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 B: Overberg District Municipality

Phase 2 Report: Overberg District Municipality Sea Level Rise and Flood Risk Modelling

Final

March 2012

REPORT TITLE	**:**	**Phase 2 Report: Overberg District Municipality Sea Level Rise and Flood Risk Modelling**
CLIENT	**:**	**Provincial Government of the Western Cape Department of Environmental Affairs and Development Planning: Strategic Environmental Management**
PROJECT	**:**	**Sea Level Rise and Flood Risk Assessment for a Select Disaster Prone Area Along the Western Cape Coast. Phase B: Overberg District Municipality**
AUTHORS	**:**	**D. Blake** **N. Chimboza**
REPORT STATUS	**:**	**Final**
REPORT NUMBER	**:**	**790/2/2/2012**
DATE	**:**	**March 2012**
APPROVED BY	**:**	

S. Imrie

S. Imrie **Project Manager**	**D. Blake** **Task Leader**

This report is to be referred to in bibliographies as:

Department of Environmental Affairs and Development Planning. (2011). Sea Level Rise and Flood Risk Assessment for a Select Disaster Prone Area Along the Western Cape Coast. Phase B: Overberg District Municipality. Phase 2 Report: Overberg District Municipality Sea Level Rise and Flood Risk Modelling. Prepared by Umvoto Africa (Pty) Ltd for the Provincial Government of the Western Cape Department of Environmental Affairs and Development Planning: Strategic Environmental Management (March 2012).

UMVOTO

EXECUTIVE SUMMARY

INTRODUCTION

Umvoto Africa (Pty) Ltd was appointed by the Western Cape Department of Environmental Affairs and Development Planning (DEA&DP) to undertake a sea level rise and flood risk assessment for a select disaster prone area along the Western Cape coast. The Phase B assessment area was defined as the Western Cape coastline within the Overberg District Municipality (DM), from Blousteen at Kogel Bay (at the boundary of the City of Cape Town) to Infanta near the Breede River mouth (at the district municipal boundary with the Eden DM). The Western Cape DEA&DP required that a literature assessment of current global and local understanding and knowledge with regards to climate change and sea level rise be undertaken, in association with the development of a sea level rise and flood inundation Geographic Information System (GIS) model for this project. Umvoto Africa proposed a three-phase work approach, namely: Phase 1 – Inception and Data Acquisition, Phase 2 – GIS Model Development, and Phase 3 – Risk Assessment. This report describes the sea level and flood inundation modelling undertaken during Phase 2.

MODEL METHODOLOGY

South Africa, despite having over 3000 km of coastline along which the majority of the country's large cities are situated, does not have basic coastal baseline data. This makes coastal modelling and shoreline prediction at anything other than a coarse regional scale difficult. DEA&DP studies have calculated that it could cost between R 20 000 – R 35 000 per kilometre to undertake detailed coastal set-back lines for the entire Western Cape coastline (1600 km in length), resulting in a total cost of between R 32 million and R 56 million for the entire province. The modelling undertaken here provides a first, basic, regional large-scale attempt at identifying areas along the Overberg DM coastline that are vulnerable to migrating shorelines and tidal reaches, and storm associated extreme sea levels and estuary/river flooding. Concurrently to this project, SSI Engineers and Environmental Consultants (Pty) Ltd. have been contracted by the DEA&DP to implement the set-back line methodology set out by the DEA&DP along the Overberg DM coastline. Two draft set-back lines were identified, namely a physical processes/hazard set-back line (PPL; based on a combination of a 1:100 year sea storm, Mean High Water Springs wave run-up height, sea level rise of 1 m, short term erosion of 20 m and long term erosion) and limited development set-back line (LDL; using the above hazard set-back line in association with non-physical social, environmental and economic issues).

The present worst case extreme sea level scenario for the Overberg DM coastline would be a 1:500 year event, such as that experienced in March 2007 along the KwaZulu-Natal (KZN) coastline, where a 1:40 to 1:50 year storm with an associated local sea level rise of between 50-60 cm would occur simultaneously on the Highest Astronomical Tide (HAT) (~ 125-150 cm above mean sea level for the Overberg DM). The end result would be a storm surge related extreme sea level of over 2 m. This may in turn become a 1:30 year event by the end of the next decade, or a one in every two-week event by the end of the century as a result of a higher base sea level due to rising seas. Using information from and erosion lines observed along the KZN coastline after the March 2007 event, the City of Cape Town sea level rise model developed three swash run-up contour lines, namely 2.5 mamsl (for sheltered or rocky coastlines), 4.5 mamsl swash (for exposed or sandy coastlines) and 6.5 mamsl (for headland and pocket bay beaches and sandy inlets) swash contour lines. For extreme sea level events along the Overberg DM, these three swash contour lines, as well as a 10 mamsl swash contour line, were used. Eskom Holdings Ltd. determined ~ 4.8 mamsl to be the best estimate extreme sea level that could occur at present, if the largest storm surge and wave set-up and run-up occurred during the Highest Astronomical

Tide at Bantamsklip. ~ 7.2 mamsl was the best estimate 1:100 year extreme sea level reached when the possible effects of climate change were included. An extreme sea level of 11 mamsl was calculated at Bantamsklip for the effects of a tsunami in combination with a 1:10 year storm surge and associated wave run-up and set-up, 90^{th} percentile high tides and climate change. The 10 mamsl contour line also correlates with one of the initial generalised set-back lines proposed by the DEA&DP in combination with the 100 m line from the high water mark. The four Overberg DM swash contour lines were generated from a 10 m x 10 m DEM (with a 3-4 m vertical resolution), and then overlain on 2008 SPOT satellite imagery in order to identify possible vulnerable areas. These areas were then compared with the draft Overberg DM physical processes/hazard set-back line, which was delineated using a higher resolution (up to 0.25 m vertical accuracy) LiDAR derived DEM. The majority of estuaries along the Overberg DM are either closed or temporarily open, and have been closing more frequently in comparison to the past. Reductions in river flows results in estuaries closing and the building up of estuary mouth sand bars and berms, which either require very large flood/storm surge induced events or artificial breaching to open (e.g. the Bot, Klein River and Uilkraals River estuaries). The Klein River estuary is usually artificially breached once or twice a year to prevent flooding of low lying properties below the 2 mamsl contour, due to natural breaching of the estuary mouth only usually taking place once estuary water levels have reached 2.5-3 mamsl. Closed estuary flooding has also occurred in the Uilkraals River estuary in the past, where 1-2 mamsl water levels resulted in flooding of the adjacent caravan park, and artificial breaching of the estuary is now undertaken. It can be expected that future higher sea levels and increased storm surge frequency and severity may cause an increased connection to the ocean for many estuaries along the Overberg DM coastline, despite possible reduced freshwater inflows. Future storm surges may in turn prevent flood waters from exiting into the ocean at open estuary mouths, resulting in extensive back flooding of the low relief estuary areas and lower course river floodplains.

Long-term shoreline evolution, whether eroding, accreting or dynamically stable, can be determined by the measurement of the shoreline position over time. This can be done using a large variety of techniques, dependent on available data sources, accepted error ranges, time and budget. A simplified approach was undertaken to model shoreline and tidal evolution, with future shoreline and tidal reach lines being modelled for a 2 m rise by 2100. Due to the DEM not extending outwards entirely along the coastline, only the sandy beach areas as digitised from the 2008 SPOT imagery (due to the SPOT imagery having the greatest shoreline coverage) were used in modelling the extent of shoreline migration. It must be noted that the vertical resolution of the DEM (~ 3-4 m) and 10 m pixel resolution of the 2008 SPOT imagery does not allow for highly accurate and detailed predictions to be made, and the modelling results should be used in a more regional planning approach, where the swash/flood and shoreline/tidal reach evolution lines are used to identify possible vulnerable areas.

MODEL RESULTS

Table A Areas most vulnerable to coastal, estuarine and fluvial erosion and inundation along the Overberg DM coastline.

Area	Coastline, Estuarine and Fluvial Erosion and Inundation
Rooiels to Kaap Hangklip	Comparisons between the swash contours derived from the 10 m resolution DEM and the PPL delineated using the LiDAR derived DEM indicate that the 10 m resolution DEM is inaccurate and highly conservative (i.e. places the various contours too far landward) with regards to coastal point features e.g. Roman Rock at Rooiels, Die Punt at Pringle Bay and the upper slopes of Kaap Hangklip. The 10 m DEM indicates that a large portion of development at Die Punt is below 2.5 mamsl, when in fact all development is above the 5 mamsl contour at least. That said, development along the coastline between Rooiels and Kaap Hangklip is generally above the 5-6 mamsl contour line, and is protected by rocky Peninsula Formation outcrop. Development is also generally above the 5-6 mamsl contour

	line in both the Rooiels and Buffels River estuaries. Development encroaches both shore and estuary high water marks however, and needs to be restricted. The major coastal hazard at Pringle Bay is the migration of mobile dunes as a result of indigenous vegetation removal and primary foredune destruction for coastal development.
Betty's Bay	The majority of development at Betty's Bay is behind the 6.5 mamsl contour line and protected by Peninsula Formation outcrop, and hence at minor risk to extreme storm surge events (with the exception of some properties near Dewetsbaai that have been developed close to the high water mark). The main coastal hazards at Betty's Bay are the current movement of mobile primary dunes into property at Nerine Road and Morea Road (and possible future encroachment of dune systems along Beach Boulevard in western Betty's Bay), and possible flooding of low elevation areas around the coastal Betty's Bay Lake system (from west to east, Rondevlei, Grootvlei and Malkopsvlei). The draft physical processes set-back line has taken both these additional coastal hazards into account.
Kleinmond	The Kleinmond coastline is dominated by relatively steep (~10 mamsl), erosion resistant quartzite outcrop of the Peninsula Formation, with development and infrastructure being situated behind this natural, vegetated coastal barrier. The Palmiet River estuary is undeveloped, with the exception of the Palmiet Caravan Park, and only the currently undeveloped eastern banks of the estuary are at risk to estuarine erosion during high flood events.
Bot River estuary and Hawston dunefield	Flood prone areas within the Bot-Kleinmond estuarine system are generally undeveloped, and should continue to remain so below (at least) the 4.5 mamsl contour. Exceptions include estuary bank fronting property at Meerenbosch near the Bot River estuary mouth, which is at risk to possible estuary flooding due to natural closing of the estuary mouth (and has required the artificial breaching of the Bot River at times). Possible increased estuary connection to the ocean due to expected future higher sea levels may increase the flood and erosion risk to estuary fronting property at Meerenbosch, as a result of possible further inland penetration of extreme storm surge events. Development within the Hawston dunefield is generally restricted behind the 6.5 mamsl contour line (with the exception of the Hawston Abalone Village caravan park/swimming pool/recreational area), and further development within the primary dune system shoreward of current structures should be restricted. Development within any section of the primary dune system may result in a dune migration however.
Vermont, Onrus and Sandbaai	Development along the coastal stretch from Vermont to Sandbaai is generally above the 6.5 mamsl contour line and is protected by rocky outcrop of Peninsula Formation. However there is some shoreline fronting property and infrastructure along Bietou and Duiker Streets (Vermont), Atlantic and Marine Drives (Onrus), and Kus and Nico Van Der Merwe Streets (Sandbaai) below the 6.5 mamsl contour line, which may be at risk to very large storm events and swash runups.
Hermanus and Voelklip	The Hermanus coastline is dominated by steep (~10-15 mamsl vertical faces), erosion resistant quartzite cliffs of the Skurweberg Formation, which provide protection from extreme sea level events (the exception being shoreward fronting properties along lower elevation coastline just west of the new Hermanus harbour and abalone farms). Development at Voelklip is currently behind the 10 mamsl line, however further shoreward development within the primary foredune in the area must be restricted. Maintenance of indigenous dune vegetation will ensure that dunes in the Voelklip area do not become mobile. The shoreward edges of the two Grotto Bay parking lots may be at risk to swash runups during extreme storm events.
Klein River estuary and Walker Bay dunefield	A number of estuary front properties along the upper northern (Maanskynkop, see and southern (Wortelgat to Stanford) banks of the Klein River estuary are below the 4.5 mamsl estuary floodline. This is problematic as the Klein River estuary only naturally breaches at water levels of 2.5-3 mamsl, and hence low lying properties are at risk to estuarine and river flooding, while septic tanks at these properties are also prone to leakage, causing estuary pollution. The estuary mouth is sometimes artificially breached to prevent flooding and remove pollution build up within the estuary. However, artificial breaching has met opposition from some residents and estuary users due to changes it sedimentary dynamics near the estuary mouth, which has resulted in increases of pollution in other parts of the estuary. The primary dune system along the Walker Bay coastline from the Klein River estuary mouth to De Kelders is relatively elevated (5-40 mamsl) and undeveloped, with the only risk from extreme sea level events being natural dune erosion and undercutting.

