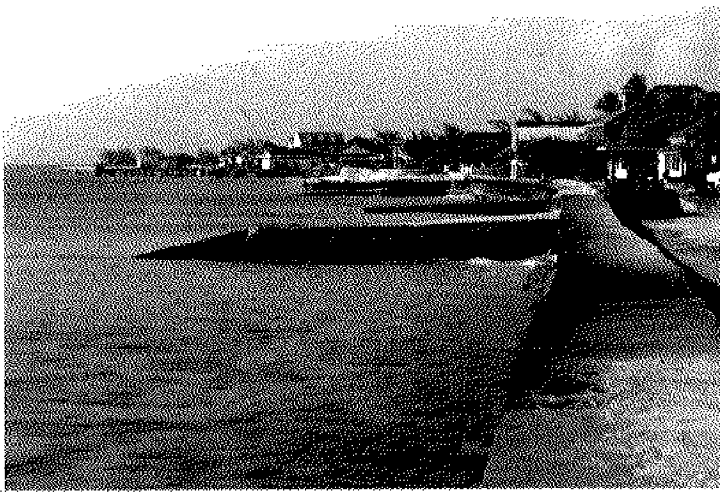


Figure 13. Features of retaining walls and bulkheads. Retaining walls are often built to separate private property from the beach. Bulkheads are designed to protect land from wave action. Neither type of structure promotes beach build-up (adapted from Bush et al., *1995).*

attack and they may collapse. They are designed to retain land and soil, but not to withstand wave impact. As one wall fails, it often takes an adjacent wall with it. A properly designed bulkhead, however, will have additional features, such as filter cloth, toe protection, tie backs and drainage holes. (See Figure 13.)

A seawall, bulkhead or revetment protects only the land and buildings immediately behind it. Erosion will continue in front of the unprotected land on either side of the structure and the waves will eventually cut in behind it.



Photograph 14. Seawall and groynes, Cockburn Town, Grand Turk, 1995. The seawall and groynes are protecting the coastal highway and buildings from inundation by the sea. Note the absence of any beach in front of this seawall.

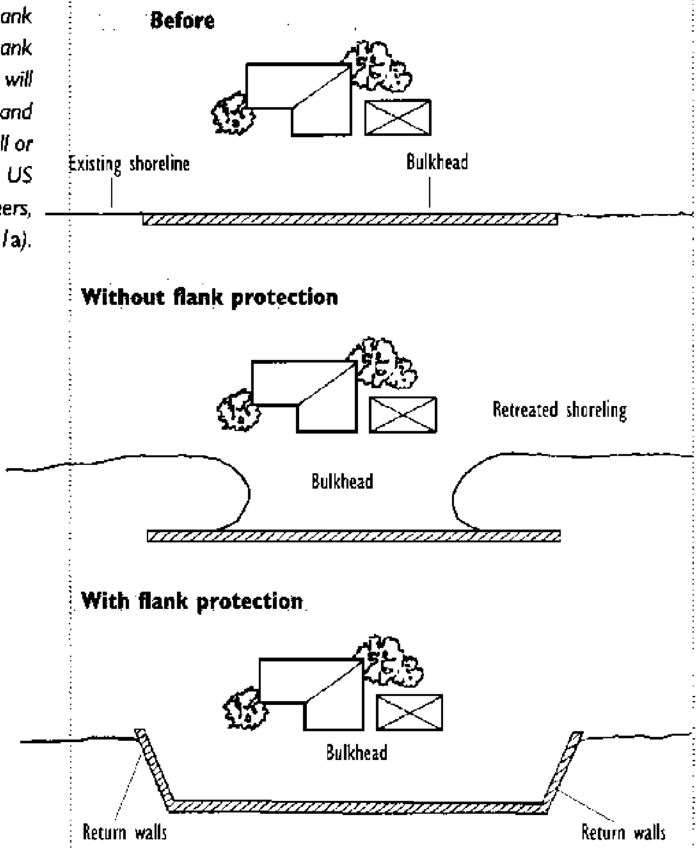


Figure 14. Bulkheads and flank protection. Without flank protection, the waves will eventually cut into the land behind the bulkhead, seawall or revetment (adapted from the US Army Corps of Engineers, 1981a).

A co-operative approach to shoreline stabilization structures is generally more effective than several individual efforts.

(See Figure 14.) This is why it is usually necessary to build return walls, which provide flank protection.

As erosion continues, however, the protected section of coast will become like a small headland projecting seaward of the main coastline. Wave energy will become concentrated on the adjacent unprotected shoreline. A community approach is often favoured. (See Figure 15.)

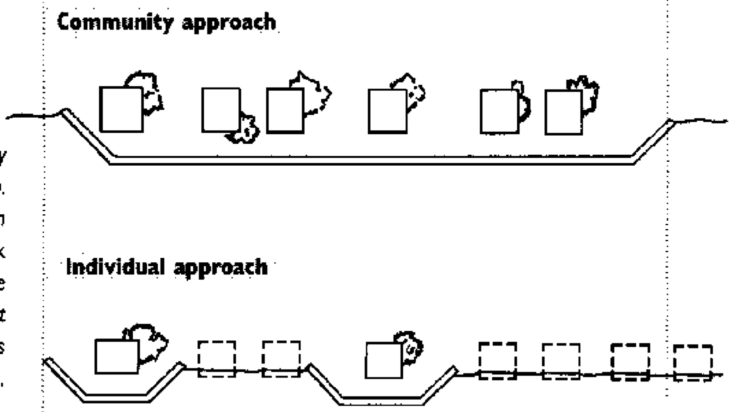


Figure 15. Community approach to shore protection. The community approach reduces the need for flank protection and is more economical and efficient (adapted from US Army Corps of Engineers, 1981a).

Photograph 15. Boulder groynes, Nisbett Plantation, Nevis, 1992. Note the sand build-up on the updrift side of the groyne in the foreground while the beach edge has eroded inland on the downdrift side.

This can reduce the need for individual return walls, as well as being more economical and efficient.

Nature does not recognize property boundaries; erosion or accretion can occur anywhere. It will usually affect more than one property along a particular beach.

Planning permission is required before any structure can be built on or near the beach.

In most of the Caribbean islands formerly under British rule, property owners have the right to protect their land. This is the case under British Common Law. However, in some of the islands, more recent coastal legislation may have established other rights. Throughout the Caribbean, it is necessary to obtain planning permission before building any structure on or near a beach.

Structures built at right angles to the shore

When waves approach the shoreline at an angle, they generate a longshore current which transports sand suspended in the water along the shore. (See Figure 16.) In

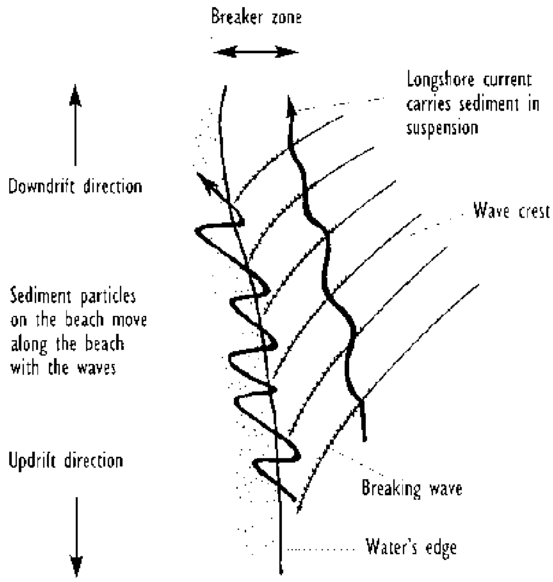


Figure 16. Longshore sediment transport. When the waves approach at an angle to the shoreline, the sediment on the beachface is moved along the beach (adapted from US Army Corps of Engineers, 1981a).

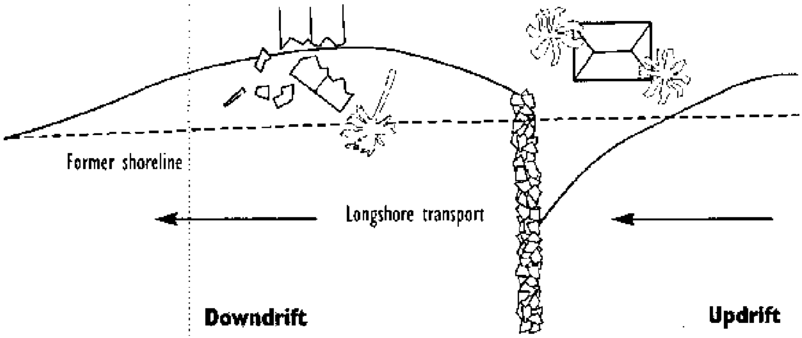


Figure 17. Effect of a single groyne. The beach has built up on the updrift side and eroded on the downdrift side (adapted from Bush et al., *1995).*

addition, the wave-generated turbulence carries sand up the beachface in the general direction of the wave approach. As the water returns seaward, it moves directly down the beachface in response to gravity. Thus, sand moves along the beachface in a zig-zag motion. (See Figure 16.)

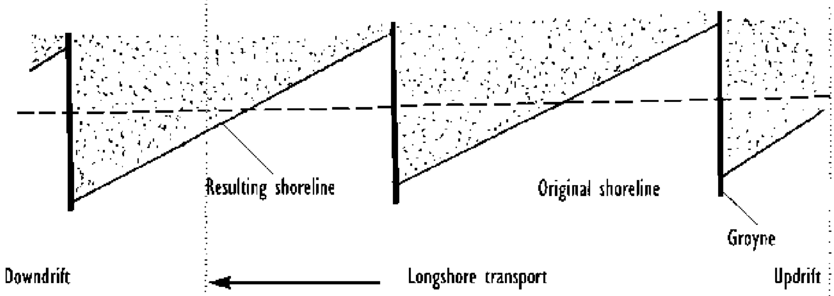
Structures designed to trap this moving sand are called groynes. They are low walls constructed perpendicular to the shoreline which extend out into the water. Their main function is to promote beach build-up by trapping sand or slowing down its movement along the beach. Groynes are usually constructed of rock or concrete. Sometimes, gabions are used, although, as mentioned in Case 1, they are not recommended as materials for groyne construction because of the need for continual maintenance. Wood or steel may also be used for groyne construction. Groynes may be built singly, or in groups known as groyne fields. (See Figures 17 and 18.)

Groynes usually result in sand accretion on one side and erosion on the other sid

While groynes trap sediment on one side, they cause a sand deficit and therefore erosion on the other side. (See Figure 17.) In effect, one property owner may gain at the expense of a neighbour.

A properly designed groyne field should ensure that, as the sand builds up to the end of the groyne, material passes over or around the end of the groyne to the downdrift shore, but at a slower rate than before its construction. (See Figure 18) It is sometimes necessary to combine

Figure 18. Effect of a groyne field. Sand moves around the end of each groyne to feed downdrift sections of the beach (adapted from US Army Corps of Engineers, 1981a).



groyne fields with beach nourishment. In such cases, the groynes help to reduce the rate of longshore transport along the beach and thereby retain the sand where it was placed during the nourishment project.

Groynes function most effectively along coastlines where the direction of longshore transport is constant. In the Caribbean islands with their prevailing Northeasterly Trade Wind regimes, the predominant longshore transport direction is from east to west. Experience has shown that groynes work best along north- or south-facing coastlines and are least effective on east- or west-facing coastlines. For example, groynes have worked reasonably effectively on the north coast of Nevis. Similarly, much of the south coast of Barbados has been stabilized with groynes.

Sometimes, solid structures built as jetties or piers, essentially used for boat docking, have inadvertently functioned as groynes. Piled structures are recommended for jetties used for boat docking.

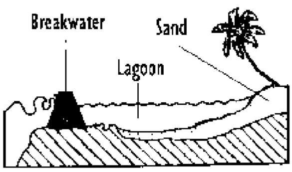
Groynes are often seen as a 'cure-all' for any erosion situation. However, this is not the case. Groynes are just one of several ways to control beach erosion. Thus, as with all coastal structures, careful design by professionals experienced in coastal processes is required.

Groynes only function well under certain specific conditions, they are not a 'cure-all' for every beach erosion problem.

Offshore structures

Offshore breakwaters are placed out in the water to intercept the energy of the approaching waves, thereby sheltering the shoreline on their landward side.

The sheltering effect of the breakwater results in a reduced rate of longshore sand transport and encourages sand accumulation behind the structure. (See Figure 19.)



Source: Crowns of Thorns Newsletter, 1990a.

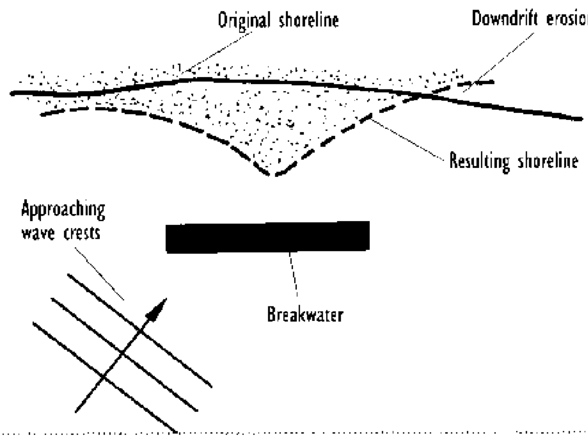


Figure 19. Plan view of an offshore breakwater. The sand builds up in the area behind the breakwater, which is sheltered from high waves (adapted from US Army Corps of Engineers, 1981a).

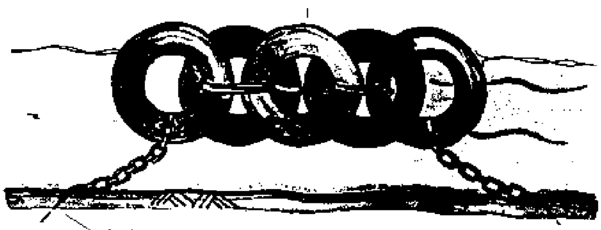


Figure 20. Floating tyre breakwater. These are only suitable for sheltered-wave environments like marinas (adapted from US Army Corps of Engineers, 1981b).

However, as with groynes, downdrift beaches may suffer erosion if they are deprived of their sand supply.

Breakwaters are built out in the sea, usually parallel to the coast or sometimes angled to the shoreline. They are usually made of interlocking concrete shapes or large boulders. Generally, they are more expensive than groynes or seawalls because they are of massive construction designed to withstand breaking waves. Also, they must be constructed in the sea, rather than placed on land. Construction material must be moved by barge or by building a temporary ramp from the land out to the construction location.

Breakwaters may emerge above the sea surface or they may be submerged. Floating breakwaters, which are constructed of buoyant materials like used tyres, may be used in sheltered wave environments like marinas to reduce the wakes caused by passing boats. (See Figure 20.) They are not suitable for open water conditions.

While it is impossible to provide specific costs for the structures described in this section since conditions and materials vary from island to island and from site to site, Table 3 provides some general cost ranges to give an order of magnitude.

TABLE 3

General cost ranges for sea defence structures in the Caribbean islands (1998 estimates).

Type of structure	Cost per metre length of structure (US$)
Rock revetments	650 – 975
Groynes (rock)	650 – 975
Groynes (pre-cast concrete)	680 – 1,170
Offshore breakwaters (rock)	2,925 – 3,900
Offshore breakwaters (pre-cast concrete)	3,250 – 4,225

Practical responses

A response is always possible, although it will differ according to whether the structure exists, is under construction or still in the planning phase.

If a structure exists or is under construction:

Take necessary action as soon as there is any sign of construction on the beach.

Act at the first sign of construction.
The best time to act is as soon as there is any sign of construction, such as a surveyor measuring the site. Once the actual coastal structure is in place, it is very difficult to get it modified or removed.

If a newly built coastal structure is affecting your property or a beach you visit, first check whether planning permission was granted.

Check whether the structure has the necessary permits.
While property owners in most Caribbean islands have the right to protect their land, planning permission is required for a structure on or behind the beach or out in the sea. Find out if permits exist and whether there are any conditions attached to the permits. Sometimes, the conditions relate to possible changes to neighbouring properties. You are in a much better position to negotiate if you are in possession of the facts.

Photographs showing conditions before and after the structure was built often provide backing for a possible complaint.

Take photographs during and after construction.
Take photographs as the structure is being built and afterwards. Always date the photographs and try to take them from the same position, so that they always show the view from the same angle.

Consult with the owner of the coastal structure that is affecting you.
This can be done verbally or in writing. It often pays to have evidence in writing and thus to build a 'paper trail' of the complaint.
If the owner does have plans to modify the structure to reduce the impact on your property, determine the nature

of the planned modifications and when they will be implemented.

Determine whether the owner of the coastal structure has any plans for modification, expansion or compensation for you.

Consult with planning and other authorities.
While you may have already checked with planning authorities concerning the permits for the structure, it will be necessary to lodge an official complaint with them if the owner of the structure is not willing to co-operate with you by modifying the structure or providing compensation. It may also be useful to make your complaint known to other authorities, such as your parliamentary representative. At this stage, you may wish to involve the local media and have them publicize the situation.

Any complaint should be made in writing with a full description of the relevant facts, such as conditions and dates.

Consult with other homeowners who are affected by the structure or who might become affected in the future.
The effects on shorelines of most coastal structures are cumulative. While only one property may be affected initially, the erosion may extend to several other property owners along the shoreline in the following months or years. Although it may be difficult to achieve a consensus approach among adjacent property owners, it is ultimately the most effective way of dealing with all shoreline problems.

Co-operate with other property owners to ensure coastal structures are effective and economical.

Carefully consider your options.
The erosion that caused your neighbour to build a seawall, revetment or similar structure in the first place may well progress in front of your property, so you may need to consider protecting your property. If this is the case, have your structure properly designed, obtain the necessary permits and try to co-operate with other property owners, since this will be in everyone's interests.
Similarly, if a groyne has been constructed, there may be opportunities for sand bypassing, which may involve moving sand from the updrift side of the groyne to the downdrift, eroded side. Alternative solutions include trucking the sand or pumping a sand and water mixture around the structure. A similar opportunity may exist with accretion behind an offshore breakwater. These approaches will require co-operation and cost-sharing among all the property owners involved.

If you are planning to build a structure:

It is always more effective and less expensive to take the necessary action before the waves start eroding your property.

