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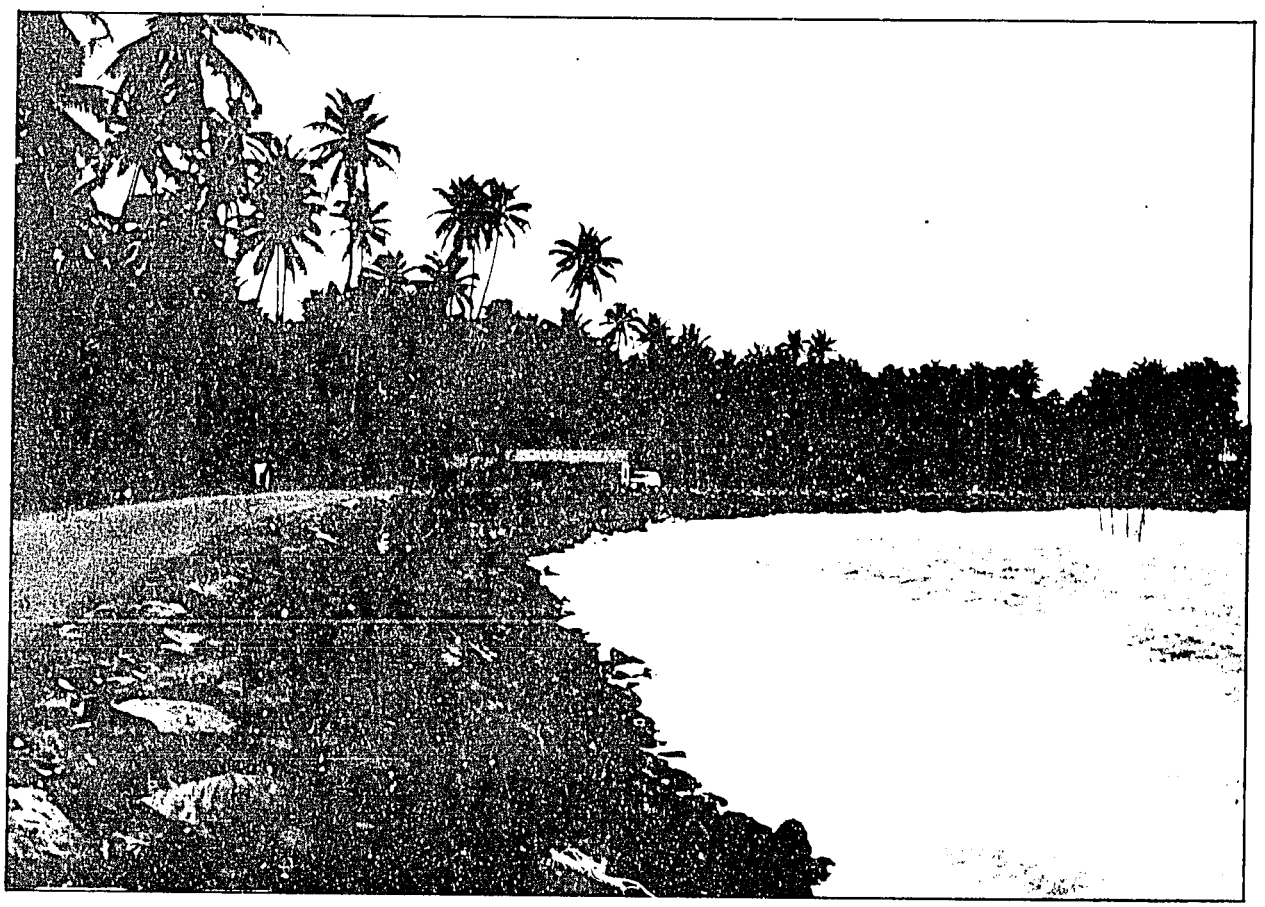
SHORELINE EROSION IN SRI LANKA'S COASTAL AREAS



By

H. V. DAYANANDA

LANKA HYDRAULIC INSTITUTE LIMITED

MORATUWA

COAST CONSERVATION DEPARTMENT

1992

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PREFACE

The problems of stability of the coasts of Sri Lanka and the intensity of erosion, as well as possible management issues, are discussed in this report. This work was carried out for the Coastal Resources Management Project at the request of the Coast Conservation Department and was funded by the USAID.

The general causes of coastal erosion, beach momenclature, and coastal dynamics are discussed in the first Chapter. The approach to the complex issues of wave and current dynamics is discussed in a simple way for the benefit of readers who do not have a technical background.

The types of coasts in Sri Lanka, sources of sediment providing nourishment to beaches and the nearshore littoral forces that move the sediments longshore and cross-shore are discussed in the second Chapter. The coasts are classified according to stability and resistance to erosion.

Coastal land use, present activities and condition are discussed, and a prediction made of possible changes in these areas. The options available for coastal resources management are then discussed.

Due to the security situation prevailing in the country at the time of the preparation of the report it was not possible to verify some of the facts through field inspections. Much of the data was obtained from available reports, data collected for other projects, aerial photographs and personal communications.

The help extended by the Coast Conservation Department, the project implementation personnel and the consultants in other areas is deeply appreciated. Without this cooperation it would not have been possible to prepare this report.

References

1. Coast Erosion Study - CCD
2. Master Plan for Coast Erosion Management - CCD

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1. DESCRIPTION OF THE COASTAL ENVIRONMENT

1.1 Coastal Land

1.1.1 General

The Coastal Zone is the boundary between the land and the sea, and is identified as a strip of land and sea rather than a line, as is the case with other types of boundaries. The reason is, that many activities, physical, chemical or biological, in the nearshore area or in the immediate onshore affect the land/water interface resulting in erosion or accretion. The activities at any coastal location may cause instabilities at the locality or sometimes in distant coastal areas.

The activities in the coastal strip of land and in the nearshore area are numerous. Only human activities can be controlled and planned so as to minimize environmental damage while optimising the exploitation of the resources. The concept of coastal resources management has arisen in response to the concentration of human activities for resource exploitation, and the fragile nature of the coastal area itself. In Sri Lanka the Coastal Zone is legally defined as the strip of land and sea bounded by a line two kilometers seaward of the low waterline and a line at least three hundred meters landward of the high water line. However, the activities which change coastal stability and cause erosion can occur outside this legally defined Coastal Zone.

1.1.2 Coastal Land

The study of coastal land forms is known as coastal geomorphology. Erosion, deposition, variations and evolution of the coastal land are aspects covered in coastal geomorphological studies. Coasts can be categorised into two very broad types. Depositional coasts are formed by the action of the ocean, which transports sand from distant places either onshore or offshore by wave and current action. Most of the sandy and muddy coasts of Sri Lanka fall into this category. Cliffed coasts are predominant in areas

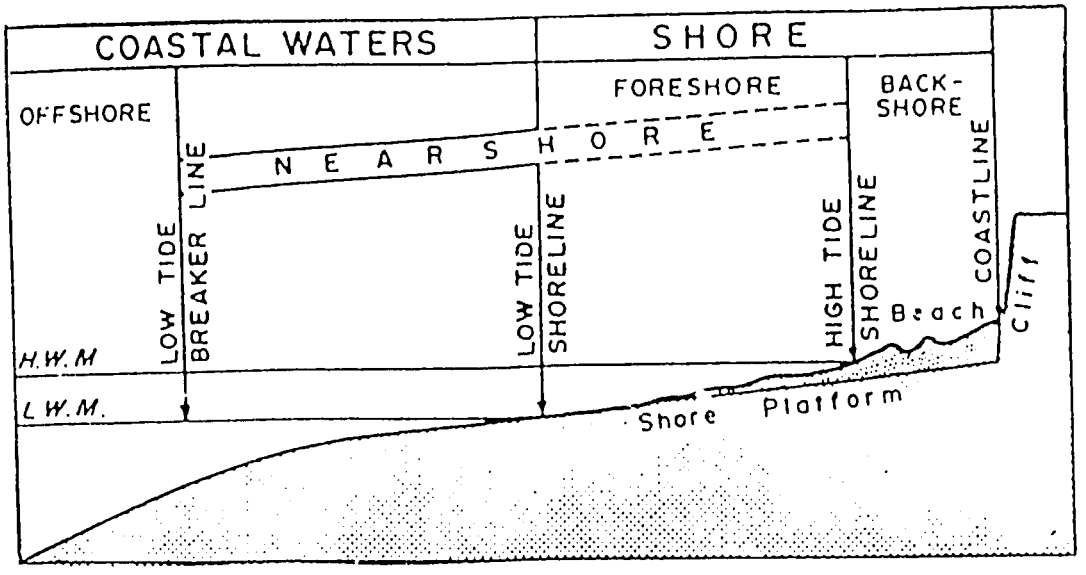


Fig 1 -- Nomenclature of a Cliff Coast

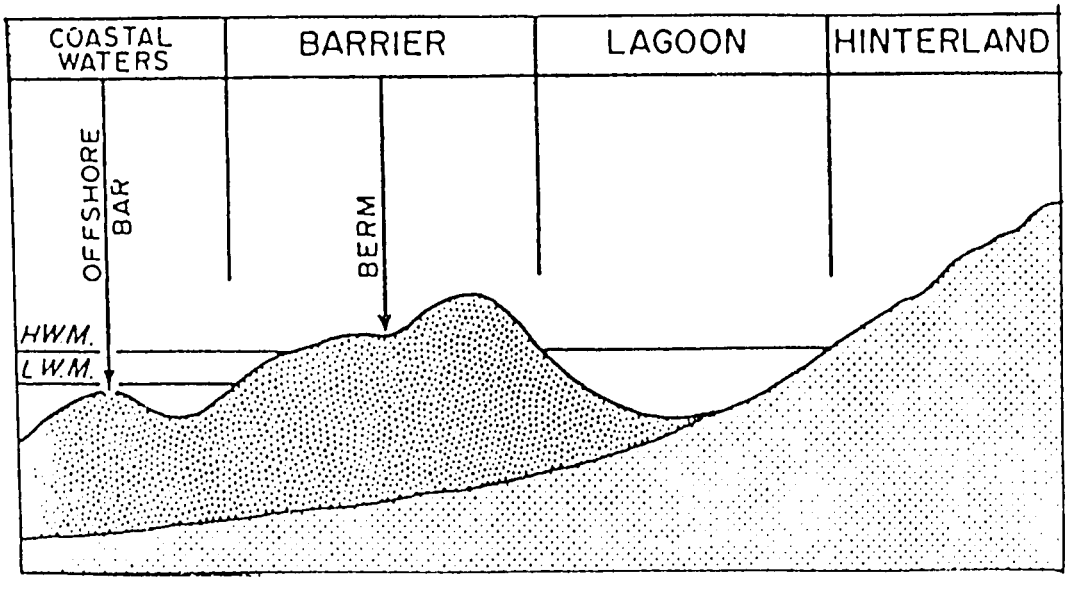


Fig 2 - Nomenclature of Depositional Coast

where the land adjoining the shore is hilly and the oceanographic forces do not supply sufficient sand to the area for the formation of sandy beaches. The terminology used in discussing these two types of coasts is shown in Figs 1 and 2. Some of the terms can be defined as follows:

The sea-shore consists of the foreshore and the backshore. The fore-shore is exposed at low tide and submerged at high tide. The backshore extends above the normal high tide level but is inundated by exceptionally high tides or large waves during storms. Thus, the shore is the zone between the water's edge at normal low tide and the landward limit of effective wave action. The shoreline is strictly the water's edge, which migrates to and fro due to changes in the water level brought about by tides and other causes. The distance of the breaker line from the shoreline varies according to changes of wave climate and beach profile. During periods of heavy wave action the breaker line is usually further out to sea. The nearshore zone lies between the breaker line and the landward edge of the foreshore. Outside the breaker line extending to deep water is the offshore zone. The term "offshore" is also used with "onshore" and "longshore" to indicate the direction of water or sediment movement. The beach is usually an accumulation of loose sediment, usually sand sometimes confined to the backshore, but often extending across the foreshore as well.

The coast is a zone of varying width which includes the shore and extends to the landward limit of marine influence. This limit can be the crest of a cliff, the head of an estuary or land including coastal dunes, lagoons and swamps.

The geomorphological forces causing the building up or loss of land are governed by geological, climatic, biotic, tidal, wave current and other oceanographic factors. These factors obviously vary from place to place.

In the tropics rapid weathering of rock formations at coastal outcrops produces bold headlands usually composed of stable quartzes and granites. The large amounts of sediment discharged during heavy rains deposit in coastal areas causing them to change continuously.

The biotic factors depend on the climatic conditions and are influenced by many parameters. Coral and associated reef building organisms are confined mainly to the tropical and inter-tropical zones. Mangrove swamps are restricted to estuaries and sheltered coastal tidal flats. A few plant and animal species may increase erosional tendencies, but most fauna and flora enhance accretion of land and stabilisation of dunes and tidal flats.

Wind is a major influence in the evolution of the coast. Its influence is mostly indirect. In some stretches exposed to strong onshore winds, sand is blown across the shore towards the land. Waves and swells produced by storms reach the shore after propagation over large distances. The heights and directions of these waves and accompanying currents play a major role in coastal processes which mould coastal landforms. The fine sediment on the beach is dried by the sun at low tide. This fine sand, moved by the wind directly, results in the formation of coastal dunes.

The modification of coastal landforms by human activities occurs when the pressure on coastal resources is high. The construction of sea walls, groynes, breakwaters, and structures associated with drainage and sewage outfall schemes, dredging for harbour projects - all impose modifications on the coast. Often human activities such as the destruction of coastal vegetation by cutting, burning, grazing or pollution by toxic substances such as oil, lead to changes in the pattern of erosion and deposition on the coast, in estuaries, lagoons and on the sea bed.

Attempts to modify coastal processes for coast protection or other development activities require an understanding of the existing factors and processes at work in the coastal morphologic

system. The sources and sinks of sediment, transport forces and quantities of sediment moved should be known at least approximately to gain an understanding of these processes. Such knowledge enables minimising and effective mitigation of unavoidable adverse effects resulting from coastal engineering works. Studies of the effects of human activities on the coast are also important in coastal management and in the conservation of natural resources, including scenery and wild life in coastal areas.

The development of a comprehensive data base on coastal phenomena and the resource uses, helps in understanding these processes and in optimising development projects.

1.1.3 Types of Beaches

The evolution of cliffed coasts is governed mainly by geological processes and formations. These hard coasts have lost most of the soft overlying material and have reached the stage of slow erosion. In general, cliffed coasts are relatively stable and erosion can be controlled by reinforcing the toe of weak cliffs and by providing for proper run-off of rainwater.