De Kelders, Gansbaai, Danger Point and Kleinbaai	The coastline from De Kelders to Kleinbaai is dominated by ~10-30 mamsl steep cliff faces of Goudini and Peninsula Formation sandstones and quartzites, which provide protection from extreme sea level events. Development at Kleinbaai is generally above the 5 mamsl contour, with Peninsula Formation rocky outcrop and Danger Point also providing natural protection from large swell events.
Franskraalstrand and Uilkraals River estuary	Development at Franskraalstrand is generally above the 5 mamsl contour, with Peninsula Formation rocky outcrop and Danger Point also providing natural protection from large swell events. Portions of the Uilenkraalsmond Resort adjacent to the Uilkraals River estuary are below the 2.5 mamsl floodline and at risk to estuarine flooding, which has occurred in the past as a result of 1-2 mamsl estuary water levels.
Pearly Beach to Quoin Point	The undeveloped primary dune system along coastline between the Uilkraals River mouth and Pearly Beach is generally between 4-40 mamsl in elevation and 1-3 km in width, with the only risk from extreme sea level events being natural dune erosion and undercutting near the shoreline. Development at Pearly Beach is generally above the 6.5 mamsl contour and is fronted by Skurweberg Formation outcrop and a 50-100 metre wide vegetated foredune. Development between the 6.5 mamsl and 10 mamsl lines may be at risk to Eskom modelled maximum extreme sea levels of ~11 mamsl however (combination of possible tsunami, 1:10 year storm, high tides and climate change enhanced sea levels). The coastline between Pearly Beach and Quoin Point is undeveloped (with the exception of Buffeljagsbaai), and composed of rocky TMG points and coastline in association with Bredasdorp Group dune systems, which both form moderate gradient coastal systems. The small subsistence fishing community of Buffeljagsbaai is situated below the 6.5 mamsl contour however and is therefore at risk to extreme sea level events.
Quoin Point to Cape Agulhas	The coastline between Quoin Point and Cape Agulhas is undeveloped (with the exception of Die Dam resort and Suiderstrand), and composed of a mix of moderate gradient sandy coastline and rocky TMG outcrops. A large part of Die Dam resort is situated below the 2.5 mamsl contour and within a degraded foredune system, and might be at risk from extreme storm swell events that refract around Quoin Point (reducing its effect as a natural protective barrier). The resort may also be at risk to migrating mobile dunes, due to it being built within the foredune (dune degradation and indigenous vegetation removal often results in dune mobilisation). A few properties east of the beach car park at Suiderstrand are below the 6.5 mamsl contour line and at risk to extreme sea level events. Dune undercutting can be observed west of Pebbly Beach at Suiderstrand, and therefore shoreward development of current properties along the dune ridge should be restricted.
L'Agulhas and Struisbaai	Development below Main Road and between Main Road and Van Breda/Cres Streets in L'Agulhas is below the 6.5 mamsl contour line and may be at risk to extreme storm swell events (as correlated by the position of the PPL), due to the relatively low gradient of the Peninsula Formation rocky coastline. Offshore rock shelves may reduce shoreline wave energy however, by causing waves to break further offshore. Coastal fronting property along southern Struisbaai is at risk to inundation by extreme storm swell events, although the predominantly rocky coastline and offshore rock shelves may also offer some protection. The sandy coastline north of Struisbaai harbour is at very high risk to coastal erosion from extreme storm events refracting around Struisbaai point (in association with it being in a sediment starved "shadow zone" of a log spiral bay), as evidenced by the current visible erosion damage and retreat at the Struisbaai Caravan Park and Nostra/Bella Luna restaurant, caused by the 2004 Mentawai tsunami and large storm swell events in 2008 and 2009. Dune undercutting to the north of the caravan park is also visible, and development shoreward of current properties and infrastructure should be restricted.
Struisbaai to Arniston	The coastline between Struisbaai and Arniston is dominated by a ~5-30 mamsl high, 1-1.5 km wide Strandveld Formation mobile dune cordon. The dune cordon, along with the Heuningnes River estuary, is undeveloped, with minor estuarine flooding, natural dune erosion and undercutting likely during extreme storm swell events.
Arniston and Waenhuiskrans	Arniston and Waenhuiskrans are situated on relatively elevated (6-10 mamsl), semi-consolidated to consolidated (i.e. immobile) dune deposits of the Waenhuiskrans and Strandveld Formations. Both developments are also relatively protected from southerly and southwesterly directed swells by Struispunt and its associated offshore rock shelves. The major risk to development in the area is the undercutting and collapse of consolidated aeolianite (dune rock) deposits, through the removal of underlying semi- to unconsolidated layers either by wave or wind erosion.

Waenhuiskrans to Kaap Infante	The coastline between Arniston and Potbergstrand is dominated by an undeveloped ~5-40 mamsl high, 1-3 km wide Strandveld Formation mobile dune cordon. Minor natural dune erosion and undercutting is likely during extreme storm swell events. Tourism development at De Hoop Vlei is also well above the 10 mamsl contour, and hence not at risk to coastal lake flooding. Rocky, highly elevated coastline between Potbergstrand and Kaap Infante is formed by the aeolianites of the Waenhuiskrans and Wankoe Formations, conglomerates of the De Hoopvlei Formation, and quartzites of the Peninsula Formation. The region is undeveloped, and in due to the rocky elevated nature of the coastline, at low risk to extreme storm swell events.
Infanta and Kontiki	Development at Infanta is well above the 6.5 mamsl contour, and in addition properties are protected from southwesterly to southeasterly directed extreme storm swell events by the Kaap Infante headland. Parts of the Kontiki resort along the southern banks of the Breede River estuary are below the 2.5 mamsl floodline however , and are at risk to river flooding and estuarine back flooding during storm events.
Breede River	A number of farm properties with housing and infrastructure at Stoffelsrivier, Matjieskloof, Lemoentuin and Malgas (all along the southeastern bank of the Breede River) are below the 2.5 mamsl floodline, and are at risk to riverine flooding.

Table B Vulnerable sandy coastlines within the Overberg DM based on shoreline evolution caused by a 2 m rise by 2100.

Sandy Coastline Section	Shoreline Evolution (for 2 m rise by 2100)
Rooiels to Kleinmond	Sea level rise may cause large scale inundation of the low gradient beach at Rooiels, although inundation will be restricted by the relatively high elevation estuary banks. Inland migration of the high water mark by approximately 50-100 metres may occur at Pringle and Betty's Bay, with the associated landward migration of degraded, mobile dune systems by up to 100-200 metres (as currently observed in the area).
Kleinmond to Hawston	Minor landward shoreline migration (~ 5-30 m, decreasing eastwards of the Bot River mouth) due to the moderate to high gradient backing foredune is likely. Frontal foredune undercutting and collapse possible over time, resulting in the development of connections between the eastern Kleinmond portions of the Bot-Kleinmond estuarine system to the ocean. Degradation of the dune system adjacent to the Hawston Abalone Village may result in mobile dune migration into the recreational area, as the shoreline migrates further inland over time.
Walker Bay	Minor landward shoreline migration (~ 5-15 m) due to the backing high gradient foredune is likely. Frontal foredune undercutting and collapse possible over time. The only development at possible future risk is the Grotto Bay parking lot and eastern access road, where future mobile dune migration may occur with shoreline evolution as a result of continuous dune degradation. Grotto Bay is not at risk to inundation however, due to the wide, relatively moderate gradient beach.
Franskraalstrand to Quoin Point	Minor landward shoreline migration (~ 10-40 m) due to backing high gradient foredune and semi-consolidated to consolidated dune rock is likely along sandy coastal areas. Pearly Beach may experience increased mobile dune migration due to current dune degradation as a result of shoreward encroaching development
Quoin Point to Cape Agulhas	Minor landward shoreline migration (~ 5-20 m) due to the backing high gradient foredune is likely. Frontal foredune undercutting and collapse possible over time. There are some areas in the coastal section at possible risk however, namely the southwestern portions of Die Dam and Suiderstrand, where development close to shorelines with thin sand cover may result in removal of the sand cover followed by inundation. The northeastern portion of Die Dam is also at risk of being covered by migrating foredunes in the future.
Struisbaai	Minor landward shoreline migration (~ 5-25 m) due to the backing high gradient foredune is likely. Studies by Theron (2010) have shown that lateral seasonal erosion over the past 60 years at Sandbaai is generally at a rate of not greater than 0.5 metres per year, with the extensive erosion observed caused by large storm or sea level events. Frontal foredune

	undercutting and collapse of the dune system is currently observed and will continue with time, and hence it is recommended that development is restricted by at least 100 metres from the shoreward edge of the foredune, and preferably not within the foredune at all (as recommended by the proposed Overberg DM physical processes/hazard set-back line).
Arniston to Potberg	Minor landward shoreline migration (~ 5-20 m) due to the backing high gradient foredune and semi-consolidated to consolidated dune rock is likely. Frontal foredune undercutting and collapse is possible over time, especially at Arniston/Waenhuiskrans, where gentle erosion by seawater over time may cause dissolution of aeolianites (dune rock) and cause cliff collapse.

Table C Tidal reach evolution for vulnerable Overberg DM estuaries, for a 2 m rise by 2100.

Estuary	Tidal Reach (for 2 m rise by 2100)
Rooiels, Buffels and Palmiet	The current narrow estuary mouths of the three estuaries, present within relatively high relief coastal Table Mountain Group outcrop, may enlarge with higher sea levels and engulf the adjacent sand bars and beaches. However the steep relief of the various estuary banks will result in little to no increased tidal flooding. Some undercutting may occur the eastern banks adjacent to the estuary mouths however, and development should be restricted by 50 metres from the estuary mouth banks if erodable material e.g. unconsolidated sand dunes, is present.
Bot	Slopes along the Bot River estuary shoreline generally have a moderate gradient, therefore minor lateral inundation of between 5-15 metres can be expected during future high tides (provided there is a consistent tidal connection to the sea). The eastern corner of Meerenbosch may be at risk to future higher tides in the estuary.
Klein	Slopes along the northern banks of the Klein River estuary generally have a moderate gradient, therefore minor lateral inundation of between 5-20 metres can be expected during future high tides (provided there is a consistent tidal connection to the sea). Development close to the estuary shoreline in the vicinity of Maanskynkop may be at risk to future lateral inundation however. The southern banks of the estuary tend to have a lower gradient (erodable Bokkeveld and Bredasdorp Group sediments versus erosion resistant TMG outcrop on the northern banks), and lateral inundation could reach up to 100 metres inland in some very low gradient (and currently undeveloped) areas, with intertidal areas possibly becoming subtidal or fully submerged in the future. As with the northern estuary banks, development close to the estuary shoreline between Wortelgat and Stanford may be at risk to future lateral inundation.
Uilkraals	As with the Overberg DM estuaries to the west, lateral inundation will only occur within the Uilkraals River estuary provided there is a future consistent connection to the sea. If future higher tidal conditions occur, then lateral inundation between 10-40 metres with associated dune undercutting along the banks of the estuary near the mouth, and widening of the estuary mouth and inundation of the adjacent sand bars/berms and beaches will occur. Increased inundation of the sand flats and salt marshes further inland of the estuary mouth (i.e. north of the R43 bridge) may occur, and development of any form should be restricted from these areas. Portions of the Uilenkraalsmond Resort along low gradient areas of the estuary shoreline may be at risk to increased lateral tidal inundation.
Heuningnes	Increased tidal intrusion due to rising sea levels will have a minor effect on the Heuningnes River estuary, with inundation of the adjacent beach and sand bars/berms likely due to an expanded estuary mouth, with minor dune undercutting just north of the mouth. The relatively moderate gradient slopes inland of the estuary mouth will result in little lateral inundation from possible increased tidal intrusion.
Breede	Tidal reach may extend up to 30 metres inland, due to moderately to steep slopes. Areas at risk may include the shoreline fronting properties at Kontiki, as well as river fronting properties at Stoffelsrivier, Matjieskloof, Lemoentuin and Malgas (dependent on the future extent of tidal influence further inland within the Breede River).

