RESPONDING TO CLIMATE CHANGE IN MOZAMBIQUE

Instituto Nacional de Gestão de Calamidades

National Institute for Disaster Management (INGC)
PHASE II

THEME 2
COASTAL PLANNING AND ADAPTATION TO MITIGATE CLIMATE CHANGE IMPACTS

ADAPTATION OPTIONS

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INTRODUCTION

Mozambique is recognized as one of the countries in Africa that is most vulnerable to climate change. Hazards such as droughts and floods, variable rainfall and tropical cyclones already significantly affect Mozambique. Following a first phase investigation (INGC Phase I) aimed at defining and locally contextualizing important drivers and impacts of climate change in Mozambique, the National Institute for Disaster Management (INGC) in Mozambique commissioned a second phase of investigation. While INGC Phase I focused on determining the impacts of climate change on Mozambique at the macro level, INGC Phase II focuses on both the macro and the micro level, with emphasis on implementation of adaptation, and providing strategic guidance.

The overall goal of the Phase II projects, led by the Mozambican government, is to help protect Mozambique against the potential impacts of climate change, and to plan for and kick start prevention through the implementation of adaptation measures at national scale, on the basis of science and in support of sustainable development. Phase II projects focus on a number of thematic research challenges that have been formulated and required a multi-disciplinary effort. To this end, Theme 2: 'Coastal planning and adaptation to mitigate climate change impacts' contributes to the 'Coastal City Protection' objective. This theme is considered to be aligned with the approach followed under Theme 3: 'Cities prepared for Climate Change' and Theme 4: 'Building Resilience in participation with the private sector'. As such, the research included a number of coastal pilot sites in high impact locations that were selected under the other themes.

The focus on pilot sites introduced a scale dimension that made it possible to approach a deeper understanding of the environmental systems represented within the pilot sites. In addition, research undertaken at this scale made it possible to conceive interventions for climate change adaptation that are of sufficient substance to aid in their likely implementation. This contrasts the generalized adaptation interventions that would be conceived through research undertaken at more expansive scales.

The following key questions were addressed in Theme 2:

- Where are the most vulnerable areas along the coast, at the local/micro level?
- What will these areas look like, with climate change, in future?
- Which key infrastructure and future investment plans are at risk in these areas?
- What recommendations are in order for planned investments along the coast, with emphasis on Beira and Maputo
- What structural coastal protection measures are needed to compensate for the potential effects of climate change?
- What shoreline management plans are most appropriate for these areas?
- What should be the strategic framework on which all coastal structures and sea defences can be evaluated? What should go into a coastal zone information system? What input can be provided for an integrated coastal management policy?

In short, it can be said that the INGC wants to follow a pro-active approach to protect lives and infrastructure (Prevention is better than Cure). In addressing this task, the conservative/ precautionary principle should be applied, to find sustainable solutions that are durable and low cost to the Municipality and/or the State.

Key points from the INGC Phase I study relating to the coastal environment are highlighted in Chapter 2 whilst Chapter 3 provides a brief overview of the study area and the study sites which form the focus of Theme 2. The research approach and methodologies are discussed in Chapter 4.

The physical factors that influence the risk to coastal infrastructure and the lives and livelihoods of coastal communities in current and future climate scenarios are discussed in Chapter 5 under the heading of Drivers of Risk. An assessment of the coastal hazards associated with these drivers of risk is provided in Chapter 6.

The results of research on adaptation strategies and measures along with associated coastal protection options are presented in Chapter 7 followed by a discussion and site specific recommendations in Chapter 8. The results of interaction with municipal and institutional leaders and technical officials at some of the study sites are provided in Chapter 9. The key conclusions with recommendations are summarised in Chapter 10.

The underlying detail of selected sections is included in the Appendices.

ADAPTATION OPTIONS

The results of a comprehensive literature survey as well as in-house coastal management and engineering experience are discussed and summarised in this Chapter.

1.1 STRATEGIC PRINCIPLES AND BEST PRACTICE GUIDELINES

As discussed in Chapter 5, in Southern Africa, including Mozambique, the most important drivers of risk to coastal infrastructure from erosion and flooding, are waves, tides and sea level rise in future. It is the combination of extreme events (sea storms occurring during high tides in conjunction with sea level rise) that will have by far the greatest impacts and will be the events that increasingly overwhelm existing infrastructure in the future (Theron *et al.* 2010). Several authors (e.g. Theron, 2007 and others) have summarised the basic options for responding or adapting to these predicted coastal climate change impacts as follows:

- Do nothing;
- Defend the existing position of the shoreline;
- Advance the existing position of the shoreline;
- Retreat.

Each of these options has a different impact on the risk. Besides these basic "climate change response options", there are other actions that can be taken to reduce risk resulting from physical coastal/marine hazards (including CC), such as for example reducing human pressure on the natural defences, as is described in more detail further in this Chapter. In the foregoing chapters, the main scenarios that were considered for changing risk in the future relate to climate change, in particular sea level rise and increased storminess (due to changed/increased oceanic wind fields). These two drivers of change were therefore incorporated directly into the modelling and results discussed in the previous chapters. Man (and especially relating to the Mozambican abiotic coastal domain) has virtually no regulatory control or significant influence over these drivers. Only in the long-term and with strong unified global intervention could these drivers eventually be significantly influenced. Thus, in terms of global change or other scenarios of change, we need to identify local mitigation/adaptation options by which resilience of the coastal area can be increased.

Anthropogenic actions /interventions in the Mozambican coastal zone that could potentially be affected and that would affect vulnerability are:

- Coastal constructions which result in a significantly steeper profile (e.g. gabion revetments or seawalls) or reduce the roughness of the profile (e.g. smooth concrete or block surface), result in relatively higher wave run-up elevations for the same input wave conditions. Such constructions also often lead to erosion hot-spots in adjacent beach areas.
- Degradation of dune vegetation or destabilisation of dunes and especially actions which lead to reduction of dune volume (and height) lead to increased risk of coastal erosion. The dune sand (volume) forms the natural buffer against erosion during sea storms, preventing

excessive landward migration of the shoreline and allowing for recuperation of the beach between storms, provided that the natural processes are not impacted by human activities.

- Increased human development within the hazard zone (i.e. usually too low or too close to the sea) directly leads to increased risk.
- Any human activities which reduce the amount of sand within the coastal zone (e.g. dams on rivers or sand mining) or which reduce the rate at which sand is replenished into the area (e.g. causing a deficit in the coastal sediment budget) almost invariably eventually leads to progressive coastal erosion (thus necessitating increased erosion setback distances for coastal developments).

Considering the above interventions, it is obvious that they all relate to actions which would exacerbate the problems or increase the risks within the coastal zone. Key mitigations/adaptations or opportunities for increasing resilience thus lie in preventing or reducing such actions or impacts (in line with Integrated Coastal Zone Management actions).

For the purpose of this document it is important to note that in coastal management programmes it is desirable, beneficial and good practise to develop a *coastal protection corridor* with various zones, including:

- the Coastal Reserves as a no development zone,
- a coastal buffer strip as a limited development zone, and
- conservation corridors that include inland areas that require additional protection.

Proper planning can often eliminate the need for protection measures that might be required for future developments. The following points, adapted from various coastal management guidelines, (including Breetzke *et al.* 2008) serve as a guide:

(1) *Avoid the hazard*
Locate the development in such a way that the hazard cannot affect it. This requires determination of setback lines and buffer zones (Theron, 2000). This will always be of long-term financial and ecological benefit.

(2) *Prevent the loss*
Accept that extreme natural events will occur. Therefore take measures to minimize damage to or loss of property against the impact of extreme natural events.

(3) *Do nothing if appropriate,* rather than ill conceived plans/actions, especially those that ignore full ("triple bottom line") long-term costs/consequences. (If, for example, the main hazard in an area is deemed to be erosion, it may in a particular case be argued that the erosion is cyclic and that the sand will be replenished naturally over time. In such particular instance it may then be appropriate not to take any action.)

The *key questions* that should be considered in planning developments near the shoreline are:

- Will disaster risk increase for the population living in/near the area of intervention? If yes,
- Is the development "location dependent", i.e. is it really necessary for it to be located on or immediately adjacent to the shoreline?

- If development must take place within the sensitive dynamic area, what mitigating and maintenance measures will be implemented?
- Can sediment movement and therefore erosion be altered by the proposed development?
- Will the existing protection e.g. foredune ridge, mangroves etc be affected in any way?
- Will the groundwater regime be affected in any way? And potable water supply for population centres nearby?
- Will the proposed development or activity affect the coast in terms of its tourism/entertainment value .e.g. aesthetic-, swimming- surfing- or sunbathing values?
- Will the proposed development or activity affect the coast in terms of its nature conservation value, or detrimentally affect the ecology e.g. breeding of birds or other organisms?
- Has an accountable body or organisation been identified to determine the mitigating measures and ensure that such measures are properly implemented?

Strategy to plan & "live" with coastal erosion:
Following the coastal erosion events of 2006 and 2007 the KwaZulu-Natal Department of Agriculture and Environmental Affairs has compiled a *Best Practical Guide for Living with coastal erosion (*Breetzke *et al.* 2008*)*. The following are adapted from the document to ensure relevance to this study:

"Living with coastal erosion" requires that the following principles are acknowledged:

- Continued global warming is likely to cause sea level rise and increased intensity and frequency of coastal storms;
- Increased coastal erosion will lead to higher and continued risk to human life and the natural and built environments;
- Best International Practice in the face of sea level rise and changing coastal dynamics is a phased retreat away from the shoreline;
- It is not inconceivable that areas along the coast will lose more sand as a result of natural processes;
- The severity of this loss will be dependent on coinciding phenomena such as storm events [winds & waves], occurring at equinox (highest annual) and spring high-tides and cyclones;
- Any construction too close to the sea/beach interferes with natural sand movement and may impede beach and foredune recovery after a serious storm event;
- Removing sand from beaches increases the severity of erosion;
- Badly planned and inappropriate sea defences may cause further loss of sand resulting in beach degradation on site and to beaches and properties further along the coast; and
- Removing vegetation from dunes destabilises these protective sand barriers and reduces its function as natural sea defences.