Beaches, on the other hand, are accumulations of sediments deposited by waves and currents, in the shore zone. They are typically composed of sand or shingle. The grain size distribution can be determined by mechanical analysis. The median diameter is less than the mean diameter for beach sand. This negative skewness results from the sorting and removal of the finer fraction of the particles through wave and wind action. Beach slopes tend to be steeper when composed of coarser sediments because of the higher permeability. The swash sweeps the sediment forward on to the beach and the backwash tends to carry it back to the water. The higher permeability of coarse sand lessens the amount of backwash because of the increased percolation. This results in steeper beach slopes. Fig 3 graphically illustrates the relation between the mean grain size and the average equilibrium beach slope.

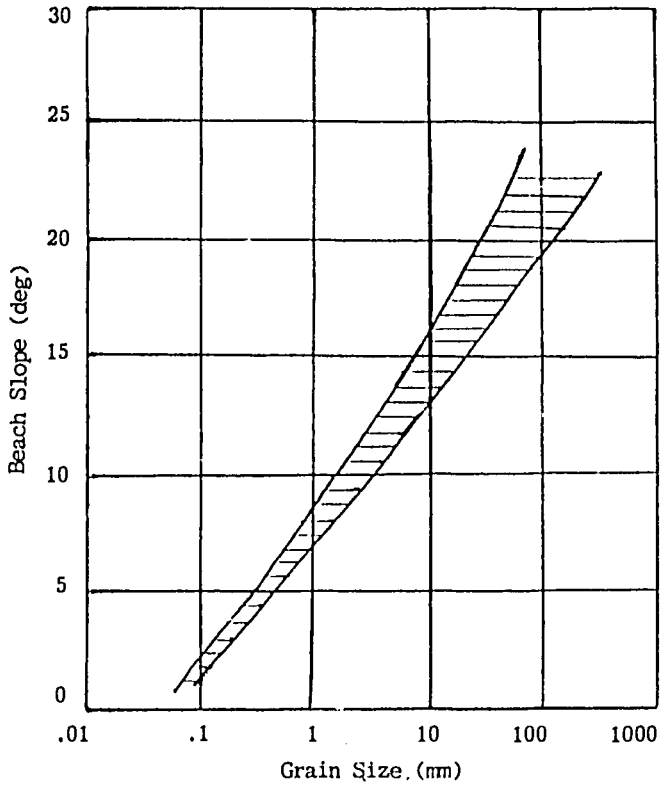


Fig 3 - Beach Slope Variation with Grain Size

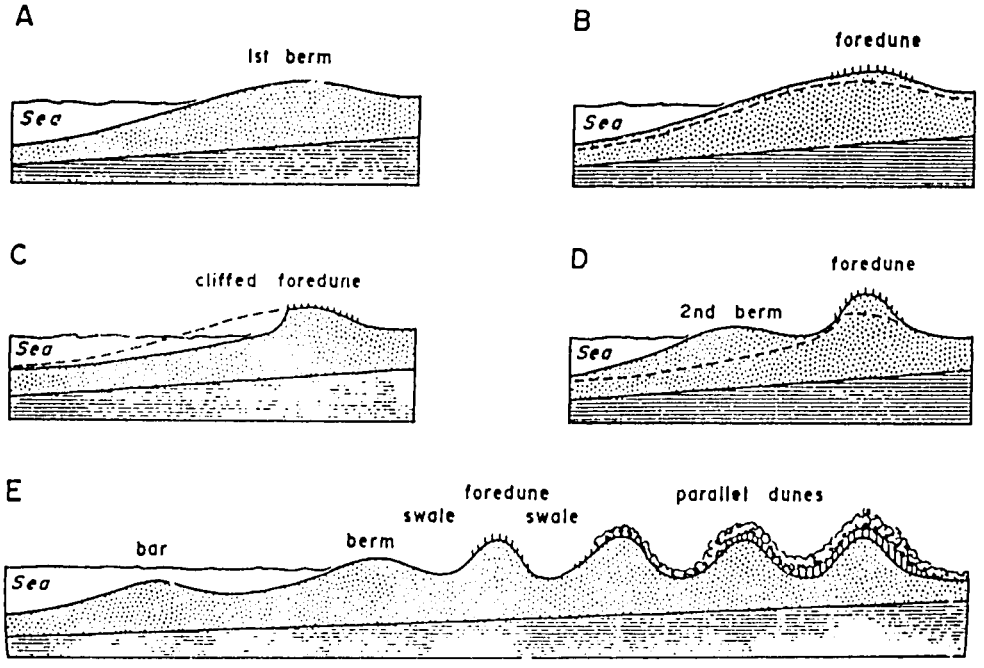


Fig 4 - Evolution of Dunes

	D50			Slope Angle
Cobbles	64	- 256	mm	24 deg
Pebbles	4	- 64	mm	17 deg
Granular	2	- 4	mm	11 deg
Very coarse sand	1	- 2	mm	9 deg
Coarse sand	0.5	- 1.0	mm	7 deg
Medium sand	0.25	- 0.5	mm	5 deg
Fine sand	0.125	- 0.25	mm	3 deg
Very fine sand	0.0625	- 0.125	mm	1 deg

The type of beach is usually determined by the nature of the sediment on it. This in turn is determined by the source of the sediment material. Shingle or gravel beaches are found where coastal landforms consist of gravelly deposits, or layers of erosion resistant formations interlaced with weaker layers, or where the source consists of intricately fissured igneous rocks. Sandy beaches are nourished by sand eroded from coastal outcrops, by the bed load of rivers and by coral reef debris.

Another factor which determines type of beaches is the nature of the landform behind the beach. Large lagoons, estuaries or tidal flats result in the formation of spits and barrier beaches. These beaches are almost always nourished by sand sources and are usually dynamic in their behaviour. Spits usually grow in the direction of the longshore drift of sand, and also show lateral movement as a result of heavy floods or very high wave activity.

Beaches with very mild slopes are formed when very fine sand sources undergo alternate drying and wetting owing to the variation of water levels caused by tides. These fine sediments, when dry, are moved by onshore winds to form sand dunes. Under these conditions extensive dune systems form immediately landward of the backshore. The characteristics and extent of the dunes are governed by the grain size, density of the sediment and the

consistency of the wind system. Under favourable conditions dunes are known to travel comparatively large distances landwards. An example of this lies in Manalkadu in the northeast corner of Sri Lanka where a whole village has been buried by the migrating dunes. This occurs when the sand supply is high and the dunes formed are not stabilised by natural vegetation. In areas with undisturbed natural vegetation dunes usually grow seawards, resulting in accretion of land. The evolution of dune beaches is shown schematically in Fig 4.

Dunes, once established, are susceptible to damage by removal of vegetation by grazing or burning or even by footpaths developed through human use. The damage is termed "blowout". A blowout forms a parabolic deformation in an otherwise parallel dune system.

Other coastal features include estuaries, lagoons, and deltaic and muddy coasts which usually form in locations where a river or a stream flows into the sea.

1.2 Ocean Climate

1.2.1 General

Coastal evolution and coastal dynamics are governed by the sources available for beach nourishment and by the forces acting at the interface between land and water. The ocean takes part in both these activities. These forces are produced as a result of waves breaking on the nearshore area, and currents caused by tides, winds and meteorological phenomena. Beach sediments are also supplied by marine organisms in the form of coral and shell fragments. The rate of supply of sediments and the intensity of forces governing coastal processes vary with location and time. As a result of this spatial and temporal variation of forces and of the sediment budget, development activities which impact on the beach have to be planned, controlled and monitored for minimising coastal degradation which will occur through erosion and deposition at undesirable locations.

1.2.2 Water Levels

The water level in the ocean changes continuously. These variations are known as tides. The difference between the mean high water level and the mean low water level is called the tidal range. The tidal range for the Sri Lankan coast is about 70 centimeters. Tides are produced by the gravitational effect of the moon and the sun. Besides these astronomical forces, other meteorological phenomena also produce variations in the sea level at the coast. When wind blows from the ocean towards land (onshore), water piles up at the coast causing a rise in the sea level, and an offshore wind produces a slight lowering of the sea level at the coast. Such a variation is called a wind set-up or set-down. Waves breaking close to the coast also produce a rise in the sea level at the beach. This phenomenon is termed the wave set-up. The water level rise can be as much as ten percent of the average wave height.

All these variations in water level occur independently. When high spring tides coincide with large waves and strong on-shore winds, unusually high water levels can occur. The seaward edge of the erosion escarpment can reach far inland under such a rare combination of events. Water levels in lagoons and estuaries connected to the sea also depend on the sea level, and flooding around these water bodies can be caused by high sea levels. Therefore the seaward boundary of important development activities should be established well above these freak water levels irrespective of other requirements.

1.2.3 Currents

Currents are movements of water masses caused by winds and other forces. The movement of sediments from place to place depends on the action of currents. Therefore, the movement and distribution of sand, supplied by different sources, along beaches depend largely on the current regimes of the region. The capacity of a current to move sediments depends on the degree of agitation

of the bottom sediments and the strength of the current. Coastal erosion or sedimentation, therefore, depends on the variation of the strength of the currents along the coast.

Nearshore currents are produced by tides as well as by wind and wave action. When waves approach the beach at an angle to the coastline a current is produced parallel to the coast. Agitation of the sediments is caused by breaking waves. In addition, in the vicinity of lagoons or estuaries, filling and emptying currents are produced by tides and floods. In these areas beaches show a high degree of instability depending on the temporal and spatial balance of the littoral forces.

1.2.4 Waves

When the wind blows over the surface of water, part of the energy from the wind is absorbed by the water to form waves. The size of the waves depends on wind speed, duration and the distance the wind blows over water. These waves travel thousands of miles after their generation to dissipate their energy on coasts of distant lands. Waves, once out of the area of generation, are called swells.

Waves are characterised by their height and period (Fig 5). The wave height is the vertical distance between two consecutive highest and the lowest points of the water surface. The wave period is the time interval between two consecutive wave crests moving past a fixed point. Swells have a longer period and are more regular than wind waves.

In most tropical areas where storms of long duration and high intensity are rare, the wave climate is generally dominated by swells, with intermittent presence of locally generated wind waves. The southern and western coasts of Sri Lanka are exposed

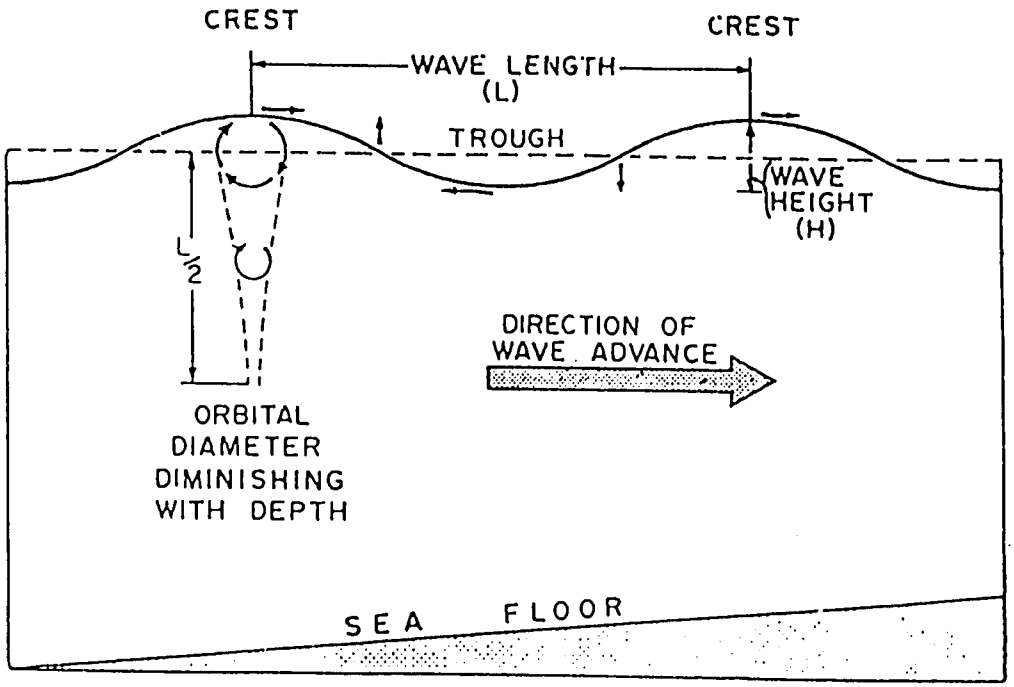


Fig 5 - Wave Terminology

to swells from the southern Indian Ocean. During the Southwest and the Northeast monsoons, the beaches in these sectors of the Island experience wind generated waves. The swells have periods of about 15 seconds whereas the wind waves have typical periods of six to eight seconds.

As waves approach the shore they change their direction so as to become more and more parallel to the coastline. This is called wave refraction and is analogous to light refraction. The wave rays, which are orthogonal to the wave front, (see Fig 6), are usually parallel to each other in the deep sea. Owing to refraction they either converge or diverge. This causes a variation of wave energy along the beach. When waves converge, the amount of energy between two consecutive rays is confined to a smaller width, and the wave height increases. The opposite occurs when wave rays diverge. The variation of wave heights causes local circulation cells. Water moves out to sea through low wave areas and flows towards the coast in high wave areas. This is shown diagrammatically in Fig 7. The refraction depends on bed level topography as well as wave periods and wave direction. In unstable coasts a small variation of any of these wave parameters can cause significant beach changes within a short period of time. Usually this type of behaviour occurs where the sea bed topography is complicated by prominent features such as ridges, shoals or deep trenches.

The presence of obstructions such as large rocks, small offshore islands or man-made structures such as harbour breakwaters, also contributes to deformation of waves. These obstructions which are exposed above water produce a sheltered shadow area behind them. Waves move around the obstruction into the shadow area. This phenomenon is termed diffraction. Wave diffraction results in a change in wave direction as well as in wave height. The net result of these changes is the movement of sediment from unsheltered beach areas towards the shadow area. Movement of beach material from the two sides of the obstruction to the sheltered area behind it results in the formation of a tombolo.