RECOMMENDATIONS

- Western Cape level:
    - Conduct modelling updates of the Eden DM, West Coast DM and Overberg DM models at least every 5 years. The modelling undertaken in these projects are at a broad scale and coarse, and new global and local climate change data and scenarios, local coastal geomorphic data and methodologies will help improve shoreline evolution prediction.
    - With regards to the Overberg DM coastline, future modelling updates should focus on the vulnerable areas identified, in order to improve the resolution of the modelling i.e. each specific vulnerable stretch of sandy coastline and estuary should have its own future coastal evolution model developed.
- Basic coastal baseline data upgrade:
    - Develop onshore and offshore 1 m x 1m LiDAR DEMs (with an approximately 0.5 m or higher vertical resolution) for the Eden, Overberg (completed in 2011 as part of the Overberg DM set-back line study) and West Coast DM coastlines.
    - Conduct beach profiling at selected beaches along the coastline, as well as detailed geophysical offshore bathymetry surveys, in order to determine various local variables and parameters that can be used in future detailed numerical modelling (see Eskom Holdings Ltd 2009a, 2009b and 2009c for detailed modelling examples).
    - Collection of all available photographic and remote sensing imagery, ensuring it is correctly georeferenced and stored in a central GIS database for simple access for future coastal modelling.
- Overberg District Municipality level:
    - Enforce the coastal buffer zone as defined in the National Environmental Management: Integrated Coastal Management Act (Act 24 of 2008) immediately, and prevent any further development within 100 m of the high water mark or 10 mamsl contour (whichever is closest to the shoreline), until detailed coastal set-back lines have been developed (currently under review for the Overberg DM).
    - Enforce the estuary zonation development plans and estuary set-back development lines for the Bot/Kleinmond (iRAP Consulting, 2009), Klein (iRAP Consulting, 2008) and Uilkraals (Anchor Environmental, 2010b) River estuaries.
    - Strictly monitor (and preferably prevent) future development below the 6.5 mamsl swash contour and 4.5 m estuary/river flood contour, as well as on any undeveloped portions of foredune or natural tidal estuary habitat.
    - Ensure development along the coastal foredune takes into account future landward dune migration, and a further dune migration buffer zone should be put in place behind the coastal buffer zone.

- Undertake a coastal education drive to make coastal residents aware of the importance of maintaining indigenous vegetated foredunes e.g. use provided walkways and pathways to the beach, as well as the possible hazards and risks faced if these natural barriers are removed.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

%	-	percent
~	-	approximately
°C	-	degrees Celsius
AR4	-	Fourth Assessment Report
cm	-	centimetre
CCRC	-	Climate Change Research Centre
CSIR	-	Council for Scientific and Industrial Research
CZMU	-	Coastal Zone Management Unit
DM	-	District Municipality
DEM	-	digital elevation model
DEA&DP	-	Department of Environmental Affairs and Development Planning
e.g.	-	for example
etc.	-	etcetera
et al.	-	as well as
GIS	-	Geographic Information System
HAT	-	Highest Astronomical Tide
i.e.	-	that is
IPCC	-	Intergovernmental Panel on Climate Change
km	-	kilometre
KZN	-	KwaZulu-Natal
LM	-	Local Municipality
LDL	-	limited development set-back line
LiDAR	-	Light Detection and Ranging
m	-	metre
mm	-	millimetre
mamsl	-	metres above mean sea level
PPL	-	physical processes set-back line
R	-	Rand
SPOT	-	Satellite Pour l’Observation de la Terre
TAR	-	Third Assessment Report
UNSW	-	University of New South Wales

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) 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 Overberg District Municipality (DM), from Blousteen at Kogel Bay (at the boundary of the City of Cape Town) to Infanta near the Breede River mouth (at the district municipal boundary with the Eden DM). This forms the second phase (in association with the West Coast DM, completed in July 2011 – see DEA&DP, 2011a, 2011b and 2011c) of 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 set-back line study for the Overberg DM (see SSI, 2011), with the coastal set-back 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 Overberg DM, based on a refined rapid assessment methodology described by Blake and Hartnady (2009) and used in the Eden DM and West Coast DM sea level rise risk assessment (DEA&DP, 2010c and 2011c).

This report describes the sea level and flood inundation modelling undertaken during Phase 2. **Chapter 1** provides a brief overview of the literature review conducted in the Phase 1 report. **Chapter 2** describes the model methodology that was used for both the shoreline evolution, and extreme sea level and estuary flooding modelling. The results from both models are described in **Chapter 3**, while **Chapter 4** 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 3 report describes the coastal risk assessment methodologies and results respectively, as well as detailing the possible mitigation and adaptation measures for sea level rise.

1.2 GLOBAL AND REGIONAL SEA LEVEL RISE

The coastal zone can be defined as the interface and transition between the sea and land, and in South Africa approximately 30% of the country's population lives within this zone (Theron and Rossouw, 2008). Twenty of the world's thirty megacities are situated within the coastal zone, with lower density peri-urban coastal areas between cities also rapidly growing (Small and Nicholls, 2003) e.g. Kleinmond, the Hermanus area from Hawston to Voelklip, and the Gansbaai area from De Kelders to Franskraalstrand along the Overberg DM coastline. A large variety of important economic and social activities take place within the coastal zone, including agriculture, tourism, recreation, manufacturing and transportation, to name a few generalised examples. Due to the dynamic interaction of biophysical factors from both the Earth's land surface and ocean, and the high populations 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 the enhanced 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 as 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 effects of regional climate circulation models (Cazenave et al., 2009). Eleven of the last twelve warmest years in the instrumental record occurred from 1995 to 2006, and the linear warming trend over the last 50 years is nearly twice that of the last 100 years (Intergovernmental Panel on Climate Change (IPCC), 2007). Temperature rise predictions range from 1.8-4 °C by 2100, with a 0.1-0.2 °C rise over the next two decades at least (IPCC, 2007). With regards to sea level rise, statistical analysis has correlated the rate of sea level rise with the rise in mean global temperature, and has indicated that the warmer it gets, the faster sea level rises (Rahmstorf, 2007 and Vermeer and Rahmstorf, 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, which is 80% faster than the IPCC Third Assessment Report (TAR) (2001) prediction of 1.9 mm/year. Global sea level rise is non-uniform however, with wide variability present in the different ocean basins as recorded by satellite altimetry (Cazenave, 2009). Current future predictions taking into account new ice sheet understanding are twice the range of the 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).

Brundrit (1984) conducted the first sea level studies in South Africa, along the west coast of the country. Little recent research into sea level rise and its effects has been undertaken however, with the majority of detailed studies occurring during the 1990s. The African sea level data set in general is limited in size and quality, and is smaller in comparison to most parts of the world (Woodworth et al., 2007). 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. An analysis of sea level records over recent decades has shown evidence for an increase in extreme sea levels (i.e. those caused by storm surges) worldwide since 1975 (IPCC, 2007). 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 Overberg 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 (in association with climate change) of 4-10.8 mamsl have been modelled for the proposed Bantamsklip Eskom Nuclear-1 site (between Pearly Beach and Buffeljagsbaai), while a maximum water level caused by a combination of a possible tsunami with storm surge, high tides and run-ups was modelled at 11 mamsl (Eskom Holdings Ltd, 2009a and 2009b). 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). Erosion modelling along the Bantamsklip coastline was also undertaken for up to 2100 (Eskom Holdings Ltd, 2009b and 2009c), with a sea level rise of 0.8 m modelled to cause 35 m of retreat, and seasonal erosion approximately 14 m of retreat, while storm events may cause ~75-85 m of lateral shoreline retreat (leading to a total retreat of between 90-135 m by 2100). These modelling trends at Bantamsklip of large storm erosion retreat in comparison to minor seasonal retreat can be confirmed by observations at Struisbaai, with only minor seasonal erosion (<15 m) to accretion occurring between 1939-1999 (Theron, 2010), while most of the current visible erosion damage and retreat was caused by the 2004 Mentawai tsunami and large storm swell events in 2008 and 2009.

2. MODEL METHODOLOGY

The majority of the world's coastlines have not been properly mapped or modelled, especially in developing countries where past shoreline evolution data can be rare to non-existent (Appeaning Addo et al., 2008). South Africa, despite having over 3000 km of coastline along which the majority of the country's large cities are situated, does not have basic coastal baseline data. This includes beach profiles, numerical wave refraction models, local bathymetry and detailed LiDAR (Light Detection And Ranging) derived digital elevation models (DEM), whose non-existence across majority of the country make coastal modelling and shoreline prediction at anything other than a coarse regional scale difficult. In an ideal world the entire coastline would be modelled to the detail undertaken for the three proposed Eskom Nuclear-1 nuclear sites, namely Bantamsklip, Duynefontein and Thyspunt (see the coastal engineering and numerical modelling reports for Bantamsklip (Eskom Holdings Ltd, 2009b and 2009c) as an example. The DEA&DP (2010d) calculated that it could cost between R 20 000 – R 35 000 per kilometre to undertake detailed coastal set-back lines for the entire Western Cape coastline (1600 km in length), resulting in a total cost of between R 32 million and R 56 million for the entire province (this is a relatively small amount in comparison to the damage a large storm event can cause to coastal areas that would not have been developed if coastal set-back lines were in place e.g. the R1 billion damage caused by the March 2007 KZN storm surge). The modelling undertaken here provides a first, basic, regional large-scale attempt at identifying areas along the Overberg DM coastline from Blousteen to Infanta that are vulnerable to migrating shorelines and tidal reaches, and storm associated extreme sea levels and estuary/river flooding.

Concurrently to this project, SSI Engineers and Environmental Consultants (Pty) Ltd. have been contracted by the DEA&DP to implement the set-back line methodology set out by the DEA&DP (2010d) along the Overberg DM coastline. Two draft set-back lines were identified, namely a physical processes/hazard set-back line (PPL; based on a combination of a 1:100 year sea storm, Mean High Water Springs wave run-up height, sea level rise of 1 m, short term erosion of 20 m and long term erosion) and limited development set-back line (LDL; using the above hazard set-back line in association with non-physical social, environmental and economic issues) (SSI, 2011).

2.1 EXTREME SEA LEVEL AND ESTUARY FLOODING MODELLING

As stated prior, sea level rise will not be felt the most by coastal residents through relatively slow shoreline migration, but by the increased frequency of storms and associated storm surge with higher tidal regimes and increased wind speeds. The present worst case scenario for the Overberg DM coastline would be a 1:500 year event, such as that experienced in March 2007 along the KZN coastline, where a 1:40 to 1:50 year storm with an associated local sea level rise of ~ 60 cm would occur simultaneously on the HAT (~ 125-150 cm above mean sea level for the Overberg DM). The end result would be a storm surge related extreme sea level of ~ 2 mamsl. This may in turn become a 1:30 year event by the end of the next decade, or a one in every two-week event by the end of the century as a result of a higher base sea level due to rising seas. The March 2007 KZN storm resulted in an erosion line approximately 4-5 mamsl (Smith et al., 2007). Rocky and sandy coastlines generally withheld against the swell and surge onslaught (Smith et al., 2007). However, mixed rock and sand beaches in the form of headland beaches and pocket bay beaches focused wave energy towards the shoreline due to their unique bathymetry, resulting in extensive erosion (Smith et al., 2007). Using this information and erosion lines observed along the KZN coastline, the City of Cape Town sea level rise model (Brundrit, 2008 and 2009, and Fairhurst, 2008) developed three swash run-up (run-up is the rush of water up the beach slope within the swash zone, above the still or mean sea level) contour lines, namely:

- 2.5 mamsl swash contour line for sheltered or rocky coastlines;
- 4.5 mamsl swash contour line for exposed or sandy coastlines; and
- 6.5 mamsl swash contour line for headland and pocket bay beaches and sandy inlets.

These three City of Cape Town swash contour lines were also used for modelling the possible effects of storm induced extreme sea levels along the Eden and West Coast DM coastlines (DEA&DP, 2010b), due to similar coastal conditions, as well as allowing for correlation between regional studies. For extreme sea level events along the Overberg DM, these three swash contour lines, as well as a 10 mamsl swash contour line, were used. Eskom Holdings Ltd. (2009b) determined ~ 4.8 mamsl to be the best estimate extreme sea level that could occur at present, if the largest storm surge and wave set-up and run-up occurred during HAT at Bantamsklip. ~ 7.2 mamsl was the best estimate 1:100 year extreme sea level reached when the possible effects of climate change were included (0.8 m sea level rise, 17% increase in wave height and 21% increase in storm surge) (Eskom Holdings Ltd., 2009b). An extreme sea level of 11 mamsl was calculated at Bantamsklip for the effects of a tsunami in combination with a 1:10 year storm surge and associated wave run-up and set-up, 90th percentile high tides and climate change (Eskom Holdings Ltd, 2009a). The 10 mamsl contour line also correlates with one of the initial generalised set-back lines proposed by the DEA&DP (2010d) in combination with the 100 m line from the high water mark. The four Overberg DM swash contour lines were generated from a 10 m x 10 m DEM (with a 3-4 m vertical resolution) (see **Figure 2-2**), and then overlain on 2008 SPOT satellite imagery in order to identify possible vulnerable areas (see **Section 3.1**). These areas were then compared with the draft Overberg DM physical processes/hazard set-back line (SSI, 2011), which was delineated using a higher resolution (up to 0.25 m vertical accuracy) LiDAR derived DEM.

