NRCA GUIDELINES FOR THE PLANNING, CONSTRUCTION, AND MAINTENANCE OF FACILITIES FOR ENHANCEMENT AND PROTECTION OF SHORELINES

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NRCA GUIDELINES

for the

PLANNING, CONSTRUCTION and MAINTENANCE

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ENHANCEMENT

and PROTECTION

of SHORELINES

prepared for NATURAL RESOURCES
CONSERVATION AUTHORITY

by Cowell L. Lyn

NRCA Guidelines for the Planning, Construction and Maintenance of Facilities for Enhancement and Protection of Shorelines

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*Note: The photos in Figs. 7 to 13 were taken by J.S. Tyndale-Biscoe.

NRCA Guidelines for the Planning, Construction and Maintenance of Facilities for the Protection and Enhancement of Shorelines.

1. INTRODUCTION

1.1 NRCA's Mandate.

By legislation passed in Parliament in April 1991, government of Jamaica has endowed the NRCA with wide-ranging general powers to manage and protect the country's natural resources, and particularly to institute approriate Permitting and Licencing procedures designed to ensure that due conideration is given to conservation and environmental protection throughout the planning and implementation stages of development projects.

1.2 The Purpose of This Document.

In order to be able to more efficiently and effectively fulfill its mandate, the Authority has decided to publish a series of Guidelines and Standards which will be made available to other Government of Jamaica agencies, and to private interests, including potential investors in the various industrial sectors, to inform them of the relevant obligations that will have to be satisfied in order for them to obtain the construction permits and operating licences from NRCA that are required by law.

1.3 The Specific Subject of These Guidelines.

This document offers guidance on the NRCA permitting process, the environmental aspects, and the coastal engineering planning and design of projects conceived for the protection and enhancement of shorelines -guidance that is intended to eliminate or mitigate the undesirable environmental impacts that these types of projects can cause.

1.4 Acknowledgement of Special Reference Source.

Special acknowledgement is hereby extended by the author, to the U.S. Department of the Army, Waterways Experiment Station, Corps of Engineers, Coastal Engineering Research Center, from whose publication *SHORE PROTECTION MANUAL*, most of the text for chapters 5, 6, 7 & 8 have been extracted.

2. PERMITTING PROCEDURES

2.1 Project Sponsors Should Make Early Contact With NRCA

2.1.1 Certain types of activities in the coastal zone give rise to particular effects, and therefore it is important for all concerned to be aware of the particular types of negative effects that are likely to arise from a given type of project. Project Sponsors are therefore encouraged to make contact with NRCA from the very earliest stages of project planning and to seek advice from the Authority in regard to the nature of the particular environmental issues that will have to be satisfactorily addressed in order for them to obtain the necessary permits.

2.1.2 Project Sponsors are advised that as a prerequisite for granting permits for shore protection works, NRCA will have to be satisfied that the least damaging methods of construction and operation will be adopted by the Developer, that appropriate monitoring and mitigation measures will be carried out during execution of the project, and that in the overall, the anticipated economic and social benefits of the proposed project will outweigh whatever disbenefits may be incurred due to either temporary or permanent damage to existing environmental resources.

2.2 Project Sponsors May Be Required To Hold Public Meetings To Inform Local Communities Concerning Their Proposals

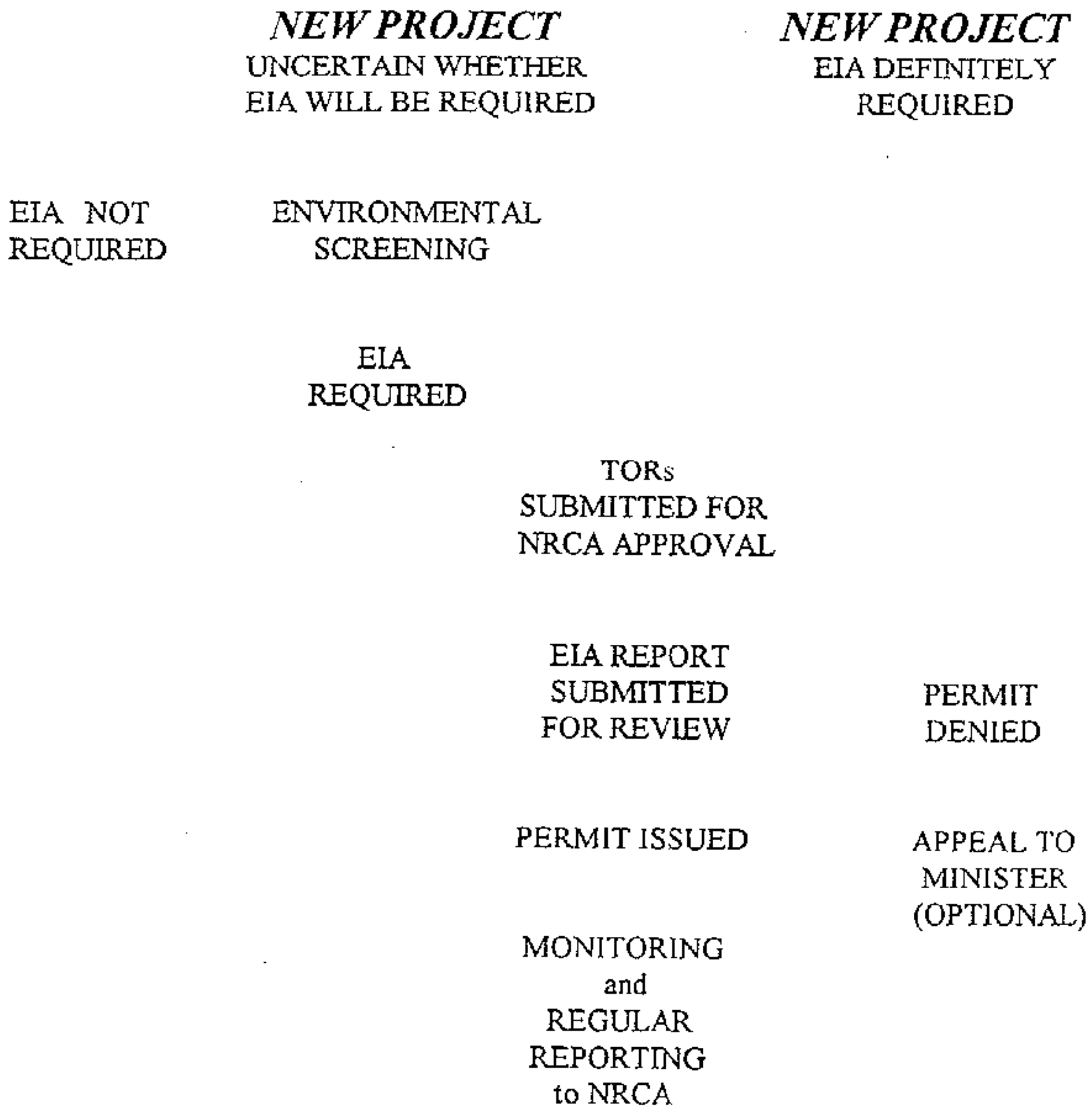
2.2.1 The NRCA may require applicants for permits to consult with other government agencies, and with local interest groups that may be adversely affected. Project sponsors must be prepared to fulfill, as part of the permitting process, NRCA requirements to hold "town meetings" to give opportunities to local populations to voice their opinions concerning proposed projects.

2.2.2 To foster genuine people participation, the site selection process itself must be comprehensive, clearly laid out, and presented in understandable language. Project sponsors should regard town meetings as very valuable opportunities for open consultations with local communities. The adoption of logical, comprehensive and open procedures in site selection may well produce the most satisfactory results for project sponsors as well as the public.

2.3 NRCA's Environmental Review and Permitting Process

Any project which has the potential for affecting the environment must be referred to NRCA for consideration. Documentary information concerning NRCA's Environmental Review and Permitting process can be obtained from NRCA upon request. NRCA's Review Process, leading up to either the granting of a Permit, or disapproval of the project, is illustrated in the flow chart below.

Flow Chart
NRCA's PERMITTING PROCESS



2.3.1 *Screening*

Every Developer whose project does not automatically require an EIA must submit a completed Project Information Form to NRCA. The form is then reviewed, and a determination made by NRCA as to whether there is need for an EIA. If the environmental impact of the project is expected to be minimal, no EIA will be required.

2.3.2 *EIA Notice.*

Based on the assessment of the environmental impact indicated by the Project Information Form, within 10 days of receipt of the Form, NRCA might issue a notice requesting the Developer to do an EIA. Every Developer so notified will have to submit draft Terms of Reference to NRCA for approval. At this stage the Developer will be given general guidelines for conducting the EIA as well as sample Terms of Reference for similar projects if any are available.

2.3.3 *EIA Review*

A draft EIA report (at least six copies) must be submitted to NRCA for review and comments. A preliminary review of the draft is done within ten working days after receival to see if any additional information is required. If additional information is needed this is requested immediately. Upon receipt of the information the NRCA EIA Review Committee will decide which external agency, if any, e.g. Port Authority, Environmental Control Division, Office of Disaster Preparedness, etc., must be asked to review and comment on the document as well. The Developer may also be granted an audience to fully explain any areas of the draft report that may not be clear enough to the Review Committee. The review process can take up to ninety days. At the end of the NRCA internal review the Developer may be granted provisional approval to proceed with the project, with specific conditions stipulated.

2.3.4 *Public Notification.*

Draft EIA reports are made available to the public at the NRCA library, at local libraries, and at Parish Councils; and the public is notified that an EIA report has been submitted, and that thirty days are allowed for comment. Any comments received from the public are brought to the attention of the Developer by NRCA.

2.3.5 *Public Presentation*

Depending upon such factors as the scale and magnitude of anticipated impacts, the ecological sensitivity of the project area, and the level of public interest, the Developer might be asked to consult with the NRCA to set a date, time and venue for a public presentation. The hearing will allow the Developer an opportunity to answer questions from the public and to make changes in his proposals wherever necessary. A period of thirty days after the hearing is allowed for acceptance of written comments from the public.

2.3.6 *NRCA Assessment.*

The NRCA will take into account any and all comments received from the public and the concerned external government agencies and give a final response to the Developer as to whether or not his project is environmen-tally acceptable. The response will summarise the findings of the review of the EIA report, and indicate areas which need further attention, or impose conditions for approval.

2.3.7 *Appeals*

In cases where a project is found to be environmentally unacceptable and is not approved, the Developer may appeal to the Minister with responsibility for the environment against the decision of the Authority, within ten days after the date of the decision.

2.4 **Schedule of Fees.**

The fees payable to NRCA by Developers for being allowed to carry out shore protection and enhancement works within the coastal zone are gazetted under The Beach Control Authority (Licensing) (Amendment) Regulations, 1996.

2.5 **Project Sponsors' *Environmental Compliance Officer***

NRCA recommends that at the time of submission of application for a Permit for carrying out shore protection and enhancement works, project sponsors should name an individual who will be responsible on their behalf for ensuring that the Developers' responsibilities to NRCA and the public, for protecting the environment, will be adequately fulfilled. The individual who is designated to be the Developers' ***Environmental Compliance Officer***, shall be suitably qualified for the post, and his/her specific functions in relation to NRCA shall be as follows:

- to oversee on a continuing day-to-day basis, the collection of data and documentation covering all site activities relating to environmental matters;
- to prepare the environmental monitoring reports called for in the approved Monitoring Plan, and submit them to the NRCA at the prescribed times;
- to be available to the NRCA at all times for consultations regarding any environmental issues that might arise during execution of the project.

3. EIAs FOR PROJECTS FOR ENHANCEMENT and PROTECTION OF SHORELINES

Typically, EIA reports for projects intended for the enhancement and protection of shorelines should include at least the following information:

3.1 General Description of the Project and its Objectives

- background information identifying the need and justification for the project.
- description of the main features and activities of the project, and identification of the construction and operation processes that could either damage the environment, or generate positive impacts.
- indications of the anticipated timing of the project and schedule of the performance of the main construction activities.

3.2 The Physical and Biological Environment.

The EIA report must include adequate descriptions of the physical and biological environment of the project area. To facilitate NRCA's review process, as well as for sound planning and detailed design of a proposed dredging project, it is essential that the following range of site-specific data be provided:

3.2.1 *Water Quality*

Water quality should be tested separately at both high and low tides.
Water samples should be tested for suspended solids, coliforms, nitrates and phosphates, and any other constituents as may be deemed necessary in relation to the particular project.

3.2.2 *Ecology* - Flora and Fauna

For projects of any appreciable size or scope NRCA will require that appropriate site surveys be carried out to properly identify existing critical habitats, any rare or endangered species or other valuable natural resources such as seagrass beds, mangroves, coral reefs -and fully document the baseline conditions. In regard to coral reefs, particular notice should be taken of any sedimentation, algal growth, patterns of live and dead coral, and the structure of fore and back reefs.

3.2.3 *The Nature of the In-place Existing Material.*

It will be essential to have good qualitative information regarding the natural in-place shoreline sediments, as well as the source and type of any borrow material that might be necessary for the project.
(Note: Guidelines on these matters are given in a subsequent chapter.)

3.2.4 *Sea-Currents and Bathymetry*

Normally, the information available on published navigation charts concerning sea-currents and water depths will not be adequate for detailed planning of shore protection works. Project sponsors will have to be prepared to carry out appropriate current studies and hydrographic surveys in order to be able to prepare site-specific charts showing local current patterns and existing seabed contours at suitable intervals.

3.2.5 *Meteorology*

Site-specific data on rainfall, wind, waves and tides will be required.
Usually, some useful data on these matters can be obtained from the Government Meteorological Office.

3.2.6 *Geomorphology*

Project sponsors should take all necessary steps to ensure that appropriate investigations are carried out to clearly identify the existing pattern of coastline dynamics -i.e. the prevailing pattern of littoral transport; whether the shoreline is stable or prograding or accreting or eroding -so as to be able to take such factors into account in the engineering of the project.

3.3 The Socio-Cultural and Economic Environment

Sometimes, the feasibility and acceptability of a development project will depend not only on its effects upon the physical and ecological environment of the project area, but also more critically upon the socio-cultural and economic impacts that are generated. Therefore it is important that EIA studies should investigate the socio-cultural and economic conditions prevailing in the project area, and assess the effects that the project would be likely to have in regard to local ethnic, cultural, historical and religious sensibilities; and upon the levels of job-creation and commercial activities that the project would bring to the local scene.

3.4 The Relevant Legislative and Regulatory Framework.

Project Sponsors will be required to include in their EIA report, a section describing all the Jamaican legislative enactments, environmental policies, Standards and Regulations that are relevant and applicable to the proposed project; and should identify the appropriate authority jurisdictions that will specifically apply to the project.

3.5 Potential Environmental Impacts

The EIA report should contain descriptions of the anticipated direct and indirect effects of the project. In identifying the potential environmental *effects* of the construction and operation phases of a project, it would be helpful for project sponsors to analyze them in terms of the following terminology:

- *adverse effect:*
  an effect that is large in magnitude and has important con- sequences. Both of these characteristics (i.e. <u>large magnitude</u> and <u>importance</u>) must be present, in order for the effect to deserve to be termed *adverse*.

- *cumulative effect:*
  an effect that gives an incremental rise in the level of an impact, when added to other past, present and reasonably forseeable activities. Cumulative effects can result from individually minor but collectively significant activities taking place over a period of time.

- *triggering effect:*
  an effect that induces other indirect effects. These effects are not directly generated by (the instant) project activities, but they develop because the project came into being.

(Note: Further guidelines concerning potential impacts from shore protection works are given in a subsequent chapter).

3.6 Monitoring, Mitigation and Contingency Plans

The EIA report should contain detailed plans for monitoring and mitigating any adverse effects, and should include contingency plans for dealing with any hazardous situations that might arise during execution of the works. The mitigatory measures and contingency plans proposed should be technically feasible and cost-effective, and should show convincingly that the proposals will result in reduction of negative effects to tolerable levels.

3.6.1 Developers will be required to maintain continuing effective liason with the concerned government regulatory Agencies and local communities throughout the construction phase of their projects, and to ensure that any issues or concerns that might arise during this phase, are clearly understood and appropriately dealt with.

3.6.2 The particular construction activities which will require monitoring as the work progresses will have to be identified in the EIA report. Each Construction Permit issued by NRCA will indicate the required frequency for submission of written reports from the Developers to NRCA.

3.6.3 Wherever possible, estimates of the financial and economic costs of the potentially degrading effects that the project might have upon the environment, and the costs of the mitigatory measures proposed, should be included in the EIA report.

3.6.4 Contingency plans should be presented in the EIA report for dealing with any emergencies that could arise during progress of the works such as fire, explosion, or accidental spillage of petroleum products or other hazardous/toxic materials. The appropriate response to leaks, breaks, explosions or fire, and any resulting spillage of fluid, will vary according to the toxicological and physical properties of the spilled material, and the potential impact it may have upon public safety and the environment.

3.6.5 To ensure the effectiveness of contingency planning, properly trained personnel and suitable equipment must be available on site. Project sponsors should therefore include in their EIA report, information concerning their plans for providing approriate personnel and equipment to deal with the types of emergency situations that could arise.

3.6.6 In developing contingency plans for dealing with emergencies, it will be useful for Developers to seek consultations with the Coast Guard of the Jamaica Defence Force, and also with the Office of Disaster Preparedness and Emergency Management, since in anycase, NRCA will refer any contingency plans to those Agencies for comments, and any comments received from those Agencies will be given due consideration by NRCA in making decisions as to the suitability of any contingency plans submitted.

4. THE COASTLINE OF JAMAICA

Jamaica's coastline is approximately 550 miles in length, punctuated by numerous inlets and bays. This varied and irregular shoreline gives rise to an ecosystem formed by the integration of coastal features that include harbours, bays, beaches, rocky shores, estuaries, mangrove swamps, cays and coral reefs. These natural features provide a coastal resource base that contributes significantly to the economic well-being of the country. For example, the worldwide promotion of Jamaica's tourism product, is based largely upon the beauty of the island's beaches, coastal waters, and coastal environment. These coastal resources, however, are especially sensitive to the effects of over-use and mismanagement, and many areas exhibit some degree of deg-radation. The island's principal commercial and population centres are also located on the coast, and urban development pressures on coastal resources are intense.

4.1 **Coastal Zone Resources.**

The coastline of Jamaica has been classified according to four shoreline types: sandy or gravelly beach; rocky shore, cliff or elevated reef; mangrove forest or swamp; and coral reef. (See Fig.1). In general, the south shoreline is edged by long, straight cliffs, mangrove swamps, herbaceous wetlands and black sand beaches. The beaches of the north coast all have white sand, and the coastline is generally very rugged.

4.1.1 Offshore Islands, Cays and Reefs.

The Morant Cays, four small limestone islands, are located off the south coast approximately 40 miles to the southeast of Morant Point. These cays are separated from the the mainland by deep water and are not continuous with the rest of the island shelf surrounding Jamaica. The cays are surrounded by the shallow water of the Morant Bank, which is a productive fishing area.

The Pedro Cays are a group of four coralline islands situated on the southeastern edge of the Pedro Bank, about 58 miles south of Great Pedro Bluff and about 100 miles from Kingston. Like the Morant Cays, they are the base for fishing on the surrounding bank.

Jamaica's nearshore cays are found mainly off the south coast with the exception of Booby Cay, which is off the west coast near Negril. The majority of these cays are small (less than 2 acres), accessible only by private boat and lack suitable infrastructure for their development as recreational amenities. Two of the larger cays however, Lime Cay, south of Kingston, and booby Cay, west of Negril, have been developed into significant recreational sites.

On the north coast, fringing coral reefs extend almost continuously along the edge of the shelf from Negril to Morant Point. On the south coast, the greater part of the shelf is devoid of coral reefs, except on the eastern portion between Kingston and Portland Bight, where larger reefs and numerous coral cays exist. On the western section of this coast, the reefs tend to be small, patchy and not as well developed. These reefs provide habitat for numerous species of flora and fauna and are important for both fishing and recreational use.

4.1.2 Beaches.

The beaches of Jamaica are of international renown, and are perhaps the greatest factor contributing to the growth and success of the island's tourist industry. Vast stretches of white sand beaches are found along the north coast and provide the location for the principal resort areas, including Negril, Montego Bay, and Ocho Rios. These white sand beaches are comprised of sediments eroded from the offshore coral reefs and deposited in the lagoon area behind the reefs.

Many of the south coast beaches are nourished by river sediments (as the offshore coral reefs are not as extensive), and typically are of black sand.