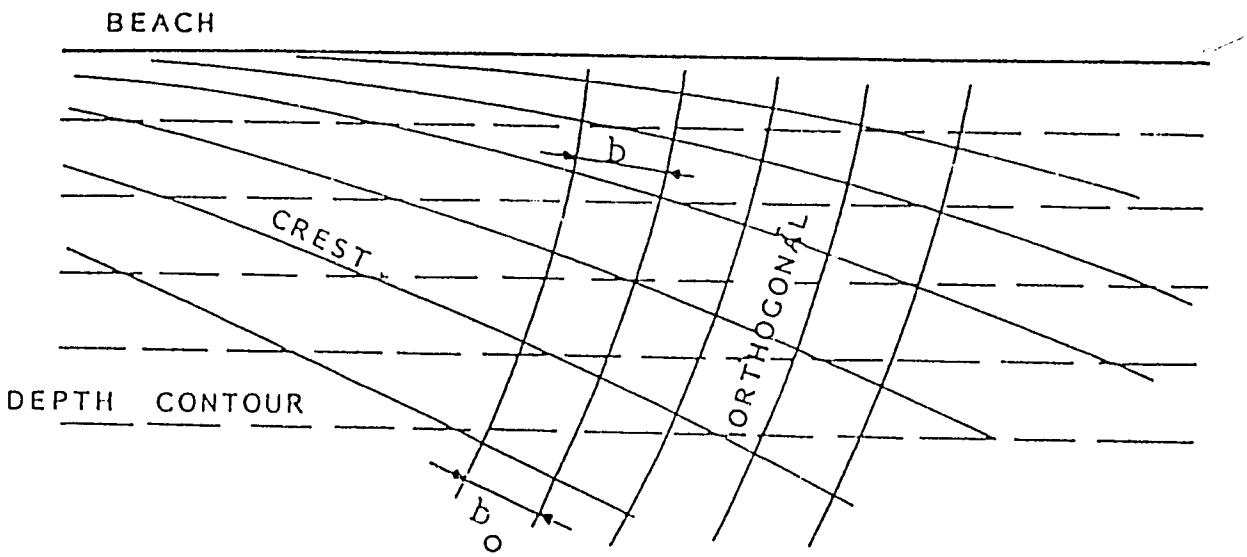


Fig. 6. Wave Refraction.

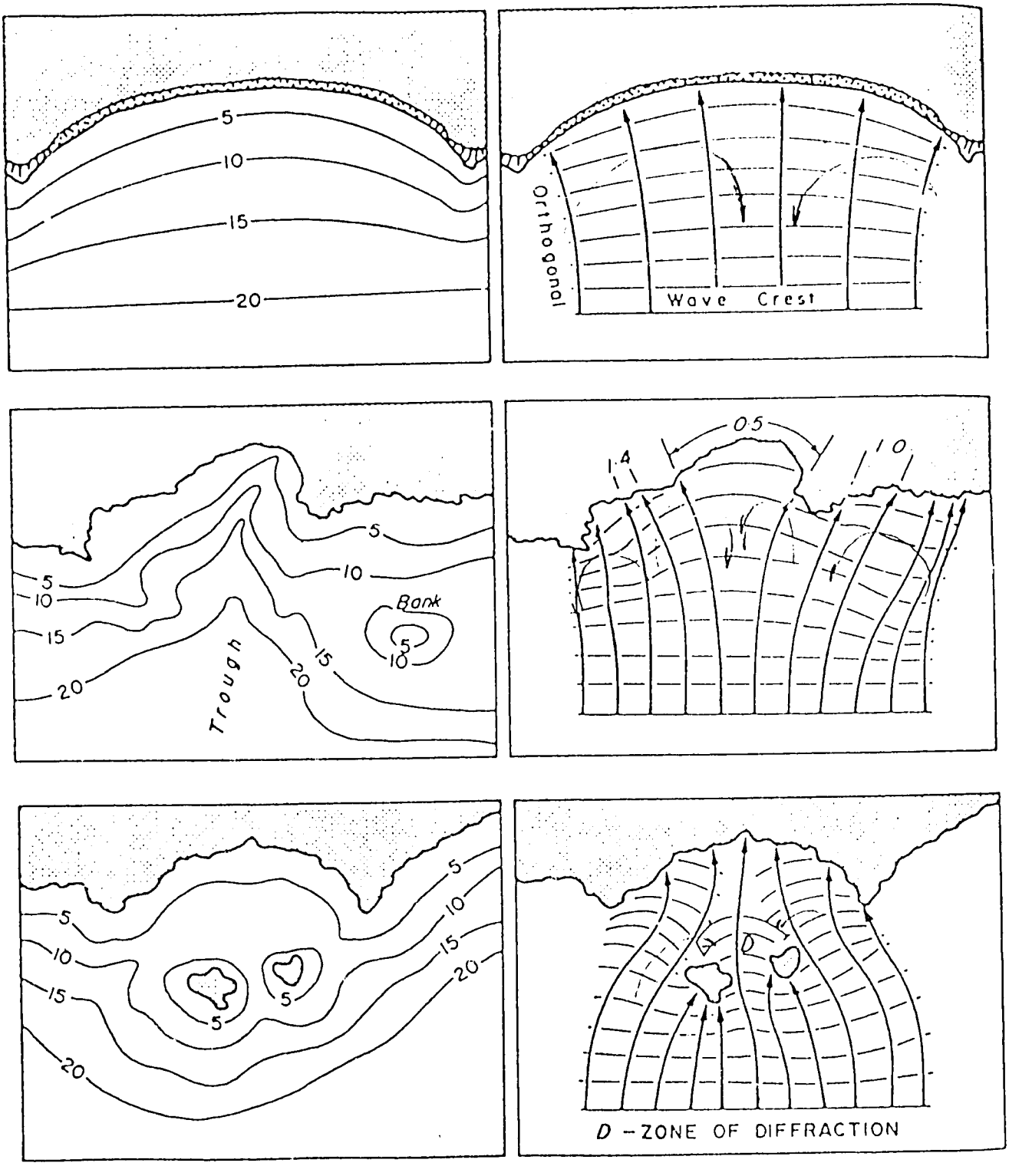


Fig 7 - Effects of Refraction and Diffraction.

This condition is sometimes created artificially as a coast protection measure. The tombolo (accretion behind the obstruction) is built artificially by providing sand from sources outside the eroding area. This prevents the erosion of the beach adjacent to the planned tombolo.

When waves approach at an angle to the shoreline and break obliquely, a part of the wave energy is converted to a current which flows parallel to the beach. This is called the littoral current. This current transports considerable amounts of sand which is agitated by breaking waves. This transport of material in the nearshore area is of vital importance to the evolution and behaviour of the coast. On long, straight coastlines which experience oblique waves, water moves parallel to the coast for some distance and flows back to the sea across areas of low wave activity. These currents are strong and extend to comparatively deep water. They are called rip currents. Rip currents move sediment out of the beach. A portion of this sediment will move back to the shore by circulation currents within littoral cells.

1.2.5 Winds

The action of wind on coastal evolution and behaviour is somewhat indirect. The formation of dunes can be considered to be a direct result of wind action and the sediment motion by waves and currents is the indirect component. Dune formation removes the finer fraction of the beach material. But dune sand is always available as a buffer for beach nourishment, during large storms. This compensating action is shown diagrammatically in Fig 8.

1.2.6 Climatic Cycles

Climatic cycles also affect the evolution of the coastal zone. During long spells of dry weather, river discharges are low and sediment supply to the coast is reduced. During such times dune formation slows down and storm damage tends to be more severe. Large areas of buffer zones could get eroded over long periods of dry weather. However, the low discharge of fresh water and sediment into coastal areas will reduce the stress on coral reef environments.

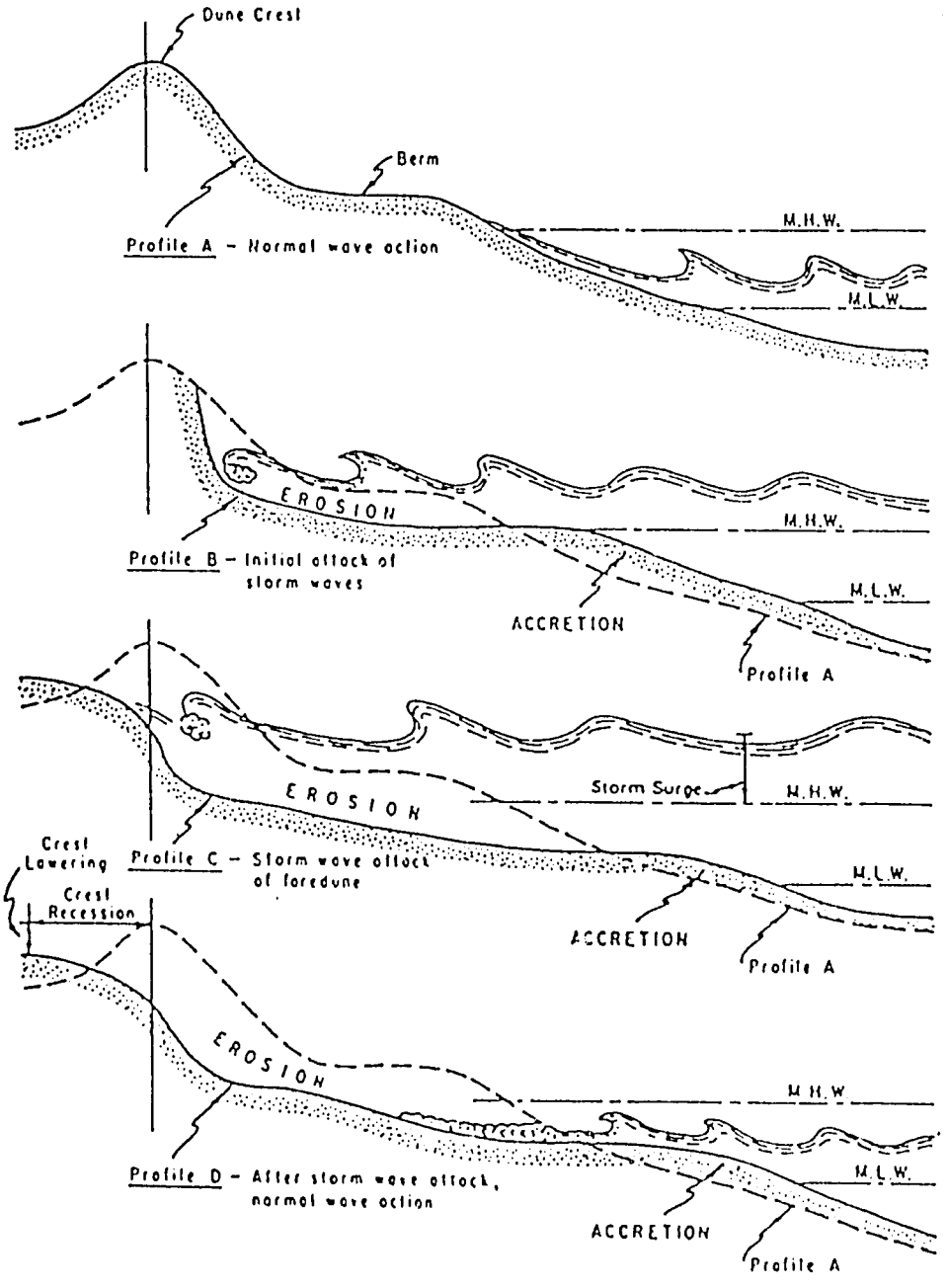


Fig 8 - Result of Storm on a Beach.

On the other hand long periods of wet weather cause large discharges of water and sediments into the coastal zone. The beaches will show improvement caused by accretion of excess sediment. Wider beaches will promote the formation of dunes and increase the available sand buffer. On the other hand fine sediments brought by the floods could settle and smother large areas of live coral, killing off entire reefs. Once smothered the reefs will take a long time to re-establish. The influx of large amounts of fresh water reduces salinity below critical levels and leads to the stunting of the coral growth.

1.2.7 Rare Events

The occurrence of cyclones and hurricanes or large waves due to earthquakes in distant areas is generally considered rare events. However, when they do occur the damage caused to the coastal zone can be very serious and would take a long time for the system to regain its original equilibrium. Large waves and strong currents produced by these events can destroy large areas of coral reefs and move huge amounts of coastal sediments both offshore, landwards or alongshore. This causes considerable changes in the sea bed topography which in turn changes the nearshore wave patterns. Once the event has passed, the available wave energy begins to establish the equilibrium which existed earlier. During this period erosion and accretion can take place in areas considered to have been stable up to that time.

The time taken to restore the earlier conditions depends on the intensity of wave activity. The damage caused by the cyclone of 1966 to Vankalai in the Mannar District could be cited as an example. It took more than fifteen years for the coast to regain the earlier shape because wave activity along this stretch was very mild.

1.3 Coastal Dynamics

1.3.1 General

For a casual observer the coast appears to be a rather serene area where changes do not occur. However, in reality, the coast, especially the beach, undergoes rapid changes due to changing water levels, currents, waves and winds. It is not rare for the main characteristics of a beach, such as width, slope at water line, nature of beach material, the beach profile and the plan shape, to change within the course of a few hours. Waves, currents, water levels and the continuously changing beach characteristics are referred to as coastal dynamics. These include relatively large periodic fluctuations which the beach undergoes due to oceanographic and meteorologic forces and the progressive advance or retreat of the coastline over long periods (several years). Beaches undergoing this type of progressive change fall under the category of unstable beaches. There is evidence of advancing shoreline resulting from accretion of beach sand in many parts of the world. For example, signs of such accretion can be observed in the aerial photographs of the northwest and east coasts of Sri Lanka.

There are other causes which contribute significantly to beach erosion or aggravate it seriously.

1.3.2 Sediment Supply to Coasts

The materials on the beach can be classified into two main categories. One category consists of quartz sand and other terrestrial minerals which are brought to the coast by rivers that erode the deposits in hilly areas. A small fraction of the materials in this group is supplied by erosion of coastal cliffs and former dune deposits. The beach materials in the vicinity of river outlets consist mainly of this type of alluvial minerals. The other category is of marine origin and consists mainly of calcium carbonate, supplied to the beach as coral debris and shell fragments of marine organisms.

Photosynthesis lowers the acidity of the sea water during the daytime. The coral polyps can then absorb the calcium from the sea water and convert it to calcium carbonate for its habitat. The activity of colonies of these animals produces extensive live coral formations. A pollution free, warm, saline and clear environment promotes the formation of these coral reefs.

During periods of heavy wave action the fragile parts of the live reef break up and are washed ashore, contributing to the mass of beach material. A live reef is capable of repairing itself during the calm season following the monsoon. Beaches in areas where nearshore live reefs occur, consist primarily of calcarious sediments. The different sources of beach sediments are shown in Fig 9.

Sediments which reach the beach are continuously moved around by waves and are ground finer and finer. When grains are fine enough to be moved as suspended sediments, they drift to the deeper and calmer sea and start settling to the bottom. The non-calcarious sediments reach the sea bottom and form thick deposits of marine sediments. These finally become sedimentary rocks, under the high temperatures and pressures encountered with the thickening of the layers. These layers are pushed up by geological movements to form exposed mountain ranges to start the erosion cycle again.

The coralline sediments settle down to depths beyond the reach of sunlight, where the acidity of the water is higher due to the absence of photosynthesis. The calcium carbonate dissolves in the acidic water and reaches the reef areas again through circulation, and is converted back to the solid state through coral polyps. These again end up as beach materials due to wave action.