Large ocean swells and storm surges along the Overberg DM are generated by strong frontal or cut off and coastal low weather systems during winter and spring/autumn respectively. These weather systems also generally cause extensive rainfall inland, which often results in flooding of the river systems within the Overberg DM. The majority of estuaries along the Overberg DM are either closed or temporarily open, and have been closing more frequently in comparison to the past. Reductions in river flows results in estuaries closing and the building up of estuary mouth sand bars and berms, which either require very large flood/storm surge induced events or artificial breaching to open (e.g. the Bot, Klein River and Uilkraals River estuaries). The Klein River estuary is usually artificially breached once or twice a year to prevent flooding (see **Figure 2-1**) of low lying properties (along the upper northern, i.e. Maanskynkop, and southern banks, i.e. Wortelgat and eastwards, of the estuary) below the 2 mamsl contour, due to natural breaching of the estuary mouth only usually taking place once estuary water levels have reached 2.5-3 mamsl (iRAP, 2007 and 2008). Closed estuary flooding has also occurred in the Uilkraals River estuary in the past, where 1-2 mamsl water levels resulted in flooding of the adjacent caravan park, and artificial breaching of the estuary is now undertaken (Anchor Environmental, 2010a). It can be expected that future higher sea levels and increased storm surge frequency and severity may cause an increased connection to the ocean for many estuaries along the Overberg DM coastline, despite possible reduced freshwater inflows. Future storm surges may in turn prevent flood waters from exiting into the ocean at open estuary mouths, resulting in extensive back flooding of the low relief estuary areas and lower course river floodplains.

Figure 2-1 High water levels in the Klein River estuary, prior to artificial breaching.

2.2 SHORELINE AND TIDAL REACH EVOLUTION MODELLING

The coastline responds to sea level rise in three ways, namely: 1) the Bruun Rule or erosional model (Bruun, 1962); 2) the rollover model; and 3) the overstepping or drowning model (Pethick, 1984). The Bruun Rule is based upon the premise that sea level rise results in sediments along sandy coastlines being removed and deposited offshore due to increased wave action closer to shore, resulting in the lateral erosion of the coastline (Bruun, 1962). The rollover model describes how sediment barriers (e.g. barriers across river mouths) migrate landwards due to overwash and accumulation of sediment on the landward side of the barrier (Pethick, 1984). The drowning model (which applies to rocky coastlines) is based on sea level rise and coastal gradient, and describes how coastal features are flooded via inundation (Pethick, 1984). It must be noted that all three responses can occur along the same coastal strip, provided there is a variable coastal geomorphic structure present.

The Overberg DM coastline was initially subdivided and delineated into sandy and rocky sections visually, using 2008 SPOT imagery and Google Earth. Eighteen sandy beaches or coastal sections were identified between Blousteen and Infanta at the Breede River mouth (see **Table 2-1** and **Figure 2-3**).

Table 2-1 Overberg DM sandy beaches/coastal sections.

1	Rooiels	10	Franskraalstrand
2	Pringle Bay	11	Pearly Beach
3	Grootbaai	12	Haelkraal
4	Holbaai	13	Plaatjieskraalbaai
5	Betty's Bay	14	Jessie Se Baai
6	Palmiet Estuary	15	Die Dam-Ratel River
7	Kleinmond-Hawston	16	Brandfontein-Suiderstrand
8	Onrus	17	Struisbaai
9	Walker Bay	18	Arniston-Potberg

Long-term shoreline evolution, whether eroding, accreting or dynamically stable, can be determined by the measurement of the shoreline position over time. This can be done using a large variety of techniques, dependent on available data sources, accepted error ranges, time and budget (as described in Moore, 2000).

Figure 2-2 Overberg DM 10 m x 10 m DEM and 2.5 mamsl, 4.5 mamsl, 6.5 mamsl and 10 mamsl swash and flood contour lines.

A simplified approach was undertaken to model shoreline and tidal evolution. Due to the DEM not extending outwards entirely along the coastline, only the sandy beach areas as digitised from the 2008 SPOT imagery (due to the SPOT imagery having the greatest shoreline coverage) were used in modelling the extent of shoreline migration (see **Figure 2-3**). The shoreward extent of vegetation on the coastal foredune was used as the indicator for the shoreline, due to the unreliability inherent in using the wet sand-dry sand high water mark line (tidal, seasonal and storm variability) (Moore, 2000). The shoreward foredune vegetation line also provides the best indication of the transition between beach and marine processes and aeolian processes.

The simplified equation: $X_2 = X_1 + (SLR/\sin_a)$

(where X_1 – old shoreline position, X_2 – new shoreline position, SLR – future sea level rise +2 m at 2100), a = slope angle from the DEM at X_1)

was used to calculate the shoreward migration of the shoreline. The same equation was applied to the position of the river/estuary banks (also delineated from 2008 SPOT imagery) at open to semi-open estuaries (up to a distance of tidal influence) in order to determine the possible change in the lateral (i.e. perpendicular to the longitudinal axis of the river) extent of the tidal reach of the estuary.

It must be noted that the vertical resolution of the DEM (~ 3-4 m) and 10 m pixel resolution of the 2008 SPOT imagery does not allow for highly accurate and detailed predictions to be made. The modelling results should be used in a more regional approach, where the swash/flood and shoreline/tidal reach evolution lines are used to identify possible vulnerable areas. Future detailed studies at these specific areas can accurately determine the amount of land that can be expected to be eroded or inundated through sea level rise and storm surges or flooding.

Figure 2-3 2008 SPOT imagery with delineated sandy coastlines and estuary/river banks.

3. MODEL RESULTS

3.1 EXTREME SEA LEVEL AND ESTUARY FLOODING MODELLING

2.5 mamsl, 4.5 mamsl, 6.5 mamsl and 10 mamsl swash run-up contour lines, which could be produced during an extreme storm swell, sea level and tsunami event as described above, were generated from the 10 m x 10 m resolution DEM for the whole Overberg DM coastline, and compared to the draft Overberg DM PPL line. Areas vulnerable to erosion and inundation from extreme sea levels related to large swells/storm surges, and estuarine flooding and back flooding were identified, and described below in **Table 3-1** to **Table 3-3**.

Table 3-1 Areas vulnerable to coastal, estuarine and fluvial erosion and inundation along the Overberg DM coastline, from Rooiels to Voelklip.

Area	Coastline, Estuarine and Fluvial Erosion and Inundation
Rooiels to Kaap Hangklip	Comparisons between the swash contours derived from the 10 m resolution DEM and the PPL delineated using the LiDAR derived DEM indicate that the 10 m resolution DEM is inaccurate and highly conservative (i.e. places the various contours too far landward) with regards to coastal point features e.g. Roman Rock at Rooiels, Die Punt at Pringle Bay and the upper slopes of Kaap Hangklip (see **Figure 3-1**). The 10 m DEM indicates that a large portion of development at Die Punt is below 2.5 mamsl, when in fact all development is above the 5 mamsl contour at least. That said, development along the coastline between Rooiels and Kaap Hangklip is generally above the 5-6 mamsl contour line, and is protected by rocky Peninsula Formation outcrop. Development is also generally above the 5-6 mamsl contour line in both the Rooiels and Buffels River estuaries. Development encroaches both shore and estuary high water marks however, and needs to be restricted. The major coastal hazard at Pringle Bay is the migration of mobile dunes as a result of indigenous vegetation removal and primary foredune destruction for coastal development.
Betty's Bay	The majority of development at Betty's Bay is behind the 6.5 mamsl contour line and protected by Peninsula Formation outcrop, and hence at minor risk to extreme storm surge events (with the exception of some properties near Dewetsbaai that have been developed close to the high water mark). The main coastal hazards at Betty's Bay are the current movement of mobile primary dunes into property at Nerine Road and Morea Road (and possible future encroachment of dune systems along Beach Boulevard in western Betty's Bay), and possible flooding of low elevation areas around the coastal Betty's Bay Lake system (from west to east, Rondevlei, Grootvlei and Malkopsvlei) (see **Figure 3-2**). The draft physical processes set-back line has taken both these additional coastal hazards into account.
Kleinmond	The Kleinmond coastline is dominated by relatively steep (~10 mamsl), erosion resistant quartzite outcrop of the Peninsula Formation, with development and infrastructure being situated behind this natural, vegetated coastal barrier. The Palmiet River estuary is undeveloped, with the exception of the Palmiet Caravan Park, and only the currently undeveloped eastern banks of the estuary are at risk to estuarine erosion during high flood events.
Bot River estuary and Hawston dunefield	Flood prone areas within the Bot-Kleinmond estuarine system are generally undeveloped, and should continue to remain so below (at least) the 4.5 mamsl contour. Exceptions include estuary bank fronting property at Meerenbosch near the Bot River estuary mouth, which is at risk to possible estuary flooding due to natural closing of the estuary mouth (and has required the artificial breaching of the Bot River at times). Possible increased estuary connection to the ocean due to expected future higher sea levels may increase the flood and erosion risk to estuary fronting property at Meerenbosch, as a result of possible further inland penetration of extreme storm surge events. Development within the Hawston dunefield is generally restricted behind the 6.5 mamsl contour line (with the exception of the Hawston Abalone Village caravan park/swimming pool/recreational area), and further development within the primary dune system shoreward of current structures should be restricted. Development within any section of the primary dune system may result in a dune migration however.

Vermont, Onrus and Sandbaai	Development along the coastal stretch from Vermont to Sandbaai is generally above the 6.5 mamsl contour line and is protected by rocky outcrop of Peninsula Formation. However there is some shoreline fronting property and infrastructure along Bietou and Duiker Streets (Vermont), Atlantic and Marine Drives (Onrus), and Kus and Nico Van Der Merwe Streets (Sandbaai) below the 6.5 mamsl contour line, which may be at risk to very large storm events and swash runups (see **Figure 3-3**).
Hermanus and Voelklip	The Hermanus coastline is dominated by steep (~10-15 mamsl vertical faces), erosion resistant quartzite cliffs of the Skurweberg Formation, which provide protection from extreme sea level events (the exception being shoreward fronting properties along lower elevation coastline just west of the new Hermanus harbour and abalone farms) (see **Figure 3-4**). Development at Voelklip is currently behind the 10 mamsl line, however further shoreward development within the primary foredune in the area must be restricted. Maintenance of indigenous dune vegetation will ensure that dunes in the Voelklip area do not become mobile. The shoreward edges of the two Grotto Bay parking lots may be at risk to swash runups during extreme storm events.

