Department of Environmental Affairs
and Development Planning

Sea Level Rise and Flood Risk Assessment for a Select Disaster Prone Area Along the Western Cape Coast

Phase 3 Report: West Coast District Municipality Sea Level Rise and Flood Hazard Risk Assessment

First Draft

March 2011

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EXECUTIVE SUMMARY

(to be included in Final document)

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LIST OF ABBREVIATIONS

%	-	percent
~	-	approximately
AR4	-	Fourth Assessment Report
C	-	coping capacity
cm	-	centimetre
CCRC	-	Climate Change Research Centre
CZMS	-	coastal zone management strategy
CZMU	-	Coastal Zone Management Unit
DM	-	District Municipality
DRR	-	disaster risk reduction
DP&R	-	disaster preparedness and response
DEA&DP	-	Department of Environmental Affairs and Development Planning
Ec	-	economic vulnerability
En	-	environmental vulnerability
e.g.	-	for example
etc.	-	etcetera
et al.	-	as well as
GIS	-	Geographic Information System
H	-	hazard
HAT	-	Highest Astronomical Tide
HFA	-	Hyogo Framework for Action
i.e.	-	that is
ICZM	-	Integrated Coastal Zone Management
IPCC	-	Intergovernmental Panel on Climate Change
km	-	kilometre
KZN	-	KwaZulu-Natal
LM	-	Local Municipality
m	-	metre
mm	-	millimeter
mamsl	-	metres above mean sea level
No.	-	number
P	-	probability
R	-	Rand
R	-	risk
RA	-	risk assessment
S	-	severity
So	-	social vulnerability
SLR	-	sea level rise
SCMP	-	sustainable coastal management plan
UNSW	-	University of New South Wales
UN/ISDR	-	United Nations International Strategy for Disaster Reduction
V	-	vulnerability
WBGU	-	German Advisory Council on Global Change

1. INTRODUCTION

1.1 SCOPE OF WORK

Umvoto Africa (Pty) Ltd was appointed by the Western Cape Department of Environmental Affairs and Development Planning (DEA&DP): Strategic Environmental Management division to undertake a sea level rise and flood risk assessment for a select disaster prone area along the Western Cape coast. The assessment area was defined as the Western Cape coastline within the West Coast District Municipality (DM), from Silwerstroom Strand (at the boundary of the City of Cape Town) to Hoekbaai (at the provincial boundary with the Northern Cape). This forms the second phase (in association with the Overberg DM) in undertaking a sea level rise and flood risk assessment for the Western Cape coastline (other than the City of Cape Town municipal area), with the Eden DM being completed as part of the first phase in 2010 (DEA&DP 2010a, 2010b and 2010c). This project is being done in association with a coastal setback line study for the Overberg DM, with the coastal setback line methodology being established and tested in the City of Cape Town and Saldanha Bay Local Municipality (LM) in 2010 (DEA&DP 2010d and 2010e). Umvoto Africa proposed a three-phase work approach, namely:

Phase 1 – Inception and Data Acquisition: Collection of GIS data to be used in the development of the sea level rise and flood inundation model; collection and review of literature on both the global and local aspects of climate and sea-level change, as well as all national, provincial and local coastal legislation; and finalisation of the GIS and risk assessment model methodologies to be used.

Phase 2 – GIS Model Development: Development of a sea level rise and flood inundation model, based on specific sea level rise scenarios that were determined from literature.

Phase 3 – Risk Assessment: Undertaking of a coastal zone hazard risk assessment for identified Coastal Zone Management Units (CZMUs) within the West Coast DM, based on a refined rapid assessment methodology described by Blake and Hartnady (2009) and used in the Eden DM sea level rise risk assessment (DEA&DP, 2010c).

This report describes the coastal hazard risk assessment undertaken during Phase 3. **Chapter 1** provides a brief overview of the literature review, and shoreline evolution, extreme sea level and estuary flooding modelling conducted in the Phase 1 and 2 reports respectively. **Chapter 2** describes the methodology used to undertake the coastal hazard risk assessment. The results from coastal hazard risk assessment are described in **Chapter 3**. **Chapter 4** describes various adaptation methods that could be employed to reduce the risk to sea level rise induced hazards, while **Chapter 5** concludes this report and provides recommendations.

The Phase 1 report details the literature and current understanding with regards to sea level rise both globally and regionally along the South African coastline, as well as the different sets of national, regional and local South African policies that have been developed to deal with future climate change induced coastal hazards. The Phase 2 report describes the shoreline evolution, extreme sea level and estuary flooding modelling that was undertaken along the West Coast DM coastline.

1.2 GLOBAL AND REGIONAL SEA LEVEL RISE

Due to the dynamic interaction of biophysical factors from both the Earth's land surface and ocean, and the high human population present, coastal areas are often at risk to natural and human-induced hazards. One such hazard, which is focused on in this study, is climate change induced sea level rise. Sea level rise causes shoreline retreat through coastal erosion and dune migration, and coastal inundation and flooding through enhanced tidal reaches and an increase in the of frequency of storm surges (whose intensity may also increase as a result of climate change). Rising sea levels can also cause groundwater and fresh coastal surface water contamination (with associated impacts on agriculture and aquaculture due to the decrease in soil and water quality), the loss of cultural and archaeological resources, and the possible destruction of important coastal habitats such wetlands, mangroves, estuaries etc.

Long term projections from coupled climate models are still uncertain with respects to global mean sea level rise and regional variations, due to the relatively unknown dynamic response of ice sheets to climate change, and the affects of regional climate circulation models (Cazenave et al., 2009). Tidal gauge and (since 1993) satellite altimetry measurements have shown that sea level has risen 20 cm since 1870, with the rise during the 20th century being approximately 17 cm (University of New South Wales (UNSW) Climate Change Research Centre (CCRC), 2009). This rise of ~ 1.7 mm/year is an order of magnitude greater than sea level rise during the last 2000 years (Church et al., 2008). Satellite altimetry measurements since 1993 have shown that sea level has risen by 3.4 mm/year since 1993. Current future predictions taking into account new ice sheet understanding are twice the range of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) projections, with an upper limit of sea level rise of 2 m expected by 2100 (Rahmstorf, 2007, Vermeer and Rahmstorf, 2009 and the UNSW CCRC, 2009). Mather et al. (2009) recently conducted the first detailed analysis of all tide gauge sites along the southern African coastline. The analysis shows that over the past 50 years, both eustatic and regional sea level rise along the southern African coastline has not been constant, varying between 0.42 and 1.87 mm/year (West Coast) to 3.55 and 2.74 mm/year (East Coast) respectively (Mather et al., 2009).

Sea level rise is often felt most not via the gradual advance of mean sea level, but by the increased frequency of storms and associated storm surge with the higher tidal regime. Higher sea levels cause an increase in the frequency of storm surge events due to the higher sea base level, even if storm intensities themselves do not increase due to warming oceans (Church et al., 2008) i.e. a storm surge event with a 1:100 year return period may start to have a return period of 1:25 years due to smaller storms having the same effect on higher sea levels. The combination of cut off and coastal low generated swell systems during spring highs in February, March and September, and swell generated by winter cold fronts are responsible for the present highest sea levels along the West Coast DM coastline. A 30-year storm of +39 cm on a Highest Astronomical Tide (HAT) for Simons Town of 1.24 metres above mean sea level (mamsl), which would be a 1:500 year event at present, could turn into a 1:30 year event by the end of the next decade with an additional 15 cm of sea level rise (Brundrit, 2008). The 19th and 20th March 2007 storm along the KwaZulu-Natal (KZN) coastline provides a modern analogue for what damage such an event can cause. A 1:35 year wave height of 8.5 m and 1:100 year storm surge of +55 cm occurred on a tide of 1.33 mamsl, which was very close to HAT for Durban (HAT in turn occurred on the 21st March 2007) (Brundrit, 2008, Smith et al., 2007 and Smith et al., 2010). This combination represented a 1:500 year extreme sea level event and caused R1 billion damage (Mather, 2008 and Theron and Rossouw, 2008). 1:100 year flood lines from the sea caused by possible extreme events of 4-7.5 mamsl have been modelled for the proposed Duynefontein (near Koeberg) Eskom Nuclear-1 site just south of the West Coast DM, while a maximum water level caused by a combination of a possible tsunami with storm surge, high tides and run-ups was modelled at 9.5 mamsl (Eskom Holdings Ltd, 2009a and 2009b). 1:100 year run-up levels have also been determined for Paradise Beach (4.5 mamsl) and Leentjiesklip (5.1 mamsl) in Langebaan (DEA&DP, 2010e). By 2100, extreme sea level events of this nature may occur every 2 weeks on spring highs with the combination of a small to moderate storm (Theron and Rossouw, 2008).

