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Global Climate Change and Adaptation – A Sea-Level Rise Risk Assessment.

PROPOSAL NUMBER:
R030800032
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GLOBAL CLIMATE CHANGE

Prepared For:
The City of Cape Town
Environmental Resource Management Department

CITY OF CAPE TOWN | ISIXEKO SASEKAPA | STAD KAAPSTAD

THIS CITY WORKS FOR YOU

Phase three:
Final Report
A Sea-Level Rise Risk Assessment for the City of Cape Town
Report prepared by
Anton Cartwright (SEI Cape Town)
June 2008

SEI STOCKHOLM ENVIRONMENT INSTITUTE

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The City of Cape Town have awarded LaquaR Consultants CC the contract for their Proposal Number: R03-404/06-07

Reference: Global Climate Change

Date: January – July 2008.

An extract from the Terms of Reference of the contract, relevant to this third Phase Three, now follows.

TERMS OF REFERENCE

Global Climate Change: Coastal Climate Change and Adaptation - A Sea-Level Rise Risk Assessment for the City of Cape Town

1. Background and Introduction:

The City of Cape Town administers approximately 307 km of coastline, arguably its single greatest economic and social asset. In October 2003 the City formally adopted a Coastal Zone Management Strategy with the intention of managing and safeguarding the coastal asset for current and future generations.

The City's coast provides a range of social and economic opportunities including recreational and amenity areas, sought after housing and development opportunities as well as core economic attributes. In addition, the City's coast is a dynamic ecological system that supports a wide range of species, ecological systems and ecological services.

Global climate change predictions suggest that amongst others, sea level rise and an increase in the intensity and frequency of storm events may have significant impact on coastlines across the globe. Cape Town with its extensive coastline may be particularly vulnerable to these predicted changes.

2. Motivation and Aim of Project

The aim of the Sea-Level Rise Risk Assessment Project is to:

- Model the predicted sea-level changes in a range of scenario's (time series, incremental climate change, shear events, and storm frequency and intensity).
- Model the form that those changes will take.
- Understand the associated impacts on existing coastal systems, infrastructure and property.
- Provide guidance and implications to future coastal development (to be included in the City's Coastal Development Guidelines).
- Identify high risk areas that are prone to high impact.
- Begin to understand and develop long-term mitigation measures.

The primary objective of this study is therefore:

To model and understand the ramifications of predicted sea-level rise and increased storm events for the City of Cape Town, thereby providing information that may be used for future planning, preparedness and risk mitigation.

3. Project Phases

The project will be undertaken in four distinct phases. Each phase of the project will provide specific outcomes and deliverables. Phase one and two have been completed and the reports were submitted in March and May 2008, respectively. This report relates to phase three:

Phase 3: Risk Assessment

- Provide a detailed assessment of the risks and costs to the City and its citizens of the potential loss of amenities, infrastructure and services from sea level rise and associated influences of climate change over the next five to one hundred years. This will be achieved from the results of the first two phases, which emphasise the physical impacts, and the use of financial, social and environmental costs to provide a fuller assessment. This is likely to be satisfactory for the shorter time scales, but to remain a challenge for times scales beyond ten years

- Assess alternative strategies to deal with the greater range of uncertainties in the projections of the impacts of climate change on time scales beyond a decade. This will be achieved through interrogating the linked climate processes (greenhouse gas concentrations, global warming, rainfall patterns, ice-melt and sea level rise) that lead to compounded climate effects and even distinct shifts in response. Of particular concern are the negative economic linkages. The objective is to identify early warning indicators that will reduce the range in uncertainties.

1. INTRODUCTION

The Cape Peninsula has long been associated with violent sea-storms. Up until now this feature of the Cape and the damage that it has caused has not impeded development. On the contrary, the rate of residential and commercial development in the City of Cape Town almost doubled (1,232 hectares per annum) between 1985-2005 (Cape Town IDP, 2006) and much of this development has been adjacent to the coast. It has been suggested that climate change and the sea-level rise will show some of the past development to have been imprudent and necessitate a review of both the location and the nature of the City of Cape Town’s growth. Most people have an intuitive understanding of sea-level rise as being undesirable, but the manner in which sea-level rise imposes risks on people and property via complex social and ecological systems is less well understood and more difficult to predict.

This Phase 3 report draws on the biophysical projections of sea-level rise for the Cape Town coastline that have been developed in Phases 1 and 2, and assesses the socio-economic risks that might be associated with this phenomenon. More specifically, the terms of reference require that this Phase 3 “quantify and detail the risks to the City of Cape Town and its citizens of sea-level rise over a time series of 5-100 years.”

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[1] Acknowledgements: This study would not have been possible without significant contributions and support from a number of people. Key among these are Geoff Dekker who produce the GIS model of sea-level rise, Gregg Oelofse, Barry Wood, Mike Hyde, Ian McDonald, Abdullah Parker and Craig Haskins of the City of Cape Town, and my colleagues Geoff Brundrit, Lucinda Fairhurst. All mistakes are the responsibility of the author.

The report is separated into sections on:

A description of the links between climate change and sea-level rise in the City of Cape Town (Section 2).

Environmental risk and its application to sea-level rise (Section 3).

An identification and quantification of the risks to the 307 km Cape Town coastline that are likely to be induced by sea-level rise at various intervals. This aggregated approach to risk assessment is capable of attaching financial estimates to the risk of environmental phenomena and is useful for comparisons and prioritization, but simultaneously conceals a large amount of important information (Section 4).

A detailed qualification of the risks and a description of the way in which they manifest for a particular segment of the Cape coast, namely Blaauwberg to the Cape Town harbour. Insight into how these risks manifest over time and space is important for efforts that aim to manage and reduce the risk (Section 5).

This Phase 3 of the study is followed in Phase 4 by an outline of adaptation and mitigation measures available to the City of Cape Town in the face of sea-level rise.

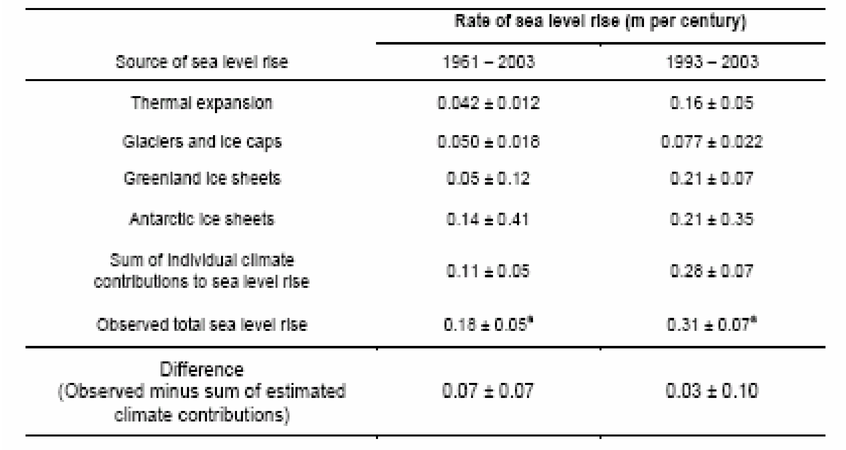
2. CLIMATE CHANGE AND SEA-LEVEL RISE

The atmospheric concentration of carbon dioxide has reached 385 parts per million, a level that Jim Hansen, a scientist with NASA's Goddard Institute, and many others believe pushes the planet beyond the "tipping point" and ensures atmospheric warming of an intensity and scale that is unprecedented in the past 120,000 years. One of the multiple changes that is anticipated as a result of an anthropogenically warmed global climate is a rise in sea level. Mean global sea-level has already begun rising; over the 20th century mean sea-level rose 0.17 metres (0.12 metres – 0.22 metres). Significantly the rate of this rise was seen to accelerate towards the end of the century.

What is modelled in this study is observed sea-level, which is a function of mean sea-level, tidal influences and meteorological forcing of the mean sea-level. All three components of observed sea-level are subject to change. Some of the most damaging sea-level rise events in the past (the Saxby Gale in Canada 1869, the 1984 storm surge off the Cape coast, "Hurricane Katrina" floods in Louisiana and the 2007 storm surge in KwaZulu Natal) have involved a concordant tidal and meteorological influence. Two of the components of observed sea-level rise, mean sea-level and meteorological forcing, are likely to be changed by global warming in a manner that could exacerbate observed sea-level.

Mean sea-level: Mean sea-level changes on a centennial scale, although this scale may be abbreviated in the future as ice-sheets in the West Antarctic and Greenland disintegrate and collapse into the sea. The three chief factors contributing to changes in mean sea-level are: (i) thermal expansion of the top 3,000 metres of the ocean. This section of the ocean absorbs 80 per cent of the energy added to the global climate system by anthropogenic warming and accounts for roughly two thirds of the rise observed in the past century); (ii) glacial melt from Greenland and Antarctica, plus a smaller contribution from other ice sheets. Melting ice accounts for roughly one third of historical increases but is increasing at a quicker rate than thermal expansion (Ringot, 2003; IPCC, 2007); and (iii) change in terrestrial storage. Greater evaporation from the ocean surface has in some instances, such as the central Indian Ocean some thirty years ago, been attributed to sea-level fall (Mörner *et al*., 2003) but these effects are small in relation to the three influences driving sea-level rise above. Similarly, land subsidence, as observed in the Nile Delta and at Ocean City Maryland in the US, is a further cause of observed rises in mean sea-level (Leatherman and Kershaw, 2001). Subsidence is caused by tectonic activity, extraction of ground water and the disruption of sediment deposits in estuaries caused by upstream dams and weirs. Subsidence induced sea-level rise is typically small (10mm per year according to Church, 2001) in comparison with changes projected by climate change, and is not covered in detail in this report.

Climate induced changes to mean sea-level are not the same in all regions of the world, but the available evidence suggests that the mean sea-level around the City of Cape Town has been increasing at a rate similar to the mean global rate, namely 2 cm per decade over the last decade (Searson and Brundrit, 1995). Higher mean sea-level around the Cape coast will render conventional storm surges and high tides more damaging.



	Rate of sea level rise (m per century)	
Source of sea level rise	1961 – 2003	1993 – 2003
Thermal expansion	0.042 ± 0.012	0.16 ± 0.05
Glaciers and ice caps	0.050 ± 0.018	0.077 ± 0.022
Greenland ice sheets	0.05 ± 0.12	0.21 ± 0.07
Antarctic ice sheets	0.14 ± 0.41	0.21 ± 0.35
Sum of individual climate contributions to sea level rise	0.11 ± 0.05	0.28 ± 0.07
Observed total sea level rise	0.18 ± 0.05[a]	0.31 ± 0.07[a]
Difference (Observed minus sum of estimated climate contributions)	0.07 ± 0.07	0.03 ± 0.10

Table 1: Respective contributions to and rates of sea-level rise over different periods

The IPCC's Fourth Assessment Report (2007) posits an upper boundary for global sea-level rise by 2100 of 0.59 meters. This estimate does not include the possibility of nonlinear changes in the extent of major ice-sheets;[2] the Fourth Assessment Report collated work published prior to June 2006 and very little research on changes to the major ice-sheets was available by this date. Since the Fourth Assessment Report there has been an increased effort to understand the factors influencing sea-level rise. These efforts have focused on the potential collapse of Greenland and West Antarctic ice sheets. The Greenland and Antarctic ice sheets contain enough water to raise the sea level by almost 70 metres, and small changes in their extent would have a significant effect on mean sea-level. A combined melting of the West Antarctic and Greenland ice sheets alone would contribute 13 metres to mean sea-level.

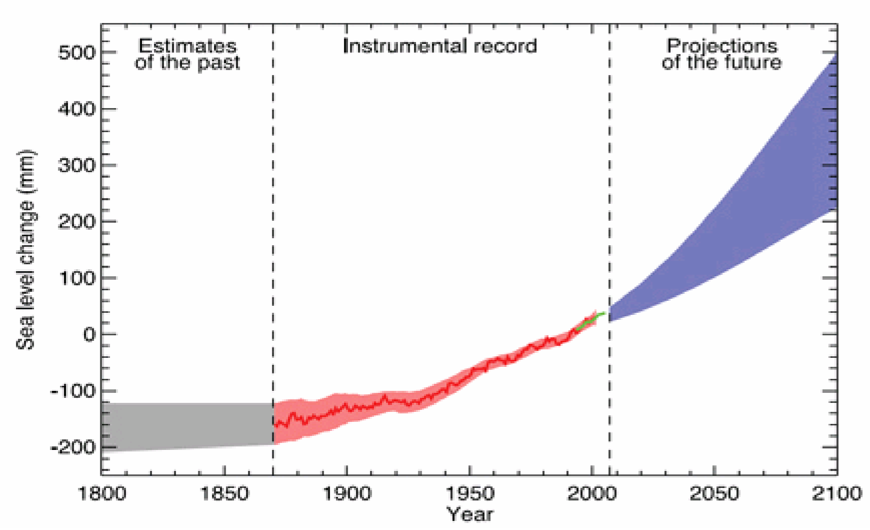


Figure 1: Past, recorded and projected sea-level rise based on existing understanding as per the IPCC 2007. More recent projections have massively increased higher-level projections.