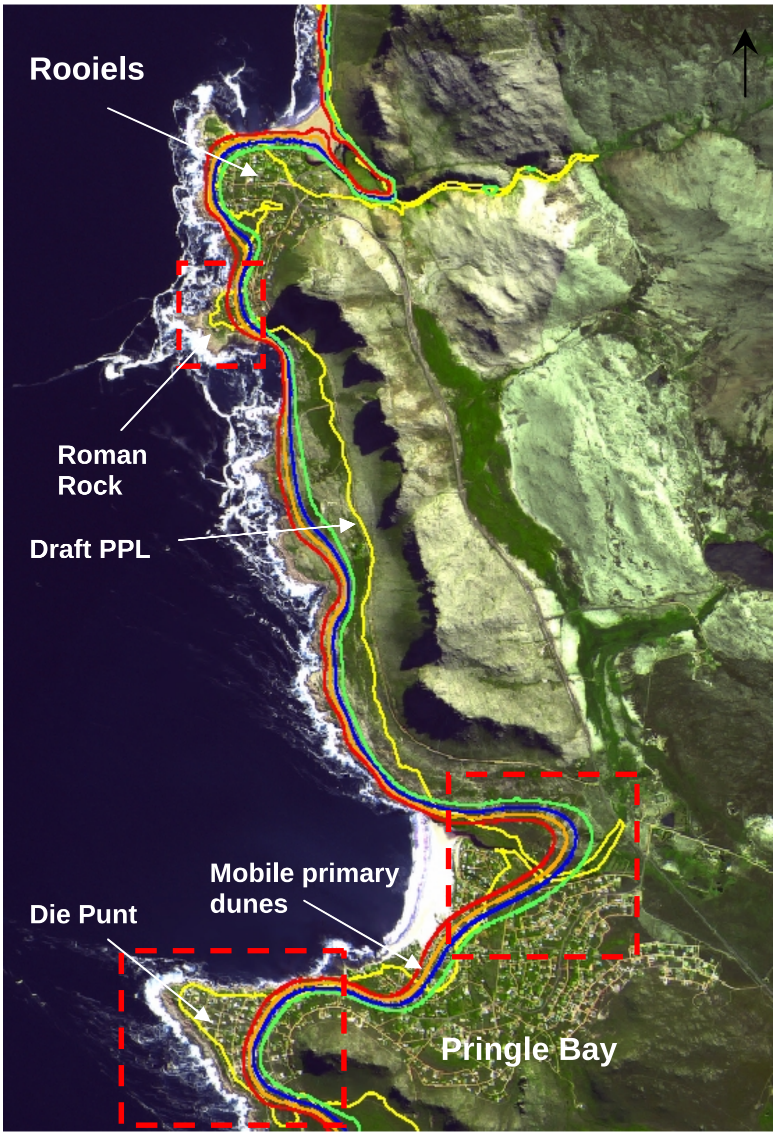

Figure 3-1 2.5 mamsl (red), 4.5 mamsl (orange), 6.5 mamsl (blue) and 10 mamsl (green) swash contour lines for Rooiels and Pringle Bay. Preliminary DEA&DP "physical processes set-back line (PPL)" in yellow (generally along the 10 mamsl contour in the Pringle Bay area; from SSI, 2011). Red dashed blocks highlight the variation in accuracy between the two DEMs used, namely the 10 m DEM used for this study, and the higher resolution LiDAR derived DEM used for the Overberg DM set-back lines study.

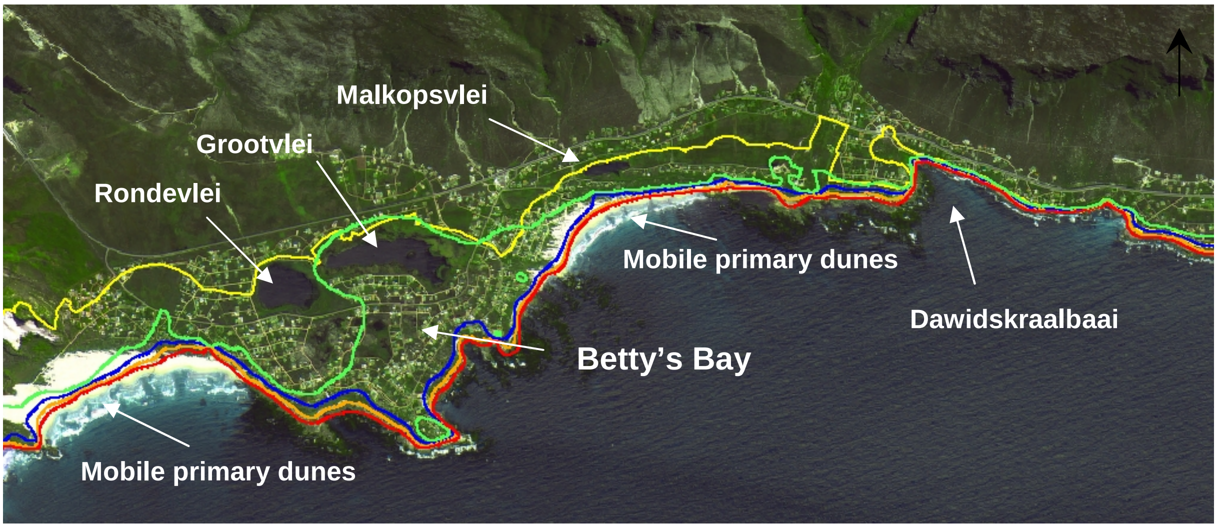

Figure 3-2 2.5 mamsl (red), 4.5 mamsl (orange), 6.5 mamsl (blue) and 10 mamsl (green) swash contour lines for the Betty's Bay coastline. Preliminary DEA&DP PPL in yellow (incorporates the flooding hazard from the Betty's Bay Lakes as well as dune migration from mobile sand dunes in the area; from SSI, 2011). Betty's Bay coastline (especially east of Dawidskraalbaai) is generally protected by elevated Peninsula Formation outcrop.

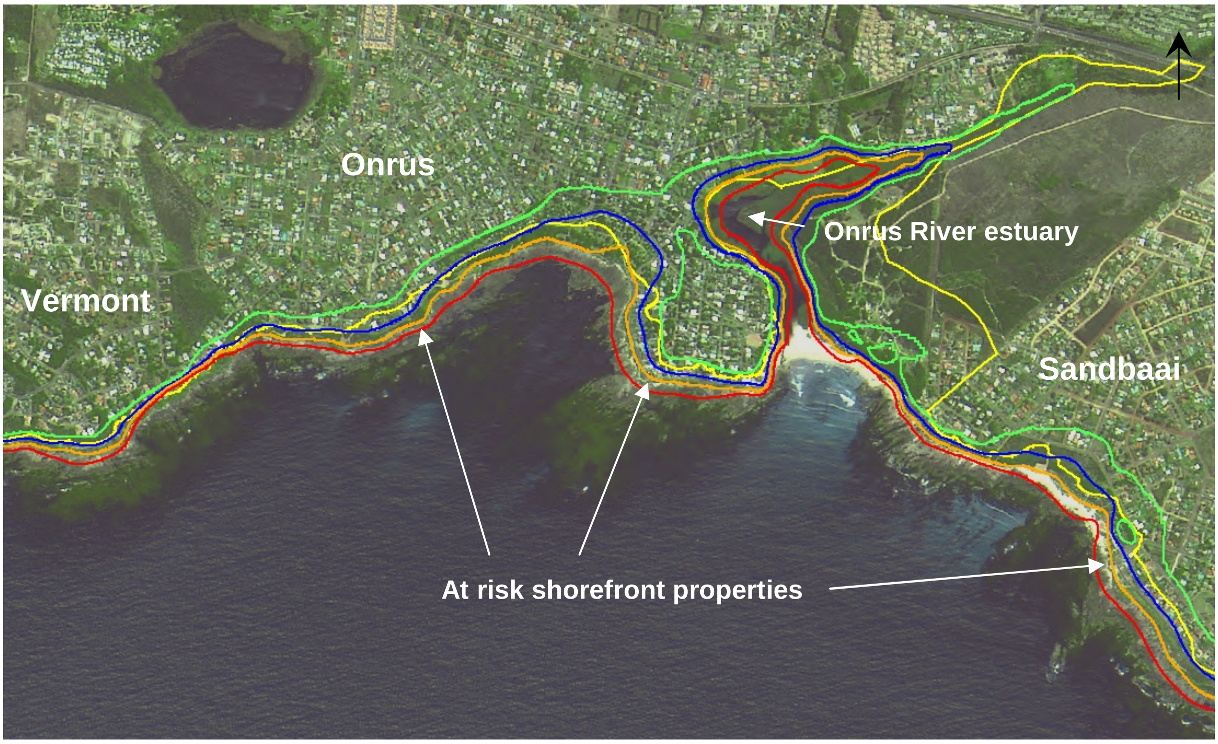

Figure 3-3 2.5 mamsl (red), 4.5 mamsl (orange), 6.5 mamsl (blue) and 10 mamsl (green) swash contour lines for Vermont, Onrus and Sandbaai. Preliminary DEA&DP PPL in yellow (from SSI, 2011). Shoreline adjacent houses in all three suburbs are at risk to extreme storm events despite being situated on rocky coastline (areas below 6.5 mamsl swash contour line, correlating with the proposed PPL). Development within the Onrus River estuary has been restricted however.

Figure 3-4 2.5 mamsl (red), 4.5 mamsl (orange), 6.5 mamsl (blue) and 10 mamsl (green) swash contour lines for Hermanus. Preliminary DEA&DP PPL in yellow (from SSI, 2011). Closely spaced contours indicate steep cliff faces, which are formed by erosion resistant quartzites of the Skurweberg Formation, and provide natural coastal protection to the area.

Table 3-2 Areas vulnerable to coastal, estuarine and fluvial erosion and inundation along the Overberg DM coastline, from the Klein River estuary to Struisbaai.

Area	Coastline, Estuarine and Fluvial Erosion and Inundation
Klein River estuary and Walker Bay dunefield	A number of estuary front properties along the upper northern (Maanskynkop, see **Figure 3-5**) and southern (Wortelgat to Stanford) banks of the Klein River estuary are below the 4.5 mamsl estuary floodline. This is problematic as the Klein River estuary only naturally breaches at water levels of 2.5-3 mamsl, and hence low lying properties are at risk to estuarine and river flooding, while septic tanks at these properties are also prone to leakage, causing estuary pollution. The estuary mouth is sometimes artificially breached to prevent flooding and remove pollution build up within the estuary. However, artificial breaching has met opposition from some residents and estuary users due to changes it sedimentary dynamics near the estuary mouth, which has resulted in increases of pollution in other parts of the estuary. The primary dune system along the Walker Bay coastline from the Klein River estuary mouth to De Kelders is relatively elevated (5-40 mamsl) and undeveloped, with the only risk from extreme sea level events being natural dune erosion and undercutting near the shoreline.
De Kelders, Gansbaai, Danger Point and Kleinbaai	The coastline from De Kelders to Kleinbaai is dominated by ~10-30 mamsl steep cliff faces of Goudini and Peninsula Formation sandstones and quartzites, which provide protection from extreme sea level events. Development at Kleinbaai is generally above the 5 mamsl contour, with Peninsula Formation rocky outcrop and Danger Point also providing natural protection from large swell events.
Franskraalstrand and Uilkraals River estuary	Development at Franskraalstrand is generally above the 5 mamsl contour, with Peninsula Formation rocky outcrop and Danger Point also providing natural protection from large swell events. Portions of the Uilenkraalsmond Resort adjacent to the Uilkraals River estuary are below the 2.5 mamsl floodline (see **Figure 3-6**) and at risk to estuarine flooding, which has occurred in the past as a result of 1-2 mamsl estuary water levels.
Pearly Beach to Quoin Point	The undeveloped primary dune system along coastline between the Uilkraals River mouth and Pearly Beach is generally between 4-40 mamsl in elevation and 1-3 km in width, with the only risk from extreme sea level events being natural dune erosion and undercutting near the shoreline. Development at Pearly Beach is generally above the 6.5 mamsl contour and is fronted by Skurweberg Formation outcrop and a 50-100 metre wide vegetated foredune. Development between the 6.5 mamsl and 10 mamsl lines may be at risk to Eskom modelled maximum extreme sea levels of ~11 mamsl however (combination of possible tsunami, 1:10 year storm, high tides and climate change enhanced sea levels). The coastline between Pearly Beach and Quoin Point is undeveloped (with the exception of Buffeljagsbaai), and composed of rocky TMG points and coastline in association with Bredasdorp Group dune systems, which both form moderate gradient coastal systems. The small subsistence fishing community of Buffeljagsbaai is situated below the 6.5 mamsl contour however and is therefore at risk to extreme sea level events.
Quoin Point to Cape Agulhas	The coastline between Quoin Point and Cape Agulhas is undeveloped (with the exception of Die Dam resort and Suiderstrand), and composed of a mix of moderate gradient sandy coastline and rocky TMG outcrops. A large part of Die Dam resort is situated below the 2.5 mamsl contour and within a degraded foredune system, and might be at risk from extreme storm swell events that refract around Quoin Point (reducing its effect as a natural protective barrier). The resort may also be at risk to migrating mobile dunes, due to it being built within the foredune (dune degradation and indigenous vegetation removal often results in dune mobilisation). A few properties east of the beach car park at Suiderstrand are below the 6.5 mamsl contour line and at risk to extreme sea level events. Dune undercutting can be observed west of Pebbly Beach at Suiderstrand, and therefore shoreward development of current properties along the dune ridge should be restricted.
L'Agulhas and Struisbaai	Development below Main Road and between Main Road and Van Breda/Cres Streets in L'Agulhas is below the 6.5 mamsl contour line and may be at risk to extreme storm swell events (as correlated by the position of the PPL), due to the relatively low gradient of the Peninsula Formation rocky coastline. Offshore rock shelves may reduce shoreline wave energy however, by causing waves to break further offshore. Coastal fronting property along southern Struisbaai is at risk to inundation by extreme storm swell events, although the predominantly rocky coastline and offshore rock shelves may also offer some protection (see **Figure 3-7**). The sandy coastline north of Struisbaai harbour is at very high risk to coastal erosion from extreme storm events refracting around Struisbaai point (see **Figure 3-7**) (in association with it being in a sediment starved "shadow zone" of a log spiral

	bay; see page 10 of the Phase 1 report), as evidenced by the current visible erosion damage and retreat at the Struisbaai Caravan Park and Nostra/Bella Luna restaurant, caused by the 2004 Mentawai tsunami and large storm swell events in 2008 and 2009. Dune undercutting to the north of the caravan park is also visible, and development shoreward of current properties and infrastructure should be restricted.

