South Africa's Second National Communication under the United Nations Framework Convention on Climate Change

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Executive Summary

In 2004, South Africa prepared its first national communication in accordance with Article 12 of the United Nations Framework Convention on Climate Change. This document constitutes South Africa's second national communication, in which substantive advances in national understanding of climate change-related issues are reported. Where appropriate, the statements in this summary include estimates of uncertainty for trends and projections that indicate how well established (i.e. the amount of supporting evidence and agreement between various sources) and complete (the scientific understanding of the various sources of information) they are judged to be. These uncertainty estimates involve some expert judgment, reflect the current state of knowledge, and are intended to guide users of this information broadly on the level of confidence associated with them.

National circumstances

South Africa is a middle-developing country whose economy is built on its large, but diminishing, mineral wealth. There are large disparities between the rich and the poor in the population of 49 million people. These disparities have resulted in rural-urban migration (urbanization is now 61.7%) to the small towns and cities, with the poor settling in burgeoning informal settlements, often on marginal and unsuitable land. Over and above the high unemployment levels, this has led to disease and related vulnerability, and which poses challenges for planning by government for socio-economic and infrastructure services.

The country is relatively well-resourced compared to the rest of southern Africa in terms of its overall energy and transport infrastructure, as well as its financial services, telecommunications and legal services, food production and waste management. It is still heavily reliant on coal for electricity generation, but has potential in terms of nuclear, solar and wind energy.

The government has adopted a pro-growth strategy with a liberalized economic policy to address poverty and unemployment, and has embraced the millennium development goals in its national policies. It has made great strides in increasing access to basic services, particularly potable water, sanitation and electricity, especially in the urban informal settlements and peri-urban settlements.

The South African population is severely affected by the HIV/AIDS pandemic, which, compounded with other poverty-related diseases, has increased the dependency ratios and affects the economy through decreased productivity and service delivery.

South Africa has a relatively dry, warm climate, with resulting water scarcity. Mean annual rainfall is roughly 490 mm, and water is derived mainly from overland runoff (surface water, as opposed to aquifer sources). This situation is exacerbated by increasing demand for water, with negative consequences for sanitation and water quality.

South Africa is endowed with significant marine and terrestrial biodiversity, and is rated as the third most diverse country globally in this regard. Our biodiversity is threatened by human activity, but it also has good legislation to protect its natural resources. Enforcement of the legislation is however weakened by a lack of resources.

South Africa has a strong national policy-making and legislative process with respect to climate change adaptation and mitigation, and recognizes the vulnerability of the poor and marginalized population to climate changes and weather-related disasters. There is a growing awareness of the need to quantify the costs of climate-related disasters, and a growing awareness by the private sector of its role (and the opportunities) in mitigation and adaptation.

National-scale climate change trends and projections

Research has been conducted in South Africa in an attempt to quantify and understand climatic trends and the nature, likelihood and consequences of potential climate change at national, provincial and finer scales. The results of this research better inform the development of national and sub-national climate-related policies, but several gaps and uncertainties remain.

It has been well established that observed surface air temperatures over land, and derived temperature measures relevant to impacts (e.g. frost days), have changed with statistical significance since 1950 across South Africa. These changes are consistent with, and have sometimes exceeded, the rate of mean global temperature rise.

The geographic pattern of temperature change varies spatially and seasonally across South Africa. There is reliable but incomplete evidence showing lower rates of warming in the higher altitude eastern interior, relative to the coast and to the lower-lying western interior. This does not fully conform with future projections of temperature change where most warming is projected to take place in the interior.

There is much, albeit incomplete, evidence that precipitation change since 1950 has included both drying trends (in parts of the summer rainfall region) and wetting trends (in parts of the winter rainfall region) that are coherent at large spatial scales, but further significant local scale topographic complexity and inter-annual variability does not yet allow a clear overall signal to be identified.

Research currently in progress on the South African climate has identified high inter-annual, decadal, and multi-decadal variability often associated with global tele-connections such as the El Niño phenomenon, which have had major socio-economic impacts in the past. This variability is projected to change in future with uncertain consequences for society.

Future warming due to increased international greenhouse gas emissions is projected to be greatest in the interior of South Africa and least along the coast. This established but incomplete projection is based on statistically downscaled output from five Global Climate Models (GCMs) used in the 4th Assessment Report of the Intergovernmental Panel on Climate Change. Assuming a moderate to high growth in greenhouse gas concentrations (Special Report on Emissions Scenarios A2 scenario), by mid-century the coast is likely to warm by around 1-2ºC, and the interior by around 2-3ºC. After 2050, under emissions scenarios that assume little mitigation effort (IPCC SRES A2 family), the rate of warming is projected to reach around 3-4ºC along the coast, and 6-7ºC in the interior.

Future rainfall projections remain challenging because complex rainfall-generating processes such as cloud formation and land surface-atmosphere interactions are not yet fully understood and resolved in GCMs. Established but incomplete GCM projections for the winter rainfall region consistently suggest future rainfall decreases, while summer rainfall region projections deviate less from present climate. With locally-developed regional downscaling techniques, rainfall projections for the summer rainfall region show a tendency towards wetting.

Observations and incomplete projections over South Africa indicate increases in rainfall magnitude per event (rainfall intensity), independent of overall annual rainfall changes, as well as an increase in the duration of dry spells.

Open water evaporation over South Africa is likely to increase by 5-10% by 2050, and by 15-25% by 2100 due to higher temperatures.

Climate change trends and future projections for South Africa show important regional-scale differences. Developing robust regional and local scale projections of these climatic changes requires further assessment.

Projected future rainfall changes are regionally complex, especially in mountainous areas, which produce much of the country's streamflow. Our understanding is limited significantly by poor coverage of high altitude monitoring stations.

Impact, vulnerability and adaptation: Water resources

Water is arguably the primary medium through which climate change impacts will be felt by people, ecosystems and economies. As a large proportion of South Africa's society is impoverished, they are rendered particularly vulnerable to impacts of climate change. Furthermore, many of South African ecosystems are climate- and water-dependent. Strategies and plans of action to adapt to climate change are therefore urgently needed to establish effective resilience.

Water resources are limited in South Africa, and thus constitute a major constraint to continued economic development and the sustainable livelihoods of people.

Water-related infrastructure such as dams, inter-basin transfers, and storm-water drains represent a long-term investment, with a typical design life of 50 - 100 years. These investments are very expensive and are designed to cope with historical extremes of floods and droughts, so it is imperative to account for potential effects of climate change in South Africa's water sector. Equally important is the realisation that changes in hydrological responses in South Africa have major associated implications for the agriculture, health, coastal management and disaster risk management sectors.

South Africa is, overall, a relatively dry country with a high variability of rainfall both over space and time, high evaporative demands, and low rainfall to runoff conversion. It is thus a country experiencing unevenly-distributed water resources. Despite impressive water engineered systems (major dams, inter-basin transfer schemes), surface water resources are already fully allocated in many catchments and these catchments are additionally experiencing high pollution from waste water treatment works, mining, industry and agriculture.

Under such conditions, it is well established that a direct signal attributable to climate change may be difficult to separate from background variability in South Africa's water sector. Nonetheless, rising temperatures and variable rainfall patterns are currently having impacts on water resources.

Any changes in rainfall, up or down, for mean values or for individual events, are amplified in changes of hydrological responses. In the case of variability from year-to-year, the amplification from rainfall to runoff over South Africa is two- to five-fold. This has important repercussions for planning for extreme events such as floods and droughts, which are well established, but not yet adequately researched.

Climate change impacts are not likely to be experienced evenly throughout the country. Some areas will be "winners", other areas will be "losers" while others still, such as the Western Cape and Limpopo provinces, are likely to become real "hotspots of concern". Furthermore, changing rainfall patterns are expected to result in more floods in the eastern part of the country and more droughts in the west. In addition, groundwater recharge could reduce significantly in the semi-arid parts of the interior and west.

Increases in physical, chemical and biological pollution from flooding, soil erosion, agricultural and industrial solutes, poor sanitation and increased temperatures will adversely effect both surface water and groundwater quality in the absence of adaptation responses, and although this is established, there is incomplete understanding of the extent of the problem.

It is well established that most of South Africa's water resources are generated in mountainous areas (the so-called "water towers" of the country, including neighbouring Lesotho). These critical and ecologically highly sensitive areas are more poorly understood with regard to their potential climate change responses and, additionally, have very sparse observation networks.

Climate change in South Africa will not occur on a "clean sheet" of undeveloped natural catchments, but will rather be superimposed onto already water-stressed catchments with complex land uses, intricate water engineered systems and a strong socio-political as well as economic historical footprint, thus adding to existing challenges in water management. This is well established, but the local consequences are not yet fully understood.

Agriculture is the largest consumer of water (for irrigation), and is vulnerable to changes in water availability, increased water pollution (particularly from toxic algal or bacterial blooms) and soil erosion linked to more intense rainfall events.

The rural and peri-urban poor are at most risk, as they rely on untreated water derived directly from rivers, wells and wetlands.

Important demand and supply-side adaptation measures include technological and structural measures, system maintenance, improvements to operating rules, sustainable surface and groundwater use, early warning systems, pollution control, risk mapping, risk sharing, policy instruments and their enforcement, improved disaster management and certain protective land use regulations. While the need for these adaptations is well established, they are not always well executed.

Impact, vulnerability and adaptation: Agriculture, rangelands and forestry

The agricultural sector is a key component of the South African national economy. While the direct contributions to GDP and employment are less than 5% and only approximately 13% respectively, its full contribution, with multipliers, comprises up to 12% of GDP and 30% of national employment.

Potential adverse impacts of climate change on food production, agricultural livelihoods and food security in South Africa are significant national policy concerns, and also are likely to have implications in southern Africa.

South Africa's agricultural sector has well established inherent vulnerabilities relating to climatic and non-climatic factors for which there is much evidence and agreement. Factors include sharp transitions between distinct climatic zones, exposure to climate variability on several time scales, a complex mix of agricultural settings and practices, as well as land transformation, sustainability goals and trends that create a high demand for support, advisory and extension services.

Overall, many agricultural sub-sectors are sensitive to projected climate change. Certain crops (or varieties thereof) grown in South Africa are more robust to climate change while others are more sensitive; similarly climate change impacts for some crops can be projected with more confidence than for others.

There will thus be "winners" and "losers" in the agriculture sector. There is sufficient evidence to be able to confidently predict that yields for certain crops will increase in some areas and decrease in others, while certain hitherto climatically unsuitable areas for specific crops will become suitable and vice-versa.

Additionally, there is some evidence to suggest that associated food production and food security are at risk especially due to future projected water supply constraints, declines in water quality and competition from non-agricultural sectors.

There is some evidence, and some agreement, that small-scale and urban homestead dryland farmers are most vulnerable, and large-scale irrigated production is least vulnerable to projected climate change, given sufficient water supply for irrigation. Intensive livestock production systems are vulnerable to increasing demand of input costs to reduce thermal stress, water use and other input costs, and pressure to contain greenhouse gas emissions.

