An Assessment of Accommodation Strategies for Coastal Adaptation in Cape Town, South Africa, in Response to Climate Change

by
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Declaration

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Abstract

As the world finds itself increasingly unable to avoid the negative impacts of the physical phenomena associated with climate change, adaptation to climate change has been brought to the forefront of the international agenda. The range of adaptation technologies available can be categorized into three basic strategies (IPCC, 1990): Protection, (managed) Retreat, or Accommodation.

The practice of adapting existing developments and infrastructure in the coastal zone by the process of accommodation has not yet seen wide implementation as a formalised adaptation strategy. In order for a community to accept and successfully implement accommodation strategies, all community stakeholders are required to accept and live with a certain level of managed risk, and to also rethink the concept of failure. As a result, accommodation practices implemented globally have been closely related to fields such as risk - and disaster management. Structural innovations in the field of accommodation measures include advanced technologies to elevate existing buildings safely above flood levels, and even "amphibious" houses.

In Cape Town, South Africa, the choice between protection, retreat or accommodation as an adaptation measure remains complex. Not much discussion has yet been generated concerning accommodation measures that could be implemented to reduce the risk to existing properties that are already inappropriately located in the risk zone (e.g. seaward of the coastal hazard line), by accommodating the dynamic coastal processes taking place.

Accommodation has been found to be most feasible in Cape Town at case study sites with a stable, non- or slowly eroding shoreline, which are also subject to flooding. The elevation of buildings and the alteration of buildings for flood-proofing, in unison with proactive risk and disaster management, could be implemented to accommodate the impacts of flooding on affected infrastructure.

Located on Cape Town's Atlantic Seaboard, Bakoven serves as a case study sample of such a site where an accommodation-based adaptation solution could be feasible. Both global and regional downscaled climate models have been found to deliver a large range of future climate conditions. Assuming best estimate future predictions, Bakoven properties have been found vulnerable to extreme flooding during both status quo and future extreme events. Environmental conditions at Bakoven are favourable for the construction of piled foundations. Stringent environmental and heritage constraints imposed by local government would, however, render accommodation strategies unviable.

It is recommended that government at all levels be willing to adopt a more flexible approach to governing coastal areas, to ensure that the regulations they impose remain as dynamic as the environments which they govern. The viability and possible benefits of accommodation measures, rather than protection or retreat approaches should be carefully considered on an individual case-by-case basis, in unison with the local community.

Opsomming

Wêreldwyd is gemeenskappe besig om toenemend te ervaar dat hul nie die nadelige gevolge van klimaatsverandering kan vryspring nie. Juis daarom, is aanpassing tot klimaatsverandering noodsaaklik. Die verskeidenheid van beskikbare benaderinge tot klimaatsverandering aanpassing kan in drie hoof kategorieë ingedeel word, volgens die IPCC (1990): Beskerming, (stelselmatige) Retireer of Akkomodasie.

Die aanpassing van bestaande infrastruktuur d.m.v. akkomodasie is nog nie wyd geïmplementeer as ‘n amptelike aanpassings strategie nie. Ten einde die sukses van ‘n akkommodasie strategie te verseker, sal gemeenskappe genoodsaak wees om ‘n sekere vlak van residuele risiko te aanvaar en die konsep van die ‘faling’ te herdefinieer. Akkommodasie oplossings wêreldwyd is daarom nouliks verwant aan risiko- en rampsbestuur. Innovasies in die struktuurindustrie om die risiko van klimaatsverandering te akkommodeer, sluit onder andere in die fisiese oplig van geboue na ‘n hoër, veilige vlak, en ook die bou van sogenaamde “amfibiese” huise.

In Kaapstad is die bepaling van die mees gepaste en voordelige aanpassings oplossing, net soos in die res van die wêreld, kompleks. Die moontlikheid van die gebruik van akkommodasie benaderinge en tegnologieë, eerder as beskermingsstrategieë, is nog nie welbekend of algemeen geïmplementeer nie. Daar bestaan wel ‘n geleentheid om hierdie tegnologieë toe te pas in die geval van bestaande strukture wat seewaarts van die dinamiese kusproses lyn, geleë is.

Hierdie studie het bevind dat akkommodasie oplossings moontlik suksesvol kan wees by spesifieke gevallestudies langs Kaapstad se kuslyn waar die kuslyn grootendeels stabiel is. Die oplig en verandering van geboue om vloedbestand te wees, tesame met proaktiewe risiko- en rampsbestuur maatreëls, word by sommige van hierdie gevallestudies aanbeveel om die impak van klimaatsverandering te akkomodeer.

Bakoven, ‘n klein gemeenskapsbuurt op Kaapstad se kuslyn, is ‘n voorbeeld van ‘n geval waar ‘n akkommodasie oplossing moontlik goed kan werk. Globale klimaatsmodelle lewer ‘n wye reeks van toekomstige klimaatsvoorspellings vir die jaar 2063. Tydens die toets van die mees waarskynlike toekomstige klimaats-scenario, is bevind dat Bakoven kwesbaar is vir die verwagte vloeding a.g.v. seevlakstyging verwag teen 2063. Daar is ook bevind dat selfs tydens huidige storms, sommige strukture aan Bakoven se kus kwesbaar is.

Die omgewingstoestande by Bakoven word beskou as voordelig vir die konstruksie van heipale as fondasies om die geboue hoër op te lig. As gevolg van streng munisipale regulasies met omgewings- en geskiedkundige bewaring as doel, is hierdie opsie egter nie moontlik nie.

Dit word aanbeveel dat die regulasies wat deur regeringsamptenare daargestel word, aanpasbaar genoeg moet wees om die veranderende kusomgewing in ag te neem. Die moontlikheid en volhoubaarheid van ‘n akkommodasie oplossing, eerder as ‘n beskermings- of opgee benaderinge, moet deeglik ondersoek word vir elke ‘n individuele geval, in samewerking met die betrokke gemeenskap.

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- Offshore wave data received from TNPA (Transnet National Ports Authority);
- LIDAR topography data received from City of Cape Town Municipality, Strategic Development Information (SDI) and Geographic Information Systems (GIS) Department;
- Satellite aerial photography received from National Geospatial Information (NGI), a component of Department of Rural Development and Land Reform.

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I honour my Lord for His love, blessing and sustenance - during this time, and always.

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List of Abbreviations

° - degrees

2D – two dimensional

3D – three dimensional

AR4 – Fourth Assessment Report

AR5 – Fifth Assessment Report

BwN – Building with Nature

CBA – Cost-Benefit Analysis

CD – Chart Datum

CEA - Cost Effectiveness Analysis

CEM - Coastal Engineering Manual

CERC – Coastal Engineering Research Centre

CETMEF - Centre d'Etudes Techniques Maritimes et Fluviales [the French Institute for Maritime and Waterways Studies]

CIRIA - Construction Industry Research and Information Association

COP – Conference of the Parties

CSIR – Council for Scientific and Industrial Research

CTCCC - Cape Town Climate Change Coalition

CUR - Civieltechnisch Centrum Uitvoering Research en Regelgeving [Centre for Civil Engineering Research and Codes]

D_{50} – median grain size diameter

DEA – Department of Environmental Affairs

DEA&DP– Department of Environmental Affairs and Development Planning

DHI – Danish Hydraulic Institute

DMB – Disaster Management Bureau

DRR - Disaster Risk Reduction

E - East

e.g. – example given

EEZ - Exclusive Economic Zone

EIA – Environmental Impact Assessment

etc. – et cetera [and more]

EVA – extreme value analysis

FAR – First Assessment Report

FEMA – Federal Emergency Management Agency

GIS – Geographic Information System

GMSL – Global Mean Sea Level

$H_{(m0,deep)}$ – deepwater wave height

H_0 – deepwater wave height

H_{0RMS} – deepwater root-mean-square wave height

HAT – Highest Astronomical Tide

H_s – Significant wave height

i.e. – id est [that is]

ICM – Integrated Coastal Management

ICMA - Integrated Coastal Management Act

ICZM – Integrated Coastal Zone Management

IPCC – Intergovernmental Panel on Climate Change

JONSWAP – Joint North Sea Wave Project

km - kilometre

ℓ - litre

L – wave length

ℓ/s/m – litres per second per metre

L_0 – deepwater wave length

LAT – Lowest Astronomical Tide

LIDAR – Light Detection And Ranging

LLD - Land Levelling Datum

LUPO - Land Use Planning Ordinance

m – foreshore slope

m/s – metres per second

MCA - Multi-Criteria Analysis

MDE - Maximum Development Envelope

MDG – Millennium Development Goals

MHWN – Mean High Water Neap

MHWS – Mean High Water Spring

MLWN – Mean Low Water Neap

MLWS – Mean Low Water Spring

MSL – Mean Sea Level

N – North

NCCOE - National Committee on Coastal and Ocean Engineering

NE – North-east

NEMA - National Environmental Management Act

NGI – National Geo-spatial Information

NGO – Non-governmental organisation

NOAA - National Oceanic and Atmospheric Administration

NW – North-west

POT – Point Over Threshold

PRDW - Prestedge Retief Dresner Wijnberg (Pty) Ltd

q – overtopping discharge per metre

R – Runup

$R_{2\%}$ - 2% wave runup value

R_c – crest freeboard height

RCP – Representative Concentration Pathway

R_{max} – maximum wave runup value

R_{mean} – mean wave runup value

s – second

S - South

SANHO – South African National Hydrographic Organisation

SANS – South African National Standards

SAR – Second Assessment Report

SBEACH - Storm-induced BEAch CHange Model

SDF - Spatial Development Frameworks

SDI – Strategic Development Information

SE – South-east

SIDS – Small Island Developing States

S_{IG} – incident component of swash

S_{INC} – incident component of swash

SLRRA - Sea Level Rise Risk Assessment

$S_{m,0}$ – wave steepness parameter associated with $T_{m-1,0}$

SRES - Special Report on Emissions Scenarios

SW – South-west

SWAN - Simulating WAves Nearshore

SWASH - Simulating WAves till SHore

SWL - still water level

SYR – Synthesis Report

t - tonne

TAR – Third Assessment Report

TAW - Technical Advisory Committee on Flood Defences

T_m – Mean wave period

TNPA – Transnet National Ports Authority

T_p – Peak wave period

UK – United Kingdom

UNCED - Conference on Environment and Development

UNEP – United Nations Environment Programme

UNFCCC – United Nations Framework Convention on Climate Change

USA – United States of America

USACE – United States Army Corps of Engineers

USD – United States Dollar

UTM – Universal Transverse Mercator

W - West

WG – Working Group

WGS – World Geodetic System

WMO – World Meteorological Organisation

ZAR – South African Rand

1. Introduction

1.1Research Problem

Throughout its existence, the human race has been adapting to its environment. Our ability to adapt our practices, resource dependencies and social structures to uniquely suit specific environments, has ensured the human race's survival and prosperity in a wide range of dynamic physical, institutional and social environmental conditions.

Since the end of the 19th century, climate change (often assumed to be the result of anthropogenic forcings, factors causing the climate of the Earth to change) has been presented as a global threat to current and future generations. A change in the climate (whether due to natural or anthropogenic causes) could have potentially disastrous impacts on the human environment, which will be felt across many sectors, such as agricultural production, infrastructure development and provision, tourism, human health science, ecology, etc. The coastal zone specifically will be impacted by physical phenomena associated with a rise in temperature of the earth and its oceans, including (but not limited to) sea level rise; an increase in the occurrence and intensity of sea storms, and a change in the hydrodynamics of ocean currents.

Engineering and technology have played a key role in enabling these coastal communities to respond to and mitigate the adverse effects of climate change. The range of technologies available can be categorized into three basic strategies (IPCC, 1990):

- Protection
- (Managed) Retreat, and
- Accommodation.

Protection and retreat measures are widely and relatively easily implemented as national adaptation strategies. Although it can be argued that accommodation might be the spontaneous or autonomous response of a community at risk, the practice of adapting existing developments and infrastructure in the coastal zone by **accommodating** the rise in sea level has been lacking as a formalised adaptation strategy.

Due to the high environmental and economic cost of the protection and retreat approaches, accommodation technologies could serve as a viable alternative to adapting to the effects of a rise in sea level in certain coastal areas. In South Africa especially, due to the financial, environmental and political constraints surrounding protection and retreat measures, accommodation measures could prove invaluable.

1.2 Research Objective

The objective of this study is to assess the viability of using accommodation technologies as a successful coastal adaption strategy for the South African coast, by focusing on case study sites along the coastline of the City of Cape Town Municipality.

1.3 Report Layout

For ease of reference to the reader, a brief overview of the layout of this report is provided here.

In order to provide the right context when discussing adaptation to climate change, Chapter 2 of this report provides an overview of existing knowledge on climate change and future climate predictions. Chapter 3 of this report reviews the different adaptation technologies available globally to respond to climate change, according to a commonly-used classification system for different adaptation approaches, provided by the Intergovernmental Panel on Climate Change (IPCC) (1990). In Chapter 4, the use of accommodation measures as a particular coastal adaptation measure is investigated and examples of accommodation measures in various sectors are provided.

Setting the scene for a local adaptation assessment, Chapter 5 provides an overview of current South African coastal adaptation legislation, focusing on three levels of government: national provincial and municipal.

Chapter 6 then aims to theoretically test the application of accommodation measures at each of ten selected case study sites along the City of Cape Town Municipality's coastline. Based on a high-level assessment and using information from existing previous research, the aim of this chapter is to evaluate the feasibility of implementing accommodation measures at a particular site, in lieu of a protection or retreat approach. A standard reporting template is used for all sites.

Of the ten sites screened in Chapter 6, one site is selected to perform a more detailed assessment of the feasibility of implementing accommodation technologies at that site. A detailed assessment of the feasibility of implementing accommodation at Bakoven (the site selected from the site screening exercise), is presented in Chapter 7.

This report concludes in Chapter 8 with a set of conclusions and recommendations on the use of accommodation measures as an adaptation response to climate change, based on the results of this study.

2. Climate Change

2.1 Introduction

Chapter 2 establishes the context of the study by defining the term climate change, (Section 2.2), providing a description of its international role players, a short history of milestone events (Section 2.3) as well as the continuing debate surrounding the issue (Section 2.4). This chapter continues to describe the future climate predictions (Section 2.5), which are presented in Section 2.6. Lastly, the adverse effects of climate change and possible responses to these effects are presented in Sections 2.7 and 2.8, respectively.

2.2 Introduction

The term “climate change” has become a controversial term used in a wide range of disciplines, from environmental science to engineering to politics - often with divergent definitions and connotations.

Climate change is defined by the IPCC (2012) as:

> a change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use
>
> IPCC, 2012.

This definition differs slightly from the definition provided in 1992 by the United Nations Framework Convention on Climate Change (United Nations, 1992). Article 1 of this document defined climate change as:

"a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."

United Nations, 1992.

For the purposes of this study, the broader definition of IPCC (2012) will be adopted.

2.3Science of Climate Change – International Role Players

The leading international role player in the science of climate change is the Intergovernmental Panel on Climate Change (IPCC). The IPCC was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO). Their mandate is to provide a clear and unbiased view on the current state of knowledge in the science of climate change as well as the potential impacts this climate change could have on various sectors (IPCC, 2012). They have published many assessment reports, including:

- First Assessment Report (FAR) – 1990
- Second Assessment Report (SAR) – 1995
- Third Assessment Report (TAR) – 2001.

The Fifth Assessment Report (AR5) Working Group (WG) Reports and Synthesis Report has been scheduled for completion over a period from 2013 to 2014 (IPCC, 2012):

- WG I: The Physical Science Basis – released September 2013
- WG II: Impacts, Adaptation and Vulnerability – due mid-March 2014
- WG III: Mitigation of Climate Change –due early April 2014
- AR5 Synthesis Report (SYR) – due October 2014.

The 1992 Earth Summit is a significant milestone in the history of climate change. This event, formally known as the United Nations Conference on Environment and Development (UNCED) took place in Rio de Janeiro, Brazil. Stakeholders from various spheres of influence, including government, NGOs and the media, gathered to discuss global problems such as poverty, war and challenges facing developing nations, as well as possible solutions to these problems (Heinrich Boell Foundation, 2003).

- Agenda 21 — a programme for global action in all areas of sustainable development. Article 17 of Agenda 21 committed countries to establishing integrated coastal zone management (ICZM), which is where this concept was first born (ICZM is discussed in more detail in Section 4.3.7).
- The Rio Declaration on Environment and Development — a series of principles defining the rights and responsibilities of States.
- The Statement of Forest Principles — a set of principles for the sustainable management of forests.

In addition, a legally binding Convention, aimed at preventing global climate change, was prepared at the Summit, i.e. the United Nations Framework Convention on Climate Change (UNFCCC) (United Nations, Department of Public Information, 1997). The decision-making body of the UNFCCC is called the Conference of the Parties (COP). All governments that are party to the UNFCCC are represented in this body (United Nations Framework on Climate Change, 2012).

A short history of the Conferences of the Parties highlighting some of the significant decisions and actions specifically relating to adaptation is presented below.

- COP 3 (the third conference of the parties) was held in December 1997 in Kyoto, Japan. At this conference, delegates agreed to a protocol (later termed the Kyoto Protocol) that commits Annex I parties (developed countries and countries making the transition to a market economy) to the reduction of carbon emissions, i.e. mitigation measures. It was not until four years later, at the adoption of the Marrakesh Accords in 2001, that adaptation became a prominent area for action (Haerlin & Heine, 2007).

- In November 2005, the Parties to the UNFCCC launched the 'Nairobi Work Programme on Impacts, Vulnerability and Adaptation to Climate Change,' making adaptation a key issue for negotiations, focusing on developing countries, including least developed countries (LCDs) and small island developing states (SIDS) (United Nations Framework Convention on Climate Change, 2011).
- In 2009, following the UN Climate Change Conference in Copenhagen, the Parties to the Convention agreed on the Copenhagen accord. This accord stated the need for:

> enhanced action and international cooperation on adaptation to ensure the implementation of adaptation actions aimed at reducing vulnerability and building resilience in developing countries, especially in those that are particularly vulnerable, such as least developed countries and small island developing states.
>
> Conference of the Parties, 2009.

- In 2011, COP 17 was held in Durban, South Africa, The main focus of the conference was on mitigation – focusing specifically on establishing a second commitment to the Kyoto Protocol (due to start on1 January 2013) and launching a process to develop a future legal framework that will cover all nations of the world and make the Protocol legally binding under international law.
- At the 2012 United Nations Conference on Sustainable Development in Rio de Janeiro, Brazil the Parties, recognizing the uneven progress over the twenty years since the Earth Summit in 1992, renewed their commitment to, amongst other things:
  - sustainable development
  - ensuring the promotion of an economically, socially and environmentally sustainable future
  - achieving the set millennium development goals (MDG's) by 2015; and
  - poverty eradication.

The Parties reaffirmed their commitment to the Rio Convention and past action plans, urging all Parties to fully implement their commitments under the UNFCCC. Eradicating poverty was identified as an indispensable requirement for sustainable development. Although not a main focus area, it was recognized that adaptation to climate change represented an immediate and urgent global priority.

2.4Climate Change Sceptics

Although the future climate scenarios predicted by the IPCC and the attribution of these climate changes to anthropogenic influences are often presented in literature as undisputed facts, not everyone in the scientific community agrees with the IPCC's opinion on the state of the climate and future climate change scenarios.

There exists a group of climate change-sceptics that challenge the climate change scenarios predicted by the IPCC, stating that the claim that anthropogenic $C0_2$ emissions are responsible for the warming of the Earth's climate is scientifically insupportable.

Some of the objections that have been raised, questioning the accuracy and validity of the IPCC predictions for future climate change scenarios, include the following:

- Data collection methods employed by the IPCC are unsound and the physics of climate science are not well enough understood (Frank, 2010)
- Climate models used by IPCC scientists have not been sufficiently validated and are therefore unreliable and inaccurate (Frank, 2010)
- The IPCC was established with a political motivation to prove that exceeding carbon dioxide emissions will harm the earth. The approach was neither objective, nor holistic in considering whether the correlation relationship between an increase in global temperature and an increase in greenhouse gas emissions is necessarily a causal relationship.
- The level of uncertainty in climate model predictions exceeds the magnitude of predicted temperature increases (Frank, 2010)

- Climate models have insufficient resolution
- It is claimed that IPCC scientists are dictated to by political government representatives (Gray, 2013) and that the conclusions of the IPCC's assessment reports are based on politician's consensus, rather than scientific experiments and evidence (Happer, 2009).

However, using an extensive dataset of 1,372 climate researchers and their publication and citation data, Anderegg *et al.* (2010) showed that:

- 97–98% of the climate researchers most actively publishing in the field surveyed, support the theories of accelerated climate change presented by the IPCC; and
- The relative climate expertise and scientific prominence of the researchers unconvinced of accelerated climate change was substantially below that of the convinced researchers and they were therefore regarded as less prominent or authoritative (Anderegg, *et al.*, 2010).

Although in science consensus does not necessarily guarantee scientific truth or accuracy, it would seem that the majority of reputable climate scientists and researchers with an authoritative understanding of climate processes, although not claiming that IPCC predictions are flawless, support the IPCC study approach and conclusions.

The IPCC has been and still is criticised for their assumptions and projections of the future climate change, but today no alternative to IPCC exists, and the compilation of climate research published by the IPCC is regarded as the best available. It should also be emphasised that the IPCC is also organised as part of the UN system and it reflects some kind of consensus of what the international research community can agree upon (DHI, 2011).

2.5Climate Model Outcomes

Climate change predictions are made using climate models - mathematical models that simulate the physical behaviour and evolution of the atmosphere and the ocean, using natural and anthropogenic forcings as input. These models are calibrated against historical climate data to ensure the validity of their results and then applied to predict future climate conditions, assuming certain input forcings. Anthropogenic external forcings are unknown for the future, but they can be assessed using assumptions of different kinds of future human behaviour.

For AR4, the IPCC developed qualitative assumptions for the future development of human society and deduced several quantitative future scenarios. Two storylines (A1 and A2) describe a world in which people strive after personal wealth rather than environmental quality, while in the other two (B1, B2) sustainable development is pursued (Erichsen, *et al.*, 2011).

In WGI report of the AR5 report, a series of new scenarios, the Representative Concentration Pathways (RCPs), was used for the new climate model simulations (Intergovernmental Panel on Climate Change, 2013). Each of the four RCPs (RCP2.6, RCP4.5, RCP6, and RCP8.5) is named after a possible radiative forcing value in the year 2100, depending on the amount of greenhouse gases that are emitted in the years to come, taking into account a combination of adaptation and mitigation (Intergovernmental Panel on Climate Change, 2013):

- RCP8.5: Rising radiative forcing pathway leading to 8.5 W/m^2 in 2100.
- RCP6: Stabilisation without overshoot pathway to 6 W/m^2 at stabilisation after 2100.
- RCP4.5: Stabilisation without overshoot pathway to 4.5 W/m^2 at stabilisation after 2100.
- RCP2.6: Peak in radiative forcing at 2.6 W/m^2 before 2100 and a decline afterwards.

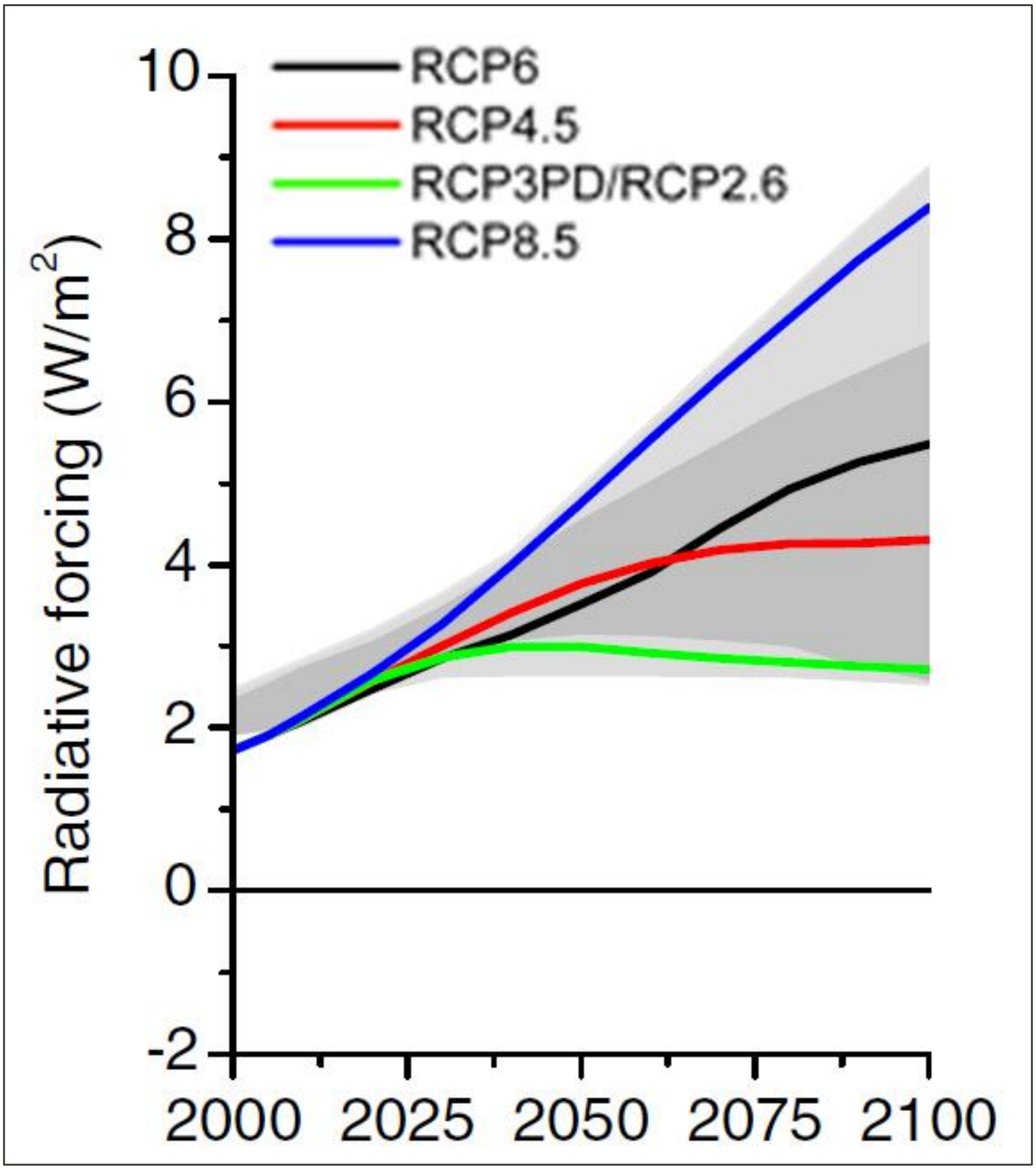


Figure 2-1: Trends in atmospheric concentration of CO_2 for RCP scenarios (van Vuuren, *et al.,* 2011)

2.6Climate Change Phenomena and Future Predictions

Global climate change will have the following consequences, which are very significant for marine infrastructures, coastal areas and the marine environment (Erichsen *et al.,* 2011):

- Increasing temperatures of air and sea water;
- Sea level rise (rise in mean sea level);
- Changing storm surge conditions, due to potential wind changes and rise in sea level;

- Changing wave conditions in terms of both intensity and direction, due to changing wind conditions;
- Changes in precipitation, which will affect (by increase or decrease) runoff to the sea;
- Increased acidity in the water due to increased CO2 in the air; and
- Changes in the hydrodynamics of ocean currents.

This section will study these climate-change related phenomena in more detail.

2.6.1 Sea Level Rise

The concept of sea level rise should be viewed in a greater historic context. According to Compton (2004), the Cape Peninsula shoreline was not always located in its current position. As illustrated in Figure 2-2 (left), a 25 m higher sea level that our current level existed around 5 and 1.5 million years ago. On the right of Figure 2 2, a sea level 125 m lower than our current, is illustrated. This level existed at the time of maximum ice build-up during cold periods – the most recent being 20 000 years ago.

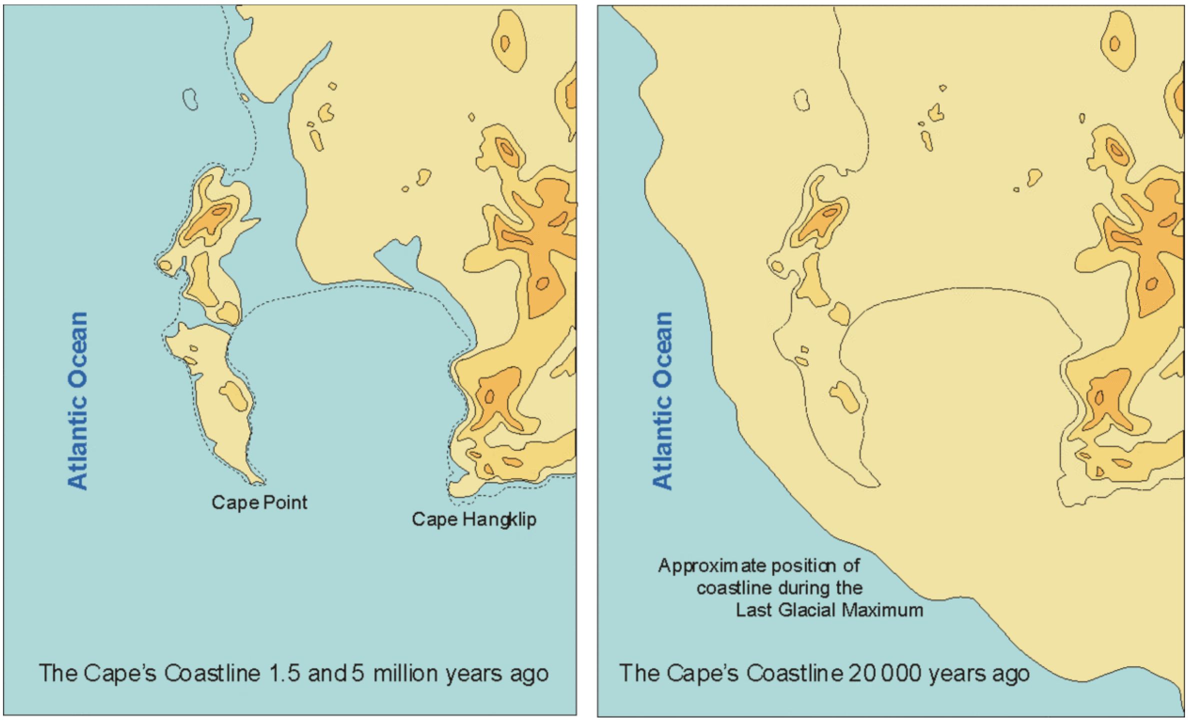


Figure 2-2: Historic shorelines for Cape Town, South Africa (Compton, 2004)

Global sea level therefore has natural cycles of rise and fall. Recent attention has been given to the accelerated rise in sea level due to anthropogenic climate change.

Global sea level depends primarily on three factors (The Ocean Foundation, 2011):

- the volume of water within the world's oceanic basins;
- the temperature (and therefore density and volume) of the oceans' waters; and
- the bottom level of the ocean floor.

The main cause of sea level rise, according to the IPCC (2007), is the thermal expansion of the oceans, contributing between 30 and 55% of the total sea level rise); the melting of glaciers and ice caps (contributing between 20 and 45%) and increased ice discharge from Greenland and the Antarctic ice sheets. Although less common, relative sea level (the sea level relative to fixed points on land) is also affected by land subsidence (due to e.g. excessive groundwater withdrawal) and human activities that influence the sea level directly (Klein, 2002).

A review of the literature history of predicted sea level rise rates shows varying predictions and very little consensus and certainty about the future rate of sea level rise.

Global Predictions

The IPCC's AR5 WG1 contribution was released in 2013, considering new evidence of climate change based on research performed since the IPCC's AR4 of 2007. A major addition since the AR4 is increased understanding of the behaviour of the Earth's cryosphere (consisting of snow, ice, glaciers and frozen ground) and climate interactions that would cause melting of the Greenland and Antarctic ice sheets, glaciers and snow cover. The observed global mean sea level rise for 1993–2010 is now consistent with the sum of the observationally estimated contributions (Intergovernmental Panel on Climate Change, 2013).

Global mean temperature change and sea level rise relative to 1986–2005 (current sea levels) for the various RCPs are presented in Table 2-1.

Table 2-1: Projected change in global mean surface air temperature and global mean sea level rise for the mid- and late 21st century with respect to 1986 – 2005 (Intergovernmental Panel on Climate Change, 2013)

		2065		2100	
Variable	**Scenario**	**Mean**	**Likely Range (5 – 95% confidence interval)**	**Mean**	**Likely Range (5 – 95% confidence interval)**
Global Mean Surface Temperature Change (°C)	RCP2.6	1	0.4 to 1.6	1	0.3 to 1.7
	RCP4.5	1.4	0.9 to 2.0	1.8	1.1 to 2.6
	RCP6.0	1.3	0.8 to 1.8	2.2	1.4 to 3.1
	RCP8.5	2	1.4 to 2.6	3.7	2.6 to 4.8
Global Mean Sea Level Rise (m)	RCP2.6	0.24	0.17 to 0.31	0.4	0.26 to 0.54
	RCP4.5	0.26	0.19 to 0.33	0.47	0.32 to 0.62
	RCP6.0	0.25	0.18 to 0.32	0.47	0.33 to 0.62
	RCP8.5	0.29	0.22 to 0.37	0.62	0.45 to 0.81

Projections from process-based models of global mean sea level rise relative to 1986–2005 for the four emissions scenarios RCP2.6, RCP4.5, RCP6.0 and RCP8.5 are illustrated in Figure 2-3. The solid lines show the median projections, the dashed lines show the likely ranges for RCP4.5 and RCP6.0, and the shading the likely ranges for RCP2.6 and RCP8.5.

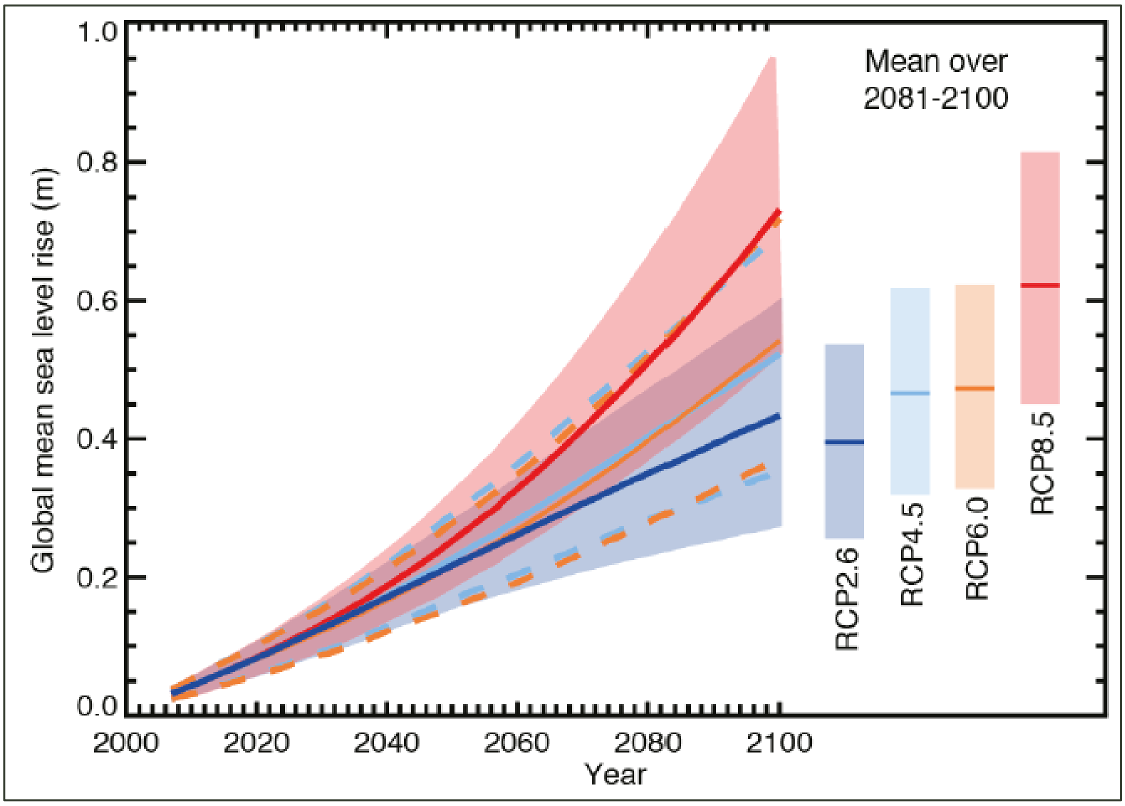


Figure 2-3: Projections from process-based models of global mean sea level rise relative to 1986–2100 (Intergovernmental Panel on Climate Change, 2013)

Based on current understanding, only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause GMSL to rise substantially above the ‘likely range’ (shown in the last column of Table 2-1) during the 21st century (Intergovernmental Panel on Climate Change, 2013). The probability of such a collapse is uncertain, but its potential impact on global sea levels is not expected to exceed several tenths of a meter of sea level rise (Intergovernmental Panel on Climate Change, 2013).

Local South African Predictions

Agreement between global long-term records and approximately 30 years of South African tide gauge records has been reported, leading to the conclusion that the local rate of sea level rise experienced along the South African coastline falls within the range of global trends (Mather, 2007)

Analysing tidal data for Durban, Mather (2007) concluded that the rate of sea level rise for Durban ranges from 2.7 mm/year (if monthly mean sea levels are considered) to 2.4 mm/year, (if yearly mean sea levels are considered). Considering the global average rate of 3.1 mm/year, Mather concluded that the rate of sea level rise on the South African coast is comparable to the global trend.

Mather *et al.* (2009) suggested that in the Western Cape, local sea level rise is less than that for coastlines further east and north, such as the Durban coastline. For Simon's Bay, the linear trend in mean sea level from 1957 to 1991 is 1.1 ± 0.2 mm/year. This is less than the globally recorded rate of 1.8 mm/year for the period 1961 – 2003 (Mather, *et al.*, 2009).

2.6.2 Change in Wave Conditions

Global Predictions

Potential changes in wave conditions due to climate change are still very uncertain. The IPCC predicts an increasing frequency of more extreme storms and cyclones for the 21st Century. It is likely that future cyclones will be strengthened by higher tropical sea surface temperatures resulting in more intense events with higher wind speeds and heavier rainfall, and possibly covering areas of higher latitudes (Intergovernmental Panel on Climate Change, 2013).

Limited information on the expected increase in the intensity and frequency of storm events is provided in WG1 of AR5. There is medium confidence based on reanalysis of forced model hindcasts and ship observations that the mean significant wave height has increased since the 1950s over much of the North Atlantic, with typical winter season trends of up to 20 cm per decade (Intergovernmental Panel on Climate Change, 2013).

Local South African Predictions

In South Africa, Hewitson (2006) predicts that the average wind velocity is expected to increase in all seasons. Due to the limited research available on the predicted increase in wind and wave regimes, Theron and Rossouw (2008) assumed a theoretical, relatively modest increase in wind average speed of 10%. Using the fully developed state wave height relationship:

$H_s = 2.4821 \times 10^{-2} \cdot {U_A}^2$, where:

H_s is the significant wave height in m, and

U_A is an adjusted wind speed according to the equation:

$U_A = 0.71 \times U^{1.23}$, where:

U is the actual wind speed in m/s;

Theron and Rossouw (2008) calculated that a modest 10% increase in wind speed means a 12% increase in wind stress and a 26% increase in wave height, potentially increasing long shore transport rates by between 40% and 100%.

As a part of the City of Cape Town's Climate Change Think Tank project, Prestedge Retief Dresner Wijnberg (Pty) Ltd (PRDW) were appointed to perform the marine inputs to a climate change impact study on the Salt River Flood Model (PRDW, 2011).

Using changes in wind conditions (both on- and offshore) and barometric pressures, as predicted by General Circulation Models (GCM's) by the Climate Systems Analysis Group (CSAG) at the University of Cape Town, PRDW used known relationships between atmospheric pressure, and wind conditions, and wave and water level conditions to predict the changes in offshore and nearshore waves and nearshore water levels (PRDW, 2011). Predictions were made for two future scenarios, 2035 and 2060, for Table Bay.

The changes to environmental conditions in Table Bay for the 2035 and 2060 future scenarios, are presented in Table 2-2.

The details of the methods used to determine these results are discussed further in Section 7.4 of this report.

Table 2-2: PRDW (2011) predicted changes in Table Bay conditions as a result of climate change

	2035		2060	
Parameter	**Best Estimate**	**Upper Estimate**	**Best Estimate**	**Upper Estimate**
Sea-level rise	+0.27 m	+0.27 m	+0.55 m	+0.55 m
Inverse barometer effect	-3 mm	+2 mm	-5 mm	+5 mm
Storm surge	-3%	+2%	-5%	+5%
Offshore wave height	+1%	+6%	+1%	+10%

PRDW found an increase of pressures above Cape Town, and changes to wind directions from predominately south-westerly to a more south-easterly component for surface winds both in Table Bay and in the southern Atlantic (PRDW, 2011). PRDW's findings are consistent with the research by Bengtsonn *et al.* (2006), suggesting a poleward (southward) shift of extratropical depressions in the Southern Hemisphere. However, it is yet unclear whether the combination of southward movement of the depressions (which will have the effect of reducing storm setup and wind setup) and increased storm intensity (which will have the effect of increasing storm surge and wind setup) has a significant impact on storm conditions for Cape Town and Table Bay (PRDW, 2011).

2.6.3 Changes in Precipitation

In most parts of the world, precipitation patterns are expected to change. From a marine point of view, this is important, as river run-off is bound to change as well. In estuaries and coastal areas, river run-off affects salinities and nutrients, which is why significant changes in river run-off potentially will have great impact on the biodiversity and the productivity and vulnerability of ecosystems (Erichsen, *et al.*, 2011).

2.6.4 Ocean Warming and Acidification

An increase in the temperature and acidification (decreasing ocean pH) of the ocean as a consequence of climate change will impact the marine environment as follows:

- Ocean warming could lead to accelerated biological and chemical processes disturbing the fine balance in marine ecosystems. It would also negatively impact oxygen levels and could worsen anoxic conditions, leading to coral bleaching - - a rather abrupt and rapid process whereby corals die as a result of a decline in numbers of their symbiotic algae, zooxanthellae, and the photosynthetic pigments that they produce (Erichsen, *et al.*, 2011).

- Ocean acidification will have detrimental impact on living organisms that depend on formations of different carbonated structures, eventually preventing these organisms and animals from reproducing and surviving. Entire food webs may collapse with unpredictable consequences for ecosystems around the world (Erichsen, *et al.*, 2011).

Decreased coral calcification and decreased coral growth have already been observed on the Great Barrier Reef of Australia as a result of recorded temperature and dissolved CO_2 increases (Erichsen, *et al.*, 2011). In many cases, small island states depend on offshore reefs for the dissipation of wave energy. The deterioration of these coral reefs, together with increased water levels and more sever wave attack would significantly increase the vulnerability of these island states.

2.7 Adverse Effects of Climate Change in the Coastal Zone

Despite the hazards that are related to settling in the coastal zone (such as fierce storms, inundation and erosion), coastal cities remain focal points for trade, fishing and tourism. Many people have settled in coastal zones to take advantage of the range of opportunities for food production, transportation and recreational activities provided here. Theron (2008) states that more than 30% of South Africa's population currently live near the coast. As a result, a rise in sea level could have disastrous impacts on these coastal livelihoods– both locally and internationally. Even a one meter rise in sea level would affect nearly six million people across South Asia and 37 million people along the river deltas of East Asia (Campbell, *et al.*, 2009).

Coastal sites will each react differently to the phenomena caused by climate change. A site already affected by non-climate stresses (e.g. development encroachment or dune degradation) is less able to cope with the additional pressure of sea level rise. The National Committee on Coastal and Ocean Engineering of Australia (NCCOE, 2004 in Theron and Rossouw (2008)) identified a number of potential major impacts on the coastal zone resulting from climate change-induced phenomena, such as sea level rise and increased storm occurrence and intensity:

- Inundation and displacement of wetlands and lowlands;
- Eroded shorelines;
- Increased coastal flooding by storms;
- Salinity intrusion of estuaries and aquifers;
- Altered tidal ranges, prisms and circulation in estuarine systems;
- Changed sediment patterns;
- Decreased light penetration;
- Changed storm patterns, windiness wave energy or direction impacting coastal stability and alignments.

According to Theron and Rossouw (2008), examples of potential impacts on various coastal livelihoods due to climate change include:

Industrial Shipping

- Significant damage on infrastructure such as piers, breakwaters and marinas;
- Hindered shipping access to ports;
- Reduced navigability due to increased storminess;
- Leading to loss of jobs in the long term.

Commercial

- Reduced fair weather fishing time and increased safety risks;
- Increased cost of maintenance to equipment (e.g. boats);

- Increased saltwater intrusion and raised ground water tables in farming areas directly adjacent to estuaries or the shoreline may result in lower earning potential;
- Detrimental effect on shoreline tourism and recreational industries due to damage to coastal infrastructure and unattractive climate conditions;
- Loss of aquaculture areas and other farmlands.

Residential

- Loss of properties e.g. houses, hotels, etc., and their associated employment opportunities;
- Increase in coastal real estate insurance costs or even the inability to insure properties in coastal areas;
- Loss of recreational areas.

Transportation Systems

- Flooding of roads, railways, transit systems, and airport runways in coastal areas.

General Infrastructure

- Potential reduction in freshwater availability due to saltwater intrusion;
- Loss of electricity systems.

Health

- Increased health problems e.g. malaria, cholera and skin diseases due to more standing water.

Environmental

- Direct loss of ecological values through loss of coastal habitats (e.g. mangrove loss due to flooding).

2.8Responses to Climate Change: Limit the Cause; or Adapt to Effect

The choice of response against the impacts of climate change and sea level rise are limited:

- Limit the emissions that cause climate change (i.e. mitigation), or
- Adapt to the effects of climate change (i.e. adaptation).

Mitigation is all human activity aimed at reducing the emissions and enhancing the sinks of greenhouse gases. Adaptation is defined as:

> "any adjustment that takes place in natural or human systems in response to the actual or expected impacts of climate change, aimed at moderating harm or exploiting beneficial opportunities."
>
> Klein, 2002.

For many years, international climate policies focused mainly on mitigation, rather than adaptation. Only in 2001, at the adoption of the Marrakesh Accords, was adaptation seen as an unavoidable response to the effects of climate change already being experienced (Klein, 2002). Mukheiber and Ziervogel (2006) state that while mitigation measures are vital and have to be implemented to reduce the future need for adaptation; this has to be combined with efforts at adaptation. Even though there is a great amount of uncertainty surrounding predicted climate change, choosing to wait to implement adaptation strategies could have fatal consequences.

Arguments for the immediate implementation of adaptation, together with mitigation measures, include the following:

- Even if mitigation measures prove successful and greenhouse gas concentrations were to be stabilized, due to the long timescales associated with climate processes such anthropogenic warming and sea level rise, the effects of climate change could continue for centuries (Theron & Rossouw, 2008);
- Large increases in coastal populations already threaten the resilience of coastal zones, and will continue to do so as populations grow;

- While limiting emissions depends on other governments too, adaptive response strategies depend largely on the applicable country's own capability in terms of finance, technology and human resources;
- Adaptation costs are likely to increase in the future;
- Specific opportunities for adaptation could be lost if they are not acted upon immediately. Certain ecosystems (coral reefs, for example) may not be able to recover from the effects of climate change (The World Bank, 2000);
- Adaptation strategies may require very long time frames to be discussed and implemented successfully in unison with local communities. These processes should not be rushed (The World Bank, 2000);
- Many of the adaptation measures can be viewed as recommended best practice, regardless of the climate change scenario that will realise ('nothing that shouldn't be done anyway').

Adaptation should be brought to the heart of the immediate international agenda in order to maximise the potential benefits that can be reaped, and avoid the potentially disastrous effects of climate change in the future.

3. Adaptation to Climate Change

3.1 Introduction

As concluded in Section 2.8, implementing adaptation strategies and technologies should form a key part of the response to climate change. This chapter reviews the concept of adaptation under the following headings:

- Section 3.2 - The definition of the term adaptation;
- Section 3.3 - The objective of adaptation;
- Section 3.4 – The classification of the different types of adaptation measures that are available; and
- Section 3.5 and 3.6 - Guidelines for choosing and evaluating the most appropriate adaptation measure to implement.

3.2 Definition of Adaptation

The Intergovernmental Panel on Climate Change defines adaptation as an adjustment in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. (IPCC, 2001) This term refers to (Jarungrattanapong & Manasboonphempool, 2009):

- changes in behaviour, processes, practices, responses or structures;
- to either:
    - moderate or offset potential damages, or
    - take advantage of the opportunities associated with changes in climate;
- by making adjustments that reduce the vulnerability of communities, regions, or activities to climate change and variability.