Extreme sea level, estuary flooding, shoreline and tidal reach evolution modelling has shown that at present Langebaan and the Berg River estuary area are vulnerable to coastal hazards induced by sea level rise, while the remainder of the largely undeveloped sandy coastal stretches along West Coast DM could be risk if excessive unplanned development occurs within the coastal foredune area or below the 5 mamsl contour line along rocky coastlines. An extreme storm event with a swash run-up of 2.5 mamsl (sheltered or rocky coastlines), 4.5 mamsl (exposed or sandy coastlines) and 6.5 mamsl (headland and pocket bay beaches and sandy inlets), in association with estuary back flooding, would only affect a relatively small proportion of development along the West Coast DM (mainly Langebaan and the Berg River estuary). This is a result of many towns being developed on elevated coastal rocky wave cut platforms that provide natural protection (e.g. Lambert’s Bay and Doringbaai) and natural westward and northward verging headlands providing shelter from the dominant southwesterly directed swell (e.g. Shelley Point protecting Stompneus and St. Helena Bays), as well as reduced development within the coastal foredune and estuarine areas (with the exception of the mouth of the Berg River estuary) in comparison to the southern Cape. Shoreline and tidal evolution modelling for a 2 m rise in sea level by 2100 has shown that the shoreline (especially along low gradient sandy coastlines) and lateral tidal reach may extend inland by a range of 20-100 m, depending on local coastal conditions. This gradual rise in sea level and slow coastal movement can be adapted to, provided the coastal section isn’t highly developed and there is space for both natural dune and development retreat.

2. COASTAL HAZARD RISK ASSESSMENT METHODOLOGY

Rapid desktop risk assessments provide an excellent tool for identifying vulnerable and at risk areas, and assisting the management of and adaptation to various hazards that these areas may be subjected too. For this study, the West Coast DM coastline was subdivided into 52 sections, termed Coastal Zone Management Units (CZMUs). The risk of each CZMU to three coastal hazards was qualitatively assessed using a modified version of the rapid risk assessment methodology described in Blake and Hartnady (2009). The three coastal hazard types that were selected in order to undertake the West Coast DM coastal risk assessment were:

- Sea level rise induced coastal erosion and inundation;
- Groundwater contamination from saltwater intrusion (as a result of sea level rise); and
- Extreme coastal events (storm surges, estuarine flooding and tsunamis).

The risk of each CZMU to each specific hazard can be determined by using the classic risk equation, where Risk (R) = (Hazard (H) x Vulnerability (V)) / Coping Capacity (C). Hazard, vulnerability and coping capacity were in turn scored from 1 to 5 (with 1 representing very low and 5 representing very high) for each CZMU for each hazard, allowing the risk to be calculated.

2.1 COASTAL ZONE MANAGEMENT UNITS

Integrated coastal zone management (ICZM) can often be complex, due to the various coastal habitats and types that can occur along a single stretch of coastline. Specific coastal units are therefore delineated in order to assist in ICZM, as well as to ensure that management decisions taken at one section of coastline do not negatively affect another section e.g. the building of a seawall in one coastal area may cause erosion further along the coastline, if the coastal section occurs within the same sedimentary cell. The City of Cape Town Coastal Zone Management Strategy (CZMS) (2003) delineated the coastline under its jurisdiction into 43 sections, and termed them CZMUs. This delineation was based on biophysical factors such as geology, geomorphology, habitat type, land use type e.g. residential development, harbour, power station etc., and administrative features. These same variables were used to delineate CZMUs for the individual LMs of the West Coast DM (see **Table 2-1** and **Figure 2-1**). The CZMUs defined here provide an initial, large-scale coastal subdivision for each LM. As each LM develops its own CZMS, different CZMUs can be delineated or defined according to that LM's specific coastal management requirements.

2.2 HAZARD

Hazard scores for each CZMU were calculated by determining the severity and probability of each specific hazard. Severity and hazard were both given a score out of 5 based on **Table 2-2** below. The equation Hazard (H) = (Probability (P) + Severity (S)) / 2 was then used to calculate a final hazard score out of 5.

For both sea level rise induced erosion and inundation, and groundwater contamination, a probability score of 3 was given for all CZMUs. This is based on a high-end sea level rise prediction of 2 m by 2100 occurring gradually over the next 90 years, which could be seen as a slow onset 1:100 year event. The predicted increased frequency of extreme sea level events (with the exception of tsunamis) due to a higher sea level base and increased wind regimes resulted in a probability score of 4 being given to all CZMUs for the extreme event hazard. Tsunamis, whether nearshore/local (e.g. submarine landslides and mud volcanoes on the continental margin south of the Walvis Ridge, meteo-tsunamis or edge waves, and submarine landslides along the Agulhas and Cape Town Slumps) or transoceanic (e.g. Sumatra megathrust near Mentawai in Indonesia, South Sandwich Island arc in the South Atlantic near South America, and Marion Island volcanic induced flank collapse) in origin, are difficult to predict and hence the probability score of 4 for extreme sea level events in association with tsunamis is kept.

Table 2-1 Initial delineated CZMUs for the West Coast DM.

LM	WCDMA01 (north)					Matzikama								Cederberg						
CZMU No.	Wn1	Wn2	Wn3	Wn4	Wn5	Mk1	Mk2	Mk3	Mk4	Mk5	Mk6	Mk7	Mk8	C1	C2	C3	C4	C5	C6	C7
CZMU Name	Hoekbaai-Malkopbaai	Goerap River	Blinkwaterbaai	Stompneus-Baaivals	Geelwal	Bakoond	De Punt	Olifants River	Strandfontein	Bamboesbaai	Doringbaai	Groothoekbaai	Doringbaai Flats	Lambert's Bay Dunefield	Lambert's Bay	Grootdrif	Wadrif	Elands Bay Dunefield	Elands Bay	Nuwedam

LM	Bergrivier				Saldanha Bay																	
CZMU No.	Br1	Br2	Br3	Br4	Sb1	Sb2	Sb3	Sb4	Sb5	Sb6	Sb7	Sb8	Sb9	Sb10	Sb11	Sb12	Sb13	Sb14	Sb15	Sb16	Sb17	Sb18
CZMU Name	Rocher Pan	Dwarskersbos	Laaiplek	Berg River	Slippers Bay	St Helena Bay	Stompneus Bay	Britannia Bay	Duiker Island	Paternoster Bay	Paternoster	Cape Columbine	Noordwesbaai	Wesbaai	Jacobsbaai	Danger Bay	North Head	Small Bay	Paradise Beach	Langebaan North	Langebaan Central	Langebaan South

LM	WCDMA01 (south)				Swartland					
CZMU No.	Ws1	Ws2	Ws3	Ws4	Sw1	Sw2	Sw3	Sw4	Sw5	Sw6
CZMU Name	Langebaan Lagoon	Postberg	Kreefbaai	16 Mile Beach	Yzerfontein	Pearl Bay	Tygerfontein-Modder River	Grotto Bay	Ganzekraal	Bokpunt

Figure 2-1 Initial delineated CZMUs for the West Coast DM (refer to Table 2-1 for CZMU names).