While there remains considerable uncertainty about the above scenarios, and the time horizon over which they may unfold, recent research (see Text Box 1) and expert opinion indicate that the existing linear predictions of climate change are probably not plausible,

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[2] In trying to account for ice-sheet melt, the IPCC AR4 took half of the Greenland mass loss and the whole Antarctic mass loss for 1993-2003, and assumed this would remain constant until 2100. This assumption lacks a scientific basis. The report itself states that this ice loss is due to a recent acceleration of flow.

and that significant sea-level rise may occur earlier than previously thought. Epstein and Mills (2006), for example, have drawn attention to the fact that polar ice is melting at rates unforeseen in the 1990s, and that as meltwater seeps down to lubricate their base, some Greenland outlet glaciers are moving 14 kilometres per year, twice as fast as in 2001.

Text Box 1

Summary of recent research on the melting of terrestrial and arctic ice

- Using satellite interferometry observations, Ringot and Kanagaratnam (2006) detected an acceleration of glacier flow in the lower latitudes between 1996 and 2000, and rapid extension of glaciers to higher latitudes by 2005 as snow deposits increased in these regions.
- Hanna *et al*. (2005) calculated a total loss of Antarctic ice in the period 1995 to 2005 that was double that in the previous decade. Applying this rate would give sea-level measures two to five times greater than those in the Third Assessment Report.
- Krabill *et al*. (2004) found that between 1993-1994 and 1998-1999 the Greenland ice sheet was losing 54 ± 14 gigatons of ice per year (Gt/yr).
- In Antarctica, Velicogna and Wahr (2006) have determined that the West Antarctic ice sheet lost 152 ± 80 cubic kilometres of ice per year. This rate is several times greater than that assumed in the IPCC Third Assessment. Were the WAIS to collapse, it would raise average sea-level by approximately 5 to 6 meters (Tol *et al*., 2006).

Tide: Tidal influences on the Cape coast’s mean sea-level are, except under extreme storm conditions, currently greater than the meteorological and climate change influences (Searson & Brundrit, 1995). The tidal range is in the order of 1.9 metres and is predictable (see Text Box 2). The high tides that occur during the bi-annual equinox - the “spring tides” - represent the periods of highest risk of sea-level rise events. The height of spring high tides varies on a cycle of just over 18 years which coincides with the lunar nodal cycle. Within this 18.6 year cycle it is possible to identify times of excessively high tide and corresponding risks of a sea-level rise event.[3]

Text Box 2

South African Tidal Records

Based on the tidal records provided by the South African Navy Hydrographic Office (www.sanho.co.za) we know, for example, that on the 6th of May 2008 at 03h31 the high tide in Simon's bay will be 15 centimetres below the HAT. In order for the sea to exceed HAT at this time it would have to be raised 15 cm by meteorological influences (because 6 May 2008 is in the immediate future we can assume that climate change influences will not affect sea-level above the existing effect).

Based on historical records we know that meteorological influences of sea-level cause a 15 centimetre rise in the sea at Simon's Bay only 3.4 per cent of the time (Brundrit, 2008). A three day swell and weather forecast, such as is available at http://polar.ncep.gov/waves/viewer.shtml or http://www.windguru.com/int/ for example, is able to provide a reasonable indication of whether or not this probability is likely to be exceeded by the approaching weather, and accordingly whether or not observed sea level is likely to exceed HAT.

Meteorological: Meteorological forcing of mean sea-level takes place on the same scale as the weather and involves the influence of wind, "coastal trapped waves" (MacDevette and Hewittson, 2007) and low pressure systems on the mean sea-level (Schumann and Brink, 1990). The South-East winds, which typically prevail along the Cape coast during the summer months, are projected to become stronger as climate change increases and may become an increasing feature of the winter months.[4] It is important to note that the

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[3] The 2007 Durban sea-level rise event, for example, coincided with the high Saros tide and accounted for a 2.28 metre rise above mean sea level.

[4] In MacDeevit and Hewitson's model, a 15% -30% increase in the number of days on which the summer south east wind blows at 6m/s or more is forecast for 2081-2100 relative to 1981-2000 and there was a near doubling of the incidents of extreme winds (7.6 m/s) or more for the same periods.

North-West winds that prevail in winter do not, as yet, show a statistically discernable change as a result of climate forcing and are not projected in regional climate forecasts to change (MacDeevitt and Hewitson, 2007). In general it is possible that both the frequency and intensity of the meteorological driver of sea-level rise will increase as global warming intensifies. This is particularly the case given Theron's (2007) finding that off the South African coast a 10 per cent increase in wind speed results into a 26 per cent increase in wave heights and a 40 per cent – 100 per cent increase in longshore transport rates (Theron, 2007). Other anecdotal evidence suggests that prevailing summer winds may be shifting from the south-east to the south and south-west. Where this is the case it will bring waves and swell into the shore at novel angles and contribute to new forms of coastal erosion.

3. ENVIRONMENTAL RISK AND ITS APPLICATION TO SEA-LEVEL RISE

South Africa's White Paper on Sustainable Coastal Management (DEAT, 2000) introduces the notion of environmental risk to the country's coastal management legislation. The application of risk analyses and terminology to environmental threats has become increasingly popular in the international literature and discourse. This has seen the risk of climate change compared to (and ranked above) the threat of terrorism by The Pentagon, water scarcity risks emphasized as more critical than warming temperatures by Swiss Re, and private sector insurers engage actively in the market for environmental risk cover.

Whilst some of these risk comparisons do not stand up to scrutiny, the use of risk to evaluate environmental phenomena has its merits. Risk is a feature of everyday life. A wide set of stakeholders have an intuitive understanding of risk and the language of risk.[5] The ability to relate environmental problems to a diverse set of stakeholders is crucial to

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[5] The same cannot be said for words such as "vulnerability" or "livelihoods" that have gained highly technical – and at times contested and politically loaded – connotations.

the formulation of remedies and responses to environmental threats. In addition risk management theory emphasizes important principles for managing environmental threats: removing the source, transferring the risk to people or institutions that are better able to cope with it, or increasing coping capacity of exposed parties. These, fundamentally, are the options for managing environmental risk too.

All risk is subjective but environmental risks are particularly subjective. They are the product not only of the magnitude of the environmental "insult" (or impact) but also of the degree of vulnerability of the human or ecological receptor (Kasperson, *et al*., 2001; Liverman, 2001). The same sea-level rise event will impose different risks in different places because some people and places are more vulnerable than others. Environmental risks are also particularly multi-dimensional; they manifest via a multiple of different pathways, generating what Leichenko & O'Brien (2002) (see Figure 5) refer to as "multiple exposures" over extended periods of time. The implication is that a single sea-level rise event can trigger biophysical, social, institutional and economic changes, all of which have the potential to impose risk over extended timeframes. Assessments that report only the immediate biophysical impacts, tend to under-report sea-level rise risks.

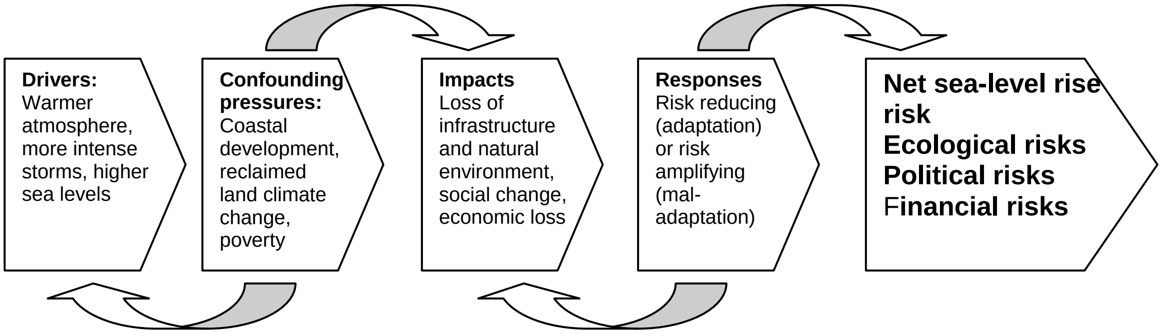

Figure 2: The interaction of sea-level rise risk with ecological, social and institutional conditions (Adapted from UNEP's GEO-4 report, 2007)

There are distinct limitations to providing a single figure in reporting environmental risk. These limitations led Kasperson *et al*., (2005) who were trying to predict the probability of major sea-level rise, to introduce the term "risk interpretation" as opposed to risk analysis.[6] Certainly there can be no single “acceptable” level of sea-level rise risk. On the contrary, environmental risk analyses are facile unless they stipulate, “risk of what”, “risk to who” and “risk when” (Kasperson *et al*., 2001; Nicholls and Tol, 2006).

It should be further noted that unlike certain other risks, the projection of environmental risks is prone to high levels of uncertainty. For sea-level rise this is, in part, due to limited understanding of interactions between atmospheric change and changes in the ocean system and the fact that by definition climate change alters the historic frequency with which environmental risks occur. But uncertainty is chiefly attributable to the innate difficult in predicting the manner in which the various influences on sea-level rise, most notably human propensity to generate greenhouse gas emissions, will react and interact with the physical phenomena of climate change (see Figure 3).

In some quarters this uncertainty is cited as a reason for doing nothing - “scientific certainty before actions” is a common refrain in this context. There is the possibility that an over-reaction will impose costs that may prove unjustified. In reality there can never be certainty with regards to the way in which sea-level rise will impose risks on a diverse population, and the far greater risk is that sea-level rise will be under-estimated. In terms of risk analysis of sea-level rise it is precisely the uncertainty that some people cite as cause for inaction, that amplifies risk. Not knowing, and being unable to know perfectly, is risky in itself.

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[6] “Such an interpretation would include an analysis of what is known about the “threat” or “threats”; including the state of knowledge about both potential consequences and likelihoods of such consequences. It would also include an evaluation of management opportunities for addressing the threats. Of particular importance would be a discussion of the nature of the uncertainties about consequences, likelihoods, and opportunities for mitigation.” (Kasperson *et al*., 2005).

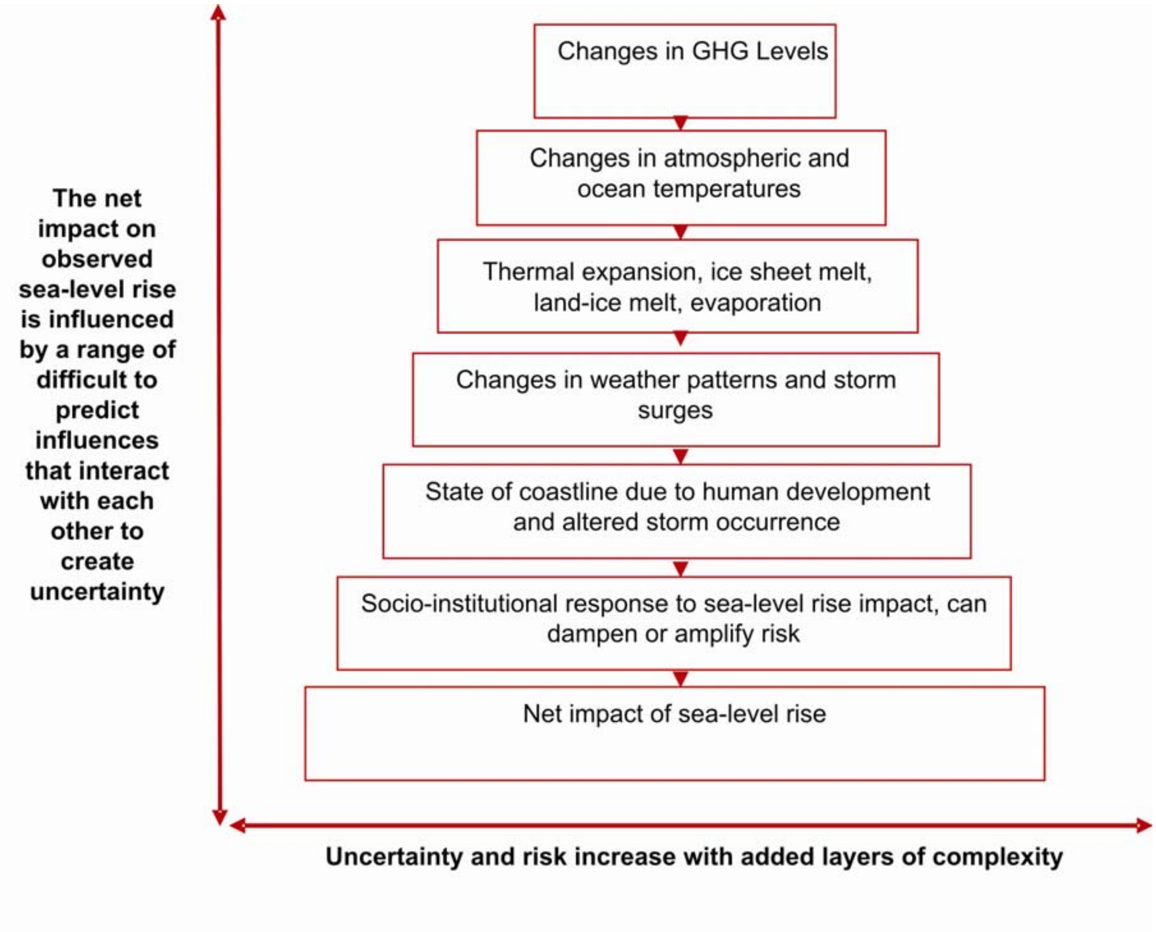

Figure 3: The "cascade of uncertainty" that is a feature of all climate change risks. Some of this uncertainty arises from natural variability while other uncertainty arises from incomplete knowledge (Hulme and New, 2001)

4. APPLYING RISK ANALYSIS TO SEA-LEVEL RISE AND THE CITY OF CAPE TOWN

Conventionally risk is calculated by multiplying the probability of a hazard occurring by the cost of the damage (or “insult”) caused by that hazard. To apply this approach in the case of sea-level rise it is necessary to have a clear notion of what is meant by sea-level rise, to attach a probability to the occurrence of sea-level rise and to anticipate and value the damage caused by sea-level rise.