4.1.3 Vegetation.

The substrate of the south coast swamps generally consists of peat or alluvial deposits. In these swamps, the vegetation consists largely of the salt-tolerant species of mangroves, Rhizophora mangle (red mangrove), Laguncularia racemosa (white mangrove), Avicennia germinans (black mangrove) and Conocarpus erectus, and the swamp fern (Acrostichum aureum). At the upper reaches of some of these wetlands, where there is a greater influx of freshwater, the vegetation is dominated by freshwater macrophytes such as Cladium sp., Typha domingensis (Bullrush).

Three species of seagrasses occur in the shallow and sheltered bays of the nearshore marine habitat: turtle grass (Thalassia testudinum); manatee grass (Syringodium filiforme); and shoal grass (Halodulk Wrightii). A rare species is Halophilia decipens.

4.1.4 Fish and Wildlife.

Marine wildlife consists of marine mammals, including manatees (Trichechus manatus) and bottlenose porpoises (Tusiops trunestus), and several transient species of whales. There is also a great variety of corals and reefs associated with fish and invertebrates. These have been adversely affected by overfishing and marine pollution. Turtle populations have significantly declined in recent years, but since 1982 have been protected under the Wildlife Protection Act. Marine birds breed mainly on the cays. The species which are exploited include Sterna fuscata and Anous stolidus, whose eggs are collected commercially. Coastal marine areas also support numerous species of fish, which are categorized either as *demersal* (bottom-dwelling), or *pelagic* (swimming).

Generally, the shallow coastal areas on the south coast are the most productive areas, and aquatic wildlife (except for coral reefs) tends to be concentrated on the south coast. Mangroves and coastal lagoons are of particular importance as breeding and feeding areas for many species of wildlife including crocodiles and birds.

4.1.5 Water Quality.

Most rivers are pollution-free at their sources, but some of the larger ones receive polluting discharges such as industrial waste, garbage and agricultural chemicals. These pollutants reduce oxygen levels in the river waters and increase nutrients, thereby giving rise to conditions which have led to a reduction in fish and shrimp life and proliferation of aquatic vegetation. Some water-quality monitoring has been on-going in recent years, and NRCA currently has available data on flows in some of the more seriously affected water ways, viz: Alligator Pond/Port Kaiser; Black River Lower Morass; Bull Bay; Swamp Safari in Trelawny; Gunboat and Bucaneer Beaches; Ocho Rios Bay, Kingston harbour.

Also, there has been some limited mapping and analysis of water circulation patterns at a few selected coastal sites: Ocho Rios Bay, Johnson Town, Negril, Black River, Alligator Pond.

4.2 A Geomorphological Overview of Jamaica's Beaches.

4.2.1 P.A.Wood, in a 1976 publication (See List of References) titled *Beaches of Accretion and Progradation in Jamaica*, produced a map showing areas of the coastline where his studies indicated that such processes had been taking place over the past century or so.

Progradation refers to the advance of the shoreline resulting from the nearshore deposition of sediments brought to the sea by rivers.

Accretion refers to beaches that are accumulating due to sediment additions from external sources.

Wood's map is reproduced below as Fig. 2 . It shows all the progradation and accretion taking place on the south coast, from Cow Bay in the East to Savanna-la-Mar in the west -none on the north coast. Longshore drift directions responsible for sediment transport are in general from east to west on both the north and south coasts.

4.2.2 Wood took samples of beach sediment from each of the locations identified as prograding/accreting, and tested the samples for carbonate and non-carbonate content. His results are shown in Table below:

Table . Percentage of Carbonate and Non-Carbonate Material in Samples Collected from Prograding and Accretionary Beaches.

Sample	Location	% Carbonate	% Non-Carbonate
#1	Cow Bay Point	10	90
#2	Cow Bay	9	91
#3	Palisadoes	9	91
#4	Hunts Bay	4	96
#5	Portland Bight	16	84
#6	Jackson Bay	> 99	< 1
#7	Carlisle Bay	> 99	< 1
#8	East of Rio Minho	6	94
#9	West of Rio Minho	< 1	> 99
#10	East of Milk River	3	97
#11	West of Milk River	< 1	> 99
#12	Drodse Point	25	75
#13	East of Bluff Point	98	2
#14	West of Savanna-la-Mar	99	1

4.2.3 Wood's explanation of the predominance of prograding and accretionary beaches on the south coast, and their absence on the north is as follows:
"This can readily be explained by the occurrence of Late Tertiary and Quatenary crustal movements. It appears that an overall tilting of the Jamaican block has occurred, resulting in uplift to the north, and subsidence (relative to sea level) in the south. This tilting would have several effects:

1. There would be a tendency for most rivers to drain south, and for those that drain south to have larger catchments than those draining north. Thus, the potential supply area of sediment for the south coast is greater.

2. The subsidence in the south has accounted for larger areas of shallow seas covering submerged landscapes, while in the north, such submerged landscapes would be relatively lacking. Indeed, deep seas occur to the north, related to the development of the Cayman Trough. The occurrence of shallow seas in the south would aid rapid progradation.

3. It would be expected that the south coast would exhibit features of a submerged coast, while the north would exhibit features of an emergent coast. Consequently, the predominance of depositional features on the south coast, and erosional features on the north coast are to be expected.

All these features would combine to encourage the regional distribution of progradational and accretionary beaches on the south. All of the sectors are on the island shelf, except for the prograding coast of Cow Bay. Here sediment brought down by the Yallahs River is building out an alluvial fan in deep water."

4.3 Shoreline Instability.

Natural forces such as wind, waves, tides and currents, and also human activities such as beach sand removal and inappropriate construction of shoreline structures, are continuously at work, causing shoreline changes at numerous locations around the island. Fig. 3 gives a catalogue of trouble spots where critical erosion has been occurring.

In Kingston, Negril and Montego Bay, the island's most famous recreational beaches are showing worrying signs of instability. The reasons for shoreline instability at these locations are discussed below.

4.3.1 Hellshire Beaches. (See Fig. 4)

(The information presented in this section is taken from a 1989 report prepared by UWI's Marine Sciences Unit and Dalhousie University).

4.3.1.1 The coastline comprises a series of pocket beaches separated from each other by outcrops of Tertiary age limestone. In the north of the study area, the coastline between Fort Clarance Point and Half Moon Bay has been extended some 300-400 metres seawards of the limestone as a result of sediment accumulation, and the beaches there enclose the Great Salt Pond and a generrally dry salt pan. The off-shore reef almost completely protects this section of the coast from incoming swell. The other beaches further southwast are more exposed, and experience stronger incident swell and sea conditions. Beach sediments are mainly carbonates derived from the marine benthic communities, although Hellshire Bay shoreline sediments contain a fairly high proportion of clastics, believed to be relict, reworked Pleistocene age shelf sediments.

4.3.1.2 Routine observation of beaches along the Hellshire coast suggests that they are in a state of dynamic equilibrium with incident wave conditions. However, severe short-term instability has been observed on Half Moon Point. This feature is a cuspate foreland, which, as deduced from aerial photographs, has been built out by beach ridge accretion along its northern and southern flanks The orientation of the beaches along this point is largely controlled by the refracton pattern of waves running through the reefs offshore. Over the last 3 -4 years the point has suffered substantial erosion. This has manifested itself in the redistribution of sediments alongshore to the north, where significant build-up has occured at a groin originally emplaced to effect an exchange of water between the playa and the sea. Movement of sediment to the southwest in Half Moon Bay has also occured, and beach progradation is noticeable at the western edge of the shoreline inside the bay.

While minor phases of accretion have been observed, the general picture through the last few years is of shoreline recession within 200 - 300 metres northwest and southwest of the point with accretion beyond. Net erosion on the north facing shoreline of the point, between 1984 and 1988, is of the order of 15 - 20 metres at its greatest extent. In so far as the point is constructed of mobile substrate the instability of the shoreline is not unexpected over a period of thime. However, because the beaches of the point provide one of the few coastal recreation sites wthin easy reach of Kingston, some concern surrounds their instability, and the apparent reasons for it.

4.3.1.3 There are at least two components to the problem of sediment transport and resulting shoreline instability at Half Moon Point. The first is marine transport of sediment from the tip of the point and their apparent redistribution to lacations alongshore. For a proper analysis, baseline data on nearshore currents and wave spectra prior to the erosion phase are needed, in order to spot any changes in these conditions that may have generated erosion at the point. Such baseline data are not available. However, changes in the distribution of seagrass beds have been observed and monitored in the area of Half Moon Bay. Because the topography of the substrate changes with seagrass deposition, a change in current patterns will result. We can therefore suggest that recent changes in current patterns have occurred. Similarly, any changes in reef structure will influence swell refraction and the residual spillover pattern of breaking waves and also the resultant nearshore wave spectra. Algal overgrowth, possibly caused by eutrophication, has been observed on Half Moon Bay reefs, and a change in the physical structure of the reef through biological and physical erosion is likely to result.

4.3.1.4 The second component in sediment transport is aeolian movement of sands. Prevailing diurnal east-south-easterly sea breeze winds of up to 25 knots of sustained velocity create a dominantly landward drift. Dunes have been built up the beach area, and are also evident in aerial photographs taken prior to growth of the fishing settlement. However, their instability has been increased through removal of vegetation cover by trampling and cutting, particularly due to the activities of people in shoreline settlements. Wind-driven movement of sand from destabilised dunes is not, however, a direct cause of the observed shoreface migration, which is controlled primarily by nearshore oceanography, but is important in so far as the beaches' natural buffer to storm attack is being removed, and also may play an important role in longer-term landward translation of the coastal beach/dune system.

4.3.1.5 Shoreline changes have also resulted from construction of the channel into the Great Salt Pond. The northern jetty at the channel has trapped sediment south along the shore from Fort Clarence Point forming a seawards prograding sand wedge, and providing clear evidence of a net southerly beach drift at this location. As a consequence, the shoreline south of the inlet has eroded, being starved of sand from the north. Roots of trees and shrubs at this section, formerly protected by margin of beach samd, have now been exposed.

4.3.1.6 Recommendations/prognosis

Shoreline management depends to a large extent on the nature of projected usage. In light of longer term trends of coastal erosion that ate likely to occur regionally due to sea-level rise and other factors, there is every reason to institute long-term monitoring and management of the Hellshire beaches. The problems at Half Moon Bay are the most pressing and deserve immediate attention; the issues are complicated however, by the presence of the fishing settlement in the area of prime erosion, which makes any attempt at coastal management exceedingly difficult. In so far as there is little net shoreline loss, rather a relocation of the beachh profile by longshore transport, the problems may not be as troublesome as they might appear. At the very least, bathing activities can be relocated to those sites where a satisfactory build-up of sediment is occurring, a few hundred metres from the present site. The integrity of the building and vending structures is at risk due to erosion at the point, but the question of beach restoration in those areas is a matter for internal decision making within the implementing and monitoring agencies. Techniques for beach rstoration are available but so long as there is no control of human activity on the coastline at Half Moon Point, and there is unrestricted access of motor vehicles to the beach, there is little purpose in a dune re-stabilisation program at that location. Total agency control over all beach activities is a pre-requisite for sound management at this site, and elsewhere.

With respect to the problem of the Great Salt Pond, should erosion south of the inlet prove a threat to amenity value and infrastructure, it is recommended that the implementing agency relocate the sand that has accumulated north of the inlet either by pumping or trucking around to the south, where it should be deposited on the foreshore thus renourishing the stressed beach area.

4.3.2 Negril Beaches. (See Fig. 5)

The information presented in this section is taken from a 1990 report titled *Beach Stability at Negril and Bloody Bay*, found in NRCD files, attributed to M. Anderson, E. Foster and A. McKenzie. The NRCD report was prepared in response to complaints from some Negril Hoteliers that ongoing beach instability was threatening the viability of their businesses.The report presented the findings of a study programme that consisted of measuring beach profiles at ten monitoring stations at monthly intervals over the fifteen-month period between May 1989 and August 1990. The ten stations designated A to J, are shown in Fig. 5 . The profiles were obtained using a T16 theodolite. Vertical measurements were made to 0.01 foot precision, while horizontal readings were at 5 ft. intervals, adjusted to incorporate natural beach features such as berms, bars and dunes. The overall length of the foreshore section of the profile depended on the depth of the water and wave conditions.

4.3.2.1 Negril is situated at the western tip of Jamaica , with an annual average rainfall of approximately 135 cm and temperature variation between 25 -28 C. Negril is sheltered from the easterly trade winds and hence the winds are predominantly calm to light during the year.

4.3.2.2 The area is centered on carbonate strata of tertiary age and exhibits four marine terraces with historic succession from as early as 690,000 years ago and are now exposed, so that they are visible south of Negril villages. Long Bay has a shallow shelf, extending 2km offshore with a shallow inner shelf bottomed with sand and seagrass beds. The outer shelf is composed primarily of carbonate hardground concomitant with the Pleistocene age. A submarine cliff extends from the edge of the shelf to a sandy slope 3 - 3.5 km offshore.

4.3.2.3 *Results*

The beaches of Long Bay and Bloody Bay are generally characterised by a duneless gently dipping backshore and an even more gently sloping near shore area. Both areas are separated by a relatively steep foreshore that migrates seasonally. With the exception of the location in Bloody Bay, vegetation is almost completely absent in the backshore areas. Within the confines of the surveyed areas there was a noticeable sbsence of seagfrass beds in Long Bay as compared to Bloody Bay.

4.3.2.3.1 Station A had the highest foreshore slope angle and mean grain size values. This was attributed to extreme exposure of a section of Long Bay to high energy waves generated from the northernly direction as well as those waves approaching the shoreline from the open sea. Only a marginal seaward advancement of the foreshore was observed. Some seasonal berm regression and transgression was noticed, and this seemed typical of most of the other sites.

4.3.2.3.2 Stations B and C (Negril Beach Club and T. Water Cottages) are closely located and both tend to experience high levels of boating and swimming activities. Both areas demonstrate dynamic equilibrium, where there is a gradual regression of the beach during the winter months and a total recovery of the beach sand over the summer months. In the month of July the berm shows the highest level of recovery, that is , 15 feet in relation to its winter position. During November and December, the beach sand is lost to two longitudinal standing bars that develop at 30 feet from high water mark. The waves produced by boating activities produce a noticeable scarp on the berm in this area.

4.3.2.3.3 During May to August 1989, the berm at Charella Inn (Station E) advanced approximately 12 feet, but by November it had retreated to its July Position. Station D, located at Negril Gardens, responded similarly. Concomitantly, the date and recordings for a similar period in 1990 revealed the same phenomena. In addition, a longshore bar developed in November 1989 and remained throughout the winter months, and although the foreshore experienced seasonal changes over the last 15 months, stable conditions existed in the backshore and nearshore area.

4.3.2.3.4 In May 1989, vegetative growth was present 70 feet from the H.W.M. during the construction of the New Swept Away Hotel, Station F. This vegetative growth was replaced with concrete walkways and a garden. In July 1989, the observed crest of berms at this location was the highest above the estimatd mean of sea level of all the survey stations. It appears possible that this area is being exposed to larger waves, as the berms advanced approximately 15 feet May to July 1989 and although this pehnomenon was duplicated in 1990, the peak position did not recur.

4.3.2.3.5 Loss of beach sand was observed at Station G (Mahagony Inn) similar to Station F, (Swept Away), although the initial profile had shown a high level of sand accumulation.

4.3.2.3.6 Station H (Sandals) is serviced by buildings in close proximity to the sea, hence it is a heavily used beach. This is compounded with a beach bar located only 10 ft. From the H.W.M. hence the movement of people is limited to a very small area. It appears that this part of the beach is artificially nourished with sand periodically. Artificial nourishment is suspected in view of the measured profile, as there is no constant beach form, as a longshore bar is located about 40 ft. From H.W.M., providing the sand for nourishing the beach. The profiles have been found to have high foreshore slope angles. This is inconsistent with the findings of malcolm Hendry, a previous investigator, who found lower foreshore gradients in this area when compared to those in the south.

4.3.2.3.7 The most used survey point within the 7km beach was at Station I (Hedonism), where due to ontropogenic factors the beach feature was not observed easily. Unlike other survey points, this beach is protected by a series of rubble mound groynes, thus the beach front did not demonstrate seasonal berm migration. Hence, the profiles showed very little change, typical for beaches protected by defence structures.

4.3.2.3.8 At Station K (Bloody Bay) the profiles exhibited the same basic features as illustrated by Hendry site 2 profiles by having a dune in the backshore area. Furthermore, in comparison with 10 years ago, the foreshore has demonstrated a seaward transgression of approximately 30 ft., which is not similar for the southern section of Bloody Bay where Hendry identified a coarsening of sand grain size.

4.3.2.4 *Discussion*

As a seaside resort, Negril's attractiveness is the shore and foreshore, hence most of the tourism physical infrastructure is located along the coastal roadway less than 500 ft. from the shore. This results in attracting tourists, local visitors and workers to concentrate on the coastal strip of land that is less than 20% of the 4.5 miles of Long Bay. It is reported that within the 17 years from 1965 to 1982, Negril's population grew from 500 to 2440. This rapid population growth has resulted in an array of problems, foremost of which is environmental degradation.

4.3.2.4.1 Hendry described the Long Bay and Bloody Bay beaches as being stable in regard to the effects of wave activity. This is consistent with NRCD findings and is probably due to Negril being located on the leeward side with respect to the prevailing north-easterly trade winds.

4.3.2.4.2 The beaches at Negril show a distinct difference in morphology during the summer and winter seasons. In the summer the berm is low and advancing which creates an underwater profile which is smooth and barless. During the winter period the berm is narrow and at times non-existent, producing a distinct sand bar. The passage of climatic fronts during the winter period and their powerful wave activity causes leaching, with the formation of long shore bars where sediments moving eastward from inside the breaker zone impact with sediments moving landward from outside the breaker zone to be deposited at the break point creating a bar. During calm weather the waves are longer and hence more of the sediments go back onto the beach. In effect there is no quantitative change in sand budget, but simply a shift of sediment from one segment of the cell to another.

4.3.2.4.3 However, it appears that an area of 1 mile extending between Sandals and Swept Away is unstable and is eroding.
The destruction of vegetattion and wildlife along the coastal zone, degradation of coral reefs, badly designed and sited buildings and other constructed structures are posing a threat to shoreline stability in Negril.

4.3.2 Montego Bay. (See Fig. 6).

This section is based upon a report by L.Alan Eyre titled *The problem of Marine Erosion at Cornwall Beach* dated December, 27th.,1972. The report was prepared at the request of the Jamaica Tourist Board, whose members were at the time very concerned over dramatic shoreline changes ongoing at Cornwall and adjacent beaches.

4.3.2.1 In his report Dr. Eyre, described the Montego Bay foreshore from Doctors Cave to Sunset Lodge as " . . . a cuspate beach promontory, a large sandpile resting on the sea floor and banked up against a rock shoreline corresponding to Gloucester and Kent Aves. It (the beach) has been a prominent topographic feature since at least the 17th century." The original sandpile might have been thrown up by a large storm surge during close passage of a hurricane; or alternatively, by a series of powerful 'norters', during an epoch when such outbursts were stronger and more frequent than they are today. In any case, the depositional trend reversed long ago, and although sand movement has been oscillatory, with long periods of loss interrupted by brief depository episodes, " . . . the overall mass budget of the shoreline has been negative for several centuries."

4.3.2.2 Further on in his report, Dr. Eyre listed the main factors then influencing the erosion/deposition episodes in the subject area as follows:

i). Longshore currents and wind directions,

ii). The configuration of the offshore reef,

iii). The location of the sand supply,

iv). The beach profile,

v). Man-made structures.

4.3.2.2.1 *Current Movements and Sand Transport*

Longshore currents in the subject area are not constant, but the available evidence strongly suggets that the main direction is from south to north, and that most of the transported material originates from the southwest and west, from the interior of Montego Bay. Most sand movement takes place during the heavy seas of "norters" and tropical storms, which initially cause erosion, but may, upon subsiding, leave behind substantial quantities of deposition.

A north/south current develops under 15-25 knot easterly or northeasterly winds, and this used to transport some sand from the old barrier beach north of the airport, down towards Doctors Cave. But since construction of seawalls along the coast road around Montego Bay Point, and installation of numerous groynes and jetties south of the Point, the supply of sand from the North to Cornwall/Doctors Cave has virtually ceased.

4.3.2.2.2 *Cornwall Beach Profile (December 1972)*

Cornwall beach was subject to intense attack by a heavy norther in early November 1972, which left the beach severely damaged. (See photograph, Fig.7). The beach was left quite steep, and the berm very unstable, favouring erosion, rather than deposition or equilibrium. The beachrock formation of a former shoreline was clearly visible, submerged at depths of up to 5 ft. below m.s.l. at a distance of around 150 ft. from the then severely eroded shoreline. It appeared that most of the eroded material had been taken out into the Bay through a gap in the reef. The presence of the relatively hard ridge of coral-encrusted beachrock near to the shoreline contributed to the severity of the erosion by enabling the development of plunge pools for wave action on the shoreline of submerged beachrock, further erosion was accelerated.