Act before the situation becomes an emergency.
Once the situation becomes an emergency, your options are going to be limited and the actual construction will be more difficult and costly.

Obtain good technical advice about design before any construction is started.
Discuss all available options at your site. In particular, ask about: maintenance costs, the life expectancy of the structure, how the structure will perform under hurricane conditions, likely impacts on adjacent properties and environmental impacts.

Obtain advice from a professional with experience in coastal structures and their environmental impact on your island. Your planning agency will be able to recommend qualified persons.

Obtain the necessary permits.
Consult with the planning authorities for advice and the necessary permits for the proposed structure.

Consult with neighbours.
Always inform your neighbours about your project, since they may be affected and there may be the possibility of a less costly co-operative approach.

Adding more sand to the beach

ENVIRONMENTAL BACKGROUND

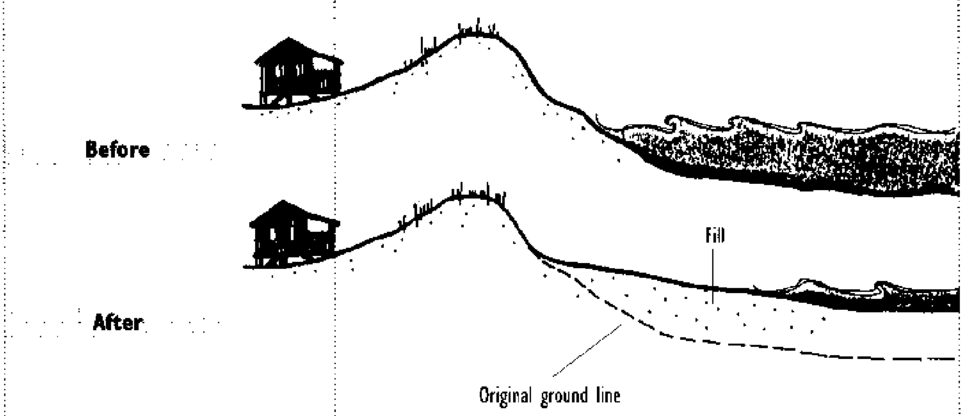
Periodic renourishment is required after the initial effort to put sand back.

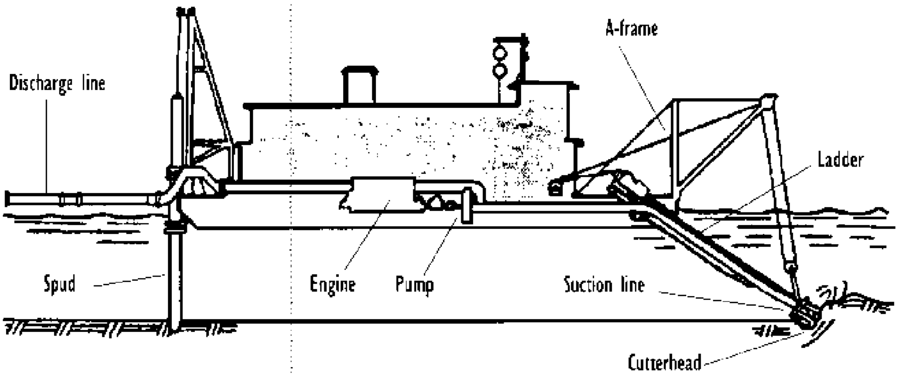
Beach nourishment consists of adding large volumes of sand to the beach. (See Figure 21.) The sand may be obtained from an inland or offshore source. Since land sources of sand are limited in the Caribbean, the sand is usually obtained from the offshore zone. The sand is pumped up often using a suction dredge. The sand and water mixture is then pumped via a floating pipeline onto the shore. (See Figure 22.)

Beach nourishment has been little used in the Caribbean islands, unlike in North America and other parts of the world. Generally speaking, it is an expensive technique and not an option individuals choose, since it includes an entire beach. In the islands, the cost of dredged sand ranges from US$5–16 per cubic yard/metre. In addition, mobilization costs for the dredge may range from US$100,000 to US$300,000 depending on the location of a suitable dredge.

Beach nourishment should not be viewed as a 'once only' operation, since periodic renourishment will be required at intervals of between two and eight years depending on the dynamics at a particular beach.

Figure 21. Before and after beach nourishment (adapted from US Army Corps of Engineers, 1981b).





Suction dredge (adapted from Clark, 1995).

**Several factors should be considered in determining the feasibility and design of a beach nourishment operation. These include the following:

The impacts of offshore dredging are often difficult to assess because they go unseen except by divers.

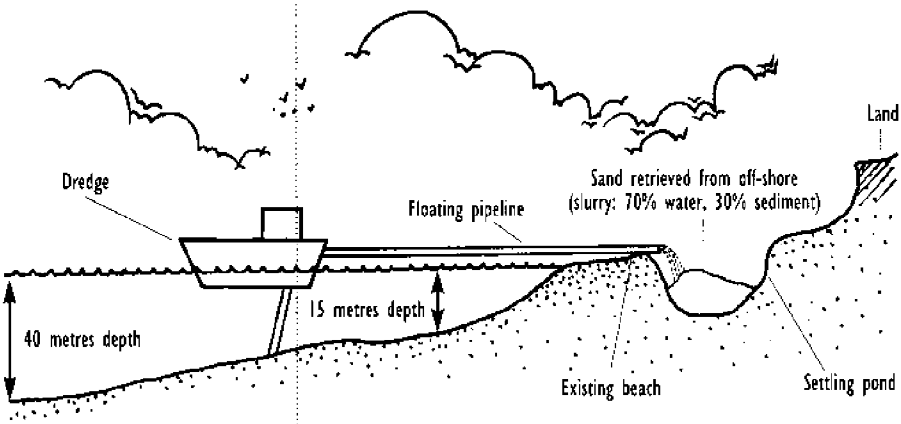
Sand Source

Offshore sand is the main source in the Caribbean islands. In order to be cost-effective, the dredge site should be as near the beach to be replenished as possible. Sand in shallow waters close to the beach is part of the natural reserve and may eventually replace eroded sand through natural beach processes. It should therefore not be disturbed. Sand found at depths of 15–40 m (49–131 ft) is generally the best source, since it lies beyond the natural beach sand replacement system and is relatively easy to dredge.

Disturbance to coral reefs and seagrass beds

Dredge sites should not be located on or near critical habitats such as coral reefs and seagrass beds. Dredging causes a great deal of siltation and turbidity, which can damage important marine ecosystems and local fisheries.

Figure 22. Beach nourishment with dredged sand. A sand and water mixture is pumped from the offshore zone into a settling pond on the beach, from which the water will drain back into the sea. The sand in the settling pond is then spread along the beach (adapted from Cambers, 1996b).



Photograph 16. Settling pond, Peter Island, British Virgin Islands, 1990. Sand has been pushed up to form the walls of the settling pond. There is an outfall pipe taking water back to the sea. This pond has been filled with dredged sand that will have to be removed by heavy equipment and placed on the beach. The pond will then be ready to receive more dredged sand.

Quantity of sand to be used as fill

During the sand replacement process, it is necessary to place about 50 per cent more sand than is actually needed, since much of the sand will be lost over time as the waves form a natural slope over the beach and offshore zone.

An environmental impact assessment should always be conducted before permits are issued for an offshore dredging operation. The assessment should include a detailed dredge plan and programme for mitigation.

Quality of the sand

The size of the sand grains used for replenishment should be the same as the original beach sand or slightly coarser.

Supply of sand to the beach

Once the sand has been pumped onto the beach, several settling ponds should be constructed to receive the slurry. Silt curtains can also be used to reduce the amount of sediment returning to the sea.

Beach nourishment has the advantage of providing a new beach quickly. However, there is the expense to consider and it requires detailed preliminary studies. In addition, beach nourishment will interfere with normal beach activities while the operation is actually in progress. Depending on the size of the project, beach nourishment may take from one to six months.

Photograph 17. Pre-beach nourishment conditions, Pinneys Beach, Nevis, 1995. One week after Hurricane Luis, the beach had been severely eroded.

PRACTICAL RESPONSES

Consult professionals to determine if beach nourishment is a suitable solution for the particular beach erosion problem.

Determine if dredging is a suitable option.

At some sites, dredging may not be a suitable option, perhaps because there are no suitable offshore deposits of sand available. Offshore dredging and beach nourishment are not necessarily options for every beach erosion problem.

Consult with other property owners.

Beach nourishment is a major undertaking and should always be done in consultation with other property owners.

Obtain permits from the necessary authorities.

It may be necessary to obtain permits from several different government agencies. Your planning authority will be able to advise you. In most islands a full environmental impact assessment must be prepared and evaluated before permission is given to dredge. The assessment may prove expensive and time-consuming; usually, it will have to be paid for by the developer or those wishing to dredge. It will usually be necessary to allow for at least twelve months to obtain the necessary permits and have the environmental impact assessment completed.

Allow sufficient time for the completion and review of the environmental impact assessment.

Obtain information about previous nourishment projects on your island.

If nourishment projects have previously been undertaken on your island or those adjacent, it is well worthwhile

Photograph 18. Post-beach nourishment conditions, Pinneys Beach, Nevis, March 1996. Three months after a sand replenishment project, there was a wide beach. However, it should be noted that the observed sand accretion will also have been partly due to natural recovery following the hurricane.

finding out details of these projects, such as costs, location of suitable dredges and time interval before a further nourishment was necessary. This information may well help you to determine the feasibility of your own project and provide a cost-estimate prior to the undertaking of the necessary studies and design, which are themselves an additional expense.

Be aware of the limitations of dredges.
Dredges usually need fairly calm conditions in which to operate, so sand sources on an exposed or windward coast may not be suitable. On leeward coasts, the best time of year for dredging will usually be in the summer months, provided there is no hurricane activity (the hurricane season runs from 1 June to 30 November).

Budget for additional replenishments.
Nourishment is almost never a once-only operation. Experience in Anguilla and other parts of the world has shown that the nourished beach may disappear in the next storm, which may very well occur the following year.

Make provisions for beach users during dredging.
The dredging operation will cause considerable disruption to the beach. For example, the settling ponds will take up most of the beach area. During dredging, the water may look 'dirty' because of the heavy silt load. It is necessary to advise beach users in advance and, if necessary, restrict access to the beach for safety reasons.

Consult local biologists about turtle nesting.
If the beach you plan to nourish is an important turtle nesting site, schedule the nourishment project outside the nesting season. Local biologists and the fisheries department will have information about turtles.

When sand has been mined from the beach

ENVIRONMENTAL BACKGROUND

The removal of sand from beaches has been taking place in many Caribbean islands for decades. In the past, however, the volumes removed were relatively small. As populations and economies have grown in the region and construction materials have changed from wood to concrete, so too has the demand for sand. There are insufficient accessible, inland deposits of sand to satisfy demand. As a result, legal and illegal sand mining along beaches and shorelines, as well as in rivers, has increased. Remote beaches with road access are often targets for illegal mining.

Removal of sand, gravel or stones from the beach or dune system will cause the water line to retreat.

River mining removes sediment before it has reached the shoreline. River sand is often regarded as good for construction because it is salt-free. However, its removal reduces the amount of sand available for transport to the beach.

Sand mining directly from a beach removes sand permanently from that system. The sand has a high salt content, which results in corrosion of the reinforcing bars and cracking of the plaster. Beach sand is, therefore, not ideal for construction unless washed. Washing requires a large volume of water which, on some of the smaller islands, may not be readily available.

On some of the volcanic islands, gravel and stones are also removed from the beach for use in construction. Removal of this material has the same effect as the removal of sand, namely erosion.

Beach processes cross man-made boundaries. An action can affect beaches that are remote from the actual intervention.

Mining anywhere along a beach may affect a particular coastal property. The mining activity does not have to be located immediately in front of the property concerned. Mining removes sand from the coastal system and may ultimately affect other beaches distant from the mining.

Mining also affects the nesting activities of endangered sea turtles. Nests may be destroyed during mining.

Furthermore, baby turtles follow the beach slope down to the sea. A mining pit may totally disorientate them and reduce their chances of reaching the sea.

In most of the Caribbean islands, beach sand mining is controlled by law, with permits having to be obtained from the relevant authorities. Some islands allow sand mining from certain designated beaches on a permit basis. Mining may vary from a few bags of sand to large-scale operations using heavy equipment. Obviously, the larger the scale, the greater the erosion.

On some islands, sand is also mined from dunes. Sand dunes are part of the beach system and must be managed as such. Dunes are built by wind action and provide reservoirs of sand that feed the beach during tropical storms and hurricanes. They are also important habitats. On some islands, dunes have been destroyed in the process of supplying construction sand, leaving beaches depleted and coastal lands vulnerable to flooding.

It is important to realize that there are other sources of sand available for construction. For example, on most of the volcanic islands, fine crusher dust from the local quarry can be substituted for most sand uses, although it is usually necessary to alter the relative proportions of sand, water and cement in the construction mix. In addition, there may be a cost factor involved. Quarry products may be more expensive. Dredging sand from the offshore zone may be another alternative, but environmental impact assessments and the like are required before such projects may be undertaken. (See also Case 5.) On many islands, the rounded grains of beach sand make it the preferred material for the final finishing or plastering.

Photograph 19. Pre-mining conditions, Diamond Bay, Saint Vincent, 1980. On this wide beach backed by sand dunes, some mining has already commenced. Note the truck and the pit in the foreground.

PRACTICAL RESPONSES

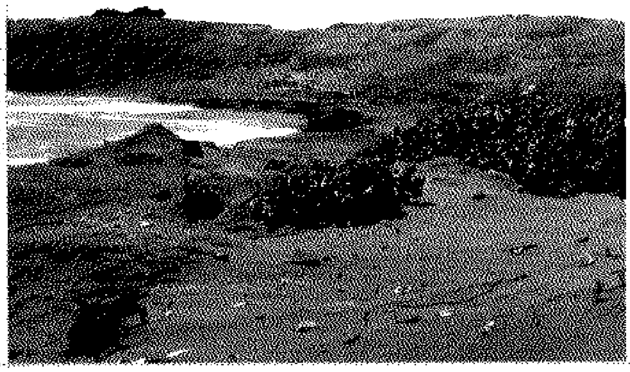
The end result of sand mining is a reduction in sediment in the beach system, regardless of whether the extraction is from the dune, the back beach area, the foreshore, or the seabed immediately adjacent to the beach.

Determine where sand mining is occurring.

It is not difficult to see where mining is taking place. Miners usually target the berm crest, back beach or dunes that are accessible from the road. They create large, uneven pits in the beach that could not possibly have a natural origin. Tyre tracks leading to and from the site are other tell-tale signs. Some legally designated mining sites may be enclosed with fences.

Determine the legality of the mining operation.

Owing to a severe sand shortage in many Caribbean islands, governments have had to take fairly drastic measures to service the supply, while also preventing uncontrolled beach mining. Certain islands have designated beaches where mining can be conducted. However, even at these designated sites, permits are usually necessary. Whether legal or illegal, mining destroys the natural coastal environment. Beaches and dunes cannot be rebuilt by nature as quickly as we are able to truck them away. Many Caribbean islands have legislation prohibiting mining of the foreshore and seabed areas. The public library or Attorney General's chambers should be able to provide this information. Most islands have an agriculture planning or public works agency that is responsible for the control of sand mining.



Photograph 20. Post-mining conditions, Diamond Bay, Saint Vincent, 1995. The dunes have been removed and the beach has disappeared. The sea is now cutting into the land that once lay behind the dunes.

Report apparent incidences of illegal sand mining to the planning authorities and police.

If you see sand mining taking place, check with your local government authorities as to whether it is legal. Sand mining is a lucrative business and there may be some personal risk involved in approaching the miners directly. There may even be an element of risk involved in alerting the relevant authorities. Nonetheless, self-interest is a strong incentive and mining affects everyone who uses the beach.

It is always best to act in the common good.

Remember that there is strength in numbers.

If possible, seek to develop a consensus among your coastal neighbours on the issues. Your problem is also your neighbour's problem – or it will be in the near future. The authorities may be more inclined to respond to a large group of concerned citizens than to an individual.

Do not take sand from the beach yourself and do not buy beach sand.

Practise what you preach.

Do not take sand from the beach yourself and do not buy beach sand for the construction of your house. Check out other sand sources available on the island. While other sand sources may be more expensive in the short term, you will be gaining in the long term, for your building will require less maintenance and may have a longer life.

Lobby your parliamentary representative.

Particularly if you cannot get any satisfaction from your local authorities, lobby your parliamentary representative for help. Invite him/her to the site to inspect the damage first-hand.

Take photographs of the mining operation.

Remember, a picture is often worth a thousand words. Take photographs of the mining and the damage caused.

When sand dunes have been destroyed

ENVIRONMENTAL BACKGROUND

Dunes may best be regarded as reservoirs of sand. They have even been likened to sand savings accounts (South Carolina Coastal Council, 1987).

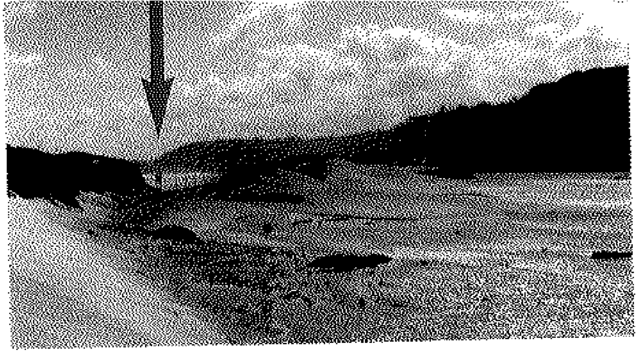
Sand dunes and beaches must be managed as one system. Dunes depend on beach sand for their formation and beaches need the reservoir of dune sand during storms.

Sand dunes are mounds of sand that often lie behind the active part of a beach. In the Caribbean, they range from very low formations 0.3–0.6 m (1–2 ft) high to large hills of sand up to 6 m (20 ft) high. There may be several parallel rows of dunes which are then usually named primary, secondary and so forth, starting from the most seaward line. Dunes form when sand is carried by the wind from the beach towards the land. When the wind encounters an obstacle, like a clump of vegetation, the wind slows down and the sand is deposited.