3.3 Objectives of Adaptation

Five generic objectives of adaptation (all applying to adaptation in the coastal zone) have been identified (Klein, 2002):

Increasing the robustness of infrastructure (for example, by designing a system to withstand a larger range of temperature or precipitation without failing), and/or changing a system's tolerance of failure (for example, by increasing economic reserves or insurance).

- Increasing the flexibility of vulnerable managed systems (for example, by allowing mid-term adjustments of a system, including change of activities or location) and/or reducing the economic lifetimes of systems and/or removing barriers to migration (such as establishing eco-corridors).
- Reversing trends that will increase the vulnerability of a system (mal-adaptation), for example introducing zoning regulations in areas vulnerable to flooding.
- Improving a community's awareness of and preparedness for the negative effects of climate change (for example, by educating the public of the risks and possible consequences of climate change, or setting up early-warning systems).

Key characteristics of adaptation measures that successfully fulfil these objectives are (Adger, *et al.*, 2007):

- Community-based , enabling communities to enhance their own adaptive capacity and increase their resilience to climate change impacts (Wong, 2010);
- Site-specific, differing from tropical to semiarid and arid regions;
- Successfully integrate modern and traditional adaptation technologies;
- Integrated and mainstreamed into development planning and all related government policies and regulations;
- Rehabilitate and protect natural resources from damage from climate change;
- Locally acceptable and involve cooperation at all stages;

- Viewed as on-going processes, reflecting many factors or stresses, rather than discrete measures to address climate change, specifically.

Because of the uncertainty associated with climate predictions and their potential impacts, the focus of developing adaptation options should be placed on 'no regrets' adaptation measures – measures that would be justified and beneficial, even in the absence of climate change (IPCC, 1990).

3.4Classification of Adaptation

Adaptations come in a huge variety of classifications. Adaptation measures can be classified as either autonomous (i.e. self-controlled or self-initiated by the community) or planned by government; reactive or anticipatory; ‘hard’ or ‘soft;’ and of either public or private interest. The most effective and cost-efficient adaptive responses will generally be planned, anticipatory adaptive measures and involve collaborations among different groups (Warren, 2004).

In this study, another classification of adaptation options, as introduced by IPCC in 1990, will be used. This classification distinguishes between the following three basic strategies:

- Protect—reduce the risk of the event by decreasing the probability of its occurrence;
- Retreat—reduce the risk of the event by limiting its potential effects; or
- Accommodate—increase society’s ability to cope with the effects of the event.

The three strategies are illustrated in Figure 3-1 (IPCC, 1990), by means of the example of a structure at risk of flooding and/or erosion damage due to sea level rise. The different adaptive response options for this example are:

- Protect— build a seawall/dike to protect the structure against the rising sea level by preventing the sea from reaching the structure;
- Retreat—move the structure out of the risk zone to a sufficiently raised inland location that will not by effected by a rise in the sea level;
- Accommodate—raise the structure on stilts to avoid damage/loss by the rising sea level;

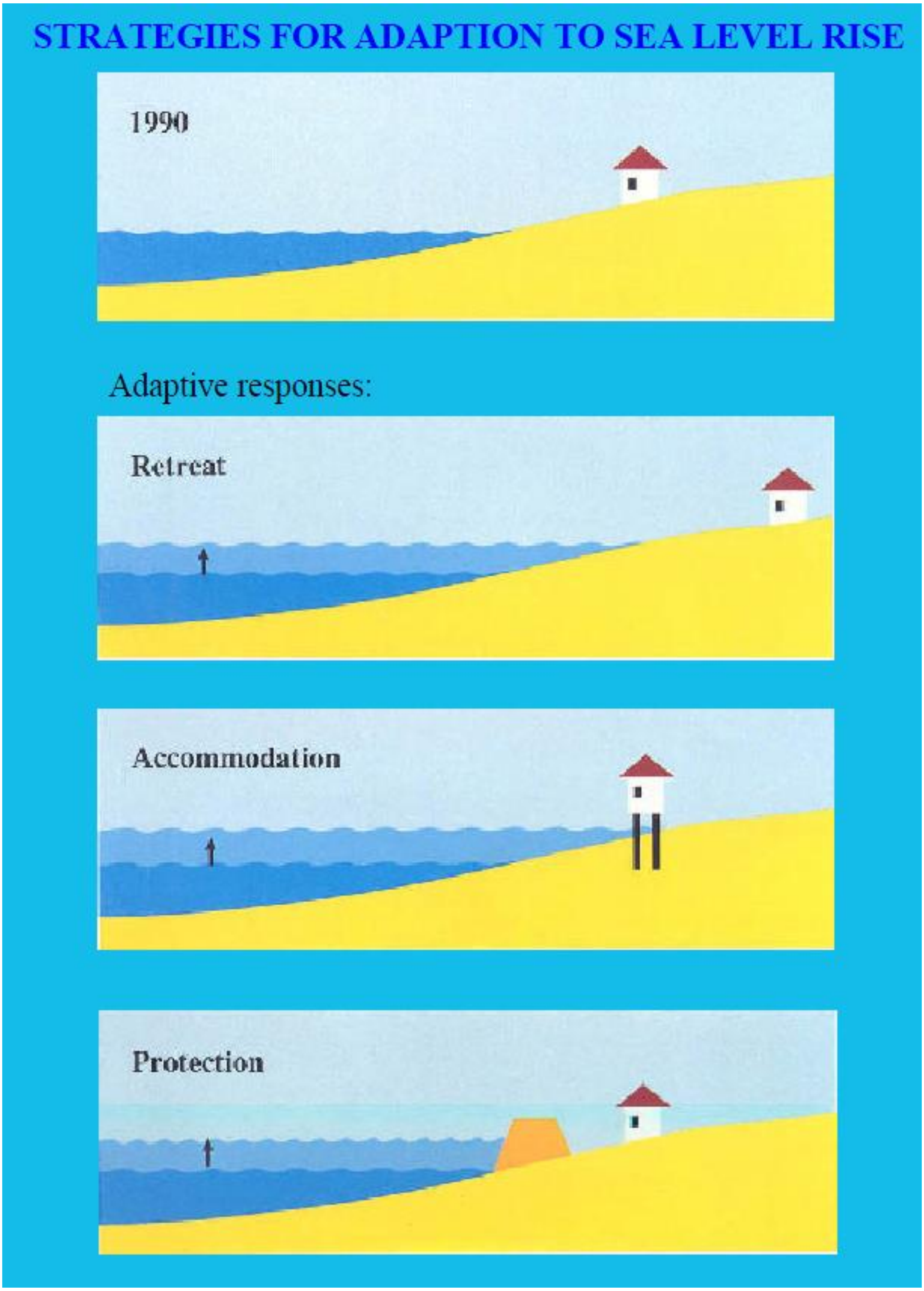


Figure 3-1: IPCC adaptation strategies (IPCC, 1990)

Each of these three strategies (protect, retreat or accommodate) are expanded upon in the following sections.

3.4.1 Protect

Protection measures aim to defend vulnerable areas of land from the ocean and its associated processes by the construction of hard or semi-hard structures (e.g. seawalls or sandbags) as well as using soft measures (e.g. beach nourishment or afforestation) to attempt to maintain a stable and safe shoreline position. This option is used to defend vulnerable population centres with high concentrations of capital, infrastructure, economic activities and natural resources.

The use of protection measures is sometimes inevitable, but can have many disadvantages. Protection adaptation measures are often viewed as financially and ecologically unsustainable because of the high maintenance and construction costs, the damage to recreational values; and the damage to integrated coastal ecosystems and processes (Volk, 2008). Although protection measures may provide local defence, “hard” protection measures often have negative effects elsewhere in the global system. As most protection measures are not easily reversible, they could be regretted, for example in a case where the sea level rise predicted in the design scenario never occurs.

Although protection measures could certainly be construed as adaptation to climate change and population growth, Jacob and Showalter (2007) argue that hard protection measures are not at all about adapting human settlements and structures to hazardous environments. For the most part these measures represent the opposite: an attempt to adapt the natural environment to human constructs.

3.4.2 Retreat

Retreat involves no effort to protect the land from the sea. This approach requires either the abandonment or managed relocation of structures in currently developed coastal areas; and the subsequent resettling of communities further inland. Any new development must then be set back specific distances from the shore, as appropriate. This option implies that all natural processes are allowed to occur without constraint and that impacts on humans and infrastructure are minimised by retreating from the coast. It involves no attempt to protect the land from the sea (Bangladesh Coastal Zone Management Centre, 1994).

Retreat is ecologically sustainable, as it allows ecosystem processes to follow their natural course and allows shoreline retreat. This approach can prove financially sustainable by avoiding costs associated with protection, particularly if long range planning occurs – provided no critical or extremely valuable infrastructure is located in the zone of retreat, in which case the grave financial losses may render retreat impossible. Retreat is often not a practical solution, because of existing high population density and the increased sharing of a small resource-base. Relocation of people within the country may also not be acceptable socially (Bangladesh Coastal Zone Management Centre, 1994).

For low-lying small island states, a retreat solution could mean than an entire country's population might need to be relocated. This could have enormous economic, cultural and human costs (Adger, *et al.*, 2007). Migration of this scale would need to be influenced by government intervention, as it is not is within the capacity or ability of all individuals (Adger, *et al.*, 2007).

3.4.3 Accommodate

Accommodation involves the continued occupation of vulnerable areas where natural ocean and shoreline processes are allowed to continue without intervention, while accepting the greater risk regarding the frequency and intensity of flooding, erosion, etc. (Bangladesh Coastal Zone Management Centre, 1994). Accommodation therefore requires inhabitants to make adjustments to human activities and/or infrastructure to accommodate the effects of climate change such as sea level rise and increased storminess and thereby reduce the overall severity of the impacts of these effects.

Accommodation strategies could include measures such as the altering of existing structures (e.g. elevating buildings on piles), the redevelopment of legislation and/or land use planning (e.g. shifting agricultural production to salt-tolerant crops, or prohibiting removal of beach sediment), the enhancing of an ecosystem's natural resilience through rehabilitation projects such as coastal dune and wetland rehabilitation, and the development of early warning systems for extreme events. More detail on this strategy is provided in Chapter 4.

3.4.4 Summary

To further illustrate the differences between the three approaches discussed in Section 3.4, an extract from the Bangladesh Coastal Zone Management Centre (1994) in Figure 3-2 illustrates the possible applications of each of these three strategies in the built environment, wetland conservation and agriculture.

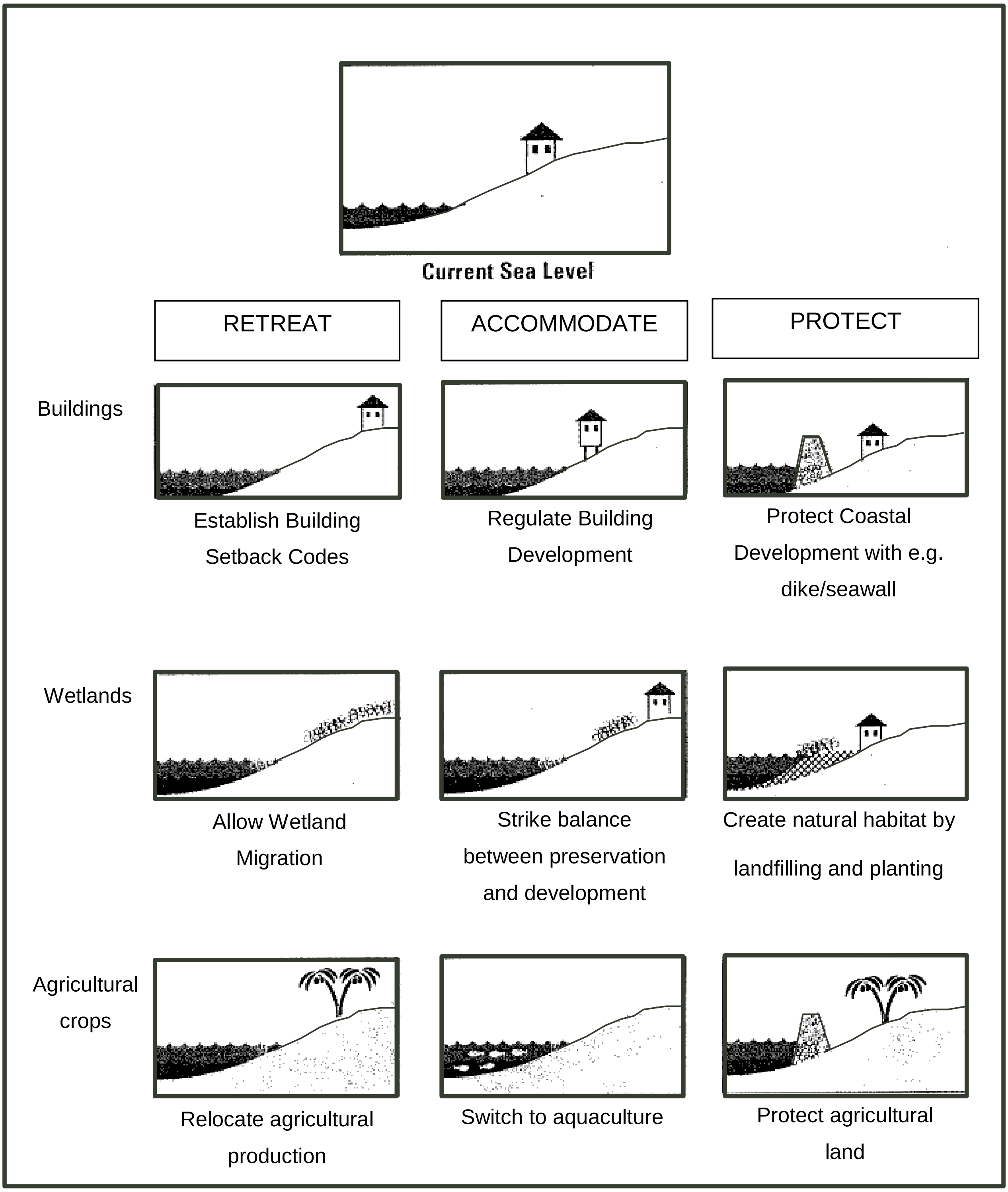


Figure 3-2: IPCC adaptation strategies (IPCC (1990) in Bangladesh Coastal Zone Management Centre, 1994)

3.5Choice of Adaptation Measure

The adaptation option (the choice to protect, retreat or accommodate) that provides the best solution will vary at each coastal site, depending on:

- the specific coastal site's physical, social and political environment;
- the coastal processes at work; and
- the technologies available.

The suitability of each adaptation option must therefore be evaluated in the context of local conditions. More than one adaptation strategies is often implemented at the same time (e.g. protect and retreat or protect and accommodate), in a complementary fashion.

The following considerations form a part of the decision on the appropriate adaptation measure to implement:

- Rate of change being experienced;
- Development objectives;
- Cost-benefit ratios;
- No regrets-approach;
- Bottom-up approach;
- Environmental impacts; and
- Cultural acceptability.

Each of these considerations is discussed below in more detail, and for each consideration an example case study of an international adaptation implementation that was implemented as a result of a need to meet the particular criteria being considered, is provided.

3.5.1 Rate of Change

An important factor to keep in mind when deciding on the appropriate adaptation measure to implement, is the rate at which environmental change is expected to occur. For example, a slowly-rising sea level could allow for the adaptation of coastal infrastructure during the course of normal maintenance or replacement. In these conditions, a retreat or protect approach may be favoured (Warren, 2004). Rapidly changing conditions could, however, necessitate ‘hard’ protective measures in order to protect specific infrastructure at risk.

Case Study: Bar Beach, Victoria Island, Nigeria

Severe erosion has been experienced at Bar Beach on Victoria Island in the city of Lagos, Nigeria, since the disturbance of the longshore sediment regime by the construction of two jetties at the entrance to Lagos harbour. The rate of erosion experienced rendered several beach nourishment projects that have been applied since 1958, unsuccessful, necessitating further construction works in 2006 (Linham & Nicholls, 2010).

A protection approach was adopted and a 1 km long seawall was constructed, consisting of X-blocs - large x-shaped, pre-cast concrete elements that are designed to interlock and dissipate wave energy upon impact. A 10 m wide concrete slab on the crest of the wall provides the area with a promenade that can be used for recreational purposes (Linham & Nicholls, 2010). The finished structure is shown in Figure 3-3.

In response to climate change, this structure can be adapted by raising the level of the sea wall.

Figure 3-3: Bar Beach seawall, Victoria Island, Lagos (Linham & Nicholls, 2010)

3.5.2 Development Objectives

The development objectives for a specific site need to be considered when selecting the appropriate adaptation measure to implement at that site. For example, in an area with high tourism value, sand nourishment could be preferred as an adaptation to beach erosion, rather than the construction of a sea wall.

Case Study: Bournemouth Beach, Poole Bay, UK

Periodic beach nourishment (the replenishment of sand on beaches) since the 1970s at Poole Bay, located on the south coast of England, has helped to maintain a wide, sandy beach as illustrated in Figure 3-4, which is important to the tourist economy of the area,. The nourishment activities, which can be seen as a soft protection measure, coupled with regular and systematic monitoring, provide a best practice case study of beach nourishment.

Figure 3-4: Beach nourishment at Bournemouth Beach, Poole Bay (Linham & Nicholls, 2010)

The benefits of the monitoring programme can be summarised as a shift in the management philosophy from a reactive to a proactive approach (Linham & Nicholls, 2010). By informing the need for re-nourishment, monitoring also ensures that the standard of coastal food and erosion protection does not drop below acceptable levels. By informing the need for re-nourishment, monitoring also ensures that the standard of coastal food and erosion protection does not drop below acceptable levels. In response to climate change, nourishment can be performed more regularly. However, should the sea level keep on rising, at some point the beach will erode and retreat. The properties at the landward edge of the beach would then need to be protected by another measure.

3.5.3 Cost-Benefit ratios

The choice of which adaptation measure to implement, will depend largely on Cost/Benefit ratios. One must ensure that the social, economic and environmental benefits of adaptation policies and measures outweigh, or at least justify, the costs thereof and that no additional negative externalities are created. Different measures of evaluating the costs and benefits associated with adaptation measures are expanded upon in Section 3.5.

Quantifying the costs and benefits of adaptation options is complicated - considerably more so than for mitigation measures. This is partly because of the fact that the performance of adaptation options cannot be measured in a single metric unit (e.g. carbon dioxide concentrations or US dollars), but encompass several non-physical parameters such as cultural acceptability or environmental impact. This makes the comparison of alternative adaptation options very difficult (Klein, *et al.*, 2009).

Limited and fragmented literature is available on the costs and benefits of adaptation. Very few studies of the effects of adaptation across various sectors and their macro-economic consequences are available. Of these limited studies available, many also adopt relatively crude relationships and assumptions (Klein, *et al.*, 2009).

Case Study: Economic Analysis of Flood Risk Reduction Measures for the Lower Vaisigano Catchment Area (Samoa)

Using a cost-benefit analysis approach, this study compared the economic feasibility of different adaptation options for the lower Vaisigano catchment area in Samoa. The options originally identified include structural defences such floodwalls, a diversion channel and the construction of homes with elevated floor heights as well as non-structural measures, such as an improved flood forecasting system and development control (Venton, 2012). The costs and benefits of all options were identified, measured and compared.

Non-structural measures were found to be the most economically viable flood management options. In the case of an improved forecasting system, the ratio of benefits to costs was estimated to range from 1.92 to 1.72, depending on the choice of discount rate used to carry out the analysis (Venton, 2012). The most significant economic pay-off from investing in flood management options is found to be from constructing homes with raised floors. For new homes, the benefit cost ratio is found to range from 4 to 44 for wooden homes, and from 2 to 28 for cement block homes (Venton, 2012).

The structural protection measures that were considered in this study, such as floodwalls and diversion channels, were not found to be as economically viable. The benefit-cost ratios for floodwalls ranged from 0.11 to 0.64, and the benefit-cost ratios for the construction of a diversion channel ranged from 0.01 to 0.09 (Venton, 2012).

The use of a cost-benefit analysis in this study allowed useful recommendations to be made to the Government on which adaptation measures were the most appropriate to invest in. This study recommended an improved forecasting system, in conjunction with public awareness campaigns, and an effective flood advisory system. It was also recommended that zoning regulations should be put into place to specify the minimum floor height of newly constructed homes to be higher than the 1-in-100-year return period flood levels for the area where it is located. It was also recommended to make flood-proofing of new homes more affordable to residents by e.g. the use of grants, tax rebates or low-interest loans to encourage residents to implement these flood-proofing measures in their homes (Venton, 2012).

3.5.4 No Regrets

It is important to give priority to ‘no regrets’ measures which would be beneficial to their environment, even in the absence of climate change. For the successful design of structural measures such as sea walls and groynes, a high degree of certainty in expected environmental conditions at a particular site is required. In the event that environmental conditions turn out to be different than had been expected during the design phase, these measures could prove ineffective, or even detrimental to their environment.

Case Study: Mangrove Afforestation, Bangladesh

The coastal areas of Bangladesh have a high frequency of cyclones and historic events have caused significant damage, high death tolls and significant numbers of casualties. In 1966 a programme of mangrove planting was initiated on the seaward sides of protective embankments in the coastal districts of Patuakhali, Barisal, Noakhali and Chittagong to create a shelter belt to protect coastal communities (Linham & Nicholls, 2010). This measure can be seen as a combination of a protection and accommodation approach.

The early success of these plantations resulted in the setting of additional objectives which included:

- providing forest products for a range of uses;
- developing forest shelter belts to protect inland life and property from tidal surges;
- producing resources such as timber into the national economy;
- creating employment opportunities in rural communities; and
- providing an environment for wildlife.

This project is an example of an adaptation measure that would be beneficial even should climate change scenarios not match current predictions.

3.5.5 Bottom-up Approach

It is beneficial to use community-based (bottom-up) rather than government-imposed (top-down) interventions, where possible. Measures that were developed in collaboration with the local community often have a greater chance at success than top-down solutions. External help from e.g. government is still required to handle certain threats (such as global carbon emissions) that are beyond a specific community's control.

Case Study: Lincolnshire Coastal Study

In 2007, a moratorium was placed on all new development in the three coastal districts of Lincolnshire, UK, until a formal coastal strategy had been agreed upon. The Lincolnshire Coastal Study, commissioned to inform the development of a Coastal Strategy for sustainable spatial development, serves as an example of how the community can be involved in the development of coastal regulations (van Dijk, *et al.*, 2011), developed as part of an accommodation measure.

The study took a scenario and stakeholder-based approach to examine future changes and to develop principles for sustainable development. Flood hazard maps and socioeconomic scenarios were developed and presented to a range of technical and non-technical stakeholders, whose views were used to develop the principles for development (van Dijk, *et al.*, 2011).

The outcome of the study was the development of a set of principles that would reduce the number of people at risk of hazard from flooding, and address the mitigation of consequences through design and emergency planning.

A leaflet that was used to promote community involvement is shown in Figure 3-5.

Figure 3-5: Lincolnshire coastal study leaflet (van Dijk, *et al.,* 2011).

3.5.6 Environmental Impacts

The environmental impact of a specific adaptation measures should be considered when selecting the preferred adaptation option for a specific site. Adaptation options should be evaluated based on their impact on the overall vulnerability of the entire coastline, not only on their impact at a particular site.

Case Study: Building with Nature Innovation Programme

Building with Nature is a new infrastructural research programme carried out by EcoShape, a consortium of private partners, government agencies and knowledge institutes operating at the nexus between nature, engineering and society (de Vriend & van Koningsveld, 2012). Building with Nature makes innovative use of natural structures and processes to create integrated solutions that:

- are flexible,
- help to safeguard economies and boost ecologies,
- are both cost effective and sustainable, and
- make countries safer and more attractive places to live (de Vriend & van Koningsveld, 2012).

One of the pilot projects of the Building with Nature (BwN) innovation programme is the Sand Engine nourishment on the Dutch coast.

Parts of the Dutch coastline require regular maintenance and strengthening, with consequences to the local ecosystem and beach use. Experiments have been made to, rather than placing sand directly on the beach, place the sand on the foreshore at one well selected location, and leave it to natural forces to distribute the material. The experiences with these foreshore nourishments are positive: although it is a larger total volume that has to be handled, the effectiveness is good, total costs are less and the area is significantly less disturbed (van Raalte, *et al.*, 2011).

Based on this idea a mega-nourishment 'sand engine' was launched for the coastal province of South Holland on the coast near Ter Heijde, one of the weaker parts of the Dutch coast. In 2011, a volume of more than 20 million m^3 of sand was placed in this Sand Engine (van Raalte, *et al.*, 2011). The whole process is being followed intensively through monitoring, and initial observations are positive.

Figure 3-6: Delfland sand engine (Rijkwaterstaat, 2013)

3.5.7 Cultural Acceptability

It is vital to ensure that the preferred adaptation option selected for a specific site is compatible with the socio- cultural traditions of local communities.

Case Study: Chandra, Bangladesh Floating Agriculture Scheme

In 2004 a floating agriculture project began in the village of Chandra, located in the southwest of Bangladesh on the banks of the River Kabodak. In the past, villagers depended on the river and fertile river banks for agriculture, aquaculture, transport and other activities (Linham & Nicholls, 2010). In the 1960s, seasonally flooded wetlands were reclaimed for permanent agriculture.

Although this brought temporary relief from floods, the reclaimed land was isolated from the fertile flood silts which, instead of being deposited on land, were deposited into the river, where they block drainage and lead to permanent water-logging (Linham & Nicholls, 2010).

Due to regular flooding, water-logging and the availability of aquatic weeds, the local situation was deemed suitable for floating agriculture (Linham & Nicholls, 2010). Villagers were supplied with training and technical support on the methods of floating agriculture, with huge success. Floating agriculture is performed by collecting water hyacinth to construct a raft, which is then covered in soil to form a base for cultivating crops. The people of Chandra currently grow 23 types of vegetable and five spices through floating agriculture. Farmers are able to produce and sell goods out of season, for high returns, and are less vulnerable to the effects of cyclones.

An example of floating agriculture crops is shown in Figure 3-7.

Figure 3-7: Floating agriculture at Chandra, Bangladesh (IRIN Humanitarian News and Analysis, 2012)

3.6Evaluating Adaptation Measures

Assessing the economic, environmental and social costs and benefits of adaptation plays a critical role in the process of evaluating different adaptation measures and selecting the most appropriate for implementation. The Nairobi Work Program (United Nations Framework Convention on Climate Change, 2011) presented three commonly used techniques to assess the costs and benefits of adaptation options, proven to be effective decision-support tools in broader development and sector planning contexts: Cost-Benefit Analysis (CBA); Cost-Effectiveness Analysis (CEA); and Multi-Criteria Analysis (MCA).

Cost-benefit analysis (CBA) involves calculating and comparing all of the costs and benefits, which are expressed in monetary terms as a cost-benefit ratio. The comparison of expected costs and benefits can help to inform decision makers about the likely efficiency of an adaptation investment (United Nations Framework Convention on Climate Change, 2011).

Cost-effectiveness analysis (CEA) is used to find the least costly adaptation option or options for meeting selected physical targets. CEA is applied in assessing adaptation options in areas where adaptation benefits are difficult to express in monetary terms, e.g. human health or extreme weather events; but where costs can be quantified. Given that CEA is performed when the objectives of the adaptation measures have been identified and the remaining task is to find the lowest-cost option for meeting these objectives, it does not evaluate whether the measure is justified (e.g. by generating a certain benefit-cost ratio) (United Nations Framework Convention on Climate Change, 2011).

Multi-criteria analysis (MCA) allows assessment of different adaptation options against a number of criteria, each assigned a weighting. Using this weighting, an overall score for each adaptation option is obtained. MCA offers an alternative for the assessment of adaptation options when only partial data is available or when cultural and ecological considerations are difficult to quantify (United Nations Framework Convention on Climate Change, 2011).

Assessing the costs and benefits does not end when adaptation measures are implemented. Costs and benefits should be monitored and evaluated during and after implementation. Besides CBA, CEA and MCA, a number of other approaches can be used to support adaptation planning. These include, but are not limited to, environmental assessments, expert panels or risk-based approaches in which options that achieve an acceptable risk level are selected (United Nations Framework Convention on Climate Change, 2011).

4. Accommodation as a Coastal Adaptation Measure

4.1 Introduction

The objective of this Section is to identify existing types of accommodation measures that are implemented internationally and to assess their implementation.

In order to understand the requirements and consequences of accommodation adaptation measures, Section 4.2 of this chapter reviews the concepts of risk, risk management, resilience and failure within the context of coastal adaptation. Section 4.3 reviews existing practice being implemented internationally, with the aim of identifying the opportunities, constraints, advantages and disadvantages associated with the implementation of accommodation technologies.

4.2 Failure, Resilience and Risk

The concepts of failure, resilience and risk within the concept of climate change are very relevant to coastal adaptation and need to be understood, interpreted and applied correctly in order to understand the approach to accommodation strategies.

4.2.1 Rethinking Failure

Failure has traditionally been defined in a narrow probabilistic sense. When the loading on, for example, a seawall due to storm conditions exceeds the structural strength of the wall, this is traditionally viewed as a failure event. Kamphuis (2000) suggests that we should rethink this concept of failure. Real failure may be when the social and economic structure cannot bear the consequences of the failure of a physical structure, e.g. a seawall. Failure of the social and economic structure to bear these consequences would result in loss of property, money and life.

The different ways of defining failure, and hence the adoption of defence measures, can be seen in the role that natural disasters played in shaping the practice of coastal engineering in, respectively, the United States of America and the Netherlands (Bijker, 2007):

- The American practice focuses on flood hazard mitigation - predicting disasters and mediating the effects during and after their occurrence (i.e. accommodation);
- Dutch practice is primarily aimed at keeping the water out (i.e. protection).

After a series of hurricanes that hit the USA in the 1950s, the USACE and the Weather Bureau of the USA put a significant amount of effort into the development of warning systems and protective measures. These measures have largely prevented loss of life, despite the increasingly higher density population in coastal areas (Bijker, 2007).

An exception to the success of the American approach to flood defence is the disaster of Hurricane Katrina in New Orleans in 2005. At least 1,833 people died in the hurricane and subsequent floods, and total property damage was estimated at $81 billion (2005 USD) (Knabb, *et al.*, 2005). This event can be seen as 'failure' in the sense defined previously – the social and economic structures of New Orleans were not able to handle the impacts of Hurricane Katrina, and major loss of life and money occurred.

It can therefore be seen to be important to empower a system to be able to be able to live with failure, although we cannot consider any loss of life as accommodation. Communities should be empowered by preventing the loss of life and increasing the system's potential to recover from damage – which leads to the next concept being discussed in this section, resilience.

4.2.2 Resilience

Resilience has been defined as the measure of a system's capacity to absorb and recover from the occurrence of a hazardous event, and is widely applied in the fields of social science and ecosystems (Klein, 2002). In coastal adaptation, accommodation measures aim to strengthen a system's resilience in order to absorb or withstand the effects of climate change whilst continuing the use of the system, and to recover from the effects of a hazardous event after its occurrence.

The concept of resilience is defined by considering three dimensions:

> The amount of disturbance a system can absorb and still remain within the same state or domain of attraction; the degree to which the system is capable of self-organisation; and the degree to which the system can build and increase the capacity for learning and adaptation. Klein, 2002.

4.2.3 Risk Management

America's National Research Council (2010) suggests that the adaptation process is fundamentally a risk management strategy. Accommodation measures are in essence measures to help people live with an increased level of risk by reducing the impact of the occurrence of a hazardous event, rather than trying to reduce the likelihood of its occurrence.

Because of the highly dynamic coastal environment, the risk assessment and management process should be continually updated and revised as the project proceeds and the likelihood and impacts of future events change (National Research Council of the National Academies, 2010).

4.3Existing Accommodation Practices

In a historical perspective, societies have always attempted to adapt to and accommodate changing climate conditions, although events related to climate change may not have occurred as frequently and dramatically as we will witness over the coming decades. As a result, many of the activities that are considered as accommodation measures are not new: e.g. risk management, coastal management and spatial planning (Haerlin & Heine, 2007). In some cases it can even be argued that effective accommodation requires no interventions that are not already recommended for safe development (Jacob & Showalter, 2007).

Meister *et al.* (2009) raise the question: Are accommodation measures then merely general measures that should be implemented anyway, regardless of the level of climate change? Climate change is likely to make scarce natural resources still scarcer and put coastlines that are already under pressure from human development under even more pressure. For this reason accommodation measures may sometimes be seen as 'general good practice guidelines,' and can lead to improved sustainable processes and practice even in the absence of climate change. Examples of accommodation measures such as these include integrated management of coastal areas, management of water supplies, pollution control, adaptable design practices and investment into preventative health care (Meister, *et al.*, 2009).

Available accommodation technologies studied in this section have been classified into nine sectors:

- The building sector
- Urban zoning and land use planning methods
- Farming practices
- The financial sector
- Design of infrastructure
- Coastal management
- Forecasting and early warning systems
- Emergency evacuation plans and disaster management

4.3.1 Accommodation Practices in the Building Sector

Buildings are complex combinations of systems - the foundation, the structure, the plumbing, electrical, heating, ventilation and air conditioning systems. A failure of any one or a combination of these systems could catastrophically affect the entire building. Introducing measures to accommodate the consequences of a hazardous event, i.e. flooding, can significantly reduce the risk of failure.

These measures can be either flood resilient (aim to limit damage when flooding occurs and speed up recovery) or flood resistant (aim to prevent water from entering the property): Some measures to increase resilience and resistance against flood damage are more applicable to new buildings, while others are suitable for retro-fitting an existing property. The cost and effectiveness of each of these measures will depend on the physical properties of the building and its location.

Elevating Buildings on Piles

Driving piles to elevate a structure above the flood hazard level can protect the structure against flooding and erosion damage.

Buildings in many locations that are prone to storm surges are already built on stilts, for example, in the Florida Keys. Figure 4-1 shows Gulf coast piling or stilt and pedestal houses that have been standing since 1980.

Figure 4-1: Elevated buildings in Florida Keys (Topsider Homes, 2012)

A South African example of elevated buildings is provided in Figure 4-2: an elevated house on Swartvlei Lake's edge in Sedgefield.

Figure 4-2: Sedgefield house elevated on piles (Toms, 2011)

Elevation of an entire building is usually only undertaken if there is a high chance of severe floods and is most cost-effective when carried out during construction, or re-construction after having been flooded. Depending on the design, it could also be possible to elevate an existing property, but costs may be prohibitive.

The ground floor of an existing building could be raised above the flood depth, provided the ceiling is high enough. For existing buildings this is not a trivial option - if all doors and windows also needed to be raised, the Association of British Insurers (ABI) estimates that this could cost between 30 and 50% of the typical rebuild cost of a domestic property (Lloyd's, 2008).

Floating Houses

An extreme example of accommodation strategies in the building sector is the development of ‘floating’ or ‘amphibian’ houses, a concept developed by Dutch architects and planners. The world’s first floating and amphibian houses have been built close to the city of Maasbommel in the Province of Gelderland, the Netherlands. Dura Vermeer, the largest construction company in the Netherlands, built 46 houses (32 amphibious and 14 floating houses). In 2011, while floods forced other villages along the affected rivers to evacuate, these floating homes survived (van der Pol, 2011).

An amphibious house, such as those on the Maas River, is constructed with lightweight wood and a hollow concrete foundation. The use of these building materials provides the building with a very high buoyancy, similar to that of a ship, causing it to float on water. The foundations of the building are not anchored in the earth but rests on the ground, fastened to mooring posts with sliding connections. This allows the building to float upwards, along with the rising water level, during floods. To prevent the houses from floating away at high water they are fixed to flexible moorings, that can absorb horizontal forces (van der Pol, 2011).

All services to the building, such as electrical cables, water and sewage, are located in flexible ducts within the mooring piles (van der Pol, 2011).

These floating houses have been designed for a maximum water level difference of 5.5 metres (van der Pol, 2011).

Figure 4-3 illustrates amphibious homes on the Maas River in Maasbommel, the Netherlands.

Figure 4-3: Maasbommel, Netherlands (Palca, 2008)

In Thailand, Architect Prisdha Jumsai has borrowed from traditional Thai concepts of 'living with water' to design Thailand's first hospital for the elderly, Bang Khun Thien Geriatric Hospital (Gray, 2012). The site for the 300-bed hospital is located over a permanently flooded area near Bangkok. Instead of landfilling the site, the building was designed with concrete stilts raising it 4 meters above the mean still water level.

Figure 4-4 presents a computer generated model image of the Bang Khun Thien Geriatric Hospital.

Figure 4-4: Amphibian hospital in Bangkok, Thailand (Gray, 2012)

A cluster of floating islands have been designed for construction in the Maldives in 2014. These islands will house hotels, a convention centre, a golf course and a yacht club, amongst others (Gray, 2012). The islands are constructed of pontoons with a core of foam, covered in concrete. These pontoons will be secured to anchored mooring piles by steel cables.

Engineered Foundations

In coastal areas, foundations should be specifically designed to withstand the forces of high water levels, wave forces, high wind speeds, scour, and the possible impact of floating debris. Because of these unique challenges to coastal construction, foundations used for inland construction (such as slab-on-ground, spread footings, and mat (or raft) foundations) would not necessarily perform well in the coastal zone (FEMA, 2010).

Engineered foundations (a foundation system that has been specifically designed to be resilient and resistant to flooding) can help maintain stability and limit structural damage if the building is exposed to severe flooding (i.e. deep water), rapidly flowing water or waves. The system might include strengthened anchorage, improving resistance to erosion caused by flooding and construction with impermeable materials (Lloyd's, 2008).

The foundations of buildings in flood-hazard areas should be constructed with flood-damage-resistant materials, defined as:

> any building product [material, component or system] capable of withstanding direct and prolonged contact with floodwaters without sustaining significant damage. The term “prolonged contact” means at least 72 hours, and the term “significant damage” means any damage requiring more than cosmetic repair.
>
> FEMA, 2008.

Because coastal areas such as bluffs often experience shoreline erosion, buildings located within these zones would need to be elevated on a very deep and open (i.e. pile or column) foundation The foundation should penetrate deeply enough into the ground to prevent failure in the event of severe storm-induced scour and erosion.

Reinforced Cladding

Cladding is the protective layer covering the exterior structure of a building. For a home, it might be brick, stone or wood, and for an industrial or commercial building it might also be corrugated metal or glass. Reinforced cladding can limit structural damage in the event of flooding by resisting the pressure of water on the building and reducing damage from any flood-borne debris. As with engineered foundations, this measure provides most benefit for buildings exposed to fast-flowing water or severe flooding.

An example of reinforced cladding is provided in Figure 4-5.

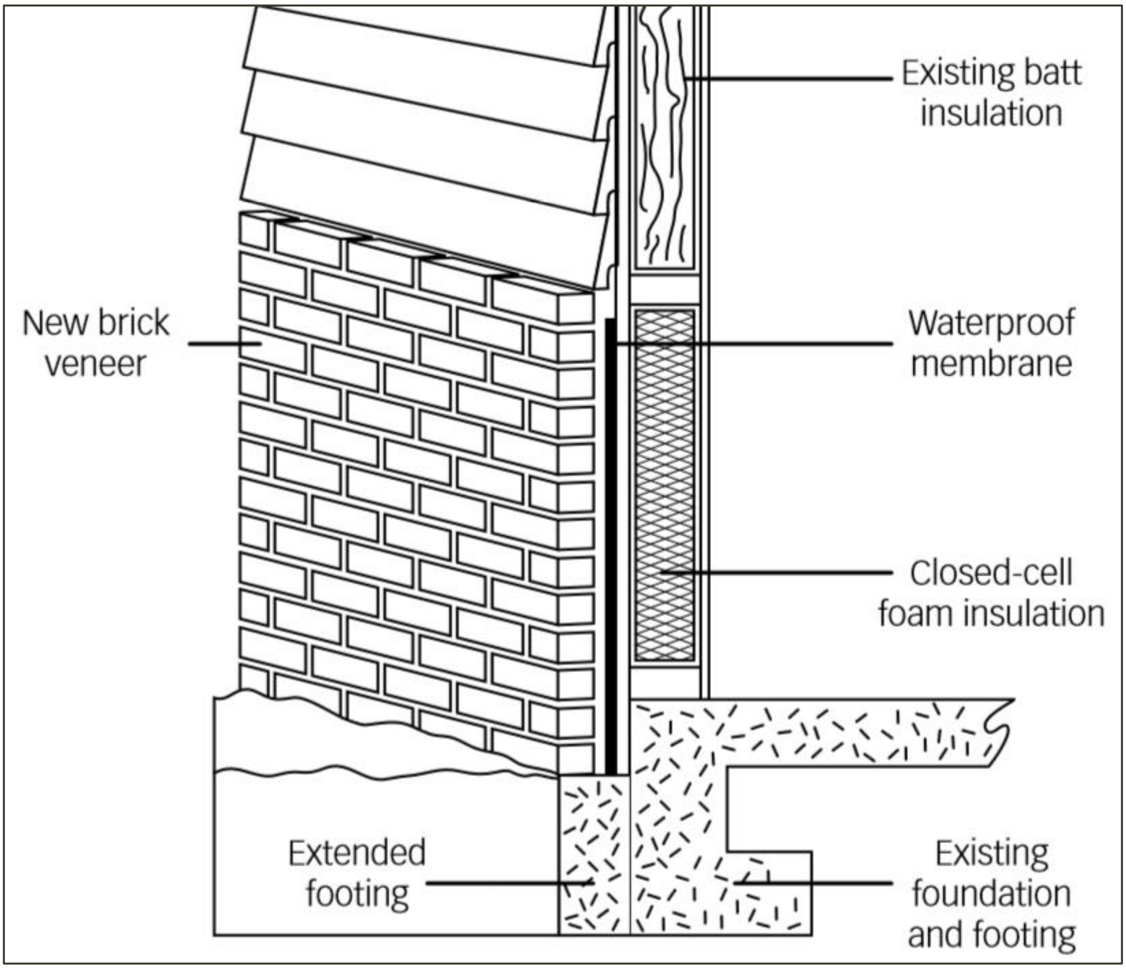


Figure 4-5: Reinforced cladding (Lloyds, 2008)

Reinforced cladding is one of the most cost-effective measures for protecting buildings at high risk. It is more easily applied to new properties but, depending on circumstances, may also be used on existing homes, particularly when under repair from flood damage.

Cladding can be waterproofed as a form of flood resistance. However, this measure is not always suitable. For example, if a building is exposed to deep flooding, it can actually lead to more damage from the additional water pressure on the walls (Lloyd's, 2008).

Protection of External Electrical and Mechanical Equipment

In coastal homes, utility systems (such as electrical and gas supply systems) should be designed specifically to withstand the unique conditions of the coastal zone. If utilities and mechanical equipment are located above potential flood water levels and connected properly, the cost of damage caused by coastal storms can be significantly reduced. Another major benefit is that homeowners could be able to reoccupy their homes much sooner (Lloyd's, 2008).

Dry Flood Proofing

The aim of dry flood proofing is to stop water entering a property. To achieve this, all areas below the flood protection height must be made watertight. This involves a range of measures, such as:

- adding waterproof membranes to the exterior walls,
- placing temporary watertight shields over doors and windows,
- installing backflow valves in pipes and
- applying plastic covers to air bricks.

Dry flood proofing can be effective in reducing damage from less severe flooding, but it is not suitable for properties at risk of very severe flooding (i.e. flood water levels of greater than 90cm) as the pressure of water on the structure can lead to collapse (Lloyd's, 2008).

An example of dry flood proofing measures is provided in Figure 4-6.

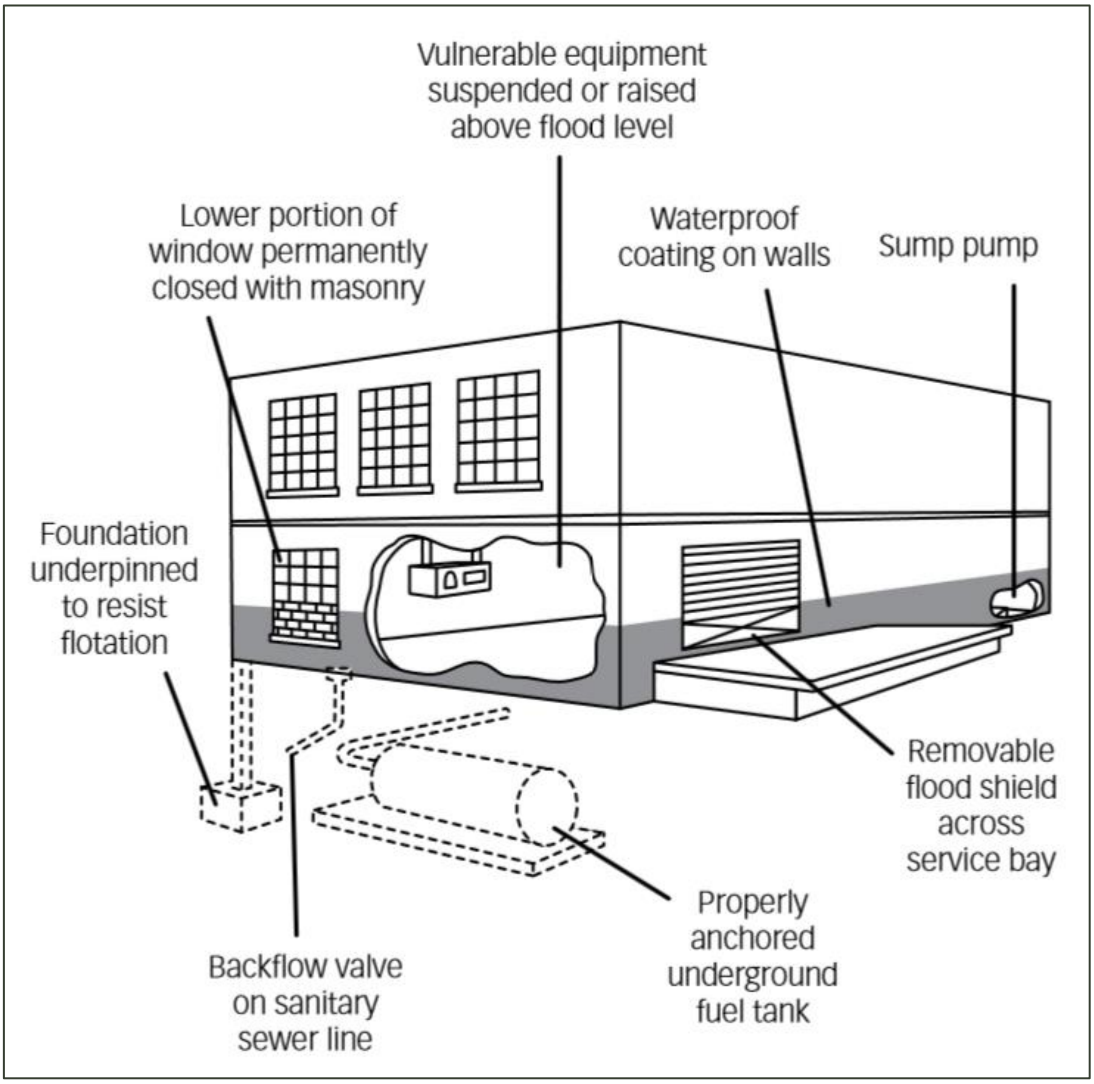


Figure 4-6: Dry flood proofing measures (Lloyd's, 2008)

Strategic Renovation of Houses

Houses can be strategically arranged and renovated in order to accommodate flooding, in one of the following ways:

- When economically possible, houses should be built with two floors. The bottom floors should be used as non-essential/non-valuable zones, e.g. parking. This is especially important when constructing public buildings e.g. schools which could be used as a community flood shelter (Kumar Pal, 2010).
- High-value items, such as furnishings and electrical devices within the property, should be moved out of the path of flood waters to limit damage. In areas at risk of severe flooding, it could be appropriate to move high-value items permanently out of danger, for example, by

keeping computers and media equipment on the upper floors, mounting white goods on plinths and moving the kitchen and heating system upstairs. Moving a kitchen and heating system is a costly option, but can be achieved more easily and cheaply if done in the course of repairs, as evidenced in the English city of York and parts of Germany following heavy flooding over the last decade.

- Tiling ground floors and using removable rugs, rather than carpets, will also limit damage.

Figure 4-7: Use of elevated platforms to protect valuable items in Bangladesh (Jarungrattanapong & Manasboonphempool, 2009)

Protection of Building Openings

Because building openings such as windows and doors are often the weak spots of a building during flood events, they should be carefully designed and constructed. Windows and doors can be designed to be resistant to the impacts from debris, or covered with protective shutters (Jacob & Showalter, 2007).