4.3.2.2.3 *Effects of Man-made Structures*

Doctors Cave Beach was originally inaugurated as a "Bathing Club" in 1906, but large-scale commercial development of the area only began to gain pace some forty years later, towards the late nineteen forties.
The beach was seriously damaged by a hurricane in August 1944. In 1946, an engineer from Florida, Mr. Sydney Makepeace Wood, was engaged by the Club to study the conditions at Doctors Cave and make recommendations for remedial works. In describing the conditions which he found when he began his study in May 1946, Mr. Wood wrote as follows:

> "....the beach (Doctors Cave) extended only a few yards to the south of the line of trees just south of the cemetery and angled off very sharply with bare rock populated by sea urchins as its bottom. The 'beach' at Cornwall Bathing Club at that time was practically zero. To get into the water there members had to cross over a jagged reef".

Mr. Wood designed and erected the first two groins for Doctors Cave in 1950. The northern groin was 150 ft. long, separating Cornwall Beach from Doctors

Cave, while the southern groin, at the Case Blanca end of the beach, was 85 ft. long. The groins were designed to be "increasingly permeable", - i.e., the space between members increased as the structure projected out from the shoreline, thereby trapping more sediment nearer the shoreline and less and less towards the deep end.

Throughout the decade of the nineteen fifties, the groins influenced wave refraction patterns favourably, and collected sand from the longshore drift for Doctors Cave to the extent that there was considerable accretion between the groins, particularly on the south side of northern groin. (See Fig.9). By the end of the nineteen fifties it was felt that the rate of further accretion at Doctors Cave could be improved if the southern groyne was longer; and the Club proceeded to instruct Mr. Wood to build another, longer groyne, at the Casa Blanca end of the beach.

Meanwhile, at Montego Beach and Sunset Lodge, beach erosion had reached the stage where foundations of some buildings located close to the shoreline were in danger of being undermined. In the early nineteen fifties, Montego Beach apparently abandoned the idea of ever being able to maintain a natural beach. They built a seawall and reclaimed 80 ft. of land forward from their old shoreline. The reclamation was protected along both its northern and southern ends by construction of two long groins which went out some 70 ft. past the line of the seawall (See Fig.10). Sunset Lodge too, built a couple of groins at right angles to their shore, of similar length to those at Montego Beach.

The effect of construction of the southern longer groin at Doctors Cave in 1960 has been spectacular. The long groin was so effective in incresing buildup of material at the Casa Blanca end of the beach that by the early nineteen seventies the entire length of the original "short" groin was almost covered over with sand. While this heavy accretion at the southern end was taking place, some concurrent (but less pronounced) loss of material had been occuring at the northern groyne, so that in fact, over the years 1960 to 1973, the Doctors Cave shoreline turned through an angle of roughly 30°. (See Fig.11).

With Doctors Cave's long southern groin cutting off all the longshore transport from the south, and the Monteo Beach, and Sunset Lodge structures picking up all material which managed to reach that far south coming down from Montego Bay Point, Cornwall beach was "caught in the middle", and , under normal conditions, received no littoral transport from either north or south.

It was mentioned above that Cornwall Beach was severely damaged by a norther early in November, 1972. During December of that year, and in January and February of 1973, detailed discussions were taking place between the owners of the property, St. James Parish Council, various concerned government agencies, and at least three independent Consultants, towards developing a plan to address the continuing instability problems of Cornwall and Doctors Cave beaches. Then, dramatically, towards the end of the first week of March 1973, a series of northers deposited approx. 2,000 Cu. Yds. of very welcome sand upon Cornwall Beach. Although there were signs that much of the new deposit on Cornwall Beach had come from off Doctors Cave, it was decided that at least some temporary action should be taken to try to retain the material on Cornwall Beach, while more extensive research was done to try to develop a more permanent overall solution. By early May, three 65 ft. long gabion groynes (wire baskets filled with stones) had been installed at Cornwall, and these worked quite well, at least up to October 1976. (See Fig. 11 and Fig.12), keeping the beach relatively stable. But by December 1976 however, Cornwall Beach was again showing signs of serious erosion, as, due to disintegration of the wire baskets, most of the rocks were scattered, and the groins are no longer effective. (See Fig.13).

Although over the past decades the shoreline changes which have been occuring in front of the central Montego Bay hotel area have certainly been influenced by man-made structures, the basic problem probably lies in the overall paucity of th gross sand budget of the area.

In the tailpiece of his 1972 report, Dr. Eyre expressed the though that: "....perhaps major replenishment will have to await a great storm surge from some north coast hurricane in the years ahead". That may be true, but inevitably, in the meantime, man will keep on carrying out studies, erecting new structures, perhapsdemolishing some existing ones, never giving up his determination to "develop" the area.

5. THE LITTORAL PROCESSES THAT IMPACT UPON SHORELINE FACILITIES

Littoral processes result from the interaction of winds, waves, currents, tides, sediments, and other phenomena in the littoral zone. Shores erode, accrete, or remain stable depending upon the rates at which sediment is supplied to and removed from the shore. Excessive erosion or accretion may endanger the structural integrity or functional usefulness of a beach or of other coastal structures. Therefore, an understanding of littoral processes is needed in order to be able to predict erosion or accretion effects and rates. A common aim of coastal engineering design is to maintain a stable shoreline where the volume of sediment supplied to the shore balances that which is removed.

5.1 **Littoral Materials.**

Littoral materials are the solid particles in the littoral zone upon which the waves, wind and currents act.

5.1.1 Classification.

The characteristics of the littoral materials are usually primary input to any coastal engineering design. Median grain size is the most frequently used descriptive characteristic.

5.1.1.1 *Size and Size Parameters.*

Littoral materials are classified by grain size into clay, silt, sand, gravel, cobble, and boulder. The two classifications most commonly used in coastal engineering are the Unified Soil Classification and the Wentworth classification (see Fig.14).

For most shore protection design problems,typical littoral materials are sands with sizes between 0.1 and 1.0 millimeters. According toWentworth classification, sand size is in the range between 0.0625 and 2.0 millimeters; according to the Unified classification, it is between 0.074 and 4.76 millimeters. Within these sand size ranges, engineers commonly distinguish size classes by median grain size measured in millimeters.

5.1.1.2 *Composition and Other Properties.*

Littoral material varies in composition, shape, and other properties. In considering littoral processes, composition normally is not an important variable because the dominant littoral material is quartz sand, which is mechanically durable and chemically inert. However, littoral material may include carbonates (shell, coral, and algal material), heavy and light minerals, organics (peat), and clays and silts.

The shape of littoral material ranges from nearly spherical to nearly disklike (shells and shell fragments). Littoral sands are commonly rounded, but usual departures from sphericity have appreciable effects on sediment setting, sieve analyses, and motion initiation.

5.1.1.3 *Fall Velocity.*

In considering the motion of littoral materials, a particularly meaningful material characteristic is the *particle fall velocity, Vf.* This is the terminal vertical velocity attained by an isolated solid grain settling due to gravity in a still, unbounded, less dense fluid. The fall velocity, usually for quartz in water, summarizes effects of grain size, shape, and composition and of fluid composition and viscosity. The ratio of fall velocity to characteristic fluid velocity has been widely applied as a measure of sediment mobility or transport.

5.1.2 Sand and Gravel.

By definition, the word sand refers to a size class of material, but sand also implies the particular composition, usually quartz (silica).

In the beach sands of countries with temparate climates, quartz and feldspar grains are usually the most abundant, sometimes accounting for as much as 90%; but in tropical islands such as Jamaica, calcium carbonate, especially shell material, is often the majority constituent.

The relative abundance of non-quartz materials is a function of the relative importance of the sources supplying the littoral zone and the materials available at those sources.

5.1.3 Cohesive Materials.

The amount of fine-grained, cohesive materials, such as clay, silt, and peat, in the littoral zone depends upon the wave climate, contributions of fine sediment from rivers and other sources, and recent geologic history.

Fine grained material is common in the littoral zone whenever the annual mean breaker height is below about 0.3m. In contrast, fine sediment is not usually found at shorelines where breaker heights are of the order of around 0.8m.

Where rivers bring large quantities of sediment to the sea, the amount of fine material remaining along the coast depends on the balance between wave action acting to erode the fines, and river deposition acting to replenish the fines.

5.1.4 Consolidated Material.

Along some coasts, the principal littoral materials are consolidated materials, such as rock, beach rock, and coral, rather than unconsolidated sand. Such consolidated materials protect a coast and resist shoreline changes.

5.1.4.1 *Rock.*

Exposed rock along a shore indicates that the rate at which sand is supplied to the coast is less than the potential rate of sand transport by waves and currents. Reaction of a rocky shore to wave attack is determined by : (1) the structure, degree of lithification, and ground-water characteristics of the exposed rock, and (2) by the severity of the wave climate. Most rocky shorelines are remarkably stable.

5.1.4.2 *Beach Rock.*

A layer of friable-to-well-lithified rock often occurs at or near the surface of beaches in tropical and subtropical climates. This material, commonly known as *beach rock,* consists of local beach sediment cemented with calcium carbonate. Beach rock is believed to be formed when saline waters evaporate in beach sands, depositing calcium carbonate from solution.

5.1.4.3 *Organic Reefs.*

Organic reefs are wave-resistant structures reaching to about mean sea level that have been formed by calcium carbonate-secreting organisms. The most common reef-building organisms are hermatypic corals and coralline algae. Organic reefs greatly help to protect adjacent shorelines from wave action.

5.1.5 Sampling Littoral Materials.

Sampling programs are usually intended to provide information about one or more of the following characteristics of littoral materials:

a). Typical grain size (usually median size)
b). Size distribution
c). Composition of the littoral materials
d). Variations in a), b), and c), with changes in vert. and horiz. locations
e) Variations in a), b), c), and d) at different times.

Beaches typically show more variation across the profile than along the shore, so sampling to determine variation in the littoral zone should usually be made along a line perpendicular to the shoreline.

5.2 **Littoral Wave Conditions.**

5.2.1 Effect of Wave Conditions on Sediment Transport.

Waves arriving at the shore are the primary cause of sediment transport in the littoral zone. Higher waves break farther offshore, widening the surf zone and setting more sand in motion. Changes in wave period or height cause sand to move onshore or offshore. The angle between the crest of the breaking wave and the shoreline determines the direction of the longshore component of water motion in the surf zone and, usually, the longshore transport direction. For these reasons, knowledge about the wave climate -the combined distribution of height, period, and direction through the seasons- is required for an adequate understanding of the littoral processes of any specific area.

5.2.2 Factors Determining Littoral Wave Climate.

The wave climate at a shoreline depends on the offshore wave climate, caused by prevailing winds and storms and on the bottom topography that modifies the waves as they travel shorewards.

5.2.2.1 *Offshore Wave Climate.*

Offshore wave climate varies among different coastal areas because of differences in exposure to waves generated in distant parts of the sea and because of systematic differences in wind patterns around the earth.
Variations in offshore wave climate affect the amount of littoral wave energy available and the directions from which it comes.

5.2.2.2 *Effect of Bottom Topography.*

As storm waves travel from deep water into shallow water, they generally lose energy even before breaking. They also change height and direction in most cases. The changes may be attributed to refraction, shoaling, bottom friction, percolation, and nonlinear deformation of the wave profile.
Refraction is the bending of wave crests due to the slowing down of that part of the wave crest which is in shallower water. As a result, refraction tends to decrease the angle between the wave crest and the bottom contour. Thus, for most coasts, refraction reduces the breaker angle and spreads the wave energy over a longer crest length.
Shoaling is the change in wave height due to conservation of energy flux. As a wave moves into shallow water, the wave height first decreases slightly and then increases continuously to the breaker position, assuming friction, refraction, and other effects are negligible.
Bottom friction is important in reducing wave height where waves must travel long distances in shallow water.
Nonlinear deformation causes wave crests to become narrow and high and wave troughs to become broad and elevated. Severe nonlinear deformation can also affect the apparent wave period by causing the incoming wave crest to split into two or more crests.

5.2.2.3 *Winds and Storms.*

The orientation of a shoreline to the seasonal distribution of winds and to storm tracks is a major factor in determining the wave energy available for littoral transport and the resulting effect of storms.
A storm near the coastline will influence wave climate due to storm surge and high seas; an offshore storm will influence wave climate only by swell.
The probability that a given section of coastline will experience storm waves depends on its ocean exposure, its location in relation to storm tracks, and the shelf bathymetry.

5.2.3 Nearshore Wave Climate.

Desirable wave climate data for prediction of littoral processes include summaries of wave height, period, and direction just prior to breaking for all major wave trains at a site of interest. Such data are rarely available. When data are available at one locality they may not be applicable to nearby localities because of localized effects of bottom topography.

The quality and quantity of available wave climate data often do not justify elaborate statistical analysis. For important projects the necessary data should be gathered by actually measuring wave conditions at the shoreline locality for a period of at least one year.

5.3 Nearshore Currents.

Nearshore currents in the littoral zone are predominantly wind and wave-induced motions superimposed upon the wave-induced oscillatory motion of the water. The net motions generally have low velocities, but because they transport whatever sand is moved by the wave-induced water motions, they are important in determining littoral transport.

There is only slight exchange between the offshore and the surf zone. Onshore-offshore flows take place in a number of ways that are not fully understood at present.

5.3.1 Wave-Induced Water Motion.

In idealized deepwater waves, water particles have a circular motion in a vertical plane perpendicular to the wave crest, but this motion does not reach deep enough to affect sediment on the bottom. In shallower depths where waves are affected by the bottom the circular motion becomes elliptical, and the water at the bottom begins to move. In shallow water, the ellipses elongate into nearly straight lines. At breaking, particle motion becomes more complicated; but even in the surf zone, the water moves forward and backward in paths that are mostly horizontal, with brief, but intense, vertical motions during the passage of the breaker crest. Since it is this wave-induced water particle motion that causes the sediment to move, it is useful to know the length of the elliptical path travelled by the water particles and the maximum velocity and acceleration attained during this orbit.

For sediment transport, the conditions of most interest are those when the wave is in shallow water; and for this condition, useful theoretical formulae are available for estimating the length of the path moved by the water particle and the maximum horizontal velocity of the particle as a wave passes in shallow water.

5.3.2 Fluid Motion in Breaking Waves.

During most of the wave cycle in shallow water, the particle velocity is approximately horizontal and constant over the depth, although right at breaking there is significant vertical velocity as the water is drawn up into the crest of the breaker. Fluid motions at breaking cause most of the sediment transport in the littoral zone, because the bottom velocities and turbulence at breaking suspend more bottom sediment. This suspended sediment can then be transported by currents in the surf zone whose velocities are normally too low to move sediment that is at rest on the bottom.

The effect of tide on nearshore currents is not discussed here, but tide-generated currents may be superimposed upon wave-generated nearshore currents, especially near estuaries. In addition, the changing elevation of the water level as the tide rises and falls may change the area and the shape of the profile through the surf zone and thus alter the nearshore currents.

5.3.3 On-shore-Offshore Currents.

5.3.3.1 *Onshore-Offshore Exchange.*

Field and laboratory data indicate that water in the nearshore zone is divided by the breaker line into two distinct water masses between which there is only a limited exchange of water.

5.3.3.2 *Diffuse Return Flow.*

Wind and wave-induced water drift, pressure gradients at the bottom due to setup, density differences due to suspended sediment and temperature, and other mechanisms produce patterns of motion in the surf zone that vary from highly organized rip currents to broad diffuse flows that require continued observation to detect. Diffuse return flows may be visible in aerial photos as fronts of turbid water moving seaward from the surf zone.

5.3.3.3 *Rip Currents.*

Most noticeable of the exchange mechanisms between offshore and the surf zone are rip currents. Rip currents are concentrated jets that carry water seaward through the breaker zone. They appear most noticeable when long, high waves produce wave setup on the beach. However, there is presently no proven way to predict the conditions that produce rip currents or the spacing between rips.

5.3.4 Longshore Currents.

5.3.4.1 *Velocity and Flow Rate.*

Longshore currents flow parallel to the shoreline and are restricted mainly between the zone of breaking waves and the shoreline. Most longshore currents are generated by the longshore component of motion in waves that obliquely approach the shoreline.

Longshore currents typically have mean values of 0.3m per second or less. Although longshore currents generally have low speeds, they are important in littoral processes because they flow along the shore for extended periods of time , transporting sediment set in motion by the breaking waves.

The most important variable in determining the longshore current velocity is the angle between the wave crest and the shoreline. However, the volume rate of flow of the current and the longshore transport rate depend mostly on breaker height. The outer edge of the surf zone is determined by the breaker position. Since waves break in water depths approximately proportional to wave height, the width of the surf zone on a beach increases with wave height. This increase in width increases the cross section of the surf zone.

5.3.4.2 *Velocity Prediction.*

The variation in longshore current velocity across the surf zone and along the shore, and the uncertainties in variables such as the surf zone hydrography, make prediction of longshore current velocity uncertain; but several credible theoretical equations have been developed and are in use for making such predictions.

5.3.5 Summary.

5.3.5.1 The major currents in the littoral zone are wave-induced motions superimposed on wave-induced oscillatory motion of the water. The net motions generally have low velocities, but because they transport whatever sand is set in motion by the wave-induced water motions, they are important in determining littoral transport.

5.3.5.2 Evidence indicates that there is only a slight exchange of fluid between the offshore and the surf zone.

5.3.5.3 Longshore current velocities are most sensitive to changes in breaker angle and, to a lesser degree, to changes in breaker height. However, the volume rate of flow of the longshore current is most sensitive to breaker height, probably proportional to H squared. The modified Longuet-Higgins equation is recommended for predicting mean longshore current velocity of fully developed flows.

5.4 Littoral Transport.

Littoral transport is the movement of sedimentary material in the littoral zone by waves and currents. The littoral zone extends from the shoreline to just beyond the seawardmost breakers.

Littoral transport is classified either as *onshore-offshore transport* or as *longshore transport*. Onshore-offshore transport has an average net direction perpendicular to the shoreline; longshore transport has an average net direction parallel to the shoreline. The instantaneous motion of sedimentary particles typically has both an onshore-offshore and a longshore component. Onshore-Offshore transport is usually the most significant type of transport in the offshore zone, except in regions of strong tidal currents. Both longshore and onshore-offshore transport are significant in the surf zone.

Engineering problems involving littoral transport generally require answers to one or more of the following questions:

- What are the longshore transport conditions at the site?
  (Needed for the design of groins, jetties, navigation channels, and inlets).
- What is the trend of shoreline migration over short and long term periods?
  (Needed for design of coastal structures including navigation channels).
- How far seaward is sand actively moving?
  (Needed for the design of sewage outfalls and water intakes).
- What is the direction and rate of onshore-offshore sediment motion?
  (Needed for sediment budget studies and beach-fill design).
- What is the average shape or range of shapes for a given beach profile?
  (Needed for the design of groins, beach fills, navigation structures, flood protection).
- What effect will a postulated structure or project have on adjacent beaches and littoral transport? (Needed for design of all coastal works).

5.4.1 Onshore-Offshore Transport.

Quantitative engineering guidance has been more firmly established for rates of longshore transport than for rates of onshore-offshore transport. This seems mainly due to the complexity involved in the respective processes. With nearshore waves propagating usually at only a slight angle with respect to a shore-normal line, an appreciable unidirectional longshore current and net sediment transport are driven by fairly steady longshore wave thrust. In contrast, net onshore-offshore transport results from usually small differences between oscillating sediment movements near to and opposite the wave direction.

5.4.1.1 *Sediment Effects.*

Properties of individual particles important in sediment transport include size, shape, and composition. Collections of particles have the additional properties of size distribution, permeability, and porosity. These properties influence the fluid forces necessary to initiate and maintain sediment movement. For usual nearshore sediment, size is the only particle property which varies greatly. Grain size changes sediment motion conditions, sediment fall velocity, and hydraulic roughness of the grain bed. The hydraulic roughness affects flow energy dissipation, which also results directly from bed permeability. Bed permeability, depending upon sediment size and sorting, can cause a net onshore sand transport from far offshore, and influences wave runup at the shoreline. Sediment size clearly figures in beach swash processes. Thus, grain size figures in a variety of processes from the landward to the seaward limit of hydrodynamic sediment transport.

5.4.1.2 *Seaward Limit of Significant Transport.*

An important question to be addressed is : *What is the maximum water depth at which sand transport occurs at rates significant in coastal engineering?* Such a seaward limit figures as a critical parameter in calculation procedures for changes in shoreline location, and must be considered in design of near-shore structures, subaqueous beach nourishment, and offshore borrow or disposal operations.