Secondary and indirect impacts of climate change (such as increases in pest and disease infestations or enhanced soil erosion) may become more important than direct or primary impacts, as may tertiary impacts such as losing [or gaining] a competitive edge against other countries for agricultural export commodities, or government policies regarding trade protection, land reform or support for commercial agriculture.

Many adaptation options have been identified, including those related to climate per se, to water availability and management, to hazards, the natural resource base, to dryland crop production, those that are irrigation, livestock and small-scale farmer specific, ones that are policy and authority related, or options linked to science, labour, finance, markets or cultures and traditions.

Current projections of climate change suggest that the area under plantation forestry is likely to remain constant or even extend in the eastern part of the country and increase slightly in productivity.

The frequency and intensity of fires is likely to increase due to an increase in temperature and dry spells caused by a more erratic rainfall, and this will impact negatively on plantation forestry. The forest industry can possibly counter this through a combination of pro-active fuel reduction and re-active fire fighting, but this will increase production costs.

Plantation forestry uses more water than natural vegetation, which has led to restrictions on forest plantation expansion. Increased demands on water could translate into further restrictions on plantation forestry, and these will be exacerbated in areas where rainfall is likely to decrease, such as the Western Cape.

Overgrazing, desertification, natural climate variability, and bush encroachment are among the most serious problems facing rangelands. External stressors such as climate change, economic change, shifts in agricultural production and land use may further negatively impact the productivity of these regions and deepen pre-existing vulnerability.

Climate change (including increased atmospheric carbon) may complicate the existing problems of bush encroachment and invasive alien species in rangelands. Rising atmospheric CO_2 levels may be increasing the cover of shrubs and trees in grassland and savanna, with mixed effects on biodiversity, and possible positive implications for carbon sequestration.

Impact, vulnerability and adaptation: Terrestrial biodiversity

There is much evidence that South Africa's unique and rich biodiversity is at risk from projected anthropogenic climate change by 2050. Several studies indicate that a majority of endemic species may show contractions of geographic range and that up to 30% of endemic species may be at an increasingly high risk of extinction, assuming mid to high range IPCC projections, by the latter half of this century. However, the modelling methods on which these studies are based require further verification due to their assumptions and known shortcomings.

The most adverse effects of projected climate change on endemic species associated with mid to high emissions scenarios are projected in the winter rainfall biomes, the fynbos and succulent karoo, with between 20 and 40% of the areas supporting these biomes exposed to novel climate conditions by 2050, and with some impacts on species already observable, including an observed increase in fire frequency.

Summer- and all-year rainfall biomes (savanna, Nama-karoo, grassland and forest) may be susceptible to changes in tree/grass and shrub/grass balance and changes in fire regime, with likely substantive but poorly quantified implications for biodiversity and ecosystem processes and services. The impacts of recent revisions of rainfall projections for ecosystems and biodiversity in the summer rainfall region have not been adequately modelled.

Additional stresses to biodiversity that will interact with climate change include fire frequency (which appears already to show climate change-related increases in the fynbos biome) and invasive alien species. The combined effects of these and stresses relating to land use and fragmentation of habitats will further increase the vulnerability of biodiversity to climate change. Rising atmospheric CO_2 levels may be increasing the cover of shrubs and trees in grassland and savanna biomes at least, with mixed effects on biodiversity, and possible positive implications for carbon sequestration.

Monitoring efforts and some key experimental studies at national and sub-national scale will be critical for evaluating future risk, for improving model projections of impacts, and designing and assessing adaptation responses.

There is a suite of adaptation responses available to conservation agencies, the most cost-effective of which include building partnerships to enable effective management of areas not under formal protection, and investment in the expansion of key protected areas (which were not originally designed with climate change trends in mind) in line with the most robust knowledge of climate change impacts.

There is increasing awareness of the value of using biodiversity in assisting societal adaptation to the adverse impacts of climate change, but more information on the potential options and their effectiveness is needed.

Impact, vulnerability and adaptation: Invasive alien species

South Africa is substantially affected by invasive alien species in the terrestrial, freshwater and marine realms, and their considerable biodiversity and socioeconomic consequences are well established.

It is well established that the extent and success of invasions is closely related to human activities, which will lead in turn to competition between people and invasive alien species for goods and services. Changes to the spatial pattern of human activities as a consequence of changes in climate must be factored into assessments of climate change effects on invasive alien species.

The impacts of invasive species on South African ecosystem services, biodiversity and the economy are known to be multifaceted, but relatively few attempts have been made to quantify these. It is well established, though, that plant invaders pose a significant threat to South African biodiversity and water resources.

Predicted climate change suggests that tropical species will become a more significant component of the invasive biota, and that distributions of many species currently limited by water availability will expand into previously drier areas. CO_2 fertilization effects will likely increase the impact of invasive woody plants, though evidence to support this is lacking. Increasing rainfall, should it occur, may not necessarily offset flow reduction owing to CO_2 fertilization effects and increased abundance of invasive woody species.

The likely future efficacy of plant biological control agents (one of the key interventions to control invasive alien species) under altered climates remains poorly investigated. This uncertainty poses a major risk for future management and control.

Many alien species present in the country have not yet reached invasive status but seem likely to do so even in the absence of climate change. If climate change projections are borne out, even more serious invasions can be expected.

The prevention and management of invasive alien species forms an integral part of South African policy, legislation, and government action. Management interventions have been implemented both nationally (Working for Water at R600 million per year) and provincially (KwaZulu-Natal Invasive Alien Species Programme at R 100 million per year), and include capacity-building via bodies such as the government-supported Centre for Invasion Biology and an Early Detection and Rapid Response programme.

Impact, vulnerability and adaptation: Marine resources

A conceptual understanding of the possible implications of climate change on many of South Africa's key marine habitats is currently possible, but a quantitative and spatially integrated evaluation of future climate change scenarios still to be undertaken in almost all marine systems. The production of accurate regional climate models, which adequately consider ocean, atmospheric and terrestrial influences, and produce reliable regional scenarios, remains an obstacle to progress.

Change in South Africa's marine and coastal environment is already being detected in a number of ecosystems to differing degrees. In most cases the understanding of the nature of this change is still poor.

Sea-level is rising around the South African coast, but there are regional differences. The west coast is rising by 1.87 mm per year, the south coast by 1.47 mm per year, and the east coast by 2.74 mm per year. Modelling has shown that some areas along the coastline will be more susceptible to sea level rise than others, but the understanding is incomplete.

Decadal sea temperature changes have been reported for both the inshore and offshore marine environments around South Africa. The data, which are derived from a number of different sources, are not in complete agreement.
Several species of tropical estuarine fishes have extended their ranges southwards, and this is thought to have been the result of increases in sea surface temperatures over the past decade.

Several strong trends have been detected in the Benguela system and associated fisheries. These include a warming at the northern and southern boundaries of the system, with potential consequences for increased hypoxia on the Namibian shelf. Zooplankton has increased (~10-fold), caused by changes in productivity and upwelling–favourable winds. Pelagic fish stocks have been decimated, resulting in the collapse of sardines in the 1960's, but by contrast, southern pelagic stocks have increased, accompanied by an eastward (perhaps cyclic) shift in sardine and anchovy. The causes of these changes are not fully understood.

The study of the Agulhas current system, which is one of the major oceanographic features in the region, is still relatively immature. Key characteristics such as the Natal Pulse remain unresolved. Climate change projections for this system are therefore still speculative.

Impact, vulnerability and adaptation: Human livelihoods and social impacts

Understanding of the impacts of climate change on human livelihoods in South Africa has developed over the past 5 years. Over the past 5 years, the science of the social dimensions of adaptation has begun to focus, internationally and locally, on complex integrative themes such as adaptive governance, effectiveness of institutional arrangements, social networks and the role of effective advocacy and information in decision-making and stronger links to disaster risk reduction.

Livelihoods are underpinned collectively by different types of assets, abilities and activities that enable a person or a household to survive. The impact of climate variability on livelihoods comes about as a result of combined effects on individual assets, including economic or financial assets, human capital, natural resource stocks, social resources, and physical capital. These assets are likely to be significantly affected by climate variability, particularly in rural areas. Extreme events, such as drought and flood, also affect assets.

Change in climate, and climate variability, is also likely to increase the risk to assets and activities. Increased temperatures and drier conditions for example, can increase fire risk which is currently a major threat in informal settlements and has the potential to cause major damage to livelihoods assets and well as threatening lives.

Adapting to climate change at the livelihood scale is critical. It is particularly important to focus on the most vulnerable groups, so that their livelihoods are not eroded by climate events, but that they rather become resilient to the expected changes in climate. This requires an integrated approach.

Several barriers to effective climate and disaster risk management and adaptation exist. These include a lack of accessible and reliable information, lack of market access and few social platforms to allow engagement of civil society on climate change issues. Experience with severe weather-related events suggest adaptation capacity to such events is challenged by compounding factors such as pervasive social vulnerability, inadequate planning, constrained, integrated and spatial development and poor climate and disaster risk management.

Progress on adjustment to climate variability in South Africa has been made in some areas: in the urban planning arena, with research linked to improved understanding of urban configurations of disaster risks; emerging debate in the energy and business sectors; and in the possibility of mainstreaming adaptation and other areas of action (e.g. integrated water management). There has been some planning and preparation by government of adaptation plans and strategies, particularly in large cities. Full implementation of such plans and strategies still needs to be undertaken.

Impact, vulnerability and adaptation: Human health

At least 30% of South Africa's 45 million population is highly vulnerable to both sudden and harmful climatic shocks, with low levels of endogenous resilience, adaptation and coping skills. The characteristics of this population include a unique disease complex burden, high mobility, a subsistence-level existence and informal settlement housing. This disease burden complex includes the highest global infection levels of human immunodeficiency virus (HIV) and tuberculosis (TB) in a setting of poor environmental sanitation, waterborne disease, malnutrition, high psychosomatic disease and emotional stress.

The dangerous secondary and tertiary effects of climate change are probably already in effect and principally due to drought, and unpredictable temperature and rainfall extremes. Without adequate adaptation strategies, the impacts will manifest as worsening food security, exacerbation of existing disease burdens, increased vector-borne and emergent diseases, human displacement, suffering and even conflict.

Protein Energy Malnutrition (PEM) is the most likely consequence of climate changes and food insecurity. PEM significantly undermines the immune system, maternal health and childhood development. HIV, TB and PEM interact to the detriment of communal integrity, exacerbating poverty.

Adaptation and mitigation to resolve the twin plague of malnutrition and infection requires a multi-sectoral integrated approach.

Programmes directed at improving public health and immediate and long-term food security and nutritional strategies should receive focused attention as they will contribute to building resilience to climate change.