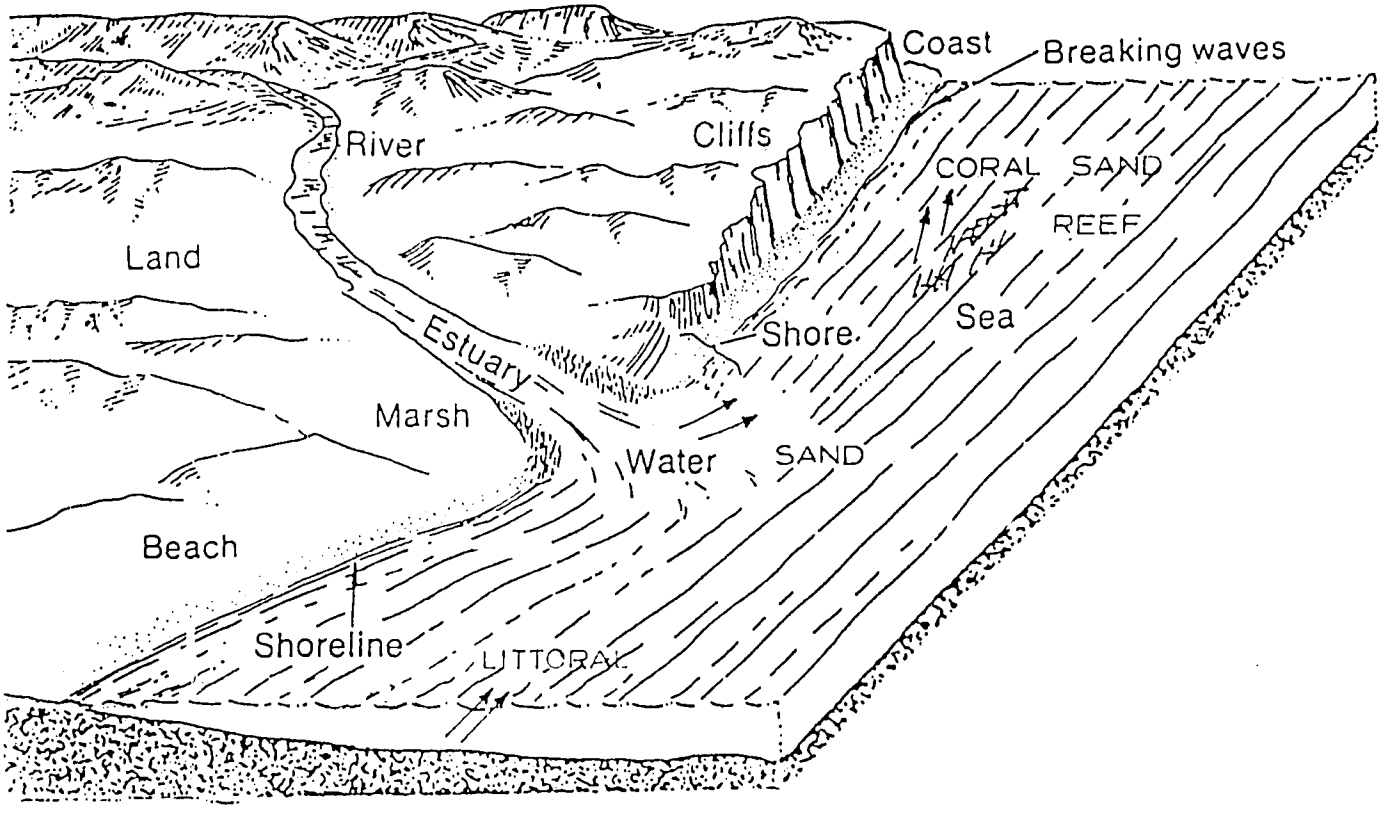


Fig 9 - Diagrammatic View of Some Common Features of the Coastal Region

1.3.3 Sediment Motion

The materials supplied to coastal areas by rivers, coral·reef formations and eroding buffs, are transported by the action of currents and waves. The currents are induced by several different forces. Wind induced currents usually occur in the deep sea. Tidal currents as well as wave induced currents such as the littoral current discussed earlier, are dominant in the nearshore area and cause the movement of large amounts of sediment. Wave induced currents move sediments along the shore as well as perpendicular to the shore.

Coastal sediments accumulated as berms of beaches and backshore dunes act as buffers of sand to be utilised during severe storms. This process is shown diagrammatically in Fig 8. Storm waves are large and have relatively short wave periods. The water rushing up the dune face will saturate the otherwise dry sand with water and move it offshore. This sand is deposited just beyond the breaker line making the nearshore area shallower. The reduced depth causes waves to break further off and widens the breaker zone. Thus, the waves lose more energy before they reach the dune area. This slows down the attack on the dunes, establishing a new equilibrium. When the storm is over smaller waves begin to move the sediment back to the shore and finally on to the dunes. Usually, a storm which would erode the first line of dunes completely would occur once in 20 years and one which would erode the second line of dunes also would occur only once in 100 years.

The onshore/offshore movement of sand by waves, combined with the longshore transport by the littoral drift causes sediments to move along the shore in a zig-zag fashion. This is shown in Fig 10. This motion can move sediments over large distances, around headlands and past artificial structures such as groynes that are built perpendicular to the beach, and extend beyond the average breaker line.

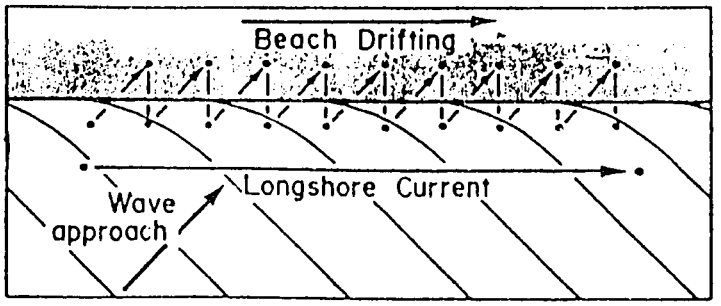


Fig 10 - Movement of Sediment due to Oblique Waves

1.3.4 Sediment Losses

The various types of sediment losses from a beach were discussed in section 1.3.2. Sediment losses to the deep sea as suspended sediment can be considered to be permanent loss because this sediment will not be available for beach nourishment during the time spans considered in coastal management. Sediment losses to the dunes are essentially temporary; this material should be readily available during periods of severe storms. However, any sand trapped beyond the second line of dunes will not be available for coastal dynamics. Storms which would erode beyond the second line of dunes have very long return periods (over 100 years). Within this time the dune area would in general be transformed by permanent vegetation and other human activities.

On a stable beach sediment loss due to littoral drift is usually balanced by the sand brought by the littoral drift from upstream (Fig 11). Sometimes, due to special conditions such as rip currents or, trenches on the sea bed, the supply rate would be lower than the rate of loss; in this case erosion would occur.

The onshore/offshore movement of sediment occurs due to changes in wave action or changes in the water level caused by tides. This material usually moves back to the beach in a few hours when conditions become more favourable.

1.3.5 Accretion and Erosion

The beach is supplied with materials by rivers, coral reefs and in some cases by erosion of the shore front. Waves, currents and winds are the natural forces which move this sand along the beach towards the deep sea and landwards. When a specific area of beach is considered materials enter and leave across its four boundaries. This phenomenon is shown in Fig 11.

When the average long-term supply of material to the area considered is lower than the material moving out of the area, coast erosion occurs. If the supply exceeds the losses, then the coast shows accretion. In a stable beach, the supply and losses balance each other. The temporary loss of a sand buffer such as a part of a dune due to storms, results only in a temporary loss of stability of the coast.

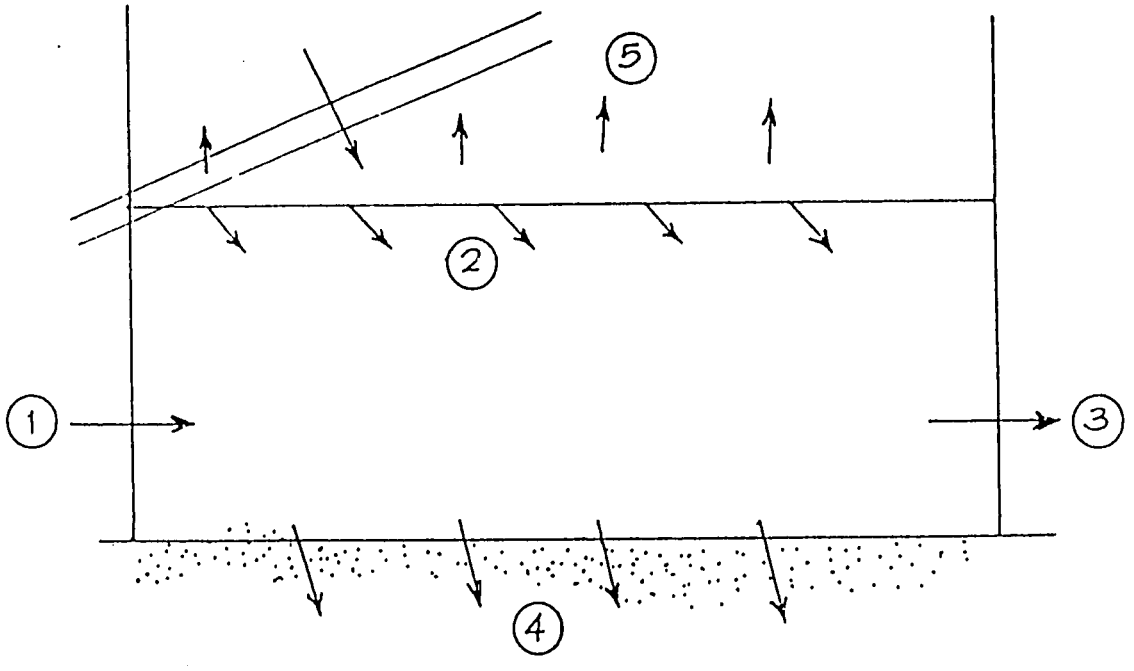
The conditions necessary for maintaining a stable beach can be summarised as follows :

(1) Availability of an adequate buffer stock of sand in order to survive a severe storm;

(2) Continuous availability of supply of sand to counteract the long-term net loss of sediment from the area;

(3) A positive or a zero balance in the daily supply to and loss of material from beach due to onshore/offshore and littoral drift.

Some of the causes that adversely affect beach stability are summarised below, and can be broadly categorised under man-made and natural causes :



1 SUPPLY FROM LITTORAL DRIFT

2 SUPPLY FROM CORAL REEF

3 REMOVAL BY LITTORAL DRIFT

4 REMOVAL TO DUNES BY WIND

5 LOSES TO DEEP SEA AS SEDIMENT

STABLE BEACH 1 + 2 = 3 + 4 + 5

Fig. 11. Sand Budget and Beach Stability.

1. **Human Activities**

(a) Sand mining from rivers and coasts;

(b) Removal of dead or live coral;

(c) Using explosives for fishing;

(d) Discharge of pollutants and untreated sewage to the coastal area;

(e) Dredging or reclamation;

(f) Construction of improperly designed structures in nearshore area and coast;

2. Natural causes

(a) Rise of sea level and subsidence of land;

(b) Storm activity;

(c) Excessive run-off following heavy rains;

(d) Blooming of coral predators;

(e) Long-term climatic changes;

(f) Migration of river outlets.

It is not intended in this report to go into detail in regard to the above causes.

2. THE COAST AROUND SRI LANKA

2.1 General

The total length of the coast in Sri Lanka exceeds 1600 kilometers and most of it consists of sandy beaches. Beach characteristics show a strong dependence on the extent and the type of the sources of sediment available for nourishing the area. Differences in the types and quantities of sediments available and the intensity of the forces moving them have resulted in many different types of coastal stretches. There are sandy beaches, rocky cliff coasts, sandstone reefs, coralline reefs, muddy beaches and vast areas of tidal flats and mangroves. Some areas especially on the west coast are highly populated and are protected from erosion by protective structures.

The formation of sand spits enclosing lagoons is a feature that can be observed along the entire coastal zone. The sea has built up the coast in these areas, enclosing low-lying marshes with extensive mangrove vegetation, which have developed into fish spawning grounds. In other areas weak littoral forces, an ample supply of sediment and consistent winds have resulted in the formation of sand dunes. This type of accretion can clearly be observed in the aerial photographs of the southeast and northeast coasts of the Island.

In areas where wave action is strong and beach nourishment is poor, the development of cliff coasts interspersed with pocket beaches can be observed as along the southern coast. The supply of fine material from streams of low gradient and suspended sediments from marine sources coupled with low wave activity create the muddy coasts which are a feature observed in the area north of the Mannar Island.

2.2 Sediment Sources and Sinks

There are several types of sediment sources that nourish the coastal zone of Sri Lanka. In this discussion only the sediments which do not originate by erosion of the shore front itself are considered as sources. The main sources which nourish the beaches are the rivers. The major rivers which start from the central hills supply the southern and western parts of the coast. Kelani, Kalu, Gin, Nilwala and Walawe rivers supply material, mainly quartz or silica based sediments with small fractions of more valuable minerals. All these river sources depend on the monsoon rainfall. Sediments are supplied in a cyclic manner with maximum supply coinciding with the heavy rains, and stronger wave climates, which occur during the South West Monsoon. Sediments supplied in this way are coarse and have typical grain diameters in the range of around one millimeter. The smaller streams whose catchments do not reach the higher slopes, carry significantly less water and sediments. In general, the sediments supplied by these sources are also silica based but of finer grain size.

The other sources of sediments have marine origins. These consist of calcareous substances derived from live coral reefs and shells of marine organisms. In Sri Lanka this type of live reefs are found in many areas. The reef that extends from Colombo northwards to Chilaw is dead. There is hardly any material supplied by this reef. There are live reefs far off-shore which provide the beaches in this stretch with a small quantity of sediment. The fraction of coral material in the beach samples indicates this. The west coast north of Colombo therefore receives a major part of its nourishment from the river sediments.

Nourishment for the coast north of the Mannar Peninsula is supplied mainly from marine sources. The calcareous and partly organic material is suspended in the sea water which floods the low lying flat areas at high tide. These sediments are made into larger particles by some organisms and settle out of the water, thus forming a muddy coast.

The northern coast is made up of Miocene limestone strata. The nearshore area also consists of live and dead coral. The only nourishment available for this coast is derived from the broken detritus from these formations. The supply is small because of the low wave activity in the area. The beaches on this shore are very sparse.

In the northeastern part of the Island the beaches consist mainly of silica materials. These materials, brought by small streams, are slowly moved northwards by wave action. The shallowness of the offshore area and the formation of the large expanse of moving sand dunes indicate a large supply of sediment to this stretch. The deep trench at the entrance to the Trincomalee Bay prevents the movement of sand from the southern part of the eastern coast across Trincomalee Bay. North East Monsoon waves tend to move sediments towards the south in this area. All these factors indicate the possible supply of material from a different source. One of the possibilities is the leakage of sediments pushed southwards along the east coast of India by the Northeast Monsoon. However, not enough research has been done to verify this hypothesis.

Trincomalee bay is relatively deep and the coastal as well as the sea bed slopes are rugged and steep. Most of the coast is rocky and some of the pocket beaches in small coves consist of pebbles probably eroded from land. A few bays consist of fine sediments and tidal flats overgrown with mangroves. There are marshy areas behind the low-lying coasts between Kinniya and Mutur. The marshes are separated from the sea by relatively narrow sand spits.

