COASTAL VULNERABILITY IN THE CONTEXT OF CLIMATE CHANGE: A SOUTH AFRICAN PERSPECTIVE

ANTON CARTWRIGHT

Centre for Criminology, anton@econologic.co.za

INTRODUCTION

People have been adapting to variability in the coastal zone for as long as they have lived there, but climate change induced sea-level rise will both amplify this historic variability and introduce novel coastal dynamics. Until quite recently it was assumed that these changes would be gradual and moderate; the IPCC's Fourth Assessment Report (2007) cited an average change in sea-levels of 0,17 (0,12-1,22) metres over the 20th century and projected an upper-limit increase of 0,59 (0,18-0,59) metres by 2100. For all but the low lying islands this meant sea-levels within the bounds of previous high tides and severe storm surges and implied that existing coping approaches would be adequate for at least another 100 years. The IPCC projection of moderate and gradual sea-level rise has, however, been recently challenged by Hansen[1] (2007), Krabill *et al.* (2004), Tol *et al.* (2008), Velicogna & Wahr (2006), Rignot & Kanagaratnam (2006) among others. The challengers raise the spectre of sea-level rise an order of magnitude greater than that projected by the IPCC. Their research highlights the accelerating rate of sea-level rise and shifts the focus from thermal expansion of the oceans which accounted for two-thirds of the rise experienced over the 20th century, to the (poorly understood) potential for non-linear, rapid melting of the Greenland and West Antarctic Ice-Sheets (Nicholls *et al*. 2008). If the West Antarctic Ice Sheet were to collapse in the dramatic fashion that the Larson B Ice-Sheet[2] collapsed in 2002, it alone would raise global sea-level by 5-6 metres (Tol *et al*. 2008), while the Greenland Ice Sheet contains a further 7 metres of water (Lonsdale *et al*. 2008). It should be noted, however, that subsequent research by Siddall *et al.* (2009) examines the relationship between sea-level and temperature over the past 22 000 years and appears to support the IPCC finding by projecting a rise of 0,07-0,88 metres in response to temperatures increases of 1,1°C to 6,4°C respectively.

There is then some uncertainty over the extent and rate of climate change induced sea-level rise, but what is clear is that sea-levels are rising (Figure 1), the rate of rise is increasing and due to the latent heat of water the sea will continue rising for at least a century after atmospheric temperatures have ceased warming. While some people cite the potential for new sea-routes and new coastal property development, the reality is that over 60% of the world's population live on coastal plain, a similar proportion of marine biodiversity is dependent on estuaries and wetlands, and 11 of the world's 15 largest cities are situated on estuaries. Even moderate sea-level rise will be overwhelmingly adverse for a large number of people and the environments on which they depend.

[1] Jim Hansen is head of NASA's Goddard Institute for Space Studies.
[2] Larsen B was floating and did not contribute to sea-level rise, but its collapse in less than a month served as a reminder of the effects of higher than average warming over the region.