The rate of sand movement depends on the wind speed, sand grain size and the amount of moisture in the sand. Fundamental research on desert dunes (Bagnold, 1954) shows that significant sand movement will take place when the wind speed measured at a height of 1 m above ground level exceeds 12 knots (6 m per second). In the Caribbean, average wind speeds equal or exceed this value, especially in the months from June to July and December to March.

If, during a storm or hurricane, the beach is eroded and the waves reach the dunes, then the dunes will also suffer erosion. The sand is then carried into the water and possibly to a deposit offshore. (See Figure 23.) This sand deposit then absorbs some of the destructive wave energy that would otherwise focus on the beach and dunes. Following the storm, the sand is moved back onto the beach. As the beach accretes, the process of sand dune formation starts over again.

This process was seen at many sites in the Caribbean during Hurricane Luis in 1995. Dunes and beaches were severely eroded and the sand was deposited in offshore sand bars. These sand bars migrated onto the beach in the weeks following the hurricane.



Photograph 21. Breach in the dune line after high seas, allowing flooding of the land behind the dune, Isabela, Puerto Rico, 1996. Extensive mining has left only a narrow strip of dune.

Sand dunes are temporary features. They are reservoirs of sand that feed the beach during storms.

Sand dune formation is a slow process. It may take decades.

Sand dune formation is a slow process when compared to beach changes. Four months after Hurricane Luis, which occured in September 1995, measurements in Anguilla showed that beaches had recovered to 75 per cent of their pre-hurricane levels (Cambers, 1996a). However, the dunes, which showed an average retreat of 9 m (30 ft) after the passage of Hurricane Luis, will take decades to recover to pre-hurricane volumes.

Dune vegetation promotes the large-scale trapping of sand. Dune plants have to adapt to harsh conditions that include high temperatures, dryness, occasional inundation by saltwater and the accumulation of sand. Generally, native beach grasses, such as seashore dropseed (*Sporobolus virginicus*) and trailing vines like beach morning-glory (*Ipomoea pes-caprae*) are the most hardy species, often being found on the seaward face of the dunes.

Unfortunately, sand dunes are often seen as prime sites for sand mining activities. (See also Case 6.) Like wetlands, sand dunes have often been perceived as 'useless' areas. Their many functions, which include acting as a sand reservoir for the beach and protecting land areas from harmful salt laden winds, have been little understood. Many dunes in the Caribbean have disappeared altogether as a result of mining activities like those formerly present at Josiah's Bay in Tortola, British Virgin Islands, and at Diamond Bay in Saint Vincent. At the latter site, dunes more than 6 m (20 ft)

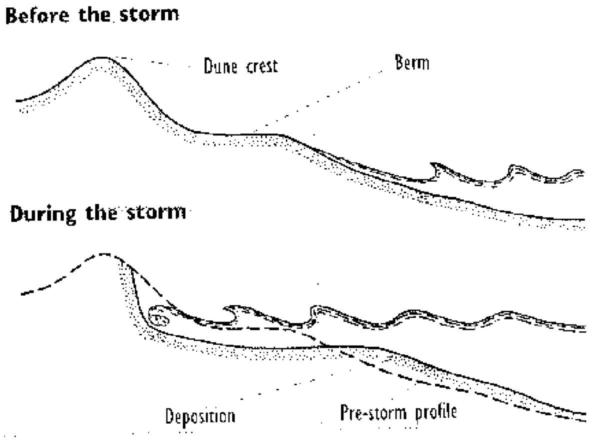


Figure 23. Storm wave attack on a beach and dune. During the storm, the beach is eroded and the waves begin to attack the dune, resulting in a vertical dune face. The dune sand is deposited offshore and will eventually return to the beach (adapted from Coastal Engineering Research Center, 1984).

Photograph 22. Sand fences help to speed up the process of dune formation by increasing the deposition of wind-blown sand.

high consisting entirely of black sand have been completely mined out, leaving the sea to cut into the lowland that once lay behind the dunes. (See also Case 6.)

Dune vegetation has to survive harsh natural conditions. It cannot withstand heavy trampling.

At Isabela on the north coast of Puerto Rico, the mining of an extensive system of dunes has left a narrow strip of dunes between the land and the sea. Erosion during winter swells results in breaching of the dune line, leaving the land behind the dune vulnerable to flooding.

The formation of sand dunes can be speeded up with sand fences and revegetation.

Dunes are the result of decades of slow accretion. The artificial pushing up of mounds of sand to form 'instant' dunes does not usually work well. Under normal conditions, as dunes grow naturally, each new layer of sand compacts the layers below, so that a firm structure forms. However, there are ways to speed up the process, such as building sand fences. While they are used in other parts of the world, sand fences have been little used in the Caribbean. Studies in other parts of the world have shown that a sand fence with a 50 per cent porosity (ratio of open space to total area) can result in a 1.2 m (4 ft) high dune forming in twelve to twenty-four months (Clark, 1995).

There must be a large area of dry-sand beach over which the wind can blow in order for dunes to form.

Obviously, dunes will not form at every beach. One of the most important criterion is that there be a large area of dry-sand beach over which the wind can blow and pick up the sand grains. Unless a wide dry-sand beach is present, dune formation is unlikely to take place.

Photograph 23. Sand fence made of wooden pallets, Arecibo, Puerto Rico, 1997. The fence of pallets resulted in a wide dune forming over a two-year period. The dune has a height of 1.2 m (4 ft). This low-cost type of fence is fairly easy to construct.

PRACTICAL RESPONSES

Conserve existing sand dunes.

While sand dunes are temporary features, every effort should be made to conserve existing dunes. Proposals to mine the primary dune or to lower it to provide for improved views should not be entertained.

However, where several rows of dunes exist, it may be possible to alter or use the secondary or tertiary dunes to build or supply construction sand. Nevertheless, special care must always be taken in developing such areas, so it is wise to consult your planning agency. In the case of mining activities, mitigation plans and site restoration activities should play a prominent role in any applications.

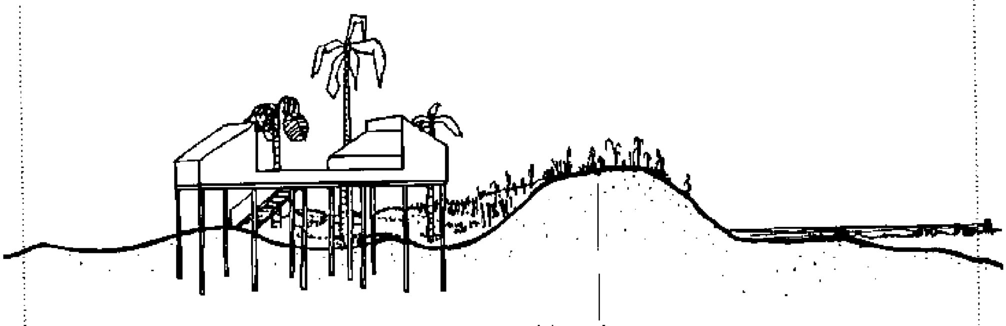
Do not build on the primary dune.

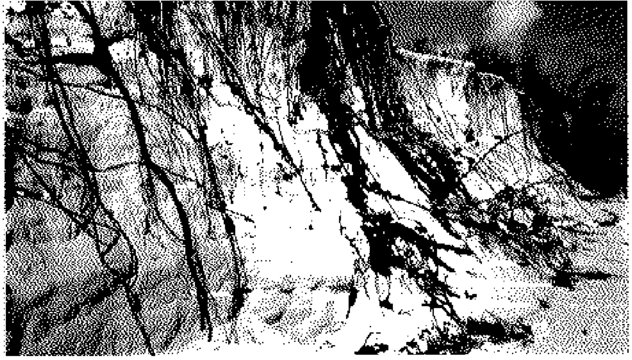
Do not build on the seaward or primary dune.

This is the first line of defence in a storm and should be left undeveloped so that it can fulfill that function. Remember that dunes are temporary features of the landscape. Always build behind the primary dune (See Figure 24.) and, if at all possible, well behind it. Building on piles is also recommended. This allows for some sand movement without the risk of building collapse.

On some islands, it may not always be feasible to avoid building on the primary dune. For instance, there may be only one dune between the beach and a salt pond or wetland. Where this dune land is privately owned, it will

Figure 24. Recommended construction on a dune. Here, the primary dune has been left intact. The building has been built on piles to allow for the uninterrupted flow of floodwater and positioned behind the primary dune (adapted from the US Department of Housing and Urban Development, 1981).





Photograph 24. Dune erosion resulting from Hurricane Luis, Rendezvous Bay, Anguilla, 1995. The hurricane waves left the dune face with a near-vertical slope. Recovery can be speeded up in such cases by regrading the slope to a natural angle and replanting the new slope.

probably be zoned for development. In such cases, the most important guideline is to try to build as far back from the sea as possible.

Encourage dune planting.

If low dunes are beginning to form on a beach, these can often be enhanced by planting grasses and vines to hold the sand and encourage further sand accumulation. Consult local horticulturists to determine which plants will best survive.

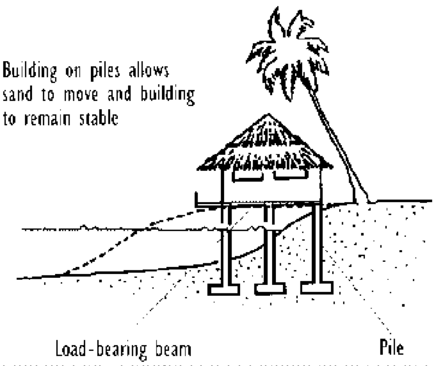
After a hurricane, regrade the slope and replant the dunes.

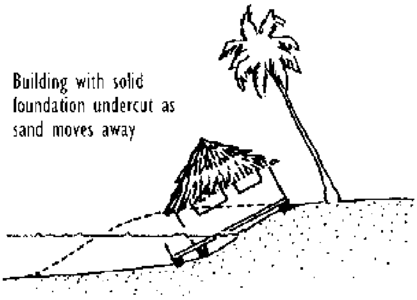
If a recent hurricane has left vertical cliffs of sand with no vegetation, it may be appropriate to regrade the slope and replant. However, it will be necessary to consult your planning agency to obtain permission first.

Consider whether sand fences could be used to speed up the process of dune recovery.

After a hurricane, the best solution for beaches is often to let them recover naturally. (See also Case 2.) However, sand fences can be erected to help dune recovery after a hurricane or a mining operation. Some guidelines for sand fences (adapted from Craig, 1984 and Clark, 1995) are as follows:

Source: Crown of Thorns Newsletter, 1990b.





- Dune fences should be well above the reach of storm waves.
- The wider the dry-sand beach area, the greater the likelihood that sand will accumulate in front of the fence.
- Fence lines should co-incide with the natural vegetation line or primary dune.
- Fencing should have a porosity (ratio of open space to total projected area) of about 50 per cent.
- Straight fence alignment is recommended rather than zig-zag.
- The fence should run parallel to the shoreline. It need not be perpendicular to the prevailing wind direction.
- A 1.2 m (4 ft) fence will usually fill to capacity within 1–2 years.
- Fence-built dunes must be stabilized with vegetation, as the fence will deteriorate over time and release the sand.

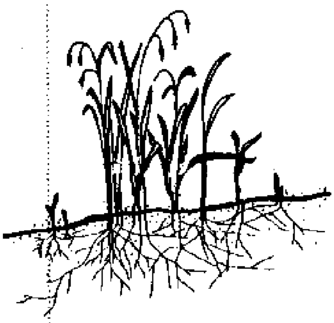
Remember to find out if the beach is a sea turtle nesting site. If it is, you may need to schedule the sand fence construction outside the nesting season, since the physical construction of the fences may disturb the turtle nests.

Avoid walking on sand dunes. Construct wooden walkways. Dune vegetation cannot withstand the continual pressure of foot traffic. This can kill the vegetation and result in low spots in the dune line. These depressions then become the lines of weakness that waves can break through during a storm. Wooden walkways should be constructed over the dunes along well-used paths that follow the existing dune contours. Notices may also be posted to advise people not to trample the dune vegetation.

Photograph 25. Wooden walkway, Grace Bay, Providenciales, 1997. Persons walking from the hotel to the beach will use this walkway, since it not only protects the low sand dunes, but also provides the easiest means of access.

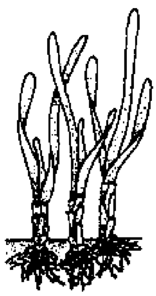
When vegetation has been removed from behind the beach

Environmental background



Roots and stems trap sand and soil

There is little other than the natural vegetation to anchor a beach or provide stability.



Turtle grass

Beaches and dunes are accumulations of loose particles of sediment. There is no 'cementing' material to hold the particles together, unlike in the case with rocks. Waves, currents and wind are the main processes acting on the loose sediments. These factors make beaches one of the most dynamic and fast-changing systems in nature.

On the dry part of the beach, above the high water mark, and on the coastal sand dunes where they exist, vegetation stabilizes the sand or other sediment. The roots of plants and trees help to hold the sediment – especially sand – in place. The deeper and more extensive the root system, the greater the degree of stability.

Offshore, seagrass beds play a similar role. The roots of turtle grass and manatee grass for example stabilize and hold the sandy offshore sediments in place, keeping the water clear and clean.

However, conditions on the beach and in the dunes are harsh for plants. Coastal plants must adapt to high temperatures, dryness, few nutrients and occasional inundation by salt water. Not all can survive in such conditions.

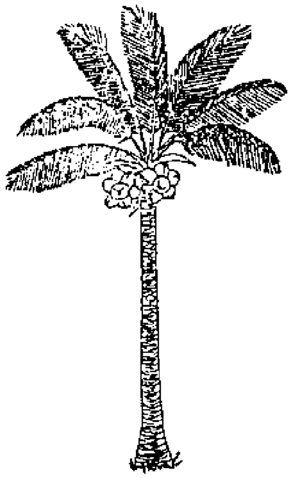
The dry beach area above the high water mark is part of the salt spray zone and is generally colonized by grasses like seashore dropseed (*Sporobolus virginicus*) and trailing vines like beach morning-glory (*Ipomoea pes-caprae*). This vine is also known as goat-foot and has pink-purple flowers. Other plants that may be found on the back beach include beach bean (*Canavalia maritima*) and sea purslane (*Sesuvium portulacastrum*). Many have fleshy stems or leaves which allow them to store rainwater. High storm waves often destroy these plants, so they are considered temporary.

Deep-rooting trees, such as sea grape, West Indian almond and manchineel, provide the land adjacent to beaches with some stability. They often help to slow down erosion, but ultimately will not stop it.

Inland from the salt spray zone, there is often a belt of trees known as the coastal woodland. These trees may be stunted and wind-blown. Consisting of a few species able to tolerate the harsh conditions, this coastal woodland includes: sea grape (*Coccoloba uvifera*), seaside mahoe (*Thespesia populnea*), manchineel (*Hippomane mancinella*) and West Indian almond (*Terminalia catappa*).

Coastal woodland trees are very deep-rooting. During storms, their roots may be exposed as the waves erode the sand, but they also provide a focal point around which sand accretes after the storm. These trees provide lands adjacent to beaches with a much greater degree of resistance to winter swells and hurricane wave attack. Furthermore, they provide shade and add aesthetic value to the beach, as well as local fruits like sea grapes.

Coconut palm



Manchineel trees are often feared in the Caribbean for their poisonous fruits and the painful rashes their sap causes. However, manchineel trees should not be cut down. Public awareness-building campaigns, such as the posting of notices and signs, should be promoted as a means of assuring the safety of beach users, especially tourists who may not be familiar with these trees.

The coconut palm (*Cocos nucifera*), while not a native tree (it was actually introduced from the Indo-Pacific region), is very common in the islands. Tourists in particular associate the coconut palm with the Caribbean. While it is a useful tree, since it provides milk, 'meat', oil and other products, it is very shallow-rooted and easily undermined by high waves. It is fine to plant coconuts for shade or fruit, but do be aware that, from a beach conservation viewpoint, it is

Photograph 26. Warning notice on a manchineel tree, Mustique, 1993. These trees provide the beach with stability and should not be destroyed, despite their poisonous nature. Public awareness-building campaigns can help tourists and other visitors to the beach to learn to live with them.

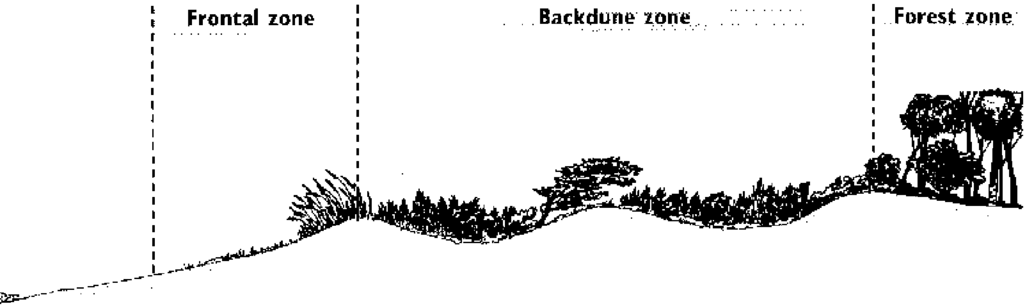


Figure 25. Cross-section showing typical vegetation zones in a coastal dune area. The frontal zone, which comprises the back beach and seaward dune slope, is covered with grasses and vines. In the back beach zone, there are more shrubs and herbaceous plants. This eventually gives way to the coastal woodland (adapted from Craig, 1984).

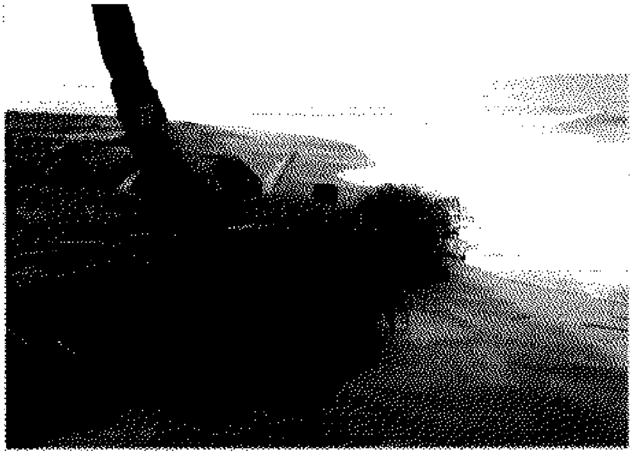
best to vary the planting effort with other trees, such as sea grape and West Indian almond.

