SOPAC

COASTS OF PACIFIC ISLANDS

SOPAC Miscellaneous Report 222

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Compiled and edited by

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PREFACE

The protection of the coasts of Pacific Island Countries is vital to the sustained economic development and livelihood of the people in the region.

People at all levels, in all communities living on islands in the Pacific must understand the risks they are taking in the "cause of development" as they increasingly interfere with and expose themselves and their properties to the natural processes acting at the coast.

This booklet is a first attempt by SOPAC to make available information on the coasts of Pacific Island Countries, including illustrated examples, to assist with increased public awareness and education. To achieve effective coastal protection, responsible actions by individuals at all levels of society can be of great assistance. Furthermore, public awareness and education are essential for the effective implementation of management policies and compliance with regulations.

The technical content is hopefully, simplified at least for use at the senior high school level. Nonetheless, it is envisaged that a series of in-country activities will follow the release and circulation of the booklet. These activities, we hope, will lead to greater simplification of the text and ultimately its translation into local languages.

The three chapters of this booklet follow in sequence; the first on the coastal physical environment; the second on coastal erosion; and the final one on coastal protection strategies and structures. However, there is deliberate overlap between the three chapters to enable each to be read on its own.

The booklet was first put together by Alan Sherwood whilst working as Technical Editor at the SOPAC Secretariat (1990-1994). Completion of the task was delayed until late 1995 at which time the Canada Fund generously agreed to support the costs of printing and distribution. Final assembly of all parts before offset printing was done by Lala Bukarau.

Russell Howorth
February 1996

BACKGROUND

SOPAC is an independent, inter-governmental, regional organisation established by several South Pacific nations in 1972, originally as CCOP/SOPAC. Its Secretariat is located in Suva, Fiji, and has about 40 professional and support staff. All of its seventeen members are developing Pacific Island Countries except Australia and New Zealand, which do not receive Work Program assistance but are major donors.

Member countries are currently Australia, Cook Islands, Federated States of Micronesia, Fiji, Guam, Kiribati, Marshall Islands, New Zealand, Niue, Papua New Guinea, Solomon Islands, Kingdom of Tonga, Tuvalu, Vanuatu, and Western Samoa. French Polynesia and New Caledonia are Associate Members.

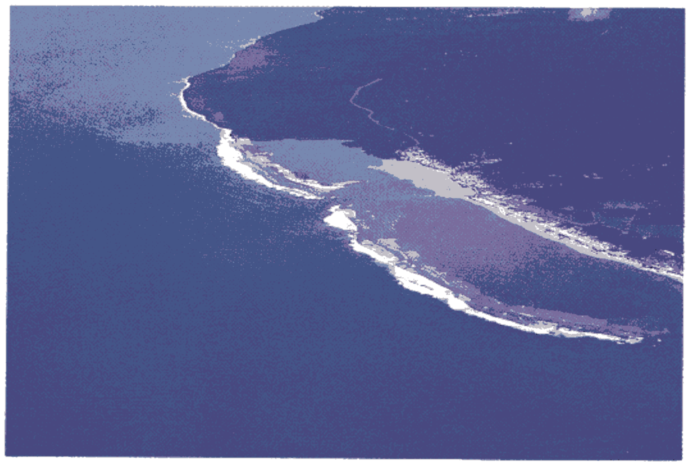
The SOPAC Mission Statement is "To improve the well being of the peoples of Pacific island member countries through the application of geoscience to the management and sustainable development of their non-living resources."

GENERAL INTRODUCTION

The coast is a vital non-living resource in most Pacific Island Countries. Important commercial and national assets, essential infrastructure, and populations lie in the coastal zone. Properly understanding and protecting this vital resource is the subject of this booklet. Chapter 1 of this booklet explains some aspects of coastal processes and some of the natural causes of coastal changes. Chapter 2 explains some of the causes of shoreline erosion and briefly suggests some ways of reducing it. Chapter 3 considers coastal protection strategies and structures in the South Pacific, including the growing appreciation of alternatives to engineering solutions in response to coastal erosion.

COASTS OF PACIFIC ISLANDS

CHAPTER 1:



The Physical Environment

INTRODUCTION

As populations grow in Pacific Island Countries, urbanisation and development expand and pressure on the coastal zone increases. Demands are made for land reclamation and coastal stabilisation. The coast is expected to provide more and more resources ranging from construction materials to food, to absorb growing amounts of domestic and industrial refuse, as well as to continue to retain its cultural importance.

There are significant risks associated with living in a mobile physical environment, yet people expect the coastline to be fixed, particularly when it is artificially defined by property ownership and coastal structures. The modifications seem to reduce the appreciation of the risks when, in fact, the risk may have been increased by reducing the coast's capacity to adjust itself. Once substantial investments have been made in coastal development, there are strong political and economic pressures to protect them, even if the protection is costly and ineffective (Plates 1 and 2).

Plate 2. Buildings at Gizo in the Solomon Islands extend out over the water and are at risk from virtually any natural coastal processes.

Plate 1. A rather elaborate vertical concrete block seawall protecting property on the ocean side of Majuro Atoll, Marshall Islands. Note the narrow reef flat, lack of sandy beach and the foundations of the seawall.

DEFINING THE COAST

The coastal zone is where the land and the sea meet, and includes parts of both. The landward and seaward limits of the coast can be set where wave activity has little or no effect, so that the width of the zone can vary substantially between calm and storm conditions. The entire land area of some Pacific Island Countries can be included in the coastal zone. It is a dynamic environment subject to considerable natural changes that operate on time scales varying from the daily rhythm of the tides, to seasonal weather shifts, to great changes in sea level over thousands of years.

The processes that shape the coast are mainly geological - the erosion and redistribution of rocks and sand. The supply of beach material may be biological - from dead organisms, including coral - or geological - from erosion of coastal rocks or by supply of sediment from rivers. The changing interaction between land and sea is primarily driven by variations in climate.

One of the problems arising from coastal development is that people expect that the coast will conveniently remain at the same position. In fact, many coastal areas are formed by the same natural processes that are a hazard to the people living there. For example many reef islands are built up from coral debris thrown up by storms; coastal plains may be formed from storm deposits or from the sediment deposited by rivers in flood, or both. These events have a major influence on physical coastal processes, including erosion (Plate 3).

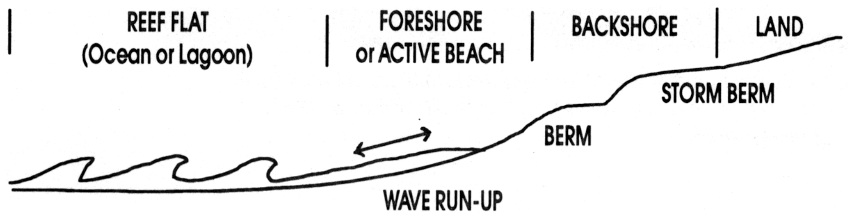


Plate 3. Part of the bank of coral rubble deposited during Cyclone Ofa on the reef edge close to Mulinu'u Point, Apia, Western Samoa. Note figure for scale.

PACIFIC ISLAND TYPES, GEOLOGY AND COASTS

There are a variety of islands in the South Pacific which can be classified into three main types:

- volcanic islands
- coral atolls and reef islands
- elevated limestone islands

There are combinations of these island types, such as elevated reefs on volcanic islands and volcanic islands surrounded by an atoll-like lagoon. These island types have a corresponding range of coastal environments, including beaches, cliffs, river deltas and lagoons.

Plate 4. The young, extinct and now severely eroded volcanic island of Rarotonga, Cook Islands, viewed from the southeast. Note the narrow fringing reef.

Volcanic islands (Plate 4) vary greatly in size and in age. Coastal types may vary from rugged cliffs and pocket beaches associated with relatively recent volcanic islands (Western Samoa, Southern Cook Islands) to extensive coastal plains and associated deltas on the larger, older islands of the Melanesian countries (Fiji, New Caledonia, Solomon Islands, Vanuatu and Papua New Guinea). Younger volcanic islands tend to be fringed with a narrow coral reef (Rarotonga, Cook Islands) while older volcanic islands have extensive barrier reefs with wide, deep lagoons (Viti Levu, Fiji).

Plate 5. Islets on the windward reef rim of Tarawa Atoll, Kiribati.

Plate 6. The central part of the raised reef limestone island of Nauru, showing an area previously mined for phosphate and now slowly becoming revegetated.

Atolls (Plate 5) are coral reefs whose growth has kept them at the surface after the volcanoes on which they are founded subsided beneath the sea. The emergent surface of an atoll is merely the top of hundreds of metres of coral built on the subsided volcanic rock. The habitable land area on coral atolls is limited to islets formed from coral rubble and sand accumulated under storm conditions and/or as the result of changes in sea level the geologically-recent past. The islets form some of the smallest and most isolated habitable land areas on the Earth and which are extremely vulnerable to natural and human-induced environmental changes. Atolls are a common type of island in the Pacific. Kiribati (except Banaba), Tuvalu, Marshall Islands and Tokelau are countries made up entirely of atolls.