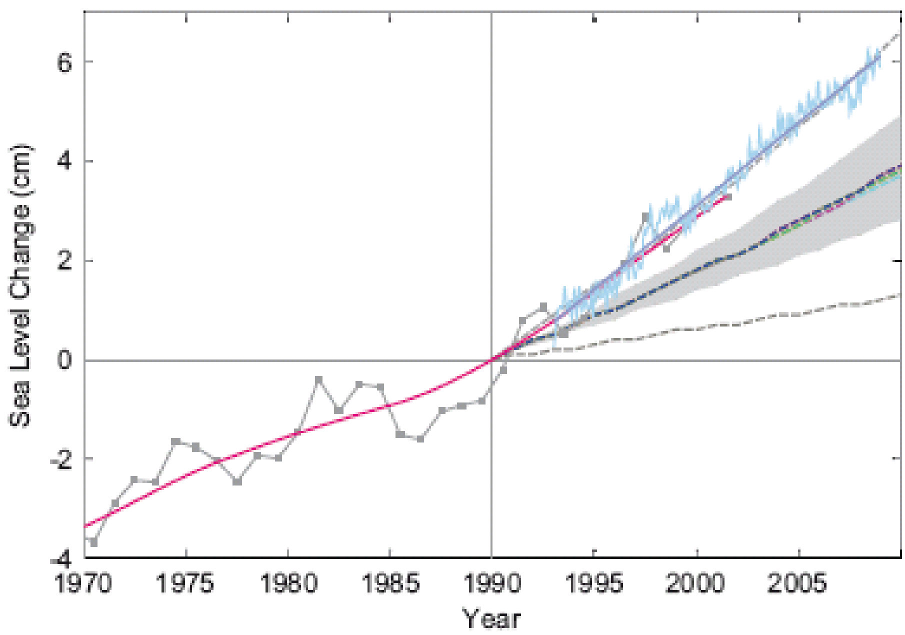

Figure 1 Change in sea level from 1970 to 2008, relative to the sea level at 1990. The solid lines are based on observations smoothed to remove the effects of interannual variability (light lines connect data points). Data in most recent years are obtained via satellite based sensors. The envelope of IPCC projections is shown for comparison; this includes the broken lines as individual projections and the shading as the uncertainty around the projections. (Source: Synthesis Report: Copenhagen Climate Conference, March 2009).

SEA-LEVEL RISE IN SOUTH AFRICA

The link between climate change and sea-level rise is most commonly understood in terms of changes to global mean sea level – sometimes called "eustatic change" (Kana *et al.* 2005). But this can be misleading when assessing sea-level at the local level because the sea is neither level nor rising at uniform rates. For all but a few highly protected coastal areas, sea-level rise tends to manifest not in a gradual advance of the mean sea-level, but via discrete, often dramatic, events associated with coinciding storms and high tides that impact the coast off the platform of a higher mean sea-level (Bindschadler[3] 2006). It is the increasing intensity and reduced return-times of these discrete events to which most coastlines are vulnerable.

To capture the influence of tides, storms, currents and topography, locally differentiated studies are essential. It is only Port Nolloth, the South African Navy's Hydrographic Office at Simon's Bay and Durban Port that have adequate time series of sea-level in South Africa. Brundrit (1995) and Mather (2008) have used the respective records to show an average 1,2±0,4 mm per annum increase along the Western Cape's west coast between 1962 and 1987, and an average 2,7±0,05 mm rise per year for Durban between 1970 and 2003. This

[3] Bindschadler is chief scientist at the Hydrospheric and Biospheric Sciences Laboratory of NASA's Goddard Space Flight Center.

places South Africa's sea-level rise more or less in line with the global mean but does not account for the influence of wind, current or swell. The Atlantic coastline, consistent with projections elsewhere (SwissRE 2009) appears to be exposed to increasingly frequent and intense south-west storms. The same storms tend to occur at the time of year at which tides are at their highest (spring and autumn) and have accounted for all of the major sea-level rise events in the past three decades (Schumann & Brink 1990; Brundrit 2009). Along the east coast the changing nature and frequency of tropical cyclones may similarly be causing an increasing number of sea-level rise events; whilst on the South Coast cut-off low pressure systems which bring large swell and heavy rain appear to be becoming more common (MacDeevit & Hewitson 2007).[4]

The situation in South Africa (as elsewhere) has been particularly aggravated by the rate and nature of coastal development over the past century. The country's White Paper on Sustainable Coastal Management of 2000 describes the coast as a "national asset" and encourages "sustainable economic use" of this asset without compromising its "ecological integrity". In the past, however, land reclamation, the removal of coastal dunes and mangroves (on the east coast), the stabilisation of sand that has historically replenished beaches, the development of much of South Africa's 600 km^2 of estuaries (Turpie 2004) and sand mining have collectively reduced many of the natural buffers, predisposing sections of the coastline to damage from increasingly variable and rising seas.

