A STATUS QUO, VULNERABILITY AND ADAPTATION ASSESSMENT OF THE PHYSICAL AND SOCIO-ECONOMIC EFFECTS OF CLIMATE CHANGE IN THE WESTERN CAPE

PROVINCIAL GOVERNMENT OF THE WESTERN CAPE:
DEPARTMENT OF ENVIRONMENTAL AFFAIRS
AND DEVELOPMENT PLANNING

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EXECUTIVE SUMMARY

The South African Country Study on Climate Change, carried out in the late 1990's, identified the Northern and Western Cape Provinces as being most at risk from projected climate change-induced warming and rainfall change (results of this study are summarized in South Africa's initial National Communication, prepared in accordance with Article 12 of the United Nations Framework Convention on Climate Change: www.environment.gov.za/Documents/Documents/2005Feb22/NatCom_Nov%202003%20(b).doc).

However, this study was based on a limited set of model projections of climate change that have now been superseded by projections using more advanced techniques. In this study we have carried out a broad reassessment of the vulnerability of the Western Cape to climate change impacts, using a wider range of climate scenarios from more sophisticated climate models, and for a range of sectors (with the exception of agriculture and fisheries, according to our brief). We also identify some key adaptive strategies that might alleviate or avoid the worst impacts of climate change in some sectors. We conclude that further detailed study of some of the implications of these findings will be necessary to explore these and further strategies in order to guide policy development.

The future climate of the Western Cape is likely to be one that is warmer and drier than at present, according to a number of current model projections. In support of these projections, recent temperature trends reveal appreciable warming in the Western Cape over the past three decades. Rainfall trends are not as clearly identifiable. A future that is warmer, and possibly drier, will encompass a range of consequences that will affect the economy, the livelihoods of people and the ecological integrity of the Western Cape region.

Coping with the consequences of a future changed climate requires the identification of the sectors that will be affected and how these effects will play out. This report lays out plausible scenarios for climate change and follows with an assessment of the impacts and vulnerabilities due to projected changes. The next step is to decide what adaptation measures taken now will have the most impact in the future in avoiding or coping with the potentially negative effects of the projected climate change. The ability to assess these and implement them successfully will facilitate the achievement of a sustainable future in this Province.

Global change – scene setting

The driving force for global climate change is primarily the rise of greenhouse gas concentrations in the atmosphere. Carbon dioxide, the principle greenhouse gas, is released to the atmosphere by the burning of fossil fuels, deforestation and conversion of land to agriculture. Greenhouse gases absorb infrared radiation emitted from the earth's surface and heats the atmosphere. The world is now warmer than at any time during the past 1000 years. Empirical evidence for this is the retreat of glaciers almost everywhere on the globe, rising temperatures, increased storminess and a constant (though globally varied) rate of sea level rise. These changes have lead to global concern and much research effort is now being directed towards understanding climate evolution and possible trajectories of the earth-climate system.

Western Cape Climate Projections

Projections for the Western Cape are for a drying trend from west to east, with a weakening of winter rainfall, possibly slightly more summer rainfall (mainly in the east of the province), a shift to more irregular rainfall of possibly greater intensity, and rising mean, minimum and maximum temperatures everywhere.

Impacts and Vulnerabilities

Water resources

Available water in the region is already fully committed in most parts of the region, and there is little scope for further development of the resource (such as constructing new dams). In some catchments a water deficit exists, when the ecological reserve is factored into the water allocation, meaning too much water is already being abstracted from the system in a way that threatens the integrity of the ecosystems that depend on this water. This is reflected in the currently poor state of this region's rivers. However, demand continues to grow from agriculture, the Cape Town Metropolitan Area and the coastal towns. The already tightening water supply situation is vulnerable to periodic drought, as is now being experienced.

Because water is already a limiting factor for economic growth in most of the province, the projected climate change has serious implications for the competing interests of environmental integrity and socio-economic development. Adaptations that will be required are much greater efficiency in use, especially in agriculture, which implies investment in technology and know-how. Investment in exploring alternative sources and importation of supplies from further afield are indicated, which may raise costs.

In a warmer and drier future, the competition for fresh water will increase sharply. The equitable sharing of the water resource will demand considerable skill. Under current rates of urbanization and population growth, new sources will almost certainly need to be developed.

Rivers, wetlands and estuaries

Reduced water in the rivers will have an impact on wetlands and estuaries. Riparian, endorheic and floodplain wetlands are already being degraded through conversion to agricultural activities. They will face increased degradation through desiccation as their water supply is reduced. Some Western Cape wetlands have global significance for providing habitat to migratory wading birds that breed along the Siberian coastline and the Taimyr Peninsula. South Africa, therefore, has an international obligation to protect its wetlands, particularly those registered under the Ramsar Convention, which implies allocating enough water to them for their continued existence.

The vulnerability of estuaries to warming and drying is particularly acute because these features are located at the end of the river systems and are therefore the final receivers of increasingly scarce water. Nevertheless, estuaries are highly productive places and serve as important nurseries for fish. They have particular requirements for fresh water to maintain salinity profiles and for flushing sediment. Estuaries are important contributors to the national economy in terms of fisheries alone. Special attention will be needed to maintain their ecological functioning in the face of increased competition for water.

Coastal impacts
Sea-level is already rising through the expansion of the ocean, melting of glaciers and polar ice, and we are committed to up to 0.3m of further sea level rise from ocean thermal expansion alone over future decades, even if fossil fuel emission were to cease with immediate effect. The impacts of sea-level rise are increased saltwater intrusion into coastal aquifers, flooding in conjunction with extreme storm events, and coastal erosion. The Western Cape coastline has many sandy areas that have high potential for erosion as a result of the high energy wave regime. The most significant impacts of sea-level rise are expected where problems are already being experienced. However, the impacts of this rise in sea level may only become apparent roughly 30 years from now. Given that buildings and structures easily last for that length of time, it will be prudent to restrict development close to sandy beaches. Set-back lines need to be reviewed and strictly adhered to.

Biodiversity
The impact of climate change manifested by a warmer and drier climate are likely to be a progressive impoverishment in species richness in the internationally recognized biodiversity hotspots, the Fynbos and Succulent Karoo Biomes, but projections are limited by high levels of uncertainty due to a lack of understanding of species tolerance limits. Species losses estimated to be ultimately as high as 30% under worst-case scenario assumptions, may occur both as a direct response to warming and drying, but also as an indirect response to changing fire regimes and interactions with invasive alien species. High altitude marshes that host some highly endemic and isolated species (e.g. ghost frog) are particularly vulnerable to desiccation. Estuaries, which need fresh water for flushing and maintaining salinity profiles, will face increased competition for water from agricultural and urban demands.

Alien invasive species
Little is known about how alien invasive species would respond to climate change. A drier environment would restrict their spread but increasing atmospheric CO_2 content (which acts as an “aerial fertilizer” for fast growing trees) and especially nitrogen fertilization would enhance growth. Invasive alien trees, if left unchecked, will continue to utilize water sub-optimally in a situation where there is increasing water scarcity, and may fuel more intense and frequent fires.

Fire danger and fire frequency
The frequency of intense wildfires is modelled to increase substantially, and high fire risk conditions are projected to increase by up to 40% in the west, and almost triple in the east of the Province. This will have a negative effect on biodiversity, soil structure and the spread of fire-adapted alien invasive plants, which would further alter and enhance fuel loads and making wildfires more intense. Plantations and buildings will be subject to increased risk.

Livelihoods
A range of hazards associated with climate change will affect the livelihoods of people living in the region. These range from the prospect of increasingly poor health that will result from air pollution (the projected increase in the number of inversions will trap pollutants in the atmosphere close to the ground), heat stress (the number of very hot days may increase) and the possibility of increased flooding (rainfall events may become fewer but heavier).

The combination of increasing water scarcity and rising temperatures will also regularly affect sectors of the economy that are particularly dependent on ecosystem goods and services, for example agriculture, forestry and fishing. Economic sectors such as insurance, banks (through the underlying secured assets), transport and communication infrastructure and construction may all be affected to some degree by climate change.

The livelihoods of people who may be most severely affected are those whose asset bases (homes, household items, money, pensions, savings, natural assets, social assets [e.g. support networks] and food security) are damaged or destroyed. The first people to suffer these consequences are the poor who are usually constrained to living in risk-prone areas.

Key Adaptations

We identify and list some adaptive strategies that may alleviate or avoid the worst effects of climate change. However, careful study, using statistical assessment of the likelihood of extreme events in particular, is needed to guide policy in this arena.

Water resources – Improved demand side management, especially in agriculture, combined with careful review of urbanization rates and urban planning, make sense both for managing the current water crisis, and for potential future greater competition for fresh water. Under a drying scenario, development of new water sources, including careful and considered use of aquifers and desalination seem well advised. A strong focus on defense of the ecological reserve should be stressed to ensure sustainability of wetland and river ecosystems.

Wetlands and the coastal zone – Protection of the ecological water reserve for estuaries, as identified above, will be critical for this sector. Monitoring of key sites would assist in refining ecological reserve fractions. More stringent set-back lines for developments need to be assessed urgently.

Biodiversity – Alien plant management and associated fire management are key strategies which make sense both for the current health of indigenous terrestrial ecosystems, and for their future persistence. Monitoring of flagship indicator species and populations will be critical in improving understanding of species responses to climate variability and change, and in identifying developing signs of impacts. Careful assessment of the protected area system and its expansion where possible, combined with reduction of other human-induced stresses on ecosystems, and involvement of commercial land managers in reducing impacts, will increase the adaptive capacity of natural landscapes and ecosystems. Possible *ex situ* conservation or transfer of key threatened species to new sites in the wild may be necessary in extreme cases, possibly guided by focused monitoring programs of populations in the wild.

Livelihoods – An assessment of livelihoods underpinned by threatened natural resources would usefully guide policy to improve their adaptive capacity. Improved management and eventual elimination of informal settlements, electrification and improved public transport in urban areas will reduce local pollution levels and improve quality of life of the poor, and will reduce their vulnerability to extreme climate events.

Key Recommendations

The work presented here is an initial, broad overview of the problem posed by projected climate change, and requires further attention to detail in many areas before clear guidelines on adaptive strategies can be drawn. We therefore adopt a tentative tone, and wish to stress that further focussed study is needed, mainly to reduce uncertainties in many areas relating to the climate projections themselves, and of inferences of impacts and sectoral vulnerabilities (especially water, urban development, natural ecosystems, and livelihoods). More detailed assessments of the vulnerability of key threatened areas, together with likely timelines of impacts should be undertaken.

Notwithstanding this cautious tone, we suggest that clear evidence of the early signs of anthropogenic climate change is evident in the temperature record in the Western Cape, and that rainfall trends, though more variable, also suggest some shifts in the "normal" climate regime. Further research is needed on assessing the most appropriate ways of improving regional forecasts of climate change. However, projections of future winter drying are of sufficient concern, supported as they are by a variety of modelling approaches, to suggest an urgent and focussed assessment of the implications for the Western Cape as a whole. Lessons learned from the impacts of recent floods and drought show clearly the vulnerability of the agricultural and infrastructure sectors, but show how poorly impacts on poor communities are reflected in economic terms. This issue has moved from the periphery to becoming a mainstream concern for the people of the Western Cape, its economy, and its potential for a sustainable future.

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ACRONYMS

AOGCM's	Atmosphere/Ocean General Circulation Model or Atmosphere/Ocean Global Climate Model
AQM	Air Quality Management
AQMP	Air Quality Management Plan
CCRG	Climate Change Research Group
CCT	City of Cape Town
CDM	Clean Development Mechanism
CMA	Cape Metropolitan Area
CO_2	Carbon Dioxide
CSAG	Climate Systems Analysis Group
DJF	December January February
GCM	Global Climate Model / General Circulation Model
GGP	Gross Geographic Product
Highmax	Highest Daily maximum temperature
Highmin	Highest Daily minimum temperature
HIV/AIDS	Human Immunodeficiency Virus / Acquired Immune Deficiency Syndrome
IDP	Integrated Development Plan
IMEP	Integrated Metropolitan Environmental Policy
IPCC	Intergovernmental Panel on Climate Change
JJA	June July August
MAM	March April May
N_2O	Nitrous Oxide
NO_2	Nitrogen Dioxide
NOx	Nitrogen Oxides
PM10	Particulate Matter up to 10 micrometres in size
PM2.5	Particulate Matter up to 2.5 micrometres in size
PPP	Purchasing power parity
RAD	Restricted Activity Days
RCM	Regional Climate Model
SANBI	South African National Biodiversity Institute
SO_2	Sulphur Dioxide
SOER	State of Environment Report/Review
SON	September October November
Tmax	Temperature maximum
Tmin	Temperature minimum
VOCs	Volatile organic compounds
WWF (SA)	World Wildlife Fund South Africa

1. INTRODUCTION

Climate change, caused by human activities (see Box 1), has now been identified by a number of influential international studies, including those of the Intergovernmental Panel on Climate Change (IPCC 2001a), to be a significant threat to human livelihoods and sustainable development in many parts of the world (MA). Observed and future predicted global warming trends are likely to be accompanied by other climatic changes, such as changes in rainfall amounts and rainfall seasonality, and changes in more derived indices of climate, such as the duration of dry spells, intensity of rainfall events and the frequency of extreme climatic events. While the regional implications of the forces of global climate change are still fraught with uncertainty, the increasing confidence in scientifically-based projections of regional changes allows the development of potential scenarios of change, and the assessment of their impacts at the regional scale.

Climatic conditions provide important limits to many modern human socio-economic activities. However, these limits are often not appreciated, because modern human societies around the world have developed under the vagaries of their current prevailing climates, and (bar occasional extreme events) have developed practices and management strategies that provide for the "current climate" milieu. It is now clear that the notion of a "current climate" is not appropriate, due to projections of climatic changes that will accompany global warming.

While there remains appreciable uncertainty about the regional manifestation of global climate change, it now seems virtually certain that the confirmed and human-attributed changes to the composition of the atmosphere have begun to increase atmospheric and ocean temperatures, accelerate glacier and polar ice melt, induce shifts in the timing of growing seasons in parts of the Northern Hemisphere, and even have begun causing shifts in the geographic distribution of natural species (Parmesan *et al*. 2004). These observed changes appear to be the result of the relatively slight global warming of the late 20th century, which is commonly characterized as about 0.6 ºC during the last century (IPCC 2001b).

Box 1: Climate change drivers and the simulation of their effects

The rapid industrialization of human society over the past century and a half has significantly altered the gaseous composition of the earth's atmosphere, and continues to do so at an accelerating pace. The burning of fossil fuels for energy production (glossary: fossil fuels), and the conversion of land cover, mainly by deforestation, are now known to be raising the global concentrations of CO_2, methane and other greenhouse gases (glossary: greenhouse gases, or radiatively active gases). These changes lead to global warming, which can be described as the enhancement of the "natural greenhouse effect", the process by which "greenhouse gases" in the atmosphere absorb long-wave radiation emitted by the earth's surface. An increase in atmospheric concentrations leads to an increase in atmospheric energy, primarily manifest by an increase in temperature, and associated changes in regional climate from altered circulation patterns and increased atmospheric water vapour content. These changes in atmospheric behaviour are simulated by complex mathematical models of the earth's atmosphere/ocean systems (glossary: atmosphere/ocean general circulation models, or AOGCM's). These models are, by necessity, significant simplifications of the full complexity of the global climate, but provide increasingly realistic representations of the global climate at ever-finer spatial scales.

What are the implications of this global trend, and future climate projections, for the Western Cape Province of South Africa? The western Cape is a diverse region that relies intimately on its characteristic Mediterranean climate regime to underpin many aspects of its economy and the persistence of its natural ecosystems. In this report we make a first attempt to assess the vulnerability of this region to the potential regional manifestations of the forces of global climate change.

1.1 Key issues addressed in this report

Climate change comprises, most obviously, global increases in atmospheric temperatures (global warming) that are projected with a fairly high degree of certainty. Impacts on rainfall patterns are far more difficult to project in anything other than quite general terms. Nonetheless, temperature increases by themselves are likely to increase the evaporative demand from the soil, and lead to drying trends even on the absence of rainfall changes. Clearly then, impacts on hydrology and water supply are among the most direct results of global warming.

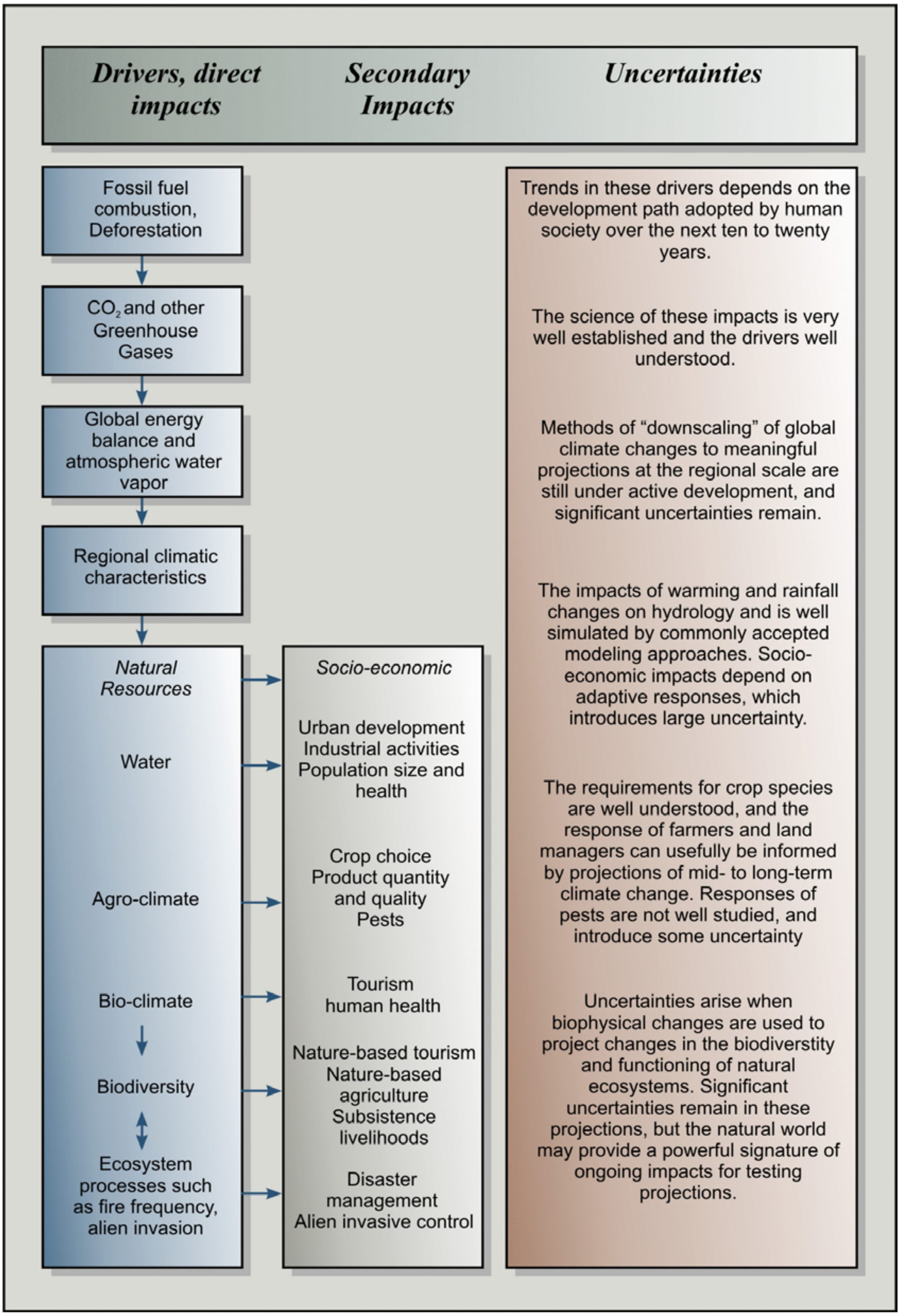
These primary responses to climate change lead to secondary impacts on urban development and water management, the competition between urban and agricultural needs for water, and the health and ecosystem implications of changing stream-flows. Increases in ocean temperatures and melting ice reservoirs are another prime example of direct responses to global warming, and both are causing increases in sea level. As a region bordered by oceans, this is a key concern of the Western Cape, especially if this trend is to be exacerbated by increasing intensity of storms. The secondary impacts on coastal developments and infrastructure are therefore likely to become increasingly significant.

Natural ecosystems are governed by the persistence of species that have adapted over millennia to certain climate limits, and these may be exceeded under future climate change, and in addition to this, ecosystem processes such as fire regimes may be altered by climate change. All of these changes appear to have the potential to impact in the economy of this region through their effects on the services provided by ecosystems, such as fresh water, and the potential attraction for the tourist market of the highly bio-diverse landscapes of the Western Cape.

Important agricultural activities rely on the characteristic Mediterranean-type seasonality and temperature regimes of the western Cape, and these are directly affected by climate change. The secondary effects of these impacts are likely to ripple through the local economy, resulting in an extremely complex interplay of socio-economic implications.

Finally, all aspects of society are affected by climate extremes, but specifically, poor communities living in low-cost housing are likely to be most strongly affected by any change in the frequency of extreme climate events such as floods and heat waves. Projected change in the frequency of extreme events will be amplified by the vulnerability of communities with limited resources to allow them to avoid or adapt to the impacts. The livelihoods of people across the economic spectrum will be impacted to some extent by climate change, but it is not likely that all will feel these impacts equally, and it is important to identify and address the needs of the most vulnerable.

Box 2: Key drivers of climate change, their direct and secondary impacts, and the uncertainties associated with them



2. BACKGROUND AND SCENE SETTING

2.1 Climate Change: An Element of the Global Change Phenomenon

2.1.1 An Emerging Consensus on Climate Change

The tenor of the scientific and political debate about climate change has shifted since the Third IPCC Assessment Report from whether climate change is occurring to what should be done about it (Houghton *et al.* 2001 and McArthy *et al.* 2001; for a succinct synthesis, see IPCC 2002). There is now very little scientific doubt that global mean temperatures have risen about 0.6°C since 1850 (the period of record); that the world is now warmer than at any time during the past 1 000 years; and that the principal cause of this warming is human-induced changes in the global radiative balance. It is highly likely that the warming will continue during the 21st Century but projections of the amount of warming that will be evident by particular marker dates (such as 2100) varies by a factor of at least 2. About half of this uncertainty range is due to disagreements between the models that simulate global climate (AOGCMs) regarding their sensitivity to a change in atmospheric energy balance. The other half is due to uncertainty regarding how the human social, political and economic system will respond to the impending problem of climate change: will it choose a radical emissions-reducing development pathway, or continue as if climate change were not an overwhelmingly important issue?

There are similar levels of certainty regarding sea level rise, but these are reducing with improved modeling capabilities. Ocean warming globally, for example, can now be directly attributed to anthropogenic warming of the atmosphere (Barnett *et al.* 2005). To date, most of the (modest) rise has been due to this thermal expansion of the oceans, and this mechanism will continue to dominate during this century, contributing up to a further 0.3 m at least *even if global greenhouse gas concentrations were stabilized at levels for the year 2000* (Meehl *et al.* 2005). However, permafrost, snow cover, pack-ice and most glaciers are in retreat around the world. Of the two great ice caps, the one in Greenland seems irretrievably set to melt, over a period of several centuries. Antarctic ice could remain fairly stable this century, but may melt to a significant degree after that, if warming continues. Indeed, very recent surveys in the Antarctic peninsula show that almost 90% of its glaciers have shown substantial reductions in volume over the past 60 years (Cook *et al.* 2005). As a result, the long-term sea level rise is likely to be in the order of several meters, enough to cause major problems in most coastal environments. There is great inertia in the climate system, conferred by the oceans and ice packs. This means that the current emissions will continue to have consequences for centuries and even millennia in the future. It is sobering to bear in mind that the 3-6°C rise projected this century represents only half of the eventual equilibrium warming, *even if the atmospheric concentration of greenhouse gases were to be stabilized this century.*

There are high levels of uncertainty regarding future changes in precipitation, especially at the local scale. It is likely that changes will not exceed about 20% of current levels, but in many regions we are unable to say with much confidence whether the direction will be up or down! At a global scale, it is very likely that a warmer world will also be a wetter world, but this is not necessarily true for every region. In particular, subtropical continental areas seem to have a tendency to receive less rainfall in the future. Considering the likely increase in evaporation rates resulting from higher temperatures, this suggests net drying of soils and reduction in groundwater and river recharge in the affected areas; but this conclusion is confounded by uncertainties regarding the long-term, large-scale magnitude of the direct effect of rising atmospheric CO_2 on the efficiency with which plants use water, as higher CO_2 levels have been shown widely to slow transpiration rate (one of the potential benefits of these changes). Certain extreme weather events (floods, droughts, windstorms and heat waves) are likely to become more frequent in the future.

It can be said, with reasonable confidence, that some biological effects of climate change are already apparent. Notable are shifts in the distributions of mobile species (such as birds and butterflies) and widespread coral bleaching. These and other effects, including direct heat-stress impacts on human health, will become progressively more severe with increased warming. The projected magnitude of warming is comparable to that which resulted in biologically highly significant change between glacial and interglacial periods. It is not directly analogous to those events, because the current warming is about ten times faster, occurs in the presence of much higher atmospheric CO_2, and in a landscape altered in many other ways by human influences (see below). Projections of a 15-30% species loss this century remain speculative, but are now seriously entertained (IPCC 2002, CBD 2004, MA *in press*).

2.1.2 Global Change is more than Climate Change

Climate change is just one manifestation of a broader set of unprecedented environmental and social changes occurring in the contemporary world, driven by the growing influence of humans. At the global level, these changes alter the way in which the biosphere functions, especially measurable in the rate at which certain key elements are cycled. These include water, transferred globally in the hydrological cycle, carbon, nitrogen and phosphorus. The change in the carbon cycle to date (which underlies much of the observed climate change is about 15% relative to the pre-industrial carbon cycle. The nitrogen cycle has been perturbed by over 100% (i.e., the current rate of exchange between atmosphere to biosphere is more than twice the pre-industrial flux), the flow of sediments to the oceans is up over 200%, and the input of phosphorus from rocks to the biosphere is now 400% of the natural weathering rate (Falkowski *et al* 2000).

The root cause of these changes is changes in human consumption. These are partly, but not mainly, caused by the growth in the human population brought about by agricultural, medical and sanitation technology. Mostly they are due to changes in the consumption per capita induced by rising wealth and increasing urbanisation. Currently the human population and its dependents (domestic animals) appropriate almost half net primary production of the world for their own consumption, even given uncertainties in this estimate (Haberl *et al.* 2002).

The first manifestations of human domination of the globe came through changes in land cover: initially the domestication of fire by hominids over a million years ago; then the extinction of large mammals virtually everywhere except in Africa with the spread of efficient human hunters about 20000 years ago, then the domestication of crops and livestock about 6000 years ago. Advances in navigation drove global trade, the deforestation of Europe and the export of Europeans and their technologies around the world. But it was the exploitation of fossil fuels that permitted mechanisation and the synthesis of fertilisers and pesticides that lead to the conversion of about ¼ of the global land surface to cultivated land; the clearing over half of the global forests and drainage of half the wetlands and the depletion of most coastal fisheries.

Apart from the contribution of land use change to greenhouse gases (about 50% of the effect, integrated from the beginning, but now about 15% per year), habitat loss and fragmentation have been the main drivers of the contemporary increase in species extinctions. Furthermore, the increase in global connectivity, coupled with deliberate species introduction policies and the propensity of stressed and disturbed ecosystems to be more easily invaded, have led to a large increase in alien species invasions that is likely to accelerate in the 21st century. The current recorded species extinction rate is an order of magnitude higher than mean rates calculated from the fossil record; future rates are projected to be an order of magnitude higher again. Even so, branding the current era as the 'Sixth Extinction' may be hyperbole (Anderson 1999).

Together, these changes in the biosphere constitute a syndrome, now widely called Global Change, which has no antecedents in the history of the Earth. They are unlikely to threaten the persistence of life on Earth, but they are sufficient in combination to threaten "life-as-we-know-it". The Earth cannot sustain even the current level of consumption by 6 billion people (MA *in press*): the anticipated peak human population of around 9 billion in mid-century, of whom the vast majority will live in cities, will require profound ecological, technological and economic adaptation.

2.1.3 Political and economic developments

The impending problems of a human-dominated world (the 'Anthropocene era' – Crutzen and Steffen, 2003) led to the Rio Conventions of 1992: the Framework Convention on Climate Change; the Convention on Biological Diversity; and the Convention on Combating Desertification. The World Summit on Sustainable Development in 1992 showed a lack of substantive progress on all these issues, and reframed them, at least in Africa, in a human development context.

The relatively greater progress on the climate change issue, leading to the Kyoto Protocol in 1996 (and its coming into force in 2005) has been partly attributed to the role of the Intergovernmental panel on Climate Change (IPCC) in translating science into policy-applicable terms. As a result 'scientific assessments' have become a fixture of the science landscape, occupying a significant fraction of global scientific effort. The Fourth Assessment Report of the IPCC, due in 2006, confirms a political shift in emphasis from impact studies (is climate change occurring, and does it matter) to adaptation and mitigation. Adaptation is favoured, partly because the findings regarding the now-inevitability of climate change make it imperative, but also because all nations benefit from investment in adaptation (even if they were not part of the cause, and if the effort varies between nations), while investment in mitigation only 'pays off' if all major emitters play the game, and the rules are agreed: a much tougher negotiation issue.

The increasing focus on energy systems is also driven by the depletion of fossil fuels, which now seems more imminent than before. New oil and gas reserve discoveries have apparently peaked; suggesting a general trend of rising prices in the future. However, in South Africa, coal reserves may last for several centuries.

The rise of China, and to a lesser extent India and Brazil (and in the African context, South Africa) will continue to dominate the *realpolitik* of global governance, on topics ranging from trade to climate change.

2.1.4 Key issues for South Africa and southern Africa

South Africa, as a non-Annex 1 (developing) country has no obligations to reduce greenhouse gas emissions *under the first commitment period* (2008-2012) of the Kyoto Protocol. Subsequent periods, or a post-Kyoto regime, will most likely have to include obligations for leading developing countries if it is to be politically viable. Decisions in the next few years regarding long-term fixed energy investments are therefore critical, and must take into account the potentially adverse environment for carbon-intensive energy sources.

Taking note of the substantial uncertainties around rainfall projections, there is nonetheless a tendency for the majority of models to suggest a decrease in rainfall over the western part of southern Africa in the coming decades. Coupled with warming, this implies net drying, with negative consequences on water supplies and agriculture (Fischer *et al.* 2002).

The South African Country Study on climate change (South Africa 2000, but only released 2004), buttressed by the studies on Botswana (Scholes, van der Merwe and van Tienhoven 2001), Namibia (Scholes, van der Merwe, van Tienhoven 2002) and Zimbabwe identify the key climate change issues in the region to be health, water and biodiversity.

It seems rather counter-intuitive that agriculture (cropping and livestock) and forestry are not seen as key issues in South Africa, given the warming and drying that is possible in the region (Fairbanks and Scholes 1998, Scholes, Midgley and Wand 1998). This is a tentative conclusion, based on two factors: firstly, the effect of rising CO_2 on plant productivity almost exactly cancels the effect of climate change *in current analyses*. This seems to be generally true, but is not true for several specific instances. For example, deciduous fruit-growing in the Western Cape may not be viable in the future. Secondly, the adaptive capacity and response time in the *commercial* forestry and agriculture sectors in South Africa is judged sufficient to make the necessary adjustments in cultivars and management needed to remain viable. This assumption *does not* necessarily apply outside of South Africa, and in the small farmer sector.

2.2 Biophysical environment

The Western Cape Province comprises a unique set of biophysical conditions in relation to the rest of South Africa, southern Africa and indeed, much of the African continent. Primarily this is due to its Mediterranean-type climate, with cool wet winters and relatively dry warm summers. But further than this, the Province contains a range of climatic gradients, namely a south-north aridity gradient that is very steep in parts, and an east-west rainfall seasonality gradient, with increasing summer rainfall towards the East (See Figure 1) A less-well known trend is that of rainfall seasonality with altitude – higher altitude mountain regions experience far greater amounts of summer precipitation than adjacent low altitude plains, such that mountain peaks can often be classified as all-year rainfall zones.

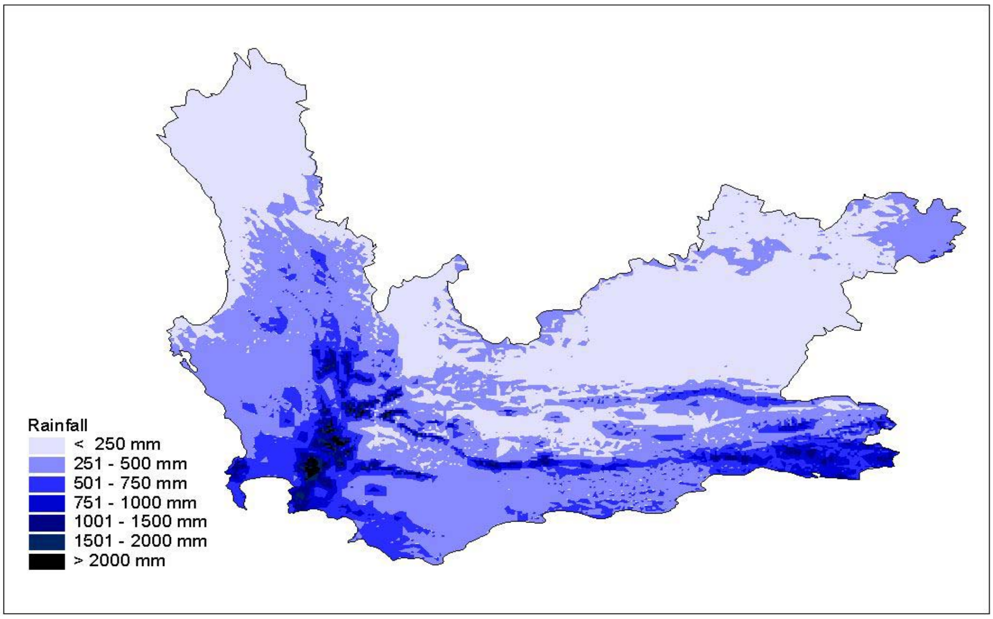


Figure 1 Mean annual rainfall of the Western Cape

These gradients are overlaid on a diverse topography and set of landscapes, dominated by the mountains of the Cape Fold Belt, which creates a spectacular rugged topography that separating interior semi-arid and arid plains from flat sandy coastal lowlands of varying extent. The Cape Fold Belt roughly assumes an L-shape, made up of the north-south-trending Cedarberg Range in the west, which merges in the south with the east-west trending Langeberg and Robertson Ranges, and the southern coastal Kogelberg/Betty's Bay ranges. In the West, the coastal tertiary sand plains trend northwards and grade into more clay-rich shale-derived substrates in the inland plains of the Knersvlakte, while the extensive Agulhas plain makes up the sandy southern coastal belt, which is interspersed with fairly infrequent limestone substrates. Interior plains are generally characterized by heavier shale derived clay soils.

This combination of climate gradients and geologically derived soil contrasts supports an immensely diverse flora. The world-famous Fynbos Biome tends to be associated with the nutrient-poor, highly leached sandstone substrates of the Cape Fold Belt and adjacent sand plains, while the less well-known but hardly less diverse Succulent Karoo Biome is found on inland plains.

Both of these typical and dominant vegetation types of the Western Cape are classified as globally recognized biodiversity hotspots – areas of exceptional biodiversity that are threatened by human impacts (the Fynbos Biome concept is often loosely conflated with the more inclusive concept of the Cape Floristic Kingdom, which includes a broader range of vegetation types and habitats than is considered true Fynbos). The Cape Floristic Region and Succulent Karoo are home to roughly 8200 and almost 5000 species respectively (Myers et al. 2000). This region therefore is identified within South Africa as particularly important in terms of unique habitat and species (Figure 2).

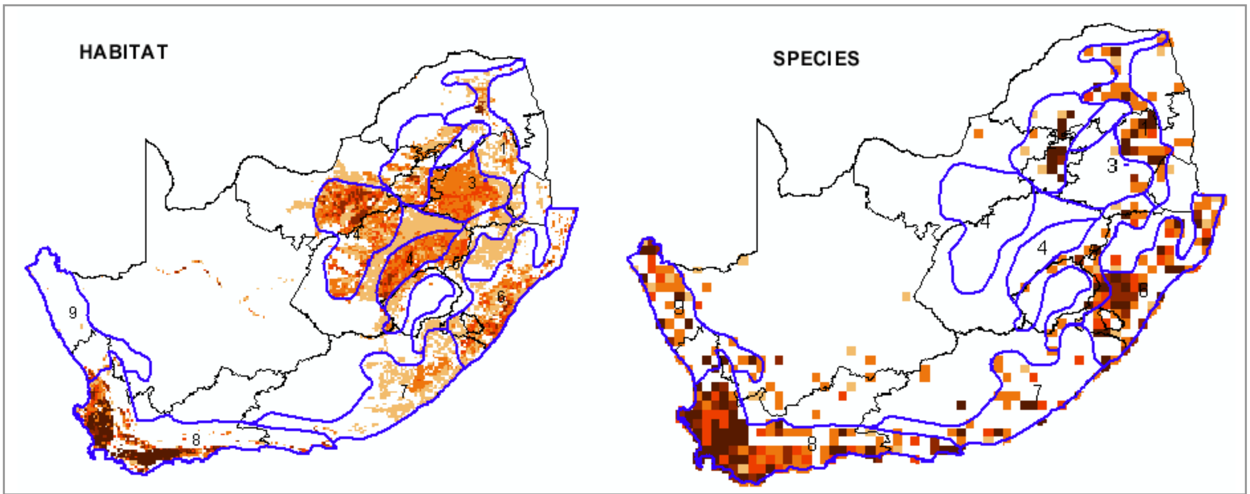


Figure 2: Indices of irreplaceability for habitats (left hand panel) and species (right hand panel) with darker colours indicating higher irreplaceability. Irreplaceability is an index of rarity and uniqueness. The Western Cape clearly shows an extreme concentration of irreplaceable habitats and species in relation to the rest of South Africa.
Figure from Driver *et al.* (2005)

2.2.1 Vegetation cover/land use change

Indigenous species and habitats are obviously directly threatened by the transformation of natural ecosystems, vegetation cover and the land surface by human activities. Three modes of land conversion dominate the land surface in the Western Cape, namely cultivation for intensive agriculture (including commercial forestry plantations), urbanization, and stands of self-sown invasive alien trees and shrubs (Rouget *et al*., 2003). Using the Cape Floral Region (CFR) as a proxy for the whole province, cultivation emerges as the most significant by far, having transformed about 26% of the land surface (Figure 3). Dense to moderately dense stands of woody aliens (between 20 and 100% cover of alien plants) cover about 2.6%, and urban areas account for only about 1.6% of the CFR each.

Lightly alien-invaded areas represent a significant surface area, and could emerge as a significant problem in future if not controlled. All three processes could transform a further 14 - 30% of the province within two decades (see Figure 4). Future land conversion would most likely take place in the lowland areas, particularly near the coast and along interior valley bottoms (Rouget *et al*., 2003).

Where climate change results in warming and drying, there is likely to be a loss of agricultural productivity and potentially a decrease in rain-fed agriculture, however, detailed study is needed to project how land use by agriculture will be affected by the interacting drivers of temperature, rainfall and irrigation water availability. The extent of woody alien invasion is likely to increase in the future, but the rate of invasion will be affected in a complex interplay between the negative effects of increasing temperature and water stress, the positive effects of rising atmospheric CO_2 that accelerates growth rates of woody plants (Ainsworth and Long 2005), the frequency of fire, and the effort invested in clearing activities.

The size of the urban areas, particularly the coastal resorts and the Cape Town Metropolitan Area, will continue to increase in size, but the rate of urban expansion may become limited by water availability in the future.

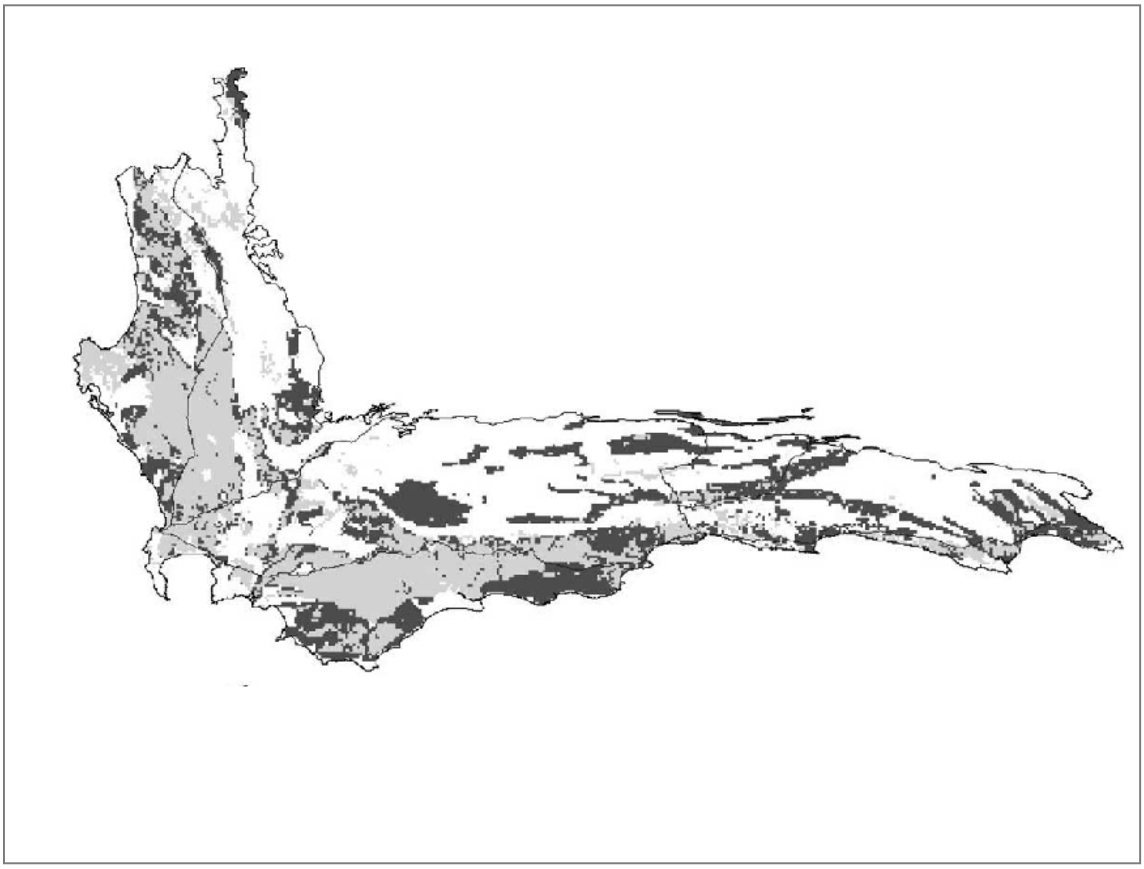


Figure 3: Current (light grey) and projected distribution within 20 years (dark grey) of land transformed by agriculture and forestry in the Cape Floristic Region (Rouget *et al*. 2003).

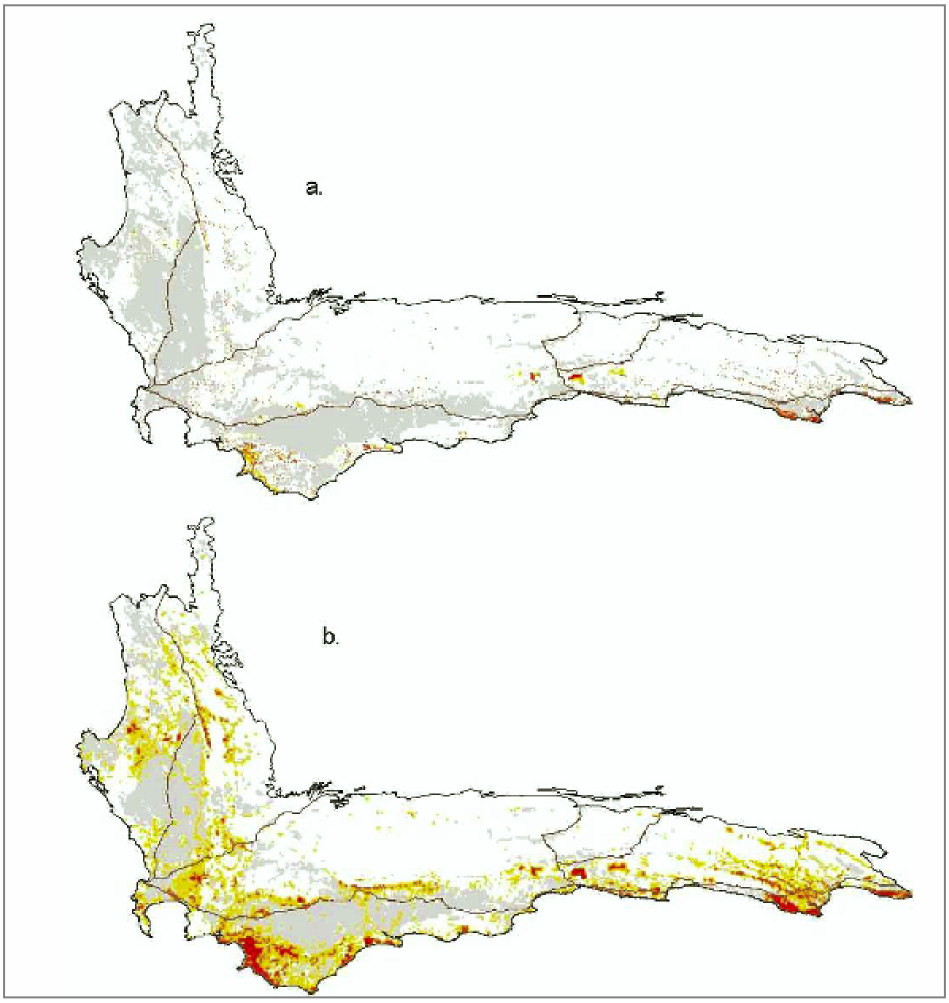


Figure 4: Current (a) and projected distribution within 20 years (b) of land transformed by alien plant infestation (lightly invaded in orange, densely invaded in red) in the Cape Floristic Region (Rouget *et al.* 2003). Current transformation by agriculture is shown in grey.

2.3 Socio-economic context

The Western Cape has one of the most diverse economies in South Africa, and has also shown robust productivity over the past decade. The provinces' traditional reliance on primary sectors, such as agriculture and fishing, has expanded with a combination of increased value-addition and exploitation of niche markets in the secondary sector and a well-established and growing services sector.

During 2004 the Western Cape contributed 14.5% to the country's economy (see Table 1), of which the City of Cape Town contributed 76.6%. Key factors in the regions' performance are the skilled workforce, a competitive infrastructure, the abundance of natural resources, the diversity of manufactured products and services and preferential access to key global markets (Wesgro

2004a). The agriculture, forestry and fishing sector, the finance, real estate and business services sector, and the construction sector recorded significant higher activity than the country average.