Emergent or elevated limestone islands (Plate 6) are former coral atolls or reef islands which have been lifted above the ocean surface leaving near vertical limestone cliffs or a very narrow limestone platform (Nauru, Niue, and Banaba in Kiribati). Variations in this type may include a makatea which is an annular ring of raised reef around a volcanic core (Mangaia and Atiu, Cook Islands). Some island groups are composed of chains of volcanic islands and uplifted and tilted coral reefs (Tonga).

VARIATIONS OF CLIMATE AND WAVE CONDITIONS

The Pacific Ocean is the largest feature on the surface of the Earth and even the area generally referred to as the South Pacific (which includes the islands of Micronesia in the North Pacific) is enormous. Variations of climatic patterns and wave conditions over the region are major causes of coastal change.

The wave environment of the region is made up of at least four major components which contribute to the wave conditions at any locality. Each may vary significantly through time and cause cycles of shoreline erosion and deposition.

- Prevailing northeast to southeast seas and swell waves generated by the trade winds.

Seas generated by westerly gales in equatorial regions during the wet season or during ENSO events (see box). Atoll islets are especially sensitive to the westerly conditions of ENSO events. These events are also of great importance in the development of atolls. The prevailing easterly tradewinds generally create offshore breezes which results in small waves and calm conditions along lagoon shorelines of the windward rim islets. During ENSO episodes, there is a significant increase in westerly winds and the lagoon wave climate is markedly altered. Waves up to 2 metres high can form in the normally sheltered lagoon environment, causing erosion on lagoon shoreline beaches which are otherwise normally stable. Oblique approach of the waves is common, causing longshore drift of sand and spit development along lagoon shorelines.

Sea and swell waves generated by tropical storms or cyclones occur with a variable seasonal frequency in all parts of the tropical and subtropical Pacific island region with the exception of a relatively narrow zone (5-10 degrees of latitude) either side of the Equator. However, the presence of coral rubble and boulders on islands near the Equator shows that cyclone storm waves can penetrate beyond the cyclone belt.

"ENSO" WEATHER CHANGES

The El Nino – Southern Oscillation (ENSO) phenomenon is a periodic fluctuation of weather conditions in the tropical Pacific that affects the weather in other parts of the globe. It has a major influence on coastal processes in the South Pacific region. The term "El Nino" originated from the name given to a warm current that flows along the coast of northwest South America. "Southern Oscilation" is a meteorological term used to describe periodic reversals of atmospheric pressure difference across the Pacific. "ENSO" is the simplest way to refer to it.

The normal state of atmospheric circulation in the Pacific is that the easterly trade winds of both hemispheres converge at the Equator and drive a strong surface ocean flow towards the west. Every few years, there are radical changes to this pattern. The trade winds slacken, there is less evaporation in the Central Pacific and so more surface heating. The effects are global in scale. In the South Pacific there are changes of cyclone frequency and pattern, rainfall distribution, wind strength and direction, and sea level.

These changes caused by ENSO, especially the increased frequency of westerly winds, have a major influence on physical coastal processes in the Pacific Islands, including beach erosion. The timing and severity of the effects vary across the region.

ENSO events occur characteristically about every 3-4 years, and lasts 12-18 months, but the interval between them can vary between 2 and 10 years. There are particularly strong events every 10-20 years. There were ENSO events in 1972 (moderate), 1977/78 (moderate), 1982/83 (strong), 1987 (moderate), and a prolonged moderate event from 1990-1993.

The high winds, large waves (Plate 7), storm surge and heavy rainfall associated with tropical cyclones have short term catastrophic and permanent impacts on all coastal environments in general and low lying islands in particular. The immediate effect of cyclones on the coastal zone is wave damage of structures, flooding and usually coastal erosion. While in the short term these events seem to be destructive, they are also necessary for the long-term replenishment of sediment on shorelines, especially in atoll environments. This is a natural process which has contributed to the formation of the habitable portions of atolls and reef islands.

Swell waves generated by mid-latitude storms in both the South and North Pacific Ocean can travel vast distances with relatively little energy loss. The south facing coasts of most islands in the South Pacific are exposed to persistent southerly swell wave conditions in all seasons.

Plate 8. Many tropical beaches are controlled by the way in which waves are refracted by coral reefs, Cuvu Bay, Fiji.

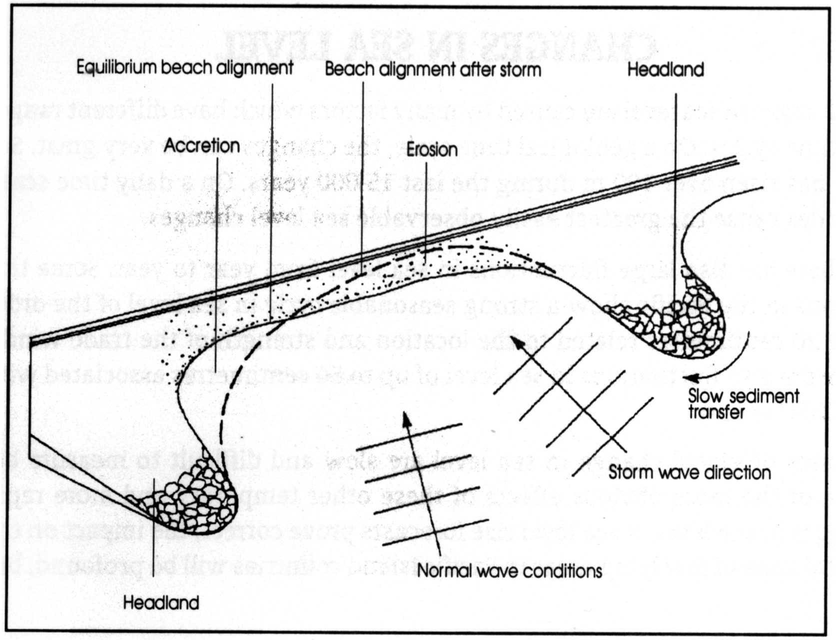
Plate 7. Cyclone waves can cause catastrophic impacts on the coast, but are also necessary for long-term coastal stability by resupplying beaches with sand and building up atoll islets.

BEACHES AND SAND MOVEMENT

Beaches are one of the most important coastal environments in the Pacific because of the extensive development that has commonly taken place along them, and because they are the most mobile of coastal environments. This gives rise to one of the fundamental conflicts of coastal management - development tends to attempt to fix the position of an environment which is naturally subject to change.

The supply of sand to the beaches of atoll islands is mainly by waves moving material from coral reefs and lagoons towards the shore. The sand may then be moved along the shore by waves arriving at an angle to the beach, causing accumulation in some areas of the coast, but requiring the supply of sand to keep pace with the amount being moved. This may come from the reef or lagoon, or from the erosion of sand from the shore at some other location.

Other beaches of coral-fringed coasts are not dominated by longshore drift and the changes in the wave directions that control it, but are adjusted to a particular wave pattern that may be strongly influenced by the reef and the



The shape and position of a beach can be affected by the strength and direction of waves. Storms can redistribute sand, causing erosion at one place and accumulation of sand at another.

shallow water on the reef flat (Plate 8). This can form beaches that are curved outwards towards the reef rather than the headland dominated beaches that are curved inwards away from deep water offshore.

The mobility of the beach - changes of shape and position - are affected mainly by variations in the strength and direction of wave action. Variations of tide, current and sea level, and changes in the supply of sediment, can also affect the nature of a beach. When wave patterns change, as the result of shifting wind strengths and directions, especially during storms, the balance of sediment supply and movement changes as well. These are natural fluctuations.

A sandy coast is seldom fixed, but maintains a state of constant adjustment. A stable coast is often one that in fact has both erosion and growth which, averaged over a long period, are in balance so that the shoreline retains its position and shape. Other shorelines may have a net gain or loss over time.

Apart from these natural fluctuations, the activities of people can also affect the shape and position of a beach. Removal of mangroves and construction of seawalls increase the amount of turbulence on a beach and frequently cause erosion. Building on sand dunes, or the removal of sand dunes behind a beach removes a vital reservoir of sand that natural processes rely on for stability during storms. Groynes, reclamation areas, and removal of sand for construction purposes, upset the natural movement of sand (Plate 9). The effects may be apparent not only nearby, but also on beaches several kilometres away.