UNDERSTANDING VULNERABILITY TO SEA-LEVEL RISE

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, property, institutions and the environment via complex social and ecological systems is less well understood. A study involving the 307 km of coastline around the City of Cape Town showed that a 2,5 metre sea-level rise could cost the city over 3 per cent of the city's GDP (Cartwright 2008). There are, however, distinct limitations to providing a single figure in reporting environmental risk. Necessarily environmental risk analyses need to stipulate, "risk of what", "risk to whom" and "risk when" (Kasperson *et al.* 2001; Nicholls & Tol 2006). In this sense it can be useful to distinguish between three categories of sea-level rise vulnerability (Cartwright 2008):

- Vulnerability to physical impacts: This involves damage to infrastructure, amenities and property and loss of human life caused by the rising sea and the salination of aquifers. Typically this risk manifests during or in the hours immediately after a sea-level rise event.
- Vulnerability to indirect impacts: This results from the biophysical impacts, and sometimes as the result of the biophysical impacts on markets and governance, and includes the like of tourism losses, re-allocation of the fiscus towards disaster relief at the expense of planned development programmes, higher insurance premiums for costal property, and withheld investment. Following the 2007 storm surge along the KwaZulu Natal North Coast, the beaches replenished themselves quickly, but damaged roads and perceptions of a spoilt coastline continued to undermine the region's tourism efforts a year later (Mather 2008; Smith *et al.* 2007).
- Vulnerability to maladaptation: This is the result, often inadvertently, of attempts to respond to the biophysical and indirect vulnerability. In trying to reduce risk these efforts

[4] The model developed by these authors for the Western Cape forecasts a doubling of the incidents of extreme winds (>7,6 m/s) by 2081-2100.

unwittingly amplify it, often through opportunistic and short-termed actions in the wake of sea-level rise incidents. Examples include poorly planned sea-walls that simply transfer wave energy to adjacent areas, attempts to fortify the coastline with rubble that further scours beach sand, and the expedient relocation of communities away from their livelihoods base.

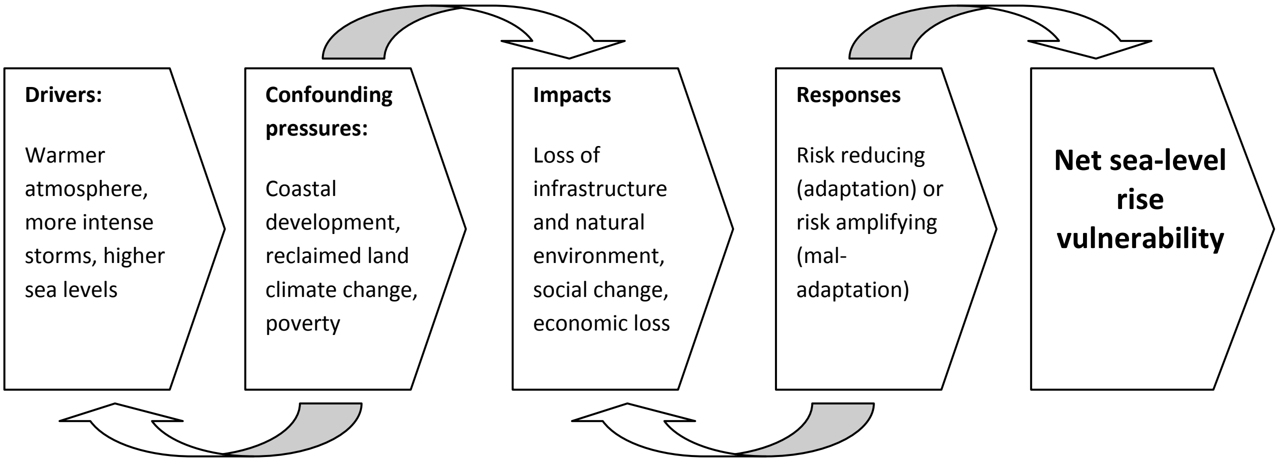

Figure 2 Understanding the origins of net sea-level rise risk is important in reducing this risk. These origins include direct biophysical drivers, as well as confounding indirect causes and maladaptation.

VULNERABILITY TO SEA-LEVEL RISE IN SOUTH AFRICA

The South African coastline is not uniformly exposed to sea-level rise. Understanding the implications of sea-level rise requires a study of eustatic change, local drivers related to topography, bathymetry and in-shore wave dynamics, as well as awareness of the country's social and institutional history, including coastal legislation and the distribution of people and physical assets.

