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IOC-UNEP-WMO-SAREC Planning Workshop on An Integrated Approach to Coastal Erosion, Sea Level Changes and Their Impacts

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Submitted Papers

1. Coastal Erosion

UNESCO

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I. INTRODUCTION: REVIEW OF COASTAL EROSION PROBLEMS IN THE WESTERN INDIAN OCEAN REGION

by A. Granlund

The intention with this paper is to give a short review of the status of Coastal Erosion Problems noted in the Western Indian Ocean, and raise some issues that could be discussed during the workshop. The phenomena of Coastal Erosion have been ongoing since the forming of the Oceans. Thus, the Man driven Coastal Erosion has accelerated erosion on several places in the Coastal Zone.

Sediment transportation is a process that has been active throughout the geological history. The dynamic development of coastal areas is affected by several well-known physical factors. To fully understand sea-level fluctuations and coastal erosion it is also important to have good knowledge about the present geological development for various coastal environments.

Important factors such as active subsidence over basin areas can result in "sea-level rise" and change the oceanographic conditions in a long term perspective. The continental drift is one of the important factors to understand and interpret the fundamental processes that govern the sedimentation processes.

It is difficult to predict the future without knowing the past. It is therefore highly important to build up **baseline studies**, as accurate as possible, over coastal erosion areas of special interest. In these efforts all different aspects should be considered and integrated. It is also important to differentiate between Man made coastal erosion and coastal erosion caused by natural processes in the environment.

1. COASTAL EROSION PROBLEMS

1.1 COASTAL EROSION PROBLEMS: IN RELATION TO GEOGRAPHICAL AREAS

The Intergovernmental Oceanographic Commission (IOC) did an "Outline of the project proposal on Coastal Erosion in the Western Indian Ocean Region - Scientific Appraisal and Management" (IOC/INF-914). In this report the IOC consultant describes several areas in the Western Indian Ocean, where Coastal Erosion has been severe. The erosion problems are concentrated to the coral-fringed coasts in the region. In Tanzania, areas north and south of Dar-es-Salaam, on Zanzibar and Pemba Islands have severe coastal erosion. In Kenya Coastal Erosion appear to be severe both north and south of Mombasa. In the Seychelles coastal erosion has been detected on the islands of La Digue, Bird Island and Praslin. The IOC report also states that various attempts have been made in all these countries to protect the coasts from further erosion but few such attempts have achieved anything beyond temporary relief.

1.2 COASTAL EROSION PROBLEMS: A CAPACITY PROBLEM

A major problem in solving the coastal erosion is the lack of baseline studies. These baseline studies can never be achieved without expansion of training components. It is therefore important to provide regional research and training activities, which will facilitate the provision and exchange of information The coastal erosion problems need to he solved regionally, with local expertise, and with some minor exchange with visiting experts. The goal is to build up a carrying capacity of local experts dealing with coastal erosion problems.

1.3 COASTAL EROSION PROBLEMS: AN INTERDISCIPLINARY PROBLEM TOWARDS ICZM

The Coastal Erosion Problems are of various sources, man driven or natural. To understand the Man driven coastal erosion problems an interdisciplinary view of the problem is needed. It has been described by many experts (e.g. Odada) that Integrated Coastal Zone Management (lCZM) will be the vehicle that could solve the problem of man generated coastal erosion. To achieve a sustainable marine coastal environment, with a clear understand of the man generated processes, an interdisciplinary strategy is needed. A combination of physical oceanographers, marine biologists, marine geologists together with sociologists and economists should make up the interdisciplinary platform.

1.4 COASTAL EROSION PROBLEMS: CLEAR DEFINITIONS

One of the major problems in the interpretation work of Coastal Erosion is the definition of the word Coastal Erosion. Much effort must be emphasized to define and describe the difference between Man driven Coastal Erosion and Natural Coastal Erosion.

1.5 COASTAL EROSION PROBLEMS: SUMMARY

The report "Outline of the project proposal on Coastal Erosion in the Western Indian Ocean Region - Scientific Appraisal and Management" (IOC/INF-914) was discussed during the IOC Regional Committee for the Cooperative Investigation in the North and Central Western Indian Ocean, Third Session, held on Mauritius 14-18 December 1992. The recommendations thought that the report was little biased towards geology driven problems concerning coastal erosion, and that effort also should be done in areas like social science and disciplines which lies in line with ICZM. It was said that the IOC Coastal Erosion workshop should be the start of the integrated regional work in this field.

Several scientists in the East African region have proposed papers on Coastal Erosion. The IOC workshop should actively try to incorporate them in the future work.

The workshop will have a unique opportunity to combine sea level rise problematic with coastal erosion problems.

2. GOALS

The outcome from the regional workshop could give a better understanding of some of the following issues;

- To be able to differentiate between Man made Coastal Erosion and Natural Coastal Erosion in order to create an acceptance of Natural Coastal Erosion
- The country profiles generated for the workshop are very important in setting up baseline studies. The country profiles need to be carefully compared at the workshop for identification of mutual problems etc.
- To set up baseline studies is important on order to create a platform for ground truth data
- With establishment of baseline studies in selected areas the base for good monitoring systems to be used for possible coastal erosion predictions is set.
- The solution to Coastal Erosion Problems and also Sea-level problems should preferably be solved in an integrated program with a stepwise goal seeking method.
- The generated information from the integrated regional work should be incorporated in an integrated database for local, regional and global use in solving Coastal Erosion Problems

ANNEX

REFERENCES

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II. NATIONAL REPORT: STATUS OF COASTLINE CHANGES IN KENYA AND ITS IMPLICATIONS ON SUSTAINABLE COASTAL ZONE DEVELOPMENT AND MANAGEMENT

By Dr. E. Okemwa, Mr. K. Kairu, Mr. T. Munyao

1. INTRODUCTION

The Kenya coastal zone extends from about 4°30'S to 4°35'N and has a total shoreline length of over 480km. From a geological perspective, the coastal zone may be extended to include the Kenya continental margin. This zone can be divided into three distinct physiographic provinces (fig. 1), defined on the basis of Litho-stratigraphic units. Moving from the east to west, the coastal plain which is the first physiographic unit, rises from sea level datum(OD) to over 200m, the foot plateau extends from an elevation of 200m OD to 500m OD and the Nyika at above 500m OD.

The coastal plain is the most important physiographic province in relation to coastline change. The near surface geology in this sector evolved in Post Miocene times on the sub-Miocene erosion bevel. The geologic evolution of this province has been influenced strongly by the relative change in sea level, the Miocene and Pleistocene erosion bevels, the reef systems and the major drainage patterns. These elements have strongly controlled to different extent the erosional and depositional cycles of the Quaternary and recent stratigraphy and evolution of the present shore configuration.

The coastal zone which is vulnerable to change can confidently be assumed to conform to the coastal plain for this study. Two distinct shore types are observed within this physiographic province. The northern sector, which shows accretional trends in Holocene times and the southern sector, which has been dominated by erosion trends at least during the Holocene. The two distinct shore types, however, exhibit wherever preserved, a similar series of fossil sea level terraces first described in Mombasa area (Rais Asa, 1978) and observed all along the coast by the authors. For coastal zone management, the terrace complexes can be grouped into four levels that can easily be recognized in the field unless obscured by the drift geology. Level I comprises of terraces at 0-5m OD elevation, level II at the 5-10m OD elevation, level III at the 10-25m OD elevation and level IV, all terraces above 25m OD. These levels constitute very important geological sub-environments in terms of coastal zone development and have a strong significance on the susceptibility of the coastal environments to coastal erosion.

2. HISTORY OF COASTAL ZONE DEVELOPMENT

Like in many world coastal nations, the earliest permanent settlements in Kenya developed along the coastal zone. Maritime trade and easy communications provided by the water ways were some of the most important driving forces in the establishment of this settlements.

Most of the old settlement therefore evolved next to favorable natural ports. Among the most important settlements observed today that date back to between 8th and 18th century include, Manda, Pate, Lamu Shanga, Omwe and Kiunga in the Lamu area; Ungwana, Mambrui and Malindi in Malindi area; and Mombasa, Mtwapa, Vumba Kuu in Mombasa area. Mombasa, Malindi and part of Lamu are located on level II environments and above and the lower parts of Lamu, and Kipini are on level I (fig.2). Due to the generic relationship between good drainage channels and relatively stable coastal geology at least in quaternary, most of these old settlements that have survived the impact of coastal processes were located on limestone terrain (fig.2). Evidence of drowned ports occur in several localities like Lamu and Ungwana bay areas. These represent settlements that were located on the more dynamic environments of the coastal zone. Up to the mid 20th century, settlement expansion occurred on the existing towns especially Lamu, Mambrui, Malindi and Mombasa.

In the last three decades, Kenya coastal zone development has transformed from trade,to service oriented industry for the tourism industry. This new industry requires beautiful low lying coastal environments comprising of unconsolidated sand deposits (the beaches) (fig.2). Unlike the old sites, these

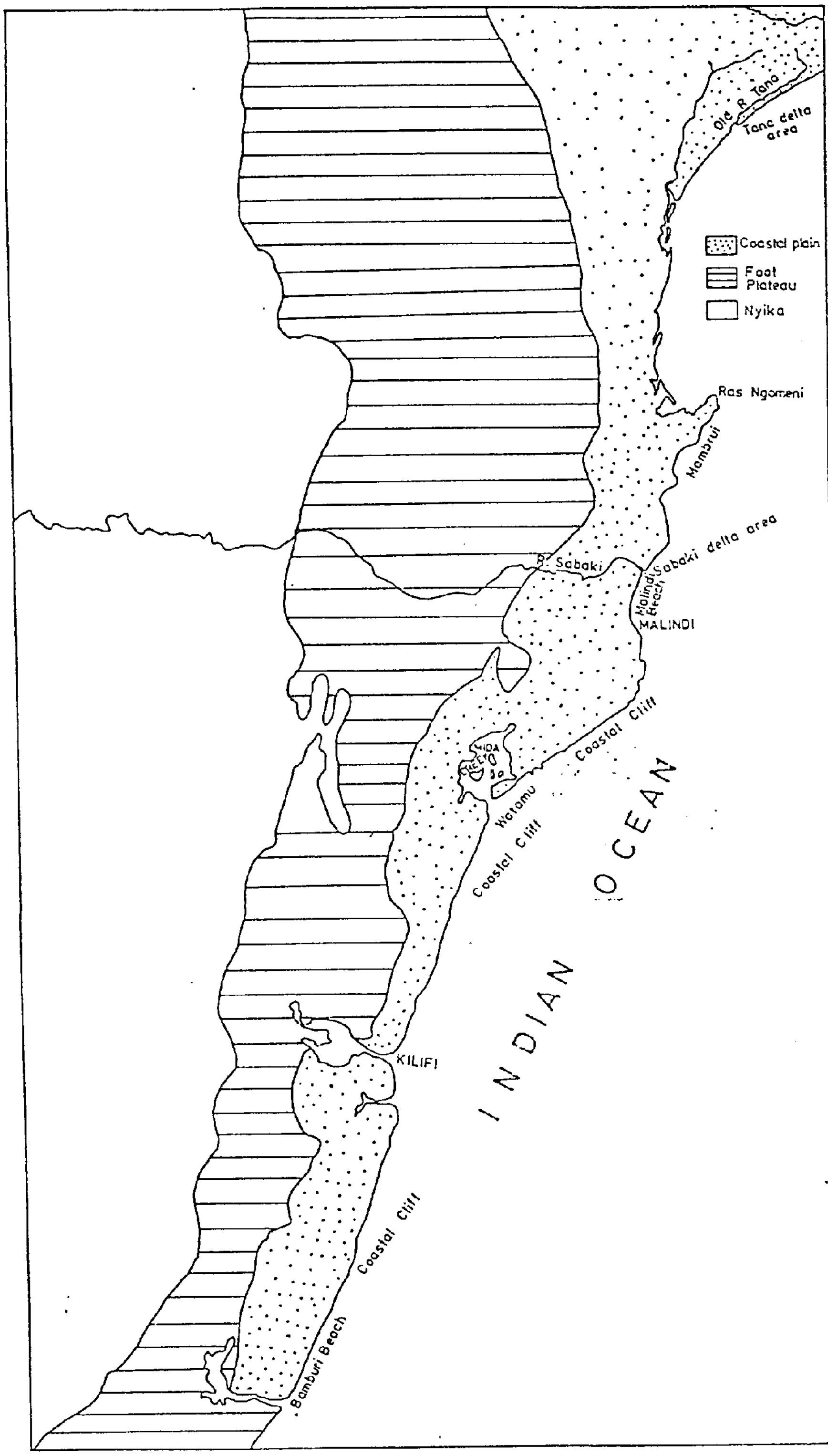

Fig: 1. Major Coastal Physiographic Provinces.

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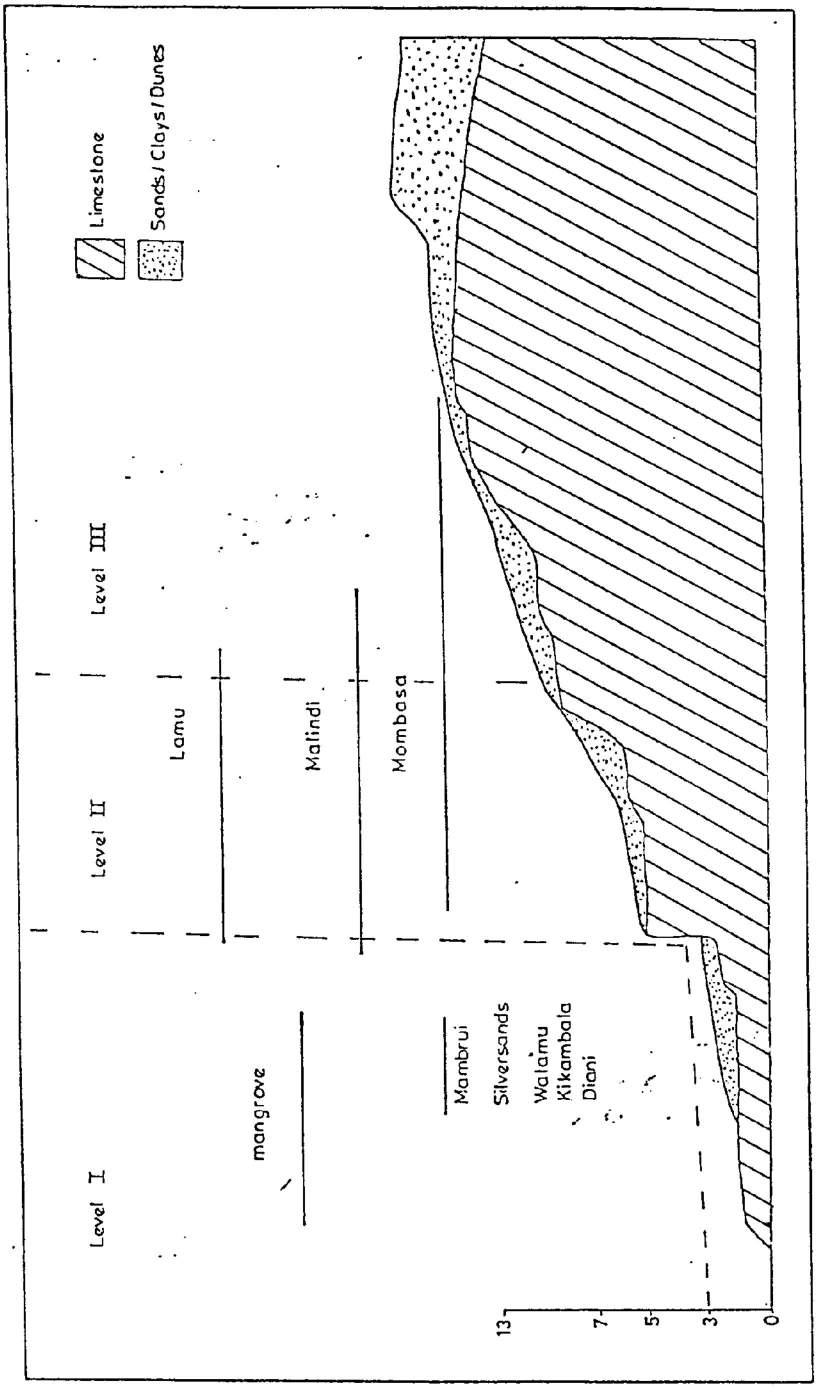

Fig 2. Geomorphic setting of major towns and settlements.

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new sites are relatively mobile geological environments, characterized by annual and longterm shoreline transformations, a fact that was not appreciated by most of the coastal zone developers. The most preferred sites are level I and II environments (fig.2). From our studies, Diani, shelly beach, Nyali, Bamburi, Kikambala Watamu and Malindi coastal tourist centers are located on level I and II environments. A good exception is the Nyali site where development was limited to level II by geological control. As a result, a massive investment of national economic importance is sited in areas that are experiencing erosion or are susceptible to erosion. This trend of coastal development will strongly influence the magnitude of the impact of coastal erosion on different settlements on the longterm.

3. MAJOR SHORE GEOTYPES

3.1 THE NORTHERN SECTOR

The northern sector extends from slightly north of Malindi to the Lamu archipelago and falls within the area of the present and pre-historic Tana and Sabaki deltaic systems. Levels I and II terraces are extensive and reach a maximum width of over 40km. In most of the area they are obscured by the accretion of quaternary unconsolidated deposits. These are represented by deltaic sands, clays, wind blown sands and lagoonal deposits. In Ungwana bay, barrier island systems associated with fossil drainage patterns form important coastal elements. This sector is dominated by secondary shorelines comprising Pleistocene to recent unconsolidated environmental rock units. Due to the deltaic setting, major sectors of this coastal area extending to over 10-40km lie only a few meters above the highest spring tide. This increases vulnerability to flooding. Most of the near surface sequences of this area are unconsolidated and are therefore readily reworked by the active coastal processes.

3.2 SOUTHERN SECTOR

This sector extends from the Tanzania border to the Malindi area. The sector encompasses the area of Pleistocene to recent reef proliferation. The area is therefore dominated by coral reef limestone and coquinoid limestone units that show good cementation. The near surface diagenesis of carbonates under normal temperature and pressure has produced the stable Pleistocene to recent topography with a positive relief that has survived during periods of frequent changes in sea level. This is evidenced by numerous relict features of raised sea level terraces, that formed important Pleistocene and Holocene depositional environments defined as level I to IV. The drift geology on terraces lower than 13m rarely exceeds 3m in thickness. However, Holocene accumulation on some of the lower level I terraces with favorable conditions have evolved into littoral cells that comprise some of the most sought after coastal environments for hotel and residential development. During the Holocene, this area has experienced gradual erosion.

4. COASTAL EROSION

Coastal erosion work was first initiated in 1987. The first step involved taking an inventory of the erosion problem. Later in 1988 and 1989, sites for monitoring coastal erosion were selected in Diani, Bamburi, Mambrui and Ngomeni. In 1990, a review of erosion inventory data indicated that coastal erosion was widespread and affected both developed and undeveloped low lying coastal environments. It was realized that coastal erosion monitoring alone could not provide quickly a reliable data base unless undertaken on a longterm basis due to the numerous forcing factors. It was also realized that the current rapid coastal zone development cannot wait until reliable data was collected. An urgent need to formulate guidelines for coastal developers required formulation of reasonably acceptable method of forecasting longterm shore movement especially for site evaluation for development. Such evaluation should consider factors that affect coastal sediment budgets and changes in the relative sea level stand. From this consideration, coastal erosion research began to also focus, in addition to monitoring, the study of environmental geology as a tool for forecasting the susceptibility of shorelines to predetermined changes in sea level and sediment budget. A report on this is being prepared covering a large section of the coastal zone. In the current proposal emphasis is also placed on coastal hydrodynamics.

4.1 OBSERVED EROSION TRENDS

From erosion inventory, erosion features have been observed all along the coast on both the two shore geotypes. Shoreline retreat is however a more serious problem on the primary shorelines of the southern sector on both developed and virgin areas. A survey of the distribution also shows that most of the affected coastal environments include those that evolved through the deposition of unconsolidated Quaternary and recent deposits on level I environments. These comprise very limited but important environments in the southern sector where they rarely exceed 500m.

5. ANTHROPOGENIC CONTRIBUTION TO SHORELINE CHANGE

Analysis of the relative contribution by the different forcing factors of coastal erosion has received only limited attention. Munyao (1992) while carrying out studies on sedimentology of Shirazi-Funzi lagoon about 70km south of Mombasa, observed that mangrove exploitation at the edges of the mangrove forest, or where a narrow cover of mangrove tress occur along the coastline exposes the shoreline to waves and currents, allowing erosion to occur. This problem, for example, is evident along the Funzi Island shoreline where structures built near the high water mark have been damaged due to erosion.

From the available evidence of erosion inventory on sediment budgets, local geology and assessment of the erosion distribution, areas where anthropogenic contributions may have played an important role in shoreline change can be identified.In addition to the above mentioned, areas with pronounced erosion due to the added anthropogenic contribution include, the extensive areas of beach recreational facilities, fish and mangrove landing areas. This may be attributed to interference with normal beach berm and dune evolution. The northern sector comprise shorelines whose sediment budgets are very dependant on the Tana and Sabaki river's contribution, both with an average annual water discharge of over $5.54 \times 10^9 m^3 yr^{-1}$ and $4.71 \times 10^8 m^3 yr^{-1}$ respectively.

Since 1937 when the first bathymetric chart of the Malindi area was drawn, accretion of both the Sabaki and Tana deltas has been recorded, deflecting the shoreline at the delta front by over 300m in the case of the Sabaki. Data on the Tana is not available though evidence of accretion is observed in the coastal form. At the end of the 18th century, the Tana was diverted to a more northerly course along the Ozi channel from its relict mouth in the mid Ungwana bay area. In the last two decades, major dam construction and irrigation schemes have affected the Tana. This may limit sediment discharge by the river significantly. Extensive agriculture from 19th century and associated erosion of top soil must have resulted in an increase in the river sediment load. However, recent dam construction must have limited inflow of these sediments to the Indian ocean. On the longterm, this negative sediment budget may result in an increase in coastal erosion on these river dependant coastal systems. The current erosion trends observed south of Ungwana bay where Holocene deposits are being reworked may be due to the natural channel switching observed for the Tana estuary, the construction of the Ozi channel, or the new dam construction. Increased water shed area agriculture in the Sabaki catchment has had a positive impact on the coastal sediment budget for the case of the Sabaki and probably the Malindi bay where most of these sediments are restricted.

In the southern sector, the most developed area, primary and secondary anthropogenic impacts are observed. Primary impacts include destruction of shoreline vegetation and flattening of the natural beach berm during development and continuous trampling of any new dune development. Secondary impacts include the construction of sea walls as erosion control structures. These have resulted in migration of beach sands and degradation of beaches of this sector (fig. 3). In the extensively protected areas, normal beach profiles which always have a beach face exposed at high water have disappeared. Coastal protection especially sea walls are therefore a major threat to the beach resource.

6. ATTEMPTS AT EROSION CONTROL

There are numerous examples of individual attempts by coastal developers to control coastal erosion. Extensive coastal protection structures are observed in Diani, Shelly beach, Bamburi, Kikambala and Silver Sands areas (fig. 1). In all these areas, no unified sectorial approach at coastal protection has been undertaken. Sea walls and rabble lines which are practical in cases of individual approach to shore protection have been the most preferred coastal defense strategies. The design of the current defense structures is based on wave refraction and reflection. This demands that the structures be robust, with a foundation protected by amour rock from toe erosion. Apart from very few localities, these considerations were ignored either due to aesthetic reasons or lack of know how. These two factors alone have resulted in the repeated failure and collapse of most of the coastal erosion defense initiatives.

6.1 SUITABILITY OF SEA WALLS IN EROSION MITIGATION FOR THE KENYA CASE

Our surveys show that sea walls actually stop shoreline retreat. Their effectiveness can be explained on the basis of the local geology which provides good foundation because the thickness of the drift geology rarely exceeds 3m. However, the aim in the Kenyan case is not only to stop shoreline retreat, conserving of the beach sands is a primary priority. Since sea walls are by design both wave refractive and reflective structures, they interfere with beach evolution and result in massive sand migration leading to beach degradation infront of the protected areas (fig. 3a). This is a problem of concern in Diani and Bamburi areas. where Wall-edge erosion in the adjacent unprotected areas (fig. 3b) associated with coastal defense structures is a major cause of erosion protection proliferation. The sea walls and rabble lines interfere with the quality of the beach, the main resource influencing site selection for the tourism based infrastructure. This factor excludes sea walls from suitable structures for erosion protection. It is therefore important that alternative measures that would have limited impact on the natural beach evolution and at the same time retain the aesthetics of the beaches be sought.

From considerations of the geologic evolution of the natural environments forming the major tourist beach centers now suffering from erosion, which comprise wide and small coral cays that have evolved in between headlands behind wide nearshore platforms, a sectorial approach to coastal erosion protection, utilizing a combination of detached offshore breakers and groynes can be utilized to limit the amount of energy reaching the shore and limit longshore sand migration. These two factors may positively influence the preservation of the limited beach environments observed today on the fossil terrace in this sector.

7. THE ROLE OF THE CURRENT DEVELOPMENT STRATEGY ON LONG TERM SOCIO/ECONOMIC IMPACT OF COASTAL EROSION

Our field surveys have shown that coastal erosion is dominant in the level I environments. Level II environments are affected to a very small degree. In most parts of the area on the developed southern sector, level I environments constitute 20-300m of the shore front. Actual construction could have been limited to level II. This alone could have put most of the infrastructure beyond reach of the current erosion problem. In this regard, its quite clear that bad site selection has increased the vulnerability of many of the coastal developments to erosion. The current need for expensive coastal defense structures for the already established massive investment along the coastal zone could have been avoided.

8. AVAILABLE DATA ON COASTAL EROSION

An erosion inventory and establishment of monitoring stations was initiated in 1987/1991. The initial project was later expanded to include other aspects of environmental geology. The area covered by these studies include sectors of the coast from the central Ungwana bay in the northern sector to the Shimoni area in the south. The areas to the north of Lamu and south of Shimoni have been ignored due to limited funding.

8.1 INVENTORY

Field excursions to selected representative sites on the basis of experience and desk studies were undertaken in the described shorelines in 1987-1991. The coastal morphology, general texture and composition of the major geological elements, and shore morphology were recorded. Evidence of erosion was analyzed by referencing to shore attributes like buildings, reworking of stabilized deposits with terrestrial vegetation or established coconut plantations. This data base has now been compiled to provide information on the general erosion trends.

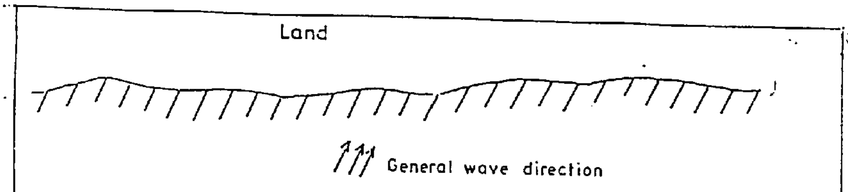

Fig 3a Initial shoreline experiencing slow shoreline retreat

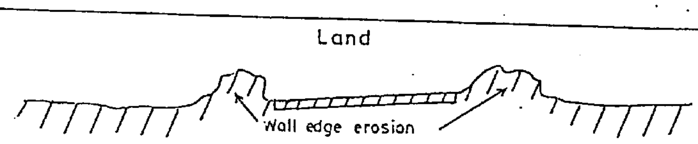

Fig 3 b Shoreline after the first sea wall construction

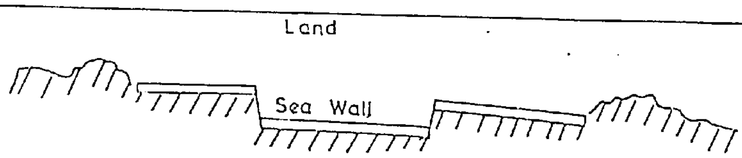

Fig. 3 c Adjacent property owners are forced to construct new defence structures further inland in response to the problem of accelerated wall-edge erosion

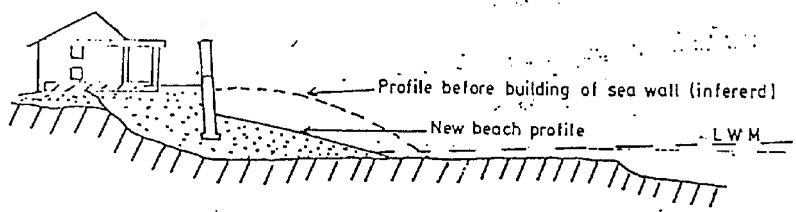

Fig 3d. Crossection view showing loss of beach sand induced by sea wall construction

Fig. 3 Impact of sea walls on the shoreline in Shelly beach, Diani, and Bamburi areas Kenya.

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8.2 MONITORING

Monitoring stations were first established from 1988-1990 in different areas. Two methods of monitoring were used. Initially the method utilized fixed poles or established shore reference structures and photography to form an indication on the movement of a selected shore elements. Levelling using an engineers level was utilized from late 1991. For this, discrete bench marks were established. This method is described by Ibe & Quelennec (1989). Referenced stations are therefore available from 1991 in some areas. However, evidence on the general direction of shore movement is available from 1987 inventory. Available evidence points out strongly that major shorelines have been retreating during 1987-1992 period, but for the time being, one cannot give an exact erosion rate due to the short period and complex cyclic behavior of shorelines. Ngomeni, one of the areas with the fastest erosion rates, an average retreat of over 0.5m per year has been calculated. In the rest of the area the rate is lower.

8.3 INFORMATION ON GEOLOGY

Extensive information on the geology is available. This is represented for the Kwale, Mombasa, Mazeras, Kilifi, Malindi and Fundi isa areas by geological reports (Geol. Surv. Kenya Report No. 24, 34, 36 and 52). The northern sector is poorly covered.

8.4 MAPS, BATHYMETRIC CHARTS AND AERIAL PHOTOGRAPHS

The area is covered by several series of maps and bathymetric charts. The oldest bathymetric charts date back to 1937. These were updated in 1950's and 1980's. The scale varies from 1:12,000 to 1:1,000,000. Topographic maps cover only recent work with only a few areas with old topographic maps. Air photographs at various scales 1:12,000 or 1:5000 are available for the different sectors of the coastal zone. The series available does not cover the whole coast continuously, this includes a 1937, 1953 and 1982 series.

8.5 HISTORICAL INFORMATION

Interview of local authority personnel, coastal developers and retired administration managers of the few Coastal Erosion Defence Works in Malindi and Lamu and people with residential houses along the shoreline give good indication on longterm coastal erosion trends for the respective areas. A few books and reports and archeological studies (Wilson, 1992) have useful historical information. A slow shoreline retreat is supported by analysis of the historical information.

9. NATIONAL POLICY ON COASTAL EROSION

Coastal erosion in the minds of many people in Kenya is a relatively new environmental problem that came into the limelight only in the last ten years, and got significant attention as an environmental problem needing special attention in the last three years. As a result no major policy considerations have been initiated specifically to deal with the problem. However, sustainable development, good environment management associated with environmental impact assessment before any project is initiated has been emphasized as a fundamental issue in the development policy in the current development plan (1988 - 1993).

Kenya Marine and Fisheries Research Institute was established by the government to play an advisory role on policy issues related to the management of marine resources. To achieve this, the institute was given a mandate covering all aspects of marine and fresh water research. Coastal erosion falls within the physical and geological oceanographic area of the mandate. The institute has already initiated a project to evaluate the erosion problem and monitor its future trends. Areas that are now covered by the study include, erosion inventory, monitoring and study of coastal sediment budgets. In the last two years due to the current threat on the immense coastal infrastructure, emphasis was also placed on producing data for planning and erosion mitigation. The project was therefore expanded to include studies on the susceptibility of different coastal areas to coastal erosion. Two more sub-projects are also proposed to deal strictly with coastal hydrodynamics and socio/economic impacts of coastal erosion. These studies should produce data that can be used for coastal development planning and management of the coastal erosion problem. On the basis of the acquired data and information from environmental geology, the susceptibility of the different coastal environmental geotypes to erosion will be computed. This will establish the extent of vulnerable areas in the different risk area categories.

The amount of investment threatened by erosion is of significant economic importance considering the fact that tourism is the leading industry in Kenya and coastal tourism is an important component.There is an urgent need to formulate a specific coastal zone development policy that will take into account the peculiar problems associated with land ocean interactions.This policy must take into account the continued viable use of the extensive coastal infrastructure and at the same time regulate development of future investment.

One of the problems that will face policy formulation is lack of reliable data sets. To overcome this, a more pragmatic approach must be adopted. This should utilize established civil engineering procedures, where case studies, preliminary field surveys, experience in working in an area and the limited data available play an important role in the preliminary project design. It is our opinion that such an approach could form basis for the initial policy guidelines. This approach is made necessary because intending developers and people experiencing erosion problems today cannot wait until reliable monitoring data is collected.

10. LAND USE PLANNING AND RELATED LEGISLATION

Land ownership along the coastal zone has experienced a lot oflegislative changes since the first real land ownership system was established under Islamic law. The first major changes occurred in 1908 when land titles act was introduced. This formed the first legal framework for adjudication of claims. In 1963, the registered land act was introduced to replace all other acts. This was also associated with drawing of suitable maps.

In 1967 and 1968 two other acts, the land control and the land planning acts were introduced. The former to control ownership and subdivision, and the latter to control planning development. The combined effect of the two acts was control over transactions and land use to avoid fragmentation and speculation Fragmentation through inheritance remained uncontrolled, even though such subdivisions could not be registered, the act had no control over their use resulting in many unplanned developments.

Other instruments that control land use include, the local authority by-laws (local government adoptive by-laws). These control plot sizes and all aspects of development in none agricultural land.

10.1 LAND POLICY

Land policy in Kenya governs the rights and obligations of land owners towards the achievement of the public interest with the aim of achieving optimal land use. The Kenya constitution guarantees the right and security of tenure subject to laws and regulations governing land usage. Land issues revolve round the specifics of land tenure systems, consolidation, adjudication and registration.

10.2 CATEGORIES OF LAND

Three categories of land are recognized in Kenya, Government land which includes all land owned by the government, Trust land which include all land held in trust by the county councils and lastly private land, owned by individuals under leasehold or freehold. Other land interests include permanent reservations incase of government departments or minor interest in case of temporary reservations.

10.3 USE AND DEVELOPMENT OF LAND

There are procedures to be followed before land is developed for the different tenure systems Approvals must in any case be given by the relevant authorities depending on the intended project. Interested bodies include, the commissioner of lands, Director of physical planning, local authorities and land control boards of the central authority. Until all applications are determined, the use or development of the land should not be carried out.

10.4 RELEVANCE OF THE CURRENT LAND USE POLICY ON COASTAL EROSION

The legislation governing land use along the coastal zone, including procedures to be followed before any development is initiated preceded awareness on coastal erosion. As a result, plot boundaries on the seaside are therefore put at the highest water mark, with no direct safeguards against coastal erosion

Adaptive local authority by-laws can be modified to control development and limit the structures that can be set up in different areas. The leasehold and freehold tenure system would be quite restrictive in development of comprehensive coastal erosion management plans due to interference directly with private land interests.

10.5 EXPLOITATION OF MARINE SAND

The building policy restrict use of marine sand due to the chloride content. As a result of this and the abundant availability of land based sand sources, permits restrict use of marine sand sources.

10.6 EXPLOITATION OF REEF ROCK

The new fisheries and wild life acts prohibits trade in shells and corals, and use of destructive fishing methods. Use of reef rock for building is therefore out of question. Building rock along the coast is obtained from coral limestones of pleistocene age, that are found along the Palaeo Marine environments.

11. PROBLEM RELATED TO LAND USE PLANNING AND COASTAL EROSION

Kenya has an established legal framework and flexible local authority by-laws to govern land transactions and development. However, the relevant acts have not achieved all the desired objectives due to various limitations. For example, the legal framework does not take into account problems related to coastal erosion especially those related to development of vulnerable environments. Another aspect that is not regulated is construction of coastal defense structures which are considered under minor improvement works. Even though local authority by-laws and the Registered land act limit subdivision to a certain criterion it has no control over divided use of the land. This aspect alone increases pressure on coastal zone environments beyond the planned levels and has been responsible for the mushrooming of unplanned structures.

12. MANGROVE MANAGEMENT POLICY

Mangroves were first gazetted as forests in 1932. Covered in this gazettment was all that land lying between the high and low water marks, and covering approximately 111,386 hectares. This was followed by a 1964 legal notice which declared mangroves as central forests and vested their interest in the Forest Department which is now responsible for their management, exploitation and use of mangrove environments for any activities. The Forest Department controls exploitation of mangroves through licensing procedures. Selective cutting of specified products in designated areas based on information from the 1967 and the 1981/83 mangrove forest inventory forms the basic control on utilization of the trees. However, illegal cutting and allocation of mangrove land to private developers are major problems. Other problems include lack of management plans to give guidelines on management objectives strategies and monitoring systems. As a result, decisions have been based strictly on intuitive, judgement and individual initiative of the field officers. This has resulted in lack of consistency and longterm sustainability of the management decisions and their objectives. A new approach bringing together all the interested parties culminating in a national workshop on mangrove management was organized in 1993. The proceedings of this workshop will form a new basis for mangrove management.

13. COASTAL ZONE PLANNING DEVELOPMENT AND MANAGEMENT POLICY

Kenya being aware of the need to develop sound coastal development strategies has set up, through various ministries, several organizations that deal directly with coastal resources. The Kenya Marine and Fisheries Research institute (KMFRI) carries out research on most marine aspects. The Coast Development Authority (CDA) places emphasis on General Coastal Zone Development and Management Planning and the Kenya Wildlife Service (KWS) is in charge of development and management of protected areas. Other important departments in coastal development include the Fisheries and Forest Departments which deal with fisheries and forest development respectively. Together, these organizations form the basic organizations in charge of coastal zone resources.

14. DISCUSSION

Coastal erosion is widespread and has a long history pre-dating most of the modern infrastructure that are located along the shorelines. These new infrastructure especially those erected on drift-geology are experiencing serious coastal erosion problems, necessitating extensive coastal protection works.