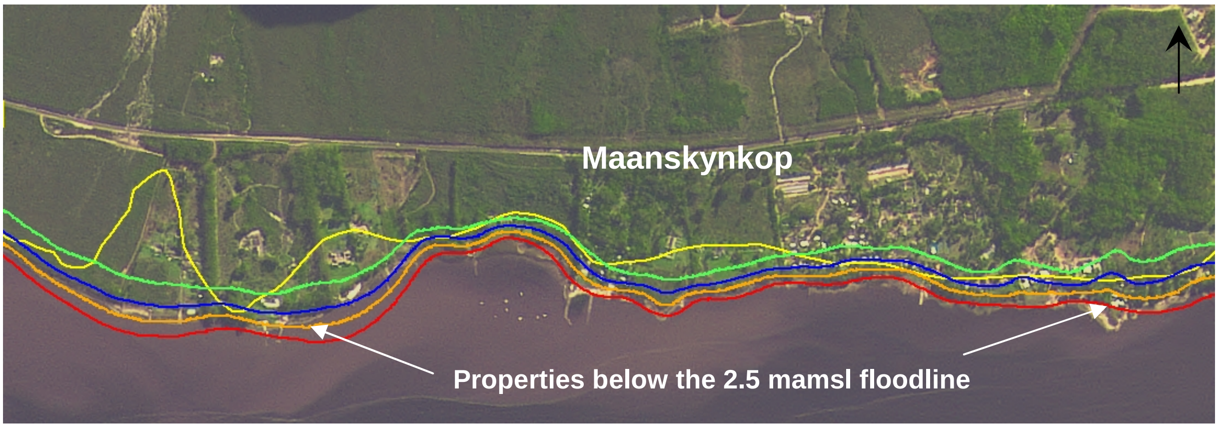

Figure 3-5 2.5 mamsl (red), 4.5 mamsl (orange), 6.5 mamsl (blue) and 10 mamsl (green) flood contour lines for Maanskynkop area along the northern banks of the Klein River estuary. Preliminary DEA&DP PPL in yellow (from SSI, 2011). Note the number of properties below or near the 2.5 mamsl flood line – the Klein River estuary only naturally breaches once water levels reach 2.5-3 mamsl.

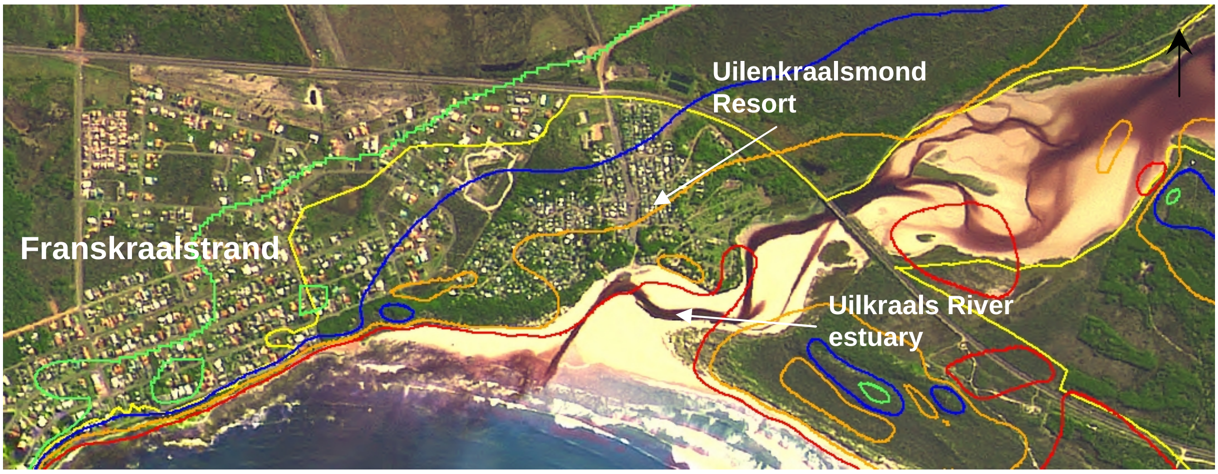

Figure 3-6 2.5 mamsl (red), 4.5 mamsl (orange), 6.5 mamsl (blue) and 10 mamsl (green) swash and flood contour lines for Franskraalstrand and the Uilkraals River estuary. Preliminary DEA&DP PPL in yellow (from SSI, 2011).

Figure 3-7 2.5 mamsl (red), 4.5 mamsl (orange), 6.5 mamsl (blue) and 10 mamsl (green) swash and flood contour lines for Struisbaai. Preliminary DEA&DP PPL in yellow (from SSI, 2011). Note extensive development adjacent to high risk storm erosion areas.

Table 3-3 Areas vulnerable to coastal, estuarine and fluvial erosion and inundation along the Overberg DM coastline, from Struisbaai to Infanta.

Area	Coastline, Estuarine and Fluvial Erosion and Inundation
Struisbaai to Arniston	The coastline between Struisbaai and Arniston is dominated by a ~5-30 mamsl high, 1-1.5 km wide Strandveld Formation mobile dune cordon. The dune cordon, along with the Heuningnes River estuary, is undeveloped, with minor estuarine flooding, natural dune erosion and undercutting likely during extreme storm swell events.
Arniston and Waenhuiskrans	Arniston and Waenhuiskrans are situated on relatively elevated (6-10 mamsl), semi-consolidated to consolidated (i.e. immobile) dune deposits of the Waenhuiskrans and Strandveld Formations. Both developments are also relatively protected from southerly and southwesterly directed swells by Struispunt and its associated offshore rock shelves. The major risk to development in the area is the undercutting and collapse of consolidated aeolianite (dune rock) deposits, through the removal of underlying semi- to unconsolidated layers either by wave or wind erosion.
Waenhuiskrans to Kaap Infante	The coastline between Arniston and Potbergstrand is dominated by an undeveloped ~5-40 mamsl high, 1-3 km wide Strandveld Formation mobile dune cordon (see **Figure 3-8**). Minor natural dune erosion and undercutting is likely during extreme storm swell events. Tourism development at De Hoop Vlei is also well above the 10 mamsl contour, and hence not at risk to coastal lake flooding. Rocky, highly elevated coastline between Potbergstrand and Kaap Infante is formed by the aeolianites of the Waenhuiskrans and Wankoe Formations, conglomerates of the De Hoopvlei Formation, and quartzites of the Peninsula Formation. The region is undeveloped, and in due to the rocky elevated nature of the coastline, at low risk to extreme storm swell events.
Infanta and Kontiki	Development at Infanta is well above the 6.5 mamsl contour, and in addition properties are protected from southwesterly to southeasterly directed extreme storm swell events by the Kaap Infante headland (see **Figure 3-9**). Parts of the Kontiki resort along the southern banks of the Breede River estuary are below the 2.5 mamsl floodline however (see **Figure 3-9**), and are at risk to river flooding and estuarine back flooding during storm events.
Breede River	A number of farm properties with housing and infrastructure at Stoffelsrivier, Matjieskloof, Lemoentuin and Malgas (all along the southeastern bank of the Breede River) are below the 2.5 mamsl floodline (see **Figure 3-10**), and are at risk to riverine flooding.

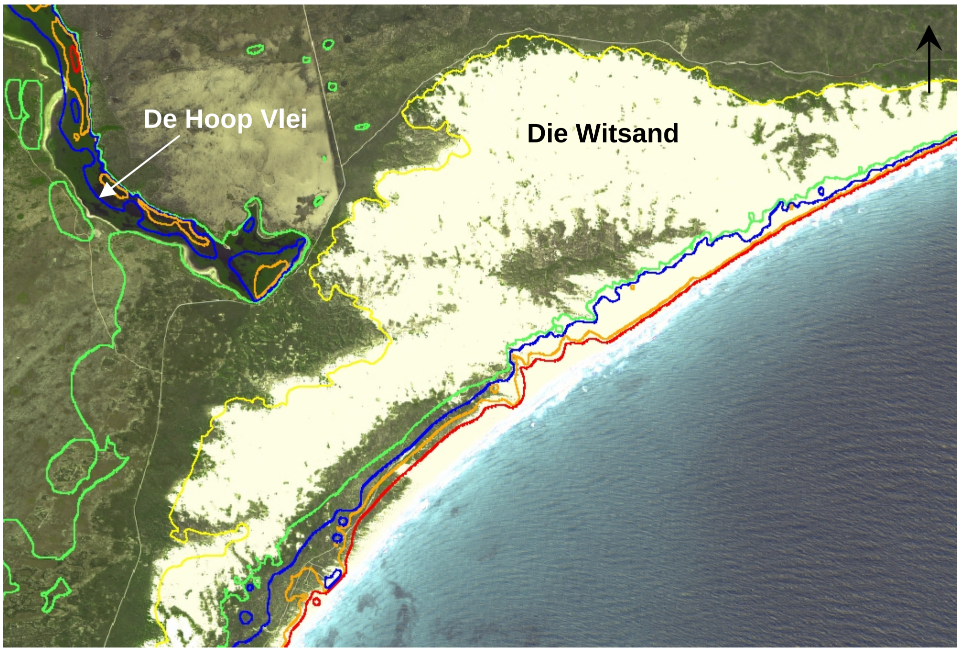

Figure 3-8 2.5 mamsl (red), 4.5 mamsl (orange), 6.5 mamsl (blue) and 10 mamsl (green) swash and flood contour lines for the coastline at De Hoop Nature Reserve. Preliminary DEA&DP PPL in yellow (from SSI, 2011), incorporating the mobile Die Witsand dune system (Strandveld Formation).

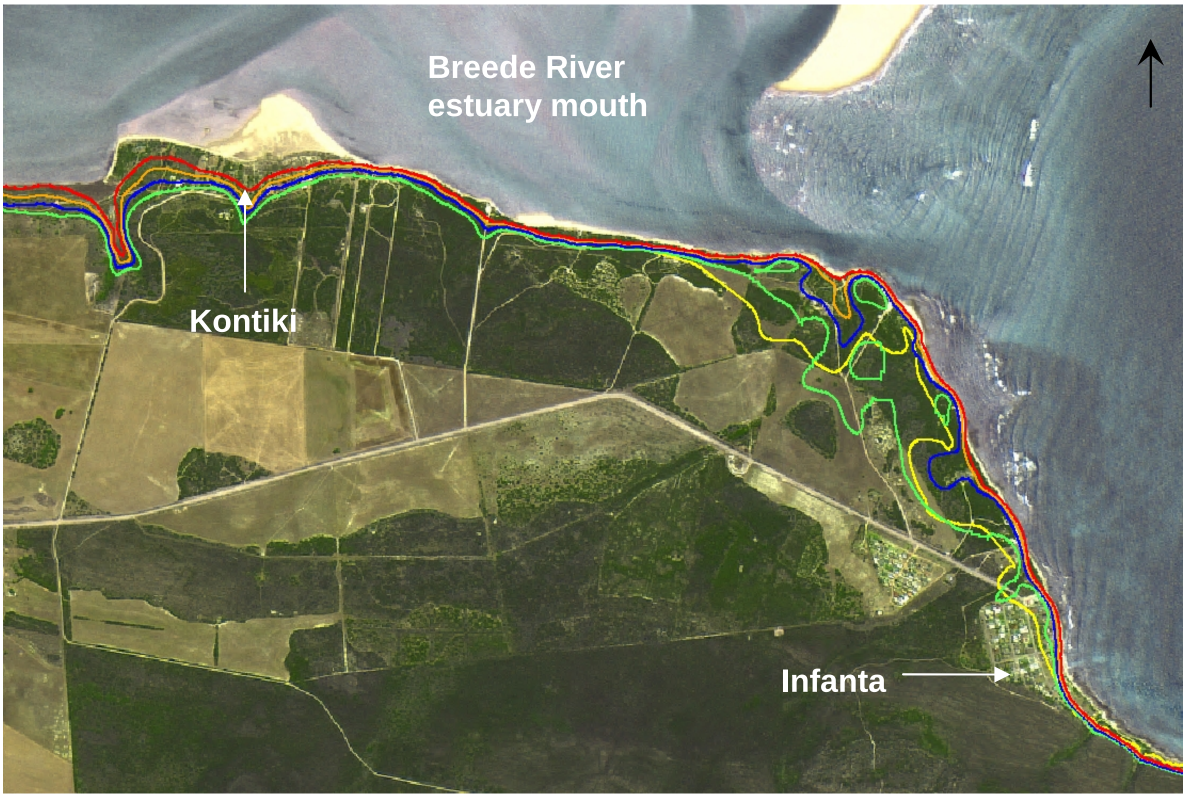

Figure 3-9 2.5 mamsl (red), 4.5 mamsl (orange), 6.5 mamsl (blue) and 10 mamsl (green) swash and flood contour lines for Infanta and Kontiki. Preliminary DEA&DP PPL in yellow (from SSI, 2011).