Unusually for climate change, vulnerability to the physical impacts of sea-level rise in South Africa is not loaded on the poor. The legacy of the apartheid space-economy sees much of the country's coastal property under the ownership of affluent people and local authorities. Vulnerability to indirect impacts and maladaptation, in contrast, manifests via access to housing, insurance, mobility, sewerage spills and access to social support networks and is disproportionately borne by poor people. Quantifying indirect and maladaptation vulnerability within appropriate temporal and spatial scales can be difficult, but studies that focus on biophysical impacts, exclusively, not only under-report the full extent of sea-level rise vulnerability but also misrepresent the socio-economically regressive nature of sea-level rise in South Africa. The exclusion of much of South Africa's population from the country's coastal amenities until the early 1990s now complicates the task of defining and implementing effective coastal zone management, some of which involves the politically sensitive issue of new restrictions to settlement and access.

The South African coast can be divided into broad regions in which the coastal topography and defining socio-institutional features are similar (see Table 1 below), but the type of sea-level rise risk assessment that is useful for planning and adaptation purposes is only possible where a detailed study has been undertaken.

Coastal zone	Defining features	Drivers of sea-level rise impacts	Defining sea-level rise impacts
West Coast: Swakopmund to Melkbos Strand	Low coastal gradients, low population density, small harbours and some lagoons. Agricultural interior.	Higher eustatic levels (circa 20 cm over past century), greater intensity and frequency of south-west storms.	Negligible. Ground water salinity, damage to fishing harbours, damage to Saldanha Bay settlements and sea wall, altered estuary and lagoon habitats.
Western Cape Coast: Melkbos to Cape Hangklip	High density and high value commercial, industrial and residential. Low and high gradient coastline, vulnerable “pocket beaches”.	Higher eustatic sea-levels levels. Coastal low pressure systems, south west winds, imprudent coastal development.	Damage to transport, electricity and water infrastructure and residential coastal property. Increasing frequency and intensity of damage to the sea-wall buffers to reclaimed land in Cape Town.
South Coast: Hangklip to East London	Coastal towns, residential, holiday and agricultural property. Tourism growing employer. Steep coastal gradients with exposed estuaries. Three major ports and smaller fishing harbours.	Cut-off coastal lows causing coinciding sea-swell and terrestrial flooding.	Coastal sand erosion, damage to property, ground water salinity. Redesign of port hauling and storage infrastructure at Port Elizabeth, Coega and East London harbours.
East Coast: East London to Northern KZN	Steep costal gradients, high energy coastline with numerous estuaries. Major city Durban, many smaller towns and tourist properties. Tourism growing employer.	Higher eustatic sea-levels, cyclonic activity, coastal development.	Damage to tourism potential and property. Damage to Durban port. Biotic perturbation to coastal habitats.

Table 1 Coastal zones of South Africa and their respective causes and vulnerability to sea-level rise

To date only the cities of Cape Town and Durban have undertaken detailed assessments of sea-level rise risks. The Cape Town study focused on the 307 kilometres of coastline from Melkbos on the west coast to Gordons Bay in the east. Mean sea-level was reported to be increasing at roughly 2 mm per annum (Brundrit 2008), but the study cited the increased intensity and frequency of large sea-swell storms striking land off a raised sea-platform as the chief concern. Scenarios representing 2,5 metre, 4,5 metre and a 6,5 metre sea-level rise events were modelled and distinction was made between protected sections of coastline where the focus should be on changes to mean sea-level, and coastline exposed to the combination of mean sea-level, wave, and wind influences. Areas combining high exposure and high levels of coastal development (Blouberg, Milnerton, Kommetjie) were identified as being particularly vulnerable. Probabilities of 95%, 85% and 20% were attached to the likelihood of the respective scenarios occurring at some stage in the next 25 years. Based on these probabilities, and using property, public infrastructure and tourism values, the risk of sea-level rise to the City of Cape Town was valued at R4,9 billion, R20,2 billion and R11,0 billion respectively. The lower risk value for the most damaging scenario is due to the lower probability attached to this scenario.