Table 1: Gross Geographic Product (2004 Rm at current prices)

Sector	*SA*	%	*Western Cape*	%
Agriculture, forestry and fishing	41,323	3.36%	8,736	4.89%
Mining and quarrying	87,058	7.08%	432	0.24%
Manufacturing	246,467	20.03%	36,325	20.35%
Electricity, gas and water	28,239	2.30%	2,951	1.65%
Construction	29,190	2.37%	5,757	3.23%
Wholesale & retail trade, hotels & restaurants	172,667	14.03%	28,447	15.94%
Transport, storage and communication	120,095	9.76%	18,520	10.38%
Finance, real estate, and business services	247,514	20.12%	49,842	27.93%
Personal services	76,880	6.25%	9,535	5.34%
General government services	180,976	14.71%	17,927	10.04%
All industries @ basic prices	**1,230,409**		**178,472**	**14.51%**

Source: Wesgro

Renewable Resources

Renewable natural resources play a major role in the Western Cape economy, as illustrated in its recent export successes. Exports in these sectors account for half of the provinces total export earnings in 2004. Fruits and nuts (19.4%), wine, beer and spirits (12.51%), fish, crustaceans and molluscs (8.68%) and processed fruit, vegetables and nuts (6.33%) are all contributing substantially to the province’s foreign exchange earnings. The Western Cape is well-known for quality fruits and wines and for growing markets in biome-specific flora (e.g. ferns, proteas, fynbos) and natural products (e.g. rooibos, honeybush, buchu).

Not only climatic conditions, but also the availability of water is interwoven with the province’s rich biodiversity and diverse economic activities. Fruits, cereals and vegetables are largely supported by irrigation systems, while the biodiversity of plant and animals are sensitive to trends in climate and precipitation. The expanding population as well as economic activity and their concentration in major urban centers e.g. Cape Town distorts the water supply story. Demands on the water supply system and infrastructure are ever-increasing.

The Western Cape’s economy is directly and indirectly sensitive to the functioning of its underlying ecosystems on a macro and micro scale. This makes the economy, and especially the agricultural, agro-processing, and tourism sectors vulnerable to natural change, and increases the incentives to pro-actively plan for adaptive measures. Other sectors, such as construction, finance, real estate and business services, government services and transport will have to adapt to increasing economic and financial demands of increased vulnerability.

Tourism

Tourism is one of the fastest growing sectors, contributing 9.8% to the Western Cape economy in 2002 (Grant Thornton Kessel Feinstein, [S.a]). Tourists are mainly attracted by the natural beauty and infrastructure of Cape Town and environments. Growth areas are eco- and adventure tourism, incentive tourism, health tourism, corporate tourism and the hosting of conferences (Grant Thornton Kessel Feinstein, [S.a]).

Utilities and Infrastructure

The current utility and infrastructure statistics for the Western Cape are listed below. In terms of basic service delivery levels (water, sanitation, waste removal, access to electricity and housing) the Western Cape exceeds the rest of the country (SSA, 2004). Due to population growth and migration into the province, additional services need to be delivered in addition to those require to meet the backlog.

Table 2: Access to services in the Western Cape as a percentage of the population

Access to services: Utilities and infrastructure	*Western Cape*	*South Africa*
Clean water (piped/boreholes/rainwater tanks)	98.6 %	89.4%
Sanitation (waterborne/VIP)	90.6%	86.4%
Refuse disposal	98.6%	91.3%
Electricity for cooking	78.7%	51.4%
Electricity for lighting	88.0%	69.7%
Electricity for heating	73.4%	49.0%
Formal shelter	83.5%	83.3%

(Source: SSA, 2004)

In addition to the uncertainty in the rate of the population growth and migration, climate change as a source of uncertainty will become increasingly relevant to service infrastructure planners in the future. Local Governments build costly infrastructure to meet expected future demand and should anticipate the uncertainties of climate change as well those of demographic and socio-economic changes.

Some aspects of the Province's physical infrastructure such as buildings, transport systems, energy supply systems, may be affected. For example, settlements may be affected by coastal and river flooding, where stormwater drains, water supply and waste management have not been designed to meet the projected impacts. Energy demand may increase due to the need for air conditioning.

Service delivery in the Western Cape has already experienced the impacts of climate variability, specifically in the form of droughts and floods.

Population trends

Rapid urbanisation has taken place in the last decade in the Western Cape, which can already be regarded as highly urbanized, with 90.4% of people living in urban areas (StatsSA, 2003b:8.) Of a total population of 4.5 million, only about 0.4 million live in rural areas. Employment in the small-scale and subsistence rural agricultural sectors has fallen substantially and continues to fall (Roux, 2002).

Economic activity in the Western Cape is dominated by activities within the Cape Metropolitan Area (CMA). It is attractive to both high- and low-income migrants in search of better living standards and employment. South Africa's main urban centres experience higher population growth rates than the smaller towns, likewise Cape Town has a faster growing population than other urban centres in the province.

The population growth rate of the Western Cape was 2.72% per annum in 2001 (StatsSA, 2003a:6). While the rate of urbanisation has started to decline, urban populations will continue to increase in absolute terms for some time to come. The growth rate is highest in the coastal urban centres. The population growth rate in the CMA is about 2.8% per annum for the 2000-2005 pentad (Haldenwang, 2004 citing UN 2004:148). UN (2004:148) expects the population growth rate in the CMA in the 2010-2015 pentad to be about 0.3% (but this might be an underestimate).

The population is also maturing, i.e. getting older on average, with a median age of 26.7, the second highest in South Africa after Gauteng (StatsSA, 2003a:27). The percentage of children under the age of 15 at the 2001 census was 27.3, the third lowest in South Africa behind Gauteng and the Northern Cape.

Continued migration of people to the Western Cape will lead to numerous urban infrastructural and environmental problems, for example increasing demands for road and rail transport, water, power, volumes of solid waste, as well as worsening water and air pollution (Haldenwang, 2004).

Future population growth in the region will continue to be concentrated along the coastline. Manufacturing and agriculture are the dominant sectors driving economic growth at present, while tourism and trade are expected to grow strongly in the future. The West Coast (especially around Vredenburg/Saldanha, Vredendal and Malmesbury) is expected to have one of the strongest of growth rates in the province in future (about 10 years in the future).

2.3.1 Lessons from recent climate extremes: Drought

The Western Cape is currently experiencing a drought, which may be attributed to climate variability, i.e. the drought will end at some stage. This variability alters the expected availability of water and adds pressure on the adaptability of future water resources. During the past 25 years, most of Southern Africa has experienced extensive droughts, the last three being 1986-88, 1991-92, 2000-2001.

Dam levels in the Western Cape are currently at their lowest levels in five years. The dams currently stand at 29.6% for the dams supplying the City of Cape Town (City of Cape Town/Water resources).

Table 3: Storage levels on 16 May 2001 – 2005 (City of Cape Town, 2005 – online at www.capetown.gov.za/water/waterresources)

	Capacity – Ml	*2001*	*2002*	*2003*	*2004*	*2005*
Wemmershoek	58.64	35.7%	48.7%	41.2%	45.1%	33.4%
Steenbras Lower	33.52	34.7%	45.8%	40.0%	36.4%	37.1%
Steenbras Upper	31.77	43.0%	38.4%	44.9%	40.1%	61.0%
Voëlvlei	164.12	28.7%	61.2%	59.1%	33.5%	21.1%
Theewaterskloof	480.25	44.2%	75.4%	60.5%	33.9%	29.5%
Total Storage	**768.30**	**39.8%**	**67.5%**	**57.2%**	**35.0%**	**29.6%**

This drought-induced shortage of water has placed stress on the water supply and management in the Western Cape, specifically the City of Cape Town. The primary approach for dealing with the impact of drought on water supplies to major towns such as Cape Town has been to increase tariffs and to impose water restriction on the consumers. The City of Cape Town has also embarked on awareness campaigned in an attempt to reduce the consumption of domestic water.

In addition to the water shortage caused by the drought, demand by the City of Cape Town, the West Coast region and the agricultural sector exceeded the available supply by 8%, as revealed in an Integrated Water Resource Planning study commissioned by the former Cape Metropolitan Council (CMC) (Geustyn Loubser Streicher & Palmer Development Group, 2001). They identified the need to adopt an integrated water resource planning approach to manage the changing water demand as well as address the effects of population, economic growth and stresses on supply of water. Note that the excess is extracted from the quantity of water needed to maintain the ecological integrity of aquatic ecosystems (rivers, wetlands and estuaries) or by over-abstraction of groundwater.

Climate change has not yet featured prominently as a real threat to existing available water resources, so that strategies have not been developed to adapt to the projected impacts. Current water management mechanisms and policies have been developed to ensure that the existing supply of water meets the growing demand. Some of the mechanisms may be appropriate to deal with the future shortage that will be brought about by climate variation, but robust long-term strategies are required to ensure the demand for water matches supply, even in times of reduced availability. In addressing future projected climate change impacts, some of the measures may need to be introduced sooner than originally planned.

2.3.2 Lessons from recent climate extremes: Flooding

Some sub-regions of the Western Cape are subjected to intense rainfall events. In recent years this region experienced damaging floods in March 2003 and April 2005 due to a particular weather phenomenon known as a “cut-off low”, which causes heavy rainfall in a short period, accompanied by gale force winds. The “March 2003 cut-off low” resulted in the Magisterial Districts of Montagu, Swellendam and Robertson being declared in “states of disaster” to give an indication of the scale of the damage, the DiMP study prepared the following table to lists the costs per sector (DIMP, 2003).

Table 4: Financial losses that resulted from the March 2003 flooding in the Montagu, Swellendam and Robertson magisterial districts.

By Organisation / Administration	*No. of Recorded Impacts*	*Losses (Rands)*	*% Total Loss*
Provincial Government*			
Dept. of Water Affairs and Forestry	48	13 850 000	6.52
Dept. of Agriculture	1	95 000	0.04
Dept. of Education	11	1 708 000	0.80
Nature Conservation (Dept. of Environmental Affairs and Tourism)	2	1 130 000	0.53
Emergency Services	n/a	100 000	0.05
Roads	139	78 584 200	36.99
Subtotal	201	95 467 200	44.94
District and Local Municipalities**			
Subtotal	36	6 921 827	3.26
Private Sector****			
Eskom	8	1 600 000	0.75
Agricultural land and infrastructure	716	89 521 136	42.14
Irrigation Boards	4	163 000	0.08
Private Insurance	91	3 201 500	1.51
Bellair Dam	1	14 000 000	6.59
Subtotal	820	108 485 636	51.07
Social Relief			
National Dept of Social Development	774	1 548 000	0.73
Total	1831	212 422 663	100.00

*Excludes SAAF costs
**Excludes Plettenberg Bay Municipality
*** This total includes the removal of trees and debris in various locations
****Excludes two factories, Ashton Canning and Tiger Brands, in Ashton

Significant damage and financial losses were incurred mainly by the roads authorities and the agricultural sector, revealing their vulnerability to such extreme events. Farmers experienced livestock losses that were attributed to the abrupt fall in temperature. Eskom infrastructure was damaged by strong winds. Poor households experienced damage due to heavy rainfall and the inadequacies of construction, but the emerging economic impacts were not large, possibly because these units are not insured. Bridges failed due to heavy river flows, often worsened by upstream debris (DiMP, 2003).

The DiMP (2003) study states that the area affected by the March 2003 event is regularly exposed to heavy rainfall events and flooding. The magnitude of the losses due to the 2003 event underlines the need to assess the management of weather and flood risks, especially when repeated flood events result in costly and ongoing reconstruction. This pattern has especially severe impacts on municipalities that have few financial resources.

Climate change which results in an increase in the number of extreme events will have the consequence of substantially raising the cost of losses to the public and private sectors, as well as increasing personal hardship for the people directly affected. Adaptations by regional and local government will need to ensure that structures are built so as to increase their ability to survive flooding, an adaptation that has significant cost implications.

2.4 National/international policies and conventions

In the growing recognition by the global community of climate change, a number of formal strategic frameworks with relevance to local government and business have been established at the inter-governmental level. Key relevant actions are highlighted below, in each case giving the date of signature and date of ratification by the SA government:

a) United Nations Framework Convention on Climate Change (UNFCCC, see http://www.unfccc.de); Signed: 15 June 1993, 27 August 1997; Ratified: 29 August 1997.

The United Nations Framework Convention on Climate Change was signed by 154 governments in Rio de Janeiro during the United Nations Conference on Environment and Development (UNCED) in June 1992. The convention addresses the threat of global climate change by urging governments to reduce the sources of greenhouse gases. The ultimate objective of the convention is to stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous interference with the climate system of the world.

b) United Nations Convention to Combat Desertification in Countries Experiencing Serious Droughts and/or Desertification, Particularly in Africa (see http://www.unccd.int); Signed: 9 January 1995; Ratified: 30 September 1997.

This related to the desertification and degradation of land in arid, semi-arid and dry sub-humid areas and does not refer to the expansion of existing deserts. It is caused primarily by human activities, through over-exploitation and inappropriate land use, and by climate variations. The Department of Environmental Affairs and Tourism is responsible for the coordination of the implementation of this convention in South Africa, with the advice from representatives from the non-governmental organisation (NGO) sector.

c) Ramsar Convention - Convention on Wetlands of International Importance, especially as Waterfowl Habitat. (see http://www.ramsar.org); Signed: 12 March 1975; Ratified: 12 March 1975.

The broad aims of this convention are to stem the loss and promote the wise use of all wetlands. The convention addresses one of the most important issues in South Africa, namely the conservation of the country's water supplies for the use of both the natural and the human environments. South Africa has designated 15 sites to the List of Wetlands of International Importance. A number of others are under consideration. A Wetland Conservation Bill has been proposed which will help South Africa to meet the aims of the convention.

d) Montreal Protocol - Protocol for the Protection of the Ozone Layer
(see http://www.unep.org/ozone/montreal.shtml and http://www-esd.worldbank.org/mp)

Ratified: 15 January 1990
Acceded: 15 January 1990

The protocol is aimed at ensuring measures to protect the earth's ozone layer. South Africa also ratified the subsequent London Amendments to the protocol on 12 May 1992, which were designed to restrict the use of chlorofluorocarbons (CFCs) and halons. Parliament has approved the ratification of the Copenhagen Amendments to the Protocol and the necessary steps are now being taken for the instrument for ratification to be deposited. South Africa has, however, acted in full compliance with these amendments.

3. CLIMATE CHANGE IN THE WESTERN CAPE

The material from this section draws on very recent work concluded as part of research for the AIACC[1] program on climate change adaptation, and project work for the Water Research Commission. As such, not all the material is yet in the public domain.

3.1 Background

The Western Cape has a Mediterranean climate, and so in contrast to much of southern Africa which experiences summer rains and dry winters, the Western Cape receives the bulk of its rainfall in winter months, and experiences relatively dry summers (see Tyson and Preston-Whyte 2004). This climatic pattern is driven mainly by the position of the southern African subcontinent in relation to the band of westerly waves and associated low pressure systems that move from west to east between roughly 40º and 50º S. These low-pressure systems bring rainfall to south-western South Africa seasonally in the form of cold fronts. The associated rainfall is augmented by a significant contribution of orographic rain due to the extensive mountain ranges in the area. These mountains also act as a barrier creating a drier interior on the lee side of the ranges.

The climate of the Western Cape is strongly affected by seasonal shifts in the position of the westerly waves., and as the persistent high pressure systems in the southern Atlantic and Indian Oceans which block the passage of frontal systems over the southern African landmass shift northwards during winter months, the westerly waves likewise shift northward. The Western Cape is therefore more exposed and susceptible to these frontal systems in winter. There are large variations in the westerly wave and high pressure cell positions during winter and both seasonal and annual rainfall in the region can thus also be subject to this variation creating regular drought conditions.

Other significant weather systems for the Western Cape climate include **coastal** low pressure systems that cause hot dry “berg” winds to blow over the landmass southwards from the interior, causing extreme warm conditions generally during late winter and early spring – if these episodes are preceded by extended dry periods, the risk of fire is heightened. **Cut-off** low pressure systems are unstable atmospheric systems that spin off from frontal systems, generally occurring in autumn and spring months and these may cause extreme rainfall events and flooding over South Africa.

3.2 Global climate trends

Clear trends are present in the global climate system. Overall, year on year, there is evidence that the global mean temperature is increasing continuously, with reasonable evidence that this change is accelerating (IPCC, 2001b). The dominant global trends of confidence include:

[1] See www.aiaccproject.org

- Increased mean temperatures, especially in higher latitudes
- Reductions in global ice sheets and seasonal snow cover
- Increased ocean heat content with related sea level rise
- An increase in the frequency of extreme events (e.g. heat waves)

Related to these is a range of more regionally specific trends of consequence to society. The analyses of these changes are clearly demonstrating that much of the change is directly attributable to human activities forcing changes in the atmospheric composition. Particularly, the change in global temperatures of the last 50 years cannot be explained without recognizing the role of human activities (IDAG, 2004).

Recognizing the human influence, Figure 5 shows the seasonal trends in temperature for the latter part of the 20th century. As can be clearly seen, for nearly all global regions with a good historical record, there is a clear warming trend.

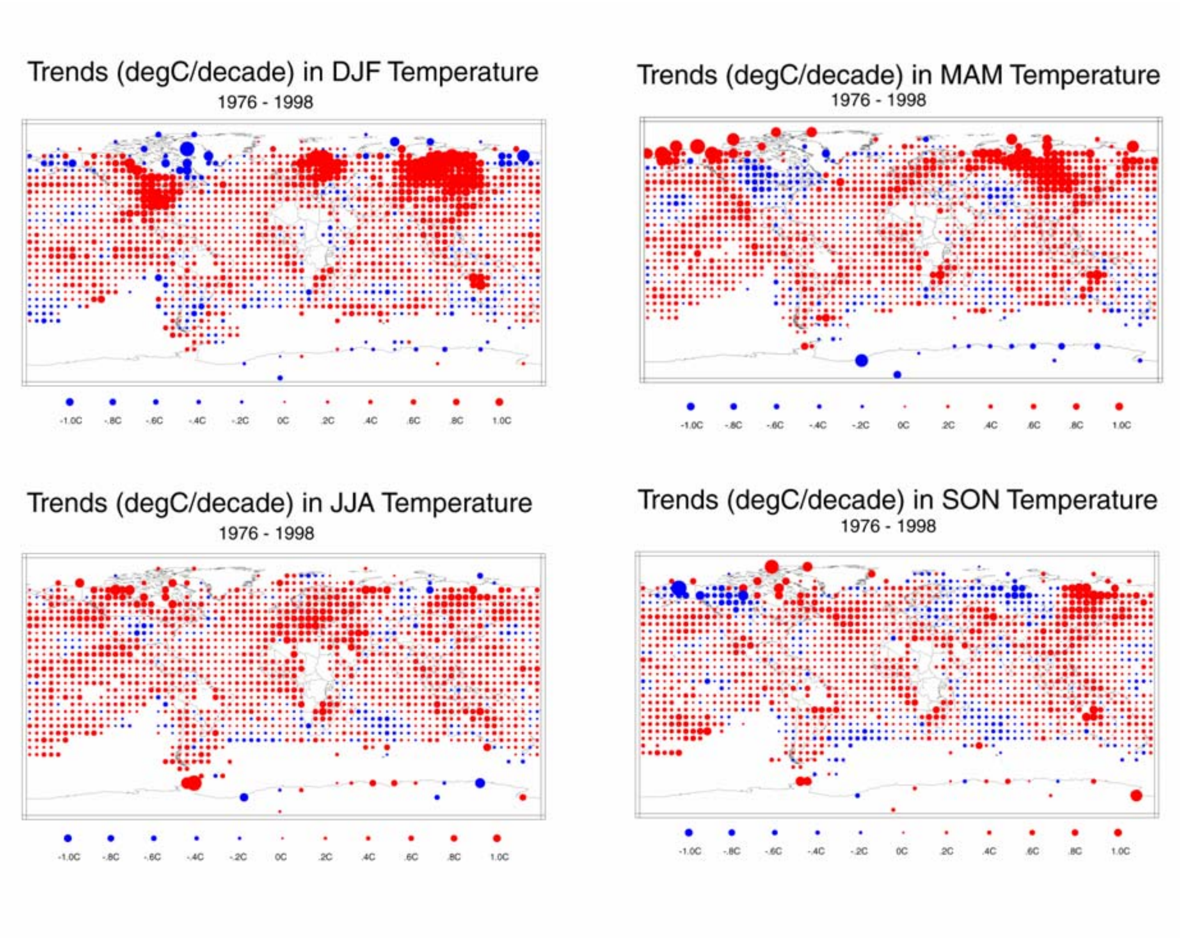


Figure 5: Historical trend in seasonal mean temperature (from IPCC, 2001b)

It is important to note that global trends may have a very different expression at the regional scale. Consequently, while global trends are important, for regional studies they serve more to provide the confidence and understanding in the reality and magnitude of human induced climate change. Secondly, the global changes serve to highlight key attributes of concern, notably that of the potential for sudden rapid climate change, and the issues surrounding irreversible changes.

Uncertainty

Climate change studies inherently have to consider the significance of uncertainty. This does not mean that there is no confidence in the understanding, or that the understanding is not certain enough to the point of allowing the development of appropriate adaptation strategies and policy for resource management. To the contrary, current research would suggest that appropriate political response is lagging the understanding of climate change.

Nonetheless, the magnitude and source of uncertainty needs to be understood. For this reason it is imperative that a probabilistic framework is used in developing projections which, at a minimum, should be an interpretive statement that draws on the multiplicity of information sources to inform the interpretation of the regional projections. In this context, one should recognize that four sources of uncertainty currently limit the detail of the regional projections:

1. Natural variability. We have a finite historical record from which to define the range of natural variability at different scales of time and space. Within this limitation it is not possible to set definitive limits of natural variability, nor the degree to which this may exacerbate or mitigate the known background trend in change of the baseline climate, nor how much of the change in variability itself may be directly attributable to anthropogenic factors;
2. Future emissions. Much of the future projected change, at least in terms of the magnitude of change, is dependent on how society will respond in the future and impact the emissions of greenhouse gases. Note that the world is already committed to a degree of change based on past emissions (estimated as at least another 0.6ºC warming in the global mean temperature). How society responds in managing emissions could result in estimated projected changes of between 1.5º and 5.6ºC of the global mean;
3. Uncertainty in the science. For Africa, perhaps more so than other regions of the world, this issue is of noted concern. Current understanding of the regional dynamics of the climate system of the sub-continent is limited. There may well be key components of the system that, under global change, will result in significant changes in regional climate through transitioning to new modes of the regional climate, possibly leading to rapid nonlinear change, with unforeseen and sudden increases in regional impacts. This issue increases the threat of climate change, rather than minimising the problem, as *change* of whatever form inherently impacts the structures of society;
4. Downscaling – the term used to define the development of regional scale projections of change form the global models used to simulate the global response of the climate system. The downscaling tools introduce an uncertainty that limits the confidence in the magnitude of the projected change, although the pattern of change can be interpreted with greater certainty.

3.3 Recent historical trends in climate for the Western Cape

The historical trends in the Western Cape climate form the foundation for assessing future change. It is important to understand that there is no guarantee trends in the recent climate record will continue into the future. The trends observed in the past few decades, especially of rainfall patterns, are the result of several competing processes in a complex non-linear system, and it is likely that future changes will follow a trajectory of change that differs from the past. Nonetheless, the historical changes observed, especially of temperature trends that can be more easily compared to global averages, is valuable in providing a context for assessing the credibility of concerns about climate change, and future climate projections.

3.3.1 Historical trends in atmospheric circulation over the Western Cape

There were significant changes in the frequency of daily atmospheric circulation patterns (high and low atmospheric pressure systems) over the western Cape during the period 1958-2001 (Tadross, 2005, in submission). For example, the frequency of strong low-pressure systems has increased significantly during March-May and decreased during June-August. The spatial pattern of rainfall has therefore changed with time. One impact of less-intense low pressure systems during winter is a weakening of synoptic forcing, this creates atmospheric conditions conducive to brown haze and smog in the Cape Town area.

The September – February period has experienced an increase in the frequency of strong high pressure systems which, when sufficiently intense, can lead to an increase in hot dry berg winds. This leads to increased fire risk, especially after long dry periods. If the strength of the wind field over the Cape Metropole is low then this hot dry air leads to inversions, capping cooler air below and traps emissions from factories and cars close to the ground where it negatively affects the health of people.

3.2.1 Historical trends in air temperature in the Western Cape

The global temperature has shown a clear warming of about 0.6ºC over the last century (IPCC 2001b), but this is made up of widely varying trends in different regions of the world (Figure 5). For this study, daily minimum (T_{min}) and maximum (T_{max}) surface air temperatures averaged over every month were analysed for 12 meteorological stations across the southwestern Cape (see Box 3 for methods). Time series analyses were conducted by month for the time period 1967 to 2000. Significant warming trends were found for December to March, and July to September for T_{min}, and for January, May and August for T_{max} (Figure 6). Very warm days have become warmer or have occurred more regularly during the last decade, particularly during January, April and August. Mean annual T_{min} and T_{max} over the same time period showed significant warming trends at most stations.

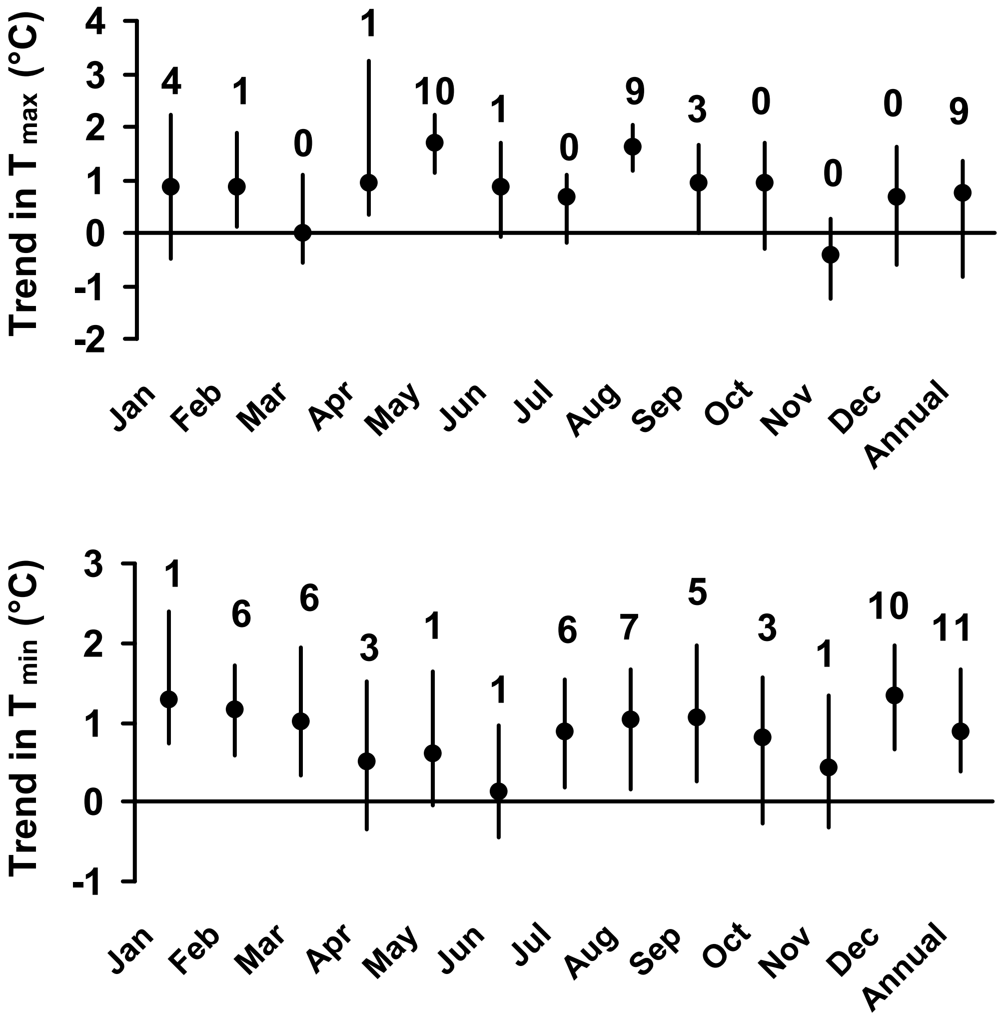


Figure 6: Trends in minimum (Tmin) and maximum (Tmax) monthly temperatures (January to December from left to right on the X-axis, followed by the annual mean), for 12 Western Cape climate stations during the last three to four decades of the 20th century. The filled circles represent mean change for all stations, and the bar represents the range between lowest and highest trend value. The number above each data entry represents the number of stations out of twelve for which the linear change is statistically significant (>95% confidence level). Trends in maximum temperatures are consistently highest in spring and autumn, while minimum temperature trends are high all year round, but particularly so in summer months.

Box 3: Analysis of historical temperature data

Data for 12 meteorological stations spanning the southwestern Cape of South Africa (Table 5), were obtained from the division AgroMet of the Institute for Soil, Climate and Water, Agricultural Research Council. The stations are spread throughout the climatically divergent fruit-growing regions, ranging from cold (e.g. De Keur) to warm (e.g. Robertson), and from predominantly winter rainfall in the west to rainfall throughout the year in the east. The selected stations were operational up to and including the year 2000, and had reliable temperature records from 1967 or earlier. This year was used as a starting point for the analysis in order to achieve an optimum compromise between numbers of stations and length of record. All stations are positioned on farms or nature reserves, and all except Nietvoorbij (Stellenbosch) are well away from urban influences. AgroMet had subjected the data to quality checks.

Data which were supplied included monthly means of daily minimum (T_{min}) and maximum (T_{max}) surface air temperatures. Time series for each station for the period 1967 to 2000 were prepared on a monthly basis for mean T_{min} and T_{max}.

For the trend analyses, the AUTOREG procedure of SAS (Enterprise Guide version 1.3) was used, giving a coefficient and P-value for the time series. The coefficient was used to calculate the average trend over the time period analysed. Significance was set at $P \leq 0.05$.

Table 5: List of meteorological stations used for the historical climate trends analysis in the southwestern Cape, South Africa.

Station name	*District*	*Latitude*	*Longitude*	*Altitude (m)*	*Period*
De Keur	Ceres (Koue Bokkeveld)	32° 58'S	19° 18'E	945	1966-2000
La Plaisante	Wolseley	33° 27'S	19° 12'E	260	1963-2000
De Doorns Exp. Farm	De Doorns	33° 28'S	19° 40'E	457	1963-2000
Veldreserve	Worcester	33° 39'S	19° 27'E	275	1962-2000
Robertson Exp. Farm	Robertson	33° 50'S	19° 54'E	156	1962-2000
Bien Donne Exp. Farm	Groot-Drakenstein	33° 50'S	18° 59'E	138	1942-2000
Nietvoorbij	Stellenbosch	33° 54'S	18° 52'E	146	1967-2000
Elgin Exp. Farm	Elgin	34° 08'S	19° 02'E	305	1963-2000
Tygerhoek Exp. Farm	Riviersonderend	34° 08'S	19° 54'E	168	1966-2000
Weltevrede	Barrydale	33° 56'S	20° 37'E	405	1965-2000
Outeniqua Exp. Farm	George	33° 55'S	22° 25'E	204	1967-2000
Langkloof Exp. Farm	Joubertina	33° 47'S	23° 35'E	722	1966-2000

3.2.2 Historical trends in precipitation in the Western Cape

Precipitation is generally a difficult parameter to analyse for trends, due to a high degree of inter-annual variability, and single extreme events can readily skew a simple analysis and hence lead to a misleading conclusion. For the analysis of historical precipitation we use the work of Hewitson *et al*. (2005), Hewitson and Tadross (2005, in preparation), based on the gridded precipitation data set by Hewitson (2005). The gridded interpolation of precipitation is used as trends calculated on station data may not be fully representative of the regional trends. The interpolated data is based on a sophisticated methodology that assesses the area average value from the station data, and uses the period from 1950-1999. Trends calculated on the station data match, qualitatively, the trends calculated on the gridded data.

The regional historical change is complex. The trends in mountainous regions are different from, and in places, opposite to the trends in the lowland regions. Generally, mountainous regions show little change or positive trends, i.e. increased rainfall, while lowland regions have negative trends i.e. decreased rainfall. Seasonally, however, the trends are more complex, with distinct patterns of trend in, particularly, summer (and especially late summer) versus early and late winter.

Figure 7 shows the baseline precipitation from the gridded data, and can be considered as the baseline climatological precipitation from which the trends reflect departures. Following the baseline monthly precipitation totals, in Figure 8 we show the trends in monthly totals.

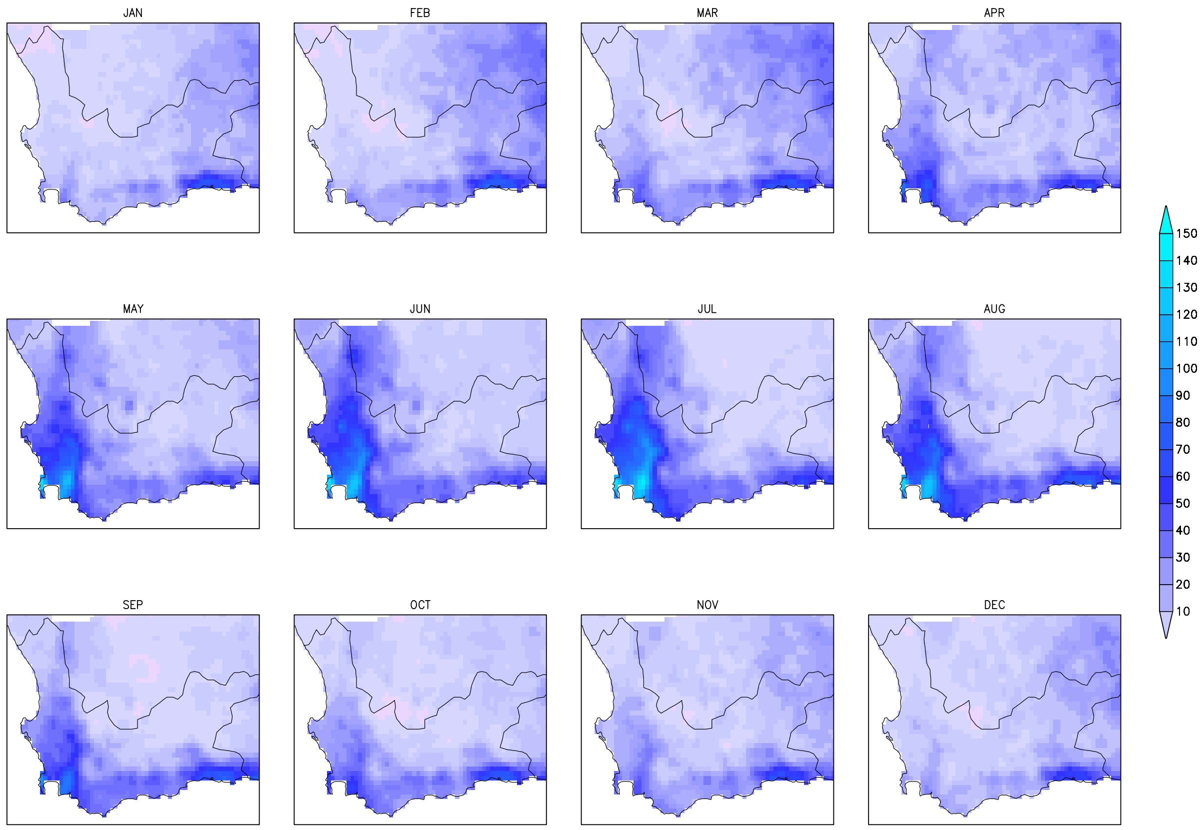


Figure 7: Climatological monthly precipitation totals (mm)

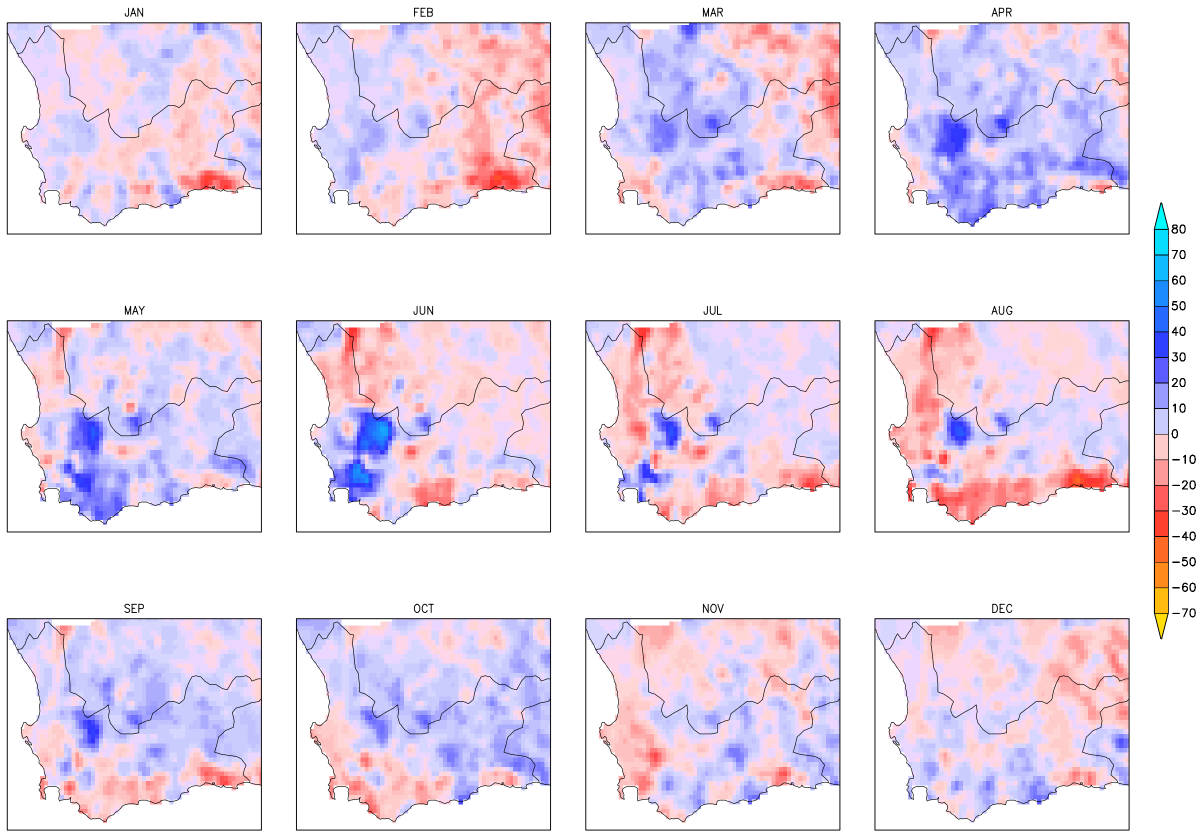


Figure 8: Trend in monthly total precipitation (mm) for 1950-1999 (as the total change in mm over 50 years), red tones represent drying, and blue tones wetting trends.

These patterns can be explained by projections that there will be fewer strong or deep low-pressure systems during the winter months of June, July and August, which would result in lower rainfalls during this period. However, the reason why there could be an increased rainfall in some mountainous regions is unknown as yet and the causes are uncertain. Further research is required to reduce this uncertainty.

3.2.3 Does sunspot activity influence climate change?

Climate variability has been linked to variations in solar activity, i.e. the sunspot cycle (Houghton et al. 2001). However, recent analyses by Foukal et al. (2005) has called this hypothesis into question, citing the small variation of solar output (0.8%) that can be attributed to the sunspot cycle and the relatively poor ability of instruments to measure accurately these variations.

The correlation between rainfall over the Western Cape and sunspot activity is weak. Sunspot activity explains a maximum of 11% of the variation in March-April rainfall over the West Coast. Additionally the sign of the correlation changes over the winter months (i.e. there is a positive correlation over some months and a negative correlation over others). Over other parts of the

Western Cape and at other times of the year the correlation is substantially weaker. In conclusion, there is, at best, a weak correlative relationship between the sunspot activity and the Western Cape climate variability. Causative mechanisms, if they exist, are unclear.

The following text quotes Ruddiman (2001), who describes the prevailing view of climate change scientists:

"*proposed correlations between long term sunspot averages and Earth's climate that appear convincing over some intervals, become weaker, or even reversed in sign, during others. For example, why did the cold of the Little Ice Age persist and even intensify through the middle and late nineteenth century, even though the average numbers of sunspots (and presumably the sun strength) were by then closer to the values typical of the warm 20th Century*?"

Tyson and Preston-Whyte (2004) detail what they term quasi-periodic variations in rainfall, primarily for the summer rainfall zone of South Africa. A medium-term cycle with a period of 18 years loosely reveals alternating 9-year periods over the past 8 decades of wetter and drier conditions than the long term mean. The causes appear to be complex, and involve variations in large-scale atmospheric pressure fields over southern Africa, the southern Atlantic and Indian Oceans. These variations, and resulting wet and dry spells, have resulted in rainfall fluctuations of between 20 and 30% of the long term mean in the summer rainfall zone, but are not as clearly evident in the winter rainfall zone. Thus it should be noted that medium term rainfall fluctuations due to natural atmospheric variations will be overlaid on the trends induced by climate change, making the detection of clear trends difficult in the initial phases of anthropogenic climate change, and possibly sometimes exacerbating, and sometimes ameliorating the anthropogenic climate changes themselves.

3.4 Climate projections

Projections of future climate are derived from computer model simulations. These models simulate whole-earth climate but have poor spatial resolution (analogous to saying it presents a grainy picture) for resolving regional scale climates (especially for precipitation). However, the models are quite good at resolving the large-scale circulation of the atmosphere (high and low pressure features, etc.), and as these determine the regional climate to a large degree, it is possible to “sharpen the picture” of projections of regional climate change. This more narrow focus may be accomplished through two techniques; using a high resolution regional scale model of the climate system, or using empirical relationships (note that a high resolution whole-earth model requires enormous computing power). Both approaches are considered equally competent at present, with relative strengths and weaknesses (IPCC, 2001b). Results are available for the Western Cape using both approaches, although the regional model results have yet to be fully assessed.

It is important to bear in mind the discussion on uncertainties presented earlier. In particular, to realize that the magnitude of the projected change is the most uncertain and depends on a number of factors, not least of which is how emissions of greenhouse gases change in the future.

Nonetheless, the pattern of change from the downscaling studies do produce a message of some consistency.

3.4.1 *Future regional climate scenarios: Precipitation*

Presented here are results from the empirical downscaling approach (Hewitson *et al*., 2005, Hewitson, 2005). Results from the regional climate models are not presented, as these tools are not sufficiently mature to draw conclusions about future change. Conversely, empirical tools have been well developed and applied to a range of global model simulations of the future. In each case, regional projections result from downscaling projected large-scale circulation changes as simulated by six global models, each using a scenario of increases in greenhouse gases that assume (conservatively) that society will continue to use fossil fuels at a moderate growth rate.

Figure 9 shows the changes projected for the Western Cape. To assess the graph, one needs to consider the pattern consensus between the models (columns) across the rows (months). In this manner, it is clear that the models differ in the projected magnitude of change, yet there are clear messages of consensus in the pattern of change. Two dominant messages may be identified:

a) Late summer increases in precipitation in the interior and to the east of the province, with the strongest changes associated with topography. This agrees with the understanding of a moister atmosphere in the future, leading to more orographic rain, and increased possibility of convective rainfall events.
b) A decrease in early and later winter precipitation for the south-west of the province, with a less clear message during the mid-winter period where the models disagree on the direction of change. This would suggest that the core season of the south-west winter rains, dominantly a function of cold fronts, are likely to shorten in duration.

Other aspects of the projected change may be seen; however, there is less the confidence in interpreting the finer scale changes is less.

Figure 10 shows the changes in the magnitude of the median rainfall event in a month. The median rainfall event may be considered the typical, or most common, rainfall event. The projected changes mirror, to a large degree, the patterns in the changes of monthly total rainfall. Notable, however, are the projected increases in magnitude of the rainfall events in the mountains, and to the east of the mountains in the mid to late summer.

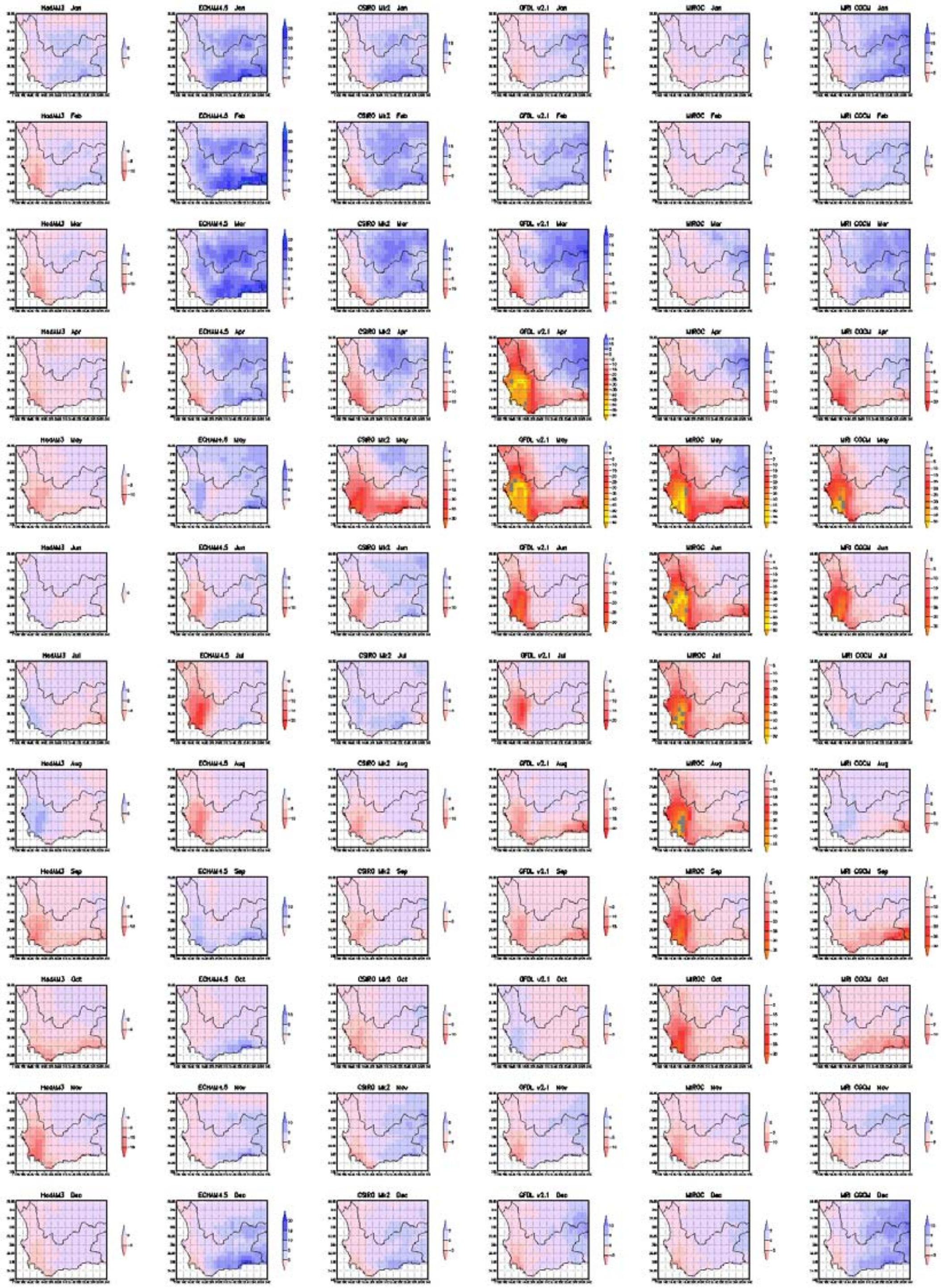


Figure 9: Projected changes in monthly total precipitation (in mm) for, nominally, the period around 2070. Columns group regional projections from independent global model simulations of the future, from left to right – HadAM3, ECHAM 4.5, CSIRO Mk2, GFDL v2.1, MIROC, MRI. The rows are the months of the year (January at the top, December at the bottom), red tones represent drying, and blue tones wetting.