At some beaches, there are sand dunes between the back beach and the coastal woodland. The dunes are often colonized with the same grasses and vines as the back beach zone although there may also be other shrubs such as sea lavender (*Tournefortia gnaphalodes*). Since vegetation on the dunes helps to encourage deposition of wind-blown sand, every effort should be made to preserve the plants. See also Case 7 for more information about dunes. Figure 25 shows a typical cross-section through a Caribbean beach/dune/coastal woodland zone.

Besides giving the beach stability and promoting accretion coastal shrubs and trees provide shade and privacy for beach users and beachfront property owners alike.

The vegetation is affected in many different ways by human activities that include: cutting and clearing for construction purposes; cutting of vegetation for barbecues and fires; replacing of native with with foreign species; walking on unmarked routes; and driving vehicles over dunes and on beaches.

Photograph 27. Undermined palm trees, Levera, Grenada, 1986. Palm trees are very shallow-rooting, as can be seen here, and are easily undermined by wave action.



PRACTICAL RESPONSES

It is in your own best interest to preserve the natural vegetation, which may help to slow down beach erosion.

Preserve all coastal vegetation.
As a general rule, try to preserve all coastal vegetation and especially shrubs and trees.

Find out about the laws governing vegetation clearing.
Many countries have laws to protect vegetation, especially trees. Establish the ground rules on what is/is not acceptable, before removing vegetation. Check with the agriculture department. Local naturalists, foresters and horticulturists are often an excellent source of information on shoreline vegetation.

Be selective when clearing land.
If it is absolutely essential to remove some shrubs and trees for your development to proceed, be selective. Do not simply send heavy in equipment with instructions to clear the land on the site. Determine which trees, if any, can be preserved. Use a local architect who can design the building to preserve most of the existing trees on site.

Be very explicit in your instructions to contractors.
In some cases, a contractor may prefer to clear a site totally even though it is not absolutely necessary. Explain at the outset that you require the trees to be left intact. It may be necessary to supervise the clearing yourself.

Act quickly if you see heavy equipment on the beach.
It takes only minutes for heavy equipment to clear decades of tree growth. If you see preparations for construction work about to begin, act immediately. Make a call to the planning agency and determine whether permission has been granted to remove the vegetation. Ask the operators of the heavy equipment if they have the necessary permits. If all else fails, at least take photographs. Photographic evidence may stop a similar thing happening in the future at another site.

Plant trees and shrubs in the coastal area.

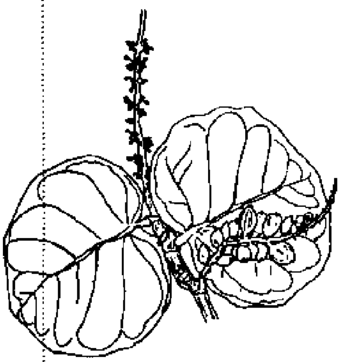
Help care for the coast by planting native trees and shrubs like those described in this section. Preserving the natural vegetation may help to slow down beach erosion. If you prefer to plant palm trees for the 'tropical atmosphere,' vary them with deep-rooting species. Whether you are a home owner or community group desirous of taking care of the beach, remember that, in order to be successful, any tree-planting project should make provision for the following factors:

- The plants need to be a reasonable size.
- The plants will need fertilizer, especially nitrogen fertilizer.
- Spreading a layer of mulch (dead leaves, seagrass) around the plant will minimize wind and water erosion and help the soil retain moisture.
- At the early stages of the project, regular watering may be necessary.
- Fences around the plants will be needed if animals graze freely in the area.

Obtain advice from local horticulturists about what species are most appropariate to plant and where.

Obtain advice from local horticulturists.

Local horticulturists will know what works and does not work on your island. For instance, some people say they do not like planting sea grape because it grows as a bushy shrub and obscures their view. Sea grape will grow as a shrub when it is near the back beach or the seaward face of the primary dune. However, farther back in the coastal woodland, it will grow as a mature tree reaching up to 8 m (26 ft) high. (See the cross-section in Figure 25.) Similarly, the casuarina tree, or Australian pine (*Casuarina equisetifolia*), is sometimes favoured for coastal planting, since it grows very fast. However, it casts dense shade and produces a thick carpet of pine needles. Both of these factors may help to reduce the number of low-growing plants nearby. A lack of ground cover under these trees may lead to greater erosion of the beach or dune.



Sea grape

Use local materials for a mulch.

Dead seagrass, which is often washed up in thick mats on the beach, especially after storms and hurricanes, is sometimes unattractive to tourists and hotel managers. This material can be collected, dried and used effectively as a mulch.

Photograph 28. Tree planting, Brandywine Bay, Tortola, 1990. Schoolchildren are planting some West Indian almond seedlings. Projects like these involve children and other residents in caring for the beach.

Construct walkways from buildings to the beach.

As mentioned in Case 7, walking over sand dunes damages the delicate vegetation growing there. Since the same applies to all coastal vegetation, it pays to construct wooden walkways along heavily used tracks and along paths from private buildings to the beach.

Organize community beach-planting projects.

If you are a beach-lover and care about the coastal environment, organize a beach-planting project for your coastal community, the local school or a specific community group to undertake. Local hotels and the tourism association may help sponsor your project. However, remember that any planting project will require follow-up care of the plants. The trees you plant will benefit all beach users by providing shade while helping to stabilize the beach.

Stabilizing the river mouth or tidal inlet

ENVIRONMENTAL BACKGROUND

Any tidal inlet, through a shoreline leading to a port, harbour, lagoon, salt pond, wetland, estuary or river can affect beaches adjacent to the inlet.

Rivers bring sand and other sediment to the beach and coastal system.

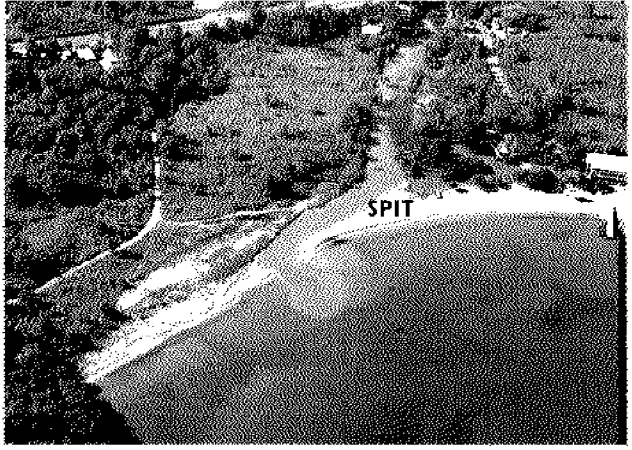
Rivers are particularly important to many coastal areas because they transport large volumes of sand and stones from farther inland to the sea. Much of this material eventually ends up on the beaches. As was seen in Case 6, mining sand from the river removes material before it can reach the shoreline. Thus, river mining reduces the supply of sand to the beach.

In the Caribbean islands, many rivers are blocked from entering the sea by sand bars, which are formed by wave action moving sand onto and along the beach. The river is then only able cut a channel through the beach to the sea during a storm or heavy rainfall. After the rain stops, the river mouth is closed naturally by a sand bar. However, even then, freshwater may continue to enter the sea by flowing through the sand beach. Sometimes, a concentration of freshwater forms a large pond behind the sand bar.

These sand bars are often favoured places for sand extraction. The excuse is often given that a channel is required to improve drainage, but removing sand from the bar is the same as removing sand from the beach.

Spits are coastal features formed by accretion. They may divert river channels.

Sometimes, the river mouth is diverted by a spit. (See Figure 5, Case 1.) Consisting of sand and/or stones and formed by wave action, the spit is joined to the shore at one end only. It forms by the process of longshore transport. Waves approaching from a constant direction result in a longshore current that moves the sand or stones along the beachface in one direction. (See Figure 16, Case 4.) The sand spit may grow across the mouth of the river, thereby diverting its path to the sea.



Photograph 29. Sand spit, White River, Jamaica, 1988. The river makes a sharp turn just before it enters the sea. The turn is caused by a sand spit diverting the mouth of the river to the left-hand side of the photograph. During periods of heavy rain, the river will break a new path straight through the spit to the sea. The process of spit formation will then start all over again (Photograph by J. S. Tyndale-Biscoe, Jamaica, 1988).

Dry river channels, often known as ghuts or guts, may become roaring torrents of water during and after heavy rains.

River mouths are areas of continuous change because they are shaped by ocean and river processes.

On many of the smaller islands, rivers may be dry for much of the year. Although the channel remains, there is no visible water flowing into it. These streams or rivers are often known locally as guts or ghuts. However, during heavy rains, these dry channels may become the paths of roaring torrents of water. Whether large or small, the river mouth is an area of constant change.

Water from wetlands and swamps may also break through the beach during heavy rainfall. Sometimes, such processes are aided by man cutting channels to drain coastal swamps. While these channels may provide for improved drainage, they also result in large volumes of sediment-laden water flowing into the sea. Seagrass beds and coral reefs may be damaged if large amounts of sediment are deposited on top of them. (See also Case 10.)

River mouths are particularly dynamic areas. They are shaped by waves, tidal currents and ocean processes, and are also acted upon by river processes.

Rivers may be influenced by tidal flows. As the tide rises, salt water flows into the river and mixes with the freshwater. This brackish water mixture may extend some

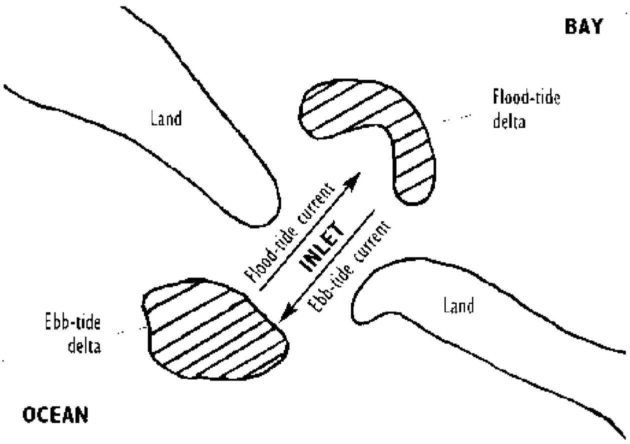


Figure 26. Typical deltas associated with a tidal inlet. On the rising tide, the flood current flows into the bay and forms the flood-tide delta. On the falling tide, the ebb current flows towards the sea and forms the ebb-tide delta.

Photograph 30. Beach drainage channel, Cotton Ground, Nevis, 1983. This channel was cut to provide for drainage of the coastal wetlands after heavy rainfall.

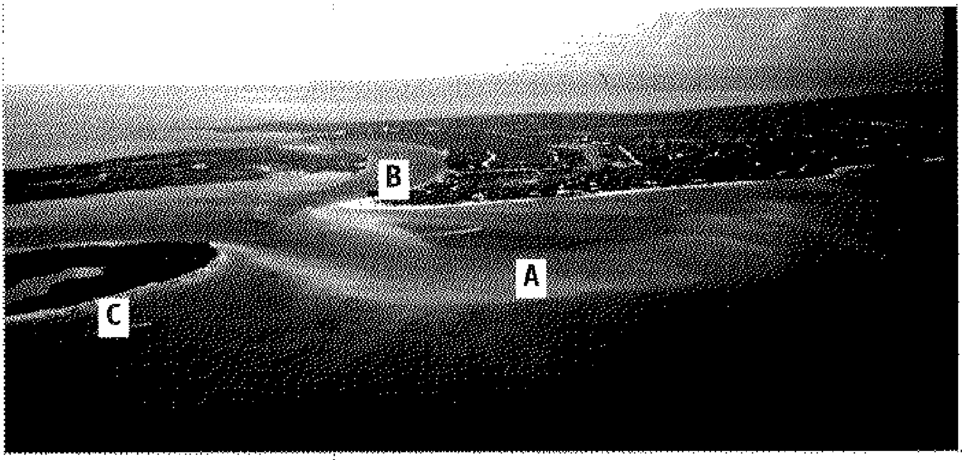
Shorelines bordering inlets are very dynamic areas. They may erode or accrete ten times faster than shorelines farther away from the inlet.

considerable distance upstream. As was seen in Case 1, tidal currents are particularly significant at river mouths and the passages between islands.

Many of the Caribbean islands are less than one kilometre apart, particularly in the Bahamas and the Turks and Caicos Islands. Tidal currents play an important role in the channels between these islands, moving and depositing sand. On the seaward side of the inlet (or channel), sand may accumulate on the sea-bottom to form an ebb-tide delta. (See Figure 26.) Similarly, on the landward side of the inlet, sand accumulates to form a flood tide delta. At some sites, sand being moved along the coast by the process of longshore transport becomes trapped in these deltas, which may extend hundreds of metres out into the sea.

These inlets are extremely dynamic and their position often changes over a few years. The sand deposits associated with inlets, particularly the ebb-tide delta, may change the wave energy in the local area. Coastal changes may be several times greater near an inlet than at a beach only one kilometre away from the inlet.

Photograph 31. Ebb-tidal delta, Leeward-going -through Channel, Turks and Caicos Islands, 1997. A large ebb-tidal delta (A) has formed seaward of the tidal inlet. The rate of coastline change near the inlet mouth (B) is several times greater than at the beach further along the shoreline (C).



PRACTICAL RESPONSES

Do not be deceived by a dry river channel. Always remember that the channel was shaped by water.

Do not build near a river mouth or inlet.

Rivers and inlets are very dynamic areas. One heavy rainstorm may completely change the shape of the river mouth, turning what was once land into a river channel. Rivers and inlets should be left to fluctuate naturally and no building should be undertaken in their immediate vicinity.

Do not build in the immediate vicinity of rivers or inlets. Look for alternative sites.

Use historical aerial photographs to determine whether a site is a 'safe' distance from a river mouth or inlet.

There is no magic distance from a river mouth that can be used to define the safety of a site. Local conditions result in variations from island to island and from site to site. Particularly in the case of tidal inlets, coastal areas within 1–5 kilometres (0.6–3 miles) of the inlet can be expected to show high rates of change over a decade. Historical aerial photographs can be used to show how a tidal inlet or river mouth has changed its position over the years. These photographs exist in most Caribbean islands for as far back as the 1960s. They are usually stored at the lands and surveys departments.

Leave rivers and inlets to change naturally.

River mouths and inlets should be left to change naturally. Structures like jetties may change the velocity of a river and in turn the amount of deposited sand. The river mouth is an area where sand from farther inland is deposited. This sand then becomes part of the beach. Similarly, when inlets are stabilized with jetties, adjacent beaches are impacted; some will accrete, others will show dramatic erosion

Conduct a full environmental impact assessment before any river or inlet stabilization structures are built.

It is sometimes necessary to stabilize a river mouth or inlet for navigational or other purposes. An environmental impact assessment is a planning tool that assesses the likely impacts of the stabilizing structures and designs ways and means of reducing negative impacts like beach erosion.

Carefully consider the impact of draining coastal swamps.
Mangrove swamps and wetlands serve many purposes. One of these is to filter sediment and debris from the land runoff before it reaches the sea. Thus, cutting a channel through the beach to drain the wetland will allow the sediment and debris to flow out into the sea. This could result in the nearshore waters becoming a dirty brown colour for several days. Furthermore, the sediment may cover adjacent seagrass beds and coral reefs. In extreme cases, accumulated sediment can result in their death. Coastal flooding may sometimes make it necessary to drain coastal wetlands. However, in each case, the advantages of draining must be weighed carefully against the disadvantages of damaging nearby seagrass beds and coral reefs.

Do not mine sand from river mouth bars.
If it proves necessary to drain a coastal area and cut a channel through the beach, even after taking into account the above responses, do not remove the sand from the beach system. Instead, place it on the beach downdrift of the river mouth.

Conserving reefs

ENVIRONMENTAL BACKGROUND

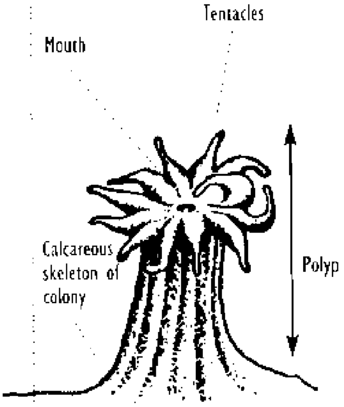
Coral reefs are an important component of the Caribbean coastal system.They may lie very close to the shore or many kilometres from it. Among the most ecologically diverse systems in nature, coral reefs play an important role in the protection and formation of many Caribbean beaches.

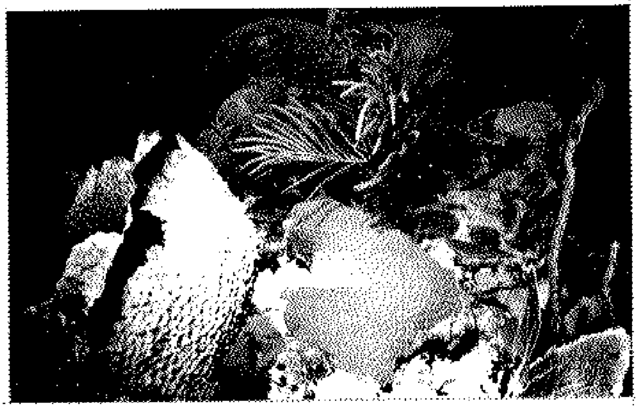
A living coral reef is a community composed of thousands of different members living in harmony with each other. The coral reef is made up of many tiny animals called coral polyps. These animals secrete limestone to surround them selves with a hard skeleton. The skeletons all join together to form the coral reef.

A healthy coral reef is home to many different plants and animals. These include algae, sponges, worms, starfish, sea urchins, lobsters and fish.

There are two basic types of coral. Stony or hard corals are the main reef builders and come in many shapes and sizes. Examples are elkhorn coral (*Acropora palmata*), brain coral (*Diploria clivosa*) and star coral (*Montastrea annularis*). Soft corals are flexible with their skeleton being inside the animal. The sea fan (*Gorgonia flabellum*) is an example of a soft coral.