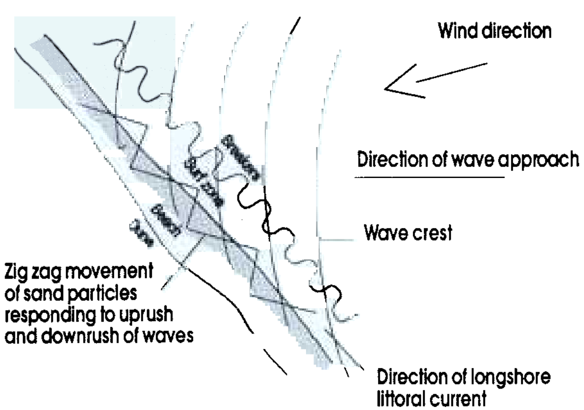
Plate 9. Foreshore development, groynes and dredging operations at Mulinu'u Point, Western Samoa, are affecting the natural movement of sand around the point. Note the small spit forming around the end of the dredging causeway, bottom right corner of photo.

HOW SAND IS MOVED

Sand movement on beaches is mainly caused by waves and the currents, which lift particles of sand and carry them to another place. Sand particles can be transported in two ways: longshore drift and onshore-offshore exchange.

Longshore drift

Waves usually do not approach exactly parallel to the beach. When waves approach at an angle, sand will be transported along the beach in a zig-zag fashion by the skewed wash and backwash of the waves. Sand churned into suspension by breaking waves will also be carried along the beach by the currents that the waves generate. If there is an equal supply of sand from the coast updrift, there will be no erosion by longshore drift. If for some reason the supply of sand is less than that moved along the beach, it will erode.



Onshore-offshore exchange

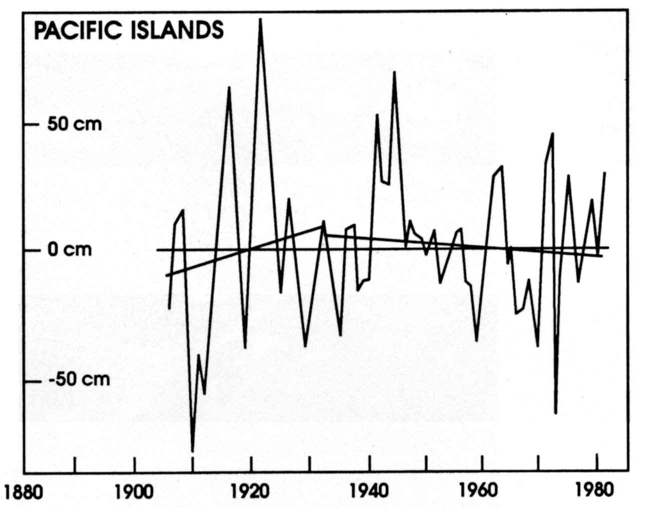
High, steep waves tend to erode the beach and move sand offshore, while low, gentle waves tend to move sand from offshore bars or from the reef flat onto the beach.

CHANGES IN SEA LEVEL

Changes in sea level are caused by many factors which have different ranges and time cycles. On a geological time scale, the changes can be very great. Sea level has risen over 100 m during the last 15 000 years. On a daily time scale, the tides cause the greatest easily-observable sea level changes.

There are also large fluctuations in sea level from year to year. Some tide stations in the Pacific show a strong seasonable cycle in sea level of the order of 10-20 centimetres related to the location and strength of the trade winds. There are also fluctuations in sea level of up to 50 centimetres associated with the ENSO events.

Rates of global change in sea level are slow and difficult to measure because of the more obvious effects of these other temporary and more rapid changes in sea level. If sea level rise forecasts prove correct, the impact on the coastal zone of low lying areas in Pacific Island countries will be profound, but



Changes in sea level in the Pacific Islands over the last 80 years show no net change, but do show cyclic changes of up to 50 centimetres which have been shown to coincide with ENSO events. These changes can cause related changes to shorelines, including erosion.

there is great difficulty in accounting for present rates of change in sea level, let alone those of the future. While sea level rise predictions are frequently quoted as being authoritative, there is a very large measure of uncertainty and qualification. Natural fluctuations at present are of the same order of magnitude as predicted sea level rise over the next century.

Plate 10. The ocean shoreline of an atoll in the Gilberts Group, Kiribati, showing how the wave energy reaching the shore is reduced by the reef.

CORAL REEFS

Coral reefs may be of several different types and may be quite narrow or up to several kilometres wide. They act as a first line of defence against ocean waves, absorbing most of the force of variations in wave conditions (Plate 10). For this reason alone, the preservation of coral reefs and coral reef environments is critical to maintaining a natural coastal protection system around islands in most Pacific Island Countries.

Coral reefs are also a vital source of supply of sand to beaches - on coral atolls, they are the main source of sand, and without the reefs there would be no habitable land.

Plate 11. A large dead coral in growth position but now uplifted above low tide level near to Port Vila on the south side of Efate, Vanuatu.

Coral reefs are also important for their effects on the wave pattern on adjacent shorelines. Refraction of waves by the reef means that ocean shorelines are commonly more stable than lagoon shorelines. The influence of reefs also means that conventional understanding of coastal processes and design of coastal structures in temperate latitudes is not applicable to many tropical shorelines.

Plate 13. Reclamation of mangroves for use as a container storage area near the Port of Suva, Walu Bay, Fiji. Note a narrow fringe of mangroves left along the exposed side of the reclaimed area to protect the fill from wave action.

MANGROVES

Mangroves are widespread in tropical and subtropical waters and play an important role in coastal systems. Many extensive mangrove areas have been subjected to severe modification and destruction over time by human activity (Plates 12 and 13). Across the Pacific there is a marked decrease from west to east in the influence of mangroves, which are absent from many small low islands and from most of Polynesia. Mangroves act as a form of natural coastal protection, but only in sheltered locations.

Plate 12. Nan Madol a prehistoric site occupied over 1000 years ago then abandoned. Construction of the site involved extensive reclamation of mangroves on the reef edge of southeast Pohnpei, Federated States of Micronesia.

COASTS OF PACIFIC ISLANDS

CHAPTER 2:

Erosion, Natural and Human-Related Changes

INTRODUCTION

Plate 14. The positions of the 1943, 1969 and 1992 shorelines of the northwest corner, Betio islet, Kiribati, show how much the land area can change. There is now intensive development right to the shoreline, including the site being used as the rubbish dump. The coast no longer fluctuates naturally without causing an "erosion problem".

Shoreline erosion and its impact on people's use of the coastal zone is a serious problem and expense in many Pacific Island Countries. A common response to coastal erosion problems is to build seawalls or other forms of coastal protection. In many cases, these projects have not only failed to stop the erosion but have made it worse.

In determining the causes of coastal erosion, it is not always easy to distinguish problems associated with natural variations in coastal conditions from other contributing factors, particularly the human modifications to coastal environments. Few coastal areas in the South Pacific have been surveyed or mapped often enough or over a long enough period of time to develop reliable data on shoreline changes (Plate 14). This lack of basic information on longer term coastal changes creates one of the most difficult problems facing the resolution of erosion-related coastal zone management issues in the region.

Shorelines and beaches are naturally subject to continual change from a number of causes, and the present position and shape of the coastal zone are not what they may be in the future. The many causes of shoreline erosion can be divided into two main types: natural and human-related. The human-related causes are essentially poor beach sand management practices.

NATURAL CAUSES OF EROSION

BEACH STABILITY AND SAND MOVEMENT

The beach and backshore areas of Pacific island shorelines are very dynamic and must not be considered as fixed features for coastal development purposes. Good coastal management is partly the practice of maintaining the natural sand volumes on a beach and locating coastal structures in a way that allows the shoreline to fluctuate naturally (Plates 15 and 16).

Sand movement on beaches is mainly caused by waves and currents which can lift particles of sand and carry them either along the beach by the process of longshore drift, or back and forth between the beach and the nearshore zone. Changes to the normal wave conditions or to the supply of sand will cause changes to the balance of beach material, which is constantly changing.

Plate 16. A beach forming part of a sand spit being eroded and threatening buildings at the Shangri-La Fijian Resort in Fiji. Note that attempts at protection using pine pole logs and large coral blocks do not appear to have been successful.

Plate 15. A bay beach enclosed by headlands near Touho on the eastern side of the main island of New Caledonia. Note the river mouth in the centre, and the erosion of the coconut trees on the section of the beach closest to the camera.

Thus, over any particular period of time (the period of a wave, a tidal cycle, a season, a year, or many years) beaches are usually undergoing some deposition or erosion, and the beach fluctuates about an average shape and position. Most beaches are in this state of constant adjustment and readjustment. When changes occur in the wave and/or current patterns, sediment transport patterns change and the beach adjusts to a new shape in balance with the new conditions. In this way the beach absorbs these continual changes and acts as a natural protection zone. A great number of erosion problems are the result of interference by humans with this natural coastal protection, *especially by attempts to fix the position of the shoreline.*

The active beach is usually backed by a higher storm ridge. During storms, waves will reach this backshore area and erode sand from it, moving it both along the beach and off the beach. One of the most important functions of this backshore area is as a reservoir of sand during times of storm. If the sand that is moved offshore during a storm remains in relatively shallow water, subsequent moderate weather and gentle waves will move this sand back onto the beach. Building on, or removal of, the sand behind a beach removes a vital store of sand that natural processes rely on for long-term stability.