Available information shows that there is a strong relationship between the coastal type and predominance of coastal erosion. The most affected areas include geological environments that are dominated by unconsolidated sediments overlying the 0 - 7 m OD terraces. Other geological environments, for example sites for the old coastal towns, Malindi and Mombasa have been relatively safe due to good site-selection. The longterm socio-economic impacts of coastal erosion could have been greatly reduced for the already developed areas by careful planning and site selection. In most of the areas, this could have been achieved by siting the permanent infrastructure from 50 - 200 m inland.

Due to the poor site selection for the case of most of the hotels, extensive coastal protection measures comprising mainly of vertical sea walls have become a necessity. These have been erected in most of the areas to stop shoreline retreat. However, the sea walls have induced secondary environmental problems especially beach erosion, resulting in rapid degradation of the beach resource, especially in Diani, Bamburi and Kikambala. While coastal protection is known to induce considerable environmental problems, considering the level of investment along Kenya's Coastal Zone, and the importance of this to the tourism industry and the national economy, a coastal erosion protection strategy must be initiated to cover the developed vulnerable areas, not only to stop shoreline retreat, but also to conserve the beaches. Careful planning must also be considered in the rest of the areas.

Other shoreline-erosion-inducing activities include the way coastal inhabitants harvest both living and non-living coastal resources. Of much importance are the living resources, especially the mangroves. To most coastal inhabitants, exploitation of the resources is inevitable due to lack of affordable alternatives for example construction materials and fuel. In light of this, strategies on curbing coastal erosion problems should include provision of alternative resources rather than those that increase the instability of the coastline. Research on anthropogenic impacts should investigate exploitation patterns of one resource (e.g Mangrove resource), in relation to increasing exploitation of another resource of relatively less importance to coastline change such as marine fisheries.

To achieve all the desired objectives of sustainable coastal zone development, there is also a need to review and strengthen the existing legislation and licensing procedures to incorporate policies that take into account coastal erosion related impacts. There is also a need to strengthen coastal erosion research to gather the relevant management data.

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ANNEX II
LISTS OF SCIENTISTS INVOLVED IN COASTAL EROSION STUDIES IN KENYA

(A) Actively Involved:

Kairu, K.K.,
Munyao, T.M. and
Abuodha, P.O. (Mrs)
all of
Kenya Marine and Fisheries Research Institute,
P. O Box 81651,
MOMBASA, Kenya.
Tel: (254 11) 475570
Fax: (254 11) 472215

Abuodha, J.O.Z.,
School of Environmental Studies,
Moi University,
P. O. Box 3900,
ELDORET, Kenya.
Tel: (254 321) 43001/8

(B) Associated with Coastal Erosion Research

Prof. M.P. Tole,
School of Environmental Studies,
Moi University,
P. O. Box 3900,
ELDORET, Kenya.
Tel: (254 321) 43001/8
(254 321) 43061

Dr. Odada E. O.,
Department of Geology,
University of Nairobi,
P. O. Box
NAIROBI, Kenya.
Tel: (254 02) 449 233

III. COASTAL EROSION IN KENYA : A CASE STUDY OF THE MOMBASA DIANI AREA

by Mrs. Pamela Atieno Abuodha

ABSTRACT

The overall objective of this paper is to identify coastal zone management problems within Mombasa Diani area. Other objectives included evaluating the effectiveness of the existing control measures and identifying response strategies for the affected areas. The results showed that coastal dunes and beach ridges, cliffed coasts and backshore areas could be developed but with proper set back lines so as not to induce erosion Coastal zone management system, and construction of stabilizing structures along the beaches were identified as major problems within the project area. From these result it is concluded that there is an urgent need for a coastal zone management system and to enact a legislation which would protect coastal resources and environment for their sustainability. Stabilizing structures should be constructed only for highly developed areas. Keeping in mind the future sea level rise, beach hotels should be put about 1 km. landward of the shoreline.

1. INTRODUCTION

1.1 STUDY OBJECTIVES

The study objectives of this paper are as follows:

(i) Identify major morphological features within the study area in order to determine the vulnerability of the coastline to sea level rise and impacts of coastal development.
(ii). Assess the vulnerability, response strategy and requirements for the affected areas.

1.2 STUDY AREA

The study area is situated on the southern section of the Kenya coast (Fig.1). It stretches over 70km. between latitudes 3°53' south and 4°26' south. The physiography of the study area include islands bays, estuaries, reefs and beaches (Fig.2). The coastline north and south of Mombasa are characterized by coral reefs and sandy beaches protected from the open Indian Ocean by the fringing reefs.

1.3 GEOLOGICAL SETTING

The coastal belt of Kenya comprises of the following main topographical features which are closely related to the geological characteristics of the area. These are the Coastal Plain, the Foot Plateau, the Coastal Range and the Nyika. Geological features within the Coastal Plain comprises of Reef Limestones, Kilindini and Magarini Sands. (6 Fig. 3). The Reef Limestones provides the carbonate sands after weathering.

2. RESULTS ON MORPHOLOGY

2.1 MAJOR MORPHOLOGICAL FEATURES

CLIFFED COASTS

Cliffed coasts were observed at Kanamai, Shanzu, Iwetine, Nyali, Likoni [Fig.4) and at Black Cliff Point as well as Tiwi (Fig.5). The height of these cliffs (Plate 1) was estimated to be 10 -15 m above sea level. (Abuodha, 1992). The cliffs are near vertical with pronounced wave cut notches at 4 m above sea level (Ase, 1978). Where the forces produced by the action of waves and the compression of trapped air puncture the roof of an overhanging cliff, water and spray are driven up through blow outs observed at Kanamai (Plate 2).

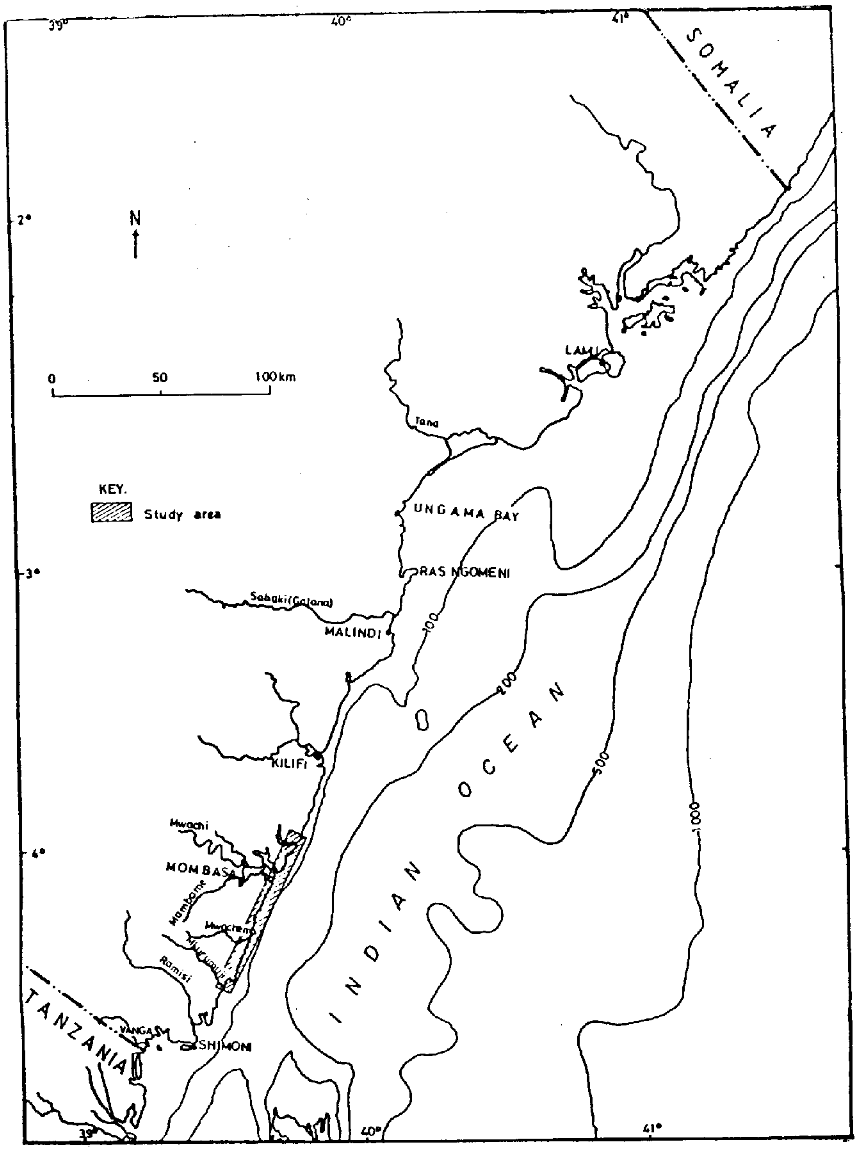

Fig. 1 shows map of Kenyan coast with the study area shaded (Source; Admiralty charts 667, 1980 and 6272, 1970).

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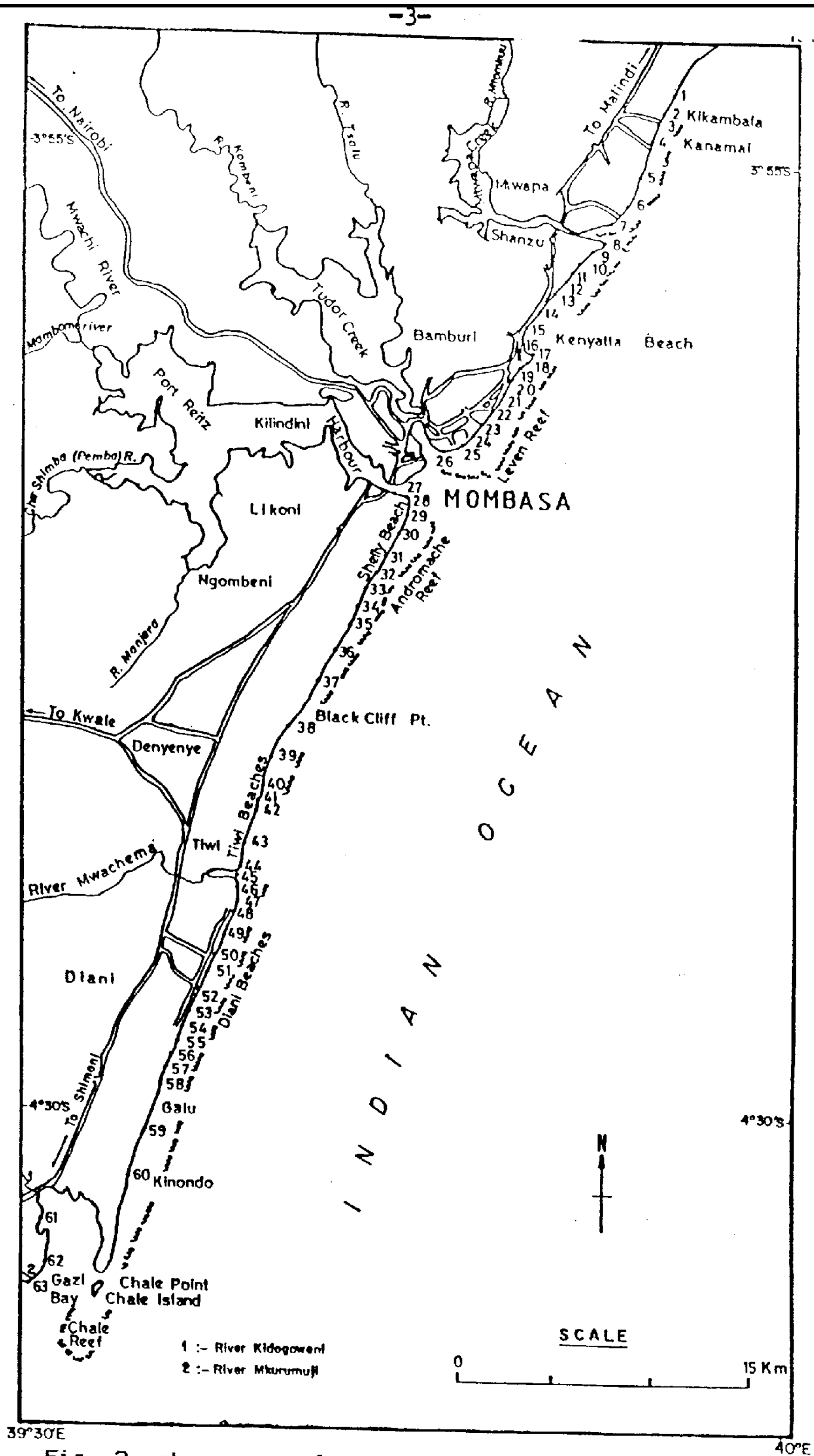

Fig. 2 shows map of the study area with sampling, profile locations and drainage.

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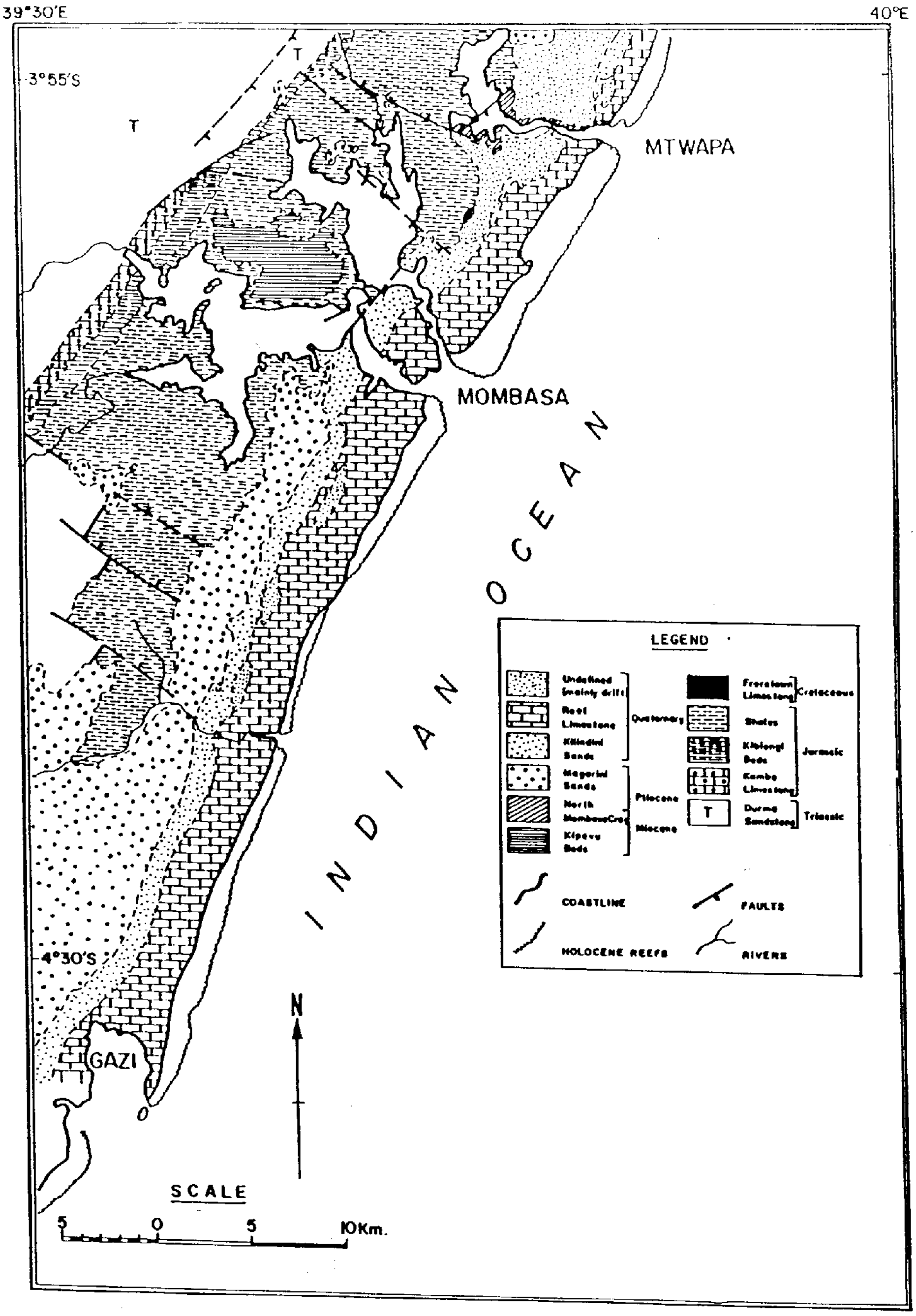

Fig. 3 shows geological map of the study area (Re-drawn from Andrew, 1981).

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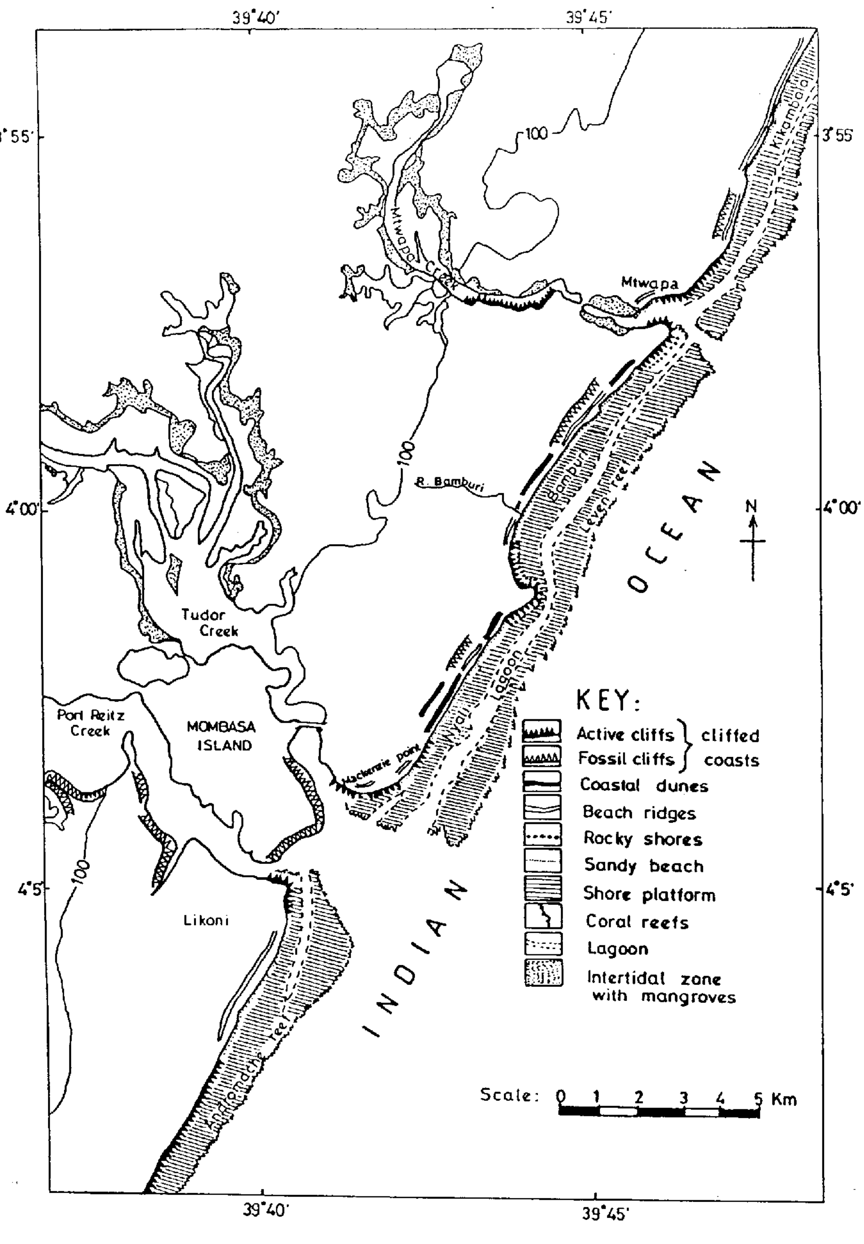

Fig. 4 shows the geomorphology of Mombasa area.

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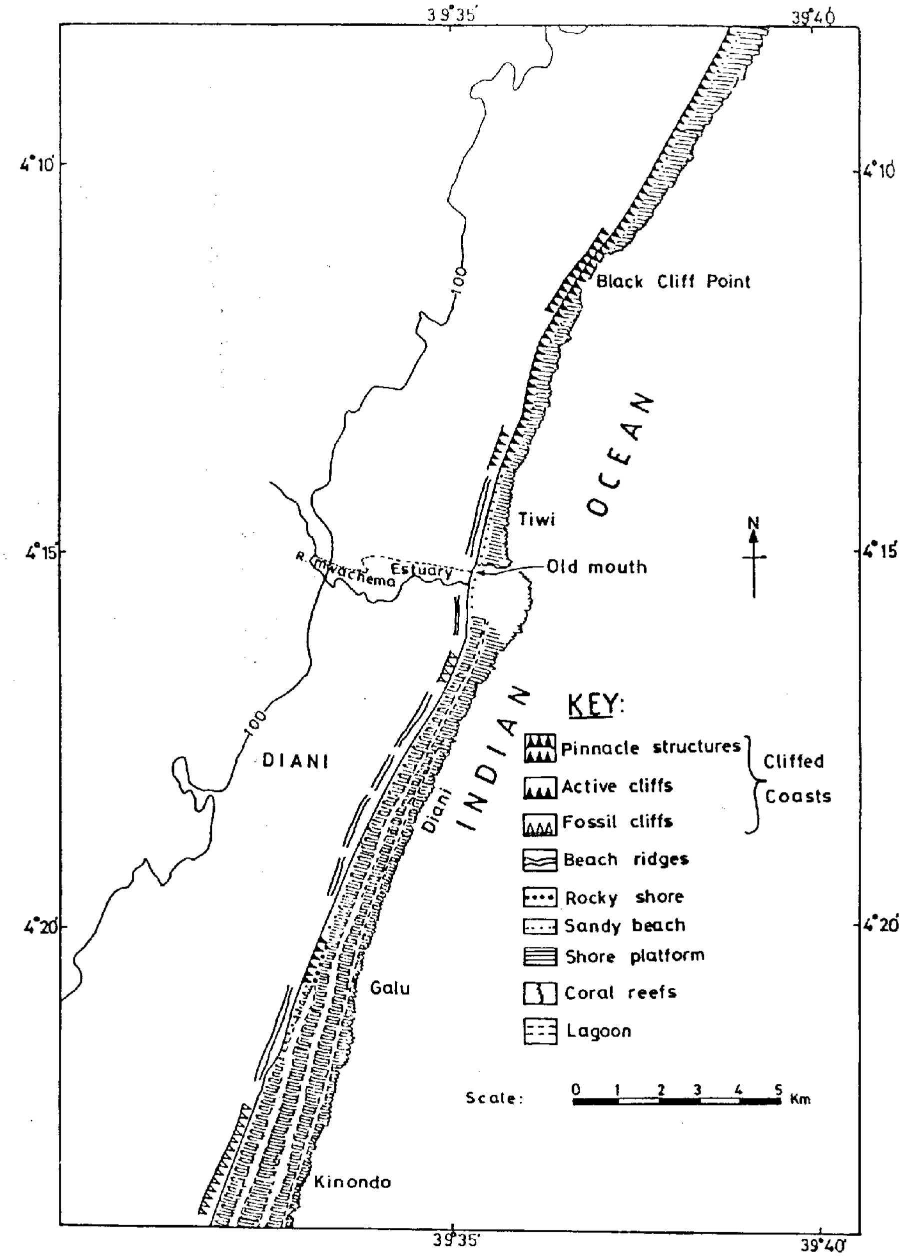

Fig. 5 shows the geomorphology of Diani area.

f8

COASTAL DUNES

Coastal dunes were observed at Shanzu, Bamburi and Nyali (Fig.4). The dunes are located close to the shoreline thus they form a bufffer stock of sediments that can be reshaped by the swell and can influence the equilibrium of adjacent beaches.

SANDY BEACHES AND ROCKY SHORES

Extended beaches occur north of Mtwapa Creek at Kikambala and Kanamai, and north of Tudor Creek at Bamburi-Kenyatta and Nyali (Fig.4). They also occur at Tiwi and Diani (Fig.5). Rocky shores occur at Shanzu (Plate 3), Kenyatta, Iwetine (Plate 4) and Galu.

SHORE PLATFORM AND LAGOONS

The shore platforms are evidently developed and widened as the cliffs recede, and shaped by the action of waves and other marine processes. Evidence of wave abrasion can be observed on shore platform where the more resistant elements of rock persist as stocks and intervening areas have been scoured out as pools (Plate -1; 4) lagoons are located within the shore platform and between the beaches and cliffs, and also within the raised shore platform. The lagoons are 5 -10 m deep and 400 - 800 m wide.

3. COASTAL ZONE MANAGEMENT

Coastal problems in the study area were identified to be:

(i) Lack of coastal zone management system
(ii) Coastal erosion; and
(iii) degradation of beaches.

Human interferences are having major impacts on the coastal zone and therefore there is increasing acceptance of the need to protect the marine environment and its resources. Coastal erosion is a prevalent phenomenon along the Mombasa - Diani area. In many places, the rate of coastline retreat and the resulting environmental degradation and economic loss is on such a scale as to be alarming (Plate 5, and 6).

Beach degradation was found to be as a result of 5 major activities namely:

(i) constructions beyond high tide mark
(ii) sweeping of the beaches,
(iii) aesthetic activities on the beaches
(iv) beach mining; and
(v) discharge of waste waters onto the beaches.

The sand used for constructing sand-infilling structures is obtained from the adjacent beaches or the dunes along the shore. Erosion is thus accelerated due to no exchange of sand between dunes and the beach. Seaweeds are swept and buried on the beach. The loosened sand is easily eroded into the lagoons or onto the shore platforms during flood time. Playing games such as volley ball foot ball and the building of castles also enhances beach erosion. Limestone is mined on the shore platform to make traditional grinding stones and sand is removed from the beaches to be used in the ash-trays.

The beach hotels dispose of their wastes especially from the swimming pools directly into the sea. These wastes erods volumes of sand which affects marine life such as coral reefs. The health of swimmers is also affected not to mention the children who play in these waters.

4. COASTAL PROTECTION MEASURES

These includes the construction of seawalls, revetments and groynes. Beach nourishment and planting of grass is also practiced along Nyali Beach. The protection using seawalls has failed as can be seen in plates 7 and 8 seawalls are the major forms of protection in the study area. Building such

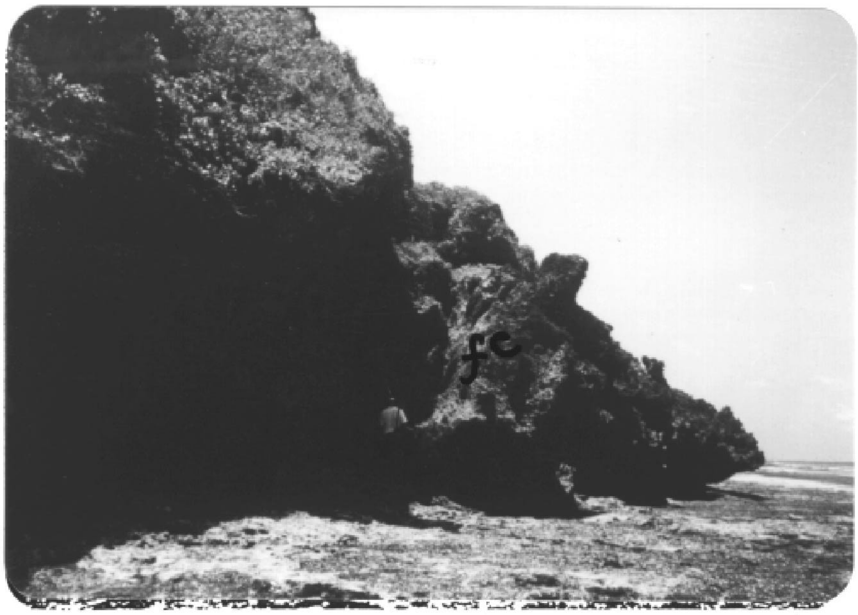

Plate 1 shows fallen cliff (fc) due to wave erosion at Mtwapa (September, 1990; Photo by P. Abuodha).

Plate 2 shows a notch (n), a blow out (b) and rugged bottom cavities (c) (September, 1990; Photo by J. Abuodha).

f9

Plate 3 shows a rocky shore platform (r) marking the lower edge of the beach at Shanzu (June, 1991; Photo by S. Langat).

Plate 4 shows jagged surface of the rocky shore (r) at Iwetine (September, 1990; Photo by J. Abuodha).

f10

Plate .5 shows reinforcement of a hanging cliff (c) at Nyali. (September, 1990; Photo by J. Abuodha).

Plate .6 shows coastline retreat in front of Kanamai beach leaving a coconut stump (s) 50 m from the present coastline (September, 1990; Photo by P. Abuodha).

f11

Plate 7 shows a thick seawall (s) at Bamburi. Note another seawall (sl) behind the failed seawall (September, 1990; Photo by P. Abuodha).

Plate 8 shows seawall along Nyali beach. Note crack (c) on the wall and sediment scour (ss) beneath the wall (September, 1990; Photo by P. Abuodha).

f12

structures causes very drastic changes on the beach which include the increase of intensity of longshore currents, hastening removal of the beach. They also concentrate wave and current energy at the ends of the wall, increasing erosion at these points.

5. RECOMMENDATIONS

(i) Shoreline areas undergoing erosion may be developed with proper care taken by creating a buffer zone.
(ii) Stable area need careful development plans so as not to initiate erosion.
(iii) Depositional areas are best for development if consideration is taken not to create erosion.
(iv) Beaches occur within transitional areas and any constructions placed adjacent to them should be with appropriate set back line.
(v) Constructions are however encouraged on raised areas such as the coastal cliffs, stable coastal dunes and beach ridges.
(vi) Structures constructed near the shoreline should be considered by law to be temporary thus should not be protected in any artificial way and should be let to fall when their time come.
(vii) There are 3 basic options in response to the erosion problem.
- no action
- relocation of endangered structures
- positive corrective measures

(viii) No action should be taken particularly if no houses are threatened and only undeveloped land or in expensive structure are in danger. In other words, erosion becomes a problem when economic losses are imminent. Kanamasi, Kenyatta, Nyali and Leven are examples.
(ix) Structure at Kikambala should be relocated. The required set back must be carefully evaluated, in order to avoid further relocation of the same structure in the near future.
(x) Positive corrective measures should only be taken for a highly developed beach such as Bamburi, and a regional breakwater should be used rather than seawalls
(xi) Whichever option(s) is chosen between the three, the present and future sea level rises should be taken into account.
(xii) Lack of coastal management system was found to be the major coastal problem within the study area. There is a urgent need to have legislative capability to safeguard the optimal use of coastal zone resources. There is also need to have a long term program on the environment and it resources.

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IV. STATUS OF COASTLINE CHANGES IN MAURITIUS

by Dr. L Joottun in collaboration with D. Gangapersad, S. Ragoonaden, K. Dunputh, I. Ujodha

1. PHYSICAL ENVIRONMENT

1.1 GEOGRAPHICAL SETTING

Mauritius is a volcanic island located at latitude 20's and longitude 58° East, in the Indian Ocean, some 800 km from South East of Madagascar (Fig. 1). It has a land area of about 1860 km² with a maximum extension of 60 km from North to South and 50 km from East to West. It has a mountaneous topography with the highest peak reaching 817 m and about 50 rivers and rivulets drain into the lagoon. The coastline is about 200 km long and is almost completely surrounded by a fringing coral reeef system, enclosing a lagoonal area totalling 243 km². With no continental shelf as such the water depth reaches 3000 m within 20 km of the coastline. Some major islands that dot the Mauritian sea are Rodrigues, St Brandon, Agalega and Diego Garcia. These islands are inhabited. There are also other and smaller islets around the mainland that still have their pristine characteristics.

1.2 THE COASTAL ZONE

Coral reef system

The coastal zone of Mauritius is surrounded by coral reefs of fringing type, except at few places and near river mouths. Off the southern coast a stretch of 15.5 km and off the west coast for 10 km this reef system is absent and waves break directly on the coastline. The total length of this reef is about 230 km, with a lagoonal area of 243 km² (Fig. 2).

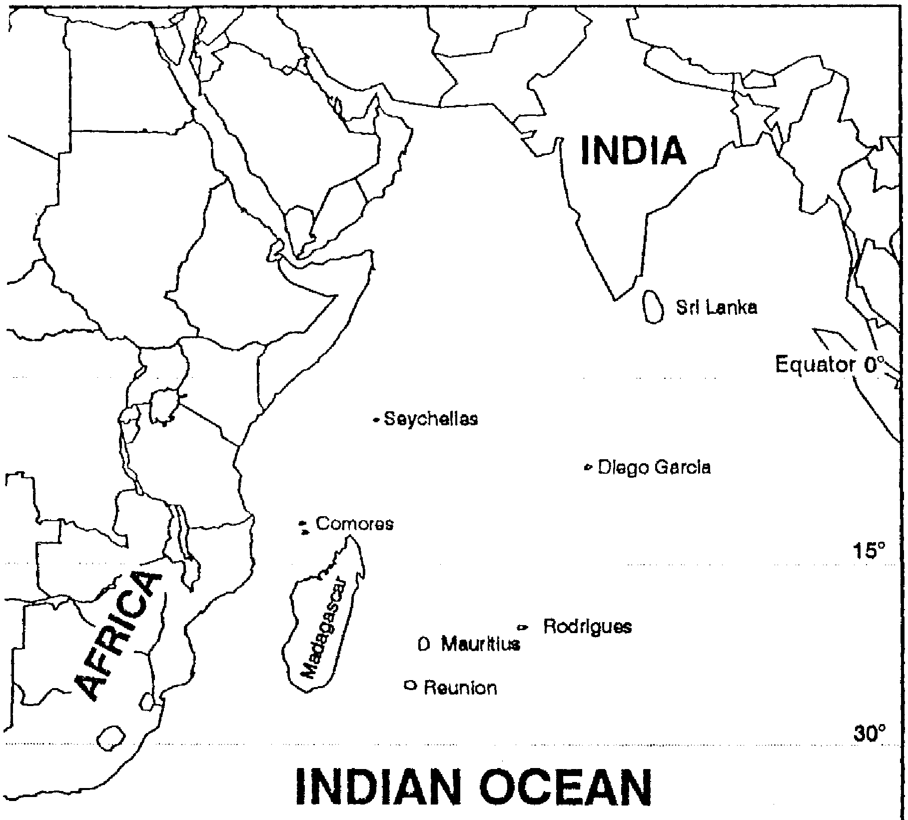
The reef system comprises:

(a) a sedimentory zone made up of an accumulation of sand, coral rubbles and basaltic and beach rock fragments and also some sea grass and algae.

(b) A reef flat at some places with coral growth but generally devoid of fine sediments. Presence of marine algae are predominant in many areas. Waves breaking on the reef front dissipate their energy at this junction.

(c) A reef front which is usually indurated and lithified coral substrate. It is generally shallow with insignificant amount of coral rubbles. This unit is generally under strong hydrodynamic conditions due to breaking of waves.

(d) Outer Slope
The outer or frontal part of the reef is composed of alternating ridges and grooves carved out by wave action armed with rock fragments. The bottom of the grooves is covered with sand and coral rubbles. On the spurs porites, pocillopora, faviidae and millepora sp. etc are noted.Coral reefs are among the most biologically productive, taxonomically diverse, aesthetically beautiful community of the coastal zone. While their massive structure provides a buttress against wave assault, their biological productivity yields a good source of protein to man. Besides, they offer many attraction to skin and scuba divers. They also produce the major percentage of calcareous sands. In many regions of Mauritius and Rodrigues human activities are inducing serious harm to the coral health. Discharge of industrial effluents, run off contaminated with silt saturated with nutrients, sewer wastes, activities such as dredging of coral sands, poling, anchoring and walking over the coral structures are gradually killing the coral population. The situation has become so dramatic that in certain regions of the island the percentage of coral population declined from 60% to 20%. It is in this connection that the Government of Mauritius is creating two marine parks; one on the western coast and the other in this south eastern one, with a view to improving the coral health and maintain their diversity, so that the present and future generations could benefit from them.



Locality Map - Mauritius

FIGURE 1

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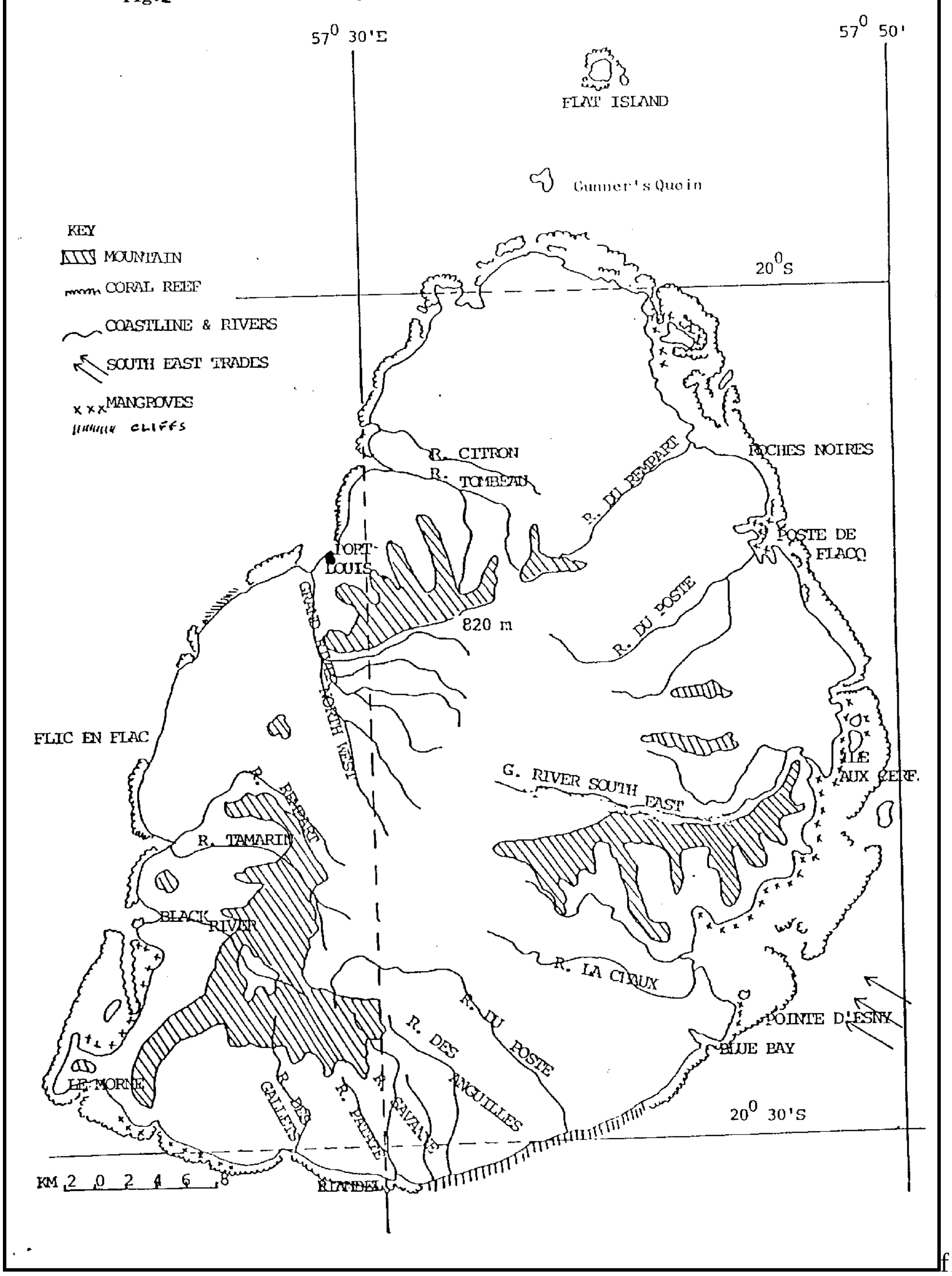
Fig.2 Coastal Ecosystems of Mauritius



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(e) Passes

These correspond to major topograhic depression which interrupt the reef formation along all its width, to the level of the back reef depression of variable length and width (15 m to 2,500 m) they have depth of mean value 20 m, exceptionally to 50 m (South and North entrances Mahebourg). This type of discontinuity is generally directly related to the hydrodynamic network, or in relation to the presence of springs or resurgences (Trou d'Eau Douce).