4.1 Risk of what?

What is modelled in this study is a dramatic change in observed sea level - a “sea-level rise event” - and the physical, biological and social impacts arising from such an event. The understanding is that global warming, in conjunction with increased intensity and abbreviated return times of storms,[7] will give rise to periods in which the “observed sea level” is between 1 and 15 metres higher than the current mean sea level. Typically this event lasts between 1 and 4 hours – corresponding with high tide periods. This surge may be repeated with sequential high tides over a period of two or three days.

This study, initially anyway, draws on the findings of Phases 1 and 2 and models changes in observed sea level in accordance with three scenarios:

- Scenario 1: The present day worst case scenario. It is assumed that this involves a 2.5 metre increase in sheltered environments, a 4.5 metre increase in exposed environments and a 6.5 metre increase in very exposed environments. This scenario

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[7] Evidence of the impact of global warming on the frequency and intensity of tropical cyclones is indeterminate. In 2001 the IPCC claimed, “There is no compelling evidence to indicate that the characteristics of tropical and extra-tropical storms has changed.” More recent studies show that a warming climate will almost certainly affect the intensity of these storms, if not the frequency. The best forecasts for the Cape Peninsula suggest increased ferocity and frequency of south east winds, and particularly the black-south easters associated with cut-off coastal low pressure systems, but no clear changes for the north west and south west winds that are associated with winter storms. What is not contested is that higher mean seal levels will allow storms to inflict greater damage.

would see 25.1 km^2 covered by the sea (1 per cent of the Cape Metro's total area of 2,499 km^2), albeit for a short time.

- Scenario 2: Based on Scenario 1 with abbreviated return times. For the sake of modelling, it is assumed that this scenario involves 4.5 metre sea-level rise event. Such a rise would see 60.9 km^2 (2 per cent of the total Metro) covered by sea for a short period.
- Scenario 3: A 6.5 metre sea-level rise linked to the melting of the Greenland and West Antarctic ice shelves, and involving permanent inundation. This scenario would permanently inundate 95 km^2 of land around the Cape coastline (4 per cent of the total land under the City's jurisdiction).

4.2 Probability of occurring

On any given day the probability of a sea-level rise event causing the impacts described in this report will be quite small. What we know, however, is that extreme high tides tend to be experienced at certain times of year, most notably during the spring and autumn full-moon spring tides. As such the probability of sea-level rise events causing the type of damage described in this report is not evenly distributed throughout the year but clustered around certain, reasonably predictable, times of year. In addition the probability of these events is set to increase as the frequency and intensity of storms increases, as mean sea-level rise increases and as the natural buffers to such events such as beach dunes, sandy beaches and coastal vegetation are progressively destroyed.

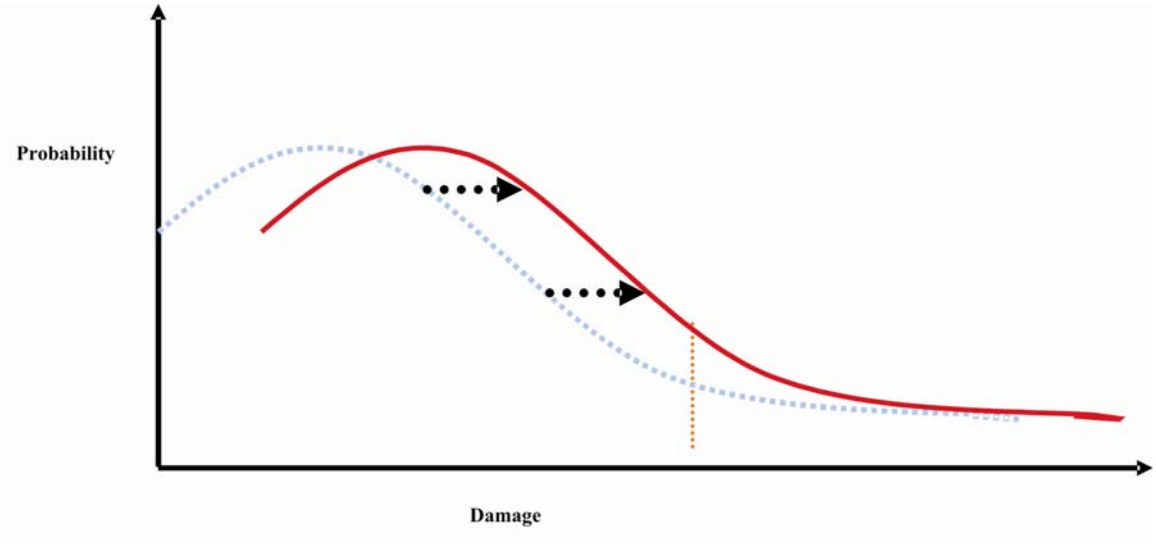

Figure 4: Probability, damage curves for environmental disasters show a typical shape, with a low probability of the very damaging events (right hand tail). Climate change in conjunction with other environmental changes, is expected to shift the sea-level rise damage curve right (from blue to red), implying a greater probability of a given amount of damage (as indicated by the dotted yellow vertical line).

This study, however, does not assume a day by day focus. Instead it is assumed that government is interested in planning for at least a 25 year period. This is the typical period over which fixed infrastructure is depreciated and also the period over which public infrastructure inventories are replaced.

- It is assumed that Scenario 1 has a 95 per cent chance of taking place in the next 25 years. What with increasing mean sea-level and increasing intensity and frequency of storms, it is almost certain that Cape Town will be buffeted by at least one storm with this impact over the next 25 years. During this time it is certain that mean sea-level will be at least 35 cm above the long-term mean – a level that will affect the energy with which wave and tidal surges approach the coast.

- Scenario 2 has been constructed as the likely prevailing scenario in 10 years time, and reflects the current worst case scenario with abbreviated return times. We cannot be sure of exactly how the frequency with which these events occur will be truncated but at the current moment Scenario 2 is assumed to have an 85 per cent probability of occurring in the next 25 years.

- Scenario 3 is linked to longer term drivers associated with the melting of polar ice sheets. Until recently this scenario was considered unlikely this century, but that has changed. It is assumed that Scenario 3 will have a 20 per cent chance of occurring in the next 25 years.

4.3 Anticipating and valuing the economic insult

Having identified what is meant by sea-level rise and attached probabilities to sea-level rise events, the second component of the risk calculus involves anticipating and valuing the impact or "insult" caused by these events.

Different people and institutions will be interested in aspects of sea-level rise impact and will place markedly different values on the affected goods and services. Private property owners will want to know the replacement cost of equipment and property that is likely to be lost in a sea-level rise event. Businesses will be interested in the loss of earnings arising from affected service infrastructure such as roads, ports and power sub-stations. Insurance companies may be interested in the extent of insured losses whilst government might be more interested in the loss of human life, or the extent of uninsured losses and the loss of rates payments from evacuated areas. Conservation groups will want to know the impact on species and their habitats.

As is discussed in Section 5 below, there is a tendency for evaluations of environmental impacts conducted by specific interest groups to mis-report certain impacts, particularly as sea-level rise and the knock-on effects that it causes can be expected to impact over wide spatial and temporal scales. As such cost estimates of environmental impact are prone to a number of biases.

On the one hand some estimates over-stylise impacts and tend to under-report costs. By way of illustration, sea-level rise can cause power outages. Outages undermine business productivity and output. This can be easily quantified and in many instances business have proven effective in keeping financial losses to a minimum. In the longer run, however, the outages affect business confidence and inward investment. They also affect the running of water purification plants and the quality of drinking water, which in turn feed through to human health and labour productivity. These knock-on effects can be difficult to attribute and are very seldom included in sea-level analyses in spite of their significance.

The second common mistake in environmental risk analysis is to confuse replacement costs - the cost of replacing a house or a road - with economic loss. After the Durban 2007 sea-level rise event, for example, Smith *et al.* (2007) reported a "provisional repair bill in excess of R1 billion; in some quarters this is being erroneously cited as the economic impact. The correct way to report economic impact is via the net impact on the economy (usually measured by gross geographic product). A road that is washed away and rebuilt may cost the local or provincial government R100 million, but the economic loss incurred, arises from reallocating the money required for road building away from its previous use to a road construction company. Economists refer this loss as the "opportunity cost" of an environmental incident. Opportunity costs provide the correct economic basis for assessing environmental damage, and in most instances are less than financial costs.

Finally, whilst impact on gross geographic product is the most widely accepted way of measuring economic impact it fails in some instances to capture the loss of those social and environmental assets that are not traded in economic markets and are not recorded in national accounting sheets (not least of which involves the loss of life). Social cohesion affects the cost of doing business and the desirability of living in a region, but can be difficult to quantify. Coral reefs, marine biodiversity, wetlands and coastal landscapes provide important components of the larger environment and contribute to the stability and functioning of the environment as a whole. They also contain intrinsic value linked to their heritage, aesthetic, psycho-emotional and spiritual contributions that are very specific to individuals but not captured by conventional analyses and estimates of gross geographic product.

In trying to take these issues into account this study first focuses on the more easily quantified economic impact of sea-level rise and then in Section 5 (below) seeks to expand on the discrepancy between this narrow value and the broader economic values mentioned above. In determining narrow economic impact the study relies on a collection of three proxy values – measures that represent economic loss:8

The first proxy value applied is the loss of real estate as the coastline becomes increasingly exposed to storm surges and existing properties are damaged and vacant land becomes both uninsurable and undesirable for development.

The City of Cape Town's coastline has attracted considerable investment in coastal property over the past century and the past 15 years in particular. Coastal locations, particularly those with sandy beaches such as Blaauwberg, Llandudno, Hout Bay, Kommetjie, Glen Cairn and Strand, have been at the forefront of this development. Not all of this investment and development is in accordance with environmental legislation. The City enforces legislation prohibiting residential development within the 50 year flood line and industrial development within the 100 year flood line. These flood lines incorporate the changes that have been observed in mean sea-level rise to date, but in some instances planning oversights and historical anomalies have afforded land owners the right develop with the threatened areas.

Under a 6.5 metre sea-level rise situation, it is estimated that the Cape Metro would lose 95 km2 of land. The figures for 2.5 metre and 4.5 metre rises are 25 km2 and 61 km2 respectively. Not all land lost to sea-level rise is private property. Based on the aerial photographs it is estimated for the purpose of this analysis that 7 per cent of the land impacted by a 2.5 metre event is privately owned, 11 per cent of the land affected by a 4.5 m rise and 18 per cent of the land affected by a 6.5 metre rise, is privately owned (much of it on the False Bay coast). The City of Cape Town has valued all property within the metro for the purpose of collecting rates. The value of private property, as

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[8] Net economic loss is usually determined by a social accounting matrix (SAM), a dynamic model of a region's economy. In the absence of a SAM, this study makes use of proxies.

reflected in the rates register, ranges between R15,000 per square metre (more in a few instances), to a R100 per square metres (and less in a few instances). The study divided coastal land into three value ranges: 0-R1,000/ m2, R1,000-R3,000m2 (the range into which most private property falls) and R3,000-R15,000/ m2. Most of the land adjacent to the beach is "crown land" and under the jurisdiction of the national government, but as a sea-level rise event encroaches, the proportion of land under private ownership increases and more of the affected land is prime coastal real estate. As sea-level rise affects an even wider extent of property the average value of this real estate actually comes down slightly. Applying weighted averages to all land, the average price of land affected by Scenario 1 sea-level rise is assumed to be R1, 860/ m2, Scenario 2 - R2,900/ m2, and Scenario 3 – R2,600/ m2. Drawing on these values it is possible to estimate private property loses at R3.2 billion, R19.5 billion and R44.5 billion for Scenario 1, 2 and 3 respectively, around the Cape Town coastline.

Table 2: Loss of real estate along the Cape Town coast under 3 modelled scenarios of sea-level rise

Scenario	1	2	3
Km^2 affected	25	61	95
% of affected land that is private property	7%	11%	18%
Weighted average value of affected property (R/m^2)	1,860	2,900	2,600
Total value of lost real estate	R 3,255,000,000	R 19,459,000,000	R 44,460,000,000

The second proxy variable applied in this analysis is foregone tourism revenue. The Cape's coastline and beaches contribute to the City's tourism appeal. In a "word association exercise" conducted by the Western Cape Tourism Board on foreign visitors in 2006, the term "beautiful, white, sandy beaches" was the second most readily associated phrase with the Cape ("beautiful" which almost certainly includes a reference to the beaches, was the most popular). The Cape receives just over 20 per cent of foreign tourists entering the country but benefits from almost a third of the total tourist spend, suggesting that some visitors flying into Johannesburg target the Cape’s coastline in their itinerary.