The coast between Foul Point and Valachchenai or Pasikudah headland is relatively smooth and consists of sandy beaches with dune formations. The coast has a few headlands, the most conspicuous of which is Elephant Point. The land immediately behind and in between the dunes is low-lying and consists of mangroves and tidal flats. The coastal stretch of land is only sparsely populated. The source of beach material is mainly the littoral drift from the south. The shape of the bays suspended between headlands indicate net littoral motion northwards. The reef formations at the southern part of the stretch also contribute a part of the beach material.

The cyclone of 1978 destroyed a large part of the live reef, and nourishment from this source may not be available for at least another ten years. The land formation indicates accretion by deposition of coral fragments over a long period of time. This is also indicated in the aerial photographs of this stretch of coast.

The coastal area south of Elephant Point to Panama is low-lying. Its most conspicuous feature is the Batticaloa Lagoon. There are no land based sediment sources in this area. However, there seems to be a large supply of sand from the south through littoral transport and partial beach nourishment from marine sources. The coast is convex and some redistribution of sediments occur with the changing of wave climates.

The coast from Panama to Kirinda is backed along almost its entire length by forest. The coast has prominent rocky headlands while the beaches are wide and backed by dunes. A few streams including the Menik Ganga discharge into the sea in this area. The beaches consist of silica sand. The littoral drift moves eastwards and the Walawe Ganga may also be contributing to nourishing these areas. The offshore reefs in the Great and Small Basses are probably too far offshore to act as sediment sources for this area.

The coastal area from Kirinda to Tangalle is backed by wide expanses of dunes except in a very few areas. The coastal zone is sparsely populated and the backshore in most areas is low-lying. Prominent headland and bay formations can be observed together with wide beaches of medium grain sand. Numerous salterns and lagoons are enclosed by spits and barriers. Salt water intrusion is considered a problem in this area. The littoral drift is eastwards and the largest source of sand is the Walawe Ganga discharging at Ambalantota. Offshore coral reefs are available in this area and a part of the beach nourishment is derived from the detritus of these reefs.

West of the outlet of Kirama Oya in Tangalle up to Dondra, the southern tip of the Island, there is very litte nourishment of the beach. The sea bed slope is comparatively steep and consists mostly of rock outcrops. The coast also shows a cliffed character with sharp indentations at weaker areas. These indentations are backed by narrow beaches formed with sand supplied by erosion of the cliff base.

The main source of beach material for the area between Dondra and Galle is the Nilwala Ganga. The quantity of sediment discharged is small. This source seems to nourish beaches between Dondra and Polhena. The insufficiency of beach nourishment is evidenced by the eroding beaches adjacent to the river outlet. Coral reefs at Polhena, Weligama and Unawatuna areas supply a limited amount of beach nourishment. This may be due to the tortuous nature of the sandstone/coral offshore features. Most of the material washed onto the beach can be lost to the deeper sea through gaps in the reef by wave induced currents .

The Gin Ganga acts as a source of nourishment for the coastal stretch from Galle to Aluthgama. The nature of the beach material changes from silica based sand at the outlet of the river to almost ninety percent coral in the Induruwa area. This

indicates that the fraction supplied from the river source slowly diminishes as the sediment moves northwards. Coral reefs in the Ahungalle and Induruwa areas provide increasing amounts of coral based material to these coasts which are stabilised by headlands.

Bentota Ganga flows through a low-lying, marshy catchment before it discharges into the sea. The quantity of sediment it discharges is therefore small and consists of fine particles. The beaches north of Bentota to Kalutara are very narrow and unstable for this reason. There are no identified reefs which nourish this stretch of coast.

The Kalu Ganga is a rich source of sediment. The area it nourishes extends to Colombo. The sediment moves north and a part of it is intercepted by the river mouth stabilization structure at the Panadura outlet. The coast north of the outlet is eroding due to the direct cut off of the longshore drift by the long groyne. The sand moving around the structure may be reaching the coast a few kilometers north of the outlet. This supply is not steady or sufficient, as evidenced by the severe erosion which takes place at certain times. The reefs in this area are not live. The erosion has left only the sandstone base of the reef. As a result there is no significant nourishment from the reefs.

Sediment sinks in the coast around Sri Lanka are limited owing to the relatively mild slope of the sea bed. Direct losses to the deep sea take place only in a very few instances. One of these is the sediment loss from the Mahaweli Ganga. This material falls directly into the submarine canyon at the edge of the Koddiyar Bay. The sediments supplied on the west coast move steadily northwards and are either deposited south of the Mannar Peninsula or get trapped by the dune formation on the northwest coast. A substantial amount of the material is removed directly from the beach for the use of the construction industry. Coral miners also indirectly trap a vast amount of the beach sediments.

The recesses formed by the digging up the coral reef are filled by the sand which moves along the coast. This sand is thus permanently lost to the coast. The smallest fraction may get past Adam's Bridge as suspended sediment and is probably responsible for the muddy deposits north of Mannar Island. Along the north coast the losses are very small. However, on this coast, the supply is also extremely small. Losses on the northeast coast from Point Pedro to Trincomalee Bay are mainly due to dune formation. Some of the sand may be lost into the canyons across the bay.

On the east coast south of Trincomalee the losses take place on to the dunes and a substantial part can get trapped on the tidal flats. Especially large dune formations can be seen from Arugam Bay to Hambantota on the southern coast. As on the northern coast the sediment supply to the southern coast is also limited. The presence of live reefs and the supply provided by them is counteracted by the strong monsoonal seas. Coral miners also are active in the area and a large amount of sand is trapped by the pits formed by coral mining. Removal of live coral for ornamental use also reduces the sediment supply to the beach.

2.3 Forces Moving Sediments

Sediment movement considered in this section is confined to the beach and the nearshore area. The movement of sand into the dunes and to the deep sea is not considered. Longshore, and onshore/offshore movement due to storm action, and the forces responsible for this motion, around the coast of Sri Lanka are described below.

The oceanic forces which move sediments along the coasts are currents and waves. The ocean currents are weak in the nearshore area and their influence on coastal sediment movement is very small. Waves are the main source of energy for sediment movement along Sri Lankan coasts.

Waves which reach the coast of Sri Lanka originate from two main processes. Storms in the southern and mid-Indian Ocean produce waves which radiate from the generating area. They travel large distances and reach Sri Lanka from the south. These waves have long periods and are known as the southern swell. During winter in the southern hemisphere the larger swells generated by winter storms reach our coast. This period coincides with the Southwest Monsoon when the wind also blows from that direction. The wind generated local waves along with the strong swells cause severe erosion problems during this period.

During the Northeast Monsoon, the swell is small and wind waves from the Northeast Monsoon are dominant. This affects only the northeast and the east coasts of Sri Lanka. During this time waves on the east coast are produced by local winds which approach from east to northeast.

Along the coast from Galle to the Gulf of Mannar on the west coast, Southwest Monsoon swells and waves move sediments northwards. Owing to the steep angle at which the waves approach the southwest and west coasts they possess a very high sediment transport capacity. During this time monsoon fed rivers on the west coast also have large runoff and sediment discharges. The coastal dynamics are therefore complicated and very intense. The processes are more complex at lagoon entrances owing to the filling and emptying currents produced by tides. These tidal currents help a portion of the sediments to cross the inlets of these lagoons and estuaries.

Sand spit formation takes place at river outlets. Spit formation depends on the average littoral drift on the coast and the quantity of sediment discharged by the river to the coast. When littoral drift is high in comparison to the sediment load of the river, the outlet shifts in the direction of the drift; when the river sediment discharge is high the river mouth mouth moves against the littoral drift. Sediment moving forces at these

locations show a seasonal variation depending on the wave climate. However, owing to the varying sediment supply by rivers the coastal dynamics at the outlets are unpredictable. This uncertainty makes the siting of development activities at these sand spits undesirable.

The weaker swells and the northwest waves during the Northeast Monsoon make the sediment transport on the west coast at this time unpredictable. At some locations there is a reversal of sediment movement at this time, but the net sediment transport on this coast over the year is northwards.

The penetration of the southern swell is extremely small north of the Mannar Island owing to the shallow depth of water at Adam's Bridge and the shelter by the peninsula. The wind induced waves are limited by the fetch. Wave action is therefore fairly mild. However, the fine sediments available in the tidal flats are easily moved by the tidal currents. The coastal formations indicate a net sediment drift northwards up to Pooneryn.

The tidal currents filling and emptying the Jaffna Lagoon are the most dominant force moulding the coast from Pooneryn to the north coast. The extremely mild nearshore slope causes tidal currents to flow fast over the sea bed of fine sediments. The transport of sand is partly resisted by the weeds and grasses of the area. The Northest Monsoon winds will also tend to push water around the Jaffna Peninsula into this area. However, no data on water or sediment movement are available for this area.

The sediment motion on the northeast from Kankesanturai to Point Pedro takes place because of the waves from the northeast. The sediment is moved westwards and passes around the west end of the northern coast. Tidal currents in the area are weak and are probably of minor importance to sediment movement. The quantities moved are small owing to the mild nature of the oceanographic forces.

The main force moving sediments from Point Pedro to Trincomalee Bay is that of the Northeast Monsoon waves. As mentioned earlier, these sediments seem to originate from river sediments discharged by South Indian rivers. Tidal currents are weak in comparison to wave induced currents. The coast of India and the east coast of Sri Lanka form a funnel shape and as a result the currents produced by winds and waves nearshore can be complicated. However, this is one of the least studied coasts and no data is available. The effect of the southern swell is minimal in this area.

South of Trincomalee Bay on the east coast both the Northeast Monsoon waves and the southern swell contribute to sediment movement. One or other of these two phenomena dominates on the stretch of coastal reach, depending on the location and the time of the year.

The coastline changes direction slowly presenting different angles to the oncoming waves. This causes one of the wave systems to be more dominant. Any decision on the development of this coast should take into consideration both the coastal shape and the intensity of exposure to the wave systems during the year. It is also important to remember that this stretch of coast is exposed to cyclones that form in the Bay of Bengal. Forested buffer areas exceeding 200 metres may be necessary to face severe storms of this type.

The coast from Kirinda to Dondra is exposed mainly to the southern swell. The net littoral forces are directed towards the east in this area. This can be observed in the coastal formations from Tangalle to Kirinda. West of Dondra the direction of the littoral force is variable depending on the complex topography of the off-shore area and the intensity of the waves. In some areas reversal of the littoral drift is observed during periods of local storms. Between Matara and Galle sediment movement is caused mainly by circulation in localised cells. The wave forces are generally dissipated by partially or fully submerged reefs.

The topographic structure of these reefs causes complicated flow patterns depending on the intensity of wave overtopping and available return paths for the water. For these reasons and owing to low beach nourishment, coastal behaviour in this area is extremely variable and complicated.

2.4 Identification of Coastal Reaches

The coastal area around Sri Lanka can be divided into different categories depending on which of the different criteria are used. These are geological, morphological, stability, backshore character, etc. However, in this section the stability criteria over a long period will be used in the classification of coastal stretches. Stability depends on the sediment budget, characteristics of the coastline, the littoral forces, and also the population pressures in the stretch being considered.

The coastal stretch from Colombo to Maha Oya where the littoral forces are high does not receive an adequate amount of material. There is a strong net drift of sand from south to north. This has caused a net loss of coast over the last few decades. This stretch can be identified as a progressively eroding one.

The littoral drift is strong between the Maha Oya outlet and the Deduru Oya outlet. The beach nourishment here is considerably higher owing to Maha Oya sediment. The coast is eroding at a slower rate,* and the eroding areas exist as singular points. However, some solutions tried at these eroding localities as well as structures erected for other purposes, have compounded the problem by adversely altering coastal processes.

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* This view is not in agreement with the Master Plan for Coast Erosion Management, Vol 1, p.59

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From the Deduru Oya to the entrance to the Puttalam Lagoon the population pressure is low and beach nourishment is high. This is evidenced by the dune formations and the extensive sandy backshore area in this stretch. The eroding points are isolated and seem to be a result of natural reshaping of the coast. The beaches show dynamic changes caused by high littoral transport and the tidal currents at the lagoon entrance. The erosion experienced at Talawila is an isolated problem. It has occurred because buildings have been constructed too close to the beach. This coast can be identified as a dynamically stable, sandy coast.*

From Puttalam Lagoon to Mannar Island the coast is rocky in parts and backed by jungle and flat land. The only incident of erosion in this stretch occurred in Vankalai. This erosion probably occurred as a result of the cyclone which passed across this area in 1966. The beaches have recovered and slow accretion is expected to occur. This stretch of coast can be considered stable in the long run.**

On Mannar Island the coasts are stable and the south bar is in fact accreting slowly.** Localised erosion has been experienced near the pier during certain periods.

North of Mannar Island up to the northern coast the beaches are muddy and show slow accretion.** The condition of mangroves and the distribution of other coastal vegetation indicate this accretion. This stretch can be identified as a slowly accreting, muddy coast.

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* Not in agreement with Master Plan for Coast Erosion Management, Vol 1, p.59

** Not in agreement with Master Plan for Coast Erosion Management, Vol 1, p.89

The northern coast from Kankesanturai to Point Pedro undergoes slow erosion. The erodibility of the base limestone is low and in many places fishermen have made safe anchorage areas for boats by constructing barriers of limestone. The coast is hard and the beaches consist of calcareous sediments.

The stretch of coast south of Point Pedro to Mullaitivu seems to receive nourishment from sediments discharged by rivers on the southeastern coast of India. The beaches are accreting and consist mainly of silica sediments.* Nourishment seems to be high, as evidenced by the series of moving dune formations in this stretch.

The coastline from Mullaitivu to Trincomalee consists of two large lagoons, Kokilai and Nayaru. A few streams with a very mild slope discharge into this coastal stretch. The coast also shows headland features and is sparsely populated. Coastal erosion is localised. It has been a problem in the short stretch of beach immediately north of Trincomalee town and in Mullaitivu. The coastline is stable and the beaches in most places are sandy and in a few places consist of shingle and coral debris.

Within the Trincomalee Bay coast erosion takes place on the periphery of Koddiyar Bay. This coast has very steep slopes and over a short distance reaches a depth of 1000 metres. Most of the Mahaweli sediments is lost into this trench. There seems to be localised erosion of the coast as a result of redistribution of sediment around the Bay due to changing wave forces. In any case, the coast is unstable and no permanent structures should be planned in the coastal zone of this stretch.

South of Foul Point to Batticaloa the coast is dominated by headlands and lagoons. The wave climate in this area is generally mild and the reefs offshore provide a portion of the sediment.