Outbreaks of cholera have been associated with increasing episodes of droughts and floods, especially in high-density populations with poor medical infrastructure, and results in morbidity and mortality.

With increasing numbers of hot days and nights, heat stress is likely to have detrimental effects in vulnerable populations, children and the elderly, especially in locations of poor housing infrastructure.

Improved, environmentally-sound, low-income housing, with the necessary support infrastructure, should particularly aim to reduce the risk of waterborne disease and exposure to indoor pollution and heat.

Despite the high success of the malaria control program in the Limpopo area, the human health and environmental consequences of the use of DDT indicates that it is possibly not an optimum strategy to combat malaria.

Impact, vulnerability and adaptation: Economic costs

An estimate of the cost of climate-related events (storms, floods, droughts and fires) in South Africa cannot be made with any level of accuracy, due to a lack of data. The direct cost of a limited number of localized events between 2000 and 2009 amounted to R9 billion (in 2008 values), or about R1 billion per year, equivalent to 0.04% of South Africa's GDP. This is almost certainly an underestimate, as one national-scale study alone estimated the annual cost of wildfires to be R0.9 billion.

Additional indirect costs can be substantial, and have important socio-economic implications. A small number of localized case studies from the Western Cape indicate that floods were followed by the need to relocate affected people, increases in illness and health costs, decreases in agricultural productivity, knock-on effects of damaged roads, and disruptions in power supply, all of which added substantially to direct damage costs.

Should the frequency and intensity of such events increase, costs will increase, and may be further heightened by the vulnerability arising from poor institutional arrangements, conflict, HIV/AIDS and malaria.

Greenhouse Gas Inventory

South Africa's national inventory greenhouse gas (GHG) inventory has been developed for the year 2000, in four categories: (1) energy; (2) industrial processes and product use; (3) waste; and (4) agriculture, forestry and other land use.
South Africa's total emissions in 2000 are estimated to be 461 million tonnes CO_2 equivalent. 83% of emissions were associated with energy supply and consumption, 7% from industrial processes, 8% from agriculture, and 2% from waste.

Energy sector emissions increased between 1990 and 2000. Between 1994 and 2000 energy sector emissions increased by 28%, and between 1990 and 2000 by 46%. Industrial Processes and Other Product Use emissions increased by 6% between 1994 and 2000, and by 4% between 1990 and 2000. Emissions from agriculture increased by 9% between 1994 and 2000, but decreased by 4% between 1990 and 2000. Emissions from the waste sector decreased byf 43% between 1994 and 2000, and by 38% between 1990 and 2000.

Carbon dioxide is the main greenhouse gas, contributing 79% of emissions (362 071 Gg CO_2, without land use, land use change and forestry). Methane (CH_4) contributes 16% of emissions
(75 062 Gg CO_2 equivalent, without land use, land use change and forestry). N_2O contributes about 5% of emissions, and other gasses (Hydrofluorocarbons, Perfluorocarbons and SF6) contribute less than 1% of emissions.

Measures to mitigate climate change

Given that 79% of the country's greenhouse gas (GHG) emissions are attributable to energy supply and use, the focus of the tension between national development objectives and climate change mitigation objectives is therefore the energy system. Major government interventions in this area include the 2003 White Paper on Renewable Energy, the 2005 Energy Efficiency Strategy, the development of the Long Term Mitigation Scenarios (LTMS) and the development of a National Climate Change Response policy to be completed by 2012.

So far, 125 Clean Development Mechanism (CDM) projects have been submitted – 96 at Project Information Note stage, 29 at Project Design Document stage, and of these, 15 have been registered. The latter are expected to generate about 37 361 000 Certified Emission Reductions (US$ 528 million in revenue) over their lifetime. Apart from mitigation projects aimed at obtaining CDM credits, a total of 56 mitigation projects have been captured in the Department of Environmental Affairs' National Climate Change Response Database, with a total emission reduction potential of 25 million tonnes of CO_2-equivalent between 2000 and 2050.

South Africa's baseline describes a scenario where there is no change from the country's current trends; where not even existing policy is implemented. GHG emissions in this scenario start from 446Mt CO_2-equivalent in the 2003 base year, and increase about four-fold by 2050 to 1637 Mt CO_2-equivalent.

Three strategic options modelled in the LTMS show that the first – start now – reduces the gap between the baseline and what is required by science by 43 %, while the second – scale up – closes the gap by 64%. The third modelled option – use the market – achieves the target only until 2035, from when a section of emissions remains to be mitigated. This remaining section of emissions implies that a new set of innovative options will have to be sought and be ready for implementation by that time.

Four major areas with the largest mitigation potential – in terms of achieving the greatest emission reductions in a cost-effective manner – have been identified as energy efficiency, electricity generation, transport and carbon capture and storage. These deserve particular attention in terms of South Africa's mitigation technology needs. Compared to the baseline scenario the investment requirements of individual mitigation actions range from savings of US$ 298 billion to a cost of US $487 billion, added up over the period 2010 to 2050.

Policy development

In developing appropriate policy responses to climate change, the South African government recognises that it must make the transition to a climate-resilient and low-carbon economy and society. This must be achieved by balancing mitigation and adaptation responses and, in the long-term, redefining competitive advantage and structurally transforming the economy by shifting from an energy-intensive to a climate-friendly path as part of a pro-growth, pro-development and pro-jobs strategy.

South Africa's climate response policy will attempt to make a contribution to the goal of limiting global temperature increase to below 2°C above pre-industrial levels.

South Africa recognises that it must continue to pro-actively build the knowledge base and capacity to adapt to the inevitable impacts of climate change. This will be promoted through enhancing early warning and disaster reduction systems, by including appropriate approaches in the development and implementation of basic services, infrastructure planning, water resource management, and health services, and by developing responses to protect agriculture and biodiversity.

South Africa's long-term mitigation options include a strategy that will see the country's greenhouse gas emissions peak between 2020 and 2025, and then stabilise for a decade, before declining in absolute terms towards the mid-century. This option has been adopted as a priority by the South African government.

Technology transfer

South Africa has completed and submitted a technology needs assessment to the UNFCCC.

In terms of this and subsequent work, a number of mitigation, adaptation and overarching technologies have been prioritised. The key constraints to technology adoption in South Africa are project finance and the development of human resources to implement and maintain the technologies.

South Africa is strongly committed to a co-development model of technology acquisition, adaptation and improvement, both as an approach that has proven successful in South Africa, and as a preferred mechanism for interaction between technology-rich and technology-poor countries.

Systematic observation, monitoring and research

In South Africa, climate change-related observation, monitoring and research programmes are guided by national policy frameworks and research strategies. Observation, monitoring and research programmes are undertaken by relevant science councils, universities, government departments, agencies of government departments, municipal councils and public corporations through local, regional and international partnerships.

South Africa is a member and contributor to the Group on Earth Observations (GEO).

Research programmes in South Africa face challenges of infrastructure, funding, human capacity and a weak science-policy interface.

Public awareness, training and capacity-building

The South African government has introduced a number of initiatives that will make significant contributions to education and awareness-raising around issues related to climate change. These include a science plan and institutional architecture for responding to global change (including climate change) over the next ten years.
Many non-government organizations have the interest, the potential, and in some cases the capacity, to make meaningful contributions to awareness-raising and education in the field of climate change, although this potential is not yet fully realized.

The current level of media reporting on climate change appears to have become more frequent, although the magnitude of this increase has not been quantified. There is a need to build links between journalists and scientists to ensure the accurate communication of information about climate change, and in particular its inherent risks and uncertainties.

Although the school curriculum could accommodate climate change learning, this is not explicitly done, nor is the capacity in place to do so consistently.

At a tertiary education level, a few hubs of capacity exist at some universities, and they offer under- and post-graduate training in climate change-related topics. The courses are not always well integrated with the rest of the curriculum, and this reduces their effectiveness.

Constraints and gaps

Despite a great deal of progress, many gaps in understanding still exist, and these need to be addressed if appropriated responses to climate change are to be made more effective. The Department of Science and Technology has developed a detailed plan to guide research in this regard over the next 10 years. The plan has identified two key knowledge challenges that have bearing on climate change.

The first knowledge challenge is that of understanding a changing planet. Proposed research under this knowledge challenge includes supporting effective observation and monitoring, developing a better understanding of the dynamics of the oceans around southern Africa, developing an ability to link the land, the air and the sea, and improving model predictions at different scales.

The second knowledge challenge addresses adapting the way we live. Proposed research will focus on preparing for rapid change and extreme events, planning for sustainable urban development, and ensuring water, food and fibre security.

A number of important gaps and constraints have also been highlighted during the preparation of this communication. They include the need for more extensive and improved monitoring networks, improved predictions of potential climate change at smaller scales, the development of appropriate simulation models, improved forecasting and early warning systems, building capacity through education and training at all levels, and improving awareness through better communication between scientists, journalists, policy-makers and other stakeholders.

Contents

Contributors

This document is based on material that was contributed by many people. The names of individuals who took responsibility for providing the bulk of the material are listed below, and a large number of additional co-authors and reviewers, not listed here, also made valuable contributions (see acknowledgments). The responsibility for the compilation of this communication lay with the Editors, who worked in conjunction with the Project Management Team (see acknowledgments).

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Contents


CAPE TOWN
WELCOMES YOU

Chapter 1:

National Circumstances

1.1 Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) was adopted in 1992 as the basis for a global multilateral response to the threat of human caused (anthropogenic) climate change. The convention invites Parties (national states) to become signatories, and to thereby commit themselves to taking actions, dependent on their common but differentiated responsibilities, to limit or reduce their contribution to climate change, and to cooperate in adapting to the impacts of climate change. The responsibilities of countries under the protocol depend on their classification as Annex I (developed countries and those with economies in transition) or non-Annex I (developing countries). The government of the Republic of South Africa signed the protocol in June 1993, and ratified it as a developing country in August 1997. In 2004, South Africa submitted its first national communication in accordance with Article 12 of the convention.

1.2 Regional context

South Africa is a significant industrial and economic power in the southern African region, with developed transport, mining and manufacturing sectors. Home to the strongest economy in southern Africa, South Africa exports energy to neighbouring countries, as well as food, telecommunications and many other goods and services. South Africa's ports provide a gateway for some of the landlocked countries of the region. South Africa's economic strength and stability have attracted many immigrants, migrants and refugees over the last century, for many of whom it has become a first or second home, creating a richly diverse population. Since South Africa's first democratic elections in 1994, the country has developed its position as a regional economic leader, and has also taken a stronger strategic lead, often representing the African voice in international dialogues.

Concurrent globalization trends have affected many aspects of the country's development, particularly its economic policies and sectors, and have also facilitated its re-entry into the global information and cultural milieu. While neo-liberal economic and development policies have replaced apartheid principles and have directed government policy to a large extent, an unintended consequence has been that South Africa remains with amongst the highest Gini coefficient (measure of inequality based on disposable income) in the world, despite several areas of advancement for South Africans as a whole. Further development is therefore a priority for South Africa.