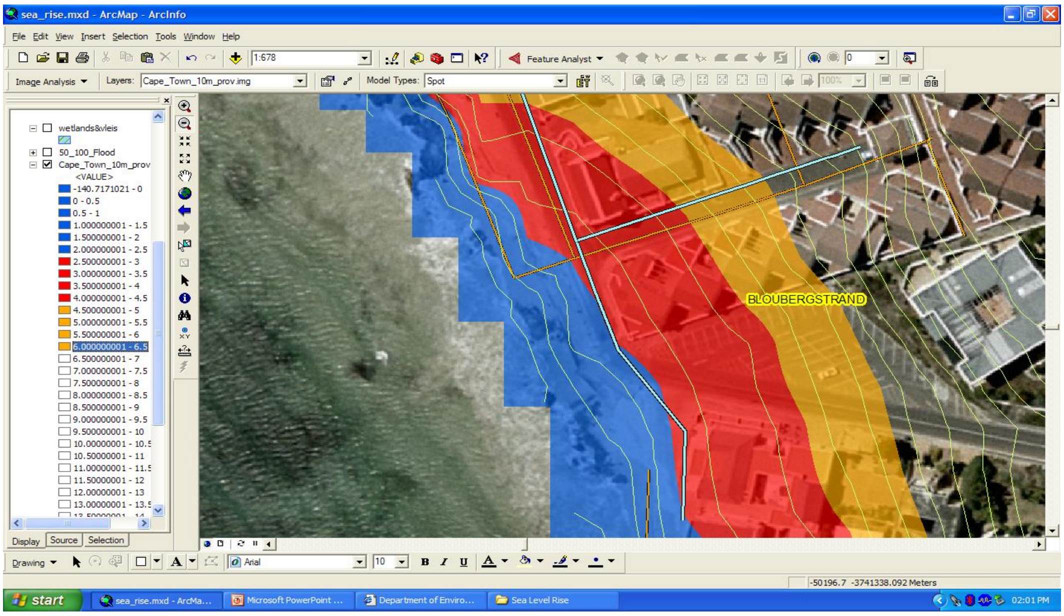

Figure 3 Modelled impact of Scenario 1 (blue), Scenario 2 (red) and Scenario 3 (orange) sea-level rise at the Blaauwberg coast, Cape Town.

The research was able to identify particularly vulnerable infrastructure such as low lying electricity sub-stations, oil pipelines and sewerage works and highlighted the vulnerability of estuaries. The study did not include the impact of wave run-up or inland flooding patterns. Surprisingly, the low lying Cape Flats, which accommodates a large number of informal and poor households, was shown to be relatively safe from sea-level rise flooding although the area is notoriously prone to terrestrial flooding.

The Durban study drew lessons from the dramatic March 2007 storm caused by a cut-off low pressure system and coinciding tides at the high point to their 18 year cycle. The storm generated waves of 8,5 metres and coincided with tides that were 0,2 metres above the usual spring-high tide levels. Based on historical occurrences the associated sea-levels were estimated to represent a one in 600 hundred year event, although the presence of climate change makes these historical records irrelevant, and Mather (2008) posits that the March 2007 levels might now represent a one in 10 or 12 year event.

Extensive damage to infrastructure and private property was incurred during the storm, but the impact was aggravated by confusion over which sphere of government should respond and private property owners undertaking piece-meal and often ill-informed measures to protect themselves and their property. Mather (2008) found Berea Red Sand and building rubble being used to fortify eroded beach fronts, with consequent scouring of the coastal zone. The cost of repairs following the storm was put at R400 million (Mather 2008) although this figure does not include foregone tourism revenue.

Both the Durban and Cape Town studies implicated confusion over who owns and is responsible for coastal property, anomalous and sometimes illegal property development, and the removal of natural buffers such as coastal dunes in aggravating the physical causes of the problem. Detailed studies for other parts of the South African coastline are not yet available, but the same issues are likely to apply. South Africa's two coastal neighbours Namibia and Mozambique have recently completed sea-level rise risk assessments. In Namibia the projected impacts are highly localised around the port at Walvis Bay and certain settlements in Swakopmund, but in Mozambique the potential for widespread impacts exists (Brundrit 2008), particularly if the anticipated saline encroachment into coastal aquifers continues to impact agriculture. Dasgupta *et al.* (2007) rank Mozambique fifth out of 29 sub-Saharan countries in terms of the proportion of population exposed to sea-level rise, a finding that implies the potential for the addition of sea-level rise refugees to the existing emigrants from Mozambique to South Africa.