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* Not in agreement with Master Plan for Coast Erosion Management, Vol 1, p.85

The area is prone to the incidence of cyclones. This was seen in the damage caused by the passage of the 1978 cyclone. The set-back has to be broader along this coastal stretch and woodland buffers at least 300 metres wide should be established. This stretch of coast shows signs of slow accretion but it should be considered to be a cyclone prone area with the risk of storm flooding.

South of Batticaloa the population pressure is low except for Kalmunai and a few other areas. The coast in general is stable* but may show oscillations of erosion and accretion due to the interaction of the northeast waves and the southern swell. This trend extends towards the southeast of the island up to about Kirinda. In general, the coast is accreting as shown by extensive dune formation. However, from Panama to Kirinda human activity on the coast is minimal owing to parklands and nature reserves.

From Kirinda to Tangalle the coast is sparsely populated except at Hambantota. The formation of dunes in this stretch shows the excess of sand in the sand budget, and strong wind activity. The coast is dominated by hard headlands and bays exposed to the southern swell and partly to the northeast waves. The bays are stable generally and the deposits show a predominance of river nourishment. This area can be classified as a stable coast.**

Between Tangalle and Dondra the coast is rocky and the beaches are poor. Headlands extending far into the sea, however, form sandy bays as seen in the Mawella and Gandara areas. The rocky coast indicates continuous erosion which has been made worse by the absence of any beach nourishment sources. This coast can be classified as an eroding coast.

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* Not in agreement with Master Plan for Coast Erosion Management, Vol 1, p.85

** Not in agreement with Master Plan for Coast Erosion Management, Vol 1, p.79

West of Dondra up to Galle the only source of material is the Nilwala Ganga, and a few pocket reefs. The beach sediments are fine and are susceptible to fast movement. The coast is continuously eroding. However, the exposed offshore reefs help in breaking up the heavy southern swells which are strongest in this area. Mining or any other extraction activities would damage the coastline severely and permanently.

Between Galle and Ambalangoda the coast receives a large amount of wave energy from the Southwest Monsoon waves. Nourishment is received from the Gin Ganga. Other features are the high population density along the coast and the mining of the coral reef. All these features have caused severe instability of this coast. Land values are high and in many places the highway runs along the coastline and is maintained by a revetment. This stretch of coast can be classified as extremely unstable.

North of Ambalangoda to Bentota the coastline comprises a series of bays suspended between rocky headlands. The beach material shows a significant calcareous component indicating nourishment from coral reefs. This stretch can be considered stable in the long run even though slight erosion can be observed at headlands caused by the temporary realignment of the beach to varying wave directions. * The population pressure is relatively small and the coast can be classified as stable.

North of Bentota up to Kalutara the coast is again unstable. The development of the Bentota-Beruwala stretch as a tourist area has contributed somewhat to modification of the coastline. The construction of the fisheries harbour at Beruwala has caused erosion in the Beruwala Bay. North of Maggona up to Kalutara the beach is receding through the imbalance between supply and loss. The railway line is close to the beach north of Paiyagala and faces potential danger from erosion.

Not in agreement with Master Plan for Coast Erosion Management, Vol 1, p.85

The Kalu Ganga acts as a source of beach nourishment providing a considerable amount of sediment to the coast. The stretch of coast north of the Kalu Ganga outlet also shows signs of erosion over isolated stretches. This stretch up to Panadura can be considered relatively stable in the long run if mining activities can be controlled.*

North of Panadura the coastline is very fragile. Starvation of these beaches caused by the long groyne at the Panadura river outlet is the main reason for the aggravation of erosion. The railway line runs very close to the beach. There have been instances when the railway line was almost lost. This stretch can be classified as extremely fragile and needing high priority for beach replenishment.

2.5 Anomalies

In addition to the general areas discussed there are places where the coast shows singular behaviour. These areas are usually close to large lagoon entrances, adjacent to discontinuities in reefs and other submerged topographical features, and in the vicinity of offshore islands.

The coastal zone close to lagoon entrances and river outlets is very dynamic and changes drastically due to rare events such as heavy floods and oceanographic phenomena. There should be adequate buffer zones in these areas on both sides of the entrances to accommodate such changes.

Close to gaps in reefs and other canyon type topographic features the coast also shows sensitivity to changes of oceanic phenomena and rare events. Such localities should be handled with care during the planning process even in areas identified as stable coasts.

Not in agreement with Master Plan for Coast Erosion Management, Vol 1, p. 67

In areas opposite offshore islands the coast is stable even though the general area may be unstable. Such localities should be considered anomalies.

3. PRESENT STATUS OF THE COAST

3.1 General

The present status of a large part of the coast cannot be determined because of the civil unrest in the country. This Chapter is based on information available prior to 1983 supplemented with data from aerial photographs. This Chapter has therefore to be updated as and when data becomes available.

3.2 Use of the Coastal Zone

The coastal zone in Sri Lanka is used for several activities. Fishing is the dominant activity all round the coast except in the coastlines bordering natural reserves. Beaching of canoes and engaging in *ma del* (beach seine) operations and associated activities occur on the coastal margins. The nearshore areas with natural protection are used for mooring larger fishing boats. The harbours and anchorages constructed round the island are used for fish landings and boat repair work. Net fishing, canoes or boat anchorages do not contribute to erosion. However, the construction of breakwaters for fishing or commercial harbours could cause instabilities in a large area adjacent to such constructions.

Another widespread coastal land use is for housing. This activity is directly related to population increase. Landlessness among fishermen leads to encroachment and the construction of temporary housing on state-owned land within the coastal zone. Settlements of this type become permanent over time. Privately owned land in urban areas are also used for residential purposes. The erosion of the coast is not directly related to settlements or residential uses of the land. However, encroachment into the first or second dune line could result in erosion affecting such houses during rare events or through a combination of events.

Such an eventuality could necessitate the erection of protective structures at short notice. These temporary structures could result in altering the coastal equilibrium and in long-term instability in adjacent areas. The control of encroachment into the second dune line would be one way of avoiding these problems.

Concentration of residential areas along the coast has resulted in the construction of highways and railways connecting these towns. During the planning and construction stages these roads may have been located well away from the beaches. Progressive coast erosion has however resulted in the erosion of the roads, as has beem experienced in the case of the Main Colombo-Galle road. Protection measures taken at short notice have resulted in the construction of structures which are sometimes detrimental to the conservation of the coast in general. The cost of maintaining these roads and railway lines already forms a considerable part of the expenditure envisaged in the Master Plan for Coast Erosion Management.

The drainage of run-off from the low-lying coastal areas to the sea through streams or canals nearly always causes problems due to sand bar formation across the outlet. The problem is more complicated when these outlets are open only during part of the year. Sand bar formation causes salt water inflow due to overtopping waves, and flooding as soon as the first rains come. In order to avoid these problems, structures are erected on the coast. These measures almost always cause other problems and general instability on the coastline. In such cases soft solutions are always more effective than hard structures which are conventionally used.

Sewage outfalls are usually constructed in urban areas with high population concentrations. The sewage is usually untreated, and pollutes the nearshore area. These areas are also used for recreational purposes which demand a high level of water quality.

Furthermore, the decomposition of the sewage uses up the oxygen in the water, producing anaerobic conditions which are detrimental to the coral reefs and to the environment. This causes instability indirectly by killing the living organisms of the reef and causing general degradation of the nearshore area.

Coral mining and sand mining cause instability in the coast. These activities take place along the west and southwest coasts of Sri Lanka. Proper control of these activities is an urgent necessity as these coasts are already eroding.

Recreational uses of the coast are mainly linked with tourism. This activity in itself does not cause instability. However, the over-use of resources such as reefs for excessive snorkling and diving, or collection of souvenirs, could damage the live reef and result in coastal instability. The construction of tourist facilities such as hotels should be controlled as development activity carried out too close to the coast, in excessive density, could lead to indirect problems of pollution and the ultimate depletion of resources.

3.3 Activities Causing Instability

The uses discussed above are the most general activities in the coastal zone. However, there is no hard and fast rule to determine whether an activity will cause coastal instability. In general, any activity which tends to change the coastal plan shape or the bottom topography of the nearshore area, or pose pollution problems, should be carefully evaluated for any adverse effects. In addition to projects which change the planshape and topography directly, there are other activities which cause changes that finally result in instability.

The construction of structures in the littoral zone almost always causes local changes in the coastal processes, which can cause instability in a large area. The area affected is generally the littoral cell in which the change is caused and, to a lesser extent, the two adjacent ones. The construction of sea walls with high reflection of waves, groynes, and breakwaters for harbours, are among these causes.

In addition, the removal of materials such as coral or sand from the beach or from offshore areas causes instability. Dumping of sand or other solid material in the nearshore area also changes the topography and causes instability at least temporarily until the material dumped is evenly distributed along the beach by wave and current action.

3.4 Status of the Coastal Beaches in Relation to Activities

In this Section the present status of the coast is discussed from the point of view of erosion or accretion. The time span considered is the last few decades. The erosion and accretion identified in this Section is therefore only short-term. Some areas may show different behaviour when longer periods are considered. The status of the coast and the present trends in resource uses which are related to stability, are presented in tabular form.

Coastal Reach	Activities	Present Status	Present Trends and and Projections for Year 2001
Colombo to Negombo	1. Residential 2. Fishing 3. Communication 4. Tourism	Progressive erosion 1m/year average. Most of the coastline protected with sea walls, revetments & groynes	Increase of residential use. An increased need for coastal stabilisation work due to continuous erosion of residential area.
Negombo to Maha Oya	1. Tourism 2. Fishing 3. Residential 4. Communication	Slow erosion except in the areas covered under the 1987 management activity. Continuous erosion North of Kammala 1m/year	Increase of residential use. Increased rate of erosion in the unprotected area between Kammala and Maha Oya
Wellamankara to Chilaw	1. Residential 2. Fishing	Slow erosion Erosion and accretion areas are modified due to structures. Continuous erosion north of Toduwawa.	Same rate of erosion between Wellamankara and Lansigama. Coast stable up to Iranawila. Slow erosion north of Iranawila Chilaw spit, stable.
Deduru Oya to Kalpitiya	1. Fishing 2. Residential	Coastline stable.	No rapid increase in use. No erosion problems anticipated in the next decade.
Puttalam to Mannar	1. Fishing	Coastline stable.	No development activities envisaged in the next decade. Coastline will remain stable.
Mannar Island	1. Fishing 2. Passenger Terminal	Northern coastline stable. Southern coastline accreting slowly.	No development activities envisaged in the next decade. Coastline character and behaviour will not change
Mannar to Pooneryn	1. Fishing	Coastline stable. No immediate pressures except the anchorage in Vidathaltivu.	No change in the behaviour of the of the coastline is envisaged by year 2001.
Jaffna to Kayts	1. Communication 2. Fishing	Coastline stable	No change in coastline behaviour is envisaged.

Coastal Reach	Activities	Present Status	Present Trends and and Projections for Year 2001
Kayts to Point Pedro	1. Fishing 2. Communication 3. Residential	Slowly eroding areas strengthened with sea walls and revetments	Development pressure increasing; Adequate protection has to be provided at selected stretches.
Point Pedro to Mullativu	1. Fishing	Coastline accreting by dune formation. Slow localised periodic erosion in Mullativu Town	No change in behaviour envisaged until Year 2001 at least.
Mullativu to Pulmoddai	1. Fishing 2. Mineral mining on coast	Coastline stable except where sand mining has resulted in erosion. No dune protection available at present	Uncontrolled beach mining will weaken coast and cause total flood ing in case of a cyclone, thereby damaging expensive facilities
Pulmoddai to Trincomalee	1. Fishing 2. Residential	Coastline stable except just north of Trincomalee Town	Coastline will be stable if no residential buildings come up close to the beach necessitating preventive measures which could cause local instability
Trincomalee Bay	1. Fishing 2. Commercial Harbour 3. Communications	Coastline stable except in Kinniya and Mutur where the river mouth migrations cause erosion	Erosion will continue locally owing to interaction of migrating river outlets and tidal streams. A permanent road link has to be planned.
Foul Point to Valachchenai	1. Fishing 2. Pollutant discharge 3. Communications 4. Drainage	Coastline stable but weakened by cyclone in 1978. Dune buffer in some areas	Severe problems may arise through destruction of the reef weakened by the 1978 cyclone. The biggest problem is the Black Liquor effluent (from paper pulping) discharged intdo Valachchenai Aru.
Valachchenai to Kalmunai.	1. Fishing 2. Residential in patches 3. Communications 4. Drainage	Coastline stable except in Kalmunai where a road has eroded	No change in the coastal behaviour is expected during the next decade
Kalmunai to Panama	1. Fishing 2. Drainage	Coastline stable Dune buffer is available	No change in the coastal behaviour is expected during the next decade.

Coastal Reach	Activities	Present Status	Present Trends and and Projections for Year 2001
Panama to Kirinda	1. Fishing 2. Anchorage 3. Drainage	Coastline stable. No development pressures. Dune buffer available.	No change in coastal behaviour. Stability at Kirinda depends on the solutions to the problem of anchorage siltation. Any dredging and discharge offshore should be carried out only after studies.
Kirinda to Hambantota	1. Fishing 2. Recreation 3. Brine intake	Coastline stable with dune buffer available	No change expected in coastal behaviour during the next decade. Anchorage harbour construction at Hambantota should be evaluated carefully for adverse effects.
Hambantota to Tangalla	1. Fishing 2. Anchorage 3. Drainage	Coastline stable with dune buffer & headland protection available	No change in coastal behaviour expected during the next decate. Instability induced by anchorage construction at Medilla needs to be corrected.
Tangalla to Dondra	1. Fishing 2. Anchorage 3. Residential	Coastline stable. Minor erosion problems encountered at Kottegoda and Pathegama. Road washout occurred in 1969 at Polgahamulla and fill up between wall and road not yet made. Most of the coastline is backed by dunes and stabilised by rocky headlands.	No change in coastal behaviour envisaged during the next decade. Development activities in coastal areas with low-lying hinterland should be investigated from the point of view of dune or barrier breaching by high waves and tides
Dondra to Galle	1. Fishing 2. Anchorages 3. Coral mining 4. Tourism 5 Communication 6. Residential 7. Drainage 8. Sewage disposal	Coastline is slowly eroding in spite of the fact that the nearshore area consists of hard sandstone and coral flats. In some areas roads are protected by revetments. Beaches are available only in bays.	Erosion will progress only slowly owing to coral mining and non-availability of source material and strong oceanic forces. Activities destroying the live reefs on this coastal stretch will endanger these areas more in the future

Coastal Reach	Activities	Present Status	Present Trends and and Projections for Year 2001
Galle to Ambalangoda	1. Fishing 2. Harbours 3. Anchorages 4. Tourism 5. Communications 6. Residential 7. Coral mining 8. Sand mining 9. River estuary 10. Drainage 11. Sewage disposal	Coastline eroding due to natural forces The problem is aggravated by coral mining and the heavy use of the coast	Coast will continue to erode and problems will become more severe in the next decade because of excessive use of the coastal resources. Action should be taken build up beaches if the problem is to be contained. Further development activities would further endanger coastal stability.
Ambalangoda to Bentota	1. Fishing 2. Drainage 3. Residential 4. Communications 5. Tourism	Coastline rendered stable by a series of headlands and by sand nourhsiment from the offshore coral reefs	No changes in the coastal reach behaviour is envisaged during the next decade. However development activities should be controlled as the buffer area available is limited
Bentota to Kalutara	1. Fishing 2. Anchorages 3. Communications 4. Drainage 5. Sand mining 6. Residential 6. Residential	Coastline eroding slowly. Seasonal accretion and erosion takes place on the reach.	Slow erosion will continue and may reach the railway line north of Paiyagala during the next decade
Kalutara to Panadura	1. Residential 2. Fishing 3. Drainage 4. Communications 5. Sand mining	Coastline in general shows very slow erosion. Beaches in this reach show seasonal variation	No severe problems are envisaged in this reach due to favourable sediment balance. However, increased sand mining in the river and on the beach will aggravate the problem which is now manageable. Development activities should be controlled as the buffer zone is limited.
Panadura to Colombo	1. Harbours 2. Residential 3. Fishing 4. Communications 5. Sewage disposal 6. Tourism 7. Drainage	Coastline eroding. Railway line is under serious threat from sea erosion. Water quality north of Mount Lavinia poor	Severe damage can be envisaged if a rare oceanic event occurs. The problem will become more severe during the next decade if no action is taken to develop beaches and provide adequate buffer areas in this reach. Water quality improvement also should be ensured.