The severity of each hazard is dependent on the geology and geomorphology of each CZMU, with the scores defined in **Table 2-2** below. Groundwater contamination refers to the increased landward intrusion of highly saline seawater into freshwater aquifer systems, due to a rise in sea level. Primary (unconsolidated sediment e.g. Sandveld/West Coast Group) and fractured (faulted and folded quartzites and sandstones e.g. Peninsula and Piekenierskloof Formations of the Table Mountain Group) aquifers are generally more susceptible to all forms of contamination in comparison to regolith aquifers (weathered soil and regolith e.g. Malmesbury Group, Cape Granite Suite, Namaqualand Metamorphic Suite, Gifberg Group, Vanrhynsdorp Group), due to their higher hydraulic conductivity i.e. ability to transmit water. The extent of aquifer use (qualitatively determined by the amount of National Groundwater Database registered boreholes within and in the vicinity of each CZMU) will also affect the severity of saltwater intrusion, as high groundwater usae draws the freshwater-saltwater interface landwards and upwards, closer to the ground surface. The severity of sea level rise induced erosion/inundation and extreme events can be affected by various factors, including mean wave height, the amount of sea level rise, tidal range, geomorphology, coastal slope and rates of accretion/erosion (Thieler and Hammar-Klose, 1999). The mean wave height, rate of sea level rise and tidal range is generally the same along the West Coast DM coastline, and the rates of accretion/erosion are unknown, therefore geomorphology and coastal slope were the two variables used to assess the severity of both hazards. Low gradient sandy coastlines with no backing foredunes generally experience the greatest coastal erosion and inundation, with steep gradient rocky coastlines experiencing the least. Headland and inlet bay beaches usually experience the highest swash run-ups during extreme storm/sea level events, due to the headland geomorphology and bathymetry often funneling wave energy directly towards the adjacent beaches. Sheltered sandy and steep rocky coastlines generally receive minor swash run-ups during extreme storms etc, reducing the severity of the event.

Table 2-2 Hazard scoring methodology for each hazard.

Score	Severity			Probability
	SLR induced erosion / inundation	Groundwater contamination	Extreme events	Frequency of return
1	Steep gradient rocky coastline	Unused regolith aquifer	Steep rocky coastline	Negligible
2	Steep gradient sandy coastline; low-moderate gradient rocky coastline	Unused primary/fractured aquifer; moderately used regolith aquifer	Sheltered sandy coastline; low gradient rocky coastline	1 : 1000 year event
3	Low gradient sandy coastline with steep backing foredune or cliffs	Moderately used primary/fractured aquifer; highly used regolith aquifer	Exposed sandy coastline	1 : 100 year event
4	Low gradient sandy coastline with minor backing foredune	Highly used primary/fractured aquifer	Headland/inlet bay beach or low gradient coastline with estuary	1 : 10 year event
5	Very low gradient sandy coastline with no backing foredune	Very highly used primary/fractured aquifer	Head/inlet bay beach with large estuary	Yearly

2.3 VULNERABILITY

Vulnerability (V) was divided into three types, namely social (So), environmental (En) and economic (Ec) vulnerability. Social vulnerability was based on the possible amount of human injury or death, economic vulnerability on the total approximate economic cost in Rands, and environmental vulnerability on the possible environmental damage to a specific ecosystem (i.e. whether sensitive/protected or not) that may result from a specified hazard or disaster (see **Table 2-3**). Each vulnerability type was scored out of 5 based on the variables in **Table 2-3**, and a final vulnerability score was calculated using the equation V = (En + Ec + So) / 3.

With the West Coast DM's and associated coastal LM's 2010/2013 budget being in the range of approximately R 1.8 billion i.e. R 600 million per year, each economic vulnerability score represents a percentage value of the budget increasing in factors of ten, ranging from 0.002 % of the total annual budget (R 1 million – score of 1) to ~ 1700 % of the total budget (R 10 billion – score of 5). An extreme coastal event comparable to the KZN March 2007 storm could cause damage almost the entire total annual budget of the West Coast DM and five coastal LM's combined, if every developed coastal area was severely affected. This is unlikely however (as described in previous reports), due to a large proportion of developments occurring on relatively elevated rocky outcrop, and headlands offering protection from strong energy swell. An extreme event in the form of a very large storm surge or tsunami would cause the highest amount of injuries or loss of life, as well as the greatest infrastructural and environmental damage, and hence the highest vulnerabilities are associated with this hazard. Sea level rise induced coastal erosion and inundation is a gradual process, and hence loss of human life or injury is unlikely. Evolving shorelines can have a high economic and environmental cost over time however, as indicated in the risk assessment. Groundwater contamination may indirectly cause sickness or loss of life and affect economic activity, due to the destruction of possible future potable water resources. Environmental vulnerability is based on the sensitivity of the ecosystem in a regional sense.

Table 2-3 Vulnerability scoring methodology.

Score	Social	Economic	Environmental
	No. injuries/deaths	Cost (Rand)	
1	0 - 10	0 - R1 million	No sensitive ecosystem
2	10 - 100	R1 million - R10 million	Sensitive ecosystem
3	100 - 1 000	R10 million - R100 million	Protected ecosystem
4	1 000 - 10 000	R100 million - R1 billion	National Park
5	10 000 - 100 000	R1 billion - R10 billion	World Heritage or RAMSAR Site

2.4 COPING CAPACITY

Coping capacity defines the resilience a community or area has to a disaster i.e. to what extent will a community be affected by and how long it will take to recover from a disaster. Each CZMU was given a coping capacity score for each hazard, based on the implementation of the various stages of the Hyogo Framework for Action (HFA): Priorities for Action (United Nations International Strategy for Disaster Reduction (UN/ISDR), 2005) (detailed in **Table 2-4** below). The HFA priority areas strive to reduce the impact of disasters through gender sensitive disaster preparedness and risk reduction i.e. by increasing the coping capacity. Each HFA priority area was given a score out of 5, depending on whether there was:

- None to very limited implementation – 1
- Limited implementation – 2
- Partially implemented – 3
- Mainly implemented – 4
- Fully implemented – 5

The final coping capacity was then calculated using the equation:

$$C = (HFA1 + HFA2 + HFA3 + HFA4 + HFA5) / 5$$

Full implementation of all the HFA priority areas will result in a CZMU having a high coping capacity, ensuring that it is able to deal with coastal disasters. Little to no implementation of the HFA priority areas will result in coastal communities within the CZMU being highly affected by and taking a long period of time to recover from coastal disasters. The CZMUs along the West Coast DM coastline have low coping capacities, due to minor implementation of the HFA priority areas. HFA1 (see **Table 2-4**) is the highest scoring priority area, due to the development of national and provincial, and in some cases policies and frameworks to deal with ICZM and coastal hazards. Little to no implementation of HFAs 2 to 5 has occurred across the entire West Coast DM coastline however.

Table 2-4 Key indicators for assessing coping capacity based on the Hyogo Framework for Action (HFA) priority areas (UN/ISDR, 2005).

HFA Priority Areas	Core Tasks for Disaster Risk Reduction	Key Indicators
HFA 1 <u>Making Disaster Risk a Priority</u>	Engage in multi-stakeholder dialogue to establish foundations	Legal framework exists with explicit responsibilities defined for all levels
	Create or strengthen mechanisms for systematic coordination	National multi-stakeholder platform
	Assess and develop institutional basis	National policy framework exists that requires plans and activities at all levels
	Prioritize and allocate appropriate resources	Dedicated adequate resources to implement plans at all levels
HFA 2 <u>Improving Risk Information and Early Warning</u>	Establish an initiative for country wide risk assessments (RA)	National RA based on H and V info/data and include RA for key sectors
	Review availability of risk related info and capacities for data collection and use	Systems are in place to monitor, archive and disseminate data on H and V
	Assess capacities and strengthen early warning	Early warning in place for all major hazards
	Develop communication and dissemination mechanisms	Early warnings reach and serve people at community level