Coral polyp





Photograph 32. Healthy coral reef. There are several different types of hard and soft corals.

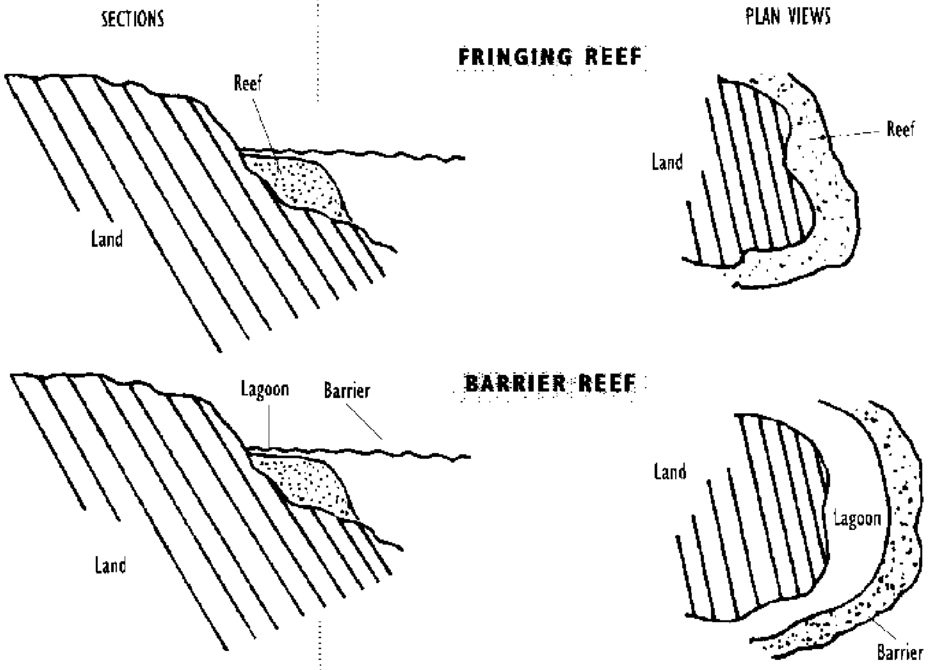


Figure 27. Fringing and barrier reefs. The former are situated close to the shore, while the latter may lie several kilometres from it (adapted from Bacon, 1978).

Coral reefs require warm, clear waters in which to grow. Reefs may be classified according to their position relative to the shore. The main types of reefs found in the Caribbean are: fringing reefs, which border a shoreline; patch reefs, which are isolated clumps of coral sometimes only measuring a few metres in diameter; and barrier reefs, which are separated from the shoreline by a deep lagoon or channel. Figure 27 shows sections and plans of fringing and barrier reefs.

Coral reefs are especially important to beaches because they protect the shoreline from high waves. Fringing reefs and barrier reefs often grow very close to the sea surface. Incoming waves break and expend their energy on the reef, thereby sheltering the adjacent coastline. (See Figure 28.) There is, nonetheless, some wave action at the beach sheltered by a coral reef. Often the waves reform between the reef and the beach. However, the wave energy is much less at the beach than if the reef were not present. Thus, in many respects, reefs are natural breakwaters and perform the same functions as those described for offshore breakwaters in Case 4.

Since even a dead coral reef may continue to act as a breakwater for adjacent beaches, dead reefs should always be left intact.

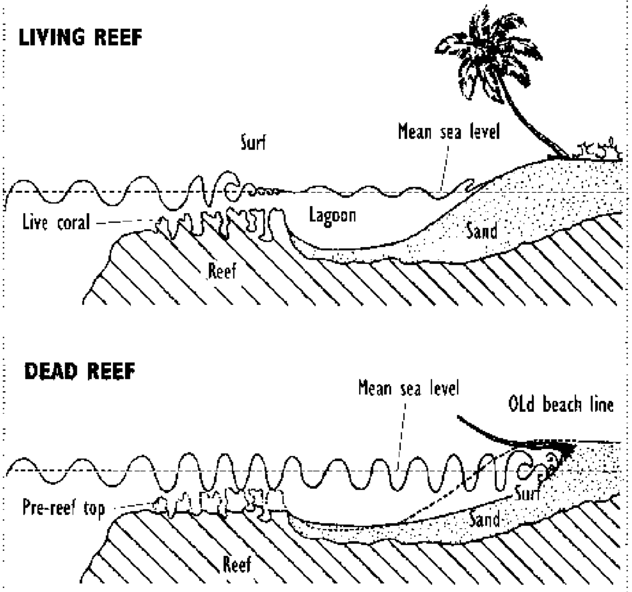


Figure 28. Coral reefs and beach protection. The living reef, with its high relief and varied topography, causes the waves to break and thus protects the beach. Once the reef is dead and flattened, higher wave energy is experienced at the beach. Erosion begins (adapted from Crown of Thorns Newsletter, 1990a).

Coral reefs act as natural breakwaters protecting beaches from high wave energy.

A dead coral reef may still provide some protection to adjacent beaches.

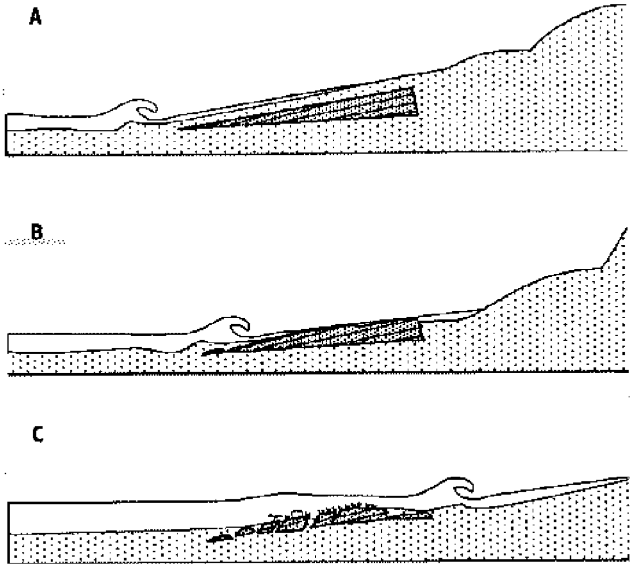
The coral reefs are a source of sand for many beaches.

Coral reefs are also important to many beaches because they act as a sand source. Many fish actively feed on the coral. For example, the parrot fish (*Scarus*) can bite off chunks of coral, digesting the living material and excreting coral sand. Other fish also feed on the coral. The butterfly fish (*Chaetodon*) and trigger fish (*Balistes*) are two examples. As a result, sand is formed which may eventually end up on the beach. However, as was seen in Case 3, not all beaches are made up of coral sand. Many Caribbean beaches are composed of land-based sand and others consist of a mixture of coral and land-based sands.

Coral reefs are vulnerable to natural forces and many human activities. Waves generated by storms and hurricanes can break off large pieces of coral. A beautiful elkhorn reef can be transformed overnight into a bare rubble reef. Sometimes, this coral rubble is thrown up onto the beach. Rising seawater temperatures occasionally give rise to coral bleaching whereby corals turn white. The same phenomenon occurs when fishermen or -women use bleach to stun fish. Large influxes of freshwater may also damage the corals.

However, human beings pose probably the greatest threat to corals. Silt resulting from offshore dredging, the removal of mangroves and vegetation clearing can literally smother a reef. Ships' anchors cause physical damage and sometimes divers may damage or break off pieces of coral simply by

Figure 29. Beachrock formation. Stage A. *Beachrock forms within the body of the beach.* Stage B. *As the sand covering the beachrock is lost, the rock exposure hardens and is visible on the beach.* Stage C. *As the coastline continues to retreat inland, the beachrock is left as a rock exposure out in the sea and may eventually function as an offshore breakwater helping to protect and stabilize the beach.*



Wherever coral reefs exist, their health is of vital importance to adjacent beaches.

touching the delicate corals with their fins. Pollution, whether large-scale resulting from sewage or small scale from water draining a field treated with pesticides, poses another threat to corals.

It may take many years before the damage to a coral reef is manifest on the beach. If a reef is lowered by one hurricane, it may not be until the next tropical storm or hurricane that the reduced breakwater effect is evident through heightened beach erosion.

There is often a time lag of several years before the effects of coral reef damage are seen on the beach.

Besides being valuable in their own right, coral reefs are also vitally important for many Caribbean beaches. Therefore, every effort should be made to protect and conserve them.

Photograph 33. Coral rubble resulting from Hurricane Luis, Cove Bay, Anguilla, 1995. Mounds of coral debris bear testimony to the underwater damage caused by the hurricane.

Photograph 34. Beachrock ledge, Vieux Fort, Saint Lucia, 1989. Over the years, this beach has retreated landwards (eroded), leaving this beachrock ledge out in the sea. Now, the rock ledge is acting as a breakwater protecting the beach from high waves.

Another rock formation, this one often found on the beach or just seaward of the shore, is beachrock. Beachrock consists of sand grains cemented together with calcium carbonate (lime). It forms within the body of a beach, beneath the sand surface and near the water table. (See Figure 29.) Once the covering sand has been stripped away, the beachrock formation hardens into rock. Exposure of beachrock ledges is indicative of an eroding shoreline. Beachrock became exposed on many beaches in the eastern Caribbean after hurricanes eroded the sand in 1995. As beaches continue to erode and retreat inland, beachrock ledges may be left out in the sea. These offshore beachrock ledges may then act as breakwaters reducing the incoming wave energy. Sometimes, sea pools behind these rock ledges form sheltered swimming areas.

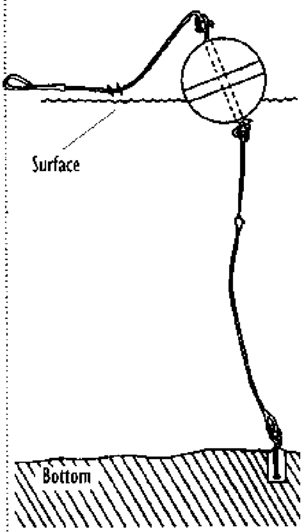
PRACTICAL RESPONSES

Do not clear the land until you are ready to build and always replant the land as soon as possible.

Preserve and protect coral reefs.

Coral reefs are important in their own right, besides being so in relation to beaches. They are already experiencing stress from such natural factors as hurricanes and higher seawater temperatures. The need is therefore all the greater to preserve and protect them from additional stress caused by human activities. It should be everyone's goal to preserve and protect coral reefs, be they a private individual, developer, fisherman or -woman, diver or government representative. There are several actions that individuals can take on their own:

- Replant cleared land as soon as possible. Whether you plan to build near the coast or inland, do not clear your building site then leave the soil bare indefinitely. Rain will erode the land and move some of the soil to the rivers and ultimately to the sea or, in the case of coastal property, directly to the sea. This soil may then be deposited on top of the coral reefs and stifle them.
- During dredging and land reclamation, it is important to reduce the amount of fine silt and clay returning to the sea by using settling ponds and silt curtains.
- Carefully dispose of all litter. Whether enjoying the beach or the sea, people should dispose of their litter in the appropriate containers. If none exist, as is frequently the case in the Caribbean, it is better to take the litter home or to your hotel and to dispose of it properly there. Remember, a plastic six-pack ring can strangle a sea turtle.
- Leave only bubbles. If you are a diver or snorkeller, do not touch or stand on the reef – you may damage or kill hundreds of coral organisms.
- Use mooring buoys to secure your boat or dinghy. Avoid using an anchor to hold your boat over a coral reef or seagrass-covered sea-bottom. If mooring buoys are available, use them, if not, look for a sandy area in which to anchor.



Mooring buoy

- Promote safe fishing practices. If you are a fisherman or -woman, several practices can help preserve the coral reef ecosystem. Fish traps with biodegradable panels are recommended. That way, if the trap goes missing, it does not become a death trap for countless fish and other animals. Similarly, such practices as dynamiting or using bleach to stun fish should be avoided, since these cause irreversible damage to the reef.
- Avoid spearfishing on the reef. This practice targets animals of certain sizes and disturbs the natural balance of the coral reef ecosystem.

Reefs should not be altered for development purposes. Look for alternative sites.

Look for alternative sites if development projects require alteration to coral reefs.

If a proposed development scheme, such as a marina, requires major or minor alteration to a coral reef, look for alternative sites for the development. This rule applies whether the coral reef is alive or dead. Even dead reefs protect the shoreline.

Environmental impact assessments are required before dredging can be permitted.

Do not undertake offshore dredging activities close to coral reefs.

If an offshore dredging project is planned, perhaps to nourish a beach, ensure that there are no coral reefs in the immediate vicinity of the proposed dredging site or nearby. Currents can carry sand and silt many kilometres away from the immediate dredging site. Ensure that detailed studies are undertaken before dredging is permitted.

Retain beachrock ledges.

Coastal property owners sometimes wish to remove beachrock ledges to improve sea bathing conditions. This is generally not a good practice. The existence of beachrock is an indicator of erosion. Furthermore, the beachrock itself protects the beach, particularly when it is out in the sea and detached from the beach.

Retain dead coral reef structures.

As with beachrock ledges, the dangers related to removing dead coral reefs in the nearshore area to improve sea bathing conditions well outweigh the advantages. In most instances where dead coral has been removed, erosion increases dramatically. Even when dead, coral reefs continue to protect the beach and, in some cases, help to anchor the shoreline.

New ways to reduce beach erosion

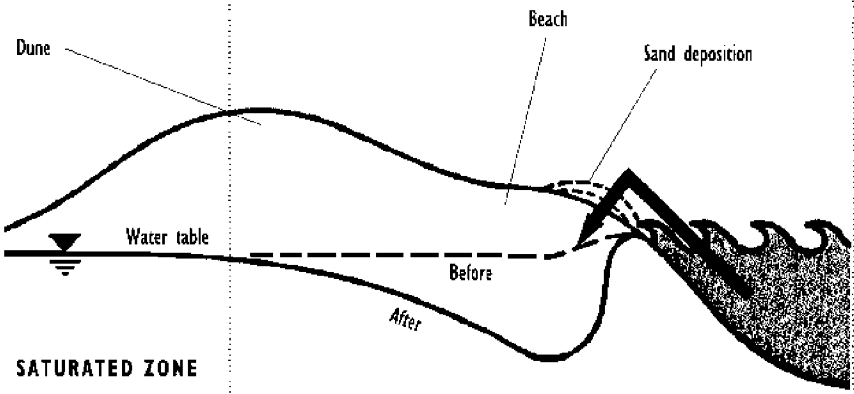
ENVIRONMENTAL BACKGROUND

Commonly used measures to protect beaches and reduce beach erosion are usually divided into two groups: hard engineering structures (such as groynes, seawalls, revetments and offshore breakwaters); and soft engineering options like beach nourishment.

The hard engineering options have been discussed earlier, particularly in Cases 1 and 4, and Case 5 was devoted to beach nourishment. There are, however, several newer techniques now being used to protect beaches. These are the subject of this case.

Beachface dewatering promotes drainage of incoming waves. Beachface dewatering basically consists of continuously pumping water away from the beachface. The system is based on the idea that, when the water table under the beach is lower than under the ocean, sand accretion is enhanced. As each wave rushes up the beach, water from the wave easily drains through the dry beach, leaving part of its suspended sand load on the beach. Less water drains back into the ocean taking less sand with it. (See Figure 30.)

Figure 30. How beachface dewatering works. When the water table under the beach is lowered, water from the wave easily drains through the dry beach, leaving part of the suspended sand load on the beach. Thus, the beach accretes (adapted from Coastal Stabilization Inc., 1989).



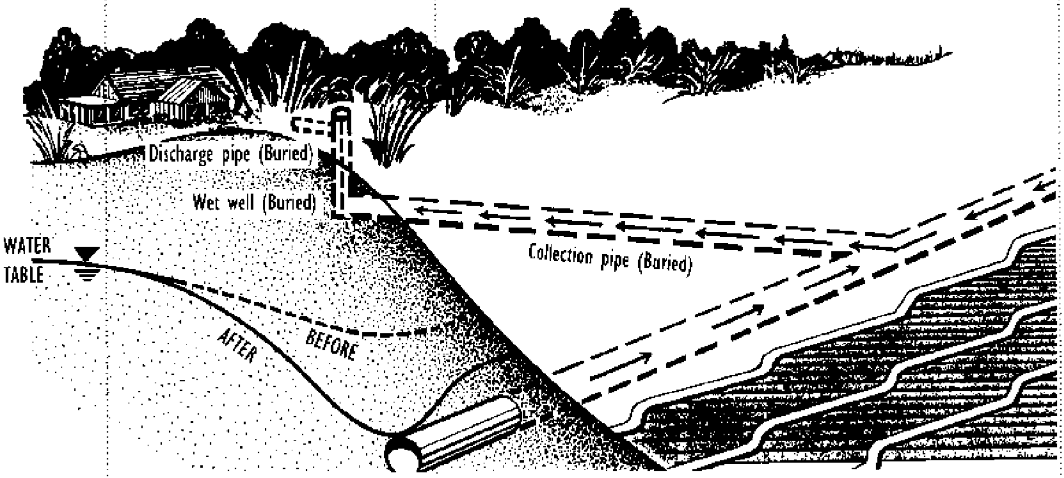


Figure 31. Beachface dewatering system. Water is continuously drained from the beachface and discharged behind the dune (adapted from Coastal Stabilization Inc., 1989).

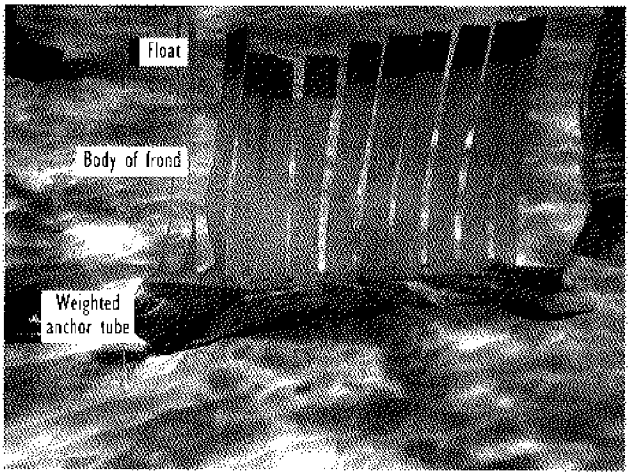
A specially designed drainage system is installed under the beach, with pumps removing groundwater from under the beach. (See Figure 31.) When considering such systems, operation and maintenance costs must be taken into account. The pumps should run continuously.