Improved Roof Construction

A common structural failure in the event of hurricanes, is the loss of roof sheathings. Improved attachment of sheathing to the roof structure, using appropriate coastal zone fasteners and fastener spacing, could help prevent sections of the roof deck from being lifted off by wind, which would lead to progressive failure and wind and water penetrating the building (Jacob & Showalter, 2007).

The installation of metal ‘hurricane clips’ or ‘straps’ along roof-wall connections would provide a continuous load path from the roof to the foundation, which could help to prevent catastrophic roof uplift failures (Jacob & Showalter, 2007).

Improved Roof-Wall Connections

Installation of metal ‘hurricane clips’ or ‘straps’ provides a continuous load path from the roof to the foundation, helping prevent catastrophic roof uplift failures (Jacob & Showalter, 2007).

Adaptable designs

Structures should be designed to be adaptable enough to allow additional strengthening or elevating to be done in the case of a design regime change, without necessitating the complete demolishing and rebuilding of the structure. This can be done by means of piles of which the height can be raised; and modular designs and construction methods.

Modified Design and Construction Codes

By ensuring that structures in the coastal zone are designed and built to be more resilient to flooding and erosion damage, codes and standards are key tools for ensuring public safety and hazard reduction. Design codes should be revised, updated and implemented to demand that adaptation measures are mandatory in the design process. South Africa is particularly lacking in this area, as there is no design manual for ports or coastal infrastructure. Although designers often follow recognised international design guidelines (e.g. USACE CEM, BS 6400, Australian standards), there is no standardized government regulation or national best practice guideline.

Ensuring the proper implementation, administration and control of engineering codes is very important. Buildings constructed without any engineering input, or using poor quality materials and unqualified workers are a great risk to society (Cruz, 2007).

Communities should be encouraged to participate in the development of building regulations and codes to ensure that the community's perception of acceptable risk is taken into account (Cruz, 2007).

4.3.2 Adaptation Practices in the Maritime Sector

As discussed in Section 2.7, the potential effects of climate changes, such as increased wind intensities, higher water levels and changes in wave and current regimes could have a significant impact on maritime infrastructure such as terminals and entrance channels, and shipping routes.

Possible accommodation practices for port terminals include (Scott, et al., 2013):

- Altering of bulk stacking regimes to avoid slumping of stockpiles during extreme heavy rains.
- Dampening of coal stacks to reduce wind-blown dust.
- Weather and camera monitoring on site for the early detection of dust.
- Altered work regimes and OHS systems during extreme heat, fog, rain and wind events to ensure safety of workers.
- Storm locks for equipment.
- Wind monitors on ship loaders to automatically switch off when the wind speed reaches a certain threshold.
- Incorporate sea level rise projections into future port infrastructure design.
- Improved weather forecasting and early warning systems.
- Reduced stacking height of especially empty containers, to prevent containers tumbling over during heavy winds.
- Ensure drainage system has the capacity to handle heavy and prolonged rain events.

- Use of recycled water, particularly during drought conditions when water restrictions are applied.
- Use of active mooring systems during high sea and swell conditions.
- Automation of logistics to remove the requirement for “cease work” during extreme wave, heat, rain and fog events.
- Schedule maintenance work that can be undertaken if other operations cease due to extreme weather events.
- Work with insurance agencies to adapt risk registers and emergency management systems.
- Climate awareness training for various levels of management, administrative and frontline staff at ports.

4.3.3 Adaptation Practices in the Financial Sector

Insurance

As a result of the increased risk of damage to property due to climate change, the demand for insurance products is expected to increase. It is also possible that the risks faced by certain infrastructure (such as buildings located close to the shoreline) could become so high that they become uninsurable (Adger, *et al.*, 2007).

Although insurance alone will not address all of the risks or adaptation challenges of climate change, it could be a strong component of a broader adaptation framework (Wong, 2010).

Insurers can play a positive role in adaptation by:

- enabling individuals to understand the risks they face, by comprehensive and accessible information tools, e.g., risk assessment tools;
- promoting adaptation investments by incentives;
- strengthening, and demanding the implementation, of building standards;

- planning risk prevention measures and developing best practices; and
- raising the awareness of policyholders and public authorities (Adger, *et al.*, 2007).

In many countries, private insurers do not insure a homeowner against flood damage. This is also the case in the USA and Australia. In America, the American Congress created the National Flood Insurance Program (NFIP) specifically to provide property owners with a means to insure their properties against flood damage. The NFIP offers flood insurance at subsidised rates, provided participants agree to adopt and enforce specific building regulations as stipulated by FEMA (FEMA, 2010). Lower insurance premiums therefore provide incentives for property owners to protect their buildings. The insurer also benefits, as the frequency and severity of insurance claims are reduced (Lloyd's, 2008).

A government insurance program may not always be an ideal solution, as this can create a moral hazard known as the ‘safe government paradox,’ essentially moving risk from those who build and live or work in the most hazardous zones, to the government. Changing the market-based actuarial rates for providing insurance in hazardous coastal environments might be a better solution than government subsidised insurance. Where subsidised insurance might be deemed inevitable (in essential port areas, for example), communities, rather than individuals, should be insured, with rates dependent on effective community planning. The focus should remain on restricting new development in hazardous areas.

While insurance can be used to transfer adaptation incentives to individuals, it does not provide the whole solution, and reduced insurance coverage can impose significant economic and social costs. Insurance should be regarded as an effective method to manage only the individual residual risk that cannot be eliminated cost-effectively by adaptation (Adger, *et al.*, 2007).

Microcredit and Microlending

In Bangladesh, the Grameen Bank’s concept of microcredit plays an important role in adaptation. The bank provides credit for the building of houses and funds preventive measures against flooding by providing small loans, issued without formal collateral. These small loans enable the poor to set up small income-generating businesses and climb out of poverty and are paid back on a weekly basis. To date 600,000 houses have been funded with credits of the Grameen Bank.

Professor Muhammad Yunus, the founder and Managing Director of Grameen Bank, was awarded the Nobel Prize in 2006 for his contribution to the field of microfinance. Professor Yunus reasoned:

> "If financial resources can be made available to the poor people on terms and conditions that are appropriate and reasonable, these millions of small people with their millions of small pursuits can add up to create the biggest development wonder."
>
> Grameen Communications, 2011.

4.3.4 Changes in Urban Zoning Methods

Urban Zoning

Even without climate change, the growth of coastal developments around the world will increase the number of properties exposed to storm surge flooding. Urban zoning policies should aim to redirect such settlements away from areas at high risk of flooding. Even within areas at risk from flooding - if new settlements are better planned, flood- resilient design can be employed at a lower cost during the build phase than to attempt to later retrofit (Jha, *et al.*, 2011).

Only temporary, non-essential infrastructure should be zoned in the most vulnerable areas (for example, recreational facilities). A relative density of urban areas should also be sought -increased density enables communities to be more selective about where developments are placed, and the higher density also means that structures can be built much more sturdily because of shared walls, for example (Jacob & Showalter, 2007).

Setback Legislation

A development setback line is a line used to define areas where fixed structures may be built. It is a tool to guide development into the right areas, and out of the wrong ones.

These setback lines are defined by Section 25 of the South African Integrated Coastal Management Act (ICMA) as:

"a line determined … in order to demarcate an area within which development will be prohibited or controlled in order to achieve the objects of this Act or coastal management objectives."

National Environmental Management Act, 2008.

Setback lines need to be sustainable and strike a balance between protecting the coast and stimulating revenue-generating development. Overly-conservative setback lines that restrict development near the coast could lead to a significant loss of revenue from property rates and taxes, and from income-generating activities such as tourism and recreational activities. However, if development is not adequately controlled by setback lines, public access to the coast could be jeopardized and valuable building infrastructure and natural beaches could be damaged or lost.

In Greenfields locations, setback lines should be established by performing an accurate assessment of the coastal processes at a specific site. Regulating development that takes place landward of this line will lower the risk of damage to property and/or loss of life in an extreme event.

Existing developments that are located seaward of the setback line should be evaluated, and re-entered into the adaptation decision matrix. The preferred approach between retreat, protection or accommodation for that property can then be determined. Should accommodation be preferred, one of the accommodation measures or technologies for the appropriate sector might be applied.

4.3.5 Changes in Farming Practices

Crop Selection

Crop selection can be employed to accommodate climate change, e.g. the selection of sorghum and maize and millet in the cooler regions of Africa, maize and beans, maize and groundnuts and maize in moderately warm regions, and cowpea, cowpea and sorghum and millet and groundnuts in hot region (Adger, *et al.*, 2007).

If adequate knowledge and forecasting of weather conditions is available, the growing season of crops should be planned accordingly based on the agricultural cycles and preferred environmental conditions for various crops (Kumar Pal, 2010).

Floating Vegetable Garden

Floating vegetable gardens involve growing vegetables on a floating base of aquatic weeds during the flood season, as illustrated in Figure 4-8.

The floating bed can be made of fresh water hyacinth that keeps the bed afloat while providing nutrients to the plants grown on it. The process involves preparation of a bamboo raft, commonly about 8 m long, 2 m wide and 0.6 to 1 m deep (Irfanullah, *et al.*, 2011). Soil, compost and cow dung are added and seeds are sown. Depending on the decomposition rate of the water hyacinth, the bed needs to be replaced about once in a year. The replaced beds could be used as compost elsewhere such as on rice fields. Crops that can be produced include beans, okra, gourds, onion and pumpkins (Irfanullah, *et al.*, 2011).

Figure 4-8: A: Bean seedlings raised on a floating garden; B: Vegetables grown on floating gardens; C: Floating platforms for seedling raising and vegetable cultivation D: Bottle gourd seedlings with good yields (Irfanullah, et al., 2011)

4.3.6 Accommodation of Service Infrastructure

Infrastructure (such as sewage treatment, storm water systems and energy plants) needs to be designed, operated and maintained with due diligence in awareness of the potential threats of sea level rise and storm events.

Electrical Power Systems

Emergency disaster management responses are often heavily dependent upon functional electrical power systems - damage to these systems can therefore severely hamper a community's capacity to respond effectively to emergency events (Cruz, 2007). Electrical systems should therefore be designed to avoid or minimize disruption in the provision of electrical power during and after extreme events. As a part of disaster response strategies, methodologies for the swift repair and restore of electrical power systems should be developed and ready for implementation (Cruz, 2007).

Drainage Systems

Effective drainage can significantly reduce the effects of flooding and drainage systems should therefore be designed with sufficient capacity for extreme flood events. Physical drainage system adaptations aimed at improving the run-off from land after flooding require two main steps:

- bring water from the land into the main drainage system (mostly performed using gravity); and
- drain the water into the sea.

High water levels experienced during flood events could impede the effective draining of storm water through gravity, necessitating pumping.

Other physical drainage systems that can be built to accommodate the increased runoff in the event of a flood include:

- Permeable pavements;
- Retention ponds; and
- Flood relief channels.

Salt-Water Intrusion

As sea levels rise, saltwater intrusion could threaten fresh groundwater supplies. Possible physical adaptations could include:

- Increasing surface water flows from upstream;
- Rainwater harvesting;
- Increasing local storage capacity of fresh surface or groundwater; or

- Desalination plants and equipment.

Institutional adaptations include

- Maintenance and operation of sluices and other regulators,
- Groundwater management,
- Land use practice (e.g. incentives to change agricultural practices so that agricultural demand for fresh water goes down), and
- Water saving techniques (Bangladesh Coastal Zone Management Centre, 1994).

4.3.7 Accommodation Practices in Coastal Management

Proper coastal management is essential to manage an environment of increased risk. Sound coastal management will also strengthen the resilience of a coastal ecosystem.

Integrated Coastal Management

Integrated Coastal Zone Management (ICZM) recognises the interconnectivity of coastal systems and the requirement for a holistic management approach encompassing a combination of sustainable measures appropriate for the coastal zone. Coastal zone management therefore requires full participation from local authorities and communities. If a specific measure, e.g. a hard protection structure, is implemented without assessing its impact on the entire coastal system of the larger area, it could cause more damage to the coast than actual benefit. This concept is known as ‘maladaptation’. An example of maladaptation is the construction of canals and levees in Louisiana. These canals drained the wetlands, starving it of natural sediments. This caused subsequent land subsidence that lowered certain properties below sea level, thereby increasing their vulnerability (Campbell, *et al.*, 2009).

Mainstreaming

The projected consequences of the effects of climate change, as well as the required adaptation measures, should be systematically integrated into all relevant planning and development strategies. Only then will true integrated management be possible. For instance, the need for adaptation has to be considered in the case of planning land use (e.g., development setbacks) as well as public health emergency plans (Meister, *et al.*, 2009).

Monitoring

Continuous monitoring of sea levels and tides, currents and beach profiles creates an essential database record of the dynamic processes in a changing coastal environment. An accurate long-term dataset on which to base design and planning measures is invaluable. Understanding the dynamic processes aids decision making to determine the most appropriate response.

Impact Assessment Studies

Impact and vulnerability assessment studies are an important tool in developing an understanding of the risk of the occurrence of an extreme event at a specific site. Once the risk and vulnerability have been determined, an appropriate response strategy can be developed. Assessment studies also aid public awareness, thereby improving social adaptation.

Reducing Ecosystem Degradation

Degradation to coastal ecosystems from human activities (such as deforestation and sand mining) often far outweighs the damage caused by climate change, as reported by Campbell *et al.* (2009). As a first point of departure, regulations should therefore be developed and implemented to regulate and/or prohibit these activities in order to reduce damage to coastal ecosystems.

Natural, healthy coastal ecosystems can provide a buffer against wave impacts, decrease the strength of waves and diminish wind flow. Mangrove forests, for instance, provide physical protection to coastal communities by reducing storm surge impact, controlling erosion control, enhancing accretion and stabilising shorelines. They also provide carbon sequestration, nursery and feeding habitats for marine species and improve water clarity. The protection of natural wetlands, mangrove and coral reef systems should therefore be a first priority in coastal zone management (Campbell, *et al.*, 2009).

Forecasting and Early Warning Systems

As discussed, one of the phenomena related to climate change is an increased occurrence and intensity of extreme events. Forecasting and early warning systems that provide timely weather and climate information can significantly reduce the impact on an area hit by one of these extreme events (Jarungrattanapong & Manasboonphempool, 2009).

A system of intelligent information technology buoys along the coastline could help generate timely data that could help protect people and property from coastal storm surges. An example of such a system is a model package developed by Cheung *et al.* (2003) to predict coastal flooding resulting from tropical cyclone events. The model simulates wave and surge generation, coastal wave transformation, surf zone processes, and run-up onto dry land and can be used to forecast extreme events (Cheung, *et al.*, 2003).

In order to be successful, early warning systems require effective communication systems and clear lines of responsibility and coordination among agencies involved in disaster prevention and response. Forecasts should be updated around the clock in critical flood areas, and the information made available on the internet and via telephone and automatic fax, so that affected or interested parties can get updates free of charge (Meister, *et al.*, 2009).

Early warning systems may need to be combined with other robust response measures, e.g. easily accessible and strong cyclone shelters in sufficient quantities to enable all the cyclone prone population to take shelter upon receipt of a cyclone warning.

Disaster Management

There is a strong link between disaster risk reduction strategies and climate change accommodation measures. An increase in the frequency and intensity of storm events (a potential effect of climate change) requires increased preparedness in disaster management organisations and rescue strategies in order to minimise fatalities during these events. In the event of cyclones, countries with properly prepared and implemented disaster management plans have shown more resilience when compared to countries without them. Bangladesh, struck by Cyclone Sidr in 2007, had significantly lower fatalities when compared to similar scale events internationally. This is partly because Bangladesh has a well-tested disaster reduction programme.

Key components of a disaster management programme include:

- Preparation of hazard map(s);
- Improved storm readiness for harbours and marinas;
- Community training on safety, evacuation and its guidance;
- Community organization into disaster management committees at
- Designing and building resilient structures to reduce extreme event impacts;
- Mock drills to sustain training
- Securing of facilities and roads for evacuation and guidance;
- Identify and improve evacuation routes in low-lying areas (e.g. causeways to coastal islands);
- Provision of community shelters for human beings, animals and property;
- Emergency supply chains;
- Search and rescues teams;
- Recovery, rebuilding and resettlement plans (build-back-better plans);
- Health plans, e.g. emergency health services, first aid provision, sanitation, etc.; and
- Standard temporary settlement designs

Although discussed under separate sections, the development of an effective early warning system and communication system to issue warnings at national and international level, as well as a comprehensive public awareness programme should also form a part of this strategy.

A primary condition for the success of a disaster management programme is that the disaster reduction and climate change communities within the government, private sector, civil society, and scientific agencies must cooperate and have clear lines of responsibility.

Innovative research and technology in disaster management is required. A research project was initiated in Bangladesh among a group of architecture students to develop a module to serve environmental refugees. An Emergency Essential Services module was proposed to serve as a sheltered space to distribute essential services, such as first aid and medical unit, dry food and goods storage, relief distribution areas, etc. The module can be easily built with local technology and moved easily, with an easy installation and dismantle system (Ahmed, *et al.*, 2011).

Public Awareness Programs

Public awareness and education activities form an integral part of not only disaster management, but also adaptation - Preston *et al.* (2011) goes as far as to define accommodation as essentially a process of social learning. Individuals, households and communities are generally unaware of the extremities of the hazards they face - they underestimate dangers while overestimating their ability to cope with any crisis.

The acquisition of the necessary information will enhance the public’s capacity to manage climate risks by making informed decisions. Awareness programmes have to be combined with education and training seminars to lead people to understand the impacts of climate change, and equip them with knowledge about what they should do about it.

As part of Bangladesh’s disaster management strategy, Bangladesh’s Disaster Management Bureau (DMB) launched a wide public awareness campaign. This included:

- Inclusion of disaster management in the educational curricula in schools.
- Educational training presented to a wide range of stakeholders, including government officials, NGO officials, the media and religious leaders.
- Public-awareness activities, such as the distribution of educational and promotional material such as booklets, calendars and posters.
- Mock drills for disaster preparedness and response.

Care should be taken to make communities aware of the uncertainty associated with climate change risks to prevent communities developing mistrust in the authorities in the event that certain climate change scenarios presented to a community do not realise.

4.4Conclusion

The acceptance and implementation of accommodation measures require communities to rethink their definition of 'failure' (Kamphuis, 2012). True 'failure' of a system may be defined as the loss of life and an inability of the system to recover from damage suffered. If adaptation measures are successful in these objectives, they could be considered as a successful means of adaptation to climate change.

This chapter has reviewed the valuable contribution of engineering to possible accommodation strategies in the fields or industries of:

- Building;
- Maritime industry;
- Finance;
- Urban zoning;
- Agriculture;
- Service Infrastructure; and
- Coastal Management;
- Disaster management; and
- Public awareness.

A wide range of technologies and new strategies have been studied. Many of these can be seen as 'no regrets' measures, or even best practice guidelines. This is one of the biggest advantages of accommodation strategies - the reduced risk of maladaptation. Even in the absence of climate change or sea level rise, the implementation of these adaptation measures would be beneficial to the community/industry at hand.

While accommodation strategies need to be pursued, it must be recognised that they only allow the country to live with the problem of climate change and neither solve nor eliminate the problems themselves. Thus it would make sense to make a major effort in the international arena to ensure that the impacts of future climate change are minimised as much as possible (Jarungrattanapong & Manasboonphempool, 2009).

5. Review of Current South African Coastal Adaptation Legislation and Strategies

5.1 Introduction

Moving from a global to a more local focus, Chapter 5 presents the current adaptation legislation and strategies formulated at various levels of government in South Africa. Geographically the focus will be on the case study area - the Western Cape's provincial legislation, practices and institutional context, as well as the City of Cape Town's municipal approach.

5.2 National Overview

At a South African national level the main focus of adaptation has been on capacity building and the development of legislation, as well as participation and collaboration in the regional and international arena. National government transfers authority and duties to provincial and municipal authorities to give effect to these conventions and legislation by implementing and adopting appropriate management strategies.

Adaptation policies and legislation advising and regulating adaptation strategies in South Africa include (in chronological order):

Sea Shore Act (21 of 1935)

The Sea Shore Act declares the State President to be the owner of the sea-shore and the sea within the territorial waters of the Republic. The act also guarantees the public status of the sea and sea shore by ensuring that they cannot be alienated, let or acquired.

Environmental Conservation Act (73 of 1989)

The objective of this Act is to

"To provide for the effective protection and controlled utilisation of the environment."

Republic of South Africa, 1989.

This document:

- provides policies for environmental conservation,
- establishes the requirement for a Council for the Environment and
- provides regulations for the protection of the natural environment, the control of pollution and any activities which may have a detrimental effect on the environment (including tools such as an Environmental Impact Assessment (EIA).

The Constitution of South Africa (Act 108 of 1996)

Section 24 of the Constitution states that all South Africans have

"…the right to an environment that is not harmful to their health or well-being."

Republic of South Africa, 1996.

The Constitution of the Republic of South Africa also presents an obligation to provide services in a sustainable manner, provide a safe and healthy environment for all communities, promote social and economic development and ensure transparent governance.

Marine Living Resources Act (18 of 1998)

The objective of the Marine Living Resources Act is:

"To provide for the conservation of the marine ecosystem, the long-term sustainable utilisation of marine living resources and the orderly access to exploitation, utilisation and protection of certain marine living resources; and for these purposes to provide for the exercise of control over marine living resources in a fair and equitable manner to the benefit of all the citizens of South Africa."

Republic of South Africa, 1998.

National Environmental Management Act (107 of 1998)

The objective of the National Environmental Management Act is:

> "To provide for co-operative, environmental governance by establishing principles for decision-making on matters affecting the environment, institutions that will promote co-operative governance and procedures for co-ordinating environmental functions exercised by organs of state"
>
> Republic of South Africa, 1998.

Municipal Systems Act (Act 32 of 2000)

One of the objectives of the Municipal Systems Act (MSA) to provide the principles, mechanisms and processes necessary for local municipalities to effectively manage and protect their natural environmental.

Initial National Communication under the UNFCCC (Department of Environmental Affairs and Tourism, 2003)

This report provides an overview of the country's national circumstances, presents its emissions profile, provides a vulnerability assessment of key sectors, and outlines adaptation options.

Climate Change Response Strategy (Department of Environmental Affairs and Tourism, 2004)

This is a strategy to support the policies and principles laid out in the Government White Paper on Integrated Pollution and Waste Management. It lays out a number of strategies objectives, principles and proposals to deal with climate change in South Africa, including measures for adaptation as well as education, research and international concern. This document notes that the health sector, maize production, plant and animal biodiversity, water resources and rangelands are areas of highest vulnerability to climate change and those which should be targeted for adaptation measures, with the mining and energy sectors also being particularly vulnerable.

White Paper for Sustainable Coastal Development in SA (Department of Environmental Affairs and Tourism, 2005)

The Policy sets out a vision for the coast, as well as principles, goals and objectives for coastal management. The objective of this policy is:

"To achieve sustainable coastal development through a dedicated and integrated coastal management approach, in partnership with all South Africans."

Department of Environmental Affairs and Tourism, 2000.

Integrated Coastal Management Act (Government Gazette, 2008)

The Integrated Coastal Management Act (ICMA) is South Africa's first legal instrument designated for promoting integrated management of the coastal zone (City of Cape Town, 2012). It forms the highest level of legislation within the defined coastal zone (other than the Constitution of South Africa (Act 108 of 1996)), with all other acts, policies, Integrated Development Plans (IDPs) and Spatial Development Frameworks (SDFs) having to follow the act's requirements (Breetzke, *et al.*, 2011).

The National ICMA aims to:

Establish a system of integrated coastal and estuarine management in the Republic, including norms, standards and policies, in order to promote the conservation of the coastal environment, and maintain the natural attributes of coastal landscapes and seascapes, and to ensure that development and the use of natural resources within the coastal zone is socially and economically justifiable and ecologically sustainable; to define rights and duties in relation to coastal areas; to determine the responsibilities of organs of state in relation to coastal areas; to prohibit incineration at sea; to control dumping at sea, pollution in the coastal zone, inappropriate development of the coastal environment and other adverse effects on the coastal environment; to give effect to South Africa's international obligations in relation to coastal matters; and to provide for matters connected therewith.

Integrated Coastal Management Act, 2008.

The ICMA aims to provide a clear definition of the coastal zone in order to allow for effective integrated coastal zone management (ICZM) to take place. To this end, the ICM Act divides the coastal zone into five areas, namely:

- the Exclusive Economic Zone (EEZ);
- coastal public property;
- coastal buffer zone;
- coastal access land; and
- specially protected coastal areas (previously designated nature reserves etc.).

ICM acknowledges the interconnectivity of coastal zone functions and therefore promotes the coordinated, integrated and systemic management of the coastal zone (DEAT, 2000). Furthermore, ICM promotes a system of cooperative governance in respect of coastal management, as opposed to the previously employed model of top-down government (Breetzke, *et al.*, 2011).

The ICM Act also promotes risk aversion and the application of the precautionary principle, and highlights sea level rise and the possible effects thereof on the coastal environment. According to Breetzke *et al.* (2011), a bigger link is still required to Disaster Risk Reduction (DRR) legislation, and especially the Disaster Management Act (Act 57 of 2002), in order to take extreme sea level events such as storm surges and tsunamis into account.

The establishment of a setback for coastal municipalities is a legal requirement of the ICMA. In terms of Section 25 of the ICMA, setbacks must be established:

- to protect coastal public property, private property and private safety;
- to protect the coastal protection zone;
- to preserve the aesthetic values of the coastal zone;
- for any other reason consistent with the objectives of this Act; and

- to prohibit or restrict the building, erection, alteration or extension of structures that are wholly or partially seaward of that coastal setback line (ICMA, 2008).

Other Acts

Other Acts that relate to local authorities and coastal management include:

- Atmospheric Pollution Prevention Act (Act No. 45 of 1965).
- Hazardous Substances Act (Act No. 15 of 1973).
- National Water Act (Act No. 36 of 1998)
- Health Act (Act No. 63 of 1977).

5.3Provincial Overview

At a provincial level, the main focus of the Western Cape Provincial Government has been on the developing of policies, strategies and methodologies to provide local government municipalities with the information and guidelines necessary to implement national legislation.

The following documents are noteworthy:

Draft Coastal Zone Policy for the Western Cape (2001)

A Draft Provincial policy aimed at promoting sustainable coastal development and long term benefits from the sustainable utilisation of the coastal resources. This policy was developed prior to the passing of the ICM Act, and hence requires revision in order to meet the requirements of the ICM Act. The Western Cape Coastal Zone Policy takes a bioregion and spatial planning approach to the Western Cape coastal plain as a whole. There is a strong focus on ecological variables and challenges, however there is little to no mention of geomorphological processes along the shoreline, especially with regard to their response to climate change and sea level rise.

Climate Change Strategy and Action Plan for the Western Cape (2008)

This document provides a longer term strategy to improve understanding of the impacts of climate change as well as planning adaptation and mitigation measures. This report acknowledges the possible effects of climate change induced sea level rise (e.g. storm surges, coastal inundation, erosion etc.). The action plan also details a research strategy to understand and mitigate against these possible future sea level changes.

A Status Quo Vulnerability and Adaptation Assessment of the Physical and Socio-Economic Effects of Climate Change in the Western Cape – 2005

In June 2005, the Western Cape Province issued a report entitled "A Status Quo Vulnerability and Adaptation Assessment of the Physical and Socio-Economic Effects of Climate Change in the Western Cape" to assess the implications of the future climate change projections for the Western Cape Province of South Africa. Key issues addressed in this report include the impacts of climate change on:

- Natural resources
- Water
- Agro-climate
- Bio-climate
- Biodiversity; and
- Ecosystem processes such as fire frequency and alien invasion (Midgley, *et al.*, 2005).

This assessment highlighted the high vulnerability of large portions of the Western Cape coastline to erosion, stating that development in close proximity to sandy beaches should be restricted. It also emphasised that the sites most vulnerable to the effects of sea level rise, will be those where problems are currently being experienced (Midgley, *et al.*, 2005).

Western Cape Provincial Setback Line Methodology - 2010

Provincially, the development of setback lines to restrict development in vulnerable coastal areas in accordance with the ICMA of 2008 (Section 25) has received a lot of attention, and municipalities have been tasked to establish and implement these lines under Provincial guidelines (Smith, 2010). Development seaward of the established setback line is regulated. In the absence of an established setback line, an EIA is compulsory for any development within 100 meters of the high water mark in developed areas and 1,000 m in rural areas.

The provincial government of the Western Cape has developed a methodology for defining coastal setback lines in a report titled, “Development of a methodology for defining and adopting coastal development setback lines” (Smith, 2010).

This methodology prescribes allowances for the following elements during the development of the setback line:

- Setback allowance for coastal erosion;
- Setback for wind-blown sand and geotechnical stability; and
- Setback distance for flooding;
- Other issues, e.g.
    - Allowance for public access,
    - Allowance for socio-economic development priorities,
    - Allowance for aesthetic features,
    - Allowance for protection of ecologically sensitive and protected areas, and
    - Allowance to minimize shading of beaches by structures.

5.4 Municipal Overview - City of Cape Town Coastline

The City of Cape Town Municipality administers approximately 307 km of coastline, from Silwerstroomstrand on the west coast to just south of Kogelbaai on the east (City of Cape Town, 2012). In order to protect and manage this asset, the City of Cape Town has published a range of strategies, framework documents and local assessments:

City of Cape Town Coastal Zone Management Strategy (2003)

The Coastal Zone Management Strategy, published in 2003, presents a proposed integrated approach to coastal zone management.

This document addresses many issues facing the Cape Town coastline, including inappropriate development, poor marine water quality, security problems and vandalism. This document proposes the implementation of an integrated, holistic, centralised and citywide coastal strategy to address these challenges, as opposed to the fragmented approach adopted prior to 2003 (City of Cape Town, 2003).

Framework for Adaptation to Climate Change (City of Cape Town Environmental Planning Department, August 2006)

This document presents an overarching framework for a city-wide consolidated and coordinated approach to reducing vulnerability to climate impacts. The ultimate goal is to develop a City Adaptation Plan of Action for the City of Cape Town. The study outlines some of the anticipated effects of climate change on the city as well as potential adaptation measures in key sectors (Mukheibir & Ziervogel, 2006).

Climate Smart Cape Town (2010)

In June 2010 an alliance of organisations and partners from the public sector, business, academia and civil society established the Cape Town Climate Change Coalition (CTCCC).

In 2012, the CTCCC recognised how important it was to take full advantage of South Africa hosting COP17 in Durban and seized the opportunity to run a campaign that leveraged the local, national and international attention given to climate change issues in the time leading up to and during COP17. That campaign, Climate Smart Cape Town, was launched to help the residents of Cape Town and others learn about what was being done locally about climate change and how they could take action themselves. While designed as a short-term campaign around COP17, it is envisaged that the campaign may continue into a second phase (City of Cape Town, 2012).

Sea Level Rise Risk Assessment Studies

In 2008, the City of Cape Town launched a sea-level rise risk assessment study to investigate the effects of predicted sea-level rise and increased storm events for the City of Cape Town, thereby providing information that may be used for future planning, preparedness and risk mitigation (Cartwright, 2008). The project was undertaken in five distinct phases:

- Phase 1: Sea-Level Rise Model (March 2008);
- Phase 2: Risk and Impact Identification (May 2008);
- Phase 3: Quantifying the Risk (June 2008);
- Phase 4: Sea-Level Rise Adaptation + Risk Mitigation Measures (July 2008);
- Phase 5: Full investigation of alongshore features of vulnerability on the City of Cape Town coastline (December 2009).

Phases 1 to 3 identified an area totalling 25 km² that is highly vulnerable to the expected impacts of sea-level rise, storm surges and subsequent coastal erosion (Cartwright, 2008). Within this area, it is estimated that there is approximately R5 billion worth of City infrastructure that is at risk (Cartwright, 2008).

Phase 5 of the SLRRA was used to further refine the model generated in Phase 1, through the consideration of local factors that influence risk from sea-level rise and storm surge events. The report distinguished areas in terms of their exposure to risk based on alongshore features such as wave set-up and wave run-up, wave shoaling, off-shore bathymetry, swell diffraction into shadow zones, focussing effects, coastal geomorphology as well as the extent and nature of coastal development. This report addressed how these local biophysical factors interact with each other and how these interactions affect degrees of risk.

The vulnerability of each of 20 locations was determined by a binary assessment of four biophysical factors, namely wave setup, wave run-up, coastal geology and development risk. A score of 1 was allocated to those areas that are perceived to be exposed to storm surges, and a score of 0 is given if the location is not exposed to that component. The assessment not only provides a reasonable measure of the total sea-level rise risk at a given location, but it also provides important insight into the specific nature of sea-level rise risk at different locations (City of Cape Town, 2012)

City of Cape Town Setback Line Delineation – Method and Process

The development of setback lines to restrict development in vulnerable coastal areas has received a lot of attention, and municipalities have been tasked to establish and implement these lines by 2013. As mentioned in Section 5.3, the provincial government of the Western Cape has developed a methodology for defining coastal setback lines in a report titled, Development of a methodology for defining and adopting coastal development setback lines (WSP, 2010).

Due to the challenges faced when developing setback lines, the City of Cape Town decided to develop a draft setback line, also termed the coastal urban edge, which follows the most seaward cadastral boundary of properties in developed areas (City of Cape Town, 2012). Due to the highly developed nature of the City's coastline, the presence of private properties with existing development rights along the coastline, and the potential complications associated with these, such areas have been deliberately excluded from the City's draft setback zone, even though they are potentially at risk from storm surges and coastal processes (City of Cape Town, 2012). The opposite is true for less developed sections of the coast (land predominantly owned by the City) where coastal ecosystems are still intact and, as such, the City's setback is extended further inland based on key informants (City of Cape Town, 2012). This setback line methodology proposed by the City of Cape Town is currently in a draft state and has not yet been accepted by the Western Cape Province.

As a consequence of this approach, there are properties and infrastructure that are located landward of the draft setback, but are still at risk from storm surges and coastal erosion, as illustrated in Figure 5-1.

Figure 5-1: Private property in Bakoven at risk from storm surges (City of Cape Town, 2012)

The city proposes the use of a ‘Coastal Overlay Zone’ to manage these risks through existing land use management regulatory systems (City of Cape Town, 2012). Providing the opportunity to impose additional regulations in respect of specifically demarcated areas, this mechanism will provide the necessary flexibility to deal with diversity and uniqueness across the city. In the case of property or infrastructure at risk from coastal hazards, additional development rules in the overlay zone are likely to be more restrictive (City of Cape Town, 2012).

The City has drafted a coastal by-law in terms of the provisions made in the Constitution of South Africa (Act 108 of 1996), which will be applicable to the space between the City's draft coastal setback (the urban edge) and the high water level. The City's draft coastal by-law is being developed with the intention of regulating a range of activities along the city's coastline (City of Cape Town, 2012).

Key activities that the by-law focusses on, include the following:

- Encroachment into coastal Public Open Space (to be addressed jointly by the overlay zone)
- Illegal structures (to be addressed jointly with the overlay zone)
- Harvesting of natural resources;
- Recreational activities: i.e. fireworks, use of jet skis etc.
- Interference with coastal processes or the littoral active zone
- Activities that impact on coastal biodiversity
- Overnighting on beaches
- The use of fires
- Activities that may impact on public access to the coast
- Pollution and littering
- Commercial activities and trading
- Private functions

The City views the development and implementation of the Coastal Protection By-law as a critical local regulatory mechanism for a variety of reasons. From an integrated coastal management perspective, the Coastal Protection By-law will aim to (City of Cape Town, 2012):

- Promote improved integration between the various City departments with respect to management of activities that have an impact on the coast;
- Equip the City to more effectively deal with illegal activities taking place along the City's coastline;

- Ease the burden on both DEA and DEA&DP with respect to ensuring environmental compliance;
- Cover the gaps in existing coastal and environmental legislation in terms of coastal activities;
- Promote efficiency of legal proceedings;
- Promote consistency in decision making with respect to regulating coastal activities, and
- Achieve the objectives as set out in the ICMA.

5.5Conclusion

This chapter has reviewed the South African adaptation legislation at various levels of government. South Africa's legislation is very comprehensive, but often the link between various pieces of legislation or policies, and the cooperative link between various spheres of government, is unclear.

The implementation of any coastal protection measure, requires an EIA process. This largely limits owners of coastal property in terms of their individual capacity to protect their properties.

Municipalities have been tasked with the responsibility to delineate and implement development setback lines, but a national guideline or standard on the delineation of these setback lines has not been set and municipalities are following different approaches to do so. The City of Cape Town Municipality has adopted the approach of using the existing urban edge as the development setback line, regardless of whether these existing properties fall within the coastal processes or coastal hazard zone. Not much discussion has been generated around accommodation measures that could be implemented to adapt these existing properties.

Due to South Africa's political history, constitutional protection of property rights is highly regarded and land expropriation is a highly emotional and very costly matter.

6. Site Screening Exercise

6.1 Introduction

In light of the various adaptation options identified and assessed in Chapters 3 and 4, and building upon the local South African context provided in Chapter 5, this chapter presents a local site screening exercise conducted within the limits of the City of Cape Town. The aim of this section is to investigate, at a high level, specific sites and their vulnerability to climate change. Within the particular constraints of each site, the available options for adaptation to climate change are assessed and a recommendation made as to which adaptation approaches could possibly be successfully implemented.

Ten coastal case study sites within the City of Cape Town Municipality's limits, that are either currently experiencing the impacts of climate change or are predicted to be at risk in future predicted climate change scenarios, were identified as possible candidates for an adaptation assessment.

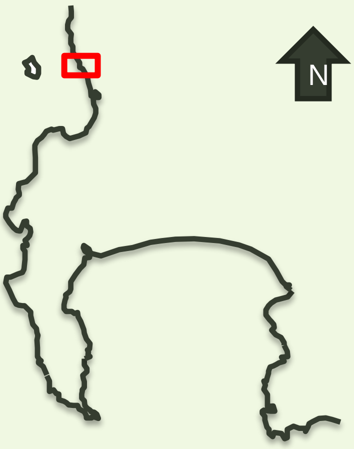
The following sites were selected as case study sites for this study:

- Tableview Beachfront;
- Milnerton Beachfront;
- Lagoon Beach;
- Sea Point Beachfront;
- Bakoven;
- Glencairn;
- Kalk Bay;
- Strandfontein;
- Strand CBD beachfront; and
- Greenways Golf Estate.

The effect of an arbitrary 1 m rise in sea level has been explored at each site to comparatively assess their vulnerability to the impacts of climate change.

6.2 Site Evaluation

6.2.1 Tableview Beachfront

Tableview Beachfront	
Site Location	Northern part of Table Bay; fronting Marine Drive and Otto du Plessis Drive, Table View.
Water Levels	LAT: 0 m CD / -0.825 m MSL (corresponding to Land Levelling Datum, LLD) HAT**:** +2.02 m CD / +1.195 m MSL (SANHO, 2012)
Coastline Description	A sandy beach backed by a vegetated dune, coastal parking lots and road. The dune field varies from fairly wide and backed by a grass embankment in the south; to a fairly steep dune face with a narrow, partially vegetated dune strip to the north.
Bathymetry	Gently sloping bottom contours.
Wind Climate	Summer: Strong south-easterly; Winter: Moderate north-westerly
Wave Exposure	Exposed to large south-westerly swells, although some local protection is offered by the remains of the Seli One shipwreck and Robben Island.
Longshore sediment transport: Generally in a northwards direction.	
	**Shoreline Stability:** Examining measured beach profiles from 1965 – 2010 and aerial photography for nearly the same period, Seifart (2012) has shown that this area of Table Bay has undergone fairly significant continuing erosion over this period, at an average rate of 0.3m/year, at times manifesting as a local beach steepening. In the lee of the Seli One shipwreck, local accretion and beach flattening has been experienced (Seifart, 2012). The long term trend of shoreline retreat evident along most of the Table View beachfront is expected to re-emerge in the lee of the Seli One shipwreck after all remains of the wreck have been removed.
	Infrastructure at Risk: Coastal roads and parking lots; residential and commercial buildings.
	Intervention Work to Date: Dune rehabilitation programmes with fenced-off walkways in some dune areas; sandbag revetments.

Desktop Assessment

In the event of a 1 m sea level rise, MSL and MHWS levels at this site would rise from +0.15m and +0.86 m MSL, to +1.15 m and +1.86 m MSL, respectively. In the event of a “Do Nothing” scenario, the sandy shoreline is expected to retreat landward as a result of this sea level rise, whilst maintaining a typical equilibrium profile as hypothesized by Bruun (1962) and Dean (1977).

Hughes, *et al.* (1993) estimated that at this site, according to the Bruun rule (Bruun, 1962), a 1 m rise in sea level would result in a 60 m horizontal shoreline retreat. This shoreline retreat value should be regarded as conservative, as Hughes *et al.* (1993) used a depth of closure of 18 m in his calculation, which is likely to be an overestimate when compared to the depth of closure calculated by Seifart (2012), -6.5 m CD.

In some northern segments of the Tableview beachfront, this shoreline retreat would mean that, should no protection measures be implemented, the MSL contour would now be located landward of the existing Otto du Plessis Road, leading to the flooding and undermining of the beach road and seafront parking lots.

According to the Bruun prediction, development located landward of Otto du Plessis Drive will not be undermined by shoreline retreat. However, the increased event frequency and severity of storm surge, extreme wave heights and corresponding wave setup and run-up, would cause the seafront development to be subject to overtopping.

Possible Adaptation Measures

In view of the potential impacts of climate change at this site, the following list of adaptation options for the Tableview beachfront shoreline have been identified and grouped under the approaches of protect, accommodate or retreat:

Protection Measures

As part of a protection approach, the construction of hard protection measures to ‘hold the line’ in the face of climate change could be considered. Examples of these could be the construction of a sandbag revetment on the face of the dunes, or a buried revetment inside the dunes along Otto du Plessis Drive to protect the bank of the coastal road against rapid storm erosion of the dune system. Another option is the construction of a field of groyne structures to prevent the northerly longshore transport of sediment and encourage sediment build-up along the shoreline.

Along shorelines such as these with high amenity value, softer protection measures are expected to have less risk of contributing to adjacent shoreline problems and be more aesthetically pleasing and are therefore generally preferred above hard protection measures. A softer protection measure that could be implemented along Otto du Plessis Drive and Beach Road is a beach nourishment project to regularly replenish the sediment lost due to erosion and thereby prevent shoreline retreat. This could be complemented by a project for the vegetation and rehabilitation of the remaining dune field strip.

Accommodation Measures

The accommodation approach generally does not offer many viable solutions to an eroding coastline. An accommodation measure that could possibly be implemented along the Tableview beachfront is the elevation of Marine Drive and Otto du Plessis Drive and the beachfront parking lots onto a road-bridge structure with piled foundations. The shoreline could then be left to establish its natural equilibrium with the rising sea level. This adaptation measure would however be very expensive, as an estimated 2 km stretch of road would need to be reconstructed and elevated with piled foundations, designed to withstand the coastal processes occurring in the nearshore.

The commercial and residential properties landward of Otto du Plessis and Marine Drives could be altered with flood-proofing measures to protect its basements and lower levels against possible flooding due to wave overtopping, as these overtopping volumes are not estimated to be significantly large.

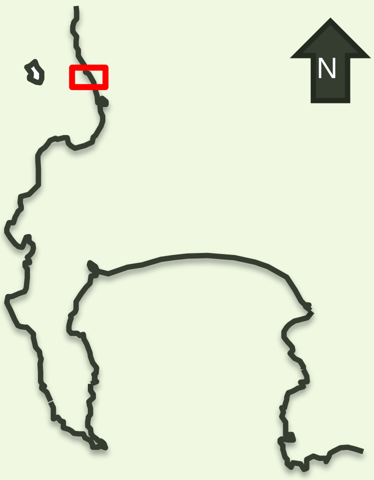
Should Otto du Plessis Drive remain in use without protection, effective disaster management and traffic diversion measures and adequate stormwater drainage systems could be implemented to mitigate the effects of flooding and overtopping of the road and to prevent the loss of life in an extreme storm event. These accommodation measures do not, however, present an acceptable and sustainable solution to the effects of climate change in isolation, but could be implemented to complement a shoreline protection solution (e.g. revetment).

Retreat

A managed retreat measure, sacrificing Otto du Plessis Drive, should be considered in the light of the high cost of protection and accommodation measures to adapt Otto du Plessis Drive to withstand the effects of climate change. There are roads parallel to Otto du Plessis Drive and Marine Drive, such as Beach Boulevard, Clam Road and Coral Road, that could be upgraded to accommodate higher traffic volumes, should Otto du Plessis Drive be decommissioned. As the existing traffic congestion levels in this area are very high, a broader traffic study might be required to improve traffic flow in the area, ensure adequate access to beach amenities and ensure alignment of these plans with the City’s future development plans for the area.

In order to implement this adaptation measure, traffic diversion and capacity planning needs to be started well in advance of the point in time when Otto du Plessis Drive is no longer fit for use due to the undermining and flooding of the road. The need to remove the existing pavement layers should be assessed as the scenario progresses.

6.2.2 *Woodbridge Island*

Woodbridge Island	
Site Location:	Northern Table Bay, North of the Diep River mouth.
Water Levels:	LAT: 0.00 m CD/-0.825 m MSL (corresponding to the Land Levelling Datum, LLD) HAT: +2.02m CD / +1.195 m MSL (SANHO, 2012)
Coastline Description:	Sandy coast fringed by low, partially vegetated dunes and occasional rocky outcrops. Shoreline is backed by the Diep River.
Bathymetry:	Gently sloping bottom contours with steeper foreshore.
Wind Climate:	Summer: Strong south-easterly; Winter: Moderate north-westerly.
Wave Exposure:	Moderately exposed to large waves. Part of the coast is sheltered by Robben Island.
Longshore Sediment Transport:	Generally northwards.
	**Shoreline Stability:** An eroding beach with diminishing steep dunes. Examining measured beach profiles from 1965 – 2010 and aerial photography for about the same period, Seifart (2012) has shown that this area of Table Bay has undergone fairly significant continuing erosion, at an estimated rate of retreat of 0.5 to 1m per year. The lower dunes are eroding more rapidly than the top profiles of the beach, resulting in beach steepening.
	Infrastructure At Risk: Woodbridge Island development; Milnerton Golf Club; Milnerton Beach Lifesaving Club; Commercial Properties.
	Intervention Work to Date: Sandbag revetments, fenced-off dunes and dedicated walkways.

Desktop Assessment

In the event of a 1 m sea level rise, MSL and MHWS spring would rise from 0.15 m and 0.86 m elevation above MSL to +1.15 m and +1.86 m MSL, respectively. In the event of a "Do Nothing" scenario, the sandy shoreline is expected to retreat landward as a result of this sea level rise, whilst maintaining a typical equilibrium profile (Bruun, 1962).

Hughes (1993) calculated that, according to the Bruun rule, a 1 m rise in sea level would result in an 80 m horizontal shoreline retreat. Hughes (1993) also estimated that due to the 80 m shoreline retreat predicted, the river bank would be breached by the ocean and a new river mouth would form north of the existing Milnerton Golf Clubhouse. These estimates of shoreline retreat should be regarded as conservative over-estimates, as Hughes used a depth of closure of 18 m in his shoreline retreat calculation – this is significantly larger than other estimates of the depth of closure at Milnerton, such as -4.5 m CD (Smith, 2010) and -5.62 m CD (Seifart, 2012).

However, despite the reservations associated with these estimates, it remains clear that, should no protection measures be implemented, the MSL contour would be located well landward of the Milnerton Golf clubhouse, the beachfront restaurant, the most seaward row of Woodbridge island residences, the Milnerton Lifesaving Club building and seafront parking lots. Large parts of the Woodbridge Island development and Milnerton Golf Course would be inundated. All of these properties could therefore be at severe risk of being undermined and flooded in the case of a Do Nothing scenario.

Possible Adaptation Measures

In view of the expected impacts of climate change at this site, the following list of adaptation options that could be implemented at the Woodbridge Island beachfront shoreline to adapt to the impacts of climate change, should they transpire, have been identified and grouped under the approaches of protect, accommodate or retreat:

Protection Measures

Examples of protection measures that could be implemented to adapt the Woodbridge Island site to the effects of climate change could be the construction of a revetment consisting of rock, sandbag, or concrete units along the foredune seaward of the Woodbridge Island residences to protect these properties against storm erosion. A crown wall structure might be required on top of the revetment to prevent overtopping. Sheet piles or buried revetments could also be used to armour the remaining dunes and prevent the retreat of the shoreline past these dunes.

Similar to the Tableview beachfront, protection measures that do not diminish the high amenity value of the beach should be considered. A softer protection measure that could be implemented along the Woodbridge Island Development and the Milnerton Golf Clubhouse is a beach nourishment project to continually replenish the sediment lost due to erosion and thereby prevent shoreline retreat. This could be complemented by a project for the vegetation and rehabilitation of the remaining dune field strip.