NATURAL SHORELINE ADJUSTMENT

Many perceived "erosion problems" in the Pacific are, in fact, primarily associated with natural beach fluctuations and conflicts created by the encroachment of human activities onto mobile shorelines.

Beach monitoring studies show that the normal position of a beach in Pacific Island Countries may fluctuate over distances of 5-20 metres over periods of 2-10 years. Sand spits can move horizontally by up to several hundred metres over fairly short time intervals. This process of change occurs more or less continually, but is usually only noticed when large natural changes occur or when human activity disrupts the natural balance by placing coastal structures within the active beach zone. These natural changes occur from a number of causes.

Changes in Weather Patterns

The direction of waves approaching a shoreline fluctuates with seasonal changes in wind patterns, annual variations in storm or cyclone frequency, and other variations in "normal" weather patterns. These changes in wave direction can have significant impacts on beaches, especially those on atoll islets, and the normal sand volume and distribution on a beach may become temporarily altered.

The wind and wave patterns and changes in sea level associated with ENSO events, which occur every 3-4 years on average, have a major influence on cycles of beach changes in some areas of the South Pacific. ENSO events cause changes to the normal trade wind and wave patterns, including reversals of their direction (Plate 17).

Plate 17. Strong westerly winds and waves caused this erosion scarp and exposure of broken slabs of beachrock on Arorae, Gilbert Group, Kiribati. These winds are commonly associated with ENSO events when a reversal of the normal wind direction occurs.

Geological Changes

All coastal environments, particularly those on coral atolls, are characterised by their relatively recent geological evolution and are subject to continual and on-going change, including both growth and erosion and shoreline realignment. Many shorelines near large river mouths and delta systems are also undergoing constant change, such as near the Rewa River Delta in southeast Viti Levu, Fiji and the Lungga River Delta on the north coast of Guadalcanal in the Solomon Islands. Geological processes also include uplift or subsidence of the land, erosion of cliffs and headlands, and transport of coastal sediment to deep water where it is removed from the beach system.

The common factor to all these processes is that they alter the rate of supply of sand to the beach system and the way it is distributed along the coast. Variations of the supply of sand from reef and lagoon sources is also significant, and may result from biological or other causes.

Changes in Sea Level

Extreme tidal variations and changes in sea level caused by short-term climatic variations are a major factor in coastal erosion in the Pacific, especially when they are associated with high winds or waves.

Changes in sea level are caused by many factors which have different ranges and time cycles. Some tide stations in the Pacific show a strong seasonal cycle in sea level of the order of 10-20 centimetres related to the pattern and strength of the trade winds. There are also fluctuations in sea level of up to 50 centimetres associated with ENSO events.

CATASTROPHIC COASTAL EVENTS

Extreme natural events cause immediate and major impacts on Pacific Island coastal areas. Cyclones (typhoons) and storm force winds are an annual occurrence in most of the tropical Pacific Ocean outside of the equatorial zone (Plates 18 and 19).

Much of the coastal damage during a cyclone is from high waves, wave run-up and the accompanying storm surge. This usually causes erosion of beaches and damage to structures. Washover of large volumes of beach and reef material into backshore areas also occurs. These impacts are especially severe on low islands and the lowlying portions of larger islands, where most development and population is concentrated. The most devastating coastal damage is generally when high waves arrive at the same time as a high sea level, either from a high tide, a storm surge, a seasonally high sea level, or a combination of these.

While in the short term these events are destructive, they are also necessary for the long-term replenishment of sediment on shorelines, especially in atoll environments.

Much of the western part of the Pacific is also subject to earthquakes. Earthquakes in the coastal zone may directly result in the subsidence or uplift of the shoreline and adjacent areas. Earthquakes may also cause various materials in beaches and other coastal deposits to become unstable, which can also result in shoreline erosion.

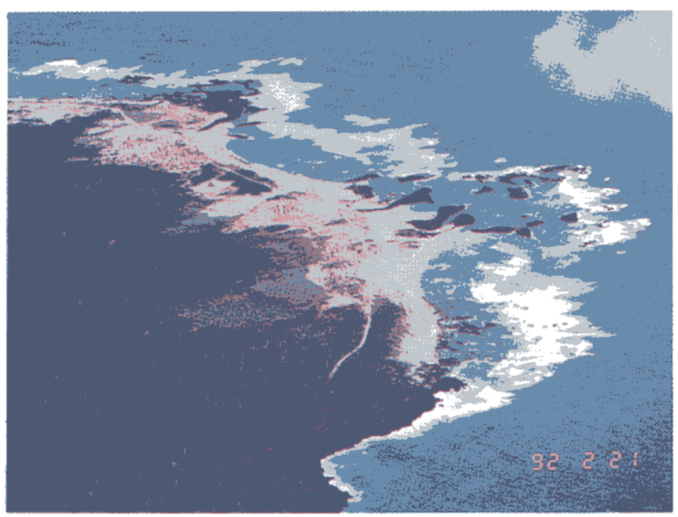
In Vanuatu, several square kilometres of coastline and nearby reef/lagoon areas were uplifted on western Malekula during an earthquake in August 1965.

Plate 18. The mouth of the Lungga River on the north coast of Guadalcanal, Solomon Islands changed the position of its mouth during cyclone Namu in 1986, affecting the shape of the river delta and the supply of sediment to the adjacent Ranadi Beach, with the Port of Honiara at the top of the photo.

Permanent changes in shorelines including the necessity to relocate villages can take place during volcanic eruptions. Such an instance occurred on the north coast of Savai'i during the 1906-1911 eruptions. Lava flowed down valleys to the coast from vents near the centre of the island. At the coast the flows extended out into the lagoon to create new land, lagoon fishing areas were lost, two coastal villages were destroyed, and many kilometres of coastline were buried together with the land used for agriculture.

Tsunamis, the result of earthquakes, submarine landslides and volcanic eruptions, are also potential catastrophic events. They may be generated locally, or travel vast distances to other parts of the Pacific Ocean. Local tsunamis may be considered the most dangerous since little or no warning can be given. The inundations of tsunamis may reach 5-10 metres above the shoreline, causing catastrophic flooding, coastal changes and loss of life. Despite the potential hazard of tsunamis, there is generally little information about their magnitude or frequency in the South Pacific. The danger from tsunamis is not widely recognised mainly because spectacular tsunamis have been rare, partly due to the protective effects of coral reefs.

Plate 19. Severe damage to the northwest coast of Savai'i, Western Samoa, caused by Cyclone Val in 1992. The damaged area was indicated by coral debris (white area) deposited by the cyclone storm surge.



HUMAN-RELATED CHANGES TO SHORELINES

SAND REMOVAL

Sand volumes on tropical beaches are often quite small because of low natural supply rates and the formation of beachrock which underlies most beaches. Historically, sand and beachrock have been mined from beaches and coral boulders removed from reefs for traditional construction activities and relatively minor shoreline reclamation purposes. When the rate of removal was slow, as it would have been before modern construction equipment was available, it is possible that new beach sand was being generated from the reef at a rate sufficient to compensate for the material removed. However, in more recent

Page 20. Dredging for sand using a dragline on the lagoon side of Majuro Atoll, Marshall Islands.

times, sand has been removed by machinery from many beaches at rates that are far in excess of the natural re-supply rates, causing chronic erosion problems in some areas.

Sand extraction often results in the long term depletion of beach sand resources. This reduces the ability of the beach to fluctuate naturally and to absorb the stress of storm and cyclone wave events, and often results in increased damage to backshore and landward areas. The time required for beach replenishment from natural sources can be decades or longer (Plate 20).

Sand and beachrock removal can also cause erosion by allowing waves to reach further up the shore.

Dredging of sand from lagoon or nearshore areas, or the creation of borrow pits near to the shore, or reef blasting may cause less of an impact, or may cause erosion problems if the sand being removed is part of the mobile coastal sediment system. Removal of nearshore sand can also lead to coastal erosion because of changes to refracted wave patterns.

Sand extraction proposals should be investigated on a site-specific basis. As a general rule, sand extraction from the active beach should be prohibited, or at least carefully regulated so that the rate of removal is not damaging.

SEAWALLS

There is an increased likelihood of erosion of a beach when vertical walls are constructed on, or at the back of a beach (Plate 21). While these seawalls may not be subjected to wave attack under normal conditions, storm waves hitting the seawall cause great turbulence, keeping sand at the base of the seawall in suspension. This sand in front of the wall will then tend to be moved in an offshore direction, thereby causing erosion. Once a seawall has been exposed to storm waves it becomes difficult for sand to re-establish itself, because the erosion has lowered the beach and the wall is now exposed to even mild waves breaking on the wall inducing turbulence and causing sand movement.

This is a world-wide problem, and only recently has it become generally recognised that seawalls often cause more problems than they solve.