The following are best practice guidelines to manage the human response to coastal erosion:

Accept and live with erosion

- Plan any coastal construction so that it is a safe distance away from the high-water mark and reinstate natural defence mechanisms with the necessary environmental authorisations.

A collective response is required

- Holistic planning and implementation by authorities in response to coastal erosion is critical. Coastal Management Programmes, incorporating Shoreline Management Plans, are required to reduce the direct and associated effects of erosion.
- Neighbours need to institute similar mitigation measures for the same reason. This collaboration will increase defence effectiveness and reduce costs.

Establish a coastal setback

- A development setback line is designed to protect both the natural environment from encroachment from buildings as well as protecting beachfront developments from the effects of storms and accelerated coastal erosion..
- Development seaward of this setback is considered to be at high risk from coastal erosion.

Work with natural processes in responding to erosion (and flooding)

- Soft coasts mostly require soft solutions.
- The preferred protection measures should make use of soft engineering solutions – e.g.:
  - A geofabric sand container or other suitable sand bags (which could be covered with dunes & vegetation),
  - Managed dune systems, which should be vegetated with appropriate dune species as per the original natural zones and maintained; maintain, or even better, increase the sand reservoir (volume) stored in the dune system.
  - Protection, restoration and maintenance of natural systems like mangroves and coral reefs.

Replace lost sand with sand (i.e. beach nourishment)

- It is important that the sand used must be of a similar nature to that found on the beach.
- Accessing beach sand from other sources should only be considered following input from appropriate experts (e.g. it might be necessary to find an offshore sand source – this is usually very expensive).

Consider hard engineering solutions in exceptional cases only

- Resort to hard engineering solutions only in exceptional cases and only after detailed environmental impact assessment and authorisation is obtained.

Be prepared, monitor and react: Employ appropriate “early warning” systems; Appropriately reconstruct coastal infrastructure and amenity

- Early warning systems (or appropriate long-term monitoring) allow plans to be made to “handle” extreme events (e.g. sea storms) and reduce the associated risks.

- Infrastructure that is damaged as a result of coastal erosion should not just be replaced. Its appropriateness should be assessed and necessary improvements made, and in the medium-to long-term, plans prepared and implemented for a managed retreat of such infrastructure.

Avoid and reduce the risk

- This includes risk factors emanating from "non-marine/coastal processes", e.g. stormwater runoff from streets, parking areas or drains:
- Coastal property owners are responsible for the maintenance of stormwater discharge and may be liable for any erosion or negative impact such discharge may have on the frontal dune or beach.
- Where stormwater has to be discharged onto a dune or beach, such discharge should be away from the dune face and toe. Discharge should preferably be onto a hardened area such as a rocky headland.

Most of the response options described in this section (7.1) are purposefully what can be termed "soft" options or "working with nature". This is in line with strategic principles and best practise guidelines in terms of coastal management and responding to climate change. The following section (7.2) has a more site specific focus and includes all appropriate adaptation measures and coastal protection options, "soft" and "hard".

1.2 POTENTIAL ADAPTATION MEASURES/COASTAL PROTECTION OPTIONS

1.2.1 Range of potential solutions

Many useful publications that address potential implications and adaptation/coastal protection measures can be found in the literature, e.g. UNCTAD (2008) – Table 1. Other examples include: NCCOE (2004), Stive *et al.* (1991), Breetzke *et al.* (2008), FEMA (2000), USACER (2004), SNH (2000), Van Rijn (2011), and others.

However, due to various factors, southern African states actually have very little adaptive capacity and their ability to halt coastal impacts on a large scale are virtually non-existent (Theron 2011). According to Tol (2004), adaptation would reduce impacts by factor of 10 to 100, and the adaptation costs would be minor compared to the damage avoided.

This is a clear imperative to set and implement adaptation measures sooner rather than later. To mitigate detrimental impacts resulting from climate change, an understanding of the adaptation options available to developing African nations needs to be reached and that these are considerably different from some traditional approaches used in the developed countries. Mozambique is also not a wealthy country and has less money available for coastal constructions; more affordable response options are required.

Table 1: Examples of potential implications and possible adaptation measures (adapted from UNCTAD, 2008)

CLIMATE CHANGE FACTOR	POTENTIAL IMPLICATIONS	ADAPTATION MEASURES
Rising sea levels • Flooding and inundation • Erosion of coastal areas	• Damage to infrastructure, equipment and cargo (coastal infrastructure, port-related structures, hinterland connections) • Increased construction and maintenance costs, erosion and sedimentation • Relocation and migration of people and business, labour shortage and shipyard closure • Variation in demand for and supply of shipping and port services (e.g. relocating) • Changes in water levels in harbours	• Relocation, redesign and construction of coastal protection schemes (e.g. levees, seawalls, dikes, infrastructure elevation) • Insurance • Raising of existing breakwater-structure to counter additional overtopping • Raising of existing quay and wharf levels
Extreme weather conditions • Tropical cyclones • Storms • Floods • Wind	• Damage to infrastructure, equipment and cargo (coastal infrastructure, port-related structures, hinterland connections) • Increased damage to ships as a result of wave current interaction • Erosion and sedimentation, subsidence and landslide • Relocation and migration of people and business • Reduced safety and sailing conditions, challenge to service reliability • Modal shift, variation in demand for and supply of shipping and port services • Change in trade structure and direction • Change in wave climate (swell and long period waves) in harbours	• Set up barriers and protection structures • Relocate infrastructure, ensure the functioning of alternative routes • Raising of existing breakwater-structure to counter additional overtopping • Increase monitoring of infrastructure Conditions (e.g. CSIR breakwater monitoring programme) • Restrict development and settlement in low-lying areas • Strengthen foundations, raising dock and wharf levels • Smart technologies for abnormal events detection • New design for sturdier ship • Designing new ports • Revising dredging maintenance programmes, amended beach nourishment programmes • Revision in ship mooring operations and equipment in ports • Alterations to ports to compensate for additional wave action (swell induced or long period waves)

1.2.2 Listing and description of potential solutions

By considering the coastal processes and characteristics of the study area, and factors governing suitability for coastal development, various potential responses can be formulated. A significant number of management options and "soft" and "hard" coastal engineering methods are available to protect the shoreline. The options described here do not include all possible coastal protection measures/options; however, the listed options include the potentially more appropriate measures:

<u>A "Management options"</u>

A1 **"Accept and retreat."** This involves repositioning infrastructure at risk so that it is no longer in danger of being affected by erosion or flooding. This requires zoning (through set-back lines) and retreat of communities and infrastructure to landward of the setback plus possibly an additional buffer zone. Ultimately this means better planning and management of both the built environment and natural resources, including specifically to increase the climate resilience of current development plans, in this case coastal infrastructure & development. Government must be directly involved in resettlement of populations to lower risk areas (this is also a good option for low cost housing projects). However, much can additionally be achieved by encouraging, incentivizing & enabling "private" migration to lower risk areas. Large costs are associated with the relocation of utility infrastructure (power, roads, water reticulation, water treatment, storm-water runoff and telecommunications), but these can be offset to some extent, e.g. through enhanced tourism & investment opportunities, or foreign aid.

This option, the "accept & retreat" option, will allow for the continued erosion of the coast by the sea. Where the coastline has not yet been significantly developed (low existing infrastructure value), as in the case of large parts of the Mozambican coast, and the cause and effect of the erosion problem is of a large scale, this is often a wise choice in the long-term (e.g. Theiler, *et al.* 2000). It is also very much in line with the strategic principles and best practice guidelines discussed before. This option implies abandoning and removing existing infrastructure located near the sea. All infrastructure and development would have to be located landward of at least the 50 year coastal development setback line, while major developments and those with a longer design lifespan should be located landward of the 100 year setback line. However, this option does not provide protection for existing strategic or high value developments/infrastructure that are likely to be considered areas that must be defended.

A2 **"Abstention"** involves the 'do nothing' option. This option can be feasible if the risk of loss of property or human life is considered to be minimal. With this option, the current status quo will prevail, i.e. the actual/potential shoreline erosion and/or flooding continues with the associated consequence to the area.

A3 **"Alternative" coastal developments**. Provide good access to and develop alternative coastal areas (including providing services such as storm-water drainage and ideally sewerage systems), which are not prone to impacts such as flooding or erosion.

It is recommended that while interventions within existing developed areas are instigated, development of these alternative areas should progress in parallel.

A4 **"Accommodation"**. The intent here is not the direct defence or protection against the rising sea or storm waves, but to increases resilience or to better accommodate the associated impacts on infrastructure. Such measures include "climate or flood proofing", such as raising property, more robust buildings, and improved early warning of climatic hazards such as extreme storms. The relevant action is to plan to build infrastructure to higher design standards to withstand higher frequency of storm wave impacts, flooding/inundation and under-scouring. Some of these measures can be employed by property owners and private developers (Figure 1). At ports the foundation should be strengthened to allow for a future raising of the levels of the wharfs and quays as SLR occurs.

Figure.1: Example of local accommodation measure
(Photo: Holland Herald, KLM, September 2011)

B "Soft engineering" or Restoration ("semi-natural" interventions in the littoral zone)

B1 **Sand nourishment:** discrete localized nourishment projects or ongoing/regular nourishment projects; to mitigate existing and/or expected future coastal erosion problems, or even to build up a wider than present beach area, which will also reduce possible wave impacts and flooding potential. Stive *et al.* (1991), argue that shore nourishment is an effective mechanism to prevent shore retreat owing to long-term sea level rise because of the uncertainties and the flexibility that shore nourishment provides. Provided that sufficient sources of suitable sand are available, this is a good "soft" adaptive strategy, often better than "hard" (e.g. structural) approaches in the long-term. However, sand nourishment is expensive (like "hard" solutions) and the need for eventual re-nourishment, although foreseen and planned for, is sometimes perceived as "failure" by the Public.