1.3/…

1.3 Geographic profile

The information for this section has not changed since it was presented in the Initial National Communication (DEAT 2004). A summary version is provided here, with additional information provided on some issues not covered in the Initial Communication. The Republic of South Africa covers 1 219 090 km^2 of the southernmost part of the African continent, situated in the mid-latitudes. It shares its international borders with 4 countries and 2 kingdoms (Figure 1.1), (both kingdoms, along with Mozambique, being classified as Least Developed Countries). The Atlantic Ocean follows its west coast, and the southern Indian Ocean follows its south and east coasts. The Prince Edward, Marion and Gough Islands also form part of the Republic.

Marine environment

For a region of its size, the coastal and marine environment around southern Africa is one of the most varied in the world (Shannon 1989). This is largely due to the dynamic presence of the two major currents: the warm Agulhas Current along its east coast, and one of the major upwelling regions of the world, the Benguela system (Hutchings *et al*. 2009) along its west coast. The Agulhas Current flows strongly southward along the east and southern coasts, transporting warm, nutrient-poor tropical water. The Benguela Current flows northward along the west coast, transporting cold water, with dynamic wind-driven upwelling close inshore at certain active upwelling sites, bringing nutrient-rich water to the surface with resultant productive fisheries and kelp beds. The South African coastline is generally subject to moderate to strong wave action.

Figure 1.1: South Africa showing provinces, neighbours, major towns and roads

Source: http://www.google.co.za/imgres?imgurl=http://geology.com/world/south-africa-

1.3.1

1.3.2 Climate

Situated in the mid-latitudes, the climate is generally sub-tropical, with warm temperate conditions. On average, 65% of the country has an annual rainfall of less than 500mm. A generally pervasive high pressure system inland prevents cloud formation, resulting in dry conditions, with abundant sunshine, and the western interior is semi-arid. The climate is affected by decadal and multi-decadal variability, notably with El Niño-dominated years generally (but not always) result in reduced summer rainfall, and La Niña conditions often associated with increased summer rainfall (see climate chapter).

Coastal zones are influenced by the ocean and their prevailing currents, which have a moderating impact on coastal temperatures. In the west, generally cold subsiding dry air results in low rainfall and semi-arid and desert conditions. The southwest of the country has a Mediterranean climate, with winter rainfall driven by westerly low pressure frontal systems. Occasionally, particularly in Spring or Autumn, these may generate "cut-off low" conditions which may cause stormy conditions along the coast, and cause extreme rainfall events over land. The south coast region receives both summer and winter rainfall. The east coast is the wettest and warmest region, with resulting high humidity.

Daytime winter temperatures are almost always above freezing point, but frost is common in the interior during clear winter nights. Frost decreases towards the tropics, and rarely occurs at the coast. While snow frequently occurs on the escarpment in winter, no part of the escarpment is permanently snow-covered.

1.3.3 Forests

In 2000, about 25.6% of the country was covered by woodlands/bushlands, 1.4% by plantations, and 0.4% by indigenous forests (van den Berg *et al.* 2008). There is currently net afforestation, as the forestry industry expands [http://soer.deat.gov.za/themes.aspx?m=45]. Natural forest areas have been reduced in extent since colonization in the 17th century, but this trend appears to have stabilized, with some local exceptions.

1.3.4 Land use

The largest natural land cover type is shrubland (34.4%), followed by woodland/bushland (25.6%) and natural grasslands (19.7%). 10.5% of land is formally cultivated; and 1.5% is covered by urban (including smallholder) use (van den Berg *et al.* 2008). This reflects human activity which is largely dependent on the natural environment to sustain its agricultural activity, but also has some adverse impacts on the environment – 3.7% of land is degraded (van den Berg *et al.* 2008), representing a loss of 4.4% of forest, woodland/ bushland, shrubland, herbland and natural grassland.

The extent of woodland has increased from 23.1% to 25.4% between 1994 and 2000; and there is evidence that the country's savannas and grasslands are being colonized by shrubs and trees (termed "bush encroachment"), possibly partly as a result of the direct effect of rising atmospheric CO_2 which can cause faster growth in woody plants. A case has been made to protect savannas and grasslands from future encroachment (van den Berg 2008).

1.3.5 Coastal zones

South Africa has about 3 650 km of coastline, which varies in terms of its vulnerability to sea-level rises and increased storm-related wave action. The East and West coasts are vulnerable because of their wide coastal plains, while only the south-west coast is more protected by the coastal mountain range. However, the estuaries are particularly vulnerable because wave and floodwater energy are channelled here. Vulnerabilities include seasonal cyclonic activity along the north-eastern coast, seasonal storm activity on the south-west coast, and anticipated sea-level rise.

Coastal effects of climate change are higher wind speeds and associated wave heights. Vulnerabilities of coastal areas have been identified as increased storm damage; damage to coastal infrastructure (including infrastructure such as breakwaters); threats to the erosion levels of shorelines; as well as change in the salinity levels of estuaries, which will affect breeding grounds of many marine species (A. Theron & M. Rossouw, CSIR, *personal communication*).

A significant proportion of South Africa's metropolitan areas are coastal, making them vulnerable to any dramatic sea level rises, as well as numerous towns and smaller settlements. South Africa has 259 estuaries, all of which are extremely vulnerable ecologically. Increasing human pressure on coastal areas gives rise to the need for sustainable coastal development through an integrated coastal management approach (SANBI 2007; DEAT 2000).

1.4 Population profile

South Africa has an estimated 49.39 million people living in nine provinces and speaking eleven official languages. In 1999 the estimated growth rate was 2.2%. Nearly one-third (31.4%) of the population is under the age of 15, resulting in high dependency ratios. There is significant geographical skewing of the distribution of people, as a result of planning under "grand apartheid", which attempted to establish African reserves in the regions peripheral to the economy. Migration plays a significant role in shaping the age structure and distribution of the provincial population (Statistics SA 2009).

Life expectancy at birth is estimated at 53.5 years for males and 57.2 years for females, and has dropped dramatically since 1994 when it was an average of 61.5 (Statistics SA 2009).

The infant mortality rate is estimated at 45.7 per 1 000 live births. South Africa is one of the countries most affected by HIV. According to UNAIDS (2008), 5.7 million people live with AIDS in the country, and it has the highest number of HIV infections in the world.

South Africa's high unemployment rate (23.5% in 2009) has lead to the growth of a large informal economy, particularly in the retail and service sectors, as well as a significant dependence on government grants (disability, child support, and old age pensions). The unemployment rate has however dropped from a 28.4% rate in 2003 to the current rate of 23.5%.

There has been a drop in the Human Development Index (HDI: a composite index measuring a long and healthy life; being educated, and having a decent standard of living) since 1995 from 0.748 to 0.658 in 2003, but this is generally higher than most of its neighbours. A national household survey of 2005/6 indicates that 40% of households were living on or below the equivalent of the international poverty line of US$2 a day per person for a family of four. About 13% lived on or below the US$1 per day per person for a family of four (Stats SA 2008). Inequality remains high, with a Gini coefficient of 0.72.

On the other hand, Statistics SA's 2007 Community Survey shows that ownership of goods such as radios, televisions and refrigerators increased between 2001 and 2007, for example the percentage of households with refrigerators increased from 51.2% to 63.9%. A recent study indicates growth in the size of South Africa's emerging Black middle class from 6.3 million in 2001 to 9.3 million in 2007 (Udjo, E. O. 2008).

The low levels of education in South Africa are being addressed through the National Qualification Framework (NQF); Adult Basic Education and Training as well as skills development programs, community education, early childhood development projects, technical colleges and distance education. In

2007, the overall national pass rate in the Senior Certificate examination was 65.2%. 28% of adults had completed at least secondary education and those with no schooling had declined from 17.0% in 2001 to 10.3% in 2007.

1.5 Settlement patterns and urbanisation in South Africa

80% of rural areas are commercial farms with low population densities, and 20% are a legacy of the apartheid system's "homelands" where the agricultural sector was undermined and which have a dependency relationship with the urban areas, reliant on remittances and government welfare. These areas are generally overcrowded, and while many have benefited from improved service delivery in the last 15 years, the so-called peasantry sector has not been able to re-emerge (making South Africa notably different from Lesotho and Swaziland, for example).

By 1985, an estimated 50% of the population resided in urban areas, which follows the current trend of rapid urbanization in developing countries (Stats SA 2006). Interestingly, significant growth has been absorbed by the smaller urban centres of less than 1 million people, and it is predicted that this pattern will continue. The majority of this growth is in the low-income sector. This has put extreme pressure on urban infrastructure, resulting in informal settlements and economies. The result of urban governments not being able to provide adequate infrastructure has been deepening urban poverty, as people have to pay higher rates for these basic services. Further, women and children have been the most marginalized and vulnerable for economic and social reasons and as a result of settlement patterns. Vulnerability in urban areas to climate variability and sea level rise is thus highly varied spatially, racially, and along gender and age lines.

1.6 Economic profile

South Africa is a so-called middle developing country with well developed financial, legal, communications, energy and transport sectors, mainly in the urban areas. The country has enjoyed a 5% economic growth rate for more than 14 consecutive years. Following the global economic recession, this figure plunged in 2009, but has recovered somewhat in 2010, and is expected to continue this recovery. The seasonally adjusted real GDP at market prices for the first quarter of 2009 decreased by an annualised rate of 6.4% compared with the fourth quarter of 2008, after peaking in 2006 at 5.6%.

South Africa has an abundant supply of mineral resources and is a world leader in mining and minerals, with significant global reserves and production. The economy was originally built on natural resources, with agriculture and mining being the major components of the GDP. Due to low gold prices and the marginal nature of many of South Africa's gold mines, several thousand workers have lost their jobs over the past few years, including migrant workers. South Africa's mining industry is, however, still one of the country's main employers. The coal industry is the second largest mining sector after gold. Although mining outputs has declined recently, coal mining saw an increase in the same period, with annual coal sales topping R70 billion. The coal mining industry contributes 65 000 jobs and iron ore another 13 000 (ILO 2009), making the extractive sector a significant job creator in South Africa.

Working from this strong base, South Africa's economy is now significantly diversified, and new growth sectors are emerging. There has been strong growth in the tourism sector since 1994, with an average growth of 6% over the past five years and a contribution of about R79 billion, or 8.2% of national GDP.

In response to problems of inequality, poverty and high unemployment, successive governments since 1994 have put in place initiatives such as the Accelerated and Shared Growth Initiative for South Africa (AsgiSA), formally launched in 2006. AsgiSA has a primary aim of the halving of poverty and unemployment by 2014 and committed South Africa to a target of a 4.5% growth rate from 2005-2009 and a 6% growth rate from 2010-2014, as the main means of poverty reduction and addressing the constraints of job creation and economic growth. The AsgiSA framework includes the Expanded Public Works Programme (EPWP), which was begun in 2004 and aimed at creating one million job opportunities over 5 years by 2009; an infrastructure investment programme; and education and skills development. It aims to address deep-seated inequalities by targeting the marginalised poor, thus bridging the gap with the so-called "Second Economy". National government envisions a substantial increase of up to 8% of GDP in government infrastructure expenditure, intended to reverse the backlog in public infrastructure.

