INTEGRITY ASSESSMENT PROCEDURE FOR BUFFER DUNE SYSTEMS ON THE CAPE SOUTH COAST, SOUTH AFRICA

by

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of the requirements for the degree of
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DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

21 February 2011

ABSTRACT

The hypothesis postulated in this research, namely that the effectiveness of natural and constructed buffer dune systems can be assessed by a set of indicators that defines the integrity of the dune system and triggers informed management decisions, was evaluated and proved to be essentially true.

Two key objectives, namely (1) the identification of key indicators that define the buffer dune integrity; and (2) the development of a scientifically defendable and practical checklist-based method of gathering qualitative information on the identified key indicators so as to guide decision-making at municipal level formed the core of the study.

The six dune integrity indicators that collectively define the risk profile of a particular site along the Southern Cape coastline are (1) the degree of protection from prevailing wave energy, (2) the characteristics of the dominant winds and sand supply during the dry season, (3) the relative height of the foredune, (4) the degree of pressure on the buffer dune due to humans, (5) the vulnerability of the type of coastline to erosion, and (6) the coastline stability considering the prevailing coastal processes.

The first two indicators relate to the natural (permanent) characteristics of the site and can be defined by experts and presented in the form of a risk and vulnerability atlas layer for direct use by non-experts. The third and fourth indicators relate directly to the implementation of proactive assessment and appropriate management actions to ensure a high level of buffer dune integrity. The last two indicators allow for management intervention to reduce the vulnerability but may entail costly engineering solutions and require expert input.

A conceptual risk profile assessment procedure and a decision support guideline incorporating these indicators were developed and evaluated for relevance and practicality through a series of workshops with municipal officials along the south coast of South Africa. It was seen that although some initial basic training may be required, carrying out rapid assessments of the environmental status of key components of an identified human–nature system, such as a buffer dune, is practical and achievable by non-experts.

OPSOMMING

Die hipotese wat in hierdie navorsing gepostuleer is, naamlik dat die doeltreffendheid van natuurlike en geboude bufferduinstelsels geassesseer kan word deur 'n stel aanwysers wat die integriteit van die duinstelsel bepaal en ingeligte bestuursbesluite tot gevolg het, is getoets en bewys hoofsaaklik waar te wees.

Twee sleuteldoelwitte, naamlik (1) die identifisering van sleutelaanwysers wat die bufferduinintegriteit bepaal; en (2) die ontwikkeling van 'n praktiese kontrolelys-gebaseerde metode wat wetenskaplik verdedigbaar is om kwalitatiewe inligting oor die geïdentifiseerde sleutelaanwysers in te samel ten einde besluitneming op munisipale vlak te bevorder, vorm die kern van die studie.

Die ses duin-integriteitsaanwysers wat gesamentlik die risikoprofiel van 'n bepaalde terrein langs die kuslyn bepaal, is (1) die graad van beskerming teen die heersende golfenergie, (2) die kenmerke van die dominante winde en sandbron gedurende die droë seisoen, (3) die relatiewe hoogte van die voorduin, (4) die graad van druk op die bufferduin as gevolg van mense, (5) die erodeeringskwesbaarheid van die soort kuslyn, en (6) die kuslynstabiliteit met inagname van die kusprosesse.

Die eerste twee aanwysers het betrekking op die natuurlike (permanente) eienskappe van die terrein en kan deur kundiges bepaal word en in die vorm van 'n kaart in 'n risiko-en-kwesbaarheidsatlas aangebied word vir direkte gebruik deur niedeskundiges. Aanwysers 3 en 4 hou direk verband met die implementering van tydige en deurlopende proaktiewe assessering en gepaste bestuursaksies om 'n hoë vlak van bufferduinintegriteit te verseker. Aanwysers 5 en 6 bevorder bestuursaksies om kwesbaarheid te verminder, maar kan moontlik duur ingenieursoplossings inhou en kundige insette benodig.

'n Konseptuele risikoprofielassesseringsprosedure en 'n besluitondersteuningsriglyn wat die aanwysers insluit, is ontwikkel en geëvalueer vir toepaslikheid en uitvoerbaarheid deur 'n reeks werkswinkels met munisipale amptenare aan die suidkus van Suid-Afrika. Hoewel aanvanklike basiese opleiding nodig kan wees, bly dit dat vinnige assessering van die omgewingstatus van sleutelkomponente van 'n geïdentifiseerde mens–natuurstelsel, soos 'n bufferduin, prakties en haalbaar deur niedeskundiges is.

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Dedication

I dedicate this thesis to my mother, for her love, to my father, for awakening my love of the sea, and my life partner for space and shared adventure.

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CHAPTER 1: INTRODUCTION

1.1 The aim and objectives of the research

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.

Management guidelines should be based on best available practice, not entail excessive costs and include a timeous response trigger that alerts non-specialists to a situation that requires the involvement of specialists for specific guidance.

The aim of this research was to develop a dune integrity risk profile assessment procedure and investigate the feasibility of a conceptual user-friendly decision support guideline to enable local authorities to manage the integrity of the naturally occurring foredunes and constructed buffer dunes in their areas of responsibility. The components of an undeveloped soft coastline along the South African south coast are shown in Figure 1.1.

Two key study requirements were defined as follows:

I. The identification of key indicators (coastal landforms/features/characteristics) that define the integrity of the coastal dune system for decision-making associated with buffer dune management.

   The key dune integrity indicators should be representative of the biological, physical and social environments.

II. The development of a practical checklist-based method of gathering qualitative information on the identified key indicators that define the dune integrity while adhering to sound coastal engineering and scientific principles.

   It was anticipated that the output would be in the form of associated risk factors that will trigger an appropriate management response. This could include the use of simple on-sight observations and/or the use of remote-sensing analytical methodologies to obtain qualitative information from images sourced from satellite and/or aeroplane-based sensors, for example.

The decision support guideline developed in this thesis does not intend to replace specialist advice, but is meant to be the 'eyes' and 'ears' at grassroots level to ensure that appropriate actions are taken at specific times. The output of the decision support guideline takes the form of a hardcopy checklist framework and not an information and communication technology (ICT)-based system, but does provide the framework for a future web-based approach.

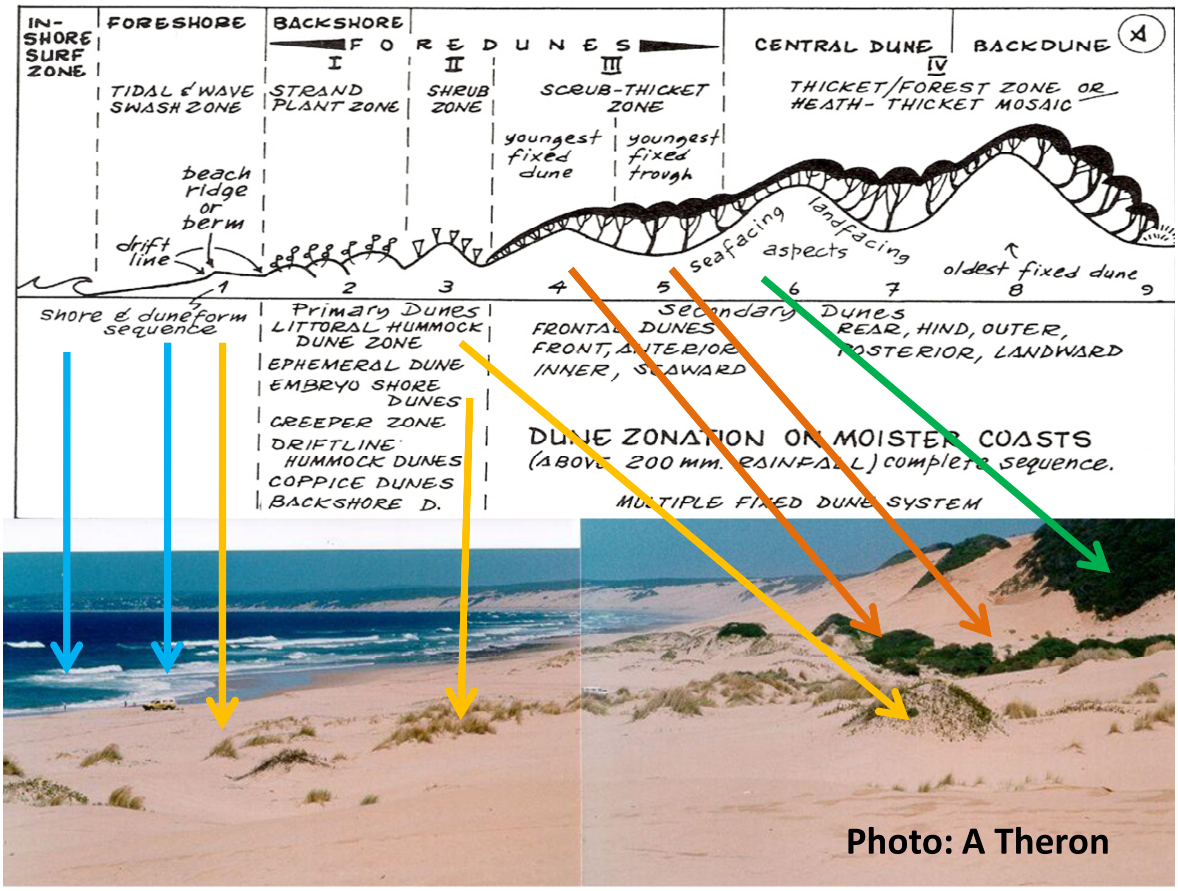


Figure 1.1: Illustration of components of an undeveloped soft coastline (adapted from Tinley, 1985)

The research methodology tested the practicality of this attempt to empower non-specialists at local level to develop the confidence to take appropriate management decisions that will maintain buffer dune integrity.

1.2 Background to the research

In excess of 80% of the more than 3 000 km of coastline along the South African seaboard is made up of so-called soft coasts (Tinley, 1985). Soft coasts mainly consist of erodible sand and include areas where there is a mix of sandy and rocky material. In 1985, Tinley assessed that almost 98% of the sand dune coasts along Southern Africa were eroding. This was due to a number of reasons, including the result of wave and wind action, sea-level rise, a reduction of the sediment supply to the coast through the damming of rivers, the mining of sand from rivers and beaches and the stabilisation of dune fields.

As is the trend internationally, development along the coastline of South Africa continues at a remarkable pace, with those properties located closest to the high-water mark in high demand. Such development is often unwisely squeezed into a limited area along the coast and is therefore often at risk from coastal processes.

This continued development pressure on the South African coastline, the dynamic nature of the coastline and its sensitivity require effective management. To support the effective management of the coastal zone, the South African National Environmental Management: Integrated Coastal Management Act of 2008 (the ICM Act) was passed in 2008 (Republic of South Africa, 2008). The ICM Act states in Section 48 (1) (a) that "[a] coastal municipality- (a) must, within four years of the commencement of this Act, prepare and adopt a municipal coastal management programme for managing the coastal zone or specific parts of the coastal zone in the municipality".

The ICM Act of 2008 allows local authorities to proclaim areas within the coastal zone as "Special Management Areas" (Clause 23) with associated specific management programmes (Clause 24).

The shortage of experienced professionals in coastal management at local authority level poses a real challenge for the successful implementation of the ICM Act and the need for user-friendly decision support methods and guidelines has been identified in recent publications (including South Africa's National Programme of Action for the protection of the marine environment from land-based activities [DEAT, 2008]).

Figures 1.2 and 1.3 show the various components of the coastline as defined in the ICM Guideline (Celliers, Breetzke, Moore & Malan, 2009). This thesis addresses developments already located within the area defined as the "coastal processes setback area" where no development should be allowed (Figure 1.3). This area forms a sub-set of the setback area as set out in the ICM Act and as illustrated in Figure 1.2.

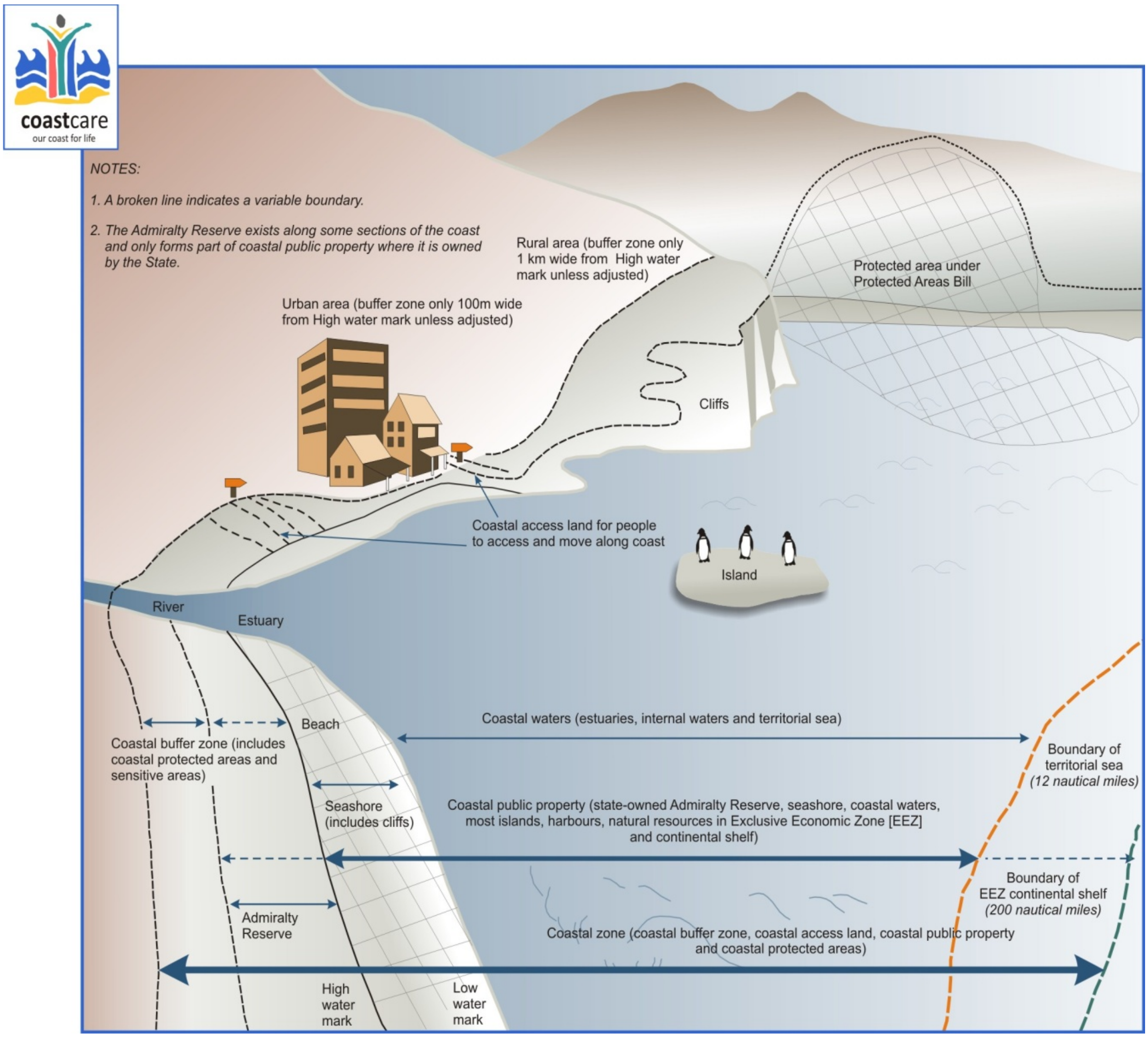


Figure 1.2: Defining the coastal zone (based on Celliers et al., 2009)

The areas located 100 m landwards of the high-water mark in urban areas and 1 000 m landwards of the high-water mark in rural areas have been defined as "coastal buffer zones", where specific activities are restricted. Foredunes typically fall within these areas along soft and mixed coasts. Foredunes, also known as frontal dunes, occur above the high-water mark along sandy shorelines. They are considered key landforms within the littoral active zone as defined by the ICM Act and are an important and crucial component of the natural sediment budget, which forms an integral part of the coastal defence (figures 1.2 and 1.3). In developed coastal areas, vegetated foredunes provide the crucial service of protecting man-made structures from damage by coastal processes, such as erosion by storm waves and inundation by wind-blown sand.

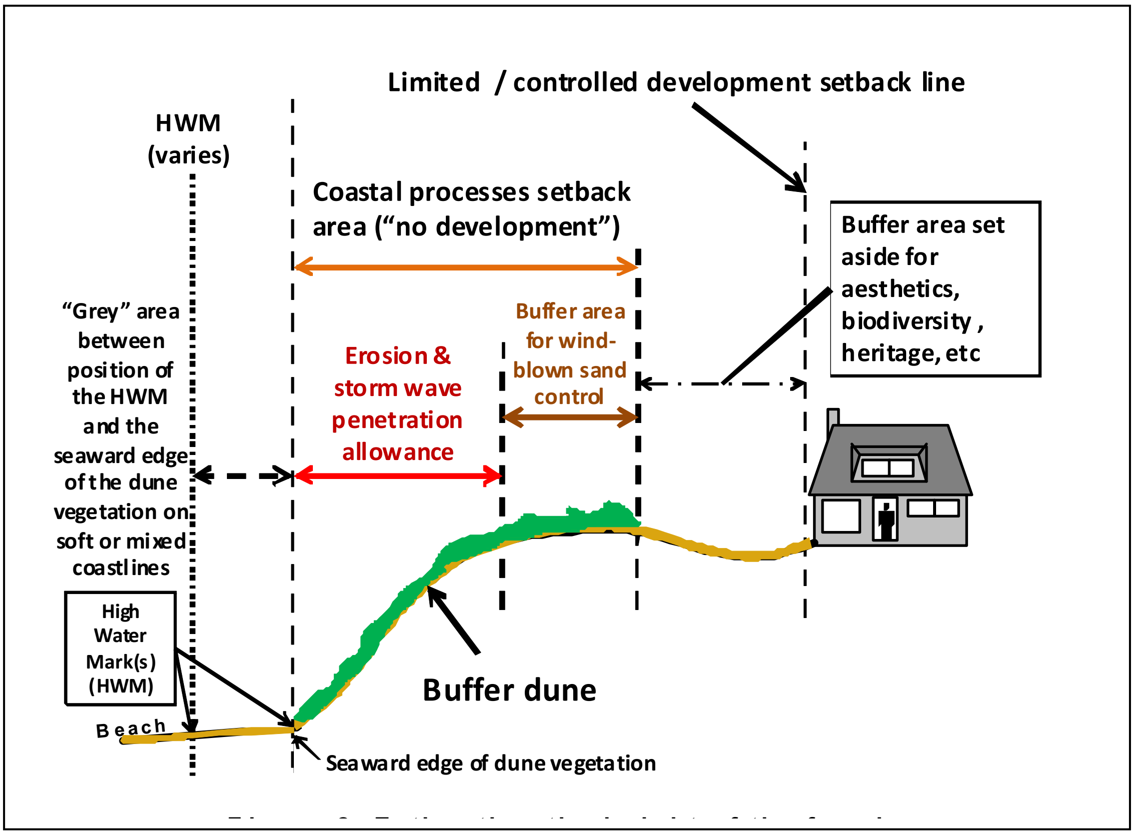


Figure 1.3: Definition of the term 'buffer dune' and 'setback' as used in this thesis

The concepts illustrated in Figure 1.3 are further discussed in Section 2.3.1.

1.3 The concept of risk

1.3.1 The definition of risk

Risk is typically defined as the product of the **consequence** (or impact) that results from an action or event and the **probability** (or likelihood) that the specific action or event will occur. Kaplan (1981) prefers to define risk as probability and consequence.

In managing and/or adapting to the risk, it is normally not possible to change or alter the consequence or impact, but it is often possible to reduce the probability of the event occurring by implementing timeous and wise management actions.

The essence of the approach taken in this thesis is understanding the risk and identifying and implementing practical actions to reduce the probability of the event occurring.

1.3.2 The consequence of system failure

Various characteristics of the coastal zone are described and discussed in the following sections of this thesis and it is concluded that by forming a coastal defence system, the foredune buffer zone provides a crucial and important 'ecosystem service' to the various components of the dune ecosystem (Figure 1.1). It also serves as protection of infrastructure and private property in coastal municipal areas (Figure 1.3).

As discussed in Section 1.4, the value of this 'service' provided by a buffer dune system can directly be related to the monetary value of the property located landward of the buffer dune system.

However, the indirect value of the protection of the natural ecosystem components such as groundwater, wetlands and mature indigenous vegetation is not easily measured. For example, how is the loss quantified should sea-water wash into a freshwater wetland located on the backdune area when the foredune fails?

In many places where the effectiveness of the foredune buffer system has been destroyed, modified or limited through the unwise placement of infrastructure and/or property development, costly hard-engineering coastal defence mechanisms are necessary and in many cases require ongoing specialised and costly maintenance actions.

The consequence of failure of the coastal defence system is often a major cost implication to ratepayers, private property owners and the insurance industry.

1.3.3 Reducing the probability of failure

The drivers of failure of a buffer dune system result from natural and anthropogenic changes in the natural coastal processes that build and maintain the integrity of the system.

For example, sea-level rise and an increased 'storminess' due to climate change can cause a change in the dimensions of the foredune system, thereby often reducing the available volume of dune sand that forms the storm defence buffer. Drought, fire or plant disease can destroy the dune vegetation, thereby increasing the exposed sand area, resulting in wind-blown sand and subsequent loss of dune volume as well as an increased threat to downwind areas.

Human activities also cause changes in the functioning of the buffer system. For example, development that has resulted in the modification of the natural foredunes, or has ignored the need for a buffer area, restricts the space required to accommodate the natural coastal processes, often resulting in the need for new or enhanced hard-engineering interventions that may cause further impacts.

Informal pathways across buffer dunes, the indiscriminate removal or destruction of sand-fixing dune vegetation (including exotic trees) and vehicle traffic (e.g. off-road vehicles, quad bikes, off-road bikes) on or across dunes cause an increase in the exposed sand area, resulting in wind-blown sand-related threats to back dune vegetation, wetlands, private property and/or municipal service infrastructure such as car parks, amenities and stormwater drainage systems.

The integrity of dunes, as the principal component of the foredune buffer system, therefore forms a critical assessment measure to assist in management decision-making aimed at reducing the probability of coastal defence failure along soft coasts.

1.4 The value or significance of the research topic

Enabling local authorities to manage the integrity of the naturally occurring foredunes and/or constructed buffer dunes is of significance from a socio-economic and a natural processes point of view.

1.4.1 Socio-economics

Globally, coastal regions are nodes for economic growth. It is estimated that between 30 and 50% of the world's population is located within 100 km of the shoreline and below an altitude of 100 m (UNESCO, 2003) in an area that makes up only 20% of the non-polar land on Earth (Olsen, 2001). Activities associated with people responding to real and perceived economic opportunities along the coast lead to a high population concentration and growth rate, which are often associated with local poverty (mainly in developing countries) and increased consumption and waste disposal in the developed regions (Olsen, 2001).

UNESCO (2003) states that recreational use of the coastal zone has become one of the world’s most significant economic activities and forms an important source of local revenue for maintaining and developing infrastructure. It is also recognised that the environmental goods and services supplied by ecosystems (including coastal ecosystems) are important to the health, safety and wellbeing of humans (UNESCO, 2003).

The value of ecosystem goods and services in the coastal zone is classified into the following three categories (UNESCO, 2003):

- **Direct use values.** These are goods and services that are market-based and can be bought and sold. Examples include the value of tourism and recreation related properties and business.
- **Indirect use values** are goods and services provided by coastal ecosystems that cannot be traded. These include flood protection and coastal defence that, for example, beaches and dunes provide against erosion by sea storms.
- **Non-use values** relate to cultural and aesthetical factors that also cannot be traded and are often based on an individual or group’s subjective evaluation. An example is the concept of ‘sense of place’ that attracts interest when development proposals are considered.

Due to the high value afforded to beachfront properties, locating a coastal development as close to the high-water mark as possible is an objective of many property developers. This is normally achievable along an elevated, stable, rocky coastline. However, planners, designers and/or owners are often ignorant of the risks involved with placing infrastructure too close to a sandy or mixed (rocky, sandy) coastline. The principle of establishing and adhering to a development setback limit is well known and fundamental to the ICM Act. Proponents of development, however, often try to bend the rules or ignore this aspect. This results in coastal municipalities then being faced with the task of evaluating new development proposals or amending existing development located within or adjacent to the littoral zone. The responsibility of maintaining beaches and buffer dunes located seawards of public and/or private property where there is a high risk to property from erosion or wind-blown sand inundation then often becomes that of the local authority.

In addition to the ongoing challenge of catering to the needs of an ever-growing permanent population, the seasonal influx of tourists and the land use associated with recreational needs form significant drivers of rapid change in coastal ecosystems. Symptoms of over-utilisation and loss of important qualities of coastal ecosystems include poor water quality, degraded and destructed critical habitat (such as wetlands) and overall loss of biodiversity (Olsen, 2001). Numerous examples of foredune blow-outs occurring due to human traffic along informal pathways exist along the South Africa coastline. This often results in a reduction of the volume of sand available in the foredune system that provides the key component of the coastal defence mechanism.

1.4.2 Climate change

Although not accurately quantified yet, the effects of climate change on the coastal processes pose an additional risk to poorly located developments. For example, the latest projections for the future sea-level rise along the South African coastline due to global warming vary between 0.5 m (as a lower limit) and 2.0 m as an upper extreme above the present level by 2100 (Rossouw, 2009). This aspect is further explored in Section 2.2.9.

1.4.3 Beaches and dunes as important natural assets

The Construction Industry Research and Information Association (CIRIA) highlights the importance of the beach and associated foredune system as vital components of coastal defence mechanisms to protect development from negative impacts from flooding and/or erosion by the forces of the sea (CIRIA, 1996). The point is made that beaches and dunes are considered important assets to coastline protection and therefore deserve specific management attention at a level on par with engineered coastal defence mechanisms such as seawalls, groynes and other methods.

This thesis therefore relates to the value of foredune zones as natural coastal defence mechanisms needed to protect natural ecosystems and infrastructure from the impact of the sea. Examples of areas that are protected by well-functioning foredune systems are habitats such as wetlands and mature back dune vegetation, and man-made areas such as municipal infrastructure and private development located landwards of the beach and foredune system.

From the above it is concluded that managing the integrity of the buffer dune system, knowing when it is at risk and knowing how to respond in an appropriate manner when natural and anthropogenic actions place the foredune system at risk are important and significant components underpinning the spirit and intention of the ICM Act.

1.5 Human development and coastal dynamics

1.5.1 Appropriate development set-back

In many urban areas worldwide, naturally occurring foredune buffer zones are maintained and enhanced though active management. The naturally functioning foredune system at Natures Valley, near Plettenberg Bay, South Africa (Figure 1.4), is an excellent example of an appropriate development setback established landwards of the high-water mark. Being totally exposed to deep-sea wave energy, the beach and foredune system undergo dramatic seasonal changes, but because there is enough space between the natural coastal processes setback area (Figure 1.3) and the development, the system is seen in a state of dynamic equilibrium with little risk to coastal development from sea storms or wind-blown sand inundation.

Figure 1.4: Natures Valley, an excellent example of an appropriate development setback landward of a well-maintained natural foredune functioning as an effective buffer dune system (DEA, 2009)

Approval of development plans by local authorities without considering the natural processes often results in costly and continuous maintenance requirements. An option is placing constructed foredunes, here defined as 'buffer dunes', as a 'soft-engineering' solution, firstly to prevent wind-blown sand inundation in areas where onshore winds and an abundance of sand exist, and secondly, to maintain an adequate volume of sediment as a buffer to limit the effect of storm erosion and thereby reduce the risk to property.

In areas such as along the coastline at Milnerton, near Cape Town, South Africa (Figure 1.5), a 50 m wide constructed foredune protects the property development (i.e. a hotel-resort complex) from the influx of wind-blown sand and provides the required volume of sand buffer between the development and the sea. The consequences on the high-value infrastructural development of any negative impact due to wind-blown sand or erosion are assessed to be high, so the probability of any such impact occurring is reduced. This reduction in the risk is achieved by actively managing the integrity of the coastal defence mechanism through the provision of a constructed foredune system acting as a buffer dune (Figure 1.5).

The area directly north of the hotel is zoned for recreational purposes only and since the consequence of impact from sea storms and/or wind-blown sand inundation on this type of land use is seen to be less than that at the hotel, the constructed buffer dune width was reduced to 30 m measured landwards of the seaward edge of the natural vegetation.

The natural foredune can be seen on the southern side and adjacent to the constructed foredune system. The consequence of wind-blown sand encroachment into the natural area landwards of the natural foredune is considered low and little management is needed.

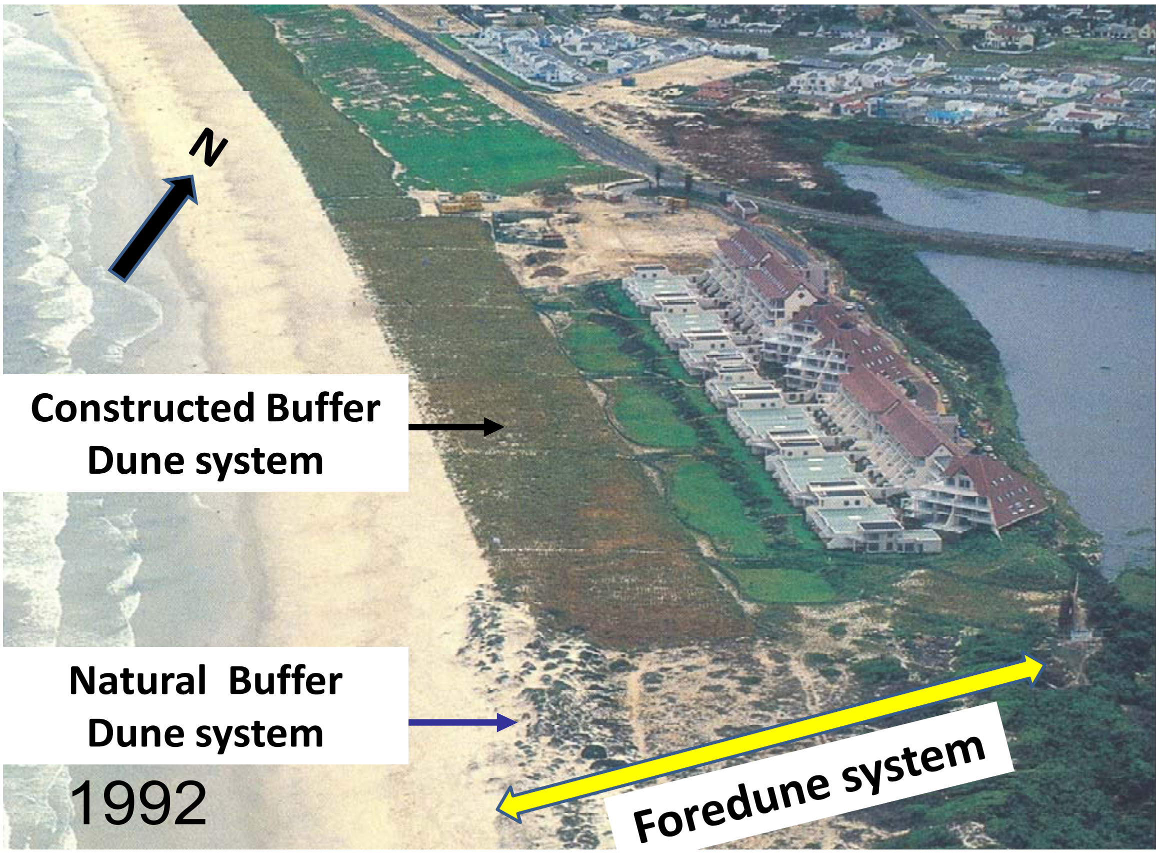


Figure 1.5: Example of constructed buffer dune (CSIR, 1992)

1.5.2 Inappropriate placement of development

When human development is located within reach of the sea, the risk of damage to such property is high. In Figure 1.6 the consequence of the removal of the foredune along with a high storm surge reaching into and surrounding human development can be seen. Figure 1.7 shows an example of inconsiderate development located within a natural wind-blown sediment pathway at the coastal resort town of Witsand at the mouth of the Breede River estuary along the Cape south coast in South Africa.

Figure 1.6: House inundated and damaged by storm surge during a storm that coincided with a spring high tide (Ethekwini Municipality, 2008)

Figure 1.7: House damaged by wind-blown sand (DEA, 2009)

1.6 The hypothesis

From the information provided in the introductory section, it can be concluded that there is significant developmental pressure on the coastal areas of the world, and this is no different in South Africa. Examples exist where unwise land use planning in the past has led to parts of developed areas in coastal municipal areas being at risk from natural processes.

Not only are current and future municipal managers faced with having to deal with the consequences of inconsiderate planning decisions that result in municipal infrastructure and private property being threatened, but new development plans have to be evaluated in the same context to avoid future problems.

Although there are many planning guidelines and regulations that assist decision-making at municipal level, the reality is that municipal officials often lack the experience and expertise to understand the potential consequences of a particular situation when it is associated with the coast–land interface. They therefore often fail to implement the necessary management actions required to reduce the likelihood of an event occurring.

Olsen (2001) concludes that the availability and use of responsible forecasting capabilities are essential for carrying out effective integrated coastal management. He suggests that such forecasting needs to integrate across the natural and societal components of the ecosystem and act as an effective tool to improve communication between scientists, politicians and society. This is especially valid in developing countries where a requirement of 'economic growth at almost any cost' often prevails and where municipalities normally cannot afford, or do not have access to, experienced coastal environmental managers (Olsen, 2001).

It is critical for decision-makers to, for example, be able to understand the relative magnitude and potential consequences of the effect of high wave energy interacting with a soft sandy coast. The influence of the coastal orientation relative to the prevailing winds and the availability of sand on the beach are all important to understand the potential threat from erosion and/or sand blown into areas located downwind of the beach or dune.

The principle of maintaining the volume of the sand in the foredune at a level that allows enough of a buffer against storm erosion is an important concept for municipal decision-makers to grasp. Furthermore, understanding the relationship between the height of the foredune and the horizontal distance that the seaward toe of the foredune can erode landwards is important in determining the development setback distance.

Understanding the role of dune vegetation in binding wind-blown sand, its importance in establishing and maintaining foredunes as coastal defence mechanisms and the effect of human activities on the ability of the dune vegetation to fulfil this function should be understood when planning, budgeting for and implementing coastal defence maintenance activities.

The requirement is therefore to assist inexperienced municipal decision-makers to take the appropriate management actions that will preserve the integrity of the buffer dune system as a soft-engineering coastal defence mechanism and thereby reduce the likelihood of the forces from the sea negatively impacting on natural and man-made coastal assets.

Olsen (2001) acknowledges that, although there are many uncertainties in the understanding of the various components of the coastal human–nature system, the fact remains that managers have to take decisions on a variety of matters related to integrated coastal management. Decision-making happens whether there is scientific information and evidence available or not. "The challenge is to identify, locate, and organize information in ways that will make it accessible and usable in the ICM decision-making process" (Olsen, 2001:333)

The significance of having simple, yet effective and robust guidelines to inform and assist decision-making at municipal level becomes extremely important when the wellbeing of humans are at stake or where ecosystems provide crucial services, such as security to expensive infrastructure important to the local economy, as well as key components of a coastal ecosystem.

The hypothesis postulated is therefore as follows:

The effectiveness of natural and constructed buffer dune systems can be assessed by a set of indicators that defines the integrity of the buffer dune system and triggers informed management decisions.

By implication, this means that managing the integrity of the buffer dune system is an effective, eco-friendly, 'soft-engineering' coastal defence mechanism. This study was therefore focused on formulating a simple, robust, yet effective management decision support guideline that allows the maintenance of the integrity of the foredunes to serve as effective coastal defence buffer systems to protect vulnerable coasts within coastal municipal areas.

1.7 Brief chapter overview

Following this introductory chapter, the background to the key coastal processes and human activities relevant to the existence and maintenance of the integrity of foredunes along the south coast of the South African coastline is discussed in Chapter 2.

The results of a background literature review on understanding the current knowledge of the use of indicators and decision support guidelines for environmental management in general, and for integrated coastal zone management (CZM) in particular, are also discussed in Chapter 2.

In Chapter 3, the selected study area along the south coast of South Africa and pilot sites are described. Both the environmental and human use aspects are discussed and a brief overview of each of the sites is provided.

The indicators that form the key components of the conceptual risk profile assessment (RPA) procedure are discussed in Chapter 4. In Chapter 5, the data gathering, the analysis method and the results of the field application and evaluation of the Risk Profile Assessment procedure (RPA) support guide are given.

A summary and discussion of key conclusions are provided in Chapter 6 along with specific recommendations and the identified limitations of the research outcome.

CHAPTER 2: BACKGROUND

2.1 Introduction

In the previous section the purpose of the study and some key definitions were provided. In this chapter the background to the coastal processes and human activities relevant to the existence and maintenance of the integrity of foredunes along the south coast of the South African coastline is discussed.

2.2 Bio-physical processes that influence foredune formation and integrity

2.2.1 Geographical characteristics

Being located at the southern tip of the African continent, the coastal processes along the coastline of South Africa are influenced by three ocean masses, namely the Southern Atlantic Ocean to the west, the Southern Ocean where the so-called Roaring Forties prevail, and the Southern Indian Ocean to the east.

Figure 2.1[1] depicts the geographical setting of Southern Africa and specifically South Africa in relation to the major Southern Hemisphere pressure, wind and ocean current systems. Two major currents prevail within the oceans around the southern point of Africa, namely the cold Benquela Current, which flows northwards along the west coast of Southern Africa causing inshore upwelling, and the warm south-flowing Agulhas Current, which flows along the east and south coasts of Southern Africa.

With Southern Africa located south of the tropics, the prevailing weather patterns across the region are principally caused by two dominating high-pressure systems, one located over the South Atlantic and the other over the South Indian oceans (Figure 2.1). These interact with a series of low-pressure systems that move eastwards from the deep south-western ocean. In winter these 'cold fronts' move further north (closer to Africa) and bring

[1] The NRF research report on Southern African dune systems (Tinley, 1985) is already 25 years old, but still remains the most comprehensive publication specific to coastal dunes in South Africa. Extensive use is made of the information and illustrations in the report in this thesis.

rain to the south-western and Southern Cape area of South Africa as well as the eastern coasts below the Great Escarpment (Tinley, 1985).

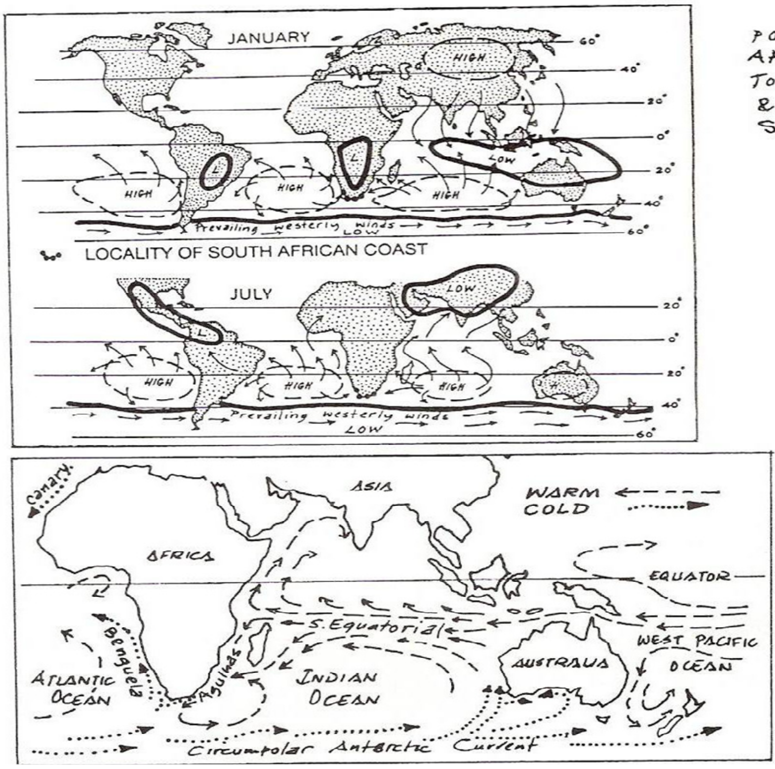


Figure 2.1: Regional weather and current systems (Tinley, 1985)

2.2.2 Climate

As can be seen in Figure 2.2 (Tinley, 1985), the rainfall regime along the south-west coast of South Africa is defined as being winter unimodal, because rain mainly falls during the winter months. The south coast region has a bimodal rainfall regime with the months of November to April being the driest on average. The south-east and east coasts of Southern Africa fall into the summer unimodal rainfall area.

From the available information in the climographs for Cape St Blaize (Mossel Bay) in Figure 2.2, it can be seen that the average annual temperature is 17.9 °C and the temperature range of the average annual temperature is 7.1 °C. The mean annual rainfall is 417 mm and a total of 10 days receive in excess of 10 mm of rain per day. There are a total of 24 fog days per year and the months of November to April are considered dry and hot. August, September and October are on average humid, where the rainfall curve exceeds the temperature curve.

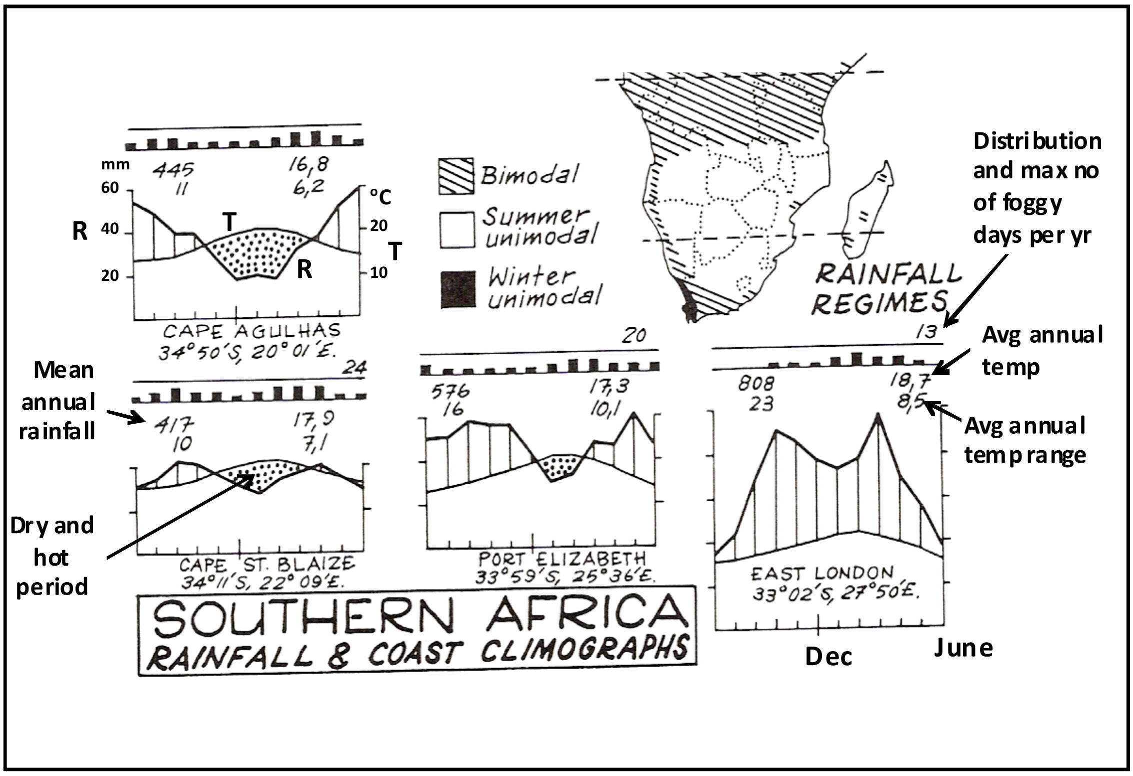


Figure 2.2: **Climographs for the area between Cape Agulhas and East London, South Africa (Tinley, 1985)**

The information on the climograph is useful in guiding buffer dune maintenance. The risk of dune vegetation die-off and subsequent wind-blown sand blow-outs occurring during the hot and dry periods is very high and is increased when this period occurs over holiday periods, when many tourists spend time at the coast and the impact due to trampling of foredunes is high. The influence of vegetation on the wind-blown sand transport rate is discussed in Section 2.2.11.

2.2.3 Tidal range

In general, tidal ranges are categorised into the following three types (Davies, 1980):

- Microtidal, where the tidal range is up to 2 m
- Mesotidal, with a range of 2 to 4 m
- Macrotidal, reaching ranges in excess of 4 m

The whole Southern African coastline falls into the upper-microtidal range, with an average springtide range of 1.8 m (Tinley, 1985). The state of the tide influences the maximum storm runup level and associated erosion risk as discussed in Section 2.2.9.

2.2.4 Wave regime

The winds associated with the low-pressure weather systems located in the south-western parts of the ocean generate deep-sea swells that move north-eastwards until they reach the coastal area around South Africa, after which they propagate northwards along and past the western and eastern coasts of Southern Africa. As an example, the deep-sea wave regime off Mossel Bay is depicted in Figure 2.3, and the statistics show that deep-sea swells originating in the south-western (225° measured clockwise from north) and south-south-western (202.5°) sectors dominate throughout the year. The data also show that swells originating in the eastern sector (90°) occur infrequently at Mossel Bay, but that the heights are significant enough to be taken into consideration when determining the risk profile of an area.

Waverider data collected in deep water (80 m) off the coast at Gouritz Mouth were analysed by Rossouw (1989). From this analysis the deep-sea significant wave height (H_{mo}) for various return periods were determined. For this thesis the H_{mo} for the 1:100 year return period is taken as 12 m with an associated wave period of 16 seconds. This is used in Section 3.5 as the basis for determining the wave transformation within Mossel Bay.

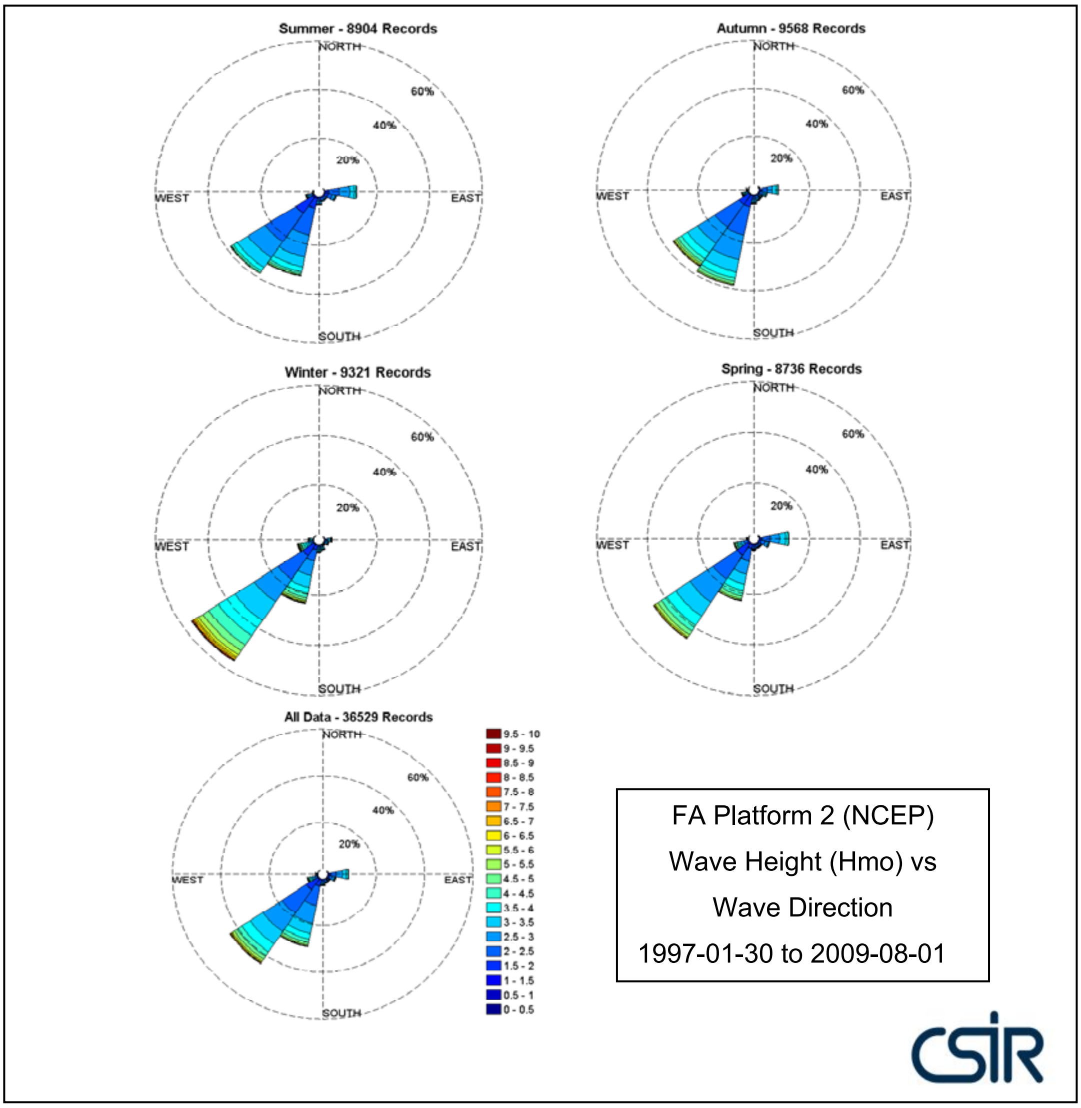


Figure 2.3: Wave roses for the area offshore of Mossel Bay

2.2.5 Alongshore processes

The processes that form, shape and maintain beaches and dunes within the littoral active zone are principally driven by wind and wave energy. Waves approaching the coast at an angle cause longshore and cross-shore currents and breaking waves mobilise sand in the surf zone, which is transported by these currents (Figure 2.4).