The internal slope of the passes are characterised by a complete morphological difference in view of their orientation in relation to major predominant currents and localised regimes of sediment dynamics.

In sheltered zones following sandy accumulations of the back reef, a narrow sandy platform develops down to 5 m approximately, characterised by the presence of necrosed coral patches, recolonised by pheophycea and sparse populations of Halophila sp. The joining towards the beds of passes is effected through the intermediary of sedimentary thallus of high declination (15°-45°), intercepted by sub-horizontal "ressauts". Under high sedimentation, these sectors offer possibilities of only low density live forms.

In unsheltered zones, are differentiated either a zone of organised spurs and grooves (South and North Entrances Mauritius) or an eroded bioconefructed thallus and highly declined (45°-60°), characterised by a succession of narrow steps of 1 to 2 m in declining levels with locally encountered patches of algal nodules (Passe Sud-Est, Rodrigues) Around 5 metres, these are replaced by decline (75°-80°), totally colonised by madrapora sp. As from 10-20 m, appears a sedimentary thallus of 15°-30° inclination, fed by the debris of organisms living in the superior horizon, and partly jointed by a muddy-sandy fraction. Where they subsist, bioconstruction are represented by Madrepora sp. Near the 20-25 m isobaths, the detritic thallus joins abruptly with a muddy-sandy bottom slightly moulded with tumulus and funnels of enteroprenetes, or with a bottom made up of rough sediments, (gravel type). (Port Sud-Est, Rodrigues).

The lagoons

The lagoon is the area between the fringing reefs and the shoreline. This distance varies between few hundred metres to six kilometres. In the west from Flic en Flac to Baie de la Petite Riviere and from south of Pointe aux Caves to Pointe aux Sables and in the south from Roche qui Pleure to Pointe Naturel the fringing reef is significantly absent. In general the lagoonal depth is comparatively shallow (1-2m) with the exception of Mahebourg where water depth reaches 15 m in the inner reef pass. Significant depth have also been recorded in the area of Ile d'Ambre, Riviere de Rempart, Riviere Noire and Blue Bay. The bottom of the lagoon harbours various plant and animal communities, coral colonies, coral rubbles, assemblages of coral sediments and terrigenous materials near the estuaries, tidal flats, mangrove fields and juxtaposing upland such as in the south west segment. At quite a few places such as Pointe d'Esny, Pointe des Regates, Deux Freres, GRSE, Roches Noires, Pointe Lascar, Poudre d'Or, sand is being mined from the lagoon with spade and bucket and transported to the shore in boats. Many fishermen gain their livelihood through catching fish, shrimps, octopus, lobster, oyster in the lagoon. With the discharge of industrial effluents in the lagoon, these marine faunas are gradually decreasing. Oceanic swells crashing against the reef form a surf area in the lagoon and the sea water move up the beach or along the beach to be drained off through the passes. Sediment are thus transported along the beach through drift or across the beach line to the deep sea through various reef gaps. The lagoonal area affords much recreational activities such as boating, skiing, surfing, pedaloing snorkelling, scuba diving, para sailing, etc, to local as well as to tourists.

The Shoreline

The shoreline of Mauritius is extremely variable in terms of size and nature of deposits, extent, slope and energy regime. The width of the beach varies location wise from few metres in the Eastern and Southern regions to about 25 m in the north Eastern and eastern ones. The sediments are coralline in nature except in the south western segment, near barachois and major river confluence, where they are muddy with large fractions of silt and clay. The coastal areas which are in proximity with the reef such as in the eastern and southern section, the sand deposits on the beach and backshore are very coarse, rounded and spherical. Abrasion of the coral fragments and their attrition during transportation have imparted such grain structures significant of high energy regime.

The shoreline has been zoned laterally into the following:

Foreshore
It comprises the intertidal areas and includes the lower and upper foreshore. It extends from a few metres to 60 or more metres. The upper foreshore is narrow and steeper (10-20%) with medium to coarse sands where as the lower foreshore is gentle (6-10%), with fine sands to pebbles, cobbles and boulders. This feature is well developed in the north eastern, north western and eastern regions, however where rocky platforms is exposed it is insignificant. Its slope and granulometry, energy regime and physical protection are the determining factors of beach stability. Besides the reefs, this is the first and foremore zone that bears the brunt of wave assault and protect the backshore and the dunes.

Backshore
It is a nearhorizontal feature comprising very coarse grainsize, with a convex surface and usually sloping landwards. The berm is a typical feature of this zone and has a steep front from where there is a change in grain size. Its width varies between 3 and 12 m. The proximal seaward slope ranges from 20-25% while the distal one varies between 5 and 10%. It represents a unique energy regime which is attacked by plunging breakers and eolian agencies. Sediments are characteristically rounded, platy, subspherical or cylindrical. Where ridge erosion is prominent the upper layer of this deposit is finer. Contamination of finer sediments from the dunes is not uncommon. The function of this deposit is attributed to strong energetic waves. During spring tides or stormy weather plunging breakers attack the berm, scouring and churing the sediments and swirling them down the beach to be rebuilt by constructive waves during conducive environment.

Dunal ridge
Dune and ridge complex are characteristic features that lie above the berm line. They are linear, undulating, hummocky and run paralell to the coastline. The ridge complex comprises sediments of different size and grade but is generally coarser. The clastic particles are subrounded and poorly sorted. The sand dune sediments are fine grained, subrounded and well sorted. Their windward face angle is comparatively gently 11-12% while the slip face angles varies between 15-20% or more. The dunal deposit has been aggressively mined and the mining vestiges could be observed at Riambel, St Felix, Pte d'Esny, Riviere des Galets, Poste La Fayette, Flic en Flacq, La Cambuise, Bel Ombre. The coastal area at and near the sand quarries have been seriously degraded. Any development in connection with residences or hotel complexes would give rise to serious consequences. As the dunal ridge acts as sand reserve and compensate for any loss due to natural forces, the beach in these areas are getting highly eroded. e.g Pomponette, Bel Ombre and in Rodrigues, Bar Brule and Anse Ali.

At Flic en Flac the mining of the dunal deposit has created a depression of more than 2 m and this site has been backfilled and parcelled out. With the rising sea level, as this parcelled area is still below the coastal road, there is a very high risk that this site would be overflooded, thus giving rise to unimaginable environmental problems. The quarried area at Pomponette would be most affected as it is behind the coastal road and 2-3 m below it, that is below amsl.

The only undegraded huge dunal deposit left is at Le Souffleur. This deposit is about 1 km long, 12 m high and about 100 m wide. The feature is presently supporting grasses and filao trees and part of which is used for grazing. The Government of Mauritius is keen to protect this last vestige and a last attempt to exploit this massive deposit has been warded off. Similarly every attempt is being made to save the few remnant dunal deposits in Rodrigues.

Backswamp
Behind the ridge lies lowlying flat ground called backswamp, tidal flats or tidal marsh. The sediments are silty and clayey and during high tide or rough sea this area is overflooded. It support an important array of coastal flora and faunas.

Mangrove Swamps
In some segment of the coastal region such as near river mouths or estuaries e.g Terre Rouge, Riviere Noire, Baie du Cap, Riviere du Rempart or where there is a resurgence of fresh water near the sea. Such as Trou d'Eau Douce, Poste La Fayette, Bras D'Eau, Roches Noires, Poudre d'Or, a

colony of salt tolerant intertidal tree species form a flat muddy ground or swamp. These mangrove trees are of direct economic and ecological importance and some of their functions are:

(1) Protection of the shoreline from erosion due to cyclonic weather conditions and storm waves. They also exert a breakwater effect in absorbing most of the energy of storm driven wave action, thus helping to protect housing and service structures further inland.
(2) Mangrove ecosystem is a major nursery ground for many economically important marine organisms including some plant communities.
(3) They also fuel food generating activities from their parts that go into the good chains and that support fisheries production.
(4) They also harbour a host of waddling and fishing birds.

They entrap terrigenous sediments that would otherwise get deposited on coral population with consequential effect on the production capacity of the marine ecosystem at that locality.

Although tolerant to high salinity condtions mangroves reach their best development in polyhaline (estuarine) conditions. Very often competition for space and nutrients limit the landward extention of mangrove swamps while salt stress may suppress maximum productivity under fully marine or hypersaline conditions. Modification of estuarine salinity patterns by upland drainage and other subsurface control structures have profound effects on mangrove community and its associated fisheries.

The present state of mangrove health in Mauritius and Rodrigues is poor. Lots of damages have been done to this plant community due to irrational coastal development. With the construction of many hotels on the coastline mangrove stands have been vanished and the remnants are in a very bad shape. The Ministry of Agriculture, Fisheries and Natural Resources has undertaken serious and concrete step to rehabilitate this important plant community. Tens of hectares of the coastal area has been planted with new stands in Mauritius and in Rodrigues and a new COI project will soon be implemented in Rodrigues for further stabilising the coastline with mangrove plantation.

Coastal Wetland

Coastal wetlands are ecologically sensitive areas and play a vital role in the functioning of coastal ecosystem and the maintenance of high level of sustainable carrying capacity. They provide the essential habitat for many important marine species such as shore birds, crabs, fish, shrimps, worms etc.

Wetland vegetation plays a keyrole in converting organic compounds(nutrients) and sunlight into the stored energy of plant-tissue. The dead leaves, branches and stems of trees are broken down in the water by bacteria and consequently, leave the storage energy and become available organic detailed food for the various organisms inhabiting there. A fraction of these nutrients are partially recycled within this system but the major portion often find its way into the coastal waters to provide basis nutrients for the food chain of the coastal water ecosystem.

Some of their other major functions are:-

1) wetland vegetation remove toxic materials and excessive nutrients from coastal waters. Silty sediments and other inert suspended materials are physically removed from the water and deposited in the marsh thus sparing the coastal water from heavy sediment load that causes incidence of entrophication and sedimentation of tidal inlets,
2) They also slow surges of flood water and hence act as flood regulator,
3) They also play an important role in absorbing and retaining dissolved chemical nutrients such as phosphates, nitrates, nitrites, ammonia etc,
4) The shape, vegetation and fauna impart a particular beauty which is unique in the coastal zone.

In Mauritius, particularly in the Northern and North Western region many coastal wetlands have either been completely filled up or partly reclaimed for major coastal development projects such hotel and bungalow constructions. The incidence of flooding of residences and hotels in Grand Baie and Pereybere regions (Fig. 6) is due to the construction or suppression of these wetlands and the obliteration of the tidal inlets and natural drains. During heavy rainfall many houses and shops lying at or near the wetland are flooded and the inhabitants have to vacate their residences. Disposal of sewage becomes a serious problems. With the filling in of Mare Michaux and Grande Mare Longue, and the resiting of Road B 13, behind Mauricia Hotel, part of Camp Carol is, during heavy rainfall flooded. This problem has been compounded with the obstruction of five natural drains that serviced these wetlands.

The incidence of eutrophication in the northern and north wastern sea has also been attributed, to a major extent, to the suppression of drains and change in the drainage pattern of the marshes that are not functioning to their optimum ecological capacity.

1.3 ENVIRONMENTAL PARAMETERS

Located in a central position in the Indian Ocean at Latitude 20'S, and Longitude 57°20'E, Mauritius is under the influence of the South East trade winds, through most part of the year. These trade winds provide the most substantial wave action that dominate the depositional dynamics particularly at the Eastern and Southern Coastline. The tropical cyclones and anti cyclones also incluence the coastal configuration and depositional pattern of the coast.

Sea Surface Temperature

The sea surface temperature obtained from weather stations on ships, in the vicinity of Mauritius is found to be lowest (23.3°C) in September and highest (27.9°c) in March, with an annual mean of 25.7°c, from 1971-1980.

Tides

Tides are diurnal to semidiurnal, with two lowtides and two high tides daily. Tidal range varies between about 0.5m at neap tides and 0.6m at spring tides. This negligible variation reflects the absence of the influence of adjacent landform features such as converging coastlines, which would favour tidal development.

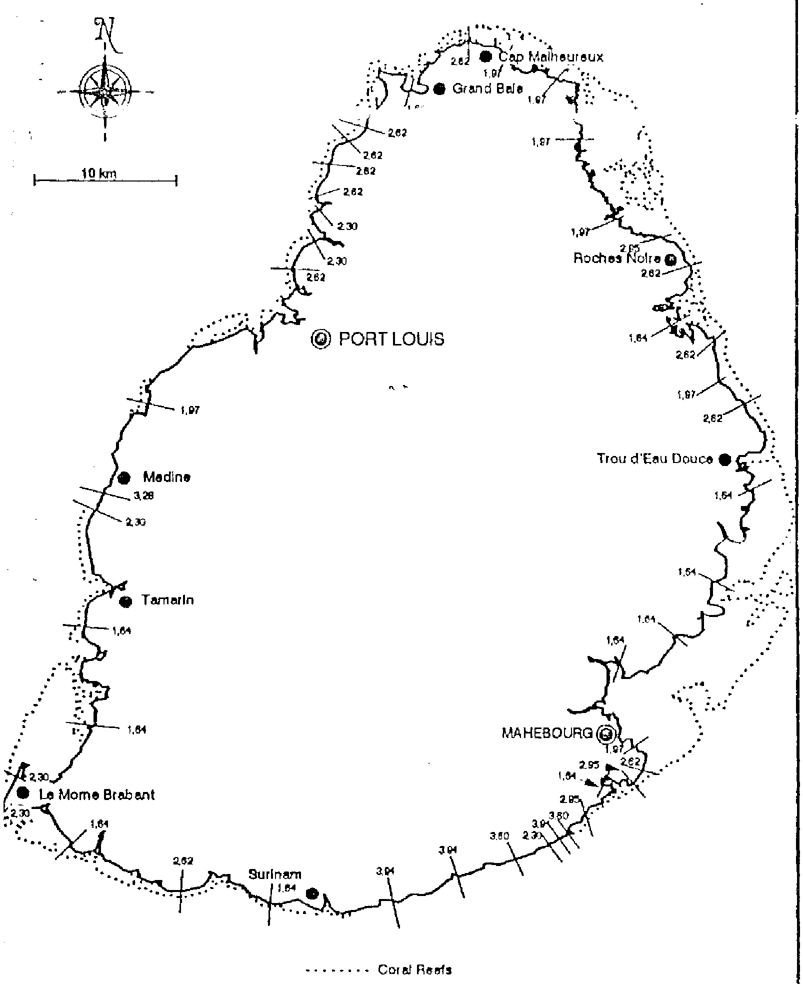
Water Levels

The decrease of the barometric pressure during the passage of cyclone has considerable effects on the rise of the sea level and such phenomenon causes dramatic effects on the coastal stability. Following cyclone Carol in 1960, Mc Intyre and Walker (1964) estimated the level of the smarsh zone above mean sea level at numerous locations around Mauritius. As per their estimates the elevators were mainly between the range of 2 to 3m, however, at some localities level approaching 4m were noted (Fig. 7). The presence or absence of the fringing reef, its configuration and distance from the shore line, form and relief of the coastline, slope and roughness of the beach face, interact together with wave and wind regime to cause the elevated sea levels.

Montaggioni (1979) suggested that Mauritian coastline has experienced episodic sea level fluctuation. The sea level was -3.5m with respect to present levels 4500 yr.B.P. The average sea rose to attain the present levels between 2000 and 1000 B.P. Studies conducted by the Mauritian Meteorological Services and reported by the National Climate Committee (1991) indicate a sea level rise of 1.2mm/yr and this rate is consistent with the projected 65cm by 2090).

Waves

Wave height, period and direction are the functions of location, wind speed, fetch area, and duration of the wave generating wind field. In Mauritius the following three principle types of waves affect the coastal zone:-



Swash line observations (in m) of McIntyre and Walker (1964) after cyclone Carol (1960)

FIGURE 7

f15

Southern Waves

Weather system consisting of low pressure cells passing the South of Mauritius (around 40° South) can generate fully developed seas due to high wind speeds, large fetch areas and long durations These waves reach Mauritius from the South West in the form of long period swells.

Trade Wind Waves

The prevailing South East trade winds may produce short or long period waves depending on wind speed and duration. These waves travel in the same direction as their associated wind fields.

Cyclonic Waves

Most of the cyclones reach Mauritius from directions between East and North West and hence produce cyclonic waves from such directions. These waves are well formed and they have devastating effects on the coastline.

Wave Data

Visually observed wave data for passing ships (VOS) is the main source of historical wave data for the Mauritian area, though a wave rider was installed in the Southern Coast of Mauritius (Riambel). With the VOS two types of waves are measured, swell and wind waves. It should be noted that the total wave height occuring at a point due to the combined influence of wind waves and swells is not equal to the sum of the heights of the wind waves and swells. The total height is a function of the wave energy which is proportional to height squared.

Wave Direction

The predominant direction for both wind waves and ENE swells is from the East (Table 2). The direction sector extending from ENE to SSE contains over 80% of all observed directions for both wind waves and swell. Wind waves and swells from the NW sector occur less than 2% of the time. The influence of Southerly swells is noted by the fact that swells in the sector S to SW occur 13.6% of the time where as wind waves in the same direction occur only 5.1% of the time.

Wave Height

It can be seen from (Table 1) that height for wind waves is less than 1m while for swells the average height is close to 2m. A height of 3.48m is exceeded 1% of the time for wind waves while the equivalent height for swell is 5.39m. For more than 13% of the time swell heights are greater than 3m.

Wave Periodicity

Most of the wind wave periods are less than 8 seconds while most of the swell periods are concentrated between 4 and 11 seconds (Table 3). The occurence of periods greater than 11 seconds (5%) for swell is significant and even longer period is expected especially from South West.

Currents

Currents are generated principally by the action of wind, waves, tides,temperature and salinity. Current generated by wind and waves are of extreme importance for sediment movement in the coastal zone. This phenomenon is more pronounced during cyclonic conditions when strong wind, high amplitudes waves and raised water level interact to give a very strong current regime.

No systematic studies on water currents in the lagoon or outside the lagoons have been undertaken,except for the NNW where recent current meters were hired from overseas and placed at 2 sites off lagoon.

Hydrographic stations from this part of the Indian Ocean indicate a general westerly to South westerly directions, as part of the Southern edge of the South equatorial current, ship drifts indicate that the flow speed should be between 0.3 and 0.5m/s.

A few free drifting, satellite-tracked buoys indicate a multitude of directions. The sector between NNW and SSW contained about two thirds of all observations. Drift speeds varied between 0 and 0.6m/S, with an average of 0.23m/S. The water current in the shallow water around the island, at some places are more than one meter/sec.

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The Fisheries Division of the Ministry of Fisheries has recently undertaken current metering in the lagoon of Mauritius and their observations and results are at ( ).

Bathymetric Chart of the exclusive economic zone of Mauritius (1988) gives the speed of water currents at specific sites around the islands.

- Off Pointe aux Cannonniers (N): 2-3 miles (M)
- Off Cap Malheureux N: 2-5N,
- Off Blue Bay (SE): 1-2N,
- Off Riambel: 2N,
- Off Baie du Cap: 2-3N,
- Off Le Morne: 4-5N in the East-West direction,
- 2-3 is in the North-South direction.

The two directions for water currents are due to the low and high tides.
In the lagoon near the passes rip currents are predominant during the ebb tide.
Longshore currents are also noted at the lower foreshore occassioned by the oblique incident water waves on the beach time. There is a reversal of direction in Summer and Winter Periods. This current is responsible for the sediment drifting on the beach.

1.4 TIDAL WAVES

Tidal waves sometimes occur around the southern coasts of Mauritius. A case study of such a phenomenon which occured in 1987 is attached in the annex.

Wind Climate

Located in the northern extent of the sub-tropical anti-cyclone area, Mauritius is under the influence of the South East Trade Winds throughout the year except for short period when tropical depressions are near the island.

2. EROSIONAL SITES

2.1. GENERAL

The coastline of Mauritius is under the process of pronounced morphological changes. There is an apparent evidence of marine transgression demarcated by:

(1) Cliffy nature of the dunal ridge complex and juxtaposing against the upland.
(2) Presences of rock stacks in the south eastern and southern segments.
(3) Crenulated nature of the coastline.
(4) Presence of newly abraded rocky platform.
(5) Presence of wave carved caves at the HWM.
(6) Inundation of the coastal roads by seawater.
(7) Extirpation of trees on the backshore by seawater.

These manifestations are observed during normal climatic conditions, thus signifying a gradual sea encroachment. The scouring of the backshore and the dunal ridge complex is ubiquitous so that a beach bluff of 1 to 2 m are invariably noted in many coastal segments, particularly in the western, southern and south eastern ones.

There is no distinct morphological features and coastal processes that could ideally differentiate and demarcate the various coastal segments into discreet characteristic sites. However, with a view to identifying the erosional patterns and the energy regimes, the whole coastal segments have been subdivided into five cells (Fig. 3).

CELL A: Segment from Roches Noires to Cap Malheureux

CELL B: Segment from Cap Malheureux to Flic en Flac
CELL C: Segment from Flic en Flac to Le Morne
CELL D: Segment from Le Morne to Mahebourg
CELL E: Segment from Mahebourg to Roches Noires.

2.2. CELL A (ROCHES NOIRES TO CAP MALHEUREUX)

The coastline in this section is bisected by many small creeks, tidal inlets and a major river, Riviere du Rempart. The tidal marsh near the Bras d'Eau and the tidal flats and mangrove swamps near the river confluence are striking.

The sediments are, depending upon the proximity of river or tidal inlets, calcareous or muddy, fine to coarse. At most of these places terrigenous sediments abound. Basaltic boulders of size varying between two centimetres and 3 metres, as well as exposed bed rocks are common. The discharge of fluviatile terrigenous sediments as well as the scouring of the upland by wave action have given rise to a muddy beach with flat topography. The cohesive nature of the sediment have imparted a good protection against wave action, so that the beach and backshore are more or less protected.

A typical cross sectional profile indicates a narrow backshore of 3-4m abutting against the upland. The foreshore varies between 3 and 10m and slopes seawards at an average angle of 8°. The coastline is retreating and beach cliff of 60cm to 1.6m is predominant. It should be noted that at Roches Noires, Pointe Lascars and Poudre D'Or lagoonal sand mining are undertaken.

The discharge of industrial effluents from three textile factories at Ile D'Ambre is taking heavy toll on the marine lives. Significantly, the presence of some structures such as fishlanding platforms, groynes and jetties at Cap Malheureux are sensibly affecting coastal protection and beach stability.

2.3 CELL B (CAP MALHEUREUX TO FLIC EN FLAC)

Because of the general orientation of this stretch of coastline, the predominant south east trade winds blows in a more or less offshore direction. Because of this orientation the northern sector is most protected from incident wave energy, both trade wind generated as well as the large swells emanating from the south. This sector is however, extremely susceptible to cyclone generated waves which usually originate from north west to north.

Unlike Cell A, this cell comprises a comparatively more curvilinear coastline except at the bays and rivers mouths. Beach deposits are predominately coralline and basaltic, with sediments medium to coarse on the beach and finer ones on the dunes. Beach cliff of 1.5 - 2.0m have been noted at Les Cannoniers, Grand Baie and Flic en Flac. Cliff of 1.0m and observed at many places. Near La Mecque basaltic cliffs of 30-35m is very striking and the foreshore deposit is cobbly and bouldery, of basaltic in nature.

The approximate length of the coastline is about 50cm; presence of wave carved caves near Pointe aux Sables and impingement of waves on the basaltic cliffs are typical of erosional features. A fairly extensive coralline beach is noted at Pointe aux Cannonniers. Because of the passes in the fringing reef and the prevailing direction of the cyclonic waves heavy beach erosion, with cliffs of 2m high are observed (Fig. 4).

The position of high water line at Flic en Flac have moved tremendously fast since the past 15 years. It was at a distance of 8m from its present position, one and a half decade ago. Since 1990 the coastline has receeded to 2m near the Flic en Flac public beach at Pearl beach hotel, as evidenced by the uprooting of filao trees from the ridge complex and retreat of the coastal line to the foot of the seawall.

The scouring of the ridge has given rise to a rectilinear coastline. The eroded materials that are deposited on the beach are reworked by long shore current, thus modifying the beach slope. The presence of a vertical seawall infront of Pearl beach has accelerated beach erosion at this junction, where wave reflection has eroded the foot of the wall as well as the section adjacent to the wall in the north.

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2.4. CELL C (FLIC EN FLAC TO LE MORNE)

The coastal segment from Flic en Flac to Le Morne is more or less protected by the south east trade winds, but is affected by some swells. This area is bisected by many rivers and estuaries e.g. Riviere Tamarin, Grand Riviere Noire, Petite Riviere Noire.

The beach deposits are generally muddy, except in the southern area which is predominately sandy. Erosional scarps of 1.2 to 1.5m have been noted at Wolmar, Tamarin and Le Morne. The beach infront of Le Morne Brabant Hotel is seriously affected by erosion. The beach line at one spot has retreated to at least 10m since the past 15 years. At one junction a retreat of 4m have been observed during the past four years. The beach deposit has been eaten up and part of a walk way has been washed away and many filao trees uprooted. Although the majority of the southerly incident deep water wave energy is dissipated following breaking on the fringing reef, a portion of this energy related to the ambient water level penetrate into the lagoon. Strong wind from the south also generate northerly flowing currents.

The extensive and deeper lagoonal area north of Pointe aux Pecheurs acts as a drainage channel to the water levels built up due to wave action along the fringing reef fronting the shoreline. The erosional problem is compounded by the presence of some ill designed groynes that are inducing rip current effects and exacerbating the erosional problems. At this locality the current speed of up to 1m/s has been measured. It is worth noting that the eroded sands from the southern region are deposited in the northen side. The littoral driff is from south to north.

The site near Berjaya Hotel, Le Morne to Pointe Sud Ouest is also under erosional process. The beach sand are coarse to very coarse and beach cliff of 1.5-1.8m are present all along. The dunal deposit has been levelled down during the construction of Berjaya hotel and wave action is gradually enacting upon the new depositional features, thus giving rise to beach bluff. The steep beach slope is not a natural declivity but is a result of beach push piling of sands. There is a very high risk that the ridge area will be overtopped by seawater during rough seas, affecting the hotel complexes and the other infrastructures.

2.5. CELL D (LE MORNE TO MAHEBOURG)

Unlike the other segments, this portion of the coastline is under constant attacks by high amplitude waves, reinforced by the south east trade winds. The impacts of the wave energy on the beach front is much pronounced. The opening of reef gap on the fringing reef have contibuted to the wearing of the beach front. Invariably all the coastal segments are heavily eroded. Beach cliff of 1.5 to 2.0 m could be observed near Riviere des Galets, Pomponette and Riambel (Fig. 4). The erosional problem is compounded by the quarrying of the dunal deposit and also because of the levelling of dunes and construction of residential complexes on them.

The worse eroded sites are at Pomponette and Riambel. At this junction the incident waves are gradually scouring the beach front, further retreating the shoreline. During the past three years beach retreat of 4m has been measured. Steep scarp of 2.0 m is common and the coastal tracts and many filao trees are gradually falling prey of wave attacks.

Beach erosion at Pointe D'Esny and Blue Bay is not so extensive because of the presence of many vertical walls and groynes. There is a total absence of beach deposit at the foot of the walls and the groynes are ineffectively arresting sediments from one direction. Near Croix du Sud, during high tide the sea water incurse upon the road and adjacent upland, clearly signifying coastline movement.

2.6. CELL E (MAHEBOURG TO ROCHES NOIRES)

This section of the coastline manifests sea level fluctuation since the pleotocene period. Rock stacks, detached basaltic rock outcrops and rocky promontories are very common. All these features are erosional relicts and have been carved out by wave action on the basaltic rock outcrops. This indicates that the strandline was about one or more kilometre and have gradually retreated since the Pleistocene period.

Because of the absence of good beach deposit from Mahebourg to Grande Riviere Sud Est, beach erosion manifestation is not vivid. However, on careful observation it could be remarked that the sea level is verily encroaching upon the backshore. Rocky cliff and wave abraded platform are commonly observed.

The area of Trou d'Eau Douce and Belle Mare are under the pronounced effect of coastline changes. At Trou d'Eau Douce a scarp of 1.6m and a landward shifting of the coastline by 3.5m had been observed in 1991, such change in morphology is due to the climatic variation compounded by the uprush of swells impinging upon the coastline. On the north of this site severe beach erosion has been noted. This problem, as per information, is due to the opening of a pass in the reef that causes seawater to funnel inshore, thus eating up the coastline.

Pointe de Flacq near St Geran has experienced beach erosion since 1988. Cliff of 1.8m have been measured all along. The proximity of the fringing reef and a gap in the north have induced this degradation. The surging water is seen to scour the beach and ridge deposit, churning them and tranporting them along shore. Very coarse sands, granules, cobbles, boulders are omnipresent. The presence of a beach rock has, to certain degree, protected the beach deposits. Towards Roches Noires the beach front is protected either by virtue of this coastal configuration, or due to the presence of rock outcrops or due to the presence of mangrove swamps. The decrease in the mangrove stands is a serious cause of concern.

From Poste la Fayette to Roches Noires, the coastline has undergone less damage, however towards the Roches Noires bridge the beach deposit is gradually decreasing and during low tide the bed rock is exposed. This situation is being seriously influenced by extensive lagoonal sand mining.

3. FACTORS CONTRIBUTING TO SHORELINE CHANGES

Fluctuation of sea level rise is a manifestation brought about by many factors, though one may predominate upon the other. Human interference have accelerated the shoreline changes through a series of unplanned and often irrational development. History testifies that during the past, sea level fluctuation occurred quite a number of times where a rise of more than 100 m have been identified at many areas. At the end of the Pleistocene period about 300,000 yrs B.P eustatic adjustment have resulted in a fluctuation of the following order:

+5 to +6 m around 0.3 my B.P

+1.5 to + 2 m around 0.15 to 0.1 my B.P

- recurring periods of decrease between 80,000 and 40,000 yrs B.P. Between 30,000 - 18,000 yrs B.P a fall of -120 m.
- from Holocene period to present level by 2000 to 1000 yrs B.P a progressive rise.

Estimates for the global sea level rise in the past century range from 0.10 to 0.15 metre. For the IndoPacific region Bernett calculated that the sea level rise almost doubled over the period 1920 - 1980, compared to the 50 years before. During that period the major factors responsible for the sea level fluctuation were waxing and waning of the glaciers, compounded by isostatic correction and even tectonic effects in certain parts. In Mauritius, shoreline changes are attributed to both natural phenomenon as well as anthropogenic effects.

3.1 NATURAL PHENOMENA

A list of natural factors that may contribute to such changes are:

(a) Tectonic
(b) Eustatic
(c) Isostatic rebound
(d) Volcanic
(e) Biologic
(f) Sedimentary
(g) Climatic
(h) Thermic

Though most of these factors do not show direct evidence of their contribution to the changes because of lack of investigation and monitoring, their direct relationship do not seem farfetched. These factors have been invoked for later studies and investigation.

Tectonic

Mauritius, being a volcanic island with many episodic manifestations since the Pliocene period till some 25,000 yrs B.P and the north easterly movement of the crustal plate, the tectonic factor should be looked into. Though tectonic movements have invariably affected the structural setting of Mauritius such as fracture pattern of the rocks, orientation of volcanic vents. crators, ridges, minor fault system, yet, their effect on the present sea level fluctuation has to be investigated.

Eustatic

The melting of the glaciers has been accepted as the most prominent and determining factor contributing to sea level fluctuation. The direct correlation of the volume of glaciers melted to the increase of the sea level is not a straight forward calculation. Various factors should be considered to determine the fluctuation level such as isostatic correction, any subsidence of the area, sedimentation rate of the region, etc. Montaggioni (1979), based on a study of radio carbon dating of coral samples suggested episodic sea level variations from a sea level of -3.5 m with respect to its present position around 4500 yrs B.P. The average sea rose to attain its present level between 2000 and 1000 B.P.

For Mauritius the established information from Mauritius Meteorological Services as reported by the National Climate Committee (1991), the annual sea level rise is 1.2 mm. This rise is inducing 0.5 to 0.75 of coastline changes on an average, though this figure has to be adequately verified.

Isostatic Rebound

Isostatic rebound is the natural correction and relief of pressure exerted on the crustal portion during any orogony, sedimentation or piling of matter on glaciers. For the Mauritian case after the volcanic periods where the piled up lavas formed the island of Mauritius with numerous prominent mountains, the erosion and the planation of these mountains may influence the isostacy of the earth crust. That is to say there might be an adjustment of the land mass and the change in the sea level which is being noted, is in fact higher in magnitude, but different rate is being experienced. The rise in the sea level should be connected with, relative sea level rise. Similarly, the weathered and eroded terrigenous materials that have been discharged on the coastline may also affect the isostatic balance. A thorough scientific investigation should be undertaken to correct any such anomaly when computing rate of sea level rise.

Biologic

It has been observed that all the coastal segment in front of a pass have undergone serious erosion. That is the coastline has retracted at places by at least 5m landwards. Coral reef is a dynamic system, growing and rising with the rising sea level in ideal conditions. This system intrinsically controls sea level fluctuations. Transgressions of sea level have been indicated by the presence of rubbles of Acropora sp. about 1 km inland. Many indications have been obtained on fluctuation of the coastline where the reef system were sick and debilitating. Conversely, if the rate of sea level rise is fast and the rate of coral growth could not keep pace with the rising sea water, the coral reef would be submerged, thus increasing the influence of water level fluctuation.

Sedimentation

Sedimentation process in the coastal zone is perhaps the most dominant factor contributing to the coastline changes. The case of Rodrigues could serve as a vivid example on this aspect. The Rodrigues lagoon is hypersedimented with terrigenous sediments, derived from the weathering and erosion of the hilly terrain. During mean water mark the lagoonal bed is subaerially exposed. There is a natural shifting of the coastline landwards.In Mauritius, because of the good land conservation practice on the hilly terrain, very little terrigenous amanations are noted. At Maconde a moderate accretion has given rise to evidence of coastline regression. The reef system being less productive, an insignificant amount of calcareous materials are produced and with the ever increasing mining of lagoonal sand, the sedimentation effect, in Mauritius vis a vis coastline changes is severe. The coastline which are near the reef system especially in the Southern and Eastern section is presently very deficient in beach deposit. Part of the sands that had been accumulated and deposited as beach and dunal deposits have been washed either alongshore or seawards. Such removal of beach materials have caused a sea level fluctuation.

Climatic

Mauritius and its outer islands are often under the influence of tropical cyclones and anticyclones that have devastating effects particularly on the coastline. The rise in the water level with low pressure and the terrific gusts of 225 to 250 km per hr often raises the water level to 2.50 m and the wave uprush to 50 m in many parts of the coastline is not uncommon. The scouring of the beach and ridge alter the coastline configuration and the ensuing beach line shifts 5-6 m inland. In 1988, the Belle Mare coastline receeded to about 5 m, forming a scarp of 1.8 to 2 m. The coastline at Pomponette, during the past 5 yrs retracted to 5 m and the recession is about 30 cm yearly with the planing down of the ridge. The storm waves in general erode the beach deposit and swells, in the form of constructive waves, reinstate the degradation area However, in Mauritius there are exemplary indications of beach erosion and coastline changes. Most of the eroded scarps have not been recouped.

Thermal

Climate change in the form of global warming is felt throughout the world. Consequently, with a rise in the sea water temperature, i.e thermal expansion of the sea, there is a corresponding change in the shoreline. Air temperature as well as sea temperature seem to have risen in the past century, as the 1980 decade has been particularly warm. This phenomenon has to be thoroughly investigated to compute the rate of the sea level fluctuation.

3.2 ANTHROPOGENIC FACTORS

Structural

From fear of being assaulted and inundated by sea waves, many people residing on the coastal zone have attempted to ward off this threat by the construction of coastal defences such as seawalls, revetment,jetty, groynes, breakwater, rip rap etc. Most of these structures, in the Mauritian context, are either unwarranted or ill designed as they are inducing unparalleled beach erosion at and near them. In Mauritius, a recent survey has revealed that there are more than 200 jetties / groynes that have been illegally constructed on the beach. In the region of La Preneuse and Pointe d'Esny, the coastline is riddled with many ill designed groynes that are not only an eyesore but are causing more harm than good to the coastal stability. They are also obstructing passage along the coastline. Instead of arresting sand, most of these structures are depleting beach deposit, and hence inducing coastline changes. As groynes entrap sediment from the updrift portion, the downdrift one has always a deficit sand budget and the spacing, dimention, orientation and their impermeable nature render their function baneful. The misorientation of jetties at Le Morne Brabant Hotel has triggered serious coastal erosion with a shoreline retreat of about 4 m in 4 years. A good segment of the coastline of Mauritius looks like a fortress, with prominent sea walls constructed to ward off marine incursion and prevent backshore erosion. Because of the improper engineering design, most of these sea walls are either crumbling down or accelerating beach erosion. Being mostly vertical in nature and without any rip rap at the toe, at all these sites the beach deposit has been washed away due to wave reflection and littoral drifting During mean sea it is practically impossible to walk along without wetting one's feet. At the regions of Pointe d'Esny, Flic en Flac and Le Cannonnier, the HWM is hitting against the sea wall at 1 - 1.2m above the seabed surface. There is a shifting of shoreline of 5 - 8m at these junction from their date of construction (between 10 and 15 years in most cases).