Recently, the newly constituted Ministry in the Presidency, Planning, released its Medium-Term Strategic Framework (MTSF) 2009-2014. This document outlines government's Vision 2025, incorporating much of the AsgiSA agenda, and encompassing a set of objectives based on the electoral mandate, with a fifteen-year time horizon from 2010.

The MTSF 2009-2014 main economic priorities are: to speed up economic growth and transform the economy to create decent work and sustainable livelihoods; an extensive programme to build economic and social infrastructure; put in place a comprehensive rural development strategy linked to land and agrarian reform and food security; strengthen the skills and human resource base; pursue regional development; and build a developmental state including improvement of public services.

1.7 Energy profile

1.7.1 Non-renewable energy reserves

South Africa has an abundance of coal (Table 1.1). Being reasonably cheap, it meets the bulk of South Africa's primary energy needs. In terms of energy reserves, South Africa is estimated to have 55 billion tonnes of coal, with technology being well developed and inexpensive. Coal resources/reserves are currently under re-appraisal. Oil reserves are sufficient for four years' production, with untested deep-water potential. SASOL monopolises the coal-to-liquid petroleum industry. Natural gas reserves are estimated at 11.8 million barrels of condensate (managed by the parastatal PetroSA) and there are additional reserves newly under production license at Ibhubesi on the north-west coast of South Africa. Uranium beneficiation (conversion and enrichment) and fuel fabrication takes place outside the country.

Table 1.1. Primary formal energy consumption and supply in South Africa in 2008-2000

	COAL	OIL	BIOMASS	GAS	NUCLEAR	HYDRO	WIND	SOLAR	TOTAL %
SUPPLY	76.5	20.2			2.3	1	negligible	localized	100
CONSUMPTION	70.8	17.8	8.7	1.2	0.7	0.7	negligible	localized	99.9

Source: Consumption: BP (2008);
Supply: http://www.dme.gov.za/pdfs/energy/planning/integrated_energy_plan_dec03.pdf

1.7.2 Renewable energy potential

Renewable energy capacity is not yet well developed or exploited and there is little official focus on renewable energy sources. There is a largely untapped solar based resource; the western parts of the country are well suited to this, as they have significant number of sunny days. There is substantial biomass used for co-generation of heat and electricity in the paper and sugar industries, as well as biogas generated from waste biomass in breweries and other private institutions, but the potential for biomass exploitation and cogeneration is substantially higher. The Department of Energy intends to encourage registration of possible projects for climate change mitigation benefits. Government has proposed a 2% penetration level of biofuels in the national liquid fuel supply (400 million litres pa) (Jumbe 2007). To this end, South Africa's Industrial Development Corporation and Energy Development Corporation have invested R3.2 billion in 2 biofuels projects that collectively should produce 190 ML bio-ethanol from sugarcane and sugarbeet, with erection of the plant set for 2009. 1 biodiesel project is also planned. There are also more than 200 small-scale biodiesel producers using recycled vegetable oil as feedstock.

Wind energy is not mentioned in the 2003 government integrated energy plan, although it was expected to contribute to the 10 000 GWh by 2013 target stipulated in the White Paper on Renewable Energy (DME 2003). Wind energy development to date has been minimal with the Western Cape having two demonstration wind farms (Klipheuwel and Darling) generating a little over 5MW. However, as South Africa has well researched, substantial wind energy potential, the country could still benefit from tapping into global technological advances, likely to be driven by private investment. A further 2.3% is provided by hydroelectric and pumped storage schemes, but as a classified "water stressed" country South Africa has limited hydropower potential.

1.7.3 Electricity generation

Eskom (the state-owned Electricity Supply Commission) enjoys a practical monopoly over the supply of electricity. It has capital up to 2013 to embark on a R385-billion (US$51-billion) new power generation expansion programme. This plan includes building new coal-fired power stations and reviving three older "moth-balled" ones. Two new power stations are currently under construction, each with an installed capacity of 4 800MW. While its loan application to the World Bank (and subsequent approval) attracted much opposition within and outside the country, the motivation was that the development of the national economy is heavily dependent on energy as its driving force, in the form of coal and electricity (see Table 1.1 above).

South Africa has a nominal capacity of 43 037MW, managed by Eskom, the national electricity utility: it sold 224 366GWh of electricity in 2008 compared with 207 921GWh in 2006. It has been one of the world's lowest-priced power suppliers: between 1998 and 2007, the real price of electricity declined by 12%. Eskom generates about 95% of the total electricity in South Africa. The company is ranked one of the top utilities in the world by generation capacity, and is among the top nine by sales. Eskom intends to begin diversifying its primary energy mix (using less coal) and is building open-cycle gas turbines at two locations. The government and the coal-mining industry are fostering clean coal technologies in South Africa and Eskom has commissioned an underground coal-gasification pilot plant.

The target mentioned above of 10 000 GWh per year of total energy demand being met by renewable energy by 2013 constitutes between 4 and 5% of current total energy generation in South Africa. Of biomass, wind, solar and small hydro, biomass is currently estimated at 8% of South Africa's primary energy supply, thus often perceived as being by far the largest potential contributor to renewables. South Africa has good potential for solar energy, with a high annual solar radiation average. So far between 2 and 5MW of electricity in the national grid is generated from wind. About 500 wind turbines on farms generate direct current electricity, usually at 36V. South Africa has 661 MW of domestic installed hydropower.

Eskom's Demand Side Management efforts include the roll-out of Compact Fluorescent Lamps (energy efficient light-bulbs), subsidized solar water heaters, and energy efficiency and load management projects. Eskom also carried out load shedding during periods of supply capacity overload, with negative impacts on industry, especially the mining sector and small businesses.

Most of South Africa's liquid fuels production comes from synthetic fuels. The Energy Information Administration (EIA) (2007) contends that over 50% of total oil consumed (519 000b/d) in South Africa comes from imports. South Africa has very limited oil reserves and about 95% of its crude oil requirements are met by imports.

Sasol and PetroSA are the two major players in the synthetic fuels market. Sasol is the world's largest manufacturer of oil from coal, using a process of gasifying the coal and then converting it into liquid fuels and petrochemical feedstock's. Environmental concerns pose the main challenge to coal as an energy source.

Natural gas production in South Africa was 3 256 million m^3 in 2008, all of which was consumed locally (EIA 2010). South Africa is endowed with large reserves; about 48 000m tonnes (5.7% of the world total) are economically exploitable (BP 2008). The three major energy-consuming sectors are industry, residential and transport. The introduction of natural gas is in compliance with the White Paper on Energy Policy (1998) by diversifying primary energy supply. The Ibhubesi gas field off the Northern Cape of South Africa is presently the only explored gasfield containing potentially commercial volumes of gas. Ibhubesi Gas is expecting to output 2.8 million m^3 a day from 2012, increasing to 6.4 million m^3 of natural gas.

1.7.4 Energy consumption

According to the BP statistics (2008), 2007 saw South Africa's primary energy consumption being at 127.8 mill tonnes of oil equivalent. In comparison, in 2008 proven oil reserves were at 15 mill barrels and the gas reserves at 0.318 trillion cubic feet. Non-commercial biomass energy is mainly used in rural areas and is currently not being replenished. There has been a massive drive through the Integrated National Electrification Programme since 1994 to increase the extent of the population with access to electricity from 36% to approximately 71% in 2004. The Government, through the former Department of Minerals and Energy, implemented a Free Basic Electricity programme, which provides that qualifying households that are connected to the national grid will receive 5okWh of electricity free per month. In 2003 this was extended to areas not on the national grid, to the Free Basic Alternative Energy Programme.

1.7.5 Government policy

The mission of the Energy Efficiency Directorate of the Department of Energy is to develop measures to promote energy saving, reduce the adverse impacts of energy use on the environment, reduce energy costs to the economy, contribute towards sustainable development, and to achieve a national energy policy. The National Energy Efficiency Strategy of South Africa, approved by Cabinet in 2005, sets the target for improved energy efficiency in South Africa at 12% by 2015. Policy changes due to the findings of the cabinet approved Long-Term Mitigation Scenarios of 2007 may potentially affect the way in which South Africa's energy use develops, particularly with regards to coal. While the country is unlikely in the short term to be deflected from its growth needs and requirements (largely coal-based), South Africa is cognisant of the necessity to avoid the potentially damaging impacts of unmitigated climate change. Efforts to achieve this outcome can already be seen in the public sector where various provinces and sectors have adopted or are in the process of examining climate change and energy strategies.

1.8 Industry profile

The South African economy was largely built on and is still heavily dependent on the mining industry (Table 1.2). It accounts for 6% of GDP directly, and about 17.5% indirectly, and is a significant contributor to net exports and to employment. However, mining production fell by 1.6% in 2006, and 0.8% in 2007 (attributable to depletion of reserves as well as to international factors). The Eskom power crisis of 2007 took its toll on this sector, with mines only receiving 90% of their required energy needs. Safety shutdowns also resulted in loss of production.

Tourism is a growth sector: its contribution to GDP is estimated to have increased from 8.1% in 2007 to 8.5% in 2008, now greater than mining's contribution. It is also a job creation sector, and tourism jobs increased by 10% in 2008. Tourists rate the country's natural scenic beauty highest in tourist satisfaction scorecards (SA Tourism 2008 Annual Report, Appendix 6), and this is seen as an economic driver.

While the economy has shifted to being dominated by the tertiary sector, it is primarily the secondary and primary sector (particularly mining) which impact most negatively on the environment, as well as the transport industry in the tertiary sector. The National Spatial Development Initiative continues to prioritize state capital investment in areas of high economic growth potential which can improve local socio-economic conditions.

Table 1.2/...

Table 1.2. The contribution (% of total value added) of different sectors of the South African economy between 1980 and 2007. Source: SA Reserve Bank Quarterly Bulletins

Sector				
	1980	1990	2000	2007
Primary	**14.3**	**12.9**	**10.8**	**8.5**
Mining, quarrying	11.2	9.3	7.6	6.1
Agriculture, forestry and fishing	3.5	3.7	3.3	2.4
Secondary	**28.7**	**25.6**	**24.2**	**23.7**
Manufacturing	20.3	20.0	19.0	17.7
Construction	4.2	3.3	2.5	3.8
Electricity, gas, water	1.9	2.6	2.7	2.3
Tertiary	**55.0**	**60.9**	**64.9**	**67.8**
Financial services, real estate, business services	14.5	16.4	18.6	22.2
Community, social and personnel services (incl govt)	19.8	23.5	22.0	19.4
Wholesale/retail trade, catering and accommodation	12.7	13.7	14.6	15.4
Transport, storage, communication	7.2	7.2	9.6	10.7

1.8.1 Transport

South Africa's transport sector is dominated by road travel, but has good port and rail infrastructure, and a growing air travel industry. Domestic travel is hindered by the vast distances between settlements, and low density settlement patterns. Nonetheless, 60% of all human transport is on foot or by bicycle, with 37% being by road and 2.5% by train. Within the road transport sector, 19% are private vehicle trips, and 11.5% are by minibus/taxi - South Africa has a higher than world average car ownership ratio. This can be attributed to poor spatial planning at an urban and regional level.