Due to the fact that the Woodbridge Island development is a relatively isolated stand-alone development and large parts of the Woodbridge Island development are so low-lying that they would be inundated by a 1 m rise in sea level, sea dikes around the development could also be proposed to protect the properties against flooding and erosion, especially should action to implement adaptation measures be taken only after much of the predicted sea level rise and its erosion effects have already transpired. Dikes are not intended to preserve beaches which may occur in front of the structure or any adjoining, unprotected beaches and would therefore not protect the amenity value of the Woodbridge Island beach. They are also expensive to construct because of the large volumes of materials required.

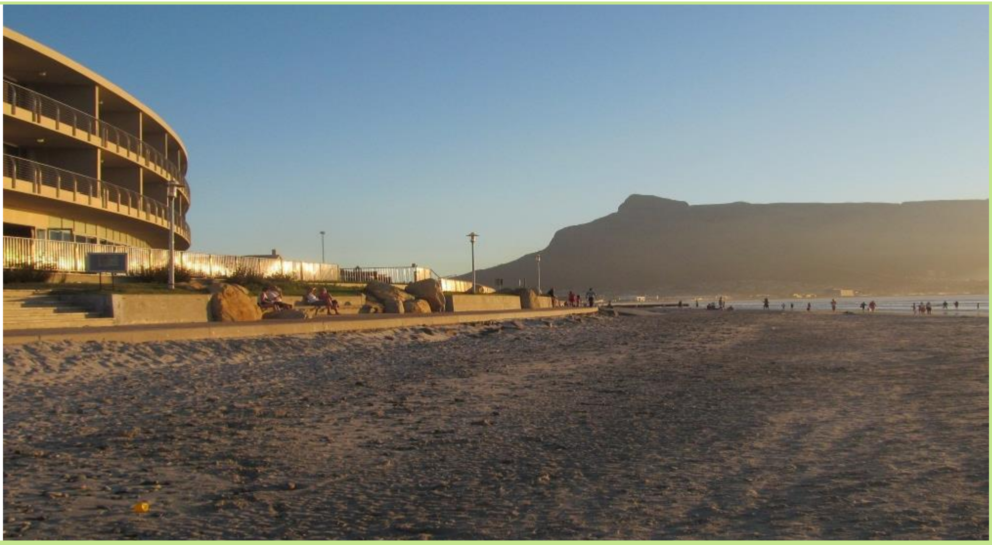
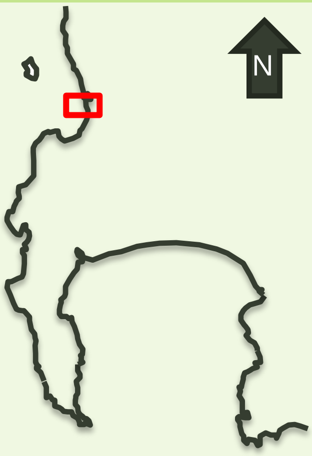
Accommodation Measures

As large parts of the Woodbridge Island development could be at risk of inundation, an accommodation measure that could possibly be implemented would be the elevation of buildings onto piles that are driven into bedrock. The retreating shoreline would then no longer threaten to undermine these properties and could then be left to establish its natural equilibrium with the rising sea level. The houses could either be elevated on to a fixed level, or be constructed with floating foundations on guide piles, such as those used in Maasbommel, as presented in Section 4.3.1. These piles would have to be specifically designed to withstand the wave, current and sediment processes in the nearshore. Constructing these foundations and elevated levels for all of the properties in the Woodbridge Island development would however be very expensive. The properties would also need to be altered by the addition of flood-proofing measures.

Retreat Measures

A managed retreat measure, sacrificing the Woodbridge Island development and other buildings along the Milnerton beachfront, should be considered due to the high cost of protection and accommodation measures to adapt these buildings. Because the onset of sea level rise is expected to be gradual, the City of Cape Town could implement a managed retreat option, sacrificing properties in stages as they become too dangerous for occupation. The construction of any new properties in this area within less than 80 m of the shoreline should be discouraged or even prohibited.

6.2.3 *Lagoon Beach*

Lagoon Beach	
Site Location:	Southern Table Bay, south of the Diep River mouth.
Water Levels:	LAT: 0.00 m CD / -0.825 m MSL HAT: +2.02 m CD / +1.195 m MSL (SANHO, 2012)
Coastline Description:	Along this coastline, the Diep River mouths into a sandy coastline. Residential and commercial developments are protected by a concrete sea wall and rock armouring. South of these developments a 2.9 km concrete revetment protects a railway embankment and the canalised outlet of the Salt River mouths into the ocean.
Bathymetry:	Gently sloping bottom contours.
Wind Climate:	Summer: Strong south-easterly; Winter: Moderate north-westerly.
Wave Exposure:	Sheltered from large south-westerly swells.
Longshore sediment transport:	Generally in a northwards direction.
	**Shoreline Stability:** Examining measured beach profiles from 1965 to 2010 and aerial photography for about the same period, Seifart (2012) has shown that this shoreline of Table Bay is retreating at a rate of 0.7 - 1m per year. The lower contours (0 m MSL) are eroding, although the upper contours (+1 to +3 m MSL) have stabilised - presumably due to the dune stabilisation project being implemented (Seifart, 2012).
	Infrastructure at Risk: Leisure Bay and Lagoon Beach hotel developments. Railway and road landward of these developments fringes coastline to the south.
	Intervention Work to Date: Concrete seawall; sandbag revetments; concrete armour revetment.

Desktop Assessment

In the event of a 1 m sea level rise, MSL and MHWS spring would rise from 0.15 m and 0.86 m elevation above MSL to +1.15 m and +1.86 m MSL, respectively. In the event of a Do Nothing scenario, the sandy shoreline is expected to retreat landward as a result of this sea level rise, whilst maintaining a typical equilibrium profile. This retreat will be constrained by the existing fixed hard structures, i.e. sea wall and revetment.

Hughes (1993) estimated that, according to the Bruun rule, a 1 m rise in sea level would result in a 135 m horizontal shoreline retreat. As explained previously, this calculation should be regarded as a conservative over-estimate and does not take into account the presence of the existing protection structures in place, such as the sea wall and revetment. However, it remains clear that, should the existing protection measures in place not be maintained or possibly increased, the new MSL contour could in future be located well landward of the Lagoon Beach and Leisure Bay developments' seaward limits. All of these properties could therefore be at risk of being undermined and flooded in a Do Nothing scenario. Both Lagoon Gate Drive and the railway line behind these developments are also at risk of being flooded and undermined, especially to the south where the beach width has already been severely diminished.

Possible Adaptation Measures

In view of the potential impacts of climate change at this site, the following list of adaptation options that could be implemented at the Lagoon Beach shoreline to adapt to the impacts of climate change, have been identified and grouped under the approaches of protect, accommodate or retreat.

Protection Measures:

In order to hold the line along the Lagoon Beach development, the height of the sea wall could need to be increased, and its scour protection increased and maintained. A recurved splash wall might be required to reduce overtopping volumes. Along the Leisure Bay development, which is set slightly further back from the shoreline, a beach nourishment project could be recommended to maintain the dune system fronting the development. These dunes could be armoured with integral protection against short term storm erosion, such as a buried revetment or sheet pile structure.

Accommodation Measures:

As large parts of the Lagoon Beach and Leisure Bay developments will be inundated in the event of a 1 m rise in sea level, an accommodation measure that could be implemented is the elevation of buildings onto piles that are driven into bedrock. The retreating shoreline would then no longer threaten to undermine these properties and could then be left to establish its natural equilibrium with the rising sea level. The houses could either be elevated on to a fixed level, or be constructed with floating foundations on specifically designed guide piles, such as those used in Maasbommel. The properties would also need to be altered with the addition of flood-proofing measures.

Constructing these foundations and elevated levels for all of the properties in this area would however be very expensive. Elevation of the multi-storey hotel buildings is not regarded as being feasible.

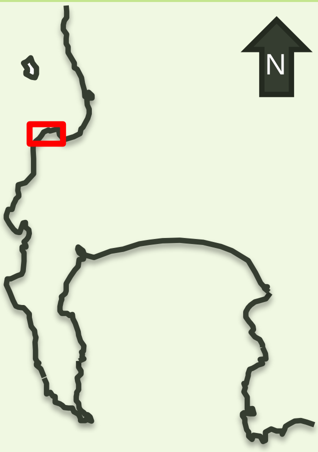
Retreat

Due to the high value of these developments and their potential to generate revenue through tourism, sacrificing the Lagoon Beach and Leisure Bay developments is not considered to be a viable option. Because the onset of sea level rise is expected to be gradual, the City of Cape Town could implement a managed retreat option, sacrificing the parking lot and other less critical infrastructure. The construction of any new properties in this area within at least 80 m of the shoreline should be prohibited.

6.2.4 Sea Point Promenade

Sea Point Promenade

Site Location:	Atlantic seaboard of Cape Peninsula; west of the port of Cape Town, stretching from Mouille Point to Bantry Bay.
Water Levels:	LAT: 0.00 m CD / -0.825 m MSL; HAT: +2.02 m CD / +1.195 m MSL (SANHO, 2012)
Coastline Description:	Artificially reclaimed land protected by a sea wall. Rocky coast with offshore reefs and extensive kelp beds. Pocket beaches are present between control structures.
Bathymetry:	Steeply sloped - deep water at a relatively short distance offshore.
Wind Climate:	Summer: Strong south-easterly; Winter: Moderate north-westerly
Wave Exposure:	Exposed to south-westerly swells. Although offshore reefs do provide some shelter, high tides and storm surges frequently overtop the sea wall.
Longshore sediment transport:	Sediment starved – no significant sources/sinks of sediment.
Shoreline Stability:	Artificially maintained by a sea wall which does require maintenance.



Infrastructure at Risk:
A 30 – 50m buffer zone exists between most of the shoreline and Beach Road, with the exception of the Sea Point Pool and adjacent residential buildings, which are located closer to shoreline. This buffer zone is used for recreational purposes such as the Sea Point Promenade and various parking lots. Beach road is backed by dense high-end commercial and residential buildings. There are storm- and waste water outlets all along this coastline.

Intervention Work to Date:
A sea wall to stabilise the shoreline, with a recurved splash wall along sections. The City of Cape Town has recently funded R35 million for the rehabilitation of the sea wall, with work having been commenced in January 2013.

Desktop Assessment

In the event of a 1 m sea level rise, the levels of MSL and MHWS spring would rise from 0.15 m and 0.86 m elevation above MSL to +1.15 m and +1.86 m MSL, respectively. The existing sea wall's crest is at a height of approximately +5.1 m MSL. As overtopping of the seawall already occurs during extreme events, a 1m rise in the sea level is estimated to significantly increase the risk of flooding and erosion along this coastline.

The higher still water level, combined with higher storm surge and increased wave heights, could lead to the undermining of the wall's foundations, breaking of wall segments/units, and increased overtopping:

- Because of the hard rocky nature of this shoreline, it is less susceptible to erosion, though the loss of sediment in the remaining pocket beaches could be expected. There is a risk that the wall's foundations could be undermined. It has been reported that this area has been developed on poorly stabilised land (Fairhurst, 2008). In the event of collapse of the seawall, rapid loss of reclamation/foundation material and infrastructure collapse could be experienced.
- The higher still water level would allow larger waves to impact upon the wall, potentially subjecting the wall to forces beyond its design capacity and damaging/removing wall block units.
- Overtopping of the sea wall, which is already a problem during current extreme events, could increase in both frequency and overtopping volumes, leading to the flooding of interior recreational areas, roads and residential and commercial property.

Because of the inconsistency of the height and construction method of the sea wall along its length, certain sections could be at a greater risk of overtopping and/or undermining.

Possible Adaptation Measures

In view of the expected impacts of climate change at this site, the following options that could be implemented along the Sea Point Promenade to adapt to the impacts of climate change, should they transpire, have been identified and grouped under the approaches of either protect, accommodate or retreat:

Protection Measures:

In order to prevent events of overtopping and the undermining of the wall, the height of the sea wall could need to be raised, and the foundations protected with scour protection. The wall would need constant maintenance to ensure that the structure remains in an acceptable condition. The wall should preferably be designed as a modular structure, so that the height could be easily raised as required in the future.

Accommodation Measures:

Should the existing sea wall not be raised, increased overtopping events could lead to the flooding of recreational facilities such as the promenade, parking lots and other beachfront amenities. Beach Road would also be flooded in certain areas. Installing draining facilities such as stormwater retention ponds that are capable of handling the increased overtopping volumes in buffer zones along the promenade and Beach Road could help in alleviating these problems. Forecasting and early warning systems could be used to warn of extreme events, during which Beach Road could need to be closed off and all traffic diverted.

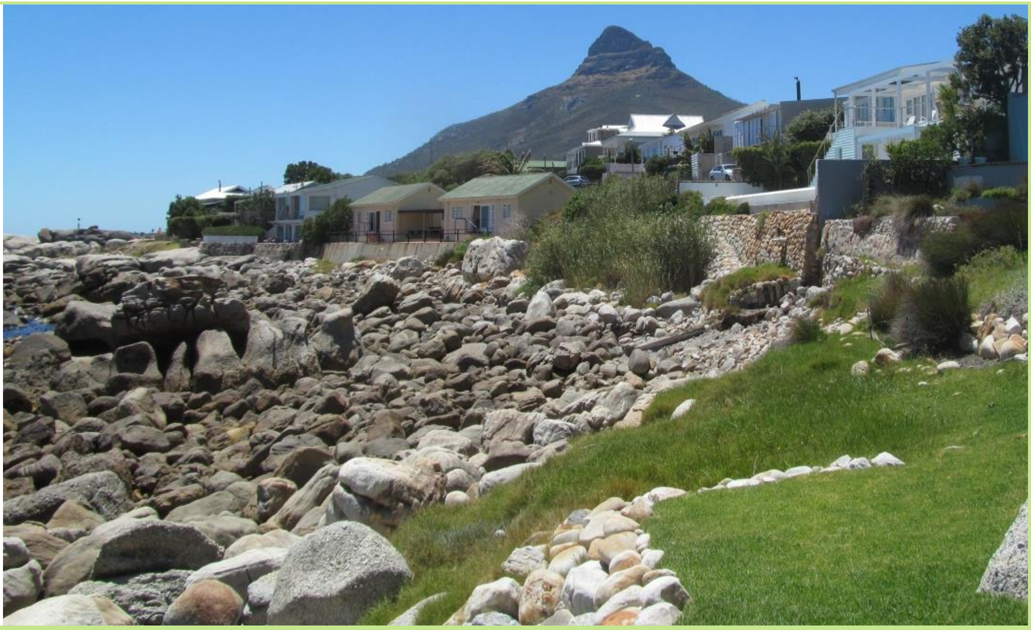
Legislation should be adapted so that no further development should be allowed seaward of Beach Road.

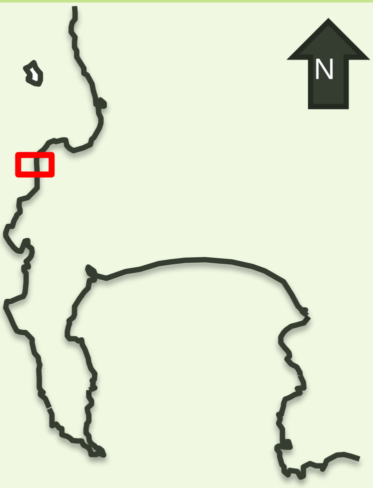
Retreat

Due to the high value of the Atlantic Seaboard developments, retreat would not be considered as a viable option. The risk of rapid, wide-spread erosion of the reclaimed area in the event of sea wall failure is too great to consider this option.

Should the wall height not be raised, and overtopping reach unacceptable levels for the use of Beach Road, this road could be abandoned and converted to recreational space, forming a part of the existing buffer zone.

6.2.5 Bakoven

Bakoven	
Site Location:	Southern Atlantic seaboard of Cape Peninsula.
Water Levels:	LAT: 0.00 m CD / -0.825 m MSL HAT: +2.02 m CD / +1.195 m MSL (SANHO, 2012)
Coastline Description:	Rocky shoreline: boulder and pebble beach severely encroached on by residential development. Some beach sand is present in protected coves.
Bathymetry:	Steeply sloped - deep water at a relatively short distance offshore.
Wind Climate:	Summer: Strong south-easterly; Winter: Moderate north-westerly.
Wave Exposure:	Exposed to large south-westerly swells, although offshore reefs do provide some dissipation of wave energy.



Longshore sediment transport:
Sediment starved – no significant sources or sinks of sediment.

Shoreline Stability:
Stable - no significant trends of shoreline movement. Historical photographs indicate loss of sediment from pocket beaches.

Infrastructure at Risk:
Residential properties.

Intervention Work to Date:
Retaining walls, informal revetments and gabions to stabilise reclamation.

Desktop Assessment

In the event of a 1 m sea level rise, the levels of MSL and MHWS would rise from 0.15 m and 0.86 m elevation above MSL to +1.15 m and +1.86 m MSL, respectively. This is particularly critical as the MHWS still water level would then be at the base of the most seaward properties in the cove, which is as low as +3 m MSL for some properties.

Because of the rocky nature of this shoreline, it is less susceptible to erosion and shoreline retreat than a sandy shoreline. However, the higher still water level, combined with higher storm surge and increased wave heights, will allow the penetration of larger wave heights, removing sediment trapped in protected coves and even lifting and transporting rocks and eroding the pebble shoreline. This erosion could cause significant damage to the seafront properties. These events could also cause severe flooding of the most seaward houses.

Possible Adaptation Measures

In view of the expected impacts of climate change at this site, the following list of adaptation options that could be implemented at Bakoven shoreline to respond to the potential impacts of climate change, have been identified and grouped under the approaches of protect, accommodate or retreat:

Protection Measures

In order to protect the properties along this shoreline, the land would have to be levelled and reclaimed seaward to form an embankment. Rock and rubble material could be cleared at the seaward edge of the embankment, so that a slope with suitable core and underlayer material for a revetment could be constructed.

The embankment could be protected by a rock revetment, possibly using the naturally occurring rock as secondary armour. A splash wall could be required on the top of the revetment to reduce overtopping during extreme events. The reclamation material could be protected against the rising ground water level by dewatering wells.

Because the most seaward houses in Bakoven are so low-lying that they could be inundated by a 1 m rise in sea level, sea dikes could also be used to protect the properties against flooding and erosion. This would however destroy the unique atmosphere of this area, and low-lying houses would lose their ocean view.

Accommodation Measures:

An accommodation measure that could possibly be implemented would be the elevation of buildings onto piles that are driven into bedrock, so that the properties are raised above their current levels. The retreating shoreline would then no longer threaten to undermine these properties and could then be left to establish its natural equilibrium with the rising sea level. Alternatively, ground floors could be sacrificed as residential areas and additional stories built on top of the existing ones. The properties would also need to be altered by adding flood-proofing measures.

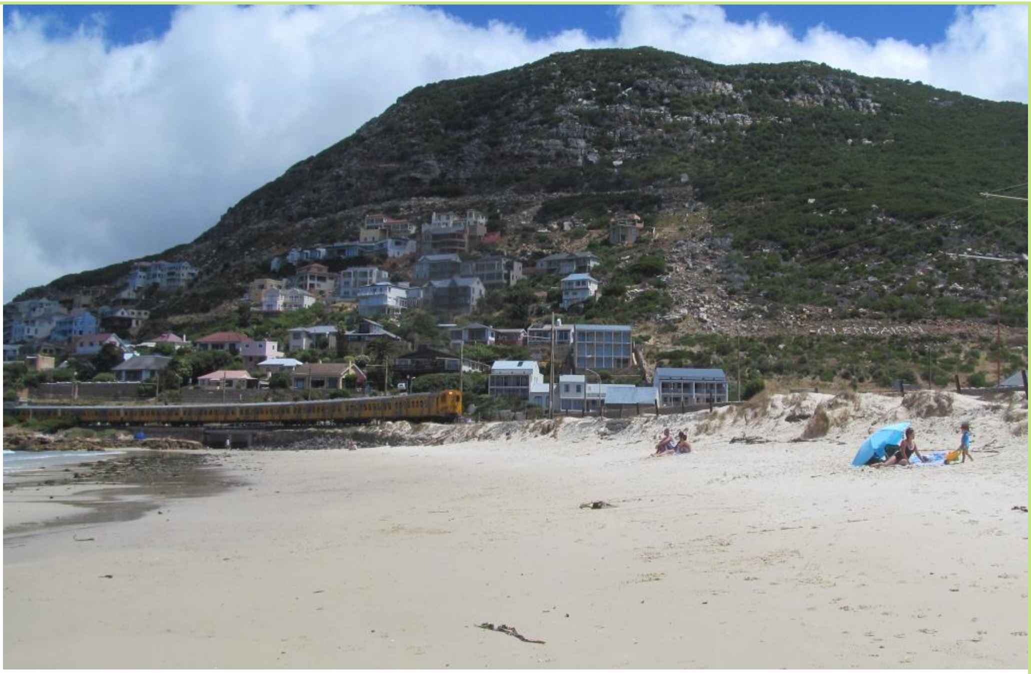
Constructing these foundations and elevated levels for all the properties in the Bakoven development would, however, be very expensive and could be comparable to the cost of constructing a new building. The funding would need to be provided by individual property owners. It is regarded as possible that, due to the perceived high value of a property located so close the shoreline, property owners might be prepared to invest in implementing accommodation measures to adapt their properties.

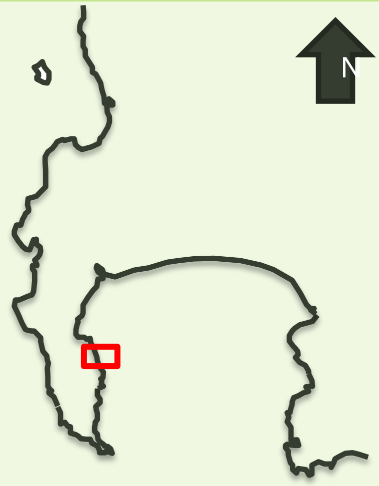
Forecasting and early warning systems could be used to forecast extreme events, during which properties could be evacuated.

Retreat

Despite the high value of the Bakoven properties, these assets are not crucial infrastructure. Should neither the municipality nor individual property home owners have sufficient funds to adapt their properties to withstand the effects of climate change; it is possible that these properties could need to be abandoned to avoid the risk to human life.

6.2.6 Glencairn

Glencairn	
Site Location:	Western False Bay.
Water Levels:	LAT: 0.00 m CD / -0.843 m MSL HAT: +2.09 m CD / +1.247 m MSL (SANHO, 2012)
Coastline Description:	Along this coastline the Elsies River mouths into a sandy beach coastline, with rail infrastructure running along the coast and crossing the river channel inside the littoral active zone.
Bathymetry:	Bottom contours are steeply sloping.
Wind Climate:	Summer: Strong south-easterly; Winter: Moderate north-westerly.
Wave Exposure:	Well sheltered from large south-westerly swells.



Longshore Sediment Transport:
No significant signs of longshore sand movement around the headlands could be detected.

Shoreline Stability:
The shoreline is retreating, but is artificially maintained by a revetment.

Infrastructure at Risk:
Railway line infrastructure; road infrastructure.

Intervention Work to Date:
Rock scour protection; sandbag revetment.

Desktop Assessment

In the event of a 1 m rise in sea level, HAT would increase from a level of +1.247 m MSL to +2.247 m MSL. This is particularly critical as the railway line embankment's crest height is as low as +4 m MSL in some sections. The higher water level, combined with higher storm surge and increased wave heights, could cause significant increase in the frequency and volumes of flooding and overtopping of the rail embankment, creating a high operational risk to the railway line.

In the event of a "Do Nothing" scenario, the sandy shoreline is expected to retreat landward as a result of this sea level rise, whilst maintaining a typical equilibrium profile. This retreat would be constrained by the existing fixed hard structures, such as the revetment. According to the Bruun rule, Hughes (1993) calculated that a 1 m rise in sea level at the Glencairn site could lead to a 48 m shoreline recession. The MSL contour would retreat to the base of the railway embankment, allowing direct wave impingement. This could cause damage to the scour protection sandbags and rock placed to protect the foundations of the railway embankment, leading to undermining of the embankment foundations.

Possible Adaptation Measures

In view of the expected impacts of climate change at this site, the following list of adaptation options that could be implemented along the Glencairn shoreline to adapt to the impacts of climate change, have been identified and grouped under the approaches of protect, accommodate or retreat:

Protection Measures:

An embankment protected by a revetment and crown wall, whether constructed from sandbags, rock or concrete units, could be built along the railway line. As an alternative, beach nourishment could be used to mitigate the shoreline retreat that could be expected as a result of sea level rise.

Accommodation Measures:

A possible accommodation measure that could be implemented to adapt the railway infrastructure to the effects of climate change would be elevating the railway line onto a piled bridge structure, founded to bedrock. The retreating shoreline would then no longer threaten to undermine the line and could then be left to establish its natural equilibrium with the rising sea level.

In combination with elevating the railway line, forecasting and early warning systems could be used to forecast extreme events, during which the railway could be closed off and all traffic diverted. A dune vegetation and management system could protect the integrity of the existing dune system and maintain or increase its resilience.

Retreat

As a part of the long term zoning of this area and the asset management plans of these buildings, a retreat solution could be developed and considered. Analysing the technical and financial feasibility of the relocation and realignment of the entire False Bay railway system, the options of protection, accommodation and retreat should be carefully evaluated to determine the preferred option.

6.2.7 Fish Hoek

Fish Hoek	
Site Location:	North Western False Bay, north of Glencairn
Water Levels:	LAT: 0.00 m CD / -0.843 m MSL HAT: +2.09 m CD / +1.247 m MSL
Coastline Description:	Extensively developed coastline: protected rail infrastructure runs along coast, residential properties in the lee of dune bluffs. Mostly rocky coastline, with some sandy beaches formed between headlands.
Bathymetry:	Moderate to steeply sloping bottom contours.
Wind Climate:	Summer: Strong south-easterly; Winter: Moderate north-westerly.
Wave Exposure:	Located in a shadow zone from the south-westerly swells, but exposed to focussing from the south-east.
Longshore sediment transport:	No significant signs of longshore sand movement around the headlands could be detected.
	**Shoreline Stability:** No signs of significant shoreline retreat, though the Silvermine River mouth was highly dynamic before being stabilised by development. **Infrastructure at Risk:** Railway infrastructure; yacht club, beach amenity facilities, restaurants, seaside cottages and caravan park. **Intervention Work to Date:** Large sections of shoreline are protected by revetment and/or sea walls.

Desktop Assessment

In the event of a 1 m rise in sea level, HAT would increase from a level of +1.247 m MSL to +2.247 m MSL. This rise in sea level is particularly critical for the beachfront restaurants, as they are at a height of +2.5 m MSL. The railway line and camping terrain is located at a height of approximately +3 m MSL. The higher water level, combined with higher storm surge and increased wave heights, would inundate the beach front development, car park, yacht club and probably the railway station (Hughes, 1993), and could cause a significant increase in the frequency and volumes of flooding and overtopping of the rail embankment.

In the event of a Do Nothing scenario, the sandy shoreline is expected to retreat landward as a result of this sea level rise, whilst maintaining a typical equilibrium profile. According to the Bruun rule, Hughes (1993) calculated that a 1 m rise in sea level could lead to a 70 m shoreline recession, retreating to within 25 m of the base of the railway embankment. This retreat could however be constrained by the existing fixed hard structures, such as revetments. It is estimated that the existing barrier dunes would be eroded and the hinterland area flooded, as the tops of the dunes are at a height of approximately +5.5 m MSL.

Possible Adaptation Measures

In view of the expected impacts of climate change at this site, the following list of adaptation options that could be implemented to adapt to the potential impacts of climate change, have been identified and grouped under the approaches of protect, accommodate or retreat.

Protection Measures

An embankment protected by a revetment and crown wall, constructed from sandbags, rock or concrete units, could be built along the road to protect it against erosion and flooding. Individual properties could be protected by small groynes or revetment embankments. A softer protection measure that could be implemented at this site is a beach nourishment project to continually replenish the sediment lost due to erosion and thereby prevent shoreline retreat. This could be complemented by a project for the vegetation and rehabilitation project of the remaining dune field strip.

Accommodation Measures

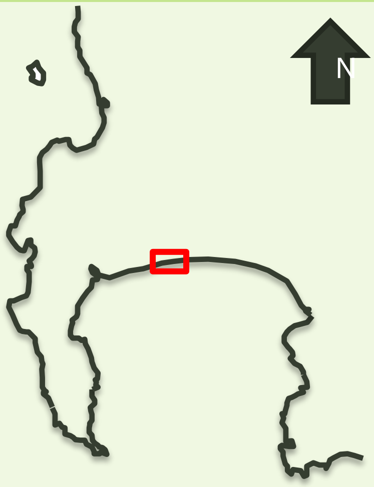
Similar to the accommodation solution proposed at Glencairn, the railway line could be elevated onto a piled bridge structure, founded to bedrock. The retreating shoreline would then no longer threaten to undermine the line and could then be left to establish its natural equilibrium with the rising sea level. In combination with elevating the railway line, forecasting and early warning systems could be used to predict and warn of extreme events, during which the railway could be closed off and all traffic diverted.

The beachfront restaurant building could be reconstructed onto piles driven into bedrock, to accommodate the expected shoreline retreat as a result of sea level rise.

Retreat

With the exception of the railway line, many of the beachfront properties are of relatively low value compared to the cost of protecting them. It is recommended that these properties be relocated further inland, as part of a managed retreat approach.

6.2.8 *Strandfontein*

<table>
<tr><td>Strandfontein</td><td></td></tr>
<tr><td>Site Location</td><td>Central northern False Bay</td></tr>
<tr><td>Water Levels</td><td>LAT: 0.00 m CD / -0.843 m MSL
HAT: +2.09 m CD / +1.247 m MSL</td></tr>
<tr><td>Coastline Description</td><td>Sandy beach with recreational amenity facilities and tidal pools. Baden Powell Drive is within the littoral active zone, with informal residential development to the north.</td></tr>
<tr><td>Bathymetry</td><td>Gently sloping.</td></tr>
<tr><td>Wind Climate</td><td>Summer: Strong south-easterly;
Winter: Moderate north-westerly</td></tr>
<tr><td>Wave Exposure</td><td>Exposed to large south-westerly swells entering False Bay.</td></tr>
<tr><td rowspan="4"></td><td>Longshore sediment transport:
Longshore sediment transport occurs in both easterly and westerly directions. Net transport is eastbound.</td></tr>
<tr><td>Shoreline Stability:
No significant long term shoreline erosion or accretion trends have been observed.</td></tr>
<tr><td>Infrastructure at Risk:
Recreational facilities, tidal pool, coastal road and parking lots.</td></tr>
<tr><td>Intervention Work to Date:
Beach improvement schemes. Fencing off of dune areas.</td></tr>
</table>

Desktop Assessment

In the event of a 1 m rise in sea level, HAT would increase from a level of +1.247 m MSL to +2.247 m MSL. According to the Bruun rule, Hughes (1993) calculated that a 1 m rise in sea level could lead to a 105 m shoreline recession in this area. This could cause the new MHWS to be located approximately 70 m landward of the existing Baden Powell Drive. In addition to the limitations of the Bruun rule, this erosion estimate ignores the presence of any hard material, such as protection measures, and assumes that the shoreline is made up of entirely erodible substrate. Therefore, this amount of erosion is likely to be an over-estimate.

However, it is clear that seafront parking lots and other amenities are at some risk of flooding and collapse as a result of erosion-induced foundation destabilisation. Baden Powel Drive is at risk of flooding and collapse due to erosion-induced foundation destabilisation. Aeolian sand transport also remains a big problem on this coastline

Possible Adaptation Measures

In view of the expected impacts of climate change at this site, the following list of adaptation options that could be implemented to adapt to the impacts of climate change, have been identified and grouped under the approaches of protect, accommodate or retreat:

Protection Measures

To protect the tidal pools, the height of the pool walls could be increased and stronger scour protection placed to avoid undermining of the wall.

The parking lots would need to be protected by revetment structures.

Accommodation Measures

The accommodation approach generally does not offer many viable solutions to this eroding coastline. An accommodation measure that could possibly be implemented along the central False Bay coastline is the elevation of Baden Powell Drive and the beachfront parking lots onto a road-bridge structure with piled foundations. The shoreline could then be left to establish its natural equilibrium with the rising sea level. This adaptation measure could however be very expensive.

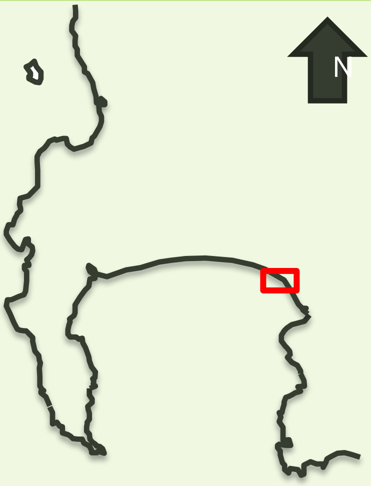
Retreat

A retreat approach is a very attractive solution along this stretch of the coastline. Although valuable infrastructure such as Baden Powell Drive is located along this shoreline, the cost of continually protecting and maintaining the infrastructure elements located in the littoral active coastal zone against the effects of climate change is not sustainable.

A realignment or decommissioning plan for the Baden Powell Drive and shoreline amenity structures could be integrated into the city zoning plan.

6.2.9 Strand Beachfront

Strand Beachfront	
Site Location:	Eastern False Bay.
Water Levels:	LAT: 0.00 m CD / -0.843 m MSL HAT: +2.09 m CD / +1.247 m MSL (SANHO, 2012)
Coastline Description:	Sandy coastline with shallow offshore reefs, heavily encroached by beachfront development so that the dune field has been significantly reduced and even completely diminished in some areas, being replaced with protection structures.
Bathymetry:	Moderately sloping.
Wind Climate:	Summer: Strong south-easterly; Winter: Moderate north-westerly
Wave Exposure:	Moderately exposed to south-westerly swell, with protection from offshore rocky banks.



Longshore sediment transport:
Longshore transport in both directions, with net longshore transport in a north-westerly direction.

Shoreline Stability:
Relatively stable – development encroachment being the biggest risk to shoreline stability.

Infrastructure at Risk:
High-end residential and commercial development; roads and public parking lots.

Intervention Work to Date:
Sea wall. Emergency measure rock revetment.

Desktop Assessment

In the event of a 1 m rise in sea level, HAT would increase from a level of +1.247 m MSL to +2.247 m MSL, within 0.4 m of overtopping the sea wall. Together with an increase in storm surge heights and frequency and wave heights, increased flooding of the parking lots, roads and shore-facing property could occur as a result of overtopping and inundation.

According to the Bruun rule, Hughes (1993) calculated that a 1 m rise in sea level would lead to a 150 m shoreline recession in this area. In addition to the limitations of the Bruun rule, this erosion estimate ignores the presence of the rocky offshore reefs and the sea wall backing the beach and assumes that the shoreline is made up of entirely erodible substrate. Therefore, this amount of erosion is likely to be an over-estimate. In the event that the sea wall holds, Hughes (1993) estimates that a local steepening of the shoreface is expected, which could undermine the foundations of the sea wall and road embankment.

Possible Adaptation Measures

In view of the potential impacts of climate change at this site, the following list of adaptation options that could be implemented along the Strand shoreline to adapt to the impacts of climate change, have been identified and grouped under the approaches of protect, accommodate or retreat:

Protection Measures

Inappropriate shoreline development within the littoral active zone has led to coastal infrastructure being at risk in the Strand. Although no significant shoreline retreat is evident, encroaching development has caused a situation where infrastructure such as public roads and parking lots and residential and commercial development are vulnerable to the effects of climate change.

Because of the extent to which development has encroached into the littoral active zone, protection measures could be implemented to hold the line. Softer protection measures, such as beach nourishment or sandbag revetments could be used to stabilise the shoreline in lieu of hard protection measures such as the construction of rock revetments or groynes.

Accommodation Measures

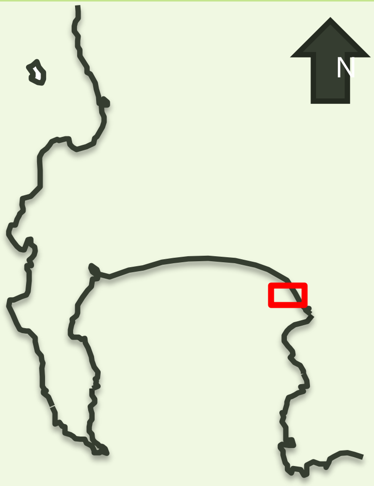
Accommodation measures are not expected to present a viable solution to this case study. Accommodation-based solutions such as flood proofing technologies, effective disaster management systems, traffic diversion measures and adequate stormwater drainage systems could be implemented together with a shoreline protection solution, in order to respond to flooding. These measures could complement protection, but do not present a feasible solution to the eroding shoreline when viewed in isolation.

Retreat

Due to the high value of the residential and commercial coastal developments, retreat is not considered a viable option.

6.2.10 Greenways Golf Estate

Greenways Golf Estate	
Site Location:	Eastern False Bay
Water Levels:	LAT: 0.00 m CD / -0.843 m MSL HAT: +2.09 m CD / +1.247 m MSL (SANHO, 2012)
Coastline Description:	Sandy coastline with shallow offshore reefs, backed by beachfront development, so that the dune field has been significantly reduced.
Bathymetry:	Moderate to steeply sloping.
Wind Climate:	Summer: Strong south-easterly; Winter: Moderate north-westerly
Wave Exposure:	Moderately exposed to south-westerly swell, with protection from offshore rocky banks.



Longshore sediment transport:
Longshore transport occurs in both north-westerly and SE directions, with the net longshore transport in a north-westerly direction.

Shoreline Stability:
Relatively stable – development encroachment being the biggest risk to shoreline stability.

Infrastructure at Risk:
High-end residential and commercial development, and associated civil infrastructure; roads and public parking lots

Intervention Work to Date:
Fenced-off dunes and dedicated walkways.

Desktop Assessment

According to the Bruun rule, Hughes (1993) calculated that a 1 m rise in sea level would lead to a 130 m shoreline recession in this area. In addition to the limitations of the Bruun rule, this erosion estimates ignores the presence of the rocky offshore reefs and assumes that the shoreline is made up of entirely erodible substrate. Therefore, this amount of erosion could be an over-estimate. A 130 m shoreline erosion would cause the new MSL contour to be located landward of the first two rows of houses.

Together with an increase in intensity and frequency of storm surge and waves, increased flooding of the walkway and shore-facing property could occur.

Possible Adaptation Measures

In view of the potential impacts of climate change at this site, the following list of adaptation options that could be implemented along the Greenways shoreline to adapt to the impacts of climate change, have been identified and grouped under the approaches of protect, accommodate or retreat.

Protection Measures

Examples of protection measures that could be implemented to adapt the Greenways shoreline to the effects of climate change are the construction of a revetment consisting of rock, sandbag or concrete units along the foredune seaward of the Greenways residences to protect these properties against storm erosion. A crown wall structure might be required on top of the revetment to prevent overtopping. As interim solutions, sheet piles or buried revetments could also be used to armour the remaining dunes and prevent the retreat of the shoreline past these dunes.

Protection measures that do not diminish the high amenity value of the beach could be considered. A softer protection measure that could be implemented along the Greenways shoreline is a beach nourishment project to continually replenish the sediment lost to erosion and thereby prevent shoreline retreat. This could be complemented by a project for the vegetation and rehabilitation of the remaining dune field strip.

Accommodation Measures

As the most seaward parts of the Greenways development could be inundated, an accommodation measure that could possibly be implemented would be the elevation of buildings onto piles that are driven into bedrock. The retreating shoreline would then no longer threaten to undermine these properties and could be left to establish its natural equilibrium with the rising sea level. The houses could either be elevated on to a fixed level, or be constructed with floating foundations on specifically designed guide piles, such as those used in Maasbommel. These piles would have to be specifically designed to withstand the wave, current and sediment processes in the nearshore. Constructing these foundations and elevated levels for all of the properties in the Greenways development would however be very expensive. The properties would also need to be altered by adding flood-proofing measures.

Retreat

As a part of the long term zoning of this area and the asset management plans of these buildings, a retreat solution could be developed and considered as no critical infrastructure is located along this shoreline.

6.3Site Screening Evaluation Conclusion

From the site screening it was found that in the case of soft, eroding shorelines, the only feasible accommodation measure that could be implemented to protect infrastructure in the affected regions is the foundation of structures onto piled foundations that stabilise these structures in the event of shoreline retreat. This could be very expensive, as adequate founding material is usually located at great depths. Protecting these structures by, for example, revetment structures, presents a more affordable adaptation measure, but might only be a short term solution and is often aesthetically undesirable.

At coastal sites with a stable, non- or slowly eroding shoreline (whether artificially or naturally maintained) that are also subject to flooding, elevation of the building is less critical could accommodation measures such as flood-proofing, disaster management and adequate stormwater drainage infrastructure be implemented to accommodate the impacts of flooding on affected infrastructure. Examples of such sites are Lagoon Beach and Sea Point.

At sites such as Greenways or Woodbridge Island, where the dune field has been diminished or damaged but not completely destroyed, accommodation measures could be implemented together with soft protection measures such beach nourishment, dune rehabilitation and vegetation projects or reinforced dunes.

At sites such as Strandfontein and Fish Hoek, the infrastructure at risk is of relatively little value value (car park areas, a caravan park and beach amenities) and a managed retreat approach could be implemented.

Based on the results of the site screening study, three sites where accommodation measures could be implemented have been identified: Woodbridge Island, Bakoven and Glencairn. Based on initial enquiries, Bakoven was the site with the most information readily available and stakeholders who were willing to participate. This case study was therefore advanced to a more detailed assessment, as described in Chapter 7, to provide a more accurate assessment of the feasibility of implementing accommodation measures at Bakoven.

7. Detailed Assessment of Bakoven

7.1Introduction

Of the ten sites screened in Chapter 6, Bakoven has been selected as the site to with which advance to a more detailed assessment. The aim of this chapter is to provide a detailed assessment of status quo conditions at Bakoven, as well as the predicted future conditions in the face of climate change.

In light of this information, the feasibility of implementing an accommodation solution at Bakoven will be assessed.

7.2Background

The Bakoven shoreline, located just south of Camps Bay, is characterised by large granite boulders and outcrops that form headlands for white sandy pocket beaches in some locations, and natural pebble beaches in others. Bakoven was named for the 'Bak Oond,' an oven-shaped rock which has a small dark recess on the inshore side, like the door of an old baking oven. Against the backdrop of the Twelve Apostles mountain range, the steep and densely vegetated slopes have been developed with wooden seaside bungalows overlooking the beaches, connected by narrow winding footpaths.

The construction of the first structures in Bakoven dates back to 1903. These structures were initially leased to the public for camping (City of Cape Town, 2007). The first recorded building is a boat warehouse that was reportedly constructed by a Mr E.E. Denny in 1904. The first bungalow was reportedly erected by a Mr D. Bosman in 1909 (City of Cape Town, 2007).

During the housing shortage after the First World War, lessees were allowed to erect wooden bungalows as a temporary measure. Bungalows in those days were little more than tin shacks, that had developed from seaside shelters, constructed in timber frame, with the exterior cladding being of corrugated iron. The only form of foundation was supporting the base of the timber frame on stones, or, more frequently, on old paraffin tins filled with rocks or stones. As they became more like homes, the construction (or upgrade) materials became more durable (Brown, 2013).

The settlement was recognized as permanent in 1934 when council introduced the first waterborne sewage (City of Cape Town, 2007). Greatly differing from the present situation, areas like Bakoven, Glen Beach and to a certain degree, Clifton, were not considered as anything but very average areas, value-wise. This was also exacerbated by the land being leasehold - which led to many residents not wishing to spend too much on the buildings (Brown, 2013). The leases mostly remained in place, until council resolved to sell the bungalow sites in the early 1990s.

In order to sell the bungalows to the public, the land had to be rezoned from Public Open Space to a Single Residential Use Zone. As a part of this process, the existing three-dimensional maximum development envelope (MDE) of all bungalows was recorded and incorporated into the Zoning Scheme (City of Cape Town, 2007). The development rights of each property owner is represented by this three dimensional MDE – it constraints all development of the bungalow upward, sideways and downward to remain within this maximum development envelope (City of Cape Town, 2007). This restriction as well as other regulations imposed upon Bakoven by the City of Cape Town is discussed further in Section 7.3.13.

The risk that comes with living at the water's edge has been there since the houses were first erected - in the early years most of the homes near the water's edge were elevated, allowing for water to wash in and out without causing too much damage, i.e. wet flood proofing (Brown, 2013).In recent times the desirability of the area has grown and due to the escalation of property prices new owners have enclosed the previously open framed footing areas (Brown, 2013).

The area being considered as a part of this study is demarcated in Figure 7-1, on an aerial image supplied by NGI (National Geo-Spatial Information, 2010).

Figure 7-1: Bakoven study area (National Geo-Spatial Information, 2010)

7.3Status Quo Environmental Assessment

7.3.1 Topography

Detailed LIDAR topography data for Bakoven was obtained from the City of Cape Town. This data contained high-detail topography data extending seaward to the MSL contour (equal to the geodetic land levelling datum), which was the zero datum of the survey. Levels of buildings, road infrastructure etc. were removed from the dataset by the data owner so that it contained only the topography levels of the ground level relative to MSL (City of Cape Town, 2013).

A graphical plot of the dataset is shown in Figure 7 2 and Figure 7 3, providing an indication of the extremely high level of detail contained in the LIDAR dataset. Red data points present the highest levels, with blue representing the lowest. Figure 7 4 illustrates a 5m-contour map generated from the data.

The plots of Figure 7 2 to Figure 7 4 were generated by the author from raw LIDAR data provided by the City of Cape Town (2013).

From the foreshore, shoreline rises very steeply such that the horizontal distance from the MSL contour to the +10 m contour varies from as little as 35m to 140 m. Within this narrow zone along the coast, properties have been built seaward of the +10 m MSL contour, with a few properties located as low as +3 m MSL.