The areas where the problem of erosion is being controlled by coast protection methods are listed below :*

Location	Method of Control
Mattakkuliya - Crow Island	Revetment and groynes
Lansiwatte to Dickowita	Revetment and groynes
Kepungoda to Duwa	Revetment and groynes
Duwa to Poratota	Revetment and groynes offshore breakwaters and sand nourishment
Wellamankara to Kolayadiya	Revetments
Iranawila to Chilaw	Revetment and groynes
Karukkapone	Groynes
Talawila	Revetment and groynes
Vankalai	Groynes
North Coast	Revetments & sea walls
Mullaitivu	Masonry groynes
Trincomalee North	Revetment
Kalmunai	Revetment
Medilla-Tangalla	Revetment and groynes
Polgahamulla	Sea wall
Kottegoda	Masonary wall & revetment
Dondra	Revetment and groynes
Totamune to Polhena	Groynes
Polhena to Madihe	Sea walls and revetments
Mirissa Bandaramulla	Revetment and groynes
Mirissa Fishery Harbour	Revetment and groynes
Weligama Bay	Revetment
Kapparatota	Revetment and groynes
Midigama	Revetment
Denuwala	Revetment and groynes
Goiyapane	Revetment
Ahangama	Revetment
Welihengoda to Kataluwa	Revetment and groynes
Palatugaha	Revetment
Mihiripenna	Revetment and groynes
Dalawella	Revetment
Galle	Revetment
Mahamodera to Dadella	Revetment
Pitiwella to Rillamba	Revetment and groynes
Dodanduwa	Revetment
Hikkaduwa to Seenigama	Revetment and groynes
Seenigama to Ambalangoda	Revetment and groynes
Bentota to Beruwala	Revetment
Beruwala to Maggona	Revetment and groynes
Paiyagala to Katukurunda	Revetment and groynes
Kalutara	Revetment
Egoda Uyana to Colombo	Sea walls, Groynes Revetments

* Source: Master Plan for Coast Erosion Management

4. FUTURE COASTAL MANAGEMENT

4.1 General

The concept of coastal resource management is comparatively new to Sri Lanka. Earlier the resources of the coastal zone, or more specifically resource capacity of the beach and ocean, were considered inexhaustible. For this reason no planning effort was made for controlling their use. The uncontrolled use and abuse of resources over the years resulted in major erosion problems and degradation of coastal wetlands and lagoonal areas. The ad hoc corrective measures taken to control beach erosion have only further complicated the issues. At the present time comprehensive efforts involving many disciplines are essential for managing the resources and controlling user activities in the coastal zone if the resources are to be conserved for posterity. The available alternative actions possible are evaluated briefly in the following paragraphs.

4.2 No Action - Costs and Implications

The option of No Action is no option at present. Activities in the past have resulted in the present situation that does not allow this option. However, it is interesting to envisage the results if this were possible.

Continuous erosion of land in the western and the southwestern sectors of the country would result in loss of valuable coastal land, and communication facilities such as roads and the railway line. Another and a more serious problem is the possible intrusion of the sea across the narrow land barrier which separates the low-lying backwaters and marshy areas from the sea. This type of topography occurs along the west and the southwest coasts. These low-lying lands extend south, from the Bolgoda basin connecting the Kalu Ganga, Bentota Ganga and Gin Ganga

basins. The areas between the Madu Ganga in Ambalangoda to Hikkaduwa Ganga in Hikkaduwa are further weakened by large pits dug for extraction of coral.

The low-lying areas to the south of Colombo are generally used for agriculture. The intrusion of the sea, which would flood these areas, will destroy agriculture in a large area, sever communications between Colombo and the southern towns, and cause loss of residential land and pollution of groundwater resources.

The hinterland north of the Kelani Ganga basin up to the Maha Oya is again low-lying. This area is used mainly for residential and fishing purposes. The immediate environmental effects would be less drastic in this case. The spit of land running along the coast is strengthened by a narrow sandstone ledge giving a false sense of safety from erosion. The seaside of this ledge has scoured to as much as three metres in certain areas, and runs the risk of collapsing. Such a failure will cause rapid erosion and loss of the old Negombo Road and developed residential areas.

North of the Maha Oya erosion has taken place in isolated patches and in the stretch between Ambakandawila and the Deduru Oya outlet. However, part of this stretch is also protected by a sandstone reef which is in a better condition. The rate of erosion of land is comparatively lower. In the other areas the likelihood is that erosion would occur only at isolated locations and would not result in large losses during the next decade. However, the continuation of activities detrimental to the coastal zone will make these areas more vulnerable by the end of the period.

From the above analysis it can be seen that losses through erosion will take place in the west and southwest coasts, and that general environmental deterioration of all coastal areas will take place if the 'No Action' option is pursued.

It is difficult to assess the costs of this option due to the complex conditions that may occur as a result of erosion. The losses can be identified as follows :

1. Loss of Land;
   (a) Loss of agricultural land;
   (b) Loss of recreational areas;
2. Loss of houses and other buildings;
3. Loss of communication facilities, roads, railway tracks;
4. Environmental changes due to salinity intrusion; and
5. Destruction of wetlands and wild life.

4.3 Control of Erosion and Coastal Activities and Implications

This, more or less, is the present situation. Erosion management has come a long way during the past decade - from *ad hoc* construction carried out at locations of severe erosion, to planned coastal defence schemes such as those carried out recently in Negombo and Moratuwa after working out the most appropriate solution, with a correct understanding of the factors creating the problem. Such schemes need high capital investment and adequate facilities for the maintenance of the structures and beaches.

This approach, if used in areas subject to erosion, will provide adequate protection from sea erosion. Investigations into the causes of erosion and the optimum solution which would not cause environmental damage to adjacent areas need to be worked out. This involves the collection of required data, evaluating the data to ascertain the causes of instability and formulating the optimum solution for each affected area.

Control of activities leading to erosion has to be incorporated into any planning, as the construction of coast protection structures without adequate measures to prevent such activities, will become less productive in the long run. Coral mining and sand

Fig 12a -Sources of Sediment for Sri Lanka Beaches

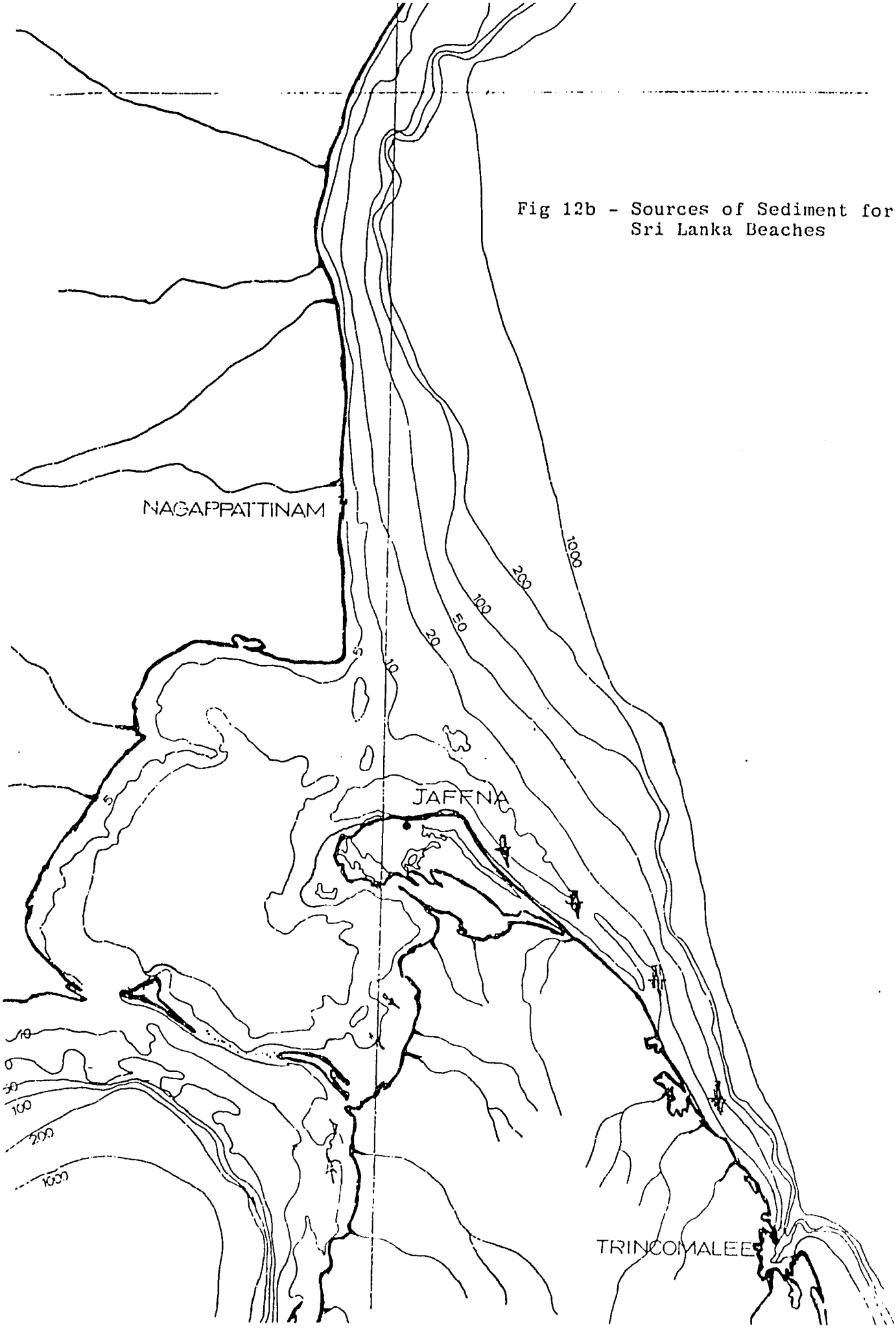

Fig 12b - Sources of Sediment for Sri Lanka Beaches

Fig 13 - Movement of Sediment

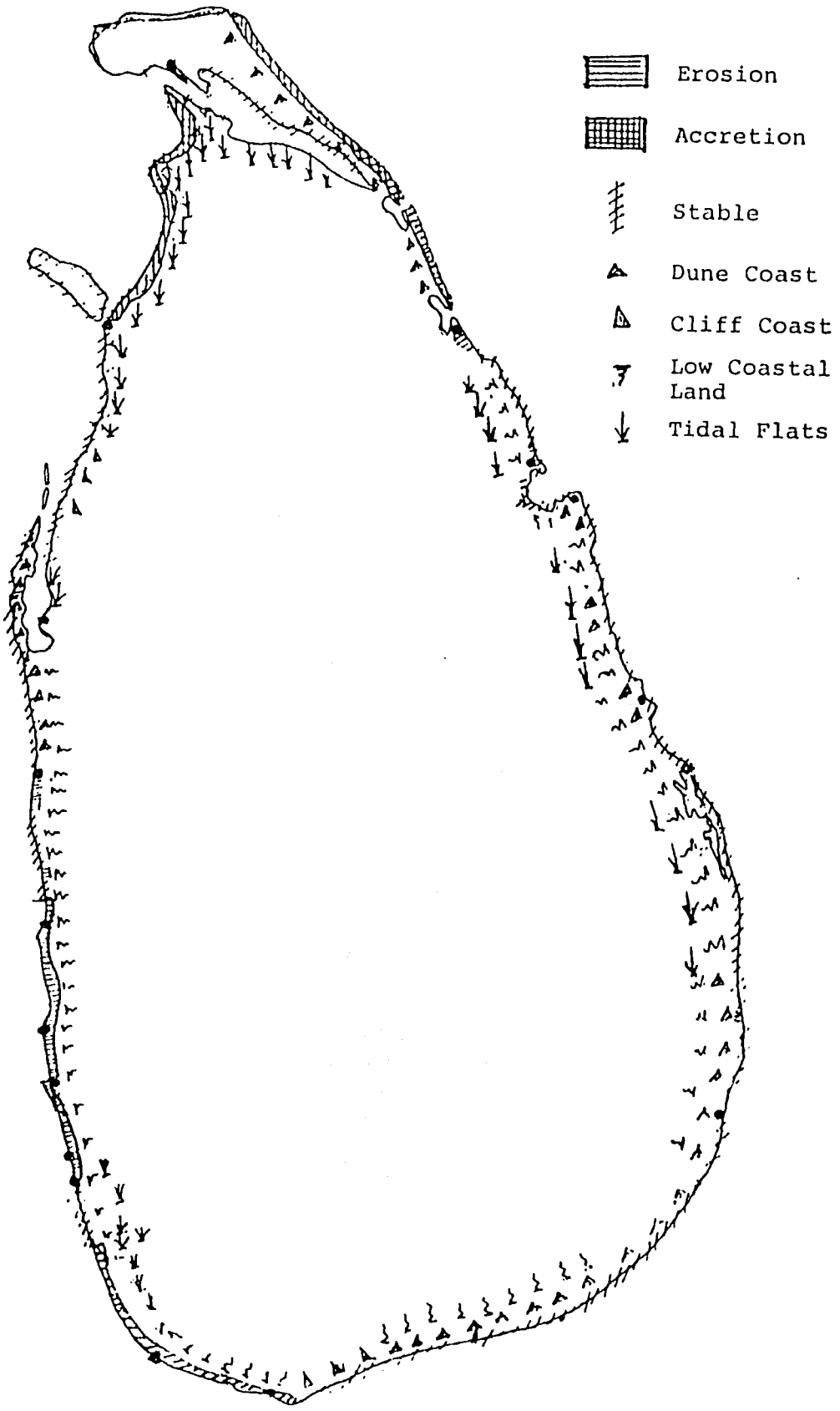

Fig 14 - Status and Features of the Coastal Zone

mining are the two main activities which are known to aggravate erosion of the coast. Control of these activities, together with solutions for presently eroding areas, will stabilize the coast for a fairly long time. However, the continuous net loss of sediments to the deep sea would deepen the nearshore area as none of these measures improve the nourishment of the nearshore area. Finally, erosion will start again once the nearshore depth increases and more and more wave forces reach the coast.