The worst repercussion of the sea wall is the impact of wave action on the adjacent coastline. Many examples and evidences abound the coastal history where the deflecting waves have scoured the adjacent coastline and caused a retreat of 5 - 8m. e.g At Belle Mare, near St Geran Hotel, At Flic en Flac near Pearl Beach, La Preneuse, Trou d'Eau Douce. Other structures that are affecting the coastline changes are construction of coastal road on the backshore or coastal ridge, and on coastal wetland, e.g Grand Baie, Maconde, La Prairie; blocking of natural drains and tidal inlets on the coastline, e.g Grand Baie to Pereybere regions, and construction of sand landing platforms, e.g Roches Noires.

Sand Mining

<u>Inland</u>
During the past twenty years sand has been mined from dune and coastal ridge for construction purposes and also for the CWA filter beds. The major mining sites were: (Fig. 5)

(1) Pereybere
(2) Flic en Flac
(3) Les Salines
(4) Bel Ombre
(5) Beau Champ

(6) St. Felix
(7) Riviere des Galets
(8) Pomponette
(9) Pointe d'Esny
(10) Poste La Fayette
(11) La Cambuse

At all these sites beach erosion has been noted but the site Pomponette is most seriously affected. Here sand have been mined from the dunal ridge adjacent the beach and coastal retreat to the tune of 4m during the past three years have been measured. Because of coarse, spherical and unimodal nature of the sediment influenced by very strongwave current and wind energy, erosion is so pronounced that a coastal strip of 3m is all that is left to protect the backland. Once this bundlike structure is breached, the coastal road and hundreds of acres of sugar cane plantation would be over flooded.

At such sites there is no exchange of sediments from the beach and backshore to the dunal ridge by onshore wind as filtrate deposits and from the ridge to the beach as feedback deposits. To attain the new equilibrium, part of the sediments that have been mined from the ridge is compensated by withdrawal from the beach deposit, with the result that beach erosion is accelerated.

<u>Lagoonal</u>
Mining of sand from the lagoon is presently undertaken at Pointe d'Esny, Pte des Regates, Mahebourg, Deux Freres, GRSE, Roches Noires, Pte Lascar and Poudre d'Or. The seabed topography have drastically been changed; needless to say that the coastal ecosystem together with the marine organisms and habitats have been gradually annihilated. The mining of sand at Pte d'Esny is seriously affecting the coastline of this area. Similarly beach deposit at Roches Noires has reached to a point of non recognition. At some segments the coastline has retreated to about 8m during the past ten years.

Planation of Dunes

In Mauritius, unfortunately most of the coastal hotels have been constructed on the dunes. The planation of the dunes upset the equilibrium and reactivates sediment dynamics, thereby impacting negatively on the foreshore and backshore. Recently, the coastline at Tropical Hotel at Trou d'Eau Douce experienced severe erosion. At one spot during rough sea last year the coastline retracted to 5m. No sediments could be compensated for the loss during scouring by wave action. The foundation of the nearest building was exposed and would have been undermined and the building collapsed if no structural protectionwere undertaken urgently.

Presently, Berjaya Hotel which has been constructed on a dune system is experiencing similar fate. Here the dunal deposit has been levelled and pushpiled on the beach, to extend the beach area as undertaken by Beachcomber Group for Shandrani Hotel at Le Chaland. Severe beach erosion is being experienced and significantly, the decrease in the height of the dune would allow storm surges during cyclonic conditions to overtop this coastal ridge. The position of the HWM is gradually shifting landwards

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and with further incursion on the levelled dune a concomitant marine transgression with coastal retreat would be inevitable.

Opening of Passes

In order to facilitate boat movement outside the reef, the reef gap are widened. Such opening changes the hydrodynamic regime, causing a strong current to reach the shore. The expended energy remove a good chunk of the coastal deposit at that particular spot, causing shoreline retreat, e.g Poste La Fayette and Flic en Flac.

4. EFFECTS OF SHORELINE CHANGES

4.1 AGRICULTURE

The coastal zone supports a number of agriculturalists who lead their subsistence by undertaking agricultural activities, particularly plantation of vegetables. Reclaimed tidal flats, flood plains, coastal ridge and sand flats have been cultivated since the last hundred years. The rise of the sea level would overflood the low lying areas and affect the higher grounds through salt spray and storm surge. This would seriously affect agricultural production and means of subsistence. Production of garlic, onion and solanaceous crops that grow well on the sandy soil would be most impacted. The area that would be affected are Belle Mare, Pointe Lascars, Bel Ombre, Ile d'Ambre, Roches Noires and Poste Lafayette.

4.2 STRUCTURES

With the rising sea level many hotels and campements that have been constructed near the coastline would be either inundated or undermined of their foundations. Hotels such as Berjaya, Meridien, Pearl Beach are most vulnerable. Overflooding of the coastal roads at Maconde, Le Morne, Mahebourg(Riviere La Chaux), Poste La Fayette is a common event even during very minor climatic upheaval. Some sections of these roads are collapsing. Coastal defences such as sea walls at Riviere des Galets, Flic en Flacq and Pointe d'Esny are getting damaged by storm surges.

4.3 TOURISM

As the tourist industry depends heavily on hotels and associated infrastructures and as most of the hotels are built right on the dunes, fluctuation of sea level will seriously impact on this sector. Beaches have to be reprofiled, protection to beach front to be effected, slipways, jetties and groynes to be redesigned anew. Treatment plants and other infrastructures have to be shifted landwards and possibly many coastal roads deviated.

Socioeconomic impacts would be quite serious through the displacement of coastal communities and with the change in their mode and pattern of subsistence. In fact the whole system would be disrupted.

4.4 AQUIFER

The increase in the sea level would shift the fresh/salt water wedge landwards thus affecting the quality of the coastal aquifer. Overflooding of the backland during adverse climatic conditions would also contaminate the coastal freshwater. Such incidence would have a serious bearing on the coastal water quality, agriculture and irrigation. The borehole at Rouge Terre, Fond du Sac is only three km from Grand Baie and this may be contaminated by saline intrusion as at Grand Baie. This problem would be compounded by tapping water in boreholes near the coastlines.

4.5 CHANGE IN ECOSYSTEM

Coral and coral reefs

Coral population are affected by salinity changes, turbidity, oxygen concentration, temperature and sunlight. A rise in the water level, if the environmental conditions are optimum, would favour coral growth. If the rate of the rise of the sea water level is very high and coral growth could not keep pace with this change, they might get drowned. Such rise in the sea level would also accompany turbidity with the washing and entrainment of terrigenous sediments.

The rise in the sea level is a consequential effect of global warming. The sea water temperature would exceed the 30ºc which is the upper sustained limit of tolerance and this would upset the coral system and the associated lives.Retardation of coral growth would increase the incidence of wave action on the beach, affecting coastal stability particularly in the Eastern, Southern and South Western and Northern regions.

Estuaries

Estuaries and estuarine lives are closely interlinked with the marine regimes. An increase in the sea level would further drown the land adjacent the estuarine mouths, causing a change in salinity and migration of the estuarine organisms. Alluvial and terrigenous deposits would be reworked and resuspended thus increasing turbidity. The tidal flats that harbour an array of estuarine and marine organisms would be seriously affected. With he overflooding of the Terre Rouge River tidal flats, the thousands of migratory birds would perhaps have to find other sanctuary. Salt Water intrusion, particularly near the river mouth, will give rise to much economic problems.

Coastal wetlands

The coastal wetlands has been functioning as flood regulator, sediment and toxic element trap, water cleanser, energy storage and important habitat for many coastal organism. These features have a direct bearing on the state and health of the adjacent marine ecosystem. With a rise of the sealevel all the coastal wetlands, which communicate with the sea through tidal inlets would be seriously affected. Not only the wetland ecosystem would be upset but also the marine ones. At Grand Baie and Perebere regions more than twenty five hectares of wetland would be overflooded with a rise of the sea level by 30 cm (Fig. 6).

Mangroves

Besides being a nursery ground for many planktons, and juvenile crustaceans and fish, mangroves entrap terrigenous sediments and act as a very effective coastal protection. As mangroves are susceptible to salinity changes, this mangrove ecosystem would be affected by the rising sea level.

Mangrove state and vitality are not healthy since they are disappearing gradually. Man, with his interference on this ecosystem, has created many environmental problems including production. Mangrove swamps would decrease further and this would have a negative bearing on coastal ecology as well as on food production and economy. The various mangrove rehabilitation programmes undertaken in Mauritius and Rodrigues would have to be reoriented with new strategies taking into consideration the increase in the sea level.

Fish Farms

Coastal fish farms commonly called barachois would be flooded and its extent would increase. Unless redesigned the walls would collapse and most of the fish would be in the open sea. The rising sea would scour soil from the upland and these would be deposited in the barachois. Many organisms inhabiting these bararchois would be affected.

Incidently oyster beds, crab habitats etc would also have an incidence with the sea level rise.

4.6 SAND MINING

Lagoonal sand mining would be slowed down. Presently the deposits that are subaerially exposed or that are covered with less than 1m water are exploited. With the rising sea only those sites near the beach would be available for mining. Since the present mining regulations require a set back of 500m from the

HWM, practically no site would be available, unless the set back is decreassed. If this is allowed 21 the adjacent beach would suffer further degradation. Unless coralline sand are substituted by basaltic sand, or mining in the deep sea with dredgers, availability of coralline sand would sensibly decrease, causing a slow down in the construction sector.

The ex sand quarries such as those of Pomponette, Pointe D'Esny, Riviere des Galets, St Felix, Les Salines and Poste La Fayetter would be overflooded and those colonised with grasses and trees would be destroyed.

4.7 SALT INDUSTRY

Most of the salt pans that are constructed on the coast would be overflooded and during slack tide seawater would still be retained. The salt pans should have to be shifted upland. Salt pans at Les Salines that obtain sea water during high tide would be ruined. There is a likelihood that the salt prodcued would be contaminated, especially at Riviere Noires.

4.8 COASTAL INDUSTRIES

Those few coastal industries that lie near the HWM e.g. Bel Ombre Sugar Factory, Tuna Canning, Power Plants of Fort Victoria and Fort Georges, MCFI, Cement Bulk Terminal, textile factories such as those at Ile D'Ambre etc would be affected. The access roads, underground storage tanks, waste water disposal system would be damaged, causing much harm to the environment.

4.9 HARBOUR INFRASTRUCTURE AND SERVICES

The Port Louis area which is the business centre for the island is more or less flat, rising a few metres amsl. The harbour area has been dredged and reclaimed and many important industries has been implanted such as power station, MCFI, oil storage tanks, Bulk Sugar terminals, Grain Milling, fish processing etc. During rough seas water splash over the quays and overflooded the adjacent areas.

The various infrastructures such as roads, quays, platform, docks, stores, oil pipes, sewage pipes etc would be affected. These infrastructures facilities and services would have to be reviewed and planned taking into consideration the upper reaches of the sea level.

4.10 SALINE INTRUSION

With the rising sea level the fresh/salt water interface would move landwards. The abstraction of fresh water in the coastal regions would no doubt increase saline intrusion. Agriculture, irrigation, potable water and many industrial activities would suffer. In some regions of the north saline intrusion is being observed (Fig. 8). Concurrently decrease in lens size of the aquifer though flooding of sea water during storm and cyclones would incidentally impair water quality.

A comprehensive study is warranted to determine the extent of salt water intrusion that is expected with the different scenarios of the rise of sea level. This study would be useful to prepare a proper resource management plan for water utilisation and development.

4.11 COASTAL WATER POLLUTION

Coastal solid waste disposal system

Presently two official dumping grounds exist near the coast- one at Roches Bois and the other at Bois D'Oiseaux, Poudre D'Or. There is a very likelihood that the rising sea water would wash the wastes together with the leachates and polluting the coastal water including the marine organism. The aquifers and the barachois would be contaminated, thus posing a real health threat. The Roche Bois dumping ground has been decommissioned and very soon that of Poudre D'Or would be sealed off, with the creation of a centralised dumping ground at Mare D'Australia.

Sewage outfall

With the reclamation of the sea at Ruisseau Terre Rouge in 1991, the flushing of the sewer outfall decreased drastically and raw wastes could be seen deposited all along this part of the coastline. The manifestation of eutrophication is also related to this problem. The sewage outfall would have to be redesigned and extended, involving heavy investment. There are no doubt many coastal hotels and bungalows that dispose of their sewage wastes through septic tanks and absorption pits. The rising sea level would contaminate the ground water and the coastal water, posing threat to the health of the coastal community.

A coastal development plan would have to be prepared to identify appropriate sites for major coastal development. It is in this context that for all major coastal development projects an Environment Impact Assessment is required to predict and mitigate associated environmental problems.

Coastal land

All the coastal land from the HWM to 81.21m landwards belong to the state, except at some localities. Most of these lands are leased either for hotel development or for bungalows. The land from the HWM to the low water marks and the public beaches are meant for the public use. Consequently, with the rise in the sea level the HWM would shift further landswards and this could give rise to many legal complications.

For example the management of one hotel at Flic en Flac has constructed a sea wall on the HWM some years ago. With the rising sea and with the reflection caused to waves this water level has transgressed landwards. During mean water mark the sea water strikes the food of the wall and during high tide the sea is 60-70cm deep. The management claims that during the construction of the seawall he had left the required set back but due to natural phenomenon the water level has risen. Presently it is impossible to walk along the beach.

According to planning guidelines new development plots on the seaward side shall be at least 300m². With the rising sea the requirement of this plot size or the set back could not be met in some cases.

5. CONTROLLED MEASURES

The effects of sea level rise is giving rise to many complicated problems that could only be addressed by judicious planning, redesigning of the existing protections and adaptation strategies.

5.1 PHYSICAL CONTROL

Structural

<u>Seawall</u>
In order to protect the beach front and the adjacent properties many structures have been put up and most of which are not giving the targetted results. Such structures have to be dismantled and redesigned. It is imperative that during their dismantling, care should be taken to remove them phase wise or the stability of the adjacent system would be upset as the case of Pointe d'Esny, when the removal of one groyne caused severe erosion of the beach and the collapse and cracking of the adjacent sea wall.

Where the beach is getting eroded a scientific investigation should be undertaken to identify the factors effecting erosion, wave climate, hydrodynamic regime and sediment disposal pattern. In most of the cases it is recommended to use either an inclined sea wall with appropriate batter angle and a rip rap of the toe or gabion wall that effectively dissipate wave energy and increase deposition. A reno mattress at the foot and a geo textile screen behind the gabion wall should be placed to prevent rilling and collapse of the village.

<u>Groynes</u>
It is recommended that groynes should be constructed where there is adequate sediment drift. These groynes should be designed by competent coastal engineers. Their length, orientation and height should be properly calculated. All these groynes should be of permeable nature so as to intercept sediments from both sides during change in current direction.

All these groynes that are misoriented and missited should be redesigned and also made permeable. There are quite a few groynes especially in the Black River Coastline that are mere rock dumps. They are very bulky and massive and of undue length. These structures should also be modified to make them function effectively.

Jetties

Jetties like groynes have been constructed in a very haphazard manner. Most of them are inducing erosion, and are blocking passages along the beach. These structures have to be corrected. New jetties should be properly designed by a competent engineer and should necessarily be on piles. The Ministry of Environment and Quality of Life recommends jetties only where they would be required and their designs should be as per the Ministry's specification.

Soft Protection

Whenever possible soft protection should be undertaken in the form of artificial beach nourishment, sand bags, tyres, etc. For artificial beach nourishment care should be taken to place sands of appropriate grain size and declivity. In the first instance the newly deposited sands should be protected from wave action till their complete stabilisation. In such cases granulometric analysis, slope and hydrodynamic studies are required.

Vegetative Protection

Vegetative cover afford a good protection against erosion. The beach and ridge scarp that has been eaten up could be reprofiled and colonised with grasses and managed. Salt tolerant trees, such as filao, bois manioc, bois matelot, velontier could be planted as a screen on the high water mark fringe to prevent erosion caused by wave and wind action. Mangrove plants could also be planted in these areas where these plants could thrive well.

However, management of such plantation in the form of recruitment, watering, protection against fire, trampling, grazing by animals are of extreme importance.

Sand Mining

Sand Mining from the dune has been stopped and no permit is granted. Mining from the lagoon should be restricted and only those areas should be exploited where sands are accreted. In the long run mining from the lagoon should be banned and coralling sand should be replaced by basaltic ones.

Control of Pollution from Landbased Sources

Coralline sands are mainly detrital products of coral, tests, spicules, bones of other marine organisms. In order to control sea level fluctuation and beach erosion the health of the lagoon with the inhabiting marine lives should be enhanced. Consequently, pollution from land base sources should be controlled through treatment plants, process changes and good management practice.

Green House Gases

The emission of green house gases in the atmosphere is the major factor contributing to climatic changes and sea level rise. Use of alternate source of energy, decrease in the utility and ultimately ban of the CFC, and other green house gases and reafforestation could in the long run alleviate global warming and sea level rise. Such action should be taken at international level and all the countries should be united as one nation and take concerted action against this problem.

Mauritius is a developing country under the definition of the Montreal Protocol with a per capita consumption of 0.07 kg of Ozone Depleting Substances (ODSs) per annum. With growing concern towards environmental protection the Government of Mauritius signed the Protocol in August 1992 and ratified the same in November 1992. This act reflects the intentions and commitment of the Government and People of Mauritius to join the international efforts to save the Ozone Layer by complying with the Protocol.

As per the terms and conditions of the Protocol, the consumption of Ozone depleting Substances

(ODSs) is required to be phased out from a level of the average consumption in the years 1995,1996 and 1997 by the Year 2010 or 2015 depending on the substances.

5.2. PLANNING CONTROL

Planning instrument is an important tool to address and accomodate the environmental effects caused by sea level rise. With the rise of the sea level many areas would be flooded, industries, houses, land resources and other economic activities affected it would be wise to plan out and relocate coastal activities and enterprises in areas that would have little effect with such changes.

One of the most important parameters that would have to be considered is the provision of the setback. All the industries, buildings and infrastructures on the coastal zone should be at appropriate distance and position. The set back should be site specific taking into consideration slope, altitute and sensitivity of the area.

Only such industries should be placed in the zone that will not cause any significant environmental problems with the sea level rise. In order to regulate such developmnent the Ministry of Environment and Quality of Life is preparing an Environmental Sensitive Areas Map with guidelines on nature and type of industries and development that could be allowed in such areas.

All major developments should be allowed on site beyond the reach of the extreme scenario of sea level rise. Some other developments should be retreated from the island.

Incidentally for the major houses on any other structures a good engineering design should be made taking into consideration wave and sea water uprush during rough sea. Structures on piles should be given due consideration.

Wherever retreat or relocation is not possible, an adaptation strategy should be developped. The existing structures and facilities should be curtailed to adapt to the present situation and when such practice is not feasible it would be wise to retreat.

6. RATE OF SHORELINE AND BATHYMETRIC CHANGES

Until recently no systematic investigation was undertaken to determine rate of coastal erosion and the factors affecting them. Coastal erosion is a phenomenon where there is a complex interplay of various natural forces on sediment distribution and dispersal. Many physical parameters are involved and in order to determine effectively the factors affecting such degradation, an indepth scientific investigation is warranted and this might take several years to come to a conclusion. It is possible to identify these factors but in order to correctly recommend the mitigative measures, particularly structural protection, a thorough investigation of the impacts of the prevailing hydrodynamic conditions, depositional energy regime on sediment characteristics is extremely important and for such studies many cyclic observations and monitoring for several years should be undertaken. In mauritius coastal erosion problem is not new. This phenomenon has been prevailing upon since many years. However, with the tremendous pressure exerted on the coastal zone, particularly with the influx of tourists requiring many hotels and with the high demand of coastal land for bungalows, and utility of coralline sand mined from dune and inshore, coastal erosion has become a serious concern for the coastal developers, coastal community and the government.

To contain the erosional problems many coastal developers sought the services of local and foreign consultants and few reports have been submitted to the department of environment on this issue. A striking case was that of St Geran where then coastline receeded many metres seawards and a scarp of 1 - 2m was prominently seen to a distance of 200m in the year 1988. The ridge sediments were scooped out and

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swirled away during the spring tide of 1988 and cyclonic conditions of 1989. The beach face angle flattened 5 - 6 % despite the coarse nature of the sands. Regular bathymetric surveys were undertaken quarterly and geotextile bags and artificial algae were placed along and across the beach in the form of groynes and breakwater. The erosional site was gradually rehabilitated and stabilised and presently a vestige of ridge scarp could be seen.

With the dismantling of a groyne at Pte d'Esny in 1991, a monitoring exercise was undertaken to investigate the environmental problems that ensued. The beach front is protected by a vertical massive stone wall and at its foot a groyne runs across the beach. About 1 m sand was trapped at the heel of this groyne. With the dismantling of the groyne all the sands at this spot got washed away and waves hit directly against the sea wall thereby fracturing and also undermining the seawall. The adjacent sea wall collapsed with its parapet. The promoter was asked to put sand bags in the form of a groyne to entrap drifting sand and three levelling exercices were undertaken at one month interval. Six points were chosen along the coastline and six other points at 2m distance were taken. It was noted that after 38 days the beach profile changed considerably. At the foot of the wall, 20 cm of coarse sands were deposited. However, at the mid portion of the sea wall, 2m from the foot about 5 - 10 cm of sand was washed away. On the third month at the foot of the wall all along, a further 20 cm of sand was deposited and the beach profile became near horizontal.

A similar beach monitoring exercise was undertaken at St Geran to evaluate the beach equilibrium and environmental repercussions caused by the removal sand bags. Eight stations were established on the dunal ridge and cross profile survey undertaken seawards to a maximum distance of 65m. Three levelling exercise were undertaken on 16.10.92, 23.10.92 And 29.10.92. The results showed that no beach erosion was caused due to the removal of sand bags. The previous erosion was caused by adverse climatic conditions as such erosional manifestations were observed all along the coastal segment of Belle Mare. It is worth noting that station g which is in front of a vertical sea wall gave rise to a concave profile at the foot.

All the other erosional sites mentioned in this report are results of visual inspection during various site visits and monitoring. The visits were not undertaken regularly and hence no solid conclusions could be derived. Still, it gave an indication of the incidence of coastal erosion both spatially and temporally.

From January 1993, with the implementation of a pilot project on the vulnerability assessment of selected coastlines of mauritius in the context of climate change and sea level rise, two sites have been identified, viz Pomponette region situated in the south and Port Louis harbour area. The objectives of this project are:

(i) <u>long term</u>
- to assist in the project preparation of a long term monitoring programme on coastal and phenomena related to climate change and sea level rise.

(ii) <u>short term</u>
- to examine the possible effects of sea level changes on the coastal environment
- to examine the combined effects of temperature elevations and sea level rise on the terrestrial and coastal ecosystem
- to examine the possible impacts of climatic and ecological changes on coastal human activities and socio economic structures
- to determine areas or systems which appear most vulnerable to the above changes
- to increase awareness on coastal impacts likely to result from climate change
- to promote multidisciplinary and integrated thinking in the assessment of climate change at the level of individual countries
- to identify and recommend appropriate policy options and strategies to mitigate the likely negative impacts

Methodology

- contour interval of 1 m were taken for the preparation of a 1 m contour map. L-sections at various points were taken to obtain a more sensitive indication of the topography of the terrain. L sections were also taken in the lagoon.

Methods of survey

- Most of the new roads on the former sand quarry sites were surveyed graphically. The plane table self reducing alidade was also used to that end.
- However, control had to be provided for the survey of the unmapped region and the riviere des galets housing estate. A long traverse was observed from ttp 17 (pomponette) to TTp 16 (near Ilot Sanchot). The traverse stations were located along the main road (89) and were iron pails hammered in the road tarmac. Angles were observed.

Levelling

Only 2 BMG's were found in that region and from these levelling loops have been observed to all the traverse stations found along the road B9. These loops were carried out at a tertiary level with a Wild Automatic Level. Spot heighting within the filao trees on the Pomponette Public Beach was carried out using the Wild RDS. Difficulties were encountered while pointing to staves within the filao trees. This same method was also used while levelling within the Riviere des Galets Housing Estate and Pointe aux Roches Villas. The landward area (e.g. the former sand quarry of Pomponette) were levelled by means of the Automatic Wild Level at every road junctions. All the spot heighting loops started from and ended on a point of known level.

Ten L-sections lines were identified and levelled using a Wild Automatic Level. Two Bench Marks have been cast in each L-Section line so that the same L-Section may be produced seaward.

Plotting

Plottings have been carried out on PFD as far as details are concerned. Spot heights were plotted on a proper plan and contours interpolated on it. These PFD's and contour plans were mounted and then traced on a permatrace to produce the final plan at the scale of 1/2500. L-Sections have been plotted at the scale of 1/1000 horizontally and 1/50 vertically.

Topographic, bathymetric, ecological and land use survey and oceanographic data collection and sedimentological analysis are undertaken. Change in the coastline, bathymetry and depositional pattern would indicate fluctuation in sea level rise quantitatively and the factors contributing to coastal erosion and deposition. The survey exercise and data collection are ongoing till end of 1994, after which a conclusive report would be submitted on the problems related to sea level changes and control measures to be undertaken. The accretionary nature of the beach and its stability are due to the presence of the dunal sand reserve. The erosion of the beach by wave action has been mitigated by the influx of dunal sediments, so that the vestige of the beach scarp is being obliterated. As long as this deposit is not depleted or disturbed the coastal zone at this segment will be protected.

It should also be noted that at this coastal segment there is a strong onshore/offshore wind regime. Even though the dunal sediments are fine size they have been completely arrested.The exchange of sediment from the beach to the dune through the backshore as filtrate deposit by onshore wind and their redispersal from the dune to beach as feedback deposit by offshore wind has been more or less stabilised. Any scouring or mining of this eolian deposit will disrupt the whole setup of the coastal system at this region.

The shape of the dune with the characteristic angle of the limbs is the deciding factor of its stabilization.The angle of repose of the grains is not a haphazard setting,but a harmoniuos balance between energy regime and sediment enertia. The levelling of this feature will bring about an unstability in the whole system affecting the coastal zone including the lagoonal and reefy areas.

This dunal deposit is also acting as a barrier against high energitic sea waves ,spring tides and salt spray that are invariably affecting the upland, including vegetation and coastal aquifer. This feature, besides acting as energy stabiliser, is a resting, breeding and nesting ground for many coastal faunas particularly birds.

7. NATIONAL POLICY ON COASTAL EROSION

The coastal zone is an area where there is a complex interplay of various energy regimes on a tristate system, i.e land, water and air. These energy regimes converge to give rise to a dynamic ystgem where the physical and depositional features are always trying to attain an equilibnrium with the energy flow. Very often acceleration or dominance of one energy force either due to natural or anthropogenic interference upset the equilibrium with consequential disastrous upheaval.

Being under constant stress either by natural forces or human needs, the coastal features and related development undergo profound changes that could not be reinstated or retransformed. It is precisely because of these changes that the discreet facets of the whole coastal ecosystem that were harmoniously bound by th edifferent energy levels are gradually being defaced, gradually rendering them and dismal liability to humans. By virtue of its natural attributes such as sites for residences, industries, vegetation, ecology, food and energy production, tranquility, aesthetism, stabilising factor, recreational and because of its limit it is in the interest of each and every nation who has been endowed with this resource should sustainably developm this zone without imposing undue pressure.Taking into consideration the size of Mauritius with limited land resources and a prolific tourist industry that depend a lot on the good beaches and clean lagoon, every effort is being made by th eState to restore the natural attributes of this zone and protect and preserve its characteristics.

Some of the measures taken are :

7.1 PLANNING CONTROL

For the optimal and sustainable use of the scarce land resources the Government of Mauritius has prepared a National Development Physical Plan wherein a fairly detailed planning strategy has been elaborated for the preservation and conservation of the coastal resources. Under the overall context of the NPDP outline schemes have been prepared in details wiht appropriate guidelines for coastal development. Under the Outline Scheme a Northern Tourist Zone plan has already been prepared and two such plans for the south-western zone and the north-eastern zone would soon be embarked upon.

All development undertaken within the coastal zone on the landwardside require permits from the planning authorities. The projects submitted are rigorously reviewed and evaluated prior to consideration. The coastal strip which is mainly used for recreational touristic and residential purposes have been further subdivided into two portions.

(a) Portion 1 comprises the lands fringing the shore and because of ts sensitive nature development is assessed and allowed on the opportunities and constrain of the site.

- development density, building height, setback form the sea, siting of septic tanks, construction of jetties and other structures need the approval of various ministries.
- dredging, sand mining, removal of beach rocks, dumping of material at the sea or on the beach require clearances from various ministries
- sensitive areas such as wetland, mangroves, water courses, nature preservation zones are generally protected from development

(b) Portion 2 extends from behind portion 1 from the coastal road inland. It is also under great pressure. Guidelines for development an this portion are generally less strict than in portion 1 but nevertheless aim at encouraging economic and orderly use of land, attractive in its setting and acts as a buffer along the coast.

7.2 SETBACK

All new developments on the coastal zone require a minimum setback that should be scrupulously observed. This buffer zone absorbs pressure exerted from marine environment as well as land based pollution. Siting of residential and hotel complexes with connected septic tands and sewage tretment plants requires consideration of slope, altitude, sensitivity of area and nature, type and size of structures.
For all such development extreme scenario of sea level rise, pressure drop, maxim;um amplitude of sea water uprush, structure, grainsize, slope adn roughness of coastlne are considered, Similarly statutory setback form water courses and even additional safety values are added for many development.
However, all existing developments are allowed to stay in situ and practical precautionary measures are undertaken to minimise any harm caused.

7.3 ENVIRONMENTAL IMPACT ASSESSMENT

In order to identify environmental problems and address them at the initial stage of a proposed project, so as to render any development sustainable, the Environment Protection Act of 1991, as subsequently amended in 1993 requires a proponent, whose project is a scheduled undertaking, to apply for an Environmental Impact Assessment Licence. The following coastal development projects are included in the scheduled undertakings:

(i) Wetlands development
(ii) Creation of islands
(iii) Removal of sand, coral, beach rock or natural vegetation
(iv) Sand crushing, screening and washing
(v) Mining of sand dunes and seabeds
(vi) Lagoon dredging and reprofiling of seabeds

(vii) Modification of existing coastline
(viii) Marinas
(ix) Construction of jetties
(x) Barachois development
(xi) Parcelling out of land into 10 or more lots in the coastal zone.

Any of the above projects are published in the Government Gazette as well as in two dailies inviting public comments on the proposed project. It is then sent to various enforcing agencies who have a concern in the project for views. The Director of the Department of Environment reviews the E.I.A and sends his review with any public comments to the E.I.A Committee. The latter further examines the Director's review and the public comments and accordingly recommends to the Minister for approval. The different phases of screening, reviewing and assessing the E.I.A report render the development fullproofed. All anvironmental parameters connected with the project are properly examined and considered and with the EIA Licence, a set of environmental conditions are imposed upon the proponent to mitigate any nuisances caused from the development. In all the cases, implications of sea level rise and marine and coastal pollution are invariably considered.

7.4 ENVIRONMENT SENSITIVE AREAS

In order to effectively control development on the coastal zone and manage the land resources the Ministry of Environment and Quality of Life has embarked on the preparation of an Environmental Sensitive Area Map that could serve as a guide to future coastal development.

Features such as beach, dunes, coastal wetland, mangroves, coral reefs, sea grasses, estuaries are very critical areas that warrant serious protection. In these areas no development would be recommended except those concerned with conservation purposes.

7.5 POLLUTION FROM LAND BASED SOURCES

The sea is a receiving media for most of the land based pollution. Control of pollution from these sources would have a positive bearing on the coastal and marine ecosystem. The improvement and enhancement of lagoonal health can, to a certain degree, mitigate the negative impacts of sea level rise through increasing the vitality and growth rate of coral reef and production of detrital coralline sands.

The Ministry of Environment and Quality of Life in collaboration with other Ministries are in the process of finalising the effluent limitation standards that would regulate the discharge of effluents in water courses including the lagoon. Incidentally as per Section 33 (2) of the Environment Protection Act 1991, the Minister may establish different standards for water quality having regards to the use and value of water for domestic supplies, propagation of fish, flora and fauna, and wild life, recreational purpose, agricultural, industrial and other uses. Action is being taken to this effect.

7.6 NATIONAL COASTAL EROSION RESEARCH STRATEGY

In addition to the various legislations enacted to preserve the natural characteristics and integrity of the coastal ecosystem, various strategies have been identified and adopted by the State. Two years before, a South African Team of the Division of Earth, Marine and Atmospheric Science and Technology (EMATEK), the Council for Scientific and Industrial Research (CSIR) was invited to:

(i) Identify the various erosional sites on the coastline
(ii) To determine the degree of severity and determine the factors contributing to these problems
(iii) To prepare short term measures to combat these problems at those sites most affected
(iv) To prepare policy guidelines and prepare a long term coastal management plan
(v) To develop sensors and systems for data handling for effective monitoring of coastal climate and sediment transport
(vi) To train Mauritian scientists on the above.

A preliminary report has been submitted to the Department of Environment, Ministry of Environment and Quality of Life.

Similarly thirteen coastal/marine projects have been identified under the Indian Ocean Commission, financed by EEC and grouping five island states. These projects would be implemented very shortly. All these projects are interlinked and among them erosion and degradatiuon of the coastline and hypersedimentation, conservation and rehabilitation of the Rodrigues coastline would be given due attention.

ANNEX I
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V. SEYCHELLES NATIONAL REPORT COASTAL EROSION, SEA-LEVEL CHANGES AND THEIR IMPACTS

By Nirmal Jivan Shah[1]

1. SEYCHELLES: BASIC INFORMATION

The Republic of Seychelles is made up of 115 islands scattered over an Exclusive Economic Zone covering an area of 1,374,000 square kilometres. The total land area is 455 square kilometres (45,250 hectares). The islands are situated in the Western Indian Ocean between 4 degrees and 11 degrees south of the equator. Mahe is the main island and the seat of Government. 41 islands are granitic and are all found within a radius of 50 km from the main granitic island of Mahe. With a land area of 148 square kilometres, Mahe amounts for one third of the total land area of the archipelago. The remaining 74 islands are all coralline. The furthermost island is Aldabra 1150 kilometres to the south of Mahe.

The population of 68,600 (1987 Census) is concentrated on the three largest granitic islands of Mahe (60,400), Praslin (5,600), and La Digue (1,900). The coralline islands support a population of 300 persons. 23,000 of the total population are under fifteen years of age, and Seychelles has recorded an average annual population growth rate of 0.8 percent. The average family size of Seychelles is 5 people. Life expectancy at birth for women and men is estimated at 72 and 68 years respectively. Seychelles is predominantly a Christian country (99%); the main church is the Roman Catholic which covers 88.6% of the population. Of the 20,000 wage earners, a total of 2,300 are employed in the agricultural, forestry and fishing sectors, 3,300 in mining, manufacturing and construction, 2,500 in tourist related industries, and 7,500 in services (Information has been taken from the last census conducted in Seychelles which was in 1987).

In 1903, Seychelles became a Crown Colony of the UK, separate from Mauritius. It gained full independence in 1976 as a Republic. Creole, English and French are today the official national languages. The Government of Seychelles is headed by an elected President, with a cabinet of 10 Ministers having specific portfolio assignments.

2. COASTAL GEOMORPHOLOGY AND CLIMATE BASELINE

The central Seychelles consist of forty-one islands and islets built of Precambrian rock approximately six hundred and fifty million years old formed from the breakup of Gondwanaland some over hundred and thirty million years ago by tectonic activity. The islands rise from the Seychelles Bank, a shoal area of about thirty one thousand square kilometres, with depths ranging up to sixty meters. The islands rise to a maximum of 914 meters at Morne Seychellois on Mahe. The granite islands are typically rugged and hilly. The coral islands consist of two types, low sand cays such as Bird and Denis, and elevated reef limestones such as the Aldabra group. The coral islands are low although sand dunes on some islands may reach as high as thirty two meters.

The coastal zone on the granitic islands consist of elevated terraces known locally as "plateau", as well as marshy areas. The terraces or plateau which lie up to two meters above sea level consists of calcareous reef material which builds up as sand dunes and pocket beaches known as "anses". The sandy deposits have accumulated in the last six thousand years. In contrast low-lying areas around river mouths are marshy and characterized by sediments of fine clays and quartz. Port Victoria, the capital, is built up on such sediments. The main island of Mahe is twenty-seven kilometres long and six kilometres wide with a land area of one hundred and forty-eight square kilometres. The coastline runs about one hundred and five kilometres in length and there are thirty-six kilometres of sandy beaches. The second largest island, Praslin, has a coastline which is forty-three kilometres long and has twenty-one kilometres of beaches. The plateau area on the islands is small, the largest occurring on Praslin and La Digue. The La Digue plateau covers about one hundred and sixty-five hectares and on Praslin total plateau area is about hundred and ninety- three hectares.

[1] Environment.Resources.Oceans (ENVI.R.O.), P.O. Box 699, Mahe, Seychelles

The climate of the Seychelles is generally tropical and humid with a mean annual rainfall ranging from one thousand five hundred to two thousand five hundred millimetres at sea level on the granitics to less than one thousand millimetres on the coral islands. Temperature ranges from a minimum of 24 degrees Celsius to a maximum of 30 degrees Celsius. During March to November the Southeast trades blow with great constancy south of the equator and extend north of the equator. The trades last for longer periods and blow more strongly in the southern than in northern Seychelles. During December to March the trades retreat south and winds are light northwesterly. The trade wind monsoon season is dry and the northwest wet.The granitic islands and most of the Northerly coral islands lie outside the cyclonic belt. Warm surface waters (23 to 27C) covers the Seychelles area during the Southeast trades. This is replaced by even warmer waters (28 - 31C) during the Northwest monsoon.