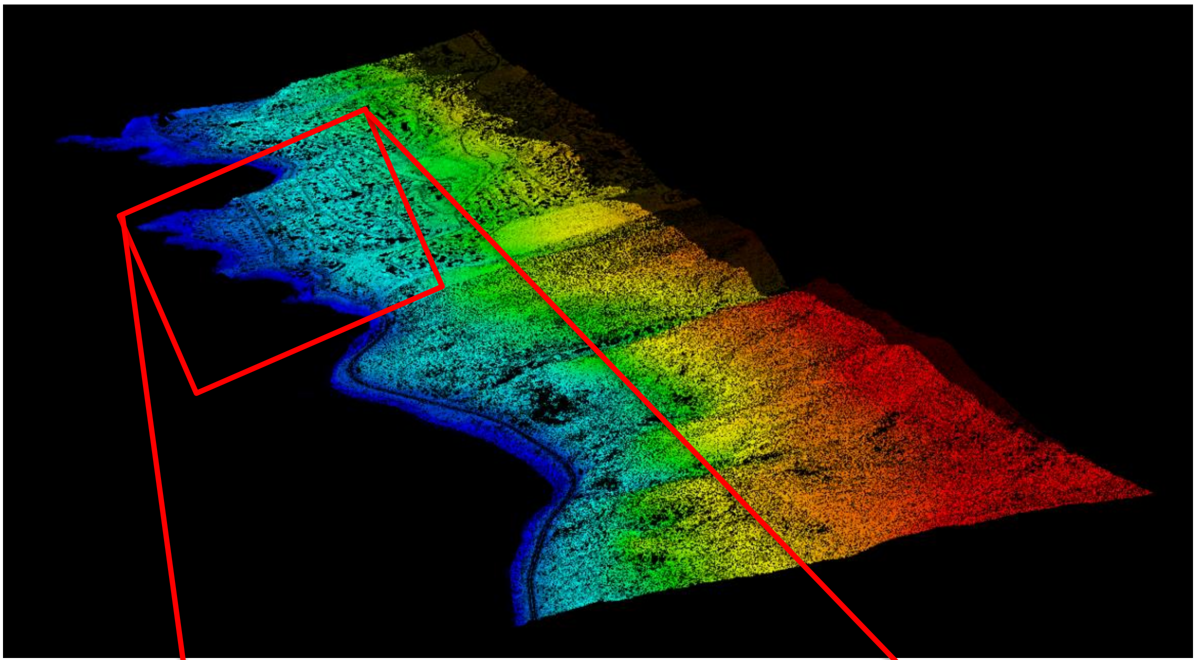


Figure 7-2: DTM generated from LIDAR data made available by the City of Cape Town (2013)

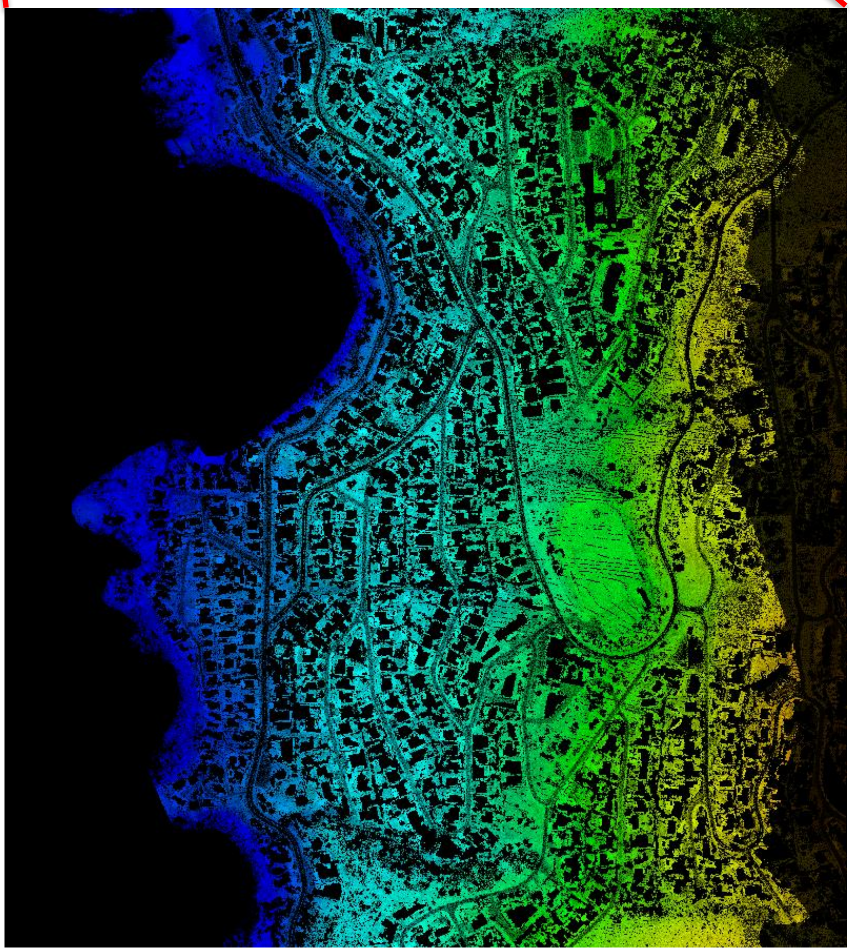


Figure 7-3: DTM generated from LIDAR data made available by the City of Cape Town (2013)

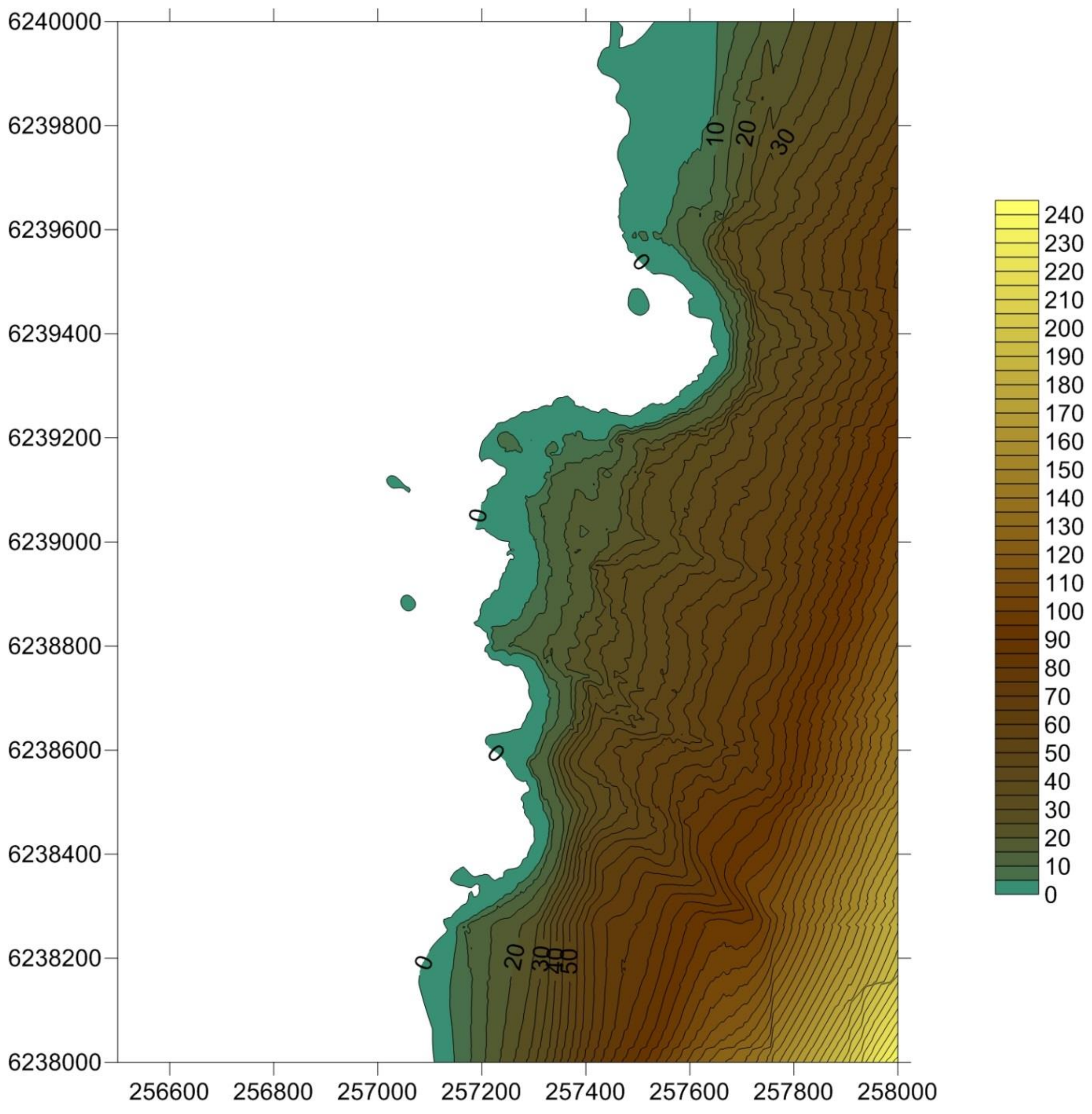


Figure 7-4: 5m Contour topography map generated from LIDAR data made available by the City of Cape Town (2013) (Contours showing heights in metres relative to MSL)

7.3.2 Bathymetry

Detailed bathymetry data for the entire Cape Peninsula region (including both Table Bay and False Bay) was obtained from SANHO (2013). The nearshore measurements near Bakoven between the -5 m CD and MSL contour were, however, limited. The coarse nature of the bathymetry also does not allow for accurate representation of the rock outcrops and boulders located in Bakoven's nearshore area.

Maps of the bathymetry data, indicating the position and density of data points, are shown in Figure 7-5 and Figure 7-6. Figure 7-7 illustrates a 5 m-contour bathymetric map generated from the SANHO data, relative to Hydrographic Chart Datum.

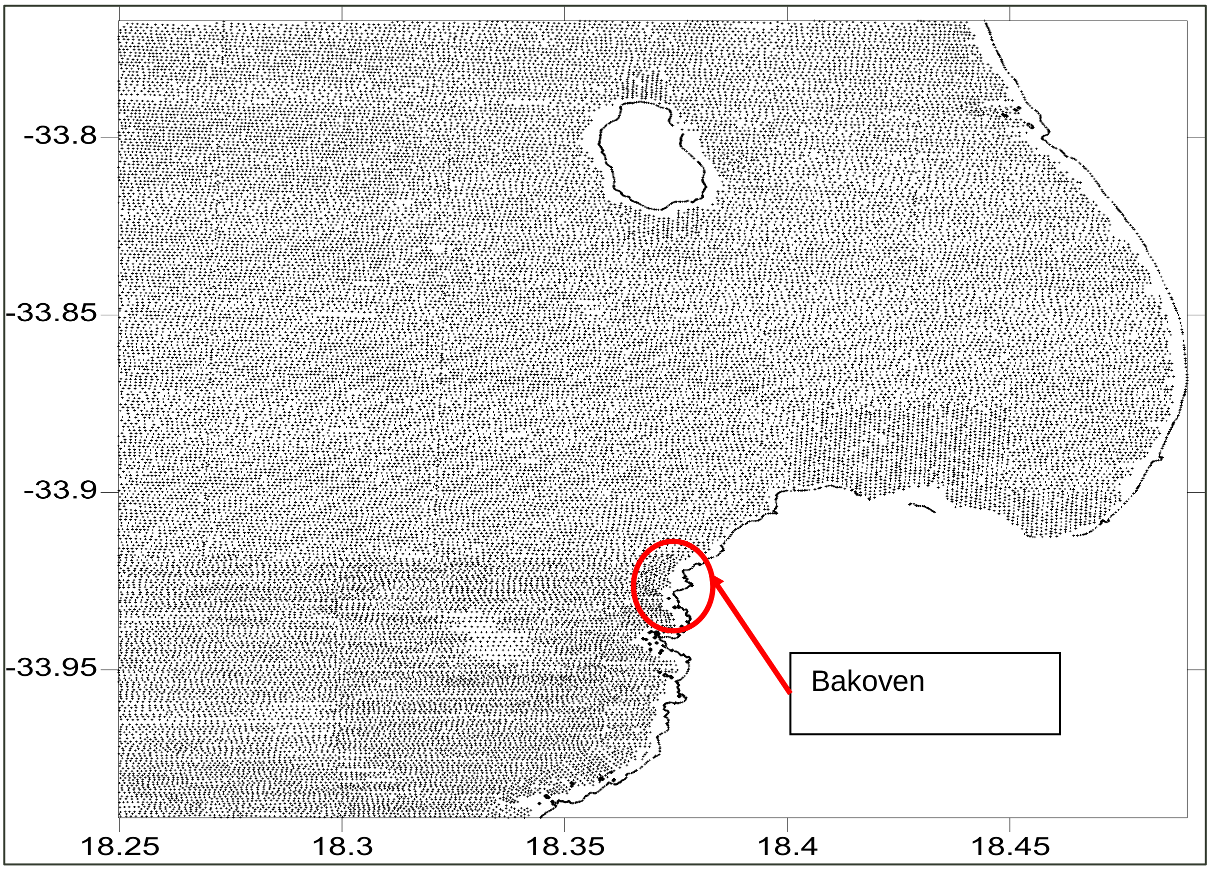


Figure 7-5: SANHO bathymetry data - Points map (South African National Hydrographic Organisation, 2013)

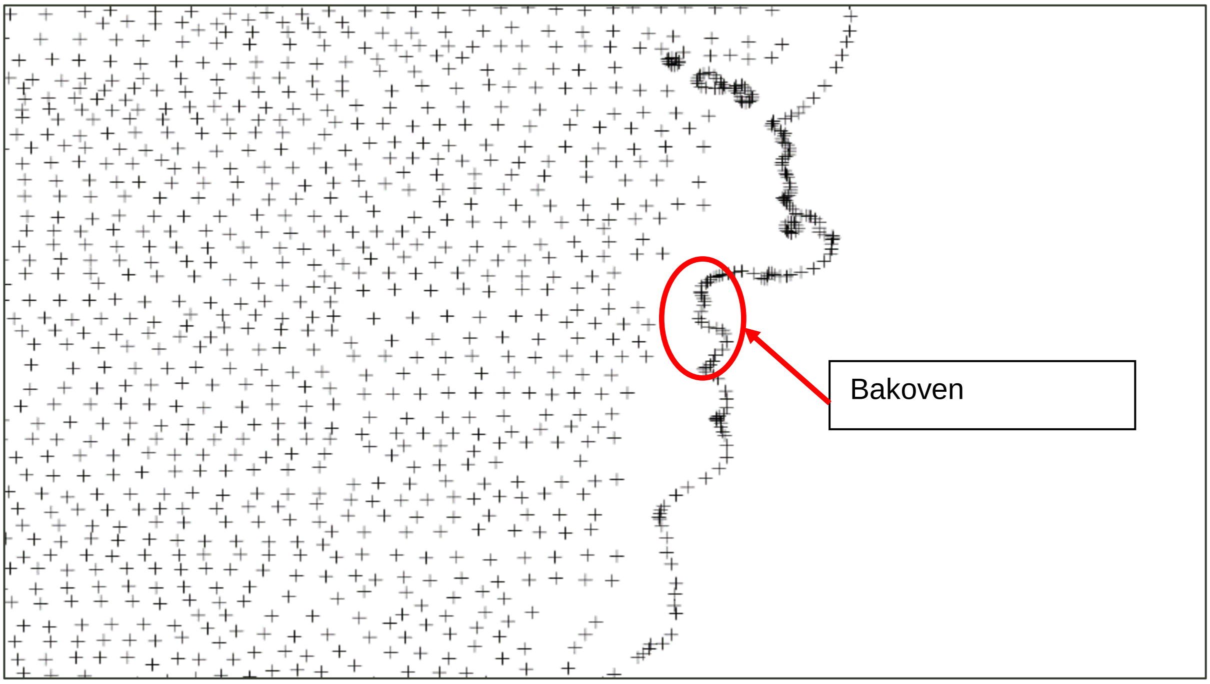


Figure 7-6: Bathymetry data - Points map (Nearshore) (South African National Hydrographic Organisation, 2013)

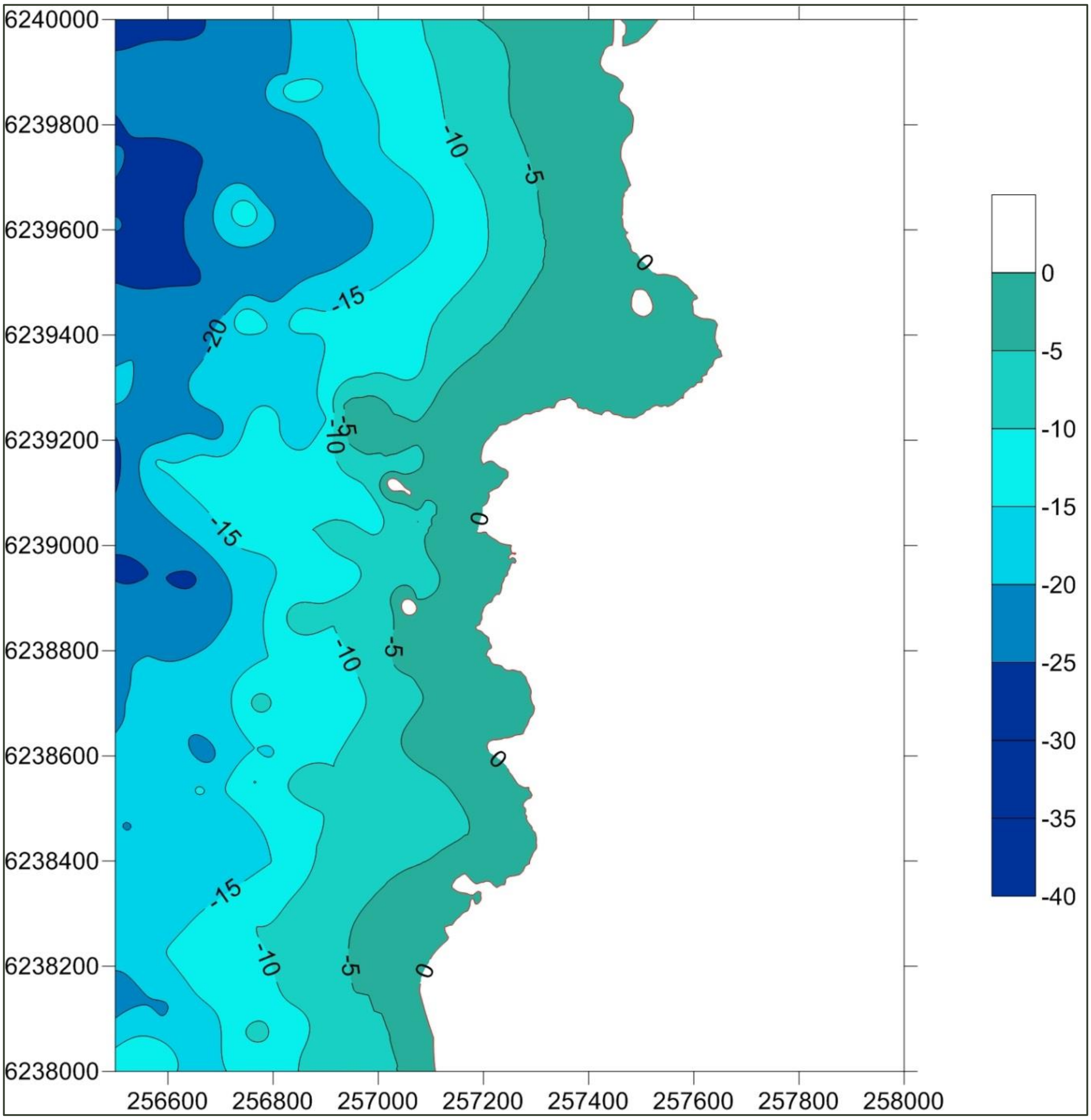


Figure 7-7: 5m Contour bathymetric map generated from SANHO data (Contours showing heights in metres relative to MSL)

7.3.3 Geology

An extract of the geology map of the Cape Peninsula is presented in Figure 7-8.

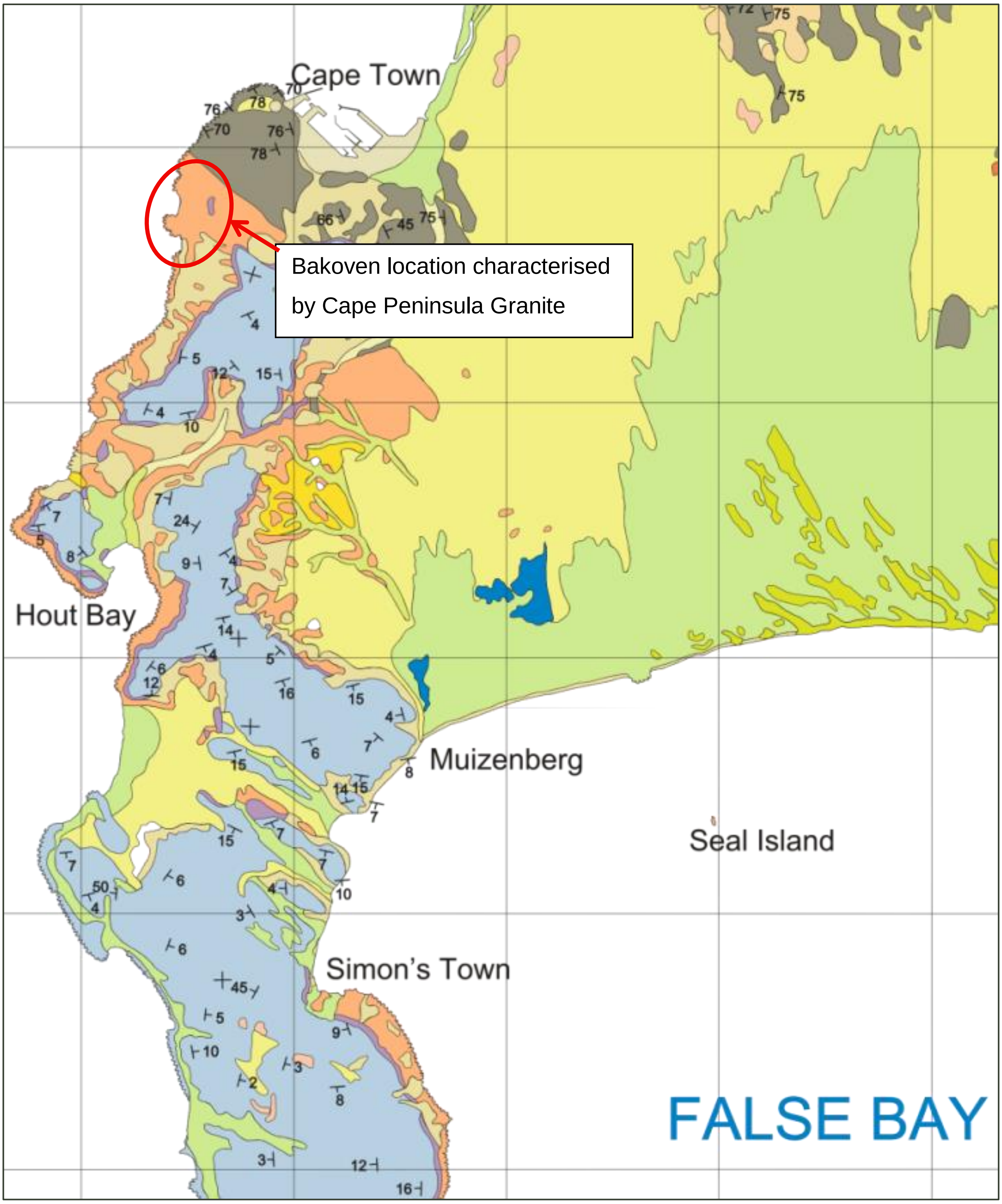


Figure 7-8: Cape Peninsula geology map: Extract from Geological Survey Map 3318 CD (Engelbrecht, 1984)

Bakoven's granite boulders originate from the Cape Peninsula Granite Suite (Compton, 2004). The granite layer was initially located at a great depth, but prolonged erosion over time has visibly exposed this granite layer at the earth's surface. Granite boulders have a characteristic spheroidal shape and are generally pale to medium grey with a fairly rough surface, with clearly visible crystals (Compton, 2004).

7.3.4 Beach Profile and Material

Topography and bathymetry datasets described in Sections 7.3.1 and 7.3.2 were merged into a single platform and used to study the cross sectional beach profile. Shore-normal transects were taken along the Bakoven shoreline as presented in Figure 7-9, stretching from approximately the +15 m MSL to the -5 m MSL contour. The beach profiles taken at cross sections 1 to 6 are shown in Figure 7-10 to Figure 7-15.

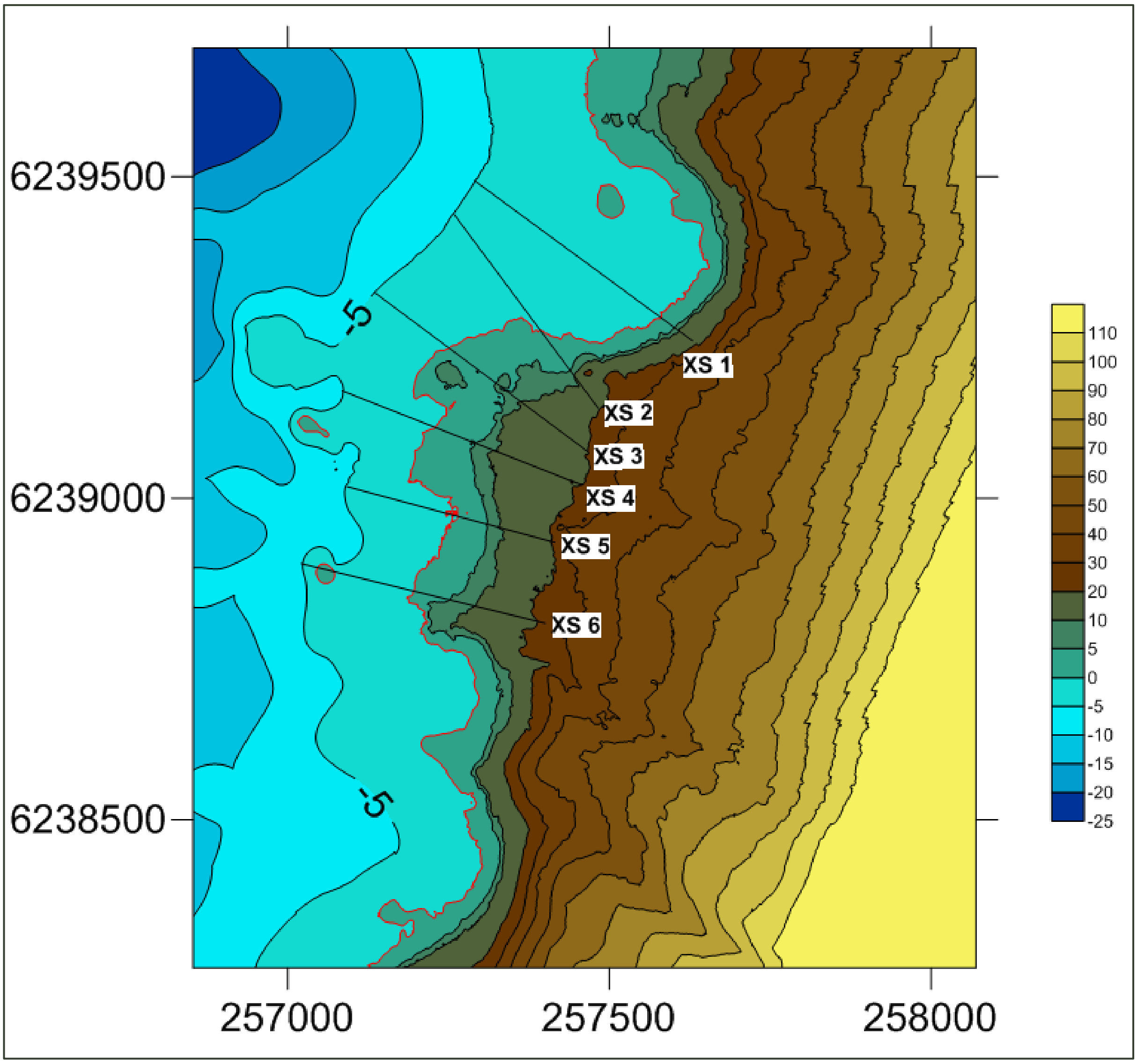


Figure 7-9: Bakoven bathymetry and topography map showing shore-normal transect locations (Contours showing heights in metres relative to MSL)

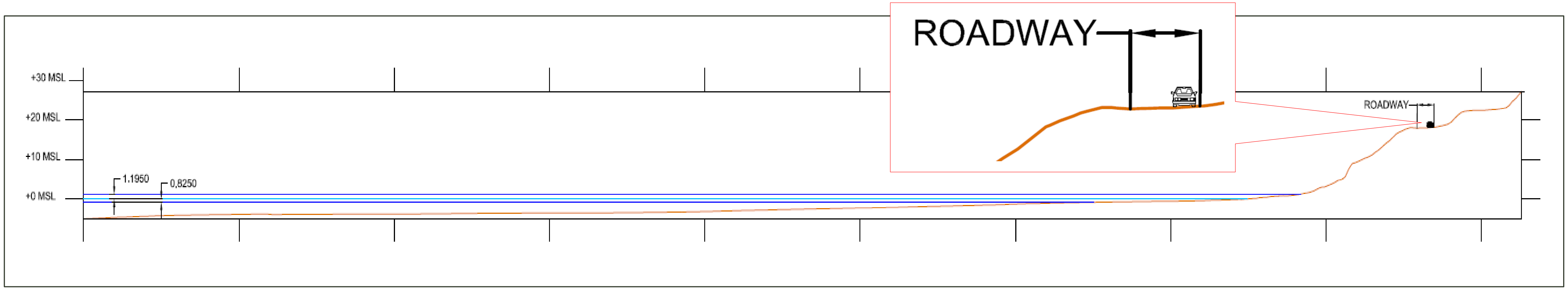


Figure 7-10: Indicative XS 1

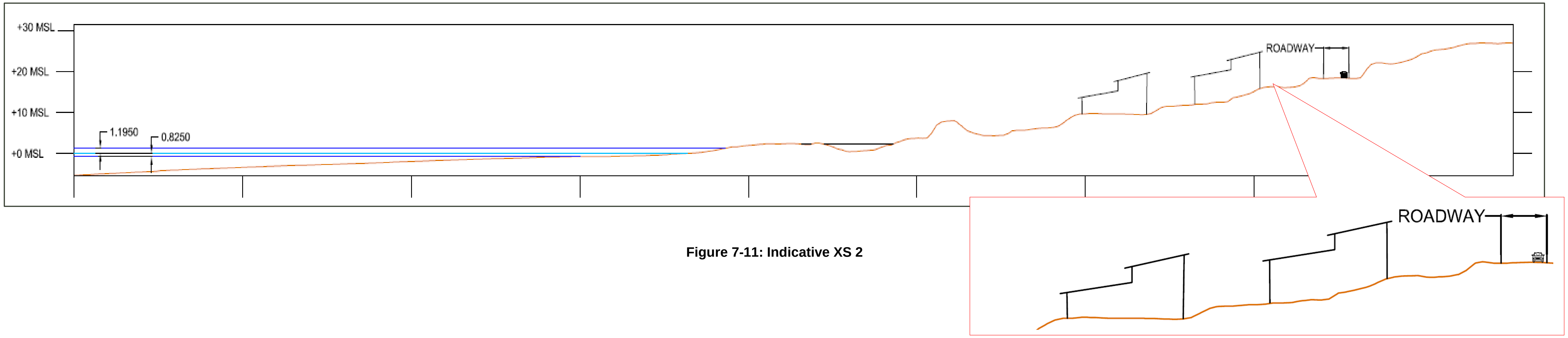


Figure 7-11: Indicative XS 2

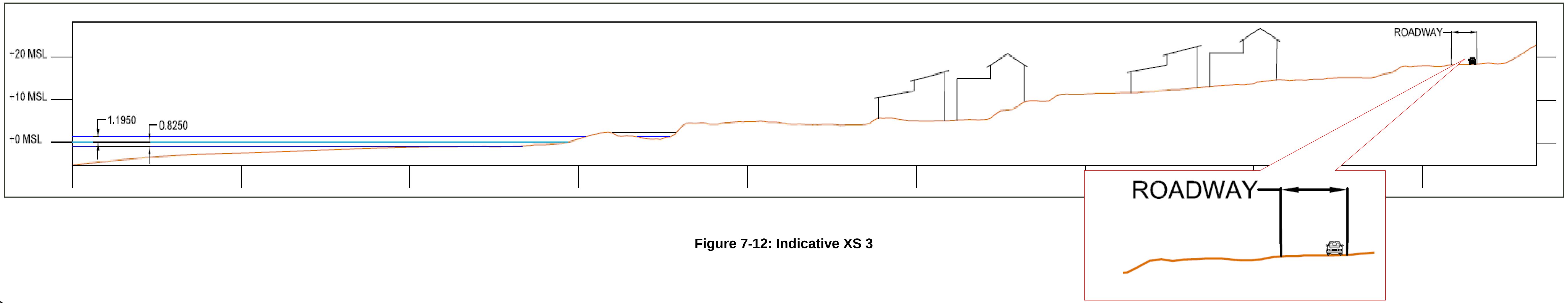


Figure 7-12: Indicative XS 3

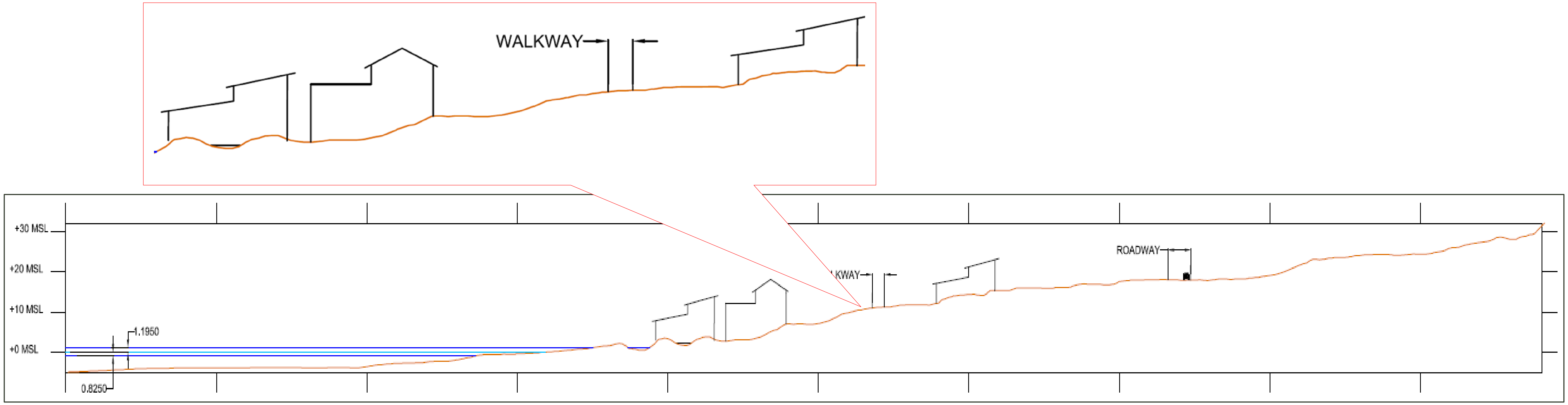
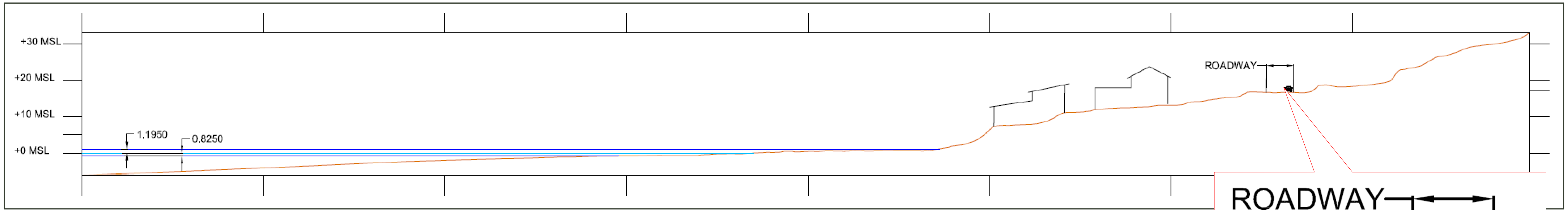


Figure 7-13: Indicative XS 4



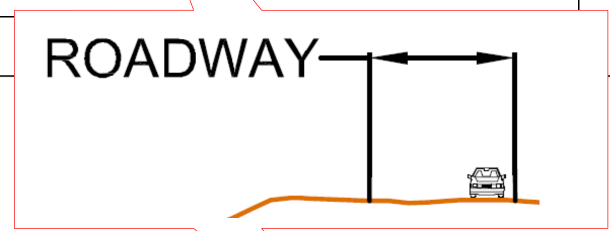


Figure 7-14: Indicative XS 5

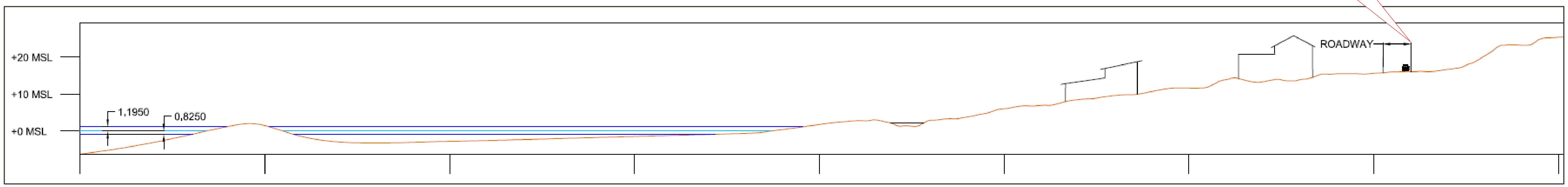


Figure 7-15: Indicative XS 6

As can be seen from the cross-sectional profiles, Bakoven is characterised by a steeply rising beach face and foreshore (up to 1:3 slope), and comparatively flat nearshore (1:20) bathymetry.

The Bakoven beach contains many large granite boulders, up to 1 to 2 m in diameter, some forming large outcrops trapping sand, as illustrated in Figure 7-16 and also creating pebble beaches in other locations (refer Figure 7-17) through weathering.

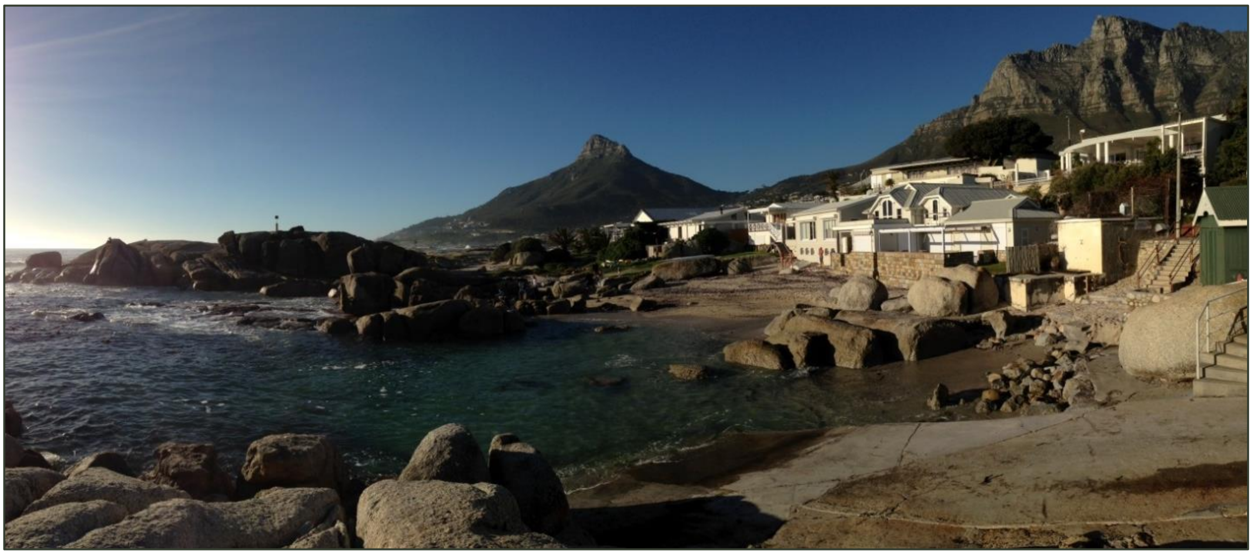


Figure 7-16: Granite boulders at Bakoven Beach forming headlands for pocket beaches

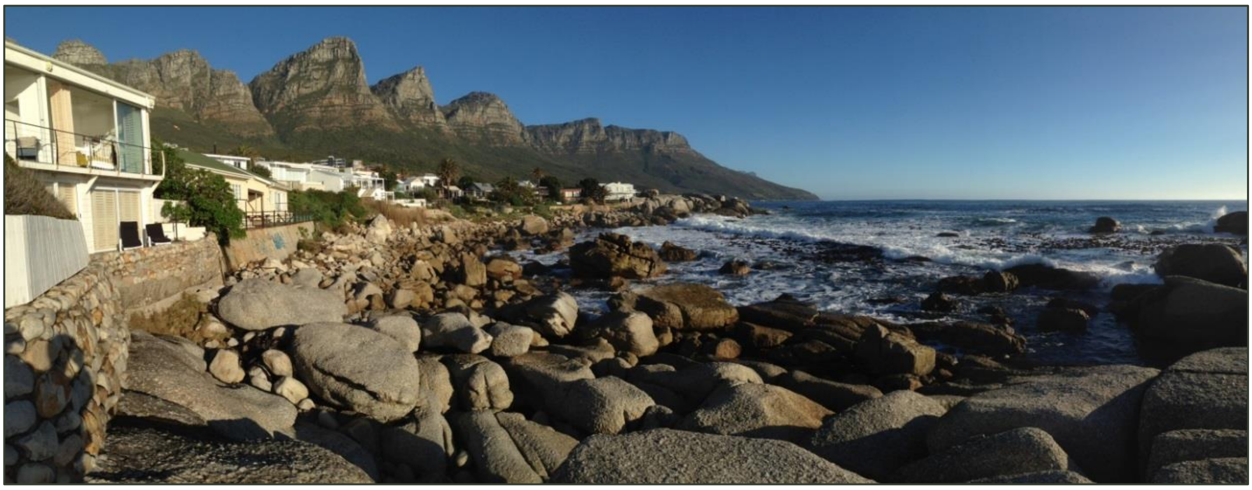


Figure 7-17: Granite boulders along Bakoven Beach

7.3.5 *Wind Data*

To analyse the wind climate of Cape Town, measured wind data was obtained from the NOAA database (NOAA, 2013), as measured at the Port of Cape Town for the period 1998 to 2013.

Figure 7-18 to Figure 7-20 provide seasonal wind roses, generated from this dataset.

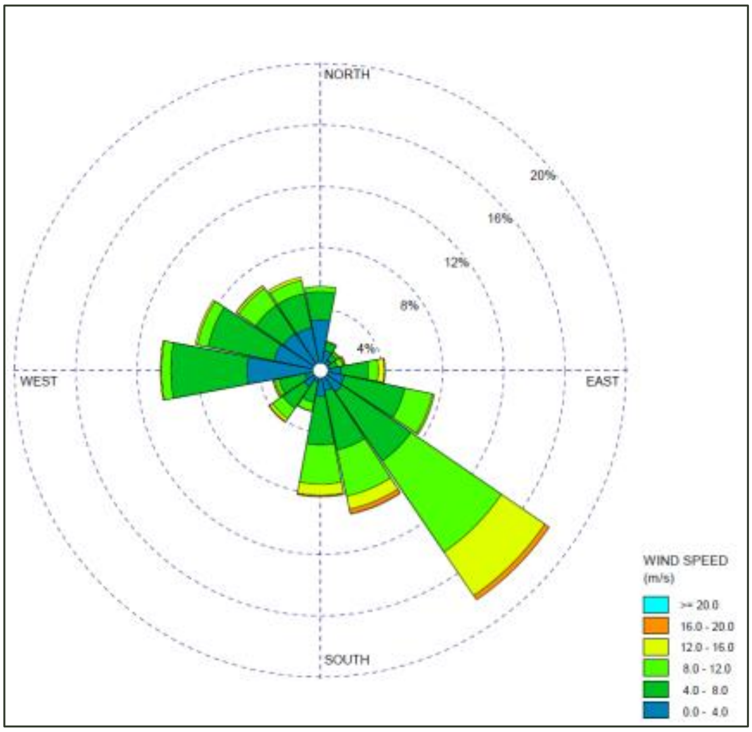


Figure 7-18: Status quo wind rose diagrams - spring

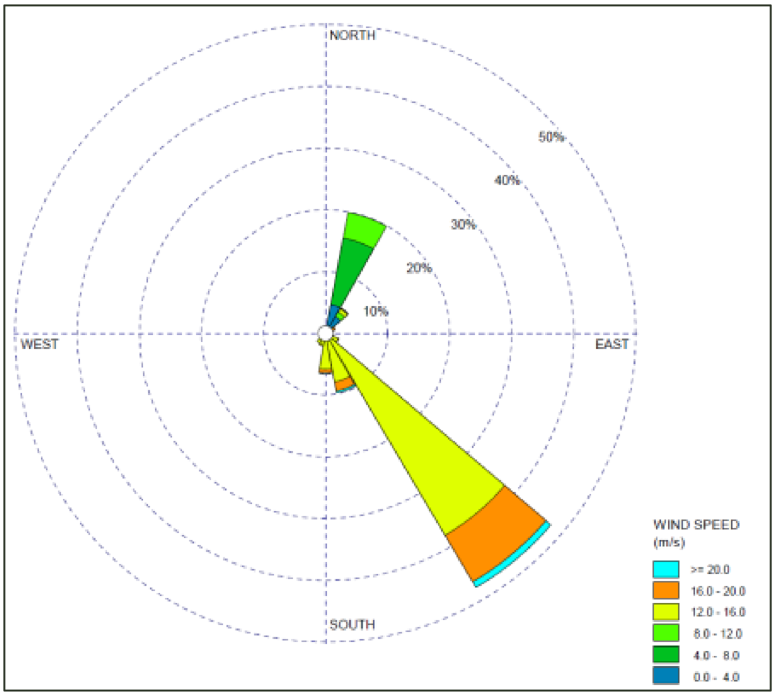


Figure 7-19: Status quo wind rose diagrams - summer

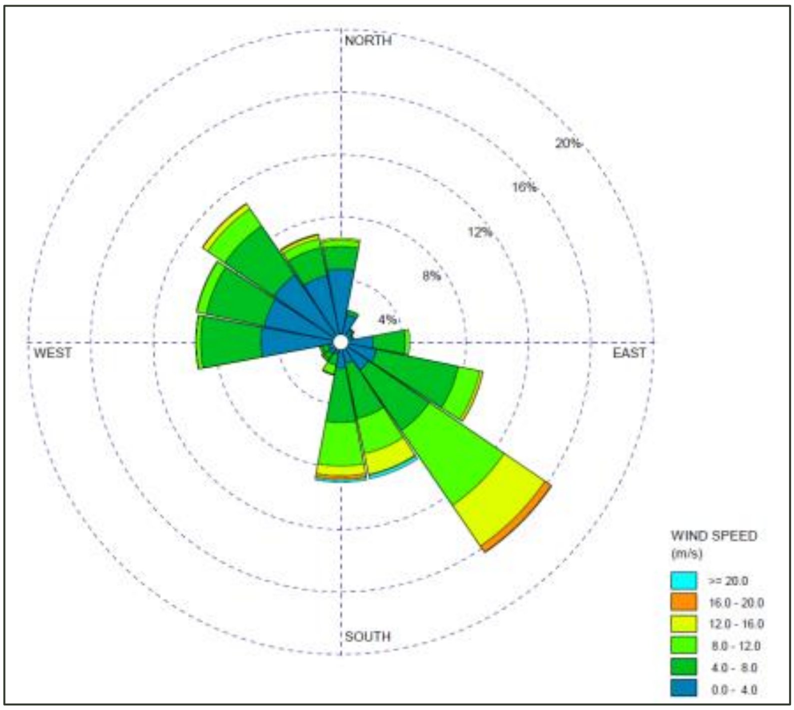


Figure 7-20: Status quo wind rose diagrams - autumn

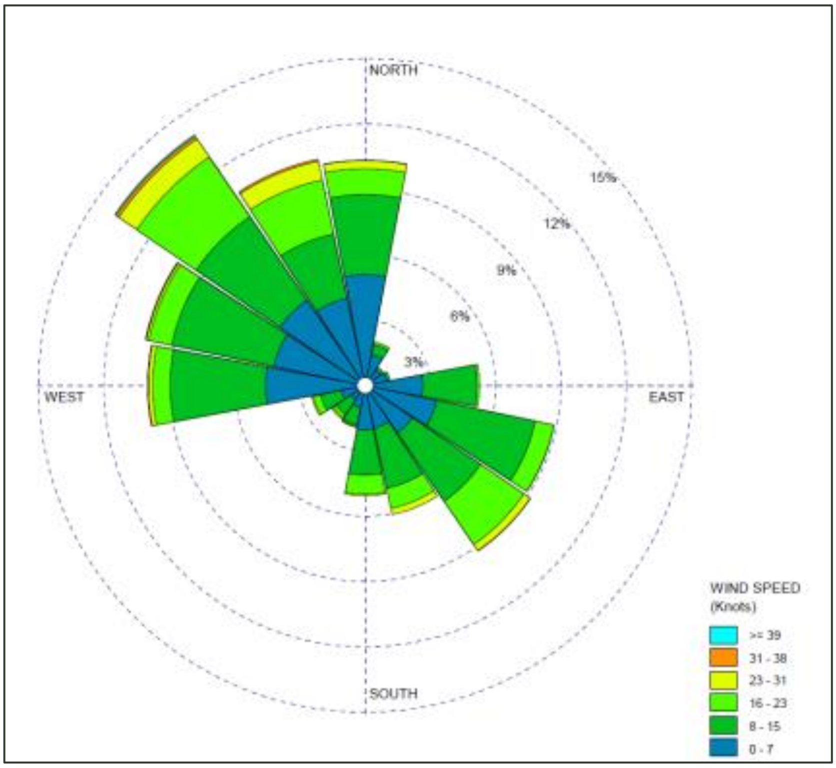


Figure 7-21: Status quo wind rose diagrams - winter

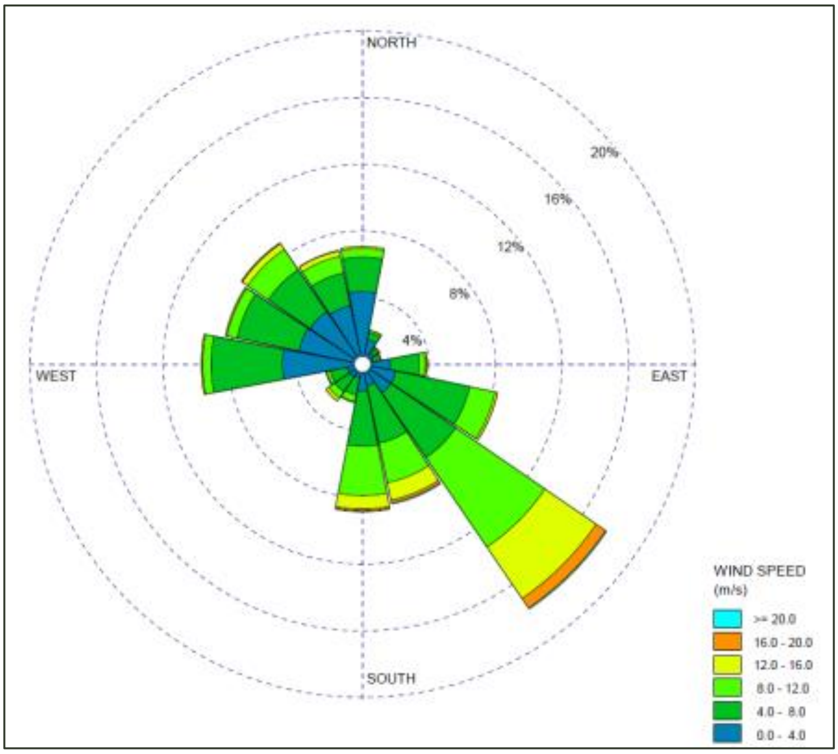


Figure 7-22: Status quo wind rose diagrams - All seasons

The wind rose diagrams clearly indicate the annual shift from a north-westerly wind in the winter to a strong south-easterly in the summer.