Beach area can often be created or expanded by artificially feeding sand to an area (beach nourishment). To maximize benefit to cost ratios, the time between required re-nourishment events (maintenance intervals) is typically found to range from 6 to 12 years. However, a lack of a sufficient sand source could rule this out as a viable option in such areas. Usually a discrete localised beach nourishment project is quite feasible in areas where the background erosion rates are up to 0.9 m per year; are marginally feasible in areas where the background erosion rates are 0.9 m to 1.5 m per year; and are generally not economically viable if the rates are greater than 1.5 m per year (USA values - Dean, Davis and Erickson 2006). However, USA back-shore property values are very high, while most Mozambican values would be much lower. The implication is that the acceptable background erosion rate for developed areas of the Mozambican coast area is probably lower than 0.9 m/yr.

At a cost of perhaps \$ 10/m^3 a project of 2 million m^3 would cost in the order of \$ 20 million. If costs are compared on a unit cost per metre basis, this option is actually very competitive. To supply a mean volume of say 300 000 m^3/yr, could cost in the order of \$ 3 million per year, or perhaps \$ 500/m of shoreline. If options for cost sharing with existing port dredging operations are not available, foreign aid could be employed to fund such projects.

Figure.2: Beach nourishment by means of direct "rainbowing" of sand from the dredger to shore (only practical in certain areas).

Figure 3: Beach nourishment by means of pumping sand onto the beach through a pipe system

B2 **Managed (vegetated and/or reinforced) dune**. Construct/reinstate and/or manage vegetated dune buffer areas. Where appropriate, it can be crucial to maintain an affordable and effective soft-engineering coastal defence mechanism that preserves the ecosystem services that protect natural backdune areas and man-made development against the forces of the sea.

Rock protection or gabions can be placed underneath a (normally vegetated) dune. During a storm the dune will be eroded, but the rock/gabion will prevent excessive erosion. After the storm the dune could recover naturally, but in some instances may require active restoration and management.

Dunes are usually the soft coast's natural protective buffer against storm seas and high spring tides. Sand trapped in a dune system is stored and can be returned to the beach, thus preventing beach erosion. Vegetated dunes protect houses, roads and recreational facilities against corrosive sea spray, sand blasting and inundation by sand blown inland from the beach, as the vegetated dune functions as a natural sand trap. The dunes should have a crest height of approximately +6 m to +10 m to MSL (depending on local circumstances), while the base width should ideally be at least 60 m. In terms of the cross section, the seaward slope of the dune should be approximately 1:6. The estimated total cost of a dune, including reinforcement, is in the order of $ 240 000 per 100 m alongshore. The dune would be aligned approximately parallel to the shoreline.

The estimated cost of constructing a non-reinforced dune is in the order of $ 1400 /m. The following items should be allowed for in costing: site establishment, bulk earthworks, shaping and trimming, irrigation system, fertilizers, mulching, harvesting of pioneer species, planting of dune vegetation, fencing, footpaths, signage and limited consultation. Estimated cost of placed rock reinforcement is about $ 100/m^3, with additional costs relating to the reinforcement, estimated at about 75 % of the cost of the rock. Such reinforcement would only be required if there were very important reasons to reduce the shoreline variability in a specific location. The use of local labour in labour intensive projects could reduce the cost of building or maintaining dune systems.

Figure.4: Example of a vegetated dune at Beira with sufficient volume and height to protect landwards areas from storm erosion or coastal flooding.

Vegetation (e.g. grass planting), thatching and fencing can be installed to hold or trap beach sand. In some instances, vegetation can reduce erosion by holding the sand. Casuarina trees have been planted in some coastal locations in Mozambique (e.g. Tofo, Maputo). However, these Casuarina trees have not been effective in preventing local soil erosion. The use of proper dune vegetation and appropriate grasses can be more effective. Suitable dune vegetation and grasses typically have a fine root system that goes over 2 meters deep, is tolerant to salt and cannot be easily uprooted. The vegetation is typically capable of tolerating sand-blasting and traps windblown sand, thereby contributing to dune development. By planting this vegetation strategically and fixing large volumes of sand in calm periods, a buffer can be created over a number of years that can erode in the stormy periods, thereby reducing erosion of the backshore areas.

The use of non-invasive dune vegetation above other alternatives can be advantageous because it is cheaper and can have a higher aesthetic value. Further, it does not have negative effects on the adjacent coast, as many engineering structures do. It can therefore be used if there are limited financial resources available and could be undertaken by the owners of the property along the beach. Thus, it is a relatively "cheap" low environmental impact quasi-natural intervention to promote natural dune volume growth.

On the other hand, it is difficult to be certain that the degree of protection is adequate for more than low erosion rates, particularly cyclones that can recur frequently result in relatively high erosion rates. It does not provide immediate protection and requires some maintenance to establish. Thus, it often has small potential for making a big difference, especially if used in isolation and not in conjunction with other management actions/interventions or protective measures. In general it can be concluded that grass planting, thatching and fencing are relatively "cheap" low environmental impact quasi-natural intervention to promote natural dune volume growth, but sometimes have small potential for making a big difference.

B3 **Mangroves, corals and wetlands**

Mangroves are not only ecologically important (especially for fisheries), but if they occur in sufficiently dense stands of sufficient cross-shore extent, they also structurally behave like a semi-permeable barrier (mostly due to their root system, much of which is above ground level). Energy is dissipated and sediments can even accumulate under suitable circumstances, thus reducing the flooding/erosion potential of waves/cyclones and proving some shore protection to landward areas. Wetlands can have a similar dampening effect and if of sufficient extent can help to dissipate flood waters and wave impacts on landward areas. Properly planned restoration of damaged mangrove areas are practical and can be used as a local job creation initiative, often in collaboration with private enterprise.

Storm waves approaching the coast (e.g. resulting from cyclones) are affected by bottom topography, and shallow coral reefs that cause wave breaking dissipate much of the incident wave energy. However, as the sea level rises, existing topographic features including coral reefs will be located in deeper water and will have a reduced effect on waves approaching the coast. Areas landward of the reef breaker zone will experience an amplified wave climate compared to the present. At low rates of eustatic sea level rise, healthy corals can grow to match the rate of SLR, thereby retaining their protective effect. Deeper water features including coral reefs may deepen to the degree that their effect on the wave energy impacting on the shoreline is negligible.

However, the coral reef areas of Mozambique are very vulnerable to CC impacts, through coral bleaching (e.g. Obura 2005), in terms of direct effect on the biota as well as on the important linked socio-economic sectors (e.g. tourism). As mentioned, the coral reefs serve other important functions, such as sheltering the coast from wave action and by providing beach building materials. Thus, loss of coral due to CC will also negatively impact these functions with detrimental impacts on the coast (e.g. erosion).

Similarly, fringing reefs are found along some areas in Mozambique. These reefs comprise tough, algal-clad intertidal bars composed largely of coral rubble, and provide protection from wave attack to the inshore areas and beach sands that are susceptible to erosion (Arthurton 2003). If the coast is subjected to the predicted sea-level rise, the protective role of the reef bars will be diminished if their upward growth fails to keep pace (Theron and Rossouw, 2008).

Mangroves, corals & wetlands therefore all have some “coastal protection” potential and can mitigate coastal climate change impacts to some degree. The opportunities therefore lie in protecting and managing these natural defences, or indeed in enhancing/expanding their positive effects by increasing such areas where practical or reintroducing such natural systems where they have been lost or impacted.

C "Hard engineering" & armouring (construct shore protection measures)

C1 **Seawalls** (mostly vertical or curved concrete structures) **and revetments** (including rock and concrete sloping revetments), involve the construction of 'hard' protective structures that are placed along the shoreline so as to act as a distinctive barrier between the land and the water, thereby directly preventing erosion and/or flooding of the back shore. Ground level (natural or raised) on the landward side of the structure is usually at the same elevation or higher than that of the crest of the structure.

There are many types of revetments and retaining walls. The material of which they consist (rock, wood or concrete) and characteristics (e.g. permeability) result in differences in costs, longelivety, effectiveness & environmental impacts. Without detailed topographic surveys of the local project sites and possible underground foundation rock, it is very difficult to estimate quantities and thus construction costs. Design and construction supervision costs could be about an additional 10% of the total cost. The estimated costs provided further on in this Chapter and Chapter 8 are mainly for comparative purposes and more exact costs can only be determined once detailed designs have been completed. The availability of suitable rock, access roads and a quarry site all have big impacts on the total project cost. The extent of work can also be tailored to suit the available budget, although the greater the number of phases, the greater the overall project cost, i.e. due to longer construction supervision required and additional costs for re-establishment of a contractor on site.

Figure 5: Examples of a revetment (left) and a seawall (right) in Mozambique

Figure 6: Example of a rock revetment protecting houses (South Africa)

C2 **Dikes,** similarly to C1, act as a distinctive alongshore barrier between the land and the water, but are often massive sloped (even landscaped and vegetated) loose standing sand or earthen mound constructions. They can be armoured (e.g. by a revetment) on the seaward side, or left unarmoured, but might then require significant maintenance or restoration after large storms. Their massive nature and large space requirements also make this an expensive option and difficult to apply in congested or very built up areas. However, they can be an option where absolutely necessary to protect current, immobile, vital infrastructure (e.g., potentially appropriate areas associated with the ports and cities of Beira and Maputo provided that sufficient space can be made available), but the development of new infrastructure directly adjacent to the dike should generally be avoided. To be effective against flooding, they have to be continuous or linked to other defences. It is essential to also plan for dispersing of floodwaters trapped inside the dike resulting from rainfall runoff or river flooding.

Figure.7: Examples of vegetated dikes (Germany)

C3 **Perched beach or sill structures,** which aim to artificially keep the upper part of the beach profile in place seaward of where it naturally would be. Wave energy is dissipated on the beach, which reduces the wave run-up.

The available beach area can be expanded significantly by constructing a "perched" beach. This is simply a structure that allows a beach to be formed at an elevated level on the upper beach and prevents significant wave erosion. The structure consists of some form of partially submerged retaining wall, bulkhead or revetment, and is usually aligned roughly parallel to the shoreline. Hard rock substrate is required to provide good founding conditions, as the structure will have to withstand significant wave action.