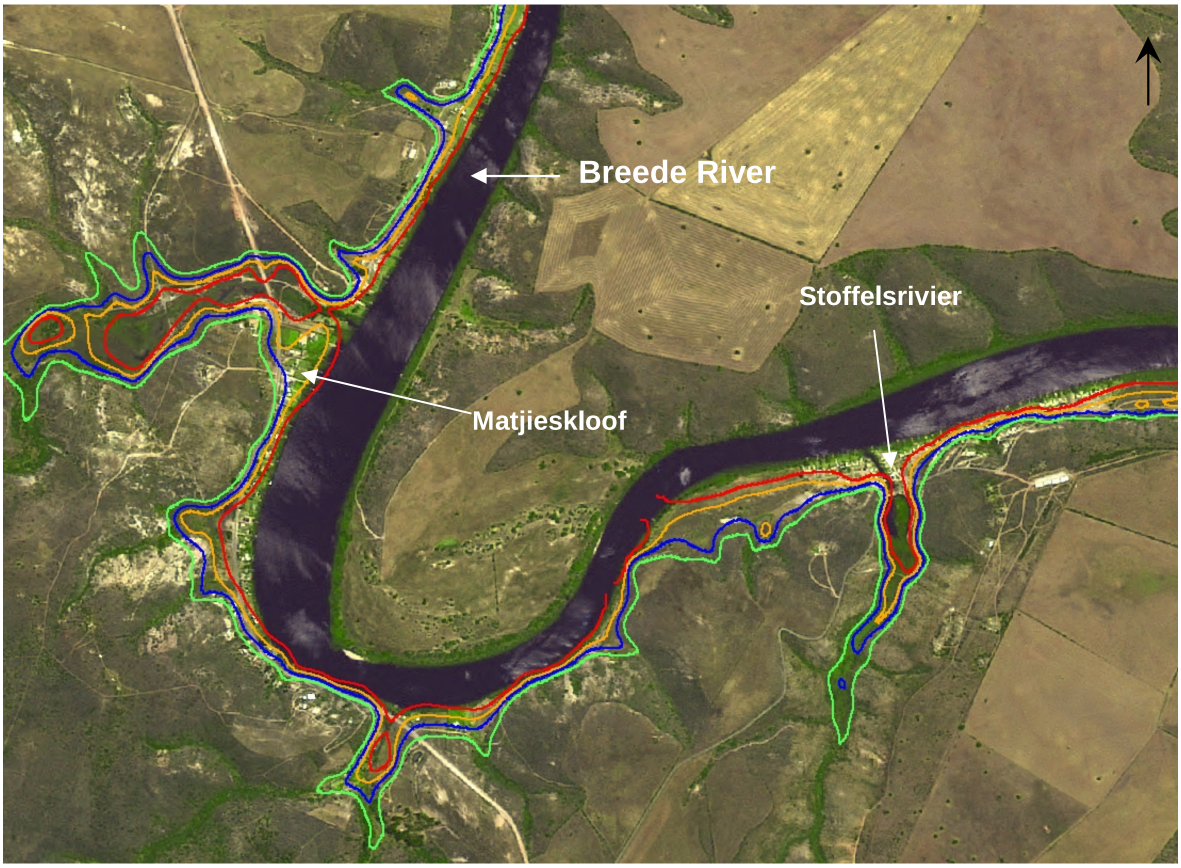

Figure 3-10 2.5 mamsl (red), 4.5 mamsl (orange), 6.5 mamsl (blue) and 10 mamsl (green) flood contour lines for the Breede River. High risk river flood areas below the 2.5 mamsl line at Matjieskloof and Stoffelsrivier.

3.2 SHORELINE AND TIDAL REACH EVOLUTION MODELLING

Future shoreline and tidal reach lines were modelled for a 2 m rise by 2100. There were also a number of data and methodological limitations as described in **Section 2.2**, which have reduced confidence limits in the results. A range of lateral evolution values have therefore been provided in **Table 3-4** and **Table 3-5**.

Table 3-4 Shoreline evolution along sandy coastlines within the Overberg DM for a 2 m rise by 2100.

Sandy Coastline Section	Shoreline Evolution (for 2 m rise by 2100)
Rooiels to Kleinmond	Sea level rise may cause large scale inundation of the low gradient beach at Rooiels, although inundation will be restricted by the relatively high elevation estuary banks. Inland migration of the high water mark by approximately 50-100 metres may occur at Pringle and Betty's Bay, with the associated landward migration of degraded, mobile dune systems by up to 100-200 metres (as currently observed in the area).
Kleinmond to Hawston	Minor landward shoreline migration (~ 5-30 m, decreasing eastwards of the Bot River mouth) due to the moderate to high gradient backing foredune is likely. Frontal foredune undercutting and collapse possible over time, resulting in the development of connections between the eastern Kleinmond portions of the Bot-Kleinmond estuarine system to the ocean. Degradation of the dune system adjacent to the Hawston Abalone Village may result in mobile dune migration into the recreational area, as the shoreline migrates further inland over time.
Walker Bay	Minor landward shoreline migration (~ 5-15 m) due to the backing high gradient foredune is likely. Frontal foredune undercutting and collapse possible over time. The only development at possible future risk is the Grotto Bay parking lot and eastern access road, where future mobile dune migration may occur with shoreline evolution as a result of continuous dune degradation. Grotto Bay is not at risk to inundation however, due to the wide, relatively moderate gradient beach.
Franskraalstrand to Quoin Point	Minor landward shoreline migration (~ 10-40 m) due to backing high gradient foredune and semi-consolidated to consolidated dune rock is likely along sandy coastal areas. Pearly Beach may experience increased mobile dune migration due to current dune degradation as a result of shoreward encroaching development
Quoin Point to Cape Agulhas	Minor landward shoreline migration (~ 5-20 m) due to the backing high gradient foredune is likely. Frontal foredune undercutting and collapse possible over time. There are some areas in the coastal section at possible risk however, namely the southwestern portions of Die Dam and Suiderstrand, where development close to shorelines with thin sand cover may result in removal of the sand cover followed by inundation. The northeastern portion of Die Dam is also at risk of being covered by migrating foredunes in the future.
Struisbaai	Minor landward shoreline migration (~ 5-25 m) due to the backing high gradient foredune is likely. Studies by Theron (2010) have shown that lateral seasonal erosion over the past 60 years at Sandbaai is generally at a rate of not greater than 0.5 metres per year, with the extensive erosion observed caused by large storm or sea level events. Frontal foredune undercutting and collapse of the dune system is currently observed and will continue with time, and hence it is recommended that development is restricted by at least 100 metres from the shoreward edge of the foredune, and preferably not within the foredune at all (as recommended by the proposed Overberg DM physical processes/hazard set-back line).
Arniston to Potberg	Minor landward shoreline migration (~ 5-20 m) due to the backing high gradient foredune and semi-consolidated to consolidated dune rock is likely. Frontal foredune undercutting and collapse is possible over time, especially at Arniston/Waenhuiskrans, where gentle erosion by seawater over time may cause dissolution of aeolianites (dune rock) and cause cliff collapse.

Table 3-5 Tidal reach evolution for estuaries within the Overberg DM based for a 2 m rise by 2100.

Estuary	Tidal Reach (for 2 m rise by 2100)
Rooiels, Buffels and Palmiet	The current narrow estuary mouths of the three estuaries, present within relatively high relief coastal Table Mountain Group outcrop, may enlarge with higher sea levels and engulf the adjacent sand bars and beaches. However the steep relief of the various estuary banks will result in little to no increased tidal flooding. Some undercutting may occur the eastern banks adjacent to the estuary mouths however, and development should be restricted by 50 metres from the estuary mouth banks if erodable material e.g. unconsolidated sand dunes, is present.
Bot	Slopes along the Bot River estuary shoreline generally have a moderate gradient, therefore minor lateral inundation of between 5-15 metres can be expected during future high tides (provided there is a consistent tidal connection to the sea). The eastern corner of Meerenbosch may be at risk to future higher tides in the estuary.
Klein	Slopes along the northern banks of the Klein River estuary generally have a moderate gradient, therefore minor lateral inundation of between 5-20 metres can be expected during future high tides (provided there is a consistent tidal connection to the sea). Development close to the estuary shoreline in the vicinity of Maanskynkop may be at risk to future lateral inundation however. The southern banks of the estuary tend to have a lower gradient (erodable Bokkeveld and Bredasdorp Group sediments versus erosion resistant TMG outcrop on the northern banks), and lateral inundation could reach up to 100 metres inland in some very low gradient (and currently undeveloped) areas, with intertidal areas possibly becoming subtidal or fully submerged in the future. As with the northern estuary banks, development close to the estuary shoreline between Wortelgat and Stanford may be at risk to future lateral inundation.
Uilkraals	As with the Overberg DM estuaries to the west, lateral inundation will only occur within the Uilkraals River estuary provided there is a future consistent connection to the sea. If future higher tidal conditions occur, then lateral inundation between 10-40 metres with associated dune undercutting along the banks of the estuary near the mouth, and widening of the estuary mouth and inundation of the adjacent sand bars/berms and beaches will occur. Increased inundation of the sand flats and salt marshes further inland of the estuary mouth (i.e. north of the R43 bridge) may occur, and development of any form should be restricted from these areas. Portions of the Uilenkraalsmond Resort along low gradient areas of the estuary shoreline may be at risk to increased lateral tidal inundation.
Heuningnes	Increased tidal intrusion due to rising sea levels will have a minor effect on the Heuningnes River estuary, with inundation of the adjacent beach and sand bars/berms likely due to an expanded estuary mouth, with minor dune undercutting just north of the mouth. The relatively moderate gradient slopes inland of the estuary mouth will result in little lateral inundation from possible increased tidal intrusion.
Breede	Tidal reach may extend up to 30 metres inland, due to moderately to steep slopes. Areas at risk may include the shoreline fronting properties at Kontiki, as well as river fronting properties at Stoffelsrivier, Matjieskloof, Lemoentuin and Malgas (dependent on the future extent of tidal influence further inland within the Breede River).

4. RECOMMENDATIONS

Extreme sea level, estuary flooding, shoreline and tidal reach evolution modelling has shown that large portions of the Overberg DM could be vulnerable to coastal hazards induced by sea level rise, if extensive coastal development had to occur along stretches of currently undeveloped coastline and within estuaries e.g. Bot River estuary and Hawston dunefield, Klein River estuary and Walker Bay dunefield, coastline between the Uilkraals River estuary and Pearly Beach, sandy coastline between Quoin Point and Cape Agulhas, and the extensive sandy coastlines and dunefields from Struisbaai to Struispunt and Arniston to Potberg. Although the future shoreline and tidal reach lines modelled will take ~ 90 years to evolve and migrate at a relatively slow rate, planning must be put in place now to prevent future possible damage to natural protective barriers such as vegetated coastal foredunes and tidal habitats. A large portion of the Overberg DM coastline is relatively protected from extreme sea level and estuary/river flooding events at present, due to the rocky and elevated coastal dune nature of a large portion of the coastline. It must be noted that the Struisbaai area north of Struisbaai harbour is highly susceptible to storm induced coastal erosion, Buffeljagsbaai is at risk to storm surge flooding, while parts of the Klein, Uilkraals and Breede River estuaries are at risk to estuarine and river flooding. Despite these at risk areas, there is an opportunity to develop a large portion of the Overberg DM holistically and safely, reducing the risk of future development to climate change induced sea level rise and extreme sea level events through the use of integrated coastal zone management and tools such as coastal set-back lines. The following is recommended:

- Western Cape level:
    - Conduct modelling updates of the Eden DM, West Coast DM and Overberg DM models at least every 5 years. The modelling undertaken in these projects are at a broad scale and coarse, and new global and local climate change data and scenarios, local coastal geomorphic data and methodologies will help improve shoreline evolution prediction.
    - With regards to the Overberg DM coastline, future modelling updates should focus on the vulnerable areas identified, in order to improve the resolution of the modelling i.e. each specific vulnerable stretch of sandy coastline and estuary should have its own future coastal evolution model developed.
- Basic coastal baseline data upgrade:
    - Develop onshore and offshore 1 m x 1m LiDAR DEMs (with an approximately 0.5 m or higher vertical resolution) for the Eden, Overberg (completed in 2011 as part of the Overberg DM set-back line study) and West Coast DM coastlines.
    - Conduct beach profiling at selected beaches along the coastline, as well as detailed geophysical offshore bathymetry surveys, in order to determine various local variables and parameters that can be used in future detailed numerical modelling (see Eskom Holdings Ltd 2009a, 2009b and 2009c for detailed modelling examples).
    - Collection of all available photographic and remote sensing imagery, ensuring it is correctly georeferenced and stored in a central GIS database for simple access for future coastal modelling.