The granitic islands are well watered by streams. Exploitation of the upper hill slopes and destruction of natural vegetation have led to a wide fluctuation in stream flow. On the coastal zone, infiltration rate of water is high and can take up to five hundred millimetres of rain an hour. However, the watertable can, and does rise. On the outer islands a stable bi-convex lens of fresh water is established in the sand. The tidal range is about one meter in the granitic islands to two and half meters on Aldabra.

3. COASTAL ECOLOGY AND SHORELINE CHANGE

The coastal vegetation of the granitic islands has been described by various authors including Vesey-Fitzgerald , Sauer and Procter. Those of the coral islands are described by Stoddart and Fosberg. The lowland or coastal vegetation has been severely modified by human activities. The plateau on the granitic islands having good and well- drained soils were cleared of forests and planted with coconuts. This has been a major disaster in ecological terms. Mangroves, formerly very extensive, especially on the East coast of Mahe have been progressively destroyed beginning soon after the first human settlement. Small pockets still remain near open stream mouths. On the western coast of Mahe a continuous belt of mangrove continues to exist in the Port Launay and Baie Ternay Marine National Parks. In Curieuse Marine National Park a well developed mangrove system thrives. Mangroves have recolonised backwater areas created by recent land reclamation between Victoria and the International Airport. Many species have been recorded with Avicennia marina being most abundant. The largest mangrove systems are on Aldabra, Cosmoledo and Astove. Lowland fresh and brackish marshes were formerly found behind almost every plateau on the granitic islands. They have virtually all been filled in or dislocated by piecemeal reclamation. The largest occur on Praslin as well as about eighteen hectares on La Digue. Both have suffered from encroachment by agriculture, housing and roads in recent years.

The coastal marine areas of the granitic islands can be systematically zoned into rocky shores or sandy beaches, rippled sand zone, marine grass beds, radial zone, algal ridge, reef edge, and outer slopes The characteristics and the types of reefs have been described by various authors including Taylor, Lewis , Taylor and Lewis, Pillai *et al*, Stoddart, Littler and Littler. Fringing reefs are found at only a few parts of the coastline on the granitic islands and extend as uneven belts which may reach one thousand five hundred meters in width on the North-western coasts of Mahe. The largest continuous fringing reef in the granitic islands stretching about twenty-seven kilometres on North East bay to Anse Marie Louise in Mahe has now been interrupted by the East coast land reclamation and by the Seychelles International Airport. Sea grass beds and the standing stock of algae especially Sargassum, are still very extensive and deserve particular attention especially as buffers of wave energy and erosion mitigating zones.

4. COASTAL PROCESSES IMPACTING ON EROSION

Physical coastal processes, which affect all coastalland forms,in Seychelles comprise:
- Water movement;
- Near shore water-borne sediment movement;
- Aeolian transport (wind blown sediment),particularly on some coral islands

The reason for detailing these processes is to provide a basic understanding of them, and how they can influence decisions on coastal change in Seychelles.

Beaches and dunes are continuously affected by both wind and waves. Waves are generated by the effect of wind on the surface of the sea and, as waves approach the shore, they become steeper and then break in the near shore zone. The interrelationship between wave height, wave steepness, wave period and the direction of wave approach gives rise to the highly dynamic nature of a beach.

Erosion (the loss of beach sand) is usually caused by high, steep waves with relatively short periods whilst accretion (beach sand build-up) is usually associated with lower waves and longer periods. Also, because waves often approach the shore at an oblique angle, long shore currents can be created.

There is a continuous interchange of sand between dunes, beaches, sand bars in the surf zone and river or estuary mouths. These 4 systems are known as the 'littoral active zone" and disturbing the natural processes of any one of these could ultimately affect some, or all of the others.

4.1 WATER MOVEMENT

Waves are generated by wind stress and then propagated by the continual movement of water particles. The particles in successive waves do not actually move shoreward even though the wave itself is moving. As a wave approaches the shore, the shallower water causes a shoaling process whereby the rolling shape changes to a steeper profile with a series of sharp crests and flat troughs and eventually the wave breaks Shoaling starts when the water depth is half of the wave-length and the wave breaks once its height is about 80 percent of the water depth.

Wave refraction takes place when angled waves turn so as to approach the shore at right angles. Wave diffraction is the process whereby wave energy is transferred around an obstruction (e.g. a breakwater) into the area behind.

Long shore currents are caused by waves breaking at an oblique angle to the shoreline and occur in the breaker zone . These currents generally move parallel to the shore, and are capable of transporting vast amounts of sand along the coast. The combination of the long shore current, together with waves "pushing" water into the surf zone can cause the formation of rip-currents (the effect of a current surging outwards counter to the in coming surf) which are recognizable by a flattening of the breakers

4.2 NEAR SHORE WATER-BORNE SEDIMENT

Breaking waves stir up the bottom sediments thereby putting them into suspension and these sediments can then be either moved onto the beach (onshore) or away from the beach (offshore) depending on the wave characteristics. Sediments can also be moved parallel to the shore by a long shore (littoral) current. In general, a beach will experience seasonal fluctuations of erosion and accretion but will still be in an overall state of dynamic equilibrium.

4.3 AEOLINA TRANSPORT

Aeolian transport occurs when sufficiently strong winds blow over open, sandy areas, putting the sediment into motion . Most of this wind-blown sand is usually transported in a layer of up to 0.5 m above the beach or dune surface. The volume of wind-blown sand transported depends on various factors including the wind regime, dune vegetation cover and also sand moisture content, grain size and shape. It must be noted that aeolian transport is more common on the coralline islands of the Seychelles than the granite ones.

4.4 APPLICATION OF PHYSICAL COASTAL PROCESSES

An understanding of these processes is necessary in order to comprehend their effect on any coastal development or activity. The ongoing processes of water and sediment movement control the prospective siting of any development and, from these, a development "set-back" line can be determined (this being the safe seaward limit development, taking into account the dynamic equilibrium of accretion, erosion and aeolian sand transport).

5. PROBLEM AREAS IN RELATION TO COASTLINE CHANGE

Coastline change in Seychelles may have various economic and ecological negative effects, such as:

• recession of beaches,
• losses of valuable arable or buildable land
• damages to coastal property or infrastructures (buildings, roads, seawalls),
• destruction of economically valuable trees
• destruction of ecologically valuable ecosystems or species

Coastine change in the Seychelles is more often than not a natural process aggravated by human interference. Under the combined action of waves, tides, winds and currents, coastlines may experience a phenomenon of net advance and retreat. Alternate phases of beach erosion and replenishment are commonly observed, particularly on the northwestern coast of Mahe (Northolme Hotel beach). During stormy periods, beach material scoured away by the action of waves may be carried by current drift and deposited either offshore, or onto another stretch of the coast (Pardiwalla's beach-Bel Ombre).

Dunelands located behind the Seychelles beaches constitute a natural reservoir of sand for the restoration of the beach. In natural conditions, i.e. in the absence of hard structures such as roads, retaining walls, etc... On the coastline, the increased erosional capacity of a storm surge would be accompanied by a transfer of material from the dune to the beach, thus flattening the beach profile and dissipating the wave energy. At other periods of the year, when winds and currents have changed direction, the waves may carry again some sand from offshore deposits onto the beach, which is thus replenished.

Under natural conditions, most shorelines thus exist in a state of dynamic equilibrium, constantly adjusting to changing environmental parameters. All beaches of an island or a group of islands participate together in this global equilibrium. However, various local factors such as a topography offering protection from dominant winds, a flat sea-bed profile, the existence of a natural barrier such as a coral reef, the presence of seagrass beds and marine algae cover may contribute to facilitate an early dissipation of wave energy. This may explain why some sites are more significantly erosion-prone than others. This global equilibrium is affected by man's activities, which may either obstruct the natural process of beach restoration, or even directly contribute to reinforce the eroding effect of waves.

6. CLIMATE CHANGE AND SEA-LEVEL RISE

Seasonal fluctuations of beach profile are a normal feature in the context of the continuously adjusting coastlines equilibrium. However, there may exist a long term trend towards a net advance or recession of the coasts, in relation to a general variation of the sea's level. This may in turn result either from changes in the volume of oceanic waters, or from slow subsidence or emergence of continental shelves. According to most predictions about 70% of all beaches in the world which have been the object of a regular monitoring over a long period of time, are actually receding. This phenomenon is primarily attributed to a rise in the sea level. It is recognized that the oceans would have been actually rising over the last hundred years. This rise is estimated at 15 cm on average over the world, with important local variations.

Substantial climatic changes have occurred in the Seychelles in the last one hundred years. Anomalous weather conditions have also been recorded recently by the Meteorological Services Division on Mahe. According to a Seychellois expert, climatic anomalies such as "hypercanes" may become pronounced (Chang-Ko pers com). Increased incidence of storms, and high waves are anticipated. In 1986, a tide gauge installed on Praslin for the TOGA Program was washed away by a storm! Rises in sea level would be catastrophic for the coastal zone, the newly reclaimed areas and the low coral islands; the majority of the population and infrastructure would be affected. The worst scenario would be the simultaneous occurrence of flash flood at high tide or worse still if there is a surge in sea level. It may be 15 to 30 years before serious problems occur, but current environmental damage, if not controlled, will exacerbate the effects of sea level rise. It is unlikely that sea-defense protection offered by coral reefs will be much use beyond the year 2050.

7. ANTHROPOGENIC EFFECTS AND SHORELINE CHANGE

Seychelles population of 68,600 is concentrated on the three largest granitic islands of Mahe (60,400), Praslin (5,600), and La Digue (1,900). Ninety percent of Mahe's population is concentrated on the coastal strip, in particular the East and North Regions. With a total land area of one hundred and forty-eight square kilometres, the population density of the island is in excess of four hundred persons per square kilometres. This is comparable to densely populated countries such as the Netherlands and Switzerland. In reality the density is much higher since almost the entire population is clustered in the lowland areas. Due to the rugged and steep nature of the granitic islands and the favorable environment of the coastal zone, all major touristic, fisheries and other economic activities are also centered in this area, competing for space. The coastal zone has therefore become **the** environmental "hot-spot" of the country.

Various anthropogenic effects leading to shoreline change are given below:

7.1 SAND EXTRACTION

Abstraction of sand for the construction industry, whether operated from the beach itself or from the "dry beach" or duneland directly contributes to the beach's recession. Mining of beaches for construction material can result in severe local coastal erosion because removing sand from a beach reduces the supply available to renourish the beach. Likewise, the mining of sand dunes and plateau sand can affect sand reserves, and can lead to severe erosion problems and the recession of beach front among other environmental problems. The extraction of gravel from river beds can also induce erosion along the coast. It must be remembered that beach and plateau sand have traditionally been used as construction materials in Seychelles. Excessive extraction at the rate of thirty-five thousand tonnes a year from one beach on Mahe has been known. Since 1991, extraction of beach sand has been banned. Removal of sand blocking river mouths may be permitted. Plateau sand is being removed in large quantities by permit. The replacement of this sand by impermeable laterite soil in the plateau could lead to dangerous flooding and drainage problems. Alternatives to sand in construction, include crushed granite dust, pulverized coral fill (reclaimed material) and sand from dunes on the outer islands.

7.2 DESTRUCTION OF PROTECTIVE CORAL REEF SYSTEMS AND CORAL BARRIERS

Coral reefs all around the main islands are under stress from multiple causes including terrestrial run-off, sewage, reclamation (mining), siltation, anchor damage, physical human impact and removal of live coral. This is the least studied but an extremely important cause of coastal erosion in Seychelles. Experts consider the area from mangrove swamps and sandy beaches, marine grass and algal beds, to the outer reef edge as part of the entire contiguous reef system, which acts as a buffer against waves, currents and storms. Therefore, all these zones are interconnected, and the health of one will affect another.

7.3 REMOVAL OF COASTAL VEGETATION

The destruction of vegetation make remaining vegetation more vulnerable to abrasion by the wind which blows sand inland (or seaward). Vegetation acts directly to reduce erosion by physically binding the sand to reduce turbulence. As stated earlier the main process by which coastal vegetation lost ground in Seychelles has been to make way for coconut plantations. Coastal vegetation is also removed for roads, playing fields, houses, hotels, fishing-related infrastructures etc. In addition, the Seychellois attitude of "netoye" or cleaning, sometimes results in removal of vegetation in the mistaken belief that by doing so the environment will be rendered cleaner and more hygienic.

7.4 BUILDING ON SAND DUNES

Building too close to the beach, on top of fore dunes or flattening them for construction sites limits the space available for the beach's natural erosion/deposition cycles. The construction of buildings or infrastructures such as roads close to the shoreline therefore artificially isolates the beach from the landward section of its ecosystem. Wind blown sand is not retained anymore by the dune system and the beach, in turn, is deprived of its natural source of replenishment. This results in the undercutting of the buildings on the dunes, which then induces property owners to construct sea-walls, and in turn cause erosion problems. This has become a major problem with most coastal roads in the three main islands of Seychelles, since those have been built on sand dunes or the foreshore and now are locked in a never-ending cycle of construction and repair of sea walls.

7.5 CONSTRUCTION OF SEAWALLS

The construction of vertical hard structures like seawalls and revetments on the shoreline itself, hinders the dissipation of wave energy, reinforces their erosional capacity and thus causes accelerated beach erosion at the foot of the structure. The construction of these structures to protect property, road or as part of a small reclamation may accelerate erosion in front of and on the down drift side of these features because of wave reflection from the hard and often vertical surfaces. Usually, what has been experienced n Seychelles is that the fixed property (such as roads, houses, hotels) is saved for some time while the beach sand is lost. In the long term, it may often lead to the substitution of a sandy shore ecosystem by a rockier shore.

7.6 CONSTRUCTION OF GROYNES

Unless correctly designed and detailed, the construction of groynes will act as barriers to longshore drift. The construction of groynes therefore , which aim at trapping sand carried by the drift current and thus fixing beach material in a definite place has the inconvenience of depriving down-drift beaches of their 'normal' supply of sand. This artificial accretion of a particular beach is therefore usually achieved at the expense of another beach. An example is at Anse Kerlans-Praslin Island (see page 10 of this report).

7.7 CONSTRUCTION OF BREAKWATERS AND PIERS

Breakwaters have been traditionally used for harbor protection, but have the side effect of starving the downndrift beaches of sand. The largest breakwater on Mahe is at Port Glaud and was constructed not as harbour protection but built by a hotel to "create" and protect a beach. It has led to severe loss of sand downdrift. Continued deposition of sand between the shore and the breakwaters may eventually tie the breakwater to the shore, thus affecting shipping. Continual dredging then becomes a necessity. This is evident at Bel Ombre on Mahe, where a breakwater constructed to provide safe anchorage for fisherman has resulted in silting and a subsequent shallow lagoon which needs dredging. Piers, unless properly constructed lead to similar consequences as breakwaters as has been exemplified at La Digue Island.

7.8 "IMPROVEMENT" OF BEACHES

Prime quality tourist beaches (characterized by parameters such as fine sand, sheltered coves, good bathing, no coral or marine debris, sandy sea bottoms and safety) are not common in Seychelles according to published reports, and in fact total only 5.6 Kilometres on Mahe, 3.5 Kilometres on Praslin and 17 Kilometres on La Digue. There is therefore a tendency for some hotels to attempt to "improve" the beaches. One hotel built a massive breakwater to create a beach and artificial lagoon (see above), another cleared live coral in front of the hotel and recently one on Praslin excavated tonnes of beach rock or sandstone.

7.9 LAND RECLAMATION

Land reclamation projects on the East coast of Mahe near Victoria by dredging reef and calcareous materials started in the 1970's and have been completed in 1991/1992. The reclamation has led to siltation of reefs and destruction of live coral cover according to scientific surveys. Siltation of nearby reefs may be due to land run-off as much as from dredging. In the final phase of the reclamation, silt screens and filter cloth were used to mitigate siltation, and filter cloth liner covered by rock armoring at the base of the fill area was utilized to trap suspended solids.

7.10 UPHILL EROSION AND DOWNSTREAM EFFECTS

Uphill soil erosion resulting primarily from deforestation has been documented as far back as the last century. Run-off of Red Earth or laterite soils from cuts in the hillside is common during heavy rains and is a threat to reef systems. The advent of heavy earth- moving machinery and implementation of large projects has probably exacerbated the problem. In 1992 and 1993 road construction on hillsides adjoining major touristic beaches resulted in large amounts of earth being washed onto the beaches and in the sea.

The importance of human interference on coastal erosion is illustrated by the results of a survey conducted at the end of 1987 in Mahe, Praslin, La Digue and Curieuse islands: Out of 40 coastal sites visited, the survey identified 11 sites where erosion was mainly due to natural causes, i.e. topography and marine hydrology factors while in 29 others, accidental erosion was mainly attributed to human activities and ill-conceived development.

8. CURRENT ISSURS AND TOPICS IN SHORELINE CHANGE

8.1 BEACH SAND AS A RENEWABLE AND INEXHAUSTIBLE RESOURCE

Sand from Seychelles beaches may be a renewable but is certainly not an inexhaustible resource. The Seychellois beach-system probably developed during the last 10,000 to 30,000 years from the action of waves, storms, calcareous algae and marine fauna such as parrot fish. The modern-day configuration and parameters took shape during the last 5000 to 6000 years. The replenishment rate is extremely slow. Sand abstraction above the replenishment rate will inevitably lead to erosion, recession and obliteration of the beaches. This is unfortunately happening in Seychelles. many beaches are eroding and receding, some beaches have already disappeared

8.2 CAN SAND BE REMOVED FROM THE DUNES AND THE "DRY BEACH" WITHOUT ADVERSE EFFECTS TO THE BEACH ?

The dune lands and the "dry beach" form storm-water barriers and natural sand storage reservoirs for natural beach repair. Removal of sand from this area will deplete the beach of repair material and lead to erosion & recession of the beaches.

8.3 CAN SAND BE QUARRIED FROM ISOLATED BEACHES WITHOUT ANY ADVERSE EFFECTS ?

All the island beaches form part of a total beach system "connected" by the coastal drift and are therefore interdependent. Sacrificing whole beaches or partially abstracting from other beaches create "holes" in the total beach system. Other beaches will start eroding and the total sand-mass including duneland and submersed storage will diminish leading to general erosion & recession of other beaches.

8.4 MINING OR DREDGING OF SAND FROM SAND BANKS, BARS AND RIDGES IN THE NEAR-SHORE ZONE

The sand banks, bars and ridges are formed from beach erosion during storms and are storage reservoirs for natural repair of the beaches. This is <u>not</u> surplus sand and it should be left alone. However sand may be mined or dredged from deposits in the ocean far enough away from the beaches and from major ecosystems, so as to not to disturb the total beach system.

8.5 CONTINUING REMOVAL OF SAND FROM THE COASTAL TERRACES

The terraces or plateau as mentioned before took about 6000 years to be formed. At the present rate of abstraction, most of the available plateau sand on the main island might be exhausted within 25 years.

8.6 CLEARING OF BLOCKED RIVER MOUTHS AND ABSTRACTION OF SAND

Clearing of blocked river mouths is necessary in order to ensure a steady drainage to the sea from the lower lying coastal plateau and marshes. This operation is normally performed by building contractors, concrete block makers etc., who are supposed to clear the river mouth itself of the blocking sand barrier and also clear the culverts under the coastal road. The contractors are allowed to abstract and take away cleared sand. Unfortunately this operation contributes to the overall depletion of sand on the beaches. If permanent sea-outfalls were installed through the sand barriers, very little contractor-assisted clearing would be required, and much of the drainage problems on the coastal plateau would be solved as well.

9. ATTEMPTED CONTROL MEASURES

9.1 CONSTRUCTION OF GROYNES SO AS TO BRING BACK THE SAND AND RESTORE THE BEACH.

Construction of groynes is a controversial matter. They are very costly and can do more harm than good. Groynes cannot re-create sand which has been lost through sand abstractions. In fact as has been noted earlier, groynes can deprive down drift beaches of their normal supply of sand. In Seychelles especially where the two biannually monsoon winds blow from diametrically opposite directions, the construction of groynes is a very tricky affair.

9.2 CONTINUING CONSTRUCTION OF SEA WALLS TO PROTECT THE SHORE AND SAFEGUARD INFRASTRUCTURE

Sea Walls constructed on eroded beaches will initially protect the shore behind the seawalls, but in the long run sea walls and bulkheads have an adverse effect on the beaches themselves as mentioned previously.

9.3 FENCING OF THE FORESHORE

The Division of Tourism has fenced certain areas on the foreshore where beach erosion has become pronounced due to human and vehicular traffic. The fencing is with wooden bollards or stakes. In areas where this has been done successful regeneration of beach vegetation has been achieved

10. CASE STUDIES OF SHORELINE CHANGE AND ATTEMPTED CONTROL MEASURES

10.1 ANSE KERLAN/AMITIE-PRASLIN ISLAND.

The beaches of Anse Kerlans and adjoining Amitie on Praslin Island are probably the most spectacular example of shoreline recession in the granitic islands. The area has a narrow reef barrier which offers little protection. This reef seems to be under stress from anthropogenic causes, and this should be investigated more thoroughly (Shah pers obs.). The proximate cause of the beach receding is due to a combination of wave action and longshore drift. Simultaneously the southerly beach of Grand Anse have been enlarging due to accretion. This process is reputed to have taken place during the last 15 to 25 years. Apparently, a delicate balance previously existed between the two biannual littoral drifts: one in a general north-westerly direction during the South East Trade Winds and the other in a general south-easterly direction during the North west Monsoon. This balance has now become upset with the result that there is a net littoral drift in a south-easterly direction away from Anse Kerlans without a sufficient return of beach material. The reasons for this are not clear, but it is thought that both natural and man-made causes play their part. It is the opinion of a professional coastal engineer that unwise development has disturbed the balance; developments on the beach and sand dunes include reclamations, houses, seawalls, roads, solid landing piers (Tilly, pers. com). As mentioned before, coral reef damage is also a factor that should be taken into consideration. There has been no attempt to monitor the beach profiles or the reef and therefore no quantitative data is available. Erosion is so severe that the coastal road has had to be diverted

During the years, it has been attempted to protect the shoreline by construction of seawalls. The seawalls have accelerated the erosion and the scouring of the sand due to increased wave reflection has led to destruction of the seawalls. Rip-rap armoring of the backshore has also been attempted. Five groynes of granite blocks were constructed in December 1990 to provide protection to the shrinking coastline of Anse Kerlans. It is clear from these that littoral drift traps sand during the North west monsoon and deprives down stream beaches such as Anse Korbiso (where there has been complaints of erosion) of its seasonal replenishment. During the South East monsoon the action may reverse itself but at the expense of the adjacent Northern beaches. Erosion is still continuing at Anse Kerlans although the beach between the groynes has stabilized.

10.2 LA PASSE-LA DIGUE ISLAND

Erosion has become pronounced at La Passe where the port and landing pier of La Digue is located. The present day beach, to the South of the granite headland of Cap Barbu, comprises of carbonate and quartz sand mixed with coarser fragmented biogenic carbonate material from nearby dredging operations. This is banked against an erosional scar up to 1 meter high in the older beach sands. The shore faces west-north-west. In 1991 a Fish Collection Center located on the backshore beach and the flattened dunelands in front of the yacht and schooner basin, was being endangered by shoreline erosion. The sea had undermined the land beneath the Center and nearby coconut trees had been uprooted.

Investigations showed that the "original" coastline had already receded by approximately 4.5 metres prior to the construction of the Fish Collection Center in early 1986. This was presumed to have been a result of previous dredging operations in the yacht basin and destruction of protective reef platform and coral Following more dredging operations in May 1990, further erosion of the beach speeded up with a recession of approximately 5 metres. This left only 4 to 6 metres of flattened duneland behind the Fish Collection Center

The short term cause was identified by local experts as an open trench for a high tension electric cable dug between the shoreline and the Fish Collection Center which had not been backfilled and served as a conduit for backwash at high tide. However, the main problem is thought to be the existing pier which is a solid structure, except for two narrow culverts, acting as a groyne and trapping longshore drift sand. The yacht basin therefore needs periodic dredging which is part of the cause of the beach erosion and shoreline recession (Tilly, pers.com.). Arthurton, who visited the area on April 8, 1992, believes the recession may be due to a net southward or south-westward drift caused by relative enhancement of the North-East monsoon over the last 20 years or so (Arthurton 1992).

Detailed recommendations by the senior engineer of the Ministry of Community Development and experts from the Division of Environment have been provided for remedial action.. Nevertheless, a sea wall has been constructed to protect the Fish Collection Center, contrary to the expert advice.

10.3 BIRD ISLAND

In 1993 public attention was drawn to Bird Island, a coral island that lies on the Northern rim of the Seychelles Bank, as tourist chalets were undermined and destroyed by the encroaching sea. Bird is a flat sand cay with a height of 3.5 metres above sea level. The island has an area of only 0.56 sq. kilometres. It rises from a shoal depth of about 55 metres. The island is located to the windward edge of the shoal facing the South-Eastern trade winds. From east to south the island is framed by a narrow reef flat. There is no reef in the western side of the island facing the trade winds. The island is mostly composed of loose calcareous sand, although the interior previously was more solid being phosphate rock (all removed during guano mining operations). The island is a popular tourist resort and supports one of the largest colonies of Sooty Terns (Sterna fuscata) a species of sea-bird, in the world. At present there is severe erosion of the southern-western shore. Since there is no reef barrier protection in the western side, sand is being eroded from the west coast, where the tourist complex is located. The island cannot expand to the east because of its proximity to the edge of the bank and washing of material into the drop-off. There is a strong possibility, therefore, that the island may disappear altogether, especially if there is a slight rise in sea level.

11. RECOMMENDATIONS THAT WOULD LEAD TO A NATIONAL POLICY ON COASTAL EROSION

Coastal protection measures for Seychelles can meet the following objectives:

- To protect coastal property and infrastructure from distruction or inundation by the sea
- To retain a usable beach for aesthetic or recreational purpose.

Unfortunately, it is generally difficult to meet both objectives at the same time, since they frequently conflict with each other. As explained previously, in the natural process a beach is normally recharged by transfer of sand from the duneland. On the other hand, the methods commonly used to safeguard coastal property, like seawalls, directly contribute to the loss of the beach. This is why the methods traditionally used in the past to stabilize the coastal system with the use of artificial structures are today questioned by most coastal engineers and planners. Learning from the failure of several ill-conceived projects, engineers now endeavor to formulate geomorphologically compatible measures and to make the maximum use of a variety of natural defenses. This is usually achievable on the less developed coastline stretches.

Where coastal development has gone so far as to prevent the coastline from reaching its natural equilibrium, the natural choice for the decision makers would probably be to sacrifice either the beach, or some valuable property or land. Neither of these are sustainable choices. In this context, it appears that a suitable coastal protection policy for the Seychelles should meet the following guide-lines :

11.1 RESTRICTION ON SAND ABSTRACTIONS

All possible means should be investigated to reduce the consumption of sand by the construction industry, and to prevent any sand abstraction from beaches, duneland and coastal plateau areas. Abstraction of sand and gravel is regulated by the "Removal of Sand and Gravel" Act, 1982. A stricter enforcement of this act appears necessary to prevent illicit removal of beach and dune sand, which still exist. Achieving a stricter control would require the following measures:

- To reinforce the means of the Environment Division to identify offenders.
- To involve more closely the police forces for the day to day control of abstraction or transportation activities.
- To involve the District Councils in the enforcement and reporting of illegal abstraction.
- To impose on authorized license holders for sand abstraction the precise recording of all sales and their periodic notification to the Controller of Sand and Gravel. This would enable the establishment of precise statistics on consumption, and facilitate cross-checks on the work sites to control the licit origin of sand used by contractors.

  Besides the necessary strengthening of the legal control, the only permanent solution to prevent sand abstractions lies in a reduction of the demand, by way of adaptation of the construction technology. In that respect, two measures might contribute to signicantly reduce the consumption of sand by the construction industry.
- Production of granite crusher dust :

  The United Concrete Products company (UCPS) has put into operation a new crusher producing fine granite crush, which can substitute for natural sand in the manufacturing of concrete blocks and ordinary masonry.

  Adequate measures, such as education, incentices and disincentives should be envisaged to encourage the use of this substitute material by the building contractors. In particular, the amount of royalties charged on the abstraction of natural sand must be raised, in order to create a disincentive for its utilization. Such a measure would of course create additional grounds for reinforcing Government's control on illicit abstrations.
- Use of non-traditional materials for construction

  The use of prefabricated buildings and of non traditional materials such as gypsum boards for internal walls must be encouraged, since fine coral sand is still apparently indispensable for the final plastering of block work.

11.2 PRESERVATION OF CORAL REEFS

Amongst the various natural defenses which contribute to the protection of the coast, natural coral reef barriers are the most effective in dissipating wave energy and limiting their eroding effects. Existing reef systems which include marine grass and algal beds as well as corals should therefore be protected from all possible causes of deterioration such as pollution, excessive dredging, siltation etc.

11.3 MANAGEMENT OF COASTAL AREA DEVELOPMENT

Enforcing a strict control of development on coastal areas is a key element of any coastal protection policy and for sustainable development. In the short term, such control is a precondition for safeguarding and restoring coastal natural defenses such as vegetation-covered dunelands. It is also a precondition to preventing the erection on the shoreline of hard structures which would disrupt the shoreline equilibrium and lead to accelerated erosion. In the long term, it is the only way to limit the economic losses which would be incurred by a rise of the sea level. In the context of such a threat, the wiser long term planning strategy would be to locate buildings and infrastructure on stable sites landward of active coastlines, and to maintain wherever possible a coastal buffer zone free of costly development.

Two practical measures can be proposed in order to improve the control of coastal development:

- <u>Amendment of the Town and Country Planning Act</u>

  Section 7(2)(b) of the Town and Coutry Planning Act stipulates that a planning permission is not required for "the carrying out by a hightway authority of any works required for the maintenance or improvement of a road". As a consequence, the upgrading of a coastral earthen track into a surfaced road is not usually subject to planning authorization, although such works involving the erection of hard structures along the shoreline may dramatically aggravate coastal erosion processes. As an illustration, the case recently occurred for the upgrading of Anse Kerlan road in Praslin. It is recommended to amend sub-section of the Act.

- Creation of State-owned coastral land reserves or Domaine Public
  In the long run, the most effective way to ensure a strict control on coastral development whilst preserving coastal environments, would be to constitute wherever possible stateowned coastal land reserves. On average, a state-owned coastal belt of 25 to 100 m in width, from the high-water mark, would seem reasonable, though the adequate width for such a reserve depends to a large extent of the coastal topography. Lorries and motor vehicles would be banned from entering this area and of course no development would be allowed.

11.4 CONSERVATION MEASURES ON UNDEVELOPED COASTAL AREAS

The appropriate design of coastal protection measures requires a great deal of research and thought. However, as an interim measure, it is recommended to carry out simple conservative activities aiming at safeguarding existing natural defenses in undeveloped, or little-developed coastal areas. Such activities would mainly consist in dune restoration and revegetation, protection of undermined coastal trees, relocation of access tracks, etc..

11.5 PROPER DESIGN OF COASTAL PROTECTION STRUCTURES

Wherever the necessity to safeguard important coastal development does not leave any other option than building coastal protection structures such as sea-walls, bulk-heads etc., it is essential to minimize as far as possible their negative impact. To that end, the determination of the appropriate location and design of such structures call for comprehensive preliminary investigations in order to ascertain the hydraulic and geomorphologic parameters of the coastal system.

11.6 EDUCATION AND INFORMATION

Legislation, government policy and good intentions do not guarantee that the shoreline will be protected or utilized sustainably. Education and public information is vital for all the actors concerned to comprehend the issues and factors involved in coastal erosion and shoreline change. A television program on this complex subject was produced locally in 1989 and broadcasted several times. A cartoon on the subject has also been made locally. However, consistent and factual information and education programs have not been attempted. The Division of Environment has had an Education and Information Unit since 1991 and it is hoped that this unit will become more active in this field.

12. MANAGEMENT PLANS AND RESEARCH PROJECTS

12.1 ENVIRONMENTAL MANAGEMENT PLAN AND OTHER REGIONAL PROJECTS

The Environmental Management Plan of Seychelles (EMPS) calls for CZM plans and studies and one study on sea level rise. They are the following:

A.5 Impact Assessment of Climate Warming and Sea-Level Rise
I.1 Coastal and Marine Environment Baseline Study
I.2 Beach Erosion Control
I.3 Alternatives to reduce sand in construction
I.4 Review of Coastal Zone Management Plans

With the exception of Project 1.3, none of these projects have been implemented. Projects I.1 and I.4 will be implemented shortly as part of a regional plan with financing from the EC under the auspices of the Indian Ocean Commission (COI). A national coordinator for the project has already been recruited.

A major regional project namely EAF5, Coastal Zone Management Planning in the East African Region, under the auspices of FAO/IOC/UNEP has been recently implemented. The project for Seychelles will use the Beau Vallon area as a test case study. This area was agreed upon between FAO/IOC/UNEP and the Division of Environment as a "hot spot" of coastal change.

It is vital that a CZM Plan is formulated, implemented and **followed** very soon. In addition, education and training programs are an essential part of the process. Anthropogenic and man-made effects on shoreline change are mainly due to ignorance and lack of understanding even by high level policy makers. Very importantly, continuous and long term monitoring of erosion and of the marine environment needs to be undertaken to provide time series data to base management decisions on.

12.2 SEA LEVEL MONITORING

A sea level bench mark was established in the early sixties. Currently the prediction times and heights of high and low water for each day is prepared by the British Institute of Oceanographic Sciences. A tide gauge has been in operation in Victoria since the fifties. The predictions for Victoria is computed from data collected in the early sixties and astronomical parameters. At present, the Hydrographic Brigade of the Seychelles Coastguard, is responsible for collecting sea-level data and maintenance of the tide gauge. Analysis of the data is being undertaken at the University of Hawaii for the TOGA Program. An automatic tide gauge which transmits real-time data to Hawaii has been installed in February of 1993.

12.3 COLLECTION OF OCEANOGRAPHIC DATA

Since 1986, the French research and development agency ORSTOM has initiated computerized oceanographic data bases for the Indian Ocean. The oceanic measurements collected by different institutions from the beginning of the century have been gathered, validated and compiled into different formats. The four databases available are :

- Oceanographic Cruises Measurements
    - Vertical Profiles of sea temperature
    - Sea surface conditions
    - Remote sensing satellite measurements

Although the databases were established for fisheries research and management, the applications are endless and can be used in monitoring environment and shoreline change.

13. RELEVANT LEGISLATION

There is no single piece of legislation which covers the management of the coastal zone. or coastal erosion. Various laws pertain to this area. A sound policy has evolved whereby considerable control is exercised in all aspects of development. Planning permission is required for all forms of development under the Town and Country Planning Ordinance (cap. 160) and the Town and Country Planning Authority regulates land utilization.

The Land Reclamation Ordinance (chap. 152) and the Removal of Sand and Gravel Act (13 of 1982) requires licenses to be obtained before any operations can be commenced.

Eleven areas have been set aside for nature conservancy under the National Parks and Nature Conservancy Ordinance (chap. 1590 and public access has been limited in 24 areas under the Protected Areas Act (chap. 40). Other environmentally sensitive areas have traditionally been protected under the Crown Land and River Reserves Ordinance (chap. 150) and the Forest Reserves Ordinance (chap. 153).

The protection, management and control of coastal trees is regulated by the Breadfruit and Other Trees (Protection) Ordinance (chap. 122).

The Beach Control Regulations (SI 77 of 1978) provides some protection for beaches. Damage caused within the tourism sector can be probably managed under the Licenses (Accommodation, Catering and Entertainment Establishment) Regulations (SI 16 of 1987).

Maritime activities are regulated by the Harbour Ordinance, (chap. 210) and the Marine Pollution

Regulations (SI 51 of 1981) which gives power to the Harbour Master to control discharges from ships.

The Fisheries Act concerns not only fish but also covers the management of marine mollusc reserves and the use of explosives on coral reefs and opening of navigational channels in reefs for fishermen.

14. MANAGEMENT AND CONTROL

There is no overall authority for management of the coastal zone or coastal erosion. The Ministry of Community Development is in charge of land surveying and controls land and infrastructure development. Development of any land must go through a planning process as mentioned above. The Division of Environment (formerly Department of Environment) of the Ministry of Environment, Economic Planning and External Relations manages some National Parks, one Reserve and all the forests. With the recent transfer of authority of the Seychelles National Environment Commission (SNEC) to the Director of Conservation and National Parks, the Division of Environment is now the executive authority governing all protected conservation areas in Seychelles.

The Department of Tourism and Transport is responsible for tourism development, land and sea transport, and cleaning of beaches outside National Parks. The ports and Marine Services Division of this Department is responsible for marine pollution and the Oil Spill Contingency Plan. The Meteorology Division of the same Department is responsible for monitoring climate change. The new District Councils are expected to make by-laws which may have a positive impact on the management of shoreline change. The Seychelles Fishing Authority is the central authority for all fisheries matters including coastal and marine acquaculture as well as collection of oceanographic data. The Island Development Corporation manages development on virtually all the outer islands.

As in most countries, there is a confusion of roles and disputes occur. In addition, gray-areas such as coral reefs and fresh water marshes present even day to day management problems. A huge constraint is the lack of technical personnel. Research, policy-making, management and administration are severely hampered by this deficit in trained manpower. Mobilization of funds is another problem, in a small island state such as the Seychelles with a diminutive economy.