The costs of this option are higher as alternative solutions are needed for the people presently engaged in these activities and also for supplying the market with alternative construction material. The administration of the measures for the control of these activities will also need additional manpower and institutional support.

The solutions, even though temporary, will need high capital investment. The estimated cost of protection at present (1990) values is about Rs 8,000 per linear metre. The maintenance cost of these schemes will also be considerable.

4.4- Total Coastal Management and Implications

Total coastal management covers a large range of activities. In this Section only activities which will reduce the erosion hazard will be touched upon. Management activity will need to have the following aims :

(a) Prevent coast erosion;

(b) Control activities which will promote erosion;

(c) Reduce the vulnerability of the coastal land to erosion;

(d) Promote environmental conditions for natural nourishment of beaches; and

(e) Avoid conflicts which are detrimental to coastal stability.

(a) The prevention of coast erosion is a pure engineering activity whatever methods are used. The combination of appropriate methods, whether soft or hard, in properly designed schemes is the best approach. In all cases the ultimate aim should be to develop a sandy beach, and to maintain it under normal wave conditions. The beach should be sufficiently wide to contain the yearly variations caused by erosion and accretion within its boundaries. Revetments and sea walls, when used for coast protection, incur yearly maintenance costs and create changes in the adjacent beach areas.

(b) Any activity on the coast will impose a change in the coast. However, changes caused by activities such as net fishing or canoe landing can easily be absorbed by the beach. Some activities where materials are excavated from the coast should be controlled drastically or banned completely. Fortunately this type of activity is not carried out on an organized basis and control has to be accompanied with alternative resources, alternative jobs and education of the public. Activities which involve deposition of materials on the beach, and drainage and discharge of pollutants to the nearshore area, damage the beaches indirectly. These activities are usually carried out by Government or private industries The effects of such effluent discharges on each area may be different. Each project has to be individually evaluated for coastal damage. Creating an awareness among the responsible organisations and the public of the undesirable results of these activities will help to minimize damage in the long run.

Residential and tourist developments in general do not damage the coast directly. However, sewage disposal, removal of dunes and vegetation, reducing buffer areas to inadequate levels, and overuse of the resource, can cause problems. These aspects should be controlled in order to ensure stability.

(c) This is a long-term planning activity that has to be considered. Population pressure on the west and the south-west coasts can be directly attributed to communication facilities. The buffer zones which would have existed earlier in certain areas are not available any more. One way of reducing the pressure would be to plan new roads and other communication facilities at a considerable distance from the coast. Ideally, adequate park or bare land should be developed as buffers between the beach and the valuable hinterland. In undeveloped dune areas two lines of dunes would provide an adequate buffer against extreme sea conditions. In developed areas the only logical alternative would be to develop wide, stable beaches by artificial means and where necessary, construct properly designed structures to retain these beaches. For optimum benefits the losses will have to be made good on a regular basis.

(d) A basic cause of coast erosion and general degradation of the coastal environment is the disturbance of the equilibrium which existed in the nearshore and coastal area. Most of the damage has been caused by the destruction of live coral reefs and the degrading of the water quality in the nearshore area, which in turn reduced the growth of the reefs. Another reason is the reduction of the sand discharge of major rivers caused by sand mining in the rivers for development activities and river training works. The damage caused by these activities can be only partly countered by control measures.

The sources of sediment supplied by the marine environment may be increased in the future by conservation and development of the nearshore reefs. Reef damage has been caused by mining in some areas. Reef degradation along the south coast appears to have been caused by the lowering of the water quality. The existence of healthy reefs in Polhena, Madihe and Weligama areas a few years ago, and the absence of this type of reef in most of the other areas indicate that there been a change in the water quality. Another

reason for the absence of protective reefs in most of the coastal areas is the absence of a proper sheltered base for the coral polyps to start on. This can be provided by establishing an artificial reef base. The abrasive action of moving sand and the smothering action of suspended sediments are two factors that inhibit the growth of and destroy live reefs.

Resource development activities should include research which will help in understanding the reasons for the change in the environmental conditions over short distances. This needs a comprehensive environmental study of reefs, water quality and other physical parameters in the nearshore zone. More appropriate corrective measures can be designed by this approach.

Conflicting activities in coastal areas almost always cause coastal instability. They can be classified as those that cause coastal pollution directly and those that use the coast for recreation. In order to optimise coastal use these activities have to be zoned and controlled on the basis of the availability of resources and the consequences of the use of the resources. Some activities can be combined in certain zones while other activities will have to be completely stopped. Any zoning exercise should be carried out very carefully as all existing activities will be affected by it.

The extra cost of this option over the control of activities is the component involved in its implementation, research and other tasks that are described under sub-sections (a) to (e). A large sum of money will be necessary for implementing the zoning option, but such expense will in the long term prove cheaper. It will also minimise most of the problems arising from present resource use conflicts.

5. DATA AVAILABLE FOR DECISION MAKING

5.1 General

Accurate data is one of the most important inputs for the successful planning of any type of project or programme. This is particularly true in the case of coastal resources development planning where the subject of interest (coastal resources) undergoes dynamic changes over fairly short periods of time. Many types of data are needed. The rate of erosion, oceanic forces and coastal geomorphologic data fall into the physical category. Sociological data include land use, land ownership and coastal resources use. Effective management of coastal resources needs data of all these types.

5.2 Adequacy and Quality of Data Available

Unfortunately at present the data available for decision making on coastal resources use is very limited. There is very little hard data available on the rate of land loss. Most of the information available on land loss has been obtained from aerial photographs and from the evidence provided by local residents. Repetitive surveys have been carried out in a very few areas. It is possible to make accurate estimates of the area of land lost in these areas and also the volume of material eroded in between successive surveys. The aerial photographs available have been prepared for land use work and are not suitable for studying the rates of land loss.

Data are available on land ownership and some aspects of coastal land use. However, these have to be checked for accuracy and updated before they can be included in a coastal data base.

There is some documentation on the coastal classification based on geomorphology. The total amount of data available however is very small, and most of it is available only in a qualitative form. Coastal land classification has been carried out in more detail. This data is available for most of the areas. However it may have to be updated at least for the coastal zone.

Data on topography of the sea bed is available in a very broad sense. Most of the data available are from the Admiralty Charts. However, two major problems with this data are that no recent updating has been done and that the details in the nearshore area, which are the most important for this exercise, are almost non-existent in these charts. Recent topographical data up to two kilometers seawards is available only for the very few locations where major coastal engineering works have been carried out. Nearshore sea bed habitats and other live structures such as coral reefs, sea grass beds and pearl beds as well as any dense patches of coral predators, are also an essential part of the data. This type of data is available in a limited sense and needs confirmation and updating.

Information is almost non-existent regarding mineral distribution, composition and quality of the beach, and of nearshore and backshore sediments in the coastal zone. These data are important for evaluating the presence and quantity of economically important minerals and for analysing source capacities. The sources of rare earth minerals found as a fraction in beach sediments at Beruwala are worthwhile exploring as these minerals are as economically important as the rutile or ilmenite found at Pulmoddai in much larger concentrations. No data is available on sources of sediments which can be used for beach nourishment or for use as an alternative material for the sand market.

Data on currents, waves and water quality are available for certain areas of the coast for short periods of time. The sophisticated instruments and the know-how for the data analysis are now available in the country. The only restraint against the development of a proper data collection scheme for the total coastal area is the lack of funds. The present status of the nearshore water quality and that of effluents and run off flowing into the coastal waters should be measured and documented as the background for future development.

No data is available for problems concerning coastal backwaters and drainage. Such data is needed for planning drainage works and for the evaluation of impacts on the coast due to the execution of drainage schemes and meteorological events.

5.3 Types of Data Necessary

In this Section the types of data necessary for erosion management are discussed briefly.

(a) Wave data

The most important factor which determines coastal stability are the waves. Wave data for planning purposes need not be as comprehensive as for engineering purposes. However, representative data for at least one complete year has to be collected for areas around the country. This data can then be supplemented by permanent data collection stations established for engineering design. The wave heights, periods and directions have to be measured for estimating the eroding and longshore forces exerted by waves.

(b) Currents

Currents move and dispense sediments, pollutants and flotsam along and perpendicular to the coast. Currents which move parallel to the coast are called longshore currents which are responsible for the littoral movement of sediments. They help in the distribution of sediments received from sources and, as discussed earlier, cause erosion or sedimentation according to imbalances. Currents which move perpendicular to the coast are called rip currents or return currents. Rip currents are concentrated and strong. They move sediments off-shore and can be hazardous for swimming and other recreational activities.

Tidal currents occur in deeper water and appear as reversing longshore currents. These show less influence on the beach but are very important in the vicinity of tidal inlets and river outlets.

Measurement of currents in deeper water can be made directly using modern current meters which can operate unattended for long periods recording data on magnetic tapes. The most important currents which occur in the nearshore zone cannot be measured directly because of the turbulence caused by breaking waves. These have to be measured by tracking floats. This is expensive and time consuming but is unavoidable. The metering in the adjacent areas with float tracking under different wave, tide and wind conditions can be used to develop correlations between the two types of measurements. These measurements have to be made in selected areas by a team of trained personnel.

(c) Water Levels

Water level variations are rather regular as the most dominant force altering water levels is astronomical and is periodic. Water level data is available for Colombo for many years, and for shorter periods in many other locations. It is important to collect at least one year's data for selected locations, and that the measurements should be made simultaneously in order to establish correlations which can be used in the intervening coastal areas.

(d) Water Quality

Water quality parameters give the degree of pollution in the coastal waters. Pollutants can be identified as flotsam, suspended sediment, fresh water, organic effluents, chemical effluents and oil. The pollutants most frequently found are fresh water and sediments followed by municipal sewage. Measurements for base line water quality have to be set up as soon as possible. Monitoring surveys can then be made at regular intervals for evaluating the degree of deterioration or improvement. Salinity, temperature, turbidity, biological oxygen demand, chemical oxygen demand, dissolved oxygen concentration, and concentration of nitrates and phosphates in nearshore waters will give the degree of stress these pollutants exert on the environment. An appropriate water quality standard has to be developed for implementing control measures.

(e) Coastal Sediments and Bathymetry

These two measurements will provide information on extent of erosion and sedimentation as well as the composition and sorting of sediments along the beach. Grain size analysis of

sediments together with mineral analysis of selected samples will establish sufficient data for classification of the coast on mineral availability and for also indications on concentrations of economically valuable sediments.

Bathymetric measurements down to 20 metres will pick up most of the topographic features which will be useful in wave and current predictions in the nearshore area. Bathymetric surveys need not be made very frequently. A ten year cycle will suffice unless major development schemes are carried out in any area. Beach surveys should be made at shorter intervals; backshore surveys are also necessary for estimation of gain or loss of material from the buffer.

(f) Land/Resource Use

In addition to the above, data relating to land use, resource use and areas of conflict are also necessary for coast erosion management.

5.4 Data Collection Programmes

Whenever a large amount of data has to be collected over a large area and over a long period of time, it is always necessary to make a comprehensive programme for the project. The most important data have to be identified and a priority list made. Then, depending on the time, funds, equipment and trained personnel available, a programme can be drawn up for execution.

Wave and current data must be collected over at least one year under different oceanographic conditions.

Bathymetry data has to be collected only once and needs only to be updated every ten years. Coastal and beach surveys have to be carried out more frequently to asses land loss. An accurate survey must be made to establish control points and repetitive surveys using these points could be made at more frequent intervals.

Water quality data has to be collected for establishing background conditions and then monitored at appropriate intervals to estimate levels of pollution.

The existing data and all new data must be included in a data base for planning purposes.

6. RECOMMENDATIONS

6.1 General

The most formidable obstruction to proper planning is the lack of adequate data. This drawback can be overcome only after implementation of data collection programmes for at least one year. When decisions have to be made in the absence of adequate data, long-term goals of resource uses have to be taken into consideration. This would appear to be very difficult in the absence of at least some data, but resource misuse may be minimised by taking only the essential steps during this period.

6.2 Policy, Planning and Management Strategies

As mentioned in the last paragraph the policy decisions that need to be taken immediately should be made only after careful consideration of coastal erosion management for the future. Such decisions should be based on the stress levels the coastal zone any area can undergo without irreversible damage. Therefore the policy should be broad at national and provincial levels with adequate flexibility to suit the realities of implementation at regional and local level. A total ban on activities that affect the coastal area is not realistic in terms of implementation. However, it may be necessary to allow exploitation of resources under controlled conditions in certain areas where the effects could be contained without permanent or extensive environmental damage.

One of the methods that could be used for coastal resource management is dividing the coastal space into zones of permissible activities and discouraging activities which fall outside these categories. The zoning process cannot be implemented on a broad basis, as has been done in countries where the coastal land

ownership is not so complicated. Zoning large areas for a single purpose such as tourism will cause problems in implementation owing to the numerous activities now taking place there. The following strategy can be suggested as one method for consideration.

The coastal space of Sri Lanka can be demarcated into smaller areas as may be necessary. A point system can be allocated to each reach depending on the status of the coastal stretch considered. The natural conditions and other factors which reduce the hazard of erosion can be given positive points. These factors will include sand supply, availability of live reefs, existence of dune buffers, coastal vegetation, favourable oceanographic conditions and water quality. However, other activities such as hard coasts, headlands and natural park conditions can also be considered as positive features in this system.

Development activities which may cause coastal instability such as residential use, mining, tourism, pollutant discharge, schemes which could change coastal processes and communications, can be given negative points. The sum total of all points would indicate the stress level to which the coastal reach is subjected to at present. In this manner, the degree to which the coastal area can undergo further stress without irreversible damage, can be quantified, and activities that can be allowed and the degree of exploitation, can be determined for the particular stretch. The identification of permissible activities should be made so as to avoid conflicts as much as possible. A matrix including the stretches and activity points, present stress levels and the present status can be used for identifying permissible activities which would optimise resources and conserve the coastal zone environment.

6.3 Broader Coordination at Local Level

With the establishment of the present system of decentralisation through Provincial Councils, the national policy should allow regional policies to be formulated without creating conflicts. The zoning and permissible activities should also be determined with the participation and concurrence of the regional policy makers. This would greatly assist at the implementation stage where the regional bodies will directly handle activities at the regional level.