- Overberg District Municipality level:

    - Enforce the coastal buffer zone as defined in the National Environmental Management: Integrated Coastal Management Act (Act 24 of 2008) immediately, and prevent any further development within 100 m of the high water mark or 10 mamsl contour (whichever is closest to the shoreline), until detailed coastal set-back lines have been developed (currently under review for the Overberg DM).

    - Enforce the estuary zonation development plans and estuary set-back development lines for the Bot/Kleinmond (iRAP Consulting, 2009), Klein (iRAP Consulting, 2008) and Uilkraals (Anchor Environmental, 2010b) River estuaries.

    - Strictly monitor (and preferably prevent) future development below the 6.5 mamsl swash contour and 4.5 m estuary/river flood contour, as well as on any undeveloped portions of foredune or natural tidal estuary habitat.

    - Ensure development along the coastal foredune takes into account future landward dune migration, and a further dune migration buffer zone should be put in place behind the coastal buffer zone.

    - Undertake a coastal education drive to make coastal residents aware of the importance of maintaining indigenous vegetated foredunes e.g. use provided walkways and pathways to the beach, as well as the possible hazards and risks faced if these natural barriers are removed.

5. REFERENCES

Anchor Environmental. (2010a). Uilkraals Estuary Situation Assessment. Prepared by Anchor Environmental for the Western Cape Nature Conservation Board, 75pp.

Anchor Environmental. (2010b). Uilkraals Estuary Draft Management Plan. Prepared by Anchor Environmental for the Western Cape Nature Conservation Board, 44pp.

Appeaning Addo, K., Walkden, M. and Mills, J. P. (2008). Detection, measurement and prediction of shoreline recession in Accra, Ghana. ISPRS Journal of Photogrammetry and Remote Sensing, 63, 543-558.

Blake, D. and Hartnady, C. J. H. (2009). City of Cape Town Disaster Risk Assessment – Coastal zone hazards. Prepared by Umvoto Africa (Pty) Ltd. in associated with Aurecon for the City of Cape Town Disaster Risk Assessment, City of Cape Town (June 2009), 34pp.

Brundrit, G. B. (1984). Monthly mean sea level variability along the west coast of southern Africa. South African Journal of Marine Science, 2, 195-203.

Brundrit, G. B. (2008). Global climate change and adaptation – A sea-level rise risk assessment. Phase one: Sea-level rise model. Prepared for the City of Cape Town by LaquaR Consultants CC, 36 pp.

Brundrit, G. B. (2009). Global climate change and adaptation – A sea-level rise risk assessment. Phase five: Full investigation of alongshore features of vulnerability on the City of Cape Town coastline, and their incorporation into the City of Cape Town Geographic Information System (GIS). Prepared for the City of Cape Town by Econologic, 35 pp.

Bruun, G. B. (1962). Sea-level rise as a cause of shore erosion. American Society of Civil Engineers, Journal of the Waterways and Harbours Division, 88, 117-130.

Cazenave, A., Chambers, D. P., Cipollini, P., Fu, L. L., Hurell, J. W., Merrifield, M, Nerem, S., Plag, H. P., Shum, C. K. and Willis, J. (2009). Sea level rise: regional and global trends. OceanObs2009, 21-25 September 2009, Italy.

Church, J. A., White, N. J., Aarup, T., Wilsong, W. S., Woodworth, P. L., Domingues, C. M., Hunter, J. R. and Lambeck, K. (2008). Understanding global sea levels: past, present and future. Sustainability Science, 3, 9-22.

Department of Environmental Affairs and Development Planning (DEA&DP). (2010a). Sea Level Rise and Flood Risk Assessment for a Select Disaster Prone Area Along the Western Cape Coast. Phase 1 Report: Eden District Municipality Sea Level Rise and Flood Risk Literature Review. Prepared by Umvoto Africa (Pty) Ltd for the Provincial Government of the Western Cape DEA&DP: Strategic Environmental Management, 30pp.

Department of Environmental Affairs and Development Planning (DEA&DP). (2010b). Sea Level Rise and Flood Risk Assessment for a Select Disaster Prone Area Along the Western Cape Coast. Phase 2 Report: Eden District Municipality Sea Level Rise and Flood Risk Modelling. Prepared by Umvoto Africa (Pty) Ltd for the Provincial Government of the Western Cape DEA&DP: Strategic Environmental Management, 23pp.

Department of Environmental Affairs and Development Planning (DEA&DP). (2010c). Sea Level Rise and Flood Risk Assessment for a Select Disaster Prone Area Along the Western Cape Coast. Phase 3 Report: Eden District Municipality Sea Level Rise and Flood Hazard Risk Assessment. Prepared by Umvoto Africa (Pty) Ltd for the Provincial Government of the Western Cape DEA&DP: Strategic Environmental Management, 22pp.

Department of Environmental Affairs and Development Planning (DEA&DP). (2010d). Development of a methodology for defining and adopting coastal development set-back lines. Volume I: Main report. Prepared WSP Africa Coastal Engineers (Pty) Ltd for the Provincial Government of the Western Cape DEA&DP, 73pp.

Department of Environmental Affairs and Development Planning (DEA&DP). (2010e). Development of a methodology for defining and adopting coastal development set-back lines. Volume II: Appendices. Prepared WSP Africa Coastal Engineers (Pty) Ltd for the Provincial Government of the Western Cape DEA&DP.

Department of Environmental Affairs and Development Planning (DEA&DP). (2011a). Sea Level Rise and Flood Risk Assessment for a Select Disaster Prone Area Along the Western Cape Coast. Phase A: West Coast District Municipality. Phase 1 Report: West Coast District Municipality Sea Level Rise and Flood Risk Literature Review. Prepared by Umvoto Africa (Pty) Ltd for the Provincial Government of the Western Cape DEA&DP: Strategic Environmental Management, 30pp.

Department of Environmental Affairs and Development Planning (DEA&DP). (2011b). Sea Level Rise and Flood Risk Assessment for a Select Disaster Prone Area Along the Western Cape Coast. Phase A: West Coast District Municipality. Phase 2 Report: West Coast District Municipality Sea Level Rise and Flood Risk Modelling. Prepared by Umvoto Africa (Pty) Ltd for the Provincial Government of the Western Cape DEA&DP: Strategic Environmental Management, 23pp.

Department of Environmental Affairs and Development Planning (DEA&DP). (2011c). Sea Level Rise and Flood Risk Assessment for a Select Disaster Prone Area Along the Western Cape Coast. Phase A: West Coast District Municipality. Phase 3 Report: West Coast District Municipality Sea Level Rise and Flood Hazard Risk Assessment. Prepared by Umvoto Africa (Pty) Ltd for the Provincial Government of the Western Cape DEA&DP: Strategic Environmental Management, 22pp.

Eskom Holdings Ltd. (2009a). Environmental Impact Assessment for the proposed nuclear power station (“Nuclear-1”) and associated infrastructure: Appendix E9 – Estimating the 1:100 year flood line from the sea. Prepared by Prestege Retief Dresner Wijnberg (Pty) Ltd for Eskom Holdings Ltd, 15pp.

Eskom Holdings Ltd. (2009b). Environmental Impact Assessment for the proposed nuclear power station (“Nuclear-1”) and associated infrastructure: Appendix E16E – Coastal engineering investigations: Bantamsklip. Report 1010/03/102. Prepared by Prestege Retief Dresner Wijnberg (Pty) Ltd for Eskom Holdings Ltd.

Eskom Holdings Ltd. (2009c). Environmental Impact Assessment for the proposed nuclear power station (“Nuclear-1”) and associated infrastructure: Appendix E16FD – Numerical modelling of coastal processes: Bantamsklip. Report 1010/04/101. Prepared by Prestege Retief Dresner Wijnberg (Pty) Ltd for Eskom Holdings Ltd.

Fairhurst, L. (2008). Global climate change and adaptation – A sea-level rise risk assessment. Phase two: Risk and impact identification. Prepared for the City of Cape Town by LaquaR Consultants CC, 82 pp.

Intergovernmental Panel on Climate Change (IPCC). (2001). Climate change 2001: The scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom.

Intergovernmental Panel on Climate Change (IPCC). (2007). Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom.

iRAP Consulting. (2007). Estuary Management Plan for the Klein River, Overberg Region, Western Cape – Situation Assessment Report. Prepared by iRAP Consulting for the Western Cape Nature Conservation Board, 113pp.

iRAP Consulting. (2008). 2008-2013 First Generation Estuary Management Plan for the Klein River, Overberg Region, Western Cape. Prepared by iRAP Consulting for the Western Cape Nature Conservation Board, 105pp.

iRAP Consulting. (2009). 2009-2014 First Generation Estuary Management Plan for the Bot/Kleinmond Estuarine System, Overberg Region, Western Cape. Prepared by iRAP Consulting for the Western Cape Nature Conservation Board, 49pp.

Mather, A. A. (2008). Coastal erosion and sea level rise. IMIESA (Institute of Municipal Engineering of Southern Africa journal), March 2008, 49-70.

Mather, A. A., Garland, G. G. and Stretch, D. D. (2009). Southern African sea levels: corrections, influences and trends. African Journal of Marine Science, 31, 145-156.

Moore, L. J. (2000). Shoreline mapping techniques. Journal of Coastal Research, 16 (1), 111-124.

Pethick, J. (1984). An introduction to coastal geomorphology. Edward Arnold, London, United Kingdom, 260pp.

Rahmstorf, S. (2007). A semi-empirical approach to projecting future sea-level rise. Science, 315 (19 January), 368-370.

Republic of South Africa. (2008). National Environmental Management: Integrated Coastal Management Act (Act 24 of 2008).

Small, C. and Nicholls, R. J. (2003). A global analysis of human settlements in coastal zones. Journal of Coastal Research, 19 (3), 584-599.

Smith, A. M., Guastella, L. A., Bundy, S. C. and Mather, A. A. (2007). Combined marine storm and Saros spring high tide erosion events along the KwaZulu-Natal coast in March 2007. South African Journal of Science, 103, 274-276.

Smith, A. M., Mather, A. A., Bundy, S. C., Cooper, J. A. G., Guastella, L. A., Ramsay, P. J. and Theron, A. (2010). Contrasting styles of swell-driven coastal erosion: examples from KwaZulu-Natal, South Africa. Geological Magazine, 147 (6), 940-953.

SSI Engineers and Environmental Consultants (Pty) Ltd. (2011). Development of Coastal Set-back Lines for the Overberg District/A quick guide to Set Back Line determination.

Theron, A. K. (2010). Approaches to determination of coastal set-back lines. Presented on behalf of the CSIR at the 2010 Set-back Lines for Coastal Developments seminar, Stellenbosch University, October 2010.

Theron, A. K. and Rossouw, M. (2008). Analysis of potential coastal zone climate change impacts and possible response options in the southern African region. Science Real and Relevant: 2nd CSIR Biennial Conference, CSIR International Convention Centre Pretoria, 17-18 November 2008, 10pp.

University of New South Wales (UNSW) Climate Change Research Centre (CCRC). (2009). The Copenhagen Diagnosis: Updating the world on the latest climate science. UNSW CRCC, Sydney, Australia, 60pp.

Vermeer, M. and Rahmstorf, S. (2009). Global sea level linked to global temperature. Proceedings of the National Academy of Sciences, 106 (51), 21527-21532.

Woodworth, P. L., Aman, A. and Aarup, T. (2007). Sea level monitoring in Africa. African Journal of Marine Science, 29 (3), 321-330.