Figure 2.4: Alongshore sediment transport (image from Google Earth™)

The alongshore transport of sediment continues while there is a non-zero angle between the nearshore wave fronts and the shoreline, the so-called incidence angle, and provided there is no blockage by structures and adequate sediment is available. This is discussed in Section 2.2.7 below.

2.2.6 Cross-shore processes

Winds out at sea generate waves. During stormy conditions, the waves become large and steep when they approach the coast. Onshore winds and low barometric pressure during storms often result in raising the water level along the coast, causing a storm surge. The resultant higher water level allows the high-energy waves to pass over the normal offshore bar system without breaking or significant energy dissipation. Wave run-up during such high-water levels poses further risks to coastal properties. The risk increases with a rise in sea level (Theron, Rossouw, Barwell, Diedericks & De Wet, 2010). The significance in terms of foredune integrity is discussed in Section 2.2.9.

As the seawater level increases during the storm, wave breaking eventually occurs close inshore, causing beach erosion (Figure 2.5) and, depending on the duration and timing of the storm energy peak within the tidal cycle, can cause the frontal dune system to erode. As illustrated in Figure 2.6, this erosion of the foredune provides a critical source of sand to the beach.

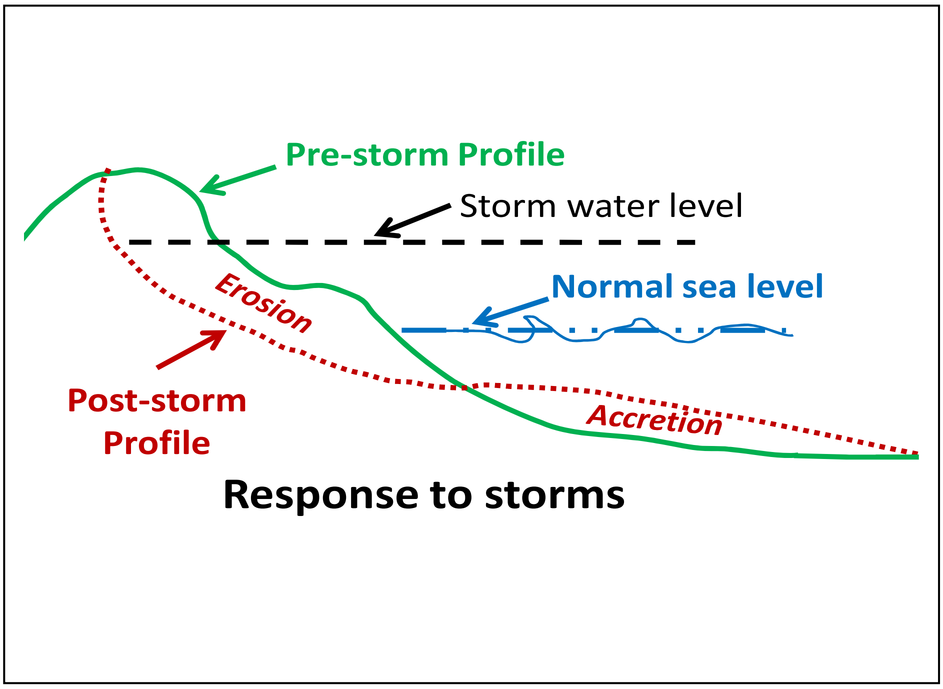


Figure 2.5: Initial attack of storm waves on the beach and dunes (redrawn from CEM, 2006)

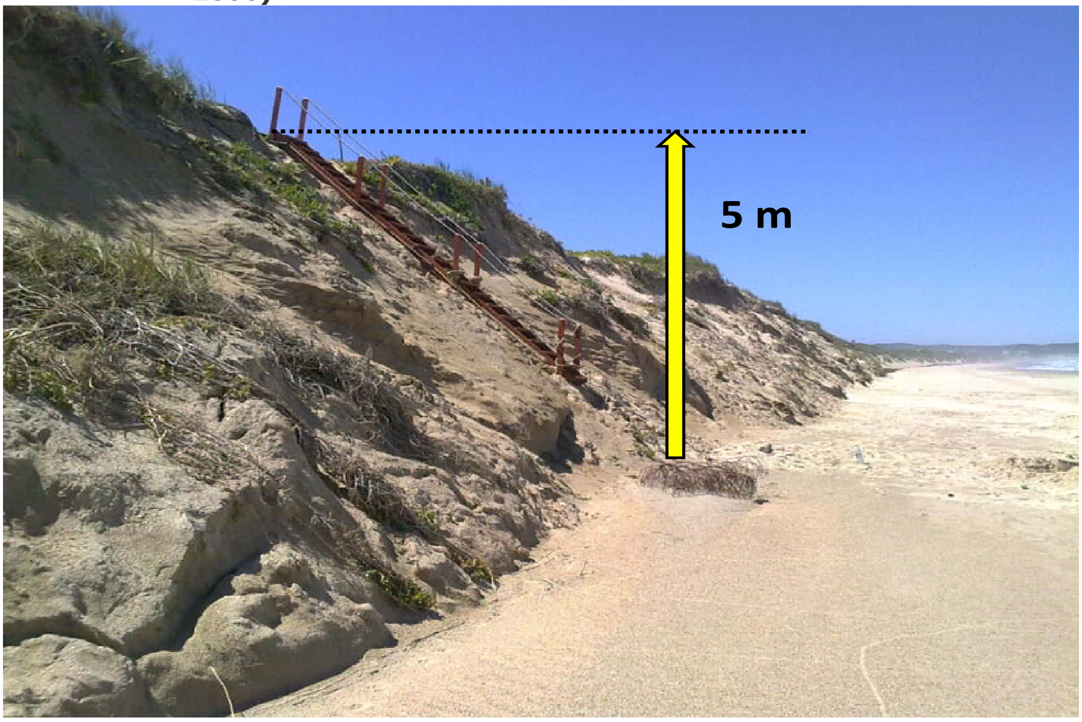


Figure 2.6: Erosion of the foredune is a source of sand for the beach

As the storm passes and wave-energy conditions return to normal, low-energy waves reach the coastline and the processes of rebuilding the beach and dunes take place over a relatively long period (figures 2.7, 2.8 and 2.9).

The process alternates between accretion and erosion and along the Southern African coast it is typically associated with summer and winter seasons (Figure 2.7), resulting in narrower eroded beaches in winter (Figure 2.8) and wider, exposed sandy beaches in summer (Figure 2.9).

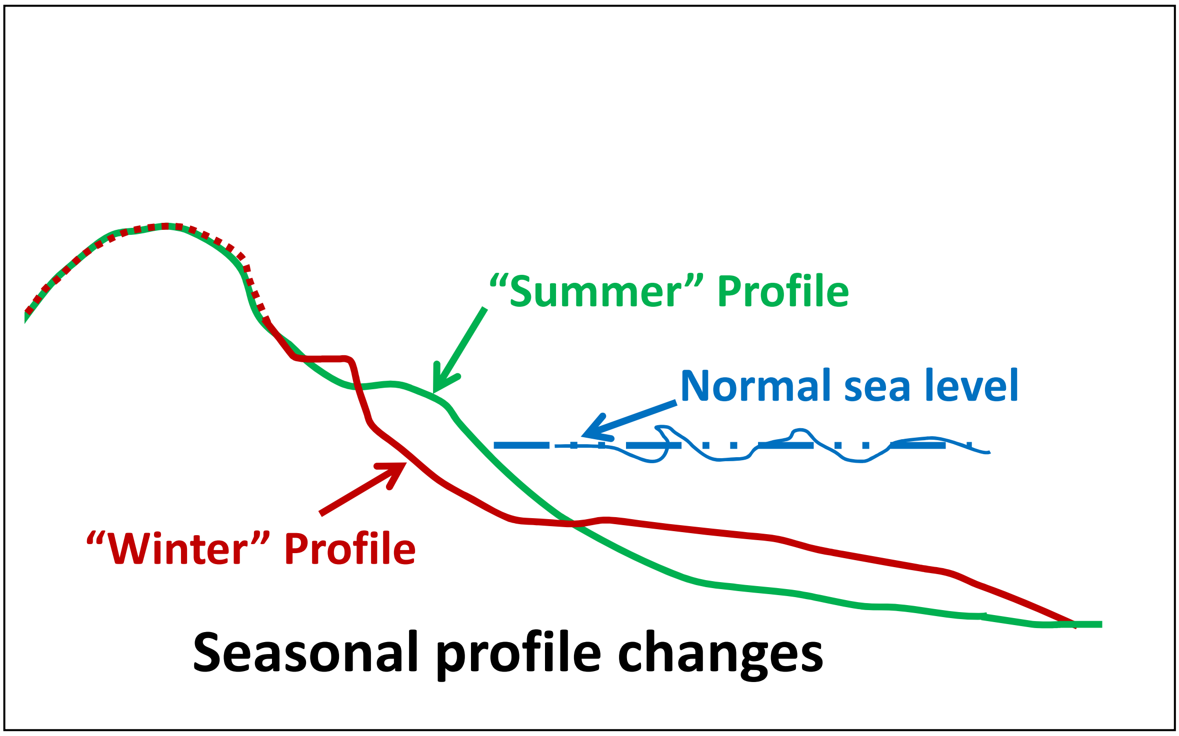


Figure 2.7: Seasonal foredune and beach profile (redrawn from CEM, 2006)

Figure 2.8: **The beach at Kogelbaai, near Cape Town South Africa, after a major winter storm. Note the reference points A and B and compare to Figure 2.9, the summer profile (photo taken on 16 October 2008 by M. Luck-Vogel)**

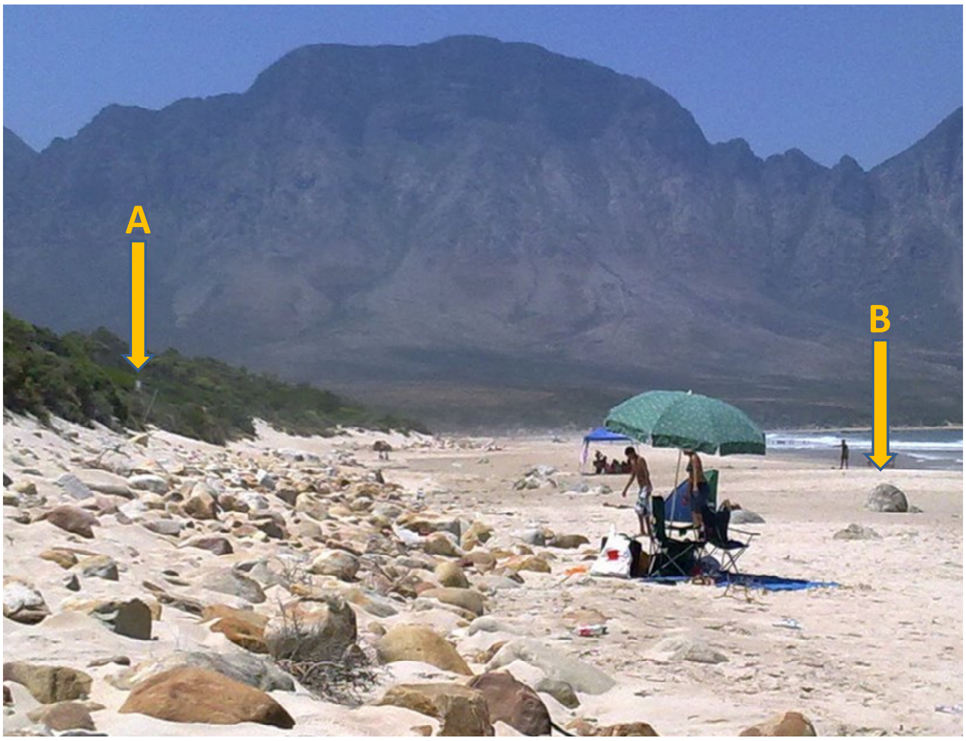


Figure 2.9: **Summer profile of the beach at Kogelbaai (photo taken on 2 January 2010)**

As illustrated in figures 2.10 and 2.11, sand is washed onshore by low-energy waves during calm periods and the beach typically becomes wider. Onshore winds blow beach sand into the foredune area. Pioneer grasses and dune vegetation start coppicing along the driftline and as sand and detritus gather around obstacles and indentations, seeds germinate and embryo hummock dunes start forming. As the pioneer vegetation increases in density, the beach surface roughness increases, thereby reducing the wind velocity, and sand settles out among the vegetation, forming larger hummock dunes (figures 2.10 and 2.11).

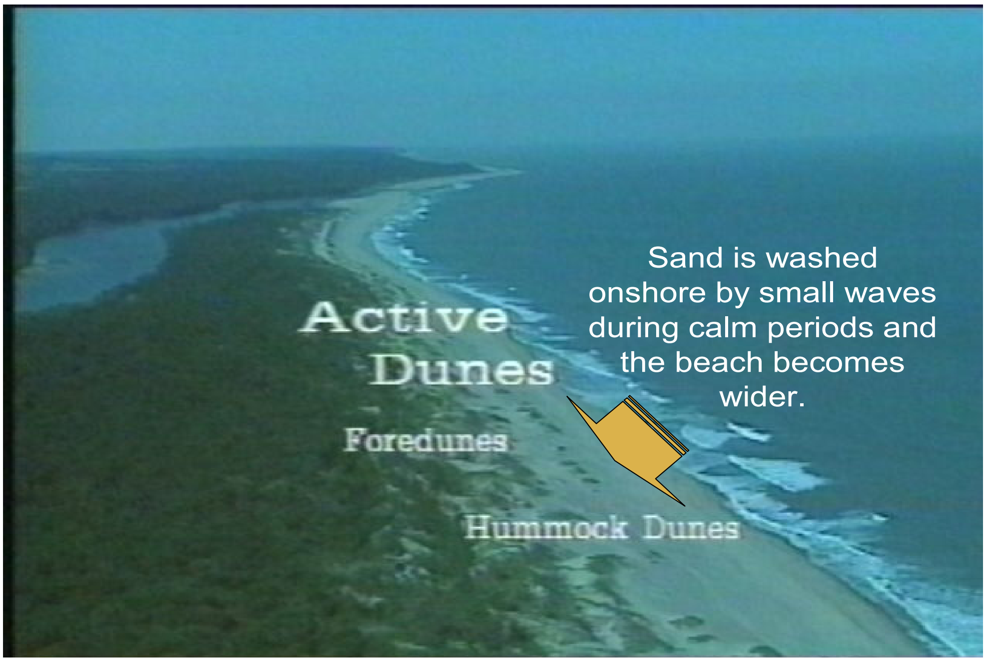


Figure 2.10: Illustration of components of an undeveloped soft coastline (adapted from CSIR, 2000a)

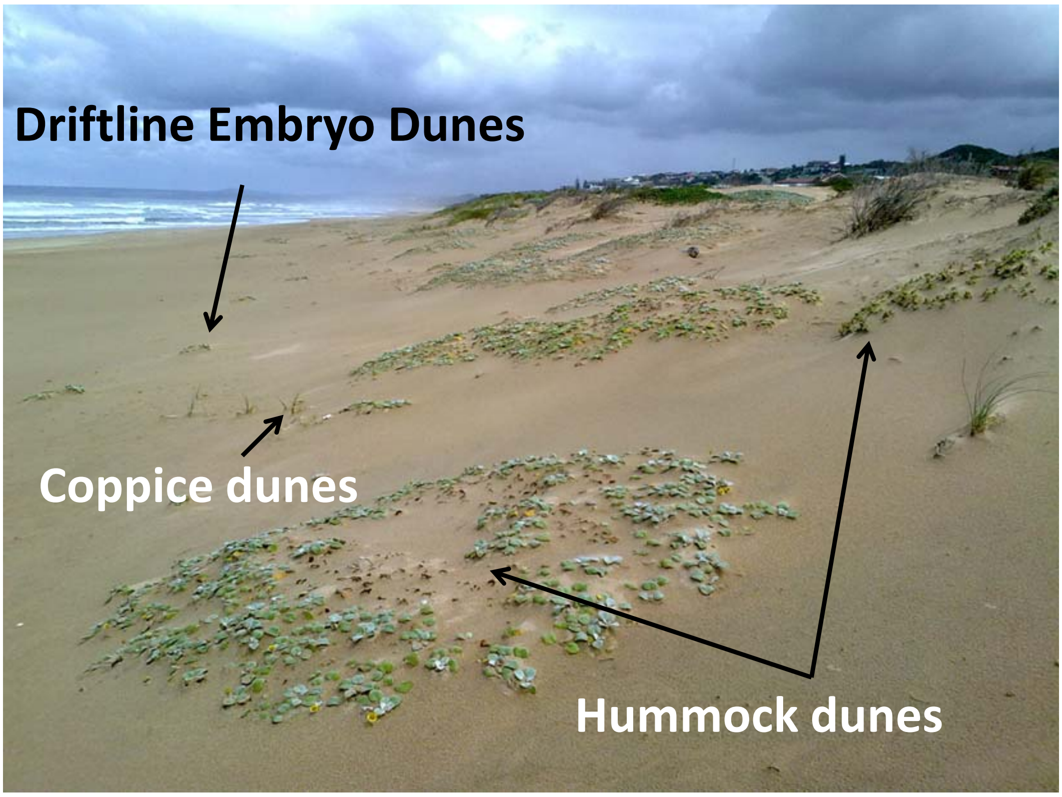


Figure 2.11: Pioneer dune vegetation starts the process of foredune rebuilding after storms

This process continues throughout the spring, summer and autumn seasons when onshore winds prevail and the climate is favourable to vegetation growth. The foredune continues to grow higher and wider until high winter storms erode the front of the dune again. Depending on the persistence of the onshore wind component and the supply of sand on the beach, foredunes along the Southern Cape coast typically grow up to a height of between +6 and +8 m mean sea level (MSL) if left undisturbed by human action such as bulldozing the dune crest to, for example, reinstate sea views, or as a result of blow outs caused by informal pathways across the dune. Field surveys carried out over ten years between 1986 and 1996 by the CSIR provide dune profile data adjacent to the Hartenbos, Klein Brakrivier and Groot Brakrivier estuary mouths (CSIR, 2000b).

2.2.7 Coastline shape and orientation

As discussed in the previous section, waves and winds have a direct physical impact on coastlines and also generate nearshore currents that, together with the turbulence associated by breaking waves, result in available sediment being transported alongshore as well as on- and off-shore. Deep-sea-generated waves reach the coastline and refract around rocky points, promontories and peninsulas. Figures 2.12 and 2.13 show the influence of the waves and currents on a soft coastline bounded by rocky promontories or rocky shores. As reported in Tinley (1985:10), typically, erosion of the sand between the headlands forms asymmetric bays or half-heart or zetaform configurations. This is further discussed in Section 2.2.8.

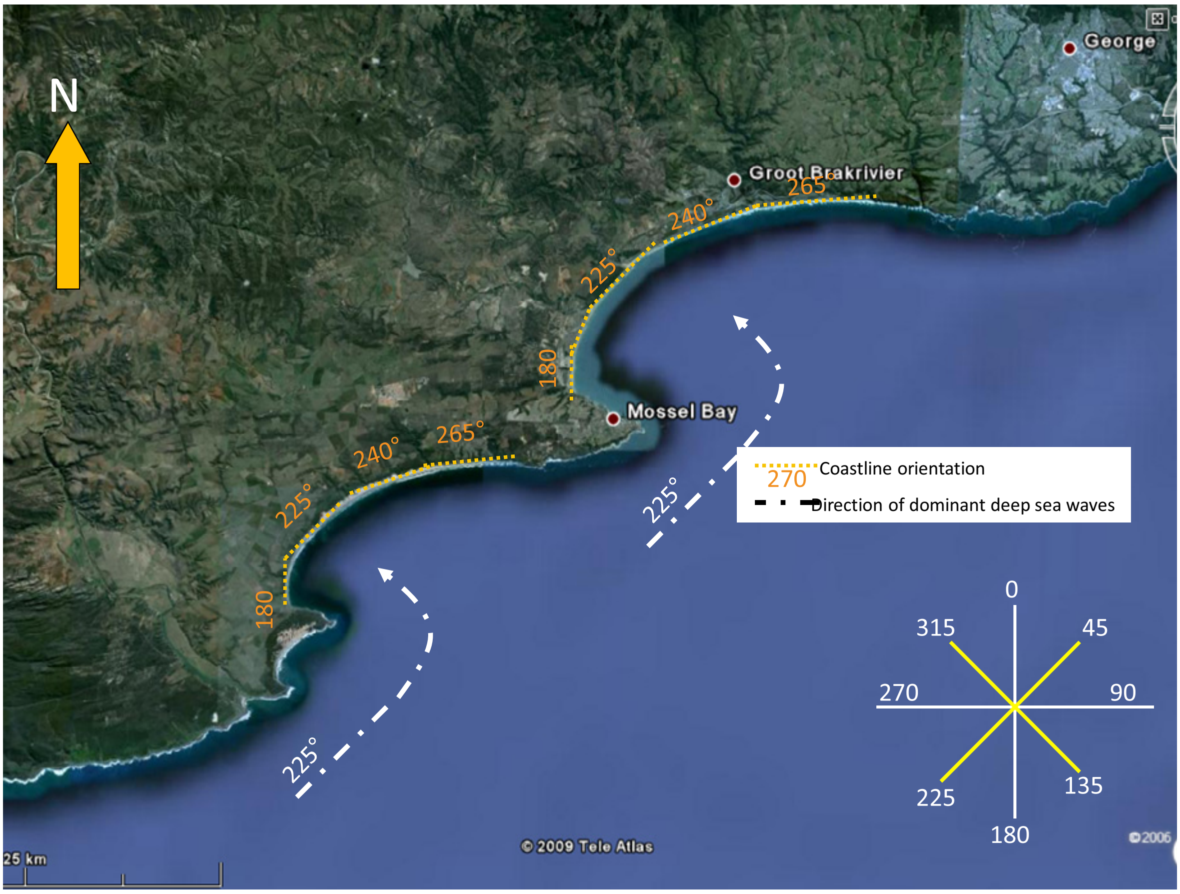


Figure 2.12: Waves refract around promontories, resulting in a variation in characteristics along typical half-heart bays (image from Google Earth™)

The coastline orientation of a soft coast over a long period approximates the inshore wave angle associated with the dominant wave regime. As shown in Section 2.2.4 (Figure 2.3), the dominant deep-sea wave direction is typical 225° to north for the area shown in Figure 2.12; the sheltering effect of the promontory results in an area of low wave energy prevailing on the south-western side of the half-heart bays typical of the south coast of South Africa. The shoreline here is often rocky and provides shelter to boats and in places provides opportunities for boat launching, small-craft harbours and commercial ports.

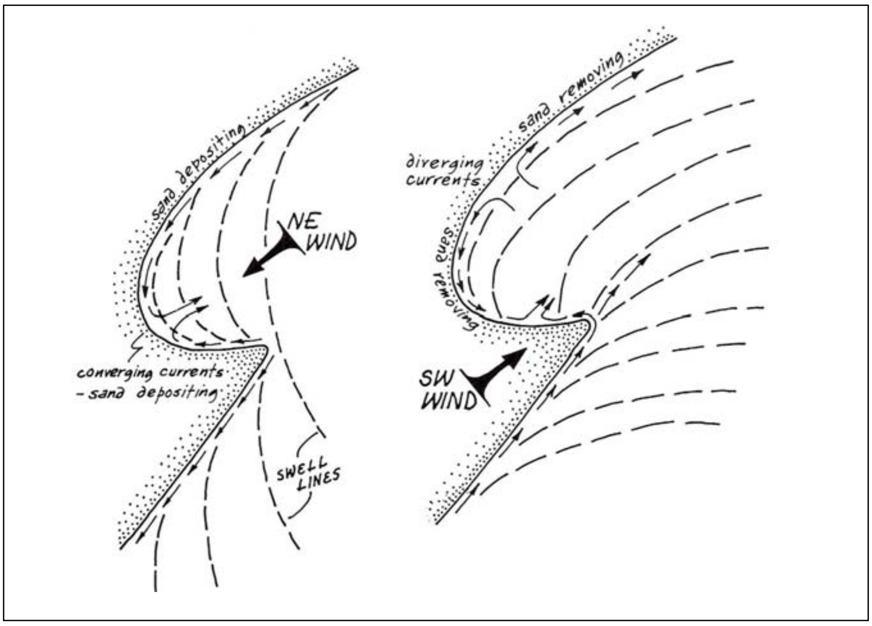


Figure 2.13: **Swells originating in different directional sectors result in different alongshore wave-energy fluxes and changes in local current patterns (Tinley, 1985)**

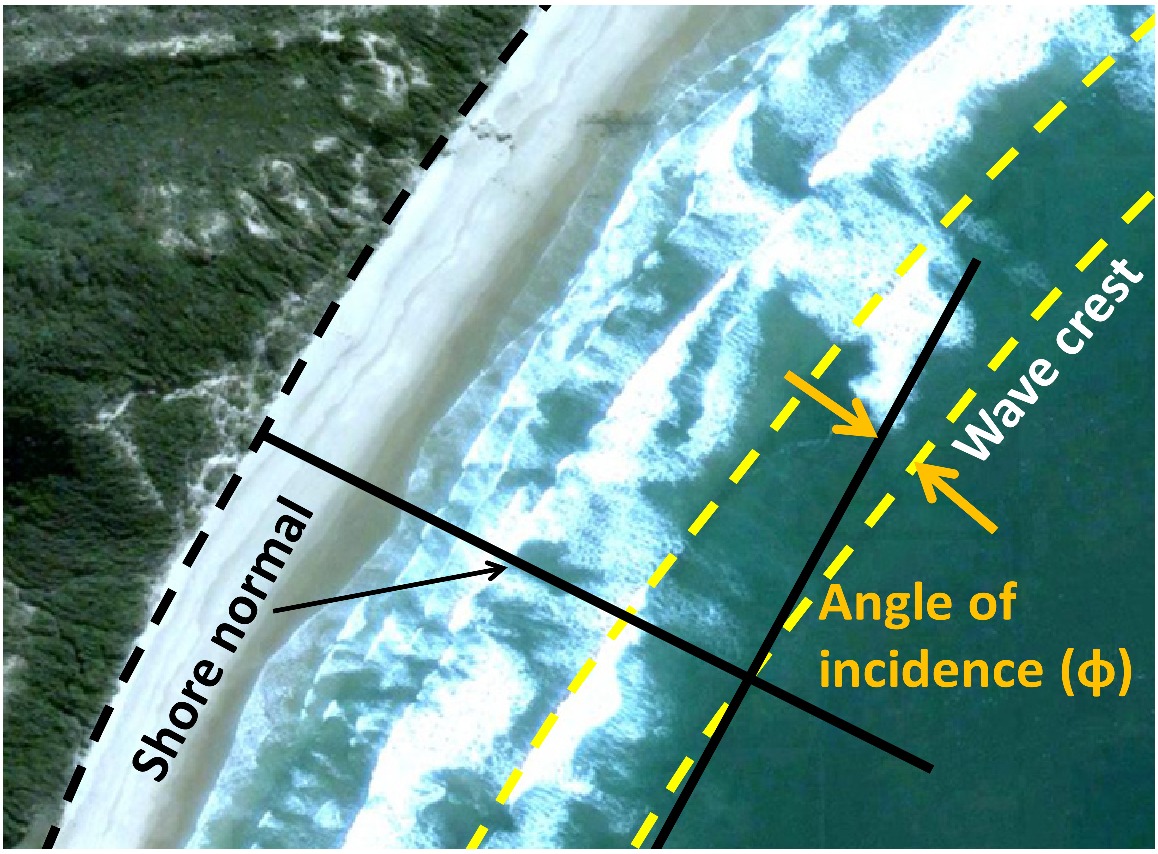


Figure 2.14: **Angle of incidence is defined as the angle between the wave crest orientation and that of the shoreline (image from Google Earth^{TM})**

As noted in Section 2.2.5, an important parameter along the coast is the influence of the angle of wave attack relative to that of the coastline. The so-called angle of wave approach or incidence (φ) (Figure 2.14) has a direct relationship to the alongshore sediment transport potential, and therefore, along with the availability of sediment, has an influence on whether the coastline is dynamically stable, in a state of erosion or accreting. The greater the angle of incidence, the larger the sediment transport potential (CERC, 1984).

The Danish Hydraulics Institute (DHI) presented a simplified coastal classification of landforms shaped through the interaction of prevailing waves, currents and sediment transport (2001). The classification is depicted in Figure 2.15 and detailed in Table 2.1 as a function of wave incidence angle and degree of exposure to wave energy. They categorised the exposure of the coastline to the prevailing offshore wave direction as being *Exposed* (E), *Moderate* (M) or *Protected* (P). As depicted in Figure 2.15 the areas sheltered behind a rocky promontory is categorised as P. Those areas directly facing the open ocean are categorised as E. Areas within a bay are somewhat protected and are therefore categorised as M.

Another useful component included in the DHI (2001) classification is the relationship of the angle of incidence, the sediment transport capacity and the exposure categories. As seen in the graph within Figure 2.15, the coastal type, depicted as Types 1 through 5, along with the relevant exposure category, is useful in describing a stretch of coastline with a variety of coastal morphological features. For example, an area directly exposed to the offshore wave direction (E) and where the coastline orientation is such that the angle of incidence (Figure 2.14) is large (say 50^{o} at a rocky cliff) is therefore classified as Type 3 and, being directly exposed (E), is depicted as 3E in Figure 2.15.

The principle of classifying coastal morphology in terms of exposure to the incident wave energy is used as the basis for the schematisation of a typical half-heart bay as discussed in Section 3.5.

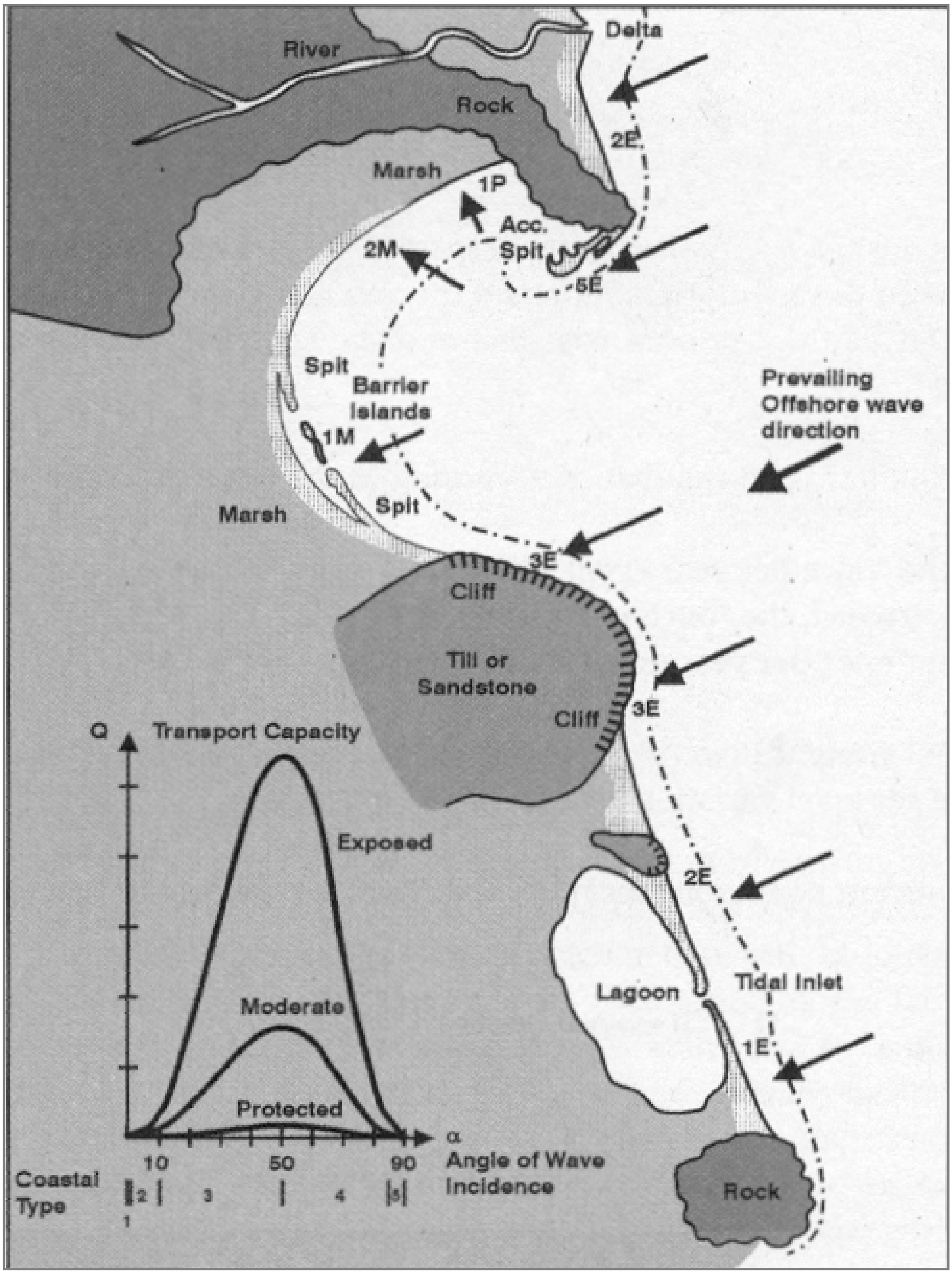


Figure 2.15: Classification of coastlines and presentation of coastal morphology (DHI, 2001) to be read in conjunction with Table 2.1

Table 2.1: Coastal classification as function of angle of incidence and wave exposure (DHI, 2001) to be read in conjunction with Figure 2.15

Coastal type (Fig. 2.15)	Angle of incidence (0^0 = shore normal) (Fig. 2.14)	Exposure	Main coastal characteristics
1P	0^0	Protected	Marshy
1M		Moderate	Narrow, stable sand beach, barrier island, sand spits
1E		Exposed	Wide, stable sand beach, barrier island, sand spits
2P	$1^0 – 10^0$	Protected	Marshy
2M		Moderate	Narrow, stable sand beach, barrier island, sand spits
2E		Exposed	Wide, stable sand beach, barrier island, sand spits
3P	$10^0 – 50^0$	Protected	Marshy
3M		Moderate	Narrow, unstable sand/shingle beach, cliff or dunes
3E		Exposed	Wide, unstable sand/shingle beach, cliff or dunes
4P	$50^0 – 85^0$	Protected	Marshy
4M		Moderate	Narrow, unstable sand/shingle beach, cliff or dunes, salients
4E		Exposed	Wide, unstable sand/shingle beach, cliff or dunes, salients
5P	$85^0 – 90^0$	Protected	Marshy
5M		Moderate	Sandy beach, accumulative land forms, spits
5E		Exposed	Sandy beach, accumulative land forms, spits

The wave energy and the direction of nearshore currents therefore vary along the coastline and contribute to the factors that define the stability of the land–sea interface. The beach and dunes become more exposed to the prevailing wave regime along the coastline and the characteristics within the littoral zone change from the low-energy, low-sediment transport capacity in the lee of a peninsula or promontory (classified as 1P in Figure 2.15 for example) to high sediment transport capacity at the exposed end of a bay (3E in Figure 2.15). Along the exposed coastline the nearshore and beaches are usually flat with a wide surf zone and the angle of incidence is small because the orientation of the wave crests are almost parallel to the shoreline orientation (Figure 2.14) and the sediment transport capacity is therefore low even though the coastline is classified as being exposed (E). The effects and implications of these physical characteristics on buffer dune integrity are discussed in more detail in Section 2.2.8.

2.2.8 *Wave transformation processes*

As was seen in the previous section, the prevailing wave climate interacting with the shoreline geology forms the coastline morphology. Half-heart bays are characteristic landforms along the south coast of South Africa (figures 2.12 and 2.16).

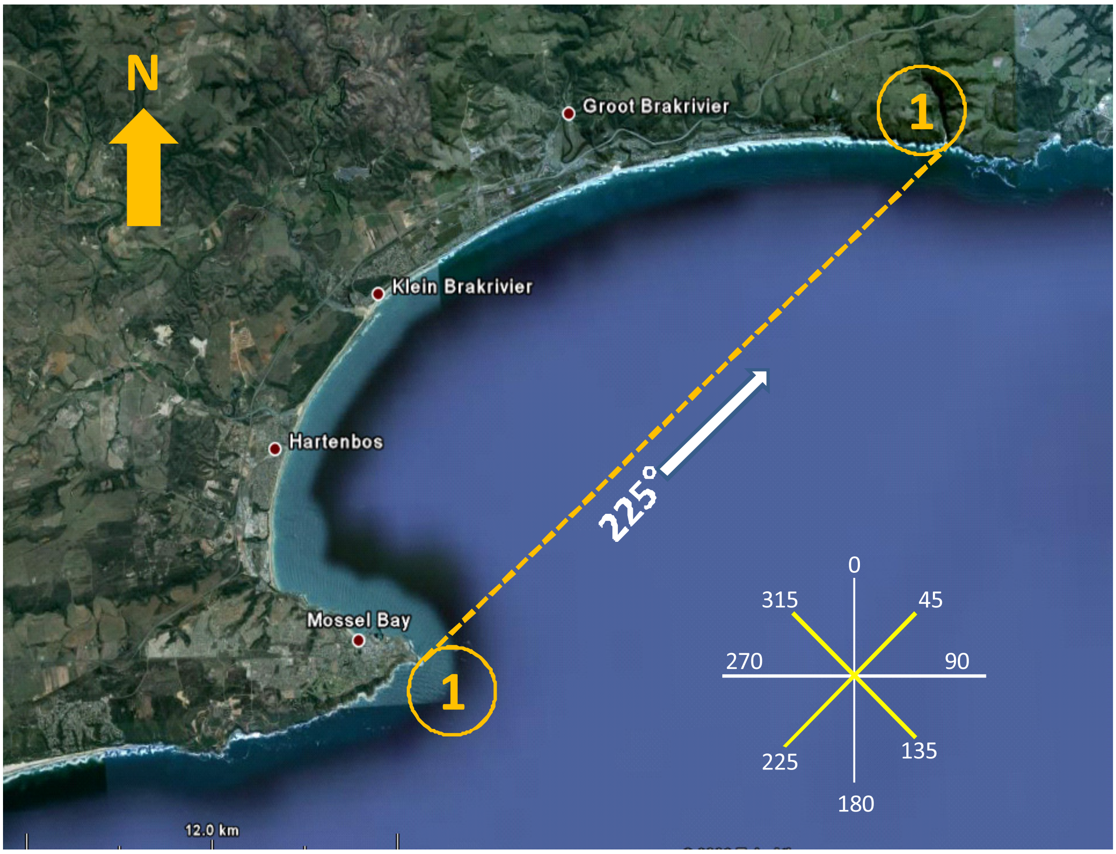


Figure 2.16: The peninsula shelters the 'shadow' area from swells approaching from the south-western sector

A typical half-heart bay is shown in Figure 2.16. Assuming the prevailing swells arrive from the south-western sector (as is the case along the south coast of South Africa), then the sheltered 'shadow' area can be roughly defined as lying to the north-west of an imaginary line drawn across the bay from the point of the promontory or peninsula (Line 1-1) in the same direction as that of the dominant wave direction (Holthuijsen, 2007).

As deep-sea waves approach the coast, they are transformed due to the horizontal variation in water depth. One of these coastal processes that influences the inshore wave regime (within the 'shadow area' in Figure 2.16) is called **refraction**. Refraction is the phenomenon where approaching waves are 'turned' towards shallower water due to depth- or current-induced changes in the phase velocity along the wave crest.

Another important influencing process is called **shoaling**. As the waves propagate closer inshore, the sloping bottom starts influencing the wave group velocity, slowing it down and causing an increase in the wave amplitude (or height). This 'bunching up' of wave energy is known as shoaling (Holthuijsen, 2007). When the wave height reaches a point where the wave steepness exceeds the typical value of 0.14 or the wave height to water depth ratio approaches 1.28, the wave breaks and energy is dissipated (Bijker, 1982).

The third process that influences the wave energy within a bay is that of **diffraction,** which often occurs along with refraction. Diffraction is usually the dominating influence in the 'shadow area' in the lee of structures like harbour breakwaters or natural features such as islands and promontories.

For this thesis, a wave transformation coefficient (K_T) is defined that represents the combination of refraction, diffraction and shoaling and is defined as the ratio of the nearshore pre-breaking wave height (H) to the deep-sea significant wave height (H_{mo}). The use of the K_T coefficient to represent the wave energy characteristics at specific points within a half-heart bay is discussed in Section 3.5.

As it will be seen in Chapter 3, output from the SWAN wave model (Booij, 1999) is used to calculate the wave transformation coefficient (K_T) at chosen points along the 10 m depth contour within Mossel Bay to infer the wave energy at the points.

The 10 m depth contour was used for Mossel Bay due to the following practical reasons:

- The position within the study area is easily decernable on the available charts and thus could be digitised fairly easily as input to the SWAN model set up.
- It closely approximates the position and shape of the half-heart bay configuration of the coastline of the study area.

- It ensures that the transformed wave characteristics are within the 'non-breaking' range where the wave steepness ratio of wave height to wave length is less than 0.14 and the wave height to water depth ratio is less than 1.28 (Bijker, 1982).

The SWAN wave model (Booij, 1999) is a freely available, open-source computer model that is based on wave theory relevant to defining the wave characteristics along the coast. The underlying theory and applicability of the SWAN model is comprehensively discussed in Holthuijsen (2007). The conceptual description of the SWAN model is available as a user manual (Deltares, 2009) as part of the Delft3D licensing agreement and is not repeated here. General background information on the coordination system, the grid orientation, resolution, the boundary conditions and so forth is provided. Guidance on how to choose the basic input for the Delft3D-WAVE module for the SWAN computations is provided as well. A brief overview of the underlying physics and numerics that have been implemented in the SWAN model is also provided in the user manual (Deltares, 2009).

2.2.9 Storm erosion and sea-level rise

Storm wave runup and erosion

As was discussed in Section 2.2.6, during stormy conditions the reach of the storm waves can pose a risk to coastal properties located within the 'coastal processes setback area' (figures 1.3 and 1.6). The erosion threat to such properties, be they located within foredunes or on sea cliffs (figures 2.19, 2.20 and 3.9), depends on the elevation reached by the water during such storms relative to the elevation of the beach seaward of the property.

Ruggiero, Komar, McDougal, Marra and Beach (2001) make the point that the actual sea water elevation can be different to the predicted astronomical tide level due to the influence of many oceanographic and atmospheric processes, such as low barometric pressure, prevailing at the time of the storm. In addition a rise in the water level occurs due to the build-up of water against the shore by waves (wave setup). On top of this the runup of individual waves occurs. Ruggiero et al. (2001) proposed a 'Property Erosion Model' as defined in Figure 2.17. The model predicts that erosion of the area directly landwards of the 'beach-property junction', defined as being at the elevation depicted as E_J, will occur when the sum of the actual (measured) tide level (E_T) and the wave swash runup reaches a higher elevation than E_J. In the example illustrated in Figure 2.17 the wave runup elevation (E_R) is lower than the beach-dune junction elevation (E_J) therefore no erosion of the foredune would occur according to the model.

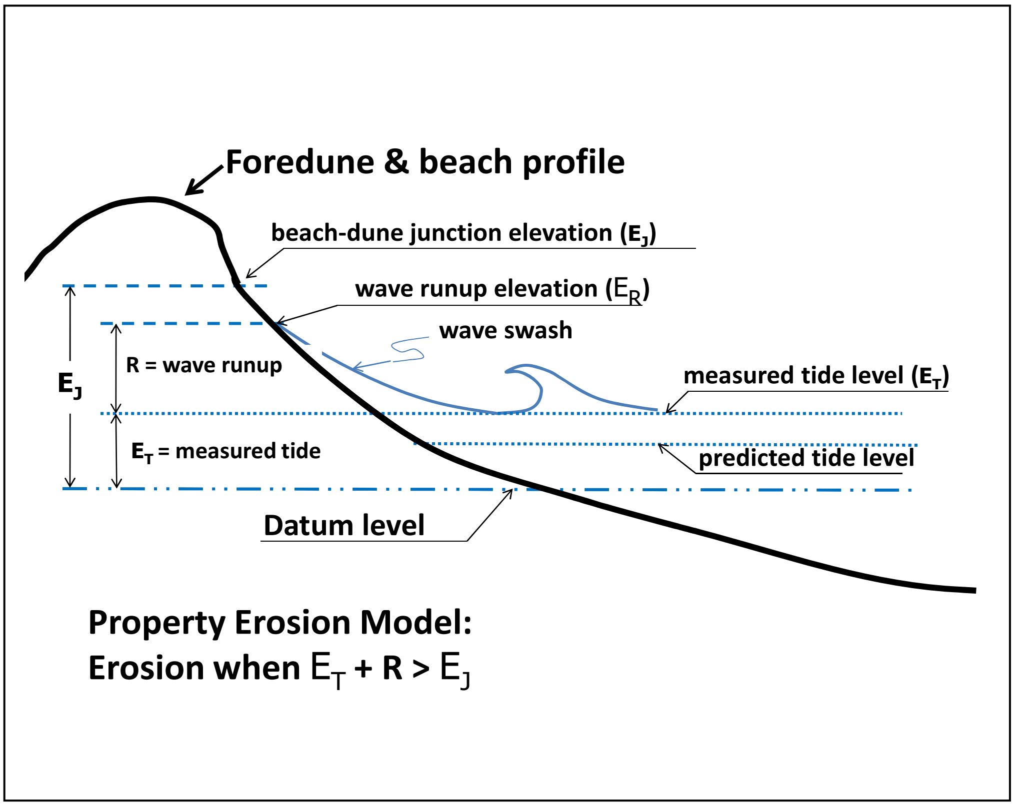


Figure 2.17: Basic wave-induced erosion model as proposed by Ruggiero et al. (2001). Sketch adapted from Ruggiero et al. (2001)

Battjes (1974) defined a relationship between the maximum vertical runup elevation, R_{max}, normalised by the deep-water significant wave height H_{mo} as follows:

$$R_{max} / H_{mo} = C\,S\,(H_{mo}/L_o)^{-0.5} \quad \text{..............} \ (1)$$

Where:

R_{max} is the max vertical runup elevation (m)

H_{mo} is the deep sea significant wave height (m)

C is a dimensionless constant

S is the beach slope (equal to tanβ)

L_o is the deep water wave length given by $L_o = (g/2\pi)T^2$ where g is the acceleration of gravity and T is the wave period.

As referenced in Ruggiero et al. (2001), Holman (1986) found that when the runup elevation is expressed as the 2% exceedence value of runup maxima, $R_{2\%}$, the dimensionless constant in Equation (1) approximates a value of 0.9.