HFA Priority Areas	Core Tasks for Disaster Risk Reduction	Key Indicators
HFA 3 Building a culture of safety and resilience	Develop a programme to raise awareness	National awareness strategy exists that reaches all communities and people of all education
	Include disaster risk reduction (DRR) in education system and research community	School curricula at all levels includes DRR elements and instructors are trained in DRR at all levels
	Develop DRR training for key sectors	
	Enhance the compilation, dissemination and use of DRR info	
HFA 4 Reducing the Risks in Key Sectors	Environment: DRR is incorporated into environmental and natural resource management	Environmental protection and natural resource management and climate change policies include DRR elements
	Social needs: establish mechanisms for increased resilience of the poor and most vulnerable	Specific policies and plans are implemented to reduce vulnerability of impoverished groups
	Physical planning: establish measures to incorporate DRR in urban and land use planning	Land-use development zoning, plans and building codes exist, include DRR elements and are strongly enforced
	Structures: strengthen mechanisms for improved building safety and protection of critical facilities	Long term national programme to protect schools, health facilities and critical infrastructure from common natural hazards
	Stimulate DRR activities in production and service sector	Procedure in place to assess the DRR implications of major infrastructure project proposals
	Financial/economic instruments: create opportunities for Private sector involvement in DRR	
	Disaster Recovery: develop a recovery planning process that includes DRR	
HFA 5 Strengthen Preparedness for Response	Develop a common understanding and activities to support preparedness	Disaster preparedness and contingency plans at all levels with regular training drills and rehearsals to test and develop disaster preparedness and response (DP&R)
	Assess preparedness, capacities and readiness	Independent assessment done and responsibilities for implementing recommendations and resources schedule assigned
	Strengthen planning and programming for response, recovery and review	All organisations, personnel and volunteers responsible for maintaining preparedness are equipped and trained for effective DP&R
		Financial and contingency mechanisms are in place to support effective response and recovery
		Procedures are in place to document experience during hazard events and disasters and to undertake post event reviews

2.5 RISK

The risk calculation, colour coding for the risk maps, and simplified conceptual spread of the ranking is shown in below in **Table 2-5** and **Table 2-6** (the entire risk matrix is too large for this document, containing ~ 2500 possible values compared to 70 shown in **Table 2-6**). The risk calculation shows that coping capacity has a significant influence on the final risk assessment, and hence the importance in developing coping capacity mechanisms to deal with disasters in order to reduce the final risk e.g. even if a specific CZMU had the highest H x V ranking possible of 25, a coping capacity of 5 (i.e. full implementation of all five HFA priority areas) would reduce the risk of the CZMU to that hazard or possible disaster to 5 (moderate risk).

Table 2-5 Risk scoring methodology.

Score	Risk Ranking
0 - 1.5	Very Low
1.50 - 3	Low
3.0 - 6	Moderate
6.0 - 15	High
15.0 - 25	Very High

Table 2-6 Qualitative risk assessment, based on the hazard and vulnerability score (H x V) and coping capacity score.

		Coping Capacity (C)				
		1	2	3	4	5
Hazard x Vulnerability (H x V)	1	1.0	0.5	0.3	0.3	0.2
	2	2.0	1.0	0.7	0.5	0.4
	3	3.0	1.5	1.0	0.8	0.6
	4	4.0	2.0	1.3	1.0	0.8
	5	5.0	2.5	1.7	1.3	1.0
	6	6.0	3.0	2.0	1.5	1.2
	8	8.0	4.0	2.7	2.0	1.6
	9	9.0	4.5	3.0	2.3	1.8
	10	10.0	5.0	3.3	2.5	2.0
	12	12.0	6.0	4.0	3.0	2.4
	15	15.0	7.5	5.0	3.8	3.0
	16	16.0	8.0	5.3	4.0	3.2
	20	20.0	10.0	6.7	5.0	4.0
	25	25.0	12.5	8.3	6.3	5.0

3. COASTAL HAZARD RISK ASSESSMENT RESULTS

3.1 SEA LEVEL RISE INDUCED COASTAL EROSION AND INUNDATION

The majority of the West Coast DM CZMUs are at a low risk to sea level rise induced coastal erosion and inundation (63%; see **Table 3-1**, **Table 3-2** and **Figure 3-1**). The regions most at risk include the Mossel Bay area, Wilderness to Knysna area, and the Plettenberg Bay to Nature's Valley area, while the CZMUs with a high risk ranking are Wilderness West (G4), Wilderness East (G5), Sedgefield-Swartvlei (K1) and Knysna (K6). The areas of low risk reflect moderate to high gradient coastal areas, often with rocky coastlines or high backing coastal dune systems, with relatively little development in lower elevation areas or within the coastal foredune.

3.2 GROUNDWATER CONTAMINATION

The majority of the West Coast DM CZMUs are at a low risk to groundwater contamination from salt water intrusion related to sea level rise (75%), with the exception being the upper Berg River and Cederberg LMs (see **Table 3-1**, **Table 3-3** and **Figure 3-2**). The CZMUs with the highest risk ranking occur within these LMs due to the extensive coastal groundwater abstraction and use by means of centre-pivot irrigation for potato and rooibos tea agriculture. The at risk areas of the West Coast DM are comprised of hydraulically conductive and therefore vulnerable primary (Sandveld/West Coast Group) and fractured quartzitic (Piekenierskloof and Peninsula Formation) aquifers, which are used to varying extents for groundwater supply. Vulnerability and risk may increase over time, due to possible future potable water shortages in the area as a result of climate change, and the associated increased exploitation of groundwater resources.

3.3 EXTREME EVENTS

The majority of the West Coast DM CZMUs are at a low to moderate risk from extreme coastal events such as large storm surges and tsunamis (54% and 44% respectively; see **Table 3-1**, **Table 3-4** and **Figure 3-3**). The regions at most risk include the Berg River (low elevation, highly developed flood prone estuary) and Langebaan area (extensive development below the 2.5 mamsl contour exposed to swell entering Saldanha Bay) CZMUs. The areas of low to moderate risk reflect moderate to high gradient coastal areas, often with rocky coastlines or high backing coastal dune systems, with relatively little development in lower elevation areas or within the coastal foredune.

Table 3-1 Number/percent of risk ranked CZMUs per coastal hazard.

Score	Risk Ranking	SLR induced coastal erosion/inundation		Groundwater contamination		Extreme events	
		No.	%	No.	%	No.	%
0 - 1.5	Very Low	0	0	0	0	0	0
1.50 - 3	Low	33	63	39	75	23	44
3.0 - 6	Moderate	19	37	12	23	28	54
6.0 - 15	High	0	0	1	2	1	2
15.0 - 25	Very High	0	0	0	0	0	0

Table 3-2 Risk assessment for the West Coast DM with respects to sea level rise induced coastal erosion and inundation (refer to Table 2-5 for risk ranking values).