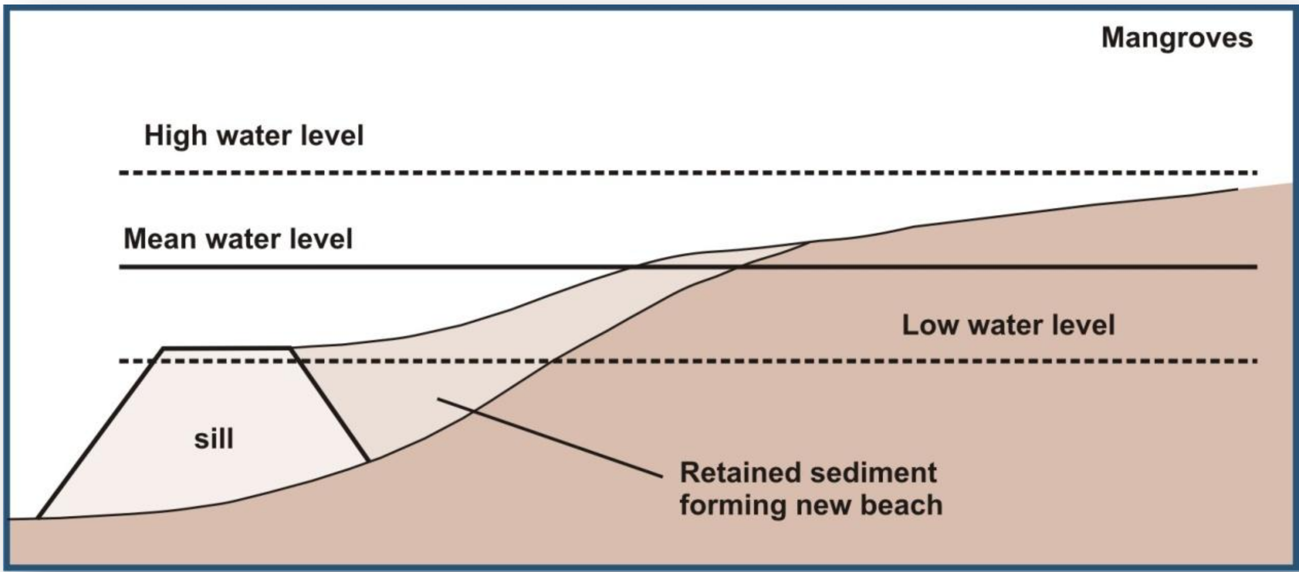

Figure.8: Perched beach with partially submerged retaining structure

A lack of good rock foundation conditions would make this an even more expensive construction. Some structures are designed to support the near-coast profile seaward of where it would otherwise be. Successful prototypes of such low structures, when designed to retain an artificial "perched" beach, are rare. The two main disadvantages are perhaps that the perched beach can easily lead to dangerous bathing conditions (due to e.g. the presence of a hard structure in the surf zone, the sudden drop-off and potential generation up rip currents), and a local intervention (i.e. small project area) would not address possible existing much wider background coastal erosion problems.

C4 **Shore-parallel structures** (e.g. artificial surf zone reefs, detached breakwaters, rock berms, etc.). These structures are normally built parallel to the shoreline and some are not connected to the shoreline. The structures are mainly designed to induce wave breaking and can either be submerged or above the water. (This could also include tidal pools, with or without beaches, as multi-functional structures.) These types of structures are usually expensive to place, require heavy plant and access roads and might need to transport both construction plant and rock material over long distances if it is not locally available (as in some parts of Mozambique), all of which can make this an expensive option.

Figure 9 Example of erosion mitigation through shore-parallel structures (Anglin, et al. 2001)

Figure 10: Example of beach accretion through submerged artificial reefs

An offshore beach retention structure is a non-shore-connected feature that acts to retain a beach larger than would exist in its absence. Most of these structures perform this function by affecting waves such that a reduction in wave energy in their lee or a changed alignment of waves in their lee results, sustaining a protrusion of the shoreline. These structures are categorized as surface piercing or submerged offshore (or detached) breakwaters and artificial reefs. Each has advantages in retaining a beach. Conversely, there are disadvantages linked with each of them, including in some instances that the beach remains depleted and erosion continues, adverse erosion impacts on adjacent beaches, and failure of the structure. The most successful offshore structures have been those that are high, surface piercing, impermeable, “two-dimensional” breakwaters. Complexity in the functional design process increases as the height of the structure is reduced. In addition to diffraction effects, wave energy that passes through or over low or submerged, “two-dimensional” breakwaters must be considered.

Thus, the concept of an artificial reef is to cause the waves that at present prevent a beach from building up, to break on this reef. By dissipating sufficient energy, a beach will form along the shore in the lee of the structure. The crest elevation and width of this reef have to be sufficient to cause such wave breaking and energy dissipation. This is similar to what occurs naturally in many areas where Tombolas are found in the lee of natural reefs. If the crest is too high, the reef will be more visually obtrusive. On the other hand, if the crest is too low, the reef will not be effective in reducing wave energy with the associated build-up of sand in the lee area. The crest of the beach-reef will probably have to be at at least +2 m to +4 m to MSL or higher (depending on which area of the Mozambican coast is considered). The crest should probably be 4 m wide or more (also for practical construction purposes). The reef should be constructed of rock armour with sufficient weight to be stable under the expected wave conditions. The reef should be founded on existing bedrock if at all possible and the side slopes should probably be one in two (that is one vertical to two horizontal). The reef would be aligned approximately parallel to the shoreline and would have a unit length of at least 150 m. A disadvantage is perhaps that the localised artificial reef would not address possible existing wider background coastal erosion problems. In addition, potentially dangerous rip currents could be generated near the extremities of the reef especially during high tides.

Similar to the artificial beach-reef, the concept of an artificial surf zone reef or alongshore breakwater is also to initiate wave breaking to allow a beach to form in the lee of the structure. The difference is that the surf zone reef is not located on the existing beach, but significantly further seawards in the surf zone (or beyond). This means that the surf zone reef is less obtrusive than the beach-reef and also presents less of a barrier between the beach and the inner surf zone area. On the other hand, the surf zone reef will obviously be much more expensive, due to the larger rock volume (larger sectional area and reef length) and the larger rocks sizes required to remain stable under the incident wave conditions in the deeper water. The surf zone reef would have a unit length of about 200 m or more, including required gaps in the reef. As the sea level rises in time, the effectiveness will be reduced and reconstruction/addition may be required. This reconstruction/addition needs to be incorporated into the design.

C5 Groynes (straight, curved, T, L etc.). Groynes constructed perpendicularly or at an angle to the shoreline, can trap sediment and provide protection.

Groynes can trap sand and aid the formation of a beach at the foot of the groyne. In general, a larger beach will tend to accrete on the updrift side of the groyne, with a smaller beach directly on the downdrift side in the lee of the groyne. A localised erosion area usually forms slightly further downdrift of the groyne. Lengthening of the groyne up to the outer surf zone will increase the beach area, but at a much greater cost. Groynes create very complex current and wave patterns. The orientation, length, height, permeability, and spacing of the groynes determine, under given natural conditions, the actual effects on breaking wave conditions, local currents, sand transport and changes in the bottom configuration. Problems sometimes arise with groynes due to cross-shore sand losses during storms or the formation of strong rip currents parallel to the structure.

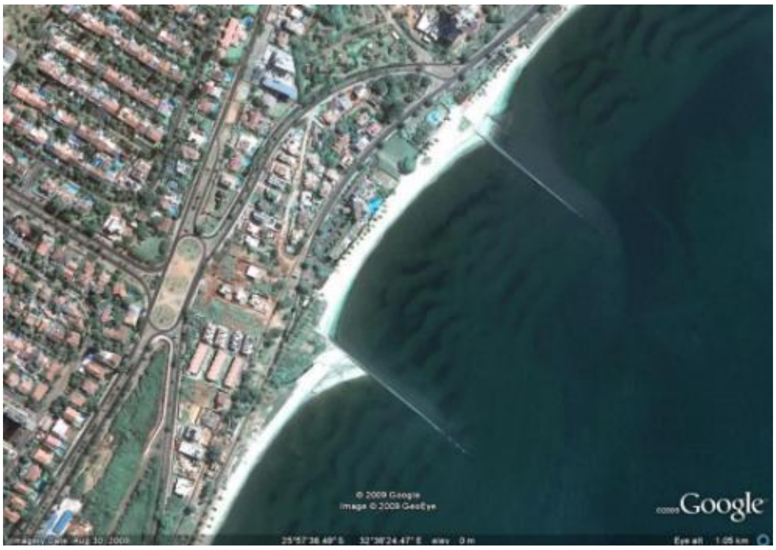

Figure.11: Existing groynes along Maputo shoreline

Figure 12: Groynes protecting Richards Bay entrance channel shoreline, South Africa (Photograph S Pillay)

C6 A **spending beach** of very coarse sand, gravel or cobbles can be used to dissipate wave energy and reduce erosion. Storm erosion of such a beach would be much less than for the natural finer grained beach material. A large source of such material is required relatively near the application site to make this option economically viable. (No obvious large deposits of such materials were observed during the Mozambique site reconnaissance.)

C7 The installation of a **beach (and dune) dewatering mechanism**. Sediment "stability" can be increased by reducing the pore water pressure.

Geotechnical assessments of Kwazulu-Natal coastal areas (Theron, 2008) indicated that the phreatic surface and the emergence of seepage water along the shoreline influence slope stability. It seems that this is the only geological parameter that could potentially be manipulated in limited local areas. The basic concept here is to decrease the pore water pressure of the beach sand/dune to such an extent that the beach sand is not fluidized by waves and/or the groundwater within the dune is drawn down to enhance the dune slope stability. The system consists of a pipe network (with relatively closely spaced water extraction points), which is placed some distance below the normal sand level (say 1 m) and to which suction is applied.