Each of the four wind direction quadrants were analysed separately, to determine the extreme wind speed from various directions associated with various return periods. The extreme value analysis was performed using the point-over threshold method and a three-parameter Weibull extreme value distribution. The results of the extreme value analysis are presented in Table 7-1.

Table 7-1: Status quo extreme wind speed analysis

Return Period (years)	3 hourly average (m/s)			
	NE	NW	SE	SW
1	14.5	13.6	16.4	15.1
5	18.4	16.4	22.5	18.3
10	19.7	17.5	25.4	19.4
20	20.8	18.6	28.3	20.5
50	22.2	19.9	32.4	21.8
100	23.1	20.8	35.6	22.7

7.3.6 Water Level Data

Tidal levels

The nearest tide measurement station to Bakoven is within the Port of Cape Town. Measured water levels at this station were assumed to be an accurate representation of those at Bakoven. Surge that is experienced within Table Bay due to shallow water effects within the bay will not be as severe for Bakoven, while the wave setup component at Bakoven will be larger than that measured at the Port of Cape Town. (The contributions of each of these components are discussed in more detail later in this section.) Extreme water levels due to surge effects, as calculated from the Port of Cape Town tidal gauge, are therefore deemed to be a reasonable estimate for Bakoven – conservative in some aspects (wind setup), and less conservative in others (wave setup).

Figure 7-23 shows the location of Bakoven and the tidal measuring station.

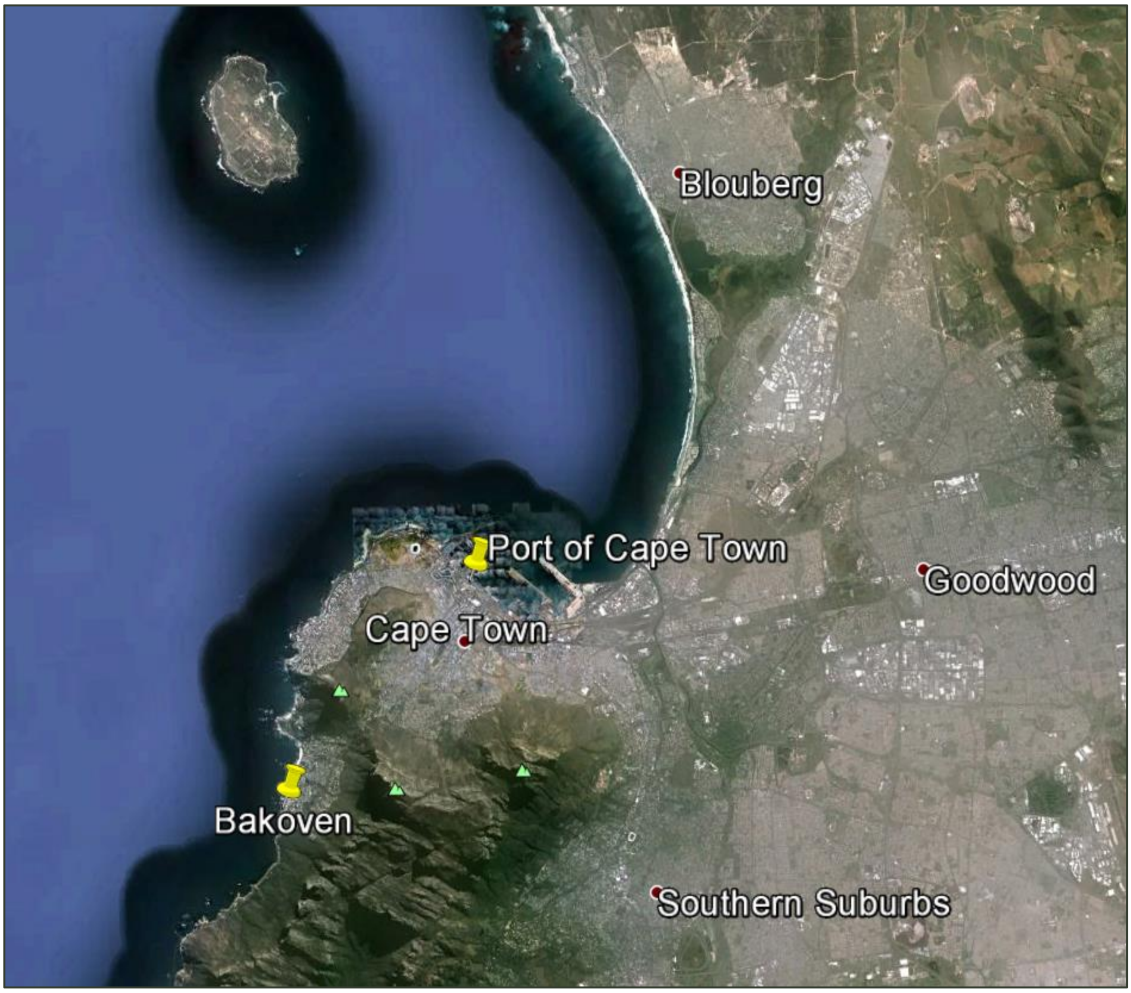


Figure 7-23: Tide Measuring Station Location (Google Earth version 7.1.2.2041, 2013)

Tidal levels for this measuring station were sourced from the SANHO Tidal Tables book (2010) and are presented in Table 7-2.

Table 7-2: Predicted tidal levels for Cape Town

Tidal Level	Metres above Geodetic Land Levelling Datum (referred to commonly as “MSL”)	Metres above Hydrographic Chart Datum (CD)
Highest Astronomical Tide (HAT)	1.20	2.02
Mean High Water Springs (MHWS)	0.92	1.74
Mean High Water Neaps (MHWN)	0.44	1.26
Mean Level (ML)	0.16	0.98
Mean Low Water Neaps (MLWN)	-0.13	0.7
Mean Low Water Springs (MLWS)	-0.58	0.25
Lowest Astronomical Tide (LAT)	-0.83	0

HAT is the highest tidal level which can be predicted to occur under average meteorological conditions over a period of 18.6 years. This level can, however, be exceeded during extraordinary meteorological conditions, such as storm surges and barometric pressure setup (elevation of the water level due to low pressure systems).

LAT is the lowest level which can be predicted to occur under average meteorological conditions, although levels lower than LAT can be reached as a result of negative storm surges.

Mean high and low water spring tides are defined, respectively, as the average of the levels of each pair of successive high waters, and of each pair of successive low waters, during spring range tides – that period of about 24 hours occurring twice during every lunar cycle, at full moon and new moon (approximately every 14 days), when the range of the tide is greatest.

Mean high and low water neap tides are defined as the respective averages of the levels of each pair of successive high waters, and of each pair of successive low waters, during neap range tide - that period of about 24 hours occurring twice during every lunar cycle (approximately every 14 days), when the range of the tide is least.

Extreme Still Water Levels

Extreme water levels observed for the years 2006 to 2012 were received from SANHO, as measured in Granger Bay, Cape Town. SANHO also provided the residuals for the same time period, defined as the difference between the measured and predicted water levels.

This difference between measured and predicted water level can be seen as a combination of the following main meteorological effects:

- Wind setup
- Negative barometric pressure
- Wave setup.

Each of these is discussed in more detail in the following sections.

Wind setup

The term wind set-up refers to the slope of the water surface in the direction of the wind stress. The magnitude of the wind setup elevation is proportional to the fetch length and the square of the wind speed, and inversely proportional to the water depth (SANHO, 2013).

Onshore winds will increase wind setup against the coast, while offshore winds will conversely cause a reduction in the surface elevation.

In shallow bays, such as Table Bay, the wind setup component will be larger than that experienced at Bakoven.

Barometric pressure component

The inverted barometer effect, resulting from low pressure systems associated with certain storms, can cause a pronounced increase in sea level, referred to as the barometric pressure component, which is linearly proportional to the difference between the measured atmospheric pressure and standard atmospheric pressure. A reduction in pressure below the standard atmospheric pressure would lead to an increase in surface elevation, whilst an increase in pressure would lead to a decrease. As a rule of thumb, variations in atmospheric pressure cause the sea level to change by approximately 1 cm per millibar, according to the inverse-barometer model (Ponte & Gaspar, 1999).

Wave Setup

Wave setup is the super-elevation of the mean water level caused by wave action (CEM, 2003). The change in wave setup is inversely proportional to the water depth and proportional to the square of the wave heights. This component is probably not present in the tide measurement data, as these are recorded within a tranquil basin. This component would, however, be present at Bakoven.

Extreme Water Level Analysis

Residual water levels (representing the surge in water levels due to a combination of wind setup, barometric pressure and wave setup) as measured at Granger Bay for the years 2006 to 2009 were made available by SANHO and were analysed using the Point over Threshold method, fitting residuals to both a Gumbel and a three-parameter Weibull extreme value distribution. Only positive surge values were included in the analysis.

Results of the extreme water level analysis are shown in Table 7-3.

Table 7-3: Estimated surge values for different return periods

Return Period (yrs.)	Gumbel Surge Value (cm)	Weibull H_{ss} (cm)
1	52.61	52.73
5	63.67	64.09
10	68.44	68.98
20	73.21	73.87
50	79.51	80.34
100	84.28	85.23

It should be noted that due to the small period of data available, the confidence in the analysis is not very high – extrapolating a 100 year extreme value from a dataset spanning only three years is not regarded as being very accurate, and a larger data set would be preferred for accurate extreme value analysis. The statistical confidence of the values presented in Table 7-3 is therefore not very high, but the values do correspond with values for Cape Town as determined by others:

- PRDW estimates of extreme water levels for Cape Town from the Climate Change Think Tank project (PRDW, 2012) were derived from a much larger dataset, with measured water levels from 1967 to 2013 compared to predicted water levels. The difference between the two datasets, termed the residual tide, was determined and all positive residuals were analysed to determine the extreme positive residuals for a range of return periods, as presented in Table 7-4 below.

Table 7-4: PRDW residual tide values

Return Period [years]	Best estimate positive residual [m]	Upper 95% confidence positive residual[m]
20	0.64	0.71
50	0.70	0.80
100	0.74	0.87

- Theron (2007) estimated some maximum values for surge along the South African coast to amount to 0.5 m for wind set-up, 0.35 m for hydrostatic set-up and 1 m for wave set-up (for breaking waves). This gives a value of approximately 0.85 m for hydrodynamic surge and wind set-up and then an additional offset for wave set-up and runup needs to be included.

As the PRDW estimates were performed from a much larger dataset, thereby providing an extreme estimate deemed to be more accurate; the PRDW estimates were used for the purposes of this study. Adding these best-estimate values to the MHWS value, +0.92 m MSL, the extreme still water levels for Bakoven are as presented in Table 7-5.

Table 7-5: Extreme still water levels for Bakoven

Return Period [years]	Extreme Still Water Level (+ m relative to MSL)
10	1.52
20	1.56
50	1.62
100	1.66

7.3.7 Offshore Wave Data

General Description of Wave Climate

The major wave-generating system resulting in high ocean waves along the southern RSA coastline is the regular occurrence of cold fronts with their associated low pressure systems that pass west to east just to the south of the continent in the latitudes between 30 and 60 °S (Rossouw, *et al.*, 1982). These fronts together with two permanent high-pressure systems, the South Atlantic high off the west coast and the Indian Ocean high off the east coast, dominate the southern generating forces in the oceans surrounding the southern tip of the continent (Rossouw, *et al.*, 1982).

These low-pressure systems typically shift toward the south in summer and towards the north in winter so that high waves along the South African coastline occur more frequently in winter. They do however, on occasion, move far enough north during summer to cause large waves, but the occurrence of these high waves is less frequent in summer than in winter (Rossouw, *et al.*, 1982).

Offshore Wave Measurements

Offshore wave measurements at two locations, the Slangkop and Cape Point wave buoys, were made available by the CSIR.

The Slangkop buoy previously was situated approximately 13 km directly off Kommetjie at the coordinates 34.12666° S, 18.17666° E in approximately 170 m of water. These measurements cover a date range from 1978/10/03 to 1993/05/14. No directional data was available from this buoy.

In 1994, the Slangkop buoy was moved to the current Cape Point location, 34.204°S, 18.28667° E in a water depth of 70 m. The Slangkop waverider buoy measured a one-dimensional spectrum, including the wave energy as a function of wave frequency. Initially, the Cape Point measurements did not include directional information either, with only the wave frequencies and corresponding wave energies being measured. From 19 April 2001 the peak wave direction, as well as the wave spreading were included in the measurements.

The Cape Point dataset formed the main focus of the study because it contains directional information.

Offshore Wave Analysis

An extreme value analysis (EVA) of the offshore wave heights was performed using a point-over-threshold method, with the storm threshold defined as an offshore significant wave height of 5.5 m (this wave height being exceeded in 10 storms per year, on average). The data was fitted to a three-parameter Weibull extreme value distribution and extrapolated to determine the significant wave height associated with various return periods. The results from the extreme value analysis are presented in Table 7-6.

Table 7-6: Extreme wave heights from CSIR Cape Point buoy

Return Period (yrs.)	Significant Wave Height (m) in 70m depth
1	7.1
5	8.8
10	9.6
20	10.4
50	11.4
100	12.2

These results correspond quite well to significant wave heights calculated by Rossouw and Von St. Ange (2011), as presented in Table 7-7.

Table 7-7: Extreme wave heights as calculated by Rossouw and Von St Ange (2011)

Return Period (years)	Significant Wave Height (m) in 70 m depth
1	8.3m
10	10.2m
100	12.2m

For the directional analysis of extreme wave heights, the wave data was binned into 15 degree bins. An EVA was performed for every bin to determine the current 1:1, 1:5, 1:10, 1:20, 1:50 and 1:100 year wave heights. An H_s-T_p relationship was determined for every bin and this correlation was then used to determine the associated assumed T_p with each predicted H_s. A simplistic linear relationship between H_s and T_p was assumed, which may lead to a slight overestimation of peak periods associated with large wave heights.

The 1:50 and 1:100 year conditions of offshore significant wave height and associated offshore peak wave period are shown in Table 7-8.

Table 7-8: 1:50 and 1:100 year offshore wave conditions

Return Period (years)	Wave Direction (degrees)	Offshore Significant Wave Height (m)	Offshore Peak Period (s)
50	158	3.40	10.08
	173	4.00	10.64
	188	5.70	14.76
	203	8.40	16.80
	218	9.90	19.19
	233	10.60	18.64
	248	10.00	15.67
	263	9.85	15.61
	278	6.40	12.89
	293	8.10	12.91
	308	5.40	10.37
	323	3.70	10.27
100	158	3.60	10.23
	173	4.20	10.67
	188	6.10	15.09
	203	9.10	17.20
	218	10.60	19.70
	233	11.30	19.08
	248	10.60	15.80
	263	10.70	15.92
	278	6.80	13.01
	293	9.30	13.79
	308	5.80	10.47
	323	4.00	10.53

7.3.8 Nearshore Wave Data

Nearshore Wave Model

As waves propagate from deep sea to shallower nearshore water, it is significantly influenced by certain physical processes. These processes include refraction, shoaling, diffraction, bottom friction, white capping, wave-wave interaction and breaking.

The numerical model SWAN (Simulating WAves Nearshore) was used to determine the nearshore wave conditions at Bakoven. SWAN by is a two-dimensional third-generation wave model developed at Delft University of Technology (Delft University of Technology, 2013).

According to the SWAN home webpage (Delft University of Technology, 2013) the following physical processes are represented in SWAN:

- Wave propagation in time and space, shoaling, refraction due to current and depth, frequency shifting due to currents and non-stationary depth.
- Wave generation by wind.
- Three- and four-wave interactions.
- Whitecapping, bottom friction and depth-induced breaking.
- Dissipation due to vegetation.
- Wave-induced set-up.
- Propagation from laboratory up to global scales.
- Transmission through and reflection (specular and diffuse) against obstacles.
- Diffraction.

Diffraction is modelled only in a restricted sense - a phase-decoupled approach, as described in Holthuijsen *et al.* (2003), is employed so that the same qualitative behaviour of spatial redistribution and changes in wave direction is obtained. This approach, however, does not properly handle diffraction in harbours or in front of reflecting obstacles (Delft University of Technology, 2013).

Modelling Approach

For the purposes of this study, the extreme wave climate was of interest. The entire wave climate was therefore not refracted, but only the extreme offshore wave conditions were modelled in SWAN's stationary mode, saving computational time. A non-stationary model was run as part of the model calibration process, as described in further detail in Section 1.2.7.3.

Each directional bin from Section 7.3.7, for the 1:50 and 1:100 year conditions, was refracted to the case study site to determine the extreme offshore wave condition (i.e. combination of wave height, period and wave direction) that would lead to the most extreme nearshore conditions for Bakoven. Extreme wind speeds for the 1:50 and 1:100 year return periods, as calculated in Section 7.3.5, were included in the respective SWAN runs. The directions of the wind and swell-wave directions were selected to be the same, as a worst case scenario.

The run cases modelled are presented in Table 7-9.

Table 7-9: SWAN run cases

Run Nr	Return period	Wind Speed (m/s)	Wind Direction (degrees)	Water Level (+m MSL)	Offshore		
					Hs (m)	Tp (s)	Direction (degrees)
1	50	32.40	158	1.62	3.4\	10.08	158
2	100	35.60	158	1.66	3.6	10.23	158
3	50	32.40	173	1.62	4.0	10.64	173
4	100	35.60	173	1.66	4.2	10.67	173
5	50	32.40	188	1.62	5.7	14.76	188
6	100	35.60	188	1.66	6.1	15.09	188
7	50	21.80	203	1.62	8.4	16.80	203
8	100	22.70	203	1.66	9.1	17.20	203
9	50	21.80	218	1.62	9.9	19.19	218
10	100	22.70	218	1.66	10.6	19.70	218
11	50	21.80	233	1.62	10.6	18.64	233
12	100	22.70	233	1.66	11.3	19.08	233
13	50	21.80	248	1.62	10.0	15.67	248
14	100	22.70	248	1.66	10.6	15.80	248
15	50	21.80	263	1.62	9.9	15.61	263
16	100	22.70	263	1.66	10.7	15.92	263
17	50	19.90	278	1.62	6.4	12.89	278
18	100	20.80	278	1.66	6.8	13.01	278
19	50	19.90	293	1.62	8.1	12.91	293
20	100	20.80	293	1.66	9.3	13.79	293
21	50	19.90	308	1.62	5.4	10.37	308
22	100	20.80	308	1.66	5.8	10.47	308
23	50	19.90	323	1.62	3.7	10.27	323
24	100	20.80	323	1.66	4.0	10.53	323

Model Setup

Three nested rectilinear grids were used to obtain the desired level of resolution at the site, whilst optimising computational time. A fourth grid was included to provide a finer grid for the calibration process.

The grids were structured as presented in Table 7-10.

Table 7-10: SWAN model - Setup of grids

	Grid 1	**Grid 2**	**Grid 3**	**Grid 4**
Length of X-axis	30,000 m	7,000 m	1,800 m	7,000 m
Length of Y-axis	30,000 m	6,000 m	1,300 m	5,000 m
Number of Meshes in X-space	300	350	450	350
Number of meshes in Y-space	300	300	325	250
Delta x	100 m	20 m	4 m	20 m
Delta y	100 m	20 m	4 m	20 m

A layout of the three grids chosen is shown in Figure 7-24.

Initially, the majority of the numerical parameters were set at SWAN's default recommended values, to be refined as a part of the model calibration run. As recommended by Rossouw (1989) for the South African coast, a JONSWAP spectrum with gamma peak factor of 2.2 was used for the input wave spectrum.

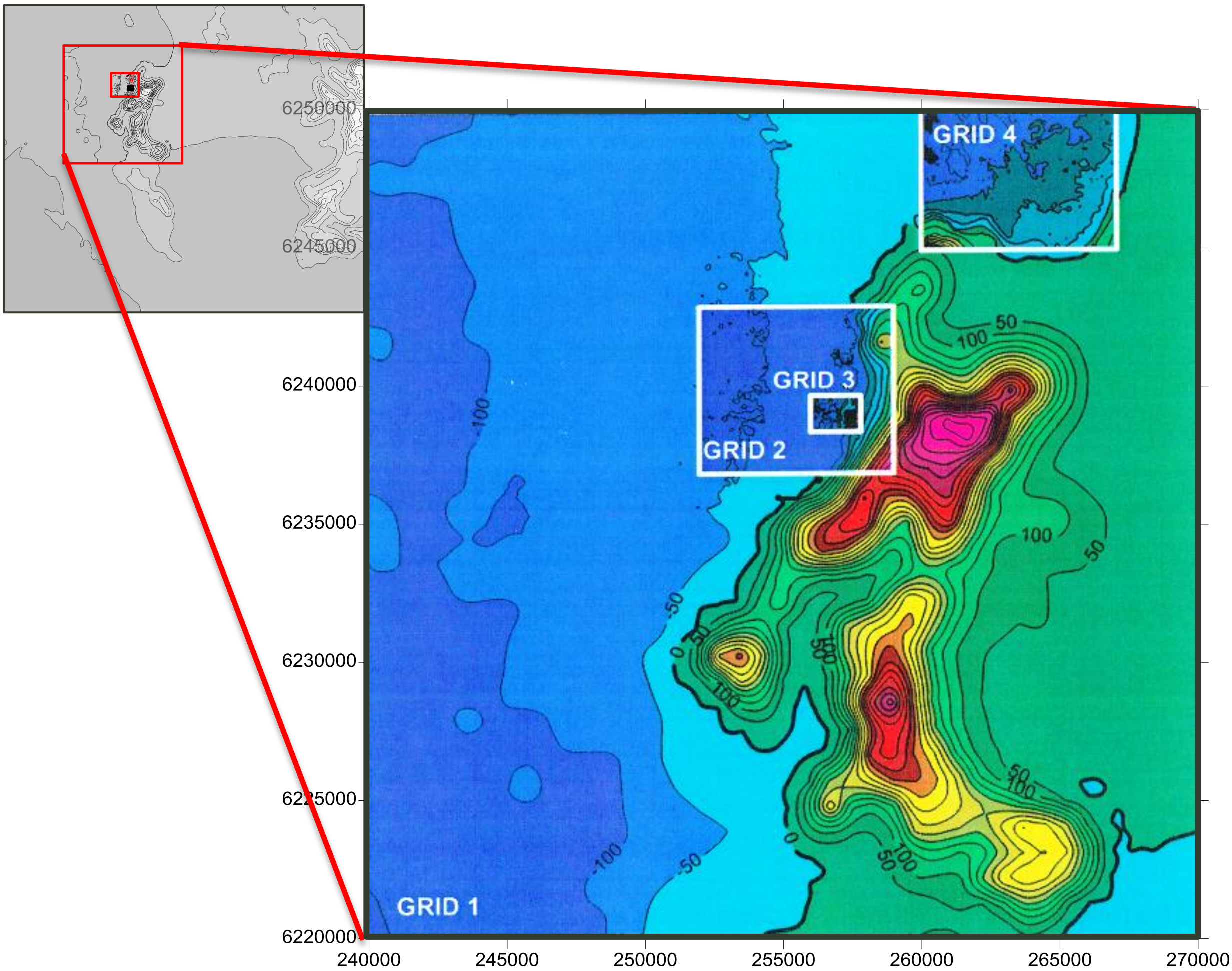


Figure 7-24: Computational Grid Setup

Model Boundaries

The model boundaries for Grid 1 were chosen along a least depth of -70 m CD. According to method of Seifart (2012), depths greater than this were set at -70 m CD to prevent waves entered into the model to be affected by the bottom contours before they reach the -70 m CD contour, which is the depth at which the measuring station was located. Boundaries were chosen sufficiently far away from the site under study to avoid any unwanted boundary effects on results near the site area of interest.

The western and southern boundary of Grid 1 was used to input the offshore wave boundary condition. Output from Grid 1 was used as the input boundary conditions for Grid 2, and so forth.

Model Calibration

Nearshore wave data, as measured in Table Bay at the SEAPAC station, located at 33.88383° S 18.4375° E and measuring wave data from 2002-02-01 to 2002-03-28 (although there were a few gaps in the nearshore measured data), was made available by the CSIR. The SWAN nearshore wave model was calibrated using this nearshore data,

The location of the nearshore wave buoy is illustrated in Figure 7-25.

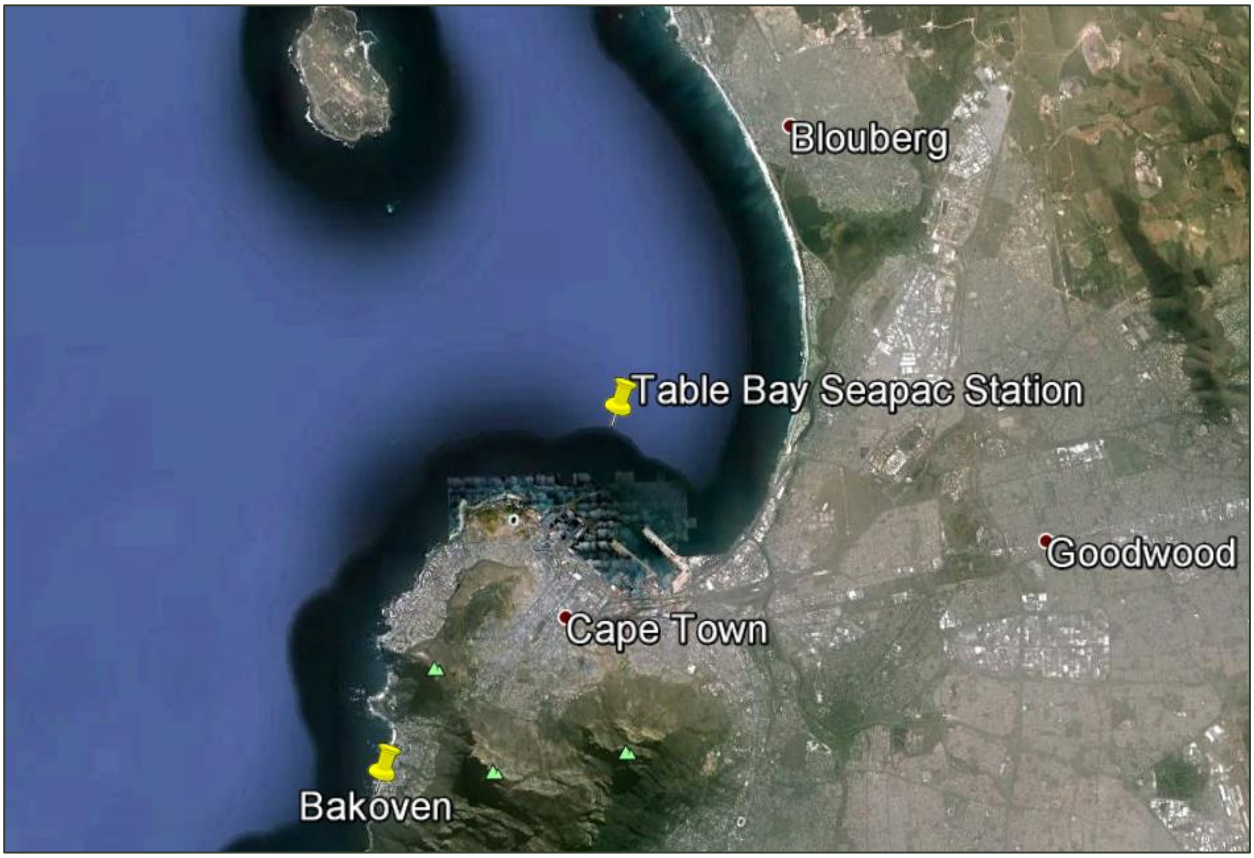


Figure 7-25: Nearshore CSIR SEAPAC Wave Monitoring Station Location (Google Earth version 7.1.2.2041, 2013)

Offshore Cape Point wave data, measured over the same time period as the CSIR nearshore data, was transformed to the location of the nearshore data. The measured and calculated (or modelled) wave climates for this period at the buoy location were compared. Adjustments were made to the numerical model in an attempt to reduce the error between the actual measured and numerically calculated wave climates.

An iterative process was followed – several model runs were performed, comparing modelled and measured wave parameters and editing parameters within the wave model until the calculated nearshore wave parameters reproduced the measured wave parameters within reasonable agreement.

The following numerical parameters were selected during the calibration process:

- Bottom friction: JONSWAP Coefficient: 0.1
- Breaking Coefficient: 0.73 (SWAN's default value).

The comparison between the measured and modelled values for H_s, T_m and Wave Direction are shown in Figure 7-26 and Figure 7-27.

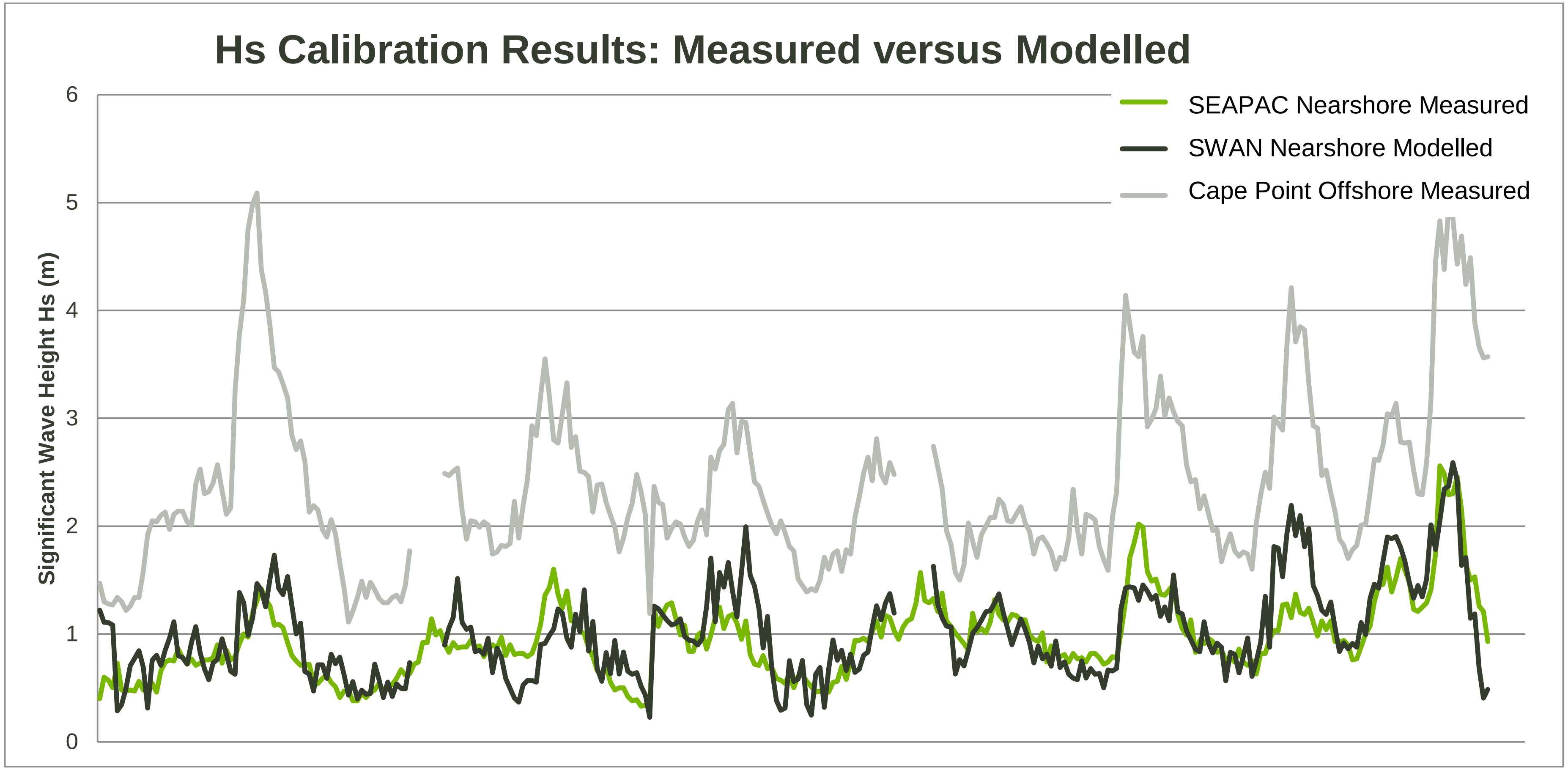


Figure 7-26: Hs Comparison - Measured versus Modelled

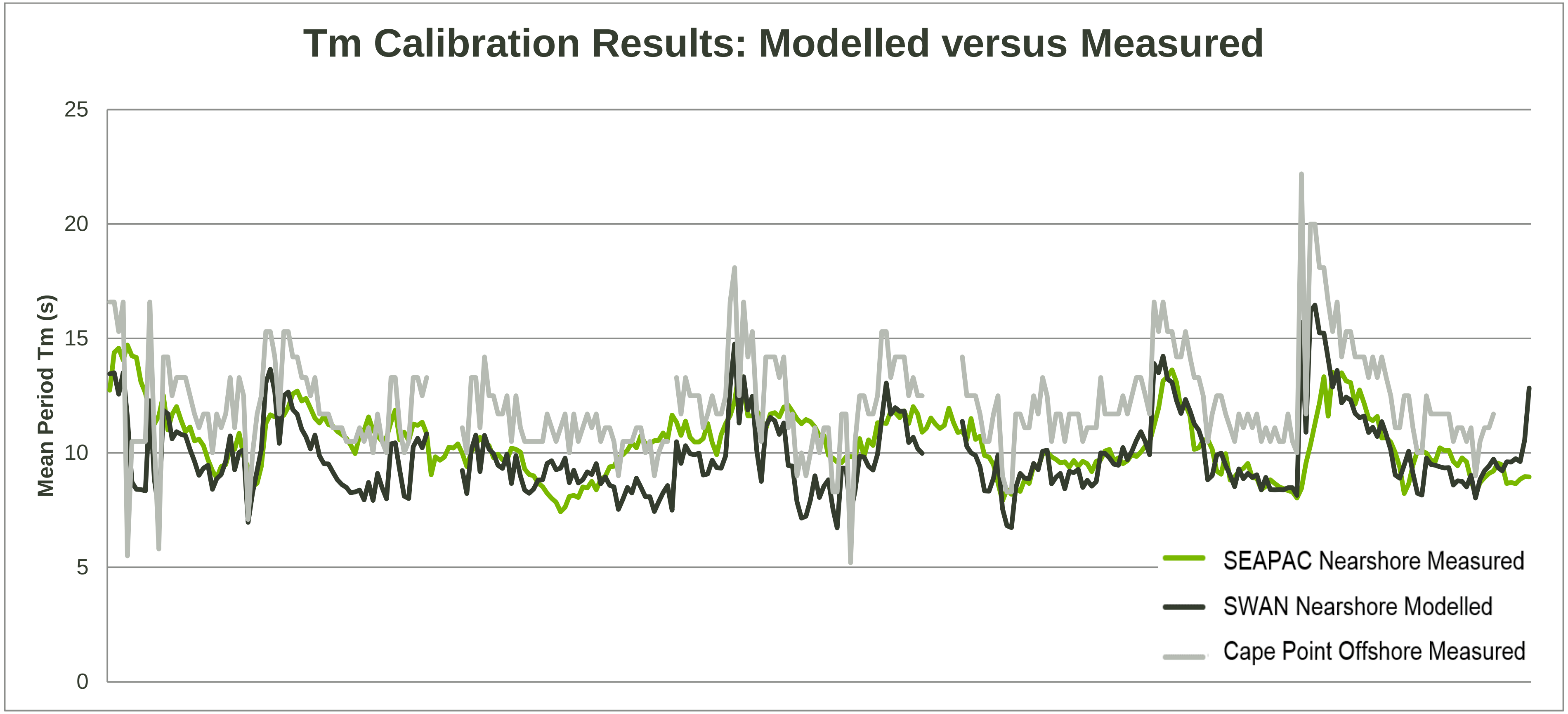


Figure 7-27: Tm Comparison - Measured versus Modelled

Nearshore Wave Model Results

Nearshore wave conditions shown were extracted from Point 257,100 E; 6,239,048 S (UTM, WGS 84 coordinate convention) at a point on the -5m MSL, illustrated in Figure 7-28.

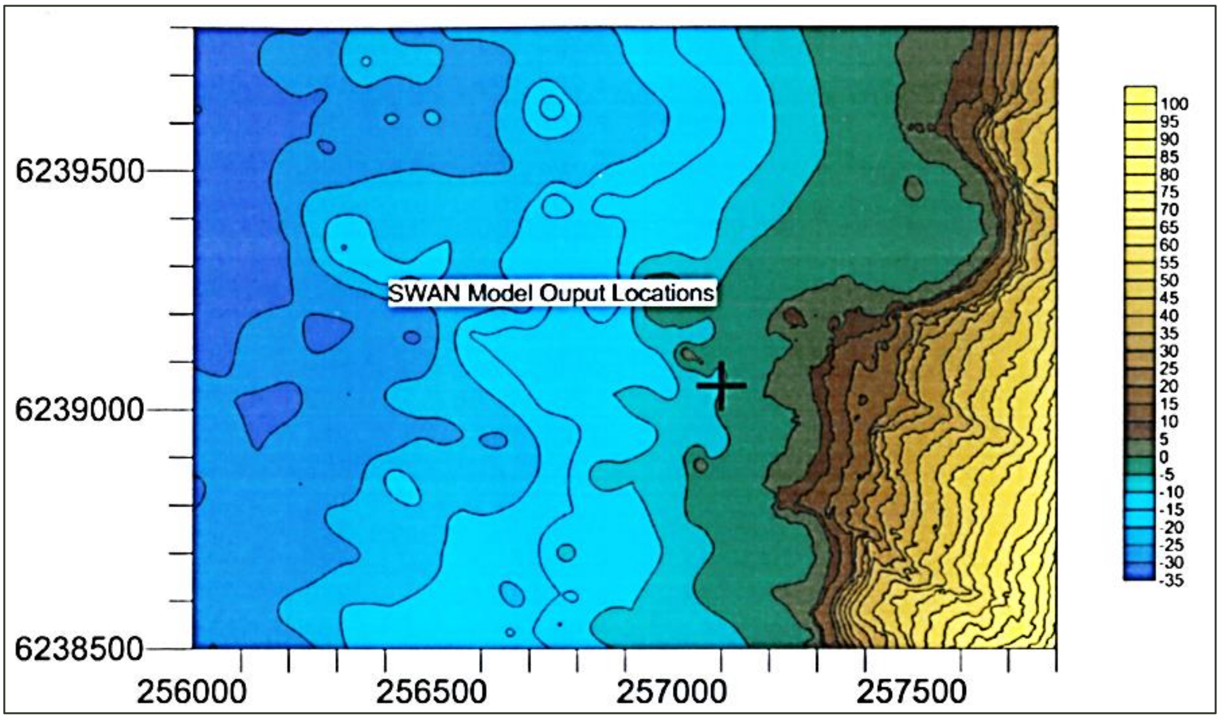


Figure 7-28: Nearshore bathymetry map showing SWAN Model Nearshore Output Location

The results from the nearshore wave modelling are provided in Table 7-11.

Table 7-11: SWAN Wave Modelling - Nearshore Wave Conditions at -5m MSL

Run Nr	Return period	Wind Speed (m/s)	Wind Direction (degrees)	Water Level (+m MSL)	Offshore			Nearshore @ -5m MSL		
					Hs (m)	Tp (s)	Direction (degrees)	Hs (m)	Tm (s)	Direction (degrees)
1	50	32.40	158	1.62	3.40	10.08	158	1.45	3.91	234.4
2	100	35.60	158	1.66	3.60	10.23	158	1.43	3.57	228.8
3	50	32.40	173	1.62	4.00	10.64	173	2.00	5.11	246.2
4	100	35.60	173	1.66	4.20	10.67	173	2.19	5.30	246.9
5	50	32.40	188	1.62	5.70	14.76	188	3.09	7.79	258.3
6	100	35.60	188	1.66	6.10	15.09	188	3.31	8.02	258.4
7	50	21.80	203	1.62	8.40	16.80	203	3.78	10.96	264.6
8	100	22.70	203	1.66	9.10	17.20	203	3.85	10.93	264.4
9	50	21.80	218	1.62	9.90	19.19	218	3.93	11.51	265.3
10	100	22.70	218	1.66	10.60	19.70	218	3.96	11.59	265.1
11	50	21.80	233	1.62	10.60	18.64	233	4.10	11.64	265.5
12	100	22.70	233	1.66	11.30	19.08	233	4.13	11.46	265.1
13	50	21.80	248	1.62	10	15.67	248	4.12	10.54	265.6
14	100	22.70	248	1.66	10.60	15.80	248	4.21	10.40	264.7
15	50	21.80	263	1.62	9.85	15.61	263	4.08	10.49	266.5
16	100	22.70	263	1.66	10.70	15.92	263	4.20	10.45	265.4
17	50	19.90	278	1.62	6.40	12.89	278	3.40	7.98	268.7
18	100	20.80	278	1.66	6.80	13.01	278	3.67	9.03	268.9
19	50	19.90	293	1.62	8.10	12.91	293	3.64	9.14	270.3
20	100	20.80	293	1.66	9.30	13.79	293	3.84	9.67	269.6
21	50	19.90	308	1.62	5.40	10.37	308	2.95	7.31	272.4
22	100	20.80	308	1.66	5.80	10.47	308	3.05	7.46	272.4
23	50	19.90	323	1.62	3.70	10.27	323	2.41	6.44	275.7
24	100	20.80	323	1.66	4	10.53	323	2.51	6.51	275.8

The conditions in runs number 13 and 14 produced the most severe nearshore conditions – showing that Bakoven is more vulnerable to storms from westerly directions. Even though the offshore wave heights in runs 13 and 14 are smaller than those in runs 11 and 12, the more westerly wave direction causes greater nearshore wave heights at Bakoven and is therefore more critical.

For the most severe run cases, runs 13 and 14, the vulnerability of Bakoven to lower return periods was also tested. Refracting 1:5, 1:10 and 1:20 year conditions to Bakoven's nearshore zone, the following results for nearshore conditions at the location illustrated in Figure 7-28, were obtained.

Table 7-12: Bakoven nearshore conditions at -5m MSL for 1:5, 1:10 and 1:20 year return periods

Return Period	H_s (m)	T_m (s)
1:5	3.92	10.57
1:10	4	10.60
1:20	4.07	10.60

According to these results, the observed nearshore difference in wave height between an offshore 1:5 and a 1:100 year event is only 7%. This indicates that Bakoven is very vulnerable to not only extreme events with very high return periods, but also storm events with return periods from 1:5 years to 1:20 years.

Wave Modelling Across Surf Zone

The numerical model, SWASH, was applied to obtain wave heights within the surf zone, as this is beyond the SWAN model's capabilities.

SWASH is a general-purpose numerical tool for simulating non-hydrostatic, free-surface, rotational flows in one, two or three dimensions (Delft University of Technology, 2010). The governing equations are the nonlinear shallow water equations including non-hydrostatic pressure and provide a general basis for simulating

- wave transformation in both surf and swash zones due to nonlinear wave-wave interactions, interaction of waves with currents, and wave breaking as well as runup at the shoreline, and
- complex changes to rapidly varied flows typically found in coastal flooding resulting from e.g. dike breaks, tsunamis, and flood waves (Delft University of Technology, 2010).

The SWASH model is applicable in the nearshore coastal regions right up to the shore. This has prompted the acronym SWASH - Simulating WAves till SHore (Delft University of Technology, 2010).

The SWAN modelling output from runs leading to the most extreme nearshore conditions, Runs 13 and 14, was used as input for the SWASH model to model wave transformation over a fourth nested grid, from the -5 m MSL contour to the shore.

The resulting significant wave heights at the +0.5 m MSL contour, for the 1:10, 1:50 and 1:100 year wave heights from the direction 248º, are provided in Table 7 13.

Table 7-13: Status quo scenario SWASH wave model output at +0.5 m MSL

Return Period	Hs (m)	Tp (s)
1:10	0.69	11
1:50	0.78	12.7
1:100	0.79	12.9

Graphical output of the 1:10 year return period significant wave height in the Bakoven surf zone is provided in Figure 7-29. The black zone shown is the area calculated by SWASH to be outside of the wave-runup zone.

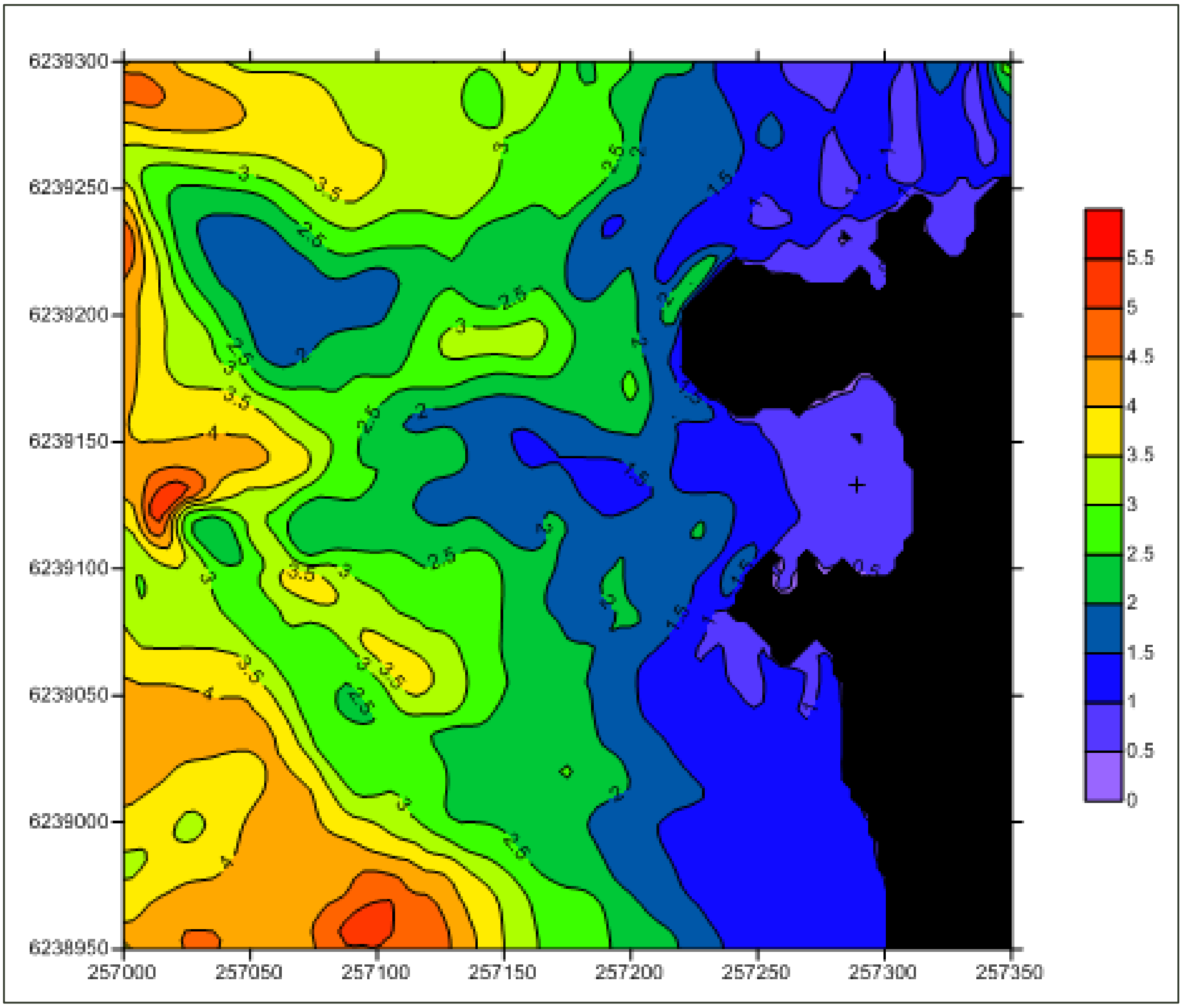


Figure 7-29: 1:10 year return period significant wave height in the Bakoven surf zone

In addition, the model provides output of the instantaneous water levels at specific points in time. Figure 7-30 illustrates a 1:10 year swell wave propagating across the Bakoven surf zone.