Analysing a large data set for the dissipative beaches in Oregon, data for intermediate sloped beaches in North Carolina Holman (1986) and for steeper beaches in Australia (Neilson and Hanslow, 1991) as reported in Ruggiero et al. (2001) it was concluded that on flatter, dissipative beaches (S < 0.10) where only the wave steepness plays a role and the influence of the beach slope is negligible, Equation (2) can be used to calculate the $R_{2\%}$ value:

$$R_{2\%} = 0.5H_{mo} - 0.22 \quad \text{.............. (2)}$$

Where: $R_{2\%}$ is the extreme value of the top 2% of the maximum vertical runup elevations (m)

For steeper beaches, where S > 0.10, the slope does influence the runup level and therefore Ruggiero et al. (2001) concluded that Equation (3) should be used in such cases:

$$R_{2\%} = 0.27 (S\, H_{mo}\, L_o)^{0.5} \quad \text{.............. (3)}$$

To determine the $R_{2\%}$ value using the Ruggiero et al. (2001) model for the South African situation the following definitions are defined in the schematic of a typical upper beach and foredune (Figure 2.18):

- The datum level for South Africa is taken as Mean Sea Level (0 m MSL).

- The tide elevation (E_T) is taken as the water level at the predicted MHWS (Mean High Water Springs) plus a storm surge provision (assumed as +0.50 m for this study) and an assumed wave set-up amount of +0.25 m due to the storm. The predicted MHWS level is defined for specific areas along the South African coast by the South African Navy and published annually in official tide tables. For the Mossel Bay area this level is at +1.2 m MSL. As discussed above, the actual tidal level during storms can vary from the predicted level and therefore for this study it is assumed that such variations are allowed for in the safety factor (SF) discussed below.

- The equivalent of the Ruggiero et al. (2001) 'beach-property junction' position is assumed to be the beach-dune interface, known as the 'foot-of-dune' position for the study area. This is easily discernible by the 'edge-of-vegetation' line, as depicted in Figure 2.32 or the toe of the dune when slumping occurs (figures 2.6, 2.30 and 3.9). Taken from beach and dune profile surveys carried out at sites within the study area (CSIR, 1994; 2000b), typical values for the 'foot-of-dune' elevation (E_J) within the study area range from +2.25 to +3.0 m MSL. An elevation of +2.50 m MSL is assumed for this study.

- Judging by the wide surfzone width at places like the Wilderness, the nearshore beach slope (S) within the study area is typically in the order of 0.10 along the exposed parts of the coastline. Available beach and dune profiles from surveys at a variety of beaches and at estuary mouths (CSIR, 1994; 2000b) show the upper beach slope to be in the order of 0.10 within the bay and up to 0.25 along the exposed sections of the bay. It is therefore assumed that Equation (3), as derived by Ruggiero et al. (2001) for beaches with slopes in the order of 0.15, is relevant to the study area. The actual beach slope should be determined on site if more accurate calculations are required.

- Typical foredunes within the study area (figures 3.24, 3.25, 3.26 and 3.27) reach elevations of between +4.5 m and +10 m MSL (CSIR, 1994; 2000b). However, there are high cliffs in places (figures 3.9 and 3.33) as described in Chapter 3 as well as significantly lower 'foredunes' in the sheltered areas, for example, at Santos Beach (Figure 3.23).

- The foredunes within the study area typically consist of unconsolidated wind-blown dune sand. For this study it is therefore assumed that, when slumping, the frontal slope can be taken as 1:3 (or 0.33), which is a close approximation of the natural angle of repose of unconsolidated sand. In places the slope may be steeper due to the binding effect that dune vegetation has, but the assumption is considered to be fair and practical.

- There are many uncertainties in the derivation of the equations as put forward by Ruggiero et al. (2001). As pointed out above, for example, the actual tide level can differ from the predicted level. It is therefore fair to allow for the uncertainties and the uncertainty in the many of the input parameters is catered for by adding a safety factor (SF) as illustrated in Figure 2.18. A value of 0.5 m added to the calculated $R_{2\%}$ elevation is considered a realistic amount in this case.

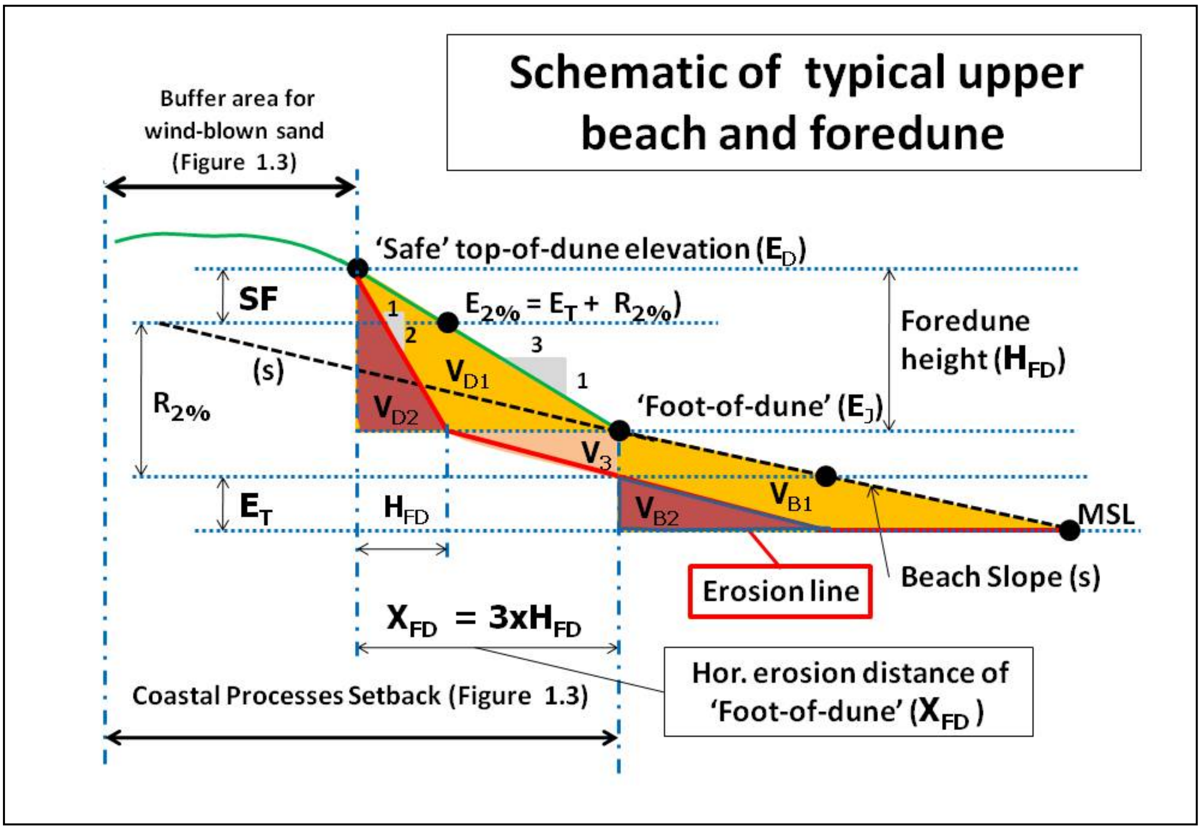


Figure 2.18: Definitions used for storm runup and erosion calculations as adapted for the study area from Ruggiero et al. (2001).

The total volume of sand eroded from the dune and beach is that area depicted between the normal beach and dune profile and the erosion line. (see Figure 2.5).

- This eroded volume is simplified in the schematic (Figure 2.18) by three triangles V_{D1}, V_{B1} and V_3

Where:

$V_{D1} = 0.5 \times H_{FD} \times X_{FD}$ m^3/m;

$V_{B1} = 0.5 \times S^{-1} \times E_J^2\ m^3/m$; and
$V_3 = (E_J - E_T) \times (0.5 \times (X_{FD} - H_{FD}))\ m^3/m$

Therefore the total volume eroded from the dune and beach:

$V_{BD} = V_{D1} + V_3 - V_{D2} + V_{B1} - V_{B2}$ as indicated in the schematic.

- The influence of long-term changes in the sea level needs to be considered when determining the risk to properties that typically have a 50 year design lifespan. This is discussed in the next sub-section below.

Equation (3), the parameter values described above and the Ruggiero et al. (2001) Property Erosion Model (Figure 2.17) are used to determine the following:

- To determine whether the 1:100 year storm condition (Section 2.2.4) will cause the foredune to erode which will be if $E_T + R_{2\%} > E_J$.

- If erosion does occur, the amount of erosion as defined by the parameters in Figure 2.18.

Assuming an open coast, (for example the exposed side on the eastern side of the half-heart bays within the study area eastwards of the 'shadow' line) and applying Equation (3) results in the following:

$$R_{2\%} = 0.27\ (S\ H_{mo}\ L_o)^{0.5} \quad ....\ (3)$$

Where: $S = 0.15$;
$H_{mo} = 12$ m for the 1:100 yr return period
$T_o = 16$ s
$L_o = (g/2\pi)T^2 = 400$ m

Substituting the above values into Equation (3):

$$R_{2\%} = 0.27\ (0.25 \times 12 \times 400)^{0.5}$$
$$= 7.3 \text{ m}$$

Testing for erosion using the Ruggiero et al. (2001) 'Property Erosion Model' Figure 2.17:

The elevation of the 2% runup ($E_{2\%}$) is therefore:

$$
\begin{aligned}
E_{2\%} &= E_T + R_{2\%} \\
&= (1.2 + 0.50 + 0.25) + 7.3 \\
&= +9.3 \text{ m MSL}
\end{aligned}
$$

and since $E_J = +2.50$ m MSL

thus erosion does takes place since $E_{2\%} = E_T + R_{2\%} > E_J$

adding on the +0.5 m safety factor (SF) for uncertainties,
the 'top-of-dune' elevation (E_D):

$$
\begin{aligned}
E_D &= E_{2\%} + SF \\
&= +9.3 + 0.5 \\
&= +9.8 \text{ m MSL}
\end{aligned}
$$

Foredune height

Referring to Figure 2.18, the height of the foredune (H_{FD}) is determined as:

$$
\begin{aligned}
H_{FD} &= E_D - E_J \\
&= 9.8 - 2.5 \\
&= 7.3 \text{ m}
\end{aligned}
$$

Bijker (1982) has shown that for a specific storm intensity and duration a specific volume of sand from the foredunes will be moved from the dune onto the beach and into the nearshore area. This principle is discussed in Section 2.2.6 and illustrated in Figure 2.5.

From the calculation above it is seen that, when taking the pre-erosion foredune slope as 1:3, the horizontal erosion distance (X_{FD}) associated with the $R_{2\%}$ runup under a 1:100 year deep sea storm condition of $H_{mo} = 12$ and $T_0 = 16$ s is calculated as follows:

$$
\begin{aligned}
X_{FD} &= 3H_{FD} \\
&= 3 \times 7.3 \\
&= 22 \text{ m}
\end{aligned}
$$

The resultant eroded dune volume (V_{Dune}) per meter length of the beach is then:

$$
\begin{aligned}
V_{Dune} &= 0.5\ X_{FD}\ H_{FD} \\
&= 1.5\ H_{FD}^{2} \\
&= 1.5 \times 7.3 \times 7.3 \\
&= 80 \text{ m}^3/\text{m}
\end{aligned}
$$

As seen in Figure 2.18, the volume of sand removed from the beach between the datum line, here taken as 0 m MSL, and the 'foot-of-dune' elevation (+2.5 m MSL in the study area) can be approximated by using the beach slope (S = 0.15) as follows:

$$
\begin{aligned}
V_{Beach} &= 0.5\ S^{-1}\ E_J^{2} \\
&= 0.5 \times 6.6 \times 2.5 \times 2.5 \\
&= 21 \text{ m}^3/\text{m}
\end{aligned}
$$

The total volume of sand removed from the upper beach (above the 0 m MSL line) and the foredune due to storm runup is thus 100 m^3/m along the exposed section of the coastline.

Research results by the Delft University of Technology along the coastline in the Netherlands described by Bijker (1982) quantified the volume of dune sand removed during major storms as being in the order of 100 m^3 of sand per meter of beach length.

In a detailed analysis by CSIR (1983) the potential short term storm erosion during extreme wave events was quantified for a site near Cape Town using a predictive technique developed by Swart (1974). The principle of the model is that a given beach profile will eventually reach an equilibrium shape and position for a given input wave, provided the wave condition persists long enough. Swart (1974) gave formulae for the prediction of the equilibrium profile. This profile was based on laboratory and field work.

The beach and dune profile used in the CSIR (1983) model setup had a 'foot-of-dune' elevation of +1.0 m MSL and a 'top-of-dune' elevation of +9 m MSL, resulting in a foredune height of 8 m. The results of the CSIR (1983) study showed that 27 m of erosion could be expected during persistent extreme wave conditions. Using the same assumption of a 1:3 foredune slope, the predicted erosion volume amounted to 96 m^3/m in that case.

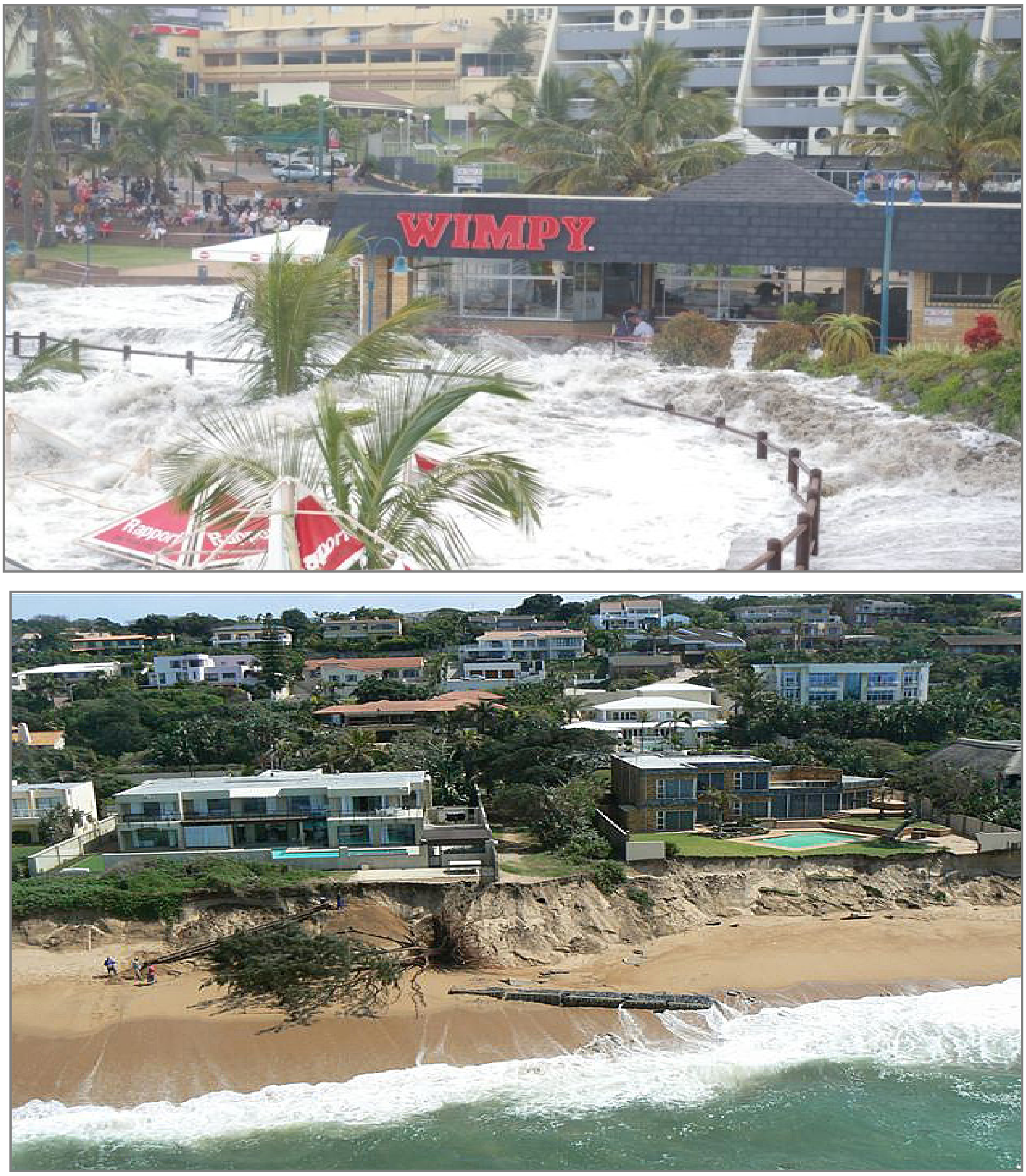
Hughes, Brundrit, Swart, and Bartels, (1993) report that the actual storm erosion observed during a major storm in 1986 at the Cape Town site compared favourably to that predicted by CSIR (1983).

It is fair to assume that surveys carried out during and soon after large storms will seldom be for the area below the mean sea level due to practicalities including safety. This was the case when the beaches along the Durban Bight were surveyed after large storms (such as the March 2007 storm depicted in figures 2.19 and 2.20) (Theron, 2011). The calculated volume eroded from the beach along the approximately 6 000 m Durban Bight beachfront for the 2007 storm was calculated as being in the order of 15 m^3/m. This compares fairly well with the V_{Beach} value of 21 m^3/m calculated in the example above.

For this study it is concluded that it is a reasonable assumption that short-term storm erosion under extreme wave conditions would result in erosion in the order of 100 m^3/m for the foredune area. The erosion of the beach above MSL could be in the order of 20 m^3/m.

As can be seen in Figure 2.18, the slope (S) used in Equation (3) to calculate the vertical runup amount above the tide level is independent of the actual foredune height. When taking the actual foredune height into consideration and accepting the 100 m^3/m foredune portion of the cross-shore erosion potential as a valid estimate, it is concluded that, during a storm, relatively high dunes supply more sand for each meter eroded, and that the resultant distance that the coastline will recede will be less than that where a lower dune is present. This is further discussed below.

According to Bijker (1982:173), the impact of a second storm of equal intensity occurring soon after the first event will be relatively little based on research in the Netherlands, where it was shown that "transverse sand transports of only 10 to 20 percent of that in the first storm have been experienced". Since the Dutch coastline is very linear, this will not necessarily be the case along the Southern Africa coast, especially within the typical half-heart bays, but is of interest for the exposed sections of the Southern African coast.



Figures 2.19 and 2.20: Storm surge along the KwaZulu-Natal coast resulted in damage to property and erosion along large sections of the coastline when high waves coincided with a very high spring tide (Ethekwini Municipality, 2008)

Read in conjunction with Figure 2.18, Figure 2.21 reflects the principle discussed above where the foredune portion of the cross-shore erosion due to storm runup at the MHWS tide level is in the order of 100m^3/m.

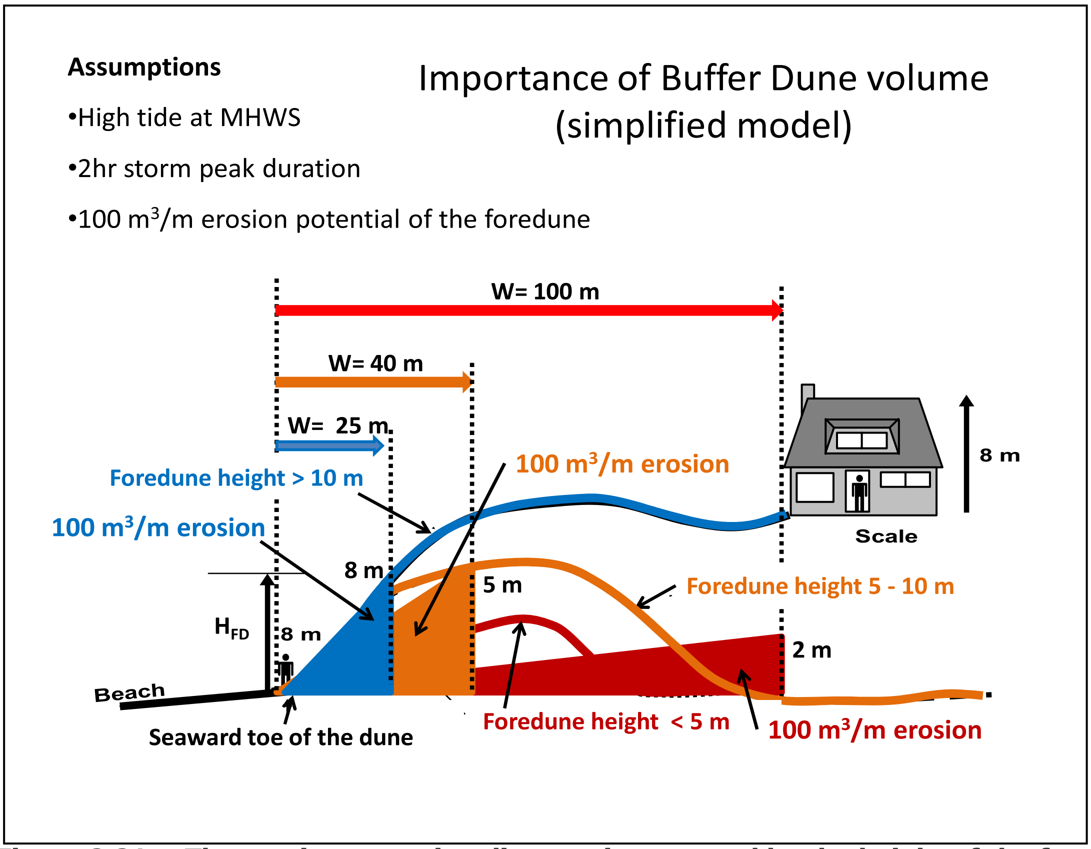


Figure 2.21: The erosion recession distance is governed by the height of the foredune prior to the storm

The volume of a 1 m wide eroded foredune section with a vertical height of H_{FD} and a horizontal base width of W works out as $V_{Dune} = 0.5\ W\ H_{FD}$ with V_{Dune} in m^3/m.

If the volume, V_{Dune} and dune height, H_{FD} are known, the horizontal base width (W) is calculated by $W = 2\ V_{Dune}\ H_{FD}^{-1}$

In Figure 2.21 a highly simplified model is shown that, when assuming a potential storm erosion volume of 100m^3/m for the foredune, the seaward toe of a 5 m high foredune can potentially erode landwards by W = 40 m. Assuming the same erosion volume of 100m^3/m occurs at a higher dune, say 8 m, the potential erosion distance is then 25 m landwards from the seaward toe of the foredune. Similarly an erosional distance of 100 m can potentially be expected for a 2 m high foredune under the storm conditions that realise erosion of 100 m^3/m if enough sand volume is available.

This simple model reinforces the conclusion by Bijker (1982) that high dunes would minimise the erosion distance, and that low dunes would minimise the volume of eroded sand. This point is important when designing a buffer dune in response to a current or predicted problem. Maintaining the design volume of the dune is therefore also a key management objective and a key aspect when assessing buffer dune integrity, as discussed in Chapter 4.

Sea-level rise

Dolotov (1992) stated that the rate of sea-level rise is one of the most important factors that will influence the changes in coastline evolution under anticipated worldwide sea-level rise scenario. Other factors are the nature of the environmental dynamics causing the changes, such as hydrodynamics, and the amount of sediment available at the site where the changes are taking place.

Theron (1994) concluded from a literature review that the probable impact of sea-level rise on the coastal zone could be divided into the following five general groups:

- Increased exposure to extreme events, which could increase in frequency and intensity;
- Increased saltwater intrusion and raised groundwater tables;
- Greater tidal influence;
- Increased in the frequency and extent of flooding; and
- Increased coastal erosion.

Most visible of these impacts will be the occurrence of more frequent and more intense storms. A higher sea level will also enable even smaller storms to reach previously unaffected areas and storm damage would be visible as the coastline adjusts to the increase and man-made storm protection works have to be adapted to the new design parameters.

Further to the normal dynamic response of foredunes to storms, the additional effect of sea-level rise increases the risk to wrongly located property. The International Panel on Climate Change (IPCC) has concluded that the sea level has risen between 0.10 and 0.25 m over the last 100 years. The latest projections for the future sea-level rise along the South African coastline due to global warming vary between 0.5 as a lower limit and 2.0 m as an upper extreme by 2100 (Rossouw, 2009) and the level is predicted to continue rising after 2100, even if measures taken to reduce global warming are successful. The most likely value of the 1:100 year sea-level rise predicted value is taken as 1 m above present (Theron et al., 2010).

The effect of sea-level rise on the horizontal migration of the erosion line is illustrated in Figure 2.22 by means of the so-called 'Bruun Rule' (Bruun, 1962; 1983, 1988).

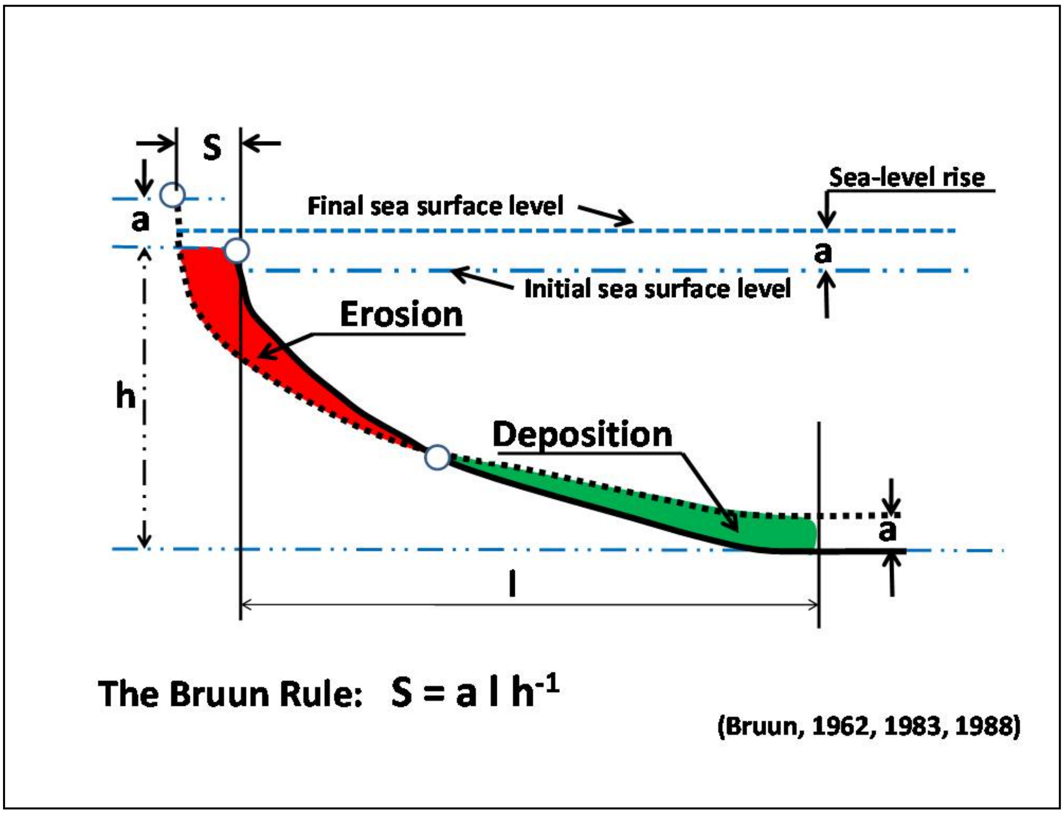


Figure 2.22: Sea-level rise results in a landward recession of the beach and dune profile and parameters used in Bruun's rule. (adapted from Bruun, 1983)

The assumption is that the post sea level rise storm erosion equilibrium profile will be similar to the profile before sea level rise. The 'closeout depth' (Figure 2.22), indicated by (h) is the maximum effective depth seawards of which no sediment exchanges due to wave action occurs between the nearshore and the offshore. This point is located at a cross-shore distance (l) from the maximum point on the beach where erosion occurs during the initial (pre-sea-level rise) conditions.

As can be seen in Figure 2.22 the equilibrium profile adjusts to the new water surface level with the volume of deposition balanced by that eroded from the beach and foredunes. This results in the landward moving of the position of the interface between the foredune and the sea surface by a distance (S) depicted as:

$$S = a\, l\, h^{-1} .$$

For the example discussed in the section above, the calculation results are as follows.

Assuming sea-level rise over 50 years to be 0.5 m, thus a = 0.5 m,

and a close-out depth of 15 m located 1000 m offshore,

then

$$\begin{aligned} S &= a\, l\, h^{-1} \\ &= 0.5 \times 1000 \times (15)^{-1} \\ &= 33 \text{ m} \end{aligned}$$

Although a relatively easy to use method, the input parameters of the position and depth of the close-out point are difficult to determine and are site specific. Other site specific characteristics, such as the local geology and geomorphology, offshore- and nearshore bathymetry, the onshore topography, the exposure to the dominant storm wave regime, the direction and strength of neashore currents and the general climatology and geography need to be considered.

As concluded by Theron (1994), the Bruun Rule appears to be valid as a first indicator to screen out areas where more intensive research is needed when formulating strategies to respond to sea-level rise. In practice, however, the natural system is far more complex and a variety of coastal evolutionary responses as a result of an increase in the sea-level are most likely to occur.

2.2.10 Wind and wind-blown sand

An indication of the long-term prevailing local wind regime in an area can be derived from studying the dune axes on aerial photos. The aerial photograph of 1942 for Still Bay is shown in Figure 2.23.

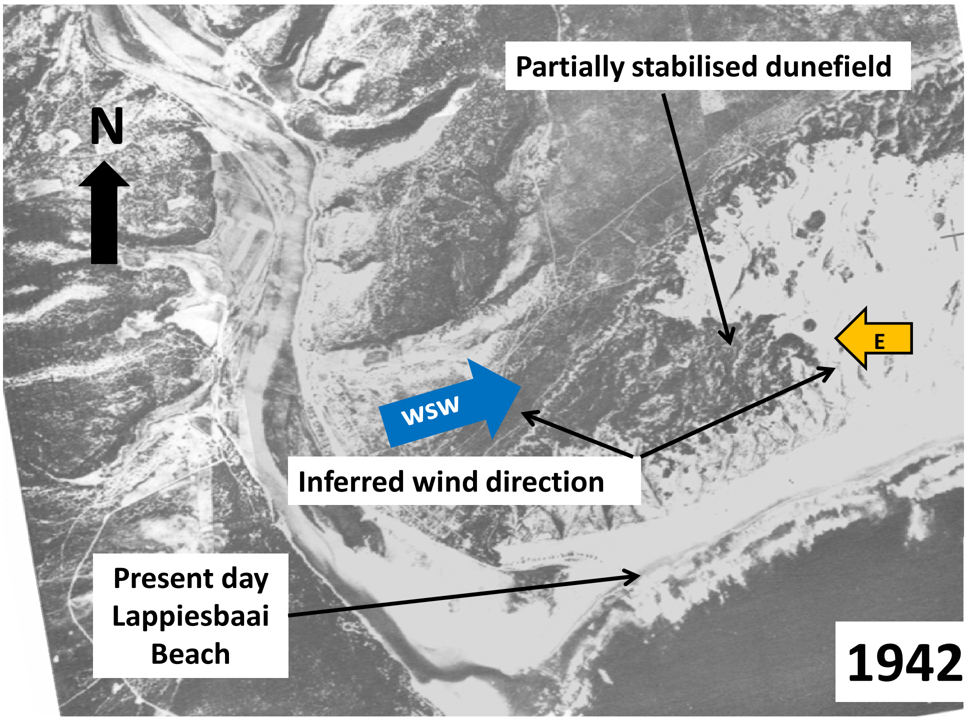


Figure 2.23: Long-term regional wind regime can be deduced from the orientation of dunes in dune fields (photo: SA Surveyor-General)

The orientation of the dune ridges in the dune field indicates that onshore winds dominate and that there is a significant amount of wind that originates from the western to the south-western sector, but that easterlies also prevail. Of interest is that it can be seen that already in 1942, the dune field was in the process of being vegetated in an attempt to stabilise the sand.

Further examples of where the long-term dominant wind direction can be deduced from the dune axes orientation can be seen in figures 2.29 and 3.31. Tinley (1985) produced a map of Southern Africa on which this information is depicted (Figure 2.24).

Since most wind-blown sand occurs during hot and dry seasons and when high winds occur, it is important to take this information into account when assessing local conditions.

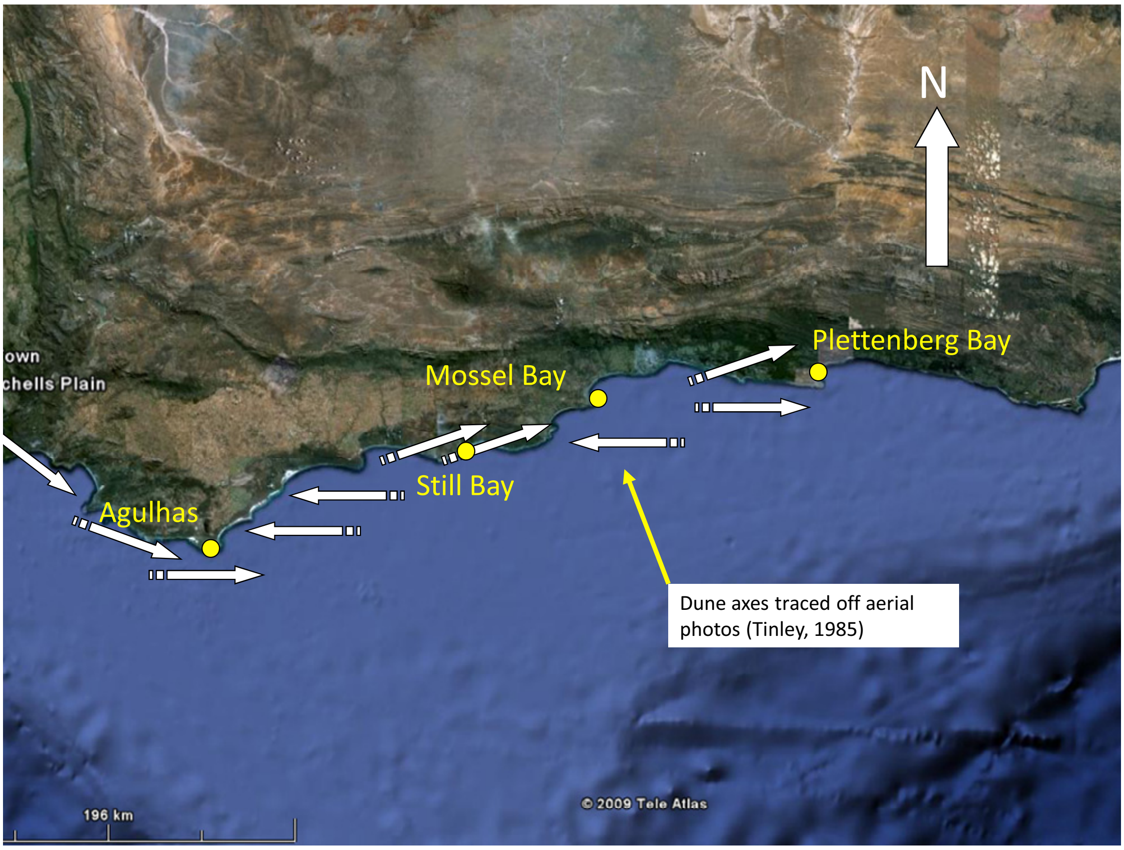


Figure 2.24: Long-term regional wind regime can be derived from dune axes (adapted from Tinley, 1985)

From the wind roses for the Still Bay coastal area (Figure 2.25), it can be seen that in terms of frequency of occurrence, winds from the westerly to the south-westerly sector predominate. Although secondary in frequency of occurrence, high-velocity easterly winds do occur and therefore have an important influence on wind-blown sand transport potential. This is especially significant during the summer to autumn period, when sands are dry.

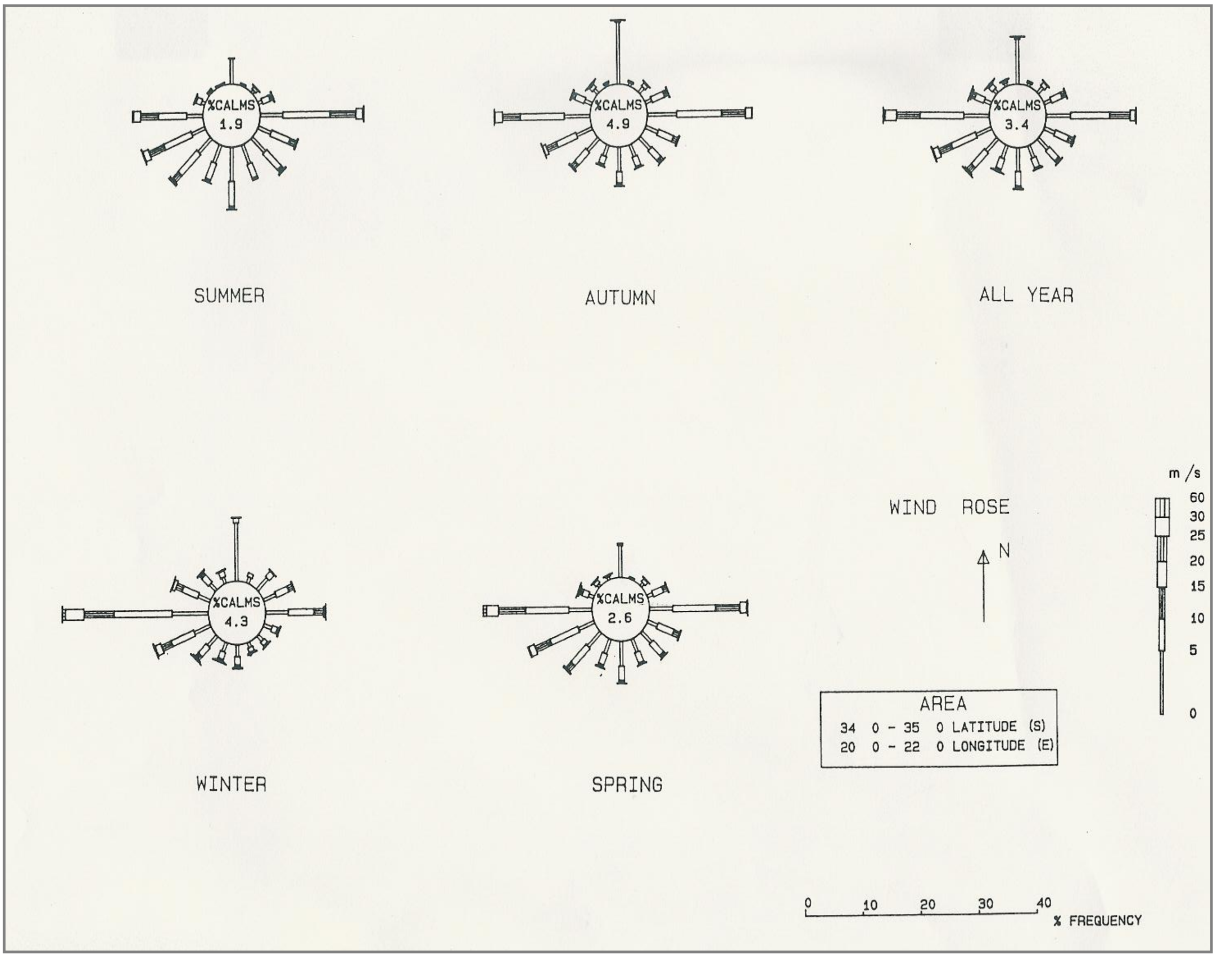
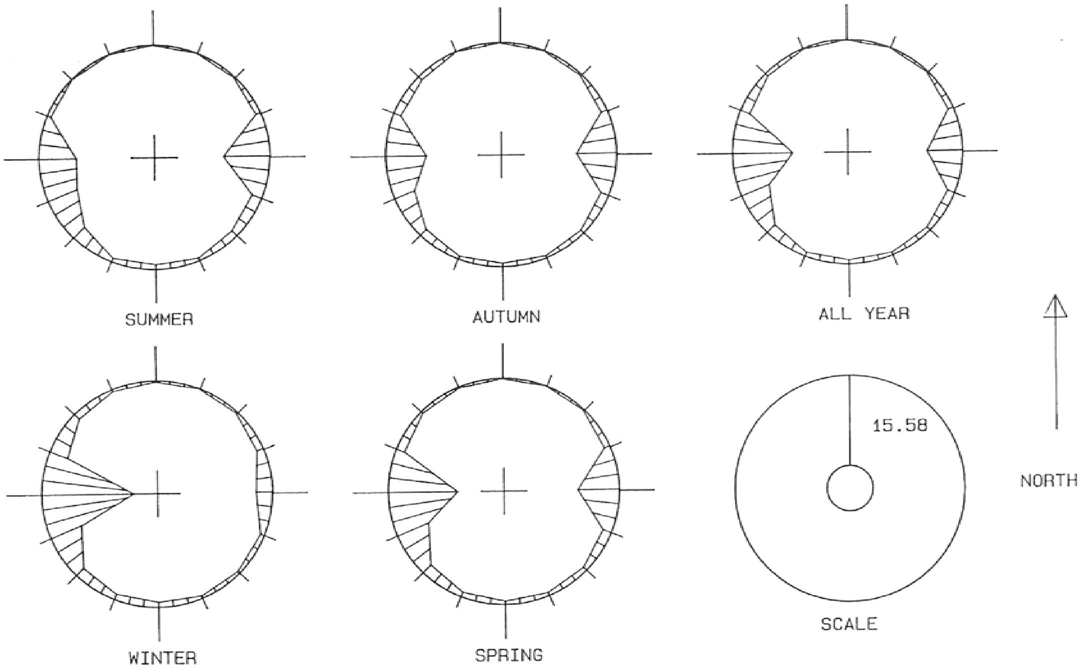


Figure 2.25: Wind roses for the southern coast of South Africa (Carter, 1990)

Continuing with the Still Bay area as an example, the available wind statistics were analysed and the seasonal and annual aeolian sediment transport rates calculated using a predictive technique described by Swart (1986). Results are presented as aeolian creep diagrams (Figure 2.26) and the predicted wind-blown sand transport rates (in m^3/yr/m) for each wind direction are summarised in Table 2.2.



AEOLIAN TRANSPORT RATES ARE GIVEN IN FRACTIONS OF 10000 CUBIC METRES / YEAR / KILOMETRE WITH DUE COGNIZANCE FOR FREQUENCY OF OCCURRENCE OF WIND EVENTS

Figure 2.26: Creep diagram for the Still Bay area (Carter, 1990)

As described in Swart (1986), the aeolian creep diagrams depict how wind-blown sand will approach the centre of an imaginary circle on the ground from the various wind directions. The aeolian transport predictions are based on theory derived for ideal conditions where an unlimited supply of dry, cohesionless sand is blown along a dry, flat beach by constant, non-turbulent wind. Since these conditions are seldom realised, the predicted rates should be seen as the potential only. Studies by Swart (1986) and Barwell & Burns (1989) have, however, shown that the actual annual transport rate for dry sand correlates fairly accurately with that predicted.

Table 2.2: Annual potential aeolian transport rate for the Still Bay area (CSIR, 1994)

Direction	Rate (m^3/yr/m)					Net rate (m^3/yr/m)				
	Ann	Sum	Aut	Win	Spr	Ann	Sum	Aut	Win	Spr
South-bound	4	2	5	8	3					
North-bound	14	14	11	15	15	10	12	6	7	12
South-west-bound	14	17	15	9	17					
North-east-bound	39	31	27	58	40	25	14	12	49	23
East-bound	47	33	32	74	48	26	7	11	62	22
West-bound	21	26	21	12	26					
South-east-bound	30	18	22	51	29	12		4	40	7
North-west-bound	18	22	18	11	22		4			

From the aeolian creep diagrams (Figure 2.26) and the summary shown in Table 2.2 (CSIR, 1994), it can be concluded that the dominant net movement of sand, over all seasons, is to the north-east and eastern sectors at Still Bay. This correlates well with the analysis done by Tinley (1985), as reflected in Figure 2.24 and can be seen on Figure 2.23. From Table 2.2 it can be seen that at Lappiesbaai (where the beach orientation is north-east/south-west), strong winter winds transport sand along the beach with a small onshore (northbound) component. During summer, the north- and north-westbound components cause wind-blown sand to move into the foredune area, restoring and building the buffer dune, and also transport sand through gaps and blow-outs onto the grass and parking areas located behind the buffer dune. This can be seen in Figure 2.27 (image taken in summer).

Of importance is that the south-eastbound component (Table 2.2) is neutralised by the vegetation in the buffer dune, so the full onshore (north-westbound) potential at Lappiesbaai, for example, should be taken into account. This amounts to 18 m^3/yr/m for the whole year (Table 2.2) and naturally builds up the foredune, as discussed below.

Figure 2.27: The orientation of blow-outs in and behind buffer dunes is indicative of the local wind regime

2.2.11 Foredune formation and the influence of vegetation

Natural dunes are formed and maintained by a combination of wind-blown sand off exposed sandy beaches that is subsequently trapped by dune vegetation, thereby forming a foredune system.

Wind picks up the dry sand from exposed beaches and blows the sand grains along the beach surface. Where the beach is wide enough, hummock dunes are formed and eventually grow or are blown landwards to merge with the foredunes.

Where the climate is conducive to vegetation growth, the foredunes become 'fixed' by vegetation. As was noted in Section 1.1 and illustrated in Figure 1.1, the areas behind the fixed foredunes are called 'back dunes'. Those areas located further landward of the foredunes and beyond the physical reach of the sea are defined as 'stable dunes'.

Where the dune vegetation is dense enough to trap the wind-blown sand, the foredune continues to grow in volume just above the high-water mark. In the previous section it was seen that a potential of 18 m^3/yr/m exists at Lappiesbaai to facilitate this growth.

Natural foredunes can be vegetated, partially vegetated or totally exposed. The latter typically occurs when the indigenous vegetation is unable to outgrow the volume of sand being blown off the beach, or has been destroyed by removal, trampling, fire or drought.

The specific aspects related to the integrity of foredunes as important components of the coastal defence mechanism against the forces of the sea are discussed in subsequent sections of the thesis (Figure 2.28).

Figure 2.28: Examples of foredunes as the buffer zone

In areas with harsh climates (e.g. high temperatures with low rainfall and high persistent winds) or where the indigenous dune vegetation is unable to outgrow the influx of wind-blown sand, large open dune fields exist (Figure 2.29). These often form so-called sand sinks, where sand is blown inland and is thereby lost to the coastal sediment budget, unless it forms a headland bypass dune system (Figure 3.31) where sand is once again returned to the littoral zone on the downwind side of the dune field.

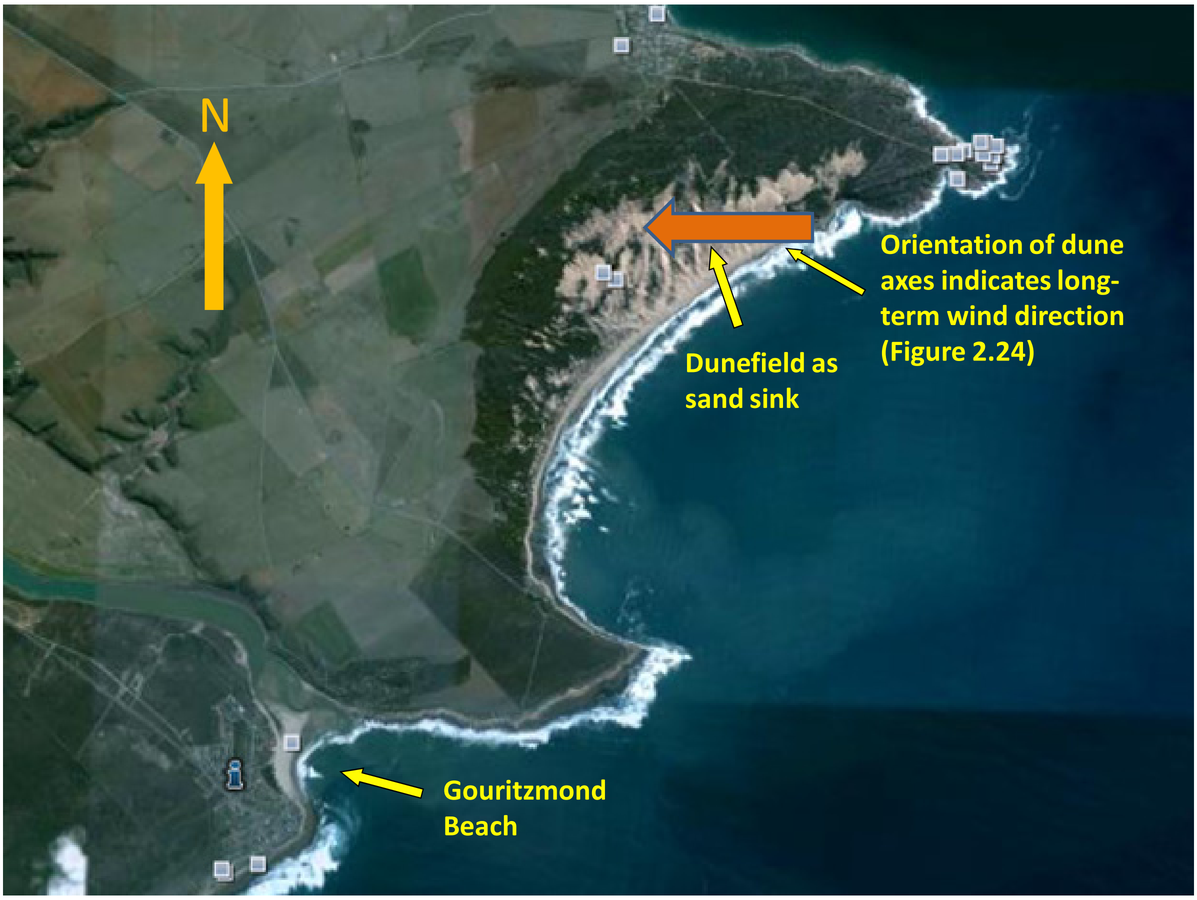


Figure 2.29: Sand is blown into large open dunefields that act as 'sand-sinks' (image from Google Earth™)

2.3 Human activities that influence foredune integrity

Tinley (1985:258) proposes an approach that entails the placement of "all development out of reach of the littoral active zone". He professes that "this alone will obviate most, if not all, problems by protecting the diversity and viability of coast resources and attractions, and at the same time secure developments and properties from wasteful damage or destruction".