Both mean sea-level rise and storm surges affect coastal infrastructure including access infrastructure such as roads, the nature of sandy beaches and the aesthetic appeal of the coastline. Not all coastal tourism will be lost to sea-level rise. Some coastal tourism such as fishing and boating can be expected to shift with the encroaching shoreline, and some of the tourism expenditure that will be lost will be compensated for by expenditure inland. However over a 25 year period narrow beaches such as Boulders may become inaccessible for large parts of the daily tide cycle, while sandy beaches such as Camps Bay and Llandudno may become increasingly rocky as wave erosion intensifies, and prone to storm and waste water spillages as the City’s infrastructure becomes inundated. There is a very real possibility that the allure of the Cape’s beaches will be diminished. As such the net loss of tourism income to the City, serves as a reasonable proxy of lost economic impact resulting from sea-level rise; certainly the KwaZulu Natal coast has experienced tourism losses in the wake of the 2007 storm and a number of beaches along this coastline lost their “blue flag” status.

In 2006 foreign tourist expenditure in the Western Cape totalled R19.80 billion, while domestic tourism receipts were R1.50 billion. The forecast for 2008 for total tourism revenue is R24.00 billion. For the purpose of this study it is assumed that Scenario 1 would account for a net 3 per cent decline in tourism revenue, Scenario 2 a 6 per cent decline and Scenario 3, which involves widespread inundation, would reduce revenue by 15 per cent. Based on 2008 figures this would represent a loss of R720 million, R1.44 billion and R3.60 billion per annum for the three scenarios respectively. In this analysis these figures are imputed on a per annum basis, the implication being that the tourism sector would be able to recover within that year and restore its revenue streams by the following year. This may not be the case. Critically, sea-level rise has the potential to curtail what is a major growth industry for the City of Cape Town by knocking the industry onto a lower trajectory and ensuring accumulated losses every year. This scenario is not modelled in this analysis.

As a third proxy, the cost of replacing certain public infrastructure that could be damaged by sea-level rise was included. The City is not responsible for all infrastructure within its boundaries. The Cape Town harbour[9], for example, is the responsibility of national government, but the City is both responsible for and dependent on much of the infrastructure that is particularly vulnerable to sea-level rise. Storm water infrastructure, electricity distribution infrastructure and municipal transport lines are used in this study to represent the fiscal impact imposed by sea-level rise. In the 2008/9 financial year the City budgeted for an investment of over R1.70 billion in this type of service infrastructure. Of potential concern from a sea-level rise perspective is the R50 million that has been set aside in this period for the Strandfontein road and the R68 million that is to be invested in the Roggebaai major sub-station – two pieces of infrastructure that will be increasingly exposed to sea-level rise. Admittedly these two pieces of infrastructure are also firmly embedded in the communities that they serve and would be difficult to relocate, but ideally future infrastructure investment would take sea-level impacts into account.

The depreciated value of the City's storm water infrastructure was recently valued at R4.20 million excluding natural rivers and unlined channels. The replacement cost of this infrastructure is R11.15 billion (SibaCon, 2006). The City's stormwater infrastructure drains into the sea, and a high proportion of the stormwater infrastructure is located along the coast. This infrastructure is designed for flooding, and is likely to stand up reasonably well to the impacts of sea-level rise; the chief impacts are likely to arise through failure of the services of this infrastructure which is dealt with in Section 5 (below). Based on the available evidence, this study assumes that Scenario 1 would require 1.5 per cent of the City's stormwater infrastructure to be repaired, relocated or modified at a cost of R167.32 million. Scenario 2 would account for 3.6 per cent (R408.25 million) and Scenario 3

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[9] The Cape Town harbour is managed by Port Terminals and the National Ports Authority, both of which report to TRANSNET. The port is critical to a number of rapidly expanding supply chains that stretch across the SADC region. The port is in the process of a R4.2 billion upgrade to its container terminal.

would require reconstructing 5.7 per cent of the existing infrastructure at a cost of R635.80 million.

The replacement value of the City's 10,000 kilometres of road transport infrastructure is estimated at R60 billion - roughly R5 million per kilometre per carriage[10] (McDonald pers. comms.). The annual maintenance budget for these roads is a paltry R200 million, some of which comes from rates and some from loans. The City is responsible for the N1 road up to the Salt River interchange. Whilst raising roads provides some buffer against sea-level rise, and an upgrade involving a 150 mm raising of the N1 at Parden Island has been budgeted for, the extent to which roads can be raised is limited by the existing height of bridges and the clearance required for freight trucks. Raising the height of bridges involves a prohibitive expense. A sea-level rise event is unlikely to affect the entire Cape Town coastline at the same time, neither is every sea-level rise event likely to completely destroy the roads it impacts. For the purpose of this study, it is assumed based on aerial photographs and the proportions of land affected in the GIS model, that a Scenario 1 event would require the replacing of R900 million worth (1.5 per cent) of the City's roads, a Scenario 2 event R 2.197 billion (3 per cent), and a Scenario 3 event – which is associated with longer and more damaging inundation periods – R 5,702 billion.

The City of Cape Town is licensed to supply electricity to 2,500 square kilometres of the peninsula and adjacent area. ESKOM is responsible for providing and servicing the necessary infrastructure, but it is the City and the City's clients and businesses that depend on this electricity. The City of Cape Town's energy unit has already modelled the impact of a 7 metre sea-level rise, and used this model to ascertain that at this level 5 (20% of total) of its high voltage switching stations[11], 7 main sub-stations (9% of total), 108 distribution sub-stations (12% of total) and 553 (7% of total) unprotected sub-stations would be affected.

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[10] Dual carriageway doubles the cost.

[11] 7 stations located at Roggebaai, Muizenburg, Steenberg, Foreshore, Koeberg Road, Jan Smuts Drive and Strand.

The City applies a depreciated book value of R1.70 billion to its energy infrastructure, although replacement value is closer to R9.40 billion excluding the high voltage underground cable feeders which are assumed (conservatively perhaps) not to be affected by sea-level rise. It is assumed, again based on the GIS model and aerial photographs, that Scenarios 1, 2 and 3 will affect 1.00%, 2.43% and 3.80% of the above surface energy infrastructure, respectively. Based on these assumptions the potential replacement cost of affected above-surface energy infrastructure is: Scenario 1 – R94.8 million, Scenario 2 – R 230.2 million, Scenario 3 – 358.9 million.

There is some overlap between the economic impact of the three proxy variables. Loss of public infrastructure such as electricity sub-stations and the associated energy, for example, affect private property values, and a booming tourism revenue is good for real estate values. Correlations between variables raises the potential for double counting of impacts, but the three proxies have been chosen to provide as wide a capture of the economic impacts as possible without too big an overlap. There are also some gaps; the proxies do not capture all impacts. In general it is considered that the proxies under-report economic impact than over-estimate it. Provided the values produced are seen as being indicative, and not definitive or precise, they are useful.

The value of the risk is estimated via the formula that multiplies the probability of the respective Scenario 1-3 sea-level rise events respectively by the sum of the damage inflicted by the respective events. Damage is captured by the three proxy variables (i) the sum of private property loss, (ii) the loss of tourism revenue and (iii) the loss of public infrastructure.

$\mathbf{R_e} = \boldsymbol{f_e}\sum$(loss of private property value+ loss of tourism revenue + loss of public infrastructure)

Where $\boldsymbol{f_e}$ represents the probability of a sea-level rise event e, where “e” is a sea-level rise event as described in Scenarios 1-3.

4.4 Results

Applying this approach, the value of the property, tourism sector and infrastructure at risk in Scenario 1 is R5.2 billion and the risk of this Scenario occurring is valued at R 4.9 billion.

The value of the property, tourism sector and infrastructure at risk in Scenario 2 is R23.7 billion and the risk of this Scenario occurring is valued at R20.2 billion.

The value of the property, tourism sector and infrastructure at risk in Scenario 3 is R54.8 billion and the risk of this scenario occurring is valued at R11.0 billion.

The risk estimate for Scenario 3, which would clearly be more damaging than Scenarios 1 and 2 if it were to occur, is lower than the risk estimate for Scenario 2 due to the lower probability of its occurrence in the next 25 years.

The estimated costs of sea-level rise risk should be compared with the 2008 GGP for the City of Cape Town of R165 billion.[12]

It should be noted that the City is unlikely to be confronted by either the full extent of these costs in a single sea-level rise incident; that would require the simultaneous rising of the sea at all points around the coastline and we know that sea-level rise events tend to be localised. Rather, the figures represent the cumulative risk and costs over a 25 year period at all points along the coast.

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[12] Based on 2006 figures of R123.6 billion

Table 3: Summary of assumptions and estimated risk to the Cape Town coastline

	Assumed probability of occurring in the next 25 years	Value of real estate at risk	Value of tourism revenue at risk	Value of public infrastructure at risk			Total potential cost to the City	Value of the risk to the city
				Stormwater	Roads	Electricity		
Scenario 1	0.95	R3,255 billion	R750 million	R167.3 million	R900 million	R 94.8 million	R5,167 billion	R4,908 billion
Scenario 2	0.85	R19,459 billion	R1.44 billion	R408.25 million	R2,197 billion	R230,2 million	R23,734 billion	R20,174 billion
Scenario 3	0.20	R44,460 billion	R3.60 billion	R635.80 million	R5,702 billion	R358,6 million	R54,756 billion	R10,951 billion

The figures reported above are highly assumption dependent but are considered reasonable estimates. Given the relative magnitude of the economic impact the estimates provide grounds for concern and action. As projections they are posited tentatively, with due acknowledgment of their dependence on the stated assumptions, in order to allow for comparisons and to provide an indication of the magnitude of the threat.

The reporting of environmental costs in this way allows for easy misinterpretation of the nature of the threat. It might be assumed, for example, that if enough money to cover the reported costs could be raised, that the problem of sea-level rise could be averted. Similarly aggregated figures, by concealing information on the way in which risks manifest over time and space, can conceal much of the information that is potentially important in formulating adaptation and mitigation strategies. These are widely acknowledged limitations to the application of conventional risk calculus to the threat imposed by environmental risk (Hoozemans *et al*. 1993, Nicholls and Mimura, 1998, Darwin and Tol, 1999, Nicholls *et al*., 2004, Nicholls and Lowe, 2006). For this reason, the impact of sea-level rise on the City's coastline between Melkbos and Cape Town port is studied in more detail in Section 5 below.

5. DETAILED RISK ASSESSMENT – MELKBOS TO CAPE TOWN PORT

The conventional risk approach applied above suggests that the threat of sea-level rise risk to the region between Melkbos to Cape Town can be valued at R516 million for Scenario 1, R7.607 billion for Scenario 2 and 4.496 billion for Scenario 3.

The reporting of these estimates is based on proxies that are intended to represent the type of impact that will be incurred and timescales over which these impacts manifest. What this approach misses is some of the descriptive insights into how sea-level rise risks manifest over time and space. It also fails to properly reflect the way in which these risks interact with, and are often compounded by, each other and existing socio-economic conditions. Sea-level rise events will affect people, governments, the environment, the economy and the interactions between these entities (Nicholl, 1994).