Detailed studies at certain sites have established that appreciable sediment transport by waves on exposed coasts is usually restricted to water depths shallower than 5 to 20 meters. The seaward limit to vigorous transport must be related fundamentally to sediment and wave characteristics for a site. Despite the absence of a dependable treatment of onshore-offshore transport rates, several useful techniques exist for estimating the seaward limit of significant transport without detailed investigation of nearshore processes at specific sites.

5.4.1.3 *Beach Erosion.*

Beach profiles change frequently in response to winds, waves, and tides. The most rapid rearrangement of a profile is accomplished by storm waves, especially during storm surge, which enables the waves to attack higher elevations on the beach.

The part of the beach washed by runup and runback is the beach face. Under normal conditions, the beach face is contained within the foreshore, but during storms the beach face is moved shoreward by the cutting action of the waves on the profile. The waves during storms are steeper, and the runback of each wave on the beach face carries away more sand than is brought to the beach by the runup of the next wave. Thus the beach face migrates landward, cutting a scarp into the berm.

The extent of storm erosion depends upon the pre-storm profile, effects of any shore-stabilizing structures or vegetation, wave conditions, storm surge, the stage of the tide, and storm duration.

For planning and design purposes, it would be useful to be able to estimate the magnitude of beach erosion to be expected during severe storms. This type of information is required for the volumetric design of beach nourishment, the required depth of burial of ocean outfall and intake structures, and the functional design of dunes, groins, jetties and revetments. Unfortunately, there is no satisfactory procedure for accurately predicting expected storm losses. Moreover, there is a general paucity of authentic field data documenting the effects of extreme events such as storms of 50 and 100year return periods. Lacking satisfactory means of predicting profile changes, the engineer can only make educated guesstimates based upon whatever information might be available from local sources.

5.4.1.4 *Beach Recovery.*

The typical beach profile left by a severe storm is a simple, concave-upward curve extending seaward to low tide level or below. The sand that has been eroded from the beach is deposited mostly as a ramp or bar in the surf zone that exists at the time of the storm. Immediately after the storm, the beach begins to recover by the following process: Sand that has been deposited seaward of the shoreline during the storm begins moving landward as a sandbar with a gently sloping seaward face and a steeper landward face. These bars have associated lows (runnels) on the landward side and occasional drainage gullies across them. These systems are characteristic of post-storm beach accretion under a wide range of wave, tide, and sediment conditions. Further accretion continues by adding layers of sand to the top of the bar which, by then, is a part of the beach.

The ideal result of poststorm beach recovery is a wide backshore that will protect the shore from the next storm. Beach recovery may be prevented when the period between successive storms is too short. Maintenance of coastal pretection requires (a) knowledge of the necessary width and elevation of the backshore appropriate to local conditions and (b) adequate surveillance to determine when this natural sand reservoir has diminished to the point where it may not protect the backshore during the next storm.

5.5 Engineering Study of Littoral Processes.

5.5.1 Office Study.

The first step in the office phase of an engineering study of littoral processes is to define the problem in terms of littoral processes. The problem may consist of several parts, especially if the interests of local groups are in conflict. An ordering of the relative importance of the different parts may be necessary, and a complete solution may not be feasible. Usually, the problem will be stated in terms of the requirements of the owner or local interests. For example, local interests may require a recreational beach in an area of limited sand, making it necessary to estimate the potential rates of longshore and onshore-offshore sand transport. Or a fishing community may desire a deeper channel in an inlet through a barrier island, making it necessary to study those littoral processes that will affect the stability and long-term navigability of the inlet, as well as the effect of the improved inlet on neighbouring shores and the lagoon.

5.5.1.1 *Sources of Data.*

Records of shoreline changes are usually in the form of charts, surveyed profiles, dredging reports, beach replenishment reports, and aerial photos. Shoreline change data are useful for computing longshore transport rates. In Jamaica, project sponsors will be able to obtain useful information from the following sources:

▪ Survey Department-	*Comprehensive topo/cadastral maps, some hydrographic charts;*
▪ Geological Survey Department-	*Geological maps, reports, earthquake hazard map, hurricane hazard map;*
▪ Government Met. Office-	*Weather data: wind, rainfall, waves, tides, storm surge;*
▪ Natural Resources Conservation Authority	*The NRCA Docucenter is the most Important source for information on on government environmental policy national environmental standards, and the permitting process;*
▪ Port Authority of Jamaica-	*The PAJ is governments chief Agency for the regulation and monitoring of all marine activities and dock and harbour construction.*

5.5.1.2 *Interpretation of Shoreline Position.*

Preliminary interpretation of littoral processes is possible from the position of the shoreline on aerial photos. In conjunction with hydrographic charts and topographic maps, aerial photos can be used to provide quick and fairly accurate estimates of shoreline movement, although the results can be biased by the short term effects of storms.

Charts show the coastal exposure of a study site, and, since exposure determines the possible directions from which waves reach the coast, exposure also determines the most likely direction of longshore transport.

5.5.2 Field Study

A field study of the problem area is usually necessary to obtain types of data not found in the office study, to supplement incomplete data, and to serve as a check on the preliminary interpretation and correlations made from the office data. Information on coastal processes may be obtained from wave gage data and visual observations, sediment sampling, topographic and bathymetric surveys, tracer programs, and observation of effects of natural and manmade structures.

5.5.2.1 *Wave Data Collection*

A wave-gaging program yields height and period data. However, visual observations may currently be the best source of breaker direction data. A visual observation program is inexpensive and may be used for breaker direction and for regional coverage when few wave-gage records are available. The observer should be provided with instructions so that all data collected will be uniform, and contact between observer and engineer should be maintained.

5.5.2.2 *Sediment Sampling*

Surface samples are usually taken at intervals along a line perpendicular to the shoreline.These are supplemented by borings or cores as necessary. Complete and permanent identification of the sample is important.

5.5.2.3 *Surveys*

Most engineering studies of littoral processes require surveying the beach and nearshore slope. Successive surveys provide data on changes in the beach due to storms, or long-term erosion or accretion. If beach length is also considered, an approximate volume of sand eroded or accreted can be obtained which provides information for the sediment budget of the beach. The envelope of a profile defines fluctuations of sand level at a site and thus provides data useful in beach fill and groin design.

5.5.2.4 *Tracers*

It is often possible to obtain evidence on the direction of sediment movement and the origins of sediment deposits by the use of tracer materials which move with the sediment. Tracers are particles which react to fluid forces in the same manner as particles in the sediment whose motion is being traced, yet which are physically identifiable when mixed with this sediment. Ideally, tracers must have the same size distribution, density, shape, surface chemistry, and strength as the surrounding sediment; in addition they must have a physical property that easily distinguishes them from their neighbours.

Three physical properties have been used to distinguish tracers: radioactivity colour, and composition.

Tracers may be either naturally present or introduced by man.

6. COMMON TYPES OF SHORELINE ENHANCEMENT & PROTECTION STRUCTURES.

In selecting the shape, size, and location of shore protection works, the objective should be not only to design an engineering work that will accomplish the desired results most economically, but also to consider effects on adjacent areas. Effects on adjacent land areas should be considered to the extent of providing the required protection with the least amount of disturbance to current and future land use, ecological factors, and aesthetics of the area. The form, texture, and colour of the construction material should be considered in the design, as well as how the material is used. Proper planning analysis also requires the consideration of legal and social conse- quences where shore protection measures may result in significant effects on physical or ecological aspects of the environment.
The following sections describe the most common structural solutions currently being adopted for shore protection and enhancement, and provide guidelines for the application of these solutions.

6.1 Seawalls, Bulkheads and Revetments

Seawalls, bulkheads, and revetments are structures placed parallel, or nearly parallel, to the shoreline to separate a land area from the sea.

6.1.1 Functions.

The primary purpose of a bulkhead is to retain land or prevent landsliding, with the secondary purpose of affording protection to the upland against damage by wave action. Bulkheads may also serve as moorings and cargo transfer points for vessels. The primary purpose of a seawall or revetment is to protect the land and upland areas from erosion by waves and currents, with an incidental function as a retaining wall or bulkhead. There are no precise distinctions between the three structures, and often the same type of structure in different localities will bear a different name.
Generally, these types of structures are used where it is necessary to maintain the shore in an advanced position relative to that of adjacent shores, where there is scant supply of littoral material and little or no protective beach, as along an eroding bluff, or where it is desired to maintain a depth of water along the shoreline, as for a wharf.

6.1.2 Limitations.

These types of structures give protection only to the land immediately behind them, and none to adjacent areas upcoast and downcoast. When built on a receding shoreine, the recession on adjacent shores will continue and may even be accelerated. Any tendency toward the loss of beach material in front of these types of structures may well be intensified. Where it is desired to maintain a beach in the immediate vicinity of such structures, companion works may be necessary.

6.1.3 Functional Planning of the Structure.

The siting of seawalls, bulkheads, and revetments is often not a difficult process,, since their primary function is usually to maintain existing fixed boundaries. Considerations for design of these types of structures include: use and overall shape of the structure, location with respect to the shoreline, length height, stability of the soil, water levels seaward and landward of the wall, availability of building materials, economic feasibility limits, environmental concerns, and institutional constraints.

6.1.4 Location of the Structure in Relation to the Shoreline.

A seawall, bulkhead, or revetment is usually constructed along that line landward of which further recession of the shoreline must be stopped. Where an area is to be reclaimed, a wall may be constructed along the seaward edge of the reclaimed area.

6.1.5 Use and Shape of the Structure

The use of the structure typically dictates the selection of the shape. Face profile shapes may be classed roughly as vertical or nearly vertical, sloping, convex-curved, concaved-curved, reentrant, or stepped. Each cross section has certain functional applications, as illustrated in Figs. 15, 16 & 17

6.1.5.1 A vertical, or nearly-vertical face structure lends itself to use as a quay wall, or docking or mooring place. Where a light structure is required, the construction of a vertical face (of sheet piling, for example) may often be quicker and less expensive than other types. This ease or speed of construction is important where emergency protection is needed. A vertical face is less effective against wave attack, and specifically against over-topping, compared to the concave-curved and reentrant face.

6.1.5.2 Course rubble slopes effectively dissipate and absorb wave energy, reducing wave runup, overtopping, and scour. Convex-curved face and smooth slopes are least effective in reducing wave runup and overtopping.

6.1.5.3 Concave-curved or reentrant face structure are the most effective for reducing wave overtopping when onshore winds are light. Where the structure crest is to be used for a road, promenade, or other purpose, this design may be the best shape for protecting the crest and reducing spray. This is especially true of the fronting beach is narrow or nonexistent, or if the water level is above the structure base. If onshore winds occur at the same time as high waves, a rubble slope should also be condisered to reduce runup on the structure face and overtopping due to wind forces.

6.1.5.4 A stepped-face wall provides the easiest access to beach areas from protected areas, and reduces the scouring of wave backwash.

6.2 Groins.

6.2.1 Definition.

A groin is a shore protection structure designed to trap longshore drift for building a protective beach, retarding erosion of an existing beach, or preventing longshore drift from reaching some downdrift point, such as a harbour or inlet. Groins are narrow structures of varying lengths and heights and are usually constructed perpendicular to the shoreline.

6.2.2 Groin Operation.

The interaction between coastal processes and a groin or groin system is complicated and not at all fully understood. However, in regard to the design and construction of groins and groin systems, there are some fundamental principles which are generally followed by the most authoritative practitioners in the field, and these are summarized and embodied in the following basic rules:

6.2.2.1 Groins can only be used to interrupt longshore transport.

6.2.2.2 The beach adjustment near groins will depend on the magnitude and direction of the longshore transport.

6.2.2.3 The groin-induced accumulation of longshore drift on the foreshore will modify the beach profile, which will then try to re-establish its natural shape.

6.2.2.4 Water pushed by waves into a groin compartment will sometimes return offshore in the form of rip currents along the sides of the groins.

6.2.2.5 The percentage of the longshore transport which bypasses a groin will depend upon groin dimensions, fillet dimensions, water level, and wave climate.

6.2.2.6 The longshore drift that is collected in the updrift fillet is prevented from reaching the downdrift area, where the sand balance is upset.

6.2.3 Functional Design.

For functional design purposes, a groin may be considered to have three sections:
1). Horizontal shore section, HSS; 2). Intermediate sloped section, ISS; and
3). Outer section, (OS). This diffrentiation is illustrated in Fig. 18.

6.2.3.1 *Horizontal Shore Section.*

This section extends far enough landward to anchor the groin and prevent flanking. The height of the HSS depends upon the degree desirable for sand to overtop the groin and nourish the downdrift beach. The standard height is the height of the natural berm, which is usually the height of maximum high water, plus the height of normal wave uprush. An economic justification for building a groin higher than this is doubtful except for terminal groins. With rubble-mound groins, a height of about 0.3m (1 foot) above the berm is sometimes used to reduce the passage of sand between large cap stones. The maximum height of a groin to retain all sand reaching the area (a high groin) is the height of maximum high water and maximum wave uprush during all but the most severe storms. Conversely, this section, or part of it, can be built lower than the berm to permit overpassing of sediment during periods of high tide. A low groin of this type can be termed a *weir groin* based on its operational similarity to weir jetties.

6.2.3.2 *Intermediate Sloped Section.*

The ISS extends between the HSS and the OS. It should approximately parallel the slope of the natural foreshore. The elevation of the lower end of the slope will usually be determined by the construction methods used, the degree to which it is desirable to obstruct the movement of the littoral material, or the requirements of swimmers or boaters.

6.2.3.3 *Outer Section.*

The OS includes all the groin that extends seaward of the intermediate sloped section. With most types of groins, this section is horizontal at as low an elevation as is consistent with economy of construction and with public safety.

6.2.4 Materials for Groin Construction.

Groins built of common construction materials can be made permeable or impermeable and high or low in profile. The materials used are stone, concrete, timber, and steel. Asphalt and sand-filled nylon bags have also been used to a limited extent. The groins commonly found around Jamaica's coastline are constructed either of rubble stones or precast concrete.

6.2.5 Permeable Groins.

Permeability allows part of the longshore drift to pass through the groin and induces sand deposition on both sides of the groin. This in turn reduces the abrupt offset in shore alignment found at impermeable groins. Many types of permeable groins have been employed. The degree of permeability above the ground line affects the pattern and the amount of deposition. Insufficient empirical data have been compiled to establish quantitative relationships between littoral forces, permeability, and shore response. Until such data are available, the evaluation and design of permeable groins will be inexact. In general, the desired degree of sand bypassing can be achieved as effectively and economically by the appropriate design of groin height and length.

6.2.6 Adjustable Groins.

Most groins are permanent, fixed structures; however, adjustable groins have been used in England and Florida. These groins consist of removable panels between piles. The panels are designed to be added or removed to maintain the groin at a specific height (usually 0.3 to 0.6 meter or 1 to 2 feet) above the beach level, thus allowing a part of the sand to pass over the groin and maintain the downdrift beach. However, if the structural members undergo even slight movement and distortion, the removal or addition of panels becomes difficult or even impossible.

6.2.7 Alignment of Groins.

The maximum economy in cost is achieved with a straight groin perpendicular to the shoreline. Various modifications such as a T or L shaped head are sometimes added with the intention of limiting recession on the downdrift side of a groin or discouraging the development of rip currents. While these modifications may sometimes achieve the intended purpose, the zone of maximum recession is often simply shifted downdrift from the groin, limiting the benefits.

6.2.8 Order of Construction and Filling of Groins.

The importance of minimizing downdrift erosion after construction of a groin or groin system cannot be overemphasized. Unless the natural longshore transport is of sufficient magnitude to quickly fill the updrift side of the updrift groin and the groin compartments or unless erosion of the downdrift area is inconsequential, artificial filling will be necessary.

At sites where a groin system is under construction, two possibilities arise: either the groin system is to be filled artificially or longshore transport is to be depended upon to produce the fill.

6.2.8.1 With artificial fill, the only interruption of longshore transport will be the period between the time the groin system is constructed and the time the artificial filling is done. For economic reasons, the fill is usually placed in one continuous operation, especially if it is being accomplished by hydraulic dredge. Accordingly, to reduce the time period between groin construction and deposition of fill, all groins should preferably be constructed concurrently. Deposition of fill should commence as soon as progress of groin construction permits.

6.2.8.2 When depending upon longshore transport, no groin will fill until all the preceding updrift groins have been filled. This natural filling will reduce the supply to downdrift beaches. The time period required for the entire system to fill naturally and the material to resume its unrestricted movement downdrift may be so long that severe downdrift damage may result. Therefore, to reduce the possibility of such occurrence, only the groin or group of groins at the downdrift end should be constructed initially. The second groin, or group, should not be started until the first has filled and material passing has again stabilized the downdrift beach. Although this method may increase costs, it will not only aid in reducing damage, but will also provide a practical guide to the spacing of the groins.

6.3 Jetties.

6.3.1 Definition.

A jetty is a structure that extends into the water to direct and confine river or tidal flow into a channel and prevent or reduce the shoaling of the channel by littoral material. Jetties located at the entrance to a bay or river also serve to protect the entrance channel from wave action and cross-currents. When located at inlets through barrier beaches, jetties also stabilize the inlet location.

6.3.2 Siting.

The proper siting and spacing of jetties for the improvement of a coastal inlet are important. Careful study, which may include model studies in some cases, must be given to the following hydraulic, navigation, control structure, sedimentation, and maintenance considerations:

6.3.2.1 *Hydraulic factors of Existing Inlet*

- The tidal prism and cross section of the gorge in the natural state;
- Historical changes in inlet position and dimensions;
- Range and time relationship of the tide inside and outside the inlet;
- Influence of storm surge or wind setup on the inlet;
- Influences of the inlet on tidal prism of the estuary and effects of freshwater inflow on estuary;
- Influence of other inlet on the estuary;
- Tidal and wind-induced currents in the inlet.

6.3.2.2 *Hydraulic Factors of Proposed Improved Inlet*

- Dimensions of inlet;
- Effects of inlet improvements on currents in the inlet and on the tidal prism, salinity in the estuaty, and on other inlets into the estuary;
- Effects of waves passing through the inlet.

6.3.2.3 *Navigation Factors of the Proposed Improved Inlet*

- Effects of wind, tides, and currents on navigation channel;
- Alignment of channel with respect to predominant wave direction and natural channel of unimproved inlet;
- Effects of channel on tide, tidal prism, and storm surge of the estuary;
- Determination of channel dimensions based on design vessel data and number of traffic lanes;
- Other navigation factors such as (a) relocation of navigation channel to alternative site, (b) provision for future expansion of channel dimensions, and (c) effects of harbour facilities and layout on channel alinement.

6.3.2.4 *Control Structure Factors*

- Determination of jetty length and spacing by considering the navigation, hydraulic, and sedimentation factors;
- Determination of the design wave for structural stability and wave runup and overtopping considering structural damage and maintenance.

6.3.2.5 *Sedimentation Factors*

- Efffects of both net and gross longshore transport on method of sand bypassing, size of impoundment area, and channel and maintenance;
- Legal aspects of impoundment area and sand bypassing process.

6.3.2.6 *Maintenance Factor*

Bypassing and/or channel dredging will usually be required, especially if the cross-sectional area required between the jetties is too large to be maintained by the currents associated with the tidal prism.

6.3.4. Functions of Jetties

Jetties have one or more of the following functions:

- to block the entry of littoral drift into a channel;
- to serve as training walls for inlet tidal currents;
- to stabilize the position of a navigation channel;
- to serve as breakwaters to reduce wave action in a channel;
- to increase the velocity of tidal currents and flush sediments from a channel.

Where there is no predominant direction of longshore transport, jetties may stabilize nearby shores, but only to the extent that sand is impounded at the jetties. The amount of sand available to downdrift shores is reduced, at least until a new equilibrium shore is formed at the jetties. Usually, where longshore transport predominates in one direction, jetties cause accretion of the updrift shore and erosion of the downdrift shore.

The stability of the shore downdrift of inlets, with or without jetties, may be improved by artificial nourishment to make up the deficiency in supply due to storage in the inlet. When such storage is done mechanically, using the available littoral drift from updrift sources, the process is called *sand bypassing*.

6.4 Shore-connected Breakwaters.

6.4.1 Definition

A *shore-connected breakwater* is a structure that protects a shore area, harbour, anchorage, or basin from waves. Breakwaters for navigation purposes are constructed to create calm water in a harbour area, which provides protection for safe mooring, operating and handling of ships, and harbour facilities.

6.4.2 Types.

Breakwaters may be rubble mound, composite, concrete caisson, sheet-piling cell, crib, or mobile. In Jamaica, breakwaters that have been built on the open coast are generally of rubble-mound construction. Precast concrete shapes, such as tetrapods of tribars, may also be used for armour stone when sufficient size rock is not obtainable.