This principle is also taken up in the ICM Act (Republic of South Africa, 2008) where a "coastal protection zone" is defined (Section 16) as well as a "coastal set-back line" (Section 25), which both have to be indicated on relevant zoning maps (see Chapter 1, figures 1.2 and 1.3).

Unfortunately, owners of properties that border the sea typically believe that it is desirable to place their buildings as close to the high-water mark as possible and to ensure an uninterrupted sea view at all costs. Such properties attract premium prices for being located 'on the beach'.

Many examples exist where developers have placed structures within reach of the natural coastal processes (Figure 2.30). In many cases, it is just a matter of time before the need for an engineering solution (Figure 2.31) to protect the property from erosion or wind-blown sand, or both, becomes necessary.

Figure 2.30: Developments placed on the foredune are at risk from erosion

Figure 2.31: Costly engineering solutions required to protect expensive development placed on the foredune

2.3.1 The importance of setting development out of reach of the coastal processes

The definitions of the various buffer areas and setback lines were discussed in Chapter 1 (see figures 1.2 and 1.3).

On soft, sandy coastlines it is good practice to define a buffer area in which no development should be located. This is to allow the natural coastal processes space to prevail. The landward line of this area is here denoted the 'coastal processes setback line' (Figure 1.3) so as to differentiate it from the broader definition of the setback line used in the ICM Act. As illustrated in Figure 1.3, the line is typically defined by up to four components, namely

- allowance for the erosion or accretion potential due to an inherent long-term stability trend;
- provision of enough dune volume for the erosion potential due to a particular storm;
- the required width of the vegetated buffer dune required to manage the potential influx of wind-blown sand; and
- provision for climate change in terms of sea-level rise (the Bruun Rule, Figure 2.22) and increased storm intensity.

Figure 2.32: The seaward edge of the dune vegetation is a practical reference line for defining the area required to buffer against hazards (image from Google Earth™)

Although the ICM Act defines the coastal protection zone (Figure 1.2) as being taken from the high-water mark, for the coastal processes setback line it is practical (and follows the precautionary principle) to take a horizontal distance measured landward from the seaward edge of existing dune vegetation at the time of the assessment (figures 2.32 and 1.3).

In the use of historic aerial photos to undertake long-term trend analysis at specific sites along the coast, it is found that the edge-of-vegetation line is distinctive enough. The influence of short-term storm erosion is effectively considered if the analyst uses the same features for all the photos being analysed.

2.4 Indicators and indices

2.4.1 Introduction

Integrated coastal management is seen as a form of adaptive management that is defined by Olsen (2001:329) as " ...to cope with the uncertainty and complexity of natural and social systems by creating spaces in which reflection and learning can occur, allowing management processes to take corrective action and modify behaviour in light of new information".

Indicators, indices and checklists are used to assist with the simplification of the complexity of coastal systems. The assessment of various components of the coastal zone, often represented by relevant indicators and indices, has been undertaken as part of integrated coastal management in many parts of the world and forms a practical way of implementing adaptive management.

As stated in Section 1, providing non-expert officials at coastal municipalities with an effective and easy-to-use mechanism (in the form of a decision support guideline) to understand and assess the various levels of risk to buffer dune systems and to manage the integrity of the buffer dune system is the topic and intended output of this research.

Available literature was reviewed with the focus on the following three core components of decision support guidelines as tools for adaptive management in integrated coastal management:

- The identification of indicators representative of the basic parameters or variables of the prevailing human–nature system and overarching indices that represent a collective of one or more of such indicators (Figure 2.33).

- The definition and use of checklists to assist non-experts to assess the risk potential of a particular coastal system or site.

- The definition and use of decision tree type decision support guidelines to assist non-experts to confidently reach a point where an informed decision on the required management action is possible.

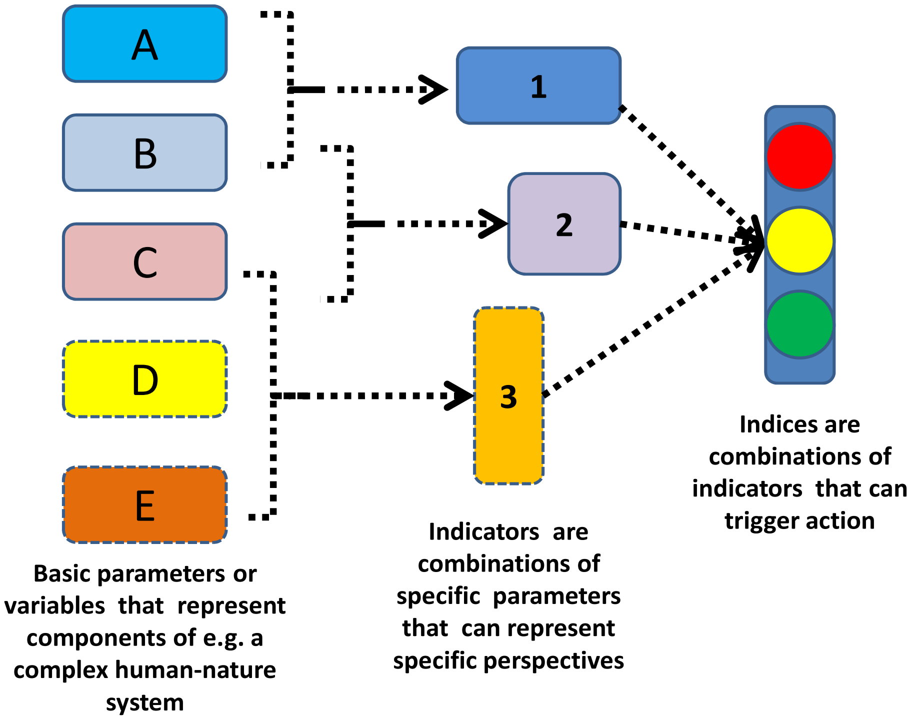


Figure 2.33: Simplified depiction of the links among parameters, indicators and indices as used in this thesis

2.4.2 Indicators and indices in context

It is well known that the state of the economy and even the day-to-day state of business are reported through indicators and indices. For example, the gold price and the value of shares on the different stock exchanges in the world are tracked and reported through indicators and indices to enable investment and portfolio management decisions.

Stated as an example of success, Olsen (2001) reflects on the usefulness of the United Nation's Human Development Index, which is aimed at tracking developmental progress (or lack thereof) in especially developing countries.

The practice of integrating a suite of variables or parameters (in the form of indicators) to represent both the natural and social aspects of the coastal system into appropriate indices of the system condition has been applied with a varying degree of success. Examples from the international and local literature are shown in Section 2.4.3.

In South Africa, this approach has also been followed and for dune systems a simple decision support guideline was developed by the Council for Scientific and Industrial Research (CSIR) (Barwell, 2010), and one component of the toolkit is shown in Figure 2.34.

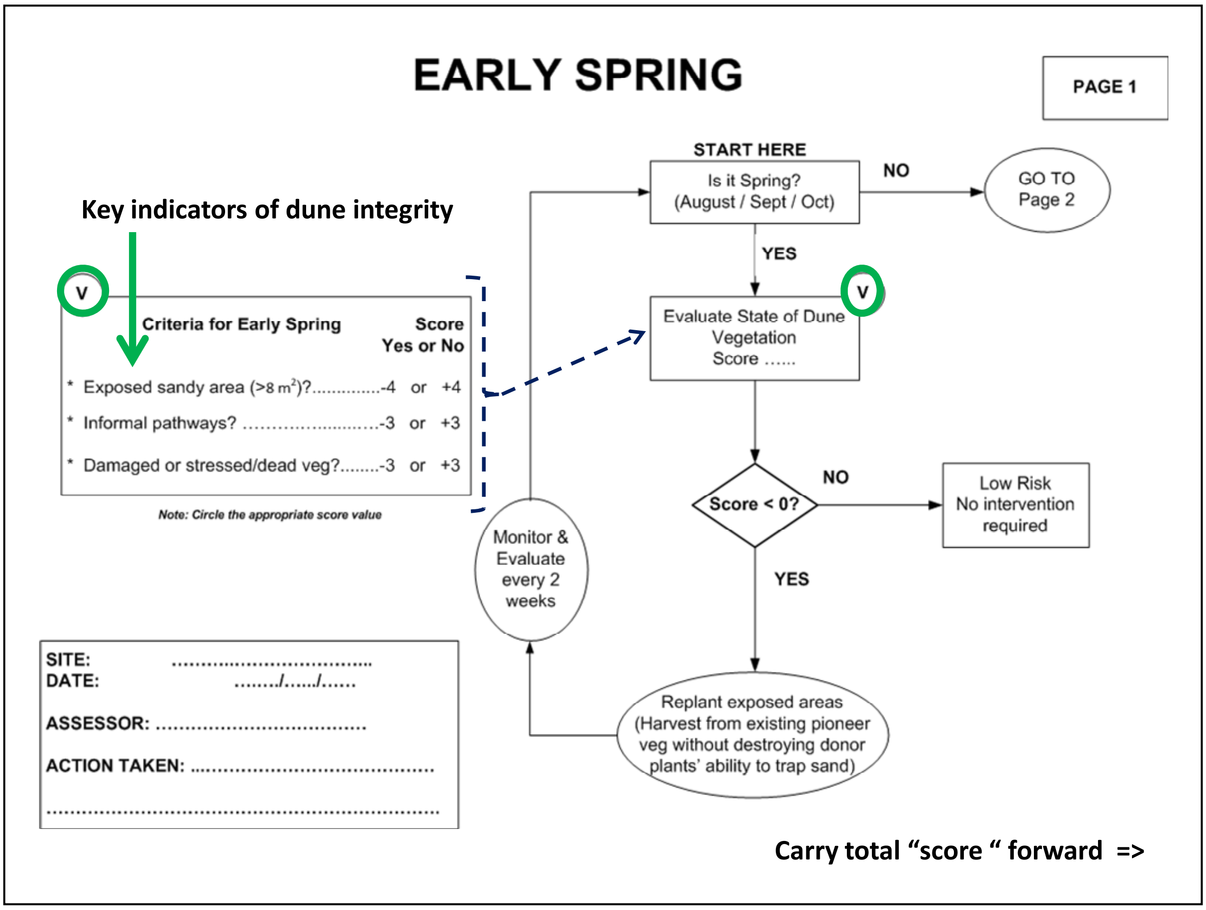


Figure 2.34: **Simple indicators of the status of the dune vegetation, which in turn is one of the indices of dune integrity (Barwell, 2010)**

Consensus and simple presentation

When defining indicators and indices that serve to track and report on the trends in ecosystem quality, Olsen (2001) concludes that reaching consensus within the scientific community on a set of valid and reliable indicators is one of the key actions to be carried out. Olsen (2001) further concludes that the costs required to obtain the data and information to assess changes should not be excessive and that the indicators should facilitate responsible use of results. The importance of being able to report the trends in a simplified visual manner was emphasised in order to communicate effectively with the public and relevant decision-makers. This was concluded to be valid for both the human and the natural elements of the ecosystem.

Emeis (2001) stressed that an effective indicator framework should be easily understood and be accepted both by decision-makers and by the general public. Indicators combined into indices of ecosystem condition are a practical and useful way of documenting and analysing coastal ecosystem changes (Emeis, 2001).

Validity

The National Research Commission (NRC) defined a checklist to evaluate the validity of the indicators defined for a specific application (2000). It was proposed that indicators had to

- provide information on the state or condition at appropriate time and spatial scales;
- be an accepted representation of the functioning and structure of the system;
- enable evidence-based reliability assessment showing fit-for-use in terms of sensitivity, accuracy, precision and robustness;
- have specified input data requirements stating monitoring frequency, accuracy and precision for the appropriate time–space scales;
- align with specified independent quality control data required to verify indicator results;
- specify the type and level of skill required by observers to ensure confidence in the results;

- be comparable and compatible with complementary indicators used elsewhere with adherence to internationally accepted standards; and
- be cost-effective in data gathering and the application of the results in decision-making.

This ‘validity check’ is further discussed and applied in Section 4.4, Table 4.8.

2.4.3 Checklist approach to decision-making in integrated coastal management

Whereas the previous section led to an understanding of the use of indicators, indices and checklists in general, this section focuses on the use of such systems in the management of the coastal zone specifically and foredunes in particular.

Although there are a number of indicators combined into indices that are appropriate for tracking changes in the coastal environment, these are not generally used in coastal governance practice (Olsen, 2001). Four examples from the literature are discussed below.

Coastal vulnerability (Doukakis, 2005)

A coastal vulnerability index (CVI) was developed by Doukakis (2005) based on the approach described by Gornitz, Beaty and Daniels (1997) and used to describe and track the coastal system’s susceptibility to change and its natural vulnerability to the effects of coastline subsidence using concepts described by Jeftic, Keckes and Pernetta (1996).

In this case, the indicators at a specific section of the coast are defined as the following:

- coastal slope (CS)
- subsidence (S)
- displacement, i.e. historic trends in erosion/accretion (D)
- geomorphology (G)
- wave characteristics in terms of significant height (WH)
- tidal range (TR)

A linear scale between 1 (low) and 5 (high) was used to rate each of the above risk variables. A CVI was calculated by taking the square root of the product mean of the six indicators.

The resultant coastal vulnerability was expressed as a percentage categorised as Low: 0–25%, Moderate: 25–50%, High: 50–75% and Very high: 75–100%.

The CVI allowed coastal sections to be ranked in terms of the possibility that physical changes would occur along the shoreline due to climate change and specifically due to sea-level rise. This assisted with prioritising management actions.

Coastal vulnerability and sea-level rise (Dwarakish, 2008)

Very similar to the approach taken by Doukakis (2005), Dwarakish (2008) identified six variables which are taken as the relevant indicators of coastal vulnerability:

(a) geomorphology
(b) shoreline change detection
(c) coastal slope
(d) mean tidal range
(e) mean significant wave height
(f) sea-level rise

The Dwarakish CVI is then calculated as follows:

$$CVI = \sqrt{[a \times b \times c \times d \times e \times f] / 6}$$

An example of the use of the Dwarakish (2008) method is provided below.

Table 2.3: Ranking of variables for the Dwarakish CVI

No.	Indicator	Ranking				
		Very low (1)	Low (2)	Moderate (3)	High (4)	Very high (5)
a	Geomorphology	Rocky cliffed coasts	Medium cliffs, indented coasts	Low cliffs, lateritic plain	River deposits, alluvial plain	**Coastal plain, beach, mud flats**
b	Shoreline erosion/accretion (m/yr)	> +15	+5 – +15	**-5 – +5**	-15 – -5	< -15
c	Coastal slope (%)	>0.6	0.5 – 0.6	0.4 – 0.5	**0.3 – 0.4**	<0.3
d	Mean tide range (m)	>4.0	3.0 – 4.0	2.0 –3.0	**1.0 – 2.0**	<1,0
e	Mean significant wave height (m)	<0.7	0.7 – 1.4	1.4 –2.1	**2.1 – 2.8**	>2.8
f	Mean sea-level rise (mm/yr)	<1.8	1.8 – 2.5	**2.5 – 3.0**	3.0 – 3.4	>3.4

For a hypothetical site that, for example, has the physical characteristics highlighted in Table 2.3, the associated ranking value (or score) for each indicator (Very low = 1 to Very high = 5) is summarised in Table 2.4 and the CVI calculated using the Dwarakish CVI formula as shown in Table 2.3.

Table 2.4: Example of how to use Table 2.3 to determine the Dwarakish CVI

No.	Indicator	Rank (score)	Calculated (CVI)[1]
a	Geomorphology	5	21.9
b	Shoreline erosion/accretion (m/yr)	3	
c	Coastal slope (%)	4	
d	Mean tide range (m)	4	
e	Mean significant wave height (m)	4	
f	Mean sea-level rise (mm/yr)	3	

Note 1: CVI = √ [a x b x c x d x e x f] / 6

By assessing the ranking of the other indicators using the descriptors in Table 2.3, the scores for the chosen example are listed in Table 2.4 and the CVI value is calculated to be 21.9. This CVI value is considered 'High' in the Dwarakish method.

Dwarakish (2008) concludes that the use of remote sensing to derive the values of the various indicators was successfully applied to a case study along the Udupi coast in Karnataka along the west coast of India. It was therefore concluded that the index is useful to assess the likelihood that physical change may occur along a shoreline as sea-level change occurs in order to plan for and take the necessary proactive action.

The beach as a natural asset (Espejel, Espinoza-Tenorio, Cervantes, Popoca, Meijia & Delhumeau, 2007)

Espejel et al. (2007) considers the beach system as a natural asset in the fact that the social value, the ecology and the amenities combine to give a value that can be seen as an index of capital. The danger of contamination by pollution served as a counter measure in defining an integrated risk index for beaches where the tourist and recreational beaches were evaluated against the following four criteria:

- Beach's suitability for recreational use (its fit-for-use)
- User's perception (safety and cleanliness of the beach)
- Economic indicators that described the monetary value of the beach (proximity to e.g. hotels and restaurants)
- Contamination vulnerability where the location of the beach relative to the cleaning ability of the open ocean processes was assessed.

Dune vulnerability (Martinez, Gallego-Fernandez, Garcia-Franco, Moctezuma & Jimenez 2006)

A coastal dune vulnerability index, principally based on dune plant functional type, was developed by Martinez et al. (2006) and applied to a coastal area. The following indicators or indices were taken into account in this approach:

- Geomorphological condition (GC): The dune length, height and width as well as the local sediment budget
- Marine influence (MI): Wave characteristics, tidal range, coastal orientation, beach slope and beach sediment size
- Aeolian influence (AI): Wind and sediment dynamics

- Vegetation condition (V): Type I (Normal), Type II (Salt tolerant) and Type III (Plants tolerant to burial by sand and/or snow) as per the definition by Mora, Rosario, Fernández, Juan and Novo (1999)
- Human effect (HE): Presence of outdoor facilities (e.g. camping and pathways) and permanent development (e.g. roads, houses, hotels, shops)

The indicators were 'scored' for a particular coastal dune site and calculated as follows:

Vulnerability index (VI) = (GC + MI + AI + VC + HE) / 5

The resultant value was categorised as either Low (0.30 – > 0.38), Low/Medium (0.39 – > 0.49), or High (0.36[1] – > 0.54).

[Note 1: This value may be a typographic error in the paper, and should possibly be 0.50.]

Checklist-based assessment (Williams, Alveirinho-Dias, Garcia-Novo, García-Mora, Curr & Pereira, 2001)

Williams et al. (2001) developed a checklist-based structured assessment procedure that identified problems with respect to dune systems. It consists of a main root checklist and two 'daughter' checklists.

The main root checklist assessed the dune state in terms of the ratio of a VI and a protection measure index (PMI). The dune system was defined as being in equilibrium if the VI : PMI ratio fell in a range of 0.80 to 1.30.

The two complementary 'daughter' checklists addressed (1) the resilience of the dune system which gave a calculated value for the PM index, and (2) which took into account the site geomorphology, wind regime, vegetation, coastal processes and human activities to enable the VI to be calculated.

The resilience checklist was based on the definition given by Pereira, Laranjeira and Neves (2000), where 'resilience' was taken as the ability of the dune system to self-regulate after natural or human-induced changes. Criteria taken into account in the resilience checklist were the

- presence of erosion landforms (e.g. scarps, slips, blowouts);
- absence of new dunes (e.g. incipient or hummock dunes);
- degree of inefficiency of the current dune vegetation to control the influx or blow-out of wind-blown sand;
- degree of degradation due to human usage (e.g. footpaths, vegetation trampling, dune slippage); and
- degree of inefficiency of management interventions.

Vulnerability assessment (Coelho, Silva, Gomes & Pinto, 2006)

Coelho et al. (2006) describes a method to assess the vulnerability of coastal zones.

He considers vulnerability assessment to be crucial for appropriate land use within the coastal zone. Since this type of assessment is a complex process that involves many parameters, he proposes a first approach, which simplifies the process. His proposed methodology was applied to the coastal region of the Aveiro district, south of Porto in Portugal, and it proved to be effective.

This methodology consists of determining a global VI, which results from the weighting of each of a number of nine independently classified vulnerability indicators.

He concludes that an accurate classification of the indicators were more important than the specific weighting assigned.

The method proposed by Coelho et al. (2006) is described in detail and applied to the study area in Section 4.4 and is therefore not repeated here.

2.4.4 Selected examples of indicators and indices used in decision trees

In order to understand and assess the approach and usefulness of using indicators and indices as core components in decision trees, two South African case studies are described and discussed below.

Wetland index (Oberholster, McMillan & Ashton, 2009)

In defining a wetland ecostatus assessment system, Oberholster et al. (2009) highlights the importance of assessing the situation in a broader landscape context in addition to the local site characteristics when explaining and assessing the prevailing processes and integrity of the system. A hierarchical approach that allowed the identification and rapid assessment of the ecostatus of wetlands at the broadest level by non-experts in different disciplines was used successfully.

The importance of identifying the specific parameter threshold or trigger points at which stressors operated, which enabled the disruption of the processes that caused adverse effects, was highlighted in the following statement: "Identifying and confirming clear trigger endpoints (with associated values) as the basis" was key to the effective rapid risk assessment procedure (Oberholster et al., 2009).

It was concluded that the objectives of a checklist-based assessment procedure included the need to incorporate compositional, structural and functional multi-scaled indicators of the system. It was furthermore concluded that the information on pressure activities (the drivers of change) as well as the resultant condition or state of the system at site and catchment scale needed to be considered and reflected on. They considered the following as key components of indicator-/index-based checklists:

- The index should contain easily obtainable field-observed or measured indicators
- The index and procedure should be easily understood by non-experts and decision-makers
- The index should be flexible enough to allow for new and relevant information to be incorporated at a later stage (for example land use changes and/or the effects of climate change)

To this end, an assessment procedure described by Kleynhans (1996; 1999) that enabled the categorisation of the 'ecostatus' of wetlands was adapted by Oberholster et al. (2009).

Taking the ideal as being an ecosystem that had an unmodified, natural functionality, site-specific categorisation was described as follows:

A: 90–100% – Unmodified, natural
B: 80–90% – Few modifications (functions naturally)
C: 60–80% – Moderately modified (basically unchanged functionality)
D: 40–60% – Largely modified (a managed system)
E: 20–40% – Seriously modified (extensive loss of natural functionality)
F: 0–20% – Critically modified (completely changed)

It was concluded that a rapid risk assessment based on appropriate indicators and indices was a useful and cost-effective way of tracking changes and carrying out adaptive management in wetland systems. It was stressed, however, that the risk processes had to be placed within the context of the whole system and that the linkages between the stressors and responses required a fundamental understanding of both the social and ecological processes that were in operation.

Great Brak River estuary mouth management plan (CSIR, 1990)

Vennix (1999) suggests that the early involvement of managers in model development would enable mutual learning and understanding of the underlying theory and could increase the chances of the approach being accepted as a management tool. Exter (2004) suggests that this approach could assist in simplifying models in relevant places and in the identification of relevant detail to assist decision-makers.

This approach (i.e. the involvement of managers in the model development stages) was followed in the development of the Great Brak estuary management decision support guideline associated with the environmental management plan. This was one of the earliest applications in South Africa of a decision support guideline that combined indicators of the social, economic and natural environments (CSIR, 1990). The system was developed for guiding the local authority in the required decisions related to the management of the Great Brak estuary mouth as part of the implementation of the environmental management plan following an environmental impact assessment.

A simple, yet representative and effective checklist and decision tree type flow diagram was developed, taking into consideration the issues that were identified by the local community, the responsible authorities and estuarine scientists during an environmental impact assessment. The specific indicator and threshold values were determined in close consultation with scientists and were customised to the specific site conditions.

The assessment process was initiated via a simple checklist (Table 2.5) completed by the local environmental officer on a monthly basis, or weekly when intense management was required (e.g. during times of drought or floods). Data for the checklist were obtained from a simple toolkit provided, which included a salinometer and a water level gauge that staff affixed to a bridge pier in the estuary. Water quality indicator measurements, for example E.Coli, were part of a routine monitoring requirement carried out by the regional office of the then Department of Water Affairs.

The outcome of the checklist assessment was a calculated score value that triggered the relevant decision support pathway along the decision tree (Figure 2.35). To enable the decision-makers and researchers to learn from decisions, the recommended response was placed on record (Table 2.6). The procedure enabled the actual management decision and outcome to be evaluated and the management to be adapted as more experience was gained. Specific data, such as the environmental conditions reflected in the actual scores captured on the checklist, were available for future analysis.

An information brochure was published and distributed to each household at Great Brakrivier town and was made available to the general public at relevant points, for example the library, schools, shops and service stations. The brochure outlined the context, rationale and approach and provided a copy of the checklist and decision tree. Since it was easy to follow, this served the purpose of educating the stakeholders as well as encouraging them to participate in observing key factors that related to the environmental health of the actual estuarine system around which the economy of the small coastal resort centred.

The approach was successful in creating awareness within the community and among interested and affected parties.

Table 2.5: The estuary status checklist for the Great Brak estuary (CSIR, 1990)

A	Criteria	Score value: Yes	Score value: No	Score?	Comments
1	Is the mouth open?	2	0		Depth: …. m Width: …. m
2	Is the estuary water level less than +1,22 m MSL?	2	0		Level = …. m
3	Is there a bad smell and/or excessive algal growth in the water?	0	1		If yes, please describe:
4	Is the E.Coli level less than 1000?	2	0		E.Coli level =
5	Is the salinity level more than 7 and less than 40?	2	0		Salinity level =
6	Are fish dying or under stress, e.g. gaping at the surface for air?	0	2		If yes, please describe:
7	Is it February? Is it June? Is it November?	-1 -1 -2	0 0 0		
TOTAL:					Action?
NOTE: OPEN MOUTH IF TOTAL < 9					

Table 2.6: Monitoring information associated with the estuary status checklist for the Great Brak estuary (CSIR, 1990)

B	Monitoring information	Date	Time	Other
1	Water release started:			Volume released: …… m^3
2	Water release stopped:			
3	Mouth opening started:			Actual bulldozer time: … hrs
4	Mouth opening completed:			
5	Mouth closed on:			Was mouth re-opened? …
6	Total rainfall recorded per month: …… mm			
7	General comments:			

The Great Brakrivier estuary environmental management plan was reviewed by Slinger, Huizinga, Taljaard, Van Niekerk and Enserink (2005) and they reported that the management had been revised based on a 10-year monitoring review (CSIR, 2003). They concluded that the process of follow-up after the initial environmental impact assessment and acceptance of the environmental management plan had to be supplemented by feeding in the learning gained through active management of the system and through evaluating available monitoring data.

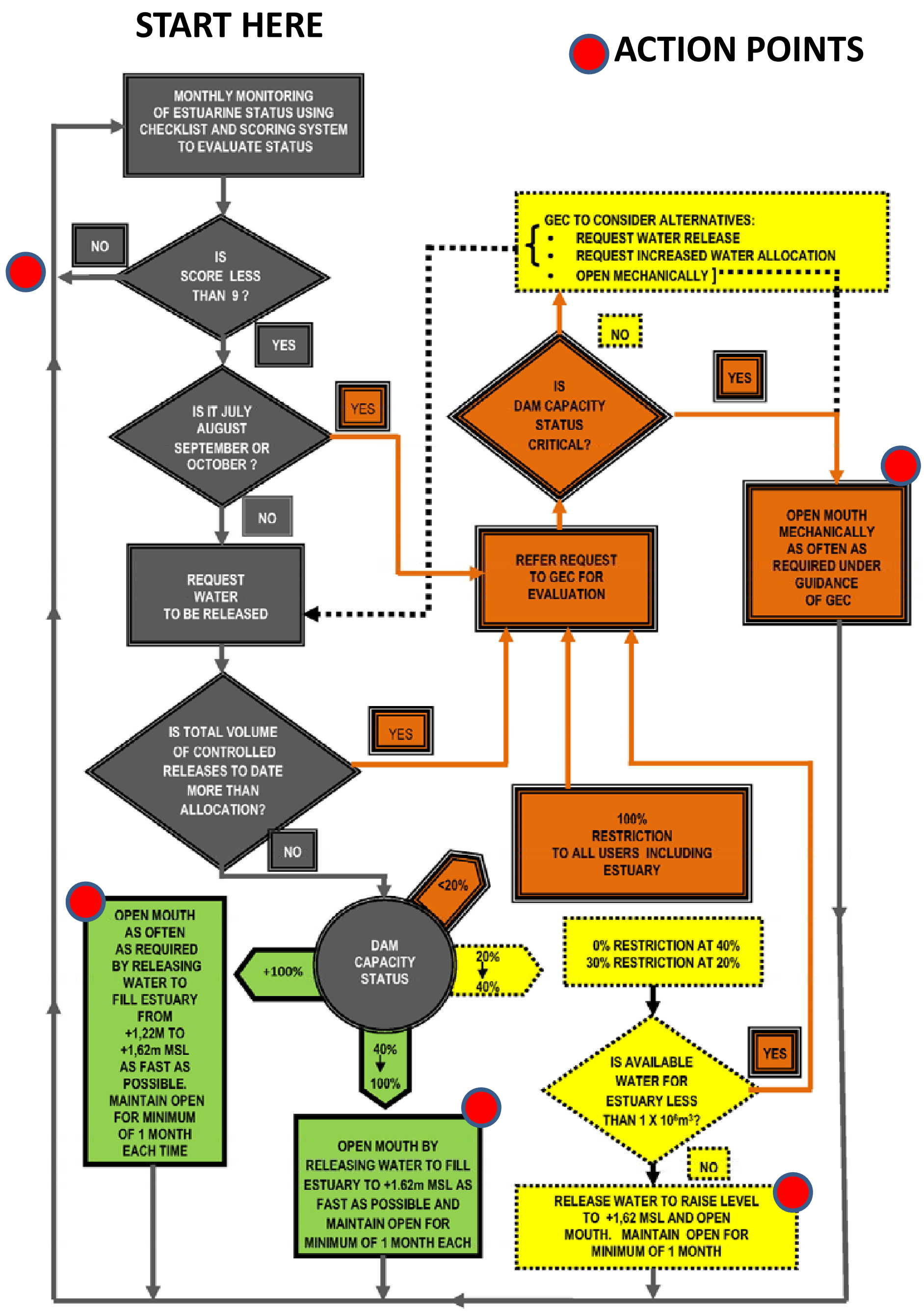


Figure 2.35: The decision tree for the Great Brak estuary (CSIR, 1990)

It was concluded that the approach was seen as a classic adaptive management process with the number of participants expanding gradually. The hands-on learning that occurred through ongoing knowledge sharing within the Great Brak Environmental Committee and in public meetings was seen as key. Slinger et al. (2005) concluded that the learning had been formalised in procedures and has resulted in the refinement of the focus of the environmental management.

2.5 Conclusion

The following conclusions are drawn from the literature review on the use of indicators and indices as components of decision support guidelines:

- Carrying out rapid assessments of the environmental status of key components of an identified natural and social system is practical and achievable by non-experts.
- Key to the success, though, is the identification of indicators and indices that are representative of the specific human–nature system components to which the non-expert can relate.
- Separating the prevailing human–nature system into logical components assists in simplifying what is a complex system.
- The checklist-based approach can practically feed into relevant decision trees that guide the non-expert to a relevant management action and considered outcome.
- Monitoring and evaluation of the decision outcomes fed back into the system leads to improved system understanding, user education and better decisions.
- This adaptive management approach can form the core of a decision support guideline that is considered a critical part of building capacity at local authority level. This approach could enable the implementation of integrated coastal management in developing countries where a lack of experienced environmental managers is often the norm.

Based on the available information, the set of indicators for assessing the risk and vulnerability along the coastline shown in Table 2.7 is proposed.

Table 2.7: Proposed indicators to assess risk and vulnerability along the coastline

No.	Indicator
1	CS: Beach slope
2	Erosion/Accretion trend
3	GC: Geomorphology
4	WH: Wave height
5	TR: Tidal range
6	CO: Orientation
7	AI: Wind and sand characteristics
8	V: Vegetation type
9	HE: Human effects
10	User perception: Fit-for-use
11	Value of protected infrastructure
12	Erosion landforms visible?
13	New dunes forming?
14	Vegetation controlling sand?
15	Buffer dune system managed effectively?

The applicability of these indicators to the South African environment and in particular to buffer dune integrity assessment is evaluated and discussed in chapters 4 and 5.

As a lead-in to the development of the conceptual risk profile assessment procedure described in Chapter 4, the study area where the procedure was evaluated is discussed in the following chapter.

CHAPTER 3: DESCRIPTION OF THE STUDY AREA

3.1 Introduction

In Chapter 2 it was seen that it is possible to simplify the complex human–nature system and to identify a set of indicators (Table 2.7) that represent the variables that define the context of dune integrity in the coastal zone.

As a lead-in to the development of the conceptual decision guideline (Chapter 4) and the application of the guideline (Chapter 5), the study area in which the proposed decision guideline is to be evaluated is described in this chapter.

3.2 Study area

The chosen study area falls within the south coast of South Africa (figures 3.1 and 3.2). During the last few years, the Eden District Municipality experienced a number of floods and high sea storms that caused extensive damage in places. This raised the awareness of the risk to property due to natural events and the possible effects of climate change. A high-profile climate change conference was held in Mossel Bay in early 2009, where the importance of integrated coastal management was highlighted and the crucial role of maintaining an adequate development setback within the coast–land interface was emphasised.

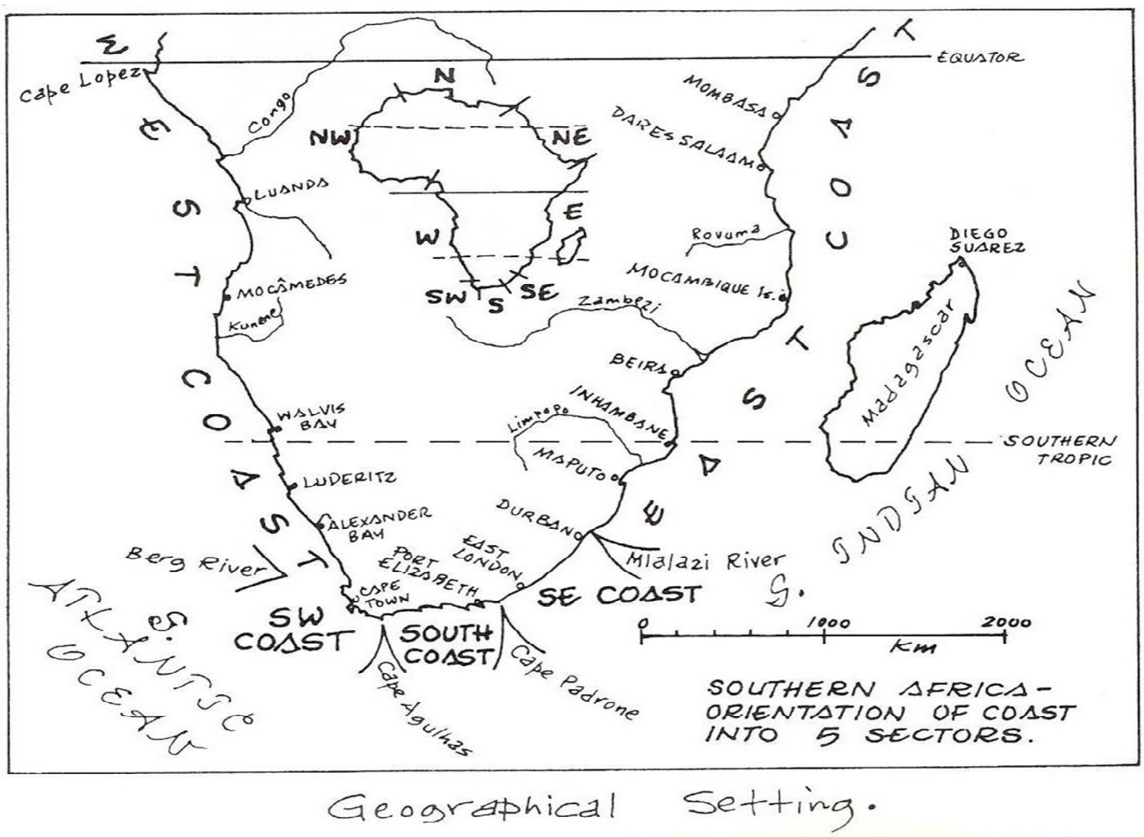


Figure 3.1: Geographical setting and orientation of the coast into five sectors (Tinley, 1985)

The Eden District Municipality was therefore selected as the study area due to the willingness and enthusiasm to participate from officials from the municipality and representatives of the five coastal municipalities, namely Hessequa, Mossel Bay, George, Knysna and Bitou (Figure 3.2).

3.3 Socio-economic factors

3.3.1 Needs and issues identified at municipal level

In an attempt to identify the actual issues and needs that coastal municipal decision-makers face, regional workshop sessions that formed part of the research methodology were held with mainly municipal officials. Interaction with participants highlighted a number of needs and issues that are prevalent within the coastal zone at municipal level.

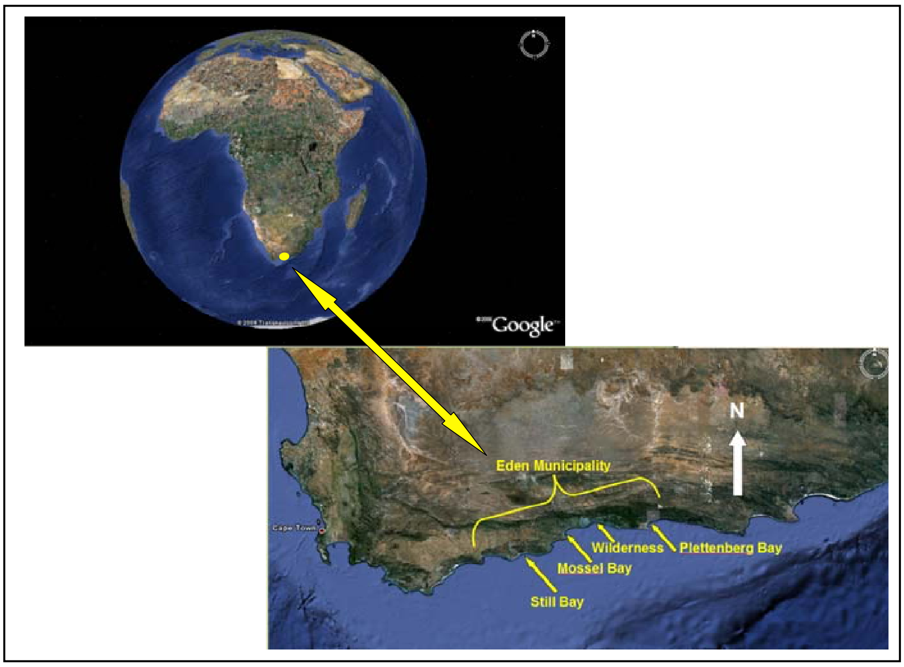


Figure 3.2: Locality map (image from Google Earth™)

Figure 3.3: Interactive needs assessment process using SmartBoard™ technology

The Google Earth™ images relevant to the municipal area under discussion were projected onto a SmartBoard™. As shown in Figure 3.3, the interactive workshop sessions allowed participants to identify, sketch and describe the various issues, problems and management challenges that they experienced within the coastal zone, including the estuaries.

Figure 3.4 shows typical results of an interactive session.

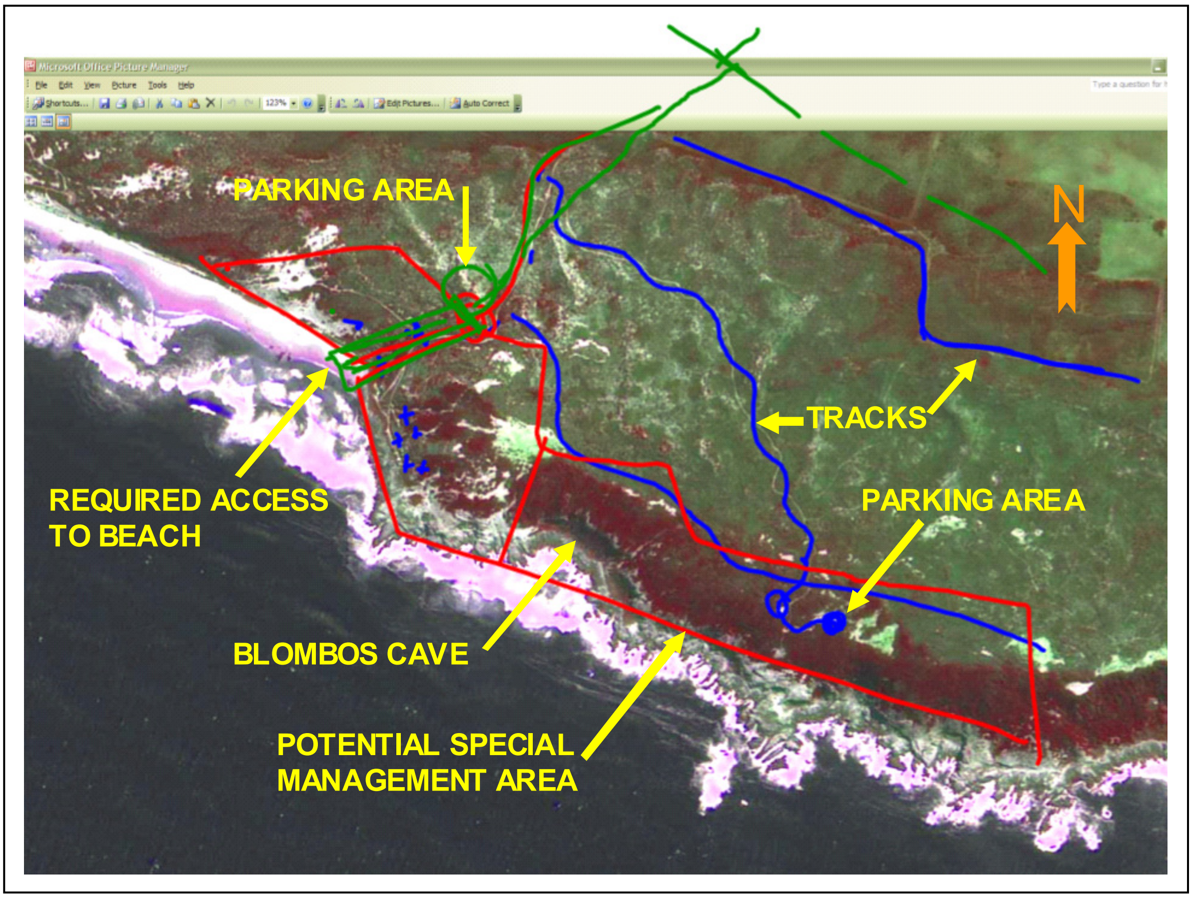


Figure 3.4: **Typical annotated output from interactive needs assessment process (overlay onto Google Earth^{TM} image using the SmartBoard^{TM} technology)**

The identified issues listed in Table 3.1 highlight the following key challenges relating to integrated coastal management that are faced by decision-makers at municipalities:

- Erosion of the coastline, threatening municipal infrastructure and private property (Figure 3.5)
- Wind-blown sand impacting on the infrastructure and private properties (Figure 3.6)
- The control and provision of public access to the coastline while preventing damage to the littoral active zone and specifically the integrity of the buffer system (Figure 3.7)

Table 3.1: Issues and needs identified by municipal decision-makers[1]

No.	Issue/Need	Relates to	Implementable design/management response
1	Public access to the coastline	Land use planning	Formal pathways
2	Encroachment of development onto primary dunes	Land use planning	Demarcate and manage a buffer zone between primary dune and development
3	Jetties/slipways (structures) on flood plain	Land use planning	Demarcate and manage a buffer zone
4	Resort zoning of coastal properties	Land use planning	Demarcate and manage a buffer zone
5	Ribbon development	Land use planning	Demarcate and manage a buffer zone
6	Public access to river and estuary	Land use planning	Formal pathways
7	Inappropriate building practices in coastal zone	Land use planning, human behaviour/education	Implement good-practice guidelines
8	Disturbance (flattening) of coastal dunes	Human behaviour/education	Demarcate and manage a buffer zone
9	Roads and erosion across dunes and in coastal zone	Human behaviour/education and law enforcement	Demarcate and manage a buffer zone and include formal emergency vehicle access pathways
10	Using of loopholes in legislation to erect buildings/structures along the coast	Human behaviour/education and law enforcement	Effective law enforcement and community involvement
11	Law enforcement to control access to sensitive areas	Human behaviour/education and law enforcement	Effective law enforcement and community involvement
12	Poaching in isolated areas	Human behaviour/education and law enforcement	Effective law enforcement and community involvement
13	Illegal building of structures along coast and estuaries	Law enforcement	Demarcate and manage a buffer zone through effective law enforcement and community involvement
14	Informal activities (e.g. camping) and informal structures erected in the coastal zone	Law enforcement	Demarcate and manage a buffer zone through effective law enforcement and community involvement
15	Erosion threatening municipal infrastructure and private property	Land use planning and natural processes	Demarcate and manage a buffer zone
16	Erosion of foredunes	Natural processes and human behaviour/education	Demarcate and manage a buffer zone
17	Local officials need education on importance of coastal processes	Education/decision support to gain experience	Implement good-practice guidelines

Note 1: This information was obtained during facilitated workshops held in the study area.

These issues are principally addressed by three actions that are achievable at municipal level, namely:

(1) land use planning that takes the current and future natural processes into account;
(2) education that influences human behaviour; and
(3) law enforcement.

Figure 3.5: Erosion threatening municipal infrastructure

Figure 3.6: Wind-blown sand impacting on infrastructure and private property

Figure 3.7: Provision of effective public access to the coastline is essential to the maintenance of the integrity of the buffer dune system

3.3.2 Sub-conclusion on local issues and needs

The definition, establishment and maintenance of **buffer areas** are seen as essential to addressing the core issues identified by local stakeholders (Table 3.1). Such buffer areas are seen to be crucial to ensuring that human behaviour and activities are managed and influenced towards the sustainable utilisation of the coastline. Implementation should be supported by effective law enforcement complemented by active community involvement.

As discussed in Chapter 2, the influence of the dynamic coastal processes within the coastal zone typically results in coastal erosion, accretion and a build-up of dunes as the natural movement of sediment (sand) along soft coastlines takes place. Where human activities, such as poor land use planning, influence or change the natural sediment budgets and pathways in the coastal zone, so-called 'problems' occur. In most cases, the 'problems' are due to inconsiderate or unwise planning and placement of infrastructure and private property within the required coastal processes setback area (Figure 1.3), thereby not leaving enough space for the natural processes to take place.

Providing decision-makers with the means to educate themselves about the key processes, the role and importance of the various components of the system and a simple way of assisting with the decision-making process that will build confidence is an important requirement. This is taken further in subsequent sections of this thesis.