The taxi industry continues to grow (63% of the commuting share, compared with 22% for the bus sector, and 15% for trains), and a recapitalisation programme was introduced to formalize the taxi industry. Major metropolitan areas are adopting Bus Rapid Transport (BRT) system along the most centralized and congested routes, and integrating it with the existing taxi industry.

While road transport offers the greater convenience, it creates air pollution, congestion, and energy consumption. The freight sector is no better, with trucks damaging road surfaces. Efforts are being made to regulate overloading in road transport, and to better integrate the secondary economy into the freight services industry.

Metrorail manages passenger rail in the major urban centres, and is heavily subsidized by the State. A turnaround strategy is being funded to upgrade rolling stock and signalling infrastructure, in an effort to revive passenger transport. The Gautrain Rapid Rail Link between Johannesburg and Tshwane is anticipated to reduce related commuter traffic by 20%. There is huge potential for freight and passenger rail to serve as an energy and carbon saver. Only 13% of freight tonnage is moved by train, and potential for expansion of the rail freight industry could be great, as the existing infrastructure is extensive and technologically advanced, with strong regional links and interests. Shortcomings have been identified by the Department of Transport (DOT 1998).

South Africa has seven international ports along its coastline, and has the best developed network of ports in Africa. About 98% of South Africa's exports are conveyed by sea. There are state plans to invest almost R50bill in rail and port infrastructure.

The air travel industry was deregulated in the early 1990's, and along with increased international travel, has resulted in a 10% increase in air travel pa over the last 3 years, to 32.8 mill passengers in 2008.

1.8.2 Agriculture

Agriculture, forestry and fishing together accounted for approximately 2.8% of GDP in 2006, following a slow downward trend. While it is diversified, it is estimated that the majority (48.2%) of income was from the sale of animals and animal products, followed by field crops (26.7%), and horticultural produce (25.1%) in 2008/9 (DST 2010). South Africa's largest agricultural commodity by mass in 2007 was sugarcane. Indigenous cattle meat is also a significant agricultural commodity, followed by indigenous chicken meat, grapes and cows' milk (http://faostat.fao.org/site/339/default.aspx). Most of South Africa's food processing industry is based in Gauteng and the Western Cape, and value-added agriculture includes canning, drying and processing. The sector is dualistic in nature, dominated by a sophisticated, large scale commercial farming sector, but including a small scale and subsistence sector.

There is a clear trend towards "corporatization" of farms (based on the globalization of food production and trade), with a corresponding drop in formal employment (28.8% over the same period) as a result of mechanization, and greater use of informal and seasonal labour (Stats SA, Census of Commercial Agriculture 2007). Only 4.3% of commercial agricultural land has changed hands through the land restitution and land redistribution programmes – against a goal of transferring 30% of land by 2014 (DEAT, undated), and boosting the small emerging black farming and subsistence sector.

The Department of Agriculture drafted a food security strategy for South Africa in 2002 in response to the lack of both coordination and effectiveness of government departments in working towards access to food and water for all. The goal is to ensure that the targeted population gains access to productive resources; or that they gain access to income and job opportunities to enhance their purchasing power; that they are empowered to have nutritious and safe food; that the state provides relief measures for the destitute; and that interventions will be informed by accurate information.

1.8.3 Fisheries

The fishing industry is a relatively small economic sector, contributing about 1% of GDP and employing about 16 854 people. South Africa has experienced significant declines in catches and loss of species as a result of over-fishing, and due to fish populations migration related with climatic and other changes. This has prompted government to apply controls to the fishing sector. The significance of subsistence fishing / marine harvesting, although small and localized, cannot be under-estimated in its role in assisting survivalist strategies. The Marine Living Resources Act has resulted in a significant restructuring of the fishing industry; however, this has not necessarily benefitted the small and subsistence fishing sector. Despite the legislation, little is being done to control poaching and illegal fishing, which are decimating particularly the high-value species. The aquaculture industry is small and growing slowly with government assistance.

1.8.4 Forestry

South Africa's plantation forests are based on alien trees, and cover 1.4% of the cultivated land. In 1996/7 the total turnover for forestry was around R13.1 billion and the industry employed more than 150 000 people. The exports are mainly converted, value-added products, with raw material exports only making up 1.8% of the total. The main products exported are pulp and paper (73% of the total export), sawn lumber, wood chips and wattle extract (OneWorld Sustainable Investments 2007). The private sector currently owns 70% of the total plantation area, as well as virtually all the processing plants. The Department of Water Affairs and Forestry (now Agriculture, Forestry and Fisheries) is currently involved in a process of restructuring the State's commercial forests and transferring ownership of these forests to the private sector. The rate of afforestation is declining due to a number of factors (DWAF 2007). The commercial forestry sector has made significant progress toward attaining sustainable forest management.

1.8.5 Waste

Following the world-wide trend, waste is becoming a growing problem, related to population growth and economic growth in South Africa. 87.7% of South Africa's waste was generated by the mining industry in 1997. The regulation of waste disposal has increased dramatically, with the Department of Water Affairs and Forestry (DWAF) Minimum Requirements (second edition 1998) for waste disposal by landfill; for the handling, classification and disposal of hazardous waste; and for water monitoring at waste management facilities. The EIA Regulations (managed by the Department of Environmental Affairs (DEA)) also curtails the environmental impact of waste activities (DEAT 2007a). There is an emerging trend at a local level to see waste as an economic opportunity.

1.8.6 Telecommunications

Telecommunications is one of the fastest growing sectors of South Africa's economy. The communications sector, together with transport and storage, accounts for almost 10% of gross domestic product (GDP). With a network that is 99.9% digital and includes the latest in fixed-line, wireless and satellite communication, the country has the most developed telecoms network in Africa. Wider access to broadband, ADSL and 3G access has boosted internet connectivity, with the number of South African internet browsers increasing by 121% between 2005 and 2007, according to research firm Nielsen/NetRatings. Bandwidth, however, remains relatively limited and expensive in South Africa, hampering the rate of economic growth. Access to telecommunication services is generally limited to the more populated areas. The government has committed to increasing accessibility and bringing down costs. The telecommunications sector has the potential to mitigate against further emissions and environmental damage, and contribute towards economic development.

1.9 Health

The high prevalence of HIV/AIDS (HIV prevalence rates in adults have increased from 15.6 to 18.8 between 2000 and 2005 [OneWorld Sustainable Investments 2007]) threatens and undermines not only the health sector, but the economy and the pursuit of the MDG's. Health indicators have declined in the research period: life expectancy has declined to about 48 in 2005 (from about 61 in 1990); infant mortality has increased from 45 to 55 per 1000 live births in the same period. The total number of new HIV infections for 2009 is estimated at 413 000, of which an estimated 59 000 will be children (Statistics SA 2009). Tuberculosis and malnutrition are also the current major health threats to people living in poverty, being impacted on, and exacerbating, the HIV/AIDS pandemic.

The other significant threat to human health is water scarcity, and its consequences of reduced water quality: "Diarrhoeal disease is the third largest cause of disease in children under the age of 5", as "3 million people still have no access to water and over 14 million do not have adequate sanitation." (OneWorld Sustainable Investments 2007). Flooding and droughts, which are common seasonal occurrences, exacerbate this problem, by reducing access to potable water.

Further, people living in informal settlements have all the major health burdens operating as a unique complex of disease by virtue of their socio economic and historical circumstances. These factors are growing, independently of any variability on climate. However, climate change and variability will increase the incidence of water scarcity. If it results in increasing forced rural-urban migration or regional migration, it will fuel the spread of HIV.

Other climate-related health concerns are the geographical spread of vector and waterborne diseases, and reduced air quality in major urban centres in zones of subsidence. South Africa's air quality is not regarded as being an overall problem, however many localised areas suffer extremely poor air quality that is harmful to health. The Air Quality Act (AQA 2004) provides for a "priority area approach", whereby the different spheres of government are responsible for developing air quality management plans. Under the AQA, the South African Weather Services and Department of Environmental Affairs and Tourism (DEAT) have established the South African Air Quality Information System, with the objective of developing the necessary information systems to set air quality improvement targets and to inform decision-making.

1.10 Education

While the number of learners in the 14-18 age group receiving secondary education has increased, there is a higher drop-out rate before completing school education. There is still a disparity between schools in resourced areas and in poor areas (and between provinces) with respect to educator:learner ratios, and learner:school ratios, but the national averages are 1:31 and 1:476 respectively.

South Africa has a well developed tertiary education system generally linked to the major metropolitan centres, with 16 universities and 7 universities of technology. South Africa spends relatively little on research and development (0.92% of GDP in 2007), as well as a low rate of research practitioners per 1000 population (0.61). Despite this low investment level, there are 73 "A-rated" researchers (considered world-class leaders in their field by their peers) according to the National Research Foundation.

A variety of research institutions do research in the field of climate change, for example the Council for Scientific and Industrial Research (CSIR), and the Human Sciences Research Council (HSRC). However, in terms of the actual number of researchers, and the number of peer-reviewed papers they have produced, the numbers have remained static in the last decade. This applies equally to those involved in climate change, and thus has a negative impact on the country's capacity to adapt to and mitigate against climate change and its effects (DEAT 2007b).

The Department of Science and Technology is responsible for "implementing the National Research and Development Strategy (NRDS), which was adopted in 2002. It provides for an integrated approach to human resource (HR) development, knowledge generation, investment in infrastructure and improving the strategic management of the public science and technology (S&T) system. Expenditure is expected to continue to increase rapidly, to R4.1 billion in 2009/10, representing an average annual increase of 20%. South Africa has to address what the NRDS identifies as the "innovation chasm", the gap that exists between the knowledge generators and the market. The establishment of the Technology Innovation Agency is expected to narrow this gap (http://www.gcis.gov.za/resource_centre/sa_info/yearbook/2009/chapter17.pdf).

1.11 Natural resources

1.11.1 Water

South Africa is a water-scarce country (annual freshwater availability is less than 1 700m^3 per capita), with limited average rainfall of about 490mm pa and unevenly distributed water resources (the majority of the land is semi-arid). The western part of South Africa is characterized by rainfall of less than 400mm per annum, increasing towards the east. A history of water system engineering has served to meet some of the demands of irrigated agriculture, mining projects and urban growth. A large proportion of people were left out of these developments during the years of racial segregation. Current government efforts to redistribute resources and to meet the needs of a growing economy, to ensure food security, maintain ecological integrity and environmental quality, are presently straining the water resource management sector severely.