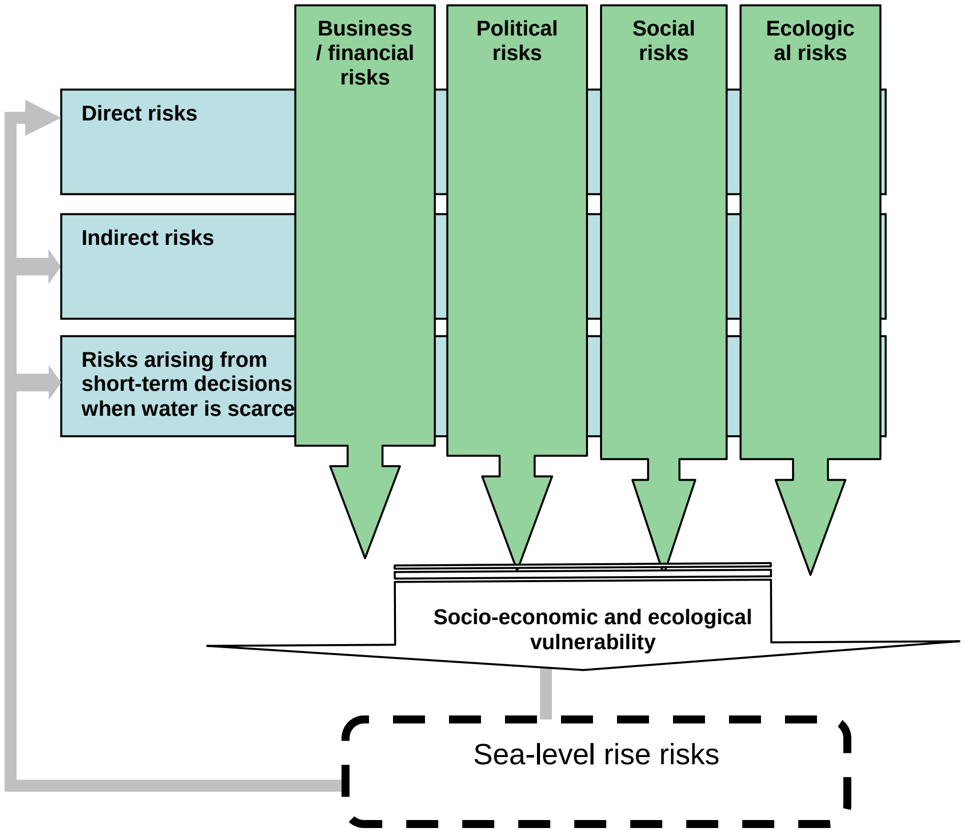

Figure 5: The interaction of biophysical risks with social, institutional and other ecological risks, over time and space. This is what Leichenko & O'Brien (2002) refer to as "multiple exposures"

The focus below is on the 55 kilometres of coastline between Melkbos (inclusive) and the city's port (exclusive). The topography of this region in conjunction with the extent of relatively new residential and commercial coastal developments, makes its particularly vulnerable to sea-level rise events. Just under 40 per cent of all land that is impacted under the three projected scenarios occurs within this coastal strip. This more detailed study makes a deliberate effort to consider the broader ramifications of sea-level rise over and above the initial impacts. To this ends the focus is on the:

- Direct biophysical impacts and risks.
- Induced risks that arise as a result of this biophysical impact, including the risks that are incurred via the market, via governance systems and through societies reactions to these events.
- Mal-adaptation risks that are incurred, often inadvertently, in attempts to respond to the biophysical and resultant risks. These risks include opportunistic and short-termed actions in the wake of sea-level rise incidents.

Figure 6: Aerial photograph of the coastline Melkbos to the port showing the inundation that would be caused by a 2.5 (blue), 4.5 (red) and a 6.5 (orange) sea-level rise event.

5.1 Direct risks

The direct risks of sea-level rise are among the easiest to identify and attribute. These include the losses of infrastructure and the built environment, damage to beaches and other amenities and changes to natural water resources.

Infrastructure risks: Small shifts in sea-level rise could have large ramifications for existing infrastructure (Auld & McIver, 2005), especially when changes in sea-level rise act in conjunction with other climate change stresses such as river flooding and increased winds.The sea-level around the Cape Town coastline was 2-5 metres higher than the current level some 130,000 years ago, a period that coincided with warm atmospheric and sea temperatures. It was during this period that the 'wave cut platform' which is now a feature of the Cape Town coastline was created. The platform has provided a convenient contour for road and rail transport routes and for bulk infrastructure such as sewerage pipes and electricity cables. Of particular infrastructural and biophysical importance in this region:

- A 2.5 metre rise in sea-level would, at the most basic level, reduce the land available in the zone between Melkbos and the Port by just under 10 km^2, with a real estate value of R1.3 billion. Similarly a 4.5 metre and a 6.5 metre rise would diminish the extent of available land by 23 km^2 (R7.3 billion) and 35.9 km^2 (R18.3 billion) respectively. The reclaimed areas of Parden Island and Salt River, both of which contain commercial and industrial property and both of which have been earmarked for intensive "mixed-use" development, are particularly vulnerable as they tend to be low-lying and on unstable land that erodes quickly when exposed to wave action. Apart from the loss of real estate, much of this land has been settled in recent years with houses and with commercial buildings. Whilst a single sea-level rise event would not necessarily ruin these buildings it would certainly damage them, make them less desirable and reduce their market value.

Figure 7: Damage to private property and tourist beaches following the KZN sea-level rise event of 2007 (Source: S. Bundy in A.A Mather).

- In the coastal zone between Melkbos and the Port, the roads of Marine Drive, Otto du Plessis and the N1 at Parden Island are particularly crucial for commuters. Marine Drive would begin experiencing flooding at sea-levels 1.5 metres above the current level and be almost completely inundated by 4 metres. The N1 at Parden Island is affected by sea-level rise of 2.5 metres and inundated at 4 metres. Otto du Plessis is relatively high, but would experience significant flooding at sea-levels 5 metres above the current level. Sections of Marine Drive and the N1[13] are on reclaimed land, land that has been protected from the sea by “dolosse”. These roads have been damaged by storm events in the past. The metro’s higher order roads are all designed to self-drain in the event of flooding, and in the past instances the road has been repaired with only minor disruptions to traffic. Most of the higher order roads are capable of withstanding a day or two under water, especially where these roads are not used while flooded (McDonald, pers. comms.). The danger is that future mean sea-levels in conjunction with more intense and frequent storms will expose these roads to longer flooding periods with increasingly abbreviated return times. Where this is the case, the City’s current road maintenance budget (which is roughly ten times below the internationally accepted norm), could be exposed as being inadequate leading to a dramatic decline in road quality.

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[13] The City of Cape Town is only responsible for the N1 up to the Salt River interchange, but the N1 is of critical importance to the functioning of the City.

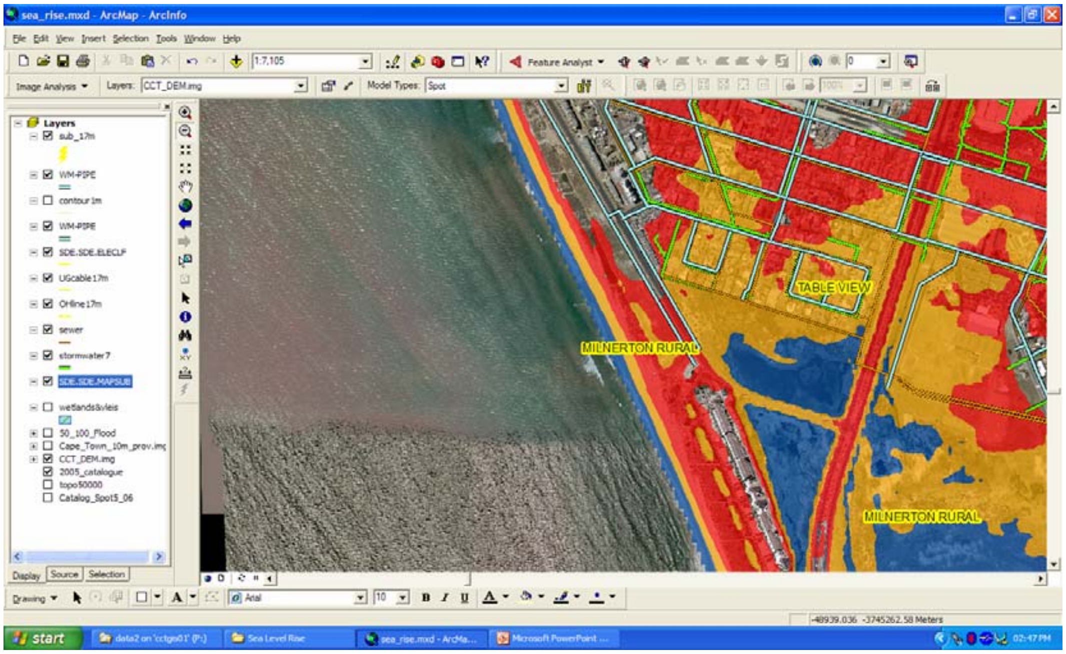


Figure 8: Modelled impact of scenario 1 (blue), 2 (red) and 3 (orange) sea-level rise, and the associated impact on the Milnerton coast

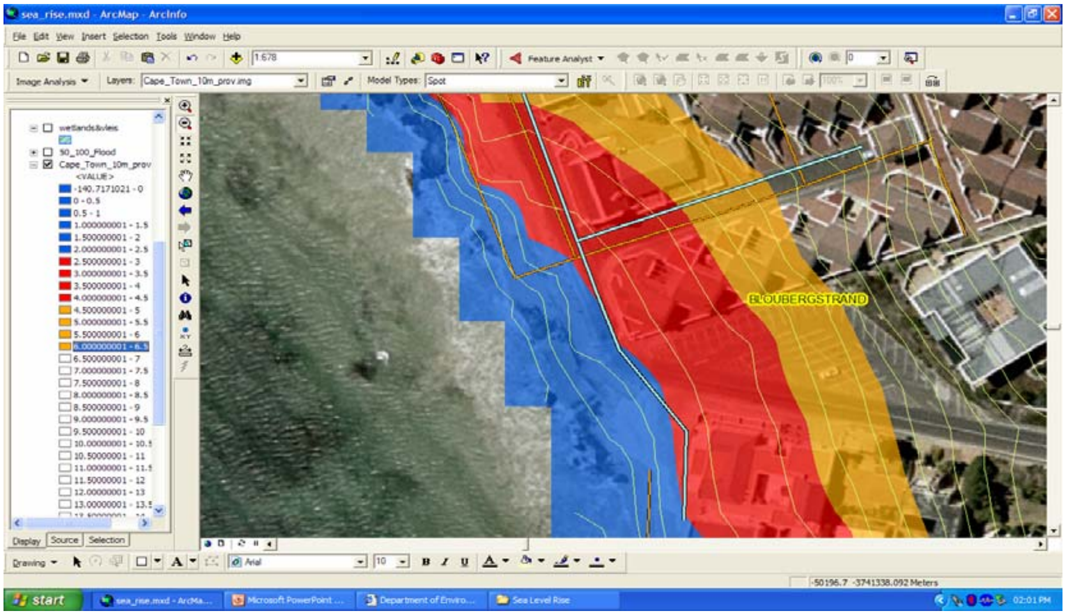
Figure 9: Damage to coastal roads cause by the KZN sea-level rise event of 2007 (Source A. A Mather)

- A rapid bus route has been planned along the former railway line between Table View and the city. Together with the planned "densification" of development at Parden Island and Salt River, this will require public investment in bulk infrastructure – bulk water piping, electrification and road development – in a region of the Metro that has been earmarked for future development but which is also low lying and partly on reclaimed land. The bus route and "mixed-use" property and associated public investment would be jeopardised by sea-levels in excess of 2.5 metres.

- The area directly inland of the coast between Melkbos and the Port is cluttered with service infrastructure, including bulk water pipes, waste water pipes, storm water drains, power cables, energy sub-stations. As population increases in this zone, so too does the demand for these services. A sea-level rise event of 4 metres would expose much of this infrastructure to direct sea-damage including the back-flooding and silting up of stormwater drains, the corrosion of sub-stations and the potential exposure and breaking of bulk water pipes. The three sub-stations that support Woodbridge Island, for example, would be flooded by sea-level rise events in excess of 3.5 meters.

- The Caltex Refinery is located on this stretch of coast. The refinery itself would require a rise of over 5 metres before its operations were threatened, but the refinery relies on a pipeline that at points runs 2 metres above sea-level for receiving its oil from the port. The pipeline can be filled with sea-water at times of high risk in order to avoid oil spills, but is at risk of being damaged by a sea-level event in excess of 2.5 metres and by wave action associated with such an event.

Beaches and amenities: Damage to beaches and natural amenities is a common result of sea-level rise. The coastline between Melkbos and the Port does not contain the peninsula's premier tourist beaches, but damage to Blaauwberg Beach and the dunes that protect the coastline both north and south of this beach would nonetheless affect tourism and the general environment that attracts tourists to the Cape.



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Model Types: Spot

Arial 10

-50196.7 -3741338.092 Meters

Figure 10: Modelled impacts of sea-level rise at Blaauwberg Beach, showing the potential for erosion, loss of the beach amenity and damage to infrastructure

- Sea-level rise tends to be associated with disproportionate levels of erosion.[14] A sea-level rise event would almost certainly exacerbate the episodic loss of sand from Cape beaches. The prevailing trend, driven by construction that impedes the natural flow of sand around the coast, is already one of increasing beach erosion. The physical constructs that make up Cape Town Port are known to affect the transport of sand to beaches on the Atlantic coast, while settlement of the Cape Flats prevents sand from this region replenishing beaches to the north during summer winds. On the coastline between Melkbos and the port further losses of sand would see rocks exposed on previously sandy beaches such as Big Bay. It would also see the sand dunes being reduced in height and width. The combined biophysical effect would be a loss of aesthetic and amenity value to the beaches on this stretch of coastline.[15]

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[14] The eThekwini (Durban) coastline lost an estimated 3.5 million cubic metres (5.2 million tons) of sand as a result of storm erosion (Smith, et al., 2007). In the UK coastal erosion is set to increase between 3 and 9-fold by the year 2080 (King, 2007).

[15] Where sand dune sand is transported to an off-shore sandbar as is often the case this would dissipate wave energy and ameliorate the erosive effects of sea-level rise.