Seawalls around Pacific islands are constructed of a large variety of materials including: solid reinforced concrete; cement blocks; cement-filled bags; cement-filled 44-gallon drums; gabion baskets filled with rocks, often coral; and stacked rocks and timber.

Whilst most vertical walls are ineffective in the long term, their life is shortened if the foundation they are placed onto is unsuitable. Unsuitable foundations include beach sand, mangrove silt and mud soils; whereas foundations into solid coral reef flat or beachrock are best.

Plate 21. Vertical concrete block seawall and 44 gallon drums full of concrete protecting property on the ocean side reef flat of Majuro Atoll, Marshall Islands.

GROYNES

A common method of stabilising a segment of the coast has been the construction of groynes to prevent sand being moved along a beach by waves, but these structures commonly cause more erosion problems than they fix (Plate 22). When sand is trapped by a groyne, the next section of shoreline downdrift from the groyne will have its sand supply interrupted and this section of coast will erode. Groynes can also cause erosion by forcing littoral drift to move offshore around the groyne where beach material may be lost to the coastal system.

CAUSEWAYS

In Pacific Island Countries, particularly on coral atolls, causeways have been constructed between sand islets on the atoll rim (Plates 23 and 24). The causeways cross and often close-off the channels which extend from the ocean reef to lagoon areas, blocking the natural current and sediment transport through the channel. In places this has resulted in both erosion and re-alignment of adjacent shorelines, usually on the lagoon shore. In other places, there has been accumulation of sand near the causeway.

Plate 22. A coral rubble mole in Abemama, Kiribati, has acted as a groyne, accumulating sand on the updrift side (right) and causing shoreline erosion along several hundred metres of beach on the downdrift side (left).

1982 photo

1989 photo

Plates 23 and 24. The atoll reef rim between Betio islet (nearest the camera) and Bairiki, at the south western end of Tarawa Atoll, Kiribati. The Nippon Causeway over 3 kilometres in length, now joining the two islets was constructed in 1986-1987.

Plates 25 and 26. The present solid waste disposal site (rubbish dump) being retained by a wall constructed of gabion baskets on the ocean side reef flat of Majuro Atoll, Marshall Islands. Note the narrow reef flat and the position of the gabions virtually at the reef edge at the top right of Plate 25, above. The end result is useable reclaimed land (Plate 26).

It is also possible that causeway construction can cause water from waves breaking on the outer reef to build up the water level inside the reef by blocking the water draining past the causeway into the lagoon. This allows more wave energy to reach the shore of the islands which can cause erosion.

RECLAMATIONS

Often because of population and development pressures shortage of land area may exist and backshore and even beach areas have been reclaimed and developed in an uncontrolled manner. Coastal management guidelines or legislation at all community levels, national, provincial and village would ensure control is established and enforced (Plates 25 and 26).

This reclamation of shorefront land encroaches on the dynamic coastal zone width and fixes sand that was previously part of the active beach system and available to move with natural fluctuations of currents and waves. The reclamation may even be filled with material taken from the beach, removing even more material from the active beach system. Often, subsequent to reclamation activities, erosion is experienced on either side of the affected area. This is because removal of sand from the active beach system increases the likelihood of erosion on adjacent or downdrift beaches, or because of the end effects of the reclamation wall.

REMOVAL OF MANGROVES

Removal of mangroves should be discouraged. Shoreline, intertidal mangrove ecosystems are an effective buffer zone between land and sea. They act as traps for sediments, nutrients and other contaminants in order to maintain coastal water quality and promote sea grass and coral reef growth offshore.

They also offer protection from flooding and erosion during storms and cyclones.

Each Pacific Island Country is known to have its own unique mangrove community, with a total of twenty three intertidal species of mangrove recognised throughout the region; less than five species occur in Kiribati, Tuvalu, Western Samoa, Niue, French Polynesia, with none in the Cook Islands. Between five and ten species occur in the Marshall Islands, Fiji and Tonga. The most prolific mangrove areas with more than ten species recognised are Guam, Federated States of Micronesia, Papua New Guinea, Solomon Islands, New Caledonia and Vanuatu.

Site specific planting programs need to be promoted in order to assist with minimising coastal erosion.

Plate 27. A repaired gabion basket seawall protecting buildings on Lelu Island, Kosrae, Federated States of Micronesia.

SUMMARY OF CAUSES OF COASTAL EROSION

Natural causes:

- A naturally high mobility of the shoreline at some locations.
- Cyclones and storms.
- Variations in wind and wave conditions causing cycles of erosion and/or accretion.

Plate 28. Designed seawall protection completed in 1994 of large boulders of volcanic rock with concrete top and walkway area behind. This structure extends from the foreground, around the two high-rise buildings on reclaimed land to the port in the distance, Apia, Western Samoa.

monly planted with coconut trees to stabilise the sand. Reforestation of sheltered shoreline areas which are susceptible to erosion can be a low cost very effective coastal protection method which has minimal environmental impact. Some of these areas are likely to continue to build up, but others will erode again after a short time. In many cases, nothing can be done to prevent erosion. Attempts at development or stabilisation of a mobile section of coast will ultimately fail.

It must always be remembered that the coast is dynamic, and erosion is a natural part of this process. The more attempts that are made to fix the position of the coast, the more erosion problems there will be (Plate 27). Where it is practicable, consideration should be given to the cost-effectiveness and advantages of doing nothing, or of using building setback and/or relocation as a viable alternative to costly coastal protection structures. The implementation of building set-back distances significantly reduces the coastal erosion hazard.

Coastal protection structures should be regarded as a last resort, to be installed when the value of the assets being protected exceeds the cost of building and maintaining the structure, and the cost of remedial work on any side effects (Plates 28 and 29).

Plate 29. Touho runway, New Caledonia, reclaimed land on reef flat with mangroves along coast. Note position of old runway, also on reclaimed land.

CHAPTER 3:

Protection Strategies and Structures

INTRODUCTION

Mainly because of increasing development pressures, shoreline erosion and its impact on people's use of the coastal zone is presently a serious problem in many Pacific Island Countries. A common response to this problem is to build coastal protection structures, but many coastal protection projects in the Pacific have not only failed to resolve the erosion problem but have made it worse. Economic restraints have often meant construction of inadequate coastal protection works that have failed. Alternatively, expensive protection works have been constructed that are difficult to justify in economic terms (Plate 30).

A more comprehensive approach to coastal management is needed to provide a better understanding of natural processes and the effects of engineering works on the coastal zone.

Plate 30. Erosion of the narrow beach threatening the road and water front area of Gizo, New Georgia, Solomon Islands. Note the attempts at protection which include a rubble rock wall in front of the road and gabion baskets around the market stalls in the distance.

COASTAL PROTECTION STRATEGY

Within the broader framework of integrated coastal management, a multi-disciplinary approach is needed for coastal protection practices in the Pacific Island Countries. Strategies to overcome coastal erosion problems need to consider more than just coastal engineering solutions.

There are three major steps to an integrated strategy to coastal erosion problems.

- The physical nature of the problem must be understood. This initial first step is often taken for granted or ignored. The decision-making and design stages of many coastal erosion projects are done without enough investigation to establish the nature of the problem. Before a solution to a problem is applied, the problem must first be understood.
- The understanding of the problem must then be integrated into the existing economic, cultural and environmental situation in order to evaluate possible responses. This is often the most difficult step to address because of the varying coastal land ownership and traditional practices of many Pacific Island Countries.
- Based on this information, a strategy can then be developed to deal with the coastal erosion problem. These strategies can be divided into three categories and very briefly summarised as follows:

retreat	relocate existing buildings, allow erosion to continue, establish building setback codes.
accommodate	continue to occupy hazardous area and accept the risk, regulate future construction.
protect	build protection structure or enhance/conserve natural protection

Often the most economical and environmentally sound way to cope with an erosion problem is to retreat in order to avoid it. Coastal protection structures should only be considered after all other options have been considered and dismissed. Other options may be sufficient. They may also be less expensive and potentially less intrusive on the coastal environment in the long term. In many situations, it can be best to accept the mobility of the coast than to use precious resources to build ineffective protection structures.

Obviously, expensive infrastructure such as port facilities must be built within the active coastal zone and require adequate protection structures. Reclamations surrounded by seawalls may be the only realistic way to meet development needs. Increasingly in recent years, runways for large planes have been built on reclaimed land in the active coastal zone. An expanding village may not have enough space. But where there are alternatives to siting buildings and other facilities very close to the shore, there can be long term benefits through avoiding the construction and maintenance costs of protection structures. Some coastal erosion problems are just natural coastal changes; some are caused by other protection or development activities nearby.

Plate 31. Erosion threatening government buildings on the ocean side of London, on Kiritimati (Christmas Island), Kiribati. Attempts to protect the buildings include dumping of large concrete slabs, junk vehicle parts and reno mattresses (a flat version of gabion baskets).