Another technique that has been tried in the Caribbean, as in other parts of the world, is artificial seaweed. In one pilot project tried in Barbados (Atherley, 1989), several hundred units of artificial seaweed were placed in the water. These units consisted of 1.3 m (4 ft) long fronds attached to an anchor tube filled with sand. (See Photograph 35.) The seaweed units reduce the speed of the current, thereby allowing sand to be deposited around and on top of the seaweed units. The end result is that the seaweed units are buried by an offshore sand bar. This offshore sand deposit will then protect the beach from wave action. However, experiments in Barbados with one type of artificial seaweed showed that the particular material was not suitable for Caribbean waters, since it showed significant deterioration within eight months of installation.

Artificial reefs are more useful for providing habitat for fish than for protecting the beach.

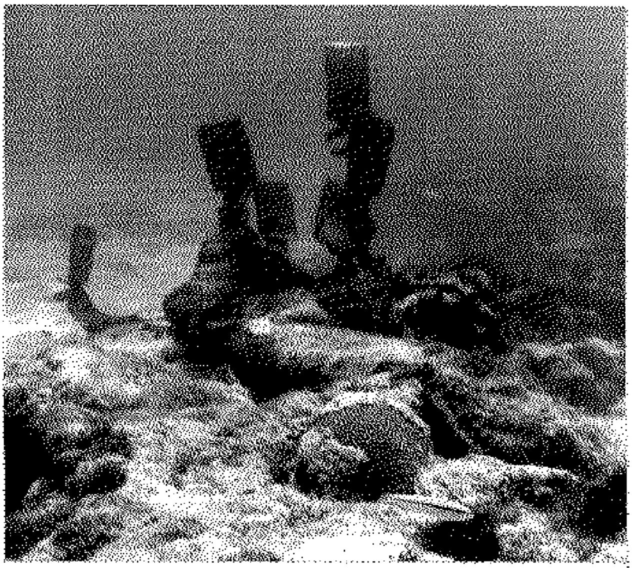
The technique of coastal vanes has been tried on a local scale, for example in front of one beachfront property. Coastal vanes are small-scale, flexible structures moored to the sea-bottom that are designed to change the wave direction in front of the property. By slowing down the longshore transport rate along a particular section of beach, they are supposed to encourage sand accretion.

One technique that is sometimes mistakenly perceived to be a beach protection measure is the construction of an



Photograph 35. Newly installed artificial seaweed units, Barbados, 1985. The fronds floating freely in the water are designed to slow down the current and promote the deposition of sand.

artificial reef. The main purpose of artificial reefs is to provide additional habitat for fish and the organisms on which they feed. These reefs are constructed of various materials, including used car tyres, old ships and car wrecks. Since they are often placed in fairly shallow depths, people sometimes suppose that they will work as offshore breakwaters. However, they rarely successfully perform this function because they are not strong enough to cause the waves to break and thus cannot provide the beach with shelter from waves. Floating tyre breakwaters are sometimes used as artificial reefs and may also be used in marinas to provide protection from boats' wakes. (See also Case 4, Figure 20.)



Photograph 36. Artificial seaweed units eight months after installation, Barbados, 1986. The fronds have deteriorated and most of them are lying on the sea-bottom. Little sand has accumulated.

PRACTICAL RESPONSES

Gather information and study all the alternatives before making a decision. Cost is only one factor.

Obtain as much information as possible.
These measures often seem attractive because they cost less than more commonly used measures. However, it is important to obtain as much information as possible both from the contractor/supplier and from others.

Visit locations where the techniques have worked.
Ask the supplier about locations where the technique has worked or use sources like the Internet for information. If possible, visit an installation to see for yourself and talk to the people involved at other installations.

Consult with experts in the field of coastal dynamics.
These individuals may be able to help you evaluate the technique or direct you to other sources who can.

Consult with local planning authorities.
Remember that it is always necessary to obtain permission from the planning authorities for any coastal construction and for using the seabed for any purpose. Planning authorities may also be able to provide advice.

Do not be influenced by low price-tags.
Low-cost measures often work very well, but only under specific conditions. It is up to you to find out whether your site fits those specific conditions. In most cases, 'you get what you pay for'. The key is to put a lot of time into evaluating the low-cost alternative. However, for a particular individual in a specific context, the alternative may be worth the attempt, even if it is ultimately unsuccessful and fails. Some of the measures described here may have high operation and maintenance costs, which can outweigh the low installation costs.

Inform your neighbours.
As with any other technique, inform your neighbours and see if they are interested in joint efforts.

Chapter 2

What to look for when investing in coastal land or property

The prospect of owning a coastal property on a Caribbean island is a dream for many people. Those who seek to make their dream come true would be well-advised to consider very carefully the potential hazards of living near the ocean before selecting and evaluating a particular site.

Before investing in coastal property, be aware of natural hazards and associated risks.

All residents of Caribbean islands, and especially those in coastal areas, should be aware of and prepared for the following natural events:

- Tropical storms and hurricanes occur each year and the evidence indicates that we are entering a twenty-year active hurricane cycle. (See Case 2 in Chapter 1.)
- Coastal erosion may have several causes, including winter swells, hurricanes and sand mining. (See Cases 1, 2 and 6.)
- Sea levels are rising globally. As a result, greater beach erosion is likely over the coming decades.
- Heavy rains and flooding have serious consequences, expecially in low-lying areas inland and near the coast.
- Landslides and rockfalls commonly occur on steep volcanic islands and on coastal cliffs. These are often triggered by heavy rainfall.
- Tsunamis are extremely high waves also known as tidal waves. They are very rare events caused by underwater earthquakes or huge undersea landslides. Several have been experienced in the Caribbean within historic times and have caused death, flooding and damage to coastal areas. During tsunamis, low-lying coastal areas, in other words those below the 6 m (20 ft) contour, may be flooded. Tsunamis can travel at speeds of 800 km/hr (500 mph), which means that an earthquake off the coast of Venezuela could result in a tsunami reaching the

Caribbean islands within a matter of minutes. At present, there is no tsunami warning system in the Caribbean region. However, there is one piece of information that could save a life: if you are at the beach and see the water suddenly recede a considerable distance, leaving parts of the seabed dry, this could be the forerunner of a tsunami. Run for higher ground!

Prospective home buyers should also consider the consequences of corrosion in salt air, which affects everything from cars and electronic equipment to nuts and bolts. The salt-laden air also influences the type of plants that can be grown around a beachfront property. Another factor to consider is that almost all beaches in the Caribbean are public. On holidays and weekends, a secluded getaway may become a noisy open-air party. It pays to check out the site very carefully.

Global climate change and sea level rise: proceed with caution

There is evidence that the increased rate of global warming experienced over the past century is the result of human activities, for example the increased use of fossil fuels like coal and oil. There is further concern that warmer air temperatures will accelerate the melting of ice sheets. Warming will also result in the expansion of ocean waters. Both effects will result in an increase in ocean volume, which may in turn be reflected in rising sea levels.

Sea level varies according to the tidal state and weather conditions, so accurate measurements have to be recorded over a number of years to determine mean sea level. In the coming decades, there will be considerable variability in the extent of sea level rise at the regional and local level. A few islands rising tectonically may actually experience falling sea levels. Sea level is being monitored in the Caribbean region; the highest rate of sea level rise measured historically in the eastern Caribbean is 1–2 mm per year.

Undeveloped beaches can adjust by changing shape and position, but inhabited shorelines will probably be subject to greater erosion.

Day-to-day wave and current action at the shoreline and the availability of sediment in a beach system are far more important to beach stability than rising sea levels. However, over a period of two to three decades, rising sea level will elevate the ocean surface, thereby allowing waves to reach farther up the beach. Beaches will adjust to this situation by changing shape. On developed shorelines where beaches

Anticipate the sea level change and build as far back from the shore as possible.

have little space to adjust, there is a possibility of increased erosion.

Land that is at, or close to, sea level will be susceptible to submergence and flooding wherever sea level is rising. Occupants of coastal land should be aware that the water table below the ground surface is linked directly with the sea surface. Hence, in the long term, a change in the sea level is likely to result in a rising water table. A rising water table can lead to ground saturation.

If building close to the ocean, sea level rise is an important factor to consider. While the impacts will not be immediate, most houses are expected to last for more than thirty years. The best response is to ensure that there is as much setback as possible between the building and the beach. Do not settle for the minimum setback, but rather allow as much distance as possible.

On a larger scale, the magnitude of the impact can be reduced by ensuring that governments are fully committed to international conventions designed to control such problems, like the International Convention on Climate Change.

PREPARING A CHECKLIST

It is often useful to prepare a checklist to assess the vulnerability of a particular site to coastal erosion. Use the blank checklist in Appendix I to evaluate the vulnerability of the site you plan to purchase. To guide you in filling it in, the various features of the checklist are explained below and a completed checklist for a beach site on the north coast of Tortola in the British Virgin Islands is given in Table 4.

Elevation of the site

Sites less than 3 m (10 ft) high are very vulnerable to seawater inundation during hurricane-generated storm surges.

The higher the land, the safer the site from seawater inundation, especially during storms and hurricanes. Recent hurricanes resulted in seawater extending more than 100 m (328 ft) inland at some low-lying sites only 1–2 m (3–7 ft) above mean sea level.

For the checklist, the following elevation categories may be used to determine site vulnerability:

- less than 3 m (10 ft) above mean sea level = high vulnerability;
- 3–5 m (10–16 ft) above mean sea level = medium vulnerability;
- more than 5 m (16 ft) above mean sea level = low vulnerability.

Landforms behind the beach

Solid bedrock is more resistant to wave energy than sandy terraces and dunes; thus, rocky shores and cliffs represent safer sites. However, even solid cliffs experience erosion and their vulnerability varies according to their geology. Harder rocks, such as granites, basalts and limestones, are more resistant to erosion than softer rocks, such as clays and sandstones.

Sand dunes are accretionary features formed by wind. Vegetated dunes are a sign of stability. However, it is important to realize that dunes are temporary features that can be completely destroyed by a hurricane. (See also Cases 2 and 7.) For example, in Anguilla during Hurricane Luis in 1995, low dunes were cut back 30 m (98 ft) and

Even though vegetated dunes are indicative of stable conditions, they may be seriously eroded during a hurricane, so new buildings should be positioned well behind the primary dune.

dunes more than 8 m (26 ft) high were cut back 10 m (33 ft). Building on the primary dune should always be avoided.

Bearing this in mind, the following categories may be used for the checklist:

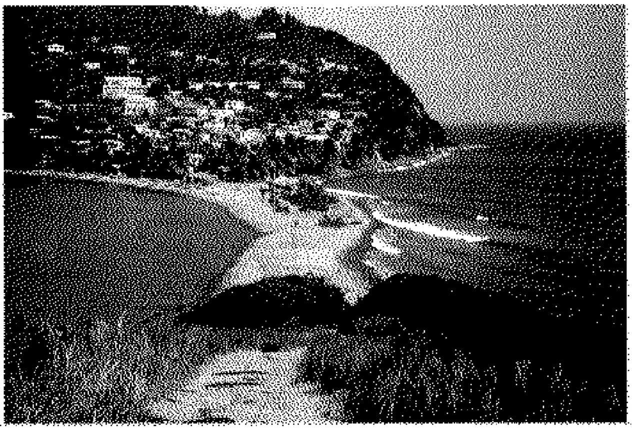
- where there is an extensive dune system with more than one row of dunes, the site should be given a low vulnerability index;
- where there is only one line of dunes present, the site should be given a medium vulnerability index.

The following list represents the major types of landforms found behind the beach and their vulnerability index for the purposes of the checklist:

- low land composed of soil formations = high vulnerability;
- low land composed of a sand terrace = high vulnerability;
- single dune line behind the beach = medium vulnerability;
- multiple dune system (more than one line of dunes behind the beach) = low vulnerability;
- sloping land (soil over rock) covered with vegetation = low vulnerability;
- low rocky shore (soft rock) = medium vulnerability;
- low rocky shore (hard rock) = low vulnerability;
- cliff (soft rock) = medium vulnerability;
- cliff (hard rock) = low vulnerability.

Wave exposure

The fetch, or distance, of open water a shoreline faces can provide an indication of the likely size of potential storm waves. For instance, many of the eastern shores of the Caribbean islands face the Atlantic Ocean, with more than 3,200 km (2,000 miles) of open sea stretching before them.



Photograph 37 Tombolo, Scotts Head, Dominica, 1994. This narrow strip of land made up of sand and stones has been formed by waves and joins the small islet of Scotts Head (foreground) to the main island of Dominica (background).

Thus, these coasts are likely to experience very large waves during storms and hurricanes. On a local scale, another island or a small offshore cay might shelter a particular bay or part of a bay.

For the checklist, the following categories may be used:

- fetch greater than 160 km (100 miles) = high vulnerability;
- fetch 16–160 km (10–100 miles) = medium vulnerability;
- fetch less than 16 km (10 miles) = low vulnerability.

Accretionary features, such as spits and bars, are temporary landforms created by waves and currents. They are very vulnerable to change and should not be developed.

Proximity of site to vulnerable accretionary feature

Accretionary features like those shown in Figure 5 (Case 1, Chapter 1) include spits, bars, tombolos and cuspate forelands. While these features are formed by the process of accretion, or sand build-up, they are nevertheless very vulnerable to sudden change, particularly during tropical storms and hurricanes. Spits, bars and tombolos should be avoided as building sites. Development on coastal lands within 100 m (328 ft) of these features should take into account the likelihood of possible major coastline changes. Similarly, cuspate forelands are vulnerable to sudden, major changes after extreme weather and, while the land behind these features may provide suitable sites for development, caution should be exercised in siting new development schemes and maximum setback distances should be adopted.

For the checklist, the following categories may be used:

- on a bar, spit or tombolo – extremely high vulnerability, on no account build here;
- within 100 m (328 ft) of a bar, spit or tombolo = high vulnerability;
- behind a cuspate foreland – low vulnerability;
- if none of these features exist, record the category as not relevant (NR).

Photograph 38. Sand dunes, Rendezvous Bay, Anguilla, 1994. These vegetated dunes, together with the newly forming low dunes at their base, indicate stability. However, dunes are merely sand reservoirs and may be completely eroded in a hurricane.

Proximity to river mouth or tidal inlet

During heavy rainfall and floods, coastal river mouths often shift their positions and there may be considerable erosion of the beach near these features. It is important to check the proximity of the site to both small and large river mouths. Be aware that, even if the channels are dry for most of the year, there is the potential for considerable beach and coastline changes during heavy rainfall. As a guide for the checklist, 'proximity' is defined as 10 times the channel width, e.g. if the channel width is 2 m (7 ft), avoid building within 20 m (66 ft) either side of the channel mouth.

Some beaches separate ponds from the sea. These ponds may be wet or dry; if wet, they usually contain brackish water. They fulfill important functions, such as filtering sediment and pollutants from the water before it reaches the sea. They are not recommended sites for any type of construction.

Inlets between islands, particularly narrow tidal inlets as exist in the Turks and Caicos Islands and the Bahamas, are influenced by waves and tidal currents. Beaches near such inlets may experience rapid and significant changes. Rates of change may be several times greater than at other beaches on an island. (See also Case 9.) Proximity to a tidal inlet may be defined here as being within 1 km (0.6 miles) of the inlet.

For the checklist, the following categories may be used:

- within a distance of less than 10 times the width of the river mouth = extremely high vulnerability, avoid building here;
- within a distance of 1 km (0.6 miles) of a tidal inlet = high vulnerability;
- if neither of these conditions exist, record the category as not relevant (NR).

Presence of coral reef

Offshore coral reefs, whether patch, fringing or barrier reefs, often come to within 1–2 m (3–7 ft) of the sea surface. They may therefore act as natural breakwaters and cause the incoming waves to break before they reach the shore. Thus, the existence of such features will help to reduce the size of storm waves. (See also Case 10.) Local fishermen and -women, the fisheries department, dive operators and bathymetric maps are all good sources of information on reefs.

For the checklist, the following categories may be used:

- absence of any reef structure at all = high vulnerability;
- presence of an offshore coral reef, but the waves are not breaking on it = medium vulnerability;
- presence of an offshore coral reef, waves are seen breaking on it = low vulnerability.

Beach size

Always check the condition of the beach during both summer and winter. Seasonable changes may be considerable.

A wide beach, which is essentially a flexible barrier, is the best form of coastal protection. The back beach, which is the section from the high water mark to the tree line, building line, dune line or land edge, is an important feature. A wide back beach covered with grass and vines indicates stability. However, always view the site during both summer and winter, since the state of the beach may change dramatically and some coastal vegetation, like vines, can grow very quickly. For the checklist, the following categories may be used:

- minimum back beach width less than 5 m (16 ft) = high vulnerability;
- minimum back beach width 5–10 m (16–33 ft) = medium vulnerability;
- minimum back beach width more than 10 m (33 ft) = low vulnerability.

Erosion indicators

There are several visual indicators of erosion. Dead trees and exposed tree roots indicate where wave action is concentrated, particularly during high seas. Buildings in the sea may be picturesque, but with no protective beach, they are extremely vulnerable to high seas and were probably built when there was a wide beach. Sea defences, seawalls, rock revetments, groynes and offshore breakwaters, all indicate erosion or the potential for erosion.

It is important to check both in the immediate vicinity and farther along the beach. Steep bluffs and slopes at the back of the beach separating the land or dunes from the beach are usually formed by waves. A gentle vegetated slope indicates stable conditions. Breaks in the dune line may also indicate areas where the waves have eroded and broken through the dune line in the past. Beachrock forms within the body of the beach and, wherever exposed, indicates erosion. (See also Case 10.)

On shorelines bordered by cliffs, signs of instability include wave-cut notches at the base of the cliff, landslides and slumping rock material, and springs issuing from the cliff face. For the checklist, the cumulation of indicators present may be used to determine the site's vulnerability to erosion:

- 3 indicators or more = high vulnerability;
- 2 indicators = medium vulnerability;
- 1 indicator = low vulnerability;
- no erosion indicators = not relevant (NR).