6.4.3 Siting

Shore-connected breakwaters provide a protected harbour fot vessels. The most important factor in siting a breakwater is determining the best location that will produce a harbour area with minimum wave and surge action over the greatest period of time in the year. This determination is made through the use of refraction and diffraction analyses. Other siting factors are direction and magnitude of longshore transport, the harbour area required, the character and depth of the bottom material in the proposed harbour, and the available construction equipment and operating capability. Shore-connected structures are usually built with shore-based equipment.

6.4.4 Effects on the Shoreline

Like the jetty, the shore arm of the breakwater interposes a total littoral barrier in the zone between the seaward end of the shore arm and the limit of wave uprush until the impounding capacity of the structure is reached and the natural bypassing of the littoral material is resumed. The same accretion and erosion patterns that result from jetties also result from the installation of this type of breakwater. The accretion, however, is not limited to the shore arm; it eventually extends along the seaward face of the shore arm, building a berm over which littoral material is transported to form a large accretion area at the end of the structure in the less turbulent waters of the harbour. This type of shoal creates an ideal condition for sand bypassing. A pipeline dredge cna lie in the relatively quiet waters behind the shoal and transfer accumulated material to nourish the downdrift shore.

6.5 Off-shore Breakwaters

6.5.1 Definition

An *offshore breakwater* is a structure that is designed to provide protection from wave action to an area or shoreline located on the leeward side of the structure. Offshore breakwaters are usually oriented approximately parallel to shore. They may also provide protection for harbours or erodible shorelines, serve as a littoral barrier-sediment trap, or provide a combined function. These are generally of rubble-mound construction, although some cellular sheet-pile, rock-filled concrete caisson, timber crib, and floating concrete cellular designs have been used. Offshore breakwaters overseas have been constructed with timber, quarrystone, concrete armor units, concrete caissons, and even sunken ships.

6.5.2 Functional Operation

An offshore breakwater provides protection by reducing the amount of wave energy reaching the water and shore area in its lee. The breakwater structure reflects or dissipates the incident wave impacting directly on the structure and transmits wave energy by means of diffractin into the barrier's geometric shadow. This reduction of wave energy in the breakwater's shadow reduces the entrainment and transport of sediment by wave action in this region. Thus, sand transported from nearby regions by a predominant longshore current or circulation will tend to be depositied in the lee of the structure. This deposition causes the growth of a cuspate spit from the shoreline. If the structure's length is great enough in relation to its distance offshore, the cuspate spit may connect to the structure, forming a tombolo. Thus, breakwaters provide protection to the backshore property not only by reducing incident wave energy, but also by building a wider protective beach which acts as a buffer during storm events.

6.5.3 Shoreline Response

The shoreline response to the construction of any offshore breakwater is predominantly governed by the resulting alterations in the longshore transport of material in the vicinity and, to a lesser extent, by the onshore-offshore transport rate. The placement of a breakwater causes the shoreline to adjust to the new conditions and seek and equilibrium configuration.

6.5.3.1 If the incident breaking wave crests are parallel to the original shoreline, the waves diffracted into the offshore breakwater's shadow will transport sand from the edges of this region into the shadow zone. This process will continue until the shoreline configuration is essentially parallel to the diffracted wave crests and longhshore transport is again zero. In this instance the cuspate spit will have a symmetric shape, with the tombolos featuring concave sides and the cuspate spits exhibiting a more rounded convex shape.

6.5.3.2 For obliquely incident waves the longshore transport rate in the lee of the structure will initially decrease, causing deposition of the longshore drift. A cuspate spit is formed which will continue to grow until either the longshore transport rate past the structure is reestablished or a tombolo is formed. Depending on where the offshore breakwater is positioned relative to the littoral zone, the formation of a tombolo can act as a complete littoral barrier which can trap all the littoral drift until it is filled to capacity, at which time sand will be shunted around the seaward side of the structure, restoring the longshore transport rate. During this process severe erosion of the downdrift beach would be expected. The cuspate spit that results from oblique wave attack can be expectd to be asymmetric with its shape dependent on the structure length, the distance offshore, and the nearshore wave conditions.

6.5.4 Siting Considerations

The most important parameters governing the shore response to offshore breakwaters are those that affect diffraction. Wavelength, wave height, wave direction, and the breakwater gap all affect the resulting diffraction pattern. The shore responds by aligning itself with the patterns of the wave crests. The response rate is governed by the amount of wave energy available to transport sediment. Other important parameters are the local tidal range and natural beach slope, the supply of sediment, and the sediment grain size.

6.5 Sand Dunes.

6.5.1 Functions.

Sand dunes are an important protective formation. The dune ridges along the coast prevent the movement of storm tides and waves into the land area behind the beach. Dunes prevent storm waters from flooding the low interior areas. Dune ridges, which are farther inland, also protect but to a lesser degree than foredunes. Well established inland ridges are a second line of defense against erosion should the foredunes be destroyed by storms.

6.5.1.1 The use of native vegetation may be desirable to stabilize the dune sand that might migrate over adjacent areas and damage property. Stabilizing dunes also prevents the loss of their protection. At locations that have an adequate natural supply of sand and are subject to inundations by storms, a belt of dunes can provide protection more effectively at a lower cost than a seawall.

6.5.1.2 Sand dunes near the beach not only protect against high water and waves but also serve as stockpiles to feed the beach. Sand accumulation on the seaward slope of a dune will either build or extend the dune toward the shoreline. This sand, once in the dune, may be returned to the beach by a severe storm and thus nourish the beach. Fig. 19 is a schematic diagram of a storm wave attack on the beach and dune. As shown, the initial attack of storm waves is on the beach berm fronting the dune. Waves attack the dune when the berm is eroded. If the wave attack lasts long enough, the waves can overtop the dune, lowering the dune crest. Much of the sand eroded from the berm and dune is transported directly offshore and deposited in a bar formation. This process helps to dissipate incident wave energy during a storm, and offshore deposits are normally transported back to the beach by swells after the storm. Onshore winds transport the sand from the beach towards the foredune area, and another natural cycle of dune building proceeds. This dune building, however, is generally at a very slow rate unless supplemented by fences or vegetation.

6.5.2 Positioning

The location of a barrier dune can have a major influence on its durability and function. Well-vegetated dunes are effective against storm surge and can withstand moderate degrees of over topping, but they are highly vulnerable to erosion if the beach berm is either overtopped or recedes due to persistent wave attack. In the positioning of a new barrier dune, an allowance should be made for the normal shoreline fluctuations that are characteristic of the site. Serious problems of dune maintenance may often be avoided or minimized by positioning the foredune far enough back from the high water line to allow a reasonable amount of seasonal fluctuations. A minimum distance of 200 meters is suggested between the toe of the dune and the high water line.

6.5.2.1 The process of dune growth is an important consideration in locating barrier dune. Fully vegetated dunes expand only toward the sand source, which is usually the beach, and a relatively narrow strip of vegetation will, in most cases, stop all wind-transported sand. This means that, where possible, an allowance should be made for the seaward expansion of the dune with time. Also, when two dunes are desired, the first must be developed landward and have enough space left between it and the sea for the second or frontal dune.

6.5.2.2 On the low-lying coasts the crests of the storm berm is the highest point in the beach-dune area with the surface sloping back from the berm crest. This places the base of a new barrier dune below the elevation of the storm berm, making it more susceptible to overtopping during the early stages. It may also encourage ponding of the water overtopping the storm berm, resulting in water pressure, salt buildup, and destruction of vegetation along the toe of the dune. Where this problem exists, the dune location will ofter represent a compromise.

7. PROTECTIVE BEACHES & BEACH NOURISHMENT

7.1 The Protective Function of Beaches.

Beaches can effectively dissipate wave energy and are classified as shore protection structures of adjacent uplands when maintained at proper dimensions. Existing beaches are part of the natural coastal system and their wave dissipation usually occurs without creating adverse environmental effects. Since most beach erosion problems occur when there is a deficiency in the natural supply of sand, the placement of borrow material on the shore should be considered as one shore stabilization measure. It is advisable to investigate the feasibility of mechanically or hydraulically placing sand directly on an eroding shore, termed *beach restoration*, to restore or form, and subsequently maintain, an adequate protective beach, and to consider other remedial measures as auxiliary to this solution. Also, it is important to remember that the replenishment of sand eroded from the beach does not in itself solve an ongoing erosion problem and that periodic replenishment will be required at a rate equal to natural losses caused by the erosion. Replenishment along an eroding beach segment can be achieved by stockpiling suitable beach material at its updrift end and allowing longshore processes to redistribute the material along the remaining beach. The establishment and periodic replenishment of such a stockpile is termed *artificial beach nourishment*. Artificial nourishment then maintains the shoreline at its restored position. Whenever conditions are suitable for artificial nourishment, long reaches of shore may be protected at a cost relatively low compared to costs of other alternative protective structures. An additional consideration is that the widened beach may give additional benefits as a recreational amenity.

7.2 Planning for Protective Beaches.

The planning process for protective beaches should be carried out by fulfillment of the following tasks in the sequence presented:

7.2.1 *Determination of the Direction of Longshore Transport and Deficiency of Supply.*

The first step should be the determination of the longshore characteristics of the project site and adjacent coast, and deficiency in supply of material to the problem area. The best method of estimating the rate of longshore transport is by comparison of surveys of the subject area of shoreline over a period of time. The deficiency of the material supply is the rate of loss of beach material, i.e. the rate at which the material supply must be increased in order to make up for the loss of material due to littoral transport. If no natural supply of sediment is available as downdrift from a major littoral barrier, the net rate of longshore transport required will approximate the defiency in supply.

7.2.2 *Determination of the Average Characteristics of the Native Beach Sand.*

It will be necessary to sample and characterize native beach sands to obtain a standard for comparing the suitability of potential borrow sediments. Native sediments constitute those beach materials actively affected by beach processes during a suitable period of time (1-year minimum). During a year, at least two sets of samples should be collected from the surface of the active beach profile which extends from an upper beach elevation of wave dominated processes seaward to an offshore depth or "seaward limit" of littoral movement. Ideally, "winter" and "summer" beach conditions should be sampled. The textural properties of all samples are then combined or averaged to form the "native composite" sample which should serve as the native beach textural standard.

Textural properties of native sand are selected for comparison because they result from the selective winnowing and distribution of sediment across the active profile by shoreface processes; their distribution reflects a state of dynamic equilibrium between sediments and processes within the system.

7.2.3 *Selection of Borrow Material.*

After the characteristics of the native sand and the longshore transport processes in the area are determined, the next step is to select borrow material for beach fill or for periodic nourishment. An average native texture, the "native composite", is used to evaluate the suitability of potential borrow sand because the native textural patterns are assumed to be the direct result of sand sorting by natural processes.

Material finer than that exposed on the natural beach face will, if exposed on the surface during a storm, move to a depth compatible with its size to form nearshore slopes flatter than normal slopes before placement. Fill coarser than the sand on the natural beach will tend to remain on the foreshore and may be expected to produce a steeper beach. However, coarser material moved offshore during storms may not be returned to the beach after the storms. If borrow sand is very coarse it will probably be stable under normal as well as more severe conditions, but it may make the beach less desirable for recreational use or as wildlife habitat. If the borrow material is much finer than the native beach material, large amounts will move offshore and be lost from the beach. Angularity and mineral content of the borrow material may also prove to be important factors in its redistribution, deflation, and the aesthetic qualities of the beach.

7.2.4 *Berm Elevation and Width.*

Beach berms are formed by deposit of material by wave action. The height of a berm is related to the cycle change in water level, normal foreshore and nearshore slope, and the wave climate. Some beaches have no berms; others have one or several. Fig. illustrates a beach profile with two berms. The lower berm is the natural or normal berm and is formed by the uprush of normal wave action during the normal range of water level fluctuations. The higher berm, or storm berm, is formed by wave action during storm conditions. During most storms, waves and wave setups will cause an increase in the normal water level on the beach. Wave overtopping and backrush with sufficient duration may completely obliterate the natural beach berm.

Beach berms must be carefully considered in the planning of a beach fill. If beach fill is placed to a height lower than the natural berm crest, a ridge will form along the crest and high water may overtop the berm crest causing ponding and temporary flooding of the backshore area. Such flooding may be avoided if the fill is placed to a height lower than the natural berm crest elevation.

Several alternative techniques may be employed to estimate the height of the berm for design purposes. If a beach exists at the site, the natural berm crest height can be measured and future berm crest elevations can be estimated. An estimate may also be made by comparing the beach profile at the site with beach profiles at sites of similar characteristics (waves and tides) and similar size beach material. If enough wave data applicable to the project site are available, wave runup can be estimated to establish a design berm crest height and adjacent beach slope.

Criteria for specifying berm width depend on several factors. If the purpose of the fill is to restore an eroded beach to protect backshore improvements from major storm damage, the width may be determined as the protective width which has been lost during storms of record plus the minimum required to prevent wave action from reaching improvements. Where the beach is used for recreation, the justification for the increased width of the beach may be governed by the area required for recrea-recreational use. Where the beach fill is to serve as a stockpile to be periodically replenished, the berm should be wide enough to accommodate the recession expected during the intervals between nourishment operations.

7.2.5 *Slopes.*

The toe of a stockpile of beach material should not extend deeper than the effective limiting depth of sediment transport by wave-driven longshore currents. The initial slope of any beach fill will naturally be steeper than that of the natural profile over which it is placed. The subsequent behaviour of the slope depends upon the characteristics of the fill material and the nature of the wave climate. The design slope of a protective beach is derived through synthesis and the averaging of available data within and adjacent to the problem area, and is usually significantly flatter than the foreshore slope. Design slopes based on such data are usually in the range of 1:20 to 1:30 from low water datum to the intersection with the existing bottom.

Because of the working limitations of equipment used to place and shape the fill, and because of the natural selective sorting of the fill by waves and currents that takes place after the nourishment, "as constructed" slopes seldom turn out to be exactly the same as design slopes. Two construction approaches are recommended. One is to overbuild the upper part of the beach, and the other is to create an initial construction profile that extends significantly offshore. Both construction approaches result in an offshore fill section that is placed to a desired berm width and has steep initial slopes. This onshore fill eventually adjusts to a natural slope and narrows the berm, leaving the impression that much of the fill has been lost, although it has only moved offshore to re-establish a stable profile.

7.2.6 *Beach-fill Transition.*

The alignment of a nourished beach segment generally parallels the existing shoreline but is offset seawards by the width of the fill. The nourished segment can be thought of as a subtle headland that protudes from the existing coast. Transition from the existing shoreline to the line of the fill can be accomplished either by constructing "hard" structures such as groins and jetties, which compartment the fill or by filling transition zones between the terminal ends of the beach fill and the unrestored beach. Groins, jetties, and headlands do allow an abrupt termination of the beach fill at the project limits. However, these hard structures are often quite costly, unacceptable aesthetically, and more importantly, they may interrupt or modify the natural longshore transport flow in the area. If groins are used to terminate a fill, very careful attention should be given to design of the configuration of the fill and key aspects such as cross section, materials, and length.

If filled transition zones are selected, their length and transition angle will determine the additional volume of fill, and hence the cost, required for the project. The orientation of the transition shoreline will differ from the natural shoreline alignment, resulting in different erosion rates since the rate of littoral transport depends on the relative angle between the breakers and a particular shoreline segment.

7.2.7 *Feeder Beach Location.*

Dimensions of a stockpile or feeder beach are generally governed primarily by economic considerations involving comparisons of costs for different nourishment intervals. Therefore, planning a stockpile location must be considered in conjunction with stockpile dimensions. If the problem area is part of a continuous and unobstructed beach, the stockpile should be located at the updrift end of the problem area. Until the stockpile material is transported by littoral processes to the beach area downdrift of the stockpile location, that beach may be expected to recede at the same rate as determined from historical survey data. If economically justified, stockpiles may be placed at points along the problem area, which will decrease the time interval between stockpile placement and complete nourishment of the area. Stockpile lengths from a few hundred meters to a kilometer have been employed successfully. If the plan involves a feeder beach just downdrift to a coastal inlet, wave refraction and inlet currents must be considered to locate the feeder beach so that a minimum of material is transported into the inlet. A supplementary structure (such as a groin) may be needed to reduce the material movement into the inlet caused by either tidal currents or a change in longshore transport.

The nearly continuous interception of littoral material on the updrift side of an inlet and the mechanical transportation of the material to a point on the downdrift shore (sand bypassing) constitute a form of stockpiling for artificial nourishment to the downdrift shore. In this type of operation, the size of the stockpile or feeder beach will generally be small; the stockpile material will be transported downdrift by natural forces at a rate about equal to or greater than the rate of deposition. For the suggested location of the stockpile or feeder beach for this type of operation. The need for a jetty or groin between the stockpile or feeder beach and the inlet to prevent the return of a material to the inlet should be evaluated.

8. TYPICAL IMPACTS FROM CONSTRUCTION OF SHORELINE FACILITIES

In recent years, the question of total environmental quality has reached high levels of public concern. Shore protection measures by their very nature are planned to result in some modification of the physical environment. However, thorough planning and design require that the full impact of that modification on the ecological and aesthetic aspects of the environment be fully considered and understood. If there is potential for a significant adverse effect to any environmental feature, the design analysis of a shore improvement project should include a multidiscipline appraisal of the total impact of the project, which includes environmental quality as well as economic benefits. The necessity for this appraisal at the planning and design stage is apparent and required by law. If there is a probability for conflict between planned construction and environmental quality, a final decision by NRCA based upon social, technical, and economic analysis, will be required.

8.1 Potential Impacts from Seawalls, Bulkheads, and Revetments

8.1.1 *Recession of Adjacent Shores.*

Construction of seawalls, bulkheads and revetments give protection only to the land immediately behind them, and none to adjacent areas upcoast or downcoast. Whenever these types of protective structures are built upon a receding shoreline, the recession on adjacent shores will continue, and may even be accelerated. Where it is desired to maintain a beach in the immediate vicinity of these types of structures, companion works may be necessary.

8.2.2 *Scouring in Front of Base.*

The use of vertical or nearly vertical walls can result in severe scouring when the toe or base of the wall is in shallow water. Waves breaking against a wall deflect energy both upward and downward. The downward component causes scouring of the material at the base of the wall. To prevent scouring, protection should be provided at the base of the wall in the form of armour stone of adequate size to prevent displacement, and of such gradation as to prevent the loss of the foundation material through the voids of the stone with consequent settlement of the armour.

8.2.3 *Beach Profile Changes.*

Vertical walls reflect wave energy back offshore where resonant effects may cause changes in beach profile.

8.2 Potential Impacts From Groins.

8.2.1 *Cut-off of Natural Littoral Transport.*

A properly designed groin system may improve a protective beach. However, this method must be used with caution, for if a beach is restored or widened by impounding the natural supply of littoral material, a corresponding decrease in supply may occur in downdrift areas resulting in continuing erosion.
The detrimental effects of groins can usually be minimized by placing artificial fill in suitable quantity concurrently with groin construction to allow downdrift bypassing of littoral material; such stockpiling is called *filling the groins.*
Groin construction should be sequential from fartherest downdrift to the most updrift location within the system in order to achieve maximum natural filling of the groin compartments.

8.2.2 *Abrupt Directional Change in Shoreline.*

The first step in the design of a groin or groin system is the determination of the eventual beach alignment. The beach alignment is the orientation that the shoreline will take near the groins. By their very nature groins will interrupt littoral transport, causing buildup of material at the updrift end and eventual advance of the shoreline, with a tendency for recession at the downdrift end. In order to reduce the abruptness of directional changes at the ends of a groin system engineers gradually increase and gradually reduce the lengths of the the groins at the updrift and downdrift ends -thereby encouraging formation of transition segments at each end, to smooth out the changes in shoreline alignment.

8.2.3 *Undesirable Change in the Beach Quality.*

The decision as to whether to use groins as part of a protective beach depends heavily upon the availability of *suitable* sand for the purpose.
The use of coarser fill material than the natural in-place material, is sometimes very tempting, as this may reduce nourishment requirements. But such material may be less suitable as wildlife habitat, or as beach sand for human recreation. Furthermore, it is to be expected that the introduction of incompatible fill material on a beach segment will, in the long term, lead to some of the added material finding its way onto adjacent downdrift sections of the shoreline, possibly causing undesirable beach-quality effects. The above undesirable effects may be mitigated by placing a sacrificial veneer of fine material over coarser, more protective foundation material.

8.2.4 *Rip Currents.*

The maximum economy in cost is achieved with a straight groin, perpendicular to the shoreline. But water pushed by waves into a groin compartment will sometimes return offshore in the form of rip currents along the sides of groins. In this way, groins may actually increase the amount of sediment which moves offshore as well as the distance that it travels seaward. Rip currents can be serious hazards for unsuspecting sea-bathers and even the strongest of swimmers are sometimes unable to extricate themselves from being carried away and drowned by the velocity and forcefulness of rip currents. In order to minimize loss of sediment and discourage development of rip currents, groins are sometimes built in a curved alignment, or with T or L-shaped sections at the ends.