ALTERNATIVES TO ENGINEERED STRUCTURES

PRESERVATION CORAL REEFS AND REEF ENVIRONMENTS

Coral reefs act as a first line of defence against ocean waves, absorbing most of the force changing wave conditions. For this reason alone, the preservation of coral reefs and coral reef environments is critical to maintaining a natural coastal protection system around Pacific Island Countries.

In this context it is important to note that at the 1995 South Pacific Forum, Heads of Governments endorsed the International Coral Reef Initiative (ICRI). In December of 1995 representatives of Pacific Island Countries drafted and agreed to a Pacific ICRI strategy.

DEVELOPMENT SETBACK STRATEGY

Setback is the distance a building is built back from the shoreline. By building permanent buildings at a safe setback distance, the beach and shoreline can be allowed to fluctuate and the buildings will not be lost or endangered (Plate 31). The advantage of using building setbacks is that the beach is left as a natural form of coastal protection with no expensive structures being necessary to protect either the beach or the land or property. The disadvantages are that setbacks require political and community agreement followed by government regulations and enforcement of these regulations.

The setback distance is usually chosen to save a building or other amenity from loss for a specific period of time. The setback should be appropriate to the cost and the intended life of the building, and the shoreline stability situation at the site. As a general guideline, a setback of about 10-15 metres from the natural boundary is appropriate for low cost and/or short-term buildings for most shorelines in Pacific Island Countries. Buildings intended for long

Plate 32. Small concrete cubes placed randomly to form an extensive length of coastal protection along the lagoon beach of Fongafale, Funafuti Atoll, Tuvalu.

term use, such as churches, stores, government offices, meeting houses, tourism and infrastructure facilities should be set back further (20-30 metres) from the shoreline, although this will be insufficient for some sites. Particularly active shorelines should not be built on at all unless a high level of risk is accepted.

The historical lack of land use planning and assessment of setback distances has led to many of the erosion problems confronting Pacific Island Countries. Many of the islands, particularly atoll islands, are narrow and low lying and a setback strategy is more difficult to apply as many of the major towns are already built up to the shoreline or even over original beaches (Plate 32). Even on larger islands, the amount of land available for the relocation of the population away from eroding shorelines is limited by population pressures and the local systems of land ownership. However, as the cost of failed coastal protection works is high, emphasis needs to be placed on developing coastal planning and management guidelines so that setback distances can be applied wherever practical. Solving these conflicts is part of the overall integrated coastal management process.

REVEGETATION

Mangroves act as a form of natural coastal protection, but only in sheltered locations (Plate 33). Although mangroves will grow in a variety of sediments, including coral sand, they attain full development on fine-grained, soft organic muds deposited in sheltered locations. Reforestation of sheltered shoreline areas which are susceptible to erosion can be a low cost very effective coastal protection method which has minimal environmental impact. Because they are vulnerable to wave action, they cannot be used to protect higher energy coasts.

In areas of exposed loose sandy soils or beaches, revegetation programs involving planting of shrubs, grasses and ground creeping vines may also be cost effective and environmentally acceptable.

Plate 33. Mangroves on the reef flat near the pre-historic site of Nan Madol, Pohnpei, Federated States of Micronesia.

BEACH REPLENISHMENT

Beach replenishment is the dumping of sand from another source onto an eroding beach. The main advantage of beach replenishment is that it does not create an obstruction, leaving the beach with a natural appearance. It requires a supply of sand for replenishment, heavy machinery to move large amounts of sand, and must be repeated from time to time if the material moves downdrift from the erosion area (Plate 34).

Beach replenishment has applications in the Pacific for restoration of beaches as natural coastal protection following damage after storms and for erosion protection of resort facilities, but is not applicable to many Pacific Island locations.

COASTAL PROTECTION STRUCTURES

SEAWALLS

A seawall is a structure built along the land-sea boundary which only protects against erosion of land and does not attempt to protect or save the beach. In general, seawalls are not recommended if a beach has to be maintained along the section of shoreline being protected.

Seawalls are usually constructed when valuable land or buildings have been built close to the shoreline, and are only advantageous when land or buildings are more valuable than the cost of the seawall. Major infrastructure developments such as a port facility obviously require protection of expensive assets, and many coastal towns and cities have extensive seawalls, usually to protect reclaimed land. In these cases, the coastline effectively becomes an artificial one at the expense of the natural shore. Such is the case around a large part of the DUD urban area of Majuro Atoll, Marshall Islands.

Many attempts at coastal protection by seawall construction have been unsuccessful throughout the South Pacific (Plate 35). Some coastal erosion sites have had one or two generations of seawalls which have failed. Precious resources have frequently been used on inneffective solutions.

Plate 34. Artificial replenishment of beach in front of the Regent of Fiji is being carried out by trucking sand to replace that lost by erosion. The erosion problem was caused by a groyne which blocked off the natural supply of sand to the beach.

Plate 35. A seawall built to protect this reclamation close to the Port of Suva, Fiji, has failed after a short time. The mangroves that were cleared from the site would have provided better protection.

It is commonly thought that if a seawall is constructed, it will produce all of its intended benefits without any detrimental interaction with normal coastal processes. In fact, seawalls seldom have a passive effect. When waves hit a seawall there is a great increase in water turbulence at the base of the seawall, which lifts sand into suspension. Erosion occurs when the sand is then removed from the beach by wave-induced currents. As well as removing beach sand, erosion at the base undermines the seawall foundation and is a common cause of collapse. The most durable seawalls, and the method of protection most commonly used on an open coast, are rubble mound structures with protecting rock sizes up to several hundred kilograms and a proper underlayer or filter. A well-constructed rubble mound seawall can absorb wave energy and minimise wave reflection (Plate 36). Heavy equipment is required to move and place the large quantities of rock needed for rubble mound seawalls. It is a very expensive structure for which neither the rock nor the equipment is available at many localities.

A vertical seawall, on the other hand, reflects wave energy which places large forces on the wall, erodes the beach, and increases wave height which in turn causes wave overtopping and scour behind the wall. There is a tendency to use vertical walls because of their neat appearance, but they are seldom effective except where they are expensive, properly-designed structures protecting facilities of high value.

Some possible alternatives to rubble mound or vertical seawalls are stepped seawalls or cemented sandbag seawalls, which may offer temporary protection against land erosion.

Plate 36. A near-vertical seawall of coral and beachrock slabs stacked over 2 metres high.

GABIONS

Gabions, rock-filled wire baskets, are another form of seawall which has been used extensively in the Pacific. They require tight packing of the rocks in the basket and will not withstand strong waves. They are best suited to lagoon shores, or buried at the back of a beach to serve as a last line of defence against storm waves. Gabions generally last only about 5 years, and should also be regarded only as temporary structures (Plate 37).

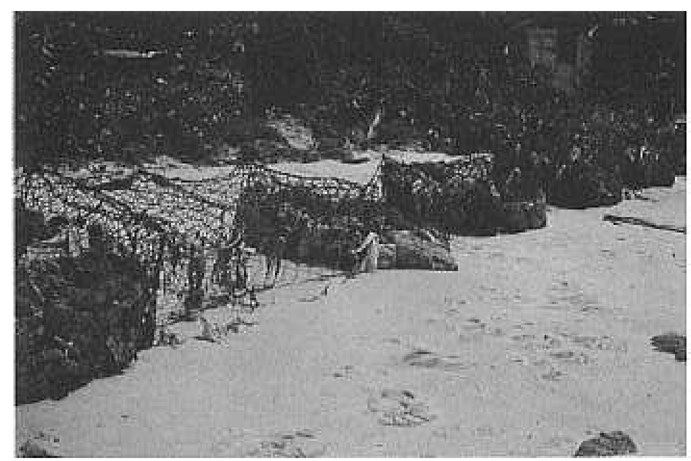


Plate 37. Total failure of a gabion basket seawall.

HAND-PLACED ROCK SEAWALLS

Hand-placed rock seawalls have been used historically throughout most Pacific Island Countries. Seawalls at least 1000 years old are known from Pohnpei in the Federated States of Micronesia. It is still the most common method of shoreline protection in the Pacific where there is no mechanical equipment or large rock available. Hand-placed rock has been used extensively in Kiribati where causeways between islands have been built.

These small-scale seawalls tend to be demolished by storm waves. The main causes of failure are damage by wave overtopping and the lack of sound foundations. Overtopping waves cause failure by scouring behind the wall, which then loses its support and collapses. Poor foundations allow scouring beneath the wall and eventual collapse.

Despite these limitations, hand-placed walls can still be successful provided that the interlocking hand-placed rock extends from the seaward face of the wall, over the top and to the back of the wall; that the founding base is deep and solid; that the wall does not extend into the active beach zone; and any damage is repaired quickly before progressive collapse occurs. Hand-placed walls that do not follow these guidelines can do more harm than good.