Most recent hurricane

Tropical storms and hurricanes cause major changes to the beach and coastline that sometimes prove semi-permanent in that they last for decades. (See also Case 2 in Chapter 1.) Tropical storms and hurricanes may cause beach instability for several years afterwards as beaches and offshore systems, including coral reefs, slowly recover. For the checklist, the site's vulnerability to change as a result of the most recent hurricane may be determined as follows:

- hurricane occurred within 1 year = high vulnerability;
- hurricane occurred 1–5 years ago = medium vulnerability;
- hurricane occurred 6–10 years ago = low vulnerability;
- hurricane occurred eleven or more years ago = not relevant (NR).

Information from neighbours

When preparing a checklist, always try to obtain local information from your prospective neighbours. A space has been left on the checklist for this kind of information, since this will help in assessing the vulnerability of some of the other features.

Calculating the overall vulnerability index

Once the nine features described above have been evaluated in terms of extremely high, high, medium or low vulnerability, an overall vulnerability index can be calculated. Each 'high' index is given a score of 3, each 'medium' index a score of 2 and each 'low' index a score of 1. Note that if any feature has been given an 'extremely high' index (See Proximity to an accretionary feature and/or river mouth or tidal inlet.), no building at all should be considered on this site. Any feature recorded as not relevant (NR) should be given a value of zero. Add together the values for all features to determine the overall index.

Making an assessment

In making your overall assessment, use the following guidelines:

- overall index value of 19 or greater equals high vulnerability; if at all possible, look for alternative sites to build. However, if this is not feasible, utilize such planning mechanisms as elevating the building onto piles or implementing very high setback distances;
- overall index value of 12–18 equals medium vulnerability: a prospective buyer might wish to take special care at this site, perhaps by ensuring there is space for setbacks between the building and the beach that are above the minimums recommended by planning authorities;
- overall index value of 11 or less equals low vulnerability: this would be a suitable site for development.

Consult other information sources on beach erosion.

If you wish to take your investigation further, you may like to consult relevant reports that have been done on coastal erosion on the island. These can usually be read at planning or environmental agencies or at non-governmental organizations (NGOs) like the National Trust. Planning and environmental agencies are likely to have information about the different beaches on an island. They can provide data from regular beach monitoring programmes or other studies and their own professional expertise and experience. Another information source are the historical aerial photographs of the particular beach, which are usually

Photograph 39. Beach erosion, Josiahs Bay, British Virgin Islands, 1990. These exposed tree roots and the fallen tree indicate the waves had reached the land behind the beach recently.

TABLE 4

Prospective buyer's checklist for site vulnerability to erosion

Sample checklist for Josiahs Bay, Tortola, British Virgin Islands (site shown in Photograph 39).

FEATURE	RECORDING	VULNERABILITY INDEX Category	Value
Elevation of the site:			
• <3 m	2 m	high	3
• 3–5 m			
• >5 m			
Landforms behind the beach:			
• low land (soil)			
• low land (sandy terrace)	yes	high	3
• single dune line			
• multiple dune system			
• sloping land (soil over rock) covered with vegetation			
• low rocky shore (soft rock)			
• low rocky shore (hard rock)			
• cliff (soft rock)			
• cliff (hard rock)			
Wave exposure:			
• fetch >160 km			
• fetch 16–160 km	yes	medium	2
• fetch < 16 km			
Proximity of site to vulnerable accretionary feature:			
• on a bar, spit or tombolo			
• within 100 m of a bar, spit or tombolo			
• behind a cuspate foreland			
• none of these features exist	NR		0
Proximity of site to river mouth or tidal inlet:			
• within a distance of 10 times the width of the river mouth			
• within a distance of 1 km of a tidal inlet			
• neither of these conditions exist	NR		0
Presence of coral reef:			
• no reef present	yes	high	3
• reef present, but waves not breaking on reef			
• reef present, waves seen breaking on reef			
Beach size:			
• minimum back beach width <5 m	yes	high	3
• minimum back beach width 5–10 m			
• minimum back beach width >10 m			
Erosion indicators:	3	high	3
• dead trees/exposed roots	yes		
• waves reach building foundations			
• sea defences			
• steep near vertical slope behind beach	yes		
• breaks in dune line	yes		
• beachrock			
• wave-cut notches at base of cliff			
• landslides/slumping of material			
• springs issuing from cliff face			
• other			
Most recent hurricane:			
• occurred within 1 year			
• occurred 1–5 years ago	yes	medium	2
• occurred 6–10 years ago			
• occurred 11+ years ago			

Information from neighbours: There used to be a sand dune system at this beach that has been mined out leaving large pits filled with water behind the beach.

Overall vulnerability index value: 19

Assessment: This site has a high vulnerability index and it is recommended that a prospective buyer consider alternative sites.

Information is critical. Find out as much as possible about a particular beach from as many different sources as possible.

stored at the government agency dealing with land survey. Local fishermen and -women and regular beachgoers are sometimes knowledgeable sources of information. A little time spent in the local bar or rum shop may also produce useful information.

Consult local insurance companies.

Always ask about insurance rates before you buy coastal property. Since the end of the 1980s, insurance premiums have been rising rapidly. On occasion, insurance has been difficult to obtain. A primary reason for rising insurance rates is the damage inflicted by recent hurricanes.

Consult planning and legal authorities about public rights to the beach .

While, in some Caribbean islands, private ownership of land may extend to the high water mark, this is not always the case. Even when private ownership covers the dry sandy part of the beach, it does not mean that a private land owner has the right to restrict public access or use across this part of the beach. It is wise to consult the local legal and planning authorities to determine the accepted practices on a particular island. It is understood in most of the Caribbean islands that beaches are always available for public use. The more detailed your investigation, the greater chance you will have to enjoy your coastal property for many years to come.

Be creative and thorough about gathering information.

Determine the planning guidelines for the site.

Planning guidelines will include setbacks, building density (the ratio of the built area to the unbuilt area on the lot), height of the building (number of stories permitted) and other essential criteria. Based on your own vulnerability assessment using the form in Appendix I, you may wish to increase the setback from the active wave zone to a distance farther than that recommended by the planning authority. Advice from a coastal specialist may influence your final decision with regard to the siting of structures.

Coastal development setback guidelines

Coastal development setbacks are especially important in the tourism-orientated islands. They provide buffer zones enabling beaches to move naturally without the necessity for seawalls and other structures: they reduce damage to beachfront property during high wave events like hurricanes; they improve the view and access along the beach; and they provide privacy for the occupants of coastal property and for beachgoers.

The use of a fixed setback for all beaches on an island has proved difficult to implement. Beaches behave differently. Some are eroding, others are accreting. The nature of the change may also vary over the short and long term. As a result of these characteristics, recently proposed guidelines (Cambers, 1997) develop specific setbacks for individual beaches based on a combination of different parameters:

Every beach has its own characteristics; setback requirements should vary accordingly.

- historical changes over the last 30 years;
- changes over the past five years, as determined from beach monitoring data;
- changes in the position of the dune line or land edge likely to result from a major hurricane;
- coastal retreat likely to occur as a result of projected sea level rise over the next 30 years;
- the existence or absence of offshore features, such as coral reefs or beachrock ledges. These provide protection during high wave events;
- factors linked to human activities, among which beach and dune mining;
- such planning considerations as lot size, marine park designations and special types of development, for example beach bars.

The actual setback for a specific beach has been determined as follows: setback = $(p + h + s)d$

Where p is the change in coastline position (based on historical and recent changes); h is the change in position of the dune line/coastline likely to result from a major hurricane; s is the change in position of the coastline likely to result from predicted sea level rise over the next 30 years; d reflects the influence of specific site characteristics and includes offshore features, human activities and planning considerations. Using this methodology, specific setbacks can be determined for each beach.

In all cases, setbacks should be measured from the line of permanent vegetation or the tree line.

Chapter 3

Protecting beaches: how you can help

This chapter describes several ways in which residents and visitors can improve the quality of beaches. Some of the activities can be undertaken by individuals, while others are more suitable for group projects. Whether you are a visitor to an island or a resident, you too can help to ensure that the beaches will be available for future generations to enjoy. Here's how.

Everyone can contribute to maintaining and improving the beach environment.

Adopt a beach

A local community, school, service group or some other adopts one particular beach and undertakes various activities over the years to enhance it. The group takes responsibility for the beach and becomes a custodian of the natural resources at the beach. These projects are a good way of getting a community or group involved in beach management and of improving the environment for all. The activities can be tailored to any particular beach. Examples are:

- vegetation replanting projects;
- beach clean-ups;
- provision of litter bins;
- warning notices for manchineel trees;
- installation of wooden walkways along public accesses; and
- demarcation using buoys of swimming-only areas.

Undertake a beach clean-up.

Beach clean-ups are often a popular activity, since the results are immediately apparent. They can be held to coincide with events such as World Environment Day (5 June) and Fisherman's Day in the Caribbean (29 June), or with other local events. However, subsequent littering can be discouraging for volunteers, particularly children. Combining clean-ups with other activities, such as public awareness-

Clean-up activities should be combined with education and information. Local authorities should also be involved.

building campaigns and the provision of litter bins, is a way of finding a sustainable solution. However, remember that it is also necessary to co-ordinate such activities with the local solid-waste disposal agency.

Take part in the International Beach Clean-up.

This is a global activity organized by the Center for Marine Conservation in Washington. It takes place every September and has four main functions: to remove debris from the shoreline; to collect information on the amount and type of debris; to educate people; and to use the information to effect positive change.

Groups select a beach to clean and gather up the debris. They then complete a data card on which they itemize the numbers and different types of debris. (A sample of the data card is shown in Appendix II.) These data cards are then sent to the Center for Marine Conservation where statistics are compiled each year and the information is then used to lobby international bodies like the International Maritime Organisation to take some form of action to control ocean debris.

Debris on Caribbean beaches originates not only from ocean-going ships but also from land sources, so it is also important to look at local sources of debris like coastal rubbish dumps.

Several Caribbean islands participate in an international campaign to clean up beaches and reduce pollution.

The actual clean-ups also serve to heighten people's awareness of the magnitude of the problem, thereby triggering interest and new ideas for solutions. Several Caribbean islands already take part in this activity.

For more information about the programme, readers are invited to contact:

Center for Marine Conservation
1725 DeSales Street, NW,
Washington DC 20036, USA
Telephone: 202 429 5609

Conduct a revegetation project on the beach or dunes.

This project is not only satisfying, but also very worthwhile. It can be carried out on a small scale using just a few plants or on a much larger scale. Various factors relating to beach planting projects are described in Cases 7 and 8. These are briefly summarized hereafter.

Photograph 40. Revegetation project, Heywoods, Barbados, 1987. These sea grape and casuarina seedlings were planted at the back of what appears to be a wide beach in the summer of 1987. However, they did not survive because, in winter, the swell waves reach the road at the back of the beach.

Consult a local horticulturist on your island for advice with your beach planting project.

Use local species. If you are planting trees in the Caribbean, here are some suggestions: sea grape (*Coccoloba uvifera*), seaside mahoe (*Thespesia populnea*), West Indian almond (*Terminalia catappa*), coconut palm (*Cocus nucifera*) and casuarina, also known as Australian pine (*Casuarina equisetifolia*).

If you are planting grasses, vines or smaller plants, here are some other suggestions: seashore dropseed (*Sporobolus virginicus*) panicgrass (*Panicum amarum v. amarulum*), beach morning-glory (*Ipomoea pes-caprae*), beach bean (*Canavalia maritima*) and sea purslane (*Sesuvium portulacastrum*).

Always plant well above the high water mark. Even if the winter storm waves only reach the young plants once in the winter season, it is unlikely that they will survive, so this decision is important. Obtain advice from people familiar with the beach about the highest reach of swell waves and plant landward of this point.

Revegetation projects work best using local species planted well above the high water mark.

Remember, the beach or dune is a very harsh environment for plants, so try to get your new plants off to a good start by: ensuring they are a reasonable size; by providing fertilizer, especially nitrogen fertilizer, and by spreading a layer of mulch (dead leaves or seagrass) around the plant to reduce wind and water erosion and to promote moisture retention.

Follow-up care is the most important element in any planting project. For the first few months, the plants will need watering on a regular basis, especially if planting takes place in the dry season. Additional fertilizer may also be necessary. Fences or tree guards are a must if animals roam freely in the area.

Remember to take 'before' and 'after' photographs to document your project.

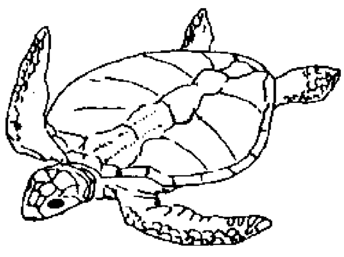
Monitor sea turtle nesting activity.

Sea turtles are reptiles that live in the ocean. The most common species in the Caribbean are the Leatherback turtle (Dermochelys coriacea), the Hawksbill turtle (Eretmochelys imbricata) and the Green turtle (Chelonia mydas). These gentle giants are endangered mainly because of over-harvesting. Hawksbill turtles are harvested for their shells, Green turtles for their meat and Leatherback turtles particularly for their oil, which has medicinal qualities.

Sea turtles live in the ocean, but nest on land. Due to over-harvesting and disturbance of their habitat, they are now an endangered species.

Sea turtles use the Caribbean beaches to nest, usually at night. Leatherback and Green turtles nest on the back beach area, while Hawksbill turtles often make their nests in the coastal vegetation. A female may nest several times each season. After a few weeks' incubation in the nest, the baby turtles emerge and head for the sea.

On account of the turtles' endangered status, many islands are seeking to protect them by banning both their slaughter and the removal of their eggs from the nest. The authorities are also trying to conserve the sea turtles' habitats, particularly the beaches and offshore feeding areas (seagrass beds and coral reefs).



Green sea turtle

Evidence of turtle nests and tracks is sometimes seen on Caribbean beaches before being eradicated by the continuous rise and fall of the tides. In some islands, people volunteer to walk the beaches early in the morning to check for turtle tracks during the nesting season. Information on the number of nests helps biologists assess the status of turtle populations and the success of protection and conservation measures. Check with your local fisheries department for more information about turtle-monitoring programmes in your island. They always need volunteers. In some islands, non-governmental organizations like the National Trust may also be involved in turtle-monitoring projects. Schoolchildren can become involved in this activity and it is an excellent way of teaching children about the beach environment and its plants and animals.

Another way in which beachfront residents can help endangered sea turtles is by reducing the lights shining directly on the beach. First of all, find out if the particular beach is a sea turtle nesting site. If so, you should be aware

Learn about coastal wildlife and join a monitoring programme.

that shore lights may deter females from coming ashore. Lights may even disorientate the turtles once they have nested, so that instead of returning to the sea, they crawl inland where their bodies dry out and they die. Similarly, artificial lighting may disorientate the baby turtles and prevent them from reaching the sea, leaving them easy prey for crabs and birds. Sodium vapour lights are one example of lights that emit wavelengths that do not disorientate sea turtles. Consult your fisheries department for more information.

Children are especially receptive to field trips that combine hands-on experience with science and environmental education

Involve schoolchildren in beach field trips and conservation projects.

Field trips to the beach can be highly educational. Primary schoolchildren can be given worksheets on which to make their observations and some simple measurements to make. Table 5 lists some activities for children in the 7 - 11 age group.

Older children can be involved in projects to measure beach changes. Daily measurements over a month of the distance from the high water mark to a fixed point, such as a wall or tree, when combined with observations about wave height, will provide children with a wealth of data to analyse and interpret. Beach changes are also useful topics for science fair projects. Beaches change so rapidly that useful data can be collected in a short period of time.

Similarly, children can be involved in the other activities listed in this chapter, such as beach clean-ups, planting projects or turtle monitoring. Inevitably, many Caribbean children take their beaches for granted, assuming that the beach will always be there for their use and enjoyment, but as we have discussed in this manual, this may not necessarily be the case. Teaching children about the beach and involving them in beach conservation projects will help to ensure that Caribbean beaches continue to exist for future generations.

Your actions can serve as an example to your children or to other beach users.

Dispose of litter properly.

Whether a bag of rubbish from a beach picnic or a single soda can, place it in the appropriate container. If there is no rubbish container on the beach, take the litter home with you or to your hotel and properly dispose of it there. There is no excuse for leaving litter on the beach or in the sea. Play your part and dispose of litter carefully.

Avoid walking on coastal vegetation.

Whether it looks like a weed or merely a clump of grass, avoid walking on coastal vegetation. Wherever possible, use walkways or marked paths to the beach or alternatively walk on the bare sand. Vegetation helps to stabilize the beach and anchor beach sand. Do your bit to help the vegetation perform that role by not walking on it.

Be vigilant.

It is up to every individual, whether a visitor or island resident, to conserve our beaches. If you see something unusual, such as a backhoe or other heavy equipment working on the beach, ask a question or make a telephone call to find out if the activity is permitted. Wardens, police officers and government officials cannot cover the whole island environment on their own. They need our help. It is up to everyone to take responsibility for safeguarding our natural resources.

TABLE 5

Beach field trip activities for primary schoolchildren.

This table includes three activities that primary schoolchildren can undertake at a beach site.

Measuring the width of the beach

Activity: Use a tape measure to determine the width of the beach from the vegetation line to the high water mark at several points along the beach.
Classroom follow-up: Discuss the variation along the beach, suggest reasons for the differences.
Skills: mathematics, use of a tape measure, data interpretation.

Observing the composition of the beach

Activity: At several places along the beach, ask the children to observe and record what the beach is made up of; e.g. white sand, black sand, stones, pieces of coral, seagrass. Let them also record any litter e.g. soda cans.
Classroom follow-up: Discuss the different materials and get the children to discuss the origin of these e.g. black sand came from the river, white sand came from the coral reef, etc.
Skills: observation, recording, interpretation.

Collecting objects that have washed up from the sea

Activity: Ask the children to collect five objects that have washed up from the sea and to list them.
Classroom follow-up: ask the children to write a few sentences describing one object they found and where it came from e.g. a piece of coral or a sea fan from the reef, a stone from the cliff, a blade of seagrass from the seagrass beds, etc.
Skills: observation, collection, recording, sentence writing and interpretation.