Local Municipality	CZMU Code	CZMU Name	Hazard			Vulnerability				Coping Capacity						Risk
			P	S	H	Ec	So	En	V	HFA1	HFA2	HFA3	HFA4	HFA5	C	R
WCDMA01 (north)	Wn1	Hoekbaai-Malkopbaai	3	1	2.0	1	1	2	1.3	3	1	1	1	1	1.4	1.9
	Wn2	Goerap River	3	2	2.5	1	1	2	1.3	3	1	1	1	1	1.4	2.4
	Wn3	Blinkwaterbaai	3	2	2.5	1	1	1	1.0	3	1	1	1	1	1.4	1.8
	Wn4	Stompneus-Baaivals	3	1	2.0	2	1	2	1.7	3	1	1	1	1	1.4	2.4
	Wn5	Geelwal	3	1	2.0	3	1	2	2.0	3	1	1	1	1	1.4	2.9
Matzikama	Mk1	Bakoond	3	1	2.0	1	1	2	1.3	3	1	1	1	1	1.4	1.9
	Mk2	De Punt	3	1	2.0	2	1	2	1.7	3	1	1	1	1	1.4	2.4
	Mk3	Olifants River	3	4	3.5	1	1	3	1.7	4	2	1	1	1	1.8	3.2
	Mk4	Strandfontein	3	3	3.0	2	1	1	1.3	3	1	1	1	1	1.4	2.9
	Mk5	Bamboesbaai	3	1	2.0	1	1	2	1.3	3	1	1	1	1	1.4	1.9
	Mk6	Doringbaai	3	1	2.0	2	1	1	1.3	3	1	1	1	1	1.4	1.9
	Mk7	Groothoekbaai	3	3	3.0	1	1	2	1.3	3	1	1	1	1	1.4	2.9
	Mk8	Doringbaai Flats	3	3	3.0	1	1	2	1.3	3	1	1	1	1	1.4	2.9
Cederberg	C1	Lambert's Bay Dunefield	3	3	3.0	1	1	2	1.3	3	1	1	1	1	1.4	2.9
	C2	Lambert's Bay	3	2	2.5	2	1	2	1.7	3	1	1	1	1	1.4	3.0
	C3	Grootdrif	3	3	3.0	1	1	2	1.3	3	1	1	1	1	1.4	2.9
	C4	Wadrif	3	3	3.0	1	1	2	1.3	3	1	1	1	1	1.4	2.9
	C5	Elands Bay Dunefield	3	3	3.0	2	1	2	1.7	3	1	1	1	1	1.4	3.6
	C6	Elands Bay	3	4	3.5	3	1	3	2.3	4	2	1	1	1	1.8	4.5
	C7	Nuwedam	3	3	3.0	1	1	2	1.3	3	1	1	1	1	1.4	2.9
Bergrivier	Br1	Rocher Pan	3	3	3.0	1	1	3	1.7	3	1	1	1	1	1.4	3.6
	Br2	Dwarskersbos	3	4	3.5	3	1	2	2.0	3	1	1	1	1	1.4	5.0
	Br3	Laaiplek	3	4	3.5	3	1	1	1.7	3	1	1	1	1	1.4	4.2
	Br4	Berg River	3	5	4.0	3	1	3	2.3	4	2	1	1	1	1.8	5.2
Saldanha Bay	Sb1	Slippers Bay	3	2	2.5	1	1	2	1.3	3	1	1	1	1	1.4	2.4
	Sb2	St Helena Bay	3	1	2.0	2	1	2	1.7	3	1	1	1	1	1.4	2.4
	Sb3	Stompneus Bay	3	2	2.5	3	1	1	1.7	3	1	1	1	1	1.4	3.0
	Sb4	Britannia Bay	3	4	3.5	3	1	2	2.0	3	1	1	1	1	1.4	5.0
	Sb5	Duiker Island	3	2	2.5	2	1	2	1.7	3	1	1	1	1	1.4	3.0
	Sb6	Paternoster Bay	3	3	3.0	1	1	2	1.3	3	1	1	1	1	1.4	2.9
	Sb7	Paternoster	3	3	3.0	3	1	1	1.7	3	1	1	1	1	1.4	3.6
	Sb8	Cape Columbine	3	1	2.0	1	1	3	1.7	3	1	1	1	1	1.4	2.4
	Sb9	Noordwesbaai	3	2	2.5	1	1	2	1.3	3	1	1	1	1	1.4	2.4
	Sb10	Wesbaai	3	2	2.5	2	1	2	1.7	3	1	1	1	1	1.4	3.0
	Sb11	Jacobsbaai	3	2	2.5	2	1	2	1.7	3	1	1	1	1	1.4	3.0
	Sb12	Danger Bay	3	3	3.0	1	1	2	1.3	3	1	1	1	1	1.4	2.9
	Sb13	North Head	3	2	2.5	1	1	3	1.7	3	1	1	1	1	1.4	3.0
	Sb14	Small Bay	3	4	3.5	4	1	2	2.3	3	2	1	1	1	1.6	5.1
	Sb15	Paradise Beach	3	3	3.0	3	1	2	2.0	3	1	2	1	1	1.6	3.8
	Sb16	Langebaan North	3	4	3.5	3	1	2	2.0	3	1	2	1	1	1.6	4.4
	Sb17	Langebaan Central	3	4	3.5	3	1	2	2.0	3	1	2	1	1	1.6	4.4
	Sb18	Langebaan South	3	2	2.5	3	1	2	2.0	3	1	1	1	1	1.4	3.6
WCDMA01 (south)	Ws1	Langebaan Lagoon	3	2	2.5	1	1	5	2.3	3	1	1	1	1	1.4	4.2
	Ws2	Postberg	3	2	2.5	1	1	4	2.0	3	1	1	1	1	1.4	3.6
	Ws3	Kreefbaai	3	1	2.0	1	1	4	2.0	3	1	1	1	1	1.4	2.9
	Ws4	16 Mile Beach	3	2	2.5	1	1	4	2.0	3	1	1	1	1	1.4	3.6
Swartland	Sw1	Yzerfontein	3	2	2.5	3	1	2	2.0	3	1	1	1	1	1.4	3.6
	Sw2	Pearl Bay	3	3	3.0	3	1	2	2.0	3	1	1	1	1	1.4	4.3
	Sw3	Tygerfontein-Modder River	3	3	3.0	1	1	2	1.3	3	1	1	1	1	1.4	2.9
	Sw4	Grotto Bay	3	1	2.0	1	1	2	1.3	3	1	1	1	1	1.4	1.9
	Sw5	Ganzekraal	3	1	2.0	1	1	2	1.3	3	1	1	1	1	1.4	1.9
	Sw6	Bokpunt	3	1	2.0	1	1	2	1.3	3	1	1	1	1	1.4	1.9

Figure 3-1 Risk assessment for the West Coast DM with respects to sea level rise induced coastal erosion and inundation (refer to Table 2-5 for risk ranking values).

Table 3-3 Risk assessment for the West Coast DM with respects to groundwater contamination (refer to Table 2-5 for risk ranking values).