3.4 Bio-physical context of the study area

A general overview of the human-nature system that prevails within the study area was provided in Chapter 2. The regional weather system, wave climate and climate characteristics including the wind regime were summarised. The coastal processes that influence the coastline shape, the formation of beaches and dunes, the influence of tides, storm erosion and a possible sea-level rise, were also discussed. Specific human activities within the coastal zone were described and conclusion drawn on the use of relevant indicators and indices to assess and track human and natural influences on the key variables.

As seen in figures 3.2 and 3.8, the south coast is characterised by half-heart bays (Tinley, 1985:19). In a comprehensive analysis of the Southern African coastline from a beach and dune management point of view, Tinley (1985) describes a large number of typical dune types (Figure 3.8) that form characteristic features of the coastline, some specifically associated with the half-heart bays. This is discussed later in this chapter.

Figure 3.8: Distribution of types of coastal dunes along the south coast (extracted from Tinley [1985] and superimposed on Google Earth™ image)

The perched dune fields (indicated as P in Figure 3.8), remnants of a previous climate regime, are no longer fed with beach sand because they are located on cliffs above the beach and are therefore considered 'relic'. However, they form an important sand supply to the coastline when storm runup causes undercutting and slumping. Such slumping of the high dune cliffs is dramatic and poses a high risk to cliff-top properties located too close to the edge (Figure 3.9). Attempts to prevent the slumping by providing hard-engineering 'solutions' could result in negative effects on adjacent areas in the long-term because the coastal system may then be starved of crucial sediment supply.

Figure 3.9: Example of relic dunes perched on cliffs slumping as they are undercut by erosional coastal processes

3.5 Wave transformation processes

The offshore wave regime was discussed in Section 2.2.4 and the local wave transformation discussed in Section 2.2.9. It was seen that the position of the site within the half-heart bay plays an important role in determining the local wave energy regime along the coastline. Furthermore, the orientation of the coastline relative to the prevailing wind regime along with the availability of sand, the beach width and the sand characteristics, influence the direction and amount of wind-blown sand in the foredune area.

The SWAN model (discussed in Section 2.2.8) was set up for the area offshore of Mossel Bay, with a more detailed grid for the Mossel Bay half-heart bay nested within the coarser grid. These grids take into account the offshore and nearshore bathymetry data sourced from available charts.

As nearshore reference, the 10 m depth contour line was digitised (Figure 3.10) as discussed in Section 2.2.8. The shoreline was also digitised and included for orientation.

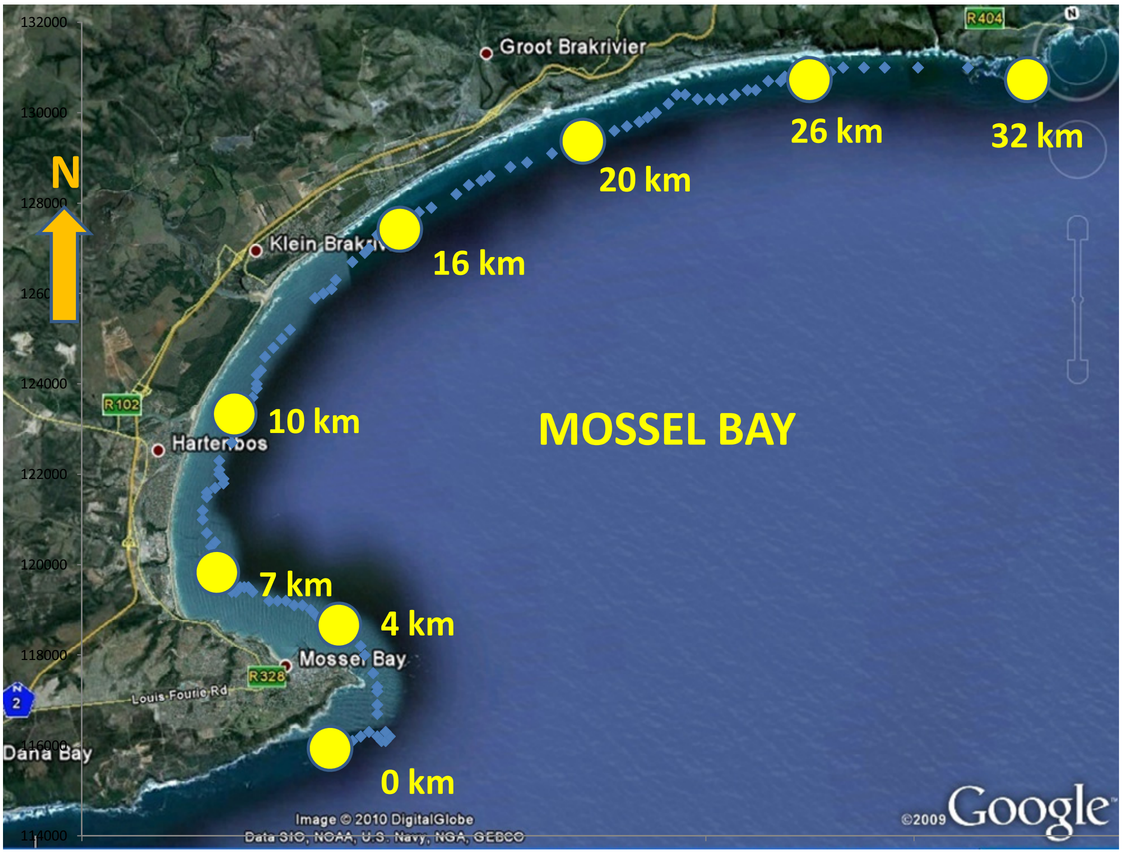


Figure 3.10: Position of the 10 m depth contour and km readings within Mossel Bay as referenced in figures 3.12, 3.13a and 13b (image from Google Earth™)

Wave data for the area off Mossel Bay are available for the period 30-01-1997 to 01-08-2009 which amounts to a total of 36 529 records recorded over the period of 12 years and 7 months. The data from the FA Platform 2 (NCEP) are stored in an electronic database at the CSIR. Standard analysis packages are available to interface with the database and products, such as the wave roses (Figure 2.3) that show wave height (H_{mo}) versus wave direction can be obtained.

Other products produced are, for example, the percentage occurrence of the wave heights (H_{mo}) versus wave period (T_p) (tables 3.2a and 3.3a) and the wave height versus the wave direction (tables 3.2b and 3.3b) for summer and winter respectively.

Using the available statistics (tables 3.2 and 3.3), the following process was followed to derive the suite of H_{mo} and T_{po} combinations of boundary conditions listed in Table 3.4:

- Considering only the data associated with the wave heights that exceed 2.0 m (80% of all records), the data were binned into representative wave heights for both winter and summer (tables 3.2a and 3.3a) and for directional sectors 225° and 90° relative to north (tables 3.2b and 3.3b).

Table 3.2a: Percentage occurrence for wave height vs period (Summer)

Hmo	Period (Tp) (s)															
(m)	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	24-26	26-28	28-30	30-32	Total
0.0 - 0.5																	0.00
0.5 - 1.0		0.01	0.11	0.02													0.15
1.0 - 1.5		0.04	0.16	0.57	0.88	0.29	0.07										2.01
1.5 - 2.0		0.01	0.97	2.28	8.01	5.55	0.39	0.04	0.02								17.27
2.0 - 2.5			1.90	3.66	10.18	16.05	2.48	0.16	0.01								34.43
2.5 - 3.0			0.65	4.84	4.57	11.12	3.45	0.20	0.02								24.85
3.0 - 3.5			0.08	2.39	1.94	4.46	2.93	0.36	0.02								12.19
3.5 - 4.0				0.69	1.02	1.95	1.46	0.16									5.28
4.0 - 4.5				0.08	0.44	0.99	0.47	0.02									2.00
4.5 - 5.0					0.19	0.51	0.40	0.03									1.13
5.0 - 5.5					0.03	0.20	0.16										0.39
5.5 - 6.0					0.01	0.07	0.06										0.13
6.0 - 6.5							0.02	0.01									0.03
6.5 - 7.0						0.02	0.01	0.01									0.04
7.0 - 7.5						0.01	0.01	0.01									0.03
7.5 - 8.0							0.01	0.01									0.02
8.0 - 8.5								0.02									0.02
8.5 - 9.0																	0.00
9.0 - 9.5																	0.00
9.5- 10.0																	0.00
Total	0.00	0.07	3.86	14.53	27.27	41.22	11.93	1.04	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.

kRFA4s: 2.5 m; 8s

kRFA5s: 2.5 m; 11.5 s

kRFA3s: 4.0 m; 11 s

kRFA2s: 6.5 m; 14 s

kRFA1s: 8.0 m; 14 s

- The H_{mo} bins for summer were chosen as 2.5, 4.0, 6.5 and 8.0 m for the 225° (south-western) directional sector and 2.5 and 4.0 from the eastern (90°) sector.

- To obtain the wave period (T_{po}) estimated to be best associated with each of the wave heights bins, the percentage occurrence of measured wave periods for each of the identified H_{mo} bins (tables 3.2a and 3.3a) was considered and a representative value within a range chosen. The results are shown in Table 3.4.

Table 3.2b: Percentage occurrence for wave height vs wave direction (Summer)

Hmo (m)	Wave Direction (degrees TN)																
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
0.0 - 0.5																	0.00
0.5 - 1.0				0.03	0.07	0.01	0.01				0.02						0.15
1.0 - 1.5					0.12	0.17	0.02	0.01	0.04	0.52	0.77	0.33	0.02				2.01
1.5 - 2.0					1.56	1.40	0.52	0.52	0.94	4.27	7.70	0.28	0.08				17.27
2.0 - 2.5					3.96	1.57	0.66	1.00	1.08	11.28	14.00	0.81	0.07				34.43
2.5 - 3.0				0.02	3.93	1.10	0.48	0.45	0.94	9.16	7.93	0.70	0.13				24.85
3.0 - 3.5					1.89	0.40	0.08	0.11	0.18	4.09	4.91	0.48	0.04				12.19
3.5 - 4.0					0.73	0.13		0.03	0.12	2.12	1.79	0.30	0.04				5.28
4.0 - 4.5					0.16	0.02			0.03	0.85	0.74	0.18	0.01				2.00
4.5 - 5.0					0.04				0.03	0.61	0.36	0.09					1.13
5.0 - 5.5									0.02	0.27	0.10						0.39
5.5 - 6.0									0.03	0.08		0.02					0.13
6.0 - 6.5										0.01	0.02						0.03
6.5 - 7.0										0.01	0.03						0.04
7.0 - 7.5										0.01	0.02						0.03
7.5 - 8.0										0.02							0.02
8.0 - 8.5										0.02							0.02
8.5 - 9.0																	0.00
9.0 - 9.5																	0.00
9.5 - 10.0																	0.00
Total	0.00	0.00	0.00	0.06	12.47	4.82	1.77	2.12	3.44	33.32	38.41	3.19	0.40	0.00	0.00	0.00	100.

kRFA3sE

kRFA2sE

kRFA1sE

kRFA4s

kRFA3s

kRFA2s

kRFA1s

- As summarised in Table 3.3a, the H_{mo} bins for winter were chosen as 2.5, 4.0, 5.5, 6.5 and 8.5 m for the 225° directional sector. As can be seen in Table 3.3b, in winter very few waves approach from the eastern (90°) sector, so no records were considered.

Table 3.3a: Percentage occurrence for wave height vs period (Winter)

Hmo	Period (Tp) (s)																
(m)	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	24-26	26-28	28-30	30-32	Total
0.0 - 0.5																	0.00
0.5 - 1.0																	0.00
1.0 - 1.5			0.01	0.02	0.13	0.41	0.02										0.59
1.5 - 2.0			0.15	0.30	1.24	5.37	0.88	0.13	0.02								8.10
2.0 - 2.5			0.31	0.99	2.66	10.31	4.71	0.48	0.01								19.47
2.5 - 3.0			0.26	1.74	2.13	8.82	7.25	1.03	0.04	0.01							21.29
3.0 - 3.5			0.05	1.62	2.17	6.28	6.28	0.79	0.04								17.23
3.5 - 4.0				0.74	1.51	4.98	4.75	0.44									12.42
4.0 - 4.5				0.26	0.97	3.19	3.30	0.27									7.98
4.5 - 5.0				0.05	0.53	2.01	1.88	0.17									4.63
5.0 - 5.5					0.28	1.36	1.52	0.21									3.38
5.5 - 6.0					0.09	0.74	0.88	0.23									1.93
6.0 - 6.5					0.04	0.34	0.60	0.11									1.09
6.5 - 7.0						0.11	0.57	0.17									0.85
7.0 - 7.5						0.10	0.28	0.11									0.48
7.5 - 8.0						0.03	0.17	0.04									0.25
8.0 - 8.5							0.10	0.02									0.12
8.5 - 9.0						0.01	0.05	0.04									0.11
9.0 - 9.5							0.01	0.04									0.05
9.5 - 10.0							0.02										0.02
Total	0.00	0.00	0.78	5.72	11.75	44.05	33.28	4.29	0.12	0.01	0.00	0.00	0.00	0.00	0.00	0.00	100.

kRFA5w: 2.5 m; 12 s

kRFA4w: 4.0 m; 10 s

kRFA3w: 5.5 m; 13 s

kRFA2w: 6.5 m; 13 s

kRFA1w: 8.5 m; 13 s

Table 3.3b: Percentage occurrence for wave height vs wave direction (Winter)

Hmo (m)	Wave Direction (degrees TN)																
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
0.0 - 0.5																	0.00
0.5 - 1.0																	0.00
1.0 - 1.5					0.01	0.01		0.01		0.15	0.31	0.09	0.01				0.59
1.5 - 2.0					0.23	0.11	0.13	0.20	0.14	1.76	4.98	0.48	0.01	0.06			8.10
2.0 - 2.5		kRFA5w		0.02	0.77	0.53	0.15	0.53	0.65	4.47	11.38	0.74	0.18	0.04			19.47
2.5 - 3.0				0.10	0.64	0.76	0.38	0.47	0.61	6.03	10.90	0.85	0.51	0.02	0.01		21.29
3.0 - 3.5				0.10	0.65	0.21	0.25	0.53	0.49	4.67	8.90	0.80	0.55	0.08			17.23
3.5 - 4.0		kRFA4w		0.01	0.27	0.14	0.02	0.26	0.50	2.51	7.36	0.93	0.41	0.01			12.42
4.0 - 4.5					0.17	0.12	0.01	0.09	0.26	1.79	4.48	0.88	0.17	0.01			7.98
4.5 - 5.0					0.13	0.06		0.02	0.09	0.98	2.73	0.51	0.11	0.01			4.63
5.0 - 5.5					0.11	0.01		0.04	0.04	0.67	2.01	0.44	0.06				3.38
5.5 - 6.0					0.09			0.05	0.05	0.40	1.03	0.30	0.01				1.93
6.0 - 6.5					0.03				0.01	0.25	0.62	0.16	0.02				1.09
6.5 - 7.0							kRFA2w			0.12	0.69	0.04					0.85
7.0 - 7.5										0.10	0.32	0.06					0.48
7.5 - 8.0										0.03	0.19	0.02					0.25
8.0 - 8.5										0.01	0.11						0.12
8.5 - 9.0							kRFA1w			0.01	0.08	0.02					0.11
9.0 - 9.5											0.04	0.01					0.05
9.5- 10.0											0.02						0.02
Total	0.00	0.00	0.00	0.23	3.10	1.95	0.93	2.20	2.85	23.94	56.15	6.35	2.05	0.24	0.01	0.00	100.

The selection of these bins are somewhat subjective, but they are considered useful to demonstrate the sensitivity of a variety of wave conditions within a bay. They are not used further in the statistical analysis in this report.

In addition to the thirteen H_{mo} and T_{po} combinations derived as described above, the 1:100 year deep sea wave condition for winter (Section 2.2.4) was included as a 14th combination.

Table 3.4: Deep- water wave parameters used as boundary conditions for the SWAN model

Directional sector	Hm_o (m), Tp_o (s)			
	Winter		Summer	
E (90° relative to north)	N/A		kRFA3sE	2.5 m 11.5 s
	N/A		kRFA2sE	2.5 m 8 s
	N/A		kRFA1sE	4.0 m 11 s
SW (225° relative to north)	kRFA5w	2.5 m 12 s	kRFA5s	2.5 m 11.5 s
	kRFA4w	4.0 m 10 s	kRFA4s	2.5 m 8 s
	kRFA3w	5.5 m 13 s	kRFA3s	4.0 m 11 s
	kRFA2w	6.5 m 13 s	kRFA2s	6.5 m 14 s
	kRFA1w	8.5 m 13 s	kRFA1s	8.0 m 14 s
	1: 100 w	12.0 m 16 s	N/A	N/A

Note: The identifiers (kRFA3sE, etc.) denote the scenarios.

The SWAN model was run for the 14 scenarios summarised in Table 3.4. The SWAN output for one scenario is shown in Figure 3.11 as an example. The wave characteristics at the 10 m water depth contour within the study area were thereby obtained. The wave transformation coefficient (K_T), defined as the ratio of the nearshore wave height (H_{10}) to the deep-sea wave height, was calculated at the points along the 10 m depth contour within Mossel Bay (Figure 3.10). The calculation procedure is summarised in Table 3.5. Output results for all 14 scenarios are provided in Appendix B.

Table 3.5: Calculation procedure of the wave transformation (K_T) coefficient

1	2		3	4	5	6	7	8	9
Node	**XP**	**YP**	**DIST. (x)**	**DEPTH (h)**	**H_{10}**	**PER (Tp)**	**DIR**	**WLEN(λ)**	**K_T=H_{10}/Hmo**
2	106400	116100	0	9.972	1.53	9.9	177	83	0.61

Note: For this example SWAN model input values of H_{mo} = 2.5 m and T_p = 12 seconds from the SW sector were used. The results for a single node point included as the basis to explain the calculation.

Column 1: The node point reference number along the 10 m depth contour.

Column 2: The x- and y-coordinates of each of the node points within the SWAN grid as part of the model set up. Shown as metres from the local grid origin.

Column 3: The calculated distance in km between the node points along the 10 m depth contour. As can be seen the zero point along the contour is taken as the node point furthest to the SW, located at the tip of the Mossel Bay promontory (Figure 3.10).

Column 4: The depth (m) calculated by the SWAN model at each node point on the 10 m depth contour reference line. The SWAN value should approximate the 10 m depth value as the reference line was chosen as the 10 m depth contour and can be used as a cross-check. This is true in the example shown in Table 3.5 where the SWAN depth output is shown as 9.972 m.

Column 5: The significant wave height (H_{10}) in metres calculated by the SWAN model at each node point on the 10 m depth contour reference line.

Column 6: The wave period (seconds) calculated by the SWAN model at the node point.

Column 7: The wave direction (degrees to True North) calculated by the SWAN model at the node point on the reference line.

Column 8: The wave length (m) calculated by the SWAN model at the node point.

Column 9: The resultant wave transformation coefficient (K_T) calculated as the ratio of the significant wave height at the 10 m depth contour reference line (H_{10}) as shown in Column 5 to the deep-sea significant wave height (H_{mo}), thus $K_T = H_{10} / H_{mo}$.

The results for all 14 scenarios are included in Table B2 in Appendix B.

The calculated values of the wave transformation coefficient for each node point along the 10 m depth contour reference line for all the scenarios are shown in Figure 3.12 and discussed below.

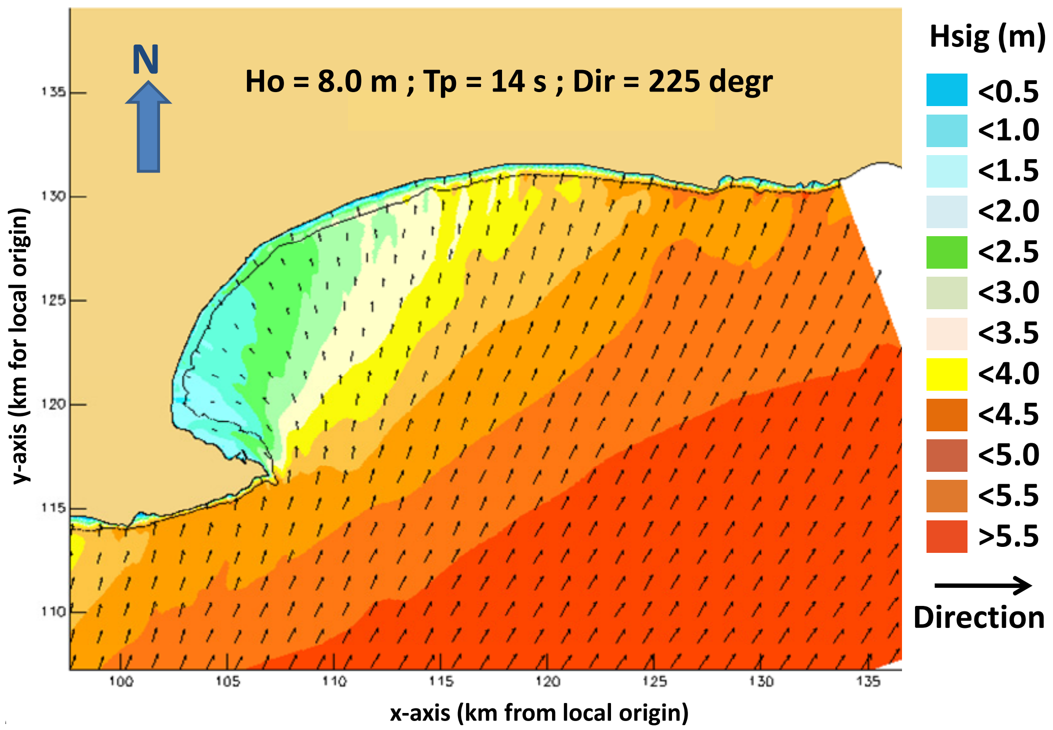


Figure 3.11: SWAN output at Mossel Bay for a deep-sea wave scenario of Hmo = 8.0 m, Tp = 14 s and direction = 225°)

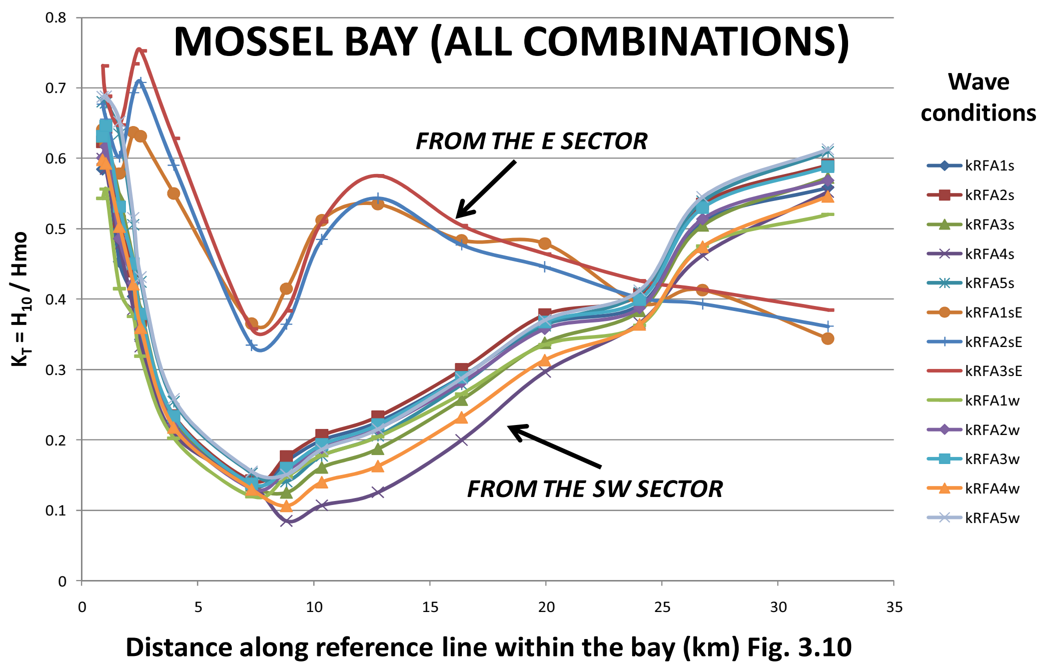


Figure 3.12: Wave transformation coefficient (K_T) within Mossel Bay (see Figure 3.10 for the x-axis positions along the 10 m depth contour)

The sheltering effect of the Mossel Bay peninsula can be seen on the waves that originate in the south-western (SW) sector. The wave transformation coefficient dropped by 83% from about 0.60 on the exposed sections down to about 0.10 in the lee at the 7 km mark. The conditions at the open end of the bay are similar to those at the exposed side of the peninsula where $K_T = 0.6$. This confirms the so-called shadow area, as depicted in Figure 2.16 and highlighted by Holthuijsen (2007).

As expected, the peninsula does not provide much shelter from the waves from the eastern (E) sector. A reduction of 0.20 (36%) is seen in the K_T range within the bay. Of interest is that the wave characteristics off the peninsula at Mossel Bay are in a similar range for both the SW and E sectors, with a K_T factor of 0.7 up to the 4 km mark during eastern conditions.

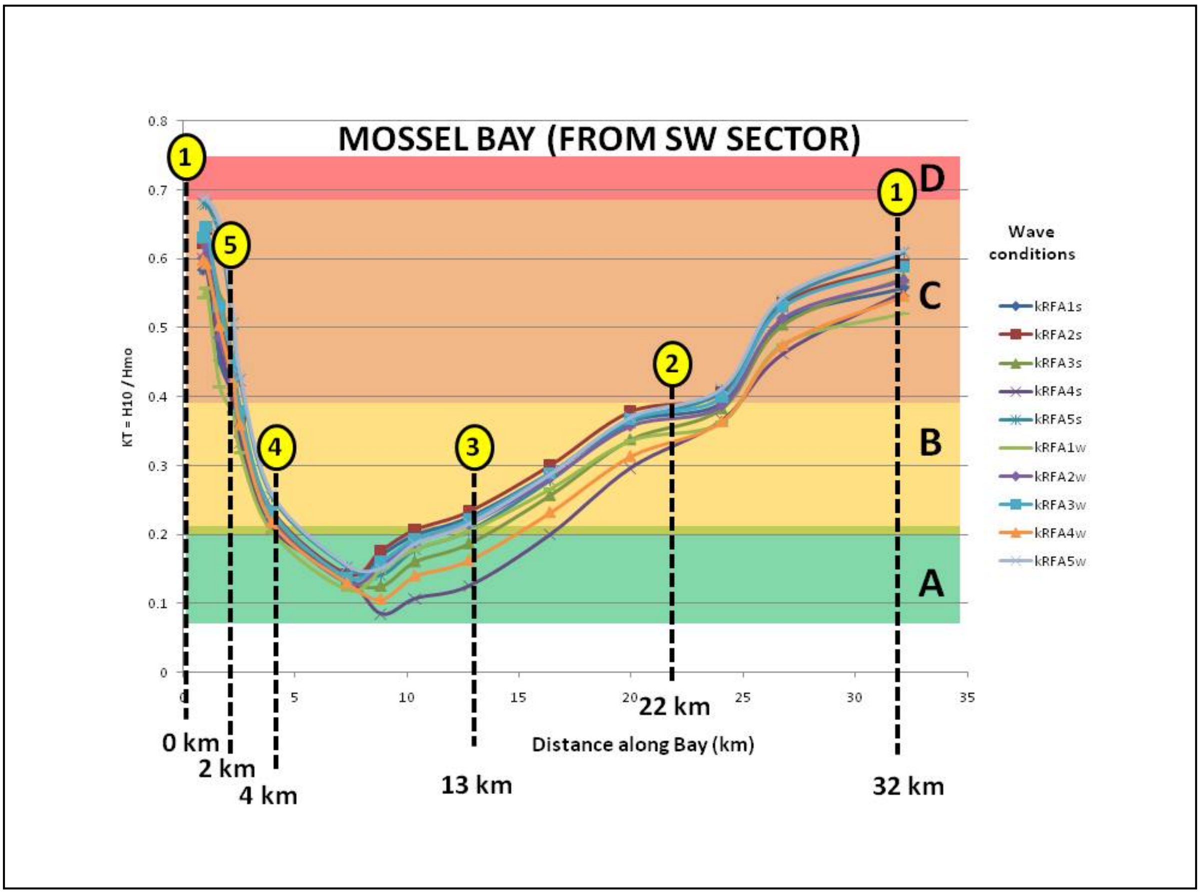
From the results it is proposed that the spread of nearshore wave energy (as represented by the wave transformation coefficient) along the coastline of the Mossel Bay half-heart bay and adjacent coastline can be categorised as depicted in Figure 3.13 and a set of threshold values and associated exposure description defined as shown in Table 3.6.

Table 3.6: Threshold values of the wave transformation coefficient for Mossel Bay

Category[1]	K_T (min)[2]	K_T (max)[2]	Exposure
A	< 0.2		Protected
B	0.21	0.4	Moderate
C	0.41	0.7	Exposed
D	> 0.7		Open coast

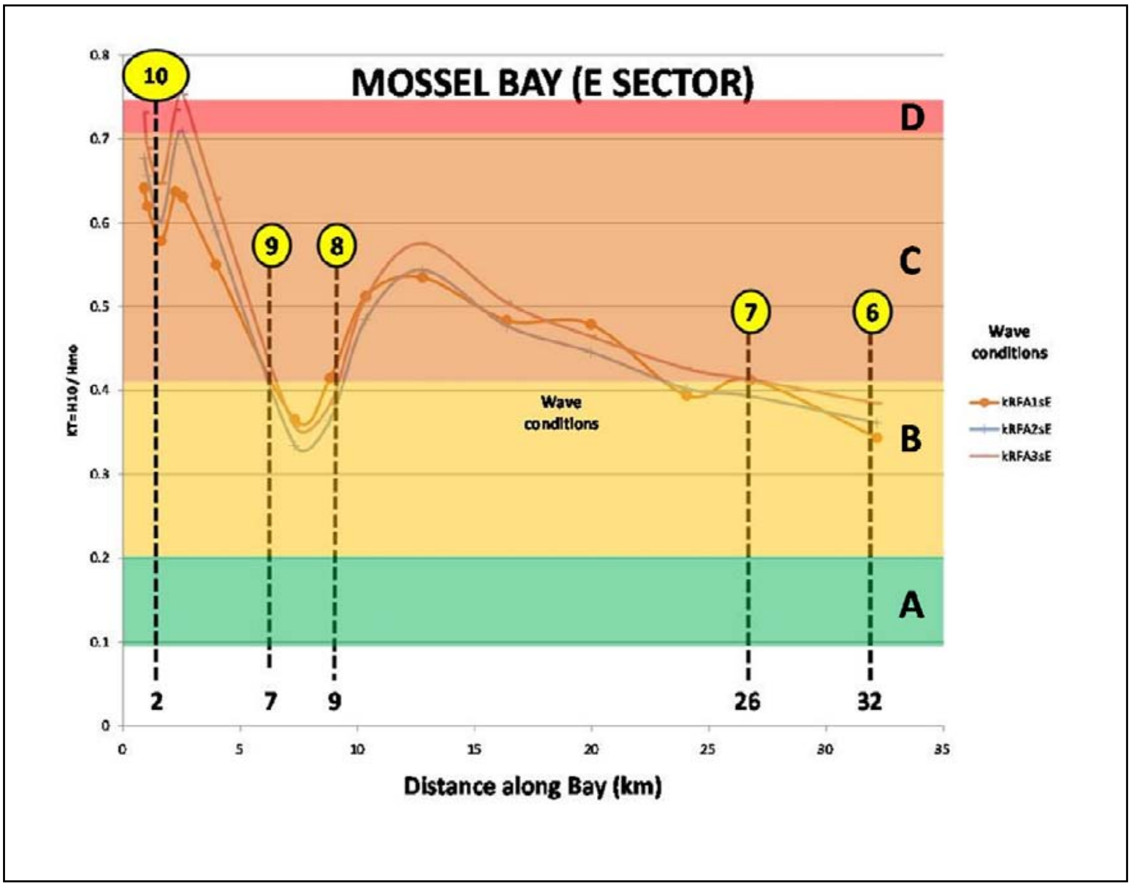
Note 1: Refer to figures 3.13. 3.14 and 3.15
Note 2: Refer to Figure 3.12

To illustrate the categories associated with each of the K_T ranges shown in Table 3.6, the derived threshold values are depicted as colour bands as shown in Figure 3.13. The categories, shown as A, B, C and D, are also indicated in figures 3.14 and 3.15 for the prevailing SW and E wave directions respectively.



Note: The numbers cross-refer to figures 3.14 and 3.15

Figure 3.13a: The area within a typical half-heart bay is categorised in terms of the value of the wave transformation coefficient. Categories as per Table 3.6.



Note: The numbers cross-refer to figures 3.14 and 3.15

Figure 3.13b: The area within a typical half-heart bay is categorised in terms of the value of the wave transformation coefficient. Categories as per Table 3.6.

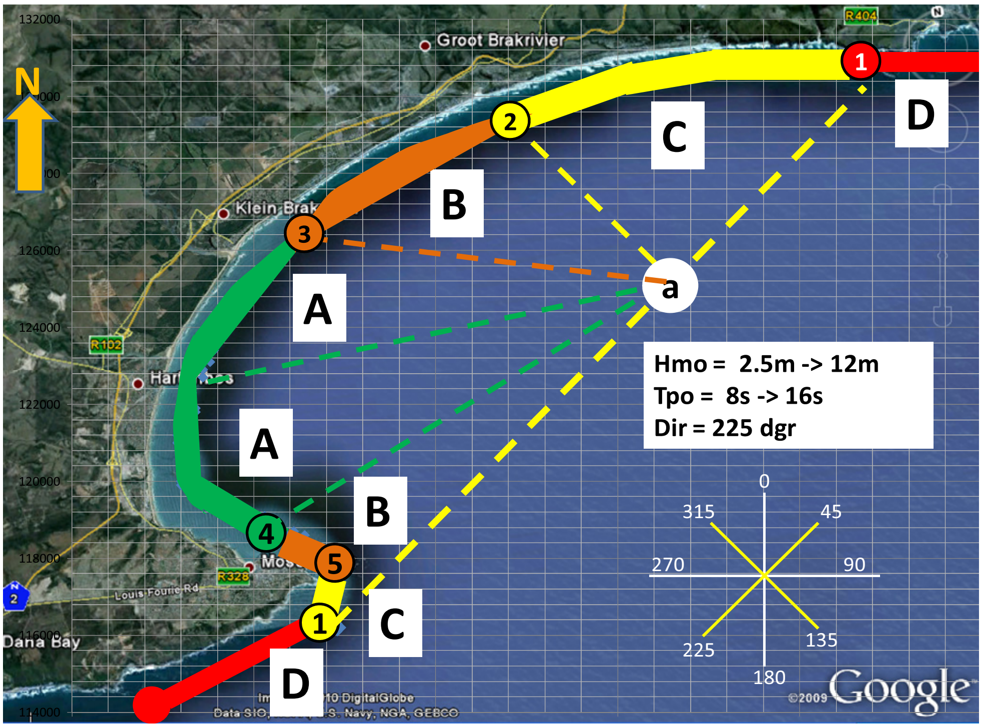


Figure 3.14: **Coastline categorised according to K_T coefficient for SW wave conditions that occur throughout the year, but mainly in winter (Colours and numbers cross refer to those in Figure 3.13a)**

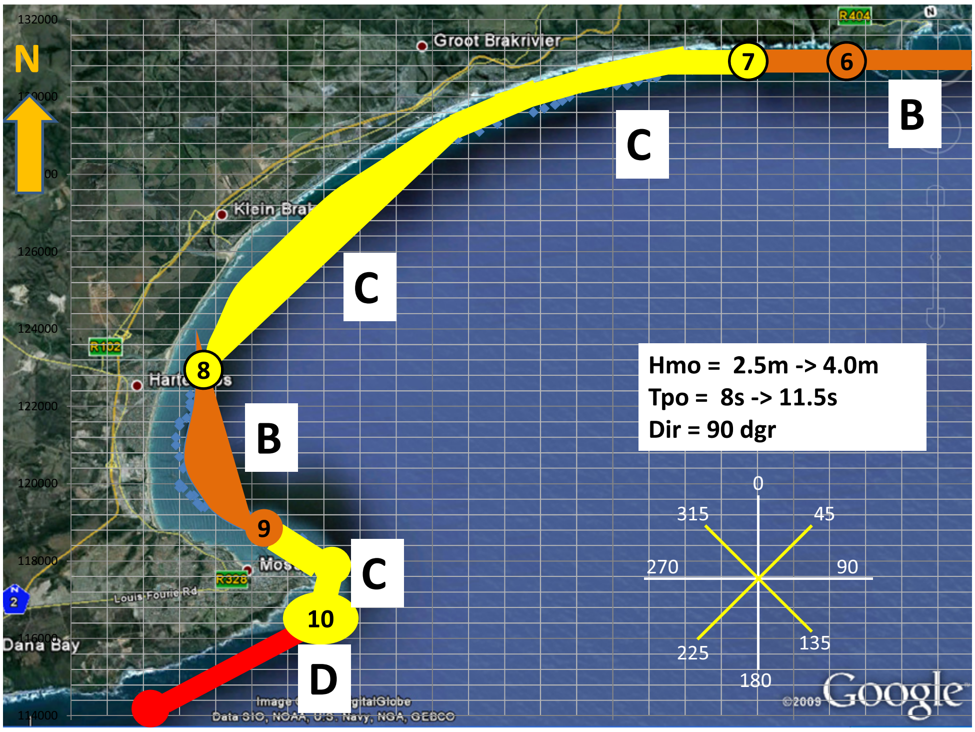


Figure 3.15: **Coastline categorised according to K_T coefficient for E wave conditions that mainly prevail in summer (Colours and numbers cross refer to those in Figure 3.13b)**

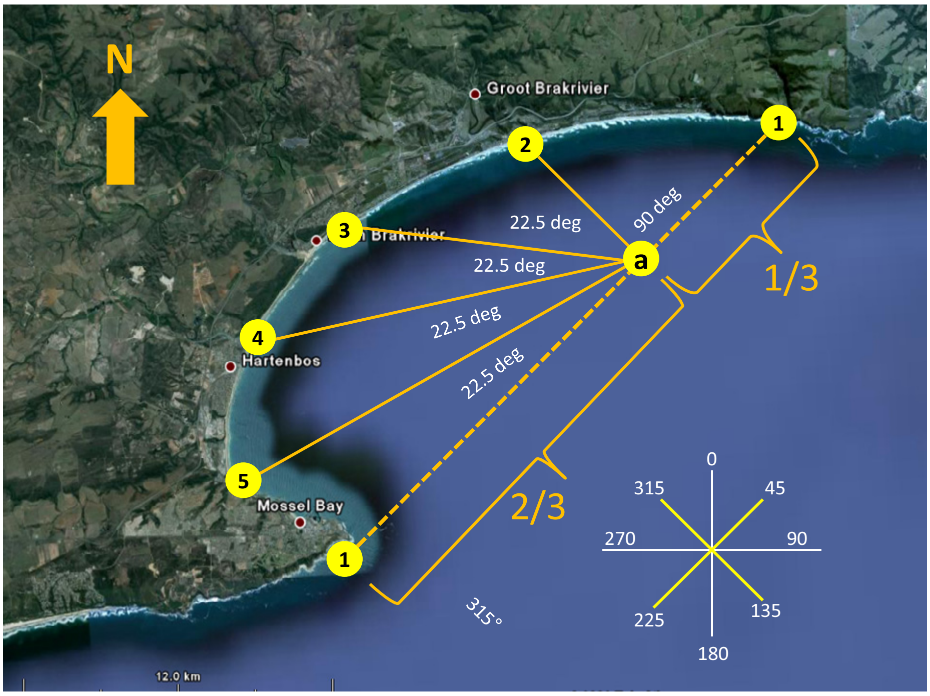


Figure 3.16: The SW 'shadow' area divided into convenient segments using the K_T threshold values as basis.

Taking the K_T threshold values discussed above as the basis, the SW 'shadow' area was divided into convenient segments, as shown in Figure 3.16. The proposed demarcation is described below.

Line 1-1:

The line that depicts the 'shadow' area is an extension of the dominant wave direction (225°) from the tip of the promontory across the bay as also depicted in Figure 2.16 and defined by Holthuijsen (2007).

Line 2-a:

In Figure 3.13 it can be seen that an interesting change-over of the K_T value occurs in the area at the 25 km node points along the reference line. Here the K_T value for both the SW and E conditions changes dramatically around the 0.4 value. For the SW condition (figures 3.13a and 3.14) the envelope of K_T values flattens out from the 20 km node point and then increases sharply from the 25 km node point. The reason for this is possibly due to the perturbation in the 10 m contour at node point 25 km as can be seen in Figure 3.10, but is not significant to the general trend observed.

Referring to Figure 3.16, when drawing a Line (2) – (a), seaward from the 22 km node point, which is normal to Line (1) – (1), it is observed that the intercept point (a) on Line (1) – (1) conveniently divides the 'shadow' line (Figure 2.16) into two sections that approximate 1/3 and 2/3 of the total length of Line (1) – (1). It is proposed that this approach is a convenient way to define the various areas of interest within the half-heart bay and that it is a useful 'reference template' for describing the various components of the bay.

The simplification of the half-heart bay 'reference template' is expanded by using the link to the K_T threshold values (Table 3.6) and associated chosen categories (A, B, C and D in Table 3.6 and Figure 3.13a). The portion of the shadow area in the half-heart bay located to the WSW of Line (2) – (a) can then be divided into four equal sectors. Lines drawn landwards from Point A intercept the 10 m depth contour reference line at Points 3, 4 and 5 (Figure 3.16). The A, B, C and D categories are then easily demarcated as shown in Figure 3.14.

Figure 3.16 is generalised and simplified, as shown in Figure 4.2 as discussed in Section4.6. It should be noted that the simplified configuration is only valid for the dominant wave sector.

Foredune height and the 1:100 yr storm runup erosion set-back requirement in a bay

In Section 2.2.9 (Figure 2.18) it was seen that the 'safe' top-of-dune elevation ($E_{D)}$ can be determined by adding a safety factor of 0.5 m to the calculated 2% storm-wave run-up elevation ($E_{2\%}$). It was seen that $E_{2\%}$ is defined as the MHWS elevation plus an allowance for storm surge (+0.5 m assumed), wave set-up (+0.25 m) and the vertical wave runup $R_{2\%}$ as calculated using Equation (3) proposed by Ruggiero et al (2001) for steep beach slopes (S > 0.1). Although Ruggiero et al (2001) used the nearshore beach slope to derive Equation (3), in this study (S) is taken as the upper beach slope. This is seen as conservative due to the fact that the 1:100 year runup will occur when the water level is very high due to wave setup off a baseline of MHWS. Under these conditions the normal beach slope will be submerged. Swash runup will therefore only occur across the upper beach.

As seen in Figure 2.18, the height of the foredune (H_{FD}) associated with the 'safe' dune elevation at a specific point along a coastline can be stated as:

$$
\begin{aligned}
H_{FD} &= E_D - E_J \\
&= E_{2\%} + SF - E_J \\
&= E_T + R_{2\%} + SF - E_J
\end{aligned}
$$

Where E_D is the foredune elevation, and E_J the 'foot-of-dune' elevation, both in metres relative to MSL.

From Equation (3) in Section 2.2.9 it follows that:

$$R_{2\%} = 0.27\,(S\,H_o\,L_o)^{0.5}$$

Where $H_o = H_{10} \times K_T^{-1}$; $L_o = (g/2\pi)\,(T_p)^2$, and

$(H_o)^{0.5} = (H_{10}^{0.5}\,K_T^{-0.5})$

Where H_o is the significant wave height in deep water (Ruggiero et al, 2001).

Simplifying further leads to Equation (4) that allows for the calculation of the 'safe" foredune height (H_{FD}) at a point (i) anywhere along the open coast or within a half-heart bay:

$$H_{FDi} = E_Ti + [0.27x\,(Si)^{0.5} \times (H_{10i})^{0.5} \times (K_{Ti})^{-0.5} \times (L_o)^{0.5}] + SF - E_{Ji} \quad \text{-----------(4)}$$

Where:

E_Ti = MHWS + Storm surge (+0.50 m) + wave set-up (+0.25 m);

MHWS = + 1.2 m MSL;

Si = the upper beach slope at point (i). Obtained from beach surveys. Taken as between 0.10 and 0.25 for the study area

H_{10i} = significant wave height at an offshore reference point where no wave breaking occurs. For the study area the reference point is taken as the 10 m depth contour offshore of the point (i). This is an output from SWAN (Appendix B).

K_T = the wave transformation coefficient at the 10 m depth contour reference point offshore of the point (i). Threshold values for points along the coastline in a bay given in Table 3.6, calculated from the SWAN output (Appendix B).

L_{10} = wave length at the 10 m depth contour reference point offshore of the point (i). This is an output from SWAN. (Appendix B).

SF = Safety Factor allowing for inaccuracies. Assumed +0.5 m for this study.

E_{Ji} = Elevation of the 'foot-of-dune' at point (i). Obtained from beach surveys. Taken as +2.50 m MSL for the study area.

The results of applying Equation (4) to calculate the 'safe' foredune height (H_{FD}) and elevation (E_D) at specific points along the bay for the 1:100 year deep sea storm design conditions of H_{mo} = 12 m and T_p = 16 seconds is shown in Table 3.7.

Table 3.7: The 'safe' foredune height and elevation for the 1:100 yr storm for Mossel Bay

1		2	3	4	5	6	7	8	9	10
Segment[1] (km)	**Cat.[2]**	**E_T (+MSL)**	**S**	**H_{10} (m)**	**K_T**	**L_{10} (m)**	**SF (m)**	**E_J (+MSL)**	**H_{FD}[3] (m)**	**E_D[4] +MSL**
22 to 26	C	2.0	0.25	6.4	0.41	129	0.5	2.50	6.0	8.5
13 to 22	C	2.0	0.20	4.3	0.36	130	0.5	2.50	4.7	7.2
7 to 13	B	2.0	0.15	2.5	0.21	138	0.5	2.50	4.2	6.7
4 to 7	A	2.0	0.12	1.4	0.15	143	0.5	2.50	3.4	5.9
2 to 4	A	2.0	0.10	4.3	0.36	138	0.5	2.50	3.4	5.9
0 to 2	B	2.0	0.25	6.5	0.54	137	0.5	2.50	5.4	7.9

Note 1: Refers to the distance (in km) from the zero point at the promontory at Mossel Bay (Figure 3.10)
Note 2: Categories relate to the K_T thresholds (Table 3.6) as illustrated in figures 3.13a and 3.14
Note 3: Calculated by using Equation (4).
Note 4: Elevation of dune ($E_D = E_J + H_{FD}$)

In Table 3.7 Column 1 refers to the position within the bay (figures 3.10, 3.13a and 3.14). The definitions and source of the data for Columns 2 to 8 are associated with Equation (4) as discussed above. Column 9 shows the calculated 'safe' height of the foredune when the 2% wave runup under the 1:100 year using Equation 4 is considered. Column 10 reflects the resultant safe 'top-of-foredune' elevation required at each position along the bay to allow the foredune to respond naturally to the storm runup associated with a 1:100 year storm.

Assuming a 1:3 slope for the seaward edge of typical foredunes within the study area, the resultant horizontal erosion setback distance landwards from the 'foot-of-dune' position is shown in Table 3.8 for the segments of the coastline with Mossel Bay. The results are shown in Figure 3.17 and are further discussed in sections 4.6 and 5.9.