8.3 Potential Impacts From Jetties.

A jetty interposes a total littoral barrier in that part of the littoral zone between the seaward end of the structure and the limit of wave uprush on the beach. Jetties are sometimes extended seaward to the contour position equivalent to the project depth of the channel.

8.3.1 *Accretion and Erosion.*

Accretion takes place updrift from the structures at a rate proportional to the longshore transport rate, and erosion takes place downdrift at about the same rate. The quantity of the accumulation depends on the length of the structure and the angle at which the resultant of the natural forces strikes the shore. If the angle of the shore line of the impounded area is acute with the structure, the impounded capacity is less than it would be if the angle were obtuse. Structures that are perpendicular to the shore have a greater impounding capacity for a given length and thus are usually more economical than those at an angle, because perpendicular jetties can be shorter and still reach the same depth. If the angle is acute, channel maintenance will be required sooner due to littoral drift passing around the end of the structure.

8.3.2 *Channel Shoaling*

Planning for jetties at an inlet should include some method of bypasing the littoral drift to eliminate or reduce channel shoaling and erosion of the downdrift shore.

8.4 Potential Impacts From Shore-connected Breakwaters.

8.4.1 *Accretion and Erosion*

Like the jetty, the shore arm of the breakwater interposes a total littoral barrier in the zone between the seaward end of the shore arm and the limit of wave uprush until the impounding capacity of the structure is reached and the natural bypassing of the littoral material is resumed. The same accretion and erosion patterns that result from jetties also result from the installation of this type of breakwater. The accretion, however, is not limited to the shore arm; it may eventually extend along the seaward face of the shore arm, building a berm over which littoral material may be transported to form a large accretion area at the end of the structure in the less turbulent waters of the harbour.

8.5 Potential Impacts From Off-shore Breakwaters.

A major concern in designing an offshore breakwater for shore protection is determining if the resulting shore adjustment should be connected to the structure. There are advantages and disadvantages for each shoreline configuration, and the designer is usually confronted with many aspects to consider before making a choice between cuspate spits and tombolos.

8.5.1 *Cuspate Spits and Tombolos*

While both shoreline adjustments affect the adjacent shoreline, cuspate spits are usually preferred over tombolos. When a tombolo forms, large quantities of sediment can be impounded, resulting in extensive erosion downdrift of the structure. A cuspate spit formation will often allow the majority of littoral drift to pass and thus have a lesser effect on the downdrift beach. During seasonal changes in wave direction, a cuspate spit is more likely to allow the littoral drift to pass landward of the offshore breakwater. Therefore, there is less chance of the material being retarded by passage to the seaward of the structure where parts of the littoral drift may be lost permanently.

8.5.1.1 Cuspate spits and tombolos do not provide uniform erosion protection along an entire project, and legal problems could arise if the protected region is not owned by government.

8.5.1.2 The formation of a tombolo increases the length of beach available for recreational use and greatly facilitates the monitoring and maintenance of the structure, but beach users may be inclined to use the structure or swim immediately adjacent to it which could be dangerous.

8.6 Summary of Potential Impacts and Mitigatory Measures.

A summary of the types of physical and environmental impacts that could result from construction of some of the most common types of facilities for protection and enhancement of shorelines is given in Table below:

Table -Summary of Typical Impacts and Mitigatory Measures

Type of Shore Protection	Typical Impacts	Mitigatory Measures
Seawalls, Bulkheads, and Revetments	Recession of adjacent shores	Provide wing-walls or tie-ins to adjacent land features. Use groins of gradually changing lengths at both the updrift and downdrift ends of the structures to encourage smooth transitions in shoreline alignment.
	Scouring in front of base	Use armour stones to make a rock blanket in front of base. Stepping the front face of seawalls reduces wave backwash, thereby reducing the tendency for scouring at the base.
	Changes in beach profile.	Stepped or concave-curved wall faces reflect less of the impacting wave energy, and therefore will tend to have lesser tendency to cause changes in beach profiles in front of the structures than vertical-face walls.
Groins & Jetties.	Cut-off of natural littoral transport	Place artificial fill in suitable quantity concurrently with groin construction to allow downdrift bypassing of littoral material.
	Abrupt directional change in shoreline.	Use groins of gradually changing lengths to encourage smooth transitions in shore alignment.
	Undesirable change in the quality of beach sand.	Place veneer of desirable material over less desirable material as necessary.
	Rip Currents.	The development of rip currents may sometimes be avoided by constructing groins on a curved alignment or with T or L-shaped ends, instead of straight and perpendicular to the shoreline.

List of References

Title	Author	Publisher
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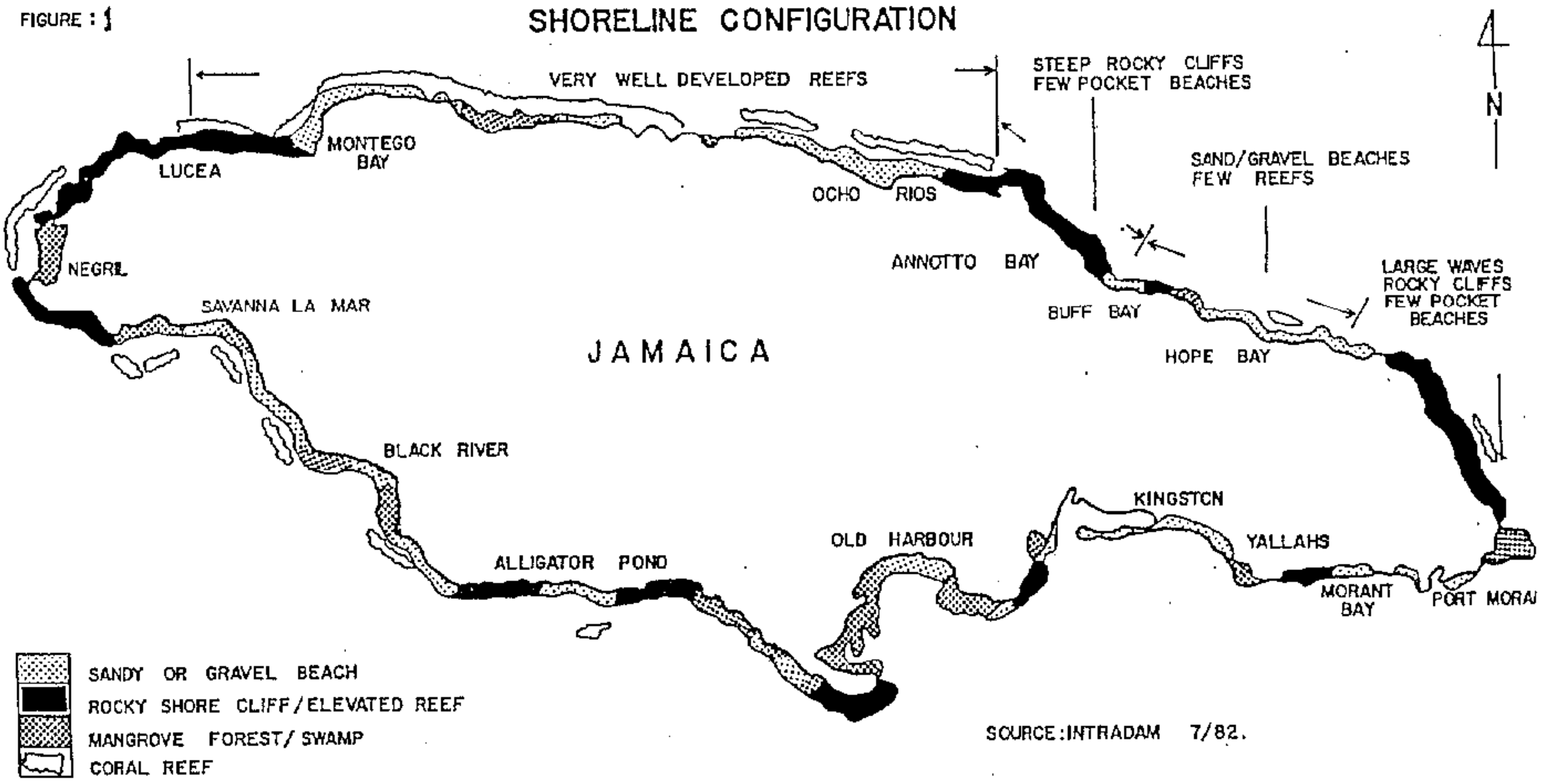
2. ENVIRONMENTAL ASSESSMENT SOURCEBOOK, Vols I, .II & III. (1991)	Environmental Department	The World Bank
3. ENVIRONMENTAL EVALUATION OF COASTAL ZONE PROJECTS. (1991)	Office of the Environment Asian Development Bank	Asian Development Bank
4. MARINE AND COASTAL PROTECTED AREAS - A Guide for Planners (1984)	Rodney V. Salm & John R. Clark	I.U.C.N
5. COUNTRY ENVIRONMENTAL PROFILE JAMAICA. (1987)	Ralph M. Field Associates, Inc.	International Institute for Environment and Development
6. BEACHES OF ACCRETION AND PROGRADATION IN JAMAICA (1976)	P.A. Wood	Journal of the Geological Society of Jamaica, Vol. XV
7. CARIBBEAN COASTAL MANAGEMENT STUDY: HELLSHIRE COAST (1989)	Edited by Ivan Goodbody	University of the West Indies Centre for Marine Sciences
8. BEACH STABILITY AT NEGRIL AND BLOODY BAY. (1990)	Marcel A. Anderson, Elaine Foster, Anthony McKenzie	Natural resources Conservation Department
9. MARINE EROSION AT CORNWALL BEACH, MONTEGO BAY. (1972)	L. Alan Eyre	Unpublished. Jamaica Tourist Board

FIGURE : 1

SHORELINE CONFIGURATION



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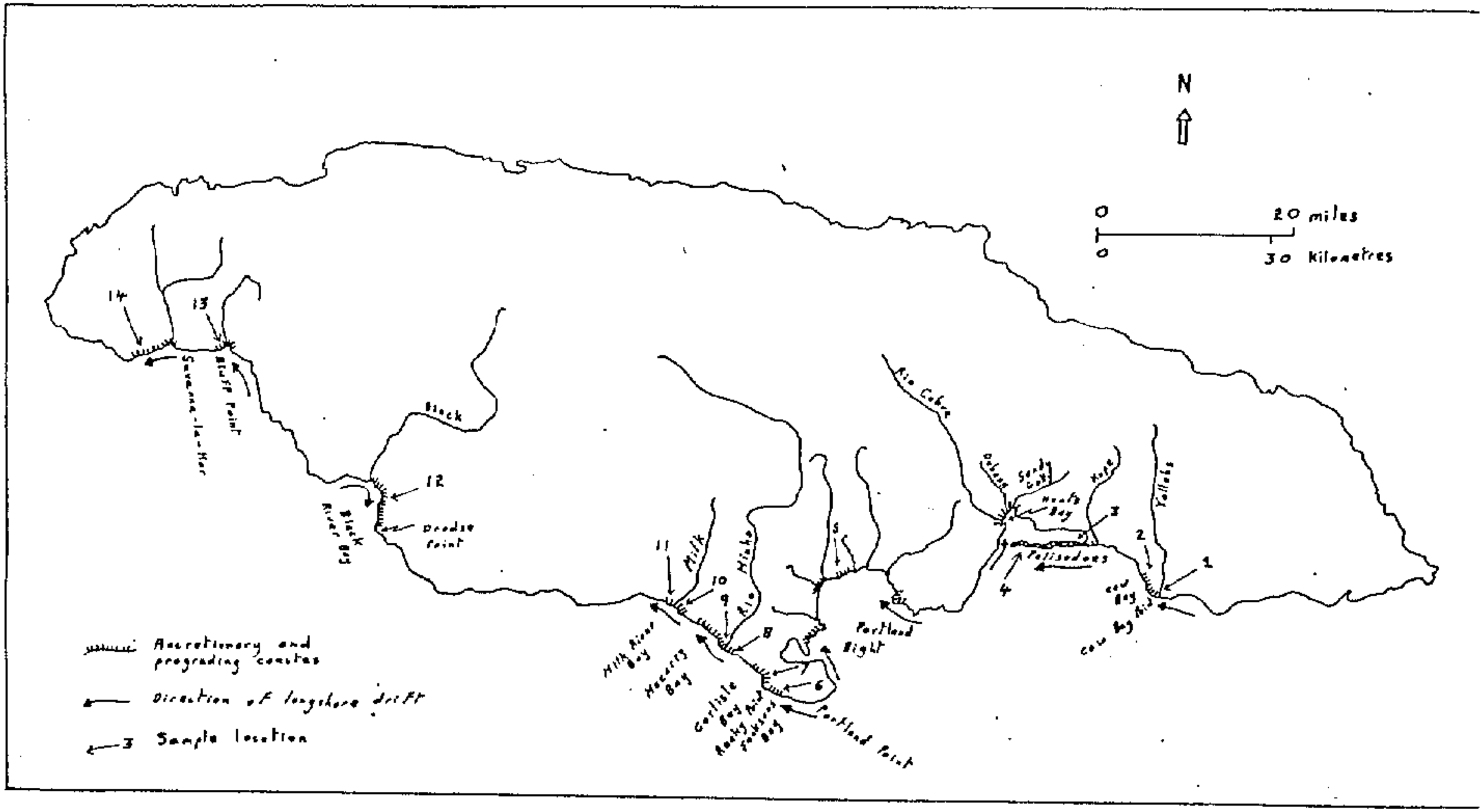
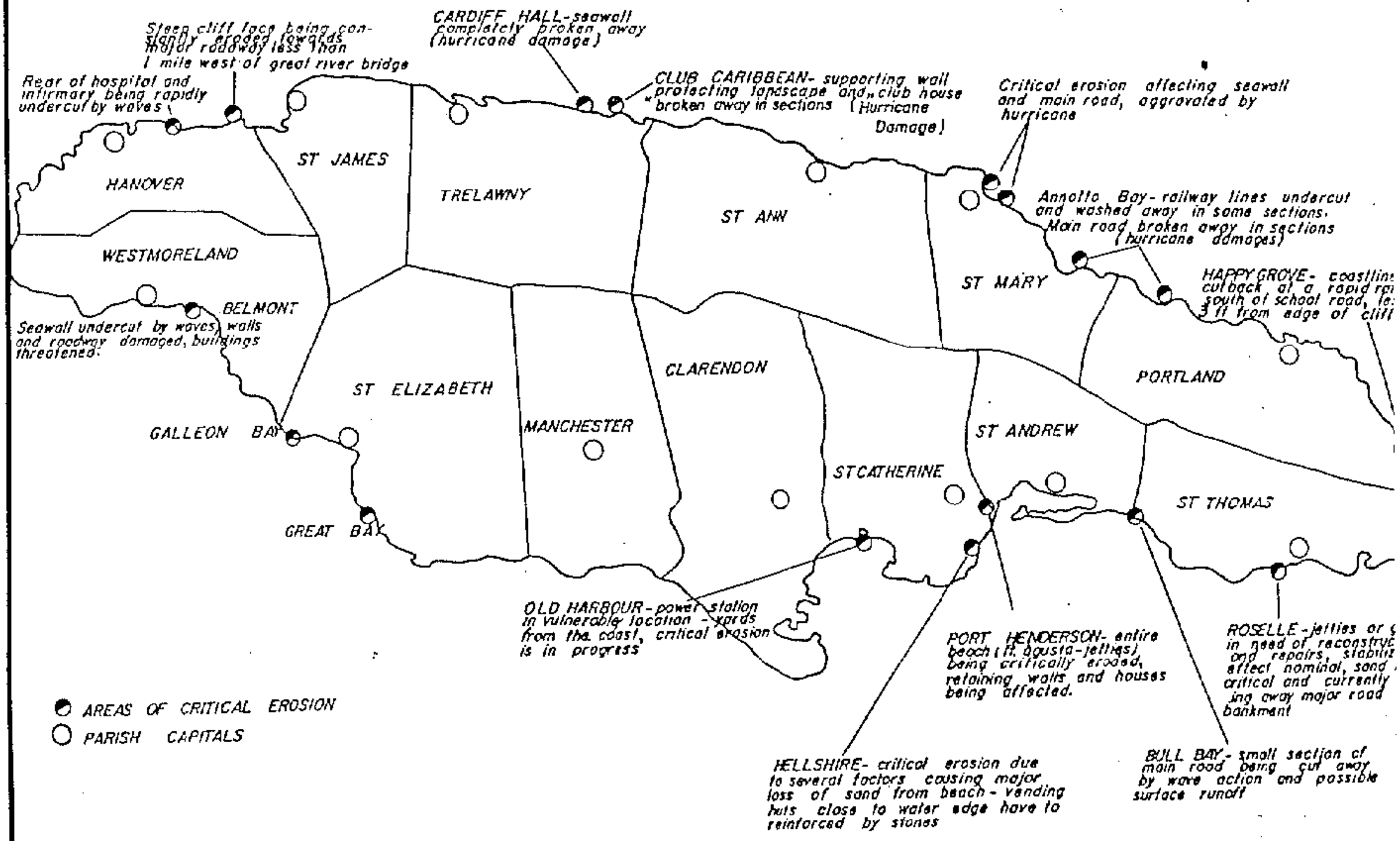


Fig. 2 Distribution of accretionary and progradational beaches, Jamaica.

FIGURE: 3

AREAS OF CRITICAL BEACH EROSION



Rear of hospital and infirmary being rapidly undercut by waves

Steep cliff face being constantly eroded towards major roadway less than 1 mile west of great river bridge

CARDIFF HALL-seawall completely broken away (hurricane damage)

CLUB CARIBBEAN- supporting wall protecting landscape and club house broken away in sections (Hurricane Damage)

Critical erosion affecting seawall and main road, aggravated by hurricane

Annotto Bay- railway lines undercut and washed away in some sections. Main road broken away in sections (hurricane damages)

HAPPY GROVE- coastline cutback at a rapid ra south of school road, le 3 ft from edge of cliff

Seawall undercut by waves, walls and roadway damaged, buildings threatened.

OLD HARBOUR- power station in vulnerable location - yards from the coast, critical erosion is in progress

PORT HENDERSON- entire beach (ft. agusta-jetties) being critically eroded, retaining walls and houses being affected.

ROSELLE- jetties or in need of reconstru and repairs, stabili affect nominal, sand critical and currently ing away major road bankment

HELLSHIRE- critical erosion due to several factors causing major loss of sand from beach - vending huts close to water edge have to reinforced by stones

BULL BAY- small section of main road being cut away by wave action and possible surface runoff

Source: Natural Resources Conservation Division.

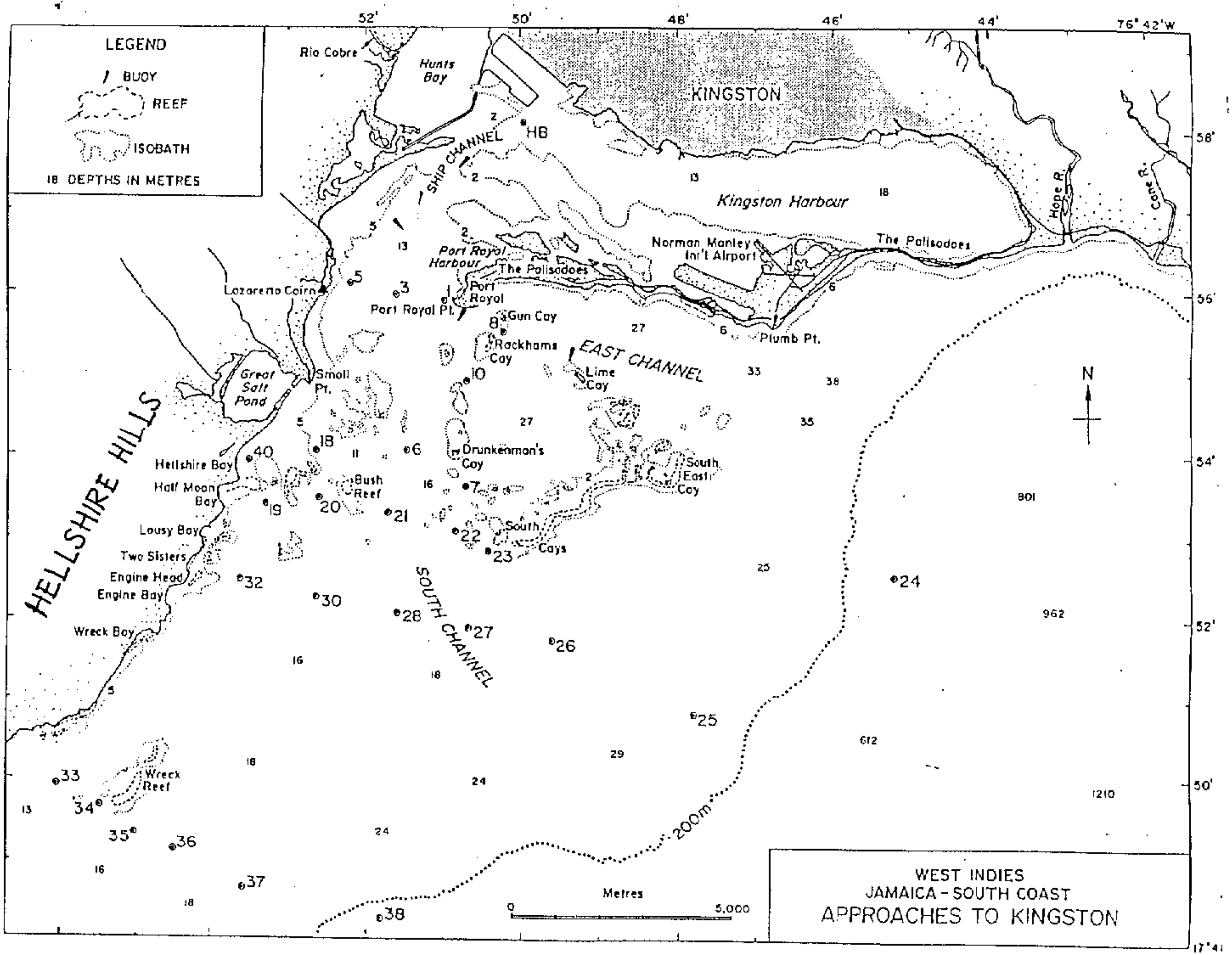


Fig. 4. Location of the Study Area.