River systems are the predominant source of fresh water, but these are small, and four of the major river systems are shared with neighbouring countries, which is leading to increased tensions over utilization and management. Ten of the nineteen river systems have water deficits, and there is competition between utilization for industrial and social demand, and to replenish the environment ("ecological reserve").

Surface water resources in most of South Africa are already fully utilised (DWAF 2004). It is estimated that there is still some undeveloped surface water resource potential, which could be captured through the construction of new storage dams or the raising of existing dams. However, there is potential in increasing re-use of return flows in some coastal cities, where waste water is currently discharged into the sea. Any further exploitation of groundwater could have negative environmental effects (DWAF 2004).

The key water-producing basins are located along the watershed of the great escarpment, and serve as the source for several large inter-basin water transfer schemes. Rainfall and hence flow in the nation's rivers is highly variable and erratic. Much of the country has a strongly seasonal rainfall climate and hence riverflow follows the same pattern. Less than 9% of rainfall runs off as river flow.

Anticipated climate changes include both an increasing intensity of extreme rainfalls, which will be good for groundwater recharge, but will have severe impacts on the sedimentation rate of the major reservoirs. Climate changes are likely to include lengthening dry periods between rainfalls when far more reliance will be placed on groundwater and water stored in reservoirs.

1.11.2 Groundwater resources

Only about 20% of groundwater occurs in major aquifer systems that could be utilised on a large scale (DWAF 2004). Groundwater is used extensively in rural and more arid parts of South Africa and is a significant resource to many irrigation farmers and especially small towns in more arid parts of the country and where surface water resources are already fully committed. Rural communities in many parts of the country are largely or wholly dependent on groundwater. A result of the intense reliance on groundwater is indicated by the constant slow decline in groundwater levels, despite the seasonal fluctuations, attesting to the unsustainable rates of use. This is also a result of poor management at national and local level. Groundwater resources of the country are poorly understood. Monitoring programmes in some regions are not adhered to and there is a lack of management of groundwater resources. Impacts of mining projects and their practice of groundwater removal are severe, but are underestimated or not taken into account. Groundwater quality is also an issue. Acid mine drainage is probably the biggest threat to groundwater, especially near coal and gold mining regions.

In general, the quality and availability of data on groundwater resources is not of sufficient standard on which to base sound management. Several trans-boundary aquifers need improved forms of management, and investment in scientific understanding. Several large dams and interbasin transfer schemes have been installed to address various needs such as urban development areas, water requirements of the thermal power generation, mining centres and some regions of agricultural activity. The sector is also under-resourced in terms human capacity.

Treatment of waste water has not tracked growth in demand and use. Poor water quality of surface waters is increasingly a problem in much of the country. Water is reserved in the National Water Act for maintenance of the ecological integrity of rivers and estuaries. Plantation forestry uses significant amounts of water, sometimes creating tensions with other streamflow users downstream. Forestry has been declared a Streamflow Reducing Activity and licenses are issued by the regulator, the Department of Water and Environmental Affairs (DWEA), so as to control the expansion of plantation forestry.

1.11.3 Use of water resources

The agricultural sector uses most of the available surface water resources in South Africa, about 62%, using various irrigation practices (Figure 1.2). Water demand by the urban centres is growing rapidly, stressing water supply systems.

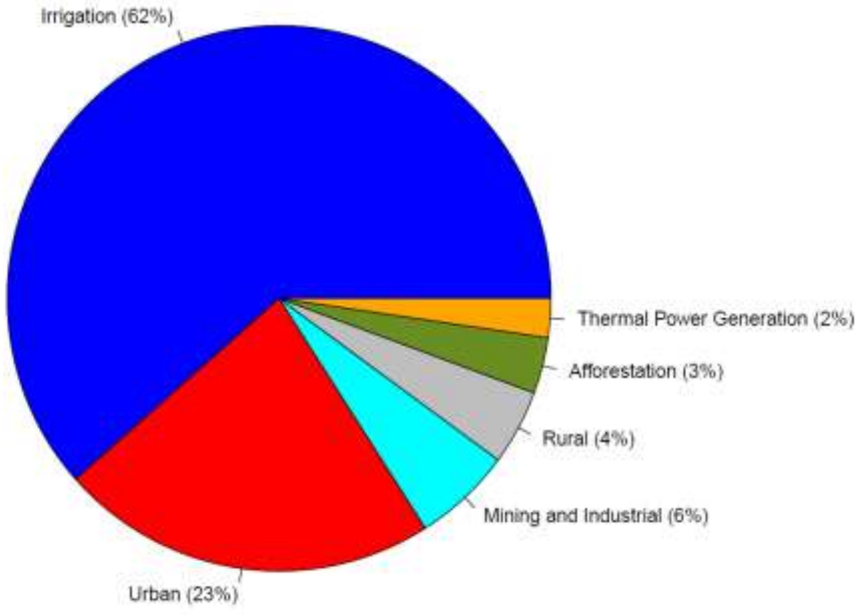


Figure 1.2: Current Water Usage per Economic Sector (Source: DWAF 2004).

1.11.4 Water distribution

In pursuit of the Millennium Development Goals, the state has increased access to basic water services by 9 million people since 1994, but this has been concentrated in the urban areas. By 2006, 3.3 million people still lacked access to adequate, clean water supplies, with another 15.3 million being without access to sanitation services (South Africa Yearbook 2006/07, 2007:600). However, it has been predicted that the water resources will be fully utilized in the next 20 years. Unless alternative water capturing methods are used and consumption patterns are changed, necessary changes will be forced on the country, and the poor and marginalized are likely to be hardest hit. Water demand is growing most rapidly in the main metropolitan centres, indicating a need for municipalities to manage and coordinate both the demand and the supply side. Generally, however, they are under-resourced, and this is likely to put them in competition with their hinterlands (DWAF 2004). Within the national department, the country is divided into 19 Water Management Areas, with the aim of decentralizing the management of water to stakeholders who are directly affected by water resource management decisions. This has however been difficult to implement successfully.

The Free Basic Water Policy of 2001 provides the first six kilolitres of water free to all households, as part of the government's strategy to alleviate poverty and improve public health. This is however widely seen as insufficient to meet basic needs, especially as many households include more than four people.

1.11.5 Marine resources

South Africa is rich in marine biodiversity, with 12 000 identified species, of which approximately 31% are endemic (generally reducing geographically from the north east coast). Sixty-five percent of South Africa's marine biozones are threatened, with 1% critically endangered, 15% endangered, 38% vulnerable, and 35% least threatened. Critically endangered marine zones occur primarily on the west coast, where both mining and commercial fishing are responsible (http://soer.deat.gov.za/themes.aspx?m=523). Apart from fishing, it is estimated that coastal resources contribute some 30% to GDP (http://www.mcm-deat.gov.za/about/index.html). Other marine resources include coral reefs, which are one of the natural systems most threatened by climate change (World Bank, undated).

1.11.6 Marine and terrestrial biodiversity

South Africa is one of the richest countries in terms of diversity of plants and animals (marine and terrestrial), and levels of endemism. But according to the *2004 South African national spatial biodiversity assessment*, 44% of river ecosystems, 23% of estuarine ecosystems, 12% of marine ecosystems and 5% of terrestrial ecosystems in South Africa are critically endangered (Driver *et al.* 2004). South Africa's forests have been reduced by 46%, mangrove swamps by 90% and grasslands by 60-80% over the past two centuries (Le Roux 2002). Invasions by alien species not only threaten endemic populations, but also consume up to 7% of the country's water resources.

Three of the 34 biodiversity "hotspots" identified internationally are in South Africa (the Cape Floristic kingdom, the Western Cape / Succulent Karoo region and the Maputoland-Pondoland region). These areas contain high concentrations of endemic species, in areas most threatened by human activity. South Africa's biodiversity management does not meet international best practice, nor does it holistically protect vital natural systems.

The White Paper on the Conservation and Sustainable Use of South Africa's Biological Diversity (1998) seeks to improve capacity to conserve and use biodiversity and to address threats; and create conditions and incentives that support conservation and sustainable use of biodiversity (http://www.environment.gov.za/soer/nsoer/Issues/land/response.htm).

1.11.7 Invasive alien species

South Africa has a long history of alien introductions through human movement, with a pronounced increase following the arrival of European settlers in the 17th century. All biomes have now been invaded, with the highest density of alien species occurring in the eastern parts of the country. South Africa currently hosts approximately 8 750 alien plant species, 180 of which are invasive (i.e. have established and are spreading) and have invaded about 8% of South Africa's surface area.

While over 700 alien terrestrial animal species have been identified, few have become invasive. South Africa is home to more alien ungulate species (for agriculture) than any other country in the world except the USA, but the impacts of these species are poorly understood. 37 of the 58 alien species of freshwater fish are invasive, and 4 of the approximately 85 alien marine species are invasive.

1.12 Antarctica and sub-Antarctic islands

While South Africa does not have a territorial claim in Antarctica, it is a founder member of the Antarctica Treaty. The South African research station, South African National Arctic Expedition (SANAE) IV has no permanent population, but maintains a small group of scientists conducting research in the natural sciences and meteorology. South Africa annexed Marion Island and Prince Edward Island, and also utilizes Marion Island as a marine and meteorological research base. Two key areas of study are meteorological and oceanographic research to better understand the process of global climate change, and geological investigations into the evolution of Gondwanaland (http://www.saasta.ac.za/antarctica/about.shtml), as well as fisheries related research.

1.13 National policy-making and legislative processes

South Africa ratified the United Nations Framework Convention on Climate Change in August 1997, giving impetus to a variety of policy-making and legislative processes, as well as institutional arrangements mentioned below. This should also be balanced with the Millennium Development Goals, to which the country is also committed.

The National Environmental Management Act (NEMA 2008) is an enabling Act providing a framework for government to meet its environmental responsibilities. The Act aims to improve environmental management while facilitating sustainable development and improving coordination and governance of environmental issues.

The purpose of the Air Quality Act (AQA 2004) is "to reform the law regulating air quality in order to protect the environment by providing reasonable measures for the prevention of pollution and ecological degradation and for securing ecologically sustainable development while promoting justifiable economic and social development; to provide for national norms and standards regulating air quality monitoring, management and control by all spheres of government; for specific air quality measures; and for matters incidental thereto." It has therefore been instrumental in monitoring and controlling greenhouse gas emissions, and in the Long Term Mitigation Scenarios.