Table 3.8: Erosion set-back distance associated with the 1:100 yr storm

1	2	3	4	5
Coastline Segment (km) (Fig. 3.10)	**Category (Fig. 3.13a)**	**Foredune height H_{FD} (m) Table 3.7)**	**Erosion setback Distance[1] X_{FD} (m)**	**Eroded dune volume[2] V_{Dune} (m^3/m)**
22 to 26	C	6.0	18	54
13 to 22	C	4.7	14	33
7 to 13	B	4.2	13	26
4 to 7	A	3.4	10	18
2 to 4	A	3.4	10	17
0 to 2	B	5.4	16	44

Note 1: X_{FD} = 3H_{FD} (Section 2.2.9)
Note 2: V_{Dune} = 0.5 X_{FD} H_{FD} (Section 2.2.9)

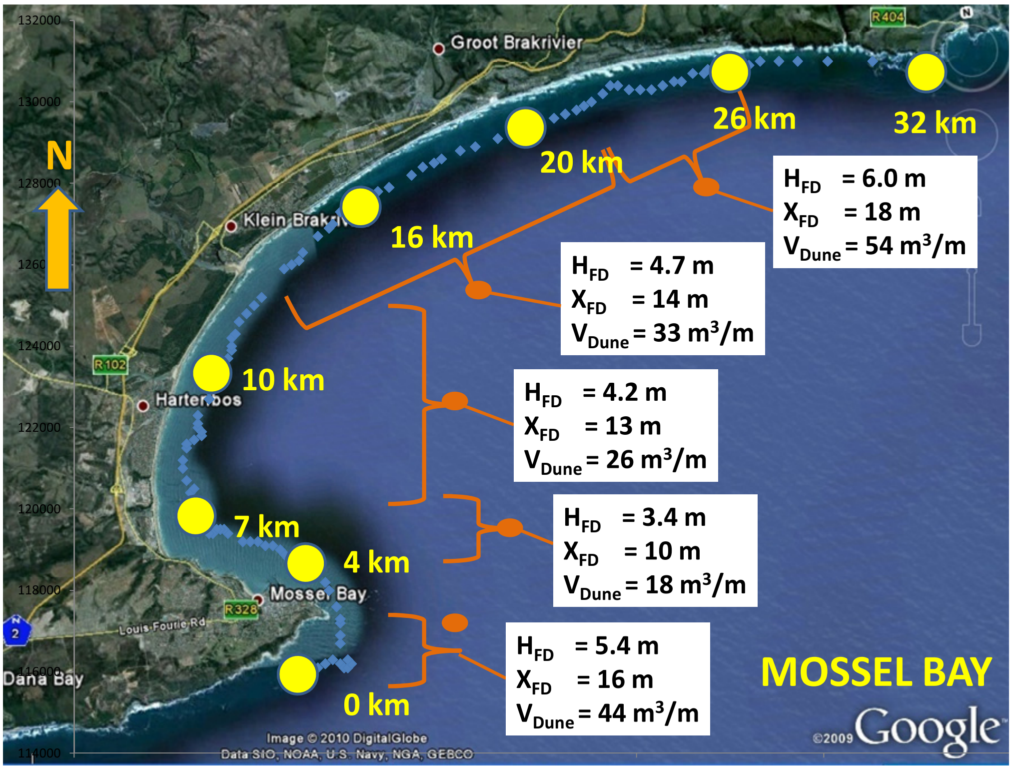


Figure 3.17: **Minimum foredune heights and dune volumes required to buffer against storm erosion due to a 1:100 yr storm (tables 3.7 and 3.8). (image from Google Earth™)**

From the results shown in Table 3.7 it can be concluded that the critical dune height for the exposed areas of the coastline (Categories C and D) within the half-heart bay is in the order of 5 m, 4 m for Category B areas and 3 m in the sheltered area (Category A).

As was seen above, using the key wave characteristics is a way of quantifying the relative amount of wave energy present along a conveniently chosen bathymetry line (where no wave breaking occurs) within the half-heart bay. Knowing the relative amount of energy at various points along the coastline (be it exposed or sheltered), the potential impact on the beach and foredune systems can be deduced.

Knowing the minimum foredune dimensions required to allow for space for the natural erosion processes that can occur during a major storm, can be used as the basis for assessing the vulnerability of property located landwards of the foredune. For example, if the current foredune volume at a specific site is less than the potential eroded dune volume (Table 3.8), then the probability of damage to natural or built environment located directly landwards of the foredune will be high.

Taking the principle of **risk** as being the product of the **impact** and the **probability** of occurrence (Section 1.3), a first estimate of the risk profile of a section of coastline can be thereby determined. This also forms the basis for defining relevant response strategies that will reduce the probability of the storm runup erosion by, for example, increasing the dune volume if it is too low.

Relating this approach to the Risk Profile Assessment procedure as an input into a dune integrity assessment and management guideline is evaluated and discussed in Chapter 4.

3.6 Description of the key characteristic of the specific study areas

The main natural characteristics and human activities that define and influence the littoral active zone at the selected pilot sites within each of the five coastal municipalities in the study area are described and discussed below in the context of the integrity of the foredune system. Categorising the position within the half-heart bay using the methods described above and the simplified approach shown in Figure 3.16, as devised by the researcher, each of the sites within the study area was analysed. The resultant site characteristics are summarised in Table 3.9 and a proposed categorised exposure framework for the rest of the South African coastline is discussed in Section 6.4.

3.6.1 Hessequa Municipality: Still Bay

The area is characterised by a typical half-heart bay with an estuary mouth located in the lee of a rocky promontory. A long sandy beach curves eastwards from the estuary mouth, ending at a rocky coastline (Figure 3.18).

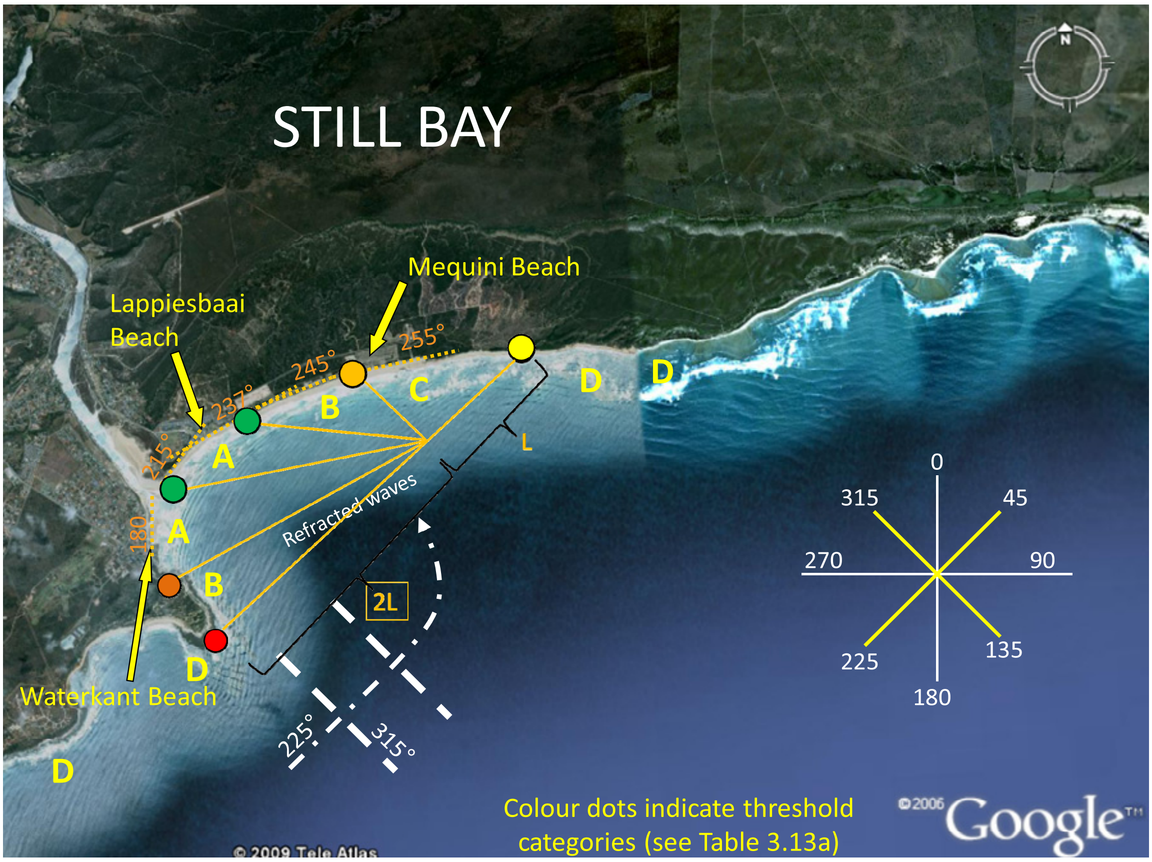


Figure 3.18: Study sites at Still Bay (image from Google Earth™)

Development has encroached into the littoral active zone with a constructed buffer dune system stretching along most of the sandy shoreline. The area to the east of the estuary mouth use to be an active dunefield (Figure 2.23) until it was stabilised in the 1960s to allow development to proceed (Carter, 1990).

At Lappiesbaai Beach, problems with wind-blown sand threatening houses, covering car parks and blocking stormwater drains were prevalent until 1994 (Figure 3.19), when a buffer dune was constructed by the municipality (Figure 3.20). A successful low-maintenance dune management programme was implemented over a period of 10 years. Unfortunately, municipal priorities changed in recent years and budgetary cuts resulted in less maintenance being done and an observed marked deterioration in the effectiveness of the buffer dune system (Figure 3.21).

Figure 3.19: Wind-blown sand inundated the car park at Lappiesbaai Beach, Still Bay (~1990)

Figure 3.20: **Constructed buffer dune at Lappiesbaai Beach, Still Bay (1994)**

Figure 3.21: **Constructed buffer dune at Lappiesbaai Beach, Still Bay, in need of maintenance (2009)**

3.6.2 Mossel Bay Municipality: Santos Beach, Diaz Beach, Hartenbos, Klein Brakrivier and Glentana Beach

The study sites are located within a large half-heart bay fixed by the Mossel Bay peninsula on the southern side and ending at Glentana Beach and rocky cliffs on the eastern side (Figure 3.22). The coastal towns of Mossel Bay, Hartenbos, Klein Brakrivier and Groot Brakrivier are located within the bay, the latter three taking their names from adjacent estuaries.

Santos Beach (Figure 3.23) is located in the lee of the peninsula and lies to the west of the Mossel Bay harbour. Sheltered from the high-energy deep-sea waves and most of the winds, this beach is wide and reasonably stable, but occasionally undergoes erosion due to waves generated in the eastern sector. Little evidence of wind-blown sand-related problems is noticeable and no defined foredune system exists. Major development in the form of a car park, a caravan resort and associated infrastructure has occurred in an in-filled area that had previously been the littoral active zone.

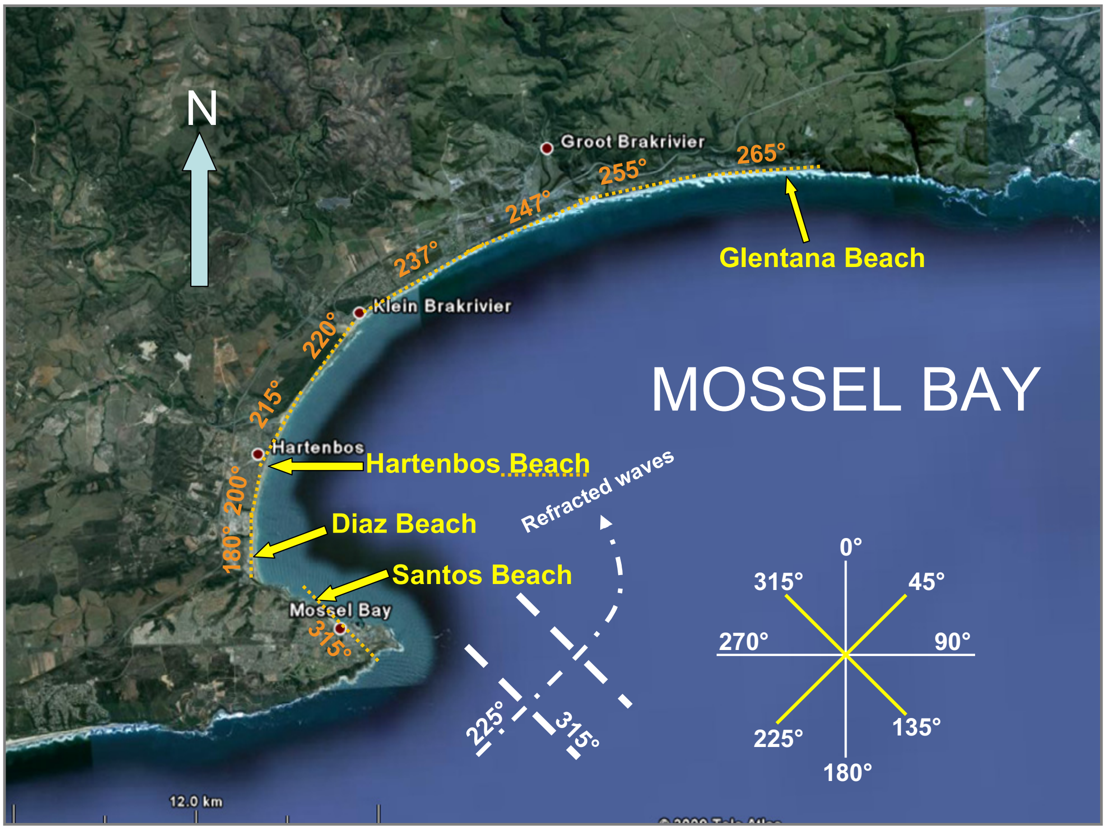


Figure 3.22: Study sites within Mossel Bay (image from Google Earth™)

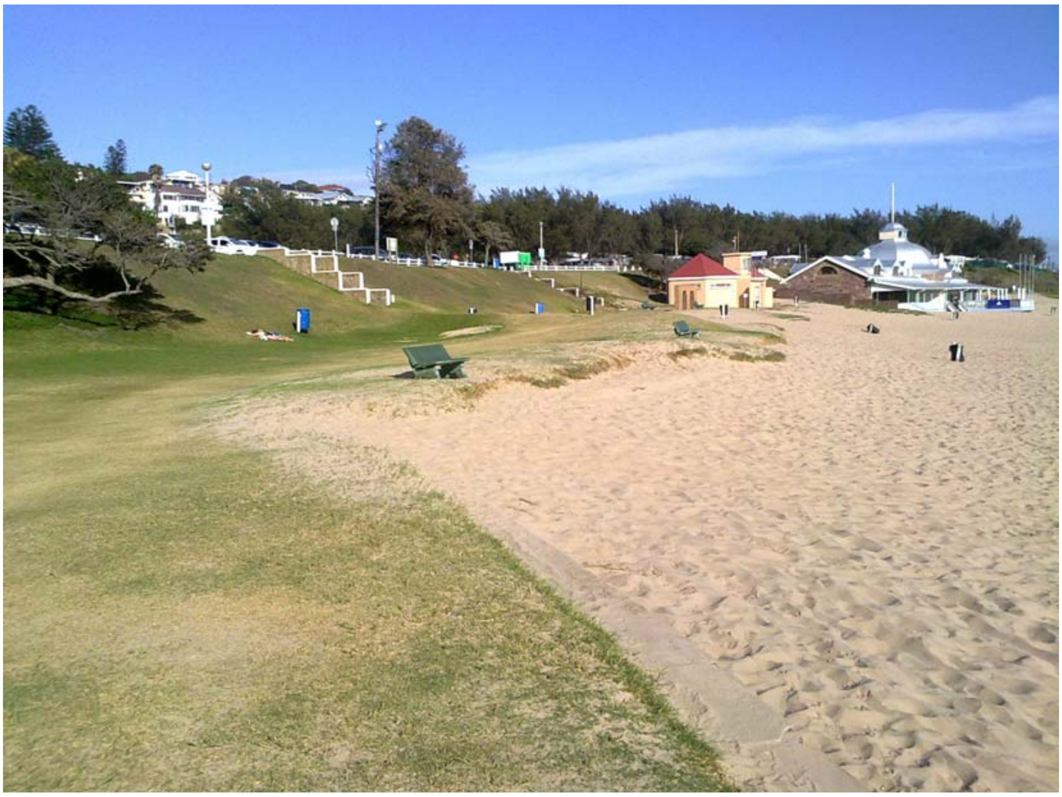


Figure 3.23: Santos Beach at Mossel Bay

Diaz Beach (Figure 3.24) is located at the south-western corner of the half-heart bay and is therefore well protected from the prevailing deep-sea swells. Ribbon development has taken place along most of this area and infrastructure has encroached into the littoral active zone in many places. A car park has been built on the foredunes and formalised access pathways with a managed vegetated buffer dune exist.

The high-water mark is at the toe of the constructed buffer dune with a narrow dry upper beach for most of the time. This is most probably the normal state of affairs due to the reduced sand supply because of the stabilisation of the natural sand supply by development. The dominant winds are offshore in this area and little evidence of wind-blown sand problems can be seen.

Figure 3.24: Diaz Beach within Mossel Bay

Ribbon development occurs along most of the sandy coastline within the bay with the foredune system modified in many places to accommodate beachfront development. At Hartenbos erosion is threatening beachfront properties and foredune slumping can be seen in places (Figure 3.25).

Figure 3.25: Modified foredune at Hartenbos (2009)

Hard-engineering structures (Gabions^{TM}) have been constructed along large stretches to act as toe protection to the modified foredunes (Figure 2.31).

A car park, protected by a managed buffer dune (Figure 2.28), is located on the eastern side of the estuary mouth at Klein Brakrivier. To the east of the car park, the unmanaged foredune system (Figure 3.26) functions naturally and unconstrained by development.

At the eastern extreme of the Mossel Bay, the resort area of Glentana Beach is almost directly exposed to the waves and the beach and foredune are highly dynamic. Foredune management is undertaken in an ad hoc manner with many developments encroaching into the 'coastal processes zone' (Figure 3.27). The foredune height is in the 5 m to 8 m range and little wind-blown sand problems occur. Informal pathways and uncontrolled storm-water run-off off hardened surfaces down the foredune slope form the greatest threat to buffer dune integrity.

Figure 3.26: Natural foredune at Kleinbrakrivier (2010)

Figure 3.27: Exposed coastline at Glentana Beach (2010)

3.6.3 George Municipality: Wilderness Beach

The coastal resort town of Wilderness lies at the western end of a long sandy coastline that is directly exposed to the open sea (Figure 3.28).

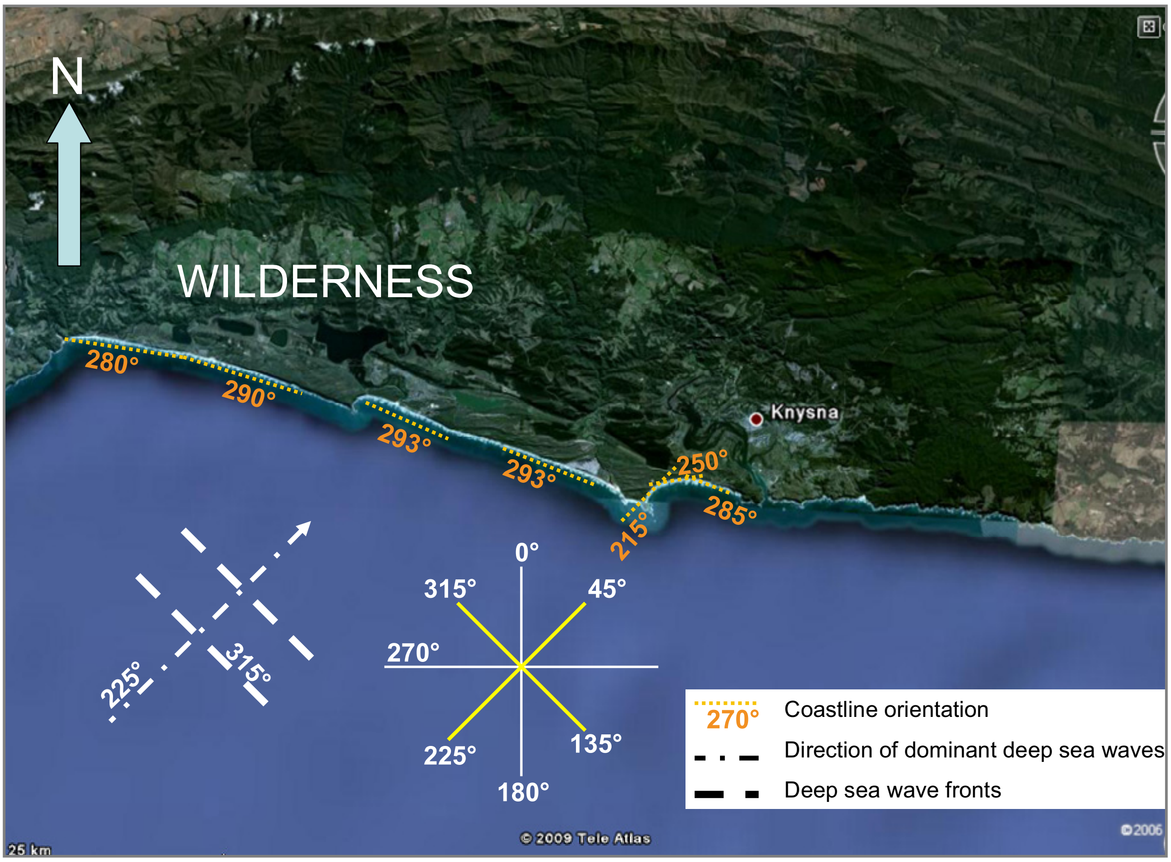


Figure 3.28: Study site at Wilderness Beach (image from Google Earth™)

Development has taken place along the whole of the coastline with expensive properties located on the foredune within the 'coastal processes zone' (Figure 1.3). Slumping is occurring and many properties are within a very close distance of the high-water mark (Figure 3.29).

Figure 3.29: Beachfront at Wilderness east of the estuary mouth

3.6.4 Knysna Municipality: Buffalo Bay

The coastal resort town of Buffalo Bay lies in the lee of a rocky headland that forms the south-western end of a small half-heart bay stretching from the resort town along a sandy coastline up to the rocky cliffs at Brenton-on-Sea at the eastern side of the bay (Figure 3.30). The natural sand supply from high sandy cliffs onto the beach has been reduced significantly due to the artificial stabilisation of the relic headland bypass dune field (Tinley, 1985) (Figure 3.31). This has resulted in a decrease in beach width and an erosion threat to beachfront development at Buffalo Bay.

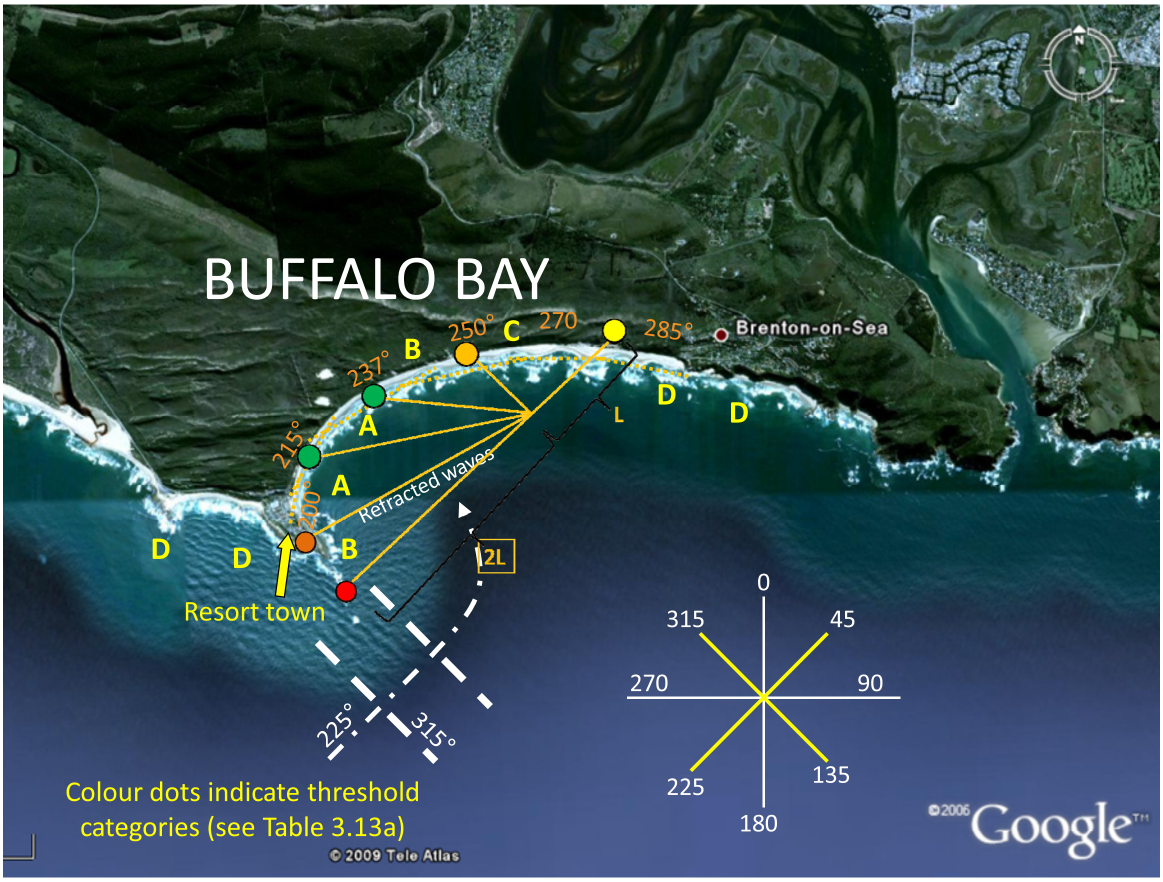


Figure 3.30: Study sites at Buffalo Bay (Knysna Municipality) (image from Google Earth™)

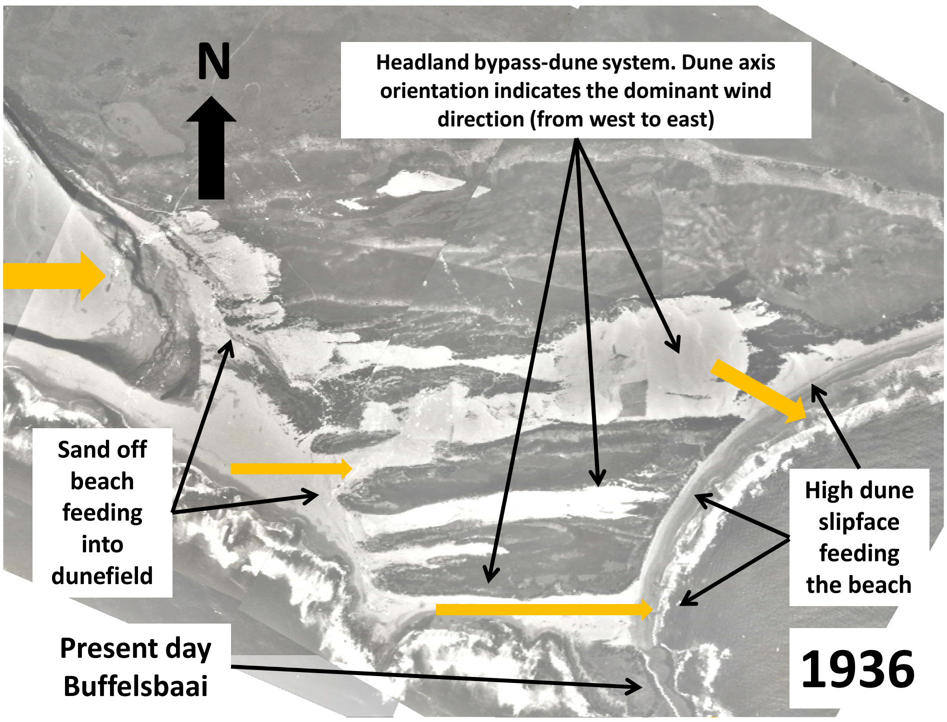


Figure 3.31: 1936 aerial photograph of headland bypass dune system at Buffalo Bay (Photo: SA Surveyor-General)

A car park and commercial complex with a beach cafe and restaurant are located close to the main beach. A combination of informal and formalised pathways exists within the foredune (Figure 3.32).

Figure 3.32: Modified foredune at Buffalo Bay (2009)

Although the dune vegetation is degraded in places, little signs of wind-blown sand problems are evident, since the prevailing winds are offshore at this point. Trampling of dune vegetation by people taking shortcuts across the foredune poses a risk to the buffer dune integrity.

The beach at Brenton-on-Sea is located at the eastern end of the half-heart bay and experiences high wave energy with the K_T coefficient close to 0.7. Swimming conditions are dangerous (Figure 3.33). The foredune is very high and exceeds +50 m MSL.

Figure 3.33: The beach at Brenton-on-Sea lies at the eastern end of Buffalo Bay (image from Google Earth™)

3.6.5 Bitou Municipality: Plettenberg Bay and Keurboomstrand

There are a number of smaller bays nested within the larger half-heart bay that defines Plettenberg Bay (Figure 3.34). Robberg Beach (Figure 3.35) lies in the lee of the Robberg Peninsula in the south and ends at Beacon Island in the north.

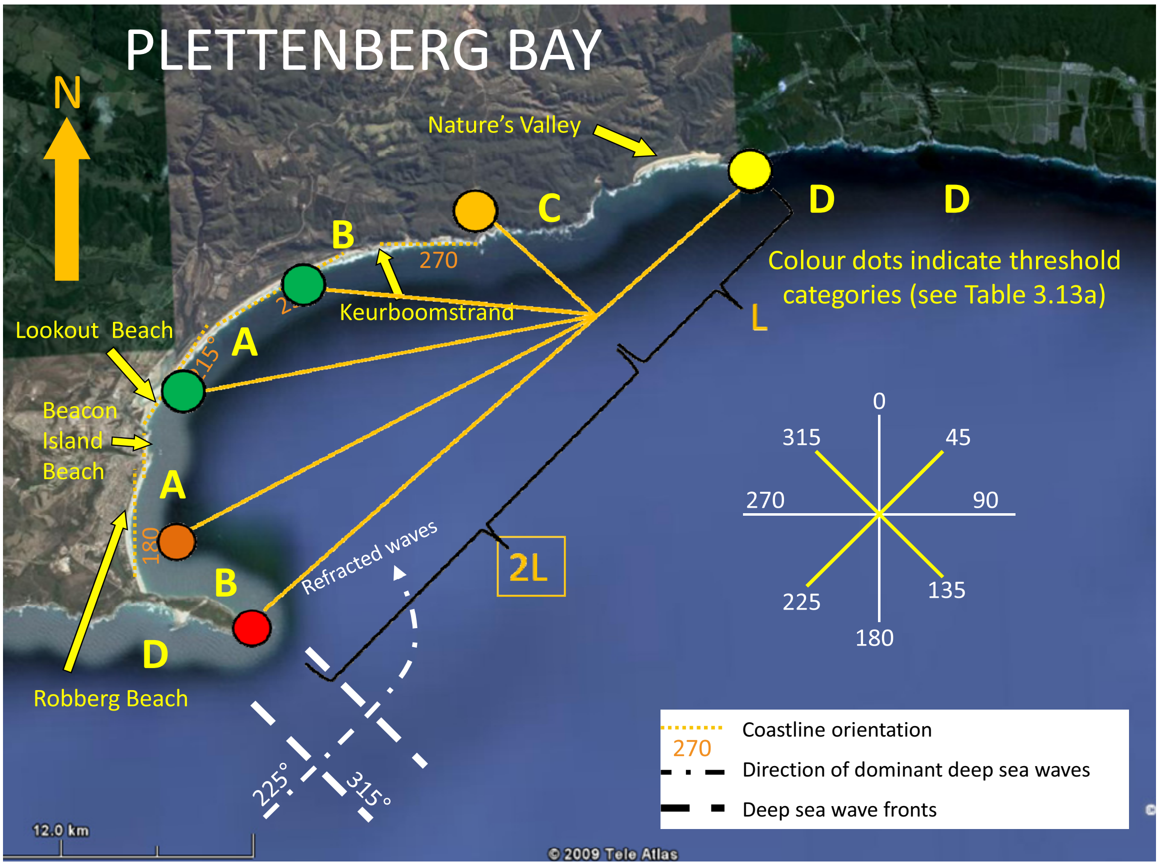


Figure 3.34: Pilot area at Bitou Municipality (Plettenberg Bay) (image from Google Earth™)

Further beaches along the large half-heart bay include the main beach at Beacon Island (Figure 3.36) and Lookout Beach at the Keurbooms estuary mouth. Further along the bay towards the east is the coastal resort town of Keurboomstrand (Figure 3.37). Further to the east, past a section of rocky cliffs, the coastal resort town of Natures Valley is situated. This point marks the eastern boundary of the Eden District Municipality and the Western Cape province.

At Natures Valley, the litoral active zone is intact and a well-functioning foredune forms a natural buffer protecting the beachfront development. As discussed in Chapter 1, this is considered an excellent example of appropriate development setback (Figure 1.4).

The coastline area at the town of Plettenberg Bay has undergone major changes due to development encroachment into the littoral active zone. However, Robberg Beach still has a natural foredune that forms an effective buffer protective zone to the beachfront development (Figure 3.35).

Figure 3.35: The natural buffer dune at Robberg Beach

Figure 3.36: **The main beach at Plettenberg Bay showing no foredune**

Figure 3.37: **The beach near Keurboomstrand**

3.7 Conclusion on the exposure framework

In the previous section, each of the pilot sites within the study area was analysed in the context of understanding the specific components that influence the buffer dune integrity. The simplified method of categorising the relative wave energy within a typical half-heart bay was applied to the pilot areas and the inferred wave transformation coefficients and associated exposure categories are summarised in Table 3.9.

Although further analytical and field surveys are required to validate the approach in the other half-heart bays within the study area, the principle of categorising the interface between coastal morphological features and the transformed wave energy regime provides an easy way of simplifying and transferring complex scientific information to non-experts in a practical manner. The information has the potential to be incorporated into a risk and vulnerability atlas for South Africa and would then be useful to local decision-makers as part of the procedure proposed in this thesis (see Chapter 4 and Section 6.4).

Table 3.9: Site characteristics of the pilot sites

Pilot site	Position[1]	$K_T = H_{10}/H_{mo})^2$	$K_T = H_{10}/H_{mo})^3$
Mossel Bay	A	< 0.2	[redacted]
	B	0.2–0.4	[redacted]
	C	0.4–0.7	[redacted]
	D	> 0.7	[redacted]
Still Bay	A	[redacted]	< 0.2
	B	[redacted]	0.2–0.4
	C	[redacted]	0.4–0.7
	D	[redacted]	> 0.7
Wilderness	D	[redacted]	> 0.7
Buffalo Bay	A	[redacted]	< 0.2
	B	[redacted]	0.2–0.4
	C	[redacted]	0.4–0.7
	D	[redacted]	> 0.7
Plettenberg Bay	A	[redacted]	< 0.2
	B	[redacted]	0.2–0.4
	C	[redacted]	0.4–0.7
	D	[redacted]	> 0.7

Notes:

1. Refer to schematisation in Figure 3.16 for positions
2. Calculated using SWAN model (see Section 3.5)
3. Inferred for other areas based on the calculated values for Mossel Bay

This information was used in the development and evaluation of the RPA procedure in Chapter 4.

CHAPTER 4: DEVELOPMENT OF A CONCEPTUAL DECISION GUIDELINE

4.1 Introduction

In the previous chapter both the environmental and human use aspects of the selected study area were discussed and a brief overview of each of the sites was provided. In this chapter the indicators that form the key components of the conceptual dune integrity risk profile assessment procedure and decision support guideline are discussed.

4.2 Key indicators for risk profile assessment

From the literature review in Chapter 2, it was concluded that carrying out assessments of the environmental status of key components of an identified human–nature system is practical and achievable by non-experts. However, the importance of using representative indicators and indices to which the non-experts can relate or about which they can learn through coaching was emphasised.

A set of indicators and indices to assess risk and vulnerability to forces from the sea and from actions by humans was compiled from the literature survey and is summarised in Table 2.7 in Section 2.5. The first nine indicators in Table 2.7 relate directly to those used in a vulnerability assessment procedure proposed by Coelho et al. (2006). This procedure is applied and discussed in the next section.

4.3 Vulnerability analysis using the method developed by Coelho et al. (2006)

As stated in Chapter 1, a guiding principle of the work done in this thesis is to enable decision-makers to take informed decisions using readily available data and information. From the literature study it was concluded that the set of indicators included in the method developed by Coelho et al. (2006) could be practical for this purpose. To evaluate this conclusion, the vulnerability analysis methodology was applied to the study area along the South African south coast.

4.3.1 Applying the Coelho et al. (2006) vulnerability classification to the study area along the south coast of South Africa

The indicators and associated vulnerability classification as proposed by Coelho et al. (2006) are shown in tables 4.1 and 4.2. Specific metrics associated with each of the indicators are listed and the assessment is done by selecting the appropriate range of values for each indicator from the tables. A vulnerability classification of Very low (vulnerability score = 1) to Very high (vulnerability score = 5) is then derived and carried forward to Table 4.3.

The first part of the assessment procedure is to determine the degree of exposure to and risk from coastal processes using Indicators Nos. 1 to 5 (Table 4.1) as the basis. Taking site H1, Morris Point near Still Bay (Figure 4.1) as the example, the indicator values are highlighted in tables 4.1 and 4.2 to illustrate the method. The associated vulnerability classification score is transferred to the summary Table 4.3. For example, for the elevation (TE) from the

Figure 4.1: Morris Point beach as an example

+5 m MSL contour line on the available orthophotomap, the elevation of the area directly landwards of the beach is estimated by the researcher to be in the order of 6 to 10 m, therefore the vulnerability classification is 'High', as indicated in Table 4.1, and the associated score of 4 is carried across to Table 4.3. The distance from the seaward edge of the foredune landwards to the nearest municipal infrastructure or private development is between 50 and 200 m, giving a score of 3. The mean tidal range is 1.8 m along the Southern African coast, so the vulnerability score is 2.

Rossouw (2009) gives the maximum nearshore wave height as being in the range of 6 to 6.9 m along the south coast, so the score is 4. The beach at Morris Point is judged to be in dynamic equilibrium, and with sea-level rise may revert to an erosion trend of between -1 and 0 m/yr, so the vulnerability for indicator No. 5 is classified as 'Low' in Table 4.1, with an associated score of 2 carried forward to Table 4.3.

Table 4.1: Vulnerability classification (I) (adapted from Coelho et al., 2006)

	Vulnerability classification	Very Low	Low	Moderate	High	Very high
	Score[5] =>	1	2	3	4	5
No. 1	TE: Elevation[1] (m)	> 30	21–30	11–20	6 -10	< 5
No. 2	DS: Distance to shore[1] (m)	>1 000	200–1 000	50–200	20–50	< 20
No. 3	TR: Tidal range[2] (m)	< 1	1–2	2–4	4–6	> 6
No. 4	WH: Max wave height[3] (m)	< 3	3–5	5–6	6–6.9	> 6.9
No. 5	EA: Erosion / Accretion[4] rate (m/yr)	> 0 (accretion)	-1–0	-3– -1	-5– -3	< -5 (erosion)

Notes:

1. From orthophotomaps (SA Surveyor-General)
2. SA Naval Charts
3. Rossouw (2009)
4. Reports and field observations (CSIR, 1994; 2000b)
5. Carry score forward to Table 4.3

Continuing with the Morris Point example, the values associated with the indicators shown in Table 4.2 are highlighted and the associated vulnerability scores are transferred to Table 4.3 as before. (Note that the indicators in Table 4.2 reflect along the top of the table.)

Indicator No. 6 (Geology) is assessed to be 'non-consolidated coarse sediment', giving a score of 4; Indicator No. 7 (Geomorphology) is taken as 'exposed beaches' (score = 4); Ground cover (Indicator No. 8) is assessed to be 'ground vegetation'; and Indicator No. 9 (Anthropogenic actions) reflects as 'without intervention or sediment sources reduction', and, as interpreted for South Africa by the researcher, means 'no active maintenance, good setback exists', resulting in a score of 4.

Table 4.2: Vulnerability classification (II) (adapted from Coelho et al., 2006)

Vuln. class. (score[5]) || V	No. 6	No. 7	No. 8	No. 9 AA: Anthropogenic actions[3]	
	GL: Geology[1]	GM: Geomorphology[2]	GC: Ground cover[3]	Coelho et al. (2006)	Interpreted for South Africa[4]
1	Magmatic rocks	Mountains	Forest	Shoreline stabilisation intervention	Hard-engineering or wide setback exists
2	Metamorphic rocks	Rocky cliffs	Ground vegetation, cultivated ground	Intervention without sediment sources reduction	Maintenance activities exist, good buffer and setback exist
3	Sedimentary rocks	Erosive cliffs, sheltered beaches	Non-covered	Intervention with sediment sources reduction	Maintenance activities exist, but inadequate setback
4	Non-consolidated coarse sediment	Exposed beaches, flats	Rural urbanised	Without intervention or sediment sources reduction	No active maintenance, good setback exists
5	Non-consolidated fine sediments	Dunes, river mouths, estuaries	Urbanised or industrial	Without intervention but with sediment sources reduction	No active maintenance, inadequate setback exists

Notes:

1. From Geology Map of South Africa and Jackson (1984)
2. From orthophotomaps (SA Surveyor-General)
3. Aerial photo analysis and observations
4. Interpreted by the researcher
5. Carry score forward to Table 4.3

To provide a degree of sensitivity analysis, Coelho et al. (2006) used a method of relative weightings to define three scenarios of vulnerability. As shown in Table 4.4, the first scenario (Weighting 1) assigns equal importance to all nine of the indicators. The 'Weighting coefficient' values are indicated in the header row in Table 4.3. Scenario 2 (Weighting 2) gives highest priority to the setback and geology, and considers the tidal range and ground cover as the least important. Scenario 3 (Weighting 3) ranks the nine vulnerability indicators from least significant (ground cover) to highest significance (geology) when assessing the coastal vulnerability.

The three scenarios, using the Coelho et al. (2006) weighting coefficients for each indicator for each weighting scenario, were applied to each of the study sites. The results are shown in tables 4.3, 4.5 and 4.6. The totals are summarised in Table 4.7 and discussed in Section 4.3.2.

Table 4.3: Vulnerability matrix for the coastline within the Eden District Municipality using Weighting 1 (Table 4.4)

Ref.[1] no.	Study sites	Indicator No.: Weighting coefficient:	Vulnerability indicator scores									
			No.1 TE	No.2 DS	No.3 TR	No.4 WH	No.5 EA	No.6 GL	No.7 GM	No.8 GC	No.9 AA	VI[2]
			1	1	1	1	1	1	1	1	1	
H1	Morris Point		4	3	2	4	2	4	4	2	4	3.2
-	Waterkantstraat		5	5	2	2	2	4	5	3	5	3.7
H2	Lappiesbaai		4	4	2	2	2	4	5	3	5	3.4
-	Mequini Beach		4	4	2	3	3	4	4	4	2	3.3
H3	Gouritzmond Beach		3	3	2	4	4	4	5	2	4	3.4
M1	Santos Beach		5	3	2	1	2	4	3	3	1	2.7
M2	Diaz Beach		4	4	2	2	2	4	3	4	2	3.0
-	Hartenbos (main)		3	5	2	2	3	4	4	4	3	3.3
M3	Hartenbos (estuary)		4	5	2	3	4	4	5	4	3	3.8
-	Klein Brakrivier		3	3	2	3	4	4	5	2	4	3.3
-	Glentana Beach		4	4	2	4	3	4	4	4	4	3.7
G1	Wilderness (main)		4	5	2	4	3	4	4	4	5	3.9
G2	Wilderness (estuary)		3	4	2	4	2	4	5	4	2	3.3
-	Wilderness (east)		4	5	2	4	3	4	4	4	3	3.7
K1	Buffels Bay (car park)		4	4	2	2	2	4	3	4	2	3.0
-	Brenton Beach		1	3	2	4	3	4	4	2	4	3.0
B1	Robberg Beach		3	3	2	2	2	4	3	2	2	2.6
B2	Beacon Island Beach		5	5	2	3	2	4	3	5	3	3.6
-	Main Beach		5	5	2	3	2	4	3	5	3	3.6
B3	Lookout Beach		5	5	2	4	4	4	5	3	5	4.1
B4	Keurboomstrand		4	5	2	4	3	4	4	4	5	3.9

Note 1: Site names as per cross-reference to Table 5.6

Note 2: Total of scores for Indicators 1 to 9 divided by the total (=9) for Weighting scenario 1 (Table 4.3) and carried forward to Table 4.7

Table 4.4: Vulnerability indicators weighting coefficients[1]

No.	Vulnerability indicators	Weighting 1 (W1)	Weighting 2 (W2)	Weighting (W3)
1	TE: Elevation (m)	1	1	7
2	DS: Distance to shore (m)	1	2	8
3	TR: Tidal range (m)	1	0.5	2
4	WH: Max wave height (m)	1	1	5
5	EA: Erosion/Accretion rate (m/yr)	1	1	3
6	GL – Geology	1	2	9
7	GM – Geomorphology	1	1	4
8	GC – Ground cover	1	0.5	1
9	AA – Anthropogenic actions	1	1	6
	TOTAL	9	10	45

Note 1: Adopted from Coelho et al. (2006).

The weighted vulnerability indicator values are calculated by multiplying the scores for each indicator by each of their associated weighting coefficients in Table 4.4. The final stage in the Coelho et al. (2006) coastal vulnerability assessment method is to determine the Vulnerability Index (VI) by calculating the average score for each site by adding the weighted scores for each indicator and dividing the total by the sum of the nine weighting coefficients depicted in tables 4.3. 4.5 and 4.6. Therefore, to calculate the VI for each site for Weighting 1, the total score for all nine indicators is divided by 9, for Weighting 2, the total score is divided by 10 and for Weighting 3 the total is divided by 45. For Morris Point, this works out as a VI value of 3.2 for Weighting 1, 3.4 for Weighting 2 and 3.6 for Weighting 3 as highlighted in the respective tables.

Table 4.5: Vulnerability matrix for the coastline within the Eden District Municipality using Weighting 2 (Table 4.4)

Ref.[1] no.	Study sites	Indicator No.: Weighting coefficient:	Vulnerability indicator scores									
			No.1 TE	No.2 DS	No.3 TR	No.4 WH	No.5 EA	No.6 GL	No.7 GM	No.8 GC	No.9 AA	VI[2]
			1	2	0.5	1	1	2	1	0.5	1	
H1	Morris Point		4	6	1	4	2	8	4	1	4	3.4
-	Waterkantstraat		5	10	1	2	2	8	5	2	5	4.0
H2	Lappiesbaai		4	8	1	2	2	8	5	2	5	3.7
-	Mequini Beach		4	8	1	3	3	8	4	2	2	3.5
H3	Gouritzmond Beach		3	6	1	4	4	8	5	1	4	3.6
M1	Santos Beach		5	6	1	1	2	8	3	2	1	2.9
M2	Diaz Beach		4	8	1	2	2	8	3	2	2	3.2
-	Hartenbos (main)		3	10	1	2	3	8	4	2	3	3.6
M3	Hartenbos (estuary)		4	10	1	3	4	8	5	2	3	4.0
-	Klein Brakrivier		3	6	1	3	4	8	5	1	4	3.5
-	Glentana Beach		4	8	1	4	3	8	4	2	4	3.8
G1	Wilderness (main)		4	10	1	4	3	8	4	2	5	4.1
G2	Wilderness (estuary)		3	8	1	4	2	8	5	2	2	3.5
-	Wilderness (east)		4	10	1	4	3	8	4	2	3	3.9
K1	Buffels Bay (car park)		4	8	1	2	2	8	3	2	2	3.2
-	Brenton Beach		1	6	1	4	3	8	4	1	4	3.2
B1	Robberg Beach		3	6	1	2	2	8	3	1	2	2.8
B2	Beacon Island Beach		5	10	1	3	2	8	3	3	3	3.8
-	Main Beach		5	10	1	3	2	8	3	3	3	3.8
B3	Lookout Beach		5	10	1	4	4	8	5	2	5	4.4
B4	Keurboomstrand		4	10	1	4	3	8	4	2	5	4.1

Note 1: Site names as per cross-reference to Table 5.6
Note 2: Total of scores for Indicators 1 to 9 divided by the total (=10) for Weighting scenario 2 (Table 4.4) and carried forward to Table 4.7

Table 4.6: Vulnerability matrix for the coastline within the Eden District Municipality using Weighting 3 (Table 4.4)

Ref.[1] no.	Study sites	Indicator No.: Weighting coefficient:	Vulnerability indicator scores									
			No.1 TE	No.2 DS	No.3 TR	No.4 WH	No.5 EA	No.6 GL	No.7 GM	No.8 GC	No.9 AA	VI[2]
			7	8	2	5	3	9	4	1	6	
H1	Morris Point		28	24	4	20	6	36	16	2	24	3.6
-	Waterkantstraat		35	40	4	10	6	36	20	3	30	4.1
H2	Lappiesbaai		28	32	4	10	6	36	20	3	30	3.8
-	Mequini Beach		28	32	4	15	9	36	16	4	12	3.5
H3	Gouritzmond Beach		21	24	4	20	12	36	20	2	24	3.6
M1	Santos Beach		35	24	4	5	6	36	12	3	6	2.9
M2	Diaz Beach		28	32	4	10	6	36	12	4	12	3.2
-	Hartenbos (main)		21	40	4	10	9	36	16	4	18	3.5
M3	Hartenbos (estuary)		28	40	4	15	12	36	20	4	18	3.9
-	Klein Brakrivier		21	24	4	15	12	36	20	2	24	3.5
-	Glentana Beach		28	32	4	20	9	36	16	4	24	3.8
G1	Wilderness (main)		28	40	4	20	9	36	16	4	30	4.2
G2	Wilderness (estuary)		21	32	4	20	6	36	20	4	12	3.4
-	Wilderness (east)		28	40	4	20	9	36	16	4	18	3.9
K1	Buffels Bay (car park)		28	32	4	10	6	36	12	4	12	3.2
-	Brenton Beach		7	24	4	20	9	36	16	2	24	3.2
B1	Robberg Beach		21	24	4	10	6	36	12	2	12	2.8
B2	Beacon Island Beach		35	40	4	15	6	36	12	5	18	3.8
-	Main Beach		35	40	4	15	6	36	12	5	18	3.8
B3	Lookout Beach		35	40	4	20	12	36	20	3	30	4.4
B4	Keurboomstrand		28	40	4	20	9	36	16	4	30	4.2

Note 1: Site names as per cross-reference to Table 5.6
Note 2: Total of scores for Indicators 1 to 9 divided by the total (=45) for Weighting scenario 3 (Table 4.4) and carried forward to Table 4.7

The final vulnerability classification as proposed by Coelho et al. (2006) is given on a scale from intermediate vulnerability (IV), high vulnerability (HV) to very high vulnerability (VHV). This is obtained by applying the rating shown in Note 2 below Table 4.7. For the Morris Point example, the results for the vulnerability classification for the three scenarios are therefore W1 = IV, W2 = IV and W3 = HV.