Although not a new technology, this concept found favour in coastal engineering applications in the late 1980s and early 1990s (e.g. Jenkins and Bailard, 1989, Parks, 1991, Ogden and Wiesman, 1991, and Wiesman *et al*, 1995) with patents being granted to Vesterby in 1987 and Parks in 1991 (Parks, 1992). In theory, this is a promising concept, but in practice it has met with limited success in coastal engineering applications. More recent publications (e.g. Turner and Leatherman, 1997, Bruun, 1989, and Bruno, 1999) are somewhat critical of earlier claims that this is a successful technology. The problems include the practical side of the application (sometimes aggravated by conditions in the harsh and dynamic coastal zone). The difficulties range from maintenance of the electrical supply, motors and pumps which extract water from the system to the robustness and durability of the pipe network. The initial position of the pipes and the flow rate through the system are also critical design parameters, but due to the dynamic nature of the coastal zone it is very difficult to ensure success under all conditions. For example, if the pipes are placed too deep or the flow rate is too low, the sand will not be effectively de-fluidised. On the other hand, if the pipes are placed in too shallow a position, the pipes may be scoured open resulting in damage. There is also a considerable risk that the system could be scoured open and damaged by wave action, especially if the shoreline is experiencing an erosion phase (or longer term trend), or localised erosion "hot-spot.

Due to the many technical and practical problems associated with this option, the high maintenance costs, as well as the largely unproven track record, this option is not recommended.

C8 **Coastal flood control gates** in "enclosed" areas (e.g. river mouths, small bays).

Well known examples include components of the Delta works in the Netherlands and the Thames flood barrier in the UK. These flood defence works tend to be very large and expensive schemes (as in the two examples mentioned), linked into wider dike defence systems. Suitable foundation conditions are ideally required, which is a major constraint in river mouth and delta areas with deep mud/silt deposits. For these reasons, this option is considered to be largely unsuitable for practical application in Mozambique.

In low to moderate wave energy environments:

C9 **Closely spaced piles or wave fences** to dissipate wave energy.

Such structures can be successful in dissipating wave energy in low to moderate wave energy environments. However, they have no effect on rising sea levels, and coastal areas will still be subject to increased risk from flooding due to SLR. Thus, this is generally considered to be an unsuitable adaptation measure for the purposes of this investigation.

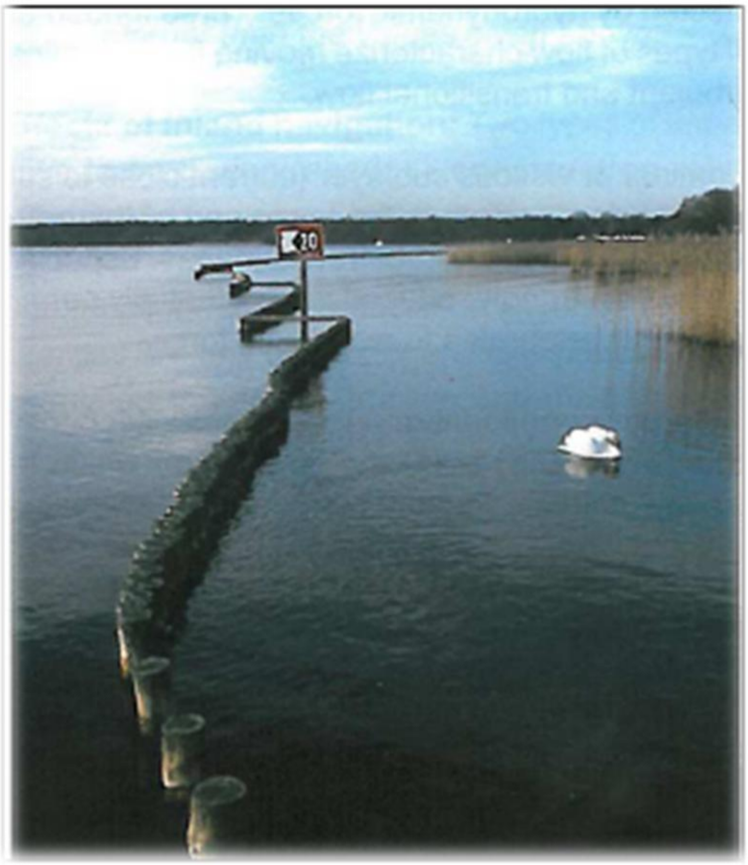

Figure.13: Piles driven to form a wave fence (about 50 % reflective - PIANC, 2008)

C10 **Floating moored "breakwater" type structures**.

Figure 14: Patented floating breakwater (www.whisprwave.com)

Such structures can be successful in dissipating wave energy in low to moderate wave energy environments. However, they have no effect on rising sea levels, and coastal areas will still be subject to increased risk from flooding due to SLR. These types of structures also require considerable maintenance, with significant cost implications. Thus, this is generally considered to be an unsuitable adaptation measure for the purposes of this investigation.

C11 **"Geotextile" shore protection**, usually sand filled geotextile containers.

Traditional forms of shore protection, such as detached breakwaters, groynes, revetments have become expensive to build and maintain (especially if not well designed or constructed in the first place). This has prompted novel designs of low-cost shore protection. These protection measures may need replacement at relatively short intervals but might still be more affordable and economic in the long term than conventional methods. Low-cost shore protection methods are especially suitable when emergency beach erosion measures are urgently required.

The CSIR has conducted comprehensive literature reviews in order to learn from international experience. Promising measures were identified and new low-cost shore protection measures were developed (Theron *et al.* 1994). These concepts were then tested initially in the laboratory and eventually in prototype (in South Africa at Strandfontein, Hermanus, False Bay and at Oranjemund in Namibia). These prototype tests enabled this new technology to be applied successfully and cost effectively to projects (Theron *et al.* 1999).

Possible applications of the low-cost shore protection include the following:

- Protection of the shoreline against erosion.

- Sleeping defence underneath a dune to safeguard against extreme beach erosion.
- Preventing scour near coastal/marine structures.
- Limiting the cost of breakwaters or groynes.

While modern geotextiles are durable, they should be regarded as temporary measures as their lifespan for longer than a decade has not been proven. Successive storms may breach the protection if it is not maintained. Maintenance will be necessary after every major storm to replace sandbags that have been moved or damaged. If they are used as “sleeping defence” structures against extreme events and covered by sufficient sand (dunes), routine maintenance costs can be much reduced. The cost of durable geotextile material is high. The work has to be done under supervision of an experienced contractor. For construction of a groyne of sandbags a typical price is $ 200/bag for 0.75m^3 bags, including placement. A sandbag revetment would have a volume of at least 11 m^3 per meter shoreline length. Thus, for a 100 meter revetment the total price will be about $ 300 000. Present low-cost shore protection measures may not to be appropriate for *permanent* solutions to the more severe erosion problems possibly encountered in some areas or expected in future. They are also generally not suitable for use as “breakwater type” structures in deeper water.

Figure.15: Examples of geotextile (sand bag) revetments (Kwazulu-Natal, South Africa)

C12 **Gabions and/or rock filled wire basket & mattress structures**.

An example of a Gabion retaining wall structure is depicted in Figure 14

Figure 16: Example of a Gabion retaining wall structure (to protect the back-beach area)

Evaluations of Gabion structures from literature and practical experience:

- "At sites where there was significant wave action, abrasion, and impact forces, the gabion baskets tended to be broken quickly. Corrosion was a significant problem at most sites, even though PVC-coated baskets were used... The hazard posed by the baskets once deterioration begins would restrict their use only to site where there is little public use." (Combe *et al.* 1989, page 61-62).
- A UK report (Welsby and Motyka, 1984) reviewed the performance of Gabion structures around the coast of the UK: "Opinion as to the lifespan of metal gabions on the foreshore is divided but the general consensus is that in areas subject to severe wave activity, gabions will succumb to rapid abrasion and as a result their lifespan can be as short as 2 or 3 years. On flat sand beaches subject to moderate or low wave activity the lifespan can be a decade or more. On the backshore, where gabion structures are not subjected to regular wave activity, they can be expected to have a considerably longer life." The report also notes that the performance of the Gabion under wave action often depends on how well they're packed (Powell, pers com. 2011).
- If there is any debris in the water or cobble on the beach, the baskets are prone to failure (Tanski, 2011 pers com.).
- In all of these types, construction practice is critical, especially regarding stone gradation and packing to resist self-destruction (McGehee, 2011 pers com.).

Gabions can also be used as “sleeping defence” structures against extreme events and covered by sufficient sand (ideally vegetated dunes), which will reduce routine maintenance costs. **While Gabion structures may be durable and relatively low-cost, they should probably be regarded as temporary measures based on the above review. Rock filled wire basket & mattress structures employed as shore protection measures may not to be appropriate for *permanent* solutions to the more severe erosion problems possibly encountered in some areas or expected in more areas in the future.**

D Combined options

Many combinations of the above options are possible. For example, to reduce the high sand loss rate from a discrete localised beach nourishment project, groynes (probably L or T shaped) could be added on either side (and within) the nourishment area. However, the disadvantages associated with groynes will still be applicable.

In areas where the beach is artificially widened a constructed vegetated buffer dune may be required to manage wind-blown sand and thereby also maintain the sand within the beach-dune system.

1.2.3 Summary list of potential solutions

The following potential options to respond and adapt to the impacts of climate change have been identified for the study areas.

A "Management options"

A1 "Accept and retreat": repositioning infrastructure at risk; zoning, set-back lines, resettlement, etc.

A2 "Abstention" involves the 'do nothing' option. (If the risk of loss of property or human life is very minimal.)

A3 "Alternative" coastal developments: develop "safe" alternative coastal areas including services.

A4 "Accommodation": increase resilience and accommodate impacts on infrastructure e.g. raising property.

B "Soft engineering" or Restoration ("semi-natural" interventions in the littoral zone)

B1 Sand nourishment: pump extra sand onto the beach to build it up and reduce wave impacts & flooding.

B2 Managed (vegetated and/or reinforced) dune. Construct/reinstate and/or manage vegetated dune areas.

B3 Mangroves, corals and wetlands. Expand/reinstate and manage/protect such natural defences.

C "Hard engineering" & armouring (construct shore protection measures)

C1 Seawalls & revetments: sloping, vertical or curved concrete/rock structures.

C2 Dikes: massive sloped (landscaped and vegetated) loose standing sand/ earthen mound.

C3 Perched beach structures: artificially keep the upper part of the beach profile in place

C4 Shore-parallel structures (e.g. artificial surf zone reefs, detached breakwaters, rock berms, etc.).