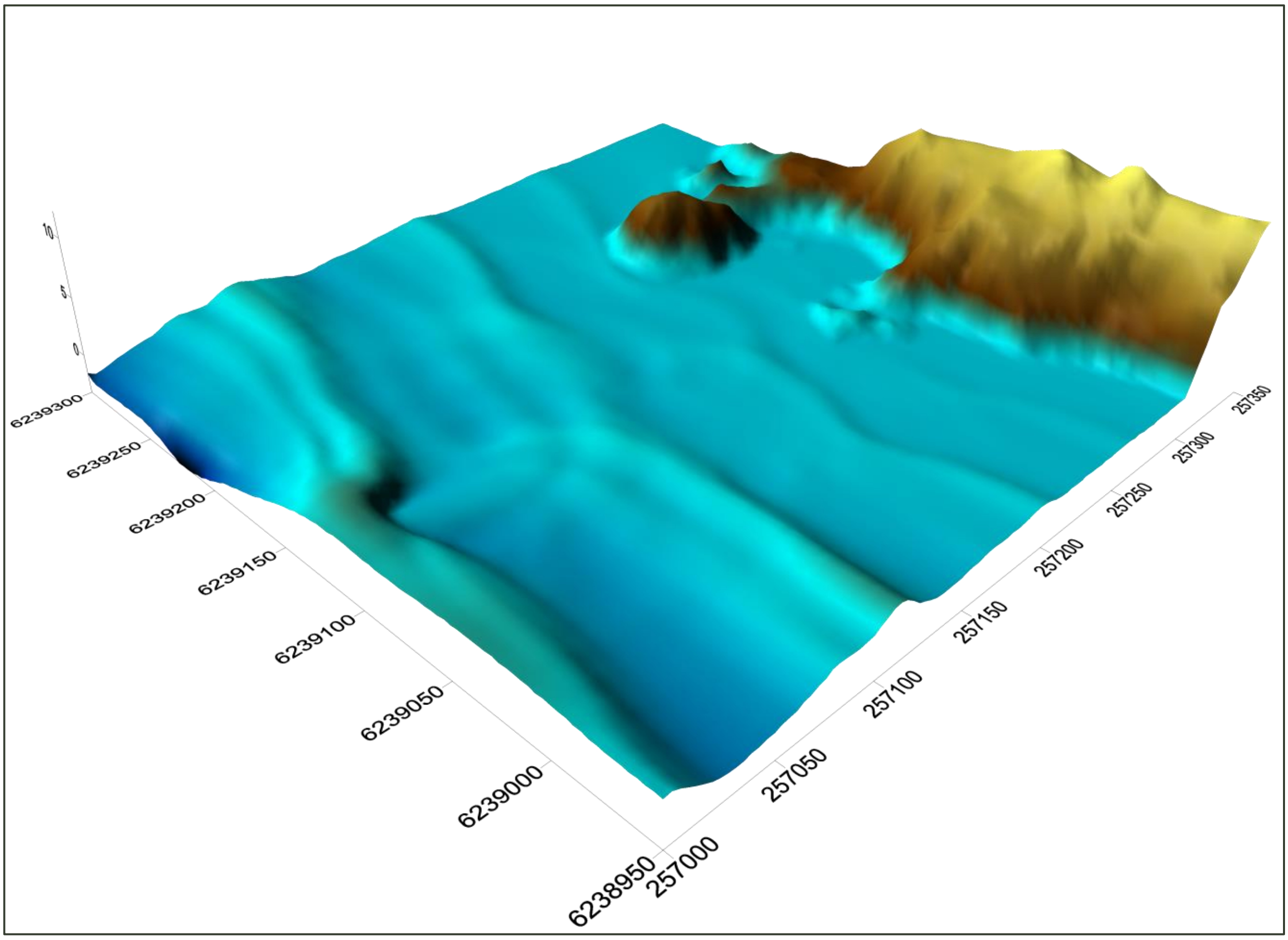


Figure 7-30: SWASH water surface elevation snapshot of 1:10 year wave propagating over Bakoven surf zone

7.3.9 Wave Runup

Wave runup is defined by the CEM as the maximum elevation of wave uprush above the still water level (US Army Corps of Engineers, 2008). This runup consists of two components: time-averaged super-elevation of mean water level due to wave action (setup) and time-varying fluctuations about that mean (swash). The definition of runup, R, as defined by the CEM, is illustrated in Figure 7-31.

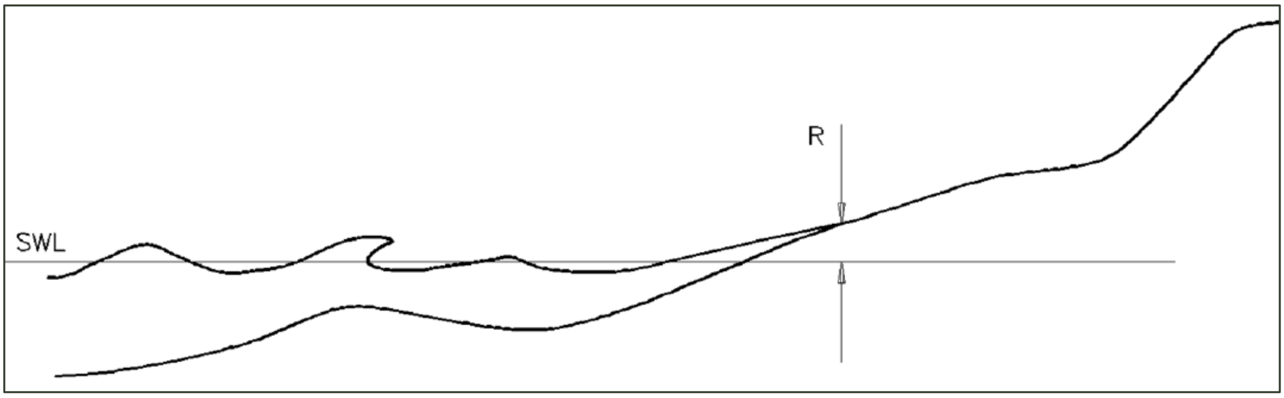


Figure 7-31: Wave runup definition diagram (US Army Corps of Engineers, 2008)

Runup is measured in various short term occurrence intervals parameters, i.e. R_{max} – maximum runup level reached; R_{mean} – mean runup level reached; $R_{2\%}$. - runup value that only 2% of the wave runup values observed within a wave event will reach or exceed.

Bakoven has two distinct beach types, which will respond differently to wave action: sandy pocket beaches, such as Big Beach, and rocky, or pebble shores. Transects 2 and 4, as defined in Section 7.3.4, are sandy beaches and transects 1, 3, 5 and 6 are rocky shores.

Early studies and laboratory testing of regular wave runup on an impermeable slope (Battjes, 1974) demonstrated a relationship between the maximum vertical runup normalised by the deep-water significant wave height, and the Irribarren surf similarity parameter (ξ_0):

R_{max}/H_0 = C.ξ_0, with $\xi_0 = \tan\beta / \sqrt{H_0 L_o}$;

Where:

- C is a dimensionless coefficient;
- $\tan\beta$ is the beach face slope;
- L_0 is the deep water wave length; and
- H_0 is the deep water wave height.

This formula has been the basis for the development of runup formulas for both natural sandy and rocky beaches. The SWASH wave model's computed wave runup was not used in this study – because of the low-resolution bathymetry data and unknown values for the porosity of various parts of the Bakoven shoreline, it was decided to rather use empirical wave runup formulae as developed from field tests of various beach profile types and slopes.

Wave Runup Formulae Available for Sandy Beaches

The formula of Battjes (1974) has since been confirmed and refined for irregular waves on natural beaches through a range of laboratory and field experiments:

- Using field data collected from a natural sandy beach at the CERC Field Research Facility in Duck, North Carolina, Holman (1986) observed a relationship between $R_{2\%}$, H_s (as measured in 20 m water depth) and ξ_0 to be:

$$R_{2\%} = (0.83\ \xi_0 + 0.2).H_s$$

During the experiment incident wave height varied from 0.4 to 4.0 m, incident wave period from 6 to 16 s, and beach slope β from 0.07 to 0.20 (Holman, 1986).

- Collecting field data from six sandy beaches on the coast of New South Wales, Australia, Nielsen and Hanslow (1991) examined the relationship between ξ_0 and the distribution of runup. Their experiments included wave heights H_{0rms} ranging from 0.53m to 3.76 m, significant wave periods from 6.4 s to 11.5 s, beach slopes from 0.026 to 0.19, and beach sand grain size from 0.2 mm to 0.8 mm (Nielsen & Hanslow, 1991).

They found that the vertical scaling for runup distributions was proportional to ξ_0 for steep beaches. However, for beaches with β<0.1, they suggest that the dimensional vertical scaling of runup distributions may be independent of beach slope and proportional to $\sqrt{H_{0rms}L_o}$ according to the equations:

$R_{2\%} = 1.98L_{zwm,}$ where

$L_{zwm} = 0.6\sqrt{H_{0rms}L_o}\tan\beta_f$ for $\tan\beta_f > 0.1$; and

$L_{zwm} = 0.05\sqrt{H_{0rms}L_o}$ for $\tan\beta_f \leq 0.1$.

- Ruggiero *et al.* (2001) also studied runup under high-energy dissipative conditions and found that the elevation of R_2 scaled best with H_0. Runup field measurements were taken on the central Oregon coast during a wide variety of wave conditions - offshore significant wave heights varied from 1.4 to 4.6 m, peak periods ranged from 7 s to 17 s and beach slopes ranging from 0.005 to 0.047 (Ruggiero, *et al.*, 2004). In addition, data from Holman's (1980) field experiments were also included. The resulting best fit relationship was found to be:

  $R_{2\%} = 0.27\sqrt{\tan\beta f.\, H_0 L_o}.$

- Stockdon *et al.* (2006) extended Holman's (1986) original analysis to datasets from ten field experiments, representing a wide variety of beach and wave conditions from the USA and the Netherlands. The individual runup processes, setup and swash, were parameterised separately to improve the runup estimates, and swash was also split into its incident ($f_0 > 0.05$ Hz) and infragravity ($f_0 < 0.05$ Hz) components, S_{INC} and S_{IG}, respectively. S_{INC} and S_{IG} were scaled with foreshore beach slope, offshore wave height and offshore wavelength – however, when the foreshore was removed from the equation, the correlation of S_{IG} improved (Stockdon, *et al.*, 2006).

  The general expression proposed by Stockdon *et al.* (2006) for all natural beaches, is:

  $R_{2\%} = 1.1\,(0.35\beta_f\sqrt{H_0 L_o} + \frac{[H_0 L_o(0.563{\beta_f}^2+0.004)]^{0.5}}{2})$

In extremely dissipative conditions, (low-sloping, high-energy beaches with $\xi_0 < 0.3$) saturation of energy in the incident band occurs and a dissipative-specific equation is proposed:

$R_{2\%} = 0.043\sqrt{H_0 L_o}$.

- Senechal *et al.* (2011) collected wave runup measurements from the Southern part of the French Atlantic coastline during extreme storm conditions with offshore wave heights up to 6.4 m and peak periods up to 16.4 s on steep foreshore beach slopes (0.05 – 0.08). Highly dissipative and saturated conditions were found in the surf zone with intermediate and reflective conditions in the swash zone. Vertical runup elevations were found to be driven by the increase in S_{IG} while S_{IC} is saturated. Runup on highly dissipative beaches could be scaled using offshore wave height only. The following equation for total runup, as the sum of S_{IG} and S_{IC} components (Senechal, *et al.*, 2011):

  $R_{max} = 0.81\beta\sqrt{H_0 L_o} + 0.78$

- Mather (2012) proposed using a wave runup model based on the bathymetric profile, rather than the beach face slope. Surveying the debris line observable along beaches along the KwaZulu-Natal and Cape Town coastline, Mather used these levels to determine the maximum runup level during storm events. The measured maximum runup was then plotted against the distance offshore from the SWL to the -15 m CD bathymetric contour. An upper bound curve was derived from these data as:

  $R_{max} = CH_{m0}\,S$;

  Where:

  - C is a dimensionless coefficient,
  - H_{m0} is the deep water significant wave height and
  - $S = \Delta H/\Delta X$ (with ΔH= 15m and ΔX = distance to the -15 m CD contour) is a representative nearshore slope (Mather, 2012).

Mather recommends a value C = 10 for the open coastline of KwaZulu-Natal and the Cape, with C = 9 for large embayments (headlands at 40km distance) and C = 6 for small embayments (headlands at 3km distance). Mather *et al.* (2012) reports that the proposed model slightly over-predicts runup values.

The Mather equation's calibrating coefficient was reduced to 5 for application in a very small embayment. Figure from Mather (2012) summarises the data collected by Mather (2012) for small embayments in the Cape Peninsula. Mather (2012) ascribes the outlier to the interaction effect of waves with a built structure, concentrating wave energy in the region and thereby increasing the wave runup at that particular point. If the outlier is ignored, C=5 provides a good fit for the data, as illustrated in Figure 7-32.

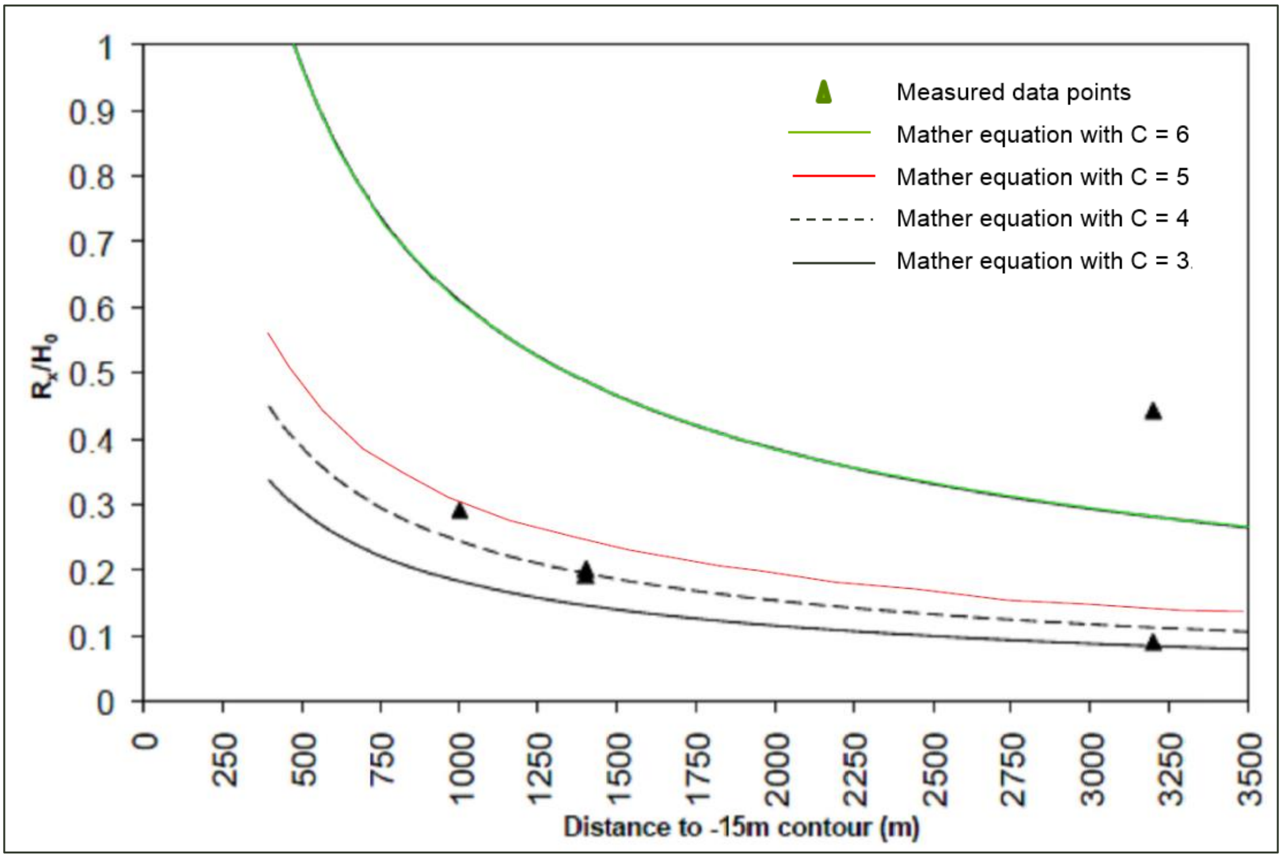


Figure 7-32: Mather runup equation for small embayments, adapted for C = 5 (red), versus C = 6 (green) (Mather, 2012)

Runup Calculation for Bakoven Sandy Beaches

To determine the vertical runup at Bakoven, it is necessary to select the most appropriate runup formula, and calibrate the calculated runup against runup values experienced at Bakoven during past events, to confirm its applicability.

The wave runup during a 1:10 year storm was selected as the calibration event, as this runup value can be compared to photographs from the August 2008 storm event along the Cape coast, which was judged by Theron *et al.* (2010) to have a return period of approximately 10 years. Where the runup formulae available provided only $R_{2\%}$ and not R_{max}, or vice versa, the Rayleigh distribution as presented in CEM (2007) was assumed to apply to the wave runup values to convert them between occurrence intervals.

The calculated 1:10 year wave runup heights for Bakoven are provided in Table 7-14 and illustrated graphically in Figure 7-33. The $R_{2\%}$ values were added to the 1:10 year extreme still water level as calculated in Section 7.3.6.

Table 7-14: 1:10 year storm event - wave runup calculations

	R_{max} (m)	$R_{2\%}$ (m)	Extreme SWL + $R_{2\%}$ (m above MSL)
Stockdon *et al.* (m)	5.2	3.9	5.4
Mather	5.2	3.9	5.4
Ahrens and Seelig	5.1	3.8	5.4
Nielson and Hanslow	7.5	5.7	7.2
Holman	3.8	2.8	4.4
Senechal	4.4	3.3	4.8
Ruggiero	5.2	3.9	5.4

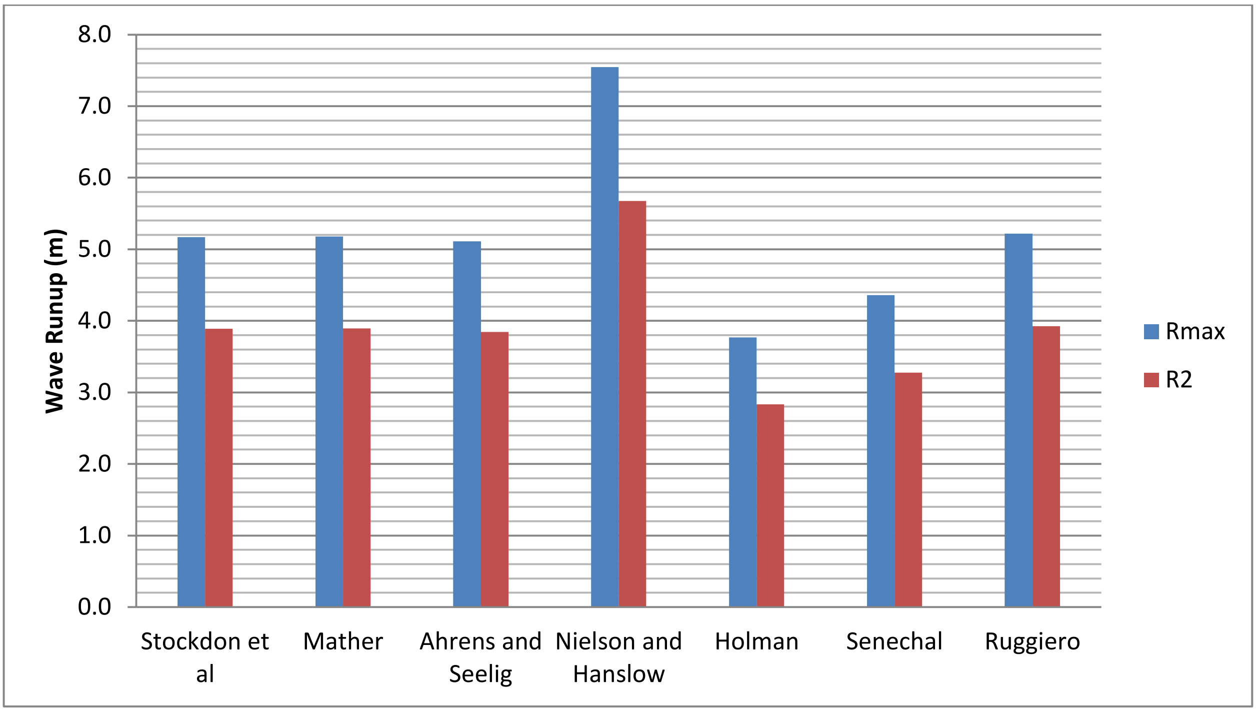


Figure 7-33: Wave runup calculation - graphical representation

From the range of formulae tested, few were deemed to be applicable to Bakoven extreme storm events, as most were tested for a range of offshore significant wave heights measurements much smaller than those experienced during Cape storms. The formulae provided by Mather (2012) and Senechal (2011) are most applicable, as both of these used extreme storm events for developing their formulae. Since Mather's equation was developed specifically for the South African coastline and is also currently prescribed by the Western Cape Methodology document for the determination of the flooding setback, it was decided to use the Mather equation.

For calibration purposes, the calculated runup levels according to Mather (2012) were compared to photographs of the August 2008 storm event at Bakoven (refer Figure 7-34).

Figure 7-34: Conditions at Bakoven during August 2008 storm event (Brown, 2013)

It is estimated that, in the absence of the built structures on the beach, the vertical wave runup during the August 2008 event could have reached the +5.4 m MSL contour predicted by the Mather equation. Mather's runup equation is therefore preferred and regarded as being sufficiently accurate for the application of determining wave runup heights at Bakoven during extreme storm events.

Wave Runup Formulae Available for Rocky Beaches

For the calculation of wave runup values on Bakoven's rocky slopes, use was made of the Rock Manual (CIRIA; CUR; CETMEF, 2007).

The basis of all formula for calculating runup on rocky slopes is similar to that of the runup formulae for sandy beaches (CIRIA; CUR; CETMEF, 2007).

$R_{u2\%}/H_s = A.\xi + B$

In the Netherlands a prediction curve has been developed (TAW, 2002a, in CIRIA, 2007) for the runup of waves on smooth slopes:

$R_{u2\%}/H_{m0} = A.\gamma_b \gamma_f \gamma_\beta \xi_{m^{-1,0}}$, for $0.5 < \gamma_b.\xi_{m^{-1,0}} < 8$; where:

- A=1.65 for values without safety margins;
- γ_b – correction factor for wave incident angle
- γ_f – correction factor for rough slopes
- γ_β – correction factor for wave incident angle
- $\xi_{m^{-1,0}}$ – Surf similarity parameter

For rough slopes, the roughness reduction factor can be taken as follows:

- Concrete, asphalt and grass: $\gamma_f = 1.0$
- Pitched stone: $\gamma_f = 0.80–0.95$
- Armour stone – single layer on impermeable base: $\gamma_f = 0.70$
- Armour stone – two layers on impermeable base: $\gamma_f = 0.55$.

As an alternative to the use of the roughness correction factors, explicit formulae have been derived from tests with rough rubble slopes on structures with permeable and impermeable cores. Analysis of test data from measurements by van der Meer and Stam (1992) has given prediction formulae for rock-armoured slopes with an impermeable core, described by a notional permeability factor *P* = 0.1, and for porous mounds of relatively high permeability, given by *P* = 0.5 and 0.6:

$R_{un\%}/H_s = a.\xi_m$, for $\xi_m \leq 1.5$

$R_{un\%}/H_s = b\,\xi_m{}^c$, for $\xi_m > 1.5$, with a = 0.96, b = 1.17, c = 0.46 and d = 1.97, for n = 2%.

Runup Calculation for Bakoven Rocky Beaches

Bakoven's pebble and boulder beaches have been assumed to behave similarly to a smooth, impermeable base. The large size of the boulders will not dissipate much of the wave energy as would happen on a permeable rock revetment. The 1:10 year R2% runup on the pebble beach slopes was calculated as presented in Table 7-15.

Table 7-15: Vertical wave runup $R_{2\%}$ on Bakoven pebble beaches

	TAW (2002)		**Van der Meer (1992)**	
	$R_{2\%}$ (m)	**Extreme SWL + $R_{2\%}$ (m above MSL)**	**$R_{2\%}$ (m)**	**Extreme SWL + $R_{2\%}$ (m above MSL)**
XS 1	1.33	2.85	0.77	2.29
XS 3	1.9	3.42	2.00	3.52
XS 5	0.76	2.28	0.44	1.96
XS 6	1.52	3.04	0.88	2.40

The equations for a smooth, impermeable rock base presented in TAW (2002) were assumed to be the most appropriate for this case study and therefore adopted.

Bakoven Wave Runup Summary

The runup levels at Cross Sections 1 – 6 for the 1:10, 1:50 and 1:100 year return periods is provided in Table 7-16 and illustrated in Figure 7-35, using aerial imagery obtained from NGI (2010) as base.

Table 7-16: Wave runup summary

	Beach Material	**1:10**	**1:50**	**1:100**
XS1	Rock	0.77	0.94	0.96
XS2	Sand	3.46	4.01	4.27
XS3	Rock	0.38	0.47	0.48Table 7-16
XS4	Sand	3.89	4.52	4.81
XS5	Rock	0.49	0.61	0.62
XS6	Rock	0.44	0.54	0.55

As expected, due to the dissipative effect of the rocky slopes, runup on the pebble beaches is much lower than that on the sandy beaches.

Figure 7-35: Bakoven status quo wave runup zone (National Geo-Spatial Information, 2010)

7.3.10 Overtopping

Bakoven property owners have built many different types of retaining walls and sea walls to stabilise their properties' slopes and protect them against the impacts of waves, as illustrated in Figure 7-36. Photographs taken from the 2008 storm event clearly show overtopping of these structures.

Figure 7-36: Retaining walls and informal sea walls constructed at Bakoven

Figure 7-37: Overtopping of Bakoven property sea wall during August 2008 storm event (Brown, 2013)

To examine the effects of increased intensity and frequency of storm events on overtopping volumes at Bakoven, and assess the impact thereof on the viability of occupying the affected living spaces, the occurrence of overtopping was quantified using various methods as presented in Eurotop Manual (Pullen, *et al.*, 2007).

The base of the property sea wall on Big Beach is estimated from the LIDAR survey to be at +2.2 m MSL. The wall crest height is at +3.6 m MSL. The base of the wall is therefore located above the extreme still water level, but within the runup zone. Limited data exists for seawall configurations where the toe of the wall is emergent, i.e. at or above the still water level (Pullen et al, 2008). Eurotop manual provides the following equation:

$$\frac{q}{\sqrt{gH^3{}_{m0,deep}}} \times \sqrt{ms_{m-1,0}} = 0.043.\exp(-2.16ms_{m-1,0}{}^{0.33}\frac{R_c}{H_{m0,deep}}),$$

Where:

- q – mean overtopping discharge (l/s)
- $H_{m0,deep}$ – deepwater wave height

- m – foreshore slope
- $s_{m,0}$ – wave steepness parameter associated with $T_{m-1,0}$
- R_c – crest freeboard height

which is valid for:

$$2.0 < m s_{m-1,0}{}^{0.33} \frac{R_c}{H_{m0,deep}} < 5.0;$$

$$0.55 \leq \frac{\mathrm{R}_c}{H_{m0,deep}}; \text{and}$$

$$s_{m-1,0} \geq 0.02.$$

Pullen *et al.* (2007) cautions against extrapolation of this relationship beyond the ranges tested. For Bakoven beach, the conditions for the EurOtop equation were not met and the equation could therefore not be applied.

Bruce *et al.* (2004) adapted the equation for plunging waves for configurations where the toe of the wall is emergent, and not submerged, by using the sea bed slope tan∝ in evaluating Q_b, and an adjusted dimensionless freeboard R_{ba}, defined as:

$Q_b = 0.06. \exp(-4.7R_{ba})\,, for\ 1.0 < R_{ba} < 4.0$, where

- Q_b – plunging wave dimensionless overtopping discharge
- $R_{ba} = R_b S_{op}{}^{-0.17}$; with
- s_{op} – offshore wave steepness based on peak period T_p
- $R_b = \frac{R_c}{H_s} \frac{\sqrt{s_{op}}}{tan\alpha} . \frac{1}{\gamma_b \gamma_h \gamma_f \gamma_\beta}$,
- H_s - nearshore significant wave height;
- $\gamma_b, \gamma_h, \gamma_f, \gamma_\beta$ are reduction factors for berm width, shallow depth, roughness and wave obliquity (Bruce, *et al.*, 2004)

Using the formula proposed by Bruce *et al.* (2004), the mean overtopping discharge of the seawall at Bakoven Beach was calculated for the 1:10 year, 1:50 year and 1:100 year return periods, as presented in Table 7-17.

Table 7-17: Status quo overtopping discharge rates of Bakoven beach seawall

Return Period	Overtopping discharge (ℓ/s)
1:10	1.56
1:50	5.11
1:100	5.7

All of these rates are above the allowable limits of overtopping for buildings, which is 0.2 ℓ/s, as illustrated in Figure 7-38. The 1:50 and 1:100 year values are also above the allowable limits for embankments and seawalls (2 ℓ/s).

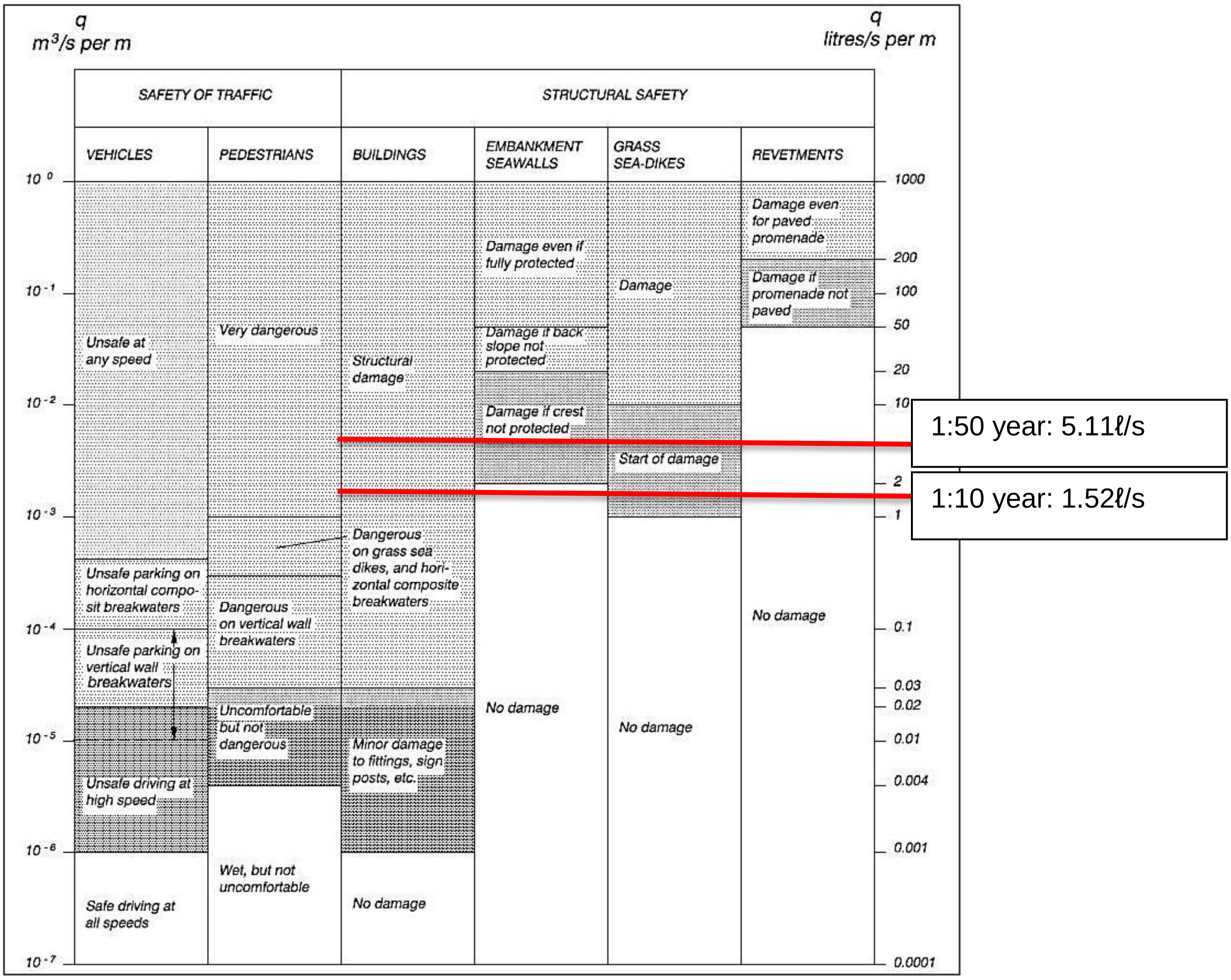


Figure 7-38: Allowable overtopping rates (CEM, 2008)

Overtopping of the most seaward buildings during extreme storm conditions are therefore already above safe allowable limits.

7.3.11 Seismic Conditions

According to SANS 10160-4:2011, Bakoven is located in Seismic Hazard Zone 1, which is prone to natural seismic activity (refer Figure 7-39).

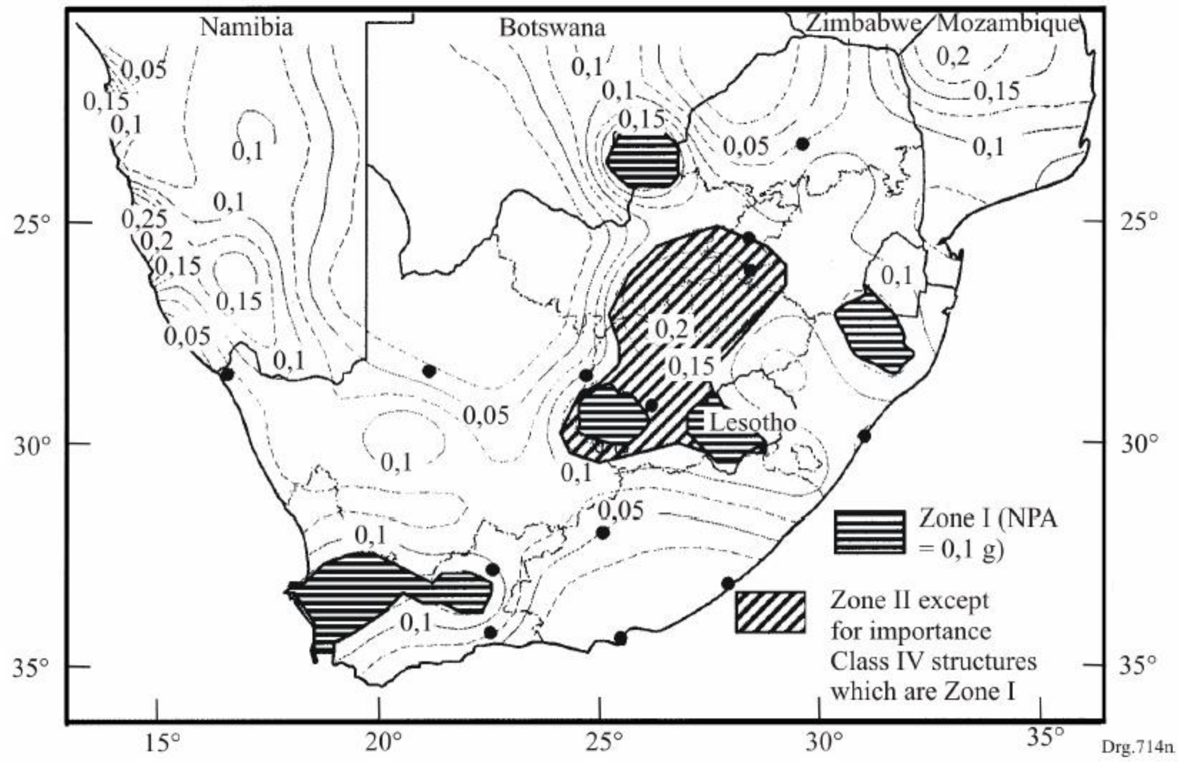


Figure 7-39: Seismic Hazard Zone Map

Seismic loads would therefore need to be taken into account during the design process of any structures.

7.3.12 Shoreline Stability Assessment

When assessing shoreline stability, it is important to assess both long term and short term shoreline movement trends.

The short term effects of storms on shorelines often overshadow long term effects it is therefore important to assess these two components separately. The long term mean of shoreline movement is often not representative of the erosion or retreat that could occur during a single storm event. Often this sudden storm-induced erosion is restored by post-storm onshore and longshore transport as the shoreline returns to its equilibrium shape. Long term shoreline retreat, however, is often a more permanent change.

Long-term Shoreline Stability Assessment

As no beach profile measurements were available to assess the stability of the shoreline, a qualitative shoreline stability analysis was performed by assessing historical aerial photographs. Although an exact quantitative analysis of shoreline retreat or accretions using this method is not possible, it does provide a reasonable qualitative indication of shoreline movement trends.

Historical aerial photographs were obtained from the Department of Rural Development, NGI for the following years:

- 1942
- 1945
- 1968
- 1976
- 1983
- 1988
- 1992
- 1996
- 2000

- 2001, and
- 2010.

As only the most recent sets of aerial photographs received from the NGI were ortho-rectified, all images were imported into a single software platform and earlier photographs rectified to reduce displacement errors caused by camera tilt, lens distortion, earth curvature and terrain relief. The rectification was performed by identifying fixed control points on each of the images that were thought to have changed very little over time (e.g. specific outcrops, engineered structures, etc.) and performing a rectification process to overlay these objects with their location on the ortho-rectified photographs. It is estimated that the rectification accuracy is about 10 m.

Various types of “shorelines” were then digitized on each of these historical aerial photographs:

- The wetted line (defined as the boundary between wet and dry material) can be approximated as the line of maximum runup. Although the position of the wetted line varies with the dynamic effects of wave runup, it has been assumed that the material below the runup-line remains visually discernibly wet, even when the tide recedes. It has therefore been assumed (similarly to other studies, such as those of Seifart (2012), Fletcher *et al.* (2012)) that the position of the wetted line is approximately equal to the average maximum wave runup level.
- The vegetation line was also mapped on each of the historical images. This line approximates the base of the stable dune field or cliff. As the vegetation along Bakoven is artificially maintained in many places, this line was not thought to be as good a representative of natural shoreline movement as the wetted line.

The positions of the vegetation line and the wetted line for the years 1942 to 2010 are shown in Figure 7-40 and Figure 7-41 respectively.

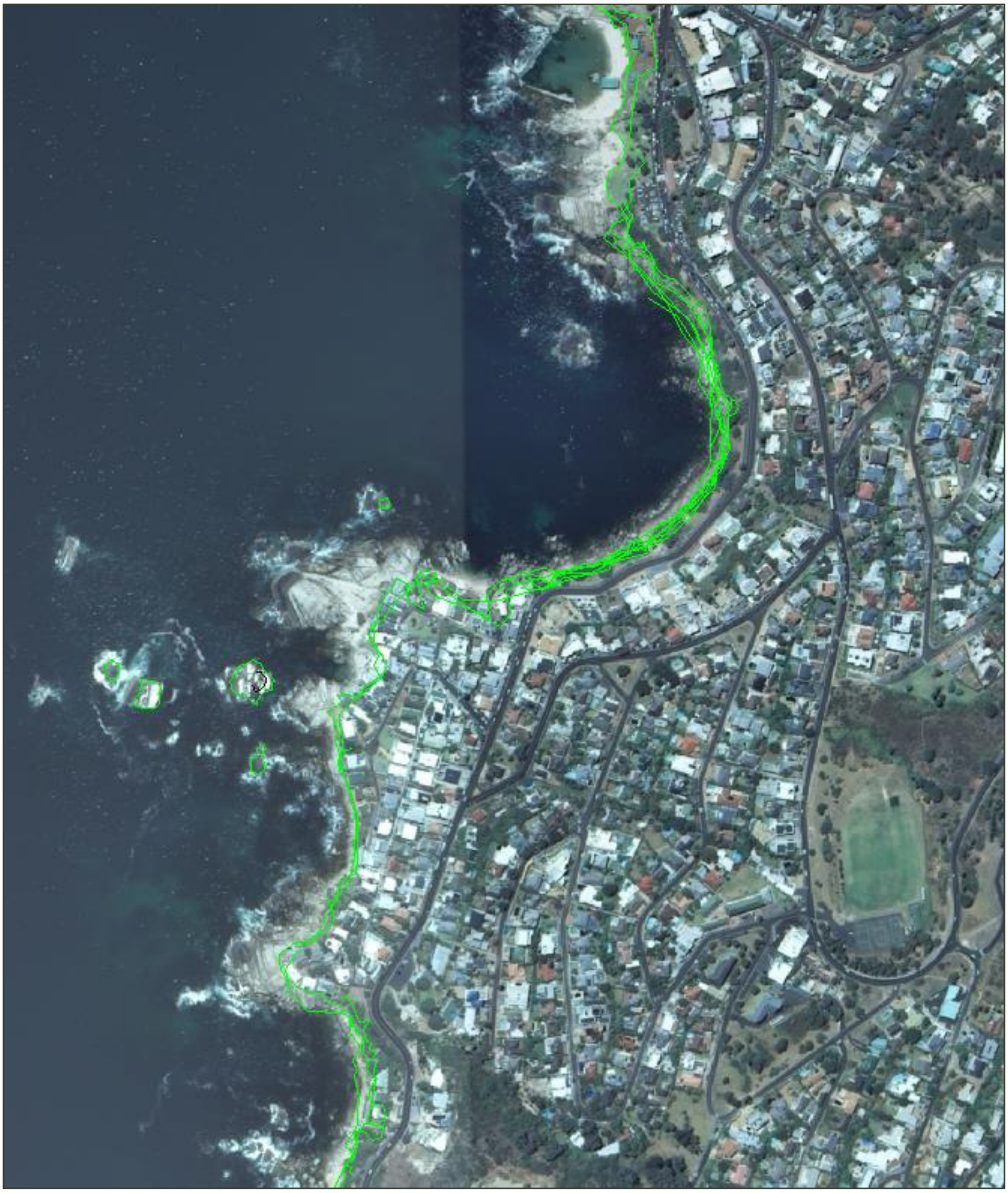


Figure 7-40: Plots of Vegetation Line 1942 - 2010 (National Geo-Spatial Information, 2010)

Figure 7-41: Plots of Wetted Line 1942 - 2010 (National Geo-Spatial Information, 2010)

The distance between the historic wetted and vegetation lines is 20 m at most. In view of the accuracy of the rectification process and the resolution of many of the photographs, this is thought to be an insignificant displacement. No significant trends of long-term shoreline erosion or accretion could be determined and the Bakoven shoreline is therefore judged to be historically stable with no significant long-term trends of either retreat or accretion.

This correlates well with existing literature on the response of hard rock granite shorelines to wave action sea level rise. The most resistant rock type and structure will experience only minor erosion along joints, faults and bedding planes which takes the form of small caves or inlets. Erosion of hard rock shorelines occurs due to air compression and cavitation along joints resulting in the infrequent removal of blocks rather than the gradual process of wearing down the surface.

Because of the stability of the rocky outcrops, the sandy pocket beaches are also held in a relatively stable position between headlands. The rates of movement of the sandy beaches shoreline positions is therefore also a lot less significant than would be expected at an open, sandy shoreline.

Short-term Shoreline Stability

Short term erosion of the granite boulder and pebble beaches at Bakoven was assumed to be negligible, as the boulders and pebbles were assumed to behave as a natural revetment, preventing any significant retreat of the shoreline during storm events.

For Bakoven's sandy pocket beaches, such as Big Beach, the evaluation of short-term erosion was performed using the model SBEACH. SBEACH (Storm-induced BEAch CHange Model) is a numerical model developed by USACE that simulates cross-shore beach, berm, and dune erosion produced by storm waves and water levels (Coastal and Hydraulics Laboratory - Engineer Research and Development Centre, 2012).

The 1:50 year storm wave conditions at a -5 m MSL position were used as input into the model. In addition, normal wave incidence was specified (assumed to be the worst case scenario) and the median grain size diameter, D_{50}, was assumed to be equal to 0.4 mm, as no sediment samples were available.

No geotechnical information was available on the different material layers along the shoreline, and the depth at which they occur, to inform the accurate modelling of the response of the cross shore profile to storm events. As no information was available on the depth at which a hard bottom, resistant to erosion, occurs, a sensitivity analysis was performed to determine the resulting short term erosion, assuming varying hard bottom profiles.

Seven fictitious hard bottom profiles were generated, with the hard bottom at various depths below the seabed and sometimes protruding above the seabed as boulders. Graphical illustrations of two of these fictitious profiles are shown in Figure 7-42 and Figure 7-43.

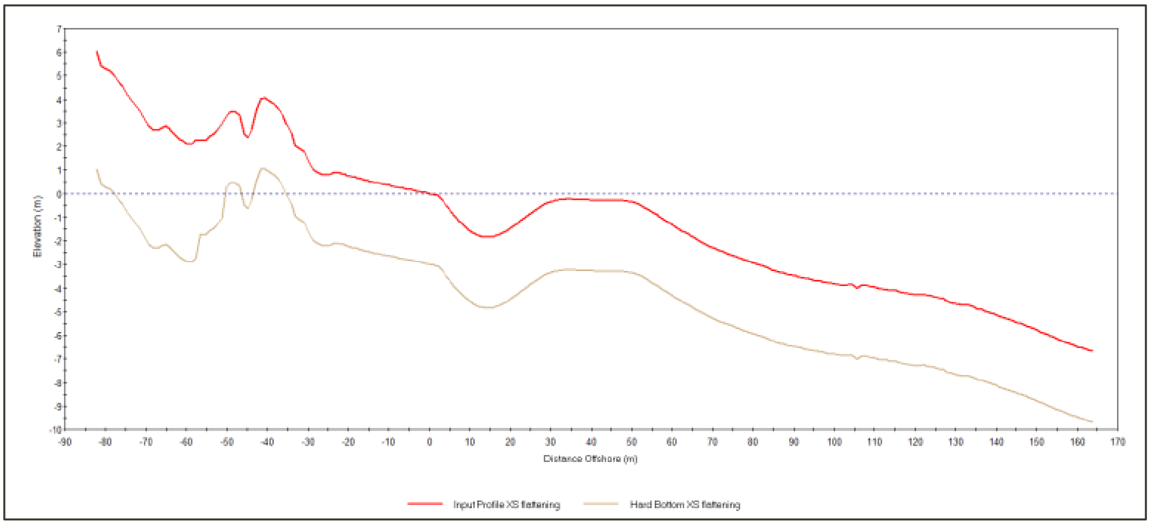


Figure 7-42: Hard bottom profile 3m below seabed

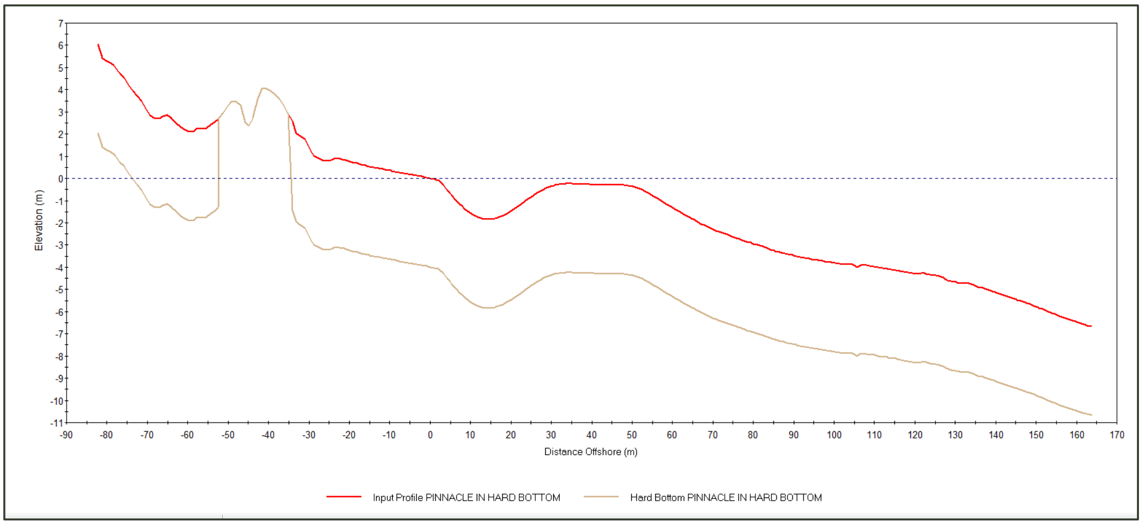


Figure 7-43: Hard bottom profile with boulder outcrop

No significant difference was found in the way the cross sections with different rock bottom profiles behave, except when the rock profile protruded above the seabed profile, hindering the cross-shore transport of sediment. In these cases, a local steepening, or zone of increased erosion, was found in front of the boulder, with sediment behind the boulder being retained.