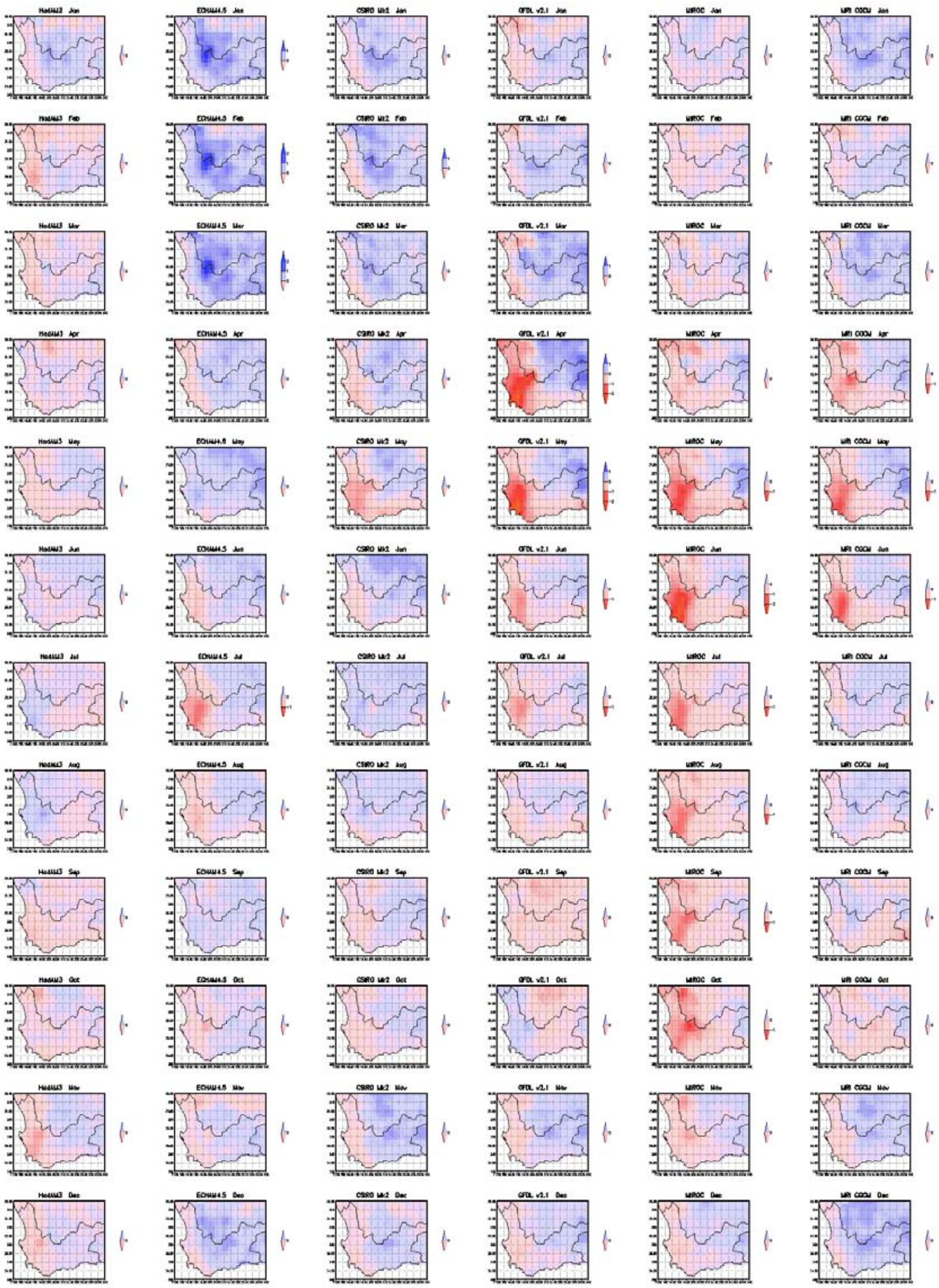


Figure 10: Projected change in the magnitude of the median ("typical") rainfall event in a month (mm). Columns group regional projections from independent global model simulations of the future, from left to right – HadAM3, ECHAM 4.5, CSIRO Mk2, GFDL v2.1, MIROC, MRI. The rows are the months of the year (January at the top, December at the bottom), red tones represent drying, and blue tones wetting.

3.4.2 Future regional climate scenarios: Temperature

Downscaling of temperature changes is not yet available. However, temperature can be expected to rise everywhere, least on the coast and more as one moves inland. Typical ranges to expect by 2050 are ~1.5º on the coast, and 2-3º inland of the coastal mountains. The absolute magnitude will depend on a number of factors and these values should be treated as a median value within a range.

3.4.3 Linking the observed trends with the projected changes

In considering the results on historical and projected changes, some more general conclusions may be drawn. Over the Western Cape the observed trends in total precipitation are strongest during March – August. This covers the late summer / early winter to mid winter periods and trends differ between early winter (March – May, MAM) and mid winter (June – August, JJA). It should be noted that stronger trends are observable within particular months, however we will concentrate on the seasonal trends to aid the clarity of the discussion. From analysis of the statistics of the rainfall (not shown), during MAM much of the region indicates positive trends (i.e. increasing rainfall) during the 1950-1999 period. These positive trends are stronger in derivative statistics of the daily rainfall; in particular the 90th percentile event i.e. the top 10% of rain events have increased in intensity. These increases in intensity are most noticeable over the mountainous interior but also extend to some of the coastal regions. During JJA the coastal regions exhibit a drying trend whereas inland mountains tend to exhibit a wetting trend. Again these total rainfall trends are most clearly reflected in trends of the 90th percentile event; the top 10% of rain events have been increasing in intensity over higher elevations and decreasing at lower elevations.

These changes in precipitation can be explained using observed trends of the atmospheric circulation. Between 1958 and 2001 the frequency of strong low pressures centred south of South Africa increased during MAM, whereas during JJA these strong low pressures decreased in frequency to be replaced by weak low pressures. If we assume that strong low pressures are likely to bring rain to all regions of the Western Cape and weak low pressures only to regions of high elevation, the trends in circulation explain the contrast between the rainfall trends in coastal and mountain environments. Even so, the increase in rainfall intensity over high elevations during JJA cannot be explained through simple circulation changes and suggests that increases in humidity also have been occurring. This is expected in a future warmer climate and emphasises the two factors, humidity and circulation, that influence rainfall. Rainfall trends during the rest of the year (September – February) are not as strong, though there was a significant increase in the frequency of strong high pressures centred to the south of South Africa. These high pressures draw air from the interior towards Cape Town and may have led to an increase in hot dry berg winds.

Before discussing the projections of future rainfall change it is useful to understand predicted changes in the atmospheric circulation that are broadly consistent between global models (our tool for projecting future change). For the Western Cape region the important aspects are a shift southward of the storm tracks, accompanied by an increase in the strength of the Hadley circulation and an overall increase in humidity, especially during summer. This suggests often competing factors affecting rainfall; although there may be more humidity for rainfall, the mechanism for bringing that rainfall may retreat from the region during winter in the future climate. During summer an expansion of convective rainfall over the interior may bring more thunderstorms to the Western Cape.

The most consistent predictions (from the statistical downscaling of 6 GCMs) are for an increase in total rainfall over the eastern regions of the Western Cape during late summer (January to March) and a decrease in rainfall, particularly over the western regions of the Western Cape, during early winter (April to June). This tendency for decreased rainfall, though not as large as during the early part of the season, continues throughout the winter season. Variations in the timing of these shifts occur for individual models and some weak increases in rainfall are suggested for individual months, but on the whole there is a consensus for winter drying.

These projected changes in total monthly rainfall are clearly reflected in derivatives of the monthly statistics (not shown); e.g. the median and 90^{th} percentile rainfall intensities. However, the frequency of days with rainfall greater than 20 mm is projected to remain the same during late summer, at the same time when the 90^{th} percentile event is shown to increase. This implies that the changes in late summer rainfall are mostly due to an increase in the intensity of rainfall.

These projections demonstrate remarkable consistency between different models, largely due to the consistency in dynamic circulation changes simulated by the GCMs. Importantly, whilst not exactly the same as the observed trends, they are equally explainable through changes in humidity and circulation; the increase in intensity in late summer rainfall is largely attributable to increased humidity, whilst the decrease in winter rainfall is largely a consequence of the southward retreat of the westerly storm tracks. For impacts researchers this raises the issue of whether a short-term (10-15 years) or longer-term strategy is required. In the short term it may be advisable to use the observed trends as suggestions for change in the near future. However, this can only be a short-term strategy and as changes in the climate begin to accelerate (as they are predicted to do) the projections will become more apparent.

Box 4: Summary of observed and predicted climatic changes in the Western Cape

Observed trends:

1) JJA tendency for weaker pressure gradients -> More days with inversions (pollution/brown haze risk);
2) Increase in days with berg winds during DJF (fire risk);
3) Rainfall in the mountain regions appears reasonably stable, possibly a slight increase. Rainfall on the coastal plain shows a slight negative drying trend.

Projected change:

1) More summer rainfall from January onwards, especially inland and towards the east;
2) Less early winter rainfall, especially towards the southwest;
3) Temperature can be expected to rise everywhere, least on the coast and more as one moves inland. Typical ranges to expect by 2050 are ~1.5º on the coast, and 2-3º inland of the coastal mountains. The absolute magnitude will depend on a number of factors and these values should be treated a median value within a range.

4. IMPACTS AND VULNERABILITIES

4.1 Physical sectors

4.1.1 Water Resources

4.1.1.1 Overview

The Western Cape is a province characterised by great variability in abundance of water resources. Where water is available, it is mostly already fully utilised, primarily for irrigation. Both surface and groundwater resources are exploited, in some places, the rate of exploitation is unsustainable. Yet, in rural areas, water consumption for irrigation appears to be one of the few ways sufficient wealth generation can take place that will make the necessary impact on the high rates of unemployment that exist in South Africa. The growing metropolitan area of Cape Town is demanding a greater share of the water resources and new ways of supplying these demands will have to be found within the short to medium-term future. At the same time, sufficient water must be left in the rivers to maintain their ecological integrity at acceptable levels. Because water is already a limiting factor in most of the province, climate change that involves a general drying of the Western Cape region has serious implications for further socio-economic development as well as maintaining the ecological integrity of the wetlands, rivers and estuaries which also depend on that same water.

The pattern of water availability in the Western Cape is determined by the location and orientation of the mountain areas, and partly by regional sea-surface temperatures which are responsible for the Mediterranean climate (See Figure 1). The Cape Fold Mountains acts as a barrier and receives most of the rainfall through orographic forcing, creating interior rainshadows. There are very strong rainfall gradients as a result, with mean annual rainfall rising more than a 1000 mm over distances of 1 –2 km in places. These physiographic characteristics also result in pronounced differences in mean annual rainfall within the region, ranging from a high of 3600mm.a^{-1} in the mountains near Stellenbosch to less than 100mm.a^{-1} in the hyperarid north of the Knersvlakte.

4.1.1.2 Administration of Water: Water Management Areas

For the purposes of water resource planning and management, 18 water management areas (WMAs) have been declared that encompass the whole of South Africa. Each water management area encompasses the drainage basin or catchment of a major river, as well as numerous other minor catchments that have direct oceanic outfalls where the water management area has a coastal boundary. The Western Cape is made up of four these, 1) Gouritz, 2) Oliphants/Doorn, 3) Breede and 4) Berg (see Figure 11 below).

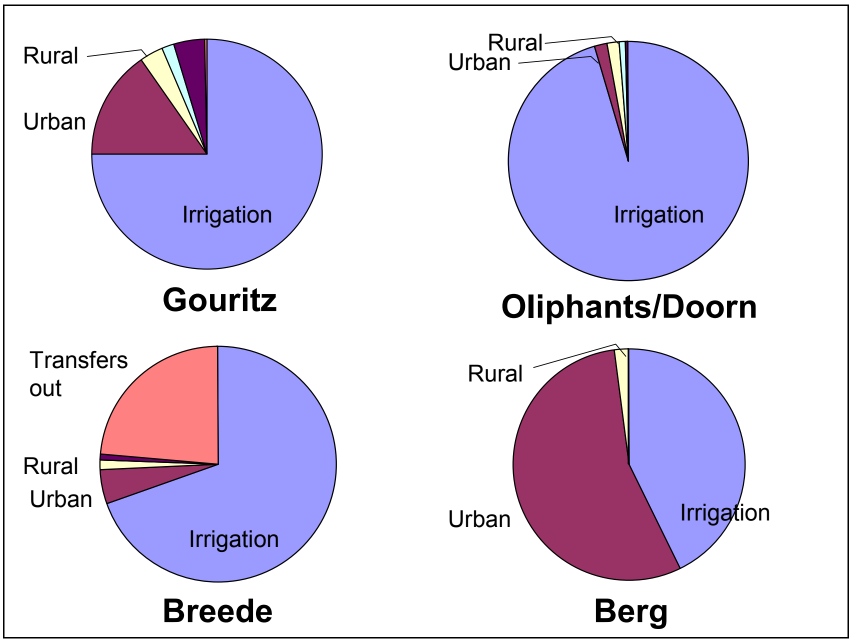


Figure 11 Water use by sector in each of the Water Management Areas within the Western Cape.

Gouritz WMA16:

The Gouritz River has as its major tributaries the Groot River and the Oliphants River. Water in the Groot River is of particularly poor quality, with high salinity. Water quality is expected to decline significantly as flows are reduced through increasing water demand. The water quality in the Oliphants River, although of initially high quality, declines rapidly downstream as it becomes more mineralised (Basson and Rossouw, 2003a). The water in the lower Gouritz is already too saline to use for most purposes. In terms of water availability – the Gouritz River is fully utilized and no more development of the water resource can be permitted (Basson and Rossouw, 2003a).

Groundwater is of major importance to irrigation in the Gouritz WMA (more than half of the water used is abstracted from groundwater). A reduction in the availability of groundwater due to a) over-exploitation and b) climate change, or c) a combination of these, will have significant financial and sustainability impacts in the region. In general, the drier it is, the greater the proportional use of groundwater (Basson and Rossouw, 2003a).

Irrigated agriculture in the region is opportunistic, in that irrigation occurs when water is available. Because of the reliance on irrigation, special attention must be given to the potential for salinisation. Irrigation efficiency is very low (Basson and Rossouw, 2003a). Reduced flows and increased evaporation will increase salinity further.

Oliphants/Doorn WMA17:

The area has a steep rainfall gradient, with a MAP of 1 500 mm $.a^{-1}$ in the mountains in the south to less than 100 $mm.a^{-1}$ in the north in the Knersvlakte. Evaporative demand is very high. The quality of surface and groundwaters of the region is generally low.

Irrigation agriculture is the mainstay of the economy and uses 95% of the water in the region. The Clanwilliam Dam was completed in 1935 and remains the prime water storage in the region. The dam wall is currently being raised to increase the supply of water to local and regional farmers. The existing small farm dams are located close to the mountains where the rainfall is higher (Basson and Rossouw, 2003b; DWAF, 2004). .

The gross regional product is very low, about 0.3% of the GDP of the national economy and the mining sector is relatively unimportant *(Basson and Rossouw, 2003b).* The region is in urgent need of socio-economic development. Expansion of irrigation, which appears to be the only option for development in the region, is limited by the availability of water. There are few strong economic stimulants in the region and the general trend is for people the urban centres e.g. Cape Town. The existing trend is a decline in rural population and little change is seen for the region in terms of economic growth for the long term as there are few drivers of growth.

Water in the Oliphants River catchment is already over-allocated and there is full utilization of the water resources. Over-exploitation of groundwater (i.e. mining of groundwater), particularly in the Sandveld (Lamberts Bay and interior) is making up current shortfalls but this is unsustainable. The implementation of the Ecological Reserve will severely affect users of water from the Oliphants River (under current efficiencies of use). The Oliphants/Doorn system is of very high biodiversity significance (for example the redfin minnow is endemic to the region and now exists only in tributaries) and this has created a conflict between the need for development with the requirements to maintain ecological integrity and biodiversity.

Further north in the hyperarid Knersvlakte (rainfall/potential evapotranspiration <0.05) there is very little economic activity. A change in water demand in this area is not foreseen, and local requirements could be met from groundwater. The Department of Water Affairs and Forestry foresee a potential for development further south in the Koue Bokkeveld with the possibility of exploitation of the Table Mountain Group aquifers and raising the Clanwilliam Dam wall (Basson and Rossouw, 2003b). In the Sandveld area, groundwater is already overexploited and sustainability is already at risk.

The issue of climate change for the region has been noted in regional water resource studies, but nothing has been proposed as possible solutions.

Breede WMA 18:

The Breede water management area is of crucial importance to the Western Cape Metropolitan Area because of water transfers that take place between water management areas. The key reservoir in the Breede WMA is the Theewaterskloof dam from which water is mostly transferred into the Berg River scheme and to supply downstream irrigators (the ability to reverse flow has been designed into the system but the facility is little used).

Agriculture is the biggest user of water in the water management area and the water resource is almost fully developed if allocations to the ecological reserve are taken into account. This gives little scope to the coastal resort towns which are rapidly approaching maximum capacities of their existing supply schemes. Groundwater is being seen as the solution to this problem but the yield and sustainability of supply has not yet been fully proven (Basson and Rossouw, 2003c).

The future use of the water resources of the Breede River will require trade-offs between development and conservation (Department of Water Affairs and Forestry, 2003). Further yields are seen as being available by taking from the ecological reserve (Department of Water Affairs and Forestry, 2003). Yield assessments have not taken into account system-wide implementation of ecological water requirements.

Berg WMA 19:

The Berg Water Management Area is the major water supply to the Western Cape Metropolitan Area and contains the Western Cape Water Supply System - includes the Steenbras Upper and Lower, Wemmershoek, Voëlvlei and Theewaterskloof dams. The Berg River Water Reconciliation Study (2000) shows the Berg WMA in general is already in deficit, under current climate conditions. This is also the water management area that is expected to show the highest population growth, which is already driving increased demands for water. There is very little potential for further water development. Six percent of water supply in this water management area is supplied by groundwater, with Atlantis the largest user, although they have a recharge scheme.

Water infrastructure is generally well developed. Increasing demand because of growth in the population is putting increased pressure on resources. This is having a negative impact on the ecological integrity and health of the mainstem rivers (see report by Nel *et al.* 2004). The main issue is the increasing scarcity of water supply for development.

4.1.1.3 Stock-take of current Western Cape Water Resources

Figure 11 shows clearly that water use by the irrigation sector is by far the largest water user in the Western Cape. Water resources in the region are already fully committed if the specified allocations to the ecological reserve are made in practice. In some places a water allocation deficit already occurs, implying that the demand is being met out of the ecological reserve, or from groundwater reserves beyond the natural recharge rate. The Department of Water Affairs and Forestry, in assessment documents, already view the ecological reserve as a source of water for further development options. Table 6 describes the potential future water resource surpluses and Table 7 describes the envisaged additions to yield as viewed by the Department of Water Affairs and Forestry.

The Western Cape therefore already experiences significant water stress, i.e. there is not enough to meet the needs or urban, irrigation and ecological needs. There is potential for the abstraction of significant quantities (approximately 70 million m^3/a) of groundwater from the Table Mountain Group aquifers, which underlie parts of the Olifants, Breede and Gouritz WMAs as well. A pre-feasibility study is currently in progress.

4.1.1.4 The Table Mountain Group Aquifer

An option being considered for water supply especially to the Cape Town Metropolitan area is the utilisation of the Table Mountain Group aquifer. Current belief is that is has great potential for water productivity. It is already significantly utilised for irrigation and for municipal use throughout the Western Cape. Some towns are completely dependent on groundwater, for example Bredasdorp, Stuisbaai, Botrivier, Lamberts Bay, Leipoldtville and Graafwater (Nakhwa and Xu, 2005). Current exploitation is as high as 11 mm^3 in places, such as Brandvlei-Sandrift and Witzenberg Valley for irrigation purposes.

Physically, it is a major sandstone unit that stretches from Vredendal in the north of the Western Cape all the way to Port Elizabeth (outside the provincial boundary) and therefore covers a very substantial part of the province. The main water bearing unit of the aquifer (the Peninsula Formation) is hundreds to thousands of metres deep in places (which gives an idea of the size of the resource). Although the sandstones of the TMG are porous, it is the storativity and transmissivity that has developed from fractures and faults that make it so attractive as a groundwater resource (known as secondary porosity). These features developed during the folding and faulting of the Cape orogeny (the mountain building processes in geological time – 200My ago).

Much uncertainty still exists however regarding productivity and sustainability of the aquifer. Flow rates or yields have been hypothesized of up to 120 litres per second for some deep boreholes (Nakhwa and Xu, 2005 citing Department of Water Afairs and Forestry/ Umvoto, 2002). Yields are spatially highly variable and a large amount of research work is still required into the distribution of the characteristics of storativity, transmissivity, porosity and yield. Threats include the incorrect calculation of recharge and transmissivity, which can lead to over-abstraction and sliming (bio-fouling that occurs when bacteria and other microbes respond to dropping water levels and the subsequent change from a reducing environment to an oxidizing one when these organisms come into contact with air). Sliming leads to a reduction in the yield capacity of a borehole (Jolly, 2002). Although the problem can be managed to some extent by chemical dosing of the borehole, once sliming begins, it will remain a problem.

The rate of recharge is a key factor in the estimation of sustainable yield and is calculated in part as a percentage of MAP. It has important implications for understanding the viability of a well-field (Nakhwa and Xu, 2005). It should be understood that recharge does not take place where the MAP is less than $200mm.a^{-1}$. Recharge is also event-driven, most recharge takes place during heavier rainfall events.

The aquifer however remains largely unexploited and it is clear there is great potential of a valuable water resource.

Table 6: Natural mean annual runoff, storage in dams, available yield and potential for development (million m^3/a) by water management area

Water Management Area	*Natural mean annual runoff $m^3 \times 10^6$*	*Storage in major dams $m^3 \times 10^6$*	*Available Yield ($m^3 \times 10^6$)*				*Potential for development ($m^3 \times 10^6$)*
			Surface water	*Groundwater*	*Useable return flow*	*Total local yield*	
Gouritz	1 679	301	191	64	20	275	110
Olifants/Doring	1 108	132	266	45	24	335	185
Breede	2 472	1 060	687	109	70	866	124
Berg	1 429	295	403	57	48	508	127
Total	6 688	1 788	1 547	275	162	1 984	546

Notes:

1. Includes dams constructed to end of 2003 with capacity exceeding 1 million m^3.
2. Yield from run-of-river and existing storage, after allowance for the impacts on yield of the ecological component of the Reserve, river losses, alien vegetation, and urban runoff.

Source: DWAF, 2004:23, 25, 39.

Table 7: Water development schemes envisaged by the Department of Water Affairs and Forestry

Water management area	*Scheme*	*River*	*Possible completion date*	*Potential yield ($m^3 \times 10^6$)*
Oliphants/Doring	Raising of Clanwilliam Dam	Olifants	2009	10
	Olifants/Doring Dam at Melkboom	Doring	2011	121
Berg	Berg River Project	Berg	2008	81
	Voëlvlei Dam augmentation	Berg	2015	30

Source: DWAF, 2004:126-128.

4.1.1.5 Vulnerability to Climate Change

Under a drying and warming scenario of climate change, irrigation requirements would increase while water availability decreases. In a situation of reduced water availability, water quality will be severely impacted (one response or adaptation to this is that effluent standards will have to be managed much more tightly). In general, it can be said that under climate change scenarios – there is a looming crisis in water supply in the Western Cape region.

A general drying this will have a negative effect on recharge and will result in reduced abstraction. However, if rainfall events become fewer but heavier, as has been hypothesized, this will increase recharge and therefore be beneficial to the groundwater resource. The picture regarding the future potential of the TMG as a water resource is still complex therefore. Much research is also still required regarding such issues as the link between aquifer draw-down and streamflow, the impacts of abstraction on aquifer-dependent ecosystems, chemistry of groundwater and the drilling of very deep groundwater boreholes, amongst others.

- Climate change will have a significant impact on agriculture because of its dependence on irrigation. The assurance of supply, i.e. the guarantee with which water can be supplied is already very low).
- Net primary productivity will decrease. This directly affects all farming activities.
- CC may exacerbate further rural depopulation, as areas in which agriculture is the mainstay activity decline, people will become poorer and schools decline, clinics and in general infrastructure may decline.
- Tourism might struggle and the growth of coastal resort towns will slow.
- The ecological integrity of wetlands, rivers and estuaries will be very significantly affected by a general warming and drying that results in declining water resources. Biodiversity related to water bodies will be reduced, perhaps some irretrievably so.

4.1.2 Rivers, Wetlands and Estuaries

4.1.2.1 Rivers

The conservation of biodiversity is necessary because people depend on functioning ecosystems for the services they provide. It is therefore significant that over 95% of the main river ecosystems of three of the four Water Management Areas of the Western Cape Province (the Berg, Breede and Gouritz) are critically threatened (Nel *et al* 2004). The main rivers of the remaining Water Management Area (the Oliphants/Doorn) are also significantly threatened, with over 75% of the main river ecosystems critically threatened. Being threatened means that the river ecosystems run the risk of irreversibly losing the ability to support their biodiversity heritage (natural river habitat, plants, animals). For the critically threatened river ecosystems, this loss is in all likelihood already irreversible. This situation is not unusual in a relatively dry country such as South Africa, in which our main rivers have to work hard to meet the social and economic demands placed on them (e.g. dam construction takes place in main rivers and changes the natural characteristics of the river and negatively impacts biodiversity). Major impacts on these rivers, which result in their threatened status, include over-extraction of water, impacts of dams, pollution, alien invasive organisms, and inappropriate land management (such as destruction of natural vegetation along river banks). In essence, these main rivers now depend on intact tributaries for conserving biodiversity pattern.

Under scenarios of climate change which involve significant drying, the conservation status of the mainstem rivers will decline even further. Of particular importance will be the reduction of the abilities of the tributaries to conserve biodiversity pattern and behave as refugia for the mainstem rivers. All Western Cape Water Management Areas should receive top priority in terms of the development and implementation of Catchment Management Strategies, in order to prevent further loss of biodiversity.

4.1.2.2 Wetlands

> ***Ramsar 1971 Definition of a Wetland***
> *Areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres.*

Wetlands are places where the main driving force is hydrologic, but have a wide range of soil and biotic components. Soil chemistry, nutrient cycling, energy flows and decomposition are tightly linked to water flows and water levels. Wetlands modify the hydrological cycle and function as a system-damping entity. They are highly productive and provide the water and primary productivity on which many species survive. In short, they are life support systems which supply significant benefits (or goods and services) to humans. Their importance stems from the number of extractive and non-extractive benefits that they supply, some of which are listed below:

- Fresh water
- Food resources – fish
- Pollution dilution and water quality protection
- Nutrient cycling
- Biodiversity – of direct economic benefit through ecotourism
- Bird and wildlife habitat
- Enhanced adjacent property values
- Flood attenuation
- Sediment trapping
- Water storage
- Groundwater recharge

Adapting the Ramsar Convention 1990 classification of wetlands, the following wetlands can be found in the Western Cape (Table 8).

There are two key types of wetland degradation and loss in South Africa: deliberate, through development such as drainage to create pastures and flooding by dams for example, and inadvertent loss through poor management in the catchments. Most wetland losses in South Africa can be attributed to deliberate degradation. However, if climate change results in a desiccation of the environment, additional wetland loss can be expected.

The amount of water in a wetland (with reference to its type) and its quality determines the livable habitat for plants and animals (Poff *et al* 2002). Deviations or excursions from the usual conditions (which includes periodic drying as a result of the summer dry period and occasional drought), constitute threats to wetlands.

The loss of some wetlands can have a global ecological impact. The loss of some wetlands will leads to a loss of habitat for migratory birds, some of which migrate as far as the northern Siberian coastline (Palaearctic waterbirds that breed in the high arctic tundra of Siberia and the Taimyr peninsula, and summer in South Africa). Affected species for Western Cape wetlands are listed as follows (Underhill, 1995):

- Ringed Plover (*Charadrius hiaticula*) – widespread, coastal wetlands, Berg River estuary, Langebaan, Wilderness Lakes;
- Grey Plover (*Ch. Leschenaultii*) – coastal wetlands, Berg River estuary, Langebaan;
- Turnstone (*Arenaria interpres*) – coastal wetlands, Langebaan;
- Greenshank (*Tringa nebularia*) - Berg River estuary, Langebaan, Wilderness Lakes;
- Knot (*Calidris canutus*) – west coast wetlands, Berg River estuary, Langebaan;
- Curlew sandpiper (*C. canutus*) - west coast wetlands, Berg River estuary, Langebaan;
- Little Stint (*C. minuta*) - west coast wetlands, Berg River estuary, Langebaan;
- Sanderling (*C. alba*) – Langebaan;
- Ruff (*Philomachus pugnax*) – Berg River estuary, Wilderness lakes;
- Bartailed godwit (*Limosa laponica*) - Berg River estuary;
- Whimbrel (*Numenius phaeopusl*) - Berg River estuary.

Long-distance migrants are a particular attraction to scientists and the public (Underhill, 1995). People pay substantial amounts of money to see these animals and wetlands that support such migratory waders generate substantial economic benefits for their regional and local economies. South African bird watchers overnight between 39 and 87 days on trips to see species of interest, paying for accommodation in the relevant area (Turpie and Ryan, 1998). The number of international bird watching visitors to South Africa is also increasing rapidly (Turpie and Ryan, 1998). International visitors result in a cascade of economic benefits throughout the economy. Wetlands therefore have a direct economic benefit to the Western Cape.

Wetland environments which might be particularly at risk of inadvertent degradation and loss are the high-altitude restio marshes which are significantly at risk from climate change that involves drying in the Western Cape region. Rare and endangered species which inhabit these restio marshes are particularly vulnerable to a drying trend. Some species have been isolated in these environments for thousands to tens of thousands of years and there has been little gene flow between the populations on the different peaks. From that point of view, these remnant populations are extremely valuable to science and society.

Adaptations to these threats should be guided by the individual characteristics of the vulnerable ecosystems and species. For all the lowland wetlands, care must be taken to ensure future supplies of water, even in the face of rising agricultural and urban demands. Water needs to be reserved to maintain their ecological functioning and existence. For other vulnerable systems such as the high-altitude restio marshes, other means for preservation of the vulnerable species must be found. If the trend towards drying takes place, including at altitude, then the loss of some of these habitats will be certain.

There are five wetlands in the Western Cape registered as RAMSAR sites to which the Government of South Africa has obligations (see map): Verlorenvlei, Langebaan, De Hoop Vlei, De Mond and the Wilderness Lakes.

Work is still required to determine the amount of water flow that must be maintained into the in order to meet the requirements of the RAMSAR convention. Further, Saldanha has been nominated as a national growth point and one of the major constraints to this growth is the supply of water. The Berg River and groundwater have been targeted as possible sources. Reserve determinations and the political will to implement these will be crucial to their survival.

Table 8: Wetland types in the Western Cape

Wetland Type (Ramsar 1990)	*Wetland*	*Features and Attributes*	*Threat*
Marine intertidal	Langebaan	Extensive saltwater marshes, highly productive with dense populations of crustaceans and molluscs and salt-marsh plants. The area supports a large number of waders, including migratory Palearctic waders.	Development. Water pollution – oil spills.
Estuarine subtidal and intertidal	Berg River estuary,	Extensive saltwater marshes and particularly mudflats. Migrant waders are a significant attraction to birding enthusiasts.	Reduced inflows through water abstraction for irrigation, land conversion for farming activities. The construction of the Berg River dam upstream near Franschoek is of particular concern with regard to changing salinity profiles and alteration of river and estuary ecology.
	De Mond	The Heuningnes estuary, otherwise known as De Mond is important for being the southern most extent of the tropical species of ginger prawn (*Penaeus japonica*), giant mud crab (*Scylla serrata*) and the gastropod (*Nerita albicilla*).	Severe competition for water by agriculture in the Agulhas plain.
Endorheic [1]	A number of endorheic wetlands exist on the Agulhas plain.	Shallow (< 3m deep), closed systems with water losses occurring by evaporation. Ephemeral (occasional) flooding and sometimes seasonal. Moderately saline. Particularly important to migratory wildfowl.	Reduced inflows through water abstraction for irrigation, land conversion for farming activities
Riverine perennial or seasonal	Breede	A riverine floodplain with an inter-connected system of wetlands containing sedges and reeds, with dense stands of *Phragmites* reeds in some places. Significant storage capabilities downstream of Rawsonville.	Agricultural development, alien invasion, water abstraction and flow modification by dam-building activities
Lacustrine permanent and seasonal (Lake based)	Verlorenvlei	A coastal freshwater lake with a reedswamp system. A wetland of significant importance for supporting migratory Palearctic and other waders, including threatened species such as the Greater and Lesser Flamingos (*Phoenicopterus ruber and P. minor*) and the Caspian Tern (*Hydroprogne caspia*).	Reduced inflows through water abstraction for irrigation, salinisation.
	Wilderness Lakes (Sedgefield)	A coastal lake system with highly variable inflows of fresh water and salinity conditions.	Catchment development for agriculture, forestry and residential purposes. Water abstraction for irrigation
	De Hoop (Bredasdorp)	The inflow is non-perrenial. It provides habitat for a number of bird species, including the Greater Flamingo (*Phoenicopterus ruber*) and the White Pelican (*Pelecanus onocrotalus*). Bird populations vary with water levels and salinity conditions.	Catchment development for agriculture, forestry and residential purposes. Water abstraction for irrigation.
	Kleinriviersvlei (Hermanus)	Coastal lake system also classed as a blind estuary or lagoon caused by a barrier system of sand dunes	Aien invasion, water abstraction and catchment development for residential purposes.
	Botriviervlei (Kleinmond)		

Wetland Type (Ramsar 1990)	Wetland	Features and Attributes	Threat
	Soetendalsvlei (Agulhas)	Coastal lake system also classed as a blind estuary or lagoon caused by a barrier system of sand dunes. Seasonal salinity fluctuations. An important migratory bird habitat.	
Palustrine (emergent marshes)	High-altitude marshes and seeps on the Cape Fold Mountains. Cyclic desiccation during the summer months	Specialized habitats supporting endangered species such the ghost frog *Heleophryne rosei* on the eastern side of Table Mountain. Other frogs include *Poyntonia paludicola*, *Rana fuscigula*, *Arthroleptella lightfooti,* the Dwarf toad *Capensibufo tradouwi* and *Breviceps montanus*.	Highly isolated on mountain ranges and dry mountain fynbos, there has been very little gene flow within each genus for thousands to hundreds of thousands of years.

1. *An endorheic wetland is a landlocked entity that has no outlet to the sea. The Okavango Delta is the famous example.*

4.1.2.3 Estuaries

> *'In South African an estuary is considered to be that portion of a river system which has, or can from time to time have, contact with the sea. Hence, during floods an estuary can become a river mouth with no seawater entering the formerly estuarine area. Conversely, when there is little or no fluvial input an estuary can be isolated from the sea by a sandbar and become a lagoon which may become fresh, or hypersaline, or even completely dry.'*

In the international literature, an estuary is defined as 'a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land' (Cameron & Pritchard 1963; Pritchard 1967). South Africa's estuaries are relatively small in comparison with those of the northern hemisphere and the mean annual runoff of South African rivers is more variable, fluctuating between floods and extremely low, to no river inflow. This combination of small size and low runoff, coupled with extreme environmental conditions, such as droughts, has led to various definitions for South African estuaries (Day, 1980, Heydorn, 1989). The most comprehensive definition for a South African estuary is the one outlined in the South African National Report for the United Nations Conference on the Environment and Development held in Rio de Janeiro (CSIR, 1992):

Estuaries are some of the most productive ecosystems on the planet (Day 1980). They also play an important role in the productivity of the nearshore marine environment. Variations in climate, topography and catchment geology give rise to a wide variety of estuarine types in South Africa. The total area of estuaries in South Africa is about 600 km^2, of which about 170 km^2 are along the Western Cape coast. The Western Cape is endowed with more than 47 of the 250 functional estuaries in South Africa (Whitfield 2000). Many of these are ranked as being of highly important for biodiversity conservation in South Africa: Knysna (1), Olifants (2), Berg (Groot) (3), Swartvlei (7), Bot/Kleinmond (8), Klein (9) (Turpie 2004, Turpie *et al*. 2002).

Estuaries lie at the interfaces between terrestrial, freshwater and marine environments. They constitute a unique habitat type that supports fauna and flora found nowhere else. Ecologically they serve as vital nursery areas for a number of marine fish and shellfish. They are also important feeding and roosting areas for a number of bird species, both resident and migratory. In addition to their ecological function, estuaries fulfill important economic and cultural functions. Their contribution to the national economy in terms of fisheries alone is considered to be highly significant. Lamberth & Turpie (2003) estimated the total value of estuarine and estuarine-dependent fisheries to be in the order of R950 million in 1997.

Being areas where rivers meet the sea, estuaries are also affected by activities in the catchments of those rivers that drain into them, as well as in the adjacent marine environment and the immediate terrestrial environs. The presence of extensive tracts of salt marshes protects adjacent land and human settlement from storm surges caused by high intensity coastal storms. Salt marshes also intercept contaminants in runoff and thus can mitigate the effects of pollution. Finding space for the burgeoning coastal population often results in encroachment on, or destroying coastal wetlands.

According to Whitfield (1992), there are about 250 estuaries in South Africa which are defined as functional estuarine systems. A classification system has been developed for South African estuaries, based primarily on the broad physical features of estuaries (see Table 9 and Whitfield, 1992).

Table 9: Whitfield's (1992) Physical Classification of Estuaries

Type	*Tidal prism*	*Mixing Process*	*Average Salinity* *	*Biota*
Estuarine Bay	Large (>10 x 10^6 m^3)	Tidal	20 - 35	Marine and estuarine organisms dominate these systems and extensive wetland/mangrove swamps occur
Permanently Open	Moderate (1-10 x 10^6 m^3)	Tidal/riverine	10 - >35	Wetlands (salt marshes), as well as submerged macrophyte beds are common and the fauna is predominantly marine and estuarine.
River Mouth	Small (<1 x 10^6 m^3)	Riverine	<10	Riverine influences dominate the physical processes in these estuaries and the related biota.
Estuarine Lake	Negligible (<0.1 x 10^6 m^3)	Wind	1 - > 35	Estuarine lakes can be either permanently or temporarily linked to the sea. Estuarine, marine and freshwater organisms all occur depending on the salinity condition of the system.
Temporarily Open	Absent	Wind	1 - > 35	Sand bars often form in the mouths of these estuaries blocking off connection with the sea. Marine, estuarine and freshwater life forms are all found in these systems, depending on the state of the mouth.

** Total amount of dissolved solids in water in parts per thousand by weight (seawater = ~35)*

Within a particular biogeographical region, the type of estuary has a major influence on the ecosystem structure within the system (Whitfield 1998). Generally a gradual decline in biodiversity occurs between estuarine bays and river mouths (as defined in Table 1). A major proportion (72%) of South African estuaries are temporarily open/closed systems (the majority of which are situated along the east coast). Permanently open systems constitute 19% (primarily along south and east coasts) while estuarine bays, estuarine lakes and river mouths constitute 1%, 3% and 5% of South African estuarine systems respectively (Maree, Whitfield & Quinn 2003).

Recent countrywide assessments of estuarine health have indicated that the majority of estuaries have been degraded to some extent, and that many are in a very poor state (Turpie 2004, Heydorn 1986, Whitfield 2000, Harrison *et al.* 2000, and Colloty *et al.* 2001). However, climate change with the associated impacts of changes in temperature, rainfall, and sea level has the potential to greatly exacerbate or even eclipse all other existing threats.

The primary objective of this component is to undertake a literature-based assessment of the effect of Climate Change on the Estuaries of the Western Cape.

4.1.2.4 Impact of global climate change on estuaries

The potential impacts of global climate change on estuaries include:

- Changes in precipitation and runoff with the following consequences for estuaries:
  - Modifications in the extent of intrusion by seawater
  - Changes in the frequency and duration of mouth closure
  - Decrease in nutrients
  - Decrease in the dilution and or flushing of pollutants
  - Changes in the magnitude and frequency of floods and sediment deposition/erosion cycles
- Rising temperatures
- Sea level rise
- Changes in ocean circulation patterns
- Increase in frequency and intensity of coastal storms

4.1.2.5 Changes in precipitation and runoff

South Africa's climate ranges from semi-arid to hyper-arid with only a few relatively humid parts where rainfall greatly exceeds 500 mm annually (Davies and Day 1998). This, together with the demand for water by a rapidly increasing population and the related demand for freshwater caused by industrialisation, agriculture and urbanisation has led to radical modifications of South Africa's available surface and groundwater in the form of impoundments, abstraction and inter-basin transfers. This has caused drastic changes to the flow and flood regimes of many of South Africa's rivers and their associated estuaries. The coastal zone is also strongly influenced by the rivers that transport water, sediments, nutrients and pollutants to the sea. One of the most important threats to estuaries is the reduction of freshwater inflow as the result of the construction of dams, direct abstraction and climate change.

In principle, all estuaries are sensitive to reductions and changes in river inflow. The two major consequences of modifications in river inflow are:

- Changes in the extent of seawater intrusion (especially relevant to permanently open systems); and
- Changes in the occurrence and duration of mouth closure (mostly applicable to temporarily open/closed systems).

i) Changes in the extent of seawater intrusion

Less than 30% of South Africa's estuaries are permanently open to the sea: examples include the Great Berg, Olifants and Breede estuaries (Whitfield 1995). Permanently open estuaries generally have large catchments and relatively high runoff throughout much of the year, which makes them a target for stream flow reduction activities in the form of major dam developments and large abstraction schemes. The extent of stream flow reduction in permanently open systems varies from nearly 100% (e.g. Kromme) to about 5% (e.g. Keurbooms).

Reduction of fluvial flow into estuaries may have a range of effects on the salinity regime. In large systems initially it may result in a reduction of the extent of the estuarine mixed zone i.e. that section of an estuary with salinity between 20ppt and 10ppt. Further reduction in stream flow can result in the complete elimination of this mixed zone so that, effectively, the system functionally becomes an arm of the sea e.g. the Kromme Estuary (Scharler and Baird 2000; Snow, Bate and Adams 2000; Wooldridge and Callahan 2000; Strydom and Whitfield 2000; Bate and Adams 2000). If there is no inflow at all a reverse salinity gradient may develop where the salinity at the head of the estuary may exceed that of seawater, e.g. the Kariega where 41ppt has been recorded at the head.

Many species of marine fishes use estuaries as nurseries. Reduced freshwater inflow may reduce the (primary) productivity of an estuary thereby reducing the food available to the juvenile fishes (Strydom and Whitfield 2000). This will have an adverse effect on growth, survival and ultimate recruitment into the adult population.

ii) Changes in the frequency and duration mouth closure

About 70% of South Africa's estuaries are temporarily open/closed systems: examples include the Botvlei, Diep and Great Brak estuaries (Whitfield 1995). This means that they are isolated from the sea by the formation of a sand berm across the mouth during periods of low or no river inflow. Such estuaries stay closed until their basins fill up and their berms are breached by increased river flow.

A major consequence of stream flow reduction is, therefore, the change in the frequency and duration of estuary mouth closure in temporarily open/closed systems. Temporarily open/closed systems are very sensitive to stream flow reduction, i.e. a small change in the runoff can extend the period of mouth closure from two months to five months in the low flow period, e.g. the Klein Estuary in the Western Cape. In extreme cases fresh water reduction can cause permanent mouth closure.

Reduction in stream flow may lead, paradoxically, to a reduction in salinity in a small system. Reduction in inflow can lead to mouth closure and, provided the river inflow still exceeds evaporation and seepage losses, a progressive freshening of the lagoon until such time as rising water levels lead to a breaching of the berm closing the mouth, e.g. the Bot and Groot Brak. The impact is an almost complete loss of the estuarine biota and its replacement with freshwater species.

The most obvious result of reduced stream inflow into estuaries is more frequent mouth closure, resulting in prolonged isolation from the sea and a change in the salinity regime. The consequences of these physical changes for the biota can be severe. For example the mudprawn *Upogebia africana* has an obligatory marine phase in its life cycle. Estuary mouth closure, particularly for extended periods (e.g. >1 yr), disrupts the life cycle and can result in local extinction of the mudprawn. Some demersal zooplankton species exhibit tidally-phased migratory behaviour. Mouth closure removes the tidal signal and thereby disrupts the life cycles of these organisms.

Extended periods of mouth closure will limit access to estuaries by juvenile fishes which could have an adverse effect on the viability of their populations. Similarly, full-grown fishes, which need to enter the sea to spawn, will be prevented from doing so by protracted mouth closure. In severe cases the number of fish will be so greatly reduced by predation (by other fishes, birds and mammals) that, should the mouth eventually open, their numbers will be so low as to make an insignificant addition to the adult population in the open sea. Alternatively the fishes may simply die in the estuary without ever having had the opportunity to breed.

Birds, generally being near the top of the food chain, are good indicators of the state of an estuary with respect to freshwater inflow. For example, mouth closure will lead to a loss of tidal action, which, in turn, will adversely affect the quantity and availability of intertidal benthic organisms to waders, which feed, characteristically on intertidal mudflats. Many of these waders are Palaearctic migrants therefore mouth closure can have an international impact on the populations of such birds. Other effects of reduced stream flow include the loss of shallow water habitats, favoured by herons, flamingos and other wading birds, and the loss of islands, which provide roosts and breeding sites safe from terrestrial predators.

Alternatively, an increase in freshwater input (e.g. waste water treatment works) can prevent the occurrence of regular mouth closure and prevent the related the back-flooding and increase in estuarine habitat. An example of this is the Eerste Estuary that discharges into False Bay. The impact of climate change in the summer rainfall areas may be an increase in open mouth conditions.

iii) Decrease in nutrients

In addition to the impacts associated with changed river flow regimes discussed above is the effect of decreased nutrient loads entering estuaries. Freshwater inflowing into estuaries is an important source of nutrients both dissolved and particulate. Dissolved nutrients include nitrates, phosphates, silica and trace metals essential for primary production. Particulates such as organic detritus derived from riparian vegetation may in some systems be an important source of carbon for the estuarine food web.

Reduction in freshwater inflow (as a consequence of dam development or climate change) will reduce the quantity of nutrients entering the estuary with the resultant impoverishment of the biota. In particular primary producers such as phytoplankton and benthic diatoms will be adversely affected with a consequent “knock-on” effect through the entire food chain e.g. Kariega (Allanson and Read 1987).

iv) Decrease in the dilution and or flushing of pollutants

In general South African estuaries do not receive a high pollutant load. In urban areas some small systems have been completely altered and in effect have become storm water drainage systems e.g. Black River, Bakens, Papkuils.

The main sources of pollution are leached agrochemicals (fertilisers and pesticides) and faecal contamination from informal settlements in the catchments and environs of estuaries. The main effect of reduced stream flow is that there is less dilution of the pollutants, which could lead to eutrophication and human health problems. This situation is most likely to occur in the small temporarily open/closed estuaries. Persistent eutrophication may lead to loss of biodiversity.

A decrease in river flow into some of the urban systems around the Western Cape could extend the closed mouth conditions in some of the temporarily open/closed estuaries, where the combination of high water retention time and warmer water would provide the ideal breeding ground for some disease-causing bacteria.

v. Changes in floods and sediment deposition

Floods in estuaries scour sediment deposited during periods of low flow. This accumulated sediment is both catchment derived and brought in from the sea by flood tides. South Africa's estuaries are flood tide dominated, this means that on every high tide more marine sediment enters an estuary than leaves it on the low tide. The result is a slow accumulation of marine sediment near the estuary mouth. An additional major concern in South Africa is soil erosion (Morant and Quinn 1999). The potential denuding of vegetation in arid catchments leading (i.e. increasing the erodibility of soils) coupled with an increase in the frequency of high intensity rain events due to climate change would lead to a significant increase in the deposition of sediment in the estuaries.