ADAPTING TO SEA-LEVEL RISE

The risks of sea-level rise and associated coastal vulnerability are overstated if they assume that people and institutions will not plan for and adapt to changes (van Koningsveld *et al.* 2008; Sterr 2008; Tol *et al.* 2008). Adaptation enables coastal communities to limit their vulnerability by averting or reducing potentially negative consequences of sea-level rise while benefiting from potentially positive consequences. Well-planned and timely action can massively reduce the damage caused by sea-level rise. The Foresight Study (King 2007) showed that in the United Kingdom effective adaptation could reduce the cost of climate change by as much as twenty seven fold.

There are numbers of options available to communities exposed to sea-level rise, but as the March 2007 storms in KwaZulu Natal showed, establishing who is responsible and liable for managing and carrying the cost of these solutions can be complicated. Most beaches are "crown land" and under the jurisdiction of national government, but the land immediately adjacent to beaches belongs to an array of national government departments, agencies and local authorities. The public company, Transnet, is responsible for the respective ports, but local municipalities are obliged to extend and maintain services to individuals and companies that own coastal land and have received planning permission. Unfortunately the authorities granting planning permission are not always cognisant of sea-level rise risks.

Broadly, sea-level rise adaptation options can be categorised into:

- Engineering approaches: sea-walls, groynes, barrages and barriers, raising infrastructure, dolosse and gabions, off shore reefs, beach nourishment and replenishment, water pumps and beach drainage.
- Biological approaches: dune cordons, coastal mangroves, estuary and wetland rehabilitation, kelp beds.
- Socio-institutional approaches: vulnerability mapping, risk communication, enforcing a buffer zone, preventing activity that compromises the coastline (sand mining), early

warning system, insurance market correction, planned relocation.

The best adaptation measures tend to include a combination of responses. The threat of sea-level rise has seen a renewed acknowledgement of the need for Integrated Coastal Zone Management (ICZM) – the approach that attempts to, “Consider over the long term to balance environmental, economic, social, cultural and recreational objectives, all within the limits set by natural dynamics” (Commission of European Communities 2000). ICZM theory is seldom disputed, but for local decision makers the difficulty is how to choose between the range of options available when responding to sea-level rise, and how to prevent piece-meal, knee-jerk reactions that compound the problem.

The most common selection approach involves applying cost-benefits analysis to the respective options for a given site. Gaining a sense of costs and benefits is clearly helpful, and can attract the necessary political attention and provide a sense of perspective as has been the case in the Cape Town study (Oelofse pers. comm.)[5]. Where effective such studies can assist in distinguishing, for example, between (SwissRe 2009):

- measures that are cost negative and therefore create savings
- measures for which economic benefits outweigh their costs
- measures that cost more than their savings.

There are however limitations to cost-benefit analysis. It can be difficult to assess accurately both cost and benefits when the exact nature and timing of the threat is unknown; this type of analysis tends to treat options as discrete while in practice it is combinations of options and incremental progress that are likely to be most effective; and there is subjectivity involved in valuing environmental goods and services and heritage products that are not traded in markets but recognised as being valuable in preventing sea-level rise impacts.

A more robust means of taking decisions on how to best respond to sea-level rise involves subjecting options to multi-criteria assessment, in which they are evaluated in terms of (for example):

- Ease of implementation – not all desirable responses are possible, either due to the institutional complexity involved in implementing them or their cost.
- Scope for maladaptation – some options, and particularly infrastructural options, are more difficult to do well. Options should be selected commensurate with capacity to deliver them effectively.
- Cost and (anticipated) benefit – budget constraints inform decisions and the extent of reduced impact per unit investment over the long term remains crucial.
- Contribution to greenhouse gases – options that involve large volumes of additional greenhouse gas emissions (beach pumping, cement structures) should be considered less suitable that those that do not.
- Reversibility and flexibility – given that the precise extent and nature of sea-level rise impacts is not known, those options that can be reversed or altered as more information becomes available should be considered preferable.
- Equality implications – South Africa is a highly unequal society and without deliberate efforts to prevent sea-level rise risks being transferred disproportionately onto the poor, these risks have the potential to exacerbate inequality and frustrate development.
- Retention of complementary options – combinations of options tend to be more effective

[5] Gregg Oelofse is head of *Environmental Resource Management*, City of Cape Town.

than single approaches but not all options permit complementary solutions. Those options that permit complementarily are favourable.