C5 Groynes (straight, curved, T, L etc.) placed perpendicular or at angle to shoreline, can trap sediment

C6 Spending beach of very coarse sand, gravel or cobbles: dissipates wave energy & erosion.

C7 Beach (and dune) dewatering mechanism. Sediment "stability" can be increased

C8 Coastal flood control gates in "enclosed" areas (e.g. river mouths, small bays).

In low to moderate wave energy environments:

C9 Closely spaced piles or wave fences to dissipate wave energy.

C10 Floating moored "breakwater" type structures.

C11 "Geotextile" shore protection, usually sand filled geotextile containers.

C12 Gabions and/or rock filled wire basket & mattress structures.

D Combined options

A combination of two or more of the identified solution options may be required.

1.3 EVALUATION CONSIDERATIONS AND CRITERIA

The considerations or criteria used to evaluate the different options focus mainly on the practical and technical aspects. The main technical consideration is whether the solution will adequately address the project aims. Another critical aspect is the expected cost. Further practical aspects include issues such as that the recommended solution should ideally address possible existing background coastal erosion problems. The solutions should also be as environmentally friendly as possible. However, ecological considerations (that is, impacts on the fauna and flora) must be taken into account; similarly social issues must be properly accounted for. Also, aesthetic impacts should be considered. Thus, the main considerations in choosing between the options are effectiveness in adapting to expected climate change impacts (e.g. increasing beach width), environmental aspects, costs, and possibly whether the option has a dual purpose in also addressing possible existing background coastal erosion problems. Impaired beach (and possible inter-tidal rocky area) usage and aesthetic impacts should also be assessed.

Useful guidelines have been published (SNH, 2000) that aid the decision making process regarding the approach to follow, as summarized in Table 2 below:

Table 2: Selection of shoreline management options based on assets at risk (adapted from the literature)

Asset	Recommended approaches:
Replaceable (e.g. caravans, golf tees/green, car parks, amenity buildings, etc)	• Move or rebuild assets inland (adaptive management), plus minor temporary works to delay the onset of the move (i.e. fencing, planting, beach re-cycling, sand bag or gabion revetments). Total costs typically range from very low to $ 90 000 per 100 m alongshore.
Moderate economic value or medium residual life (5-25 years*) (Low density housing, roads, large caravan sites, military installations, etc)	• Series of nearshore breakwaters • Rock groynes (on mixed sediment beaches where littoral drift is active and downdrift erosion is not an issue) • Beach nourishment (with future top-ups, and possibly buried rock revetment) • Rock revetment • Total costs typically range from $ 150 000 to $ 750 000 per 100 m alongshore. • However, it is emphasised that if the erosion is long-term, backshore assets should not be enhanced or replaced, thereby allowing for ultimate abandonment.

**Note: These useful guidelines have been adapted from the literature, which includes a suite of responses including short lifespan options, although the main planning period considered in this report is generally 50 to 100 years.*

A critical consideration in evaluating the different options is the expected cost. Some costs have been estimated as summarized in the table below. (These estimates are mainly adapted from South African experience, but are supplemented by some experience in other African countries and limited international inputs.)

Table 3: Summary of some adaptation option cost estimates

DESCRIPTION	Approximate Minimum Costs (excl tax) for 1km	Approximate Maximum Costs (excl tax) for 1km	Approximate Minimum Costs (excl tax) for 10km	Approximate Maximum Costs (excl tax) for 10km
Sand feeding (beach nourishment) new @ rate of 300 000 m^3/a for 10 yrs)	$4 000 000	$60 000 000	$40 000 000	$600 000 000
Sand feeding (beach nourishment) maintenance	$400 000?	$7 780 000?		
Revetments & walls (permeable)	$2 300 000	$24 000 000	$23 000 000	$240 000 000
Vegetated dune	$750 000	$7 200 000	$7 500 000	$72 000 000
Geotextile sand containers, Geobags (semi-sheltered location)	$1 100 000	$23 000 000	$11 000 000	$230 000 000
Gabions (semi-sheltered location)	$600 000	$7 000 000	$6 000 000	$70 000 000
Rock groynes	$1 000 000	$29 200 000	$10 000 000	$292 000 000
Wave Fence (semi-sheltered location)	$2 300 000	$40 000 000	$23 000 000	$400 000 000
Floating pontoons (semi-sheltered location)	$2 250 000	$31 600 000	$22 500 000	$316 000 000
Rubble-mound breakwater structure land based	$1 500 000	$15 100 000	$15 000 000	$151 000 000
Rubble-mound breakwater: marine based	$2 900 000	$42 800 000	$29 000 000	$428 000 000
Sheet piling seawall (shore parallel)	$2 700 000	$36 000 000	$27 000 000	$360 000 000

A significant proportion of the costs for most coast protection materials is in the transport and placement. Work on dune systems can impose additional costs due to concerns over destruction of landforms and habitats, and the problems of working in locations lacking access. Delivery from the sea of bulk materials (rock or beach sediment) is often preferred as backshore damage is minimised, although land access will still have to be provided for plant, labour and additional materials. Parts of the Mozambican coast are very exposed or have very shallow in-shore areas; thus sea access is also very difficult (expensive and risky). Haul roads will have to be built across the dunes unless access can be provided from an existing route. (Rock supply, plant availability and access are big cost factors especially relevant to parts of Mozambique.) Thus, there are many local factors and other details such as local supplier pricing, which will have a big impact on project costs. (This is why the band between minimum and maximum cost estimates in Table 3 is so wide, to ensure as far as can be foreseen that the actual costs should be between these limits.) These can only be assessed properly at the detail design stage of specific projects. Besides direct capital costs it is critical to consider maintenance costs and life expectancy of the option. *Solutions MUST be sustainable*, which means the recommended options must also be durable and affordable to the Municipality and/or State (or responsible authority).

In choosing adaptation options it is also very important to consider the impacts to habitat, landform, landscape, coastal processes, etc. Consideration should be given to the full life environmental impacts of proposed management intervention/operations. The manager/responsible authority must consider not only the local short-term impact of a scheme, but also the following aspects (adapted from literature):

- the impact on the source area for materials (offshore dredging areas, rock quarry, etc)
- the impact of transport to the site (road congestion and surface damage, noise levels, risk of accidents at sea or on roads, access through dunes, etc)

- the impact of damaged or life expired materials on the shoreline (synthetic fencing materials, geotextile sand bags, gabion baskets and rock fill, timber, concrete, rock, etc).
- the long term evolution of the beach and dunes and the effectiveness of structures over their full life.

Management plans should allow for these environmental impacts during the decision process, particularly where costs are being passed on to future generations. Mitigation measures and good working practices to minimise impacts should be built into designs, agreed with contractors and monitored rigorously during initial and ongoing operations.

A pertinent comparison and assessment of most of the options has been reported in the literature, as summarised in Table 4, below.

Table 4: Relative costs, life expectancy and potential environmental impacts associated with shoreline management options (adapted from SNH, 2000)

(= low, ***** = high)*

Option	Impacts [1]				Costs [5]		
	Habitat	Landform	Landscape	Processes	Capital	Maintenance [2]	Life Expectancy [3]
Adaptive management	**	**	**	*	Dependant on assets	*	*****
Grass planting, Thatching, Dune fencing	*	*	*	*	*	***	*
Sandbag structures	**	**	**	**	**	*	**
Beach drainage	*	*	*	**	***	**	*
Beach nourishment	**	*	*	*	***	***	**
Gabion revetments [4]	***	***	***	***	***	**	***
Artificial headlands	**	**	***	***	***	*	***
Artificial reefs	**	**	***	***	***	*	***
Nearshore breakwaters	***	**	****	***	***	*	***
Groynes	***	***	***	***	***	*	***
Rock revetments [4]	****	****	*****	****	****	*	*****
Timber revetments [4]	***	***	****	***	****	*	***
Impermeable revetments/seawalls	****	*****	*****	****	*****	*	****

1. *Impacts over full life-cycle of option*
2. *Maintenance cost relative to capital cost (to retain design benefits)*
3. *Life expectancy of benefits without maintenance*
4. *If buried into the dune face the impacts associated with these approaches are lowered and the life expectancy increased; capital costs may be higher but maintenance costs lower.*
5. *These cost indications are more applicable to Europe and possibly less so for Mozambique*

Note, Table 4, as taken from the literature, does not include all the options considered for Mozambique. A further assessment by the authors (based on southern African experience) of some of the options is summarized in Table 5 below.

Table 5: Comparative functionality/suitability of some potential adaptation measures

Suitability Criteria / Adaptation Alternative	Shoreline stability	Wave attenuation potential	Inundation due to SLR mitigation potential	Environmental & social impact	Relative cost	Relative design life	Maintenance Cost	Maintenance Frequency
~~Do nothing~~	~~Low~~	~~Nil~~	~~Nil~~	~~Nil to high~~	~~Nil~~	~~-~~	~~-~~	~~-~~
Shoreline Nourishment	Medium to high	Low to high	Low to high	Low	Medium to high	Short to medium	Medium	Medium
Revetment	High	High	High	High	High	Long	High	Low
Detached Breakwater	Limited	Limited	Nil	Medium	Medium to high	Long	High	Low
Sill	Medium to High	Medium	Low	Medium	Medium	Long	Medium	Low
Submerged breakwater	Limited	Limited	Nil	Low to medium	Medium to high	Long	Medium	Low
~~Wave fence – fully reflective~~	~~Medium to high~~	~~High~~	~~Nil~~	~~Medium to high~~	~~Low to medium~~	~~Medium~~	~~Low~~	~~High~~
~~Wave fence – partially reflective~~	~~Medium~~	~~High~~	~~Nil~~	~~Medium~~	~~Low to medium~~	~~Medium~~	~~Low~~	~~Medium~~
~~Floating breakwater~~	~~Medium~~	~~Medium~~	~~Nil~~	~~Low to medium~~	~~Medium~~	~~Medium~~	~~Medium~~	~~High~~

Note: Effectiveness, impacts and costs can vary significantly due to local site characteristics, availability of materials, access and transport costs

In Table 5 the functionality and suitability of some coastal climate change (CC) adaptation measures are assessment and compared:

- The 1st column lists 9 adaptation alternatives/options. Columns 2 to 4 assess the functionality of each option, respectively in terms of: "shoreline stability" (i.e. how effectively will the shoreline location be "fixed" in place), "wave attenuation potential" (i.e. how effectively will wave energy be dissipated), and "inundation due to SLR (sea level rise) mitigation potential" (i.e. how effectively will flooding due to SLR be prevented). The most direct measure of effectiveness in meeting the objective of reducing the coastal CC impacts is "inundation due to SLR mitigation potential". Thus, a score of "nil" here should almost eliminate such options.
- Columns 5 to 9 assess the suitability of each option, respectively in terms of: adverse "environmental or social impacts", relative cost of each option, relative design life (or

durability), cost of maintenance required for each option, and required frequency of maintenance.