It is also foreseen that the potential water shortage, especially in the Western Cape, would lead the need to build more dams to secure water supplies to urban areas and agriculture. Major dams may have the effect of capturing minor (annual) flood peaks entirely and attenuating major flood peaks. The degree to which this will occur depends on the ratio of the dam volume to the MAR, the level in the dam preceding the flood, and the size of the flood. Therefore, if floods are reduced in intensity and frequency, sediment deposition and accumulation occurs and the estuaries are reduced in water volume and surface area.

Numerous small farm dams, as well as barrages and weirs, collectively may also have a major impact on the variability and duration of stream flow and, consequently, on estuaries. Instead of being available as stream flow the water is stored and subjected to consumption and losses, including evaporation and seepage. It is estimated that as little as 8% of the total annual runoff reaches the coastal zone (Department of Water Affairs 1986). Higher temperatures with the related increase in evaporation due to climate change, will not only increase the need to build more farm dams but also will exacerbate the impact of the existing dams on the aquatic environment.

4.1.2.6 Rising temperatures

Species are adapted to specific ranges of environmental temperatures. As the temperature changes, the geographical distribution of species will contract or expand, creating new combinations of species that will interact in unpredictable ways, i.e. the known species composition of the South African estuaries might change. Species that are unable to migrate, or compete with other species for resources, may face local or global extinction. Although higher temperatures might not result in the extinction of a species throughout its range, the species may be eliminated from part of its range. Movement into newly suitable habitats depends on: 1) the number of adults available in the original habitat and their ability to bear young; 2) an adequate number of potential colonisers; 3) the ability of potential colonizers to move into new habitats; 4) the survival of an adequate number of individuals in the new habitat to ensure genetic diversity to meet challenges and to produce succeeding generations (Kennedy *et al.* 2002). Thus the loss of species from an estuary that has become too warm may reduce species diversity in that estuary in the short term, depending on the mobility of new colonizers, their ability to tolerate higher temperatures and their tolerance for the higher salinities of the marine environment. Mobile organisms such as fish, swimming crabs, and shrimp can quickly colonisers new habitats, while immobile/relatively immobile invertebrates such as oysters will migrate more slowly. Changes in temperature will also affect coastal vegetation with more subtropical species moving further south.

Temperature influences the biology of organisms (mortality, reproduction, growth, behaviour). Temperature can also influence interactions among organism (e.g. predator prey, parasite-host, competition for resources). Temperature changes can even influence water circulation patterns within an estuary (Kennedy *et al.* 2002).

Temperature also influences the amount of oxygen that water can hold, warmer water holds less oxygen than cooler water. Most aquatic organisms extract oxygen from the waterbody they live in. the effect of higher temperatures and less oxygen could be to constrict the available habitat for certain species.

4.1.2.7 Changes in ocean circulation patterns

The large-scale ocean currents (thermohaline circulation) are driven by surface fluxes of heat and freshwater and subsequent interior mixing of heat and salt, and can be summarised as a global-scale deep overturning of water masses. A prominent feature of the circulation process is the sinking motion in the North Atlantic Ocean, which, as the water cools and sinks, releases vast amounts of heat to the atmosphere and makes northern Europe significantly warmer than other regions of the Earth at that latitude.

This large scale ocean circulation process has proven to be a fragile system that can respond in a highly non-linear fashion to changes in surface climate (Steffen *et al.* 2004). There is strong evidence that this has occurred repeatedly in the past, and reason for concern that it might happen again.

Climate change can substantially alter the freshwater balance of the North Atlantic in the future and thereby trigger variability in the large-scale ocean currents or even collapse of the thermohaline circulation. This in turn can trigger strong regional cooling in the midst of global warming. When the air temperature rises, surface waters also tend to warm up, an effect which is enhanced in the high latitudes via the retreat of snow and sea ice with warming. In addition, the hydrological cycle may be accelerated in a warmer atmosphere; the observed increase in river runoff in the high latitudes may be due to this phenomenon. These effects tend to reduce the thermohaline circulation because heating and freshening both decrease surface water density.

Significant uncertainties persist in the prediction of change in the large-scale ocean currents as a result of climate change. The majority of global climate models indicate a reduction of the thermohaline circulation from 10% to 80% in response to increasing CO_2 concentrations in the atmosphere for the next 100 years (Steffen *et al.* 2004). Long-term simulations with different climate models suggest that the maximum projected CO_2 concentration may constitute a threshold beyond which the large scale circulation processes stops. Model simulations indicate that the threshold may be crossed if the forcing is strong enough and applied for long enough. The threshold may well lie within the range of warming that is expected in the next 100 years or less under a business-as-usual scenario. The risk of major ocean circulation changes becomes significant for the more pessimistic warming scenarios, but can be greatly reduced if global warming is limited to the lower end of the IPCC range.

Of concern for South Africa is the potential change in the Agulhas Current. The current flows southwards along the east coast of South Africa hugging the shelf-edge. The Agulhas Current diverges from the coast between East London and Port Elizabeth as it follows the shelf-edge of the eastern Agulhas Bank. The current overshoots the southern tip of the Agulhas Bank and on entering deeper waters, turns back on itself (retroflects) to flow eastwards as the Agulhas Return Current. Large anticyclonic rings of warm water, so-called Agulhas Rings, are shed from the Agulhas Retroflection (Gordon and Haxby, 1990, Duncombe Rae *et al*., 1990). However, flow of the Agulhas Current is periodically (4-6 times per year) interrupted by a meander (the Natal pulse) which moves down the current until its reaches the retroflection area off the southern Cape where it causes the current to shed a ring of warm water. These rings drift off into the South Atlantic or up the west coast, raising the temperature of the nearshore waters and occasionally interacting with upwelling plumes, both of which have important consequences for fish recruitment (Gordon & Haxby 1990). Such events have been linked to the failure of certain year classes of pelagic fish, mortalities and anomalous recruitment patters of invertebrates in the coastal waters off the west coast (Duncombe Rae *et al*. 1992). Increases in wind stress over the southwestern Indian Ocean is expected to increase the flow of water in the Agulhas Current and the incidence of the Natal pulse, both of which will enhance advection of warm Agulhas water onto the South African west coast, with serious consequences for both marine and terrestrial ecosystems and the humans that depend on them: for example significant reduction in marine productivity with severe consequences for the fisheries (inshore and demersal) of the Western Cape (Clarke *et al.* 2000).

What is of significance for the Western Cape is that the predicted increase in temperature due to global warming implies that the Polar Regions will experience higher temperatures that will reduce the thermal gradient between the poles and the equator. This may result in a weakening of the overall wind driven surface currents, which can result in a change in coastal upwelling events. Alterations in offshore-onshore transport corridors may have negative consequences for the growth and survival of organisms as these circulation patterns influence the distribution, recruitment and survival of coastal and marine fishes and invertebrates.

Most greenhouse gas models project a greater increase in the temperature on land than in the ocean. This would strengthen low-pressure cells typically occurring over the land adjacent to high pressure cells. The strengthening of these cells can result in the strengthening of alongshore winds that drive upwelling. On the West Coast the Benguela Upwelling system delivers nutrient from deeper colder waters to the sunlit surface where primary production can occur. An increase in upwelling events will increase phytoplankton production which in turn will increase pelagic and demersal fisheries production (Clark *in prep)*. In contrast, upwelling may be diminished if the water is stratified by differences in temperature or salinity (Kennedy *et al.* 2002).

Coastal currents also influence the residence time of water near the shore and serve as transport mechanisms for pollutants. Changes in local circulation patterns might influence the effectiveness of current marine outfalls (pipelines) used for the disposal of land-derived waste to the marine environment.

In view of short- to medium term planning horizon of this project and the large degree of uncertainty pertaining to climate change and the ocean currents, this report does not deal with the possible consequences of this scenario. However, it is strongly recommended that further studies be conducted in South Africa on this aspect as it would have significant consequences for South Africa's coastal fisheries (Clark *et al.* 2000, Clark *in prep*)).

4.1.2.8 Increase in the frequency and intensity of coastal storms

River inflow is the major driving force that maintains open mouth conditions in South African estuaries. In small estuaries it is the <u>only</u> driving force that maintains open mouth conditions (In larger system, tidal flows assist in maintaining open mouth conditions). Wave energy is the main force, in association with an adequate sediment supply, responsible for estuary mouth closure.

A number of small estuaries (e.g. Great Brak) show great sensitivity to increased wave action. In general, large storms at sea create the wave conditions that will close small estuaries, unless there is significant river flow to maintain the open mouth condition. An increase in storminess due to climate change will therefore increase the occurrence of mouth closure and generally transport more marine sediment into an estuary than at present.

4.1.2.9 Sea level rise

Sea level rise can either counteract the reduction in runoff to an estuary or exacerbate the effect depending on the size of the estuary, the sediment available, and the wave energy near or at its mouth. In the case of small, temporarily open/closed estuaries sea level rise could assist in maintaining open mouth condition, if the system is sheltered from wave action and/or little sediment is available near its mouth. Alternatively, sea level rise can merely reset the level at which an estuary closes (increase by 20 to 50 cm) and the increased storminess might actually increase the frequency and or duration of the mouth closure. In the case of permanently open estuaries, sea level rise may lead to an increase in the saline penetration and require additional freshwater to maintain the same salinity gradient as at present, i.e. it may be necessary to increase the ecological flow requirement to maintain present ecological production levels.

Estuaries are often the focus of intense development along the South African Coast. Unfortunately this has resulted in numerous low-lying developments around these estuaries, e.g. Klein River, Botvlei, Groot (Wes), Wilderness, Swartvlei. The consequence is the need to breach them artificial which has serious consequences for the estuarine biophysical processes, both in the short-term (e.g. flushing of biota, reduction in production) and in the long-term (e.g. increased sedimentation due to inefficient flushing during breachings).

Climate change and sea level rise will increase the pressures on management agencies to implement assisted (and often premature) breaching as more and more properties will be below the level of the sand berm near the mouth. Response of humans to sea-level rise may take the form of actions destructive to wetlands such as armouring coastlines with berms or dikes that will prevent biological systems from adjusting naturally (e.g. by inland retreat of wetland). An example of an impact on the biophysical processes is the loss of salt marsh vegetation leading to a decrease in estuarine habitat and food supply. An indirect impact is an increase in turbidity as sediment is no longer trapped by the fringing vegetation around an estuary. This, in turn, reduces light penetration thus causing a decrease in primary production by microalgae and benefits “tactile” feeders at the expense of “visual” feeders (e.g. Estuarine Round herring *Gilchristella aestuaria* vs Cape silverside *Atherina breviceps*).

4.1.2.10 Overall impacts of climate change on Western Cape estuaries

A previous study overestimated the reduction in runoff to the Western Cape estuaries, for example as much as a 84% reduction was predicted for the Diep Estuary (Clarke *et al.* 2000). This overestimate was based on the results of simulated runoff data provided for the arid coastal (lower) quaternary catchments only. This approach exaggerates the impact of climate change on the large catchments such as the Olifants. Therefore, with the exception of the Keurbooms Estuary, it is unlikely that the permanently open estuaries would start closing in the short to medium-term. The majority of the permanently open systems in the Western Cape maintain open mouth conditions under low flow conditions due to significant tidal flows and mouth protection (e.g. rocky outcrops protecting the outflow channel). The Keurbooms Estuary on the other hand has large bedforms in its mouth region which can very easily lead to mouth closure under slight flow reductions as it is currently estimated that a decrease of as little as 5% during the low flow period could cause closure.

What is expected with a high degree of certainty is a significant increase in seawater penetration upstream from the mouth resulting loss of biological productivity. In certain instances this could be severe enough that estuarine and coastal fisheries would be affected, e.g. the potential closure of the Olifants Estuary small-scale commercial fishery near Ebenhaeser.

Temporarily open / closed estuaries, in conjunction with the estuarine lakes, represent about 50 % of the estuarine area in the Western Cape. Climate change will affect on the majority of these systems by means of an increase in the frequency and duration of mouth closure. This is especially significant for the coastal lakes as they represent important biological habitats for a number of estuarine dependent species particularly in spring and summer when closure is most likely to occur. The increase in storm frequency and in wave action is also likely to contribute to mouth closure in regions where marine sediment is freely available, e.g. estuaries next to long, wide beaches such as the Klein Estuary at Hermanus. Sea level rise might, in the long term, assist in maintaining open mouth conditions in systems where the marine sediment supply is limited since higher sea levels could assist in maintaining tidal flows, e.g. Bloukrans Estuary.

Of great concern is that in a number of instances there may not be sufficient space available for the eco-systems (biota) to migrate landwards as the sea-level rises because low-lying developments occupy the areas into which the biota would have moved. Thus, there may be direct effects on the biota resulting from changes in the water level and the coastline. In relation to the total Western Cape coastal zone, the potentially affected areas may be very limited, but the impact could be critical for estuarine species.

About 83 % of the commercial and recreational inshore linefish and netfish catch comprises partially and obligated estuarine dependant fish (Lamberth and Turpie 2003). Increased mouth closure in temporarily open/closed systems and reduce salinity gradients and olfactory cues in permanently open systems are likely to lead to a drastic decline in recruitment and ultimately lead to stock collapse of important commercial fish species. Obligated estuarine dependant species e.g. white steenbras may face extinction.

In terms of direct economic impacts, mariculture may be affected by estuary responses to climate change. Mariculture is a minor but locally important industry in South Africa with production in the region of 4 000 tons per annum, mainly abalone and mussels (Fishing Industry Handbook 2004). Higher temperatures could enhance the growth rates of cultured species and allow for the culture of species, e.g. prawns, in areas that are currently too cold for them. Alternatively, a region may become too warm to allow the culture of heat- sensitive species. This might require a change in the species cultured in a particular region. In addition the increase in frequency and severity of storms might threaten mariculture facilities such as mussel rafts and moored fish cages.

The functional estuaries of the Western Cape (numbering 47), their estuarine type, and the potential impacts resulting from climate change are presented in Table 10. Where information is not available, this is indicated by “?”.

Table 10: The potential impacts of Climate Change on the estuaries of the Western Cape

No	*Estuary*	*Type*	*Potential Impacts of Climate Change*	*Size (ha)*
1	Olifants	Perm Open	▪ Significant increase in the seawater penetration due to a reduction in runoff and sea level rise ▪ Significant loss of estuarine productivity ▪ Potential closure of the Olifant small-scale commercial fishery near Ebenhaezer.	702

No	*Estuary*	*Type*	*Potential Impacts of Climate Change*	*Size (ha)*
			▪ If runoff reduced by more than 80% mouth closure could occur	
2	Verlorenvlei	Est Lake	▪ Potentially permanently cut-off from the marine environment due to reduction in runoff ▪ General low water levels in lake due to decrease in surface runoff (and groundwater) and an increased evaporation ▪ Significant loss of estuarine productivity ▪ Sea-level rise may reestablish connection to the sea in the long-term (~100 years) depending on sediment processes near the mouth.	?
3	Berg (Groot)	Perm Open	▪ Significant increase in the seawater penetration due to a reduction in runoff and sea level rise ▪ Significant loss of estuarine productivity	3 615
4	Rietvlei/Diep	Temp	▪ Increase in mouth closure, especially in spring and summer (the biological active period) ▪ Significant loss of estuarine productivity	515
5	Disa (Houtbaai)	River	▪ ?	?
6	Wildevoëlvlei	Temp	▪ Increase in mouth closure, especially in spring and summer (the biological active period)	76
7	Bokramspruit	Temp	▪ Increase in mouth closure, especially in spring and summer (the biological active period)	**?**
8	Schuster	Temp	▪ Increase in mouth closure, especially in spring and summer (the biological active period)	**?**
9	Krom	Temp	▪ Increase in mouth closure, especially in spring and summer (the biological active period)	**?**
10	Silvermine	Temp	▪ Increase in mouth closure, especially in spring and summer (the biological active period) ▪ Sea level rise would cause inundation and flooding of low-lying areas adjacent to estuary and increase the occurrence of artificial breaching.	**7**
11	Sand	Temp	▪ Increase in mouth closure in spring and summer (biological active period), ▪ Sea level rise would cause inundation and flooding of low-lying areas adjacent to estuary and increase the occurrence of artificial breaching ▪ Significant loss of estuarine productivity	**155**
12	Eerste	Temp	▪ No change as a number of Waste Water Treatment Works augment the inflow	**10**
13	Lourens	Temp	▪ Increase in mouth closure, especially in spring and summer (the biological active period) ▪ Sea level rise would cause inundation and flooding of low-lying areas adjacent to estuary and increase the occurrence of artificial breaching	**7**
14	Sir Lowry's	Temp	▪ Increase in mouth closure, especially in spring and summer (the	**3**

No	Estuary	Type	Potential Impacts of Climate Change	Size (ha)
	Pass		biological active period)	
15	Steenbras	Perm Open	▪ Increase in mouth closure, especially in spring and summer (the biological active period)	**2**
16	Rooiels	Temp	▪ Increase in mouth closure, especially in spring and summer (the biological active period)	**11**
17	Buffels (Oos)	Temp	▪ Increase in mouth closure, especially in spring and summer (the biological active period)	**17**
18	Palmiet	Temp	▪ Increase in mouth closure, especially in spring and summer (the biological active period)	**33**
19	Bot/Kleinmond	Est Lake	▪ Significant increase in closed mouth conditions due to changes in runoff and increase in evaporation, An increased need for irrigation due to higher temperature is also expected contribute to a decrease in runoff ▪ Sea level rise would cause inundation and flooding of low-lying areas adjacent to estuary and increase the occurrence of artificial breaching ▪ Concern that changes in landcover (due rise in temperatures) and rain intensity might increase sedimentation ▪ Change in the frequency and duration of mouth closure, will change the salinity regime, which in turn will endanger the endemic Botriver Klipvis ▪ Significant loss of estuarine productivity	**1 698**
20	Onrus	Temp	▪ Increase in mouth closure, especially in spring and summer (the biological active period), ▪ Sea level rise would cause inundation and flooding of low-lying areas adjacent to estuary and necessitate artificial breaching ▪ Change in the frequency and duration of mouth closure, will change the salinity regime which in turn endanger the endemic Botriver Klipvis	**41**
21	Klein	Est Lake	▪ Significant increase in closed mouth conditions due to changes in runoff and increase in evaporation. The system would definitely not breach annually. ▪ Sea level rise would cause inundation and flooding of low-lying areas adjacent to estuary and increase the occurrence of artificial breaching ▪ Concern that changes in landcover (due rise in temperatures) and rain intensity might increase sedimentation ▪ Change in the frequency and duration of mouth closure, will change the salinity regime which in turn endanger the endemic Botriver Klipvis ▪ Significant loss of estuarine productivity	**2 959**
22	Uilskraals	Temp	▪ Increase in mouth closure, especially in spring and summer (the biological active period)	**105**
23	Ratel	Temp	▪ Increase in mouth closure, especially in spring and summer (the biological active period)	**10**

No	*Estuary*	*Type*	*Potential Impacts of Climate Change*	*Size (ha)*
24	Heuningnes	Perm	▪ Mouth closure would occur due to a decrease in runoff (reduction in rainfall and an increase in evaporation (e.g. large surface area of Soetendalsvlei). ▪ Higher seawater levels into the estuary may cause increased saltwater intrusion and raised groundwater tables in agricultural areas where farming occurs directly adjacent to the estuary & shoreline. ▪ Significant loss of estuarine productivity ▪ Change in species composition due to changes in sea temperatures	**173**
25	Klipdrifsfontein	Temp	▪ Increase in mouth closure, especially in spring and summer (the biological active period) ▪ Change in species composition due to changes in sea temperatures	**?**
26	Breë	Perm Open	▪ Increase in the salinity penetration due to a reduction in runoff and an increase in sea level rise ▪ Change in species composition due to changes in sea temperatures ▪ Significant loss of estuarine productivity	**455**
27	Duiwenhoks	Perm Open	▪ Increase in the salinity penetration due to a reduction in runoff and an increase in sea level rise ▪ Change in species composition due to changes in sea temperatures ▪ Significant loss of estuarine productivity	**203**
28	Goukou	Perm Open	▪ Increase in the seawater penetration due to a reduction in runoff and an increase in sea level rise ▪ Change in species composition due to changes in sea temperatures ▪ Significant loss of estuarine productivity	**155**
29	Gourits	Perm Open	▪ Increase in sedimentation due to change in landcover, ▪ Increase in the seawater penetration due to a reduction in runoff and an increase in sea level rise ▪ Change in species composition due to changes in sea temperatures ▪ Loss of estuarine productivity	**113**
30	Blinde	Temp	▪ Increase in mouth closure, especially in spring and summer (the biological active period) ▪ Change in species composition due to changes in sea temperatures	**?**
31	Hartenbos	Temp	▪ Increase in mouth closure, especially in spring and summer (the biological active period) ▪ Change in species composition due to changes in sea temperatures	**41**

No	*Estuary*	*Type*	*Potential Impacts of Climate Change*	*Size (ha)*
32	Klein Brak	Temp	▪ Increase in mouth closure, especially in spring and summer (the biological active period) ▪ Change in species composition due to changes in sea temperatures	**96**
33	Groot Brak	Temp	▪ Increase in mouth closure, especially in spring and summer (the biological active period) ▪ Sea level rise would cause inundation and flooding of low-lying areas adjacent to estuary and increase the occurrence of artificial breaching ▪ Change in species composition due to changes in sea temperatures	**114**
34	Maalgate	Temp	▪ Increase in mouth closure, especially in spring and summer (the biological active period) ▪ Change in species composition due to changes in sea temperatures	**14**
35	Gwaing	Temp	▪ Increase in mouth closure, especially in spring and summer (the biological active period) ▪ Change in species composition due to changes in sea temperatures	**?**
36	Kaaimans	Perm Open	▪ Increase in the seawater penetration due to a reduction in runoff and an increase in sea level rise ▪ Change in species composition due to changes in sea temperatures	**8**
37	Wilderness	Est Lake	▪ Increase in closed mouth conditions due to changes in runoff and increase in evaporation, An increase need for irrigation due to higher temperature is also expected contribute to decrease in runoff ▪ Sea level rise would cause inundation and flooding of low-lying areas adjacent to estuary and increase the occurrence of artificial breaching, ▪ Change in species composition due to changes in sea temperatures ▪ Loss of estuarine productivity	**?**
38	Swartvlei	Est Lake	▪ Significant increase in closed mouth conditions due to changes in runoff and increase in evaporation, An increase need for irrigation due to higher temperature is also expected contribute to decrease in runoff ▪ Sea level rise would cause inundation and flooding of low-lying areas adjacent to estuary and increase the occurrence of artificial breaching, ▪ Change in species composition due to changes in sea temperatures ▪ Loss of estuarine productivity	**1 077**
39	Goukamma	Temp	▪ Increase in mouth closure in spring and summer (biological active period)	**270**

No	*Estuary*	*Type*	*Potential Impacts of Climate Change*	*Size (ha)*
			▪ Change in species composition due to changes in sea temperatures ▪ Loss of estuarine productivity	
40	Knysna	Bay	▪ Increase in the seawater penetration due to a reduction in runoff and an increase in sea level rise ▪ Large surface area makes it sensitive to changes in wind patterns and an increase in storm events ▪ Sea level rise would cause encroachment on low-lying developments ▪ Change in species composition due to changes in sea temperatures ▪ Concern that changes in landcover (due rise in temperatures) and rain intensity might increase sedimentation which is a threat to the endemic Knysna seahorse. ▪ Loss of estuarine productivity ▪ Potential impact on mariculture due to change in temperatures and increase in storm events and intensity	**3 594**
41	Noetsie	Temp	▪ Slight increase mouth closure, especially in spring and summer. ▪ Change in species composition due to changes in sea temperatures	**8**
42	Piesang	Temp	▪ Slight increase in mouth closure, especially in spring and summer. ▪ Change in species composition due to changes in sea temperatures	**92**
43	Keurbooms	Perm Open	▪ Mouth closure could occur if flow reduces and land-use change, Increase in the salinity penetration due to a reduction in runoff and an increase in sea level rise, ▪ Shoreline erosion and under-scouring of houses and access roads due to more wave energy penetration through mouth. ▪ Loss of estuarine productivity ▪ Change in species composition due to changes in sea temperatures	**295**
44	Matjies/Bitou	Temp	▪ Slight increase in mouth closure, especially in spring and summer. ▪ Change in species composition due to changes in sea temperatures	**?**
45	Sout (Oos)	Perm Open	▪ Slight increase in mouth closure, especially in spring and summer. ▪ Change in species composition due to changes in sea temperatures	**52**
46	Groot (Wes)	Temp	▪ Slight increase in mouth closure, especially in spring and summer. ▪ Change in species composition due to changes in sea	**39**

No	Estuary	Type	Potential Impacts of Climate Change	Size (ha)
			temperatures	
47	Bloukrans	River	▪ Change in species composition due to changes in sea temperatures	**?**

4.1.3 Coastal structures and beaches

4.1.3.1 Background

The primary effect of climate change on the coastline will be felt in the form of sea level rise. Since the 1970s the "greenhouse effect" and sea level rise have continued to generate interest and concern. Coupled with this have often been dramatic predictions of massive coastal impacts usually based on the indiscriminate use of the so-called Bruun rule. The Bruun rule (Bruun, 1983, 1988) is based on the following concepts: As sea level rises along the beach with an equilibrium profile, sediment is eroded from the upper beach and deposited on the nearshore bottom. The material eroded from the upper beach is equal in volume to the material deposited on the nearshore bottom. The rise in the nearshore bottom elevation as a result of this deposition is equal to the rise in sea level. (A slightly more sophisticated approach is described in Mimura and Kawaguchi, 1996.) However, in predicting possible future impacts on the coastal zone and planning, certain aspects should first be considered.

4.1.3.2 Causes of eustatic sea level rise

It is important to note that the greenhouse mechanism has not been proven conclusively as of yet. However, a change in global surface temperature should be accompanied by a eustatic sea level rise through three main mechanisms (UNESCO, 1994):

- Warming and associated thermal expansion of the oceans (52%).
- Melting of glaciers (49%).
- The polar ice balance (Greenland and Antarctic; net effect -1%).

4.1.3.3 General discussion of the effects of a rise in sea level

A rise in eustatic sea level cannot be simply related to local coastal erosion. Changes in global temperatures and weather patterns will have many different effects on the processes that shape the coastal zone.

The sediment availability and the overall sediment budget are important. With an adequate supply of sediments having appropriate sizes for the littoral zone, beach accretion can prevail over modest rates of sea level rise. The retreat of the shore owing to a long-term increase in sea level is episodic rather than continuous, as it depends on sediment movement produced by storm waves and on associated processes such as storm surges. Therefore, any satisfactory understanding of the long-term response of beaches to sea level change must come from the accumulated knowledge of nearshore processes, including waves, currents and sediment transport.

The probable impacts of the sea level rise on coastal areas can be divided into five general groups (Hughes *et al* 1991) (in approximate order of significance):

a) Increased exposure to extreme events (which themselves might increase in frequency or intensity).
b) Increased saltwater intrusion and raised groundwater tables.
c) Greater tidal influence.
d) Increased flooding (frequency and extent).
e) Increased coastal erosion.

The apparent increase in storm activity and severity will probably be the most visible impact and the first to be noticed: higher sea levels will require smaller storm events to overtop existing storm protection measures.

It is likely that the impacts of the sea level rise will only be clearly recognised some 30 years from now. Before then the relatively small expected rise in sea level (smaller than 0,3 m) will probably not have clearly recognisable impacts. However, after about 30 years (or a rise of more than 0,3 m) the effects should become increasingly clear as time goes by and the sea level continues to rise (at an increased rate).

Ewing and Michaels (1991) discuss some of the effects of sea level rise in more detail. Waves approaching the coast are affected by bottom topography. As the sea level rises, existing topographic features will be located in deeper water and will have a different effect on wave trains approaching the coast. Features landward of the breaker zone will be in deeper water and will have a greater effect on the wave climate than at present. Deep water features may deepen to the degree that their effect on wave climate is negligible. Thus, deepening will change the local wave climate. The points of energy convergence and divergence will change. The new locations of energy convergence could be expected to experience an increase in erosion, while those locations currently subject to energy convergence could accreted if they are exposed to less energy in future. Changes in waves approach would change longshore currents and longshore transport. Specific changes could only be determined through detailed modelling. Nevertheless, the probability of such changes should be recognised.

The Bruun rule can be applied only to give a first estimate of possible erosion of "soft" sandy beaches. In some cases, broad dunes and wide beaches could mitigate such predicted erosion. In other situations narrower beaches backed by hardened dunes will resist erosion, resulting in less erosion than predicted by the Bruun rule.

Hands (1977) argues that slow, long-term profile adjustments may permit the littoral forces to spread shore-eroded material over a more extensive area and therefore result in a greater shore loss than would be the case during a short period of equal but rapid subsidence. He found that in areas having broad active profiles or low back shore, offshore or longshore sediments sinks, as well as in areas where the eroding backshore contains a large percentage of material that would be unstable as a nearshore deposit, the ratio of retreat to submergence should be larger. Narrow active profiles, higher back shore deposits, coarse grain sediments and increased supplies of sediment from outside the control section will all tend to diminish the ratio of shore retreat to submergence.

4.1.3.4 SA perspective: Previous studies

A number of articles regarding sea level rise effects in southern Africa have been published (e.g. Hughes and Brundrit 1990, Hughes *et al* 1991, Hughes and Brundrit 1992). These concluded that in terms of national vulnerability to the impacts of sea level rise, four high-risk areas stood out:

- Greater Cape Town, Melkbosstrand to Gordon's Bay.
- The south Cape coast, Mossel Bay to Nature's Valley.
- Port Elizabeth.
- Natal South Coast and Greater Durban, Southbroom to Ballitoville.

Within these areas the greatest and most immediate risk was considered to be a combination of rising sea levels and extreme storm events, especially in the relatively sheltered environments like tidal inlets, estuaries, coastal wetlands and marinas.

Hughes and Brundrit (1992) also developed a risk-analysis procedure, based on the coastal vulnerability index of Gornitz and Kanciruk (1989) and using an economic hierarchy. They applied these procedures to the developed areas of the southern Cape coast and concluded that the most vulnerable areas are those surrounding estuaries and lagoons. The greatest hazards overall were concluded to be extreme storm and flood events and the most vulnerable infrastructure that of private housing.

Specific locations that were also investigated are Durban (Hughes and Brundrit 1990), northern False Bay (Hughes and Brundrit 1991), the Diep River/Rietvlei system (Hughes *et al* 1991a) and Walvis Bay (Hughes *et al* 1991b). In 1995 the Town and Regional Planning Commission of Kwazulu-Natal published a report on sea level rise and its potential physical impacts on the shoreline of Kwazulu-Natal (Cooper, 1995). The report was aimed at facilitating optimum coastal zone management.

4.1.3.5 Application of Bruun's erosion rule to the study area

In assessing the erosion potential of the coastline for various areas and types of coastline, coastal areas must first be defined in terms of two main shoreline geographical characteristics, i.e. hard erosion resistant shores, or sandy erodeable beaches. Hard, erosion resistant shores are usually rocky or have been “artificially” armoured, e.g. revetments, seawalls, breakwaters, etc.

- Hard shores will generally respond to sea level rise as follows: In most cases, there will be no noticeable erosion as such (and the Bruun Rule is not applicable). However, the high-water line will still move landward according to the slope above the high-water line. (This approach is based upon a rudimentary upward transferal of the existing profile.) For example, if the present slope is 1 in 10, then a rise of 0.2 m or 0.4 m means a landward movement of 2 m or 4 m respectively. Slopes above the high-water line are usually much steeper than those of the sub-aerial beach or nearshore profile. In most instances, the landward movement of the high-water line will only be in the order of a few metres. However, in a few unusual situations, where the slope above the high-water line is very flat, the landward movement could be in the order of 10s of metres. For example, if the slope is 1 in 100, then a rise of 0.2 m or 0.4 m means a landward movement of 20 m or 40 m respectively.

  Cliffed coasts, consisting of hard (weather & wave resistant) rock, will tend to respond in the same manner as described above. Cliffed coasts consisting of softer material (prone to weather & wave erosion), are often already undergoing a slow long-term erosional tend. Although the high-water line would tend to respond in the same manner as for hard cliffs, sea level rise and especially increased storminess, may increase the rate of cliff retreat. A possible local example, is Swartklip (Northern False Bay coast), which has been reported as subject to slow long-term erosion.

- The WP coastline includes many sandy areas, which have no or very little hard protection and where the wave regime is regarded as high energy. This leads to a high potential for erosion of these sandy coastlines. In addition, encroachment by historical development has threatened and destroyed many dunes along the sandy coastline areas. This is problematic as the dunes serve not only as a natural asset for biodiversity but also form an important coastal defence system. During high seas the dunes are eroded and the sand moves into an offshore bar which changes the slope of the incoming beach. This causes waves to break earlier and therefore reduces the energy at the shoreline and erosion potential of each breaking wave.

  The implications for sandy coastlines of two scenarios of sea level rise of 20 and 40 cm are investigated using Bruuns erosion rule. The main parametres that are taken into account in Bruuns rule are the amount of sea level rise and the slope of the nearshore. Thus, sandy areas along the WP coastline with a steep nearshore slope are predicted to erode between about 5 m to 20 m for the given scenarios, while areas with relatively mild or flat nearshore slopes are predicted to erode between about 20 m to 80 m. A few site-specific examples are as follows:

Table 11: Prediction of beach erosion risks for specific sites

Location	*Predicted erosion (m) for 0.2 m SLR*	*Predicted erosion (m) for 0.4 m SLR*	*Nearshore slope*
Northern False Bay	18	35	Moderate
Struisbaai Beach	9 to 32	18 to 64	Varying
Umdloti	6.6	13.2	Steeper (1 in 33)

4.1.3.6 General conclusions regarding sea level rise impacts and the use of Bruun's erosion rule

- The eustatic sea level will probably continue to rise in the future and the rate of this rise is likely to increase.
- Best current estimates of the future eustatic sea level rise range from 20 cm to 90 cm (best estimate = 50 cm) by the year 2100 (IPCC, 1996).
- In general, one effect of a relative rise in sea level is an increased tendency towards coastal erosion. However, the response of any coastline to a global sea level rise is site specific. Factors other than increased coastal erosion are also likely to be more important (for example changes in the wave climate and ocean currents).
- In general, the two-dimensional theory of the Bruun rule appears to be valid. However, the practical situation is far more complex and a variety of coastal evolutionary responses different from the basic Bruun concept are likely.
- The Bruun rule is sensitive to the chosen value of the input parametres and the values of these parametres are also difficult to determine. Many other factors besides the amount of sea level rise and the slope of the nearshore need to be taken into account to predict future coastal evolution on the longer time and space scales. Site-specific aspects such as local geology, hydrology and sedimentology, near and offshore bathymetry, exposure to waves, currents and general climatology and local geographical features as well as human influences should all be considered. The Bruun rule can be used only as a first indicator of where broader investigation of future impacts may be required.

4.1.3.7 Assessment of vulnerable WP areas and impacts

The previous studies referred to in Section 4.1.2.4 can be used as a first indication of vulnerability to sea level rise for any site included in these studies. The results of these studies should, however, be used with circumspection. More recent best estimates of eustatic sea level rise have resulted in a significant reduction compared to the predictions of the late 1980s and early 1990s. In Theron (1994) it is shown that some of the previous predictions of coastal erosion were based on relatively conservative application of the Bruun rule. Better data should in many cases now be available to make perhaps more realistic predictions/estimates of vulnerability at specific locations.

Keeping in mind also the arguments put forward in Sections 4.1.2.3, 4.1.2.5 and 4.1.2.6, it is suggested that specific locations are carefully evaluated in terms of their vulnerability to the five potential impacts listed below.

a) Increased exposure to extreme events (which themselves might increase in frequency or intensity).
b) Increased saltwater intrusion and raised groundwater tables.
c) Greater tidal influence.
d) Increased flooding (frequency and extent).
e) Increased coastal erosion.

In general, it can be said that the most significant impacts of sea level rise are expected where problems are already experienced at present along the WP coast. In most cases these are the areas where development has encroached too close to the high-water line, or at a too low elevation above mean sea level.

Table 12: Identification of some of the most vulnerable areas where the impacts will potentially be the most severe

Specific area/location (Along WP coastline, from east to west.)	*Impact*	*Extent*	*Possible ranking (1-5; 1=most important)*
Nature's Valley	Inundation & flooding of low-lying areas adjacent to estuary, mainly residential & holiday homes.	Small area, few properties.	
Plettenberg Bay – Keurbooms mouth.	Shoreline erosion & under-scouring of houses and access roads due to more wave energy penetration through mouth.	Small area, few properties.	4
Knysna Lagoon	Inundation & flooding of low-lying areas adjacent to estuary, residential & holiday homes, commercial.	Small area, few properties.	
Victoria Bay	Shoreline erosion & under-scouring of houses, retaining walls and access roads; due to increased storminess.	Small area, few properties.	
Still Bay & Skipskop/Rys Punt	Increased damage to historical "visvywers" (archaeological heritage sites) due to increased wave impacts through deeper water & increased storminess.	Small areas, but important	
Bredasdorp Plain	Higher seawater levels into the Heuningnes Estuary may cause increased saltwater intrusion and raised groundwater tables in agricultural areas where farming occurs directly adjacent to the estuary & shoreline.	Relatively large land area, but actual impact very uncertain.	
Danger Point (Gansbaai)	Damage to mariculture (perlemoen) infrastructure (intakes, pipes, pumps, buildings) due to increased wave impacts through higher water levels & increased storminess.	Localised – individual operators.	
Strand	The coastal road here, is very close to the high-water mark. Thus, the low wall on the pavement is overtopped even if only a moderate storm occurs during spring high tides (e.g. Slide 3). This results in temporary road safety problems and necessitates regular maintenance. Both sea-level rise and increased storminess will increase the number of occurrences and the scale of the impact.	Small area	5
Northern False Bay	Baden Powell Drive, parking areas and ablution facilities have been located within the littoral zone. The continuous influx of windblown sand off the beach has resulted in a costly, ongoing sand clearing exercise that peaks during the summer period when the south-easterly and southerly winds prevail. More mechanical effort will be required to clear the road. From Cementery Beach to Strandfontein Point the road itself and any structures seawards of the road are often inundated (e.g. Slide 2) and are considered to	Relatively longer stretch of coastline, but mainly limited to impacts to the road.	1

Specific area/location (Along WP coastline, from east to west.)	*Impact*	*Extent*	*Possible ranking (1-5; 1=most important)*
	be vulnerable to storm damage.		
Table Bay (Diep River mouth -Milnerton – Blaauwberg)	Existing problems with shoreline erosion (e.g. Slide 1), aeolian sand transport and stormwater drains outlets on the beach will be aggravated; due to sea-level rise, as well as increased storminess.	Relatively longer stretch of coastline, but incremental impact still small?	2
Table Bay	Koeberg Nuclear Power Station seawater intakes could potentially be affected.	The relatively small rise in seawater level is highly unlikely to have any significant impact.	
Langebaan Point (& Paradise Beach and Blouwaterbaai; all in Saldanha Bay Area)	Shoreline erosion & under-scouring of house foundations, retaining walls and access roads; due to sea-level rise, as well as increased storminess.	Small area, few properties.	3
Generic area/location	*Impact*	*Extent*	
All ports/harbours (recreational, commercial, industrial, etc.)	More damage to breakwaters due to increased wave impacts through higher water levels & increased storminess (sea & swell components).	Incremental increase due to climate change probably small.	
Many coastal areas susceptible to windblown sand problems, e.g. Still Bay, Betty's Bay, Strand, Macassar, Blouberg, etc.	Increased storminess, thus more marine sediment transport, thus more sand deposited on upper beach for potential aeolian sediment transport. Additional increase due to more & stronger winds.	Already a significant maintenance problem in many places, but incremental increase due to climate change possibly small	
Many areas where anthropogenic development has encroached too close to the high-water line.	In some instances there may not be sufficient space available for biota/ echo-systems to migrate upwards with sea-level rise. Thus, there may be direct effects on the biota resulting from changes in the coastline.	In relation to the total WP coastal zone, the impacted areas may be minute, but they could potentially impact critical habitat areas.	

4.1.4 Terrestrial ecosystems

As discussed in section 2.2 of this report, the Western Cape contains a variety of ecosystem types, exceptional levels of species richness and endemism with a high index of irreplaceability. Relatively few studies have attempted to assess the response of these diverse terrestrial ecosystems to projected climate change. As a result, we focus here on projections on two priority aspects of natural ecosystems, namely the potential change in fire regime, as dominant ecosystem process and important for disaster management strategies, and biodiversity, which underpins the nature-based tourism industry and many ecosystem services critical for human livelihoods and well-being.

4.1.4.1 Wildfires

The Western Cape is characterised by the particular dominance of fynbos vegetation, which is well-known to be fire-prone, and indeed adapted to fairly frequent fires (Cowling 1987).

Historically, fire has been a feature of fynbos vegetation for millennia, as is clear from the many adaptations to fire displayed by indigenous species that must have evolved over eons. Before significant numbers of humans occupied the Western Cape, most fires in the Western Cape were probably ignited by lightning, and fuelled by fynbos and renosterveld shrublands of the area (although humans may have played a role in using fire in the Western Cape for at least 100 000 years (Deacon 1983)). An extended warm dry summer is a feature of the Western Cape, and today both humans and lightning provide ample sources of ignition. Fires are inevitable when three necessary elements are brought together – enough fuel of the right kind, warm, dry weather, and a source of ignition.

While many people regard fires as causing environmental damage, the facts contradict this sweeping and generalised view. Fires are needed to maintain healthy ecosystems and biodiversity in the Western Cape (fynbos is fire-dependent as well as fire-prone, and without fires many fynbos species would face extinction). But fires can and do destroy crops, houses, and kill livestock and even people, and this is what makes fires seem undesirable.

Fires in the Western Cape province

Fires in the Western Cape normally occur, on average, every 15 years or so, with actual intervals between fires ranging between 4 and 40 years. This means that fires occur on the same spot roughly every 15 years (the mean “return period”), and if the fires are evenly spread over time, it means that, on average, about 7% of the region will burn every year. The prevailing warm, dry summers are conducive to fires, which are common between November and March each year, especially when hot, dry and windy conditions prevail for several days. The fire climate of the region has been described in detail by van Wilgen (1984). Prescribed burning is sometimes put forward as a means of preventing unwanted wildfires, but this is may not be successful. For example, in the Cedarberg wilderness in the Western Cape, a policy of “no fires” (suppressing all fires that occurred) still resulted in many wildfires. When this was replaced by one of prescribed burning in an attempt to reduce the incidence of large wildfires, the number and size of wildfires was found to be unaffected despite regular prescribed burning for 14 years (Brown *et al*. 1991).

Impacts of fires

Fires in the fynbos are of moderate to high intensity, and can destroy crops and houses on occasion. Several fires over the past decade have made the news, with the fires on the Cape Peninsula in the year 2000 probably being the best-known recent incident (van Wilgen & Scott 2001). The Cape Peninsula fire destroyed 14 houses and other structures, and burnt about 8000 ha. However, it should be pointed out that the problem in the Cape is very much smaller that that which prevails in other parts of the world with Mediterranean-type climates (for example in California and Australia), where strong dry winds can exacerbate extreme fire events. Recent fires in Sydney and Canberra burnt hundreds of thousands of hectares, and destroyed over 750 houses. A local increase in similar events in the future could therefore have significant impacts in the Western Cape.

Fires and climate change

Will climate change will have an impact on fire frequency and intensity in the Western Cape? Should fires become more frequent, there could be serious negative impacts on biodiversity. For example, if fire frequencies are reduced from once in 15 years to once in 5 years, many plant species that are killed by fire, and that rely on re-seeding to survive, would become extinct as they would not have enough time to mature and set seeds between fires (van Wilgen *et al*. 1992).

In a study by Van Wilgen & Scott (2001), the number of days per year when the fire danger index exceeded 50 for 4 days or more was found to be "more frequent in the last decade of the 20th century than in the preceding two and a half decades", and suggested that this "may be indicative of changing climatic conditions". However, the data presented were not comprehensive enough to support any such conclusion. The factors that would promote higher fire frequencies and intensities would include lower rainfall (reducing the moisture content of fuels), lower relative humidities, longer droughts, and higher windspeeds. Predictions of future climate change show that the frequency and intensity of fires will increase.

For this study, we used the United States of America National Fire Danger Rating System (NFDRS) to test whether the frequency of days falling into the different Fire Danger Rating categories changes within a scenario of future climate change. This system calculates an index that is related to the potential for fires to be ignited, and of the intensity at which they will burn, on a daily basis. The daily Burning Index (BI) for two weather monitoring stations (Paarl and George) was calculated by the NFRDS, both for a historical data set that represents current climate and for a simulated future climate. This future climate was developed by using the predictions of the PRECIS model to alter temperature, relative humidity and wind speed. No alterations were made to rainfall, given the limited time available for this study.

An earlier study (van Wilgen *et al*. 2003) had calculated threshold values for the BI that delimit categories of fire danger (the categories were extreme, high, moderate, low and insignificant) at a number of weather recording stations. We compared the number of days in each category, as delimited by these thresholds, using the results generated by the NFDRS with current and future weather variables (Table 13).

In both weather stations, the number of days falling into the high and extreme categories increased, while those in the low or insignificant categories decreased somewhat. The changes were more marked (more than double) at the Paarl than at the George stations. The implications of these changes would be as follows:

- Most destructive fires (those causing damage to crops and property, and resulting in injury and death to livestock and people) occur when the fire danger is in the extreme category. An increase in the prevalence of days in this category would probably be accompanied by an increase in the number of destructive fires in the region.

- Costly, destructive fires (those where fire-fighting forces are required to combat extensive fires over several days) usually occur when fire danger indices are in the high or extreme categories for several consecutive days. These currently occur once or twice per year.

With the increase in the number of days in these categories, the occurrence of such extended periods of fire danger can also be expected to increase, with consequences for the costs of firefighting.

- If the opportunities for more and larger fires become more frequent, the fire return periods can be expected to decrease. So, for example, areas that experienced fires once every 10 – 15 years may experience fires at shorter intervals, say every 5 – 10 years. This will have negative consequences for many plant species that are not adapted to such short intervals between fires, and some species may become extinct.

Our analysis has not considered that rainfall patterns may change, and that, overall, rainfall may decrease. These changes could result in the actual situation resulting from climate change being worst than that suggested by the predictions in Table 13.

Table 13: A comparison between the number of days in different fire danger rating categories for current climate and for a future climate derived from a climate change prediction. The time periods over which fire danger was calculated were equal for each weather station (3 104 days for Paarl and 3 316 days for George)

Weather Station	*Fire Danger Rating Category*	*Burning Index (BI) Thresholds*	*Reference condition (days exceeding BI threshold)*	*Climate Change scenario (days exceeding BI threshold)*	*% Change*
Paarl (n = 3104)	Extreme	> 132	6	14	133
	High	123 – 131	7	21	200
	Moderate	95 – 122	38	60	58
	Low	21 – 94	1 728	1 744	1
	Insignificant	0 - 20	1 324	1 244	- 6
George (n = 3316)	Extreme	> 103	116	153	32
	High	71 – 102	261	359	38
	Moderate	41 – 70	1 323	1 467	11
	Low	19 – 40	1 178	899	-23
	Insignificant	0 - 18	438	404	-8

Plantations, which are commonly located along the slopes of the Western Cape mountain ranges will be highly vulnerable. Societal response could be to increase the capabilities for fire fighting, including greater training and investment in capacity for fire fighting, as well as rapid and effective response to fires using aircraft, for example. Another response may to be remove plantations, especially in areas where future climate change might make them less productive.