Local Municipality	CZMU Code	CZMU Name	Hazard			Vulnerability				Coping Capacity						Risk
			P	S	H	Ec	So	En	V	HFA1	HFA2	HFA3	HFA4	HFA5	C	R
WCDMA01 (north)	Wn1	Hoekbaai-Malkopbaai	3	2	2.5	1	1	2	1.3	3	1	1	1	1	1.4	2.4
	Wn2	Goerap River	3	2	2.5	1	1	2	1.3	3	1	1	1	1	1.4	2.4
	Wn3	Blinkwaterbaai	3	2	2.5	1	1	1	1.0	3	1	1	1	1	1.4	1.8
	Wn4	Stompneus-Baaivals	3	2	2.5	1	1	2	1.3	3	1	1	1	1	1.4	2.4
	Wn5	Geelwal	3	1	2.0	1	1	2	1.3	3	1	1	1	1	1.4	1.9
Matzikama	Mk1	Bakoond	3	1	2.0	1	1	2	1.3	3	1	1	1	1	1.4	1.9
	Mk2	De Punt	3	1	2.0	1	1	2	1.3	3	1	1	1	1	1.4	1.9
	Mk3	Olifants River	3	2	2.5	1	1	3	1.7	4	2	1	1	1	1.8	2.3
	Mk4	Strandfontein	3	4	3.5	2	2	1	1.7	3	1	1	1	1	1.4	4.2
	Mk5	Bamboesbaai	3	2	2.5	1	1	2	1.3	3	1	1	1	1	1.4	2.4
	Mk6	Doringbaai	3	3	3.0	2	2	1	1.7	3	1	1	1	1	1.4	3.6
	Mk7	Groothoekbaai	3	2	2.5	1	1	2	1.3	3	1	1	1	1	1.4	2.4
	Mk8	Doringbaai Flats	3	2	2.5	1	1	2	1.3	3	1	1	1	1	1.4	2.4
Cederberg	C1	Lambert's Bay Dunefield	3	3	3.0	1	1	2	1.3	3	1	1	1	1	1.4	2.9
	C2	Lambert's Bay	3	3	3.0	2	2	2	2.0	3	1	1	1	1	1.4	4.3
	C3	Grootdrif	3	5	4.0	3	2	2	2.3	3	1	1	1	1	1.4	6.7
	C4	Wadrif	3	4	3.5	2	2	2	2.0	3	1	1	1	1	1.4	5.0
	C5	Elands Bay Dunefield	3	4	3.5	1	1	2	1.3	3	1	1	1	1	1.4	3.3
	C6	Elands Bay	3	5	4.0	1	2	5	2.7	4	2	1	1	1	1.8	5.9
	C7	Nuwedam	3	4	3.5	2	1	2	1.7	3	1	1	1	1	1.4	4.2
Bergrivier	Br1	Rocher Pan	3	4	3.5	2	1	3	2.0	3	1	1	1	1	1.4	5.0
	Br2	Dwarskersbos	3	2	2.5	1	1	2	1.3	3	1	1	1	1	1.4	2.4
	Br3	Laaiplek	3	2	2.5	1	2	1	1.3	3	1	1	1	1	1.4	2.4
	Br4	Berg River	3	3	3.0	1	2	3	2.0	4	2	1	1	1	1.8	3.3
Saldanha Bay	Sb1	Slippers Bay	3	1	2.0	1	1	2	1.3	3	1	1	1	1	1.4	1.9
	Sb2	St Helena Bay	3	1	2.0	1	1	2	1.3	3	1	1	1	1	1.4	1.9
	Sb3	Stompneus Bay	3	1	2.0	1	1	1	1.0	3	1	1	1	1	1.4	1.4
	Sb4	Britannia Bay	3	1	2.0	1	1	2	1.3	3	1	1	1	1	1.4	1.9
	Sb5	Duiker Island	3	1	2.0	1	1	2	1.3	3	1	1	1	1	1.4	1.9
	Sb6	Paternoster Bay	3	2	2.5	1	1	2	1.3	3	1	1	1	1	1.4	2.4
	Sb7	Paternoster	3	1	2.0	1	1	1	1.0	3	1	1	1	1	1.4	1.4
	Sb8	Cape Columbine	3	1	2.0	1	1	3	1.7	3	1	1	1	1	1.4	2.4
	Sb9	Noordwesbaai	3	1	2.0	1	1	2	1.3	3	1	1	1	1	1.4	1.9
	Sb10	Wesbaai	3	2	2.5	1	1	2	1.3	3	1	1	1	1	1.4	2.4
	Sb11	Jacobsbaai	3	1	2.0	1	1	2	1.3	3	1	1	1	1	1.4	1.9
	Sb12	Danger Bay	3	2	2.5	1	1	2	1.3	3	1	1	1	1	1.4	2.4
	Sb13	North Head	3	1	2.0	1	1	3	1.7	3	1	1	1	1	1.4	2.4
	Sb14	Small Bay	3	1	2.0	1	2	2	1.7	3	2	1	1	1	1.6	2.1
	Sb15	Paradise Beach	3	2	2.5	1	1	2	1.3	3	1	2	1	1	1.6	2.1
	Sb16	Langebaan North	3	1	2.0	1	2	2	1.7	3	1	2	1	1	1.6	2.1
	Sb17	Langebaan Central	3	1	2.0	1	2	2	1.7	3	1	2	1	1	1.6	2.1
	Sb18	Langebaan South	3	1	2.0	1	2	2	1.7	3	1	1	1	1	1.4	2.4
WCDMA01 (south)	Ws1	Langebaan Lagoon	3	3	3.0	1	1	5	2.3	3	1	1	1	1	1.4	5.0
	Ws2	Postberg	3	1	2.0	1	1	4	2.0	3	1	1	1	1	1.4	2.9
	Ws3	Kreefbaai	3	1	2.0	1	1	4	2.0	3	1	1	1	1	1.4	2.9
	Ws4	16 Mile Beach	3	2	2.5	1	1	4	2.0	3	1	1	1	1	1.4	3.6
Swartland	Sw1	Yzerfontein	3	2	2.5	1	2	2	1.7	3	1	1	1	1	1.4	3.0
	Sw2	Pearl Bay	3	2	2.5	1	1	2	1.3	3	1	1	1	1	1.4	2.4
	Sw3	Tygerfontein-Modder River	3	4	3.5	2	1	2	1.7	3	1	1	1	1	1.4	4.2
	Sw4	Grotto Bay	3	1	2.0	1	1	2	1.3	3	1	1	1	1	1.4	1.9
	Sw5	Ganzekraal	3	1	2.0	1	1	2	1.3	3	1	1	1	1	1.4	1.9
	Sw6	Bokpunt	3	1	2.0	1	1	2	1.3	3	1	1	1	1	1.4	1.9

Figure 3-2 Risk assessment for the West Coast DM with respects to groundwater contamination (refer to Table 2-5 for risk ranking values).

Table 3-4 Risk assessment for the West Coast DM with respects to extreme events (refer to Table 2-5 for risk ranking values).

Local Municipality	CZMU Code	CZMU Name	Hazard			Vulnerability				Coping Capacity						Risk
			P	S	H	Ec	So	En	V	HFA1	HFA2	HFA3	HFA4	HFA5	C	R
WCDMA01 (north)	Wn1	Hoekbaai-Malkopbaai	4	1	2.5	1	1	2	1.3	3	1	1	1	1	1.4	2.4
	Wn2	Goerap River	4	2	3.0	1	1	2	1.3	3	1	1	1	1	1.4	2.9
	Wn3	Blinkwaterbaai	4	1	2.5	2	1	1	1.3	3	1	1	1	1	1.4	2.4
	Wn4	Stompneus-Baaivals	4	1	2.5	2	1	2	1.7	3	1	1	1	1	1.4	3.0
	Wn5	Geelwal	4	1	2.5	2	1	2	1.7	3	1	1	1	1	1.4	3.0
Matzikama	Mk1	Bakoond	4	1	2.5	1	1	2	1.3	3	1	1	1	1	1.4	2.4
	Mk2	De Punt	4	1	2.5	2	1	2	1.7	3	1	1	1	1	1.4	3.0
	Mk3	Olifants River	4	3	3.5	1	1	3	1.7	4	2	1	1	1	1.8	3.2
	Mk4	Strandfontein	4	2	3.0	2	2	1	1.7	3	1	1	1	1	1.4	3.6
	Mk5	Bamboesbaai	4	1	2.5	1	1	2	1.3	3	1	1	1	1	1.4	2.4
	Mk6	Doringbaai	4	1	2.5	2	1	1	1.3	3	1	1	1	1	1.4	2.4
	Mk7	Groothoekbaai	4	3	3.5	1	1	2	1.3	3	1	1	1	1	1.4	3.3
	Mk8	Doringbaai Flats	4	3	3.5	1	1	2	1.3	3	1	1	1	1	1.4	3.3
Cederberg	C1	Lambert's Bay Dunefield	4	3	3.5	1	1	2	1.3	3	1	1	1	1	1.4	3.3
	C2	Lambert's Bay	4	2	3.0	2	2	2	2.0	3	1	1	1	1	1.4	4.3
	C3	Grootdrif	4	3	3.5	1	1	2	1.3	3	1	1	1	1	1.4	3.3
	C4	Wadrif	4	3	3.5	1	1	2	1.3	3	1	1	1	1	1.4	3.3
	C5	Elands Bay Dunefield	4	3	3.5	1	1	2	1.3	3	1	1	1	1	1.4	3.3
	C6	Elands Bay	4	2	3.0	2	1	5	2.7	4	2	1	1	1	1.8	4.4
	C7	Nuwedam	4	3	3.5	1	1	2	1.3	3	1	1	1	1	1.4	3.3
Bergrivier	Br1	Rocher Pan	3	3	3.0	1	1	3	1.7	3	1	1	1	1	1.4	3.6
	Br2	Dwarskersbos	3	3	3.0	2	2	2	2.0	3	1	1	1	1	1.4	4.3
	Br3	Laaiplek	3	2	2.5	2	2	1	1.7	3	1	1	1	1	1.4	3.0
	Br4	Berg River	4	4	4.0	3	3	3	3.0	4	2	1	1	1	1.8	6.7
Saldanha Bay	Sb1	Slippers Bay	3	1	2.0	1	1	2	1.3	3	1	1	1	1	1.4	1.9
	Sb2	St Helena Bay	3	1	2.0	2	2	2	2.0	3	1	1	1	1	1.4	2.9
	Sb3	Stompneus Bay	3	1	2.0	3	2	1	2.0	3	1	1	1	1	1.4	2.9
	Sb4	Britannia Bay	3	2	2.5	2	2	2	2.0	3	1	1	1	1	1.4	3.6
	Sb5	Duiker Island	4	2	3.0	1	1	2	1.3	3	1	1	1	1	1.4	2.9
	Sb6	Paternoster Bay	4	2	3.0	1	1	2	1.3	3	1	1	1	1	1.4	2.9
	Sb7	Paternoster	4	2	3.0	2	2	1	1.7	3	1	1	1	1	1.4	3.6
	Sb8	Cape Columbine	4	1	2.5	1	1	3	1.7	3	1	1	1	1	1.4	3.0
	Sb9	Noordwesbaai	4	2	3.0	1	1	2	1.3	3	1	1	1	1	1.4	2.9
	Sb10	Wesbaai	4	3	3.5	2	1	2	1.7	3	1	1	1	1	1.4	4.2
	Sb11	Jacobsbaai	4	2	3.0	2	1	2	1.7	3	1	1	1	1	1.4	3.6
	Sb12	Danger Bay	4	4	4.0	1	1	2	1.3	3	1	1	1	1	1.4	3.8
	Sb13	North Head	4	4	4.0	1	1	3	1.7	3	1	1	1	1	1.4	4.8
	Sb14	Small Bay	2	1	1.5	2	1	2	1.7	3	2	1	1	1	1.6	1.6
	Sb15	Paradise Beach	4	4	4.0	3	2	2	2.3	3	1	2	1	1	1.6	5.8
	Sb16	Langebaan North	4	4	4.0	3	2	2	2.3	3	1	2	1	1	1.6	5.8
	Sb17	Langebaan Central	4	4	4.0	3	2	2	2.3	3	1	2	1	1	1.6	5.8
	Sb18	Langebaan South	4	2	3.0	1	1	2	1.3	3	1	1	1	1	1.4	2.9
WCDMA01 (south)	Ws1	Langebaan Lagoon	2	1	1.5	1	1	5	2.3	3	1	1	1	1	1.4	2.5
	Ws2	Postberg	4	2	3.0	1	1	4	2.0	3	1	1	1	1	1.4	4.3
	Ws3	Kreefbaai	4	1	2.5	1	1	4	2.0	3	1	1	1	1	1.4	3.6
	Ws4	16 Mile Beach	4	3	3.5	1	1	4	2.0	3	1	1	1	1	1.4	5.0
Swartland	Sw1	Yzerfontein	4	2	3.0	2	2	2	2.0	3	1	1	1	1	1.4	4.3
	Sw2	Pearl Bay	4	3	3.5	2	2	2	2.0	3	1	1	1	1	1.4	5.0
	Sw3	Tygerfontein-Modder River	4	3	3.5	1	1	2	1.3	3	1	1	1	1	1.4	3.3
	Sw4	Grotto Bay	4	1	2.5	1	1	2	1.3	3	1	1	1	1	1.4	2.4
	Sw5	Ganzekraal	4	2	3.0	1	1	2	1.3	3	1	1	1	1	1.4	2.9
	Sw6	Bokpunt	4	1	2.5	1	1	2	1.3	3	1	1	1	1	1.4	2.4