Plate 38. A line of CPUs in place on the reef flat in front of the beach at the Rarotongan Hotel, Cook Islands.

PROPRIETARY COASTAL PROTECTION DEVICES

Many types of proprietary coastal protection devices which act primarily as wave energy absorbers have been utilised in the Pacific, especially in attempts to protect expensive infrastructure such as port, and runway facilities. These have included placement of specially designed rock mounds and manufactured heavy concrete units of a large variety of shapes.

Proprietry coastal protection systems being developed in the Cook Islands in recent years include coastal protection units (CPUs) and coastal protection and energy dissipaters (COPEDs). The latter are at an early stage of development.

CPUs have been in place along part of the beach front at the Rarotongan Hotel since mid-1991 (Plate 38). Reports indicate that they have been successful in trapping sand and preserving the beach which in previous years had been severely eroded. Indicative costs are NZ$450 per metre. Each CPU is basically a pre-cast, high strength concrete structure with a series of apertures which channel water and suspended sediment through them. The units are 1.7 metres in length, 1.3 metres high, with a base of 2 metres tapering to 0.5 metres at the top. The total weight of each unit is 2.9 tonnes and uses 1.2 cubic metres of concrete.

Plates 39 and 40. Heavy concrete armouring units being constructed on site, and put in place as an artificial breakwater at the Naval Base in Nuku'alofa, Tonga.

BREAKWATERS

A breakwater is a double-sided protection structure where there is water on both sides of the structure. They are usually built to provide protected water for anchorages or navigation (Plates 39 and 40). Pacific Island Countries do not generally need substantial breakwaters because of the protection from nearby fringing reefs.

An offshore breakwater is a structure located parallel to the shoreline a short distance offshore, sheltering the shore from wave action and causing a build-up of beach material between the structure and the shore. They have been little used in the Pacific, and are expensive structures for which neither the rock nor the heavy equipment are available at many Pacific Island localities.

GROYNES

A groyne is a structure placed approximately at right angles to the shoreline on a beach (Plate 41). The groyne acts as a dam to the littoral drift process and accumulates material on the updrift side. The build up of the beach on the updrift side is an immediately apparent benefit, which makes the groyne initially look successful. The major disadvantage is what while accretion is occurring on one side of the groyne, erosion is occurring on the downdrift side. Groynes may also force littoral drift to move offshore around the groyne and thus beach material may be permanently lost from the beach. Groynes do not reduce the wave energy striking the shore.

Because of the downdrift erosion effects and the possibility that they will force material offshore, groynes are not generally recommended, although they can be successful where specifically designed for a site. Initial artificial nourishment may be required if an erosion problem is to be avoided. The effects on the downdrift shoreline must be taken into account or the erosion problem will be just transferred to another location. The orientation of the groyne has to be related to the wave climate of the site.

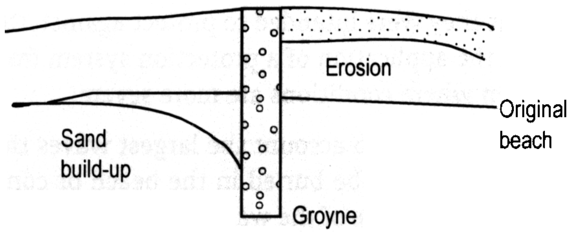
Small scale reclamations for houses and boat ramps can act effectively as groynes (Plate 43).

COASTAL PROTECTION DESIGN

DESIGN SELECTION

Protection systems used elsewhere are not necessarily directly applicable to Pacific Island shorelines, and there is no system that is suitable everywhere in the Pacific Islands. The causes of erosion at each site have to be understood and then a cost-effective protection system method selected that is suitable for that site. The exposure conditions, the availability of construction materials and the value of facilities to be protected will all influence the protection system selected.

There are many constraints on design of coastal protection in the Pacific Islands, including a lack of cheap construction materials and modern construction equipment, limited funds and remote locations. Many structures are built



Groynes trap sand that is moving along a beach, but usually cause erosion on the downdrift side.

Plate 41. The groyne has been built out across the beach to trap sand prior to making a reclamation. Sand will be lost to the beach on the other side of the groyne, and beach erosion will take place.

to cope with normal wave conditions and then fail when they are exposed to storms - the very conditions they were intended to protect against. Other failures result from extending the application of a protection system from a protected site to a new location where conditions are more severe.

Designs for seawalls must take into account the largest waves that could occur at the site. Foundations should be buried in the beach or constructed with additional rock to protect the base of the wall and prevent undermining. The ends must be rounded and the wall tied back into the land to avoid end scour. It is usually more economical to build a continuous structure than to protect short stretches of a shoreline with separate structures.

A seawall should be placed as far back from the beach as possible to increase its chances of survival. The further the seawall extends into the sea, the greater the wave force will be on the wall and the greater the beach erosion will be in front of the wall. Seawalls which extend onto the active beach area usually only worsen existing erosion problems.

CONSTRUCTION MATERIALS

Many Pacific Island Countries have no sources of the hard rock that is normally used for the construction of coastal protection. On many outer islands, the sources or sizes of hard rock are limited. This means that conventional

Plate 43. Traditional practices will increasingly need to be regulated if the coastal zone is to be protected, especially as it comes under increasing pressure from growing populations. This private reclamation, and the new development behind it, are within the active beach zone and are likely to cause coastal erosion problems.

Plate 42. Concrete-filled mattress protection for the Nippon causeway in Tarawa, Kiribati, is designed to flex so that it will not fail as settlement takes place, but it is not suitable for exposed conditions.

rubble mound seawalls and breakwater designs are not directly applicable and that permanent coastal defence requires individual design, often using coral boulders or concrete protection units (Plate 42).

COST OF COASTAL PROTECTION

The construction of conventional effective coastal protection works is expensive, in the order of A$500 to $5000 per metre length. Reinforced concrete is very much more expensive and is normally restricted to special circumstances or to very exposed locations. Hand placed walls are cheaper, but are commonly ineffective. Regardless of the system used, protection costs can be a significant component of development budgets at the local or national level. The costs, effectiveness and alternatives should be carefully considered before a decision is made to build protection works.

MAINTENANCE

Regardless of the type of protection system used, repairs and maintenance should be carried out as soon as the structure is damaged. Progressive failure resulting in complete collapse can take place very rapidly once initial failure has occurred, and the investment in the structure becomes wasted.

MONITORING

Although large sums of money are routinely expended on coastal protection projects, there is very seldom any follow up monitoring or evaluation of the engineering, of the economic success of the project or of its environmental effects. Coastal protection, harbour development and causeway construction projects have caused unintended coastal erosion problems which have not been properly documented. If follow-up monitoring of coastal construction projects was implemented, the experience gained could then be applied for the benefit of future projects.

POLICY AND REGULATION

Historically, much coastal erosion has occurred at development sites within the coastal zone. This has often resulted in either the construction of poorly designed and inadequate protection works that have failed, or expensive protection works that are difficult to justify in economic terms. It is important to develop coastal planning regulations for the coastal zone that are sensitive to the varying traditional practices and coastal land ownership systems currently in place in each Pacific Island Country.

An important component of the planning process which can be implemented without developing legislation is to produce an Environmental Impact Assessment (EIA) for major projects. EIA is a process to determine the effects of a development project on the natural and human environment. It is a part of project management and should take into account many of the engineering, geological, ecological and sociological aspects of coastal management.

The application of planning and regulatory procedures, no matter how well they are developed, requires coordination between the government agencies concerned and the means and the will to enforce regulations (Plate 44). Without coordination and enforcement, regulations will not be effective.

Plate 44. A recreational beach on the sheltered lagoon side of Cocos Island, Guam.

SUMMARY OF COASTAL PROTECTION ALTERNATIVES

TYPE OF PROTECTION	ADVANTAGES	DISADVANTAGES	SUITABILITY FOR PACIFIC ISLANDS
Preservation of Reef Environment	• Minimum disruption to the environment • Low cost	• Not appropriate where much development has occurred • Requires a "will" to implement at all levels of the community • Requires regulations and enforcement • A long term strategy	• Highly desirable since many coasts are still little developed
Setback/Relocation	• Preserves the natural beach. • Avoids many future coastal erosion problems. • Usually less expensive than engineering structures.	• Requires government regulation and enforcement. • Requires compensation for land and trees. • Offers no protection for existing shoreline.	• Can be implemented by enforcement of regulations. • Recommended where possible, especially new development sites.
Revegetation	• Low cost • Re-establishes natural coastline • Does not disrupt coastal processes	• May hinder access by people to the coast • Only effective in sheltered areas	• Recommended where possible
Beach Replenishment	• Preserves the natural beach. • Does not disrupt natural processes.	• Requires periodic replenishment. • Requires heavy equipment and a supply of sand.	• Not feasible for small projects.
Seawalls (Many options refer to text)	• Protects land area only. • Some designs can be built by manual labour and from local materials.	• Can cause beach erosion. Seawalls which extend onto the active beach area usually make existing erosion problems worse. • Require proper design and construction supervision. • Designs for exposed situations require large boulders. • Inexpensive designs are often ineffective.	• Should be used only where threatened property and buildings are valuable and cannot be relocated.