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Appendices

I. Prospective buyer's checklist for site vulnerability to erosion, *p. 108*

KEY

EH	extremely high vulnerability, do not build (DNB)
H	high vulnerability, index value is 3.
M	medium vulnerability, index value is 2
L	low vulnerability, index value is 1
NR	feature not relevant, index value is 0.

II. Beach clean-up data card, *p. 109*

Prospective buyer's checklist for site vulnerability to erosion.

FEATURE	RECORDING	VULNERABILITY INDEX Category	Value
Elevation of the site: • < 3 m (H, 3) • 3–5 m (M, 2) • >5 m (L, 1)			
Landforms behind the beach: • low land (soil) (H, 3) • low land (sandy terrace) (H, 3) • single dune line (M, 2) • multiple dune system (L, 1) • sloping land (soil over rock) covered with vegetation (L, 1) • low rocky shore (soft rock) (M, 2) • low rocky shore (hard rock) (L, 1) • cliff (soft rock) (M, 2) • cliff (hard rock) (L, 1)			
Wave exposure: • fetch >160 km (H, 3) • fetch 16–160 km (M, 2) • fetch < 16 km (L, 1)			
Proximity of site to vulnerable accretionary feature: • on a bar, spit or tombolo (EH, DNB) • within 100 m of a bar, spit or tombolo (H, 3) • behind a cuspate foreland (L, 1) • none of these features exist (NR, 0)			
Proximity of site to river mouth or tidal inlet: • within a distance of 10 times the width of the river mouth (EH, DNB) • within a distance of 1 km of a tidal inlet (H, 3) • neither of these conditions exist (NR, 0)			
Presence of coral reef: • no reef present (H, 3) • reef present, but waves not breaking on reef (M, 2) • reef present, waves seen breaking on reef (L, 1)			
Beach size: • minimum back beach width <5 m (H, 3) • minimum back beach width 5-10 m (M, 2) • minimum back beach width >10 m (L, 1)			
Erosion indicators : *3 indicators (H, 3), 2 indicators (M, 2), 1 indicator (L, 1), no indicators (NR, 0).* • dead trees/exposed roots • waves reach building foundations • sea defences • steep/near vertical slope behind beach • breaks in dune line • beachrock • wave-cut notches at base of cliff • landslides/slumping of material • springs issuing from cliff face • other			
Most recent hurricane: • occurred within 1 year (H, 3) • occurred 1–5 years ago (M, 2) • occurred 6–10 years ago (L, 1) • occurred 11+ years ago (NR, 0)			
Information from neighbours:			
Overall vulnerability index value:			
Assessment:			

BEACH CLEANUP DATA CARD

Thank you for completing this data card. Answer the questions and return to your area coordinator or to the address at the bottom of this card. This information will be used in the Center for Marine Conservation's National Marine Debris Data Base and Report to help develop solutions to stopping marine debris.

Name ______________________ Affiliation ______________________

Address ____________ Occupation ____________ Phone (______) ____________

City ______________________ State ________ Zip ________ M____ F____ Age: ________

Today's Date: Month: ________ Day ________ Year ________ Name of Coordinator ______________________

Location of beach cleaned ______________________ Nearest city ______________________

How did you hear about the cleanup? ______________________

SAFETY TIPS

1. **Do not go near any large drums.**
2. **Be careful with sharp objects.**
3. **Wear gloves.**
4. **Stay out of the dune areas.**
5. **Watch out for snakes.**
6. **Don't lift anything too heavy.**

WE WANT YOU TO BE SAFE

Number of people working together on this data card ________ Estimated distance of beach cleaned ________ Number of bags filled ________

SOURCES OF DEBRIS. Please list all items with foreign labels (such as plastic bleach bottles from Mexico) or other markings that indicate the item's origin (such as cruise line names, military identification or debris with names and/or address of shipping/freighting or fishing companies, or oil/gas exploration activities)

SOURCE	ITEM FOUND
Example: ABC Shipping Company	plastic strapping band

STRANDED AND/OR ENTANGLED ANIMALS (Please describe type of animal and type of entangling debris. Be as specific as you can.)

____

____

____

What was the most peculiar item you collected? ______________________

Comments ______________________

____

Thank you!

PLEASE RETURN THIS CARD TO YOUR AREA COORDINATOR OR MAIL IT TO:

Center for Marine Conservation
1725 DeSales Street, NW
Washington, DC 20036

A Membership Organization

Center for Marine Conservation

United States Environmental Protection Agency

Formerly Center for Environmental Education, Est. 1972

Printed on recycled paper.

ITEMS COLLECTED

You may find it helpful to work with a buddy as you clean the beach, one of you picking up trash and the other taking notes. An easy way to keep track of the items you find is by making tick marks. The box is for total items, see sample below

Example: egg cartons ~~||||~~ ~~||||~~ ~~||||~~ | TOTAL [16] — cups ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ || TOTAL [22]

PLASTIC

	Total number of items		Total number of items
bags:		fishing nets	
food bags/wrappers		hard hats	
trash		light sticks	
salt		pieces	
other bags		pipe thread protector	
bottles:		rope	
beverage, soda		sheeting:	
bleach, cleaner		longer than 2 feet	
milk/water gal. jugs		2 feet or shorter	
oil lube		6-pack holders	
other bottles		strapping bands	
buckets		straws	
caps, lids		syringes	
cigarette filters		tampon applicators	
cigarette lighters		toys	
cups, utensils		vegetable sacks	
diapers		"write protection" rings	
fishing line		other plastic (specify)	
fishing lures, floats			

STYROFOAM®
(or other plastic foam)

buoys		packaging material	
cups		pieces	
egg cartons		plates	
fast food containers		other Styrofoam® (specify)	
meat trays			

FOLD ALONG THIS LINE

GLASS

bottles/jars:		fluorescent light tubes	
beverage bottles		light bulbs	
food jars		pieces	
other bottles/jars		other glass (specify)	

RUBBER

balloons		tires	
condoms		other rubber (specify)	
gloves			

METAL

bottle caps		55 gallon drums:	
cans:		rusty	
aerosol		new	
beverage		pieces	
food		pull tabs	
other		wire	
crab/fish traps		other metal (specify)	

PAPER

bags		newspapers/magazines	
cardboard		pieces	
cartons		plates	
cups		other paper (specify)	

WOOD
(leave driftwood on the beach)

crab/lobster traps		pallets	
crates		other wood (specify)	
lumber pieces			

CLOTH

clothing/pieces ______ [ ]

Remember to turn the card over and fill out your name and address and to record sources and entangled wildlife!

Glossary

Accretion: accumulation of sand or other beach material due to the natural action of waves, currents and wind; a build-up of sand.

Armour: structural protection for the shoreline.

Artificial reef: a man-made marine habitat constructed for the purpose of improving fisheries.

Back beach:the section of beach extending landwards from the high water mark to the point where there is an abrupt change in slope or material; also referred to as the backshore.

Backfill: material used to build up and consolidate the land behind a seawall or similar structure.

Backhoe: an excavator in which the bucket faces the operator and is pulled towards him.

Bar: fully or partially submerged mound of sand, gravel or other unconsolidated material built on the sea-bottom in shallow water by waves and currents.

Barrier reef: a coral reef separated from the land by a large lagoon or, in some cases, by several kilometres of open sea.

Beach downdrift: area of beach towards which material is being moved by longshore transport.

Beachface: upper surface of the beach.

Beachface dewatering: a technique whereby water is continuously pumped away from the beachface, thereby lowering the water table under the beach.

Beach nourishment: artificial process of replenishing a beach with material from another source that lies either inland or is dredged offshore.

Beach profile: side view of a beach extending from the top of the dune line into the sea.

Beach recovery: process whereby accretion takes place at a beach, usually after a major storm or hurricane.

Beachrock: ledges of rock formed within the body of the beach consisting of sand grains cemented by calcium carbonate and formed by chemical processes. Erosion of the sand leaves the beachrock exposed.

Berm crest: ridge of sand or gravel deposited by wave action on the shore just above the normal high water mark.

Bioerosion: process by which animals, through drilling, grazing and burrowing, erode hard substances, for example rocks and coral reefs.

Bluff: high, steep bank at the water's edge; often used to refer to a bank composed primarily of soil. See also Cliff.

Breaker: a wave as it collapses on a shore.

Breaker zone: area in the sea where the waves break.

Brackish water: freshwater mixed with seawater.

Bulkhead: structure that retains or prevents the sliding of land or protects land from water damage.

Bypassing: movement of sand from the accreting updrift side of a structure, inlet or harbour entrance to the eroding downdrift side.

Cay: low island or reef of coral, sand, etc.

Cliff: high steep bank at the water's edge; often used to refer to a bank composed primarily of rock. See also Bluff.

Coastal vanes: curved structures moored to the seabed, designed to change the direction of part of the wave.

Coastal woodland: area of coastal trees and large shrubs located behind the beach, also referred to as coastal forest zone.

Conservation: the political/social/economic process by which the environment is protected and resources are used wisely.

Coral reef: complex tropical marine ecosystem dominated by soft and stony (hard) corals, anemones and sea fans. Stony corals are microscopic animals with an outer skeleton of calcium carbonate that form colonies and are responsible for reef-building.

Corrosion: wearing away of material especially by chemical action.

Cuspate foreland: an accretionary feature consisting of a triangular accumulation of sand projecting seawards from the shoreline.

Deep water: area where surface waves are not influenced by the sea-bottom.

Downdrift: Direction of longshore movement of beach materials.

Dredging: excavation, digging, scraping, draglining, suction dredging to remove sand, silt, rock or other underwater sea-bottom material.

Dune: Accumulations of wind-blown sand in ridges or mounds that lie landward of the beach and usually parallel to the shoreline.

Ebb-tidal current: flow of water in a given direction that takes place between high water and low water.

Ebb-tide: the falling tide, part of the tidal cycle between high water and the next low water.

Ebb-tide delta: an accretionary deposit of sand found on the seaward side of an inlet and usually formed by tidal currents.

Ecosystem: organization of the biological community and the physical environment in a specific geographical area.

Environmental impact assessment: detailed studies which predict the effects of a development project on the environment. They also provide plans for mitigation of the adverse impacts.

Equilibrium: state of balance.

Erosion: Wearing away of the land, usually by the action of natural forces.

Estuary: mouth of a river, where fresh river water mixes with the seawater.

Fetch: area of water where waves are generated by the wind.

Filter cloth: Synthetic textile with openings for water to escape, but which prevents passage of soil particles.

Filter material: layer of fine gravel used in slope stabilization structures that allows water to escape and retains soil particles.

Flank protection: angled section of wall at the end of a shore protection structure, for example a seawall or revetment.

Flood-tide: rising tide, part of the tidal cycle between low water and the next high water.

Flood-tide current: flow of water in a given direction that takes place between low water and high water.

Flood-tide delta: accretionary deposit of sand found on the bay or river side of an inlet and usually formed by tidal currents.

Foreshore: zone between the high water and low water marks.

Fringing coral reef: coral reef closely associated with the land; it may be joined directly to the beach or separated from the beach by a shallow lagoon.

Frond: shoot of a seaweed resembling a leaf in more advanced plants.

Frontal system: weather system where there is a line of separation between cold and warm air masses, usually associated with strong winds.

Gabions: wire mesh rectangular containers filled with stones.

Greenhouse effect: heating of the earth's atmosphere due to an increase in gases like carbon dioxide.

Groyne: Shore protection structure built perpendicular to the shore; designed to trap sediment.

Groyne field: Series of groynes acting together to protect a section of beach.

High water mark: the highest reach of the water at high tide. It is sometimes marked by a line of debris, e.g. seagrass, pieces of wood.

Hurricane: intense, low-pressure weather system with maximum surface wind speeds that exceed 118 km/hr (74 mph).

Jetty: structure projecting into the sea for the purpose of mooring boats; also solid structure projecting into the sea for the purpose of protecting a navigational channel.

Land reclamation: process of creating new, dry land on the seabed.

Lee: sheltered.

Leeward: the lee side.

Leeward coast: coast sheltered from the waves.

Longshore current: a movement of water parallel to the shore, caused by waves.

Longshore transport: movement of material parallel to the shore, also referred to as longshore drift.

Low water mark: the highest reach of the water at low tide.

Mean sea level: average height of the sea surface over a 19-year period.

Monitoring: systematic recording over time.

Northeast Trade Winds: dominant wind regime in the Caribbean region; the winds blow from directions between north and southeast.

Ocean current: flow of water in a given direction in the ocean.

Offshore breakwater: structure parallel to the shore, usually positioned in the sea, that protects the shore from waves.

Offshore step: break in the offshore slope; the point where, upon walking into the water, one suddenly steps into deeper water. Usually located at about the same place as the wave breakpoint.

Offshore zone: extends from the low water mark to a water depth of about 15 m (49 ft) and is permanently covered with water.

Patch reef: small colonies of corals, sometimes less than 10 m (33 ft) in diameter.

Pile: long heavy section of timber, concrete or metal, driven into the earth or seabed as support for another structure.

Retaining wall: wall built to hold back the earth.

Retreat: movement backwards towards the land.

Revetment: shore protection structure made with stones laid on a sloping face.

Sand bar: accretionary deposit of sand formed across a river mouth or bay by wave action and joined to the shore at both ends.

Scour: removal of underwater material by waves or currents, especially at the toe of a shore protection structure.

Seagrass bed: area of the offshore sea-bottom colonized by seagrasses.

Seasonal deposition: accumulation of sand or other beach material, usually layered, resulting from winter/summer variations in coastal processes.

Seasonal erosion: loss of sand or other beach material resulting from winter/summer variations in coastal processes.

Seawall: massive structure built along the shore to prevent erosion and damage by wave action.

Sediment: particles of rock covering a size range from clay to boulders.

Setback: prescribed distance landward of a coastal feature (e.g. the line of permanent vegetation), within which all or certain types of development are prohibited.

Settling pond: man-made depression created to receive water and sand mixture directly from a dredging operation.

Shore: narrow strip of land in immediate contact with the sea.

Shoreline: intersection of a specific water height with the shore or beach, e.g. the high water shoreline is the intersection of the high water mark with the shore or beach.

Silt curtain: fine, meshed material suspended in the water to prevent silt escaping from a construction site.

Siltation: deposition of silt-sized particles.

Slurry: mixture of 70 per cent water and 30 per cent sand/silt/clay size particles; term used in dredging.

Spit: accretionary deposit of sand or stones located where a shoreline changes direction, formed by wave action and joined to the shore at one end only.

Storm surge: a rise in the sea surface on an open coast, often resulting from a hurricane.

Swamp: low-lying areas that are frequently flooded and support vegetation adapted to saturated soils e.g. mangrove swamps. See also Wetlands.

Swell: waves that have travelled out of the area in which they were generated.

Tectonic: processes that build up the earth's crust.

Tidal current: movement of water in a constant direction caused by the periodic rising and falling of the tide. As the tide rises, a flood-tidal current moves in one direction and as the tide falls, the ebb-tidal current moves in the opposite direction.

Tidal inlet: a river mouth or narrow gap between islands, within which salt water moves landwards during a rising tide.

Tide: periodic rising and falling of large bodies of water resulting from the gravitational attraction of the moon and sun acting on the rotating earth.

Toe protection: material, usually large boulders, placed at the base of a sea defence structure like a seawall to prevent wave scour.

Tombolo: accretionary deposit of sand or gravel joining a small islet or rock to a larger island or landmass. Formed by wave action.

Topography: configuration of a surface including its relief and the position of its natural and man-made features.

Tropical depression: organized low-pressure system forming in tropical latitudes with wind speeds of between 37 km/h and 60 km/h (23 mph and 37 mph).

Tropical storm: low-pressure weather system with maximum surface wind speeds between 61 km/h and 118 km/hr (38 mph and 73 mph).

Tropical wave: low-pressure system forming in tropical latitudes with wind speeds of up to 36 km/h (22 mph).

Tsunami: wave caused by an underwater earthquake or landslide; can rise to great heights and cause catastrophic damage to the coast.

Turbidity:reduced water clarity resulting from the presence of suspended material in the water.

Updrift: direction opposite to the predominant movement of longshore transport.

Vegetation edge: place where the vegetation (e.g. grasses, vines) meets the bare sand area of the back beach.

Water table: the upper surface of groundwater; below this level, the soil is saturated with water.

Wave breakpoint: the point where the waves break.

Wave direction: direction from which a wave approaches.

Wave refraction: process by which the direction of approach of a wave changes as it moves into shallow water.

Weep hole: hole through a solid revetment, bulkhead or seawall for relieving water pressure.

Wetlands: low-lying areas that are frequently flooded and which support vegetation adapted to saturated soils e.g. mangrove swamps. See also Swamps.

Wind waves: waves formed in the area in which the wind is blowing.

Windward: side facing the wind.

Windward coast: coast exposed to wave action.

SUBJECT INDEX

Coping with Beach Erosion is a practical guide for beach users, builders and homeowners as well as other coastal stakeholders. Written in a language and style accessible to the non-specialist, it provides expert advice concerning the dangers to consider when buying property and constructing houses, hotels, etc., in erosion-prone beach areas. The question of how to conserve existing beaches is dealt with by demonstrating well-tested shoreline protection and other management measures for current and potential erosion and accretion problems. [illegible] this user-friendly book includes a glossary of terms and a subject index. Its popularized and well-structured guidelines are based on technical information gathered over a decade and a half of field studies jointly sponsored by UNESCO and the Sea Grant College Program of the University of Puerto Rico.

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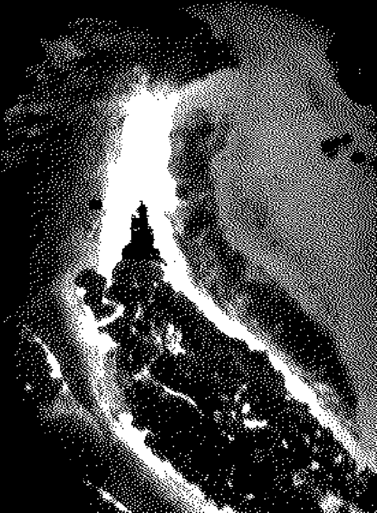

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