Figure 3-3 Risk assessment for the West Coast DM with respects to extreme events (refer to Table 2-5 for risk ranking values).

The coastal risk hazard assessment for the West Coast DM identifies six CZMUs that have an average risk score of greater than 4, which are highlighted by the top six CZMU names and orange blocks in the Average Risk column in **Table 3-5**. These CZMUS are: Berg River (Br4), Elands Bay (C6), Grootdrif (C3), Langebaan North (Sb16), Langebaan Central (Sb17), Rocher Pan (Br1) and 16 Mile Beach (Ws4).

Table 3-5 Summarised coastal hazard risk assessment scores and highest risk CZMUs.

CZMU Code	CZMU Name	SLR Induced Erosion and Inundation	Groundwater Contamination	Extreme Events	Average Risk
Br4	Berg River	5.2	3.3	6.7	5.1
C6	Elands Bay	4.5	5.9	4.4	5.0
C3	Grootdrif	2.9	6.7	3.3	4.3
Sb16	Langebaan North	4.4	2.1	5.8	4.1
Sb17	Langebaan Central	4.4	2.1	5.8	4.1
Br1	Rocher Pan	3.6	5.0	3.6	4.0
Ws4	16 Mile Beach	3.6	3.6	5.0	4.0
Ws1	Langebaan Lagoon	4.2	5.0	2.5	3.9
Br2	Dwarskersbos	5.0	2.4	4.3	3.9
Sb15	Paradise Beach	3.8	2.1	5.8	3.9
Sw2	Pearl Bay	4.3	2.4	5.0	3.9
C2	Lambert's Bay	3.0	4.3	4.3	3.8
C4	Wadrif	2.9	5.0	3.3	3.7
Sw1	Yzerfontein	3.6	3.0	4.3	3.6
Ws2	Postberg	3.6	2.9	4.3	3.6
Mk4	Strandfontein	2.9	4.2	3.6	3.5
Sb4	Britannia Bay	5.0	1.9	3.6	3.5
C7	Nuwedam	2.9	4.2	3.3	3.5
Sw3	Tygerfontein-Modder River	2.9	4.2	3.3	3.5
C5	Elands Bay Dunefield	3.6	3.3	3.3	3.4
Sb13	North Head	3.0	2.4	4.8	3.4
Sb10	Wesbaai	3.0	2.4	4.2	3.2
Br3	Laaiplek	4.2	2.4	3.0	3.2
Ws3	Kreefbaai	2.9	2.9	3.6	3.1
C1	Lambert's Bay Dunefield	2.9	2.9	3.3	3.0
Sb12	Danger Bay	2.9	2.4	3.8	3.0
Sb18	Langebaan South	3.6	2.4	2.9	2.9
Mk3	Olifants River	3.2	2.3	3.2	2.9
Sb14	Small Bay	5.1	2.1	1.6	2.9
Mk7	Groothoekbaai	2.9	2.4	3.3	2.9
Mk8	Doringbaai Flats	2.9	2.4	3.3	2.9
Sb7	Paternoster	3.6	1.4	3.6	2.9
Sb11	Jacobsbaai	3.0	1.9	3.6	2.8
Sb6	Paternoster Bay	2.9	2.4	2.9	2.7
Mk6	Doringbaai	1.9	3.6	2.4	2.6
Wn4	Stompneus-Baaivals	2.4	2.4	3.0	2.6
Wn5	Geelwal	2.9	1.9	3.0	2.6
Sb5	Duiker Island	3.0	1.9	2.9	2.6
Sb8	Cape Columbine	2.4	2.4	3.0	2.6
Wn2	Goerap River	2.4	2.4	2.9	2.5
Mk2	De Punt	2.4	1.9	3.0	2.4
Sb3	Stompneus Bay	3.0	1.4	2.9	2.4
Sb2	St Helena Bay	2.4	1.9	2.9	2.4
Sb9	Noordwesbaai	2.4	1.9	2.9	2.4
Sw5	Ganzekraal	1.9	1.9	2.9	2.2
Wn1	Hoekbaai-Malkopbaai	1.9	2.4	2.4	2.2
Mk5	Bamboesbaai	1.9	2.4	2.4	2.2
Mk1	Bakoond	1.9	1.9	2.4	2.1
Sb1	Slippers Bay	2.4	1.9	1.9	2.1
Sw4	Grotto Bay	1.9	1.9	2.4	2.1
Sw6	Bokpunt	1.9	1.9	2.4	2.1
Wn3	Blinkwaterbaai	1.8	1.8	2.4	2.0

4. SEA LEVEL RISE ADAPTATION

There are three different options for sea level rise adaptation, namely (German Advisory Council on Global Change (WBGU), 2006):

- Protection – protect the coastline from sea level rise by structures;
- Managed retreat – retreat from or reduce development in coastal areas; and
- Accommodation – modify land use and infrastructure to accommodate coastal hazards.