- To facilitate a quick comparison of the different options, all “good” assessments of functionality/suitability have been coloured in green, while unfavourable assessments are coloured in red. Thus, in general, the “better” or “more suitable” options have relatively many green blocks and few red blocks. Of the 9 options listed here, “shoreline nourishment” and “revetments” are therefore generally preferred. Note, however, that the effectiveness, impacts and costs can vary significantly due to local site characteristics, availability of materials, access and transport costs.
- Four of the options have been identified as generally not suitable to most of the study sites in Mozambique (in terms of effectiveness in meeting the objective of reducing coastal CC impacts); red lines have been drawn through these options in Table 5.
- All of the structural options would have significant environmental impacts, including enhanced downdrift coastal erosion.
- Some of the best options available are to address the causes of existing erosion (i.e. for Maputo: feed dredged port entrance channel sand to the main beachfront area with appropriately coarse sand or large scale ad hoc nourishments). All large sand nourishment projects are likely to benefit a much more extensive (alongshore) area in the long-term. In this respect, the opportunities presented by future capital dredging projects for port expansions must be fully exploited. Even if a fairly large percentage of such dredged material is considered less suitable or inappropriate (too much fine sediment) for “ideal” beach nourishment, this must be critically reviewed. In view of the present and future erosion impacts and hazard prone state of the coastal environment, the negative ecological environmental impacts (probably temporary) from pumping otherwise too fine material onto the beaches, are likely to be considerably less than the ultimate environmental (and socio-economic) good that would result from beach nourishment even with a much lower than “normally” acceptable proportion of coarser sediment.

Based on the foregoing evaluation consideration and criteria, and including all appropriate options, the priority adaptation/”no-regret” measures were grouped according to type and impact, covering the most relevant Climate Change issues for Mozambique coastal towns and cities, as summarized in Table 6 below. The measures were assessed in terms of general feasibility, cost/benefit applicability (CBA), suitability/effectiveness and area of applicability. Thereafter the general priorities for implementation were identified and the preferred order of implementation was determined as also indicated in the table.

Table.6: Priority adaptation/no-regret measures

No regret measures			Suitability / effectiveness	Area if applicability	Implementation priorities *& order (#)*
New zoning, "accept & retreat", etc.	Medium, High	Medium	"Must do" management options, but need socio-economic & political push	All coastal towns	1 "Must do" management options mitigate present & future hazards & enable better socio-economic
Alternative safe area developments	High	High			
Accommodation: raising property, etc	Medium	Medium	With high value infrastructure & seaward defenses	Site specific	4 Manage/adapt where unavoidable to protect high value infrastructure
Sand nourishment	High	High	Good in Maputo & Beira with port dredging	Local	2 Ideal win-win "soft engineering"/restoration opportunity where local conditions allow
Managed vegetated/reinforced dune	High	High	Best "environmental" options	All coastal towns/Local	
Rehabilitated mangrove/wetland	High	High			
Seawalls (vertical / curved concrete)	Medium	Medium	Mostly where high value development exists & space/sand is limited	Site specific	3 Implement "hard engineering" or armouring where unavoidable to protect high value development/infrastructure.
Revetments (sloping rock)	Medium	Medium			
Dikes (sand/earthen mound)	Low	Low	"Last resort" alternative to dunes	Site specific	
Detached breakwaters/artificial reefs	Low	Low	Can be good with major development	Site specific	
Groynes (rock/concrete)	Medium	Medium	Mostly with sand nourishment	Site specific	
"Geotextiles" sand filled	Medium	Medium	Only in low/moderate wave energy - medium term	Site specific	
Gabions & rock filled mattresses	Medium	Medium			

Key: ***Feasibility & CBA:*** ○ Low ◐ Medium ● High

Key:

(Note, a high CBA (Cost/Benefit Assessment) is taken as a positive indicator, meaning in fact that the benefits outweigh the costs, and could thus perhaps be stated more logically as BCA (Benefit/Cost Assessment) in terms of a positive metric. However, to remain consistent with the terminology used in the other themes, CBA is retained here.)

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GLOSSARY OF TERMS (DEAD & P, 2010)

Accretion	The accumulation of (beach) sediment, deposited by natural fluid flow processes
Alongshore	Parallel to and near the shoreline; same as longshore
Astronomical tide	The tidal levels and character which would result from gravitational effects, e.g. of the earth, sun and moon, without any atmospheric influences.
Bar	An offshore ridge or mound of sand, gravel, or other unconsolidated material which is submerged (at least at high tide), especially at the mouth of a river or estuary, or lying parallel to, and a short distance from, the beach.
Bathymetry	The measurement of depths of water in oceans, seas and lakes; also the information derived from such measurements.
Bay	A recess or inlet in the shore of a sea or lake between two capes or headlands, not as large as a gulf but larger than a cove.
Beach	(1) a deposit of non-cohesive material (e.g. sand, gavel) situated on the interface between dry land and the sea (or large expanse of water) and actively "worked" by present-day hydrodynamics processes (i.e. waves, tides and currents) and sometimes by winds. (2) the zone of unconsolidated material that extends landward from the low water line to the place where there is marked change in material or physiographic form, or to the line of permanent vegetation. The seaward limit of a beach – unless otherwise specified – is the mean low water line. A beach includes foreshore and backshore. (3) (smp) the zone of unconsolidated material that is moved by waves, wind and tidal currents, extending landward to the coastline.
Beach erosion	The carrying away of beach materials by wave action, tidal currents, littoral currents or wind.
Beach profile	A cross-section taken perpendicular to a given beach contour, the profile may include the face of a dune or seawall, extend over the backshore, across the foreshore, and seaward underwater into the nearshore zone.
Bed	The bottom of a watercourse, or any body of water.
Benefits	The economic value of a scheme, usually measured in terms of the cost of damages avoided by the scheme, or the valuation of perceived amenity or environmental improvements.
Buffer area	A parcel or strip of land that is designed and designated to permanently remain vegetated in an undisturbed and natural condition to protect an adjacent aquatic or wetland site from upland impacts, to provide habitat for wildlife and to afford limited access.
Cay	A small, low island composed largely or coral or sand.
Cliff	A high steep face of rock.
Climate change	Refers to any long-term trend in mean sea level, wave height, wind speed, drift rate etc.
Coast	A strip of land of indefinite length and width (may be tens of kilometres) that extends from the seashore inland to the first major change in terrain features.
Coastal management	The development of a strategic, long-term and sustainable land use policy, sometimes also called shoreline management.
Coastal processes	Collective term covering the action of natural forces on the shoreline, and the nearshore seabed.
Coastal zone	The land-sea air interface zone around continents and islands extending from the landward edge or a barrier or shoreline of coastal bay to the outer extent of the continental shelf. In its wider meaning it is often taken as extending landward up to where littoral processes are active or could have an effect (which could be some kilometres inland in certain areas).
Coastline	(1) technically, the line that forms the boundary between the coast and the shore. (2) commonly, the line that forms the boundary between land and water. (3) (smp) the line

	where terrestrial processes give way to marine processes, tidal currents, wind waves, etc.
Conservation	The protection of an area, or particular element within an area, accepting the dynamic nature of the environment and therefore allowing change.
Continental shelf	The zone bordering a continent extending from the line of permanent immersion to the depth, usually about 100 m to 200 m, where there is a marked or rather steep descent toward the great depths.
Contour line	A line connecting points, on a land surface or sea bottom, which have equal elevation. It is called an isobaths when connecting points of equal depth below a datum.
Cross-shore	Perpendicular to the shoreline.
Debris line	A line near the limit of storm wave up-rush marking the landward limit of debris deposits.
Deep water	In regard to waves, where depth is greater than one-half the wave length. Deep-water conditions are said to exist when the surf waves are not affected by conditions on the bottom.
Deep water waves	A wave in water the depth of which is greater than one-half the wave length.
Depth	Vertical distance from still-water level (or datum as specified) to the bottom.
Design storm	Coastal protection structures will often be designed to withstand wave attack by the extreme design storm. The severity of the storm (i.e. return period) is chosen in view of the acceptable level of risk of damage or failure. A design storm consists of a design wave condition, a design water level and a duration.
Design wave	In the design of harbours, harbour works, etc. the type or types of waves selected as having the characteristics against which protection is desired.
Direction of waves	Direction from which waves are coming.
Direction of wind	Direction from which wind is blowing.
Dunes	(1) Accumulations of windblown sand on the backshore, usually in the form of small hills or ridges, stabilized by vegetation or control structures. (2) a type of bed form indicating significant sediment transport over a sandy seabed.
Duration	In forecasting waves, the length of time the wind blows in essentially the same.
Ecosystem	The living organisms and the non-living environment interacting in a given area.
Erosion	Wearing away of the land by natural forces. (1) On a beach, the carrying away of beach material by wave action, tidal currents or by deflation. (2) The wearing away of land by the action of natural forces.
Estuary	(1) a semi-enclosed coastal body of water which has a free connection with the open sea. The seawater is usually measurably diluted with freshwater. (2) the part of the river that is affected by tides.
Event	An occurrence meeting specified conditions, e.g. damage, a threshold wave height or a threshold water level.
Fetch	The length of unobstructed open sea surface across which the wind can generate waves (generating area).
Fetch length	(1) the horizontal distance (in the direction of the wind) over which a wind generates seas or creates wind setup. (2) the horizontal distance along open water over which the wind blows and generates waves.
Gabion	(1) steel wire-mesh basket to hold stones or crushed rock to protect a bank or bottom from erosion.
Geology	The science which treats of the original, history and structure of the earth, as recorded in rocks, together with the forces and processes now operating to modify rocks.
Georeferencing	The process of scaling, rotating, translating and de-skewing the image to match a particular size and position (2) establishing the location of an image in terms of map projections or coordinate systems.
High water (HW)	Maximum height reached by a rising tide. The height may be solely due to the periodic tidal forces or it may have superimposed upon it the effects of prevailing meteorological conditions. Non-technically, also called the high tide.
High water mark	A reference mark on a structure or natural object, indicating the maximum stage of tide or flood.
Mean high water springs	The average height of the high water occurring at the time of spring tides.