All activities, whether residential, farming or forestry, that share borders with the natural vegetation, would need to participate in management of the adjacent natural vegetation so that wild fires will not become especially intense

The control of alien invading plants would be a specific focus for managing the risk of damage by wildfire. Many alien invading plants burn readily, are adapted to fire and spread readily and faster when fires become more frequent (particularly species such as the Australian acacias). Therefore a future climate which has more frequent and intense fires would favour alien invasions, raising the fire hazard because the invading species tend to have greater biomass than the indigenous fynbos. Invasion of natural ecosystems by alien plants is a global threat to ecosystem integrity. Such invasions can alter the fuel properties and fire regimes of ecosystems (van Wilgen and Richardson 1985). In South Africa, the largest threats arise from the invasion of fynbos shrublands by alien trees and shrubs, which increase fuel loads and fire intensity, leading to severe erosion and impoverished plant communities. While ecosystems in the Western Cape are normally quite resilient to regular burning, increased fuel loads associated with invading alien trees and shrubs lead to higher intensity fires and a range of detrimental effects.

Physical damage to the soil is also likely to occur, resulting in increased erosion after fire. For example, 6 tonnes of soil per hectare was lost following fires in pine stands compared to 0.1 tonnes per hectare following fire in adjacent fynbos in the Western Cape (Scott, Versfeld & Lesch 1998). The viability of indigenous seeds can be reduced, causing poor regeneration from soil-stored seed banks. The seeds of some alien species such as *Acacia saligna* are able to tolerate the high soil temperatures associated with intense fires, while the seeds of some indigenous fynbos species, such as *Podalyria calyptrata*, are killed after brief exposure to this temperature (Cocks & Stock 1997; Jeffrey, Holmes & Rebelo 1988). Intense fires will therefore favour recruitment for some alien species by promoting their germination over that of indigenous species. The physical damage caused by fires is also increased. Fire intensities in normal grassland or fynbos fires range from 200 to 5000 kW m^{-1}; indications are that fire intensities in stands of invading plants can be as high as 50 000 kW m^{-1} (van Wilgen & Richardson 1985). Damage to physical structures, and mortality in plants, is directly proportional to fire intensity.

Invasion of other ecosystems by alien grasses, and the consequent introduction of fire into previously fire-free areas, also poses a large potential threat to the species-rich succulent karoo (the world's only arid biodiversity hotspot).

4.1.4.2 Terrestrial Biodiversity

Relatively few studies have addressed the impact of climate change on biodiversity in the western Cape, and much of what has been done has concentrated on the flora. An early study highlighted qualitatively the potential vulnerability of biodiversity to projected drying and warming (Midgley and O'Callaghan 1993), following on similar qualitative projections of endemic species vulnerability were made by Sunter *et al.* (1990), but these were limited by available climate scenarios and modeling techniques.

Recently, more detailed studies using spatially explicit climate scenarios projected for roughly 2050 have confirmed earlier results, and demonstrated the potential loss of up to 55% of the Fynbos Biome, and the potential extinction of an appreciable fraction of endemic plant diversity (Rutherford *et al*. 2000, Midgley *et al*. 2002, 2003, Thomas *et al*. 2004). Scenarios for the Succulent Karoo Biome seem even more extreme, with potentially extensive loss of endemic species possible (Rutherford *et al.* 2000). In the Succulent Karoo, empirical warming experiments have shown that endemic succulents are sensitive to warming alone (Musil *et al.* 2005), and may suffer increased mortality with a temperature rise of only a few degrees. These empirical results lend support to the projections of significant model-projected loss of biodiversity in this extraordinary desert hotspot in the coming decades.

Very little work has assessed the potential response of indigenous fauna, but includes early work on endemic birds (Simmons *et al.* 2005) suggesting some potential negative impacts on Cape species such as Cape Sugarbird, Orange Breasted Sunbird and the Cape Bulbul (Figure 12). Projected losses of geographic range for these species is between 20 and 40%, with most range losses occurring along their northern borders, and in the north western parts of the province (Namaqualand region and northern Cedarberg).

The time scale over which species extinctions can be expected is difficult to estimate, as the major impact of climate change is to cause the contraction of many species' geographic ranges, and in some cases cause new areas of geographic range to become available to species. These processes are not yet well understood or modeled, and introduce significant uncertainty into these projections.

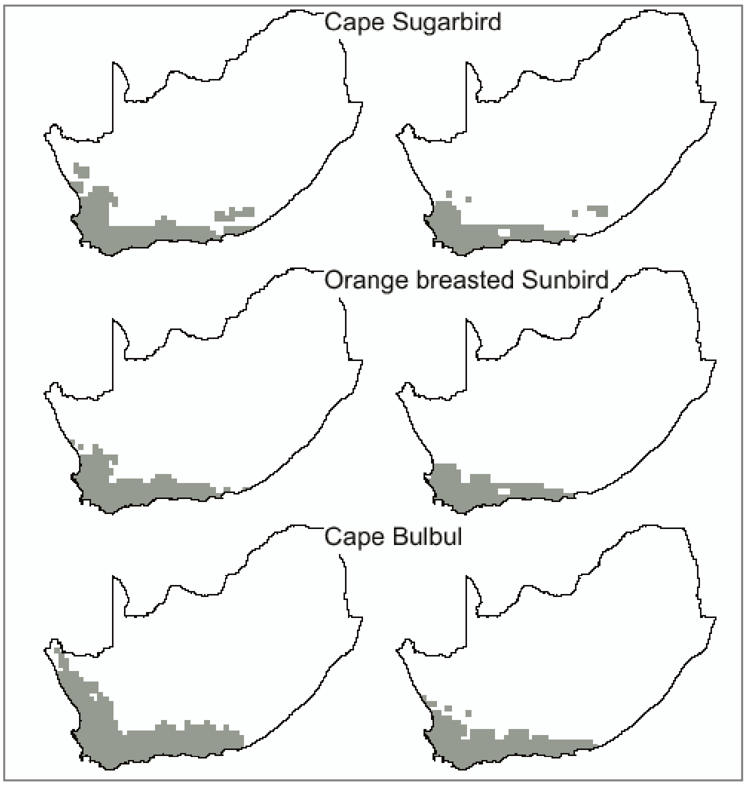


Figure 12: Current (left hand column) and future (right hand column) modeled geographic ranges for three Cape bird species, according to a climate scenario for ~2050 (from Simmons *et al.* 2005)

Nevertheless, using the most advanced species modeling techniques available today, and combining these with assumptions of minimum areas needed to conserve species, some estimates of new pressures on the current system of protected areas have been made (Bomhard *et al. in press*). These estimates suggest that pressures due to climate change on species persistence will rival those due to land-use change by as early as 2020 (Figure 13), and identify the potential need either to expand the current protected area system or encourage land-owners to ensure the persistence of species not protected in nature reserves.

Analyses of high altitude sites with unique vegetation and faunas suggests that these may come under threat and possibly suffer elimination as warming proceeds (Macdonald *et al.* 1992), and it is unlikely that these systems can be assisted to persist in the wild. For these and other species and systems threatened to such an extent by climate change, it will be necessary to preserve them out of the wild, such as in gardens, or in the form of seeds or in gene banks as a last resort. Identifying such threatened species and systems, monitoring their ability to persist in the wild, and designing programs to conserve them is a conservation priority.

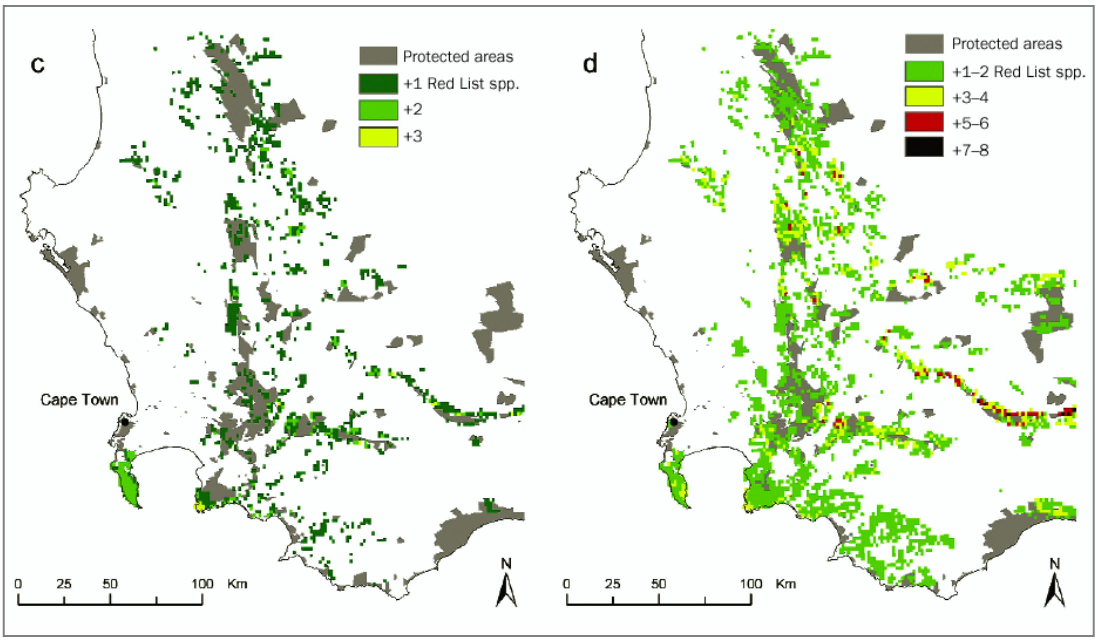


Figure 13: Projected change, by ~2020, in the number of threatened Protea species found in the current protected area network in the Western Cape under two different scenarios: Change in red-listed species induced by land transformation alone (left hand panel) and the change in red listed species induced by a combination of land transformation and climate change (right hand panel). Climate change impacts will therefore place a greater burden on the current protected areas system, will increase the importance of this network in conserving endemic species, and will create a need to increase the size of the protected area system.

The uncertainty inherent in climate scenarios does not yet allow an explicit spatial plan to be developed to ensure the persistence of endemic biodiversity under future climate change. However, general planning principles such as linking lowland and mountain regions in continuous stretches, and maximizing the spatial connections between reserves on east-west and north-south gradients provide sound guidance in conservation planning, and are already guiding the implementation of the regionally focused programs, for example (Cowling *et al.* 2003). The world-leading nature of conservation research in the Western Cape was internationally recognized (Balmford *et al.* 2004), and provides a solid base on which to build further adaptive capacity.

In a very recent paper, Pyke et al. (2005) suggested a novel GIS-based method of assessing the capacity of the protected area in the Western Cape to withstand the projected impacts of climate change. These authors showed how a focused acquisition of additional land would help to improve the range of bioclimates represented in the protected area system in the Cape Floristic Region, using a relatively simple and generic technique not dependent on species richness data. These proposed new acquisitions tend also to address current priority areas for conservation.

4.1.4.3 Alien invasive species

Alien species are those species that have been relocated outside of their normal distribution ranges. A relatively small number of these become invasive – that is they display the ability to reproduce and spread in their new environment, often dominating vegetation and water bodies or displacing native species. South Africa's Biodiversity Act (Act 10 of 2004) defines an alien species as: (a) a species that is not an indigenous species; or (b) *an indigenous species translocated to a place outside its natural distribution range in nature.*

If, as has been discussed in the previous section, climate change may cause species to occupy new geographic ranges, definition (b) of alien species will either become redundant, or will conflict with the need to conserve indigenous species displaced by climate change.

Invasive alien plants in the Western Cape

The Western Cape has the most serious invasive alien plant problem in South Africa (Le Maitre *et al*. 2000), with mountain catchments, riparian zones, and coastal dune systems being particularly badly affected. Many of the invasive species are large woody trees, and important species include pines, and Australian wattles, hakeas, myrtles, and eucalypts. Versfeld *et al*. (1998) provide detailed estimates of the infestations for the province. Rooikrans (*Acacia cyclops*) is by far the most abundant invasive species, with over 300 000 ha of dense infestations along the coast. Up to 70% of the remaining natural fynbos is invaded to some degree, about 2.5% severely (Rouget *et al*. 2003). In the Western Cape, alien plant species have been estimated to be using significant amounts of water (van Wilgen, Cowling and Burgers 1996), and are a threat to the biodiversity of fynbos and other ecosystems, where thousands of endemic plant species are at risk.

Invasive alien animals

The Western Cape is also affected by invasive alien animals, notably freshwater fishes and a few important invertebrates. Invasive alien freshwater fishes are widespread in our rivers, and include species of bass, trout, bluegill and carp. Invasive alien invertebrates include the Argentine ant (which displaces native ants and disrupts the beneficial role that native ants play in seed dispersal and plant survival); and the parasitic *Varroa* mite, which is a significant threat to native and commercial bee populations.

Impacts of invasive alien species

Invasive alien species can have significant impacts on the economies of areas that they invade. Arriving at a comprehensive figure for the total costs of invasive plants is not possible at this stage. However, the indications are that the total costs are substantial, and a number of studies can be quoted to support this contention. Two examples are listed below.

- One of the few detailed studies calculated the value of a hypothetical 4 km2 (4000 ha) mountain fynbos ecosystem at between R18 million (with no management of alien plants), and R300 million (with effective management of alien plants), based on six components: water production, wildflower harvest, hiker visitation, ecotourist visitation, endemic species and genetic storage (Higgins *et al*., 1997). Given that there are over 1 million ha of protected fynbos areas in South Africa, the potential reduction in value due to invasion could amount to over R70.5 billion.
- Turpie and Heydenrych (2000) estimated that the value of lost water amounts to R978/ha on the Agulhas Plain area of South Africa; thus, if 20 000 ha of this area became invaded (20 000 ha is the target area to be incorporated in the proposed Agulhas National Park), the total cost would be in the region of R19.5 billion.

Invasive alien species and climate change

Climate change could change the relative distribution and importance of invasive alien species in a number of ways. Firstly, changes in climate could result in areas becoming more (or less) suitable for alien species. Thus species that are currently a problem could expand (or shrink) their distribution ranges as climate changes, with corresponding changes in impacts. Secondly, alien species that are currently present in the area, but not invasive, could become invasive under altered climatic conditions. Climate change is also accompanied by other elements of change, especially changes to the levels of carbon dioxide (CO_2) in the atmosphere, and significantly increased levels of nitrogen deposition (although the latter is not an environmental problem in much of the Western Cape). These other elements can increase the relative competitive ability of alien species relative to native species. In addition, new alien species are arriving all of the time, and some of these may also become invasive. Unfortunately, few detailed studies of the consequences of climate and atmospheric change for the spread and distribution of invasive alien plants have been carried out, so it is not yet possible to estimate these consequences with any confidence.

Climate change could also have indirect, and negative, effects of water resource security in the Western Cape through an interaction with invasive alien plants, particularly invasive alien trees and shrubs in catchment areas and along rivers. Not all alien plant infestations use more water than the natural vegetation that they replace but, as a general rule, trees tend to use more water than grasses or shrubs (Bosch & Hewlett 1982; Dye 1988; Dye 1996; Smith & Scott 1992). Thus, where grasslands or shrublands are invaded by alien trees, the overall water use by the vegetation increases, leaving less water for the streams. In the Western Cape, several studies (Le Maitre *et al*. 1996; van Wilgen *et al* 1996; van Wilgen *et al*. 1997) have estimated that alien plant invasions will both reduce the amount of water available for human consumption (by around 30%), and increase the unit cost of water. More detailed, catchment-level studies (Le Maitre *et al*.

2002) have shown that about 44% of the Sonderend, and 54% of the Keurbooms catchments has been invaded to some degree. The corresponding reductions in the natural river flows attributed to these invasions are about 7.2, and 22.1%. If the invasions are not controlled they could potentially spread, and occupy 51, and 77%, of the Sonderend and Keurbooms catchments respectively. At an annual expansion rate of 10–15% this would take about 13, and 26 years respectively. The projected flow reductions for the two catchments would increase to 41.5, and 95.5%, respectively. The estimated cost of the control programmes to prevent these losses would be about R79.2, and 59.4 million for the Sonderend, and Keurbooms, respectively. Should the catchments be allowed to become fully invaded before control operations were started, then the costs would rise to R519 and 123 million, respectively. These studies underscore the importance of maintaining adequate control programs for invasive alien plant species, given the prognosis for drier climates that would further increase these impacts if alien plants are allowed to spread and dominate catchments.

4.2 Socio-economic sector

4.2.1 Overview

The adverse effects of climate change have long been recognized in international negotiations on climate change impacts. Adverse effects are those changes in the physical environment or biota resulting from climate change which has significant deleterious impacts on the composition, resilience or productivity of natural and managed ecosystems or on the operation of socio-economic systems or on human health and welfare (De Wit 2001)[2].

The IPCC's Third Assessment Report considers climate change vulnerability as the extent to which a natural or social system is susceptible to sustaining damage from climate change (IPCC 2001a). It is a function of

- the sensitivity of a system to changes in climate (the degree to which a system will respond to a given change in climate, including beneficial and harmful effects),
- adaptive capacity (the degree to which adjustments in practices, processes, or structures can moderate or offset the potential for damage or take advantage of opportunities created by a given change in climate), and
- the degree of exposure of the system to climatic hazards.

The sensitivity and adaptive capacity need to be assessed for all socio-economic activities in the Western Cape. For the purpose of possible further regional economic analysis, socio-economic impacts were reported as close as possible to existing economic categorizations.

The impacts of climate change on agriculture, water supply and human health (services) have dominated the literature on vulnerable populations. However, the IPCC's definition of vulnerability also includes those sectors impacted by knock-on effects and climatic events (such

[2] UNFCCC Art 4.8 and Art. 4.9; Articles 2.3 and 3.14 of the Kyoto Protocol.

as manufacturing, insurance, electricity, construction, transport, tourism etc.). The economy is a complex, integrated system and impacts on one sector will influence other sectors as well, a fact illustrated well with regional input-output models.

This standard macroeconomic approach is only one component in the assessment of the socio-economic impacts of climate change. The economy is not only a complex system, but also a dynamic system that operates on and can be described on various levels (for example on household, community, local, municipal, regional, provincial, national levels). Several *pressures* (whether biophysical, political, social, technological or economic) will continuously change the *state* of the economy on all of these levels, raising the need for flexibility in *response* measures. For example, the process of urbanization (a particularly important issue for the Western Cape with a relatively higher urban population then South Africa (see Table 14)) changes the demand for products and services in the economy and, in turn, the vulnerability to climatic changes. Such changes cannot be captured in static regional economic statistics and models, and would need to be supplemented by approaches focused on human well-being at various levels.

Table 14: Urban population (as percentage of total)

	1975	*2001/2004*	*2015*
South Africa	48.0	57.6 (2001)	67.2
Western Cape		63.9 (2004)	

Source: UNDP 2003, Wesgro 2004b

The rest of the discussion will focus on a discussion of possible socio-economic impacts of climatic changes as predicted for the Western Cape (for a short overview see Box 4), for the various socio-economic sectors.

Table 15: Typical climate change impacts on economic sectors

Sector	*Linkages and Impacts*
Agriculture, fishing	Change in production
Manufacturing	Change in processing of primary products (volume, quality)
	New markets (climate control, sea defense, water conservation and supply)
	Government policies (carbon, fuel taxes)
	Customer preferences
Tourism	Change in tourist numbers due to temperatures and precipitation
	Sea-level rise and beach degradation
	Reduced stream-flow and water-based recreation
Finance and investment	Insurance for weather-events
	Banks, asset managers and underlying secured assets, investments
Transport, communication and trade	Temperature, precipitation and physical infrastructure
	Temperature, precipitation and travel demand, accidents
	Trade and communication and volumes/quality of production
Construction	Sea level rise and properties, rehabilitation of degraded bathing beaches

Source: Based on IPCC (2001b), Kiker (1999).

The types of sectoral impacts that have been described in climate change literature such as the IPCC's Third Assessment Report (IPCC 2001a) and the South African Country Studies on Climate Change are listed in an abridged version in Table 15. A full possible impact table for the Western Cape is attached as Appendix A, and discussed in the following paragraphs.

4.2.2 Economic sectors

Agriculture

The Western Cape's range of climates provides many niches for high quality agricultural production. The long, hot and cloudless summer days stimulate photosynthesis (and thus sugar production) in citrus and grapes, while warm autumn days and cool nights encourage the colour development of citrus (Wesgro [S.a]a). Cold winters and winter rainfall provides a perfect climate for deciduous fruits such as apples, grapes and pears, and for stone fruits such as plums, peaches and apricots. Winter wheat production is sensitive to rainfall in late autumn (May) and spring as well as optimum warming in August and September (Talbot 1947 as quoted in Barrable 2004). Vegetables generally thrive in sunny conditions and precipitation all year round if cultivated in the open. Dairy production is higher then in the rest of the country; one of the reasons being the lower levels of heat stress. The vast plant biodiversity initiated various conservancy areas for nature-based tourism as well as expanding flower, herbs and natural products enterprises (Wesgro, [S.a]b).

The vulnerability of these agricultural products to changes in temperature and precipitation on a site-specific level such as the Western Cape is the focus of another part of this study. It is recommended that the linkages between these sensitivities and the value-adding processing activities in the Western Cape economy need to be researched in more detail.

The agricultural sector is indirectly impacted by government or sector initiatives to respond to climate change, such as water restrictions on irrigation, irrigation charges or technology specifications that may have an impact on production processes.

Fisheries

Relevant climate features for fishing include temperature, wind (speed and direction), the shifting of streams and currents (upwelling), sea level rise, availability of sunlight, the occurrence of storms and freshwater run-off into the marine environment (Schjolden 2004). Fish growth depends primarily on the availability of food and differences in temperatures (Cushing 1982 as quoted in Schjolden). These changes are predicted to have second-order impacts on aquaculture as well. It is generally accepted that the way climate affects marine life is complex and largely undocumented (IPCC 2001a, Glantz 1992 as quoted in Schjolden). Climatic variation is expected to have an important impact on fisheries in the Western Cape, as already evident in recurring El Nino events. If a change in the passage or volume of the Agulhas current is set to occur, the impacts on fisheries in the province would be substantial (Kiker 1999).

A more immediate impact is the reduction of freshwater run-off reaching Western Cape estuaries, a situation that may be aggravated by lower levels of precipitation (Kiker 1999). It is well-known that the fisheries productivity of estuaries correlated strongly with size and mouth conditions (Lamberth & Turpie 2003). It is estimated that up to 18% of inshore fisheries, or around R450 million per annum, is already lost due to a change in estuarine functioning (Turpie, Winkler & Midley 2004). Although these figures provide a useful rough estimate of impacts, they are point-estimate aggregates and it is recommended that research on the correlation between catch data for different species and sectors and estuarine attributes is done. This will increase confidence in estimates of socio-economic losses incurred by such changes.

Forestry

The South African forestry industry is sensitive to climate and predicted climatic changes indicate that they are of a sufficient magnitude to affect the plantation industry (Kiker 1999). With the very unreliable national rainfall predictions used it would be premature to develop refined estimates of economic losses. For the Western Cape this is also not needed as forestry is small in comparison to the rest of country (5.1% of total planted area (Mayers, Evans & Foy 2001)), and because the major softwood species, *Pinus Radiata*, is phased out for other reasons than climate change.

Manufacturing and Industry

Manufacturing and industry is impacted by climatic changes through changes in supplies, employment, operations, and customer preferences. Most directly impacted are those processes adding value to renewable natural resources such as agricultural products, forestry products and fish catch. These sectors contribute 9% to the Western Cape economy and 7% to the national economy (Wesgro 2004a)[3]. The vulnerability of these processing sectors to climatic changes was not included in the South African Country Study on Climate Change (Kiker 1999) and no information was available to reasonably estimate potential impacts. These impacts may be negative or positive though. For example, a recent study found some (admittedly weak) evidence that warmer temperatures *could* lead to more processing of fruit as export-intended fruits do not meet required grades (Turpie, Winkler and Midley 2004), but further tests are required before conclusions can be drawn[4]. It is recommended that existing studies on the volumes and quality of primary products and on the processing sectors need to be enriched with studies on the possible impacts of climate change.

Some manufacturers will be positively impacted by climatic changes, such as those operating in climate control (e.g. air-conditioning, coping with extreme events), water conservation and recycling businesses, in defensive construction such as engineering solutions to sea-level rise, beach stabilization, the creation of freshwater supply options such as dams, and those involved in alternative water supply projects such as desalination and use of aquifers[5].

[3] The manufacturing sectors assumed to be most sensitive to changes in the availability and/or prices of natural resources are food, beverage and tobacco; textiles, clothing and leather; wood and paper, publishing and printing; furniture and other manufacturing.

[4] This study did not test for the influence of exchange rates on the shifting markets for fruit and can therefore not be seen as conclusive.

[5] The negative impacts of climate change on water supply have been documented for the Western Cape, although the study uses several under stringent assumptions that need to be tested further (New 2002).

Manufacturers that are not directly vulnerable to climate change could be influenced in other ways. Government policies, such as carbon taxes increase the cost of production, and customer behaviour and preferences may change due to climatic changes, for example clothing needs. The government of the Western Cape is currently considering a carbon tax (Business Day, 9 March 2005).

Tourism

The impact of climatic changes on tourism is uncertain (IPCC 2001a). It is accepted that tourism in coastal zones and mountainous regions (most notably winter sports) are most likely to be impacted by climate change (WTO 2003). The length of the season may be affected by changing temperatures and precipitation, a rise in sea-level could lead to a loss of resources such as bathing beaches, a reduction in stream-flow run-off could limit water sports and recreational fisheries and changing ecosystems could impact niche-market activities such as bird watching. Knock-on effects will occur in sectors that are dependent on tourism demand, such as transport, restaurants, agricultural products, crafts and small business services such as tour operators. These impacts are very specific and can only be tested when the nature of tourism demand is understood better.

Table 16: Implications of climate change on tourism

Destination Region	*Climate Change Predictions*	*Possible implications for tourism industry*
Sub-Saharan Africa	Small decrease in rainfall in Jun-Aug in Southern Africa	Little clear indication of climate change affecting tourism Hotter and drier months in Southern Africa could diminish demand
Western Cape	More summer rainfall from January onwards Less winter rainfall in July though indication of weak increase in convective rainfall over Swartland	Peak arrivals in April and December not directly affected by predicted changes in rainfall Drier winter months would allow more winter outdoor activity Changes in rainfall patterns affecting supply of water and ability to meet growing tourism demand

Sources: For Sub-Saharan Africa adapted from Travel Research International as quoted in WTO (2003), and for Western Cape results of this study and own analysis.

Several recent studies focused on the nature of tourism demand in the Western Cape. The Western Cape Tourism Score Card compiled by Grant Thornton Kessel and Feinstein [S.a], illustrates that the six most popular attractions in the Western Cape are the Victoria & Alfred Waterfront, Table Mountain, Cape Point, Wine Route, Kirstenbosch and the Garden Route. Nine of the country's 11 top overseas tourist attractions are also in the Western Cape. Domestic tourists to the Western Cape visit the Cape Metro pole and the Garden Route and most (71.8%) rate visiting the beach their preferred activity, followed by visiting nature reserves (58.8%), shopping (54.5%) and visiting Robben Island (51.7%).

The link between these preferred activities and climatic change is at best speculative (Table 4). On a macro-level, scenery and shopping, more then specific attributes (such as charismatic species that may be impacted by temperature or climate changes) seem to drive tourism behaviour in the Western Cape. This may indicate that a suggested link between species richness and tourism may not be that strong. There is some evidence of a rapidly growing, but small niche market in nature-based tourism activities such as bird and whale watching, hiking and nature retreats.

Increased rainfall in summer may affect outdoor activities such as visits to the beach, but given existing predictions on precipitation (Hewitson, this study), these impacts are likely to be limited as increased summer rainfall is only expected in late summer; that is after the domestic holiday season. Warmer and drier summers can have implications such as droughts and fires, water shortages and poor urban air quality (WTO 2003), all of which impact on tourism as well. Heat stress affects mostly the elderly and small children, but tourism statistics are not disaggregated to this level to perform a vulnerability analysis.

An increasing trend in extreme events such as flash floods could also impact negatively on tourism in sensitive areas. An increase in the number of visitors to the Western Cape will bring increased demand for water resources.

It is recommended that the sensitivity of tourist behaviour to climatic changes (temperature, precipitation), extreme events, induced physical changes such as beach degradation and induced biological changes such as a loss or migration of species is researched in more detail before more informed estimates on potential socio-economic vulnerabilities and damage costs can be made.

Finance and Investment

The IPCC (2001a) refers to the financial services to include private and public institutions that offer insurance, disaster preparedness/ recovery, banking, and asset management services. Insurers are sensitive to a diversity of climate changes. Weather-related losses account for 75% of the economic and 87% of the insured losses worldwide, and account for 100% of losses in Africa (IPCC 2001a)[6]. Extreme events, higher summer temperatures, and lower precipitation emphasis the vulnerability of private and public insurance.

Banks and asset management may be impacted through impacts on underlying secured assets (e.g. property losses due to weather-related disasters), impacts on credit applications that may not prove to be viable (e.g. tourism ventures impacted by beach degradation), and impacts on investments (e.g. flooding, vulnerable agricultural ventures). The economic assessments of investment decisions (expected revenues, operating costs and risks) can be impacted by climate change (IPCC 2001a).

[6] Based on analysis by Munich Re Insurance.

Banks could adapt and provide services and develop financing techniques that accommodate and facilitate adaptation to weather extremes (e.g., private insurance, catastrophe bonds, weather-related trading) (IPCC 2001b). Banks and asset managers could use indicators to assess for social responsibility (including climate sensitive) as part of their investment decisions.

Transport, communication and trade

Transport and communications infrastructure may be physically influenced by extreme events, such as flooding. Sustained higher temperatures could have damaging impacts on roads such as asphalt. Heat could also have an effect on aircraft down times, as there is a lack of lift in the air. Drier conditions re expected to have a positive impact on road accidents, although rain events during drier conditions produce a greater frequency of accidents and injuries (IPCC 2001b). Seaports and airports will be disrupted by windstorms and other extreme events (IPCC 2001b). A comprehensive assessment of the impacts of climate change on transport is not even available worldwide and these impacts are at best speculative for the Western Cape.

Transport activities are also vulnerable to government actions on emissions, such as carbon taxes, increasing the direct costs of transport.

Trade activities are impacted by the volumes of products that are traded, the prices at which these products trade, and the networks that bring buyers and sellers together. Any trade activity, depending on exposure to climate risk, could therefore be impacted and be vulnerable.

Construction

A rise in sea-level may lead to property damage, beach degradation and habitat loss. Hughes (1992) (as quoted in Turpie, Winkler & Midgley) has identified four particularly sensitive regions in South Africa, two of which occur in the Western Cape: Greater Cape Town (Melkbosstrand to Gordon's Bay) and the Cape south coast (Mossel Bay to Nature's Valley). Recent damage estimates for vulnerable properties are not available, but expansion in coastal real estate in the Cape metro pole as well as price rises in this asset class would suggest a possible important impact on the local economy. The extent to which beaches will be impacted by a rise in sea level is also unknown, but the popularity of beaches to domestic tourists suggests a potentially vulnerable socio-economic activity. It is recommended that the previous assessment of vulnerable properties along the coast is updated with new property data and insights in expected sea level rise.

4.2.3 Health

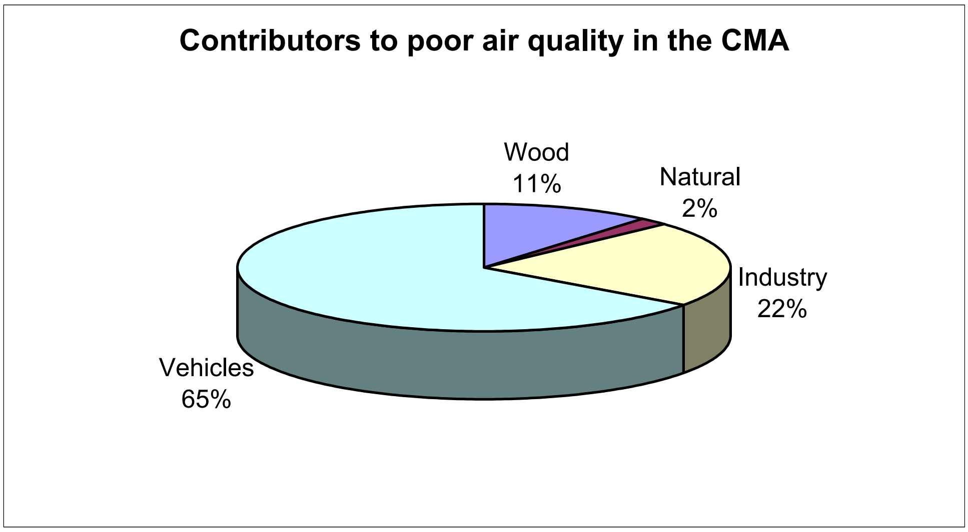
Air pollution

Air pollution in the Western Cape is evident in a few main areas. They are Cape Town, the Saldanha/Vredenburg region; Robertson, Riebeeck West; Mossel Bay; Knysna, Oudtshoorn and George. Since Cape Town is home to 70% of the population of the province and approximately 80% of the pollution, this section focuses on the city.

Air pollution in Cape Town has historically been a minor problem due to the frequency of the SE winds in summer and frequent rain events in winter. As the amount of industry grew, various hot-spots were identified, such as central Cape Town, and high-polluting sources such as the power station and other light industry were shut down or moved away. The rapid growth of motor vehicle transport in the city has changed the spatial nature of the pollutants. Over 500 000 commuters from all over the peninsula drive to and from work every day. Most of them use bus or private vehicles. Every day approximately 15 000 tons of industrial and domestic by-products, e.g. CO_2, SO_2, NO_2 and PM_{10} are emitted into Cape Town's atmosphere (Wicking-Baird *et al*. 1997).

The pollution only becomes a problem when it is visible or begins to affect human health, and this occurs during "brown haze" episodes. At these times the build up of photochemical smog reduces visibility and is undesirable from both health and aesthetic standpoint. Brown haze episodes occur frequently when a temperature inversion exists over the city.

The latter requires specific suitable meteorological conditions in order to exist – these are described in detail by Wicking Baird *et al* (1997) and show that they occur mostly (but not exclusively) in the months from May to October. The lower layer of the troposphere is trapped beneath cold descending air, when calm conditions exist, causing pollutants emitted at ground level to recirculate in a layer, which may be from 50 –200 m thick. The inversion will break up if the wind speed increases and/or when surface heating increases to create sufficient uplift to the air to overcome the downward pressure of the colder air.



When a sequence of inversion days exists, the situation is exacerbated. The pollutants recirculate without dispersing and each day become more concentrated. A rain event, usually be accompanied by wind soon disperses and "washes" the pollutants from the air. The seasonal south-easter will also create enough dispersion to prevent any brown haze build-up. Land and sea breezes may cause the haze to clear temporarily but horizontal recirculation may occur with pollutants being transported back into the metro airspace. Exceedances of the accepted international standards for pollutants are found to occur during the brown haze days.

A synopsis of pollutants, contributing sources and key impacts areas is presented in the table below (after Scorgie and Watson, 2004)

Table 17: Pollutants, contributing sources and key impact areas in the Cape Metropolitan Areas (after Scorgie and Watson, 2004)

Pollutants	*Main Contributing Sources*	*Key Impacted Areas*
PM10, PM2.5	- Transport (primarily diesel vehicle emissions) - Industrial (coal combustion contribution notable) - Household fuel combustion (notable given high exposures) - Other sources (primarily wild fires, tyre burning - significant in terms of episodes)	Elevated concentrations over much of the CCT resulting in widespread health risks, with significant health effects anticipated in residential fuel burning areas (e.g. Khayelitsha).
NO_2	- Transport (petrol vehicles, diesel vehicles then airports and port activities) - Industrial processes (specifically gas burning appliances) - Household fuel combustion - Wild fires, tyre burning, etc. as minor sources	Notably elevated concentrations (likely non-compliance events) within the city center.
Ozone	- Secondary pollutant associated with NOx and other precursors releases - Transport (petrol vehicles as key contributor, also diesel vehicles, airports, port activities) - Household fuel combustion - Industrial processes - Wildfires	Large spatial variations in concentrations noted during monitoring. Due to this being a secondary pollutant, the identification of key impact zones require further monitoring and/or modelling
SO_2	- Industrial sector (particularly due to HFO combustion) - Transport (diesel vehicles, petrol vehicles, port operations) - Household fuel combustion - Tyre burning, wild fires	Relatively small spatial variations in concentrations apparent, with elevated levels occurring at all sampling locations
VOCs	- Transport (petrol vehicles as key contributor, also diesel vehicles, airports, port activities) - Household fuel combustion - Industrial processes - Wildfires	Main impact zones to be established following additional monitoring and modelling efforts
CO	- Transport - Industrial processes - Household fuel combustion - Wild fires, tyre burning	Notably elevated concentrations (likely non-compliance events) within the city centre
Air Toxics	Incinerators, landfill operations, specific industries (refinery, printers, dyers, etc.)	In close vicinity to sources

The Likelihood

Climate change projections indicate 2 trends that apply.

a) Reduction in number of days on which it rains
b) Increase in number of days with a temperature inversion

Both of these trends will increase the frequency of brown haze days. Inversion frequencies are higher in drier winters and with a doubling of CO_2 are expected to increase by 25% (Shannon and Hewitson, 1996). The annual average of exceedance days from 2001-2004 was 117 days. In 2003 (a particularly dry year) 162 brown haze days occurred where pollutant levels exceeded international guidelines (Draft AQMP, 2005). Other sources quote lower numbers for air pollution days (see Figure 14). This may be due to different measurement standards. The SOER of Cape Town (2002) distinguishes between pollution days and “poor visibility days” (Figure 15).

An increase of only 10% in days with inversion conditions will not only increase the number of brown haze days by a similar percentage, but also increase the concentration of pollutants during subsequent consecutive inversion days. This would exacerbate the health effects.

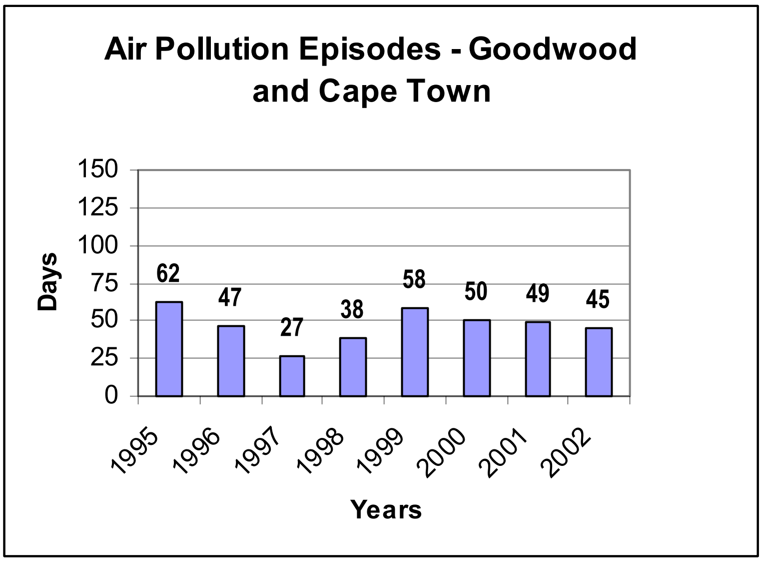


Figure 14: Annual number of Air Pollution events - Cape Town city Centre and Goodwood

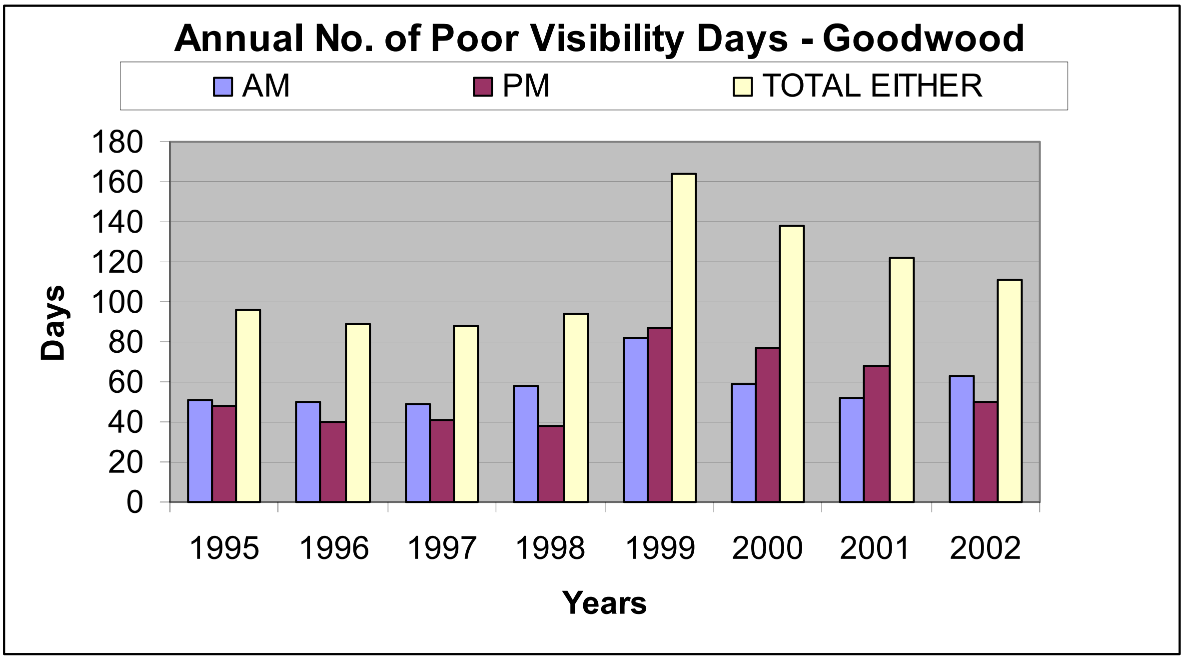


Figure 15: Annual number of poor visibility days - Goodwood

The Effects

Table 18: Guidelines for used in Cape Town for atmospheric emissions (SOER 2002, CCT)

Pollutant	*Guideline*	*Organisation*
Nitrogen dioxide	200 µg/m^3 – hourly mean	World Health Organisation, UK
Sulphur dioxide	125 µg/ m^3 – 24 hour mean	World Health Organisation, UK, SA
Ozone	120 µg/ m^3 – 8 hour running mean	World Health Organisation
Lead	0.5 µg/ m^3 – annual mean	World Health Organisation, UK
Particulates (sub 10 microns)	50 µg/ m^3 – 24 hour running mean	United Kingdom

Of the pollutants, particulate matter poses the most serious health risk as it can penetrate deep into the lungs and has been linked to respiratory problems and cancer (Kinney, 1999). Concentrations of PM10 in the Khayelitsha have consistently exceeded guidelines during winter since 2002 (see Figure 16).

Many studies from cities around the world have shown that there is a markedly higher incidence of asthma among children who live in areas with high levels of air pollution. The future health of residents in this area is at risk.

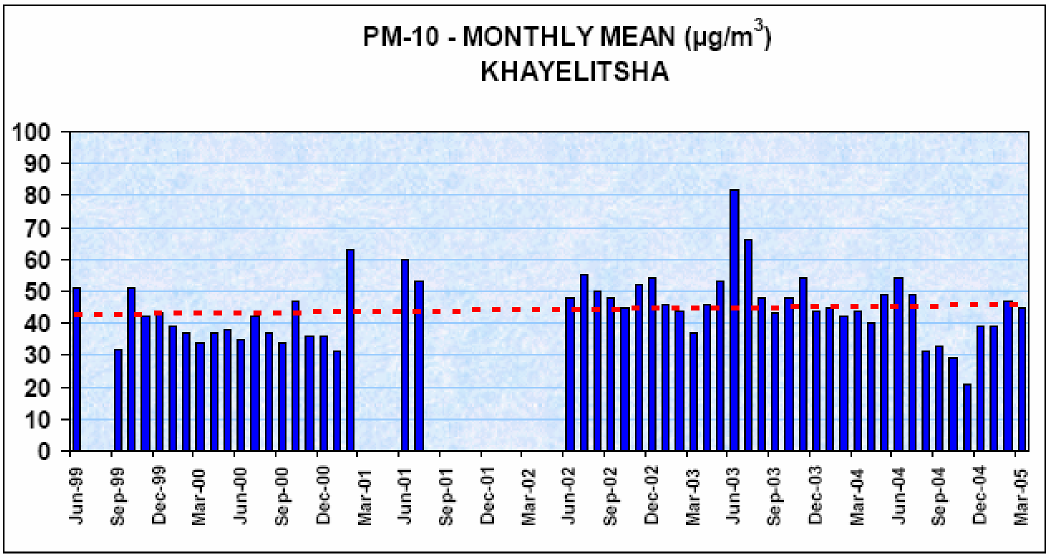


Figure 16: Monthly mean PM10 values at Khayelitsha

Assuming 'business as usual' it was estimated that health effects due to exposures to ambient pollutant concentrations resulting from burning emissions will increase during the next decade in the range of 3% to 22% for Cape Town (Scorgie and Watson 2004).

Table 19: Health impacts, given as number of cases or incidences, predicted to be associated with human exposures to fuel burning emissions in the Cape Town conurbation for the base year 2002(a). (Scorgie and Watson, 2004)

Health Endpoint	*Incidence/Year*
Respiratory hospital admissions (due to PM10, SO_2 and NO2 exposures)	29,481.7
Cardiovascular hospital admissions (due to PM10 exposures)	234.9
Premature mortality (due to PM10 and SO_2 exposures)	90.9
Chronic bronchitis (due to PM10 exposures)	28,806.6
Restricted activity days (RAD, due to PM10 exposures)	217,563.3
Leukemia cases (due to 1.3 butadiene and benzene exposures)	26.7
Nasal carcinoma cases (due to formaldehyde exposures)	0.5
Number of children exposed to > 2µg/m³ & hence topotential for IQ point reductions	0

(a) Exposures to photochemical products such as ozone and exposures to indoor pollutant concentrations are not accounted for.

Health costs of air pollution

Table 20: Predicted total direct health costs due to respiratory illnesses, non-fatal paraffin poisonings, burns and cancer cases caused by fuel use for the Greater Cape Town area

Source Group		*Total Cost of Respiratory Conditions (2002 Rand)*	*Total Costs of Non-fatal Paraffin-Poisonings (2002 Rand)*	*Total Costs of Burns (2002 Rands)*	*Total Cancer Costs (2002 Rands)*	*Total Direct Health Costs (2002 Rands)*
Domestic fuel burning	Coal burning	15,507,904		598,967	316	16,107,187
	Wood burning	691,237,956		8,240,465	428,237	699,906,658
	Other fuel	2,311,778	834,219	55,854,748		59,000,744
Vehicles	Petrol	12,908,609			2,611,232	15,519,841
	Diesel	21,965,326			1,681,616	23,646,941
Industry & commercial		110,906,673			9,524	110,916,197
Power generation		3,776,940			21	3,776,960
TOTAL		**858,615,184**	**834,219**	**64,694,180**	**4,730,946**	**928,874,529**

From the current trends and forecasts it can be assumed that climate change will lead to an increase of 5-10% more inversions over the next 50 years, which in turn lead to 5-10% more brown haze days or pollution episodes. If one accepts that the link between pollution episodes is strong, then a concomitant increase of 5-10% in health costs is not unreasonable. This could amount to over R46-92m per annum at today’s values.

Health and climate change

Human health can be affected by climate in 3 ways (IPCC, 2001b). Firstly, there are those that are direct and usually caused by extreme weather events, such as tsunamis, flooding and heat waves. Secondly, processes of environmental change and ecological disruption that occur in response to climate change can have health consequences. And lastly, there are those with diverse health consequences, including traumatic, infectious, nutritional, psychological and other, that occur in vulnerable populations in the wake of climate-induced economic dislocation and environmental decline.

The overall global temperature increase can have health impacts. Global climate change may lead to change directly in morbidity and mortality through global warming and through UV-B radiation increase. Global climate change is likely to affect the ecosystem and alter the human hazards such as parasites and chemical pollutants and also affect human health by producing changes in air quality and water quality (IPCC, 2001b).