ANNEX I
List of Key National Experts (by Sector)

Environment
* Waldemar Tilly, Division of Environment, Ministry of Environment, External Relations and Planning (Expertise: Coastal engineering; coastal planning; erosion control; environmental assessment)

Jean-Claude Michel, Division of Environment, Ministry of Environment, External Relations and Planning (Expertise: Town and Country Planning; National Parks and Protected Areas)

Willy Andre, Division of Environment, Ministry of Environment, External Relations and Planning (Expertise: Forestry; erosion control; marsh and estuary management)

Fisheries
Edwin Grandcourt, Research Section, Seychelles Fishing Authority. (Expertise: Fisheries research)

Hydrography
Michel Rosette, Hydrographique Brigade, Seychelles Coastguards. (Expertise: Hydrography)

Lands and Planning
Gerald Pragassen, Lands Section, Ministry of Community Development.(Expertise: Land and Surveys)

Belinda Micock, Planning Section, Ministry of Community Development(Expertise: Town and Country planning)

Meteorology
Luc Chang-Ko, Meteorology Section, Ministry of Tourism and Transport.(Expertise: Meteorology)

Marc Desnouesse, Meteorology Section, Ministry of Tourism and Transport. (Expertise: Meteorology, GLOSS Engineer)

Non Governmental Organization (NGO)
Nirmal Jivan Shah, Environment.Resources.Oceans (ENVI.R.O) (Expertise: Coastal Zone Management; coastal and marine ecosystems; conservation and protected areas)

Tourism
Lindsay Chong Seng, Tourism Division, Ministry of Tourism and Transport.(Expertise: Beach control and maintenance; conservation; natural history; botany)

(All experts listed are Seychellois Nationals only, except for * who is a long time resident and the country's foremost authority on the subject of coastal engineering and erosion control measures)

ANNEX II
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VI. NATIONAL REPORT ON THE STATUS OF COASTAL EROSION, SEA-LEVEL CHANGES AND THEIR IMPACTS, TANZANIAN CASE

by Y.W. Shaghude, M.K.D. Mutakyahwa , and Ms. Shufaa K.Mohamed

ABSTRACT

The coastline development had been influenced naturally and artificially. The shoreline had been constantly retreating since Jurassic time until Upper Tertiary times. Between Pleistocene and today it has been encroaching the continent. The reasons for that are attributed to sea level rise. However, coastal erosion in general has been observed to occur at different areas with varying intensity due to the fact that the causative factors themselves vary along the coast. Mtwara, Mikindani, Kilwa, Dar es Salaam, Tanga and Zanzibar regions are cited examples of the most affected areas. The geometry of the coastline has been very much modified by wave actions which are controlled by bathymetry, to result into convergence or divergence waves which create bays and headlands respectively. Field observations have indicated that there are natural and anthropogenic factors which influence significantly the coastal erosion. Natural factors include geological (unconsolidated to semi consolidated sediments disturbed by tectonic movements), sea level rise, storm and wave actions. Anthropogenic activities include dynamite fishing, construction along the beach premises, sand and heavy mineral mining, mangrove cutting, coral limestone and beach rock blasting. It is suggested that legislative laws be closely followed, coordination between ministries, mass education on the question of coastal erosion and planting mangrove trees where they do not occur naturally be insisted.

1. INTRODUCTION

Coastline changes or sea level fluctuations relative to the land is an ageless phenomena. The variationss can be worldwide or localised. It can also be a long lasting natural, geomorphic process or short term anthropogenic (man made) process. Long lasting geomorphic processes include isostatic adjustments, a process involving vertical movements of the land in response to an overlying load such as ice or sediments. Eustatic adjustments involve worldwide movements of sea level resulting from either the changes in the total volume of sea water, or the total volume of ocean basins. Usually the total volume of sea water decreases during glacial epochs. It is also believed that the total volume of ocean basins is affected by the rate of sea floor spreading. Fast rates of sea floor spreading increases the volume of the mid ocean ridges and hence reduce the total volume of ocean basins, the result is a high sea level. The opposite would be true for slow rate of sea floor spreading. Epeirogenic movements involve broad gentle up warping or down warping of relatively large crustal areas which may sometimes be associated with faulting.

Coastline changes may also result from local human actions, which tend to interfere with natural sedimentation processes or other processes which take at the interface between the ocean and land. Examples of such activities include, removal of coastal natural vegetation such as mangroves, destruction of offshore barriers such as coral reefs, offshore dredging, sand and gravel mining along streams which drain the beaches etc.

The present report discusses the status of coastline changes in Tanzania. In particular, attention has been made to review the current problem of coastal erosion in Tanzania (mainland as well as Zanzibar island).

Fieldwork done from the southern to the northern part of the territory include Mtwara, Lindi, Kilwa, Dar es Salaam, Tanga and Zanzibar regions. This has been done to assess the extent of erosion at the affected sites. It can be generalized that there has been excessive erosion accentuated by sea level changes. These processes are supported by the disappearance of ancient towns, modern buildings and infrastructures.

In order to acquaint the reader with the Tanzania coastal zone, attempt has been made to give a general view of the coastal environment of Tanzania. This is then followed by a discussion on the main theme of the subject by citing specific examples of coastal segments where coastline changes have been documented. Our recommendations on what could be done to improve our future understandings of the critical coastal segments which are being adversely affected by coastline changes are also suggested.

2. THE COASTAL ENVIRONMENT OF TANZANIA

2.1 TECTONIC SETTINGS

The history of coastal geology of Tanzania can be traced back to Jurassic times. It is believed that, sometime during Jurassic, splitting between the continents of the eastern Gondwanaland (Australia, India, Madagascar and Antarctica) and western Gondwanaland (South America and Africa) took place along a transform fault parallel to the eastern coast of Africa (Le Pichon and Heitzler, 1968) and by Albian, that is about 100 m.y. ago the opening between the eastern Gondwanaland and western Gondwanaland was complete (King, 1962).

Following the opening of the Indian Ocean, full marine coastal environments developed along the eastern coast of Tanzania. The sedimentary column along the coast contain series of transgressive and regressive events which indicated that the shoreline had been moving relative to the present shoreline (Fig. 1).

Fault movements have at large controlled the coastal development. The topographic break between the interior and the coastal plain is a geologic boundary marked by the sedimentary rocks of the coastal area and metamorphic crystalline rocks of the interior plateau (Alexander, 1969; Kent, 1971). Faulting and warping are also responsible for the formation of the three islands Pemba, Zanzibar and Mafia in the late Eocene (Kent, 1971) and for the formation of the coastal marine terraces discussed by Alexander (1968, 1969).

2.2 GEOLOGIC AND GEOGRAPHIC SETTINGS

The coastal belt of Tanzania consist of a narrow belt along the mainland coast as well as all the three islands Pemba, Zanzibar and Mafia (Fig. 2). In the mainland as has been mentioned in section 2.2 the distinction between the coastal belt and the interior plateau is based on rock formations. The coastal plateau is characterised by thick sedimentary rocks, varying in width between 17km at the Kenya boarder and 150km in the vicinity of Dar es Salaam. The sediments which vary in age from Jurassic through Cretaceous to Tertiary and Quaternary are composed of both marine and terrestrial sediments (Kapilima, 1984; Kent, 1971). The sediments are generally getting younger towards the east, and also dipping eastwards.

The inland plateau on the other hand is characterised by metamorphic crystalline rocks of the Mozambique belt, believed to have been formed during Pan African Episode, about 550+100 m.y. ago (Windley, 1977). The contact between the crystalline Precambrian basement and the coastal sedimentary belt is sharp, and it is recognised as Tanga fault.

The three islands Pemba, Zanzibar and Mafia resemble in many ways; they are all approximately 40 km from the mainland, all aligned roughly in a north south trend, all composed of rocks ranging in age from Miocene to Recent calcareous sediment with some marine clays, sandstones and coralline limestones, all are believed to be tilted and raised basement blocks whose size is comparable to other African fault blocks (Kent et al, 1971). The islands of Zanzibar and Pemba can be separated into three land forms:-

(i) The channel country in Zanzibar and on the east coast of Pemba.
(ii) The undulating and elevated to precipitous and Brocken Miocene rock.
(iii) The flat coastal periphery or 'coral rag'country developed mainly in Zanzibar.

It is believed that the presence of these islands has influenced the structure of the continental margin. Along the East African coast, the continental shelf is generally narrow except off Tanzania where it widens to include the three islands. The continental slope is 150Km east of Zanzibar.

2.3 CLIMATIC SETTINGS

The entire coastal belt of Tanzania experience a tropical climate which is influenced by the monsoon wind system. The NE monsoons are often recognised during December to March, bringing short rains while the SE monsoons are recognised during June to September, bringing the long rains. The rains trigger the landslides in gullies which are followed by severe erosion. Associated with the winds are the ocean currents. The SE trade winds which blow with greater strength and constancy of direction is responsible for the northward moving long-shore current. It can obtain a velocity of 4 knots. The NE trade winds on the other hand is weaker and only impedes the northward moving long-shore current but never reverses it.

2.4 OTHER NATURAL SETTINGS

The coast of Tanzania is characterised by mangrove forests, fringing coral reefs, sweeping sand beaches and rock outcrops (Kamukala, 1984). In the mainland mangroves are very common especially at the mouths of both large rivers like Rufiji and other seasonal streams (fig. 3). Their total coverage along the mainland coast is estimated to 79,937 hectares. Mangroves are also well represented along the coast of Zanzibar and Pemba (Fig.3), occupying a total area of 4,700 and 12,000 hectares respectively. Fringing coral reefs, sand beaches and rock outcrops occur elsewhere along the shore. Unlike the mangrove forests which are well established at the mouths of rivers and other seasonal streams, fringing coral reefs are completely absent at the river mouths and other seasonal streams. This is due to the fact that high siltation takes place at these areas and hinder their growth.

3. THE PRESENT STATUS OF COASTLINE CHANGES IN TANZANIA

3.1 PREVIOUS STUDIES

The earliest studies on the present status of coastline changes in Tanzania were conducted in 1960´s (Alexander, 1966,1969). Both Alexander (1966) and Alexander (1969) noted that shore erosion had been active along the Tanzania mainland from Tanga to Dar es salaam. On the basis of under rooted coconut trees, Alexander (1966) concluded that the present shore erosion along Tanzania mainland had been active at least before early 1940´s.

Alexander (1966, 1969) further observed that although erosion along the shore was discontinuous, it was still evident that the over all rate of erosion was increasing southward. Supporting this conclusion were three pieces of evidence:

(i) The shore zone mangrove stands indicated signs of increasing destruction south of Pangani than north of it
(ii) The incidence of under rooting of coconut trees (which are generally common all along the shore) through shore erosion was much greater in the south than in the north
(iii) Exposure of beach rocks through marine erosion was relatively common in the south than in the north.

Alexander (1966, 1969) attributed the southward intensification of shore erosion to non- uniform rate of coastal uplift. He believed that the rate of coastal uplift was relatively higher in the north than in the south. After the work of Alexander (1966, 1969) many other workers documented the problem of coastal erosion along different parts of the mainland coastline. Worth noting are the studies conducted at Maziwi island and Dar es salaam area. These studies are the subject of the foregoing sections.

3.2 MAZIWI ISLAND OFF PANGANI (TANGA)

Fay (1992) discusses the history of Maziwi island (Fig.4). The island used to be located approximately 50 km south of Tanga town and about 8 km southeast of themouth of Pangani river. According to Stuhmann (1894), the original shape of the island was roughly circular with a diameter of about 500-600 m, corresponding to a terrestrial surface of 20-80 hectares. Fishermen interviewed by Fay (1992) reported that it took about 45 minutes to walk once around the island during colonial times. The island was originally famous for being the most important single nesting ground in East Africa for three endangered marine turtles (Olive ridley turtle, green turtle and hawksbill turtle), but has recently disappeared.

Fay (1992) noted that this island was essentially composed of a shallow coral reef flat, reaching the sea level only during neap tides. On the western margin of the reef platform there is a sand spit composed of carbonate particles. He believes that the carbonate particles were derived from the coral reef flat and deposited in a manner analogous to a submarine fan.

Fishermen interviewed by Fay (1992) reported that between 1920´sand 1950´s there was no significant loss of the beaches belonging to Maziwi island, but the most significant loss of beaches is a recent phenomena which was first observed during 1960´s as evidenced by uprooting of casuarina trees. Fay (1992) reports that some zoologists eg. Shedd (1974) noted that by 1970´s the life of turtles was already under threat. The zoologists used to salvage the situation by transferring eggs of turtles that were laid below the beach crest to a safer place, further inland.

According to Fay (1992), the last casuarina tree is believed to have fallen by 1977 and by 1978 the entire island was already submerged. Fay (1992) also discusses the possible causes of the disappearance of the island. He believes that direct interference of human with the ecosystem of Maziwi island can be ruled out as the main causal factor. Fay (1992) also rules out the possibility of the island disappearing due to subsidence caused by crustal movements. Using the earthquake data between 1971-1986 he observed that all of the earthquake epicentres were much too distant from Pangani (> 100 km) to cause any appreciable crustal movement. Also he argued that the movement along the NNE trending Tanga fault which resulted into the formation of the Pemba channel is of middle Jurassic age and there is no indication of any reactivation of this fault during the Holocene. Also noting that the general trend of crustal movements along the East African coast since the Pleistocene has been positive as evidenced by raised Pleistocene coral reef terraces which occur almost every where in the coastal belt from Mozambique to Somalia, he concluded that the disappearance of the island cannot be attributed to tectonic causes.

Fay (1992) also ruled out the possibility of disappearance of the island by erosion due to extraordinary heavy storm events. Interviewing four local fishermen, he was informed that the wind, current or wave regime around Pangani have not changed, since they started fishing (1924, 1926, 1948, 1955). All fishermen reported that erosion of Maziwi island beaches was most intensive during SE monsoon and this situation came to be repeated more or less regularly on annual basis. On the other hand majority of the fishermen believed that the sea level today is higher than in former times and estimated a rise of 1 to 1.5 ft (30-45cm) since 1920´s. Fay (1992) believes sea level rise to be the main cause for the disappearance of Maziwi island. He argued that although the rise of 1 to 1.5 ft since 1920 seem to be over estimated (since the rise is relatively bigger when compared with the average eustatic rise of global relative sea level of 10 cm during 1920 to 1980), Their estimation still conform with the globally observed trend. Fay (1992) argued that such a rise will inevitably affect the equilibrium of sand supply that may result into sand removal along beaches and will cause sand to be deposited further offshore. This will finally result into retreat of low-lying coastline composed of unconsolidated sediments by horizontal distance, hundreds to a few thousand times the amount of the vertical rise.

3.3 COASTLINE CHANGES ALONG KUNDUCHI BEACH, NORTH OF DAR ES SALAAM

Physical setting

Kunduchi beach is located approximately 18km north of Dar es Salaam harbour. It has the form of a gently protruding headland, treading roughly NW and stretching from Msasani Bay in the south and Ras Kiromoni in the north (Fig. 5). The beach is drained by five major streams, namely, Nyakasangwe, Tegeta, Mbezi, Mlalakuwa and Kijitonyama. The entire stretch of the coastline consist of a beautiful sand beaches, making it a nice recreational area. Because of this, five beach hotels have been built along the coastline. The hotels are: Hotel Africana, Kunduchi beach Hotel, Silversand Hotel, Rungwe Oceanic Hotel and Bahari beach Hotel. Other important buildings found adjacent to this coastline include, a Marine Biology building of the University of Dar es Salaam and Fisheries Institute building. The beaches of the headland are erosional formed in the old beach ridges with the frontal crest only 0.5-1.5m above HHW. The beaches are steep (10-13^0) and end rather abruptly on the bordering sands, almost level tidal flat, which has a mean width of 600m and a maximum width of 1,000m (NEMC, 1985).

Literature review

Outstanding documentation of beach erosion problems along this stretch of coastline appeared during the late 1970's and 1980's. Griffiths (1987) reports that members of the University of Dar es Salaam, being aware of the problem formed an inter-disciplinary committee during 1977 and 1979 with the aim of undertaking appropriate studies in the area (Schiller et al, 1977). Following these studies, several papers were published (eg. Schiller and Bryceson, 1978; Bryceson and Stoemer, 1980; Harvey et al, 1977, Mushala, 1978; Norman, 1985). For a better review of these studies, the reader is referred to Griffiths et al (1987).

It is important to note that, some of the early papers reported erosion rate of up to 50m within a 10-year period (NEMC, 1985). Consequently some panic actions of beach protection measures were taken, mainly to protect the beach Hotels. The actions involved construction of 54 groynes north of Kunduchi-Manyema estuary. These were constructed within two year period from 1983. The groynes were constructed by loosely piled-up coral limestone boulders with an estimated average of 250-500kg, having an average length of 30m and height of 1.5m, a width of the base of 2m and the crest of 1m (NEMC). The spacing between groynes varied from 15 to 35m. Immediately south of Kunduchi-Manyema estuary where Africana Hotel is situated, other types of groynes were constructed. These groynes were composed of sand filled with nylon textile woven tubes, with a diameter of at least 1m and average length of 70m. These were laid parallel to the beach and distributed with an interval of alternatively 60 and 120.

All groynes were inspected on February 1985, and the inspection revealed that most groynes, especially those laid north of Kunduchi-Manyema estuary, were not built up high enough to cover the crest of the beach. They were also too short at the lower end, and the spacing was too close (Norman, 1985). In view of this it became obvious that the groynes could not arrest the beach erosion problem. It was this state of affair that the National Environment Management Council (NEMC), by then, an organ under the Ministry of Lands Housing and Urban Development, decided to form a committee, which thereafter became known as the Beach Erosion Monitoring Committee (BEMC). BEMC was composed of members of different science disciplines, most of them coming from the University of Dar es Salaam. The main objectives of the committee was to establish a comprehensive database from which to monitor the beach erosion problem in the vicinity of Dar es Salaam (ie. Kunduchi beach). Thus, scientific data was collected in the following aspects:

(i) Waves, current, tides and winds.
(ii) Beach profiles.
(iii) Aerial photographs and maps.
(iv) Sedimentology.
(v) Sand extraction along stream beds.

This data will be the subject of the foregoing discussion.

The study of waves, current, tides and wind patterns

This study involved measurement of height and period of waves for the duration of one year, current tracking using drogues, wind measurement using autographic anemometer and tidal recording at Dar es Salaam harbour. An account of this study is given by Lwiza (1987). Lwiza (1987) observed that erosion occur during both SE and NE monsoon seasons, but it was more severe during the latter as the wave energy was higher. He believed that erosion was caused by a combination of high tides and big waves. He was led to this conclusion after observing that daily Mean Sea Level could reach 20cm. Investigations of drogues showed that there was a general tendency of being displaced offshore confirming a hypothesis put forward by Norman (1985) that some sand was going offshore. Lwiza (1987) suggested that the sand is being erode from the beach by offshore drift and then moved and deposited offshore by tidal current.

The study of beach profiles

The study of seasonal variation in beach profiles (configuration) is discussed by Hemed (1987), who took fortnight measurements of beach profiles at seven different localities for a duration of one year. Investigations of the profiles revealed the following:

(i) Large variations in the spot-levels were observable only on the first 40m of most profiles, so that points further than 40m from the beach crest showed little or no variation at all. This suggested that there was nothing to be gained by extending the groynes across the tidal flat as apparently no erosion is taking place there
(ii) The groynes built north of Kunduch-Manyema estuary were totally ineffective in stopping erosion; serving no useful purpose but only spoil the beauty of the beach, suggesting that they should either be removed or rebuilt following proper specifications (fig.6). On the other hand the other type of groynes, south of Kunduchi-Manyema estuary, built at Africana Beach Hotel and their way of alignment seemed effective as there was a net accretion on the profiles
(iii) Msasani beach is least affected by erosion.

Sedimentological study

A sedimentological study was conducted to analyze the ancient back shore sediment between Bahari Beach and Mbezi Beach. The purpose of this study was to affirm the hypothesis that the Holocene sand that is being erode from the shoreline between Ras Kiromoni and Mbezi beach is of marine origin (Fay, 1987). This would indicate that the intensive beach erosion affecting the study area is a recent phenomenon, probably of anthropogenic cause (caused by man).

In order to test the above hypothesis, attempt was made to collect samples by impact drilling along 5 different traverses between Bahari beach and Mbezi beach (Fig. 7). Analyses of the core samples indicated frequent occurrence of charcoal pieces, giving an evidence of sand accretion along this part of the coast during historic times and up to perhaps few decades ago. It was also apparent that the uppermost layers of the youngest beach ridge contained heavy mineral concentrates, indicating a low sand supply at present in contrast to the high sand supply of the former times.

Sand extraction along stream beds and the study of Aerial photographs and maps

From the study of Fay (1987), it was apparent that the amount of sand supply on the present beaches of the study area was significantly low. Also, analysis of Aerial photographs and maps showed that the morphology of beach ridges and sand spits suggested that longshore drift has always been towards the north and has been a long continuing process (Griffiths, 1987). In view of this it was therefore clear that something else must have changed to influence the low sand supply at the beaches.

Griffiths (1987) noted that there has been a drastic change in land use such that natural vegetation has been largely replaced by cultivation, secondary bush or buildings. However, removal of natural vegetation leads to greater surface run-off and increased sediment load in rivers, and if this were the only change, one would expect the supply of sand and silt to the beaches to have increased and not decreased Hence the dramatic change in land use cannot explain the current observed decrease in sand supply on the beaches. Griffiths (1987) observed that there has been a dramatic boom in building constructions in Dar es Salaam since the beginning of the 1980's. The present authors examined aerial photographs between 1970 and 1993 and noted the same thing. It is clearly evident that a such a dramatic boom in building constructions goes hand in hand with a great demand for building materials namely, sand for the manufacture of concrete blocks. In Dar es Salaam, the majority of people who build concrete blocks obtain there sand requirement by buying lorry loads of sands which other people have dug from local stream beds. Griffiths (1987) reports that sand digging from stream beds around Dar es Salaam is a big business which employ many youths, especially ex-standard seven.

Bryceson (1980) put forward the hypothesis that sand extraction in the Tegeta stream with the destabilization of the beach crest in the vicinity of the Heavy Mineral Plant (which used located at Silversand in the Mid 1970's) accelerated the erosion to the north. Griffiths (1987) examined the aerial photographs along the mouth of Tegeta to affirm Bryceson's hypothesis. Examination of the photographs between 1960's and 1980's revealed two contrasting situations (fig.8); the latter photographs showing a progressive evidence of disturbance. A field survey was conducted by Griffiths (1987) to estimate the extent of sand extraction along the four main streams (Tegeta,Mbezi, Mlalakuwa and Kijitonyama) which drain the hinterland of Kunduchi beach. The survey involved among other things:

(i) Walking along each stream bed to estimate its length, width and depth of sand extraction. This information was subsequently used to calculate the annual volume of sand for each stream
(ii) Count the daily number of lorry loads coming from the sand extraction sites of the above streams. The average daily counts was multiplied by 300 to obtain the annual estimate of sand extraction.

It is interesting to note that the annual estimates obtained by both methods were more or less similar (Table 1). Griffiths (1987) found that a minimum of 100,000m^3 of sand was extracted annually from the four disturbed streams that drain the hinterland of Kunduchi beach. She concluded that, if the sand extracted from rivers equalled the deficit on the beach, then 100,000m^3/year would be equivalent to a retreat of 10m to a depth of 1m along a length of 10km of coastline; which is approximately that distance suffering severe erosion between Mbezi beach and Ras Kiromoni.

Table 1: Annual volume of sand extracted along various stream beds draining Kunduchi beach.

Name of stream	segment of stream	Method 1	Estimated vol. of sand (m^3) Method 2
TEGETA	Between the bridge on the old Bagamoyo road and the stream mouth	12,000	13,446
	Between the bridges on the old and new Bagamoyo roads	5,000	-
	Upstream of the bridge of New Bagamoyo to Telegraph line	48,000	65,000
MBEZI	Between bridges on the old and new Bagamoyo roads	37,000	33,615
	Upstream of the bridge of New Bagamoyo road	150	-
MLALAKUWA	Between military camp and University perimeter	32	-
	Within University premises	-	936
	Downstream from the bridge and outside University premises	2,000	
KIJITO- NYAMA		-	5,603

Other important studies

One important conclusion which draws from the studies conducted by the Beach Erosion Monitoring Commettee is the affirmation that the ongoing beach erosion at Kunduchi beach area has by far been accelerated by certain human activities conducted in the hinterland. Bryceson (1978) and Mushala (1978) had earlier observed other human activities conducted offshore which had similar effects on the coastline.

In the offshore zone of the study area there are three islands (fig. 9), namely, Bongoyo, Pangavini and Mbudya. The islands are believed to be uplifted coral reef platforms (Alexander, 1968). These islands are surrounded by vast active coral flats. In addition to these three islands there are two other relatively smaller coral reef platforms, namely Mkadya and fungu Yasin and several more submarine ridges.

Bryceson (1978) and Mushala (1978) reported that the reefs were in great danger of being destroyed by dynamite fishing. Since these natural structures protect the shore from wave attack, Mushala (1978) believed that their destruction would ultimately intensify the coastal erosion.

4. COASTAL EROSION IN ZANZIBAR

Zanzibar consist of main Islands (Unguja and Pemba) with a number of islets doted almost all along their costs. Most of these islets are found on the Western side of the island. The islets, around the islands are of Pleistocene corals. Very beautiful extensive corals can be found around some of these islets and reefs, for example Mnemba, an island North East of Unguja, Misali island South East of Pemba, Nyange reef and Murogo, near Zanzibar town etc. A continuous fringing reef, a high energy reef with a back reef /lagoon system which dries up at low water, runs along the length of the island, from Ras Nungwi to Ras Kizimkazi. This, together with the islets, the mangrove habitats found in areas like, Kisakasaka, Chwaka, Bumbwini and parts of Zanzibar town form natural barriers against the strong waves and current, around Zanzibar.

Zanzibar island is generally flat. Due to lack of positive relief features, there are no rivers. There are only few streams, most of which dry up during the dry season. One can therefore see that hinterland sand resource is very scarce. The current population of Zanzibar, according to the 1988 census is about 640,578 people with 314,864 males and 325,714 female. The average household is 4.6 with an annual growth rate of 2.9% and a fertility rate of 8.24. In the urban areas such as Zanzibar town, Chake, Mkoani and Wete, the growth rate is much higher than the above quoted figures. The same is true for the overall coastal strip. Since the coastal strip is not expanding in response to population growth, one should expect to find intensification of coastal activities and an overall continuous degradation of the coastal environment and significant loss of beaches. This is indeed what has been, and is still happening.

Coastal activities which are believed to create negative impacts on the coastal environment include fishing, beach sand mining, quarrying along coral rag areas and mangrove cuttings. The foregoing sections will elaborate how these activities degrade Zanzibar coast.

4.1 FISHING

As stated above, the island is encircled with a number of islets most of which are made up of corals. The islets therefore offer the coast a natural protection against strong wave actions, which normally erode the beaches. A number of bad fishing practices are occassionally practiced although they are not allowed legally. The bad fishing practices include dynamite fishing, 'Kojani' fishing etc.. Apart from bad fishing practices, careless anchorage of the vessels and pollution outfalls from the urban areas and industries all continuously degrade the coral habitats.

4.2 BEACH SAND MINING AND QUARRYING

The island of Zanzibar is mostly covered with coral rags, with only minor sand patches in the hinterland. Due to lack of sand in the hinterland both the governmental sectors and local people frequenly use beach sand and sometimes coastal limestone quarries for building requirements and road constructions.

4.3 MANGROVE CUTTINGS

Mangrove ecosystem trap sediment and maintain coastal water quality. Mangrove coverage along the coast of Unguja island is estimated to 4,700 hectares. It is of interest to note that the entire mangrove habitat has been declared as reserves. However, cutting for daily local uses such as fuel, building poles etc. is allowed. Cutting for selling is only allowed on selected areas. Not all mangrove users adhere to these regulations. Once in a while it is common to observe destructive cuttings.

4.4 MAGNITUDE OF EROSION

In order to visualise the magnitude of erosion experienced in Zanzibar, two localities, Nungwi and Maruhubi, which are believed to among the worst affected have been taken for elaboration.

Ras Nungwi

Ras Nungwi is at the North tip of Unguja. The area is of coralline and reef lime stone with the exceptional of a small area which is top covered with sand. Due to the poor soil formation, Nungwi is poorly vegetated with coral rag thickets. A number of casuarina trees are found along the beach. A salt lake, with its depth changing according to tidal movement, is at the Eastern side of Ras Nungwi. There are other patches of salted areas with very weak mangrove habitat.

The areal photographs shows an increase in population growth from almost zero 1947 to a highly density area in 1989. Due to lack of mangrove poles, Nungwi houses are normally of stone and masonry. Sand used in the masonry is from the sea shore. Other activities on the sea shore are boat building, which involve general boat building, launching and repair.

The coral cover of Nungwi is poor, 15 to 30% [UNEP, 1989] and those colonies present were encrusting on a scoured Pleistocene coral substrate. The fore reef had been extensively colonised by soft coral species. There is heavy pressure on the area by local villagers who literal swam onto the back reef in search of octopus and mollusc species [UNEP, 1989].

Waves at Nungwi are wind driven, and they are believed to be the main cause of erosion. The areal photographs shows the erosion of the area to be very high, suggesting an average rate of erosion of 3m/year between 1947 and 1977, and 4.5m/year between 1977 and 1989. The increase in the latter is thought to have been caused by the collapse of the sea retaining wall in 1984. This wall was a very weak structure and was build in an attempt to protect the area, but lasted only for one year.

The study made by the Institute of Marine Sciences, stated that, no definite single cause is responsible for erosion; sea level rise, destruction and low growth of corals and sand beach mining are the major contributor to the problem.

Maruhubi

Maruhubi is at the Western side of Zanzibar Island. It is in the vicinity of Zanzibar town. To the North is bounded by Beit el Ras and to the South by the Malindi spit. The area accommodates three seasonal streams and a tidal flat, with a tidal range of 4m. The study was based on the existing knowledge on East African waters, admiralty charts and wind data. With basic interest on the relationship between coastal erosion and long-shore drift, geology and of the coastal rocks, wind generated sea waves and geomorphology of the area. This was done during the months December to March, the most active months with regard to land recession by erosion.

<u>Geology and Geomorphology</u>

The beach is of sands which are in a continuous process of erosion and deposition. Sand is transported from Malindi spit area during S.E monsoon and the another possible source of sediment is the Pepo stream neighbouring the restaurant on the north. Adjqcent to the berm of the beach is a terrain of unconsolidated raised beach sands [Nyandwi, 1986]. These sands are quite unstable against wave erosion.

The important geomorphological features include the coral islands of Zanzibar town and stream indentions. The islands protect the beach from the wind generated waves. At the mouth of the stream a group of mangrove existed. Their disappearance is thought to have been caused by the pollution coming from industries which are discharging their effluent in this stream. The stream mouth, which is of 'V' shaped, is invaded by the tidal current and when the current coincide with strong waves they erode the channel walls.

<u>Beach Erosion</u>

Erosion at Maruhubi is a threat to the Maruhubi restaurant. Due to the high rate of erosion the restaurant management built a wall to protect their property. However, this wall failed to stand the strong waves battering it. Examination of admiralty charts indicates an amount of > 3m a year [Nyandwi, 1986]. Wave battering increase during high tide and N.E monsoon period. The action takes away any available sand in front of the wall as a backwash, and hence no deposition is affective at the site [Nyandwi, 1986]. Underground seeping under the wall increase the problem and weaken the sea wall farther. It was observed that long-shore sediment transport from the north was interfered by the break water, built perpendicular to the beach neighbouring the river, constructed to hold back the waves in order to accommodate the transportation of road construction equipment, during 1979.

The total course can be summarised to have been due to net Northward long-shore sediment transport deposits.

5. SUMMARY, DISCUSSION AND CONCLUSIONS

5.1 OBVIOUS RECOGNITION OF COASTAL EROSION

(i) Dar es Salaam - Ras Kiromoni, Msasani Bay and other areas along the coast like Silver sands, Bahari

Beach, Oysterbay and Kunduchi Beach Hotels are being threatened by erosion.

(ii) Bagamoyo shoreline is as well being threatened by the same effect and so is the Ocean Road a part of Dar es Salaam City.

(iii) At Kilwa Kivinje the wall built by Germans to protect the houses nearby has been broken down by oceanic waves and some of the houses have been eroded.

(iv) At Kilwa Kisiwani some of the ancient buildings and an ancient cemetry have been eroded. The erosion of the ancient cemetry has left some exposed skeletons. The foundations of the Great Tower at Songo Mnara has been affected as well.

(v) The disappearance of ancient towns like Kaole and Maziwi Island and archaeological sites is due to excessive coastal erosion. This leads to the disappearance of important archaelogical information. ODADA, 1993 sees that also the sea level rise is the main cause of erosion in most parts of eastern Africa Coastline.

(vi) Mikindani town a part of Mtwara is constantly being eroded. This results in destruction of ancient houses and productive land. A part of the railway line is currently about 10 m in the sea.

(vii) At Lindi, most of the houses at the beach have been eroded including the present Beach Hotel. The place is being undercut by the oceanic waves.

(viii) In Zanzibar, Maruhubi, Nungwi and Paje are the most affected areas where the rate of beach erosion is estimated to be more than 3m per year.

(ix) Cutting of the mangrove trees for making salt pans along the coastal area.

5.2. REASONS FOR COASTAL EROSION IN TANZANIA

(i) Dynamite fishing - this type of fishing is illegal according to national legislations. It destroys the fishing beds and the coral reefs which protect the coast against the oceanic waves. The coral reefs are barriers and once they are destroyed, wave energy is intensified thus causing major erosion along the coast.

(ii) In some areas like Mtwara and Mikindani quarrying of beach rocks and coral limestone for house construction is common. In Zanzibar coral limestone is mined for lime making.

(iii) Sand mining from the inland rivers and streams limits the amount of sands from reaching the coast; heavy mineral mining from the beach distabilize the beach.

(iv) Construction of buildings and cultivation along the coast. The on going construction of hotels near the beach must discouraged.

(v) Geological influence - Tanzania coastal sedimentary belt is constituted by unconsolidated to semi - consolidated sediments; and hard coral limestone and sandstones. The former are very succeptible to erosion. Landslides followed by gully erosion start along tectonic linearments (faults and streams).

(vi) A natural process which is geological is the rising of the sea level. Its effect can be recognized after a long period. However small change in sea level may induce significant coastal erosion.

(vii) Blasting of hard rocks e.g. limestones at Wazo Hill, Dar es Salaam for industrial purposes create land instability leading to landslides.

(ix) Parking of cars along the beach premises.

5.3 MEASURES TAKEN

(i) Groynes have been constructed using coralline limestone blocks and piping along Silver Sands, Bahari Beach and Rungwe Oceanic Hotels. This is not done for the entire coastal line. It has been pointed out by the Glasgow University - Tanzania expedition 1991, that groynes do not stop erosion but increasingly interfere with sand transportation.

(ii) Concrete sea walls along Ocean Road in Dar es Salaam, near Zanzibar Harbour. The old sea wall built by Germans at Kilwa Kivinje has been broken down by oceanic wave action. Sea walls have to be constructed and maintained regularly.

5.4 NATIONAL LEGISLATION ON COASTAL EROSION

In Tanzania mainland, all mining activities are vested upon the Ministry of Water Energy and Minerals. The legislations which govern the extraction of minerals including heavy minerals, mineral sand and gravel are defined in the mining Act of 1979 and the subsidiary legislation on Mining regulations of 1980. According to these Regulations, all prospectors who wish to extract coastal sand are required to submit formal applications to the City Council and prospecting Licence from the Ministry of Water Energy and Minerals to obtain permission to prospect for sand in a specified area. After getting permission, the applicant is required to peg the Claim by erecting temporary markers at one corner of the Claim indicating its dimension and bearings together with posts or cairns of stones at the remaining corners. The applicant's claim is then entered in the Temporary Register of Mines. After getting permission from the City Council the applicant is required to apply to the Regional Mines office for a prospecting license. The Regional Mines Officer scrutinize the application and if the application is approved the Claim is entered in the Rent Register Claim Ledger. The ledger contain among other things, the information on the length of time specific lease have been held.

Griffiths (1987) analyzed both the Temporary Register of Mines and the Rent Claim ledgers, only to find that there were very few claims in spite of the fact that a lot of sand extraction had taken place over the years. This was an indication that most of the sand extraction was taking place illegally in front of the governments' eyes. She noted that attempt to stop the illegal sand extraction activities by the Ministry of Lands, Housing and Urban development had been made several times but with very little success. Griffiths believed that one of the reasons why it was difficult to stop illegal sand extraction activities was because the activities were already becoming big money earning ventures for contractors, lorry owners and the sand diggers. She reports that most of the sand diggers were young youths and ex-primary school students, from the surrounding villages.

In the case of Zanzibar attempts are being made by the responsible Departments (Department of Environment and Department of Fisheries) to minimize activities like improper sand mining, coral destruction and mangrove cutting.

The problem of coastal sand mining in Zanzibar, is similar to what has been discussed for the mainland. In particular, all prospectors who wish to mine sand are required to apply for legal permits before they start mining sand in the selected areas. However, most people do not go for these permits. Instead, they do not only mine in the selected areas, without permits, but they even mine along the beaches and other restricted areas.

Concerning the coral destruction, one approach which has been used is "Community Management Program". This is a program which have been started in a number of villages southwest of the island of Unguja, involving the control of destructive fishing methods and over fishing by the local villagers. The selection of southwest Zanzibar for this program was basically done on the fact that this part of Zanzibar has more fishermen than other parts of Zanzibar. Elsewhere in Zanzibar, traditional protecting methods are used. These involve the closing and opening of fishing periods. The closing normally is only for a certain type(s) of fish. Village leaders carry the responsibility.

Another measure which is being taken is to discourage coral and shell for tourist market. In 1950-1970's shell export trade was very common. It is known that the main collection was coming from Nungwi. No permits are issued for this kind of trade at present.
Collection of corals for lime, is a well known business in many parts of the islands. In Pemba for instance, people collect coral stones from the Kwata island for TSh.400/=, a cart. Given the availability of rocks on land, it is unnecessary, though in some areas coral lime is preferred. However, there is no study done to investigate the extent of annual collections.

Fisheries (general) law covers the destructive fishing methods under section 14.1 and 25.
25. "Any person who contravenes any of the provisions of section 14(1) shall be guilty of an offence and shall be liable on conviction by a court to a fine not exceeding ..... Shillings".
Section 14.1 of this legislation forbid the use of destructive fishing methods like, Kojani, poisoning and dynamite fishing. There is no law covering collection of corals at the moment, but this issue is covered in the Environmental Policy. An environmental legislation is in preliminary preparation.

The first attempt to managing the mangrove resources started in the 1940's. It is interesting to note that, by then mangroves were managed not for beach protection purposes but just as an ecological resource. In 1945, mangrove areas were declared as Government land (under wood cutting Decree N.18). The Decree provides for controlled issue of cutting permits. In the year 1959 certain mangrove areas were declared as reserves. By 1965 all Mangrove forest were gazetted as reserves (L.N 92 of 1965) and they are under direct responsibility of Commission for Natural Resources at the moment.