Table 4.7: Weighted vulnerability index (VI) for specific sites in the study area

Ref[1] #	Study site	Vulnerability Classification[2]					
		Weighting 1		Weighting 2		Weighting 3	
H1	Morris Point	3.2	IV	3.4	IV	3.6	HV
-	Waterkantstraat[3]	3.7	HV	4.0	HV	4.1	HV
H2	Lappiesbaai	3.4	IV	3.7	IV	3.8	HV
-	Mequini Beach	3.3	IV	3.5	HV	3.5	HV
H3	Gouritzmond Beach	3.4	IV	3.6	HV	3.6	HV
M1	Santos Beach	2.7	IV	2.9	IV	2.9	IV
M2	Diaz Beach	3.0	IV	3.2	IV	3.2	IV
-	Hartenbos (main)	3.3	IV	3.6	HV	3.5	HV
M3	Hartenbos (estuary)[3]	3.8	HV	4.0	HV	3.9	HV
-	Klein Brakrivier	3.3	IV	3.5	IV	3.5	HV
-	Glentana Beach[3]	3.7	HV	3.8	HV	3.8	HV
G1	Wilderness (main)[3]	3.9	HV	4.1	HV	4.2	HV
G2	Wilderness (estuary)	3.3	IV	3.5	IV	3.4	IV
-	Wilderness (east)[3]	3.7	HV	3.9	HV	3.9	HV
K1	Buffels Bay (car park)	3.0	IV	3.2	IV	3.2	IV
-	Brenton Beach	3.0	IV	3.2	IV	3.2	IV
B1	Robberg Beach	2.6	IV	2.8	IV	2.8	IV
B2	Beacon Island Beach[3]	3.6	HV	3.8	HV	3.8	HV
-	Main Beach[3]	3.6	HV	3.8	HV	3.8	HV
B3	Lookout Beach[3]	4.1	HV	4.4	HV	4.4	HV
B4	Keurboomstrand[3]	3.9	HV	4.1	HV	4.2	HV

Note 1: Site names as per cross-reference to Table 5.6
Note 2: Classification as specified by Coelho et al. (2006):

Very high vulnerability: ...... V > = 4.5 ....VHV

High vulnerability: .... 3.5 > = V > 4.5............... HV

Intermediate vulnerability 2.5 > = V > 3.5............. IV

Note 3: These sites are considered by experienced coastal engineers as potentially having a classification of VHV. This is discussed in Section 5.9

4.3.2 Discussion of the application of the Coelho et al. (2006) methodology

On considering the suite of indicators proposed by Coelho et al. (2006) and those listed in Table 2.7, the following is observed:

- Indicators Nos. 1 (Elevation), 2 (Distance to shore), 5 (Erosion/Accretion rate), 8 (Ground cover) and 9 (Anthropogenic actions) relate to management considerations and interventions carried out (or not carried out) by humans. For example adhering to planning guidelines that relate to an appropriate development set-back line when locating municipal infrastructure and private development. Furthermore, the erosion/accretion rate can be influenced by the cutting off of a natural sand supply to the section of the coastline by, for example, stabilising a headland bypass dune system (Figure 3.31). Another example of a reduction of sediment supply is by an engineering intervention to protect development (Figure 2.31) which effectively cuts off the natural supply of sand to the beach from slumping foredunes (Figure 2.30).

- In many cases the natural topography landward of the high water mark has been altered by human action. For example, development has occurred in areas where the height of the natural foredune has been altered (figures 2.31, 3.27, 3.29 and 3.37). The vulnerability of such development is assessed by all nine indicators.

- Indicators 3 (Tidal range), 4 (Wave characteristics) and 9 (Anthropogenic actions) relate to the degree of risk associated with coastal processes and the 'coastal processes setback area' as defined in Figure 1.3. The beach slope was considered an important indicator as listed in Table 2.7 compiled from the literature but the list of indicators proposed by Coelho et al. (2006) excludes the beach slope. The beach- and nearshore slopes are, for example, important for determining the relative vulnerability of the site in terms of storm run-up and the effect of sea-level rise as discussed in Section 2.2.9. In Section 3.5 it was argued that the risk associated with the wave characteristics can be depicted as a wave transformation factor (K_T) which allows for the assessment of the relative vulnerability of various sections of the coastline as reflected in figures 3.14 and 3.16. It was argued that a combination of the elevation (Indicator 1) and the distance to shore (Indicator 2) along with the K_T factor provides the necessary information to enable conclusions to be drawn on those elements where beach slope plays a role, such as the storm run-up and the influence of sea-level rise.

- The description of the anthropogenic actions (Indicator 9) put forward by Coelho et al. (2006) had to be interpreted (by the researcher) to reflect the situation in South Africa (Table 4.2). This enabled a more objective and consistent assessment of the specific sites within the study area.

- When comparing the results of the weighting scenarios, it is concluded that the classification range may not be sensitive enough to reflect the actual situation within the study area. A 71 % correlation is shown when all three scenarios (W1, W2 and W3) are compared (i.e. for 15 out of a total of 21 sites the same vulnerability classification was returned – Table 4.7). When W1 and W2 are compared the correlation is 81%. When W1 and W3 are compared the correlation is 71%. A value of 81% is calculated when comparing W2 and W3. No sites reflected a vulnerability classification of VHV, which is surprising as some sites (Table 4.7, Note 3) within the study area should possibly be classified as VHV based on personal observations and in discussion with experienced coastal engineers. An alternative weighting scenario could be considered as future work.

From these observations it is concluded that the suite of indicators by Coelho et al. (2006) has the potential to assist non-experts decision-makers at municipal level with assessing the vulnerability along the South African south coast. An important consideration, however, is the validity of the indicators and indices to enable dune integrity assessments. This aspect is considered in the next section.

4.4 Summary and evaluation of indicators and indices

An objective of this thesis is to develop a practical checklist-based method of gathering qualitative information relating to key indicators that define dune integrity. In Section 2.4 it was noted that for indicators and indices to trigger key actions, and for the actions then to be carried out efficiently and effectively, the cost of gathering data and information that relate to the specific set of indicators should not be excessive.

In this context, a useful method for assessing the validity, applicability and practicality of indicators was put forward in NRC (2000). An interpretation of the evaluation criteria, as listed in Section 2.4.2, was done and is summarised and reflected in columns (i) to (vii) in Table 4.8.

A list of 15 indicators that assess risk and vulnerability along the shoreline was derived from the literature (Section 2.4) and summarised in Table 2.7. This list is shown in Table 4.8. The first 9 indicators relate to the suite of indicators proposed by Coelho et al. (2006) as was discussed in the previous section. The rest of the indicators were compiled from the literature as discussed in Section 2.4.

As reflected in Table 4.9, it is proposed that the indicators are classified into two types, namely (1) site-specific indicators that undergo little change in time and can be seen as a 'constant' for that particular site; and (2) those that undergo change in space and time, classified as being 'dynamic'.

Table 4.8: Evaluation of indicators and indices applicability to dune integrity assessments in the South African context

No.	Indicator (Table 2.7)	Validity criteria for indicators and indices (derived from NRC, 2000)						
		(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)
		Data readily obtainable?	Data independently verifiable?	Data gathering cost-effective?	Can non-experts understand?	Allowance for new info?	Represents system processes?	Evidence-based reliability?
1	CS: Beach slope	2[1]	4	2[1]	3	4	4	4
2	Erosion/Accretion trend	2	3	2	3	4	4	4
3	GC: Geomorphology	4	4	4	3	4	4	4
4	WH: Wave height	3	3	3	3	4	4	4
5	TR: Tidal range	3	3	4	4	4	4	4
6	CO: Orientation	4	4	4	2	3	4	4
7	AI: Wind and sand characteristics	4	4	4	3	4	4	4
8	V: Vegetation type	4	4	3	2	4	4	4
9	HE: Human effects	4	4	4	4	4	4	4
10	User perception: Fit-for-use	4	2	4	4	4	4	2
11	Value of protected infrastructure	4	4	4	4	4	4	4
12	Erosion landforms visible?	4	4	4	4	4	4	4
13	New dunes forming?	4	4	4	4	4	4	4
14	Vegetation controlling sand?	4	4	4	4	4	4	4
15	Managed effectively?	4	4	4	4	4	4	4

(Rating of practical achievability at South African coastal municipal level: 1 = Low; 5 = High)

Note 1: The fact that detailed coastal topography data are limited to the +5 m (MSL) contour places a severe limitation on obtaining sufficient information for assessment.

It is argued that those factors that are site-specific and constant, for example the coastal geomorphology (Indicator 3) and the tidal range (Indicator 5) only need to be evaluated for a specific site when the programme is initialised, possibly with the assistance of an expert, or sourced from available documentation such as a geological map for Indicator 3 and the SA Navy Tide Tables for Indicator 5.

Examples of dynamic factors are represented by Indicator 9, i.e. human related actions such as the destruction of dune vegetation by informal pathways, (or by bulldozing to better sea views or for construction) and Indicator 13 where the presence or absence of 'new dunes' on the upper beach (figures 1.1, 2.6 and 2.11) indicates the current state of the beach (recovering after a storm, stable or eroded). Furthermore, Indicator 14 where blow-outs can result in wind-blown sand migrating into areas where the type of vegetation is unable to control this influx (figures 1.7 and 2.27), or where the vegetation is able to naturally control wind-blown sand (Figure 2.28) is another example of a 'dynamic' type.

As indicated in Table 4.9, for both types there are indicators that may need more specific training by a specialist before they can be used with confidence by non-experts. For example Indicator 8 needs expertise in coastal botany to assess whether the specific vegetation is thriving in the specific area within the foredune, and if not, what can be done to ensure recovery, or to facilitate replacement with the correct species.

Evaluating Indicator 2 (erosion/accretion trend), for example, requires a detailed analysis and interpretation of long-term data such as obtained from a series of historic aerial photographs and/or beach surveys. This can only be done after experience is obtained under expert guidance.

Table 4.9: Classification of indicators listed in Tables 2.7 and 4.8

Classification	Non-expert assessment practical	Expert training required
Site-specific and constant	1, 7,11 and 12	2, 3, 4, 5 and 6
Dynamic	9, 10, 13, 14 and 15	8

Note: The numbers refer to the indicator reference number in Table 4.8

To assess the ability of non-expert decision-makers at municipalities to obtain the relevant data and information required for each indicator, the researcher provided a rating of practical achievability between 1 = Low up to 5 = High (Table 4.8). The ratings were obtained after exploring the available resources. For example, it is very difficult to obtain data on the actual beach slope (Indicator 1) without very expensive surveys. The lack of topographical data at a resolution of less than 1 m makes it difficult to determine the elevation of the area directly landwards of the beach, and specifically the height of the foredune which is required for assessing storm run-up elevation and the sand volume of the buffer dune. For the validity criteria in columns (i) and (iii) the rating is therefore given as 2. The reason is noted as a footnote to Table 4.8.

Similarly for Indicator 2, obtaining data on the long-term coastline stability, depicted by the erosion / accretion trend, is difficult and requires specialist studies and insight which can be expensive. A rating of 2 is therefore given as depicted in Table 4.8. Determining the orientation (Indicator 6) of a section of coastline accurately enough to estimate the angle of incidence is difficult for non-experts. As discussed above, it is difficult for a non-expert to understand all the various aspects related to coastal vegetation dynamics, thus Indicator 8 is rated 2 for the criteria 'Can non-experts understand?' in column (iv).

The validity criteria related to 'Evidence-based reliability' in Column (vii) for Indicator 10 ('fit-for use') in terms of the sensitivity, accuracy, precision and robustness of the outcome (NRC, 2000) is rated as 2 because it is argued that this is highly subjective and depends on the evaluator's perspective. For example, a beachfront property owner may naively think that a low foredune that does not obstruct his sea view (Figure 1.6) is highly "fit-for-use", but those who understand the importance of having a well functioning foredune system to act as a buffer against storm run-up, and thereby prevent the situation depicted in Figure 1.4 from occurring, will define 'fit-for-use' differently.

By grouping and consolidating the validity and practicality aspects of the list of indicators, as summarised in tables 4.8 and 4.9, it is proposed that the set of Dune Integrity Indictors (DII) shown in Table 4.10 be used as the core of a Risk Profile Assessment procedure. This is further discussed in this chapter.

Table 4.10: Proposed indicators that define the DII of the buffer dune system

No.	Proposed indicator for the RPA	Cross-reference to indicators in Table 4.1
DII 1	Location relative to approaching wave energy	1, 3, 4, 6
DII 2	Dominant wind orientation in dry season	6, 7, 14
DII 3	Foredune height	2, 7, 8, 13, 14, 15
DII 4	Human effects	9, 10, 11, 14, 15
DII 5	Erosion vulnerability	2, 3, 5
DII 6	Coastline stability	2, 12

Note: The tidal range indicator (no. 5 in Table 4.1) is seen as a constant and is not deemed a significant variable along the South African coastline. However the state of the tide during a storm has an influence on the run-up elevation during a storm.

4.5 Conclusion on the use of indicators for assessment of the risk to buffer dune integrity

Using the essence of the indicators listed in Table 2.7 as assessed in Table 4.8 and summarised in Table 4.10, it is concluded that the following six indicators of the human–nature coastal system can collectively define the dune integrity and risk profile of a particular site along the coastline.

DII 1: Degree of protection from prevailing wave energy
DII 2: Characteristics of the dominant winds during the dry season
DII 3: Relative height of the foredune buffer
DII 4: Pressures from human activities
DII 5: Vulnerability to erosion
DII 6: Coastline stability

It is suggested that indicators DII 1, DII 2, DII 5 and DII 6 are the key elements that represent the natural environmental context of the site and indicators DII 3 and DII 4 mainly relate to human needs and activities. Whereas no human intervention can change the risk factors associated with indicators DII 1 and DII 2, for indicators DII 5 and DII 6, management intervention to reduce the vulnerability of the dune integrity to the coastal processes is possible, but will typically entail major costs (such as hard-engineering interventions).

The reduction of the risk factors that relate to indicators DII 3 and DII 4 are practically achievable through the implementation of good practice that will not necessarily require expensive intervention. Actions like proper planning (e.g. adhering to the principle of setting buffers and implementing development setback lines), soft-engineering interventions such as pedestrian management across sensitive buffer dunes (e.g. formalised access pathways and associated fencing), obtaining local buy-in through education (e.g. through appropriate signage and the media) and pro-active reparation of foredunes and access pathways (e.g. when blow-outs occur and/or after holiday seasons) are some examples.

Each of these indicators is discussed in Section 4.6 within the context of the proposed site RPA procedure. The RPA procedure addresses DII 3 (Foredune Height) and DII 5 (Erosion Vulnerability), both being components important to the integrity of the dune system.

4.6 Development of a conceptual risk profile assessment procedure

In this section, the various indicators are combined into a conceptual assessment procedure that results in the definition of a risk profile index of the integrity of the buffer dune system at a particular site. The conceptual RPA procedure, set up for use at municipality level, is presented in Appendix A as a template used for determining the risk profile of a particular site under consideration.

Each of the indicators, along with an allocated risk score for each, forms the components of the RPA procedure that combine into an overall risk profile index, which is discussed below.

4.6.1 Description of the RPA indicators (Appendix A)

Indicator DII 1: Exposure to wave energy (Appendix A)

The degree to which the specific site is exposed to the prevailing ocean swells determines the wave energy impacting on the shoreline. Wave transformation calculations done with the SWAN model were discussed in Section 3.5. It was seen that the relative wave energy along a typical half-heart bay can be depicted in schematic form, as shown in figures 3.16 and 4.2.

Referring to Figure 4.2 and Appendix A, Location A is in the lee of a peninsula, headland or rocky point and enjoys maximum protection from the dominant ocean swells, but is exposed to local wind waves during periods of onshore winds as well as swells originating in the Eastern sector. The shoreline is often a mix between being rocky and sandy, often becoming a totally rocky environment closer to the point. Where the sandy beach starts, the beach profile is normally gently sloping. Swimming conditions are generally considered safe under normal (non-storm) conditions. Coastal resort developments or small-boat harbours or sheltered anchorage or mooring facilities are often located in these areas.

As depicted in Figure 2.13, the alongshore wave-energy fluxes vary within the half-heart bay. This was discussed in Section 2.2.7 in the context of the coastline classification system put forward by DHI (2001) (Figure 2.15).

Typically a convergence of currents takes place in the area in the central portion of the half-heart bay where the potential longshore sediment transport capacity is lowest and sediment deposition takes place. As also depicted in Figure 2.15, the potential longshore sediment transport capacity is at a maximum at the end of the bay where the longshore currents reach a maximum (Coastal Type 3 in Figure 2.15). Typically these areas are prone to large shoreline changes due to the variation in longshore sediment transport potential.

Since the position of convergence is different under deep sea swells entering the bay from the SW as to those entering the bay from the Eastern sector, the alongshore sediment transport capacity also changes and can lead to sediment deposition in the lee of the promontory.

A risk score of 1 is assigned to Location A, as there is a low risk of the dune integrity being damaged by wave energy originating from the ocean swells that enter the bay. An example for Location A is seen in Figure 3.23 (Santos Beach) and Diaz Beach (Figure 3.24).

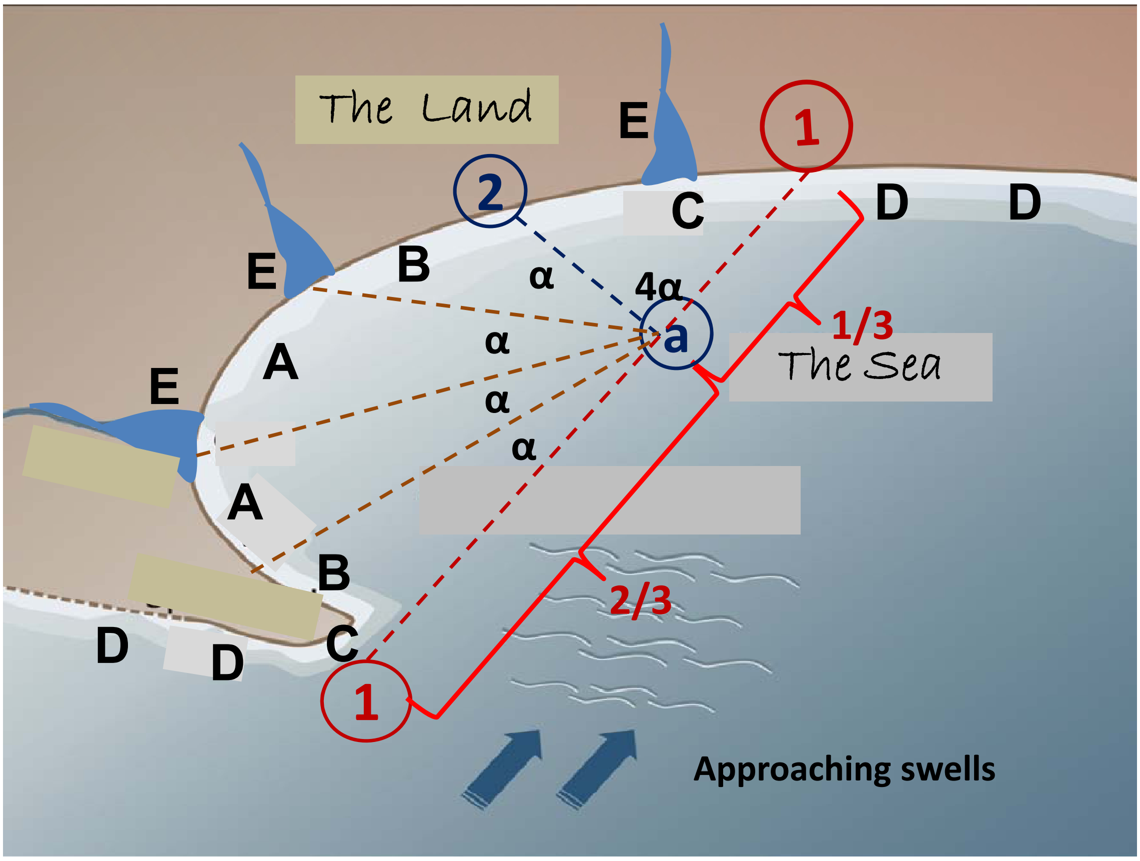


Figure 4.2: Typical half-heart shaped embayment along the South African south coast

Location B represents a site relatively protected from deep-sea wave energy, but more exposed than Location A. A risk score of 2 is therefore assigned to this area, as there is a medium risk of the buffer dune integrity being compromised by wave energy originating from the approaching ocean swells that enter the bay. Another B location is located in the lee and in close proximity to the tip of the promontory. Here the coastline is typically rocky. Being sheltered from high energy deep-sea swells, as for Location A, conditions at Location B are normally favourable for safe bathing. Public amenities and parking areas are typically located here.

Location C is more exposed to the prevailing ocean swells and is often more susceptible to seasonal short term (cyclical erosion / accretion) and may therefore exhibit signs of an eroding state to an observer. Due to the exposure to higher wave energy, a relatively steep upper beach profile (in the order of 0.2) occurs as reflected in beach surveys (CSIR, 1994). The shoreline orientation relative to the dominant wave direction is such that the transformed waves reach the shoreline at an angle, which results in strong alongshore currents and associated alongshore sediment movement. The angle of incidence is typically in the order of 5 to 10^{o} in this part of the bay.

Swimming conditions are often dangerous because of the strong nearshore currents and series of cusps and deep gulleys or 'rips' are noticeable. The area often consists of a mix of a sandy and a rocky shoreline, often with submerged rocky reefs in the nearshore area even if the beach is mainly sandy. The upper beach is narrow and the foredunes often appear to be in a state of erosion (Figure 2.6). In many cases these are signs of the 'dynamic' nature of the coastline as depicted in figures 2.7, 2.8 and 2.9. Private residential development often occurs in these areas where seascape views, surf fishing and beachcombing are the main attractions (versus swimming).

This exposed area is given a risk score of 3, as there is a high risk of the buffer dune integrity being compromised by wave energy originating from the approaching ocean swells.

<u>Location D</u> is directly exposed to the prevailing ocean swells and attracts a risk value of 4. The coastline orientation approaches being parallel to that of the approaching waves (i.e. the angle of incidence is often shore-normal, or 0^{o}). The surf zone is typically very wide; the waves break on sandbanks far out and a number of rolling waves can be seen approaching the beach at the same time. Swimming conditions are very dangerous due to the high-energy waves and strong nearshore currents and series of cusps and deep gulleys or rip currents are prevalent. At the open end of the half-heart bay the coastline often ends in a rocky coastline.

<u>Indicator DII 2: Wind (Appendix A)</u>

The characteristics of the dominant wind during the dry season determine the risk of dune blow-outs forming.

When blow-outs are formed in dunes, the volume of sand in the buffer dune system can be reduced, thereby compromising the effectiveness of the coastal defence mechanism.

As was discussed in Chapter 2, wind-blown sand often forms an important component of the natural movement of sand in the coastal zone. Obliquely onshore winds typically blow over a longer expanse of exposed sand and can therefore move a larger volume of sand (Figure 2.27). A risk score of 3 is allocated where oblique onshore wind conditions prevail during the hot and dry seasons. A score of 2 for directly onshore wind conditions is allocated due to the reduced expanse of open sand across which the wind can blow. For prevailing offshore wind conditions, the risk is low, and a score of 1 is assigned.

Indicator DII 3: The height of the foredune (Appendix A)

As discussed in Chapter 2, the foredune height is an important factor when considering the coastal defence along a soft coast. As noted in Section 4.4 and Table 4.8, the fact that topographical information along the South African coastline is limited to the +5 m MSL contour line. Until a higher resolution dataset becomes available, decision-makers are forced to use the +5 m MSL contour line. In many cases this provides a good first estimate of the foredune height.

From the analysis and discussion in Section 3.5 (table 3.6 and 3.7) the following was concluded on the critical foredune heights within the bay:

- In the sheltered / protected areas of the half-heart bays in the study area (Area A in Figure 4.2), the critical foredune height is in the order of 3 m above the 'foot-of-dune' elevation.
- The critical foredune height in the moderately exposed areas (B) is taken as 4 m, and
- A critical foredune height of 5 m in the exposed areas categorised as C and D in Figure 4.2.

As discussed in Section 2.2.9 and shown in figures 2.18, 2.21 and 4.3, where the foredune height is predominantly less than the critical height for the specific exposure area, the foredune has relatively less volume and the risk to the integrity of the buffer dune as an effective coastal defence mechanism is high, and therefore a score of 3 is assigned. Foredunes that reach heights in excess of the critical height at the site contain a reasonable volume of sand that can feed sand back onto the beach during a storm at high tide. A dune integrity risk score of 2 is assigned in these cases.

Very high foredunes and sandy cliffs (> 10 m) release large volumes of sand onto the beach when the dune or cliff toe is eroded or undercut. A dune integrity risk score of 1 is assigned in these circumstances.

Although the ideal would be for a professional surveyor to do this accurately, the foredune height can be estimated by comparing it to the height of an average male adult standing at the seaward foot of the dune. Alternatively, a known height (e.g. the height of a typical single storey house, or access stairs – Figure 2.6) can be used to assist, as illustrated in Figure 4.3.

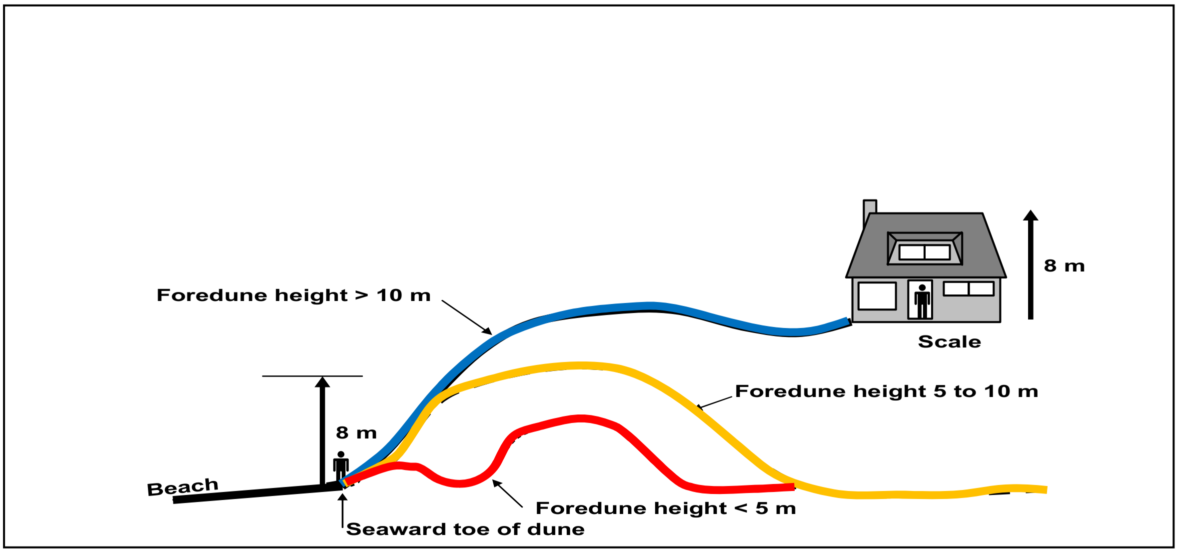


Figure 4.3: Estimating the height of the foredune

<u>Indicator DII 4: Pressures from human activities (Appendix A)</u>

As discussed in Section 2.2, dune vegetation serves an important role of trapping wind-blown sand within foredunes as well as binding the dune sand. This maintains foredunes by preventing blow-outs and thus keeping the sand within reach of the storm waves, thereby providing the necessary volume of sand available to limit the landward movement of the high-water mark during storms (as described above).

Dune vegetation is extremely vulnerable to trampling by people. Informal pathways create exposed sandy areas where blow-outs can occur, especially where onshore winds prevail.

The burning of foredune vegetation can also expose large areas of sand. Fires often occur during dry, summer seasons (e.g. during fireworks displays, barbeque fires getting out of hand, or due to vandalism or neglect).

The highest risk of this occurring is close to public amenities such as parking lots, toilet blocks and beach shops due to the high degree of associated human activity. People tend to follow the shortest route from their position on the beach to their destination (e.g. the toilet or car), often straight across the foredunes and not along the formal pathways, even if these are provided (Figure 4.4).

Risk scores associated with a range of land use categories that result in pressure on the buffer dune system have been assigned, as shown below. The 'proximity' assessment rules are defined, as described below.

Using the Lappiesbaai Beach at Still Bay as an example (Figure 4.4), the risk to the buffer dune integrity associated with the proximity of the beach user to public amenities and private residences is categorised. The various categories are described below.

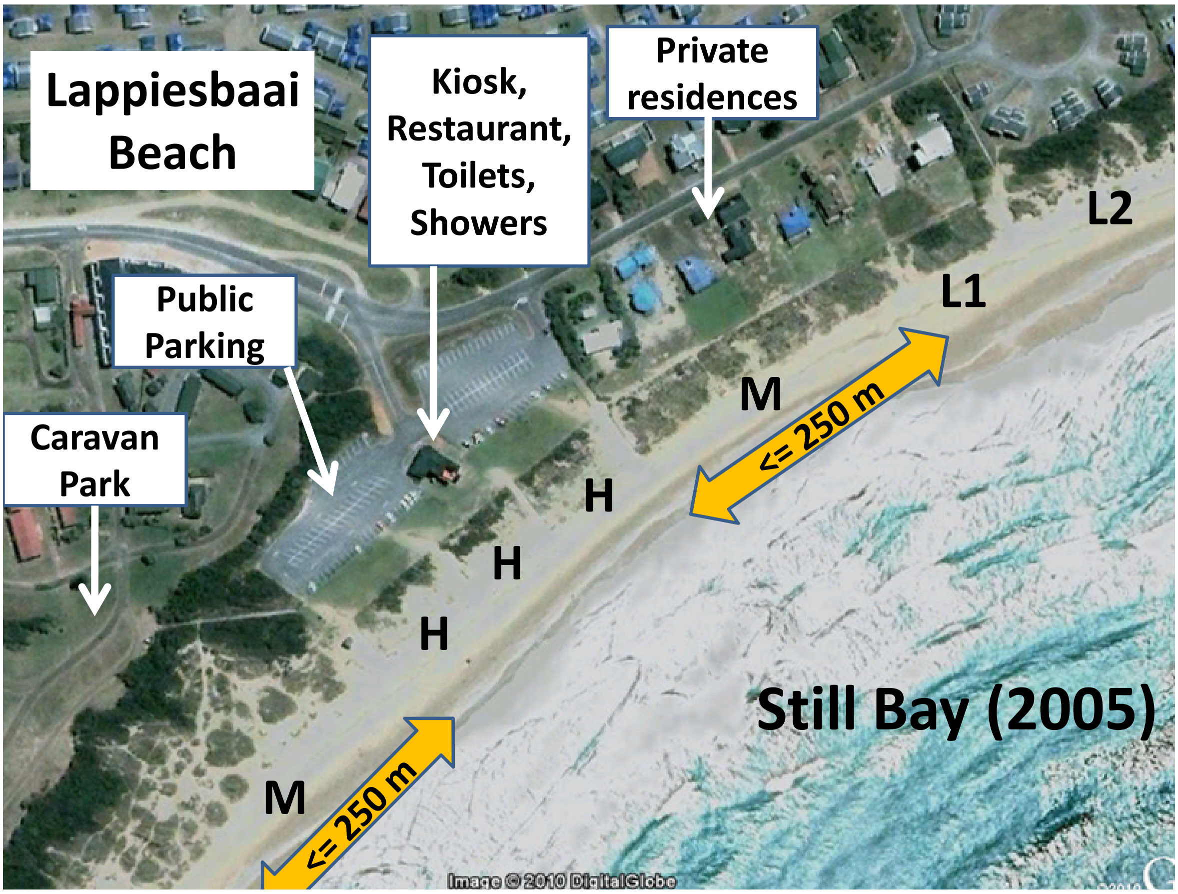


Figure 4.4: **Categorised areas due to their proximity to amenities (image from Google Earth™)**

High risk to dune integrity (H: Score = 3): When public parking areas and amenities and facilities such as a beach kiosk or restaurant, toilets or children's playing facilities are located directly landwards of a beach and buffer dune system, there is a high degree of pressure due to pedestrian traffic across or within the dunes. This results in a high likelihood of the destruction of the sand-binding dune vegetation and can result in blow-outs, especially when the prevailing winds are onshore.

Medium risk to dune integrity (M: Score = 2): If the beach or dune area is less than 250 m away from the public parking area and/or amenities and facilities as described above, the pressure is somewhat lower, but still exists.

Low risk to dune integrity (L1: Score = 1): Where the beach or dune area is more than 250 m away from the public parking area and/or amenities the tendency is for fewer beach goers to walk that far away from where they have parked their vehicles or from the facilities.

Low risk to dune integrity (L2: Score = 2): Where the buffer dune is located seawards of a residential area with limited public access possible, the risk due to pedestrian pressure is low. Here the residents (or their guests) are the main culprits, because they typically want to take the shortest route from their house to the beach and back. This is often along an informal pathway across the foredune.

Low risk to dune integrity (L3: Score = 1): When the beach is located at a remote site away from ongoing human activities, the dune system can function in a natural manner and the risk due to human pressure is very low.

Indicator DII 5: Vulnerability to erosion (Appendix A)

The geological characteristics of the shoreline determine the vulnerability of the shoreline type to erosion. The degree of exposure to wave energy (Indicator 1) is a complementary factor when determining the risk. Where buffer dunes are located landwards of a rocky shoreline, the rocks can reduce the wave energy and thereby the erosion risk to the buffer dune system (risk score = 1).

A sandy shoreline is soft and highly erodible. Depending on the location along the shore, the score varies from 1 in the sheltered areas (Location A) up to 3 where the dune system is fully exposed (locations C and D). Being somewhat protected from the open ocean wave energy, Location B is assigned a score of 2.

In some localities, the coastline is mixed, which means that there could be a sandy upper beach and dune system with a flat rocky area in the nearshore area and/or rocky outcrops. For mixed coastline conditions in Location A, the risk to the buffer dune system is low and a risk score of 1 is assigned. A risk score of 2 is assigned for mixed conditions in any other location along the coastline.

The existence of a river mouth and an estuary (E) attracts an additional risk factor. River and estuary mouths tend to meander over time and often need a large area to move. Buffer dunes can be undercut and washed away by floods, incoming waves and surges during high storm seas or the meander of the estuary mouth. River mouths are treated as estuaries (E) since a high risk to the integrity of the buffer dune defence system exists when in flood and this attracts a risk score of 3 that is added to the other risk score associated with Indicator 5.

Due to the specialised circumstances that are often associated with the coastal geology and geomorphology, a total risk score that exceeds 2 prompts reference to expert advice.

Indicator DII 6: The coastline stability (Appendix A)

The coastline undergoes constant interaction with the coastal processes. A combination of the geomorphology, sand supply and human-induced land use factors determines the stability of the coastline as these factors relate to the potential of the coastline characteristics to change over time.

Rocky coastlines are essentially stable, and in the context of buffer dune integrity assessment, attract a risk score of 0.

In addition to the long-term trends (being either stable rocky shorelines, accreting or eroding soft or mixed coastlines) a soft coastline (sandy or mixed) undergoes ongoing changes due to coastal processes, as discussed in Chapter 2.

This type of coastline is in dynamic equilibrium with the high-water mark moving seawards (typically during summer) and landwards (typically during winter) within a band of typically between 30 and 100 m in the medium to long term (figures 2.8 and 2.9). The risk to buffer dune integrity is medium in this case and a score of 2 is assigned.

In areas adjacent to sediment-bearing rivers where sand is washed out to sea during floods, the coastline can be in a state of accretion. The high-water mark typically moves seawards and onshore winds blow sand landwards to form hummock dunes. A series of foredune ridges are noticeable and later a dune field can form. This can be seen on the northern side of the Tugela River on the east coast of South Africa (Figure 4.5).

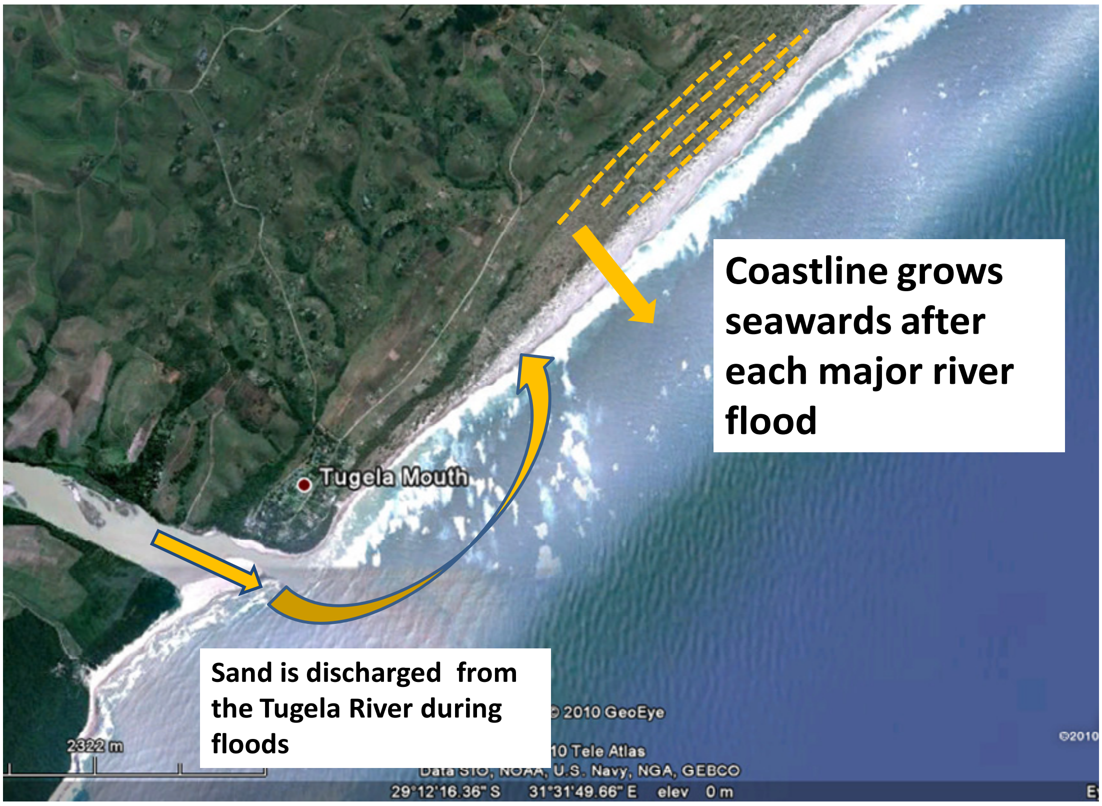


Figure 4.5: **The coastline to the north of the Tugela River is in a state of accretion due to the large amount of sand that discharges from the river during floods (image from Google Earth™)**

In some cases, the dune field functions as a headland bypass dune field, thereby forming a sediment pathway across a headland (or peninsula) between two half-heart bays (Figure 4.6). Since there is a constant supply of sand, the risk to buffer dune system integrity is low and a score of 1 is allocated.

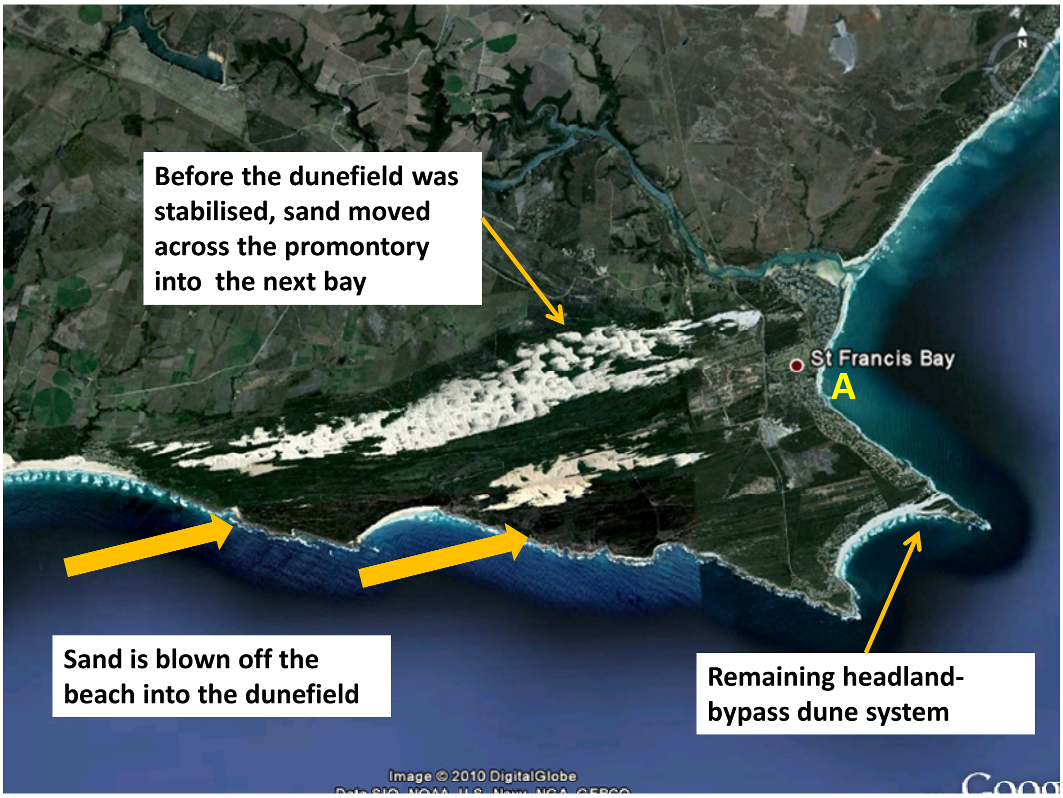


Figure 4.6: The headland bypass dune system at Cape St Francis fed sand across the promontory between the bays before being stabilised

An eroding coastline typically occurs where there is a limited sand supply to the beach (such as in Location A, depicted in Figure 4.6), when the natural sand supply to the coast has been cut off. This can happen due to:

- the building of a dam in a river that traps the sand;
- breakwaters at a port entrance, such as at Coega (Figure 4.7) that interrupt the alongshore sediment transport; or
- through the stabilisation of a naturally occurring dune field that historically fed wind-blown sand to downwind beaches, including headland bypass dune fields as in figures 3.31 and 4.6.

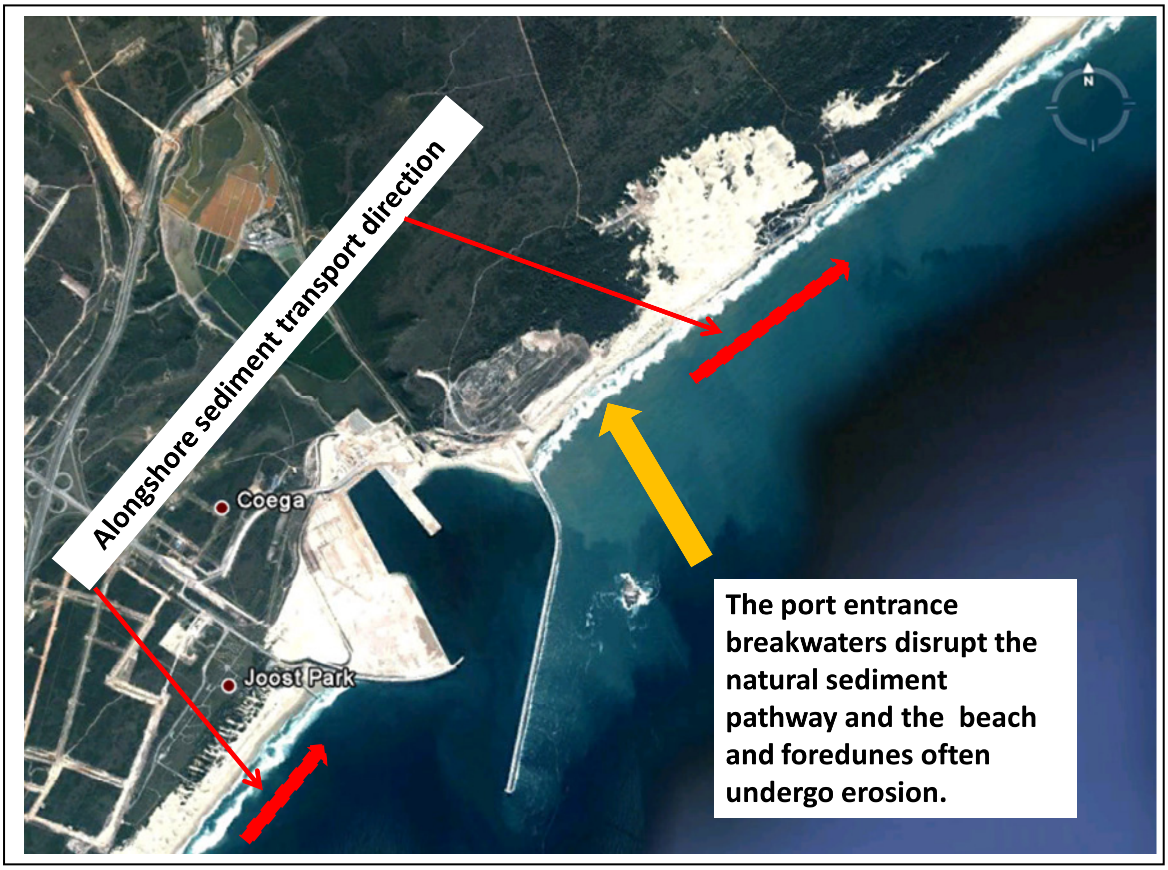


Figure 4.7: **The port entrance at Coega disrupts the natural sand supply to the eastern beach and erosion occurs despite the engineered sand bypass system (image from Google Earth^{TM})**

As was seen in Section 3.5 (Table 3.7) the height of the foredune also plays an important role in such cases, especially if the placing of existing development ignored the eroding nature of the coastline. Due to the real risk of the buffer dune integrity being compromised in this manner along eroding coastlines, a risk score of 3 is assigned, which triggers the need for specialist advice.

4.6.2 Determining the risk profile at the site

The final step in the conceptual RPA procedure as described above is to add the scores determined for each of indicators DII 1 to DII 6 and to determine the risk profile category. Four categories of risk are defined:

Very high risk (VHR): The functioning of the buffer dune system as an effective coastal defence mechanism is seriously threatened
High risk (HR): The buffer dune system is at risk of being compromised
Medium risk (MR): The buffer dune system functions close to normal
Low risk (LR): A naturally functioning buffer dune system

The risk profile for the site is one of a number of input factors that determine the buffer dune integrity index at the particular site and the subsequent management action required. This method is applied to the study area and is discussed in Chapter 5.