It is not clear at present what health impacts a change in temperature would have in the Western Cape. Warmer average temperatures combined with a change in precipitation can also alter the pattern of exposure to temperature extremes and resultant health impacts, in both summer and winter. This is of particular importance for people living in informal housing, where there is little insulation. Infectious diseases that include vector-borne infections such as malaria and dengue fever are linked to one of the most detectable changes in human health (WHO, 2003). In the Western Cape this is not a key concern, although the range of Malaria could spread southwards in future and should not be ignored. It should be noted that food-borne infections (e.g. salmonellosis) have been known to peak in warmer months. The most important communicable disease in the Western Cape is Tuberculosis (TB), with more than 99% of reported communicable diseases related to TB (DiMP, 2001). There has been an increase in the number of TB cases in the last decade that can be linked to HIV/AIDS. The spread of TB is linked to the standard of living conditions as well as climate conditions and therefore it is important that these linkages are explored further in light of future climate change.

An increase in extreme events is an important consideration as it increases exposure to the hazard. Flooding is a key concern in the Western Cape, because there are many vulnerable groups, living on or near the poverty line and susceptible to flooding because of the high water table in the Cape Flats area. Flooding often stresses sewage and stormwater systems and can lead to water pollution associated with excessive levels of micro-organisms and the subsequent increase in water-borne diseases, which manifests as diarrhoea and dehydration. The impacts can be widespread and are particularly important to monitor for children’s health, as can lead to death if there is not adequate health care. World Health Organisation estimated that climate change was responsible for approximately 2.4% of worldwide diarrhoea in 2000 (WHO, 2002). Flooding can also lead to loss of human life.

It is highly likely that flooding will continue and possibly increase in frequency as rainfall is likely to become more intense. The clear demand for disaster assistance when intense rainfall occurs in the Western Cape, suggests that the current system is not adequately equipped to deal with flooding. An increase in flooding is going to place an increased burden on flood response and the associated health stress. The Directorate of Pollution and Waste Management is responsible for ensuring that pollution is managed as best as possible and Directorate of Environmental Management is responsible for managing situations that are conductive to diarrhoea, cholera and tuberculosis. They therefore need to address the risk of increased flooding.

A change in temperature and rainfall affects food production and this can have an impact on health (WMO, 1999). Drought or stressed food systems can lead to decreased food production and decreased nutrition that can lead to an increase in disease. It is particularly important that food security is monitored given the numbers of HIV/AIDS infected people in the Western Cape that are more susceptible to malnutrition and opportunistic infections.

Increased health impacts can affect the social system. Increased mortality and increased deaths can have a direct burden on the health system. Increased morbidity can impact on treatment costs (direct cost) and days of work lost (indirect cost) (Turpie *et al*, 2002). The value of the loss of human life is hard to quantify but impacts at many levels. An increase in disease associated with climate change can therefore have widespread economic and health costs.

4.2.4 Infrastructure and Utilities

The critical utility sectors that emerge from our initial analysis are discussed further and are listed here:

a. Water services
b. Stormwater
c. Transport
d. Housing
e. Property

Water services

The Western Cape region has a history of water shortages due to recurring drought. In the past three years, the Western Cape has seen its water reserves slowly diminish, The current cumulative capacity of the dams are at 29.6% of total volume (Cape Times, 2005). The City of Cape Town has embarked on a programme of rising block tariffs, water restrictions and public education in order that the water supply does not reach crisis proportions.

On the other side of the scale, heavy rains and flooding have recently caused damage to water infrastructure and financial losses. In March 2003 the total reported losses to DWAF infrastructure were estimated at R 13 850 000. 75% of the damage was to hydrological gauging infrastructure (DiMP, 2003).

It is interesting to note that international experience has shown that countries with renewable freshwater resources below 1000 m^3 per capita per year are prone to experience severe water scarcity that will impede development and be harmful to human health (WRI, 1996). In 1995 the population for the W-Cape was just over 4 million. The per capita water resources (including transfers in) was therefore 1 600 m^3. By 2025 the per capita water resources are well below the 1000 m^3 benchmark viz 768 m^3.

Table 21: Mean Annual Runoff per catchment management area.

Water management area	*Mean Annual Runoff*	*Ecological Reserve*	*2001*		*2025*	
	10^6 m^3	*10^6 m^3*	*Population*	*m^3 per capita*	*Population (using growth rate of 2.72%)*	*m^3 per capita*
Gouritz	1679	325	515000	3260	980680	1712
Olifants/Doring	1068	156	114000	9368	217083	4920
Breede	2472	384	437000	5657	832150	2971
Berg	1429	217	3482000	410	6630542	216
Total for W Cape	6648	1082	4548000	1459	8660455	768

(Source: (BKS (Pty) Ltd, 2003a, b, c, d) (Ninham Shand (PTY) Ltd, 2005))

The NWRS (DWAF, 2002) specifically, amongst others, draws attention to the fact that the Berg Water Management Area will need to consider the provision of water to meet future requirements in the greater Cape Town area, as is illustrated in the tables below. The Western Cape is already stretched to the its limit in terms of supply meeting demand, and this is likely to worsen in the future. Further, these projections are based on current available yields and do not take climate change into consideration.

Table 22: Reconciliation of water requirements and availability for year 2000 base scenario (million m³/annum)

Water management area	*Local yield*	*Transfers In*	*Local needs*	*Transfers out*	*Balance*
Gouritz	275	0	338	1	-64
Olifants/Doring	335	3	373	3	-38
Breede	864	37	632	232	37
Berg	482	194	704	125	-153
Total for W Cape	1956	234	2047	361	-218

Source: (DWAF, 2002)

Table 23: Reconciliation of water requirements and availability for year 2025 base scenario (million m³/annum)

Water management area	*Local yield*	*Transfers In*	*Local needs*	*Transfers out*	*Balance*	*Potential for develop*	*Planned schemes by 2025*	*Indicative costs (Rm)*
Gouritz	278	0	353	1	-76	110	5	31
Olifants/Doring	335	3	371	0	-33	185	141	819
Breede	869	1	639	203	28	197	0	0
Berg (incl. Skuifraam)	506	203	829	0	-120	210	111	1413
Total for W Cape	1988	207	2192	204	-201	702	2282	2263

Source: (DWAF, 2002)

Storm water drainage

Due to variations in the rainfall patterns, storm water drains are prone to blockages. Sand from the Cape flats is blown into the drains during the summer months (dry) and then obstruct the drainage of the rainwater during the rainy seasons (winter), and more specifically during times of unpredicted heavy storms and intense rainfalls. In the "leafy" suburbs, the drains get blocked by leaves, particularly in autumn, with the same result. The blocked drains cause flooding of property and infrastructure with consequential damage.

In some cases the infrastructure has been under designed and have not been designed for more frequent food events.

Transport – Road & Rail

Low lying road and rail run the risk of being flooded during heavy storms and storm surges in areas close the coast line.

The following table provides an indication of the scale (economic terms) of damage that can be caused by severe flooding. The March 2003 cut-off low resulted in damage to Provincial roads in many areas.

Table 24: Economic losses for Provincial Roads (DiMP, 2003)

Administrative Area	*No. of Recorded Impacts*	*Losses (R)*	*%Total Loss*
Boland District (excl. Kogmanskloof)	43	5 684 200	7.23
Eden District	96	13 900 000	17.69
Kogmanskloof	1	59 000 000	75.08
Total	**140**	**78 584 200**	**100**

Damages to road and rail are expensive to repair and cause inconvenience to commuters and financial losses to transport dependant businesses and livelihoods.

Housing

Housing, both low cost and upmarket housing, built on flood and coastal plains run the risk of flood damage due to heavy rainfalls or coastal storm surges. Due to the pressures for residential sites, more houses are being located on potentially flood prone areas. Informal settlements located below the flood lines of rivers are especially susceptible to flooding.

Poorly constructed low-cost housing and informal settlements are vulnerable to heavy storm conditions. The financial losses further burden the lives of the poor and in some cases impact on their livelihoods.

Property

In a study conducted by P Hughes, four particularly sensitive regions were identified: Greater Cape Town (Melkbosstrand to Gordon's Bay); the Cape South coast (Mossel Bay to Nature's Valley); Port Elizabeth; and the KwaZulu-Natal South coast including Durban (Southbroom to Ballitoville) (Hughes, 1992). He developed a vulnerability assessment at the national level based on local case studies and regional assessments, which considered sections of the coast. Population density was also taken into account as a key variable.

Hughes' summary description of impacts at the national level is worth citing:

In reviewing the impacts of sea level rise the first observable impact will probably be an increase in storm damage along the coast. With rising sea level, smaller and therefore more frequently occurring storms will be capable of over-topping existing defences – formal or informal. Soft erodible coastlines will retreat, though not at a constant rate, and must be allowed "room" to retreat. Where there is no room and the profile has been fixed by a structure, the characteristics of the shore/beach will change and the very presence of the structure's protection will results in its own increased vulnerability. Inlets, estuaries river mouths and tidal lagoons will become more tidal with resultant changes to channel and mouth characteristics and nearby shoreline. A greater flooded areas will be formed and this may stress certain wetland habitats if development around these environments is not carefully managed. Some new lagoons/inlets may even be created where they previously did not exist. Associated with the sea level rise will be a rise in the groundwater table. Areas which were previously dry may become marshy or at least suffer from high water-tables, possibly with accompanying engineering problems. This may be particularly important for islands in estuaries. Note that the coastal water-table will rise everywhere along the coast, even in urban areas, unless suitable aquifer management is carried out. Likewise increase saline intrusion into the coastal aquifers must be managed and may also be necessary in some rivers." (Hughes, 1992: 170-171).

Despite the significant indications of impacts, no estimates of infrastructure losses at the regional or national level, neither in Rands nor in area lost have been made. While some work has been done in identifying the most vulnerable sections of the coast, no quantification of impacts at the larger scales has been conducted.

Future research is needed to quantify the impacts of sea-level rise at regional level, before valuation could be attempted. One cannot simply scale up the results from case studies to the whole coast – Hughes explains clearly the different impacts in different areas, and identifies the most vulnerable segments of coastline. Even in some detailed case studies, damages need quantification per unit area. A further research need is to consider impacts other than the rise of mean sea-level, including extreme events (storm surges) and the ecosystem impacts, e.g. through intrusion of saltwater into estuaries and freshwater bodies.

In terms of rand value, initial indications are that the order of magnitude of damages could lie in the tens of millions of Rands for local areas as is illustrated in the Woodbridge Island and Muizenberg case studies. While not large compared to national figures, these figures are significant in the local context and to individual home-owners.

Woodbridge Island (Milnerton, Cape Town) (Hughes, 1992)

Woodbridge Island in Cape Town exemplifies a partially developed shoreline with river mouth, estuaries and backing wetlands and lagoon. The most serious problems arising from a 50cm increase in sea-level would be storm flood damage to the spit protection the lagoon, the town margin and developing margins of the vlei, as well as potential increased erosion (Hughes, 1992: 58). Storm erosion after a 1m rise in sea level would 'probably be sufficient to erode half of Woodbridge Island' (Hughes, 1992: 53). Flooding after a storm of the type that occurs once 1:50 years would completely swamp the island.

The average price of properties on Woodbridge Island was estimated by estate agents to be R750 000 (PGP, 2001). Assuming that approximately half (or all) of the 350 properties on Woodbridge Island will be affected by the sea-level rise (with storm surge), the total damage would be R131 million (R263 million). Given the uncertainties in the estimates of house prices and exact number of houses affected, one could say that the damages from sea-level rise may be in the order of magnitude of hundreds of millions of Rands.

Muizenberg (False Bay) (Hughes, 1992)

The coastline of False Bay is a developed coastline with some room for manoeuvring coastal buffer zones, being exposed and low-lying, with development close to sandy beaches in many places. A 50cm rise in sea level would lead to increased erosion, storm flooding and groundwater flooding in the Fish Hoek, Muizenberg/ Sandvlei and Zeekoeivlei areas. Lessons to be learned are that highly developed open coasts are vulnerable to erosion, inlets are susceptible to increased storm activity, ribbon development close to the shore should be avoided and buffer zones should be maintained (Hughes, 1992: 74-5).

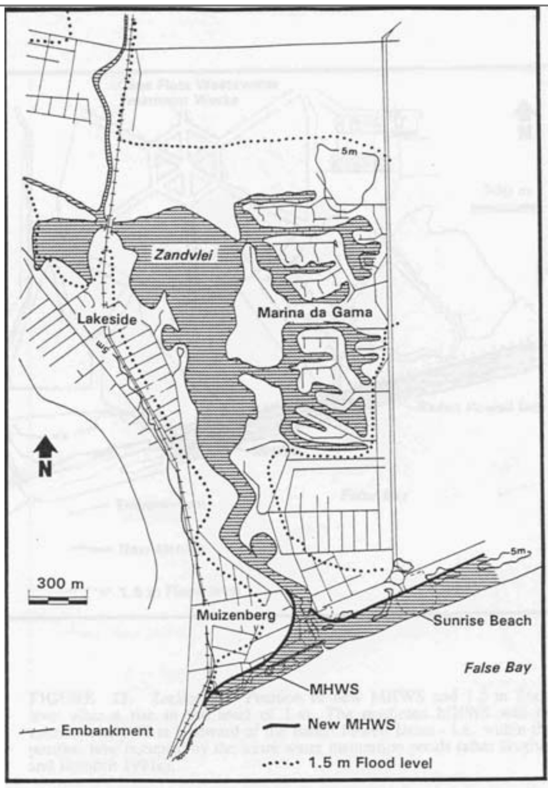


Figure A: Muizenberg after 1.5 m sea-level rise

A 1m rise in sea-level would increase coastal erosion and put the new mean high-water mark back about 100m, beyond the first block of property on the west side of Muizenberg (Hughes, 1992: 65). The average price in Muizenberg for three-bedroomed houses was estimated by estate agents at R285 000, while 'big houses' were in the region of R800 000 (PGP, 2001). An average of R500 000 per house appears reasonable, given that these are by definition properties close to the beachfront. Estimating approximately 40 houses in the flooded area, this would amount to damages of R20 million. This estimate does not add the impacts of a 1.5 m storm surge, which would threaten a much larger area of property, as shown in Figure A.

The predicted sea-level rise assumed here is beyond the range predicted by the IPCC this century, but on the other hand, the impacts of extreme events is not considered. The valuation does not count the lost infrastructure (which would not be replaced), nor the increased value of other properties that are subsequently on the sea-front. Given the uncertainties, one could say that the damages from sea-level rise for west Muizenberg would be in the order of magnitude of tens of millions of Rands.

4.2.5 Livelihoods

> ***Definition of livelihoods***
> *"A livelihood comprises the capabilities, assets (including material and social resources) and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its assets and capabilities whilst not undermining the natural resource base." Chambers and Conway (1991)*

Livelihoods consist of the bundle of different types of assets, abilities and activities that enable a person or a household to survive. These assets include physical assets such as infrastructure and household items; financial assets than include stocks of money, savings and pensions; natural assets that include natural resources; social assets that are based on the cohesiveness of people and societies and human assets that depend on the status of individuals and can involve education and skill. These assets change over time and are different for different households and communities. The ability to access these assets is a key determinant of sustainability and resilience.

These five assets can change depending on the policies, processes and institutions which they are exposed to. If favourable, assets can be accumulated and resilience can increase but if conditions are not favourable people can become more vulnerable. This change in conditions is often impacted by shocks and stresses to which livelihoods are exposed.

In the context of livelihoods, climate can manifest itself as a shock or a stress (Ziervogel and Calder, 2003). Discrete climate events that are significantly different to the average conditions, such as tropical cyclones, tsunamis, floods or drought, can be classed as shocks. More gradual changes in the climate, such as long-term climate variability or a few months of above- or below-normal rainfall, can be classed as stresses. These shocks and stresses fluctuate over space and time and contribute to patterns of household vulnerability (Francis, 2000). The level of stress or the impact of a shock will also depend on what coping strategies are available to the household to respond to or buffer the impact (Blaikie *et al*., 1994, Bohle *et al*., 1994, Carney, 1998).

The possibility of managing the likelihood of variation from the normal climate, before it becomes a shock or a stress that has negative impact, could contribute to increasing livelihood resilience. Unfortunately, in developing countries the benefits might be short-lived as other stresses might start to erode the livelihood assets (Smith, 2001). Factors, such as unstable economies, variable government policies and health crises threaten households directly. For example, HIV/AIDS is eroding many facets of rural livelihoods: financial assets deplete when used for health care and when those of working age are sick; agricultural labour decreases when the work force is not strong enough and social networks erode when young family members die and traditional practices are compromised (SADC, 2003). If one puts the shock of a climate extreme on top of an already vulnerable livelihood, the individuals might have little ability to resist the shock. It is therefore critical to understand the environment in which the livelihood of interest is situated and to realise that climate variability is just one stress or shock that is often added to a number of other vulnerabilities. It is these complexities that require vulnerability to climate to be assessed in a holistic sense that addresses the other stresses that livelihoods are subject to. These multiple factors determine the adaptive capacity of individuals and households and are often ignored when a sectoral approach is used. The livelihood approach therefore provides a baseline to probe adaptation to risks such as climate variability.

4.2.5.1 Key livelihoods potentially impacted by climate change

Livelihoods are such diverse bundles of strategies and assets that there are many ways in which they can be grouped. Three key livelihood groups are focused on in this report as being the most vulnerable to climate change impacts in the Western Cape: coastal, informal settlements and rural livelihoods of marginal groups. Food security is addressed as a separate issue as it cuts across all livelihood groups. There are many linkages that can be drawn when assessing livelihood impacts that can result in complex analysis. For this reason, some initial key areas are highlighted that suggest why each of these livelihoods is vulnerable to climate impacts. In-depth research is needed to understand the nature and extent of the linkages in light of potential climate change.

Informal settlements

Informal settlements have developed on the periphery of towns and cities in South Africa, initially because of past colonial and apartheid development policies. These settlements are characterised by inequities in land tenure, shelter and services that often lead to overburdened health and education and social problems (Napier and Rubin, 2000). The poor physical and social conditions make these settlements particularly vulnerably to the negative impact of physical hazards (UNEP, 2002).

It is predicted that there will be an increase in intensity of heavy rainfall events in the Western Cape, particularly in late summer. This would lead to increased flooding that could threaten large areas of the province. As past flood events have shown, it is often those people in informal settlements whose livelihoods are most disrupted (DiMP 2003). In Cape Town many of the informal settlements are situated on the Cape Flats where the high water table and inadequate infrastructure makes them particularly vulnerable to flooding. The quality of housing in informal settlements is often poor and therefore easily washed away during floods. Landslides are more frequent because settlement areas have usually been cleared of natural vegetation. Often the people in these areas do not have access to the range of service that people in formal housing areas have and so are more vulnerable to the climate impacts because they do not have the means to cope and recover from the shock (Moser, 1998). If there is flooding, informal settlements might not have tarred roads and the dirt roads may wash away which reduces access to areas, sewage and stormwater infrastructure may be poor and stagnant pools of water can lead to disease outbreaks. The post-event trauma is very costly and requires large amounts of time and money to address.

An increase in temperatures is also of great significance in informal settlements as it could be linked to increased fires. There are two main forms of fires in informal settlements; large fires destroying many dwellings and smaller ones affecting a few people but still leading to livelihood loss (Napier and Rubin, 2000). One of the reasons that the frequency of fires is already so high is because of the housing density in informal settlement. A holistic approach to adapting to increased fire risk would therefore have to focus on livelihood options as well as housing policy and how informal settlement will be developed at the same time as acknowledging the impact of increased temperature. On the 15th and 16th January 2005 large fires in Langa/Joe Slovo left 12 000 people homeless. The Mayor's office issued a statement (http://www.capetown.gov.za/clusters/viewarticle3.asp?conid=10080) outlining how they would deal with it: emergency shelter and meals, then prefabricated fire-resistant structures and more formal housing in the long-term. The strategy shows that there are disaster response and risk reduction measures in place, but it is critical that the victims are consulted and the broader impact on livelihoods understood.

The MANDISA database, managed by Disaster Management for Sustainable Livelihoods Programme, University of Cape Town, has a record of informal settlement fires in the Cape Town Metropolitan area (DiMP, 2004). This helps to show the trends in fire events and where they are occurring. This type of information system need to be integrated into management and response strategies at the same time as integrating with other information systems.

Increased temperatures can also lead to increased heat stress. This is particularly important when combined with old age or ill health. Change in wind and dust can also have health and physical impacts on informal settlements.

It is important to assess the access people within informal areas have to resources to cope with and adapt to the shock of having their home washed away or burnt. Access to finance or to social networks is often important. In the Western Cape there are many people that originally come from other countries or provinces. This can limit the social networks that people have access to particularly when needed during disasters. Access to finance is also important as a means to recover from shock. In the informal areas unemployment is particularly high and levels of income low. It is important to note that the source of employment for people might also be impacted by climate variability. Formal employment may not be directly linked to climate, but may have indirect links where climate extremes might cause working hours to be disrupted or might increase costs, which could lead to loss of jobs. Informal activities can also be impacted by climate. Informal traders may not be able to access trading areas if they are flooded or they may have to pay higher prices for agricultural produce if there is a drought. It is these linkages across all aspects of the livelihoods of those in informal settlements that make them particularly vulnerable to climate impacts. Adaptation therefore has to focus on the nature of vulnerability and should take an integrated approach.

Coastal livelihoods

Sea level rise has potentially far-reaching consequences for the Western Cape Province where the great majority of the population live and work in, or near, the coastal zone. Coastal areas can be defined in terms of the current uses of the coastal zone. Some of the potential impacts on livelihoods in coastal areas are as follows:

- Industrial, e.g. Koeberg Nuclear Power Station and Cape Town Harbour. If the Power station had to shut down or shipping access to the port was hindered significantly (through storm wave damage to breakwaters or increased storminess impacting navigability), jobs could potentially be lost in the long-term.
- Commercial**,** e.g. Small harbours. If fishing boat access to the harbour was hindered significantly (through storm wave damage to breakwaters or increased storminess impacting navigability), jobs could potentially be lost in the long-term. The increased storminess will probably have a more significant impact, by reducing fair weather fishing time and increasing the risks.
- Residential areas, e.g. numerous coastal suburbs. Commercial enterprises such as hotels or guesthouses that are located too low or close to the sea may have to close in the long run due to sea level rise and increased storminess. Thus, jobs could potentially be lost.
- Recreational areas, e.g. numerous recreational beaches. If beaches became too narrow, they would loose some of their recreational appeal. This would impact negatively on tourism and the related income generated, thus livelihoods.
- Natural or untransformed area, e.g. the Cape Point area. Similar to recreational areas, if the biophysical environment was negatively impacted, they would loose some of their appeal. This would impact negatively on tourism and the related income generated, thus livelihoods.
- Agricultural areas, e.g. farming directly adjacent to the shoreline such as at the Bredasdorp Plain. Higher seawater levels into the Heuningnes Estuary may cause increased saltwater intrusion and raised groundwater tables in the agricultural areas where farming occurs directly adjacent to the estuary & shoreline. Thus, the livelihoods provided by these farms may be negatively impacted.

Rural livelihoods of marginal groups

Rural livelihoods of *marginal* groups could be impacted by climate change significantly. The marginal groups include those who exist with few resources and little access to power and so have limited capacity to adapt to changes in climate that could negatively impact them. The livelihoods focused on here are based in rural areas that may have small towns or settlements but not large urban areas.

Rural livelihoods are often exposed directly to climate risks. Many production activities in rural areas are agriculturally-based and depend on temperature and precipitation. Crops and livestock are sensitive to cold and heat; certain crops may be destroyed by frost and cold spells can kill livestock. Precipitation is critical for crops. Importantly, it is not just the total amount of rainfall that is critical but the intensity and frequency of precipitation and the change in these characteristics could impact small-scale farmers negatively. Those involved in farming take risks because of the nature of farming that is highly dependent on climate variability, yet few marginal farmers have insurance to support them if their investment provides little or no yield. This lack of insurance makes it hard to take the kind of risks that might result in increased profit and makes them vulnerable to the damage of climate extremes.

Other components of rural livelihoods are often based on natural resource availability and these resources are also directly impacted by climate. For example, water may need to be collected from rivers or wells and drought can therefore impact directly on water supply. When water supply is limited the quality can often decline and lead to ill health. Another impact on livelihoods is that when water sources dry up, woman may have to walk greater distances to find water and this reduces the time spent on other activities. Producing crafts and undertaking carpentry might provide income for some households, but if the natural resources become depleted these activities may be hard to carry out. Land quality is also impacted by the climate, with well distributed precipitation leading to improved rangeland quality, whereas heavy rains can cause erosion and decrease land productivity. Many of the activities undertaken in rural areas depend on the access that households have to land, inputs, knowledge about activities and support. Table 27 provides an example of how changes in rainfall may impact on rural livelihoods. This example is based on households who try to produce their own food (Ziervogel and Calder, 2004). There are many impacts and it is important to explore this range, as it might be a concatenation of stresses that push a household over the edge.

Food security and climate change

Food security is a priority focus when assessing the vulnerability of livelihoods. In rural areas there is a significant aspect of food security that is provided directly through production, but in urban areas food insecurity is a key concern as well. The impact of climate on food security is both direct and indirect. The climate impacts directly on food security through the food production system and indirectly through prices, availability and job opportunities. The percentage of household income spent on food is proportionately very high for low income households and a change in the food commodity chain can therefore have a high impact on livelihoods and make them vulnerable to food insecurity. Research undertaken in Cape Town’s informal settlements showed that food represented the largest expense of household spending accounting for an average of 39% of total monthly expenditure and 70% of households had been unable to access to sufficient food during the year preceding the study (de Swardt, 2004).

Food passes through the system and does not remain an asset. If food is produced by a household, then a change in climate can impact on production. Changes in water availability can impact crops directly, as can changes in temperature. Extremes climate events are often devastating for crops. Floods can wipe away entire fields.

There are many indirect impacts a change in climate can have on food security. Most food is not produced by individual households but acquired through buying, trading and borrowing (Du Toit and Ziervogel, 2004). If the climate impacts on job opportunities, it can impact on the ability to buy food. Similarly a change in climate or climate extremes may impact on the availability of certain food products which may impact on their price. High prices may make certain foods unaffordable and can in turn impact on individual nutrition and health. The change in seasonality attributed to climate change, can lead to certain food products being more scarce at certain times of the year. These seasonal variations in food supply, in addition to vulnerabilities to flooding and fire, can overlay to make livelihoods more vulnerable at certain times of the year. Although these impacts might appear indirect, they are important to consider, given that many livelihoods in the Western Cape are close to the poverty margin and food is a key component of their existence.

Table 25: Potential impact of climatic variation on household assets and strategies

Source of livelihood (assets and strategies)	*Prolonged drought*	*Delayed onset of rains*	*Normal rains*	*Above-normal rains*
Economic	Crop failure, livestock death, deterioration of dwellings (due to diminished thatch grass), erosion of savings, depletion of seed resources in granaries, trees cut down for income generation, wealth and productive resources liquidated, reduced animal feed.	Shortage of water resources, later planting leads to short maturing and lower yielding varieties and less sale, animals get weak and sick, vegetation suffers, resources not as plentiful for crafts such as weaving or thatching, wealth resources liquidated	Potential good harvest improves food security and excess for sale, good grazing conditions, adequate water supplies, housing can be repaired, nearby sources of firewood, animals strengthen	Water logging and increased pests destroy crops, increased diseases affect humans and livestock, water damages housing and grain stores, increased pests in grain stores, small animals drown or washed away, disrupted transport reduces sale of goods
Human	Increased labour migration, malnutrition, undernutrition, disease epidemics (cholera, dysentery, AIDS) due to poor sanitary conditions and increased unsafe sex as income generation activity, morbidity and mortality of income earners.	Malnutrition, undernutrition, education suffers as children can't concentrate and sometimes have to stop school until money is acquired to pay school fees	Clinics function more efficiently as not overloaded with epidemics, education is readily available, fewer epidemics and less undernutrition	Disease epidemics, schools and clinics might be structurally damaged or closed because of restricted access
Natural	Firewood depleted, poor pastures, limited water supply, dry soils, increased erosion, gathering of wild food.	Firewood depleted, poor pastures, limited water supply, dry soils, increased erosion, gathering of wild food.	More firewood available, improved pastures, moist soils, increased pests	Abundant pastures, areas of flooding and waterlogging, increased pests
Social	Kinship networks weaken as resources depleted (claims not met) and increased migration, exploitation of common property resources, increased conflict	Temporary exploitation of communal resources, minor claims not met	Kinship networks able to support poorest households, personal resources used so communal resources can improve, increased competition as many households try to sell goods	Kinship networks weaken as resources are depleted (claims not being met), increased conflict, safety nets destroyed, employment opportunities decrease, increased migration for work

5. KEY ADAPTATIONS

5.1 Physical sectors

5.1.1 Water resources

The Irrigation demand sector

As the irrigation sector is the largest user of water, the biggest benefit in terms of adaptation must come from that sector. Irrigation efficiencies must increase dramatically. Farmers in some areas, for example, use very low-efficiency methods for irrigation, such as the "leibeurt" systems (flood irrigation from a common furrow). Investment in water resource management should focus on increases in efficiency (demand side) rather than trying to increase the quantity supplied (supply side). An increase in efficiency can be driven by a change in irrigation practices. In practice this is achieved by:

- Water pricing mechanisms
- Investment in technology (e.g. drip irrigation systems)
- Changing crops and cropping practices – move up the value chain
- Implement soil-moisture conservation practices.

It is possible to "do more with less". Water made available by these conservation measures can be used for freshening releases from storage dams to combat salinity in the rivers. Increased efficiency of irrigation applications will also result in less return-flow, which is usually the source of saline water.

The urban demand sector

Increase efficiency of use through pricing mechanisms. Improve the quality of effluent through the use of life-cycle assessment and the investment in technology. These activities will allow the increase in the re-use water, particularly where some users might not need drinking water quality standards within their enterprises.

Resource management

Resource management is planned and co-ordinated use of the river basin. DWAF has developed a draft National Water Resource Strategy (NWRS) (DWAF, 2002) to address the management of the water resources to meet the development goals of the country. One of the key objectives of the NWRS is to identify areas of the country where water resources are limited and constrain development as well as development opportunities where water resources are available. In addition, industrial users will be required by December 2005 to develop and submit water management plans if they draw their water directly from a water source (DWAF, 2002). Strict groundwater management systems would need to be put in place to prevent over-abstraction and subsequent damage of the resource.

Biodiversity and aquatic ecosystems

The water-use efficiency of the ecological systems and biodiversity that depend on the water cannot be increased. The solution therefore is to allocate water to them in a way that achieves both optimal benefit to society and maintenance of functioning ecosystems. The way to do this is to determine the Rand values of biodiversity in their different ecosystems. When a value can be placed on a water user, then a water allocation can be made by trading-off the costs and benefits of the different competing users. For example, the value generated by supplying a unit volume of water to an irrigation scheme compared with that of an estuary is not, at present, understood. When society understands that maintenance of healthy ecosystems has a financial benefit, then there will be more willingness to allocate a fair share of water in order to maintain those benefits.

5.1.2 Rivers, wetlands and estuaries

Proposed response strategies (e.g. planning measures and mitigation measures) to manage the potential changes resulting from climate change are presented below:

- All future development around to estuaries must be setback to above 5 m mean sea level (MSL). Currently, numerous low-lying developments necessitate artificial breaching of estuaries along the South African coast. As the sand berm at the mouth of an estuary typically builds up to levels of 2.5 to 3 m above MSL and considerable flooding can occur during closed mouth conditions, the 5 m level is being proposed for all estuaries in South Africa under the new Coastal Zone Bill. Site specific conditions may dictate even higher levels in a few cases.

  The 5 m MSL level also has the advantage that it allows a buffer zone to absorb the impacts of global climate change, e.g. increased storminess and sea level rise. The 5 m MSL contour is also available on the standard 1:10 000 Orthophoto maps from Trigsurvey and therefore expensive and time consuming determination of flood lines is not required.
- National Environmental Management: Coastal Zone Bill (version 10) proposed that all estuaries in South Africa be managed according to a National Estuarine Management Protocol (Van Niekerk and Taljaard 2003). The Protocol advocates an adaptive management approach which requires: 1) the setting of a strategic vision and management objectives, 2) the development of management strategies, 4) the implementation of the strategies, 5) the monitoring of the estuary, and 6) an evaluation or assessment of the results.

  The Protocol also calls for the development of Estuarine Management Plans that address aspects such as 1) Water quantity and quality; 2) Infrastructure and development; and 3) Exploitation of living resources. In short, Estuarine Management Plans provide the ideal proactive planning tools for incorporating proactive planning measures for global climate change. It is therefore strongly advised that any future Integrated Development Plans or the Spatial Development Frameworks include an Estuarine Management Plan that addresses the above mentioned aspects.
- The consequences of climate change (e.g. freshwater reduction) must be considered in determining the freshwater requirements for estuaries. For example, future Reserve studies should include a climate change scenario as part of the evaluation process.
- A network of Estuarine Protected Areas should be developed to conserve estuarine biodiversity in South Africa. Such a network should ensure an adequate distribution, sufficient

abundance and genetic diversity of species occurs along the South African coastline to allow for the successful migration (and settlement) of species to new habitats. Links with the terrestrial and aquatic systems should also be considered, where possible, in the establishment of the network.

- The overexploitation of living marine resources should also be prevented to ensure a sufficient abundance and genetic diversity to assure the resilience to respond to climate change and to accommodate the redistribution of species to new habitats.

5.1.3 Coastal structures and beaches

Proposed response strategies (e.g. planning measures and mitigation measures) to manage the potential changes:

- Development of a provincial vulnerability atlas/GIS where sites are assessed according to scale of potential impacts with respect to sea level rise. Such an assessment could be completed by a professional coastal engineer and provide for mapping on a GIS.
- Furthermore, sufficient physical environmental data should be available for most locations along the SA coast to draw up a point rating system whereby the vulnerability of sites can be evaluated objectively on a relative scale in terms of the 5 potential impacts listed above.

  Each vulnerable stretch of coastline should be studied in terms of aspects such as wave energy, sand budgets, future sea levels and potential storm erosion setback lines. Existing expertise and information lies with the University of Cape Town, the South African Weather Services and the CSIR. It is important to consider all environmental impacts during the life of a project so that the real costs and functionality can be estimated. Sea level rise will affect both the built and natural environment. At the very least coastal zone managers, coastal engineers and planners need to remain informed on the probable future impacts of global weather changes.

- Draw up a Shoreline Management Plan (SMP). The SMP should focus and provide four principal policy options for consideration at management level. These options relate to the movement of the shoreline and are listed as follows:
  - Do nothing
  - Hold the existing line
  - Advance the existing line
  - Retreat

  In terms of developments and infrastructure, this will provide the strategic framework in which all coastal structures and sea defenses are evaluated. This plan should provide the layperson and the authorities with a clear framework to work within. Coastal engineering groups usually undertake Shoreline Management Plans. Specialist studies and monitoring of the shoreline is an essential ongoing element of the SMP.

- Design coastal protection/developments/structures specifically to compensate for the effects of sea level rise. This requires a good understanding of the coastal evolution on the longer time and space scales. Stive *et al.* (1991) argue that shore nourishment is an effective mechanism to prevent shore retreat owing to long-term sea level rise because of the uncertainties and the flexibility that shore nourishment provides. All forms of coastal land use should allow flexibility for adjustment to possible futures sea levels. Bruun (1989) supports beach and near-shore profile nourishment as a protective method to combat erosion owing to sea level rise. For a more detailed discussion of the effects of a rise in sea level on coastal structures such as sea walls, reference can be made to Sorensen (1992).

The question arises as to when and to what extent coastal protection measures should be implemented to compensate for a possible future sea level rise. Vrijling and Van Beurden (1990) have developed an economic model to calculate the optimal height of sea defences in the case of a sea level rise as well as the optimal strategy for heightening of sea defences in the case of an uncertain sea level rise.

5.1.4 Terrestrial ecosystems

5.1.4.1 Wildfires

The occurrence and spread of wildfires in indigenous vegetation can be prevented only with great difficulty and at high cost, and must ultimately fail due to the impossibility of fire prevention over large spatial scales under optimal fire-climate conditions. Management strategies to influence fire frequencies and intensities in fynbos vegetation have been remarkably unsuccessful (Brown *et al.* 1991). Because high fire-risk conditions are likely to increase in the future, it will be important to adopt defensive measures. These include increased protection of assets, through the maintenance of sufficient firebreaks on the interfaces between natural vegetation and residential areas. Investment in fire fighting personnel and equipment will be essential for protecting assets, and clear strategy for their assignment under competing demands needs to be established. Given that fires might become more intense, especially if “berg wind” conditions become more severe, personnel should have sufficient training to deal with these and the equipment available to fight these fires would need to be adequate. Finally, removal or control of flammable alien species that accumulate large fuel loads will become an even greater imperative.

*5.1.4.2 Biodiversity*Conservation strategies for high biodiversity regions such as the western Cape are described by Hannah *et al.* (2002). Effective planning for the protection of biodiversity is underpinned by the availability of data on the distribution and abundance of species. The Western Cape has access to relatively rich databases that are able to guide these strategies. However, it is necessary to continue to develop these spatial databases to include species and habitats that may not be well represented in them, in order to guide and fine-tune them. Further development of GIS-based modeling techniques and applications will enable the use this information in even specific planning initiatives.

The value of good historical monitoring of ecological events and species population sizes and locations has been shown in many studies carried out in the northern Hemisphere – focused monitoring programs that are designed to maximize information on the early signs of specific climate changes need to be designed and implemented in key habitats in order to reveal the rate at which natural ecosystems are being affected by climate change, or indeed, if natural adaptation is occurring. This is a developing field of expertise and would serve as an excellent way to train and involve younger scientists and other interested people in a useful adaptive action. The use of remote-sensed data, particularly, has not been fully explored for this purpose.

Conservationists and spatial planners are already collaborating on the optimal design of reserve networks for robustness to climate change impacts (e.g. by incorporating lowland-upland connections in reserves, by increasing the size of reserves or by increasing connectivity between reserves). However, much more can be done to involve managers of land outside of reserves – this sector represents a substantial fraction of natural habitats and species threatened by climate change, and their protection *in situ* is possibly the most cost-effective strategy to ensure their persistence. It may be possible to use incentives of various types to encourage land owners to engage with conservationists in protecting key threatened species and habitats.

In cases where it is possible to identify key threatened populations of rare species, it may be possible to establish populations in areas where the threat is lower – this has often been done by translocating animal species, or by re-introducing species after some period of rehabilitation and population growth under controlled conditions – but this has seldom been undertaken with plant species. However, this strategy is likely to be expensive and have a high risk of failure, and would only be appropriate in extreme circumstances.

Failing all of the above strategies, and possibly as a subsidiary strategy, it may be useful to carry out *ex situ* conservation approaches for key species, for example, by maintaining plant populations in controlled gardens, in seed banks or in gene banks. The disadvantages of these strategies involve high input and maintenance costs, and the risks of equipment failure and staff commitment for the long-term maintenance of collections. Furthermore, these strategies do not guarantee the conservation of the full range of genetic variability contained in natural populations.

5.2 Socio-economic sectors

From a regional planning point if view, macro indicators on adaptive capacity signal the ability of society, on average, to cope with change. Table 26 shows that the Western Cape has a relatively higher adaptive capacity then South Africa as a whole.

On a sectoral level, various adaptation options have been suggested in a recent workshop on the topic for the Western Cape. Appendix B provides an overview of the adaptation options suggested in the economics working group.

Table 26: Selected aggregated indicators of adaptive capacity

Determinants	*Indicators*	*South Africa*	*Western Cape*
Economic wealth	Real GGP/capita (PPP $US	$2782	$3925

	1999)[a]		
Technology	% of household with telephone in the dwelling or cell phone, 1999	61.3%	34.0%
Information and skills	Adult illiteracy rate, 1996	14.07%	4.24%
Infrastructure	% of household with tap water in the dwelling, 1999	38.7%	76.2%
Equity	% of household income less than R1 000 pm	40.7%	16.8%

Source: SSA (2004)

Note: [a] Purchasing power parity (PPP$) measures the number of units of a country's currency required to buy the same amount of goods and service (in the domestic market) that the dollar would buy in the United States of America. PPP$1 has the same purchasing power in the domestic economy as $1 has in the United States.

Although macro and sectoral level evaluation of adaptive capacity is helpful, several considerations need to be taken into account.

First, what these indicators do not reveal is the spatial and human variance in adaptive capacity. This is important for the Western Cape with its micro-climates and spatially diverse socio-economic activities, as well as the reality of exclusion to the economy and thus, adaptive capacity, of marginalized people. Prioritisation of adaptation options need to be spatially sensitive and take account of the vulnerability of different layers of society. Ecosystems and social systems that are already under stress are particularly vulnerable and may not have the capacity to cope with climatic changes as well. Climate change will continue to happen even if global greenhouse gas emissions are reduced significantly. When climate change is viewed as incremental to "normal" climate variability, the present vulnerabilities and adaptive capacities of people will be artificially separated and can easily be overlooked (O'Brien *et al* 2004, Eriksen & Naess 2003). Sectoral adaptation strategies still need to be considered, but only after taking cognizance of existing vulnerabilities of people in these sectors, and the synergies between the sectors and the synergies with existing response procedures to deal with vulnerable people. Vulnerability, in fact, determines future adaptive capacity, and is a threat to human well-being all the time. A possible more general starting point in the categorization of adaptation strategies from a planning perspective, as updated from the IPCC's Third Assessment Report, is provided in Table 27.

Table 27: General adaptation strategies

Adaptation strategies	*Examples*
Prevent losses	Building sea walls, modify reservoirs operating rules, air conditioning
Reduce losses	Redesigning crop mixes, switching crops and species, adjusting planting and harvesting dates, altering input use, early warning systems for climate hazards
Spreading or sharing losses	Government disaster relief, adjusting insurance premiums (restricting coverage, raising premiums)
Change use or activity	Abandon agricultural land
Change location	Relocating agricultural activities
Restore site	Historical monuments vulnerable to flooding

Sources: UNEP/UNFCCC (2002), UNEP (1998)

A second important element is that adaptation to various shocks takes place autonomously. This influences the perceived role of the public sector in evaluating, planning and implementing adaptation options (UNEP 1998). Sector level adaptation studies also tend to focus on technological rather then behavioural responses.

Third, the costs of adaptation need to be included in designing response strategies, also an overlooked aspect in South Africa's response strategy on climate change (DEAT 2004).

Fourth, an issue highlighted in the economic stakeholder workshop as part of this study (Appendix B), is that adaptation to climate change needs to be part of a developmental strategy that improves human well-being. Adaptive technologies may play an important role in the response to climate change, but need to be integrated in measures of human well-being.

5.2.1.1 Infrastructure and Utilities

Strategies for future sustainable water supplies

The challenge for the future is to balance the demand for water with the available supply. Since it is not possible to increase the amount of water, except to extract more from the available resources, the opportunity exists to satisfy both urban and rural needs using appropriate management mechanisms.

In order to address the impact of climate change, three basic areas of adaptation for water resources have been suggested ((Benioff et al., 1996) in (Schulze & Perks, 2000)):

- Increased water supply: eg modified catchment vegetation, construction of reservoirs and dams, reduction of evaporation, development of groundwater resources and utilisation of inter-basin transfers
- Reduced water demand: eg demand side management, re-use and recycle water
- Different management of supply and demand: eg crop substitution, conjunctive use of ground and surface water, apply climate forecasts to manage water resource operations, provide more versatile inter-basin transfer schemes and more flexible operating rules for water systems.

The following list of existing and possible adaptation measures are considered for the water resources sector as a response to changes in climate. (Mukheibir & Sparks, 2003).

- Increased water supply:
  A key challenge will be the reconciliation of water demand and supply both for the medium and long term. While there is planning for future sources of water supply, it appears as if the demand-side of the equation has, until recently, been neglected. Reducing demand can increase excess in supply thereby creating a greater margin of safety for future drought periods. This could be through a range of measures that encourage efficient water use including education, voluntary compliance, pricing policies, legal restrictions on water use,

rationing of water or the imposition of water conservation standards on technologies? (Schulze & Perks, 2000).

- Inter-basin transfers
  As is the current practice in some catchments, transfers of water between basins may result in more efficient water use under the current and future changed climate. Inter-basin transfers are considered an effective short-term measure for addressing drought and water supply on a regional scale. This, however, is an expensive option (Schulze & Perks, 2000).

- Modification of catchment vegetation
  DWAF have initiated the Working for Water programme to remove invasive alien tree species (wattles, pine etc) from catchments in South Africa. Through the modification of the vegetation in various catchments, where water-thirsty vegetation with high transpiration rates has reduced the stream flow, the available water supply can be increased. Invading alien plants cause the loss of some 7% of the annual flow in South Africa's rivers each year (this excludes their severe impact upon groundwater reserves.) (Kasrils, 2000).

- Control of water pollution / water quality
  Polluted water that is unfit for drinking or other uses can have a similar effect as reduced water supply. Reducing water pollution effectively increases the supply of water, which in turn increases the safety margin for maintaining water supplies during droughts (Schulze & Perks, 2000).

- Marginal changes in construction of infrastructure
  Marginal increases in the size of dams through the raising of walls is a relative inexpensive way of increasing the storage capacity of existing dams.

- Desalination
  The tightening water supply situation in the Western Cape is already causing a search for greater efficiency of use as well as alternative sources, of which desalination is one option. The energy intensity and high financial costs of production have, so far, made this technology unviable. However, the unit price of desalinated water is dropping continually as technology improves. It is a matter of time before desalination becomes cheap enough to compete with conventional water supplies. The unit price of conventional water supplies will also unavoidably rise because the cheapest options are always developed first.

  Desalination is an option that needs to be seriously considered by the Western Cape. However, this solution requires prodigious amounts of energy and it should be noted that energy supply in the Western Cape will be affected by the looming “energy crunch” that is developing in South Africa. Power consumption is strongly linked with growth in the national economy, which has seen continuous growth during the previous decade and is projected to keep growing for the foreseeable future. .

The scenarios facing the Western Cape in terms of desalination is that the projected "energy crunch" will occur about 2007, while the "water crunch" will occur about 2012. The desalination option therefore needs more research. An example of what can be done is given by a planned development by the city of Perth, Western Australia, which intends to build a reverse osmosis desalination plant of 123 Ml/day (123 000 m^3/day) powered by wind (see Box 5 below). .

Box 5: Examples of technological adaptations elsewhere in the world

Wind turbines to power Australia's largest desalination plant

Fifty giant wind turbines will power an eco-friendly desalination plant to make Perth drought-proof and provide 2 million people with their biggest single source of water. In unveiling plans for the biggest desalination plant in the country, West Australian Premier Geoff Gallop said the $387 million venture would produce 45 gigalitres a year by October next year. But Dr Gallop would still not say where the turbines for the joint project between construction giant Multiplex and French company Degremont would be built. The plant will be owned by the West Australian Water Corporation but operated by Degremont for 25 years. (*The Australian/news.com.au 4/15/05*)

Santa Cruz, California, water officials pursue pilot desalination project

The city has applied for $2.8 million in grants, mostly to finance a small-scale plant to study desalinating ocean water during dry years. The pilot project would enable the city to gauge what kind of treatment of the water is needed in different conditions, including during times when the water is more turbid, for example. Desalination takes the salt out of seawater, usually through reverse osmosis in which the water is slammed through membranes at high pressure. Critics say the desalination, in its modern form, harms sea life as water is sucked into a plant and is an energy-intensive process. Supporters say the method is a way to capitalize on the vast water supply offered by the sea. More than 20 desalination plants are proposed on the state's coast, according to a 2004 California Coastal Commission report. (*Santa Cruz Sentinel. 1/25/05)*

Strategies for reducing water demand

- Conservation of water / demand management

  In 1997, the Cape Metropolitan Council accepted the following policy statement (ARUP, 2002) "To develop and manage, in a participatory manner, the implementation of a socially beneficial, technically feasible, economically effective, ecologically sustainable water demand management strategy, which will reduce the (DWAF 1994) projected demand in greater Cape Town by 20% (or more) by the year 2010". The City of Cape Town have set about addressing the current water shortage by imposing water restriction, increased rising block tariffs and initiated an education campaign on water efficiency. These are punitive measures, which could be further augmented with incentives to encourage consumers to recycle and install rainwater tanks.