In view of the above it seems that in order to effectively succeed in banning the illegal sand extraction activities, the following issues need to be given some further attention:

(i) Youth employment
(ii) Mass education
(iii) Alternative source of sand
(iv) Creation of a buffer zone

It is quite interesting to note that employment opportunities particularly in the urban areas like Dar es Salaam is not keeping pace with the fast increasing number of youths completing primary school education. This trend inevitably goes hand in hand with the increase of criminal cases as most of the youth find no alternatives, but earning their living requirements by doing illegal activities such as unlicensed sand mining and even robbing! Therefore it is high time that the Governments policy should critically address the present unemployment crisis.

The question of mass education is also of vital importance especially in the situation like the present one where the people themselves are required to assist in enforcing the law. However, the people would not effectively enforce any law unless they are carefully educated on the 'overall gains' of the law. In the present case, the people should be educated on the importance of preserving our coastal environments, and how certain human actions could adversely affect the coastal environments. Mass education could be achieved through Radio and/or Television programs, Newspapers and Education curriculums. Although one may not see the immediate outcomes of such measures, the long term outcomes are quite certain.

Also, the government need to identify other suitable sources of sand resource. Suitable in the sense that, it is technically of good quality and at the same time environmentally safe. Such areas should be surveyed by skilled geologists to determine the amount of sand resource present and this data should be used by land use planners.

Finally, the authors strongly support the suggestion put forward by BEMC of setting a buffer zone along the cost. The buffer zone would serve the following purposes:-

(1) It would decrease the intensity of human activities in the coastal zone.
(2) The natural vegetation present in the buffer zone would help to stabilize the beach.

BEMC had earlier recommended a 200m for the mainland. However, due to conflict of interests between different users of the coastal zone, it had been difficult to implement the suggestion. Recently NEMC had proposed a 60m buffer zone. Zanzibar case is a bit different; setting for instance of a 60m buffer zone would imply a significant loss of useful land. A suggestion of 30m buffer zone has been made instead. The suggestions of setting buffer zones in both the mainland and Zanzibar has been accepted in principle by the departments (or Ministries) concerned.

5.5 ESTABLISHMENT OF COASTAL INVENTORY

The present authors are of the opinion that, the problem of coastal erosion in Tanzania is not yet full understood. In particular, the information concerning areas which are critically being affected by coastal erosion have only been gathered or documented in few areas of the coastline.

In view of the above it is suggested that attempt be made to establish a coastal inventory for the entire coastline (including the main islands Pemba, Zanzibar and Mafia). An inventory of this type may contain among other things (Fay, 1992), the modern classification of the coast following the guidelines discussed by Quelennec & Ibe (1989). This can be achieved by analysis of aerial photographs and maps, accompanied by ground control methods. The results of such studies could then be used to identify coastal segments which are critically endangered by coastal erosion. Once such segments are identified they form a base for advising the government regarding future coastal plans and coastal protection measures. Thus, continuous monitoring of shore processes and prompt decisions on appropriate beach defense measures are the key elements for fighting coastal erosion.

5.6. OTHER RECOMMENDATIONS

Mangrove plantations along the coast may help to break the wave energy and thus protect the coast from erosion. They also interfere with sediment transport along the beaches. These trees are usually natural but they can as well be artifially planted.

ANNEX I
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VII. BEACH EROSION NORTH OF DAR ES SALAAM

by Kamzima M.M. Lwiza

1. INTRODUCTION

The study area Kunduchi beach, is located at 06° 40's and 39° 13'E approximately 20 kilometers north of Dar-es-Salaam, Tanzania (see Fig.1). It is a shelving beach with a gentle slope (the inclination rarely exceeds 3°), protected by inshore reefs and islands giving it a rather complex bathymetry. The mean spring tidal range is 2.98m, (Lwiza and Bigendako, 1988). The total catchment is 175 square kilometers (Griffiths, 1988). Kunduchi area is interest because of its high economic importance and because it is under heavy pressure by man. Its associated mangrove vegetation (described in detail by McCusker, 1975) is an important habitat for larvae of fish and crustacea. It is also the site of both the Kunduchi Marine Biological Station of the University of Dar-es Salaam, Kunduchi Fisheries Institute and several tourist hotels. Directly behind the beach there are extensive salt evaporation pans covering more the 200 hectares, and not long ago a pi lot heavy mineral (filimenite, kyanite, garnet, zircon etc.) extraction plant was operating. However, most of the building and development of the area has occurred in the last 25 years.

Erosion of the beach posed a serious threat to the beach hotels during 1977 and 1978 (Schiller and Bryceson, 1978) although the problem was recognized much earlier. Alexander (1969) observed that the shore erosion generally occurs with increasing intensity from Tanga (near the border with Kenya) southward. Duyverman (1978) made a sedimentological study of black heavy mineral sands in the Dar-es-Salaam-Bagamoyo area and observed large seasonal changes in beach profiles during one year.

In 1980 a team of scientist and engineers from the University of Dar-es Salaam was formed to look for a solution to this problem. Due to the alarming rate of erosion, the team hastily proposed the erection of groynes and a revetment at Silversands hotel. The groynes were constructed of coral limestone boulders about 500 kg, each. They had an average length of 30 m, a height of 1.5 m, a width of 3 m at the base and I m at the crest. The spacing between them was 50 m. At African Hotel the groynes were constructed by sand filled plastic tubes with a diameter of 1 m and a length 70 m. The spacing between them being 60 m. Later in 1984 the old groynes at Silversands were elevated by 1.5 m with ungraded coral rocks and new groynes were introduced in between the old ones and extended to the north right up to Bahari Beach hotel. The spacing between the new groyne system varied from 15 to 25 m. Since the second generation did not follow any particular recommendation, erosion tended to increase in the area. So, in 1986 the Tanzania National Environmental Protection and Management Council mounted a research project to (a) find out the amount of sand taken out of the streams feeding into the area, (b) measures beach profiles on a fortnightly basis for one y ear, (c) conduct a sedimentological study of the area, and (d) determine patterns of wind, currents and the tides. This paper covers objectives (b) and (d) and highlights on the effects of the physical parameters on beach erosion in Kunduchi area.

2. MATERIALS AND METHODS

2.1 WIND

An autographic anemometer was installed at Kunduchi Marine Biological Station (KMBS) at a height of 2 m on 20 January, 1987 and started collecting data on 2 February, 1987. Data was read from the monthly rolls then stored on an Ericson micro-computer.

2.2 WAVES

The wave staff was made of a wooden piece of 8 m high graduated at 5 cm intervals. It was placed at about 1 m below datum, 450 m from the sea-water intake of KMBS. Heights and periods of ten waves were recorded each time a wave measurement was required at 0630 East African Time (EAT).

2.3 CURRENTS

Drogues were used to track currents. The design was modified version of that used by Harvey (1977) in the same area, see Fig. 2. The length between the float and the drogue was 1.5m. It had to be shortened in order to avoid getting stuck in shallow waters. Observations were done from 0600 to 1800 East African Time (EAT) for 30 days during the northeast monsoon and southeast monsoon. To supplement the data a current meter was also used to measure currents in the Kunduchi creek due to the shallow water depth.

Tide: A conventional float- operated Stevens tide gauge (Type A Model 71) was installed at the Dar-es Salaam harbor, in front of the regional Marine Police quarters on 6 July, 1986. The gauge was not levelled to a standard bench mark. So, throughout this report, it has been assumed the zero of the tidal staff at the tide gauge is 1 m below datum.

In order to obtain the daily mean sea level values a 30-hour low pass Doodson filter (Doodson Warburg, 1941) was applied to the data in the following form:

$$\bar{x} = \sum_{-19}^{19} f_i x_i$$

f_i = multiplier of ith hour
x_i = tide level at ith hour
and x = tide level at noon of the central day

Beach Profiles: In October 1983 a pilot program for measuring beach profiles was conducted at Silversands Hotel. The engineer's level-and -rod method (Aubrey, 1978) was applied. The concrete platform on the hotel veranda 1 m from the entrance to the bar was used as a bench mark. In order to establish a permanent range-line, two armored iron rods were placed 40 m apart in a line perpendicular to the shoreline. The inner pole was placed 2 m backshore from the berm crest. Elevations were recorded at 2 meter intervals. The measurements were taken once a week during low tide for a period of five months (September 1983 to February 1984). Thus covering the whole of Northeast monsoons season .

In 1986 Hemed (1988) used a similar method (without range rods) to measure seven profiles in the study area. To reduce labor cost profiling was done on a fortnightly basis from October 1986 to August 1987.

3. RESULTS

Wind: During the Northeast monsoon wind speed varied between 1.5 and 8 m/s. The wind blew from the North except in the afternoon from 1630 EAT to midnight when it blew from the East. During the Southwest monsoon the wind had an average speed of 8 m/s with the main direction being from South. For both seasons the wind speeds were fairly low, typical of this area. Figs. 3 and 4 are examples of wind roses for February and August, 1987.

Waves: In the Northeast monsoon most waves were aligned to the wind direction. Wave action south Mbezi river was very low, with an average height of 0.2 m. It was low probably because it is in the shadow zone of both Mbudya and Pangavini islands. About three kilometers northwards from Mambwe river waves increased in size (0.4 m) up to African hotel. East of sand spit at Kunduchi waves were choppy and confused caused by interference and the ebbing current form the Kunduchi creek

For the stretch between Kunduchi hotel and Silversands hotel the wave condition was the constant at 0.5 m. Then it started increasing up to Bahari hotel where it was 1.2 m and it stayed high to Ras Kiromoni. Usually in the morning small locally generated waves wouldbe riding on a swell of 6-7 seconds with a height of 1.3 m. The swell stayed until l000 EAT. The maximum immersed weight of sand transported longshore was found to be 600 newtons/see

In the Southwest monsoon the waves were not entirely aligned to the wind direction, they were was predominantly from the Southeast. Coral reefs and the islands play an important role in refracting and diffracting the waves in this area. The submerged coral reef patches (e.g. Fungu Mkadya) act like lens by focusing (i.e.concentrating) wave energy on some particular parts of the beach. The exercise of analysing wave refraction diagrams was not part of this study. However, from few available aerial photographs some areas could be identified to be at high risk. These are: (i) the area between Ras Kiromoni and Bahari hotel, (ii) the sketch between Rungwe hotel and Tegeta stream and (iii) the area northward of Mbezi river for about 2.5 km.

Even during the Southwest monsoon south of Mbezi river was still a low energy area, average wave height was 0.5 m. Between Mbezi river and Africana hotel the height was almost double, 0.9 m. The stretch between Kunduchi and Rungwe had an average wave height of 1.5 m. The area north of Bahari hotel to Ras Kiromoni had a 2 m wave height. The maximum immersed weight of sand transported longshore was 1000 N/s whereas the average wave energy was 2.5 kW/m^2 which is quite a considerable amount of energy.

Current: The drogues were cast about 800 m from the shore in order to avoid getting stuck. On average the drogues were tracked for 11.5 hours each day. Most of the drogue tracks were restricted within an area not more than 1.5 km from the shore. Fig. 5 shows a composite plot for selected drogue tracks during the Northeast monsoon. During a tidal period the drogues drifted back and forth parallel to the shore. The maximum tidal excursion during spring tides (range= 3.4 m) was 6.2 km compared to 2.5 km at neaps (range=0.9 m). The maximum excursion could only be obtained if the drogue was deployed between Silversands hotel and Ras Kiromoni just after high water. For example a drogue set 800 m east of KMBS had an excursion of only 5.1 km. Another interesting feature was the persistent easterly deflection of the drogues during flooding. A typical example is illustrated by Fig. 6 which shows a drogue track for 20 February 1987. The tidal range was 2.2 m and tidal excursion for the drogue was 5 km.

The average speed obtained from drogues over the tidal cycle was 0.25 m/s: maximum speed was 0.5 m/s. The results agreed very well with direct current meter measurements with daily maximum speed at 0.3 m/s for neap and 0.75 m/s for springs.

In the Southwest monsoon, the current pattern did not change very much. There was still an easterly deflected. Another feature which was not affected by seasons was the current pattern in the Kunduchi creek. Ebbing velocity reached 3.5 m/s while during flooding the maximum velocity was slightly above 4.5 m/s. The motion was very turbulent and in most cases too strong for the boat to anchor. Also the bed is formed by coarse sand which is very loose. Although the main channel is oriented in an east-west direction parallel to the Kunduchi sand spit, the flood tide drives the current into the creek from south-southeast. During ebb the current starts by flowing parallel to the spit but as it gains speed it becomes more turbulent with a general direction changing to east-southeast.

North of the spit, much closer to the shore the ebb current flowed parallel to the shore towards African hotel. This might affect sediment transport in the vicinity of the hotel especially the northern end during the Northeast monsoon when the creek current is most significant. Figs. 8 and 9 show a general current pattern during ebb and flood, respectively.

Tide: The annual mean sea level was 1367 mm above datum. The maximum mean sea level was 1487 and the lowest was 1264 mm. The daily mean sea level (MSL) kept fluctuating throughout the year, see Figs. 10 and 11. Some changes were spectacular, for example a drop of 160 mm in MSL on 13 August, 1986. The drop is equivalent to an increase in the atmospheric pressure of 16 mb. There are also strong 10 to 30 day fluctuations in the tide gauge records but 30 day period tends to dominate.
Beach Profiles: All Silversands 1983/4 beach profiles had uniform concave shape. In Figure 12 time series of spot levels of 1983/4 data from one position for 125 days. There are bouts of erosion and accretion occurring in succession within a period of 33 to 35 days. However there is still an observable net erosion Results from Hemed(1988) show similar features with erosion immediately followed by accretion of almost the same amount. There was no discernable period from the time series of Hemed's profiles.

4. DISCUSSION

The year in question, 1987, was a typical year according to the wind figures 2 and 3. There are no marked differences from previous years (c.f. Niewolt, 1987). The wind energy along the Kunduchi beach is low. Occasionally it picks enough strength to form sand dunes and erodethe backshore. Erosion occurs during both seasons but it is more severe during the Southwest monsoons when the wave energy is higher. Episodic events like the storm surge of August 7, 1987 cause more damage than the normal erosion-accretion cycle. Tide is a wave riding on the mean sea level and therefore any change in MSL is important to the beach morphology. Daily changes in MSL have been observed to reach 200 mm. This can affect the tide a great deal. There are several factors that can affect the MSL, e.g. storm surge, atmospheric pressures changes and seiches. In the tropics meteorological tidal forcing is such that the diurnal frequency is driven by anchor-offshore winds and the semi-diurnal frequency is by atmospheric pressure (Pugh, 1979). However, a low-pass filter eliminates errors with short periods like seiche and S2 components of radiation tides. It is very likely that the strong 30 day fluctuations in MSL are caused by wind driven Kelvin waves similar to observations made in the Pacific (Miller et al.,1988). Therefore the frequency 0.30 cpd observed in 1983/4 data of beach profiles at Silversands Hotel is most probably also a response to the forcing of zonal atmospheric wind. The 30 to 60 day oceanic response has been observed elsewhere in the Western Indian Ocean, (Schott et al.,l988). Investigators (e.g. Nummedal et al., 1984) in beach morphodynamics when they say the energy spectrum is dominated by long-period infragravity oscillations they normally refer to edge-waves. However, this study has shown that longer periods (~30 days) are also important in the morphology of Kunduchi beach. The 1986/7 beach profiles do not show a 30 day cycle probably due to levelling to the method used, since the profiles were measured on a fortnightly basis Also there was no correlation between mean sea level changes and erosion measured from beach profiles because, first, spring high water does not necessarily coincide with maximum sea-level, and second, the beach profiles were measured on a fortnightly basis. So a profile measured on a particularday could have been caused by an event which took place ten days earlier.

An intriguing question has always been to know where the sand goes from Kunduchi. Bird (1985) and Griffiths (1988) proposed that the sand is transported by longshore drift past Ras Kiromoni into Ununio Bay. Most drogues described 8-shaped tracks with a net displacement offshore. This confirms the hypothesis put forward by Norman (1985) that a good percentage of the sand was going offshore. It is supported also by the fact that Ras Kiromoni acts as a point of divergence during the ebb tide and convergence point at flood tide. Therefore one would expect a lot of sand transport past the headland from the south into Ununio bay especially during the Southwest monsoon but there was no sign of sediment transport. For more than 1.5 km southward of Ras Kiromoni there is no beach, the 4 m cliff more or less falls straight into deep water (ca. 7m), the sea-bed is extensively covered by sea-grasses (especially *Syringodium thallasodendron)* and the current at mid-tide reaches 0.75 m/s. Seldom, does the sand pass this point that it actually does not interfere with the grasses. The only possible way for the sand to reach Ununio bay would be to go offshore first and then, maybe, move back inshore by wave action thus bypassing Ras Kiromoni. Therefore it seems the sand is eroded from the beach by longshore drift then deposited offshore by the tidal current at the following sites: (i) area between Bahari hotel and Fungu Mkadya, (ii) in front of Kunduchi creek. The latter is more significant than the former because most sand eroded from the south is caught by the creek. Some sand is used to build up the sand spit, the rest goes offshore. How much goes offshore is not known yet but it is most likely that more is transported offshore because it has been found elsewhere that in small tidal creeks of mesotidal swamps sediment transport is predominantly seaward (Kennedy and Pinkoski, 1 987).

Several reasons have been given for the marked increase of beach erosion in the area. Some investigators propose that the damage to the reef by dynamite fishing has reduced the barrier height which used to protect the beach from the battering action of waves. Another proposed cause is the hauling of sand for construction from the streams feeding into the area; Griffiths (1988) estimates 100,000 m^3 are extracted annually. Visual inspection of the coral reef platform around the islands showed that despite the crater-like pot holes on the seaward side, caused by dynamites, there was no appreciable decrease in the platform level to change the wave pattern. The average width of the barrier reef in the area is about 200 m. Therefore we can conclude that the rate of beach erosion at Kunduchi has increased in recent years because of (i) sand malnourishment caused by extraction of sand from the streams and (ii) intensification of isostatic adjustment of the land which is assumed to be responsible for the submergence of Maziwi island (in the north near Tanga) in 1981. Dynamite fishing has very little effect if any on beach erosion. Future research should concentrate on determining the amount of sand going offshore. Also it is important to explore the role of coastal-trapped Kelvin waves and quantify the effects of isostatic adjustment so that they can be distinguished from sea-level rising effects.

In order for the sea-level and erosion monitoring programs to work we need to select two or three pilot projects where erosion is acute, but the area should be readily accessible. The program should measure the following parameters: beach profiles, atmospheric pressure, sealevel, temperature and salinity. Along with in situ measurements other means, especially remote sensing techniques like aerial photographs and satellite images should be employed. We should also try to develop hydrodynamical models incorporating sediment dynamics and use them to asses various remedial scenarios. This will provide environmental managers with a much needed tool for objective management policies.

ANNEX I
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VIII. LITTORAL SEDIMENT MANAGEMENT

by Otavio Sayao, P.Eng.
WORKSHOP NOTES Presented at
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1. LITTORAL SEDIMENT MANAGEMENT

1.1 INTRODUCTION

In order to undertake a coastal zone management plan (CZMP), a basic understanding of littoral sediment processes, management and control is needed. This paper presents a review of littoral sediments and processes for sandy shorelines. More comprehensive reviews of littorai processes are available in the literature, such as given in Zenkovich (1967), King (1972), Silvester (1 974), Komar (1976), Bowen (1980), Sayao and Kamphuis (1983), Komar (1984), U.S. Army Corps of Engineers (1984) and Horikawa (1988).

In Canada, the Ontario Ministry of Natural Resources (MNR) has recently sponsored a shoreline mapping campaign for the Great Lakes, as well as two coastal engineering studies which would provide background data for future coastal management plans: a wave climate database for the Great Lakes (MNR, 1988a; 1 988b; 1 988c) and a general shore sediment study (MNR, 1 988d). The Great Lakes shoreline comprises about 1 0,000 km and correspond to 4% of Canada's total coastline. As shown in Tables 1 and 2 (from Ibbott and Whittington, 1991) the amount of money spent by Canada on its shorelines in 1988 was approximately $1 billion. The portion of shoreline expenditure in the St. Lawrence and Great Lakes is about 40% of this total, which justifies the general concern with land and properties erosion losses, and thus the need for management procedures.

1.2 SHORE MORPHOLOGY CLASSIFICATION FOR THE GREAT LAKES

General shore morphology information for the Great Lakes may be obtained from the Coastal Zone Atlas (Haras and Tsui, 1976). More detailed site-specific information (such as shoreline structures inventories, shoreline recession rates, etc.) is recently available, and all of this information will form part of a Geographical Information System (GIS) database (Law et al., 1 991). The basic shore types may be classified into five groups (MNR, 1988d):

1. Sandy
2. Composite
3. Cohesive Material
4. Rock
5. Marsh

Sandy shore is defined as the shoreline composed of cohesionless material of sufficient thickness to provide protection to underlying tills or backshore bluffs from wave attack. Cohesive material mainly refers to glacial till, clays and silts. Composite is defined as cohesive material overlain by a thin layer of sand, insufficient to provide any degree of protection from wave induced erosion (Kamphuis, 1986). Marshy areas are classified separately because of the unknown nature of sediment types within these areas.

Tables 1 and 2

Exhibit E.1
Spending On Shore and Nearshore Facilities, 1988 (5, 000)

Activity	Atlantic	St. Lawrence Great Lakes	Paciflc	Arctic	Total
Harbours, Waterways & Navigation	207,062	193,143	121,500	10.307	532,012
Oil & Gas Exploration and Production	31,700	673	---	115,000	147,373
Industry and Public Utility	8,867	46,339	16,910	---	72,116
Aquaculture	20,148	6,130	7,811	---	42,089
Municipal Water-front, Marina & Yacht Club Developments	27,701	104,756	24,329	---	156,786
Erosion Protection	3,309	77,683	2,550	1,000	84,542
Habitat 1,550 Enhancement	4,676	1,102	---	7,328	
All Activities	308.337	433,400	174,202	126,307	1,042,246

- less than $ l,000 identified.

Exhibit E.4
Average Annual Rates of Land Losses to Erosion

	Area Lost m^2
Nova Scotia	650,000
Prince Edward Island	260,000
New Brunswick	500,000
Lake Ontario	70,000
Lake Erie	290,000
Lake Huron	50,000
Beaufort Sea	1,500,000
Strait of Georgia	10,000
NE Howe Island	25.000
Total	3,355,000

The definition of the sand lower boundary differs in literature. Therefore, discrepancies may occur from one reference to another, in the amount of sand present at a given area, because of inconsistent classification systems. Figure 1 iliustrates the grain size scale for the Unified Soils and Wentworth Classification systems. For example, work by Rukavina (1976) defines sand/silt boundary based on Shepard's (1954) classification at the 4 phi (0.063 mm) boundary. This boundary is smaller than sand normally found on beaches in the Great Lakes, which approximately 2 phi (0.25 mm) above water (Boyd, 1981). Any further work in this field should be based on one system that defines the lower limit of beach sand at a value representative of that found in the Great Lakes beaches (0.1 5 mm, for example).

A classification system for nearshore slopes on the Great Lakes was put forth by Boyd (1981) as:

Group 1 - Extensive sand deposition with a number of active large sand bars within 500 metres from shore.
Group 2 - Extensive amounts of sand and bars nearshore but dominated by silts and clays offshore.
Group 3 - Little sand nearshore, of insufficient quantities to maintain an appreciable dry beach. Usually found in front of eroding glacial bluffs.
Group 4 - Devoid of sand and nominated by till or lag deposits and bedrock.

Figure 2 shows the 4 types of profiles (from Boyd, 1981). There are many locations around the Great Lakes where sand deposits are found to be completely contained between rocky headlands. Such deposits are 'relict' remnants from old glacial lake beaches, left behind when the glaciers retreated (Boyd, 1981).

1.3 LITTORAL CELL BASICS

General

A littoral cell is a section of coast where no inflow or outflow of sediments takes place across it's boundaries. A cell is a self-contained coastal system where the on-going shoreline processes do not affect, and are not affected by, the processes of neighbouring cells. The definition of the littoral cell limits is essential to the development of a SMP, for the natural coastal processes may be quite different from cell to cell, along the same stretch of shoreline (Figure 3, from MNR, 1988d).

Littoral transport in the nearshore zone is the movement of beach sediment both parallel to the shore (longshore) and perpendicular to the shore (cross-shore), under the influence of waves and currents. The longshore limits of a littoral cell are defined by natural formations or artificial (manmade) barriers, where the net sediment movement changes direction or becomes zero.

Subcells and Non-Drift Zones

Littoral cells may contain smaller structures or headlands that act as partial barriers to transport; some littoral sediments bypass these barriers. Segments of shoreline between partial barriers are referred to as subcelis. Most of the littoral cells in the Great Lakes have been artificially segmented into subcells by man-made structures (Smith and Sayao, 1989). It is thus important to distinguish these from the natural subcells that occur where headlands partially block the littoral drift.

The definition of 'littoral cell' implies that littoral sediments are moving within the cell. There are, however, many areas around the Great Lakes where the supply of littoral sediments is limited to the extent that very little actual transport occurs. Current and wave action still occurs in these locations and would, given a supply of sediment, induce sediment transport. Therefore, even though shoreline features and structures could function as a potential barriers within these areas, (i.e., littoral cells exist by definition), it would be pointless, from a shore management perspective, to identify littoral cells in the absence of longshore transport. Sections of the shoreline that are characterized by the above are called 'non-drift zones'.

Human Influences

Barriers to littoral transport can be either natural (e.g., rock headlands or sediment sinks) or manmade (e.g., harbour piers). The natural barriers have been in existence for several thousands of years. Man-made structures have only been in place for the last hundred years or so, and they will likely disappear within the next few hundred years (although new structures will undoubtedly be constructed). However, while they exist, these 'artificial' barriers may alter the natural transport patterns. For examp le, the Goderich Harbour piers and dredged navigational chan nel on Lake Huron now act as total barrier and form the limit of two separate cells (Figure 4, from Smith and Sayao, 1989). Before these features were built, a single natural cell existed from McRae Point in the north, to Kettle Point in the south. Sediment derived from the high bluffs north of Goderich can no longer be transported south of the harbour. Similar examples of man's influences on the shoreline may be observed in the Eastern Beaches (see Figure 5) and Scarborough Bluffs areas of the Toronto waterfront.

Sources and Sinks

The area of the littoral cell where sediments accumulate is called a sediment sink. The source of materials in the littoral cell is the location where sediments are available to be erode or transported.

Primary sediment sources in the Great Lakes are the shore bluffs and nearshore lakebed, however, gully erosion, river discharge and artificial nourishment activities may also be significant sources in some areas. The offshore zone may act as source of littoral material due to seasonal and storm induced profile changes and to erosion of the nearshore bottom and beaches.

Major sediment sinks occur in areas of low wave energy and include (Figure 6, from MNR, 1 988d):

- accreting natural beaches;
- offshore shoals;
- fillet beaches due to man-made littoral barriers;
- shoals or tombolos due to offshore structures, and
- areas of dredging or mining activities.

Dredging and mining can have significant impacts on sediment budgets and littoral processes. Material is lost to the littoral zone when dredged from navigable waters (channels and harbour entrances) within a littoral cell and dumped outside the littoral cell, such as at landfill areas or in deep water.

The offshore zone may also act as a potential sink. Typically, the finer-grained silts and clays are deposited in the offshore area but sand transport to the offshore may occur as a result of:

- storm waves which stir up sand, particularly when onshore winds create a return lake flow;
- turbulent mixing along the sediment concentration gradient which exists between the sediment/water mixture of the surf zone and the clear water offshore;
- the slight offshore component of gravity which acts on both the individual sediment particles and on the sediment-water mixture; and
- comminution of sand grains.

1.4 LITTORAL PROCESSES

Introduction

The movement of sediment in the nearshore zone by waves and currents may be divided into two general types: transport parallel to the shore (longshore transport) and transport perpendicular to the shore (cross-shore transport). Sediment movement resulting in erosion or accretion of a beach section is actually an interaction of these two types of motion.

The transport of sediments parallel to the shore in the surf zone is called littoral transport and is caused by obliquely incident waves. Figure 7 shows a schematic diagram of the two mechanisms for the littoral transport:

(a) beach drifting in the swash zone, and
(b) bed and suspended load transport in the breaking zone.

The two-phase flow phenomena are different in the nearshore zone, in the continental shelf (offshore zone), in rivers and in estuaries so that different theories exist for the estimation of sediment transport rates. The modelling of littoral processes will be briefly presented in the following sections.

Cross-shore sediment transport is the movement of material perpendicular to the beach both in the onshore and offshore directions, causing beach profile accretion and erosion. Figure 8 shows the cross-shore time scales (from Stive, 1991). The interaction of longshore and cross-shore sediment transport has been the subject of a great deal of research efforts recently, both for short and long term shoreline evolution studies.

Figure 9 shows one approach towards the analysis of sediment transport (from Kraus, 1991). Recent work on modelling morphological problems in the coastal area are described in Larson et al., (1990), Hanson and Kraus (1989) and de Vriend (1991), among several others. The classification of the shoreline models is shown in Figure 10 (from Kraus, 1989).

Sediment Supply

The existing methods to calculate littoral transport rate assume that an infinite amount of sand is available in the beach. Usually this is not the case and thus it is necessary to distinguish potential transport rates (resulting from calculations using these expressions) from actual transport rates, the amount of material actually moving along the shore.

Potential longshore transport rates may be calculated using both the CERC expression (U.S. Army Corps of Engineers, 1984) and the Queen's formula (Kamphuis et al., 1986). The Queen's formula has the advantage to take into account the wave parameters as well as beach slope and sediment grain size. This is further discussed in the next sections.

The intermittent, thin, narrow beaches that are characteristic of some littoral subcells in the Great Lakes are indicative of a sediment deficit. That is to say that the actual wave energy which is available to transport beach-sized sediments (i.e., sand and gravel) both cross-shore and longshore, exceeds the actual supply of sediments. The actual supply of beach sand and gravel from the eroding bluffs is a relatively small percentage of the total volume. The bulk of the volume consists of silts and clay and these fine materials are transported offshore out of the littoral system. There is not enough of the remaining coarser materials to provide sufficient protection against erosion to the underlying cohesive profile during periods of high water and/or severe storms.

A procedure to calculate actual sediment transport rates has been recently proposed in Kamphuis (1990a). It assumes that sand is only available to be transported to a certain depth h (see Figure 11) and thus the wave energy offshore of 'h' is not accounted for in the littoral drift computations.

Sediment Budget

In order to fully describe the littoral processes occurring along a particular stretch of shoreline, it is necessary to estimate the amount of sediment transported, its origin and where it is deposited. The system accounting for the quantities of littoral transport is called the sediment budget. The sediment budget gives an estimate of material entering the littoral zone from each source, and the amount of sediment deposited at each sink or barrier along the shore. The sediment budget must balance. That is, the total amount of supply must equal the total amount deposited plus the amount still in transport. Typically sediment budgets are concerned with the long-term transport rates and transport patterns. However, it must be noted that short-term impacts may be significant and should also be accounted for. Thus, the estimation of the short-term transport patterns are also important.

Shore bluff recession rates have been measured for most of the shorelines around Lake Ontario, Lake Erie and Lake Huron. Boyd (1981) conducted measurements of bluff recession rates between 1973 and 1980 for the Great Lakes shorelines using erosion-monitoring stations data. Other information collected included grain size analyses, descriptions of vegetation cover and existing shore protection works. From the survey information, annual volumetric erosion rates (volumetric change per unit height per unit length/per year, in m^3/m/m/y) were calculated for similar reaches of shore bluffs. Also, after making allowances for the percentage of sand and gravel (littoral material), and after accounting for the percentage of shore that is protected, the amount of sediment input to the littoral zone from shore bluff erosion was estimated, i.e. the sediment supply.

The erosion monitoring programme, described by Boyd (1981) was discontinued in 1980, so the estimate values are based on seven years of data. Ideally, such surveys should be based on a continuous record of shoreline position, rather than on localized data from monitoring stations. It is recognized that nearshore sounding surveys need to be conducted in erosion prone areas, in order to estimate the amount of littoral sediment contributed from subaqueous erosion. It is possible that in some areas the amount of sediment contributed from nearshore erosion is of the same order of magnitude to that of shore bluff erosion.

1.5 BEACH PROFILES

Introduction

Beach profiles are classified according to their seasonal variations in three basics forms (Figure 12):

- the bar profile, or the storm profile (also referred to as the 'winter profile') formed by waves of high steepness, with a milder foreshore slope and one or more bars depending on wave and grain size characteristics;
- the step profile, or the berm profile (also referred to as the 'summer profile) formed by waves of low steepness, with a steeper foreshore slope and no bars; and
- the welded bar profile (Sunamura, 1989), a neutral profile that transforms itself into both the bar and the step profiles depending upon the wave conditions.

Several criteria for on-offshore transport in sandy beaches are given in literature:

(1) the criterion proposed by Iwagaki and Noda (1962). where the line of transition is a function of the parameters H_0 / L_0 and H_0 / D_{50};
(2) the criterion proposed by Dean (1973), in which the transition is a function of the dimensionless fall time parameter, $H_b/(w_sT)$, where w_s is the fall velocity of the grains. Since most of the available data sets presented the measured value of the deep water wave steepness, rather than the breaker steepness, Dean's (1973) correlation was based on plotting H_0/L_0 versus $(\prod w_s)/(gT)$. Also, the Shore Protection Manual (U.S. Army Corps of Engineers, 1977; based on Kohler and Galvin, 1973) shows results of the prediction of profile types based on a deep water fall time parameter, $F_0 = H_0 /(w_sT)$, where for $F_0 < 1$ profile accretion occurs and for $F_0 > 1$ to 2 erosion is most likely;
(3) the criterion proposed by Sunamura and Horikawa (1974), where beach erosion and accretion is a function of 3 parameters: deep water wave steepness, the ratio of grain size to deep water wave length, D/L_0, and bottom slope; and
(4) Sunamura (1984; 1989) criterion based on the parameter $K = H_b^2/(gT^2D)$.
(5) Kraus et al., (1991) criteria, including a new Froude-type parameter w_s / sqrt$\sqrt{(g\ H_0)}$/ which is a combination of H_0 /L_0 and F_0 to predict beach erosion and accretion.

Figure 13 (from Sayao and Graham,1991) shows the 3 typical profile regions of Sunamura (1989) and field data from Takeda and Sunamura (1982). This on-offshore criterion is similar to the one by Iwagaki and Noda (1962). The equations for the demarcation of field and laboratory profiles are also shown in Figure 13. However, Sunamura (1989) found different trends for field and laboratory data, with no apparent reasons.

Beach Slope Definitions

The foreshore slope of the beach under the wave swash zone, also called the beach face slope, was found to be related to median grain size D_{50} (Wiegel, 1964; King, 1972; Bascom, 1980). A steep foreshore slope corresponds to coarse sandy beaches, and a flat beach face is an indication of finer material. The degree of exposure to wave action was also found to be a factor affecting the foreshore siope (Wiegel,1964; Komar,1976; Bascom,1980). The beach face becomes flatter when eroding and steeper when accreting.

Wave action on beach profiles has been the topic of many investigations in two dimensional laboratory flumes, both with plane fixed slopes or movable bed beaches. This topic was reviewed in Sayao (1982). The plane initial beach slope is tanß where ß is the angle above the horizontal. The movable bed beach slope m, which develops under wave action inside the breaking zone, may be defined as:

$$m= d_b / \lambda_b \tag{1}$$

where d_b is the breaking depth and λ_b is the breaker distance. Figure 14 shows the terminology used here related to beach profiles and surf zone processes. As long as the breaking point location is defined in every test, the beach slope m is also determined. With the development of a movable bed model experiment, the beach slope is constantly changing with time and dynamically adjusting under wave action. Thus, on beach studies m should not be mistaken for tan

For prediction purposes it is necessary to have some means of schematizing the beach profile. The definition of the various slopes related to the surf (active area of beach profile) is only possible if the position of the breaking point is defined. The breaking point position is usually the position along the beach profile where the wave height is maximum. Breaking wave height measurements in a 3-dimensional movable bed model were made by Sayao (1982; see also Sayao and Kamphuis, 1982). The breaking point position was obtained by changing the position of the probe near breaking and observing were the maximum value occurred. The breaker distance Ab was defined in the modei as the horizontal distance from the breaking point to the shoreline, at still water level (SWL). Thus, Lambda, was determined from the plotted beach profiles and did not depend on visual measurements.

An equation for the prediction of beach profiles was presented in Sayao and Graham (1991) for both field and laboratory data:

$$m=0.10\left(\frac{H_b}{D}\right)^{-1/4}\left(\frac{H_b}{L_0}\right)^{-1/4} \tag{2}$$

This relationship was developed based on the work of Sunamura (1984) and agrees with his data set as well. For engineering applications it is important to note that different definitions for beach face slope and beach profile would yield different slope values.

Dean (1977; 1990) studied beach profiles along the East and Gulf Coasts of the USA and developed a general formulation for equilibrium beach profiles that can be useful in a number of coastal engineering modelling applications (Figures 15 and 16):

$$h = A\,x^{2/3} \tag{3}$$

where h is the water depth at a distance x from the shoreline and A is the sediment-dependent scale parameter. Figure 17 (from Dean, 1990) show the characteristics of beach profiles in and out of equilibrium.

Kemp (1960, 1962) showed that the ratio between the wave uprush time tut measured between the breaking zone and the limit of uprush, and the wave period T influences coastal processes. His results demonstrated the importance of the 'phase difference' parameter t_u/T in relation to the beach profile type: for low t_u/T, a step profile is formed whereas for high t_u/T, a bar profile develops. The relationship between wave action and beach slope for low phase differences was investigated by Kemp and Plinston (1968) for coarse sands. The results showed that the beach face slope and the width of the surf zone are dependent on the breaker height and on the wave period. Further experimental evidence of the influence of the wave period on the beach profile formation was given by Sitarz (1963) and Motta (1964).