Multi-criteria assessments have been criticised for their subjectivity. The questions, “Who gets to select the criteria?” and “Who gets to perform the assessment?” are legitimate. One of the central benefits in applying this approach, however, involves not the results that are produced but the institutional capacity for better decisions that is created during the process of selecting criteria and assessing options. Climate change adaptation theory emphasises the importance of “socio-institutional learning” (Downing *et al.* 2007), monitoring, reflexive institutions, ongoing decision making and iterative implementation. This is in contrast to efforts that aim to predict risks and provide “climate proof” solutions – an approach that is seldom tenable and often disingenuous in the context of climate change impacts. Multi-criteria assessments of sea-level rise risks are capable of bringing together South Africa’s particularly divergent development needs as well as integrating the needs of private land owners, local governments, provincial governments, various departments within national government and conservation authorities all of which are responsible for sections of South Africa’s coastline.

CONCLUSION

South Africa’s coast has long been vulnerable to storm surges but climate change has the potential to increase the intensity and frequency of these events and expose the imprudence and expedience of much of the country’s coastal development. Effective adaptation offers the potential to reduce vulnerability to the difficult-to-predict, but inevitable risk of sea-level rise, and should be seen as a component of development in an increasingly hostile coastal environment.

The correct responses to sea-level rise are location specific, and effective responses usually require a detailed study of in-shore current, wave dynamics, winds and sand transportation. Whilst the raising of the Cape Town port may represent the best option for the City of Cape Town, the Milnerton Golf Course 10 kilometres along the coast may be better served by relocation or the creation of vegetation buffers on the coastal dunes.

It is possible, however, to draw some generalisations.

- No regrets options: From a financial perspective there are a number of “no-regrets” options that would probably be desirable even if sea-level rise were not a risk, and which save more money than they cost to implement. These options are closely aligned to conventional sustainable development and include an early warning system, the prevention of additional coastal land reclamation, improved quality housing and transport routes and conservation of estuarine vegetation and dune buffers. No-regrets options represent an appropriate point of departure for sea-level rise adaptation.
- Social and institutional options tend to represent an appropriate first call: With regards to retaining flexibility and adaptation options, institutional responses tend to be better than biological options and significantly better than infrastructural approaches. The same options pose less threat of maladaptation and can offer high levels of protection. The ultimate institutional approach involves the implementation of a coastal buffer zone that is void of settlement. In some instances in South Africa this will involve planned relocations with compensation. South Africa’s Integrated Coastal Management Bill of 2007 proposes a coastal buffer zone 100 metres wide in the case of urban areas and 1 000

metres wide in the case of rural areas, but acknowledges that there will be anomalies and local compromises to the zone.

- Biological options: Biological options can be highly cost effective, but are difficult to implement well. The great advantage of these approaches is that they retain rather than truncate the option set available: it is still possible to build a sea-wall having attempted to provide protection with dune vegetation, but it is much more difficult to promote dune vegetation once a sea-wall has been constructed and the coastline habitat altered permanently.
- Information is crucial to effective adaptation: Sea-level rise is caused by a combination of factors and knowing which of these to monitor at different locations is important. At locations protected from direct swells and wind, it may be that mean sea-level rise is the most important parameter, but at other locations the net impact of sea-level rise will be a function of a number of factors. In addition to local information on coastal dynamics, is the need to inform the insurance market of changing risk profiles. Household and property insurance tends to base its assessment of risks on past events. Under climate change induced sea-level rise scenarios, the past becomes a very poor proxy for the future. An informed insurance market has the potential to influence the type and distribution of development.
- Ownership and liability: The White Paper on Sustainable Coastal Management of 2000 describes coastal management as a "shared responsibility". The reality is that coastal jurisdictions in South Africa are varied and give rise to planning disputes and critical delays in responding to sea-level rise risks. The responses required to counter sea-level rise vulnerability are location specific, but there is a need for a shared set of principles to inform these responses. Who integrates and coordinates whom in this process is a matter of governance, but critically important is the inclusion of sea-level rise responses in broader climate change adaptation plans. Many of the principles and reactions required to adjust to sea-level rise have value in addressing other climate change threats. The potential for joint solutions in reducing costal vulnerability should not be lost.

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