(MHWS)	
Mean sea level (MSL)	The average height of the surface of the sea for all stages of the tide over a 19-year period, usually determined from hourly height readings.
Ocean	The great body of salt water which occupies two-thirds of the surface of the earth, or one of its major subdivisions.
Offshore	(1) in beach terminology, the comparatively flat zone of variable width, extending from the shoreface to the edge of the continental shelf. It is continually submerged. (2) the direction seaward from the shore. (3) the zone beyond the nearshore zone where sediment motion induced by wave alone effectively ceases and where the influence of the sea bed on wave action is small in comparison with the effect of wind. (4) the breaker directly seaward of the low tide line.
Offshore wind	A wind blowing seaward from the land in the coastal area.
Outcrop	A surface exposure of bare rock, not covered by soil or vegetation.
Overtopping	Water carried over the top of a coastal defence due to wave run-up or surge action exceeding the crest height.
Peak period	The wave period determined by the inverse of the frequency at which the wave energy spectrum reaches it's maximum.
Photogrammetry	The science of deducing the physical dimensions of objects from measurements on images (usually photographs) of the objects.
Port	A place where vessels may discharge or receive cargo.
Reach	(1) an arm of the ocean extending into the land. (2) a straight section of restricted waterway of considerable extent; may be similar to a narrows, except much longer in extent.
Recession	(a) a continuing landward movement of the shoreline. (2) a net landward movement of the shoreline over a specified time.
Refraction	The process by which the direction of a wave moving in shallow water at an angle to the bottom contours is changed. The part of the wave moving shoreward in shallower water travels more slowly than that portion in deeper water, causing the wave to turn or bend to become parallel to the contours.
Retum period	Average period of time between occurrences of a given event.
Revetment	(1) a facing of stone, concrete, etc., to protect an embankment, or shore structure, against erosion by wave action or currents. (2) a retaining wall. (3) (smp) facing of stone, concrete, etc., built to protect a scarp, embankment or shore structure against erosion by waves of currents.
Rocks	An aggregate of one or more minerals rather large in area. The three classes of rocks are the following: (1) igeneous rock – crystalline rocks formed from molten material. Examples are granite and basalt. (2) sedimentary rock – a rock resulting from the consolidation of loose sediment that has accumulated in layers. Examples are sandstone, shale and limestone. (3) metamorphic rock – rock that has formed from pre-existing rock as a result of heat or pressure.
Run-up	The rush of water up a structure or beach on the breaking of a wave. The amount of run-up is the vertical height above still-water level that the rush of water reaches.
Sand	An unconsolidated (geologically) mixture of inorganic soil (that may include disintegrated shells and coral) consisting of small but easily distinguishable grains ranging in size from about .062 mm to 2.0 mm.
Scour protection	Protection against erosion of the seabed in front of the toe.
Sea defences	Works to prevent or alleviate flooding by the sea.
Sea level rise	The long-term trend in mean sea level.
Seawall	(1) a structure built along a portion of a coast primarily to prevent erosion and other damage by wave action. It retains earth against its shoreward face. (2) (smp) a structure separating land and water areas primarily to prevent erosion and other damage by wave action. Generally more massive and capable of resisting greater wave forces than a bulkhead.
Sediment transport	The main agencies by which sedimentary materials are moved are: gravity (gravity transport); running water (rivers and streams); ice (glaciers); wind; the sea (currents and longshore drift). Running water and wind are the most widespread transporting agents.

	In both cases, three mechanisms operate, although the particle size of the transported material involved is very different, owing to the differences in density and viscosity of air and water. The three processes are: rolling or traction, in which the particle moves along the bed but is too heavy to be lifted from it; saltation and suspension, in which particles remain permanently above the bed, sustained there by the turbulent flow of the air or water.
Setback	(smp) a required open space, specified in shoreline master programs, measured horizontally upland from a perpendicular to the ordinary high water mark. More commonly used in CZM and coastal engineering terms as a required distance landward of a selected contour line (or the shoreline) to safeguard e.g. infrastructure from marine impacts (such as storm waves or esosion).
Shallow water	Water of such depth that surface waves are noticeably affected by bottom topography. Typically this implies a water depth equivalent to less than half the wave length.
Shoal	(1) (noun) a detached area of any material except rock or coral. The depths over it are a danger to surface navigation. Similar continental or insular shelf features of greater depths are usually termed banks. (2) (verb) to become shallow gradually. (3) to cause to become shallow. (4) to proceed from a greater to a lesser depth of water.
Shore	That strip of ground bordering any body of water which is alternatively exposed, or covered by tides and/or waves. A shore of unconsolidated material is usually called a beach. The *shoreline* is often used as the term for delineating between the land and the sea (e.g. selected as the 0 m to MSL contour line).
Significant wave height	Average height of the highest one-third of the waves for a stated interval of time.
Significant wave period	Average period of the highest one-third of the waves for a stated interval of time.
Soft defences	Usually refers to beaches (natural or designed) but may also relate to energy –absorbing beach-control structures, including those constructed of rock, where these are used to control or redirect coastal processes rather than opposing or preventing them.
Spring tide	A tide that occurs at or near the time of new or full moon, and which rises highest and falls lowest from the mean sea level (msl).
Stillwater level (SWL)	The surface of the water if all wave and wind action were to cease. In deep water this level approximates the midpoint of the wave height. In shallow water it is nearer to the trough than the crest. Also called the undisturbed water level.
Surf zone	The nearshore zone along which the waves become breakers as the approach the shore.
Surf zone	The zone of wave action extending from the water line (which varies with tide, surge, set-up, etc). Out to the most seaward of the zone (breaker zone) at which waves approaching the coastline commence breaking, typically in water depths of between 5 m and 10 m.
Surge	(1) long-interval variations in velocity and pressure in fluid flow, not necessarily periodic, perhaps even transient in nature. (2) the name applied to wave motion with a period intermediate between that of an ordinary wind and that of a tide. (3) changes in water level as a result of meteorological forcing (wind, high or low barometric pressure) causing a difference between the recorded water level and that predicted using harmonic analysis, may be positive or negative. (2) NOAA: *Storm surge*: "A rise or piling-up of water against shore, produced by strong winds blowing onshore. A storm surge is most severe when it occurs in conjunction with a high tide." (3) Expansion by the authors:In southern Africa, sea storms (i.e. high waves with run-up, impacts and scouring) are also a big risk; these can be exacerbated by strong winds and high tides.
Survey, control	A survey that provides coordinates (horizontal or vertical) of point to which supplementary surveys are adjusted.
Survey, hydrographic	A survey that has as its principal purpose the determination of geometric and dynamic characteristics of bodies of water.
Survey, photogrammetric	A survey in which monuments are placed at points that have been determined photogrammetrically.
Survey, topographic	A survey which has, for its major purpose, the determination of the configuration (relief) of the surface of the land and the location of natural and artificial objects thereon.
Swash zone	The zone of wave action on the beach, which moves as water levels vary, extending from

	the limit of run-down to the limit of run-up.
Swell	Waves that have travelled a long distance from their generating area and have been sorted out by travel into long waves of the same approximate period.
Toe	(1) lowest part of sea- and portside breakwater slope, generally forming the transition to the seabed. (2) the point of break in slope between a dune and a beach face.
Topographic map	A map on which elevations are shown by means of contour lines.
Updrift	The direction to which the predominant longshore movement of beach material approaches.
Wave crest	(1) the highest part of the wave. (2) that part of the wave above still water level.
Wave direction	The direction from which the waves are coming.
Wave height	The vertical distance between the crest (the high point of the wave) and the trough (the low point).
Wave hindcast	The calculation from historic synoptic weather charts of the wave characteristics that probably occurred at some past time.
Wave length	The distance, in meters, between equivalent points (crests or troughs) on waves. Wave period: (1) the time required for two successive wave crests to pass a fixed point. (2) the time, in seconds, required for a wave crest to traverse a distance equal to one wave length.
Wave rose	Diagram showing the long-term distribution of wave height and direction.
Wave set-up	Elevation of the still-water level due to breaking waves.
Wave steepness	The ratio of wave height to its length. Not the same thing as the slope between a wave crest and its adjacent trough.
Wave train	A series of waves from the same direction.
Wave trough	The lowest part of the wave form between crests. Also that part of a wave below still water level.
Wave variability	(1) the variation of heights and periods between individual waves within a wave train. Wave trains are not composed of waves of equal heights and periods which vary in a statistical manner. (2) the variability in direction of wave travel when leaving the generating area. (3) the variation in height along the crest.
Wind rose	Diagram showing the long-term distribution of wind speed and direction.
Wind setup	(1) the vertical rise in the stillwater level on the leeward side of a body of water caused by wind stresses on the surface of the water. (2) the difference in stillwater levels on the windward and the leeward sides of a body of water caused by wind stresses on the surface of the water. (3) synonymous with wind, tide and storm surge. (Storm surge is sometimes reserved for use on the ocean and large bodies of water. Wind setup is sometimes reserved for use on reservoirs and smaller bodies of water. This “incorrect” distinction is not employed in this report.)
Wind waves	(1) waves formed and growing in height under the influence of wind. (2) loosely, any wave generated by wind.
World Geodetic System, 1984 (revised 2004)	An earth fixed global reference frame used for defining coordinates when surveying and by GPS systems.