1.6 SEDIMENT TRANSPORT MODELLING

Introduction

A sound approach to coastal processes studies is to couple local experience with coastal engineering methods (numerical models). In this context, Kraus (1989) has succeeded to summarized in writing the approach towards solving coastal engineering problems:

> "The best 'model' is to know the optimal project design from experience. Because of the complexity of beach change, design decisions should be grounded on "empirical modelling," i.e, adaptation and extrapolation from other projects on coasts similar to the target site. Coastal experience and understanding of coastal processes (wave, currents, sediment transport) and geomorphology are essential. However, prediction through coastal experience without the support of an objective, quantitative tool, such as numerical model, has limitations:
>
> a. It relies on the judgement of specialists familiar with specific regions of the coast and on experience with previous projects, which may be limited, inapplicable, or anachronistic.
> b. It is subjective and does not readily allow comparison of alternative designs with quantifiable evaluations of relative advantages and disadvantages. Also, conflicting opinions can lead to confusion and ambiguity.
> c. It is not systematic in that it may not include all pertinent factors in an equitable manner.

d. It does not allow for estimation of the functioning of new, novel, or complex designs. This is particularly true if the project is built in stages separated by long time i ntervals.
e. It cannot account for the time history of sand transport as produced, for example, by variations in wave climate, modifications to coastal structures, and modification of the beach
f. It does not provide a methodology and criteria to optimize project design.

Finally, complete reliance on coastal experience places full responsibility of project decisions on the judgement of the engineer and planner without recourse to external and alternative procedures."

Littoral Transport Models

The available literature regarding littoral transport of sand by waves is extensive and a review shows that many theories and expressions for the prediction of littoral sediment transport rate exist (Sayao and Kamphuis,1983). Analysis of the littoral sand transport volumes and rates may be approached in two ways:

(i) by relating directly to wave parameters such as wave energy flux (or wave thrust),
(ii) by modification of river sediment transport formula for the coastal zone.

The so called 'Wave Energy Flux Approach' is one of the methods of analysis of littoral transport. It is based on wave energy flux and similar relationships, and results from early empirical developments. As stated by Longuet-Higgins (1972): "it represents the pioneer's first intuitive attempt at grasping the quantity lateral wave thrust".

Similarly, another method of analysis may be based on modifications of river sediment transport formulae, the 'Steady Flow Modification Approach'. Einstein (1948) suggested a basic similarity between the sand movement on a beach and in a river. He said: "The motion of sand along a beach resembles in many respects the motion of a sand in a river. This latter problem has been solved in large part, and it is reasonable to expect that a solution of the beach problem might be found by application of these same principles". In river engineering there are numerous sediment transport theories, often evaluated for limited ranges of sediment sizes and hydraulic conditions. A review of some of these theories may be found in White et al., (1975). Some recent modifications may be found in van de Graaff and van Overeem (1979) and in Swart and Fleming (1980). Their reliability may be summarized with van de Graaff's (1980) own words: "The question of the most reliable prediction technique is probably for the moment a matter of 'belief', however, not every new technique is automatically better than an older one".

These methodologies are also referred in literature as:

- Bulk-energy predictors, such as the CERC formula (U.S.Army Corps of Engineers, 1984) or the Queen's formula (Kamphuis et al., 1986; Kamphuis, 1990b); and
- Detailed predictors, such as the ones developed in Bijker (1971), Willis (1979) and Nielsen (1979), among others.

All predictive methods for littoral sand transport rates and volumes are based on field and laboratory data points. Some of the data sets available in the early 1970's were compiled by Das (1971). The need for field measurements was identified in the United States and Japan, were major studies were carried out, which included extensive data collection at several beach sites. In the USA, the NSTS (Nearshore Sediment Transport Study) was reported in Seymour and Duane (1978), Seymour and Gable (1980) and other publications. In Japan, the NERC (Nearshore Environment Research Center) program was carried out from 1976 to 1982 and was reponed in Horikawa (1988) .

Further random wave measurements (both outside and inside the surfl in the laboratory and in the field are now available for comparison of prediction techniques, including various publications on DUCK 82 and DUCK 85 field data sets (see Figure 18, from Birkemeier,1991), Thornton and Guza (1986) field data from Leadbetter Beach (NSTS), Hotta (1980) and Hotta and Mizuguchi (1986) field data from the Japanese coast (see also Horikawa, 1988).

Essentially, to compute littoral drift, the following steps are necessary:

- Deep water wave climate input data, available from NMR wave hindcast.

- Shallow water wave transformations are then performed, leading to the definition of breaking wave climate.
- Littoral transport rate calculations are performed. For this, detailed surficial sediment data and beach profile data are needed, as well as breaking wave conditions.

Nearshore sediment transport models include algorithms for the calculation of:

- roughness and friction of bottom sediments
- longshore currents
- littoral drift
- cross-shore transport

Recently, these modelling techniques were used in the Canadian Coastal Sediment Study (C2S2). This was a research oriented study of sand transport on two Atlantic beaches carried out by the National Research Council of Canada over 4 years (1982/1986). Most of the available transport rate predictors were used in this study. A discussion of results, conclusions and recommendations are reported in Willis (1987).

The Bijker (1971) method did not show consistent results during the C2S2 study, and is very sensitive to the roughness values used. Sayao et al., (1987) have shown how sensitive sediment transport equations may be to roughness and friction parameters. This has been known for several years (Bijker, 1971) and is still the subject of further research. Also, the Nielsen (1979) formula is very sensitive to wave diffusivity and needs as input data the distribution of the suspended sediment transport concentration, a difficult parameter to measure or guess. However, we will investigate the option to use both formulas during the study.

The Wave Energy Flux Approach

An expression for predicting longshore sediment transport rate by waves has been in general use in the United States since the 1950's. Watts (1953) made the first field measurements relating longshore sand transpont to local wave characteristics He measured the rate at which sand was being pumped to bypass South Lake Worth tidal inlet, in Florida, and found that the volumetric littoral transport rate was a function of the longshore wave energy flux factor. This factor may be expressed as follows:

$$P_l = \frac{1}{16} \rho g H_b^2 n_b C_b \sin 2\alpha_b \qquad (4)$$

where n is the energy flux coefficient, H is the wave height (subscript b denotes breaking waves), ρ is the water density g is the gravity acceleration, C = L/T is the wave celerity, L is the wave length, T is the wave period, α_b is the breaking angle. Watts (1953) used significant wave height when evaluating Equation 4 to obtain P_{ls}. Caldwell (1956) measured the rate of erosion downdrift of a littoral barrier at Anaheim Bay, California. Using Caldwell's and Watts' data, Savage (1962) found:

$$Q_s' = 4100\, P_{ls} \qquad (5)$$

where Q_s' is the volumetric littoral transport rate in cubic yards/year and P_{ls} is the longshore wave energy flux factor in ft-lbs/sec/ft of beach. P_{ls} can be calculated using Equation 4 with H defined as significant wave height. This equation was adopted by the U.S. Army Corps of Engineers as an earlier version of what has become generally known as the 'CERC formula'.

Bagnold (1963) proposed a theory in which wave energy was expended to suspend and support the sand particles above the bottom, and any unidirectional current superimposed on the orbital wave motions could transport sand and produce a net drift in the direction of the current. The relationship may be expressed as:

$$I_a = K' P \frac{v_a}{u_o} \qquad (6)$$

where I_a is the immersed weight sediment transport rate per unit width, at an angle a to the wave crest, K' is a dimensionless constant, P is the available power from the wave motion, v_a is the unidirectional current at an angle a to the wave crests, and u_0 is the orbital velocity of the waves at the bottom. Equation 6 was further developed by Inman and Bagnold (1963), Komar and Inman (1970), and Baillard (1981).

CERC Formula for Littoral Transport

Inman and Bagnold (1963) suggested the use of the immersed weight longshore transport rate 11, rather than a volumetric transport rate Q'5. The two are related using the following expression:

$$I_l = \gamma_s \ (1\text{-}p)\ Q_s' \qquad (7)$$

where p is the beach sand porosity (p - 0.4 for quartz sands), and γ_s in the underwater specific weight of the grains. The immersed weight longshore transport has the units of power or energy flux, and thus may be related directly to the wave energy flux factor Pls. In 1973, based on the field data by Komar and Inman (1970), the CERC formula for littoral sand transport was updated from its earlier version (Equation 5) to read (U.S.Army Corps of Engineers, 1977):

$$Q_s' = 7500\ P_{ls} \qquad (8)$$

where Q_s' is the volumetric rate of littoral transport, in cubic yards/year, and P_{ls} is the wave energy flux factor, in ft-lbs/sec/ft of beach, calculated using significant wave height H_s .Using Equation 7, the CERC formula may be written in terms of the immersed weight of sand moved, (Vitale, 1980; Bruno et al., 1981) as:

$$I_l = K_p\ P_{lr} \qquad (9)$$

where P_{lr} is calculated using the root-mean-square wave height H_{rms}. I_l is expressed in N/s and P_{lr} in N-m/s-m. K_p is a dimensionless constant, equal to 0.77 for significant wave height data and 0.39 for root-mean-square wave height data. Figure 19 shows the CERC formula predictions ploted against field data compiled by Davies (1984).

Equation 8 gives 83% higher volume transport rates than its predecessor Equation 5. The reasons for this upward revision on the dimensional coefficient of the CERC formula are given by Galvin and Vitale (1976). The major change is the deletion of all laboratory data from the curve fiting. Thus, Equation 8 results from a plot of only the available set of field data, e.i. Wats (1953), Caldwell (1956) and Komar and Inman (1970), and is shown in Figure 19, taken from U.S. Army Corps of Engineers (1977). A review of this data base is given in Greer and Madsen (1978), who critically question their quality and conclude that Equation 8 should be used with caution, only as an order of magnitude estimate for the littoral transport rates. However, the CERC formula continues to have the preference of researchers in the USA (Bodge, 1991) and was included in the CERC's model for shoreline evolution GENESIS (Gravens, 1 991).

Queen's Formula for Littoral Transport

Kamphuis and Sayao (1982) have shown that there is a strong dependence of the dimensionless litoral transport rate on the surf similarity parameter, as may be seen on Figure 20, for model data of medium and fine sands. The following expression was derived:

$$\pi_{Qs} = \kappa\ \xi_b \qquad (10)$$

where π_{Qs} is the dimensionless sediment transport rate, κ is the suspended load coefficient and ξ_b is the surf similarity parameter (or Iribarren number; Batjjes, 1974) defined as:

$$\xi = \frac{m}{\sqrt{H/L_0}} \qquad (11)$$

The surf similarity parameter in the breaking zone (4b) is calculated with Hb as the wave height value. This parameter gives an indication of the rate of energy dissipation in the surf zone. The breaker type and other surf zone phenomena are also related to 4 as shown in Figure 21.

Equation 10 may be written as follows:

$$\frac{\rho_s (1 - p)\, Q_s'}{\frac{1}{2}\, \rho\, \frac{H_b^3}{T} \sin 2\alpha_b} = \kappa \xi_b \qquad (12)$$

where ρ_s is the sediment density, Q_s' is the volumetric transport rate.

Figure 22 shows a plot of 1c versus the relative grain size parameter, in order to investigate on the form of the functional relationship of Equation 10. Nairn (1985) has demonstrated in model experiments with sacrificial sand islands that an H/D value of about 300 is a limit for inception of suspended load. For values of H/D less than 300, larger grain sizes display greater erosion rates. Consequently, laboratory data points with H/D less than 300 were omitted from the analysis (Sayao et al., 1985).

An expression was determined for available laboratory data with H/D greater than 300 and for field data points compiled by Davies (1984) as follows (see Figure 22):

$$\kappa = 0.002 \left(\frac{H_b}{D_{50}}\right) \qquad (13)$$

where D_{50} is the median grain size of the beach sediment. Equation 13 was used to calculate sediment transport rates at Pointe-Sapin, see Kamphuis et al., (1986), with good results. Using Equations 11, 12 and 13 comes:

$$Q_s' = 4 \times 10^{-4} \frac{m}{(1 - p)\frac{\rho_s}{\rho}} \cdot \frac{\sqrt{g}\, H_b^{3.5}}{D_{50}} \cdot \sin 2\alpha_b \qquad (14)$$

Also, Sayao and Chow (1992) have further enhanced Queen's formula (Equation 14) to include a term first proposed by Ozasa and Brampton (1980) to take into account the iongshore variation of wave breaking heights.

<u>Steady Flow Modification Approach</u>

Most formulas for sediment transport in unidirectional steady flow can be expressed by using the Einstein (1950) dimensionless parameters ¢ and Nr, as follows:

$$\varphi = f(\psi) \qquad (15)$$

with the parameter φ related to the sediment transport itself:

$$\varphi = \frac{q_s \rho^{1/2}}{(\gamma_s D)}$$

and ψ related to the flow characteristics:

$$\psi = \frac{1}{F_*} = \frac{\gamma_s D}{\rho v_*^2}$$

Here q_s is the weight sediment transport rate per unit width, F_* is the mobility number (or Shields parameter), γ_s is the underwater unit weight of sediment, $(\rho_s - \rho)g$, ρ is the fluid density, ρ_s the sediment density and v_* is the shear velocity. Equation 13 is known as the 'φ- ψ'curve' and may be found in most sediment transport textbooks, e.g. Yalin (1977). A modification of Equation 15 to enable its use for two dimensional oscillatory flow, i.e. coastal sediment transport, has been the subject of many research efforts (Madsen and Grant, 1976; Swart, 1976; Bijker, 1971).

Owing to the lack of any comprehensive field data on littoral transport rate, van de Graaff and van Overeem (1979) decided to compare some of the more detailed formulas with the CERC formula for littoral transport. As a result of this comparison the Bijker formula appeared to be better than other steady flow modification formulas, but it may be argued that the CERC formula cannot be used as a standard in such a comparison.

Swart and Fleming (1980) have made an attempt at comparing the mean sediment transport rate obtained by using six predictors, including the CERC formula, with a prototype situation, a high energy beach located north of Cape Town, South Africa, where the transport rates were inferred from quarterly bathymetric surveys over 2 years. The result showed good agreement between prototype data and mean predicted rates but no appraisal of each individual formula was made.

Cross-Shore Transport Models

Beach profile evolution and cross-shore sediment transport have in the past been neglected in coastal studies and design. Only recently the relevance of cross-shore transport has been identified. However, existing prediction methods have not yet been validated. In fact, Seymour and King (1982) and Seymour and Castel (1988) have compared several first generation (empirical, based primarily on laboratory data) models to field data collected in both USA coasts, during the Nearshore Sediment Transport Study, with very poor results.

As far as cross-shore transport is concerned, Seymour and Castel (1988) discuss that only the Swart profile model (Swart, 1976) showed "interesting skill in predicting unbarred type profile sets", however it failed to predict the evolution of a profile data set dominated by longshore bar movements. Also, Seymour and Castel (1988) concluded that "a realistic model for cross-shore transport, involving the necessary physics, appears to be well beyond the present state of the art".

The CERC experience in two-dimensional profile modelling shows that the predictor developed by Kriebel (1990; see Figures 15 and 16), based on a 'Dean Profile', the exponential form for the equilibrium beach profile put forth by Dean (1977; 1990), may well suit their needs along the Atlantic Coast. However, the Kriebel profile model cannot handle longshore bar evolution. Recent work by Larson et al., (1990) and Kriebel et al., (1991) has included these processes in the new versions of the model.

Presently, research efforts in Europe have yielded new second generation profile models, where the physics of cross-shore processes are taken into account (see Stive, 1986; Nairn, 1988; Hedegaard et al., 1991; Southgate, 1991; de Vriend, 1991). Profile changes and cross-shore transport may now be modelled with a model that can predict the evolution of barred beaches, which is the case for most beaches in the Great Lakes. This cross-shore transport numerical model provides a description of coastal processes in both the longshore and cross-shore directions for random waves and currents such as tides on a sandy beach profile. The model has four predictive phases including (Nairn, 1988 and Southgate, 1988):

i) wave height transformation,
ii) hydrodynamics,

iii) sediment transport in the cross-shore and longshore directions, and iv) cross-shore profile evaluation.

Beach Evolution Models

Further to the calculation of sediment transport in the cross-shore and longshore directions, beach evolution analyses may be carried out, such as:

- A beach plan evolution model may be used to access the impact of littoral barriers on sediment processes along the shoreline.
- The effects of natural beach areas on the sediment regime may also be assessed by comparison of supply, potential rates and predictions of beach evolution with time.

In general, the following types of numerical models of beach evolution exist:

- a '1 -line' type model, which takes into account the evolution of one contour only, typically the shoreline; with or without seawall and revetments on the beach;
- a 'n-lines' type model, which takes into account the evolution of several contours; and
- a cross-shore profile evolution model, a 2DV nearshore model (2-dimensional in the vertical and cross-shore horizontal dimensions).

The 1 -l i ne type beach model assumes that the beach profi le always remai ns in equi librium and that the beach profile changes from the shoreline to the depth of closure occur with parallel slopes. Hence, only one contour is sufficient to describe the change of shoreline position from initial.

These numerical models were developed based on the work of Pelnard-Considere (1954). Several applications are available in literature, including Ozasa and Brampton (1980), Komar (1984), Kraus and Harikai (1983) and Hanson and Kraus (1989).

The 'n-lines' model was originally developed by Perlin and Dean (1983) and has been used by CERC and others for prediction of short term shoreline changes (Figure 23). The model consists of a representation of the nearshore zone, with the bathymetric contours represented by 'n' lines, each one of a specified depth. Three basic equations are used to simulate two-dimensional sediment transport rate and bathymetric changes; the equation of continuity of sand; a longshore transport predictor, and a cross-shore sediment transport equation. The bulk longshore sediment transport rate is determined with the CERC formula (U.S. Army Corps of Engineers, 1984), coupled with Fulford (1 983) distribution in the cross-shore direction. The cross-shore sediment transport rate is determined by using an activity factor as suggested by Bakker (1968) and Dean's (1977) equilibrium profile shape. A detailed description is found in Perlin and Dean (1983).

The 'n-lines model may be modified according to the site-specific modelling situation. For instance, Johnson and Kamphuis (1988) have used an 'n-lines' model to predict morphological changes in large sand islands; Sayao and Chow (1992) have used a grided wave transformation model based on Resio's (1988) work, to better predict waves in the lee of offshore breakwaters.

Another type of evolution models is the 2DV nearshore profile model, that include wave transformation procedures, tidal and wave-induced currents, cross-shore undertow velocities, crossshore and longshore sediment transport rates to compute beach profile changes, assuming straight shoreline with parallel contours (Nairn, 1988; 1991; Southgate, 1988; 1991). Presently, this modelling work is being extended to 3-dimensional shoreline situations.

Recently CERC has developed a '1 -line' shoreline change model called GENESIS (generalized model for simulating shoreline changes; see Hanson and Kraus,1989 and Gravens,1991). GENESIS allows simulations of shoreline changes occurring over a period of months to years as caused primarily by the action of breaking waves. The project horizontal length scale typically varies from one up to tens of kilometres. The model is generalized in the sense that the it can be used to simulate shoreline change under a wide variety of user specified beach structure configurations. In addition, the input wave conditions can be entered either by assuming parallel bottom contours (Snell's Law), or through interaction with a more rigorous wave refraction model (see Figure 24).

GENESIS is based on the one-line theory of beach change (Pelnard-Considere, 1954). The same concept has been used in a number of previous studies (e.g., Price et al., 1973, Perlin 1979, LeMehaute and Soldate, 1 980). In particular, Hanson et al., (1988; 1989), Kraus et al., (1988), and Hanson and Kraus (1989) present applications of the GENESIS model employed as an engineering tool for making shoreline change forecasts for real (prototype) beaches (see Figure 25).

These models proved to be powerful tools for the prediction of short term and long term beach evolution at coastal sites. The results of the simulations may be used for conceptual planning of coastal projects, by assessing the impact of structures on shoreline changes, as well as enabling the development of mitigation measures.

The typical phases of a modelling analysis of existing coastal processes are as follows:

<u>Short Term Modelling Analysis</u>

At this phase of a modelling analysis, an understanding of the existing coastal processes is developed, considering both detailed longshore and cross-shore sediment transport patterns. Selected storms, selected extreme events, and/or a selected 1 year time series may be used to investigate typical storm and recovery periods. This exercise would elucidate the role of cross-shore transport on the littoral processes at the site under consideration, as well as, the distribution of longshore transport across the beach profile. Also, importantly, gradients of longshore transport rate must be investigated for they may play a role in littoral processes along curved or partially, protected beaches.

<u>Long Term Modelling Analysis</u>

In this phase of the studies, the deep water wave hindcast data (MNR, 1988a; 1988b; 1988c) may be used to investigate shoreline changes. The models could be applied to long term data in a chronological format to establish yearly averages of net and gross sediment transport rates, as well as shoreline and nearshore changes. In this phase of the work only gross shoreline changes will be considered and their interpretation will be based on the detailed understanding developed during the short term investigation.

<u>Conceptual Shoreline Planning</u>

In this phase, prediction of shoreline changes may be carried out for master planning purposes. Future shoreline changes are modelled, for periods of 5 years, 10 years or 25 years. An important consideration here is the effect of wave variability on transport rates. This aspect was considered by Le Mehaute et al., (1983), as well as in past coastal studies such as the ones presented in Kraus and Harikai (1 983) and Brampton and Motyka (1 987).

ANNEX I
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IX. REGIONAL. ASPECTS OF COASTAL EROSION IN WEST AFRICA - THE CASE OF THE BIGHT OF BENIN

by J WELLENS-MENSAH

ABSTRACT

The paper gives a brief general description of the Bight of Benin which forms part of the West African Coast. It examines the general coastal conditions and the causes of erosion in the Bight It then discusses coastal protection measures in the various countries in the Bight and finally discusses the future direction of coastal erosion control in the Bight of Benin .

1. INTRODUCTION

The information contained in this paper has been drawn mainly from the following publications:

(i) Coastal Erosion in the Bight of Benin. Report on Expert Findings. E E.C. (1989).
(ii) Coastal Erosion in West and Central Africa. UNEP (1985).
(iii) Coastal Erosion in Ghana. Situation Report and Action Programme. Team of Consultants on Coastal Erosion Report to the government of Ghana (1986)

Those three reports have in turn drawn heavily on information available in technical reports on coastal erosion in the West African Sub-region. These three reports have thus become compendia of coastal erosion information in the sub-region.

2. GENERAL DESCRIPTION OF THE BIGHT OF BENIN

The Bight of Benin is part of the Coast of Guinea. The coasts that comprise the Bight are those of Cote D' Ivoire Ghana, Togo, Benin, Nigeria and part of the coast of Cameroon. More specifically these coasts with distinct geo-morphologicl characteristics are (Fig.1):

(i) the coast from Cape Palmas in La Cote d' Ivoire to Cape Three Points in GChanc
(ii) the coast form Cape Three Points to the Western extremity of the Niger Delta in Nigeria
(iii) the Niger Delta up to the promontory of Mount Cameroon.

The entire length of the Bight measures about 2000 km end lies between longitudes 8°W and 9°E close to latitude 5°N. The notable rivers discharging into the ocean in the Bight are River Niger in NNigeriaand River Volta in Ghana. Other smaller rivers discharging into the ocean are the Pra ln Ghana; the Sassandra, Bandama and Komoe in Cote d' Ivoire; the Mono and Oueme in Benin and the Cross River in Nigeria. The Niger which is the largest river in the Bight splits into a pronounced delta around longitude 6°E, the Volta forms a smaller delta around 1°E longitude.

The coastal area in the Bight is generally low-lying with the lOOm contouring occurring at a distance of 25 km to 100 km inland . It is characterized by steep coasts with small bays and narrow sandy beaches between Cape Palmas and Cape Three Points and low beach ridges, marshes and lagoons for the rest of the coast.

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The continental shelf in the Bight is generally narrow with widths of:

* 20 to 25 km along the coast of Cote d'Ivoire, Togo, Benin and West Nigeria.
* 20 to 80 km between Cape Three Points and the Volta Delta, and
* 50 to 65 km in front of the Niger Delta

The Continental Slope in generally steep. Distinct submarine canyons exist off the Canal de vridi in Cote d'Ivoire, Western Nigeria, the Volta Delta, the western coast of the Niger Delta and off the Calabar Estuary.

3. CLIMATE

The climate in the Bight is tropical and is characterized by varying amounts and distribution of rainfall. The western part of Ghana, Cote d'Ivoire as well as the coast to the east of Cotonou in Benin record rainfall amounts above 1500 mm in a year The vegetation in these areas is tropical rain forest. In response to the movement of the Inter Tropical Convergence Zone (ITCZ), two rainfall maxima occur in May - June and October - November. The coast between Takoradi in Ghana and Cotonou in Benin receives much less rainfall (about 100 mm,/year), and is relatively dry with a Savanna type of Vegetation. Temperature Variation is small. The average daily maxima varies between 27° - 29°C in August - September and 31° -33°C in February - March The average daily minima are from 21°- 22°C in August to 23° - 24°C in March.

The Prevailing winds are the south-westerly monsoons, modified by land and Sea breezes in the coastal area Wind speeds vary between 0 5 - 2.5 m/s at night and 2 - 6 m/s during the day Storms are rare. However, line squalls with heavy rains and strong winds of short duration occur occasionally .
Between December to February the hot dry Harmattan winds are felt. Evaporation and evapo-transpiration rates are higher especially in the coast between Takoradi in Ghana and Cotonou in Benin during the dry season. The effect of the high evaporation rates in the dry season is very much reflected in the state of lagoons and marshes, which record very low depths or completely dry out.

4. HYDROLOGY

The large rivers discharging into the ocean, notably the Niger and the Volta, peak around August - October. Low discharges are recorded for the rest of the year. Smaller Coastal rivers and streams flow only in the wet season. Relatively little is known about the sediment discharges of the rivers flowing into the ocean in the Bight. Based on information on a few local rivers and other areas with similar conditions, an estimate of sediment yields of 30 to 80 tons/km2 per year has been calculated. The estimated sediment loads of the main rivers and small coastal catchments is 92 .6 Million tons per year. The percentage of sand in the total load has been estimated to be 10 to 15%. The corresponding volume of sand in the total load has been estimated to be 7.14 million m3/year.

5. OCEANOLOGY

The Bight of Benin faces the South Atlantic Ocean. The continental shelf in this region is generally narrow with no offshore islands to protect the coast against tides, currents and waves.
The tide is semi-diurnal and occurs almost synchronous in the Bight with an average range of about one meter. The tidal range is however higher towards the for east of the Bight. The coastal currents caused by these tides are generally weak.

The Guinea current which is experienced in the Bight flows offshore from west to east as a continuation of the Equatorial Counter Current in the middle part of the Atlantic Ocean (Fig 2). Its velocity varies between 1m/s (max 1.5 m/s) in December - February and 0.5 m/s (max. 0.75 m/s in August- October. It is weaker in the east. Generally, this ocean current is hardly felt near the coast
except near promontories.

Upwelling of cold water (about 22 - 25°C) occurs especially off the coast of Ghana in August - October. Otherwise the sea temperatures vary between 27° and 29°C. The annual variation of the mean sea level is about 0.1 to 0. 7 m near Cape Palmas in the west and the Calabar Estuary in the east. It is negligible in the middle portion of the Bight. The waves experienced on the coast are of two distinct origins:

* the sea, generated by the local monsoon winds
* the swell generated by storms in the southern part of the Atlantic Ocean.

The local monsoon-generated waves come from the south-west with the wind They are generally weaker rarely exceeding 1.25 m in height with a maximum period of 3 to 4 seconds. The storm-generated swells occur throughout the year but become stronger during the southern hemisphere winter. The period of these swells vary between 8 and 20 seconds, averaging about 12 to 13 seconds. Their height in deep water is 1 to 1.5 m as an average but occasionally heights of 9 to 3 m and above occur. They arrive from directions between south and south-west. From observations made from ships in the area north of the equator and east of 18°W and at the coast at Sekondi, Tema (Ghana) and Kpeme (Togo), it appears that waves that are relevant to the coast have a morphologically effective wave height of 1.2 to 1.5 m with periods of 10 to 16 seconds around a mean of 12 to 13 seconds The effective direction of the waves varies from N 190° - 220°E off Cape Palmas to N 200°- 220°E off the Niger Delta The long waves come with long crests and in trains with periods of a few minutes.

The effect of littoral transport along the coast is felt very strongly and is the main mode of displacement of sand along the coast. Its direction is mainly west to east. The littoral transport of sand is mainly caused by the incessant action of waves in the Bight, in particular the Atlantic swell. Its persistency leads to one of the highest rates of transport observed on earth .

6. GENERAL COASTAL CONDITIONS

The coast in the Bight shows three distinct features:

(i) The concave coast between Cape Palmas in Cote d' Ivoire and Cape Three Point in Ghana. The western part of this stretch is rocky and from Fresco a Sandy beach stretches almost to the eastern extremity.

(ii) The coast from Shalla to west Nigeria, with a similar concave shape between Cape Three Points and the western extremity of the Niger Delta; the Volta Delta forms an interruption The western part of this stretch is also rocky and sandy beaches prevail from the Volta Delta eastwards.

(iii) The convex coast of the larger Niger Delta with beaches and mouths of estuaries The estuaries of the Cross River form its extremity.

Thus there are three characteristic types of coasts in the Bight namely, the two rocky coasts, the two sandy coasts and the two delta coasts.

7. THE ROCKY COASTS

The two rocky coast in Cote d' Ivoire and Ghana run practically parallel WSW - ENE. Both receive a small supply of sediments which is less than the littoral transport capacity. Thus very little sand has accumulated along the coast. The pleistocene ridges perpendicular to the coast, now appear as rocky promontories. The valley in between are closed by sand bars. forming lagoons in the lower parts of the valleys. Because of the strong eastward sand transport, the short beaches fit against the eastern promontories and form a curved arc against and almost behind the western promontories. The process has given rise to stepped coasts. Essentially. these coasts are eroding. The strong waves hardly damage the hard Pre-Cambrian rocks, but more recession is observed at the cliffs of younger sand stones between Sassandra and Fresco in Cote d' Ivoire and at a few locations along the coast of Ghana.

8. THE SANDY COASTS

These coasts have essentially the same origin and evolution as the rocky beaches, the difference,

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however, is that sediment supply predominates and much more sediments have accumulated. A coastal plain has thus formed with lagoons in the Pleistocene valleys and on the plain parallel to the coast The orientation of these coasts changes gradually from WSW - ENE in the west to WNW - ESE.

The beach ridges along the coast are built by the waves up to a height of 2.5m above the mean spring tide. The marshes in the lagoons are gradually silted up to the level of the highest tides. The shore is generally flatter then along the rocky coasts. There is some equilibrium in sediment supply and loss.

9. THE DELTA COASTS

These coasts have formed along the fringes of the old deltas of rivers Niger and Volta. The Niger presently debouches through a great number of estuaries from River Forcados to River Brass The sands reaching the Sea are distributed along the coasts by littoral transport and form wide bands of successive beach ridges Lagoons and mangrove swamps with many tidal creeks have formed behind this sandy barrier and in between the estuaries.

These estuaries disturb the coastline depending on their sizes. Generally, an underwater delta with a shallow bar protrudes from the shoreline. The Volta debouches through a single outlet at the western side of its delta. The greater part of its supply of .sand has been accumulating between its mouth and a point eastward from Cape St. Paul where the littoral transport almost ceases because the south-westerly waves cannot reach this area. Heavy erosion has been occurring more north-eastward where the transport capacity picks up again and feeds the coasts of Togo and Benin.

10. CAUSES OF EROSION IN THE BIGHT OF BENIN

Coastal areas and, in particular, beaches are inherently unstable. Erosion and accretion occur naturally as a result of the action of wind, waves, stream and currents and also as a consequence of human intervention such as alteration of shorelines through the building of ports, harbours, inlet jetties, improperly sited coastal works, extraction of sand from beaches for construction and removal of vegetation from beaches and dunes. In addition to the above causes is the global sea level rise which has been estimated to be 15 mm/year in the last century. Higher estimates have been obtained over the past few decades.

More specifically the human intervention activities that have influenced coastal processes in the Bight of Benin are:

(i) the regulation of inlets with jetties and dredging in the cases of the canal de Vride (Cote d'Ivoire) and Lagos Harbour (Nigeria)
(ii) the construction of large harbours with breakwaters extending into the Sea at Takoradi, Sekondi, Tema (Ghana), Lome (Togo) and Cotonou (Benin)
(iii) the construction of Sea defence structures such as revetments, groynes and sea walls at various locations
(iv) the extraction of sand for construction purposes at various locations as well as the supply of sand at Victoria Beach (Nigeria) to the beach
(v) dredging in some estuaries along the Bight.
(vi) the construction of dams form irrigation and hydropower generation, notably the Akosombo (Ghana) and KanJi (Nigeria) dams
(vii) the extraction of gas and oil from porous reservoirs in coastal areas which lead to land subsidence as is suspected in the Niger Delta.

Significantly, it is only the coastline between Lome (Togo) and Cotonou (Benin) that presents a true regional coastal erosion problem in that erosion at Lome affects the coast at Cotonou in neighbouring Benin; all the other erosion problems are contained within individual countries or, in the case of the Federal Republic of Nigeria, individual states.

The damming of rivers results in the entrapment of sediment material from upstream in the reservoirs and also in the reduction of transport capacity of the modified flow downstream of the dam. Estimates for the

Volta river after the construction of the Akosombo dam show a reduction of about 40% of the original transport of sand to the coast.

The regulation of inlets like at Lagos and the construction of the harbours at Tema, Lome and Cotonou have interrupted the littoral transport. Consequently, sand has accumulated on the western sides and erosion has occurred on the eastern sides of these structures. These processes continue and the influence of the works spreads along the coast in both directions. Sea defence structures such as revetments and sea walls prevent erosion but hardy influence the littoral transport . Groynes have similar effects as harbour moles with the effect spreading to both sides. The extraction of sand from the beaches may cause recession depending on the quantity of abstraction compared with the supply by rivers and/or littoral transport. Short enbayed beaches are particularly vulnerable .

11. COASTAL PROTECTION IN THE BIGHT OF BENIN

Coastal protection measures that have been employed in the Bight have tendered to be the structural approach rather than a coastal zone management approach This has been the case in spite of anticipation of erosion problems precipitated by the construction of structures along the coast. The practice has been to construct the structures first and deal with erosion problems when they later arise
In Ghana several coastal protection measures have been tried.

These include iron sheet piling and timber sea walls at Keta, which both failed. Stone and Rubble mound groynes and revetment have been successfully employed at location like Nkotompo, Sekondi Naval Base and parts of the coast at Labadi and Tema. Due to reasons of cost, the emphasis is now on gabion revetments and groynes These have been very effectively employed at Labadi, James Town, Teshie, Nungua, Tema, Elmina and Krokobite beaches. The use of gabions holds a great promise for coastal protection in the future, its greatest advantage being cost effectiveness. The table below gives a cost comparison of gabion revetment gabion groynes and a combination of gabion/armour rock revetment structures constructed in Accra Ghana.

Table 1: Comparative costs of Coastal Protection Structures
Source: Nai et al, 1993

Project Title	Type of Structure	Length of coastline Protected	Total Project Cost $	Average cost of Protecting 1m of coastline $
Labadi. Phase I&II	Gabion Revetment	900m	1,171,575	1,300
Labadi Phase III	Gabion/Armour Rock Revetment	290m	463,490	1,600
Jamestown Phase I	Gabion Revetment	200m	86,920	435
Jamestown Phase II	Gabion Groynes	300m	33,650	l15

Other advantages of gabion structures are that:

* the technique is labour intensive requiring no or very little heavy machinery

- * the high porosity of the gabion structure and the low area of contact of the stones with sea waves makes it an efficient energy dissipating structure with good drainage characteristics
- * It tolerates differential settlement without fracture while increasing its structural efficiency.
- * its maintenance cost is low.

In Togo, rock groynes and breakwaters have been employed at a few locations. At Agbodrafo, a system of eight stone groynes of length between 60 - 110 m has been constructed A 150 m long rock breakwater has been constructed at Anecho and another system of 4 small groynes spread over 1.5 km length of coastline has been constructed east of the breakwater. Benin, like Togo, has not undertaken any major protection works along the coast. The few structures are two rock breakwaters to the east and west of the port of Cotonou and a groyne at the port itself.

An attempt to construct a system of nine groynes using concrete rings and gabion material to protect a tourist complex failed probably due to poor design and construction.

Coastal protection measures that have been employed in Nigeria are construction of groynes, revetments and sand replenishment . The table below gives erosion measures employed from 1958 to date at Lagos Bar Beach on Victoria Island.

Table 2: Erosion control Measures Applied from 1958 to date
Source: EEC Report (1989)

1958	Construction of a groyne at the foot of the eastern breakwater to avoid the undermining of the breakwater by erosion.
1958-1960	Dumping of sand dredged from the commodore channel at the extremity of the eastern breakwater for dispersal along the beach by waves.
1960-1968	Permanent pumping station built on the eastern breakwater supplied an average of 0.66 M m^3 pa of sand from the commodore channel to the beach; in between, in 1964, a zig-zag timber groyne (palisade) running parallel to the coastline was driven in some 26 m from the shoreline.
1969-1974	Some artificial sand replenishment was carried out; however, no reliable records of quantities or frequency are available.
1974-1975	3 M m^3 of sand dumped and spread on the beach
1981	2 M m^3 of sand dumped and spread on the beach
1985	3 M m^3 of sand dumped and spread on the beach

In addition to the above stone revetment has been constructed at Forcados to protect oil well installations. A sandbag revetment has also been used as a temporary measure in the Forcados erosion zone.

12. THE FUTURE DIRECTION OF COASTAL EROSION CONTROL IN THE BIGHT

With the identification of the causes of erosion attributable to human intervention and the increasing number of erosion sites being detected, it is becoming increasingly clear that a holistic approach to coastal erosion control should be the future direction of coastal protection in the Bight.

In this wise, Coastal zone planning and management in which the structural approach to coastal erosion control is only one of several options and may indeed be regarded as a last option should be the desired approach.

The structures that can sustain such an approach are:

(i) A coastal Zone Management Body with Co-ordination, planning, supervisory and sanctioning functions
(ii) A well-defined institutional arrangement for implementation of plans, monitoring and policing research and development in the coastal zone
(iii) A legal framework to guide and facilitate the management of the coastal zone
(iv) The development of local manpower and expertise
(v) Finally the resources to deliver the goods.

Adoption of the holistic coastal zone management approach will thus equip the sub-region to cope with coastal erosion particularly in view of global warming and sea level rise both now and in the future.

ANNEX
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