TYPE OF PROTECTION	ADVANTAGES	DISADVANTAGES	SUITABILITY FOR PACIFIC ISLANDS
Gabions	• Portable, can be imported and taken to outer islands • Can be removed if not effective	• Deteriorate rapidly • Expensive • Require supervision to place fill with rocks properly • Require suitable size and shape of rocks	• Not suitable since they are generally expensive and do not last
Proprietory Protection Devices	• Can be designed to particular wave conditions	• Expensive • Require heavy equipment	• Are often necessary to protect expensive infrastructure built on exposed coasts
Breakwaters	• Shore-parallel breakwaters can be effective for erosion control.	• Requires heavy equipment and construction supervision. • Expensive	• Not generally required because of protecting reefs. • Large boulders and heavy equipment not available every-where. • Concrete units can be used.
Groynes	• Immediate sand build-up on updrift side. • Some designs can be con-structed from local materials	• Immediate erosion on downdrift side. • Unnatural beach obstruction. • Can force sand off beach into deep water.	• Generally not recommended because of detrimental effects on coastline.

FURTHER READING

Workshop on Costal Processes in South Pacific Island Nations. SOPAC Technical Bulletin 7. (1991).

Coastal and Environmental Geoscience Studies of Southwest Pacific Islands. SOPAC Technical Bulletin 9. [In Press].

Summary Report of the First Coastal Protection Meeting. SPREP and SOPAC (1994).

Summary Report of the Second Coastal Protection Meeting. SPREP and SOPAC (1994).

Coastal Protection in the South Pacific. SOPAC Technical Report 190. SOPAC and SPREP (1994).

Keimami sa vakila na liga ni Kalou (Feeling the Hand of God): Human and Nonhuman Impacts on Pacific Islands Environments by Patrick D. Nunn 1991. Occasional Paper 13, Environment and Policy Institute, East-West Center, Honolulu, Hawaii. [68 pages; available from the University of the South Pacific bookshop in Suva.]

Oceanic Islands by Patrick D. Nunn 1994. (Blackwell. Oxford, UK and Cambridge, USA). [This 143 page book is a fairly advanced account of the geology and geomorphology of oceanic islands, presenting an enormous amount of information that is otherwise inaccessible in such an integrated way. It is available from the University of the South Pacific bookshop in Suva.]

Summary Report of the Third Coastal Protection Meeting. SPREP and SOPAC (1995).

Coastal Protection in the Pacific Islands: Current Trends and Future Prospects. SPREP and SOPAC (1994). SOPAC Miscellaneous Report 177.

How to Assess Environmental Impacts on Tropical Islands and Coastal Areas. Richard A. Carpenter and James E. Maragos. SPREP Training Manual. (1989).

In addition, SOPAC has produced numerous Technical Reports on site-specific coastal erosion and protection problems in the Pacific.

For further information contact The Director, SOPAC Secretariat, Private Mail Bag, GPO, Suva, Fiji.

GLOSSARY OF TERMS

BEACH – The zone of unconsolidated loose material that extends from the low water mark to the limit of storm waves. The beach is an important natural form of protection of the land from waves. A beach includes FORESHORE and BACKSHORE areas.

• *BACKSHORE* – The upper zone of the shore or beach lying between the beach and the land, and acted upon by waves only during storms, especially when combined with exceptionally high water.

• *BERM* – A nearly flat part of the backshore formed by the deposit of material by waves. Some beaches have no berms, others have one or several. Storm waves tend to erode the berm, so it is an important form of natural coastal protection.

• *FORESHORE* – The active beach that is the part of the shore lying between the crest of the seaward berm (or upper limit of wave wash) and the water's edge, that is ordinarily traversed by the RUN-UP and BACK-WASH of waves.

• *DUNES* – Ridges or mounds of loose, wind-blown sand that may form part of the backshore.

BEACHROCK – A rock formed by cementing of calcareous sands an shell fragments which acts as a protective cover around a low reef island. The formation of beachrock is an important part of the formation of permanent reef islands. Beachrock is one of the few building material resources available on atolls, but its removal can cause shoreline erosion.

COASTAL PROCESSES – The action of mainly weather-generated natural phenomena such as wind, waves, tides, changes in sea level, and storms on the coast that result in the physical phenomena of SEDIMENTATION and EROSION.

COASTAL PROTECTION – Preservation of the coast by natural features or engineered structures. Note that many engineered structures only protect the land and not the foreshore.

COASTAL ZONE – The zone where the sea and land are in contact. There can be many more precise definitions which usually include the concept that the coastal zone is of indefinite width and has components of both land and sea.

COASTAL ZONE MANAGEMENT – The planning, decision-making and management of development and conservation of the coastal zone.

COASTLINE – see SHORELINE

CORAL REEFS – • *ATOLL* – A coral reef on which various types of low REEF ISLANDS may occur.

• *BARRIER REEF* – A coral reef separated from the shore of a high island by a broad, deep lagoon.

• *FRINGING REEF* – A coral reef that grows outwards from the shores of a high island.

DOWNDRIFT – The direction of predominant movement of beach materials by longshore drift.

ENSO – The El Nino - Southern Oscillation (ENSO) phenomenon is a periodic fluctuation of weather conditions in the tropical Pacific that affects the weather in other parts of the globe. In the South Pacific there are changes of cyclone frequency and pattern, rainfall distribution, wind strength and direction, and sea level. The changes caused by El Nino, especially the westerly winds, have a major influence on physical coastal processes in the Pacific Islands, including beach erosion.

EROSION – The wearing away of land by the action of natural forces. On a beach, the carrying away of beach material by wave action, currents or wind.

EQUILIBRIUM – A state of balance or equality of opposing forces. Dynamic equilibrium describes the state of constant fluctuation of a beach about an average position and shape with no net erosion or accretion.

FETCH – The distance over which seas are generated by wind of constant direction.

GABION – a plastic coated wire-mesh basket commonly 1 metre by 1 metre by 2 metres in size filled with rocks and held together with internal tie wires.

GROYNE – A shore protection structure built (usually perpendicular to the shoreline) to trap sand moving by LONGSHORE DRIFT.

LONGSHORE CURRENT – The current in the breaker zone moving essentially parallel to the shore, usually generated by waves breaking at an angle to the shoreline.

LONGSHORE DRIFT – The movement of beach material along the beach under the influence of LONGSHORE CURRENTS and wave RUN-UP and BACKWASH. The predominate direction of longshore drift can vary with seasonal or other changes to wind and wave directions.

POCKET BEACH – A small beach between two headlands.

REEF ISLANDS – Islands usually only a few metres above sea level which are of recent origin and always associated with coral reefs.

- *CAY* – An island formed from sand and gravel accumulated on broad reef flats, usually devoid of vegetation and often overtopped by waves. These islands are generally of a temporary nature unless they become established motu.
- *MOTU* – An island which has become more established than a cay by development of formations that are resistant to erosion, including beachrock.
- *EMERGED REEF ISLAND* – A reef island that shows evidence of emergence resulting from falling sea level over the last few thousand years.

RIP CURRENT – A strong surface current flowing seaward from the shore, usually appearing as a visible band of agitated water. It is the return movement of water piled up on the shore by incoming waves and wind.

RUN-UP – The wash of water up a structure or beach associated with the breaking of a wave. Back-wash is the water returning to the sea.

SEDIMENTATION – The process of accumulating sediment (gravel, sand, and mud).

SEAWALL – A structure separating land and water areas, primarily designed to prevent erosion and other damage due to wave action. Some seawalls are called revetments.

SHORELINE – The boundary between the sea and the land at the limit of the combined effect of normal high tide plus wave run-up. Along an undeveloped coastline, it is usually marked by a line of vegetation. (Other definitions are possible).

STORM SURGE – The rise of sea level during a storm from a combination of reduced barometric pressure, WAVE SET-UP and WIND SET-UP. The effects can be particularly devastating if the storm surge coincides with a high tide. Storm surges are commonly miscalled "tidal waves".

TSUNAMI – A long period wave caused by an underwater disturbance such as a volcanic eruption or an earthquake. Commonly miscalled "tidal wave".

UPDRIFT – The direction opposite that of the predominant LONGSHORE DRIFT of beach material.

WAVE REFRACTION – The process by which the direction of a wave moving in shallow water at an angle to the depth contours is changed. The part of the wave advancing in shallower water moves more slowly than that part still advancing in deeper water, causing the wave crest to bend towards alignment with the underwater contours.

WAVE SET-UP – The rise of the sea level caused by onshore transport of water by wave action.

WIND SET-UP – The rise of sea level on the leeward side of a body of water caused by wind blowing on the surface of the water.

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