- *Reduction in water services losses*
  Efficient use of water would reduce treatment and distribution costs. The level of unaccounted for water in urban distribution systems is between 15 and 20%, which is viewed as high by international standards (Goldblatt et al., 2002). The unaccounted-for-water has been estimated at 23% for Cape Town (Geustyn Loubser Streicher & Palmer Development Group, 2001).

  The implementation of a leak detection and repair programme has been implemented in some municipalities, but a wider role out of this programme would reduce the water loss from reticulation systems in the Province.
  In addition, the introduction of pressure management systems, as is the case in Khayalitsha, where water lost from undetected leaks is reduced by reducing the off peak water pressure in the pipes. This also reduces the water lost (not used) through leaks within the piping on private property.

Re-use and recycling of water

Water not used in a consumptive manner should be re-used or recycled. This could be either by returning the water back to the river in a fit state for further use downstream or for reuse within the system from which it was first abstracted, specifically for industrial and domestic users. Coastal towns specifically could look to recycling as a potential source of additional water, before discharging waste water to the sea. Currently the City of Cape Town re-uses 9% of its treated effluent (Geustyn Loubser Streicher & Palmer Development Group, 2001).

Allocation of water supplies by market-based systems

Most policy papers dealing with natural resource management in South Africa recognise the need for economic instruments and market mechanisms for efficient utilisation and allocation of natural resources and environmental resources. The provision of water at prices below the true economic value is considered the main reason for inefficient use of water and allocation in South Africa. Further, in the context of water scarcity, an argument can be made for the introduction of economic incentives in water-stressed catchments to encourage the conservation of water and its shift from low to higher value use. This can be done administratively or by using market-related mechanisms. Issues to be considered when reviewing the pricing of water are (Hassan et al., 1996):

- Marginal cost pricing is more appropriate than average cost pricing since it sends the right signal to efficient water users.
- Variable tariff rates, as apposed to flat rates, to provide for periods of scarcity and peak demands.
- Opportunity cost of water, especially when water is scarce.
- Pricing undelivered water i.e rainfall runoff that is absorbed by crops vs natural vegetation.
- Property rights and tradable permit systems in water.
- Lifeline tariffs and equity.
- Rewarding quality return flows from waste streams.

Market-based allocations are able to respond more rapidly to changing conditions of supply and also tend to lower the water demand, conserve water and consequently increase both the robustness and resilience of the water supply system (Schulze & Perks, 2000).

- Different management of supply and demand

  Contingency planning for drought

  Much research has been conducted into the adaptation to climate variability (droughts and floods) and specifically measures that could be taken to prevent or minimise the disruption and damage caused by such occurrences. In the past, most of this research has been conducted in agricultural sector; more recently research has been focused on the impacts of drought and floods on people and their livelihoods. If the development goals of the country and province are to be achieved despite the impacts of climate change, then the appropriate lessons need to be incorporated into national and local water management policy. The cost of developing contingency plans to adapt to water shortages and mitigate droughts is relatively small compared with the potential benefits (Schulze & Perks, 2000).

  Improved monitoring and forecasting systems for floods and drought

  It is possible that climate change will affect the frequency of floods and droughts. Monitoring systems will help in coping with these changes, even without the impact of climate change (Schulze & Perks, 2000). Water planners and managers need to use the available climate data to make strategic decision on an ongoing basis.

  Maintain options for new sites

  Potential sites for new dams should be kept open till they are required, since there are a limited number of sites that can be used efficiently as reservoirs and removing structures once an area has been developed may be very costly or politically difficult (Schulze & Perks, 2000).

  Reduction of losses due to agriculture

  Irrigation accounts for almost 60% of water used in South Africa (DWAF, 2002). There are significant losses in many distribution and irrigation systems as well significant evaporation losses. Alternative irrigation methods and practices should be investigated that would maximise the irrigation effectiveness and the available runoff for domestic and industrial consumption.

5.2.2 Health

The reduction of greenhouse gas emissions has been prioritised by the City of Cape Town, as is evident from the recently drafted Draft Energy Strategy for the City. Such gases, which include carbon dioxide, nitrous oxide and methane, are significant in terms of their potential for contributing to global impacts. (Scorgie and Watson, 2004).

Significant sources of greenhouse gas emissions include industrial, institutional and commercial fuel burning, household fuel burning, biomass burning, vehicle tailpipe emissions and waste disposal sites.

Although the total contribution to Greenhouse gas emissions from the W Cape is small in terms of South Africa's total, the strategy demonstrates an important awareness and positive response to the problem of climate change, but more importantly will undoubtedly contribute to an improvement in the air quality of the region

Table 28: Workshop response (see also Appendix B):

Air Quality Impacts of Climate Change	*Adaptations*
▪ Greenhouse gas emissions impact on ozone, vegetation and animals ▪ SO_2 deposition in form of acid rain ▪ Increase in PM 10 and 2.5 with health effects ▪ Increased concentrations of NO_2 ▪ Increased inversions = more brown haze episodes	Alternatives to burning of tyres and other waste disposal ▪ Cleaner technologies (vehicle and fuel) for cleaner air – CDM for Kyoto P ▪ Improved monitoring

Several other recommendations have been made.

- Enforce the diesel black smoke legislation.
- Introduce measures to reduce the number of smoking petrol vehicles.
- Enforce the industrial black smoke legislation.
- Initiate discussions with the oil industry about the potential benefits from fuel reformulation.
- Initiate the upgrading of air pollution control capacity in the Cape Metropolitan Council.
- Initiate the development of an air quality management system for Cape Town.
- Existing national air pollution legislation should be re-assessed, as much of it is outdated.
- Manpower of the Air Pollution Division be increased.
- Adequately qualified and experienced manpower be taken on.
- The necessary budget for facilities to test and monitor emissions be allocated.
- The Air Pollution Division be given sufficient power to be able to enforce standards and have a say in metropolitan planning. (Wicking-Baird *et al*, 1996)

Three role players are currently involved in the management, control of air pollution and monitoring of air quality within the CCT, viz.:

- Air Pollution Control Section, within the Directorate: City Health, City of Cape Town
- Air Quality Monitoring Section within the Scientific Services Department, Water & Waste Directorate, City of Cape Town
- Environmental Management Department, Directorate: Planning and Environment, City of Cape Town

Some of the initiatives taken by the city are listed below.

Table 29: Air pollution control and air quality management initiatives being implemented within the CCT (after Scorgie and Watson, 2004)

Initiative	*Initiative*	*Key Performance Indicators (KPI)*	*Progress*
Improve national and local legislation	Local level Air Pollution Control By-laws	Produce the by-law	By-law passed in March 2003
	Support of national law reform process	Promulgation of the National Environmental Management: Air Quality Act	Air Quality Bill to be resubmitted to Parliament in August 2004
	Control of Scheduled Industries to become a Unicity function	Draft strategy document	Pending the promulgation of the Air Quality Act
PM10 concentrations in informal sectors	Investigate the health risk associated with high levels of PM10 experienced in informal areas	Undertake indoor and ambient air quality monitoring	Indoor air quality monitoring and health risk assessment study conducted in 2002 for Khayelitsha. Ongoing ambient air quality monitoring in Khayelitsha extended to include SO2, NOx and CO monitoring in addition to PM10; PM2.5 is being monitored on a project basis (6-day schedule followed)
Reduce the incidence of Brown Haze	Enforce diesel vehicle emission control	Number of vehicles tested	The% failures of vehicles to decreased from 23% to 7%. New by-law permits testing of turbo-driven vehicles and makes it an offence to drive a vehicle that emits smoke – permits issuing of spot summons.
	Tyre burning – Support national incentives for a Cradle to Grave management plan	Reduction in the incidence of burning tyres	Initiative on-going
	Control black smoke from industries	Less visible emissions from industry	Notices and summonses served under the new by-law
Air Quality Management Plan	Liase and get support from Environmental Management Department	Identify subsections of plan	Support received from Environmental Management Department for AQM Plan development.
	Liase with internally affected departments	Setting up of housing, energy, transport task teams to inform AQM planning	Workshops with personnel from key departments (transport, housing, energy, etc.) organised for end June 2004
	Liase with outside interested and affected parties	Setting up of an air quality stakeholder group	Workshop with stakeholders organised for end June 2004
	Compilation and submission of AQM Plan to Council	Publication of comprehensive AQM Plan	Initial workshops to be held in June 2004 for brainstorming AQM Plan development
Monitoring Air Quality	Operating existing monitoring system	90% data availability	Produce reports daily on internet; Evaluate trends in pollution over time; Episodes of exceedance for NO2, SO2, O3, PB & PM10
	Consolidate and maintain existing monitoring stations	Availability of instruments; good calibration records	On-going maintenance of monitoring network with good data availability
	Determine hot spots and expand monitoring system	Move mobile monitoring station 1 – 2 times per year	Monitoring campaigns being undertaken at Potsdam and Vissershok. Trailer purchased to record total reduced sulphur (TRS) so as to conduct odour monitoring in response to complaints, particularly those related to waste water treatment works
Public awareness of air pollution issues	Status of air quality reported on the internet daily for public and press	Number of enquires	Routine reporting of air pollution concentrations in the press and on the internet.
	Take part in annual environment exhibitions	No. of delegates (school pupils) attending exhibition	On-going
	Lecture on air pollution at school	No. of invitations received	On-going
Staff Training	Staff to attend and participate in workshop, courses, seminars and	Improve skills of staff	On-going capacity building

Initiative	*Initiative*	*Key Performance Indicators (KPI)*	*Progress*
	conferences		
Initiate and Take Part in Research Projects	Evaluate air pollution from informal areas	Evaluate concentrations of critical pollutants	Pilot project to be followed by more comprehensive project should need arise
	Evaluate pollution from agricultural sector	Produce discussion document	On-going
	Evaluate ambient radiation monitoring	Produce detailed document and action plan in partnership with KNPS and I & AP's	Need to install equipment to measure ambient radiation to determine background intervention / health risk-levels for civil protection

Applicable resources and documents

The Brown Haze study by Wicking-Baird *et al* (1996) is being updated currently and the Brown Haze 2 study should soon be released.

The City of Cape Town's Draft Air Quality Management Plan (AQMP) is being presently subjected to public review. The mission statement is "to reduce the health effects of poor air quality on the citizens of Cape Town, especially during 'Brown Haze' episodes." Within the objectives listed is the strategy to maintain and improve the monitoring network within the city.

The new national Air Quality Act of 2005 (to replace the Air Pollution Act no 45 of 1965has yet to be enacted, as, among others, the issue of minimum standards, has not been finalised. The act will give local authorities power to enforce their own standards, depending on the extent of the problem.

The Integrated Metropolitan Environmental Policy (IMEP) recommended that tools not be implemented in isolation but rather that they be integrated as part of a comprehensive management system. The manner in which the various tools and methods required to support effective air quality management may be implemented as part of a comprehensive AQM system by the City of Cape Town is demonstrated in Figure 17.

It is proposed here that an early warning system be created where high pollution episodes are predicted 1-2 days in advance, allowing authorities and the public to take mitigating action such as minimising effluent release either at a factory level or by voluntarily reducing dependence on private vehicle transport. There is very little that can be done to adapt to the brown haze once it is there – but prevention during high-risk days will certainly help. Presently it would seem that the capacity within the city and outlying municipal structures is not sufficient for this.

The city and Provincial IDPs need to take a holistic view when considering transport, development (e.g. in the planning of factories) and health. In the context of air quality these are interlinked. The development of the city and the benefits derived there must be balanced by the responsibility of health maintenance and the cost of remedial health care.

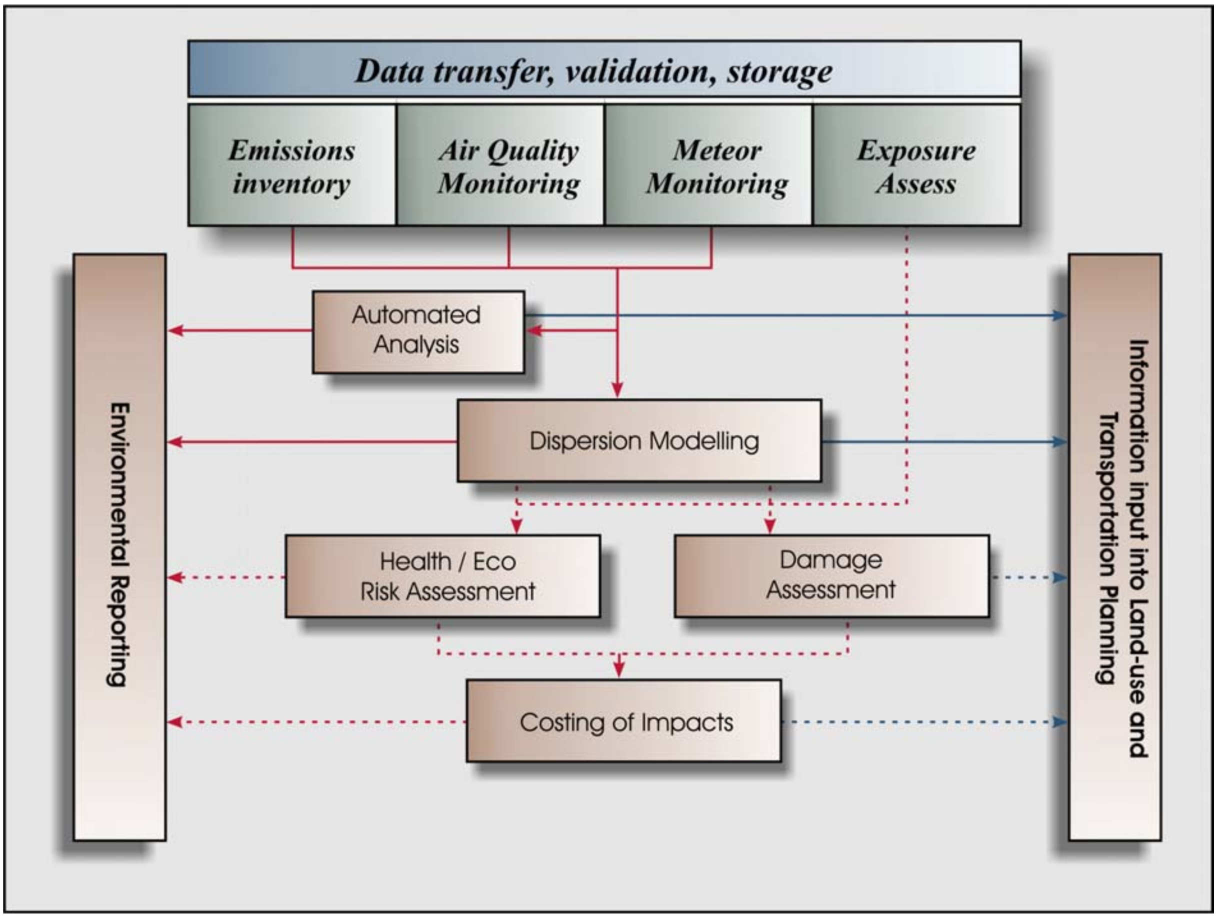


Figure 17: Air quality management system recommended for consideration by the CCT (after Scorgie and Watson 2004)

5.2.3 Livelihoods

Livelihoods change over space and time and are difficult to assess in terms of their vulnerability to stressors. At one instance, it might be clear that people living in a certain area are vulnerable to a certain stress because of their location. At another time, it might be people in a wide area that are engaged in specific activities that make them vulnerable to another stress. At the same time, there are factors such as access to power or social networks that will determine the vulnerability of different livelihoods. These characteristics make it challenging to understand who is vulnerable to what, where and when. It is therefore difficult to know how to target vulnerability to climate change for these individuals. Although this may not be the primary goal, it is important that measures to decrease of vulnerability to climate change are assessed in a holistic manner, so that the various impacts on livelihoods are recognized.

Provincial Disaster Management Centres (PDMC) and Metropolitan Disaster Management Centres (MDMC) are expected to plan integrated disaster management strategies. If they could improve their capacity to reduce the impact of disasters, it would be one way of adapting to climate change. IDP structures are expected to feed in to Municipal disaster management advisory forums (MDMAFs). As stated in the National Disaster Management Framework, 'The PDMC must initiate and co-ordinate disaster risk management capacity building, education, training and research in the province, placing particular emphasis on the development of community awareness programmes and promoting the incorporation of such programmes into school curricula' (South African National Disaster Management Framework, 2005). These integrated strategies need to reflect the diversity of livelihoods and ensure that a holistic approach is taken to improve response to the consequences of climate variability and particularly extreme events.

Because of the detailed, location specific nature of vulnerability to climate variability at a livelihood scale, it is the vulnerability assessments that need to be improved. In southern Africa, there has been an effort to improve vulnerability analysis at the regional and national level by forming committees to undertake further studies. The Regional Vulnerability Assessment Committee (RVACS) and the National Vulnerability Assessment Committees (NVACS) have produced vulnerability assessment reports (SARPN, 2004). This approach could be adapted for use at the provincial scale, with a focus on urban areas, to ensure an integrated, holistic downscaled vulnerability assessment that identifies key gaps and can focus on climate-related vulnerabilities.

If livelihood vulnerability to climate change is hard to assess, then adaptations of livelihoods to climate change is a greater challenge. A downscaled vulnerability assessment would help to focus on key vulnerability areas which could be targeted for adaptation. Detailed research is needed in order to understand how adaptation can be supported at the livelihood level. There is a growing body of literature that focuses on how to support adaptation to climate change among marginal groups (Adger *et al*, 2003; Mortimore and Adams, 2001; Huq *et al*, 2003). For example, work in Lesotho and South Africa, has examined how small-scale farmers might use information about seasonal rainfall, as provided in the seasonal climate forecast, as a means of adapting to current climate variability (Ziervogel, 2004; Archer, 2003). It is important to note that it is not just the climate information that is going to support adaptation but rather a range of other factors, such as access to inputs, the nature of decision making and strategic priorities that are going to determine how effective this response is as an adaptation strategy. Facilitating improved adaptation to annual climate variability is seen to be an important process in facilitating adaptation to longer term climate variability. A livelihoods approach will help to address the multi-dimensional nature of vulnerability and the needs of the most vulnerable.

Improved management of flooding could be a key adaptation response. This is an important area to focus on in terms of disaster management, as improved flood management is an anticipatory action which helps to reduce risk which is preferred to disaster response (South African National Disaster Management Framework, 2005).

Loss of life is the most significant of the health impacts of floods, followed by water-borne diseases. A potential increase in flood frequency and intensity suggests that response to flooding events needs to be better managed. Flood early warning systems could help alert communities to potential disaster. These systems might have to expand on traditional early warning systems or develop new systems. At present, there are warnings issued by the South African Weather Services that warn of extreme events. However, these systems are not well integrated between SAWS and Disaster Management as was seen in a recent intense precipitation event in the Western Cape (Weekend Argus, 14 May 2005). A warning was issued earlier in the week but this was not updated. Effective communication needs to be established with a focus on reaching a range of stakeholders. As well as more effective warning systems, there need to be more organised response operations. This might include volunteers to help with victims during an emergency and increased access to temporary housing and food.

The increase in water-borne diseases linked to increased flood events could be addressed through improved sanitation. Part of the problem is that drains are blocked as highlighted in the newspaper article, ‘Choked drains pose winter threat to city’ (Cape Argus, 20/4/05). The limited capacity of the stormwater system is also a problem, as was seen when it ‘crashed’ in 2004 in numerous places throughout Cape Town. In order to address this problem, it is necessary that intakes, gullies, pipes and culverts are kept as clean as possible from the sand and leaves that block them. System capacity needs to be addressed as an infrastructure priority that increases capacity during extreme events. An increase in solid waste means that not only are current facilities inadequate to cope (State of the Environment, 2004), but capacity will need to be increased in the future. It is of paramount importance that increasing capacity of waste and storm water facilities takes into account the potential impact of increased flooding.

An example of repeated flooding illustrates the necessity to adapt to climate variability rather than continuous pollution and rebuilding. The area along the Cape south coast, between Cape Town and Plettenberg Bay has been hit by three devastating floods in as many years due to excessively heavy rains caused by cut-off low weather systems. This has resulted in the repeated flooding of the Heidelberg sewage works into the Duiwenhoks River. This repeated flooding of the sewage works and subsequent effluent pollution of the Duiwenhoks River lends itself to further examination. The current location of the sewage works presents a high risk to those living downstream and to the ecology of the river itself. However, the Langeberg Municipality do not have the funds to relocate it. According to a fax received by Langeberg Municipality from Kwezi V3 Engineers (Pty) Ltd. on the 7 January 2005, relocation would cost R7 227 800 as opposed to R2 485 200 to repair *in situ*. The placement of the sewage works therefore remains highly problematic, particularly if weather events of this nature are to become a common feature of this region due to possible climate change. One can therefore motivate that the Heidelberg sewage works be relocated as a municipal level climate change adaptation strategy, and in the event of such a relocation, the new works be fitted with biogas driven turbines in order to power the pumps that will be required with an elevated sewage works.

6. CLIMATE CHANGE-RELATED ACTIVITIES, POLICIES AND PROGRAMMES

Due to the complex nature of climate change, responsive policies will be a combination of various different policy areas. Policies need to address adaptation to adverse impacts of climate change on terrestrial, freshwater and marine ecosystems, hydrology and water resources, food and fibre, human infrastructure and human health or mitigation options in all economic sectors. Several socio-economic and natural resource policies provide an indirect framework for adaptation to climate change. The steps taken towards addressing a changing climate system will therefore be integrated in many other sustainable development policies and work programmes. There are a few areas where policies and programmes have addressed climate change in the Western Cape:

Government:

- The government of the Western Cape is currently considering a carbon tax, mainly to boost revenue streams (Business Day, 9 March 2005). Government policies, such as carbon taxes may impact on the cost of production and consumption and need to be researched for their environmental effectiveness as well.
- The National Response Strategy to Climate Change, released in October 2004 will have implications on provincial level as well. The National DEAT will, where appropriate, enlist the cooperation of other government departments, provincial and local government and non-government entities. The document states that "certain provincial governments are already officially represented at the NCCC and the further involvement of provincial and local government in climate change matters should be actively solicited".
- The City of Cape Town is involved in the Cities for Climate Protection Project. The city progressed from completing the greenhouse gas inventory for Cape Town to launching the CCP Campaign locally through an awareness programme and initiating a number of pilot projects to reduce emissions from City of Cape Town operations. They are investing in retrofitting energy-saving light bulbs in municipal buildings and informal settlement housing, bicycle feasibility study and exploring options such as encouraging household resource efficiency.
- The City of Cape Town's Draft Air Quality Management Plan (AQMP) is being presently subjected to public review. The new national Air Quality Act of 2005 (to replace the Air Pollution Act no 45 of 1965) has yet to be enacted, as, among others, the issue of minimum standards, has not been finalized.
- Cape Town Energy Strategy: ENERGY VISION 2: A leading African city in meeting its energy needs in a sustainable way, and thus fulfilling its constitutional obligations and global responsibilities.

  'Sustainable' implies:

  - reducing dependence on non-renewable energy (increasing use of renewable energy, improving energy efficiency)
  - reducing harmful environmental impacts of energy production and use (pollution and global warming)

Benefits of being more sustainable include:

- Health benefits (clean air)
- Employment creation (renewable energy generally creates more jobs per GWh)
- Increased energy security for city (less dependent on external, centralised sources) and an environmental profile that will enhance competitiveness in investment, trading and tourism

Goals:

- Increasing renewable energy contribution to the energy supply mix (starting with the most financially viable options)
- Improved energy efficiency
- Cleaner air
- Reduced CO2 emissions

Civil Society:

- WWF has a climate change research programme on the resilience of small-scale rooibos tea farmers to climate change. This project will serve as a demonstration project with a view to building a future research program under WWF and partners on supporting adaptation to climate change in frontline ecosystems and communities.
- Climate Action Network:
- This network operates nationally and is afficiliated internationally. CAN members operate in the mitigation and adaption fields of climate change. The Western Cape members consists of, amongst others, the following members:
  - SouthSouthNorth (SSN)
  - Earthlife Africa – Cape Town (ELA-CT)
  - Development Action Group (DAG)
  - Environmental Monitoring Group (EMG)
  - Sustainable Energy Africa (SEA)

  The NGOs provide a useful interface with development and climate sectors. NGO’s like DAG work in the urban housing sector would need to consider adaptation strategies when developing new housing projects. SSN operates exclusively in the climate sector, having recently started a programme that will investigate both mitigation and adaptation opportunities in South and Southern Africa as they relate to sustainable development and poverty.
- Research

  The Energy Research Centre (UCT) have just concluded a study on the cost-benefit anaylsis of adaptation for the Berg River project.

  Climate Systems Analysis Group (UCT) has been involved in the development of regional scale climate change scenarios and capacity building for Africa, as part of the

Assessment of Impacts and Adaptation to Climate Change Programme (AIACC). There are a number of other projects including climate change in the water sector and adaptation to climate change among marginal groups.

Business:

Apart from the rise in companies specializing in home water-recycling installations, boreholes and well-points, there does not seem to be evidence of businesses addressing climate change impacts directly but this could be explored further.

Integration of climate change into provincial and municipal planning strategies and frameworks

There are a number of provincial and municipal documents that outline strategies and frameworks that guide provincial and municipal development. These documents include Provincial growth and development strategy (PGDS), Provincial spatial development framework (PSDF), Integrated development plan (IDP) and Spatial Development framework (SDF). There are numerous other documents that might be addressed to examine how climate change could be integrated. For example, the Water Services Development Plan (WSDP) are required to inform the water strategy of the municipalities and could integrate information about climate variability.

These documents cover a wide range of topics. Climate change does not appear to be explicitly addressed in any of these documents. However, issues relating to climate are addressed. At the same time, there are topics that are covered that do not mention links to climate, despite being impacted by climate. For example the WSDP for the City of Cape Town provides information on the existing water supply options and future alternatives, but no discussion is provided on the uncertainty of the expected rainfall and recharge of the water resources (Geustyn Loubser Streicher & Palmer Development Group, 2001). The DWAF guide on the WSDP provides a comprehensive checklist on the demand and supply of the water, but is also silent on the matter of climate change (DWAF 2004).

If climate change is to be adequately addressed, it is imperative that climate-related issues are flagged in these strategies and frameworks. This can be done in many places, but would require a systematic approach. It is important that stakeholders are involved in the process, as those involved in the sectors are aware of the multiple impacts that climate might have on their sectors. It could be useful to have climate scientists interact with sector stakeholders in order for the stakeholders to be aware of the potential climate impacts.

For example, the Integrated development plan (IDP) for City of Cape Town 2005/2006 has a section entitled ‘Managing water supply and demand to meet future need’. They state that,

> *'Greater Cape Town is part of a water scarce region with the current drought highlighting the need to implement strategies to increase water supply and reduce consumption.*
>
> *A new Water Demand Management strategy has been developed in conjunction with the Department of Water Affairs and Forestry (DWAF) to help ensure a long term sustainable approach to water conservation. It will help to achieve our target of a 20% reduction in the projected consumption in 2010. The Berg River Project is well underway and once commissioned in 2007, will provide an acceptable assurance of supply for at least another six years, subject to average rainfall.' (IDP, Cape Town, Pg 30)*

The role of drought has been acknowledged and this is important, although there needs to be further investigation of how drought frequency might change. The supply of water has been established without addressing the impacts of climate change which could change the precipitation amount and intensity which will affect the incoming water. Increased temperatures will also increase evaporation. On top of this, there is population growth which will increase consumption.

The section on health in this document suggests that increased intensity of rainfall could lead to increased flooding in urban areas. This in turn can lead to ill health through water-borne diseases. This is particularly important in addressing the impact of climate on the most vulnerable, as flooding tends to impact marginal groups living in informal housing. An adaptation measure would be to ensure that the water and sewage system can cope with increased flooding events. In the IDP it is stated that,

> *'The upgrading of existing infrastructure and provision of new infrastructure to meet urban growth and development pressures is proving to be a financial challenge.'(Pg 30)*

Upgrading infrastructure is a challenge even before integrating the potential for impacts of climate variability. This can be expanded to assess the impact on housing, transport, agriculture and other sectors. Therefore, climate priorities need to be on the agenda when allocating finances if adaptation to climate change is to be addressed.

The recently gazetted Disaster Management Framework (2005) emphasizes the threat of climate related hazards,

> *'South Africa ... is exposed to a wide range of weather hazards, including drought, cyclones and severe storms that can trigger widespread hardship and devastation.'(Pg.1)*
>
> *'The national disaster management framework recognises a diversity of risks and disasters that occur in southern Africa, and gives priority to developmental measures that reduce the vulnerability of disaster-prone areas, communities and households. Also, in keeping with international best practice, the national disaster*

management framework places explicit emphasis on the disaster risk reduction concepts of disaster prevention and mitigation as the core principles to guide disaster risk management in South Africa. The national disaster management framework also informs the subsequent development of provincial and municipal disaster management frameworks and plans, which are required to guide action in all spheres of government.'(Pg. 2)

The framework also emphasizes the need to reduce vulnerability to disasters rather than the traditional response approach. This can be seen as a key adaptation to climate change. They also highlight the need to integrate across all spheres of government. This is particularly important if the vulnerability of local livelihoods is a priority, as the impacts need to be addressed in a holistic manner that covers a range of sectors. A dedicated effort is needed to address issues related to climate change within these documents.

7. KEY RECOMMENDATIONS

This study has attempted, in a very short time, to draw together essential issues relating to climate change impacts and regional and local vulnerabilities in the Western Cape, and has attempted to distil some potential adaptive measures that might facilitate avoidance of or coping with these impacts. The work presented here is an initial, broad overview of the problem, requiring considerable further attention to detail in many areas before clear guidelines on adaptive strategies can be drawn. We therefore adopt a tentative tone is this final section, and wish to stress that much further study is needed, mainly to reduce uncertainties in many areas relating to the climate projections themselves, and of inferences of impacts and vulnerabilities.

Notwithstanding this cautious preface, we are of the opinion that clear evidence of the early signs of anthropogenic climate change are evident in the temperature record in the Western Cape, and that rainfall trends, though more variable, also suggest some shifts in the “normal” climate regime. We suggest further research is needed on assessing the most appropriate ways of improving regional forecasts of climate change. However, projections of future winter drying are of sufficient concern, supported as they are by a variety of modelling approaches, to suggest an urgent and focussed assessment of the implications for the Western Cape as a whole. The lessons learned from the impacts of recent floods and drought show clearly the vulnerability of the agricultural and infrastructure sectors, but show how poorly impacts on poor communities are reflected in economic terms.

Given that an increase in temperature alone is likely to cause additional stress on water resources, we re-iterate here that the water resources sector is possibly the most critical sector in the Western Cape, and even without climate change impacts, the increase in human population and the needs of agriculture will place an insurmountable burden on the current sources in the very near future. Climate change will exacerbate that burden inexorably into the future. It is clear then that the identification and establishment of alternative water resources is essential for the Western Cape in general, and the Cape Town Metropole in particular. At the same time, efficient demand-side management, especially in the agricultural sector, would greatly alleviate the competing needs for this resource, and might even allow an increase in the “ecological reserve” that would allow ecosystems and biodiversity associated with local rivers to be re-invigorated. Holistic analysis of the competing needs for water, using clear assumptions of future demands and future changes in supply, are an essential need for policy making in this region. These should guide, for example, the definition of levels of water storage and supply that will ensure a dependable resource even under extreme drought conditions. Water availability should be the first concern in considering any new housing or infrastructural development.

Likewise, the reduction in water flow in rivers and the inexorable rise in sea level are indicated to cause changes, mostly negative, to many estuaries and wetlands in the Western Cape. These are systems that integrate the impacts of climate change effectively, and are therefore potentially excellent candidates for careful monitoring to establish the rate of change. They should receive clear focus from this perspective, allowing this Province to assess ongoing climate change impacts at the interface between land and ocean. The worrying impacts of sea level rise coupled with storm surge activities should encourage planning authorities to adopt conservative guidelines for coastal developments.

The potential impacts of climate change on the function and biodiversity of the terrestrial ecosystems of the Western Cape are cause for concern, and also suggest clear indicators that could serve as useful monitoring tools, especially with the use of remote sensing techniques. The future increase in fire frequency and intensity provide a clear warning for improved investment in fire-fighting equipment and teams, and the need for good vegetation management and alien invasive control. In addition to carefully identified land acquisitions, the involvement of private landowners in both monitoring and ensuring the persistence of indigenous diversity will become even more essential into the future. Contingency plans for especially threatened rare species should be put in place to ensure storage at least of genetic material (or seeds, in the case of plants).

While much of northern South Africa is threatened by increasing likelihood of the occurrence of malaria (in the absence of control programs), the key health issues in the Western Cape centre on air quality. Efforts to improve air quality will improve the lives of citizens even under current conditions, and therefore are attractive interventions in the context of future climate change.

Our focus here on livelihoods has allowed the identification of key vulnerabilities of the assets of citizens whose voices are not often heard clearly in studies of this type. Because this is a relatively new approach in climate change assessments, we suggest a far more comprehensive attempt to develop these insights through further research. More detailed work would allow the identification of interventions that local and regional government could make to alleviate the worst impacts of climate change on the poor.

Given that the Western Cape faces climate changes that are already underway, it is clear that a good research base will be needed to facilitate monitoring of ongoing climate change, the identification of key thresholds, and the development of adaptive strategies that maximise utility under both current and future climate scenarios. It is important to involve all those with the requisite skills and expertise in the Western Cape in ongoing assessments of the “state of play” in climate change research and climate trends, and engage them with spatial planners, in order to ensure sustainable development of this region. A climate change strategy group of experts could be assembled annually to ensure continuity of this expertise, and the ongoing input of up to date advice to regional government.

8. REFERENCES

ARUP (2002) *Trans-Caledon Tunnel Authority - Berg Water Project* – Available online at: www.tcta.co.za/project/berg_bid.htm

Adger, W. N., Huq, S., Brown, K., Conway, D. and Hulme, M. (2003) *Adaptation to climate change in the developing world*. IIED, London.

Anderson, J. (ed) (1999) *Towards Gondwana alive: promoting biodiversity and stemming the sixth extinction*. National Herbarium, Pretoria.

Archer, E.R.M. (2003) Identifying Underserved End-user Groups in the Provision of

Barrable, A. (2004) *The effects of climate change on soil erosion and land degradation in the Swartland*. Unpublished START/PACOM mid-thesis report, University of Cape Town.

Barnett, Tim P., Pierce, David W., AchutaRao, Krishna M., Gleckler, Peter J., Santer, Benjamin D., Gregory, Jonathan M., Washington, Warren M. (2005) Penetration of Human-Induced Warming into the World's Oceans. *Sciencedirect* 0: 1112418

Basson, M.S. and Rossouw, J.D. (2003a) *Gouritz water management area: Overview of water resources and availability*. Department of Water Affairs and Forestry Report P-WMA 16/000/00/0203. Pretoria.

Basson, M.S. and Rossouw, J.D. (2003b) *Oliphants/Doorn water management area: Overview of water resources and availability.* Department of Water Affairs and Forestry Report P-WMA 17/000/00/0. Pretoria.

Basson, M.S. and Rossouw, J.D. (2003c) *Breede water management area: Overview of water resources and availability*. Department of Water Affairs and Forestry Report P-WMA 18/000/00/0. Pretoria.

Basson, M.S. and Rossouw, J.D. (2003d) *Berg water management area: Overview of water resources and availability*. Department of Water Affairs and Forestry Report P-WMA 19/000/00/0. Pretoria.

Basson, M., Van Niekerk, P., & Van Rooyen, J. (1997) *Overview of Water Resources Availability and Utilisation in South Africa*. Department of Water Affairs and Forestry, Pretoria.

Benioff, R., Guill, S., & Lee, J. (1996) *Vulnerability and Adaptation Assessments*. In An International Handbook, Vol. Version 1.1. Kluwer Academic Publishers, Dordrecht.

BKS (Pty) Ltd (2003a) *Berg Water Management Area. Overview of the water resources availability and utilisation,* Vol. P WMA 19/000/00/0203. DWAF.

BKS (Pty) Ltd (2003b) *Breede Water Management Area. Overview of the water resources availability and utilisation,* Vol. P WMA 18/000/00/0203. DWAF.

BKS (Pty) Ltd (2003c) *Gouritz Water Management Area. Overview of the water resources availability and utilisation*, Vol. P WMA 16/000/00/0203. DWAF.

BKS (Pty) Ltd (2003d) *Olifants/Doorn Water Management Area. Overview of the water resources availability and utilisation*, Vol. P WMA 17/000/00/0203. DWAF.

Blaikie, P., Cannon, T., Davis, I. and Wisner, B., (1994) *At Risk - Natural Hazards, People's Vulnerability, and Disasters*. London, Routledge.

Bohle, H. G., Downing, T. and Watts, J., (1994) Climate change and social vulnerability. *Global Environmental Change*. **4**. 37-48.

Bosch, J.M. and Hewlett, J.D., (1982). A review of catchment experiments to determine the effect of vegetation changes on water yield and evaporations. *Journal of Hydrology* **55**, 3-23.

Brown, PJ, Manders, PT, Bands, DP, Kruger, FJ and Andrag, RH (1991). Prescribed burning as a conservation management practice: a case history from the Cedarberg mountains, Cape Province, South Africa. *Biological Conservation* **56**, 133 - 150.

Bruun, P (1988) The Bruun rule of erosion by sea-level rise: a discussion on large-scale two and three-dimensional usages. *Journal of Coastal Research*, **4 (4)**, 627-648. Charlottesville (Virginia), USA.

Business Day (2005) *MEC moots carbon tax for Western Cape*. 9 March.

Cameron, W.M. and Pritchard, D.W. (1963) Estuaries, In Hill, MN (ed.) *The Sea,* **2.** 306-324. New York. John Wiley & Sons.

Cape Times (2005) Weather Outlook. 18 May 2005

Carney, D., (1998) Approaches to Sustainable Livelihoods for the Rural Poor. Overseas Development Institute (ODI) Poverty Briefing.

CBD (2003) *Interlinkages between biological diversity and climate change. Convention on Biological Diversity Technical Series 10*. Montreal.

Chambers, R. and Conway G. (1991) *Sustainable rural livelihoods: practical concepts for the 21st century.* IDS Discussion Paper 296. Brighton, IDS.

City of Cape Town Draft Air Quality Management Plan (2005) Produced by the City Health Directorate – Air Pollution Control Section

Clark, B.M., Steffani, N.C., Young, S., Richardson A.J., and Lombard A.T. (2000) *The effect of climate change on marine biodiversity in South Africa*. Report prepared for the Foundation for Research Development, South African Country Study on Climate Change, Vulnerability and Adaptation Assessment, Marine Biodiversity Section. 123 pp.

Climate Information. *Bulletin of the American Meteorological Society*, **84 (11)**, 1525-1532.

Cocks, M.P. and Stock, W.D. (1997) Heat-stimulated germination in relation to seed characteristics in fynbos legumes of the Western Cape Province, South Africa. *South African Journal of Botany* **63**, 129-132.

Colloty, B.M., Adams, J.B. and Bate, G.C. (2001) *The Botanical Importance Rating of the estuaries in former Ciskei/Transkei.* WRC Report no TT 160/01, 135pp.

Cook, A.J., Fox, A.J., Vaughan, D.G., Ferrigno, J.G. (2005) Retreating glacier fronts on the Antarctic Peninsula over the past half century. *Science*, **308**, 541-544.

Cooper, J.A.G. (1995) Sea-level Rise and its Potential Physical Impacts on the Shoreline of KwaZulu-Natal. *Natal Town and Regional Planning Report* Volume **80**, Pietermaritzburg.

Cooper, J.A.G. (2001) Geomorphological variability among microtidal estuaries from the wave-dominated South African coast. *Geomorphology,* **40.** 99-122.

Cowan G.I. (1995) South Africa and the Ramsar connection. In GI Cowan (ed.) *Wetlands of South Africa*. SA Wetlands Conservation Series, Department of Environment Affairs and Tourism, Pretoria.

Cowan G.I., van Riet W. (1998) *A directory of South African wetlands*. SA Wetlands Conservation Series, Department of Environment Affairs and Tourism, Pretoria.

Cowling, R.M. (1987) Fire and its role in coexistence and speciation in Gondwana shrublands. *South African Journal of Science*, **83**, 106-112.

Cowling, R.M., Pressey, R.L., Rouget, M., Lombard, A.T. (2003) A conservation plan for a global biodiversity hotspot .the Cape Floristic Region,South Africa. *Biological Conservation,* **112**,191-216.

Crutzen, P.J., Steffen W. (2003) How long have we been in the Anthropocene Era? *Climatic Change*, **6**, 251-257.

CSIR (1990) *Set-back analysis for the Durban Bight and Glenashley Beach*. CSIR Report EMA-C 90147, Stellenbosch. pp 30.

CSIR (1992) *Building The Foundation For Sustainable Development in South Africa.* National report to the United Nations Conference on Environment and Development (UNCED) held in Rid de Janeiro, June 1992. Pretoria. Department of Environmental Affairs. 268 pp.

CSIR (2000) *Recession line evaluations*. CSIR Report ENV-S-C 2000-02, Stellenbosch.

CSIR (2001) *City of Cape Town State of the Coast: Coastal zone Strategy Development Phase 1,* CSIR Report ENV-S-C-2001-071, 142pp+App.

CSIR (2003) *Setback line for coastal zone : Msimbazi- to Mahlongwana River Mouth and Mgeni-to Ohlanga River Mouth*. CSIR Report EMAS-C 2003-088, Stellenbosch.

CSIR Environmentek Durban. ENV-D-C 2002-032

Davies, B. and Day, J. (1998) *Vanishing Waters.* UCT Press. 487 pp.

Day, J.H. (1967) The ecology of Knysna Estuary, South Africa. In: G. Lauff, (ed.) *Estuaries.* American Association for the Advancement of Science, Washington D.C., pp. 397-407.

Day, J.H. (1980) What is an estuary? *South African Journal of Science*, **76,** 198.

Day, J.H. (1981) Summaries of current knowledge of 43 estuaries in southern Africa. In: Day, J.H. (ed.) *Estuarine Ecology with Particular Reference to southern Africa.* Balkema, Rotterdam. pp. 251-330.

Department of Water Affairs and Forestry (2003) *Regional Yield Assessment.* Breede River Basin Study, Department of Water Affairs and Forestry Report No. PH 00/00/2602

Department of Water Affairs and Forestry (2004) *National Water Resource Strategy. First Edition*. Pretoria: Department of Water Affairs and Forestry.

Department of Water Affairs and Forestry/Umvoto (undated leaflet) *Groundwate- enhancing water supply of the Western Cape*, DWAF. Groundwater Division, Western Cape, Geological Society of South Africa (2002) Tales of a hidden treasure. Conference proceedings.

De Swardt, C. (2004) *Cape Town's African poor.* Cape Town: Programme for Land and Agrarian Studies, University of the Western Cape. Chronic poverty and development policy series; no. 2.

De Wit, M.P. (2001) *Climate Change Research in South Africa*. Presentation at Department of Mineral and Energy Parliamentary Portfolio Committee, 28 August.

Deacon, HJ (1983). The peopling of the fynbos region. In: *Fynbos palaeoecology: A preliminary synthesis* (ed by HJ deacon, QB Hendey and JJN lambrechts). SANSPR number **75**, CSIR, Pretoria.

DEAT (2004) *A National Climate Change Response Strategy for South Africa*. Pretoria: DEAT.

Department of Water Affairs (1986) *Management of the water resources of the Republic of South Africa.* Pretoria: Department of Water Affairs.

DiMP (2003). *March 2003 Cut-off low: Consolidated Report*. Department of Social Services and Poverty Alleviation of the Provincial Government of the Western Cape, Cape Town.

Disaster Management for Sustainable Livelihoods Programme, University of Cape Town. (2004) *Report on Informal Settlement Fire Occurrence and Loss: Cape Town Metropolitan Area 1995-1999.*

Driver, A. Maze, K., Rouget, M., Lombard, A.T., Nel, J., Turpie, J.K., Cowling, R.M., Desmet, P., Goodman, P., Harris, J., Jonas, Z., Reyers, B., Sink, K and Strauss, T. (2005) National Spatial Biodiversity Assessment 2004: priorities for biodiversity conservation in South Africa. Strelitzia 17, South African National Biodiversity Institute.

Du Toit, A. and Ziervogel, G. (2004) *Vulnerability and Food Insecurity: Background concepts for informing the development of a national FIVIMS for South Africa*. FIVIMS-ZA Unpublished Typescript.

DWAF (2002) National Water Resource Strategy - Summary. In Proposed first edition.

DWAF (2004) *DWAF's framework and checklist for the development of water services development plans*. 21 September 2004

Dye, P.J. (1996) Climate, forest and streamflow relationships in South African afforested catchments. *Commonwealth Forestry Review* **75**, 31 - 38.

Dye. P.J., (1988). How plants make water flow uphill. *African Wildlife* **42**, 7-8.

Eriksen, S. and Naess, L.O. (2003) *Pro-Poor Climate Adaptation. Norwegian development cooperation and climate change adaptation: An assessment of issues, strategies and potential entry points.* Centre for International Climate and Environmental Research (CICERO), Report 2003:2. Oslo: CICERO.

Fairbanks, D.H.K. and Scholes, R.J., (1999). *South African Country Study on Climate Change. Vulnerability and adaptation assessment for plantation forestry*. Environmentek, CSIR, Pretoria. ENV-P-C 99013.

Falkowski, P., Scholes, R.J., Boyle, E., Canadell, J., Canfield, D., Elser, J., Gruber, N., Hibbard, K., Hogberg, P., Linder, S., Mackenzie, F.T., Moore III, B., Pedersen, T., Rosenthal, Y., Seitzinger, S., Smetacek V. & Steffen, W. (2000). The global carbon cycle: a test of our knowledge of earth as a system. *Science 290*, 291-296

Fischer, G., van Velthuisen, H., Shah, M. and Nachtergaele, FO. (2002) *Global agro-ecological assessment for agriculture in the 21st century.* International Institute for Applied Systems Analysis, Austria.

Fishing Industry Handbook (2004) South Africa, Namibia, Mocambique. George Warman Publications, Cape Town.

Francis, E. (2000) *Making a living: changing livelihoods in rural Africa*. Routledge, London.

Geustyn Loubser Streicher & Palmer Development Group (2001) Water Services Development Plan. City of Cape Town

Goldblatt, M., Gelb, S., & Davies, G. (2002). *Macroeconomics and sustainable development in Southern Africa*. Development Bank of Southern Africa.

Gornitz, V. and Kanciruk, P. (1989) *Assessment of global coastal hazards from sea level rise.* Proc 6th Symp.on Coastal and Ocean Management ASCE, July 11-14 1989, Charleston, SC.

Grant Thornton Kessel Feinstein [S.a]. *Internet*: http://www.wesgro.org.za/assetlibrary/assets/221925102.pdf. Access: 26 Aril 2005.

Haberl, H., Krausmann, F., Erb, K.-H., Schulz, N.B., Rojstaczer, S., Sterling, S.M., Moore, N. (2002) Human appropriation of net primary production, letter and response. *Science*, **296**,1968-1969.