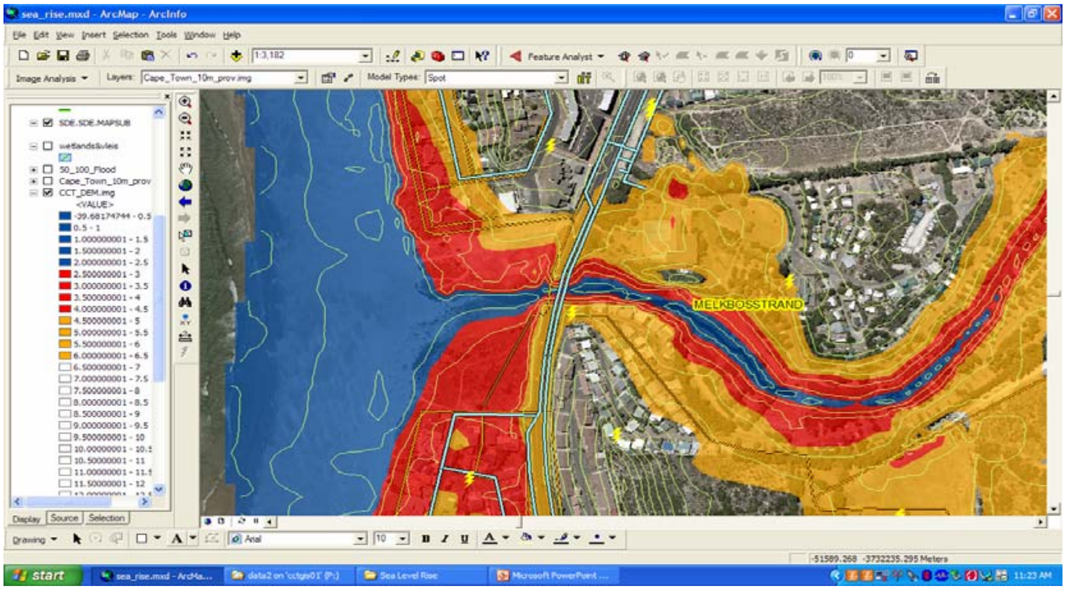

Figure 11: Loss of beach, coastal amenity and infrastructure at Melkbosstrand under 2.5m (blue), 4.5m (red) and 6.5 m (orange) sea-level rise scenarios

- Sandy beaches and sand dunes, apart from being a tourist attraction and a component of Cape Town's natural heritage, provide a key component of the natural defence to sea-level rise. Much of the region between Melkbos and the Port is protected by a sand dune cordon at the back of the existing beach (see Phase 2). These dunes range between 2 metres and 7 metres in height and 3 metres and 100 metres in width and as such offer a natural buffer against intermediate sea-level rise events. Repeated and more intense erosion of these dunes from storm and high-sea conditions is likely to result in these dunes being breached, a contingency that would see the land and buildings interior to these dunes being exposed to direct wave action. Phase 2 of this study shows, for example, that 4.5 metre sea-level rise event would breach the dune protecting Woodbridge Island and damage property on the interior of Milnerton lagoon.

Water resources: Sea-level rise will alter the physical and chemical nature of estuarine and freshwater resources.

- From a water resource perspective, a critical part of this coastline's interior includes the Milnerton Lagoon and Rietvlei wetland. The wetland is connected to the sea via the water table and via the Diep River. Rietvlei is segmented into a zone that is used for recreation purposes and a conservation area. Sea-level rise has the potential to expand, even enhance, this wetland in the medium-term. In the short-term infiltration will result in habitat disruption and a loss of biodiversity. Given the known anthropogenic pressures, including pollution, encroachment and disruption of hydrological flows, that Rietvlei is under, a disruption presents the risk of an irrevocable collapse of the ecosystem. A similar scenario is likely in the Milnerton Lagoon. The lagoon provides an important spawning ground for Atlantic fish species[16] and is connected to Rietvlei by the Diep River. Sea-level rise may ultimately increase the size of this lagoon and linked wetlands, but would simultaneously increase the salinity of the water resource. Altered salinity in conjunction with existing pressures could result in collapse of the ecosystem in the short term and the ultimate emergence of an ecosystem that is far less biodiverse (Holling, 1973).

- A rise in sea-level would also increase the salinity of the groundwater under the west coast interior – the so called "Atlantis Aquifer". The dynamics that govern the flow of this aquifer are not perfectly understood. The aquifer is known to be 'brak' already (some of this salinity is from the bedrock that surrounds the aquifer), but an encroaching sea would increase this salinity. The aquifer remains the exclusive source of water for a number of small-holder agricultural enterprises east and north-east of Melkbos. The impact of sea-level rise on groundwater salinity could make

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[16] The lagoons contribution as a spawning habitat has been reduced by pollution.

some of these areas non-arable and possibly uninhabitable even without them being inundated.[17]

- Cape Townians generated an average of 702 kilograms of solid waste per capita in 2005 (Coetzee, 2006) and this waste is very poorly sorted to remove harmful content. The City of Cape Town's largest solid waste disposal site, "Vissershok", is located north east of Milnerton. The site is sealed with clay only, no membrane, and leaches landfill chemicals and dioxides especially in the winter months. A sea-level rise event would raise the water table under this solid waste site and accelerate the existing leaching and the dispersal of contaminants into groundwater.

5.2 Induced risks

Less obvious than the biophysical risk, sea-level rise is likely to have a range of implications that themselves present risk. This "induced risk" is not always attributed to sea-level rise in peoples' minds, but where biophysical events impact on economic and social systems they lead to changes, some of which are adverse.

It is typically the concatenation of sea-level rise risks with existing problems and vulnerabilities (including vulnerability to other climate change impacts such as droughts, fires and floods) that is most damaging. To a certain extent this vulnerability to sea-level rise is indexed by socio-economic status. Poor and marginalised communities around the Cape coast, that lack livelihood options, should be recognised as being particularly vulnerable to the multiple effects of sea-level rise (and climate change in general). In this sense, super-imposing the information contained in Figures 12a and 12b on the coastal inundation models presented in Phase 2 can provide foresight into the locations where

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[17] A similar risk is prevalent in the Cape Flats region. The groundwater that is a feature of the Cape Flats in the winter months rests on a clay lens, and is not directly connected to the sea. Much of the Cape Flats is 6 metres and more above sea-level. The salt content of the Cape Flats, which in some places is already as high as (18,000 mg/ L TDS) is a function of the salt lens deposits formed during the deposition of these sands. However sea-level rise could result in further saline infiltration of this groundwater, by leaking through fissures in the clay lens.

sea-level rise is likely to have the most devastating impact. Those communities with low socio-economic status and high exposure to sea-level rise should be seen as particularly vulnerable. Conversely, households and companies with access to social support structures and financial reserves, tend to survive environmental change better than those that are poor or marginalized. However, the ability to cope with and survive sea-level rise events should not be confused with the notion that the affluent will be somehow insulated from these events. In some instances those families and businesses with the most assets are precisely the ones that stand to lose the most, particularly where these assets are sunk into immovable coastal infrastructure or where business activities are directly dependent on environmental goods and services (Ionescu *et al*., 2007).

The following induced risks are considered pre-eminent in the Melkbos to City of Cape Town Port zone given a sea-level rise event.

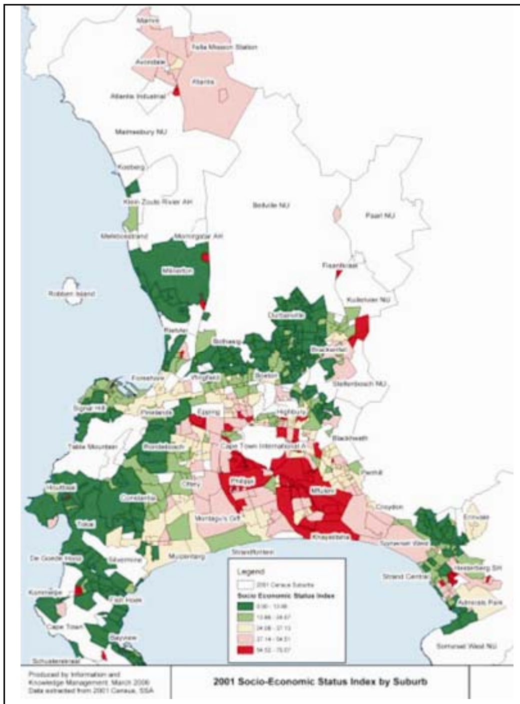

Figure 12a: Socio-economic status of Cape Town's suburbs (Source: IDP, 2006)

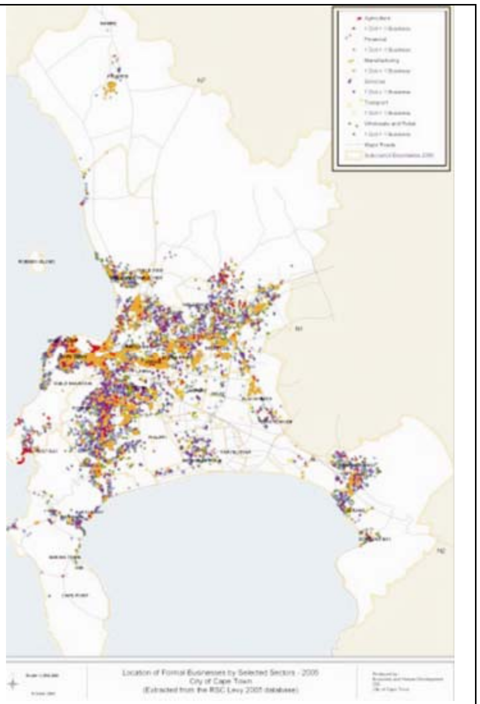

Figure 12b: Distribution of Cape Town's businesses by sector (Source: IDP, 2006)

Compounded flooding risks and disruption of services: The impact of a two and a half meter rise in sea level would be, in many ways, similar to two and a half meter rise in storm flood levels. The City of Cape Town invests R50 million annually on flood prevention capital, deploys an additional R80 million on maintenance of existing structures, and is reasonably adept at managing this type of flood. It is highly likely, however, that the type of storm surge that would cause a sea-level rise event would be accompanied by heavy precipitation. In this instance the built and natural environment would have to cope with the compounded pressure of water from the ocean meeting water from inland systems. Where, for example, the sea-level rise impact along this stretch of coastline negated the natural flood buffering capacity of the Rietvlei wetland and Milnerton Lagoon, this would dramatically increase the impact of the flood on the surrounding environment.

One implication would be the failure of the City's gravity operated stormwater drains due to the back-flooding of these systems. Almost all of the Peninsula's drains operate under a gravity system. High sea-levels, in conjunction with sand that is transported by the sea and which clogs stormwater drains, prevents this system from draining and causes localised flooding upstream. The City's stormwater system is deliberately designed to spill excess water into the streets. Cape Townians living in certain parts of the City are accustomed to the disruption caused by flooded streets at certain times of year – a disruption that has been aggravated in places such as Barclay Road, Maitland – by power outages and the failure of the few energy dependent drainage systems. The problematic impact would come where larger than normal areas became inundated on a more regular basis providing for more than a simple inconvenience to traffic and escalating the need to repair and maintain roads. In these instances communities might find their transport routes cut off. The situation would also expose the few locations in which the City's stormwater and waste water systems remain inadequately separated, raising the prospect of sewerage spills into streets. Where extensive flooding was repeated regularly, this would lead to water borne disease and create a safety hazard.

Insurance: As the impacts of sea-level rise and coastal flooding become apparent, the cost of property insurance for all Cape residents will increase and some households and companies may decide to remain uninsured. Property that is clearly exposed to flooding will become uninsurable. The inability to secure insurance will in turn undermine the ability to raise finance against properties in the region and in general will contribute to a down-turn in property investment.

Loss of tourism resources and revenue: The Cape coastline is a key drawcard in the City's rapidly expanding tourism sector, but the tourism market is competitive and volatile. Repeated storm damage in conjunction with a decline in investment in the coastal zone will see affected tourist attraction lose revenue to those that are not affected and those that are located inland.

Rates base: A decline in property and tourism investment will be accompanied by out-migration from the affected zones. The combined effect will be reduced ability to raise rates from the affected area, and the need to cross-subsidise fiscal investment from other regions. This in turn will affect the maintenance of City infrastructure at a time, ironically, when there will be a heightened demand for such maintenance due to accelerated weathering.

Disrupted economic services: The temporary flooding and inundation of City infrastructure caused by sea-level rise, will disturb the flow of people and goods that sustain the City's economy. The area between Melkbos and the Port has experienced a rapid densification of residential properties in the past 10 years. This in turn has placed pressure on the waste water, storm-water and energy distribution network, not to mention the transport routes that feed these areas. Whilst sea-level rise might cause some outmigration from the worst-affected margins of this area, much of the public infrastructure that does exist is so embedded within the societies and built environment that it serves, that moving it would be implausible. Of particular concern in this regard is the Potsdam wastewater works. The works rely on 47 MWh of power to operate (and are due to be upgraded to 110 MWh) and located on the north east edge of Rietvlei. The waste water works would be flooded if the sea rose by 6 metres, but could be damaged by moderate sea-level rise if this was combined with heavy rainfall and flooding of the Diep River. Combined inflows from the sea and the Diep River would see the Rietvlei wetland expand rapidly. Together with the Melkbos Sewerage plant which is similarly exposed the water works service sixty five thousand households. Inundation of the Potsdam waste water works, which includes waste water ponds, could lead to sewerage spills into the region's streams and water resources. Such contamination would cause eutrophication and disease. A similar scenario is likely to emerge at the same time in the Parden Island, Milnerton and Saltriver region, much of which is reclaimed land. Where waste and sewerage water systems were overtopped, sewerage spillages into the Salt River would be inevitable.