It is difficult to represent the complex bay bathymetry accurately in 2D – the sheltering effect of boulders is not adequately calculated. As shown by SBEACH runs, the presence of boulders or granite pinnacles could cause local erosion in front of the rock, with some sheltering behind. This would, however, only happen immediately in front of or behind a boulder, and not all along the bay.

Results from the SBEACH model showed that the maximum recession of 0 MSL contour could be up to 10 m, in the case of local steepening in front of a boulder. The +5 m and -5 m contours were not found to recede. For all profiles tested, the position of a 1.5 m erosion depth was found at a distance of 50 m inland from the MSL contour. This distance reduced to 34 m in the lee of boulders.

It is important to note that, since no geotechnical information was available to include an accurate hard bottom profile, the accuracy of these short-term erosion calculations are only indicative. Although not accurate, they do indicate that, in the event of a major storm, there is a risk that the Bakoven shoreline could lose almost all of its sandy pocket beaches. This observation is in agreement with local observations of the effect of severe storms at Bakoven – local residents reported a significant loss of sandy beach material after the storm event of 2008 (Brown, 2013), which has since not been fully restored.

7.3.13 Bakoven Social and Environmental Constraints

Bakoven is one of three bungalow areas along the Atlantic coast (the others being Clifton and Glen Beach at Camps Bay) recognised by the City of Cape Town Municipality as significant cultural landscapes which have been declared National Heritage areas.

The modern bungalow in Bakoven is now governed by heritage considerations and a City-imposed maximum development envelope (MDE). The aim of these design criteria and guidelines is to raise awareness of the unique qualities that exist in this cultural landscape, and how to conserve and enhance them, as well as to advise how the legislation that protects these areas. The rules stipulated by the City Council provide strict and detailed regulations concerning:

- Architectural style of bungalows
- Scale of buildings
- Height of buildings
- Roofscapes and silhouettes
- Chimneys
- Windows and doors
- Materials and structure
- Boundary treatment
- Pools
- Decks
- Garages and carports
- Aerials and dishes
- Signage.

Any development in the three defined bungalow areas, including the construction of any building or structure, and the removal of any vegetation, is subject to the following legislation (City of Cape Town, 2007):

- National Building Regulations and Building Standards, (Act No 103 of 1977),

This document forms the basis of how all buildings in South Africa must be constructed.

- National Heritage Resources Act, No 25 of 1999

The National Heritage Resources Act (No. 25 of 1999) provides for the conservation and management of heritage resources and empowers society to assist in this management. With the introduction of this act, the bungalow areas are declared provincial heritage areas and any development needs to obtain authority from Heritage Western Cape (City of Cape Town, 2007).

- The Land Use Planning Ordinance (LUPO) & City of Cape Town Zoning Scheme

The LUPO, along with the Zoning scheme, are designed to manage the physical development and use of land. LUPO provides the legal framework for the application of the city's zoning scheme, in particular the following two sections of the scheme which deal with the bungalow areas:

- City Zoning Scheme, Section112: Bakoven, Clifton, Glen Beach

All the bungalow sites are zoned single dwelling residential use Zone in terms of the city's Zoning scheme. Section 112 of the scheme deals specifically with the bungalows areas as depicted on the plans TPZ 10557, TPZ 11167 and TPW 10556. Each bungalow has a 3D maximum development envelope which represents the development rights of each bungalow owner and controls all development of the bungalow upward, sideways and downward. No point on any structure erected or to be erected on any site shall project or extend beyond the maximum development envelope. This includes ground-level decks and pools which are also defined as structures. This section also covers other criteria such as allowable materials, definitions, etc. (City of Cape Town, 2007).

- City Zoning Scheme, Section 93(1): Scenic Drive Regulations

The Clifton and Glen Beach Bungalow Areas and a small portion of the Bakoven area lie below a designated scenic drive. these regulations controls all development abutting the lower side of any scenic drive, such as maintaining existing public views, to ensure that no structures or vegetation project more than 1,2 m above the sidewalk of Victoria Road.

- National Environmental Management Act, No. 107 of 1998; Section 23: Duty of care and remediation of environmental damage.

The city might require a “construction phase environmental management plan” as well as the lodging of financial guarantees to ensure preservation of vegetation and other natural and physical elements. The act also regulates and restricts certain activities within 100 m of the high water mark and requires authorisation from the Department of Environmental Affairs and Development Planning (DEADP).

- Title Deed Restriction

All South African properties have a title deed registered in the Deeds Office. In addition to standard information such as the erf number, property address, owner’s details, etc., it may also contain specific restrictions on development.

7.3.14 City of Cape Town Setback Line

Currently, the City of Cape Town's draft setback line, expected to be taken through the public participation process in 2014, follows the existing urban edge of bungalows, irrespective of whether the existing properties are located seaward of the coastal hazard line, as presented in Figure 7-44 and documented in Section 5.4.

Figure 7-44: Private property in Bakoven at risk from storm surges (City of Cape Town, 2012)

Any development seaward of this line is prohibited. The City of Cape Town proposes a coastal overlay zone for managing the properties located within the coastal hazard zone by providing additional regulations for properties located within these zones.

7.4 Assessment of Vulnerability of Bakoven to Climate Change

7.4.1 Introduction

The purpose of this section is to quantify the effects of climate change on the site conditions described in Section 7.3.

Section 7.4.2 describes the methodology that served as the basis for the calculation of future site conditions. After selection of the appropriate design life when considering the adaptation options for the Bakoven bungalows in Section 7.4.3, the expected change in site conditions at Bakoven over the time period being considered are determined in Section 7.4.4.

7.4.2 Method for Determination of Future Site Conditions

In 2011 PRDW, in cooperation with the Climate Systems Analysis Group (CSAG) from the University of Cape Town, performed an assessment of the vulnerability of the Salt River catchment in Cape Town to climate change. The study was performed for the City of Cape Town's Climate Change Think Tank project, focusing on the marine inputs to this project.

Ten different global climate change models, known as General Circulation Models (GCMs), were used to model the impacts of climate change for the City of Cape Town. The A2 SRES scenario future emissions scenario from IPCC (2007) was used to force each GCM (PRDW, 2011). This scenario describes a world in which people strive after personal wealth rather than environmental quality, and most closely resembles the RCP8.5 scenario from WG1 of AR5 (IPCC, 2013). Using the A2 SRES scenario as input, the models provide the resulting daily wind velocity and the atmospheric pressure at sea level for locations near Cape Town. The aim of this study was to understand the potential changes in intensity, occurrence and directions of extreme storm events, as these events have the biggest impact on infrastructure near the coast. The changes in conditions that were exceeded 1% of the time were therefore extracted (PRDW, 2011).

The changes in wind velocity and atmospheric pressure over the various time periods modelled were used to determine the changes on storm surge and wave heights in Table Bay using known relationships between these environmental conditions (PRDW, 2011). Changes were calculated for the period 2045 to 2065 and 2081 to 2100, relative to the period 1960 to 2000 which was assumed to be the status quo.

To calculate the change in storm surge conditions, local wind components and the inverse barometer component of the decreased pressure experienced during a frontal depression were investigated (PRDW, 2011).The point for local wind components is illustrated in Figure 7-45.

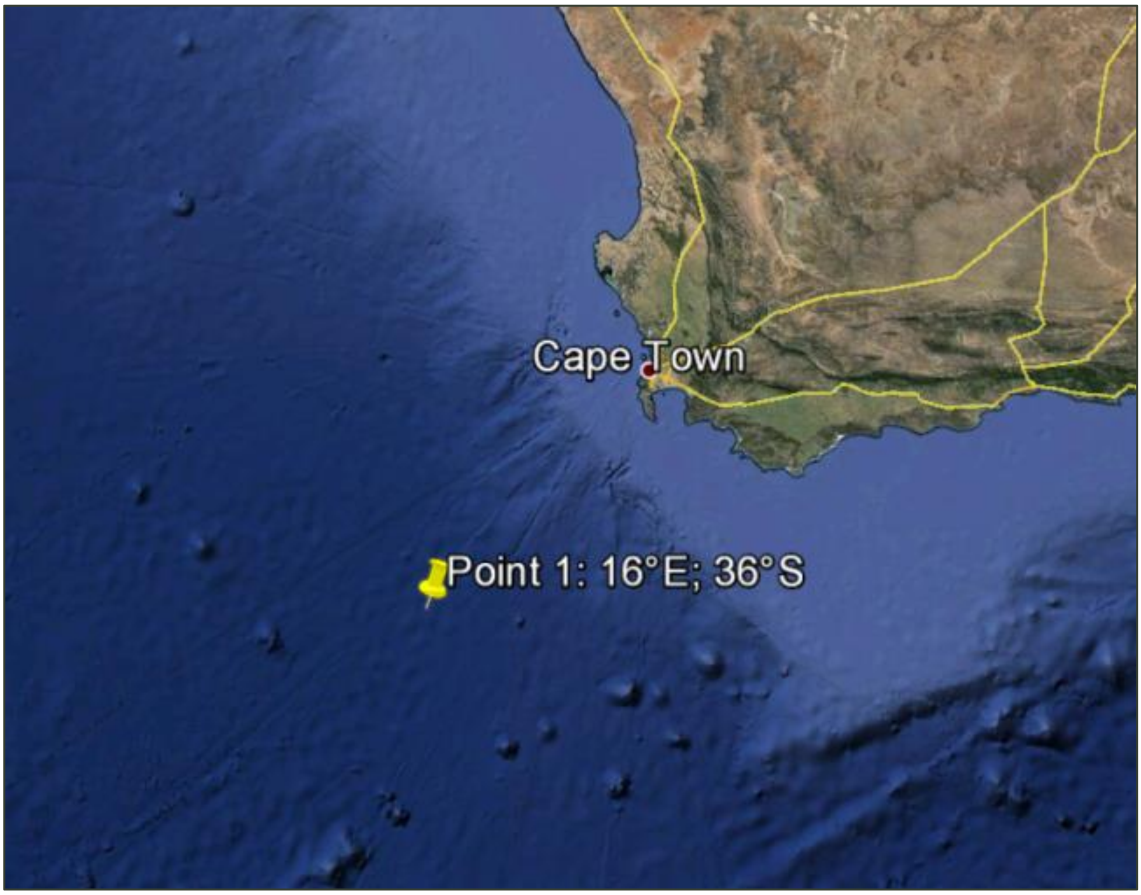


Figure 7-45: Local GCM Output Location - Point 1 (PRDW, 2011) (Google Earth version 7.1.2.2041, 2013)

To evaluate the change in wind generated waves, wind components were evaluated offshore, at locations Point 2 and Point 3 as shown in Figure 7-46 (PRDW, 2011).

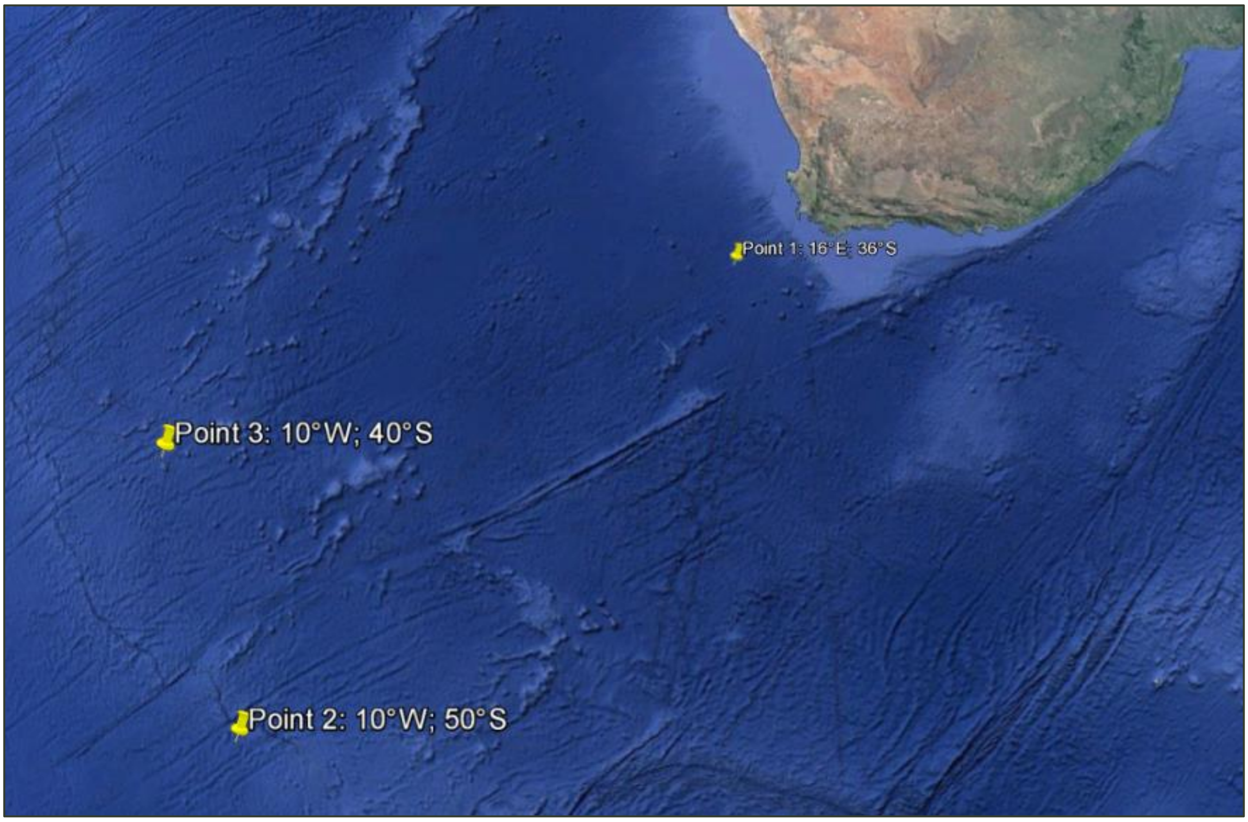


Figure 7-46: Offshore GCM Output Locations - Points 2 and 3 (PRDW, 2011) (Google Earth version 7.1.2.2041, 2013)

Based on the ten model results, two values for each of the parameters have been extracted - the median (50th percentile) of the ten models, and the upper 90th percentile, i.e. second highest of the ten models. These can be interpreted as a best estimate from the climate change models, and a conservative upper estimate, respectively (PRDW, 2011).

7.4.3 Design Life

The design life to taken into account when developing options for adaptation was determined considering the influence of the consequence of structural failure on the appropriate level of reliability, as stipulated by SANS 10160 Part 1: Basis of Structural Design (SANS 10160, 2011).

Table 7-18: Indicative design working life (SANS 10160: Part 1 - Basis of Structural Design, 2011)

Design working life category	Indicative design working life years	Description of structures
1	10	Temporary structures.
2	25	Replaceable structural parts, for example bearings, agricultural structures and similar structures with low consequences of failure
3	50	Building structures and other common structures.
4	100	Building structures designated as essential facilities such as those having post-disaster functions (hospitals and communication centres, fire and rescue centres), having high consequences of failure or having another reason for an extended design working life

In accordance with this table, the Bakoven structures should be designed for a design life Category 3 of 50 years. Changes to boundary condition parameters influencing flood water levels and storm conditions at Bakoven will therefore be calculated for the year 2063 and applied cumulatively to current conditions at Bakoven.

7.4.4 2063 Bakoven Site Conditions

The future site conditions for Bakoven in 2063, in the face of climate change, are quantified in this section based on the work done by PRDW and CSAG (2011).

Wind

The percentage change in extreme local wind speeds over the periods 1980 to 2055 and 2055 to 2090 are presented in Table 7-19 (PRDW, 2011).. These changes in wind climate were used to describe the changes in local wind climate and wind setup due to the onshore wind.

Table 7-19: Percentage Change in Local Extreme Wind Speeds (PRDW, 2011).

	Winter				Summer			
	1980 - 2055		2055 - 2090		1980 - 2055		2055 - 2090	
Wind Direction	Best estimate	Upper estimate	Best estimate	Upper estimate	Best estimate	Upper estimate	Best estimate	Upper estimate
Southerly wind	1%	6%	-2%	6%	2%	6%	0%	4%
Easterly wind	3%	5%	6%	13%	6%	15%	4%	11%
Northerly wind	-7%	1%	-1%	3%	-27%	-14%	-8%	18%
Westerly wind	-2%	3%	-2%	6%	-5%	0%	-7%	-1%

The CSAG results show that the magnitudes of the best estimate of both westerly and northerly winds are seen to reduce during the summer and the winter months for the modelled future dates (PRDW, 2011), while the southerly and easterly components show an increase (with the exception of the best estimate change in southerly wind over the period 2055 to 2090, which is estimated to be -2%).

The predicted extreme wind conditions for the year 2063, based on the best estimate percentage increase in 1% wind speeds show in Table 7-19, are presented in Table 7-20.

Table 7-20: Extreme Nearshore Wind Conditions for the Year 2063

Return Period (years)	3 hourly average (m/s)			
	NE	NW	SE	SW
1	13.6	12.0	17.0	14.9
5	17.3	14.6	23.3	18.0
10	18.5	15.6	26.2	19.1
20	19.5	16.5	29.3	20.2
50	20.8	17.6	33.5	21.4
100	21.7	18.5	36.9	22.3

The average percentage increase of each of the wind speeds, compared to the status quo extreme nearshore conditions presented in Table 7-1, is presented in Table 7-21.

Table 7-21: Average percentage increase in wind speed from status quo to 2063 scenario

NE	NW	SE	SW
-6 %	-11%	3.5%	-1.6%

Water Levels

Extreme water levels are again analysed by quantifying the changes in each of the three meteorological components discussed in Section 7.3.6:

- Wind setup
- Negative barometric pressure
- Wave setup.

In addition, an estimate for sea level rise up to 2100 will be included.

Wind Setup

Wind setup is proportional to wind speed squared, according to the Zuiderzee formula:

$S = \frac{\rho_a . C_d . V^2 . F}{\rho_w . g . D}$, where:

- ρ_a = density of air
- C_d = wind-stress drag coefficient
- V – wind speed
- F = Fetch along the wind direction
- ρ_w = density of water
- g = gravitational acceleration
- D = average depth along F.

The percentage change in the onshore wind speed can be used to evaluate the change in wind setup. The onshore wind direction for Bakoven is predominantly from the westerly sector, as illustrated in Figure 7-47.

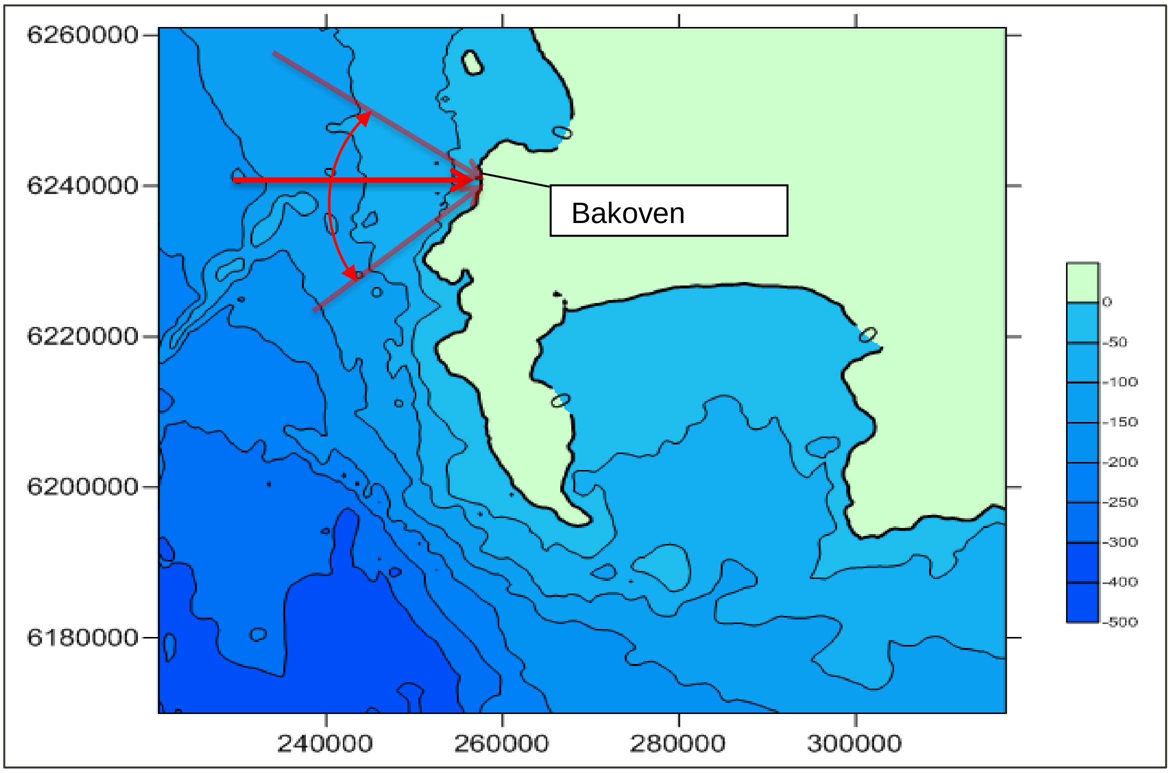


Figure 7-47: Bakoven Onshore Wind Direction

The estimated % increase in wind setup with a 1% exceedance is shown in Table 7-22.

Table 7-22: Best Estimate % Increase in Wind Setup (PRDW, 2011).

	Winter		Summer	
	1980 - 2055	2055 - 2090	1980 - 2055	2055 - 2090
Westerly wind – Best estimate	-4%	-4%	-10%	-14%
Westerly wind – Upper estimate	6%	12%	0%	-2%

Based on the above results the elevation of the water level due to wind setup during storms for Bakoven is expected to increase only for the upper estimate values, but not for the best estimate values. No increase in wind setup for Bakoven for the year 2063 was therefore included.

Pressure Component over Table Bay

Changes in atmospheric pressure calculated from the models were converted to potential changes in storm surge due to the inverse barometer effect (PRDW, 2011). Expected changes in water levels exceeded 1% of the time, as a result of atmospheric pressure, are presented in Table 7-23.

Table 7-23: Expected changes in 1% exceedance atmospheric pressure-induced water levels (PRDW, 2011)

Winter				Summer			
1980 to 2055		2055 to 2090		1980 to 2055		2055 to 2090	
Best estimate	Upper estimate	Best estimate	Upper estimate	Best estimate	Upper estimate	Best estimate	Upper estimate
-3 mm	8 mm	0 mm	18 mm	-1 mm	4 mm	4 mm	10 mm

Interpolating the best estimate values to the year 2063, no increases in storm surge due to the inverse barometer effect are found, for winter or summer seasons.

Sea Level Rise

An upper estimate of sea level rise by 2063 has been included according to the latest WG 1 report published by the IPCC (IPCC, 2013). The RCP 8.5 scenario was selected as a worst case scenario, predicting a rise in sea level of 0.37 m by 2063.

As no significant increases to the barometric or wind setup for Bakoven have been found to occur, by the year 2063, the allowance for sea level rise has been added to the extreme still water level calculated in Section 7.3.6. The results are presented in Table 7-24.

Table 7-24: Extreme Still Water Levels for Bakoven for 2063

Return Period [years]	Extreme Still Water Level (+m relative to MSL)
10	1.89
20	1.92
50	1.99
100	2.03

Due to the relatively steep shoreline, there is little difference between the locations of the still water levels for the various return periods. An illustration of the still water level for the 1:10 year return period (in green) and the 1:100 year return period (in red) for the 2063 scenario is provided in Figure 7-48.

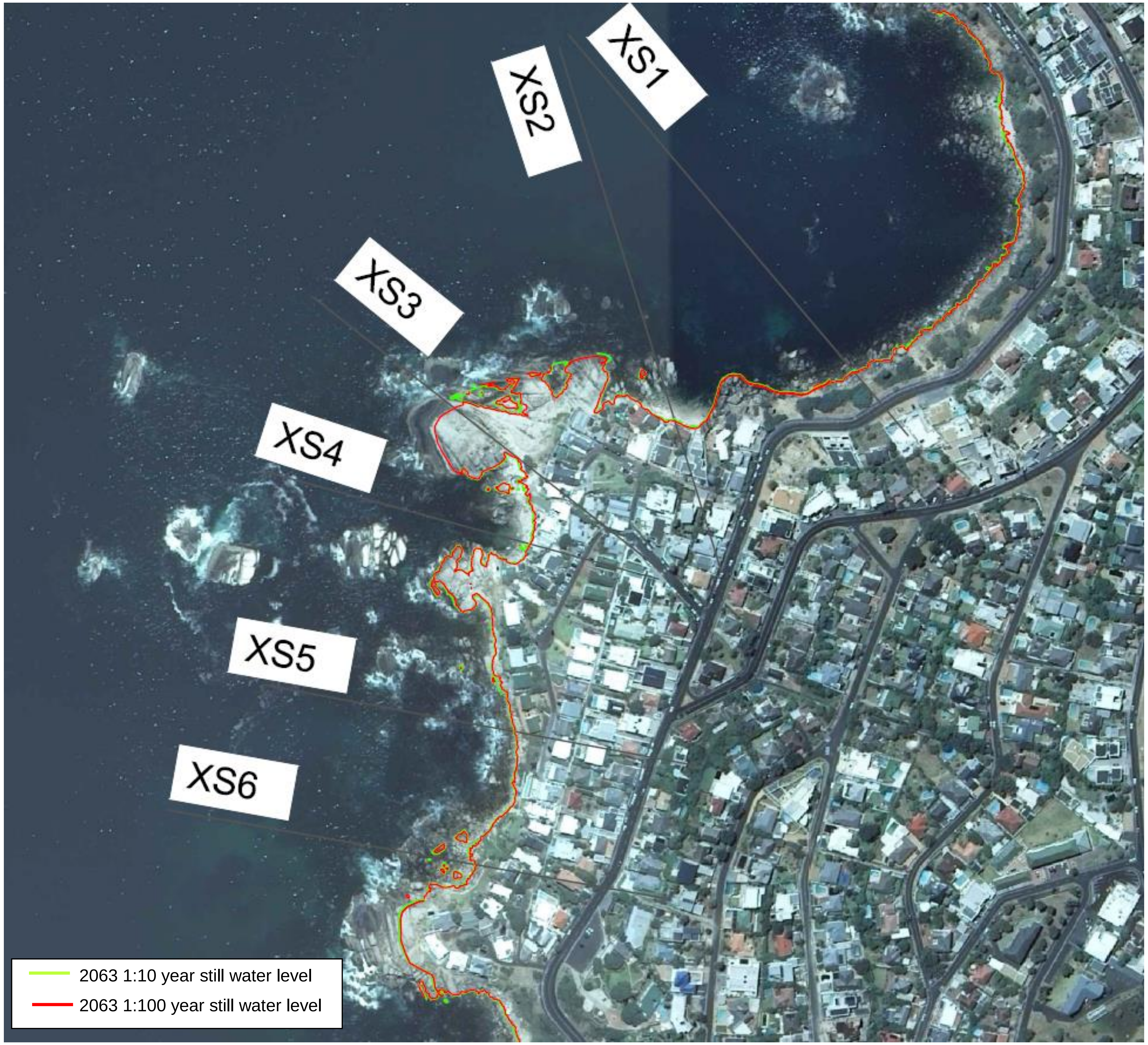


Figure 7-48: Bakoven 2063 Scenario 1:10 (green) and 1:100 year (red) extreme still water levels (National Geo-Spatial Information, 2010)

Offshore Waves

Since the GCMs (general circulation models) used by CSAG (2011) do not include wave parameters, changes in wave heights at Cape Town were based on the changes in the southerly and westerly wind speeds in the South Atlantic (PRDW, 2011), as explained in Section 7.4.2.

The best estimate and upper estimate values for the expected percentage change in South Atlantic wind speeds exceeded 1% of the time for future dates, are presented in Table 7-25 and Table 7-26, respectively.

Table 7-25: Expected % change in 1% exceedance wind speeds over South Atlantic (Best estimate)

		Winter		**Summer**	
		1980 - 2055	**2055 - 2090**	**1980 - 2055**	**2055 - 2090**
Points	Wind Direction	Best Estimate	Best Estimate	Best Estimate	Best Estimate
2	Westerly	1%	1%	2%	1%
	Southerly	0%	0%	-6%	-6%
3	Westerly	-1%	-2%	-6%	-3%
	Southerly	-2%	0%	-3%	1%

Table 7-26: Expected % change in 1% exceedance wind speeds over South Atlantic (Upper estimate)

		Winter		**Summer**	
		1980 - 2055	**2055 - 2090**	**1980 - 2055**	**2055 - 2090**
Points	Wind Direction	Upper Estimate	Upper Estimate	Upper Estimate	Upper Estimate
2	Westerly	4%	3%	4%	3%
	Southerly	3%	5%	5%	8%
3	Westerly	4%	4%	-4%	1%
	Southerly	3%	4%	6%	4%

The results indicate some variability between Points 2 and 3: westerly wind increasing for Point 02 (southern point) and reducing for Point 03 (northern point. This finding is consistent with the research by Bengtsonn *et al.* (2006), suggesting a poleward (southward) shift of extratropical depressions in the Southern Hemisphere.

A duration limited wave growth equation (CEM, 2006a), has been used to calculate percentage changes for offshore wave height based on the percentage change in winter wind speed for the maxima of Points 02 and 03 to the years 2055 and 2090 (PRDW, 2011).

The best estimate and upper estimate values for the expected percentage change in offshore wave heights exceeded 1% of the time for future dates are presented in Table 7-27 and

Table 7-28, respectively.

Table 7-27: Expected % change in 1% exceedance offshore wave heights (Best estimate)

		Winter		**Summer**	
		1980 - 2055	**2055 - 2090**	**1980 - 2055**	**2055 - 2090**
Points	Wind Direction	Best Estimate	Best Estimate	Best Estimate	Best Estimate
2	Westerly	2%	2%	5%	2%
	Southerly	0%	0%	-14%	-14%
3	Westerly	-2%	-5%	-14%	-7%
	Southerly	-5%	0%	-7%	2%

Table 7-28: Expected % change in 1% exceedance offshore wave heights (Upper estimate)

		Winter		**Summer**	
		1980 - 2055	**2055 - 2090**	**1980 - 2055**	**2055 - 2090**
Points	Wind Direction	Upper Estimate	Upper Estimate	Upper Estimate	Upper Estimate
2	Westerly	10%	8%	10%	8%
	Southerly	8%	13%	13%	21%
3	Westerly	10%	10%	-10%	2%
	Southerly	8%	10%	15%	10%

Interpolating to 2063, the best estimate for the increase in offshore wave heights by 2063 is 2% and the upper estimate, 14%.

Nearshore Waves

The same wave model as described in Section 7.3.8 was used to transform the best estimate values for offshore wave conditions to the nearshore. The results from the wave model for the same output location as presented in Figure 7-28, is provided in Table 7-29.

Table 7-29: Results of 2063 Scenario Bakoven Nearshore Wave Conditions

Run Nr	Return period	Water Level (+m MSL)	Wind Speed (m/s)	Wind Direction (degrees)	Offshore			Nearshore @ -5 m MSL		
					Hs (m)	Tp (s)	Direction (degrees)	Hs (m)	Tm (s)	Direction(degrees)
1	50	2.03	33.5	158	3.47	10.13	158	1.53	3.97	234.20
2	100	2.07	36.9	158	3.67	10.28	158	1.54	3.64	228.76
3	50	2.03	33.5	173	4.08	10.65	173	2.10	5.16	246.07
4	100	2.07	36.9	173	4.28	10.69	173	3.45	6.26	260.12
5	50	2.03	33.5	188	5.81	14.85	188	3.22	7.80	258.20
6	100	2.07	36.9	188	6.22	15.19	188	3.46	8.02	258.30
7	50	2.03	21.4	203	8.57	16.90	203	3.94	11.13	265.04
8	100	2.07	22.3	203	9.28	17.30	203	4	11.10	264.93
9	50	2.03	21.4	218	10.10	19.34	218	4.10	11.70	265.91
10	100	2.07	22.3	218	10.81	19.86	218	4.12	11.78	265.72
11	50	2.03	21.4	233	10.81	18.77	233	4.26	11.60	266.07
12	100	2.07	22.3	233	11.53	19.22	233	4.31	11.66	265.73
13	50	2.03	21.4	248	10.20	15.71	248	4.31	10.52	265.72
14	100	2.07	22.3	248	10.81	15.85	248	4.40	10.54	265.23
15	50	2.03	21.4	263	10.05	15.68	263	4.28	10.50	266.75
16	100	2.07	22.3	263	10.91	16	263	4.39	10.62	266.07
17	50	2.03	17.6	278	6.53	12.93	278	3.67	9.18	269.71
18	100	2.07	18.5	278	6.94	13.05	278	3.77	9.28	269.72
19	50	2.03	17.6	293	8.26	13.03	293	3.77	9.49	271.20
20	100	2.07	18.5	293	9.49	13.93	293	3.97	10.03	270.76
21	50	2.03	17.6	308	5.51	10.39	308	2.92	7.46	273.11
22	100	2.07	18.5	308	5.92	10.50	308	3.05	7.60	273.03
23	50	2.03	17.6	323	3.77	10.33	323	2.33	6.44	277.06
24	100	2.07	18.5	323	4.08	10.60	323	2.49	6.68	276.62

As was reported in Section 7.3.8 for the status quo scenario, Bakoven will be also vulnerable to storm events of much lower return periods in the 2063 Scenario. The nearshore wave conditions for the 1:5, 1:10 and 1:20 wave condition from the direction 248º is provided in Table 7-30. There is only a 4.6% (0.2m) difference between the 1:5 year condition's nearshore wave heights. This confirms that Bakoven will be extremely vulnerable to events with much lower return periods than a 1:100 year event.

Table 7-30: Bakoven nearshore conditions at -5 m MSL for 2063 Scenario lower return periods

Return Period	H_s (m)	T_m (s)
1:5	4.12	10.60
1:10	4.19	10.69
1:20	4.25	10.70

Wave Modelling Across Surf Zone

The SWASH model was again used to simulate the transformation of nearshore wave heights results for the 1:50 and 1:100 year wave conditions from the direction 248º (the wave direction leading to the largest nearshore wave heights at Bakoven) across the surf zone.

The results from the modelling of the 2063 scenario wave conditions from the direction 248º, are provided in Table 7-31.

Table 7-31: 2063 Scenario SWASH Wave Model Output at the +0.5 m MSL contour (1.5m water depth)

	H_s (m)	T_p (s)
2063 1:50 Year – Best estimate	0.9	13
2063 1:100 Year – Best estimate	0.95	13.3
2063 1:50 Year – Upper estimate	1	13.5
2063 1:100 Year – Upper estimate	1	13.8

A graphical illustration of the significant wave height (in m) for the best estimate 2063 1:100 year wave condition, is illustrated in Figure 7-49.

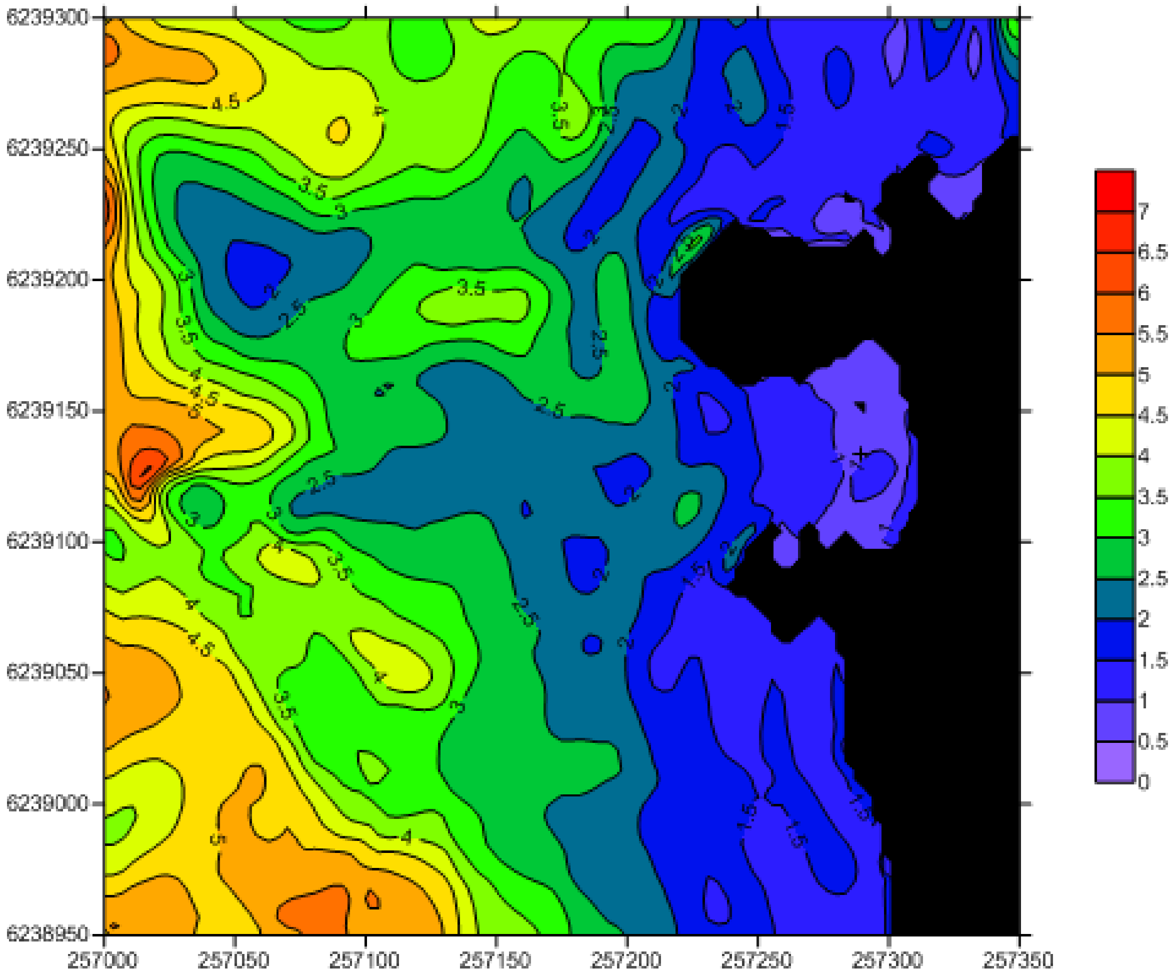


Figure 7-49: SWASH model output plot showing significant wave height (m) in the surf zone, for 1:100 year offshore condition (Hs - 10.81m, Tp - 15.85 s)

Wave Runup

Wave runup for the 2063-scenario was calculated using the same methods as stated in Section 0. As a relatively small 2% increase in offshore wave height is expected, no significant changes in the wave runup for 2063 are expected.

The expected wave runup values for the 2063 scenario are presented in Table 7-32.

Table 7-32: 2063 Scenario Wave Runup

	1:10	**1:50**	**1:100**
XS1	1.41	1.78	1.87
XS2	3.53	4.09	4.35
XS3	2.01	2.54	2.67
XS4	3.97	4.61	4.90
XS5	0.8	1.02	1.07
XS6	1.61	2.03	2.14

Figure 7-50: Bakoven 2063 Scenario Wave Runup Zone (National Geo-Spatial Information, 2010)

Overtopping

Using the same methods as stated in Section, the overtopping for the new wave conditions expected at Bakoven for 2063 were calculated and are presented in Table 7-33.

Table 7-33: 2063 Scenario Overtopping

Return Period	Overtopping q (ℓ/s/m)
1:50	9.94
1:100	13.3

A relatively small increase in the nearshore wave height and period at the toe of the beach has led to a significant increase in overtopping in the 2063 scenario. The overtopping volumes presented in Table 7-33 are well above the safe allowable limits for buildings.

Shoreline Stability

Long-term erosion due to SLR

The Bakoven shoreline was determined as historically stable in 7.3.11. Because the shoreline consists mainly of hard rock, it is estimated that it will suffer only negligible erosional recession from sea level rise. Long term shoreline retreat due to sea level rise was therefore ignored, save for inundation effects.

Short-term storm erosion

To determine the short-term storm erosion, the same method was used as presented in Section 7.3.11, using update wave conditions and water levels for the 2063 scenario/

Results from the SBEACH model greatly resembled the status quo conditions. It was shown that the maximum recession of 0 MSL contour increased slightly from the 10 m calculated previously, to 11 m - again, in the case of local steepening in front of a boulder. The +5 m and -5 m contours were not found to recede. The furthest inland position of a 1.5 m erosion depth was found at a distance of 50 m inland from the MSL contour, while a 1 m erosion depth could occur at a distance of up to 42 m inland of the MSL contour. This distance reduced to 34 m in the lee of boulders. As stated in Section 7.3.12, due to the lack of accurate geotechnical information, these values should be regarded as indicative only.

7.5Constructability Assessment

The elevation or relocation of existing structures is not a practice that South African contractors are commonly familiar with, although this technology is commonly applied abroad, in countries such the USA. International contractors were therefore approached to obtain inputs into the feasibility of elevating the bungalows situated along Bakoven.

Internationally, the physical relocation of structures has been related to such events as railway construction through built environments and the saving of historic buildings. In recent years the number of structures such as bridges and houses being re-built on a higher, flood-safe-level has increased significantly (Perez, 2013). Typically a contractor provides services for the static verification of the building and reinforcement; as well as the relocation. The structure can be moved by sliding it on strand jacks – pulling or moving them by a skidding-jack-system. The method mostly used in USA is for moving structures along a considerable distance, and therefore the buildings are jacked up and loaded on trailers (Perez, 2013).

The cost for such a structure elevation depends on the size and weight of building, the distance and also the required monitoring control during the movement. In case of older masonry buildings, this is an especially important issue and there are more lifting points, equipped with sensors which monitor the deformation between lifting points. An indicative cost for a sliding job of, for example, 30 m of a 500 t building, with dimensions 12 m x 30 m, would cost in the order of ZAR 550,000 – although this cost is based on a foreign quote and a significant cost increase might be incurred for performing such operations in South Africa (Perez, 2013).

Contractors approached were confident that, provided the existing ground subsurface is able to take the introduced loads (and if not there was the possibility of ground anchoring), the jacking up of the Bakoven buildings could be performed in order to elevate the houses (Perez, 2013). Temporary strengthening bars or other installations would be required to prevent cracks in the building and the windows would have to be specially secured or the glass removed. Beneath the houses a new basement floor could be installed or the building could be elevated on piles. If necessary, retaining walls could also be constructed to stabilise the site's slope.

7.6Conclusion

The vulnerability assessment performed has shown that Bakoven is very vulnerable to extreme events, for the status quo regime and increasingly so, for the future 2063 scenario.

Because Bakoven has a steep foreshore with hard rock, it is relatively resistant to erosion. Major impacts of climate change are increased flooding due to inundation, wave runup and the overtopping of embankments. Unacceptably high levels of overtopping will be experienced.

The elevation of buildings onto piled foundations would work well to remove existing buildings from the hazard zone. This would however impede other home owners' right to an ocean view. Technically though, it is a feasible engineering solution – Bakoven is expected to have shallow bedrock for the socketing of piles.

This would, however, not be allowed in the Bakoven heritage zone due to the strict regulations in terms of the maximum development envelope and the required architectural style of buildings. These same regulations would make any means of protecting properties, such as sea walls or dikes, impossible - which leaves home owners with little option but to accept the retreat option. In the case of Bakoven, this would result in a major capital loss due to the high value of properties. The same heritage regulations that aim to protect Bakoven's unique atmosphere and sense-of-place, will effectively lead towards their eventual sacrifice and abandonment.

Less visually disturbing accommodation solutions that could be implemented at Bakoven would be the implementation of dry- and wet flood-proofing measures and the preparation of good disaster management strategies and early warning systems in conjunction with cooperative local property owners and stakeholders. This would require home owners to accept the level of risk involved in living close the water's edge, and gear up for resilience accordingly. The community would need to work together to develop an integral solution to protect entire area's assets, instead of holding on to the tendency to want to protect an individual property or the right to a view.

8. Overall Conclusion and Recommendations

8.1 Conclusions

This study has assessed the feasibility of implementing accommodation measures at specific sites along the Cape Town coast.

The future climate change predicted by the IPCC could have disastrous impacts on many sectors and industries in South Africa. Coastal developments are particularly at risk of sea level rise and changing wind and wave storm frequencies and intensities. Climate change predictions for Cape Town have been found to vary greatly between different prediction models, with large differences between minimum and maximum values, and best estimate and upper estimate values. It is therefore crucial that Cape Town and the greater South Africa have informed and holistic adaptation strategies in place to enable societies and infrastructure to be adapted to these potential impacts.

Internationally, accommodation measures as a means to adapt to climate change have seen fascinating advances in technology. Amphibious, floating homes have been constructed and strategies to ‘build with nature’ have become increasingly popular. Less spectacular, but as important, are accommodation measures such as disaster management, risk management, building regulations and coastal management to prevent the loss of lives and create resilient communities and infrastructure.

As a result of the City of Cape Town’s approach of using the existing urban edge as the regulatory setback line, certain properties, although located landward of the draft setback, will be located in a zone that is at risk of flooding and/or erosion. Accommodation measures could be a feasible means of regulating building methods and material in these at-risk areas, providing disaster management services and encouraging property owners to strategically renovate their properties by the measures presented in Section 4.3.1, such as strategic renovation and use of areas at risk of flooding, elevating of homes, reinforced cladding, flood proofing, etc.

Of the sites investigated as a part of the site screening exercise of this study, accommodation measures have proven to be unfeasible in the case of soft, eroding shorelines. Non- or slowly eroding shorelines, where flooding is a greater problem than erosion, have been found to be more likely candidates for the successful implementation of accommodation measures.

It has been found challenging to design for a future scenario before it has realised, without knowing at exactly which point in the unfolding of the future scenario the solution will be implemented. Depending on the point in time at which the design is implemented and what impacts have become manifest at that point, the most appropriate adaptation solution might differ greatly.

Short-term measures implemented to deal with only the effects currently being experienced, without taking into account the eventual future condition, run the risk of being unsustainable. However, due to the uncertainties surrounding climate change science, there is a very real risk of overinvesting should one to decide to implement an adaptation measure that was designed for a future scenario.

Designing a protection adaptation measure to protect against an extreme event with a statistical occurrence of only once in, for example, a 100 years, could be seen as an overinvestment. The cost of rebuilding or repairing the structure should be compared to the additional cost of constructing a protection measure to withstand this event. More important than the ability of the structure to withstand failure, should be the ability of the social structure (community) to be able to predict the occurrence of the extreme event, for them to be educated regarding the appropriate response, regarding e.g. evacuation, after having been forewarned. Cardinal to the concept of accommodation is the ability to prevent the loss of lives and for a community to be able to rebuild itself after the occurrence of an extreme event.

8.2 Recommendations

To improve confidence in the accuracy of local climate models and their predictions, it is recommended that more detailed downscaled climate modelling be performed to improve the reliability of future predictions for local climate conditions, to inform adaptation design. Engineers, environmental scientists and policy makers should work closely together, in a continually iterative process of informing each other's inputs and outputs.

The viability and possible benefits of accommodation measures, rather than protection or retreat approaches, should be carefully considered on an individual case-by-case basis, in unison with the local community. As has been found in this study, specific sites along a certain stretch of coastline could have so many unique and diverging characteristics, that a blanket-approach could lead to great inaccuracies. It has found that in specific circumstances, accommodation measures could serve as a viable and attractive alternative to more traditional protection approaches. As many of the accommodation measures presented in this study can be seen as 'no regret' options, the implementation of these across sectors should be encouraged.

The viability and success of accommodation measures will depend greatly on the willingness of the particular community at hand to accept and live with an increased level of risk. Accommodation measures should always be implemented through a bottom-up process of engagement with stakeholders, ensuring that the adaptation solution developed will be acceptable and beneficial to all stakeholders. In specific circumstances, it may be required for local or provincial government to relax their imposed regulations in order for the most sustainable adaptation solution to be found. Regulations imposed by governments at all levels should be flexible to adapt to the changing conditions of the environments which they govern.

In short, accommodation measures, although having many limitations, have been found to have certain benefits for various sectors. Potential opportunities for implementation in South Africa and Cape Town exist, although detailed adaptation assessments for each site under study, is recommended.

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