Haldenwang, B.B. (2004) Urbanisation trends in South Africa. Institute for Futures Research, Social Environment, Strategy Insights, **9**, 1-4.

Hannah, L., Midgley, G.F., Millar, D. (2002) Climate change-integrated conservation strategies. *Global Ecology and Biogeography,* **11**, 485-495.

Harrison, T.D., Cooper, J.A.G., Ramm, A.E.L. (2000) *State of South African Estuaries: Geomorphology, ichthyofauna, water quality and aesthetics*. Department of Environmental Affairs and Tourism, Pretoria. 127 pp.

Hassan, R., Breen, C., & Mirrilees, R. (1996) *Management of Water Resources and Emerging Water Policy Challenges in South Africa.* In The Economics, Policy & Natural Resource Management Southern Africa Workshop (ed S. Fakir). IUCN, Pretoria.

Hewitson, B.C. and Crane, R.G. (2005) Consensus in empirically downscaled regional climate change scenarios. *International Journal of Climatoilogy*, submitted.

Hewitson, B.C. and Crane, R.G. (2005) Gridded Area-Averaged Daily Precipitation via Conditional Interpolation, *Journal of Climate*, **18**, 41-57.

Hewitson, B.C. and Tadross, M. (2005) *Historical precipitation trends over South Africa,* draft.

Hewitson, B.C., et. al., (2005) *The development of regional climate change scenarios for sub-sahara Africa,* AIACC final report AF07, START, Washington DC, USA.

Hewitson, B.C., Tadross, M. and Jack, C.J. (2005) Climate Change Scenarios in WRC final report (draft).

Heydorn, A.E.F. (ed) (1986) *An assessment of the state of the estuaries of the Cape and Natal in 1985/1986.* South African National Scientific Programmes Report, No. 130. Pretoria, CSIR. 39 pp

Higgins, S.I., Azorin, E.J., Cowling, R.M. and Morris, M.J. (1997), A dynamic ecological-economic model as a tool for conflict resolution in an invasive alien, biological control and native-plant scenario, *Ecological Economics,* **22**, 141-154.

Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dhai, X., Maskell K., and Johnson C.A. (eds) (2001) Climate change 2001: the scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge. pp183-237

Hughes, P. and Brundrit, G. (1991) The vulnerability of the False Bay coastline to the projected rise in sea level. *Trans. Roy. Soc. of S.A.*, **47(4&5)**, 519-534.

Hughes, P. (1992) *The impacts of sea level rise on the South African Coastal Environment.* Unpublished Phd. thesis, Department of Oceanography, University of Cape Town, Cape Town.

Hughes, P. and Brundrit, G.B. (1992) An index to assess South Africa's vulnerability to sea level rise, *South African Journal of Science*, **88**, 308-311.

Hughes, P., Brundrit, G.B. and Shillington, F.A. (1991a) South African Sea level measurements in the global context of sea level rise . *South African Journal of Science*, **87**, 447-453.

Hughes, P., Searson, S. and MacArthur, C.I. (1991b) Stormy waters ahead: The missing link between storminess and sea level rise. *Conserva*, **6**, 16-22.

Huizinga, P., Taljaard, S., Van Niekerk, L., Turpie, J. and Lamberth S. (2000) *The Effects of Water Abstraction on the Estuaries of the Eerste and Lourens Rivers.* CSIR Report ENV-S-C 2001-007.

Huq, S., Rahman, A., Konate, M., Sokona, Y. and Reid, H. (2003) *Mainstreaming Adaptation to Climate Change in Least Developed Countries.* IIED, London.

IDAG, T.I.a.h.D.a.A.G., (2004) Detecting and Attributing External Influences on the Climate System: A 10, Review of Recent Advances. *Journal of Climate*, In press.

IPCC (2002) Climate change and biodiversity, edited by H. Gitay, A., Suarez, R. T. Watson and DJ. Dokken. Intergovernmental Panel on Climate Change Technical Paper V, Geneva.

IPCC (2001a) Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change Cambridge University Press, United Kingdom and New York, NY, USA.

IPCC (2001b) Climate Change 2001: Synthesis Report; Contribution of Working Groups I, II and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change, edited by R.T. Watson and the Core Writing Team. Cambridge University Press.

Jackson, L.F. and Lipschitz, S. (1984) *Coastal Sensitivity Atlas of southern Africa*, Department of Transport, South Africa.

Jeffery, D.J., Holmes, P.M. and Rebelo, A.G. (1988) Effects of dry heat on seed germination in selected indigenous and alien legume species in South Africa. *South African Journal of Botany* **54**, 28 - 34.

Jolly, J.L. (2002) *Sustainable use of the TMG aquifer and problems of scheme failure.* In: Pietersen & Parsons(ed.) A Synthesis of the hydrogeology of the TMG - Formation of a research strategy, Water Research Commission.

Kasrils, R. (2000) *A water perspective on invasive species*. In The best management practices symposium, Kirstenbosch.

Kasrils, R. (2002) Parliamentary Media Briefing. DWAF.

Kennnedy, V.S., Twilley, R.R., Kleypas, J.A., Cowan, J.H., Hare, S.R. (2002) *Coastal and Marine ecosystems and Global climate change. Potential effects on US Resources.* Pew Centre on Global Climate Change: Arlington.

Kiker, G.A. (1999) *Synthesis Report for the Vulnerability and Adaptation Asessment Section.* South African Country Study on Climate Change. Unpublished document. School of Bioresources Engineering and Environmental Hydrology, University Natal, Durban.

Kinney P.L. (1999). The Pulmonary Effects of Ozone and Particle Air Pollution. Seminar in: Respiratory and Critical Care Medicine, **20**, 601-607. Thieme Medical Publishers. New York.

Lamberth, S. and Turpie, J., (2003) *The role of estuaries in South African fisheries: economic importance and management implications*. WRC Report No. 756/2/03.

Lamberth, S.J. and Turpie, J.K. (2003) The role of estuaries in South African fisheries: Economic importance and management implications. *African Journal of Marine Science*, **25,** 31-57.

Le Maitre, D.C., Versfeld, D.B., and Chapman, R.A. (2000). The impact of invading alien plants on surface water resources in South Africa: a preliminary assessment. *Water SA,* **26**, 397-408.

Le Maitre, D.C., van Wilgen, B.W., Gelderblom, C.M., Bailey, C., Chapman R.A. and Nel J.A. (2002) Invasive alien trees and water resources in South Africa: Case studies of the costs and benefits of management. *Forest Ecology and Management* **160**, 143 - 159.

Le Maitre, DC., van Wilgen, BW., Chapman, RA. and McKelly, D. (1996). Invasive plants and water resources in the Western Cape Province, South Africa: modelling the consequences of a lack of management. *Journal of Applied Ecology* **33**, 161 - 172.

MA (*in press*) [Four reports of the Millennium Ecosystem Assessment, to be published by Island Press in 2005].

MacDonald D.J., Midgley, G.F., Powrie, L.W. (2002) Potential scenarios of plant diversity in South African mountain ranges related to climate change. In: *Mountain Biodiversity – A Global Assessment*. Eds. Korner Ch. & Spehn E. Parthenon Publishing, London.

Makin, A. (2005) *Desalination in focus*. In News Drop, Vol. Vol 22 Issue 1. Australian Water Association.

Maree, R.C., Whitfield, A.K. & Quinn, N.W. (2003) *Prioritization of South African estuaries based on their potential importance to estuarine-associated fish species*. Pretoria: Water Research Commission. WRC Report No TT203/03.

Maree, R.C., Whitfield, A.K. and Quinn, N.W. (2000) *Prioritization of South African estuaries based on their potential importance to estuarine-associated fish species*. Report to the Water Research Commission.

Mayers, J., Evans, J. and Foy, T. (2001) *Raising the stakes. Impacts of privatization, certification and partnerships in South African forestry*. Instruments for sustainable private sector forestry series. London, IIED.

McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken D.J., and White K.S (eds) (2001) Climate change 2001: impacts, adaptation and vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Meehl, G. A., Washington, W. M., Collins, W. D., Arblaster, J. M., Hu, A., Buja, L. E., Strand, W. G., Teng, H. (2005) How much more global warming and sea level rise? *Science*, **307**, 1769 – 1772.

Mfeketo addresses needs of fire victims: http://www.capetown.gov.za/clusters/viewarticle3.asp?conid=10080

Midgley, G.F. & O'Callaghan, M. (1993) Review of likely impacts of climate change on South African flora and vegetation. Prepared for the Southern African Nature Foundation and the World Wildlife Fund.

Midgley G.F, Stock W.D, Juritz J.M. (1995) The effects of elevated CO_2 on Cape Fynbos species adapted to soils of different nutrient status: Nutrient- and CO_2-responsiveness. *Journal of Biogeography,* **22,** 185 – 191.

Midgley G.F, Wand S.J.E, Pammenter N.W. (1999) Nutrient and genotypic constraints on CO_2 responsiveness: Photosynthetic regulation in congenerics of a nutrient-poor environment. *Journal of Experimental Botany* **50**, 533 – 542.

Midgley, G.F., Hannah, L., Millar, D., Rutherford, M.C. & Powrie, L.W. (2002) Assessing the vulnerability of species richness to anthropogenic climate change in a biodiversity hotspot. *Global Ecology and Biogeography* **11**, 445 – 451.

Midgley, G.F., Hannah, L., Millar, D., Thuiller, W. & Booth A. (2003) Developing regional and species-level assessments of climate change impacts on biodiversity: A preliminary study in the Cape Floristic Region. *Biological Conservation* **112**, 87 – 97.

Mimura N., Kawaguchi E. (1996) *Responses of Coastal Topography to Sea-Level Rise.* 25 International Conference On Coastal Engineering, **2,** 1349 - 1360.

Morant, P. D. and Quinn, N. (1999) Influence of man and management of South African estuaries. Chapter 12 in Allanson, BR and Baird, D (eds), *Estuaries of South Africa*, pp 289- 321. Cambridge: Cambridge University Press, UK.

Mortimore, M. and Adams, W.M. (2001) Farmer adaptation, change and 'crisis' in the Sahel. *Global Environmental Change*, **11** 49 – 57.

Moser, C.O.N. (1998) The asset vulnerability framework: Reassessing Urban Poverty Reduction Strategies. *World Development*, **26.** 1.

Mukheibir, P. & Sparks, D. (2003). *Water resource management and climate change in South Africa: Visions, driving factors and sustainable development indicators*. EDRC, University of Cape Town.

Munasinghe, M. (ed.) (1995) *Global Climate Change: Economic and Policy Issues*. World Bank Environment Paper No. 12. Washington D.C: World Bank.

Musil, C.F. and Wand, S.J.E. (1999) Impact of UV-B radiation on South African Mediterranean ecosystems. *In*: *Stratospheric Ozone Depletion: the effects of enhanced UV-B radiation on terrestrial ecosystems* (Eds. Rozema, J) pp. 265 – 291. Backhuys Publishers, The Netherlands.

Musil, C.F., Schmiedel, U., Midgley, G.F. (2005) Lethal effects of experimental warming approximating a future climate scenario on southern African quartz-field succulents: a pilot study. *New Phytologist*, **165**, 539 – 547.

Myers, N. Mittermeier, R.A., Mittermeier, C.G. da Fonseca, G.A.B., Kent, J. (2000) *Biodiversity hotspots for conservation priorities*. Nature 403: 853-858.

Nakhwa, R.A. and Xu, Y. (2005) *Evaluation of water supplies from the Table Mountain Group Aquifer – a brief overview.* Conference Paper, Biennial Ground Water Conference 2005. Council for Geoscience, Pretoria.

Napier, M. and Rubin, M. (2002) *Managing environmental and disaster risks affecting informal settlements: Lessons in innovative practice from South African local authorities.* Accessed 20 May 2005. http://www.livelihoods.org/lessons/project_summaries/urban4_projsum.html

Nel, J., Maree, G., Roux, D., Moolman, J., Kleynhans, N., Silberbauer, M. & Driver, A. 2004. *South African National Spatial Biodiversity Assessment 2004: Technical Report*. Volume 2: River Component. CSIR Report Number ENV-S-I-2004-063. Stellenbosch: Council for Scientific and Industrial Research.

New, M. (2002) Climate change and water resources in the southwestern Cape, South Arica. *SA Journal of Science*, **98,**1 – 7.

Ninham Shand (PTY) Ltd (2005) *Profile on Water Management in the Berg, Brede, Gouritz & Olifants/Doorn water management areas*. In The utilization and availability of water. Department of Water Affairs.

Noble R.G. and Hemens J. (1978) *Inland water systems in South Africa – a review of research needs*. South African National Scientific Programmes Report Number 34, CSIR, Pretoria.

O'Brien, K., Eriksen, S., Schjolden, A. and Nygaard, L. (2004) *What's in a word? Conflicting interpretations of vulnerability in climate change research*. Centre for International Climate and Environmental Research (CICERO), Report 2004:4. Oslo: CICERO.

Papini, G.. (2003) Groundwater Assessment: *Breede River Basin Study.* Department of Water Affairs and Forestry Report Number PH 00/00/2502. Department of Water Affairs and Forestry, Pretoria.

Poff, N.L., Brinson, M.M. and Day, J.W. (2002*) Aquatic Ecosystems and Global Climate Change: Potential Impacts on Inland Freshwater and Coastal Wetland Ecosystems in the United States.* Pew Centre on Global Climate Change.

Pritchard, D.W. (1967) What is an estuary: physical viewpoint. In Lauff, GH (ed.) *Estuaries* pp 3-5. Washington DC: American Association for the Advancement of Science.

Pyke, C.R., Andelman, S.J., Midgley, G.F. (2005) Identifying priority areas for bioclimatic representation under climate change:a case study for Proteaceae in the Cape Floristic Region,South Africa. *Conservation Biology*, **125**, 1-9.

Report. Volume 2: River Component. CSIR Report Number ENV-S-I-2004-063.

Rouget, M., Richardson, D.M., Nel, J.L., Le Maitre, D.C., Egoh, B. and Mgidi, T. (2004). Mapping the potential ranges of major plant invaders in South Africa, Lesotho and Swaziland using climatic suitability. *Diversity and Distributions* **10**, 475 – 484.

Roux, A. (2002) The dimensions of employment and unemployment in South Africa in September 2001. Institute for Futures Research, Economic Issues, Strategy Insights. **10**, 1 – 4.

Roux, A. (2003) Which sectors are driving economic activity and growth in South Africa? Institute for Futures Research, Economic Issues, Strategy Insights. **1(04)** 1 – 5.

Rutherford, M.C., Midgley, G.F., Bond, W.J., Musil, C.F., Powrie, L.W., Roberts, R. and Allsopp, J. (2000) Plant biodiversity: Vulnerability and adaptation assessment. South African Climate Change Country Study. DEAT, Pretoria.

SADC FANR Vulnerability Assessment Committee (2003) Towards Identifying Impacts of HIV/AIDS on Food Insecurity in Southern Africa and Implications for Response: Findings from Malawi, Zambia and Zimbabwe. Harare, Zimbabwe.

Sampson, N.R. and Scholes R.J. (2000) Additional human-induced activities – Article 3.4. In: Watson, R.T., Noble, I.R., Bolin, B., Ravindranath, N.H., Verardo, D.J. and Dokken, D.J. (eds) Land Use, Land-Use Change, and Forestry; a special report of the IPCC, Cambridge University Press, 181 – 281

SARPN (Southern African Regional Poverty Network). (2004) *Scoping study towards DFIDSA's Regional Hunger and Vulnerability Programme*.

Schjolden, A. (2004) *Towards assessing socio-economic impacts of climate change in Norway. Sensitivity in the primary sectors: fisheries, agriculture and forestry*. Centre for International Climate and Environmental Research (CICERO), Report 2004:3. Oslo: CICERO.

Scholes RJ., de Wit, M., van der Merwe, MR. and van Tienhoven, AM. (2002) *Namibia Initial National Communication to the United Nations Framework Convention on Climate Change.* Report prepared for the Directorate of Environmental Affairs, Ministry of Environment and Tourism, Republic of Namibia.

Scholes, R.J. (2004) Carbon storage in southern African woodlands. In: Lawes, M.J., Eeley, H.A.C., Shackleton, C.M., and Geach, B.G.S. (eds) *Indigenous Forests and Woodlands in South Africa: People, Policy and Practice*.

Scholes, R.J., Midgley, G.F. and Wand, S.J.E. (1999) *South African Climate Change Country Studies. Vulnerability and adaptation of rangelands*. Environmentek, CSIR, Pretoria. ENV-P-C 98169.

Scholes, R.J., Schulze, R.E., and Kunz, R.P. (1996) Possible consequences for the South African forest industry. In: Shackleton, L.Y., Lennon S.J., and Tosen. G.R. *Global Climate Change and South Africa*. Environmental Scientific Association, Cleveland, South Africa. pp 100 – 103

Scholes, R.J., van der Merwe, M.R. and van Tienhoven, M. (2001) *Botswana initial national communication to the United Nations Framework Convention on Climate Change. A report to the Botswana Ministry of Works, Transport and Communication*. Environmentek, CSIR, Pretoria.

Scholes, RJ. and Biggs, R. (2004) *Ecosystem services in southern Africa: a regional assessment*. CSIR, Pretoria.

Schulze, R. & Perks, L. (2000). *Assessment of the Impact of Climate Change on Hydrology and Water Resources in South Africa.* Rep. No. ACRUcons 33. School of Bioresources Engineering and Environmental Hydrology, University of Natal, Pietermaritzburg.

Scorgie Y. and Watson R. (2004) Updated Air Quality Situation Assessment for the City of Cape Town Report No.: APP/04/CCT-02.

Scott, D.F., Versfeld, D.B. and Lesch, W. (1998) Erosion and sediment yield in relation to afforestation and fire in the mountains of the Western Cape Province, South Africa. *South African Geographical Journal,* **80**, 52 – 59.

Searson S. and Brundrit G. B. (1995) Extreme high sea levels around the coast of southern Africa. *South African Journal of Science*, **91**: 579 – 588.

Shannon D.A. and Hewitson B.C. (1996) Cross-scale relationships regarding local temperature inversions at Cape Town and global climate change implications. *South African Journal of Science*, **92:4** 213 – 216

Simmons, R., Barnard, P., Dean, W.R.J., Midgley, G.F., Thuiller, W., Hughes, G. (2005) Climate change and birds: perspectives and prospects from southern Africa *Ostrich,* **75(4),** 295 – 308

Smith, A. (2005) Choked drains pose winter threat to city. Cape Argus. 20/4/05.

Smith, J. (2001) *Living on the Edge of Rain: Rural Livelihoods, Vulnerability and Resilience on the Southern Periphery of the Kalahari*. PhD dissertation. Johannesburg, University of Witwatersrand.

Smith, R.E. and Scott, D.F. (1992) *Simple empirical models to predict reductions in annual and low flows resulting from afforestation.* Report FOR-DEA 465. CSIR Division of Forest Science and Technology, Pretoria.

South Africa (2000) Initial National Communication under the United Nations Framework Convention on Climate Change. Dept Environment Affairs and Tourism, Pretoria.

South African National Disaster Management Framework (2005)

State of the Environment Report (2002), City of Cape Town.

StatsSA (2004). *Stats in brief: Ten years of democratic governance*. Pretoria, Statistics South Africa SSA.

Statistics South Africa (SSA) (2004) Provincial Profile 1999. Western Cape. Pretoria: SSA.

StatsSA. 2003a. Census in brief. Pretoria: StatsSA.

StatsSA. 2003b. Urban/rural discussion document. [online] URL: http://www.statssa.gov.za

Stellenbosch: Council for Scientific and Industrial Research.

Sunter, C., Huntley, B.J., Siegfried R. (1990) South African environments into the 21st century. Tafelberg, Cape Town.

Theron, A.K. (1994) Sea level rise, impacts and the use of Bruun's erosion rule. *J. SA Inst Civ Eng*, **36(3)**, 6 – 10.

Thomas, C.D., Cameron, C., Green, R.E., Bakkenes, M., Beaumont, L.J., Collingham, Y.C., Erasmus, B.F.N., de Siqueira, M.F., Grainger, A., Hannah, L., Hughes, L., Huntley, B., van Jaarsveld, A.S., Midgley, G.F., Miles, M., Ortega-Huerta, M.A., Peterson, A.T., Phillips, O.L., Williams, S.E. (2004) Extinction risk from climate change. *Nature* **427***,* 145 – 148

Turpie (2004) *South African National Spatial Biodiversity Assessment 2004: Technical Report. Estuarine Component.* Pretoria. South African National Biodiversity Institute.

Turpie, J. and Heydenrych, B. (2000) Economic consequences of alien infestation of the Cape Floral Kingdom's Fynbos vegetation, in . In: C. Perrins, Williamson, M. and Dalmazzone, S. (eds), *The economics of biological invasions*, Edward Elgar, Cheltenham, pp 152 – 182.

Turpie, J., Winkler, H., Spalding-Fecher, R., Midgley, G.F. (2002) *Economic consequences of global warming in South Africa.* Energy and Development Research Centre (EDRC), University of Cape Town.

Turpie, J.K. (2004) *South African National Spatial Biodiversity Assessment 2004: Technical Report. Estuarine Component.* Pretoria: South African National Biodiversity Institute.

Turpie, J.K., Adams, J.B., Joubert, A., Harrison, T.D., Colloty, B.M., Maree, R.C., Whitfield, A.K., Wooldridge, T.H., Lamberth, S.J., Taljaard, S. and van Niekerk, L. (2002) Assessment of the conservation priority status of South African estuaries for use in management and water allocation. *Water SA*, **28,** 191-206.

Turpie, J.K and Ryan, P.G. (1998) *The nature and value of birding in South Africa.* Birdlife South Africa Research Series No 1.

Turpie, J.K., Winkler, H. and Midgley, G. (2004) *Economic impacts of climate change in South Africa: A preliminary assessment of unmitigated damage costs, in Sustainable Options. Development Lessons from Applied Environmental Economics*, edited by J.N Blignaut & M.P. de Wit. Cape Town: UCT Press.

Turpie, JK (2004) *Improving the biodiversity importance rating of estuaries*. Water Research Commission Report. 126pp.

Tyson, P.D. and Preston-Whyte R.A. (2000) *The Weather and Climate of Southern Africa*. Oxford University Press, Oxford.

UN. (2004) World Urbanization Prospects: The 2003 Revision. [online] URL: http://www.unpopulation.org

Underhill, L.G. (1995) Migratory birds. In: GI Cowan (ed.) *Wetlands of South Africa.* SA Wetlands Conservation Series, Department of Environment Affairs and Tourism, Pretoria.

UNDP, 2003 Human Development Report (2003) Millenium Development Goals: A compact among nations to end human poverty. Internet: http://www.undp.org/hdr2003. Accessed: 25 April 2005.

UNEP (1998) *Mitigation and Adaptation Cost Assessment. Concepts, Methods and Appropriate Use.* Riso, Denmark: UNEP Collaborating Centre on Energy and Environment.

UNEP. (2002) Africa Environment Outlook – Past, present and future perspectives. UNEP.

UNEP/UNFCCC (2002) *Climate Change Information Kit*. Geneva: UNEP.

Van Ballegooyen, R., Theron, A.K. and Wainman, C. (2002-2004). Final input to the Risk and Vulnerability Assessment (RAVA) for the Western Cape (included in the final report to the Provincial Government of the Western Cape).

Van Wilgen B.W., Bond, W.J. and Richardson, D.M. (1992) *Ecosystem management. The Ecology of Fynbos: Nutrients, Fire and diversity* Ed: Cowling, R.M. Oxford University Press, Cape Town, pp 345-371.

Van Wilgen, B.W. (1984) Fire climates in the southern and western Cape Province and their potential use in fire control and management. *South African Journal of Science* **80**, 358-362.

Van Wilgen, B.W. and Scott, D.F. (2001) Managing fires on the Cape Peninsula: Dealing with the inevitable. *Journal of Mediterranean Ecology,* **2**, 197 - 208.

Van Wilgen, B.W. and Richardson, D.M. (1985) The effect of alien shrub invasions on vegetation structure and fire behaviour in South African fynbos shrublands: a simulation study. *Journal of Applied Ecology* **22**, 955-966.

Van Wilgen, B.W., Bridgett, J., Jayiya, T., Forsyth, G.G., and Chapman, R.A. (2003) *The selection of a Fire Danger Rating Model to underpin a national fire danger rating system for South Africa*. CSIR Report ENV-S-C 2003-090, Stellenbosch, South Africa.

van Wilgen, B.W., Cowling, R.M. and Burgers, C.J. (1996) Valuation of ecosystem services: a case study from the fynbos, South Africa. *BioScience,* **46**, 184 - 189.

Van Wilgen, B.W., Little, P.R., Chapman, R.A., Gorgens, A.H.M., Willems, T. and Marais, C. (1997) The sustainable development of water resources: History, financial costs and benefits of alien plant control programmes. *South African Journal of Science,* **93**, 404 - 411

Versfeld D.B., Le Maitre D.C. and Chapman R.A. (1998) *Alien invading plants and water resources in South Africa: A preliminary assessment*. .WRC Report No. TT 99/98 by the CSIR to the Water Research Commission, 149pp.

Wesgro, (2004a) *Gross Geographic Product 2004*. Internet: www.wesgro.org.za. Accessed: 25 April 2005.

Wesgro, (2004b) *Demographics 2004.* Internet: www.wesgro.org.za. Accessed: 25 April 2005.

Wesgro, [S.a]a. *Agriculture Sector Fact Sheet*. Cape Town: Wesgro.

Wesgro, [S.a]b. *Fruit Sector Fact Sheet. Cape Town*: Wesgro.

Whitfield, A.K. (1995) *Available scientific information on individual South African estuarine systems.* Report to the Water Research Commission by the Consortium for Estuarine Research and management. WRC Report No. 577/1/95. Pretoria: Water Research Commission.

Whitfield, A.K. (2000) *Available scientific information on individual estuarine systems.* WRC Report no. 577/3/00.

Whitfield, AK (1992) A characterisation of southern African estuarine systems. *Southern African Journal of Aquatic Sciences,* **12**, 89-103.

WHO. (2002) *World Health Report 2002: Reducing risks, promoting healthy life*. WHO, Geneva.

WHO. (2003) *Climate change and human health - risks and responses. Summary*. WHO, Geneva.

Wicking-Baird M.C., De Villiers M.G. and Dutkiewicz R.K. (1997) *Cape Town Brown Haze Study. Report No 182* Energy Research Institute, University of Cape Town. Cape Town.

World Meteorological Organization. (1999) *Weather, Climate and Health.* WMO-No. 892. Geneva, Switzerland.

World Tourism Organisation (WTO) (2003) Climate Change and Tourism. Proceedings of the 1st International Conference on Climate Change and Tourism, Djerba, Tunisia, 9-11 April 2003.

WRI (1996) *World Resources 1996-97*. World Resources Institute, Washington D C.

Ziervogel, G. (2004) Targeting seasonal climate forecasts for integration into household level decisions: the case of smallholder farmers in Lesotho. *The Geographical Journal.* **170**.1. 6-21.

Ziervogel, G. and Calder, R. (2003) Climate variability and rural livelihoods: assessing the impact of seasonal climate forecasts. *Area*, **35. 4.** 403-417.

9. GLOSSARY OF TERMS

Adaptation	Adjustment in natural or human systems to a new or changing environment. Adaptation to climate change refers to adjustment in natural or human systems in response to climate stimuli and is instituted to moderate the effects climate change. Adaptation response depends on land-use.
Anthropogenic -.	Human made. Usually used in the context of emissions that are produced as the result of human activities.
AOGCM's	Atmosphere/Ocean General Circulation Model or Atmosphere/Ocean Global Climate Model. Fully coupled atmosphere-ocean Global Climate Model of the three-dimensional global climate (see GCM).
Bathymetry	The measurement of ocean depths and the charting of the topography of the ocean floor
Beach berm	A nearly horizontal part of the beach or backshore formed by the deposit of material by wave action.
Benthic organisms -	Those organisms living at or near the bottom of a body of water. They include a number of types of organisms, such as bacteria, fungi, insect larvae and nymphs, snails, clams, and crayfish. They are useful as indicators of water quality.
Berg Wind	Warm dry airflow from the NE, commonly (but not always) caused by a coastal low off the west coast, predominantly in winter. Dry air descending off the continental plateau warms, and results in a hot, dry wind creating an opportunity for veld fires. Berg winds can occur with both strong and mild winds. Temperatures can rise to over 30 deg C.
Biodiversity:	The variety of organisms found within a specified geographic region.
Carbon cycle	The term used to describe the flow of carbon (in various forms such as carbon dioxide) through the atmosphere, ocean, terrestrial biosphere and lithosphere.
Carbon Dioxide (CO_2)	CO_2 is a colorless, odorless, non-poisonous gas that is a normal part of the ambient air. Of the six greenhouse gases normally targeted, CO_2 contributes the most to human-induced global warming. Human activities such as fossil fuel combustion and deforestation have increased atmospheric concentrations of CO_2 by approximately 30 percent since the industrial revolution. CO_2 is the standard used to determine the "global warming potentials" (GWPs) of other gases. CO_2 has been assigned a 100-year GWP of 1 (i.e., the warming effects over a 100-year time frame relative to other greenhouse gases).
Clean Development Mechanism (CDM)	One of the three market mechanisms established by the Kyoto Protocol. The CDM is designed to promote sustainable development in developing countries and assist Annex I Parties in meeting their greenhouse gas emissions reduction commitments. It enables industrialized countries to invest in emission reduction projects in developing countries and to receive credits for reductions achieved.
Climate	The average course or condition of the weather over a period of years, as exhibited by temperature, humidity, wind velocity, and precipitation.
Climate change	A change in climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural variability observed over comparable time periods.
Convective rainfall	Typically summer rainfall related to thunderstorms, but also can be triggered by the arrival of cold fronts. Rainfall is associated with thunderstorm activity, heavy

	but localized rainfall, lightning, and with hail possible.
Desertification	Land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climate variations and human activities.
Ecosystem	The complex of plant, animal, fungal and micro-organism communities and their associated non-living environment interacting as an ecological unit. Ecosystems have no fixed boundaries; instead, their parametres are set according to the scientific, management, or policy question being examined. Depending on the purpose of analysis, a single lake, a watershed, or an entire region may be considered an ecosystem.
Emission taxes	Taxes levied on air or water emissions, usually on a per ton basis. Emission taxes provide incentives for firms and households to reduce their emissions and therefore are a means by which pollution can be controlled. The greater the level of the emissions tax, the greater the incentive to reduce emissions.
Emissions	Anthropogenic (human-caused) releases of greenhouse gases to the atmosphere (e.g., the release of carbon dioxide during fuel combustion).
Endemic species	A species native to a specific location, occurring naturally in a specific region of a characterisation of biogeophysical features; a species or a race native to a particular region
Estuaries	A somewhat restricted body of water where the flow of freshwater mixes with saltier water transported, by tide, from the ocean. Estuaries are the most productive water bodies in the world.
Fossil fuel	A naturally occurring organic fuel formed in the Earth's crust, such as petroleum, coal, or natural gas. Fossil fuels result from organic matter being laid down and compacted over very long periods of time (hence 'fossil'). This means that stocks of these fuels are finite (compare to renewable energy).
GCM	Global Climate Model / General Circulation Model. A computer-driven numerical representation of the climate system based on the physical, chemical and biological components, their interactions and feedback processes. GCMs are applied as a research tool to study and simulate the climate, but also for operational purposes, including monthly, seasonal and interannual climate predictions.
Greenhouse gases / radiatively active gases	Those gases, such as water vapour, carbon dioxide, tropospheric ozone, nitrous oxide, and methane, that are transparent to solar radiation but opaque to long-wave radiation, thus preventing long-wave radiation energy from leaving the atmosphere. The net effect is a trapping of absorbed radiation and a tendency to warm the planet's surface. The three major greenhouse gases covered by the UNFCCC and Kyoto Protocol are carbon dioxide, methane, nitrous oxide and three trace gases (hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride). Ozone falls under the Montreal Protocol.
Intense rainfall	A subjective term, typically referring to rainfall that is in the upper tail of the distribution of historical rainfall. A useful threshold for Cape Town is of the order of 20mm in 12 hours. This significant quantity of rain over a short period of time and has two impacts; stress on storm water drainage, causing flooding of streets, and high input into streams causing flooding of rivers.
Intergovernmental Panel on Climate Change (IPCC)	A panel established jointly in 1988 by the World Meteorological Organization and the United Nations Environment Programme to assess the scientific information relating to climate change and to formulate realistic response strategies.
Inversions	Cold surface air overlain by a warmer elevated layer of air, suppressing vertical motion in the atmosphere. The net consequence of relevance to the city is the build-up of pollutants near the surface and leading to "brown haze". Most

	frequent in winter, on clear, windless days, particularly preceding the onset of a frontal system. The lack of wind further exacerbates the impact of the inversion by preventing mixing and dispersion of the layers. The situation can persist for a number of days.
IPCC Third Assessment Report	The latest report by the Intergovernmental Panel on Climate Change released in 2001. Since the IPCCs inception it has produced a series of assessment reports (1990, 1995 and 2001). The Fourth Assessment Report is due for publication in 2005.
Mediterranean-type climate	The wet winter and dry summer seasonality of precipitation is the defining characteristic of this climate. Extremely dry summers are caused by the sinking air of the subtropical highs and may last for up to five months. Wet winters are dominated by mid-latitude cyclones associated with low-pressure systems.
Microclimates	Generally the climate of small areas, especially insofar as this differs significantly from the general climate of the region.
Mitigation	An anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases.
Nitrogen cycle	The steps by which nitrogen is extracted from the nitrates of soil and water, incorporated as amino acids and proteins in living organisms, and ultimately reconverted to nitrates
RCM	(Regional Climate Model) and Empirical downscaling - two complementary methods used to producing projections on a horizontal resolution from point scale to about 50 km.
RCM (Regional Climate Model) and Empirical downscaling	Two complementary methods used to producing projections on a horizontal resolution from point scale to about 50 km.
Renewable energy	Energy obtained from sources that are essentially inexhaustible (unlike, for example, fossil fuels, of which there is a finite supply). Renewable sources of energy include wood, waste, geothermal, wind, photovoltaic, small hydro and solar thermal energy.
Riparian zones	The bank of a body of flowing water; the land adjacent to a river or stream that is, at least periodically, influenced by flooding.
Scenario	A plausible and often simplified description of how the future may develop, based on assumptions of key driving forces. Each climate change scenario depends on future governmental decisions made about greenhouse gas emissions. A range of climate change scenarios leads to a range of climate change predictions, dependant upon the scenario followed.
Seasonality	Periodic fluctuations in the climate related to seasons of the year e.g. wet winters, drier summers.
Sustainable development	A broad concept referring to a country's need to balance the satisfaction of near-term interests with the protection of the interests of future generations.
Trend	Evidence of change from observations over a period (in this case1958-2001)
Vulnerability	Defines the extent to which climate change may damage or harm a system. It depends not only on the sensitivity of a system but also on its ability to adapt to new climatic conditions.

APPENDIX A: DIRECT AND INDIRECT SOCIO-ECONOMIC IMPACTS OF CLIMATE CHANGE ON THE WESTERN CAPE

Socio-economic sector	**Functional relationships between climate change and economic activity**	**Possible Impacts**
Agriculture	Photosynthesis, colour development, cold winters, rain season, low heat stress, water availability	Loss in volume (yields) and quality of production Vulnerability of these agricultural products to changes in temperature and precipitation on a site-specific level such as the Western Cape is the focus of another part of this study
Fishing	Fish growth dependant on availability of food and differences in temperatures. Important climate features include temperature, wind (speed and direction), the shifting of streams and currents (upwelling), sea level rise, availability of sunlight, the occurance of storms and freshwater run-off into the marine environment Loss of habitat, migration to new habitats, invasion of new species	Fisheries productivity of estuaries correlated strongly with size and mouth conditions, estimated that up to 18% of inshore fisheries, or around R450 million per annum, is already lost due to a change in estuarine functioning Fish processing affected by varying yields in other parts of South Africa
Forestry	Reduction of inhabitable range	Little impact - forestry small in comparison to the rest of country, and major softwood species, *Pinus Radiate*, is phased out
Manufacturing and industry	Changes in supplies, employment, operations, and customer preferences	Most directly impacted are processes adding value to renewable natural resources: agro- and fish processing, furniture, pulp and paper sectors

		Some businesses positively impacted by climatic changes: • climate control • water conservation and recycling • defensive construction • water supply options Impacts of government policies, such as carbon taxes Customer preferences may change due to climatic changes, for example clothing and recreation
Tourism	Length of the season may be affected by changing temperatures and precipitation Rise in sea-level could lead to a loss of resources such as bathing beaches Reduction in stream-flow run-off could limit water sports and recreational fisheries Changing ecosystems could impact niche-market activities such as bird/whale watching Knock-on effects would occur in sectors that are dependent on tourism demand, such as transport, restaurants, agricultural products, crafts and small business services such as tour operators	Peak arrivals in April and December not directly affected by predicted changes in rainfall Warmer and drier summers can have implications such as droughts and fires, water shortages and poor urban air quality Heat stress affects mostly the elderly and small children Changes in rainfall patterns affecting supply of water and ability to meet growing tourism demand Link between species richness and macro tourism value may not be that strong on macro level Increasing trend in extreme events such as flash floods could also impact negatively on tourism in specific areas
Finance and investment	Private and public institutions that offer insurance, disaster preparedness/ recovery, banking and asset management services.	Impacts on insurance: • Weather-related losses account for 75% of the economic and 87% of the insured losses worldwide • Flooding events in Western Cape Banks and asset management may be impacted through

		• impacts on underlying secured assets (e.g. property losses due to weather-related disasters), • impacts on credit applications that may not prove to be viable (e.g. tourism ventures impacted by beach degradation), • impacts on investments (e.g. flooding, vulnerable agricultural ventures).
Transport, communication and trade	Deterioration of physical infrastructure, risks to coastal roads Change in transport patterns Change in frequency of accidents Change in volume and quality of products traded Government actions on emissions, such as carbon taxes, increasing the costs of transport	Transport and communications infrastructure may be physically influenced be extreme events, such as flooding and sea-level rise Sustained higher temperatures could have damaging impacts on roads such as asphalt. Heat could also have an effect on aircraft down times, as there is a lack of lift in the air. Drier conditions signal less road accidents, although rain events during drier conditions produce a greater frequency of accidents and injuries. Seaports and airports will be disrupted by windstorms and other extreme events Any trade activity, depending on exposure to climate risk, could be impacted.
Construction	Sea-level may lead to property damage, beach degradation and habitat loss. Physical impacts on infrastructure	Four particularly sensitive regions in South Africa, two of which occur in the Western Cape: Greater Cape Town (Melkbosstrand to Gordon's Bay) and the Cape south coast (Mossel Bay to Nature's Valley) Popularity of beaches to domestic tourists suggests a potentially vulnerable socio-economic activity

Major sources: IPCC (2001), Kiker (1999), Turpie, Winkler & Midley (2004), Munasinghe (1995)

APPENDIX B: CLIMATE CHANGE IMPACTS AND ADAPTATION WORKSHOP

A workshop was held at Kirstenbosch on 9 May 2005 to which over 30 interested experts were invited (23 were able to attend). The aim was to present the findings of the researchers in terms of impacts on the biophysical, social and economic sectors, after which the delegates would be able to discuss the impacts, prioritise them and then present adaptation strategies that would apply to their sector. The latter would form part of the final report.

The workshop was run in 2 parts: Firstly the researchers presented their findings in a plenary session. Thereafter participants selected a sector for a breakaway visual gathering and prioritising session. For the prioritising each person was given 5 votes that they could use at their discretion to indicate the importance of the impacts in their view.

The agenda of the meeting, attendance list and workshop output is given below.

AGENDA

Introduction, definitions and outline of workshop

Climate change scenarios and questions

Impacts and vulnerabilities by sector – Project participants give presentations on direct and indirect impacts on:

Coastal zone
Biodiversity/conservation
Wetlands
Alien invasives
Fire/disasters/services
Water/flooding/drought
Population movement/migration
Air quality (and link to Health)
Utilities
Urban development
Tourism
Investment, trade, industry and manufacturing
Health
Employment/poverty/food security

Break out into groups

a. Physical (water, atmosphere, biodiversity etc)
b. Social (flooding, health, fire, utilities etc)
c. Economic (trade, investment, development etc)

Group discussion will be around two questions.
Which impacts do you think will affect you most (prioritise)
What adaptation strategies, actions would you have or can you suggest?

WORKSHOP ATTENDANCE LIST

Delegates	Institution
Amanda Dinan	Frater Asset Management
Rob Little	WWF
Ruth Massey	Cape Town City Env manager
Ernst Baard	Cape Nature Conservation
Pavs Pillay	DEAT/SANCOR
Rae Wolpe	City of Cape Town - Trade Promotion
Moeniba Isaacs	UWC, PLAAS
Karen Shippey	Ninham Shand – civil engineers
Johannes Loubser	Durbanville Agricultural Society
Robert Blyth	HHO civil engineers (roads)
Gerrit van Zyl	Dept Water Affairs and Forestry
Leila Mahomed	Sustainable energy Africa
Lance Greyling	Independent Democrats – Environmental portfolio
David Oliver	Air Pollution Control City Health
Kim Kline	WCPG - Disaster Management
Sampie Steenkamp	WCPG - Disaster Management
Mark Pluke	Cape Town City - Disaster
Leigh Sonn	UCT – Disaster Mitigation and Prevention
Phoebe Barnard	SA National Biocdiversity Institute
Johan VD Berg	SA Centre on Climate Change
Nikolaas VD Merwe	WC Game Management Assoc
Steve Lamberth	Marine and Coastal Management (DEAT)
Anton Cartwright	Ecological Consultant

WORKSHOP OUTPUT:

Physical Impacts of Climate Change:

This group consisted of individuals representing organisations that were concerned mainly with conservation and management of natural biodiversity.

Impacts	Votes	Specific Adaptations
Biodiversity Lower rainfall in coastal lowlands will significantly impact biodiversity conservation status Extinction likely to be driven by physiological response to temperature changes Loss of biodiversity Rising temperatures impact plant physiology, and therefore animals and agriculture Impact on evolutionary process – natural speciation eg, fynbos/ succulent karoo Increased fire frequency will reduce vegetation cover in mtns and affect water yield	12	Establish succulent karoo protected areas Expansion of protected areas to prevent biodiversity loss All protected areas (Terrestrial, marine, estuarine) must take future CC, migration into account
Water Resources Decreased fresh water resource Increasing demand for water Alternative water resources	12	Water effluent recycling Desalinisation Increase efficiency of supply to metropoles Manage water demand Develop alternative water resources – diversion Equalisation – more dams
Ecological Water reserve Affected by rainfall change Lower runoff will destroy wetlands and their contribution to conservation	8	Fresh Water reserve determination for FW, marine and estuarine environments Include CC in ecological reserve requirement Retain un-impacted priority rivers
Floods, Droughts Flood prediction and frequency More frequent droughts	6	

Impacts	Votes	Specific Adaptations
Fishing CC driven decline in fish stocks compounded by increase in fishing effort/demand Seasonal reversals/changes in rainfall/freshwater patterns will disrupt spawning events and recruitment success of marine and FW fish and invertebrates. Impact on fisheries and fish stocks Decrease in run-off leads to increase in duration and frequency of mouth closures affecting estuarine productivity and fisheries	5	Exploitation levels should be set at predicted, not current biomass/stock levels
Game, commercial wildlife management Impact of vegetation change and problem of game movement restrictions	4	Provide unfenced corridors (esp mountains) for natural movement of wildlife Reduce regulatory bureaucracy regarding translocation
Air Quality Greenhouse gas emissions impact on ozone, vegetation and animals SO_2 deposition in form of acid rain Increase in PM 10 and 2.5 with health effects Increased concentrations of NO_2 Increased inversions = more brown haze episodes	3	Alternatives to burning of tyres and other waste disposal Cleaner technologies for cleaner air – CDM for Kyoto Protocol
Alien vegetation CO_2 increase leads to alien vegetation spread eg Rooikrans, Port Jackson)	3	
Coastal Erosion Loss of infrastructure – roads etc Impact of coastal protection structures on biodiversity	2	

11 participants 55 votes

Social Impacts of Climate Change:

This group was concerned with the impact of climate change on social issues including employment, health, food security and livelihoods.

Impacts	**Votes**	**Specific Adaptations**
Food security Direct – consumption Indirect – jobs Food production	8	Invest in newer technology – drip irrigation, drought resistant cultivars
Livelihoods Farmers/SMMEs/farmworkers/households Fishers – communities/workers/households	8	Basic needs grant Develop diversification strategies
Water Resources Decreased fresh water supply Stress and competition – crops, sanitation, watering, human needs Urbanisation leads to increased demand	7	Invest in increased water-efficiency Utilise groundwater more

Impacts	**Votes**	**Specific Adaptations**
Health Flooding leading to poor sanitation Individual impact linked to housing and response to changes Increased costs to city/province Increased pollution leads to more lung diseases Spread of insect borne illnesses	7	Reduce private– increase public transport – pollution reduction Improve legislation AND enforcement to reduce exhaust emissions – increase fines Incentives for car/fuel manufacturers to improve efficiency and implement green technology Education/awareness programmes Improve health infrastructure
Agriculture Increased droughts Increased crop vulnerability – food security Agricultural decline Urban migration and informal settlement development	7	See **Food security** Develop extended farmer support structures: Crop alternatives/water efficiency/subsidies/ groundwater
Infrastructure Impact on low cost housing – durability ito flooding Increased flooding and damage to infrastructure Location of informal housing Costs of service delivery to households Effect of extreme events Lack of services to settlements	5	Forward planning with CC in mind Housing material/design/structure alternatives Put in place response strategies for vulnerable housing Upgrade and improved maintenance of stormwater/sewage

Impacts	Votes	Specific Adaptations
Fire Increased opportunity for fires in informal settlement urban and veld burning	2	
Flooding time between fire and floods may shorten		1:50 flood line strict adherence
Migration rural to urban – seeking alternative likelihoods migration into wetlands immigration from ex SA		

9 participants, 44 votes

General Adaptations
Better management of resources
Improved technology to manage CC risk
Develop modelling and early warning system
Strengthen social networks for sharing future risk
Smarter development required
Build up resilience through strengthening assets and capital and ensuring access for vulnerable groups

Economic Impacts of Climate Change:

This group discussed the importance of integrating climate change and adaptation into planning and development processes and frameworks, such as EIA guidelines, Spatial Development Frameworks, Integrated Development Planning and resource allocations such as quotas to fisheries.

In the same vein, it was argued that monitoring plans needed to be sensitive to climatic changes and adaptation measures needed to respond to these.

Impacts	**Votes**	Specific Adaptation
Vulnerability of communities (eg fishing agriculture) to climate changes	5	Diversification of livelihoods Integrate community concerns into water resource planning
Return on investments	4	Better information and shareholder activism Individualise information to various industries Unpack impacts associated with carbon footprint, this will better inform carbon liabilities Promote renewable energy opportunities (e.g. biodiesel)
Impacts on production and quality of fruits/wines Deciduous fruits: No winter dormancy if increase minimum temperatures Heat waves lead to blemished fruit	3	Diversification of production and processing
Water scarcity constraining development	3	Differential price structures for natural resources such as water
Tourism	3	
Energy sector impacted by energy/carbon taxes and changing demand	2	
Fishing resources	2	

Impacts	**Votes**	Specific Adaptation
Beach degradation and tourism	1	
Clean Development Mechanism and Energy/Carbon Finance is a positive opportunity.	1	
Drought leads to loss in production and deterioration in water quality	1	Drought relief Ploughing practices Organic farming practices
Infrastructure and construction		Design and construction of houses for heating and cooling
Heat stress: in animals, loss in dairy production; loss of moisture.		

5 participants, 25 votes