Relocated infrastructure: Infrastructure – roads, stormwater pipes, sub-stations – that are damaged by sea-level rise have to be replaced, protected or relocated. Much of this infrastructure is very difficult to relocate – stormwater drains for example are buried in the City of Cape Town's underground infrastructure. Whether the best option is to "hold the line" and protect infrastructure or relocate it, some form of additional construction is typically required. Construction of physical infrastructure poses risks of its own. The relocation of Baden Powell Drive, for example, has been delayed by concerns over the environmental impact that the relocation would impose on the environment in the proposed site. Similar concerns would be encountered if Marine Drive or a section of the exposed N1 were to be relocated, especially given their proximity to sensitive wetlands and high density residential areas.

Fiscal reallocations: Whether it is via the need for a stronger disaster relief unit, better infrastructure maintenance, re-positioned infrastructure, the formulation of new response programmes, land restitution required for enforcing buffer zones, or support for destitute victims sea-level rise will impose costs on the City. Meeting these costs will come at the expense of other fiscal investments, including those aimed at stimulating economic growth, employment and poverty alleviation.

Business costs: Disrupted electricity and water services, transport delays, the need to raise fiscal revenue and higher insurance premiums place an indirect burden on the cost of doing business in the City of Cape Town. More specifically sea-level rise is likely to place upward pressure on the cost of energy, water and on rates. In a rapidly integrating global economy, higher transaction costs act as a deterrent to companies deciding where to locate, and to the private investment in new infrastructure and business activities that is import if the City's economy is to continue growing. Vulnerable economic infrastructure in this region includes the Caltex refinery pipeline and the coastal rail network. The refinery's pipeline runs adjacent to the coastline at a height of 2 metres above mean sea-level. Only marginally higher than this is the rail network that feeds the City. Both pieces of infrastructure are already prone to sea damage18 and could be disabled by repeated high sea-level events. The combination of rail and oil losses would dramatically undermine business activity in the City.

Business uncertainty: The threat of sea-level rise creates uncertainty for business. This uncertainty relates to not knowing whether they will be directly affected by storm surges, such as is the case for the proposed AECI plant in Strand, or future construction of buildings at Blaauwberg, it includes not knowing if land will be rezoned so as to extend the coastal buffer zone, not knowing if services such as water, electricity supply and sewerage will be sustained and not knowing if insurance premiums will be escalated or insurance removed altogether. Business copes with uncertainty by raising costs, which in turn inflates the cost of the products and services produced by these businesses, and truncates the extent to which local economies are able to grow.

Risks to governance: Locally municipalities in South Africa were given a suite of new responsibilities in 2000 when new boundaries were demarcated and the Municipal Systems Act (2000) made local governments the centres of socio-economic development. Whilst the metropolitan areas such as Cape Town have been better able to deal with these responsibilities than some of the rural (B and C) municipalities, the City of Cape Town

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[18] In the 1974 flood and storm event that impacted particularly severely on the Atlantic coast north of the City, Otto du Plessis Drive and the railway had to be protected with sandbags.

has nonetheless found the new responsibilities exacting. There is no surplus budget or capacity within the City, and stormwater, road maintenance and disaster relief efforts operate on a fraction of their required budgets.

An important governance lesson in this regard has been highlighted by Mather (2007), drawing on the Durban experience of March 2007. Following that event confusion prevailed over whether national, local or private insurance should assume initial responsibility for rehabilitation and repairs (see Text Box 3). In the ensuing lacuna, individuals took responsibility for their own repairs and protection. In many instances the piece-meal and individual responses that were instigated represented a breach of environmental and coastal legislation, and yet in the midst of the crisis it proved very difficult to prevent this and the damage that arose. Where people feel vulnerable, and particularly were vulnerability is accompanies by a sense that public institutions are not heeding their need, such actions become inevitable and public authority is haemorrhaged. Similarly where people feel a local authority has inadequately protected them and their property there tends to be a political backlash that can be both irrational and destabilising. Peter Sandman19 describes the level of risk that communities are prepared to live with as being influenced by “impact plus public outrage”. He highlights the scope for angry citizens to seek revenge against authorities or companies that are perceived to have exposed them to environmental hazards.

Migration: A sea-level rise event to the City’s coastline will induce sudden population and business retreat from affected areas. Sea-level rise induced migration will cause inward migration to areas adjacent to affected zones. This migration will place increased pressure on infrastructure and services of the affected areas. It will also disrupt the social fabric of affected communities, and spread the impact of sea-level rise beyond the inundated zones. While observed sea-level rise events of the type that are analysed in this report tend to be localized, increases in mean global sea level is likely to create the prospect of sea-level rise refugees in developing countries and their neighbours. Nicholl

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[19] Peter Sandman, “The risks that kill you are not necessarily the risks that anger and frighten you” – quoted in Levitt and Dubner (2005)

(1994) estimates that a 2 metre sea-level rise event would displace 89 million across the developing world, a significant portion of whom would be in sub-Saharan Africa (and most notably for South Africa, Mozambique, see Figure 13). Such displacement would see the City of Cape Town being affected even without any impacts to its own coastline. The violence directed at perceived foreigners and refugees in South Africa in May 2008, provides a vivid illustration of the social risks that could be associated with the mass displacement of people within the Southern African region due to sea-level rise.

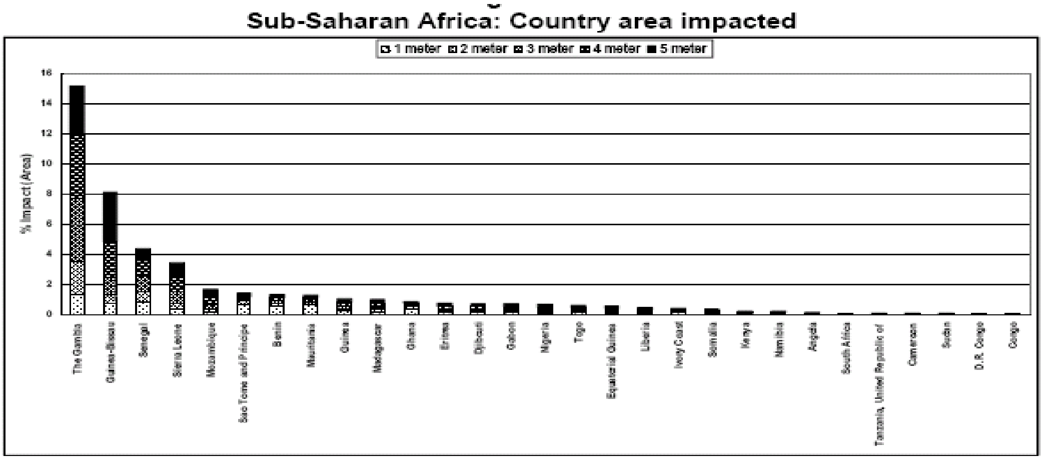

Figure 13: Sub-Saharan countries ranked by perceived exposure (by area) to sea-level rise (Dasgupta, 2007)

- **Water pollution:** Sea-level rise events have the potential to backwash through waste-water works, storm water drains, solid waste sites, “french drains” in informal settlements, through landfills and underground chemical storage sites including the petrol storage tanks located at service stations. Whilst in most instances these waste and storage systems are insulated from storm water damage they are all prone to leaks. The risks of damage and leaks would increase as the intensity and frequency of flooding increased, and accordingly the broad risk to water contamination will increase with sea-level rise. This in turn will aggravate the challenge faced by the Provincial Department of Water Affairs and by the city in keeping domestic water within the potable range.

- **Disaster relief services:** The City has a sophisticated disaster relief unit located in Parow. Coastal storm damage is ranked by the unit as the “fourth highest risk to the

City" after mountain fires, high risk mega-events (such as concerts) and shack fires, and this type of flooding is one of the disasters that the unit has learnt to deal with relatively well. A sea-level rise event could, however, cause flooding on a scale that has not yet been experienced. In conjunction with other natural disasters there is the very real possibility that both the frequency and extent of sea-level rise flooding could stretch the City's disaster relief efforts to the point where they become overwhelmed. This is particularly true given that sea-level rise is likely to induce novel risks for which the City and its residents are not well equipped. The combination of widespread flooding and wave surges, electricity failures, road and rail inundation and the need to relocate a significant portion of the population could, for example, overwhelm the City's response mechanisms.

- **Increased inequality:** South Africa is a highly unequally country; the third most income-unequal in a 2000 survey of 86 countries (Hausmann, 2008). Within South Africa the city of Cape Town is conspicuously divided along economic grounds, a feature that contributes to social disquiet and complicates the task of governance. Efforts at all three spheres of government aim to reduce this gap between "haves" and "have-nots", but these will be undermined by sea-level rise (and other climate change disasters) which tend to impose a disproportionate burden on the poor. This is not because the affluent are not impacted, but rather that affluent people's access to insurance, transport, buffer resources and information tends to result in them coping with these disasters better than the poor.

- **Psychological stress:** Both the threat and the experience of natural disasters generates psychological stress that affects some people more than others. Among those affected by the Asian tsunami in 2005, for example, the World Health Organization estimates the likely prevalence of psychological distress to be on the order of 20 per cent to 90 per cent among the affected populations, with approximately 20 per cent to 40 per cent expected to suffer mild distress and 30 per cent to 50 per cent expected to suffer moderate to severe distress. Mental illness is a feature of South African society, and already over-burdens the resources created to cope with the problem. Were sea-level rise events to become more frequent and intense, this would almost certainly contribute to the high levels of anxiety and illness that afflict the Cape’s population. Certainly where such events were perceived to overwhelm public capacity to deal with them or were met with an inadequate public sector response, they would undermine public confidence in the future of the region.

5.3 Mal-adaptation risks

The impacts of sea-level rise can not be fully understood without some discussion of human activities in the coastal zone. There is a growing awareness of the potential for (often well-meaning) efforts aimed at responding to natural disasters to inflict unforeseen consequences and damage of their own that outweigh the benefits of the action (Parry and Carter, 1998). It is, for example, now accepted that in the wake of the tsunami that devastated the Indonesian coastline, ill-conceived and mis-directed relief efforts contributed to the undermining of local livelihoods.

Some of the risks associated with sea-level rise result from short-sighted and inappropriate responses to the physical and social phenomena that are caused by sea-level rise. It is possible for the decisions taken in response to sea-level rise to lock-into vicious or virtuous risk pathways (Blaikie & Brookfield, 1987). Sea-level rise could provide the catalyst for positive changes such as land use zoning, renewable and decentralised energy provision and the maintenance of natural buffers such as sand dunes and wetlands, that would reduce vulnerability to sea-level rise as well as a range of other environmental and social phenomena. However, in the absence of a coordinated effort and informed planning, it is more likely that responses to sea-level rise events will be piece-meal, short-term and reflecting the narrow interest of lobby groups or a particular business. Such responses come at the expense of broader risk reduction efforts and actually increase risk by truncating the set of economic options available to exposed communities, undermining livelihoods and contributing to ecological degradation.

Specific mal-adaptation risks in the region Melkbos to the Port include:

Coastal development: The Atlantic coast between Melkbos and the Port, like much of the rest of South Africa's coastline, has been aggressively developed with both residential and commercial property. This development is part of the Cape's economic growth which on one sense has contributed to the resources available for coping with environmental risks. However some of this development, most notably at Blaauwberg and at Woodbridge Island is at risk of being damaged by sea-level rise events. The development has also contributed to a potentially more widespread risk by fragmenting the coastal habitat and increasing vulnerability to sea-level events. By preventing the flow of sand and the replenishment of coastal dunes, by necessitating the excavation of coastal terrains for foundations and pipelines and thereby removing vegetation and destabilising the coastal terrain, and by reducing the size and buffering capacity of coastal lagoons, estuaries and wetlands and by constructing hard engineering buffers such as sea-walls, this development amplifies the risk of sea-level rise events for everybody.

Figure 14: This photograph of a proposed up-market development site on the False Bay coast (not between Melkbos and the Port) shows the exposure of much coastal development to sea-level rise events. The photo also shows the vulnerability of Baden Powell Drive (road in foreground) and the importance of the beach sand, dune cordon and dune vegetation as a natural sea-level rise buffer.

Sand mining and cleaning: The mining of beach sand for construction purposes is a feature of the Cape coastline, most infamously at Macassar. Although not to the same extent the Melkbos and Milnerton beaches, too, have been exposed to sand mining in the past. Extraction of beach and dune sand reduces the physical dimensions of the beach and dune buffer and also destabilises these assets making them more prone to erosion form wave action. Similarly a number of the Cape's beaches, especially on the Atlantic side are graded and sifted in the summer months to remove kelp and litter. The intention is to enhance the beaches as tourist venues, but this beach cleaning destabilises the beach sand rendering more vulnerable to wave and wind erosion.