CHAPTER 5: APPLICATION OF THE CONCEPTUAL PROCEDURE

5.1 Introduction

Determining the accuracy, user-friendliness and usefulness of the conceptual RPA procedure as described in the previous section forms the intended research outcome. In this section, the conceptual RPA procedure is applied to the study area within the Eden District Municipality and the results are evaluated.

5.2 Method

The approach to the evaluation of the conceptual RPA procedure is summarised in Table 5.1.

Table 5.1: Methodology and research instruments used to evaluate the RPA procedure

Step No.	Research instrument	Target group	Intended outcome
1	Individual interviews and observation of approach and decision-making process when applying the RPA procedure	CZM experts	To establish an evaluation standard
2	Workshop sessions during which the approach and decision-making process when applying the RPA procedure were observed	Non-experts that are unfamiliar with the coastal environment	To establish the importance of having local knowledge
3	Regional workshop sessions during which the approach and decision-making process when applying the RPA procedure were observed	Non-experts that are familiar with the coastal environment	To establish the influence of having local knowledge
4	Undertaking no. 2 and 3 before and after basic coaching on the relevant coastal processes	Same groups as for no. 2 and 3 above	To establish the need for and level of coaching required
5	Discussion of learning points and recommendations for improvement during the workshop sessions in no. 1, 2 and 3	Participants of sessions in no. 1, 2 and 3 above	To obtain input to improve the procedure
6	Rating of user-friendliness of the procedure	Same groups as for no. 2 and no. 3 above	To establish the user-friendliness of the procedure
7	Written YES/NO response to usefulness of the approach to coastal decision-makers	Municipal officials that participated in no. 2	To establish the usefulness of the approach
8	Invitation to provide written feedback	All participants	To obtain input to improve the procedure
9	Comparative analysis of results	Researcher	To determine the accuracy of the outcome of the procedure

5.3 Participants

The Environmental Sectors Skills Plan being drawn up by the Department of Environment Affairs (DEA) (2010 – in preparation) concluded that in South Africa there is a vacancy rate of between 30 and 50% in the environmental management leadership level at municipalities. The implication is that many of the 284 local authorities in South Africa do not have access to adequate professional expertise, such as experienced environmental managers or officers, to assist with the decision-making requirements associated with implementing the relevant legislation.

To counter the lack of decision-making expertise and capacity at the coastal municipal level in particular, it was concluded that making use of a simple, robust but scientifically defendable checklist-based decision support guideline that allows for feedback is an effective way of building relevant decision-making confidence and capacity. By acknowledging that this type of approach is not an exact science, the principles of adaptive management could be followed without jeopardising the integrity of the research.

The conceptual RPA procedure was applied by the five categories of participants, which are discussed in more detail in Table 5.2.

Table 5.2: Details of the participants in each category

Ref code	Category	Number of participants	Comments
E	Expert reference group	5	Each has +15 years of experience in CZM in South Africa
NE1	Non-expert, non-coastal group	6	Inland-based – no experience in CZM- related matters and no site visits took place
NE2	Non-expert, local coastal group	8	Hessequa municipal area
		9	Mossel Bay municipal area
		11	George municipal area
		13	Knysna municipal area
		16	Bitou municipal area
	NE2 TOTAL:	57	98% municipal officials, mostly familiar with the pilot sites

5.3.1 Categories of participants

E: EXPERTS

The independent application of the RPA procedure at the specific pilot sites by five experienced experts in CZM formed the benchmark against which the results of the other participants were validated.

NE1U: NON-EXPERT GROUP 1 (UNCOACHED)

The NE1U category of test user is defined as being independent and untrained or uncoached. This group of non-experts was unfamiliar with the coast or the concept of CZM. They applied the RPA procedure to the pilot sites without visiting any of the sites and only used available aerial photographs and information available via the internet.

NE1C: NON-EXPERT GROUP 1 (COACHED)

The same group of non-experts was given a short introduction to the basic processes that prevail at the coast and that are deemed important to CZM and relate to the variables that influence the human–nature system. They then independently applied the RPA procedure to the same pilot areas.

NE2U: NON-EXPERT GROUP 2 (UNCOACHED)

Workshops were held at each of the participating coastal municipal areas within the Eden District Municipality. Attendees were non-expert officials and interested parties. Being local, it was assumed that they were familiar with the local conditions at the pilot sites. Each of the workshop participants independently applied the RPA procedure to the pilot site in their municipality without any coaching or guidance. Use was made of detailed aerial photographs, available maps and relevant information.

NE2C: NON-EXPERT GROUP 2 (COACHED)

The same group of local non-experts from the pilot coastal municipalities were given a basic introduction on the processes that prevail at the coast and that are important to CZM. They then independently applied the RPA procedure to the same pilot areas as before.

5.4 Workshop procedure and data

A template (Appendix A) for the RPA procedure was handed to each participant. Google Earth™ images of the specific pilot site were made available. Each participant was asked to complete the procedure independently without any guidance or coaching.

For both groups of non-expert participants, the exercise was repeated after a short interactive 'coaching' lecture followed by a discussion led by the researcher.

After the coaching, the participants were requested to complete a second form for the RPA procedure for the same area as before. A comparison of the results to those obtained from the expert group gives an indication of the degree of accuracy of the non-expert group's assessment results. A comparison of the 'uncoached' results to the results obtained for the same site by the same participants after the coaching session gives an indication of the importance and influence of basic training.

After the exercise, each participant was requested to evaluate the RPA procedure in terms of its user-friendliness (rating 1–4) and usefulness (Yes or No). They were also invited to provide specific written notes, comments and/or feedback on the RPA procedure and toolbox approach in order to improve the practicality and applicability of the procedure.

The results are shown and discussed below.

5.5 Quantity and quality of the data

The number of forms received and used in the analysis is shown in Table 5.3. The interaction with the participants was determined by their work pressure and the limited time the volunteer municipal officials could spend on evaluating the process. For this group (reference code NE2), 18 people did not repeat the assessment exercise after receiving coaching.

A total of 19 forms were 'matched', which means that the same person completed the exercise for the same site before and after being coached. The matched forms provide a good basis for the quality assessment process.

Table 5.3: Quantity of data

Ref. code	Category	Number of forms returned				Comments
		U	C	M	F	
NE1	Non-expert, non-coastal group	14	10	10	4	No experience in CZM-related matters and no site visit
NE2	Non-expert, local coastal group	42	24	19	5	Assumed to have local knowledge of coastal sites
		55				Total number of delegates that attended the regional work sessions

KEY: U: Uncoached; C: Coached; M: Matched sites ('matched' means that the same person completed the exercise for the same site before and after being coached); F: Feedback, comments or suggestions received

5.6 Analysis

The results from the application of the conceptual RPA procedure in the five pilot areas by the various categories of participant groupings are summarised in Table 5.4. A comparative analysis and discussion of the assessment results for each of the six indicators in the RPA follows below.

Table 5.4: Range of total scores for the RPA

Row No.	Ref code	Hessequa			Mossel Bay			George		Knysna	Bitou			
		H1[1]	H2[1]	H3[1]	M1[1]	M2[1]	M3[1]	G1[1]	G2[1]	K1[1]	B1[1]	B2[1]	B3[1]	B4[1]
1	E	12	15	16	11	11	17	19	18	12	11	17	18	16
2	NE1U	8	13	10	15	-	16	-	11	-	-	-	-	-
3	NE1C	11	-	12	11	-	-	-	16	-	-	-	-	-
4	NE2U	11	16	17–18	16–19	16	16	14–17	13	11–14	11–13	12	12–19	13–16
5	NE2C	11	16	17–19	10	12	-	-	-	11	12	17	13–20	12–15

Note 1: Cross-reference to the site names in Table 5.6.

The accuracy of the RPA outcome was determined by comparing the risk profile determined by the groups of non-experts (NE) to the benchmark established by the group of experts (E).

Values associated with the categories of Low risk (LR), Medium risk (MR) and High risk (HR) and Very high risk (VHR), as discussed in Section 4.6.2, were used to translate the numerically calculated accumulated risk score shown in Table 5.4 into the risk categories as described above and summarised in Table 5.5.

Table 5.5: Risk profiles for the various sites showing the accuracy

Row No.	Ref code	Hessequa			Mossel Bay			George		Knysna	Bitou			
		H1[1]	H2[1]	H3[1]	M1[1]	M2[1]	M3[1]	G1[1]	G2[1]	K1[1]	B1[1]	B2[1]	B3[1]	B4[1]
1	E	LR	MR	MR	LR	LR	MR	HR	HR	LR	LR	MR	HR	MR
2	NE1U	VLR	MR	LR	MR	-	MR	-	LR	-	-	-	-	-
3	NE1C	LR	-	LR	LR	-	-	-	MR	-	-	-	-	-
4	NE2U	LR	MR	MR	HR	MR	MR	MR	MR	MR	LR	LR	MR	MR
5	NE2C	LR	MR	MR	LR	LR	-	-	-	LR	LR	MR	MR	MR

Note 1: Cross-reference to the site names in Table 5.6

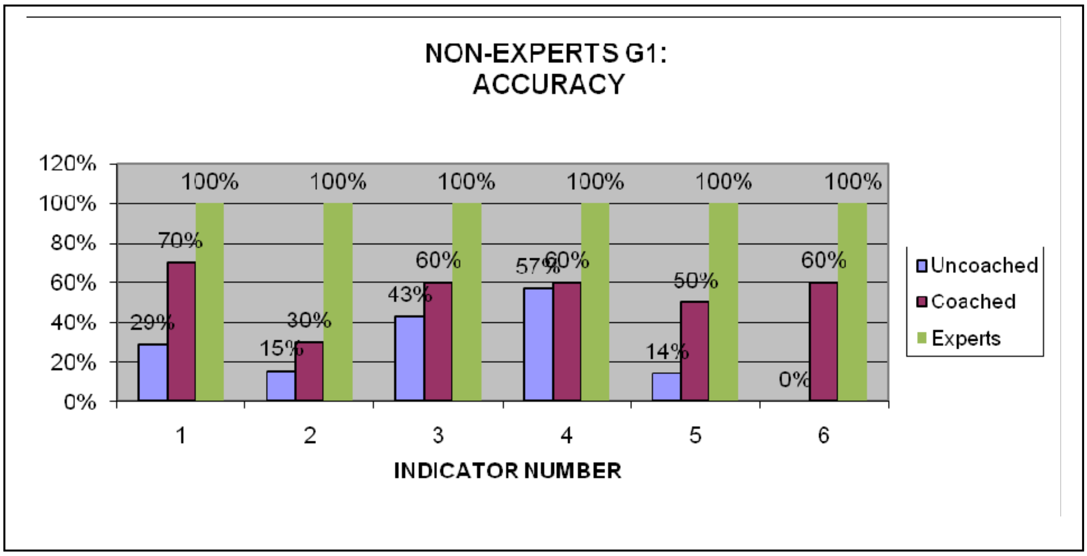
Note 2: Colour shading depicts alignment to the expert reference group (Row 1) where green shows a match and red indicates a mismatch

5.7 Sub-conclusion on the result of the overall risk profile

Tables 5.4 and 5.5 show that for a fair number of sites, the outcomes determined by the non-experts groups are fairly closely correlated. The benefit of the coaching is more noticeable in the non-expert coastal group (NE2C). The importance of local knowledge is clear.

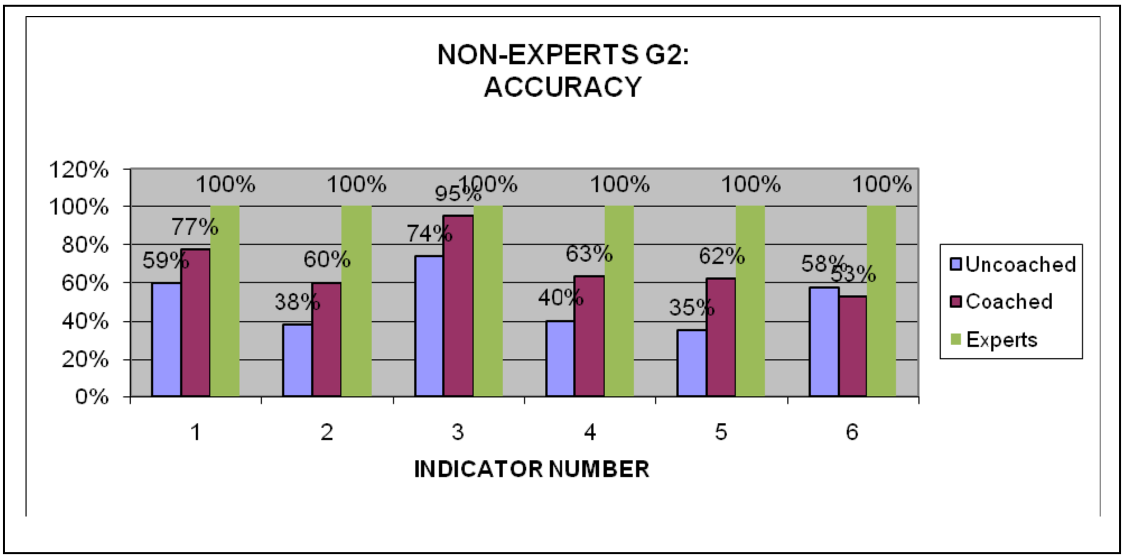
5.8 Sub-conclusion on the accuracy of the individual indicators

Although the degree of accuracy of the overall risk profile outcome seems fair, the analysis of the accuracy of individual indicators that make up the risk profile shows that non-experts had difficulty in interpreting the situation using the available information (figures 5.1 and 5.2). The results and direct feedback from the participants, including the expert group, show that there was particular difficulty in assessing indicators DII 2 (wind), DII 3 (dune height) and DII 6 (coastline stability) without going on site and/or without local knowledge.



Note: The experts are used as the 100% benchmark

Figure 5.1: Comparison of results obtained from Group 1 (non-experts, no local knowledge)



Note: The experts are used as the 100% benchmark

Figure 5.2: Comparison of results obtained from Group 2 (non-experts, local knowledge)

Recommendations on how to address this issue are included in Chapter 6.

5.9 Comparison of the Coelho et al. (2006) coastal vulnerability assessment method to the concept RPA procedure

As a benchmarking exercise the results obtained using the concept RPA procedure are compared to those obtained from the internationally accepted coastal vulnerability analysis methodology developed by Coelho et al. (2006) and discussed in Section 4.3.

It is assumed that the assessment of the indicators in the concept RPA by the South African panel of coastal engineering and dune management experts (Table 5.2) for the sites in the study area is as accurate as can be done with the level of information available. The totals shown in Row 1 of Table 5.4 and the associated RPA risk categories shown in Row 1 of Table 5.5 are therefore considered to be the 100% level. This is also reflected in figures 5.1 and 5.2.

In the Coelho et al. (2006) method, three categories depicting the vulnerability of a particular coastal site to erosion forces from the sea were defined as Intermediate vulnerability (IV), High vulnerability (HV) and Very high vulnerability (VHV), whereas the concept RPA procedure developed as part of this thesis defines four categories of risk to the buffer dune integrity, namely (1) Very high risk (VHR), (2) High risk (HR), (3) Medium risk (MR) and (4) Low risk (LR).

A comparison of the results of the Coelho et al. (2006) method to that of the concept RPA procedure was undertaken (Table 5.6). The classification depicted in Table 4.7 for the three Weighting scenarios by Coelho et al. (2006) is compared to those that were obtained when the expert group followed the conceptual RPA procedure for selected study sites (Table 5.5). The results of the comparison for each of the pilot sites in the study area are shown in Table 5.6.

Table 5.6: Comparison of the Coelho et al. (2006) vulnerability classification and that used for the concept RPA developed in this thesis

Ref.	Site	Position	Vulnerability			RPA[2]
			W1[1]	W2[1]	W3[1]	
H1	Morris Point	D	IV	IV	HV	LR
H2	Lappiesbaai	B	IV	IV	HV	MR
H3	Gouritzmond	A	IV	HV	HV	MR
M1	Santos Beach	A	IV	IV	IV	LR
M2	Diaz Beach	A	IV	IV	IV	LR
M3	Hartenbos estuary	CE	HV	HV	HV	MR
G1	Wilderness Beach	C	HV	HV	HV	HR
G2	Wilderness estuary	CE	IV	IV	IV	HR
K1	Buffalo Car park	A	IV	IV	IV	LR
B1	Robberg Beach	B	IV	IV	IV	LR
B2	Beacon Island Beach	B	HV	HV	HV	MR
B3	Lookout Beach	CE	HV	HV	HV	HR
B4	Keurboomstrand	C	HV	HV	HV	MR

Note 1: W1, W2 and W3 are the Coelho et al. (2006) Weighting scenarios (Table 4.7)
Note 2: From the assessment by the expert group (Row 1, Table 5.5)
Note 3: Green shaded cells within Table 5.6 indicate perfect alignment and red shaded cells indicate misalignment

The data in Table 5.6 are summarised in Table 5.7. It can be seen that 62 % of all sites assessed in terms of W1 (Table 4.4) are aligned to the RPA assessment. For both W2 and W3 the overall alignment with the RPA assessment category is 69%.

Table 5.7: Alignment assessment

Perspective		Vulnerability			Comments
		W1[1]	W2[1]	W3[1]	
Overall		62%	69%	69%	Well aligned for most sites
Position on the coast (exposure to erosional forces) (Figure 4.2)	A	75%	100%	100%	Well aligned for W2 and W3
	B	66%	66%	100%	Well aligned for W3
	C	50%	50%	50%	Under assessment for open coast
	CE	33%	33%	33%	Not suitable for open beaches at estuaries
	D	-	-	-	Only one sample

Note 1: W1, W2 and W3 are the Coelho et al. (2006) Weighting scenarios (Table 4.4).

When comparing the specific position within the bay (Figure 4.2), the results from the Coelho et al. (2006) method are well aligned to the RPA assessment at positions A and B, and specifically when firstly W3 and then W2 are used.

However, for position C which is along a partially sheltered open coast, all three the weighting scenarios underestimate the vulnerability. Where an estuary (E) or river mouth coincides with the partially open coast (Position C), depicted as CE, there is a very poor alignment.

It is therefore concluded that the Coelho et al. (2006) weighting scenarios do not sufficiently reflect the situation within the study area.

Although the sample size for each of the positions may be too small to be statistically meaningful, it can be concluded that the six dune integrity indicators (DII 1 to DII 6, Table 4.10 and Section 4.5) and the four simplified risk profile categories as proposed for the RPA (Section 4.6.2) could better reflect the situation at the study site. This is probably due to the inclusion of key coastal characteristics such as the wave transformation factors including the beach slope and foredune height (implicit in assessing DII 1 and DII 3 - see Section 3.5. Based on the comparisons seen in tables 5.6 and 5.7, the alignment is summarised in Table 5.8.

Table 5.8: Alignment of the Coelho et al. (2006) and the RPA risk categories

Concept RPA classification (this thesis)	Classification by Coelho et al. (2006)
Very high risk (VHR)	(VHV) Very high vulnerability
High risk (HR)	
Medium risk (MR)	(HV) High vulnerability
Low risk (LR)	(IV) Intermediate vulnerability

5.10 Sub-conclusion on the evaluation of the RPA procedure

From the information depicted in figures 5.1 and 5.2, the following is concluded:

In general, it is difficult for non-experts to use satellite images or aerial photographs to determine specific characteristics of the coastline accurately.

- Having local knowledge and realising that information is available via the internet do marginally improve outcome.

- Coaching also increased the accuracy of some of the conclusions.

- Comparison of the accuracy of evaluation results shows that the outcome from the RPA method seems fair.

- Analysis of the accuracy of individual indicators that make up the risk profile, showed a 60% accuracy score when comparing the Non-Expert outcome to the benchmark set by the Expert reference group.

Adapting the procedure using the learning gained through observations made during the work sessions with all three groups and from written and direct feedback received from some participants (especially the expert group), it is concluded that the results can be improved. Including more visual aids such as diagrams and photos of examples of the key indicators on the RPA template are common to the recommendations received.

The customisation of a set of basic information packs for each local municipality that shows the expert assessment of the various elements of the risk profile for their area is a strong consideration as an alternative to the requirement of local non-experts to do this. This information could be reflected in a detailed risk and vulnerability atlas developed for each region.

5.11 Revised RPA template (Appendix A1)

From the analysis and discussion in Section 3.5 (tables 3.7 and 3.8) the following was concluded on the critical foredune heights within the bay:

- In the sheltered / protected areas of the half-heart bays in the study area (Area A in Figure 4.2), the critical foredune height is in the order of 3 m above the 'foot-of-dune' elevation.
- The critical foredune height in the moderately exposed areas (B) is taken as 4 m, and
- A critical foredune height of 5 m in the exposed areas categorised as C and D in Figure 4.2.

This means that areas are at risk where the natural (or human-made) foredunes are lower than the critical heights indicated above. This risk is countered by ensuring an appropriate set-back or an adequate buffer dune volume as indicated in Table 3.7.

To allow for this spread of critical dune height within the bay, Step 3 of the RPA template (Appendix A) is revised as shown in Table 5.9 below. The revised RPA template is included as Appendix A1.

Table 5.9: Foredune height scores for the RPA risk categories

Estimated dune height	Site location (from Step 1)			
	A	B	C	D
H < 3 m	3	3	3	3
H = 3 to 5 m	1	1	2	3
H = 5 to 10 m	1	1	1	1
H > 10 m	1	1	1	1

When foredunes exceed 10 m in height they can be seen as 'cliffs' (Figure 3.9).

5.12 Limitations of the research method

The limitations of the research method include the following:

- It was not possible for the members of the expert group to undertake on-site assessments. Therefore, the benchmark was defined by relying on their ability to interpret available information (e.g. the aerial photographs and reports) and their understanding and knowledge of the study area and specific sites.

- Since the coast-based non-expert group volunteered to participate in the exercise, it was not possible to ensure their full commitment over the duration of the three-part workshop procedure, which took two hours. This resulted in a number of 'spoiled' assessment forms where only the uncoached assessment was done. In some cases, participants left after the short lecture and therefore did not complete the coached assessment for the same site. This left a number of unpaired or unmatched sites.

- The research method only allowed for one round of interaction with a representative stakeholder group during which the conceptual procedure was tested. The feedback obtained from participants along with the researchers' observations during the exercise allows for an improvement of the procedure as shown, and the RPA template was updated and shown as Appendix A1. Retesting of the improved template by following the same methodology, but within a different study area, is recommended.

CHAPTER 6: CONCLUSION

6.1 Summary of findings

The hypothesis postulated in this research is as follows:

The effectiveness of natural and constructed buffer dune systems can be assessed by a set of indicators that defines the integrity of the dune system and triggers informed management decisions.

The aim of the research was therefore to develop and evaluate a conceptual user-friendly decision support guideline. The guideline should enable local authorities to manage the integrity of the naturally occurring foredunes and/or constructed buffer dunes in their area. The reason is to maintain an affordable and effective soft-engineering coastal defence mechanism to protect natural backdune areas as well as man-made development against the forces of the sea.

The study had two key objectives:

1. The identification of key indicators (coastal landforms/features/characteristics) that define a dune integrity index for guiding decision-making associated with coastal buffer dune management.

2. The development of a scientifically defendable and practical checklist-based method of gathering qualitative information on the identified key indicators for the dune integrity index.

In developing an approach to South African conditions, the reality was recognised that decision-makers at coastal municipalities often lack the experience and confidence to take the appropriate management action within the littoral active zone.

As described in chapters 4 and 5, a *participant-oriented* evaluative research methodology was applied in this research and a conceptual decision support guideline was developed and evaluated for relevance and practicality within the context of the identified needs of the target users.

In this chapter, the research conclusions are summarised, recommendations are put forward and suggestions for further work given.

6.2 Conclusions

Decision-making happens whether there is scientific information and evidence available or not. "The challenge is to identify, locate, and organize information in ways that will make it accessible and usable in the integrated coastal management decision-making process" (Olson, 2001:327).

From the literature review it was concluded that the significance of having an effective and robust system to inform decision-making at municipal level becomes extremely important when the wellbeing of humans are at stake or where ecosystems provide crucial services, such as providing security to expensive infrastructure important to the local economy. The following key points were noted:

- A comprehensive baseline of checklist-based procedures has already been defined for the coastal zone and is applied in many parts of the world.
- Although some initial basic training may be required, carrying out rapid assessments of the environmental status of key components of an identified human–nature system is practical and achievable by non-experts.
- Key to the success is the identification of indicators and indices that are representative of the specific system component and that lead to a simplification of the complex system.
- A checklist-based approach can practically feed into relevant decision trees that guide the non-expert to relevant management actions and a considered evidence-based outcome.
- Monitoring and evaluation of the decision outcomes fed back into the system leads to improved system understanding and better decisions.

- The adaptive management approach can form the core of a decision support guideline. This is considered a critical part of building capacity at local authority level.
- This approach can enable the implementation of integrated coastal management in developing countries, where a lack of experienced environmental managers is often the norm.

The interaction with the stakeholders at the participating municipalities within the Eden District Municipality highlighted the needs and issues relevant to integrated CZM in the study area. To this end, the innovative use of the SmartBoard™ technology during the interactive work sessions was successful in that interaction with stakeholders on 'live' Google Earth™ images resulted in good debate and storytelling, during which the local issues and needs were rapidly defined. The output from the interactive sessions then formed the basis for specialists to identify the key issues and management options.

In the application of the vulnerability classification as proposed by Coelho et al. (2006) to the sites within the study area, the following conclusions are reached:

- The information associated with the classification indicators is practically obtainable for Southern Africa, albeit by experts.

- An interpretation of the generic descriptions to suit the South African circumstances was required to ensure consistency in the application.

Using the essence from the Coelho et al. (2006) vulnerability classification method as the basis, it is concluded that the following six indicators of the human–nature system can collectively define the risk profile of a particular site along the coastline.

DII 1: Degree of protection from prevailing wave energy
DII 2: Characteristics of the dominant winds during the dry season
DII 3: Relative height of the foredune buffer
DII 4: Pressures from human activities
DII 5: Vulnerability to erosion
DII 6: Coastline stability

It is suggested that indicators DII 1, DII 2, DII 5 and DII 6 are the key elements that represent the natural environmental context of the site and indicators DII 3 and DII 4 mainly relate to human needs and activities. Whereas no human intervention can change the risk factors associated with indicators DII 1 and DII 2, for indicators DII 5 and DII 6, management intervention to reduce the vulnerability of the dune integrity to the coastal processes is possible, but could typically entail major costs (such as hard-engineering interventions).

The reduction of the risk factors that relate to indicators DII 3 and DII 4 are practically achievable through the implementation of good practice that will not necessarily require expensive intervention. Actions like proper planning (e.g. adhering to the principle of setting and implementing development setback lines as required in the ICM Act of 2008), pedestrian management across sensitive buffer dunes (e.g. formalised access pathways and associated fencing), regular maintenance of the buffer dune system and effective communication to educate the relevant stakeholders.

From the evaluation of the conceptual RPA procedure it is concluded that the RPA method outcome seems fair. Analysis of the accuracy of individual indicators that make up the risk profile index, however, shows that non-experts had difficulty in interpreting the situation using the available information.

Although the procedure developed and evaluated in this thesis still needs to be 'field tested' over a number of seasons and for a variety of sites, the initial feedback and the results show that the approach has potential. It is therefore concluded that the hypothesis is essentially valid, but that improvements to the details and procedures need to be made. These are discussed below.

6.3 Recommendations

In general, it is believed that by adapting the RPA procedure using the learning gained through observations made during the work sessions (Chapter 5) with all three groups and from written and direct feedback received from some participants (especially the expert group), the results can be improved. The inclusion of more visual aids such as diagrams and photos of key factors is common to the recommendations received.

Specific recommendations on future improvement to the RPA procedure are the following:

1. That the simple ABCD wave-energy exposure categorisation system as devised in this thesis (Figure 4.2) serves as a good first risk screening guideline for indicator DII 1 in the RPA procedure.
2. That a site visit is essential to assess the information for indicator DII 3 (dune height and current setback) and that the inclusion of typical photographs to illustrate the various foredune heights would enhance the accuracy factor.
3. For indicator DII 4 (human impact), that typical photographs be included to illustrate the various categories.
4. That a set of basic information packs be customised for each local municipality that incorporates the information from points 1 to 3 above, including the expert assessment of the various elements that relate to DIIs 2, 5 and 6 of the risk profile for the specific area. This is a strong consideration as an alternative to the requirement of local non-experts to source the information themselves. This information could be reflected as a CZM layer in a detailed risk and vulnerability atlas developed for each region (as suggested below).

6.4 Future consideration

6.4.1 Possible use in other parts of South Africa and beyond

In sections 3.6 and 3.7 the simplified method of categorising the relative wave energy within a typical half-heart bay was applied to the pilot areas and the inferred wave transformation coefficients and associated exposure categories are summarised in Table 3.9.

More work is required to see if the 'categorisation rules' can be transposed to the rest of the South African coastline. An example of how this could be done is illustrated in Figure 6.1. Using the basic elements of the half-heart bay as reference, and borrowing from the concept put forward by DHI (2001) discussed in Section 2.2.7, typical coastline configurations are depicted. For example, it may be possible to infer that the relative wave energy distribution within a large bay, such as False Bay, could be seen as two half-heart bays joined as mirror images as shown in Figure 6.1.

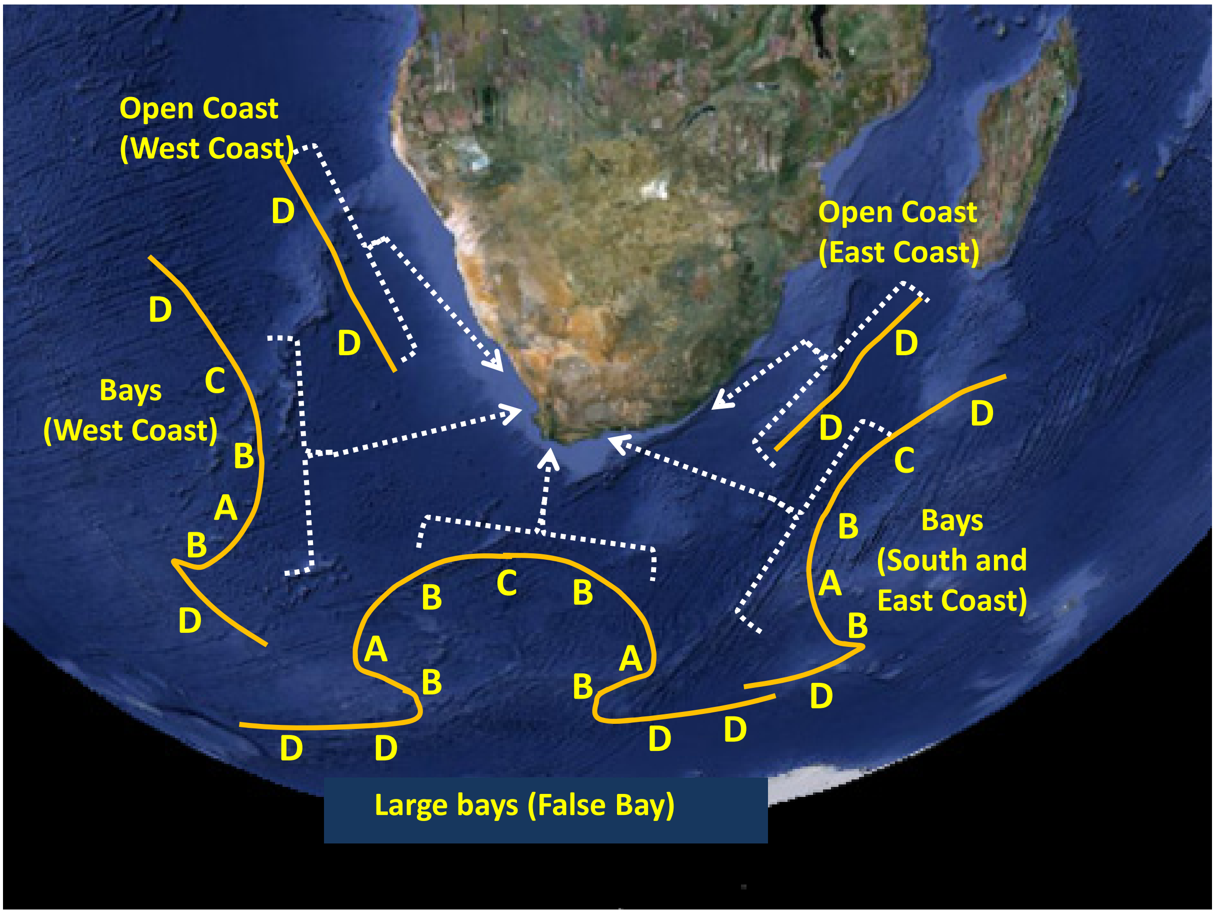


Figure 6.1: **Inferred wave transformation coefficients and associated exposure categories for the rest of the South African coastline (overlay on Google Earth™)**

6.4.2 General considerations for future work

The following points are put forward for consideration for future research and data gathering activities since, in this researcher's opinion, it would enhance the ability of decision-makers to effectively manage key aspects of the coastal zone, including the setback areas defined in the ICM Act of 2008.

- Consideration should be given to updating the *Coastal sensitivity atlas of Southern Africa* (Jackson, 1984) and the maps on the 'Dynamic features of the Cape Coast' included in Heydorn (1980). This is especially important in view of the threat from sea-level rise.

- Since information on the topography of the shoreline is limited to the +5 m MSL contour line shown on orthophotomaps, consideration should be given to obtain a high-resolution digital elevation model (DEM) for the South African coast to reflect the +1 m contour interval levels within the coastal protection zone (Figure 1.1). This layer of information will enable more accurate assessment of risk and vulnerability due to storm erosion and future sea-level rise.

- The main limitation of the conclusions of this thesis is that the focus is on the south coast of South Africa (Figure 3.1). Although this study area represents a good mix of the biophysical and social characteristics of the Southern African coastline and the conclusions on the transposition of the ABCD exposure categorisation to the rest of the South African coastline is an interesting prospect (Figure 6.1), but it cannot be assumed that the findings are scalable to other parts of South Africa and beyond without further work.

CHAPTER 7: REFERENCES

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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, gravel) situated on the interface between dry land and the sea (or other 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 public access.

Cay: A small, low island composed largely of 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 kilometers) 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 of a barrier beach or shoreline of coastal bay to the outer extent of the continental shelf.

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 the 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 isobath 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 nonliving 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 origin, history and structure of the earth, as recorded in rocks; together with the forces and processes now operating to modify rocks.

Georeferencing: (1) 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 (MHWS): the average height of the high water occurring at the time of spring tides.

Mean sea level: 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 waves 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 zone 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: (1) 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.

Return 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) igneous 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.

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 alternately exposed, or covered by tides and/or waves. A shore of unconsolidated material is usually called a beach.

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 they 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 point of the zone (breaker zone) at which waves approaching the coastline commence breaking, typically in water depths of between 5 m and 10 m. See figure 6.

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 wave and that of the 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.

Survey, control: a survey that provides coordinates (horizontal or vertical) of points 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 a 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, but rather of 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 usually reserved for use on the ocean and large bodies of water. Wind setup is usually reserved for use on reservoirs and smaller bodies of water.

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.

APPENDIX A: RPA TEMPLATE

RISK PROFILE ASSESSMENT (RPA)

SITE:... DATE: ....../....../......

ASSESSOR ....

STEP 1: Determine the site location along the coast.

Refer to Figure 1 and select where the site is located

A	B	C	D
1	2	3	3

Note: Circle the appropriate score value

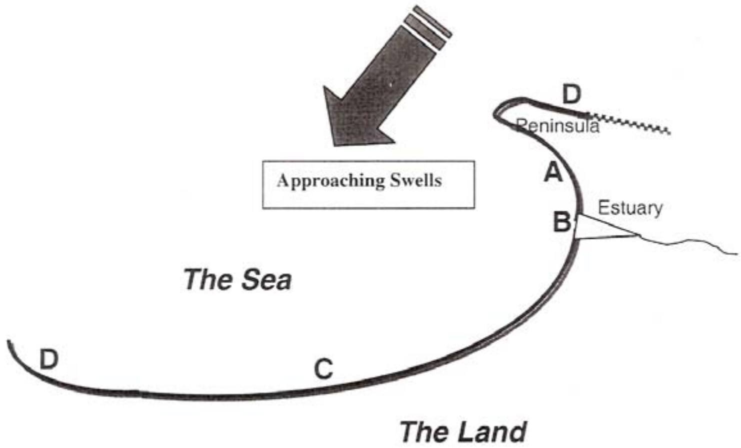

Figure 1: Typical half-heart shaped embayment along the South African coast.

STEP 2: Determine the characteristics of the dominant wind at the site during the dry season(s).

Directly Onshore	Obliquely Onshore	Offshore
2	3	1

Note: Circle the appropriate score value

STEP 3: Determine the height of the foredune.

HIGH H > 10m	MEDIUM H = 5 to 10m	LOW H < 5 m
1	2	3

Note: Circle the appropriate score value

Sub-total:	

Note: Add the circled amounts on this page
Carry forward to next page

STEP 4: Assess the likely degree of pressure due to human activity (e.g. recreation).

HIGH	MEDIUM	LOW1	LOW2	LOW3	Comments
3	2	1	2	1	If score > 2, refer to a Specialist

Note: Circle the appropriate score value

High: For example if there are public parking areas or amenities directly landwards of the beach and dune.

Medium: If the beach or dune area is less than 250 m away from the public parking area and/or amenities.

Low1: If the beach or dune area is more than 250 m away from the public parking area and/or amenities.

Low2: The beach/dune is located seawards of a residential area with limited public access possible.

Low3: The site is at a remote beach.

STEP 5: Assess the vulnerability to erosion.

	Site location (from 1)					
TYPE	A	B	C	D	SCORE	Comments
Rocky	1	1	1	1		If score > 2, refer to a Specialist
Mixed	1	2	2	2		
Sandy	1	2	3	3		
Estuary	3	3	3	3		

Note: Circle the appropriate score value and add to obtain total score for this step

STEP 6: Assess the coastline stability.

		SCORE	Comments
Dynamic Equilibrium	2		
Accreting	1		If score > 2, refer to a Specialist
Rocky	0		
Eroding	Dune height < 5m ....3 Dune height 5 to 10m.....2 Dune height >10m.........3		
Don't know	3		

Note: Circle the appropriate score value

Sub-total:	
Sub-total:	
TOTAL:	

STEP 7: Total the scores and determine the risk profile.

	TOTAL SCORE	Mark relevant box
Very High Risk (VHR)	> 20	
High risk (HR)	18 to 20	
Medium risk (MR)	13 to 17	
Low risk (LR)	10 to 12	
Very Low Risk (VLR)	< 10	

Note: Areas with HR and VHR profiles require ongoing maintenance (See DTMB)

APPENDIX A1: REVISED RPA TEMPLATE

RISK PROFILE ASSESSMENT (RPA)

SITE:... DATE: ....../....../......

ASSESSOR ....

STEP 1: Determine the site location along the coast.

Refer to Figure 1 and select where the site is located

A	B	C	D
1	2	3	3

Note: Circle the appropriate score value

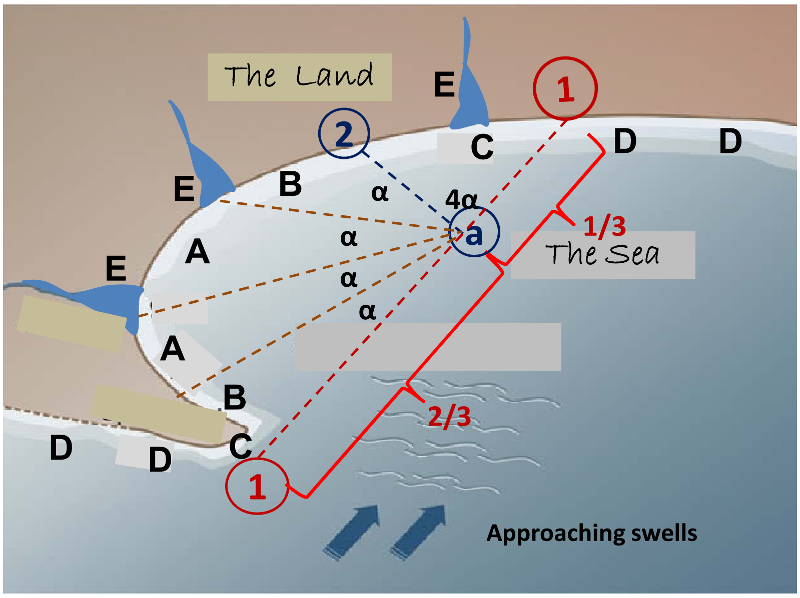

Figure 1: Typical half-heart shaped embayment along the South African coast.

STEP 2: Determine the characteristics of the dominant wind at the site during the dry season(s).

Directly Onshore	Obliquely Onshore	Offshore
2	3	1

Note: Circle the appropriate score value

Sub-total:	

Note: Add the circled amounts on this page
Carry forward to next page

STEP 3: Determine the height of the foredune.

Refer to Figure 1 and select where the site is located

	Site location (from 1)					
Estimated dune height	**A**	**B**	**C**	**D**	**SCORE**	**Comments**
H < 3 m	**3**	**3**	**3**	**3**		**If score > 2, refer to a Specialist**
H = 3 to 5 m	**1**	**1**	**2**	**3**		
H = 5 to 10 m	**1**	**1**	**1**	**1**		
H > 10 m	**1**	**1**	**1**	**1**		

Note: Circle the appropriate score value

STEP 4: Assess the likely degree of pressure due to human activity (e.g. recreation).

HIGH	MEDIUM	LOW1	LOW2	LOW3	Comments
3	2	1	2	1	If score > 2, refer to a Specialist

Note: Circle the appropriate score value

High: **For example if there are public parking areas or amenities directly landwards of the beach and dune.**

Medium: **If the beach or dune area is less than 250 m away from the public parking area and/or amenities.**

Low1: **If the beach or dune area is more than 250 m away from the public parking area and/or amenities.**

Low2: **The beach/dune is located seawards of a residential area with limited public access possible.**

Low3: **The site is at a remote beach.**

STEP 5: Assess the vulnerability to erosion.

	Site location (from 1)					
TYPE	**A**	**B**	**C**	**D**	**SCORE**	**Comments**
Rocky	**1**	**1**	**1**	**1**		**If score > 2, refer to a Specialist**
Mixed	**1**	**2**	**2**	**2**		
Sandy	**1**	**2**	**3**	**3**		
Estuary	**3**	**3**	**3**	**3**		

Note: Circle the appropriate score value and add to obtain total score for this step

Sub-total:	

Note: Add the circled amounts on this page
Carry forward to next page

STEP 6: Assess the coastline stability.

Dynamic Equilibrium	**2**	**SCORE**	**Comments**
Accreting	**1**		**If score > 2, refer to a Specialist**
Rocky	**0**		
Eroding	**Dune height < 5m ……...3** **Dune height 5 to 10m…..2** **Dune height >10m………3**		
Don't know	**3**		

Note: Circle the appropriate score value

Sub-total:	
Sub-total:	
TOTAL:	

STEP 7: Total the scores and determine the risk profile.

	TOTAL SCORE	**Mark relevant box**
Very High Risk (VHR)	> 20	
High risk (HR)	18 to 20	
Medium risk (MR)	13 to 17	
Low risk (LR)	10 to 12	
Very Low Risk (VLR)	< 10	

Note: Areas with HR and VHR profiles require ongoing maintenance

APPENDIX B: WAVE TRANSFORMATION CALCULATION

EXAMPLE: SWAN boundary conditions

H_{mo}	2.5	m
Tp_o	12	S
Dir_o	225	degr from North

Table B1: Calculated output values at the 10 m depth contour

1	2		3	4	5	6	7	8	9
Node	**XP**	**YP**	**DIST. (x)**	**DEPTH (h)**	**H_{SIG} (H_{10})**	**PER (Tp)**	**DIR**	**WLEN(λ)**	**K_T=H_{10}/Hmo**
2	106400	116100	0	9.97	1.53	9.9	177	83	0.61
8	107300	116100	0.90	9.88	1.72	9.8	190	83	0.69
9	107400	116200	1.04	9.96	1.72	9.9	181	84	0.69
11	107100	116700	1.62	9.87	1.63	10.7	152	96	0.65
14	107100	117300	2.22	9.95	1.29	10.7	147	97	0.52
15	107000	117600	2.54	9.96	1.08	10.6	141	96	0.43
20	106100	118700	3.96	9.99	0.65	10.5	115	96	0.26
45	103000	120000	7.32	10.0	0.39	10.3	95	94	0.16
51	103000	121500	8.82	9.99	0.38	11.7	111	109	0.15
60	103600	122900	10.35	9.98	0.47	11.6	125	107	0.19
70	104800	125000	12.77	9.97	0.54	11.4	143	106	0.22
80	107400	127500	16.37	9.96	0.72	10.8	157	98	0.29
90	110700	128900	19.96	9.93	0.93	10.3	169	89	0.37
100	114500	130400	24.04	10.01	1,03	9.7	180	81	0.41
110	117200	130700	26.76	9.95	1.36	9.9	181	85	0.55
119	122600	130800	32.16	10	1.53	9.7	195	82	0.61

Key:

1. Node point along 10m depth contour reference line (Figure 3.10).
2. Node coordinates
3. Distance along reference line (km)
4. Depth at node point (m)
5. Significant wave height (m)
6. Peak wave period (Tp)
7. Main wave crest direction (degrees to north)(Figure 2.14)
8. Wave length (m)
9. Wave transformation coefficient.

Table B2: Calculated values for $K_T = H_{10}/H_{mo}$ at the 10 m depth contour for SWAN input scenarios (Table 3.4)

Accum dist (km)	WINTER: SW Sector(225°)					SUMMER: SW Sector (225°)					SUMMER:E sector (90°)			SW storm
	kRFA5w	kRFA4w	kRFA3w	kRFA2w	kRFA1w	kRFA5s	kRFA4s	kRFA3s	kRFA2s	kRFA1s	kRFA3Es	kRFAE2s	kRFA1Es	1 : 100
0	0.61	0.55	0.59	0.57	0.52	0.60	0.51	0.56	0.61	0.58	0.56	0.53	0.51	0.51
0.90	0.69	0.60	0.63	0.60	0.54	0.68	0.60	0.63	0.62	0.58	0.73	0.68	0.64	0.49
1.04	0.69	0.59	0.65	0.62	0.56	0.68	0.58	0.63	0.64	0.60	0.69	0.66	0.62	0.49
1.62	0.65	0.50	0.53	0.49	0.41	0.63	0.48	0.55	0.51	0.45	0.65	0.60	0.58	0.54
2.22	0.52	0.42	0.45	0.42	0.38	0.51	0.39	0.45	0.44	0.40	0.73	0.69	0.64	0.54
2.54	0.43	0.36	0.38	0.36	0.32	0.42	0.33	0.38	0.37	0.34	0.75	0.71	0.63	0.58
3.96	0.26	0.22	0.23	0.22	0.20	0.25	0.21	0.23	0.23	0.22	0.63	0.59	0.55	0.36
7.32	0.16	0.13	0.14	0.13	0.12	0.15	0.14	0.14	0.14	0.13	0.36	0.33	0.37	0.20
8.82	0.15	0.11	0.16	0.16	0.15	0.14	0.08	0.13	0.18	0.17	0.38	0.36	0.41	0.16
10.35	0.19	0.14	0.19	0.19	0.18	0.18	0.11	0.16	0.21	0.20	0.51	0.48	0.51	0.19
12.77	0.22	0.16	0.22	0.22	0.20	0.21	0.13	0.19	0.23	0.23	0.58	0.54	0.53	0.21
16.37	0.29	0.23	0.29	0.28	0.27	0.28	0.20	0.26	0.30	0.29	0.50	0.48	0.48	0.28
19.96	0.37	0.31	0.37	0.36	0.34	0.36	0.30	0.34	0.38	0.36	0.46	0.45	0.48	0.33
24.04	0.41	0.36	0.40	0.39	0.36	0.41	0.37	0.38	0.41	0.39	0.43	0.40	0.39	0.40
26.76	0.55	0.47	0.53	0.51	0.48	0.54	0.46	0.50	0.54	0.51	0.41	0.39	0.41	0.46
32.16	0.61	0.55	0.59	0.57	0.52	0.61	0.55	0.57	0.59	0.56	0.38	0.36	0.34	0.51