Shoreline protection can be in the form of engineering or hard structures, or biological/geomorphic or soft structures. Hard structures include sea walls, dykes, dolosse, groynes, gabions and offshore reefs (see **Figure 4-1**). Hard structures are often very expensive protective options with regards to construction and maintenance, are aesthetically unpleasing and can form a hazard to bathers and other beach users (Breetzke et al., 2008). They also often only have a positive effect at the exact site (although they can exacerbate the effects of sea level rise on site in some cases), and can cause changes in and increased stress upon neighbouring ecological and littoral systems e.g. triggering or acceleration of erosion due the disruption of longshore sediment transport, and the reduction of wetlands on the landward side of the barrier due to reduced water inflow (WBGU, 2006). This has been observed in Langebaan, where rock revetments constructed following large storm erosion in 1997 caused erosion along parts of the coastline adjacent to the revetments, and this in turn required the construction of two “soft” groynes (comprised of geofabric or geotextile sand containers) to prevent further erosion (Anchor Environmental, 2010).

Figure 4-1 Rock revetments along the Langebaan coastline, constructed following storm erosion in 1997.

Soft protective structures can either be biological e.g. the conservation, rehabilitation and protections of wetlands, mangroves, kelp beds and dune vegetation, or geomorphological in nature e.g. dune cordons and offshore sedimentary bars, geofabric bags, and beach nourishment, water pump and beach drainage systems (see **Figure 4-2**). Soft structures (especially natural systems) are often more cost effective and offer better protection than hard structures, although they are difficult to implement and also require continuous maintenance (Breetzke et al., 2008). Soft structures have a reduced safety hazard, are more flexible and usually allow for the continuation of natural processes. Soft protection structures have been employed at Langebaan in the form of geofabric bag barriers in place of rock revetments along some coastal sections, as well two geofabric bag groynes. The groynes were constructed as part of a larger beach reclamation and replenishment programme, which also involved the dredging of sand offshore of the southernmost groyne, and depositing it north of the northernmost groyne (~ 380 000 m^3 between 2005-2008) (Anchor Environmental, 2010). Human developed soft structures have to be implemented properly in order for them to be effective however e.g. beach nourishment requires sand of the right size grade to be used (finer beach sediment can erode quicker and large rocks or rubble can develop into a hazard to beach users), while drainage systems can hasten salt water intrusion into coastal aquifers.

Figure 4-2 Geofabric barriers and groynes along the Langebaan coastline.

Managed retreat is often not possible in highly urbanised environments, and this is especially the case in the Saldanha Bay-Langebaan and Berg River estuary mouth areas along the West Coast DM coastline, where little to no retreat space exists presently due to extensive coastal development. Coastal setback lines provide a system of employing managed retreat, and the methodology has been developed for the Western Cape coastline (DEAD&DP 2010d and 2010e) and is currently being implemented in the Overberg DM. Institutionalised retreat, although the best option to deal with sea level rise in most cases, may require compensation if relocation of settlements is to take place. Accommodation in the form of modified land use can take place by converting inundated coastal land to fish farms or commercial marinas and waterfronts, or cultivating grain varieties resistant to increased salinity for example (WBGU, 2006). Infrastructure modifications can include raised or floating buildings, water tight sealed lower levels and canalised developments (WBGU, 2006). Both managed retreat and accommodation options require planners to understand both short-term coastal processes (days to years in length) and long-term coastal evolution (50 to 100 year changes) however, and coastal specialists should be used to assist in coastal planning decisions in the future (Pethick, 2001). Breetzke et al. (2008) and Cartwright et al. (2008) provide a detailed overview of the various adaptation and mitigation strategies that can be employed with regards to coastal hazards.

A combination of all three strategies and the principles of ICZM have proved the best means to adapt to sea level rise e.g. the development of protective measures where there are high unmovable populations or critical infrastructure, allowing for coastal retreat in undeveloped areas, and land use conversion of newly flooded areas. South Africa has little to no adaptive capacity unfortunately, with the ability to halt climate change and sea level rise on a large regional scale virtually non-existent (Theron and Rossouw, 2008). Municipalities are not succeeding in addressing the issues of coastal erosion and sea level rise, and they often struggle to communicate their plans and visions not only to communities, but their own staff as well (Mather, 2008). This often results sea level rise just becoming another issue pushed down the list of municipal worries, resulting in negative perceptions of readiness of the municipality to respond extreme events being inherent in the local population's mindset (Mather, 2008).

The best option for South African and West Coast DM managers (especially with regards to the possible future development of currently pristine sandy coastal sections along the West Coast DM e.g. Grotto Bay to Pearl Bay, Dwarskersbos to Elands Bay, and Elands Bay to Lambert's Bay) is the "no-regrets" approach, as recommended to the City of Cape Town with regards to sea level rise (Cartwright et al., 2008). This involves a collective response, from both municipalities and local residents, where long term institutional, accommodation, retreat and soft protective approaches are undertaken to understand and manage long term coastal evolution, instead of haphazard, reactive hard protective approaches to specific extreme events. The no-regrets approach, which should be undertaken even if sea level rise does not occur as it forms good coastal management practice, includes (Cartwright et al., 2008):

- no further land reclamation;
- the development and management of healthy natural systems, i.e. the conservation and rehabilitation of wetlands, estuaries, kelp beds, dune cordons etc.;
- decentralisation of strategic infrastructure, in order to ensure sea level rise does not affect large areas;
- maintenance of current sea walls, dolosse etc., but no development of new hard protective structures, with other adaptation options being preferred;
- insurance market correction i.e. incorporate sea level rise into long term economical risk assessments (which isn't currently done), which will increase coastal premiums and affect current coastal land owners in the short term, but will prevent further future excessive coastal development and reduce future liabilities;
- develop coastal management capacity in municipalities and other local, regional and national institutions;
- build disaster management capabilities and incorporate the HFA priority areas into all future coastal planning and disaster management activities;
- public (community and individual) and private (businesses and industry) coastal education drive in order to build an accountable and responsible coastal community, as well as increasing the resilience of coastal communities through poverty alleviation; and
- undertaking of detailed risk assessments, development of sustainable coastal management plans (SCMPs), and the development of basic early warning systems e.g. combination of tidal information and storm forecasts to determine if there is an extreme storm surge hazard a few days prior to an actual event.

5. RECOMMENDATIONS

A coastal hazard risk assessment of the West Coast DM has indicated the West Coast DM coastline is at a low to moderate risk to all three coastal hazards, with the Berg River and Langebaan areas, and Cederberg LM at relative risk to extreme sea level events and groundwater contamination respectively. The six highest risk CZMUs to all three hazards are Berg River (Br4), Elands Bay (C6), Grootdrif (C3), Langebaan North (Sb16), Langebaan Central (Sb17), Rocher Pan (Br1) and 16 Mile Beach (Ws4). The Berg River and Langebaan areas are at relative risk as expected, with the high ranking of the undeveloped Grootdrif, Rocher Pan and 16 Mile Beach CZMUs indicating the need for careful planning if any future development is to occur. The ecological importance of Verlorenvlei, and the coastal flooding and groundwater contamination risks it is exposed to, have enhanced the Elands Bay CZMU ranking. It is recommended that:

- West Coast District Municipality level:
  - Employ the "no-regrets" approach in an ICZM framework along the West Coast DM coastline.
  - The HFA Priorities for Action are integrated into all phases of planning, and disaster risk reduction is made a necessity in municipal structures (if not already incorporated in line with the Disaster Management Act (Act 57 of 2002)), especially with respect to coastal zone hazards.
  - CZMSs are developed for all the LMs of the West Coast DM (WCDMA01 is to be incorporated into various municipalities following the 2011 local government elections).
  - CZMUs are identified and delineated for each LM (using the initial CZMUs defined here as a working template if desired).
  - SCMPs should be developed for each CZMU, with the six highest risk CZMUs identified in the risk assessment (Berg River, Elands Bay, Grootdrif, Langebaan North, Langebaan Central, Rocher Pan and 16 Mile Beach), as well as Pearl Bay, Paradise Beach and Dwarskersbos, receiving the highest priority.
  - Detailed adaptation studies on each high risk CZMU are conducted, in order to determine which best combination of methodologies should be developed to adapt to sea level rise induced hazards.
- Conceptual studies:
  - Begin to undertake architectural research into alternative housing technology e.g. lift houses, used in the Netherlands, Germany and flood prone areas of the United States of America. These new housing technologies take into account rising water levels due to storm surges or floods, and can be used in highly developed estuarine zones within the Berg River estuary.

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