Sand relocation: The transport and dumping of sand to fortify beaches and sand dunes that have been eroded is one of the potentially effective responses to sea-level rise. "Beach sand replenishment" has proven reasonably effective at Ocean City in Maryland, the United States (Titus *et* al., 1999) and has periodically been deployed in the Cape, most notably on the beach in front of Woodbridge Island. It is critical that sand fortification is well researched and particularly that the sand that is used is compatible with the sand that it is meant to be replacing. Where sand is of different sizes, for example, this type of sand fortification can accelerate erosion by destabilizing sandscapes (Mather, 2007). More obviously where the sand used to replenish beaches is dredged from the coastline or from the sea-bed adjacent to the beach, this can aid erosion and the landward advance of the sea.

Poorly designed physical barriers: Sea walls and other "engineering solutions" to sea-level rise are common. The reclaimed coastline at Milnerton and Parden Island is protected by "dolosse", a famous South African bollard that is especially shaped to dissipate wave energy and protect the mainland. More classically, as is the case in Sea Point and at Strand, engineers have sought to protect land from the sea by building sea-walls. These can be effective, but they can also be very expensive to maintain.[20] Where

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[20] The Sea Point seawall is currently being assessed for repair. Provisional estimates given to the City show that at least R 12.6 million would be required to repair existing damage and an additional R 250,000 per annum would be required to maintain the wall after that.

they are poorly designed, sea-walls do not dissipate wave energy but transport it and concentrate it on weaknesses in the wall or on points where the wall comes to an end. In these instances sea walls can exacerbate sea-level rise impacts. In similar instances in outside of South Africa: a sea-wall constructed at Slapton-Sands (in Devon, UK) to protect a road actually accelerated the erosion of the road in certain parts, in Tollesbury (Essex, UK) the constructed sea-wall simply relocated erosion down-drift and did not (as hoped) remove the need for a managed retreat in 1995.

Similarly the construction of artificial off-shore reefs has been proposed to remove wave energy as it approaches the shore. Certainly where natural off-shore reefs and rock outcrops exist, as is the case at parts of Big Bay and sections of the coastline off Sea Point, and at Strand they do offer protection against wave action. Such artificial structures, however, become part of complex natural environments and have the potential to trigger unforeseen consequences including disrupted sand flows, loss of marine life and the channelling of currents and waves. Where this is the case these engineering solutions can aggravate and not ameliorate the problem. In the United Kingdom the option of using sea-barriers to protect against sea-level rise is considered to offer a 38 per cent chance of improvement, but a simultaneous 17 per cent chance of making the impact of sea-level rise worse (King, 2007).

A more general danger with engineering solutions is that they provide a false sense of security. Protected by a sea-wall, commercial property owners in Parden Island might forget about their proximity to the sea, or the fact that they operate on reclaimed land. It is only when the sea-wall is over-topped or collapses that the reality of their situation is realized. Very often this is too late, and leaves victims poorly prepared. In advocating sea-walls, dykes and barriers people often reference the example of the Netherlands, but fail to reflect on the fact that in the Netherlands the social and institutional capacity to manage sea levels has evolved together with physical infrastructure over many years. South Africa does not have this capacity, or public mind-set with regards to the way in which it manages its sea-defences.

Land reclamation: For the past two hundred years property developers in Cape Town have reclaimed land from the sea and from lagoons and estuaries. Parden Island is predominantly on reclaimed land as is the Cape Town foreshore and the Sea Point promenade. Some residential properties and infrastructure at Woodbridge Island and Blaauwberg is established on partially stabilised beach sand. Apart from the obvious fact that proximity to the sea renders reclaimed land vulnerable, this land is typically unstable and easily eroded when storm surges do encroach.

Sand dune and wetland encroachment: A number of residential developments have been established on the City's sand dunes and lagoon edges in an attempt to capture the benefits of a coastal lifestyle. Such developments disrupt the flow of sand that would normally replenish the dune cordon that protect the interior from storm surges and the associated wave action. Where these developments lower the height of dunes or remove wetland vegetation they render the coastline and adjacent areas more vulnerable to wave action and storm surges. This is true in the study area of Melkbos to the Port, on the banks of the Milnerton Lagoon, Rietvlei and on Woodridge Island.

Piece-meal, private solutions: In the wake of the Durban sea-level rise event of March 2007, a number of residents sought private solutions to their perceived exposure (Mather, 2007). These included the dumping of building rubble on the beach and the dropping of sandbags on the shorefront. Mather documents the abrasive and exacerbating impacts of deposited building rubble, whilst in some instances sand-bag walls focused wave energy on specific points of the beach which ended up being particularly badly damaged.

In most instances where individuals are permitted to pursue piece-meal solutions to sea-level rise, at the expense of overarching environmental governance and well researched solutions, they tend to simply transfer the risk of sea-level rise to new regions and communities. Where risk is transferred to communities that are less able to cope with it, the risk is amplified in the process.

Social panic: The spectre of sea-level rise has been seized upon by science fiction film-makers precisely because of its ability to capture people's imagine and provoke terror. The threat of sea-level rise is easily misrepresented and misunderstood, something that this study has had to deal with repeatedly in the course of its consultation. Precisely because of its ability to generate fear, sea-level rise creates the potential for irrational, disproportionate and short-sited responses. The building of physical sea-barriers is one such response; a response that is often deceptively limited in the protection that it offers, extremely expensive to construct and expensive to maintain. Mass panic-stricken outward migration, sometimes to regions that are vulnerable to other climate change risks (such as fire), and the turning on authorities or high profile companies that are somehow associated with the problem, is a common response. Some of these responses are irrational. More critically some responses to the biophysical risks of sea-level rise generate risks of their own. At the very minimum responses to sea-level rise impose costs and so typically come at the expense of other activities. The City’s aim should focus on supplying the sort of information and supporting the types of co-ordinated responses that result in risk reducing responses. In some instances this will involve jolting people out of apathy (see Figure 13), but in other instances it will involve assuring people of coping mechanisms and preventing the types of panicked responses that generate risks of their own.

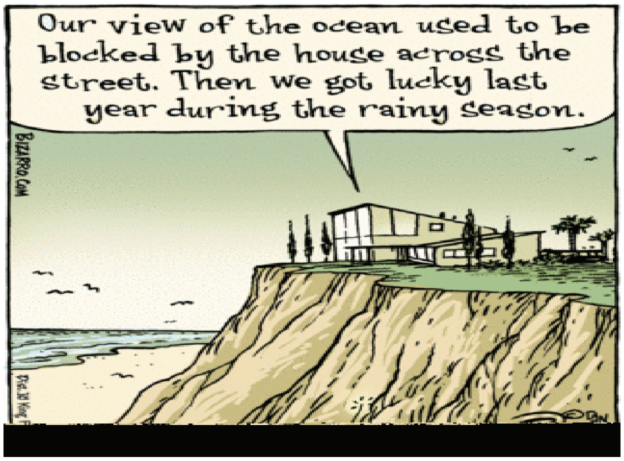

Figure 15: Social perception of sea-level rise risks can be both inappropriately complacent or anxious. Both perceptions can lead to responses that amplify the risk associated with sea-level rise. Public responsibility for managing sea-level rise risk should focus, in part, on communicating the appropriate level of risk and inducing considered and appropriate responses.

6. SUMMARY AND CONCLUSION

The study provides a localised and specific example in support of the broad consensus emerging from the Stern Review (2006) and the IPCC's Fourth Assessment Report (2007), namely that in the absence of an urgent global response, climate change is likely to cause serious economic and social impacts, in addition to environmental impacts, and increasing crises of a human, economic and environmental nature.

Until recently the range of sea-levels that is systematically introduced by tides had been far greater than the projected changes in sea-level due to global warming, and for all but the small island states sea-level rise has not been considered as one of the acute Western Cape climate change risks within scientific circles (see for example, Midgley *et al*., 2005). As historical records and understanding of the complex influences on sea-level rise have improved, so too has concern over the possibility of sea-levels that could be more immediate an order of magnitude greater than the IPCC's "0.59 metres by the end of the century" (IPCC, 2007). Research by Jim Hansen of NASA's Goddard Institute, has presented a plausible scientific case to show that linear projections of sea-level rise are no longer acceptable.

This study begins by defining a sea-level rise event as the combination of tidal, weather and climate change influences that manifest over different timeframes and with different degrees of predictability. The worst sea-level rise events can be expected when extreme high tides, exacerbated by storms, strike land off a platform of mean sea-level that has been raised by climate change. These events tend to last for the duration of high tide periods – typically 1 to 4 hours. Since both mean sea-level and the frequency and intensity of storms is increasing around the Cape Coast under the influences of global warming, it can be reasonably expected the City of Cape Town will experience increasing exposure to sea-level rise events. The only mitigating caveat in this projection arises from the possibility that the types of storms that are most affected by climate change ("cut-off" low pressure storms associate with south-easter winds) are not those that have been associated with high-sea events around the Cape Town coast in the past.

Within the next 10 years sea-level rise is likely to manifest in the form of abbreviated return times for the types of events that have struck the Cape occasionally in the past – the high seas and storms of 1974, 1984 and 2001, for example. There is the very real possibility however that the frequency of these events will prevent the restoration of natural and engineered defences (such as the erosion of coastal dunes and the reconstruction of sea-walls) in between events. Where this is the accumulated impacts of sea-level rise will present unprecedented challenges. In the longer term as the impact of global warming continues to raise mean sea-levels and perturb existing weather patterns it is probable that the City of Cape Town will be confronted with sea-level rise events, the likes of which it has not experienced in the past 130,000 years.

In estimating the risk to the City of Cape Town, this phase of the study draws on the three scenarios developed in phase 2:

- Scenario 1 - present day worst case scenario which is described as causing rises of 2 metres, 4.5 metres and 6.5 metres for sheltered, exposed and very exposed environments respectively. This scenario would threaten R5.2 billion worth of real estate, tourism and public infrastructure at current prices.

- Scenario 2 – the same levels of sea but with reduced return times. This scenario would threaten R23.7 billion worth of real estate, tourism and public infrastructure.

- Scenario 3 – linked the melting of the Greenland and West Antarctic ice sheets and involving a 7 metre increase in mean sea-level. This scenario would threaten R54.8 billion worth of real estate, tourism and public infrastructure.

By attaching a probability of these levels of sea-level rise occurring once within the next 25 years, and estimating the economic cost of lost public infrastructure, private property and tourism revenue under the three scenarios, the study puts a monetary value to the direct risk of sea-level rise.

- Scenario 1: R 4.9 billion
- Scenario 2: R20.2 billion
- Scenario 3: R11.0 billion

There are necessary caveats in applying this conventional risk analysis to environmental disasters. The reporting of discrete figures can misrepresent the complexity and uncertainty of these problems – both of which are defining features of the risk to people. It can also misrepresent the way in which sea-level rise events interact with the prevailing ecological, social and institutional environment to generate risks for specific people, in specific places and at certain times (see Figure 8). Perhaps most critically, a single figure estimate of sea-level rise risk might give the impression that raising the required money would remove the problem. This is not the case, on the contrary, unless the complexity, details and uncertainties surrounding sea-level rise events are understood, it is highly unlikely that appropriate responses to this risk will emerge.

One of the findings of this study is that the risks of sea-level rise are caused not only by the biophysical impact of high seas, but also by the social and institutional changes that these high-sea events trigger. It is for the above reasons that a detailed study of the broader sea-level rise risks that could be imposed on the coastline between Melkbos and the Cape Town Port in included in this section. For this section of coastline sea-level rise risks are broken down into the:

- Direct risks that arise from bio-physical sea-level rise impacts to infrastructure, natural water resources, beaches and real-estate.
- Induced risks caused that arise because of the effect that the direct impacts have on economic social and governance systems.
- Mal-adaptation risks caused by inappropriate, opportunist or short-term reactions to a sea-level rise event, and which amplify risk for the broader society.

Evidence from the more detailed study of the coastline between Melkbos and the Port illustrates the potential for social and institutional decisions to affect, either positively or negatively, the level of risk generated by biophysical events linked to climate change. Of particular concern in this regard, is the encroachment onto and destruction of natural buffers to sea-level rise including beaches, dune cordons, wetlands and estuaries. The risks generated by these developments affect a wider group of people than benefit from the development. This is the result of the spread of biophysical impacts such as flooding, but also linked to the fiscal reallocation required to mobilise disaster responses, infrastructure relocation and protection measures, and the increased cost of insurance for properties and assets. Typically this transfer of risk is regressive, resulting in disproportionate burdens for the people that are least well equipped to deal with them. Where this is the case, risk is amplified.

The two salient questions that emerge from this phase 3 risk analysis are, “How seriously should we prioritise sea-level rise risk?” and “What can be done, based on this understanding of the problem, to reduce the risk of sea-level rise for the City of Cape Town?”

These questions are addressed in phase 4 of this study. By way of conclusion to this phase it is necessary to say that the sovereign risk of sea-level rise for the City of Cape Town is significant and will increase in the next 25 years regardless of reductions in greenhouse gas emissions. However, because the risk of sea-level rise is likely to manifest in conjunction with other environmental risks, and because the nature of sea-level rise risk is affected by social, economic and institutional influences, these risks are best understood and managed within an encompassing risk management strategy as opposed to a strategy that focuses on sea-level alone. This encompassing risk management strategy should, on the grounds of this study, include dedicated sea-level monitoring and early warning capacity.

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