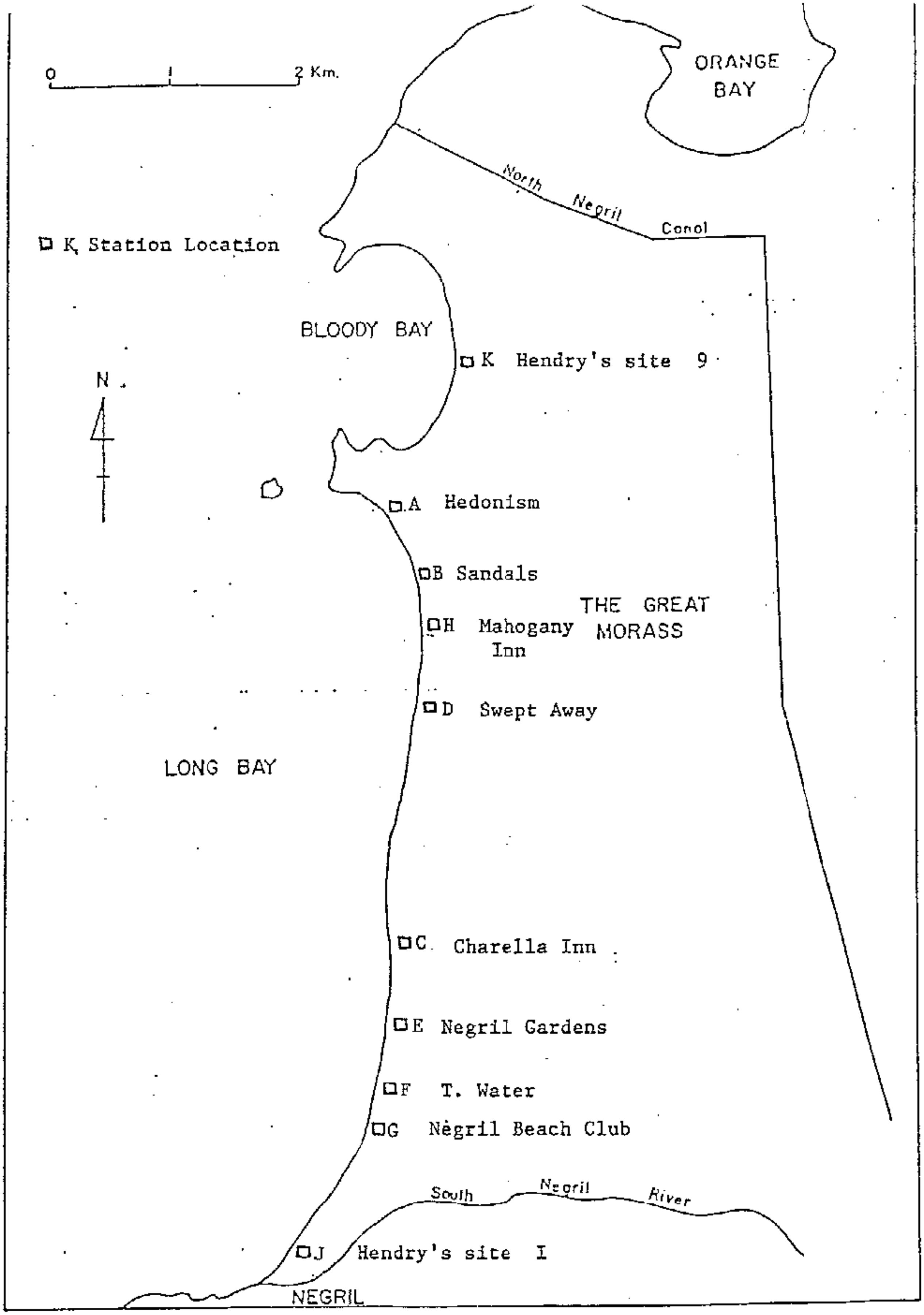


Figure 5 Location of beach survey monuments. NEGRIL

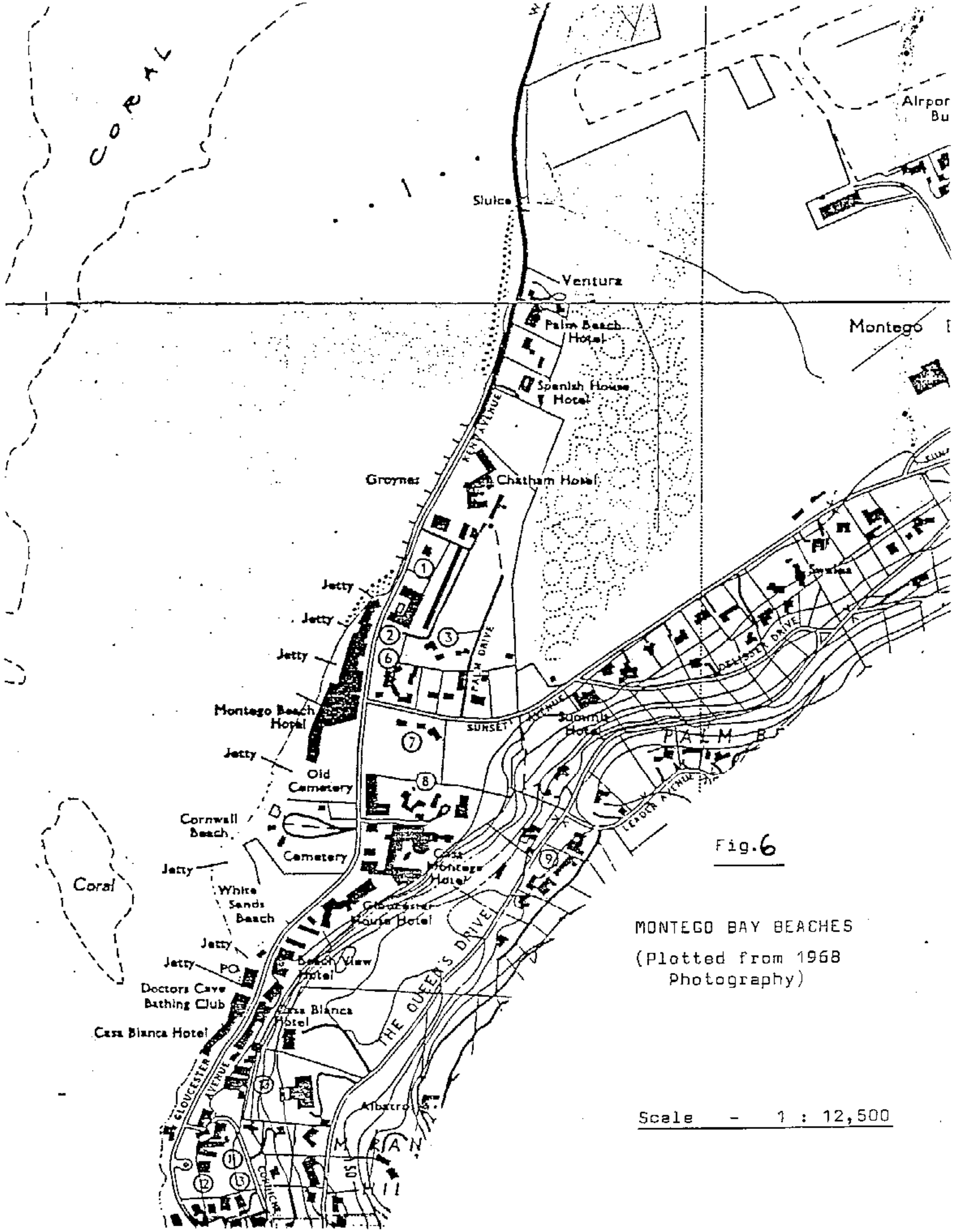


Fig. 6

MONTEGO BAY BEACHES
(Plotted from 1968
Photography)

Scale - 1 : 12,500

SEVERELY ERODED CORNWALL BEACH - NOVEMBER, 1972

Fig. 7.

Photograph taken 10th November, 1972 looking southwest along Cornwall Beach, showing severe beach erosion caused by northers over the previous few days.

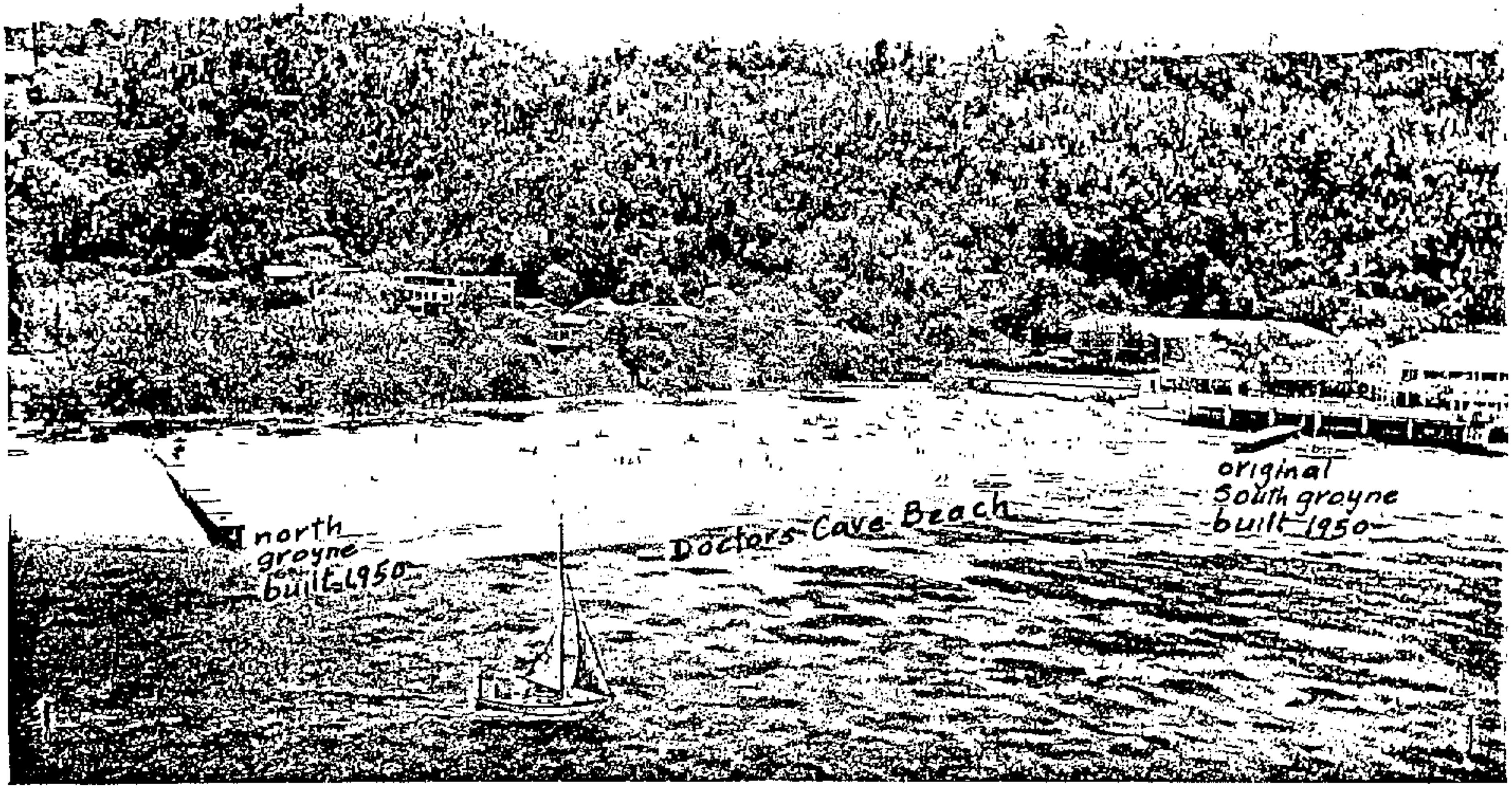
Note the high, unstable beach berm at left foreground.

SEVERELY ERODED CORNWALL BEACH - FEB.. 1973

Aerial photograph taken Feb. 17th, 1973, showing severely eroded shoreline of Cornwall Beach which took place during northers in early November, 1972.

Note that while there has been further build-up of sand at the southern end of Doctors Cave, the shoreline has moved back to a point approximately halfway along the northern groyne.

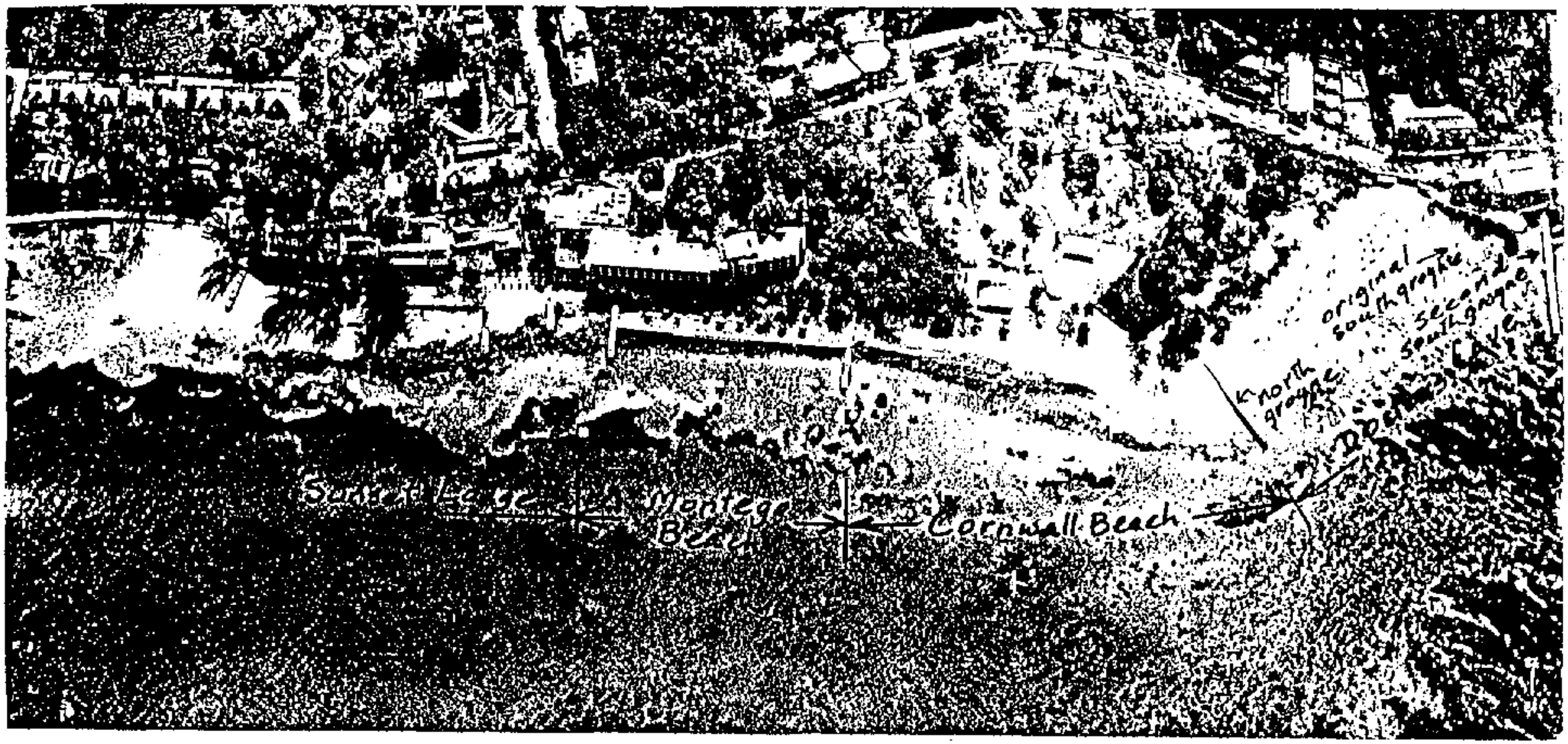
Fig. 8.



DOCTORS CAVE BEACH - 1955

Fig. 9.

Photograph taken 17th April 1955 showing wide white sand beach at Doctors Cave Bathing Club. This was five years after the first two groynes were installed. The northern groyne was 150 ft. long, the southern groyne 85 ft. long. Note, at left, the shoreline almost out to the tip of the northern groyne.

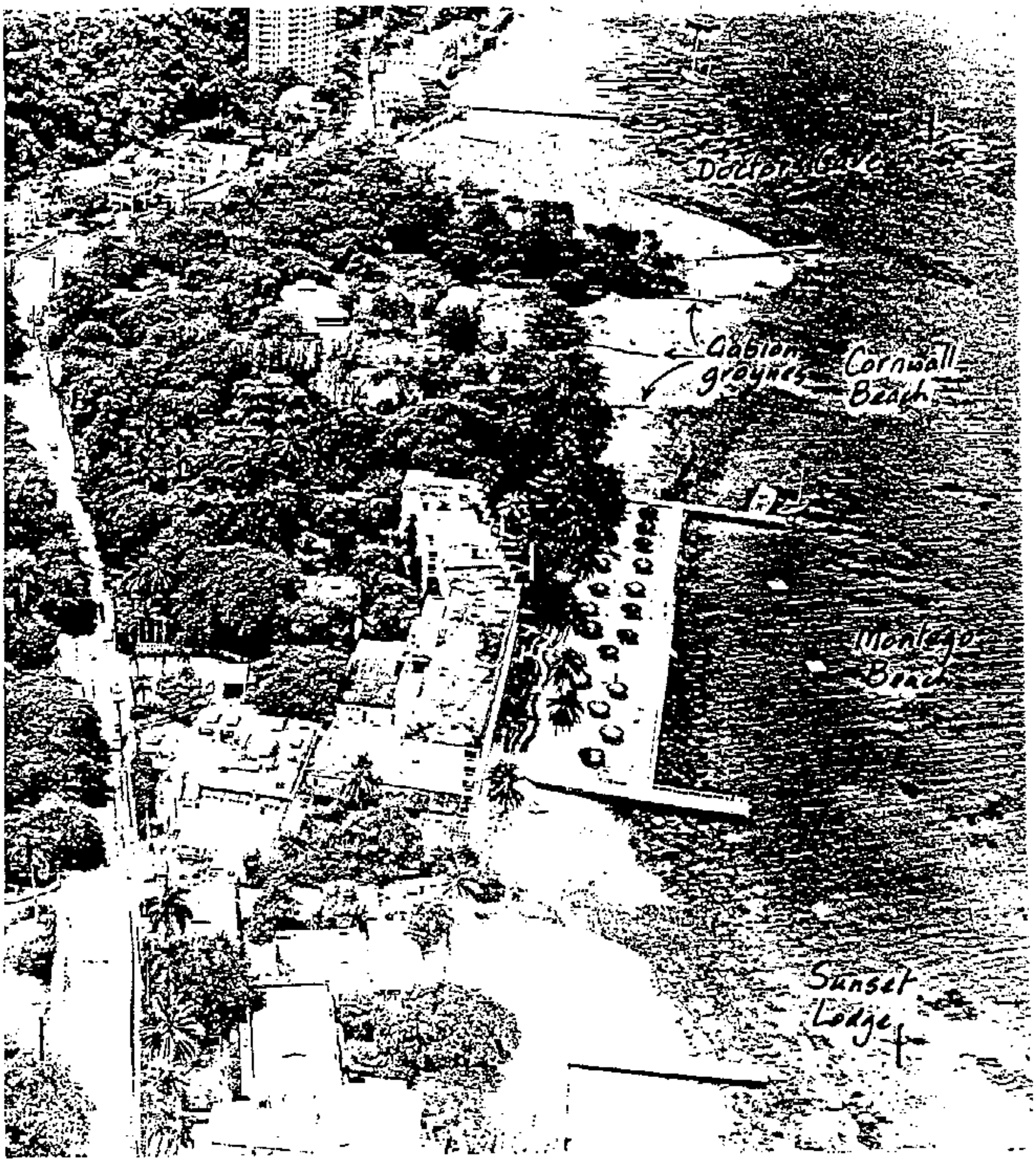


SEAWALLS & GROYNES ALONG MONTEGO BAY BEACHES - FEB. 1963

PLATE NO. 8 - Photograph taken Feb., 1963 showing the various seawalls and groynes along Doctors Cave, Cornwall, Montego Beach Hotel, and Sunset Lodge beaches.

Fig. 10.

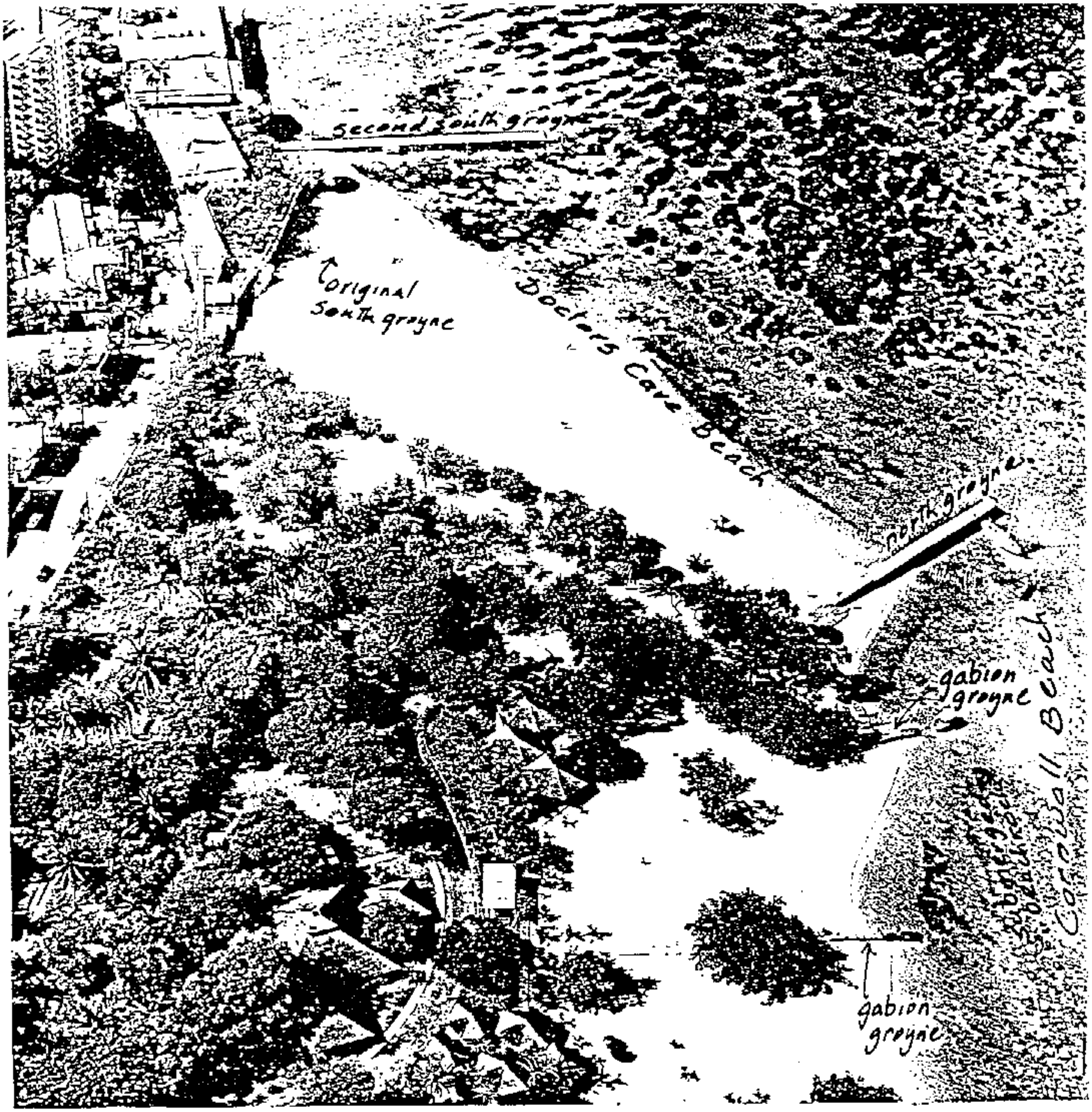
Note that there has been significant accretion at the southern end of Doctors Cave, since the new, longer southern groyne was installed in 1960. Concurrently, the beachline has moved back a little at the northern groyne.



GABION GROYNES ON CORNWALL BEACH - SEPT., 1973

Fig. 11

Photograph taken 2nd Sept., 1973 showing three 65 ft. long gabion groynes installed on Cornwall Beach in May, 1973 to try to retain a sudden deposit of around 2,000 Cu. Yd. of sand which was thrown up by a norther during the first week of March, 1973.



EFFECT OF GABION GROYNES ON CORNWALL BEACH - OCT., 1976

Fig. 12.

Photograph taken 1st Oct., 1976 showing stabilizing effect of gabion groynes on Cornwall beach.

Note also, at top left, that the original short southern groyne on Doctors Cave is now completely embedded in sand, and an additional stretch of beach has been built up between the short groyne and the long groyne.

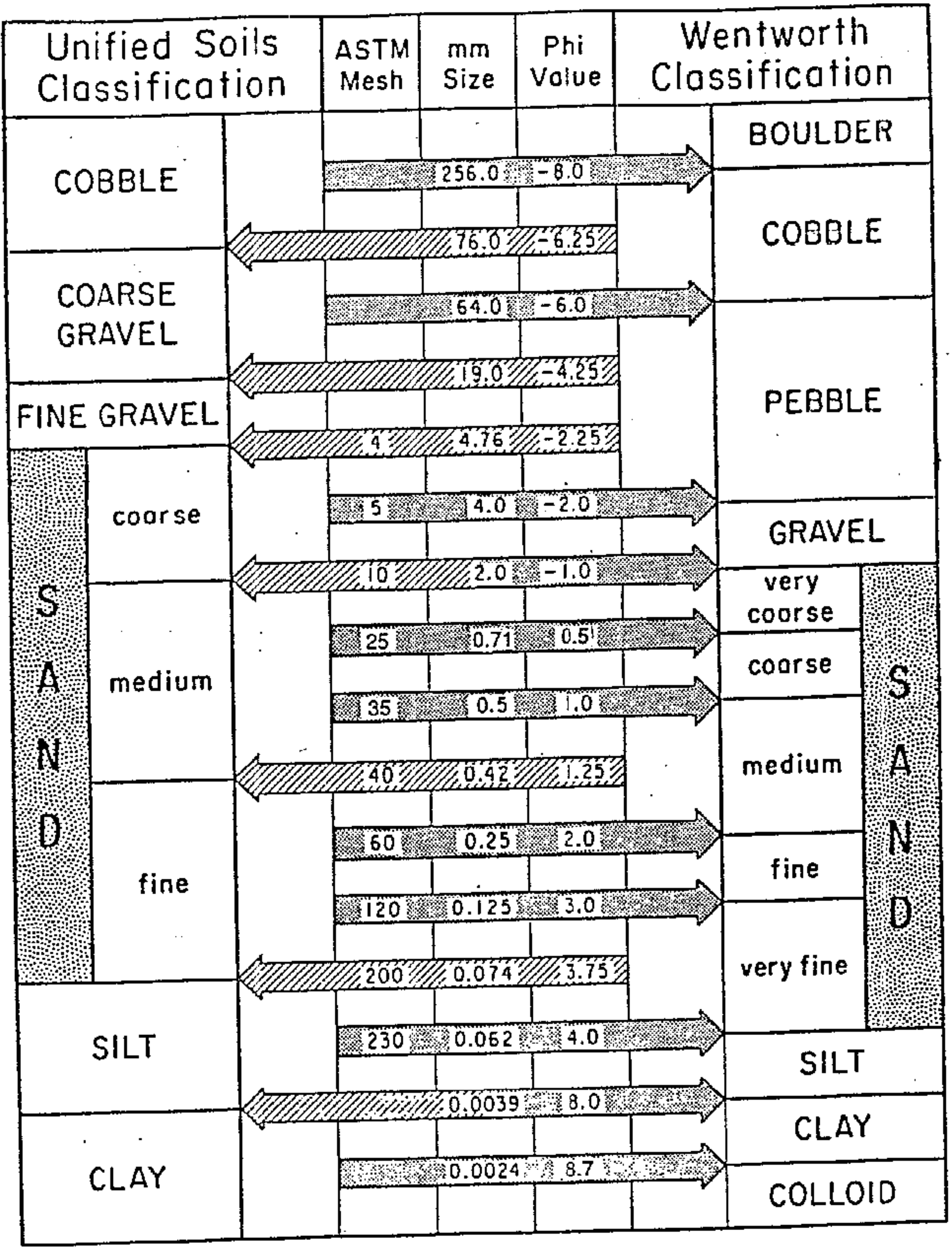


Figure 14 Grain-size scales (soil classification).

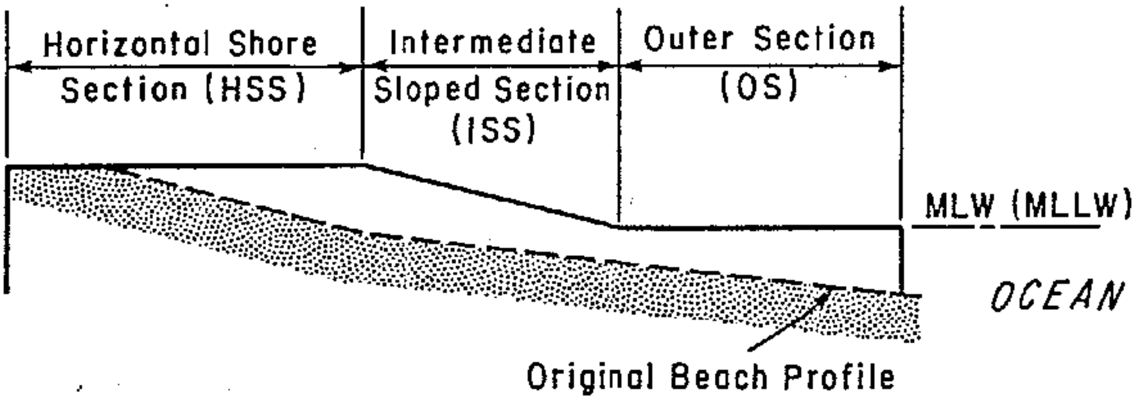


Figure 18 Sections of a typical groin.

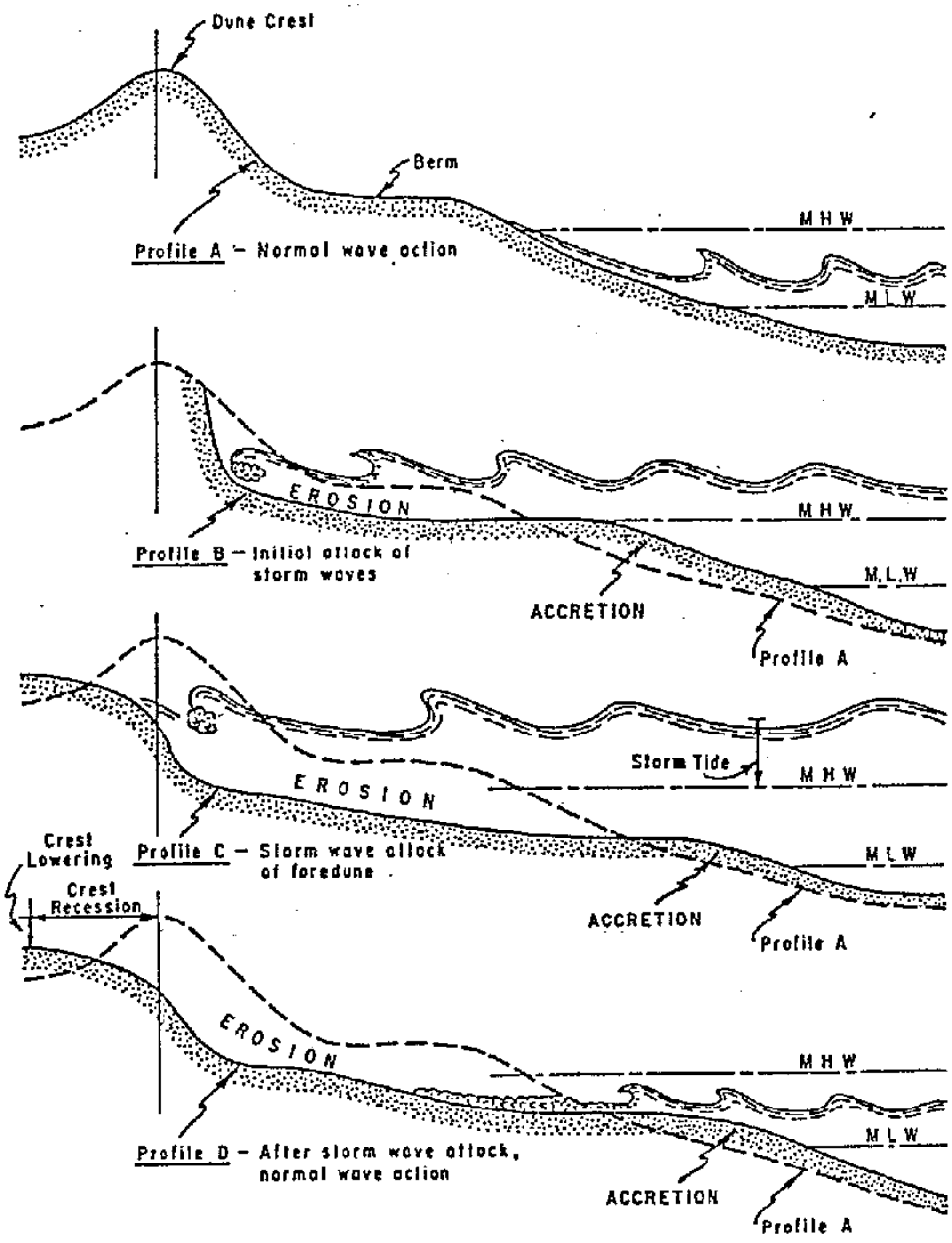


Figure 19 Schematic diagram of storm wave attack on beach and dune.

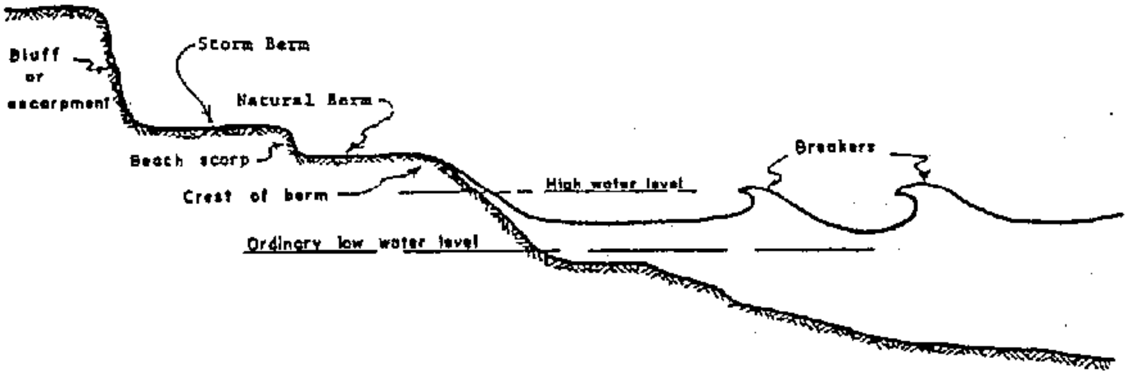


Figure 20 Beach berm system.

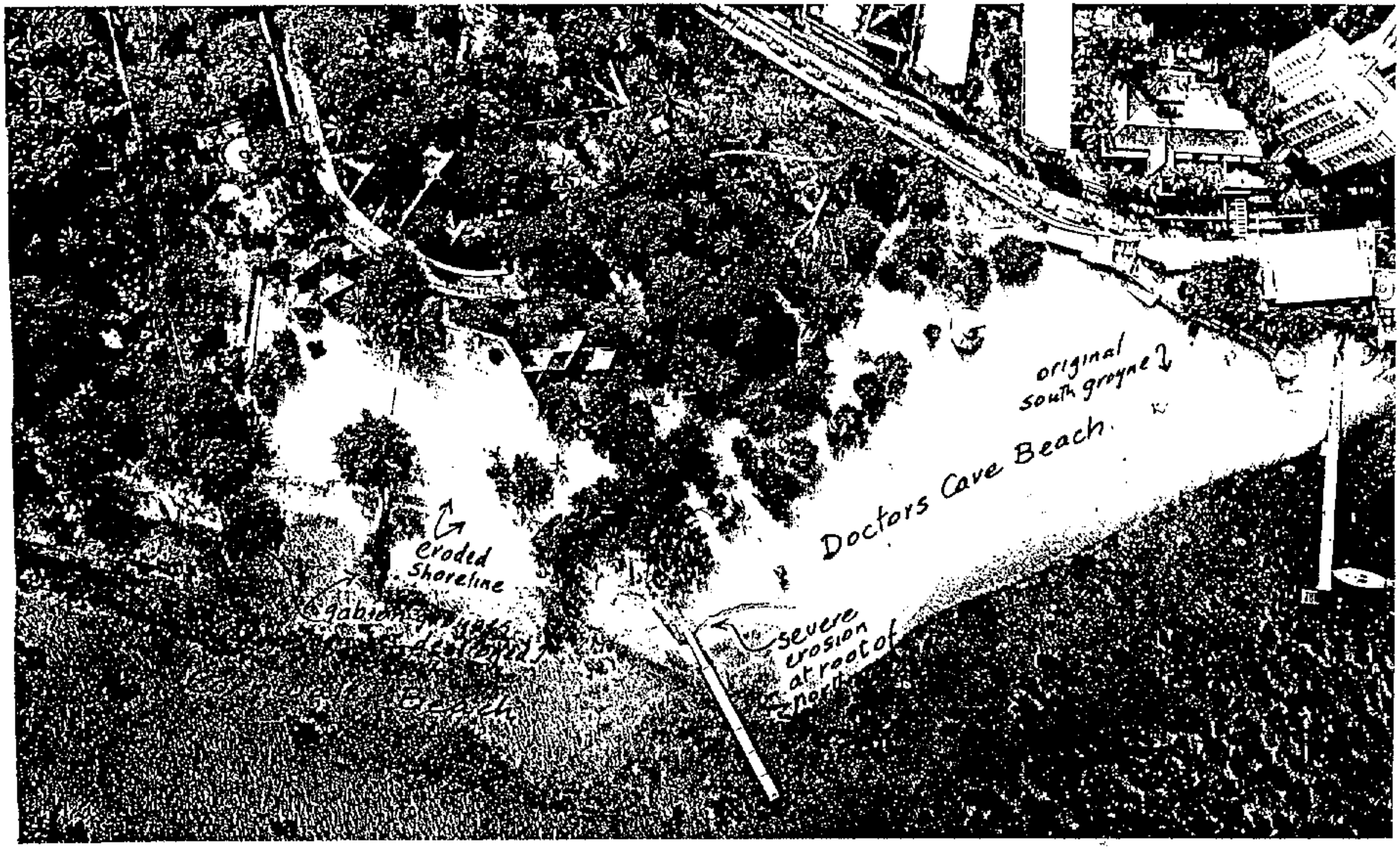


Fig. 13.

AGAIN, SEVERE EROSION AT CORNWALL BEACH - JULY 1982

Photograph taken 23rd July 1982, showing the gabion groynes destroyed and severe erosion again at Cornwall Beach.

Note also the clear evidence of strong eddy currents which have cut back the shoreline around the root of Doctors Cave's north groyne.