1.13.1 The long term mitigation scenarios process

The Long Term Mitigation Scenarios process (under the then Department of Environmental Affairs and Tourism) brought together a team of the leading strategic thinkers from government, business and civil society in 2006 in a Scenario Building Team. Their focus was to inform Cabinet on what options it had in reducing carbon and greenhouse gas (GHG) emissions as part of its international, but also national, responsibility. It first developed the two extreme scenarios: Growth without constraints (greenhouse gas and carbon emissions continue to increase); and required by science (immediate stabilising and future reduction in emissions). Within these two "envelopes", the team developed four possible scenarios ranging from Current Development Plans (projections based on current policies and legislation) – still a "high growth" scenario; to Reach for the Goal (a suite of parallel options, emphasising future technologies and behaviour change) (DEAT 2007b). It is now broadly accepted that the key question is how to manage South Africa's emissions through a period of unavoidable increase to a plateau, and thereafter to decline. This is thought to be the most realistic to achieve.

1.13.2 National climate change strategies

A National Climate Change Response Strategy for South Africa was compiled in 2004, which aimed to address priority issues for dealing with climate change. The focus of the strategy is on adapting to climate change; developing a sustainable energy programme; adopting an integrated response by relevant government departments; compiling inventories of greenhouse gases; accessing and managing financial resources; and research, education, and training. This is being translated into a National Climate Change Response Policy, with work on sector-based adaptation strategies currently being launched under the mandate of the Department of Environmental Affairs.

Climate change-related observation, monitoring and research programmes are guided by national policy frameworks that include *the Climate Change Research and Development Strategy, the South African Earth Observation Strategy, and the Global Change Grand Challenge, part of Ten-Year Innovation Plan for South Africa (2008-2018)* under the mandate of the Department of Science and Technology. A science plan for the Global Change Grand Challenge is currently being finalised.

In terms of energy, in addition to the Renewable Energy White Paper target, a Renewable Energy Feed-in Tariff (REFIT) has been introduced by the National Energy Regulator of South Africa, although this is currently only a guideline, with institutional arrangements still outstanding.

The 2003 Renewable Energy White Paper makes a commitment for a mid-term (5-years) review. The policy is currently halfway through the target period of ten years. The Department has established a Renewable Energy Market Transformation (REMT) Project Unit which aims at eliminating barriers to renewable energy development, thus reducing greenhouse gas emissions and assisting the country to reach the 2013 renewable energy target and beyond.

The first national Integrated Energy Plan (2003) was a step in the direction of improving South Africa's energy mix, by taking a broad view of the energy sector, and while it still saw heavy reliance on coal and nuclear in the next two decades, it also emphasized renewable energy, energy efficiency, diversifying the energy resource base, greater environmental considerations with respect to energy production, consumption, and ensuring more equitable access to energy.

In terms of water, a complete revision of the water laws occurred when the National Water Act (Act 38 of 1998) was published. This effectively created the principle of "public" ownership of all water resources through the state. The Free Basic Water Policy of 2001 laid the ground for provision of the first six kilolitres of water free to all households, as part of the government's strategy to alleviate poverty and improve public health.

1.13.3 Other climate change strategies

Several Departments, parastatals and provinces are pursuing this route to address their needs and obligations. The Western Cape province launched their Climate Change Strategy and Action Plan in 2008. The city of EThekwini (Durban) has a strategy, and Cape Town produced an Energy and Climate Change Strategy in 2005. The Gauteng province is initiating theirs, as is Transnet.

Other stakeholders such as private and state enterprises are making headway in adopting climate change strategies, for example the Development Bank of South Africa (DBSA), Transnet, SASOL, Eskom, and the private sector through the National Business Initiative (NBI). ICLEI (International Council for Local Environmental Initiatives, now Local Governments for Sustainability) organizes the local government sector, and has its Africa headquarters in the City of Cape Town (http://www.iclei.org/).

1.14 Institutional arrangements around climate change

South Africa acceded to the Kyoto Protocol in 2002 but, as a developing country, it is not currently required to reduce its greenhouse gas emissions. However, during the second commitment period, which begins in 2012, South Africa may need to make commitments to cut back these emissions. The Department of Environmental Affairs and Tourism (DEAT, now the Department of Environmental Affairs, or DEA) is the designated lead department responsible for co-ordination and implementation of South Africa's commitments in terms of the Convention.

1.14.1 National climate change committees and bodies

There are some important cross-sectoral institutional arrangements in place: The Inter-Ministerial Committee on Climate Change, made up of political representatives, oversees the Intergovernmental Climate Change Committee (IGCCC), which consists of the relevant government departments. There is also a National Committee on Climate Change (NCCC), a multi-stakeholder forum, which advises the Minister of Environmental Affairs. Many relevant government departments, science councils, research institutions, organisations and agencies participate in various regional and international climate-change related work.
From within the DEA, the Chief Directorate for Air Quality Management and Climate Change set up a Government Committee on Climate Change (GCCC) to advise it on matters relating to national responsibilities with respect to climate change, composed of relevant government departments including: Agriculture; Health; Housing; Local and Provincial Government; Minerals and Energy; Trade and Industry, and Transport. The terms of reference for the IGCCC are to advise the Directorate on the formulation of National Climate Change Strategy and Policy. The GCCC participates equally in the NCCC to strengthen the Government's position. It also sits to discuss proposed Global Climate Change projects, including proposals under the Clean Development Mechanism (CDM) and other flexible mechanisms. It may also promote and, in certain circumstances, initiate research.

The NCCC includes representatives from relevant government departments, as well as members representing business and industry, mining, labour, community based organisations and environmental non-governmental organizations. The functions of the NCCC include advising and consulting the Minister of Environmental Affairs and Tourism on matters relating to national responsibilities with respect to climate change

– and in particular in relation to the United Nations Framework Convention on Climate Change and the Kyoto Protocol. The functions of the committee, among others, are: to design and participate in a process leading to the formulation of a national climate change policy and a national implementation strategy; to propose what studies need to be undertaken in support of the national climate change policy process, advise the Department to perform them, and review and disseminate the results; to communicate developments within the national and international climate change arena to their constituencies (http://www.deat.gov.za/Documents/Documents/2003May26/climate_change_sa_responsibility_26052003.html).

Observation, monitoring and research programmes are undertaken by relevant science councils, universities, government departments, agencies of government departments, municipal councils and public corporations. There is no over-arching coordination framework of the programmes although collaboration among research teams takes place from time to time.

Programmes at science councils cover wetlands and inland water systems, the atmosphere, agricultural land and rangelands, the Southern and Indian Oceans, marine ecosystems, coastal and estuarine ecosystems, savanna, forests and woodlands, and arid and semi-arid regions. The work involves detection of climate change, and assessment of its impacts on these diverse ecosystems. It also extends to developing mitigation and adaptation strategies. The foci of programmes at universities range from the scientific fundamentals of climate change, through the assessments of vulnerability and impacts, to the development of mitigation and adaptation technologies and strategies.

The programmes at agencies of Government Departments look at the meteorological fundamentals of climate change, impacts of climate change on biodiversity and habitats, impacts on the hydrological cycle and water resources, and climate change mitigation and adaptation. Provincial departments responsible for agriculture and environmental affairs have programmes that focus on greenhouse gas emissions and air quality, impacts of climate change on livestock, crops and rangeland activities, and the impacts of climate change on the frequency and severity of veld fires. Metropolitan Municipalities carry out monitoring of greenhouse gas emissions and air quality.

Eskom has a climate change related observation and research programme which focuses on the atmosphere, water systems and settled areas in and around selected power stations.

South African technicians, researchers and research institutions, organisations, agencies and departments also participate in various regional and international climate change-related observation, monitoring and research programmes.

By and large, research programmes in South Africa face challenges of design, infrastructure, funding, human capacity and weak science-policy interface. Priority areas for climate research are climate modelling, economic modelling of climate change impacts and response measures, climate change mitigation and adaptation, and stakeholder engagement and outreach.

1.14.2 Clean development mechanism

A Designated National Authority was set up in 2004, under the Department of Mineral and Energy (now the Department of Energy), to manage the domestic approval process of Clean Development Mechanism (CDM)projects. As a non-Annexure 1 (or "developing") country, South Africa is able to attract funding from "developed" countries for projects which have been measured to have high carbon offsets. Only one province has set up its provincial desk, with others to follow.

To date, 131 projects have been submitted to the Designated National Authority (as of 13 July 2009) and include 102 Project Idea Notes (PINs) and 29 Project Design Documents (PDDs).

Out of the 29 PDDs, 17 have been registered by the CDM Executive Board as CDM projects (four issued with Certified Emission Reductions). The projects cover various sectors (manufacturing, petrochemical industry, mining and energy supply) and involve renewable energy, cogeneration, fuel switching, waste gas reduction and energy efficiency. Most of the potential annual emission reductions come from fuel switches at 73% of the total number of projects, with cogeneration taking up the next 10%. The uptake of CDM projects has been slow because of the perceived low reward for setting up these projects (PACE 2009). They require strict validation and monitoring, have high technology requirements and intense management focus.

Contents

Chapter 2:

South African Regional Climate: Trends and Projections

2.1 The climate system: a brief overview

2.1.1 Planetary scale circulation and the South African climate

The regional climate of South Africa is determined mainly by large-scale hemispheric and global circulation in the ocean and atmosphere. Importantly for South Africa, it is located in a subtropical latitudinal band that is subject to subsiding air, resulting in a dry climate relative to the global average. The large scale global circulation pattern responsible for this is driven primarily by solar energy absorption which on average decreases gradually from the equator towards the poles. . Mid-latitude zones of subsiding air results from meridional planetary scale "Hadley cells" transport surface air from Earth's warmer equatorial regions by convection over Earth's heat equator (Inter-tropical Convergence Zone), to higher latitudes where the air subsides towards the surface. Because of coriolis forces caused by Earth's rotation, this air subsides mainly approximately 30º North and South, between the so-called Hadley (± 0º to 30º North and South) and Ferrel (± 30º to 60º North and South) meridional cells, as well as over the poles. While surface convection with adequate moisture can lead to adiabatic cooling and rain, the subsidence of air leads to a lack of rain and dry conditions. The latitudinal atmospheric pressure gradients also vary with inter-annual, seasonal and diurnal cycles, and while South Africa has a comparatively dry climate, these variations are associated with high intra- and inter-annual variability in rainfall. Changes in regional climatic conditions due to human causes are induced mostly by their impact on these circulation systems.

2.1.2 Synoptic disturbances and South African rainfall

The regional climate is further modulated by local and remote factors, including land surface and ocean interactions with the atmosphere. For example, during summer, differences in surface energy between the warmer southern African continent and colder surrounding oceans might lead to the development of continental synoptic scale surface troughs (lower pressures). These troughs are of great importance since their circulation pattern allows transport of atmospheric moisture from wetter equatorial African regions towards the eastern parts of South Africa where most of the summer rain falls. Figure 2.1 (middle) illustrates the zonal increase in January median rainfall from less than 5mm over the west to more than 160mm over the east.

In the westerly wind zone of the mid-latitudes cold fronts frequently propagate eastwards and towards the subtropics. They periodically sweep over the southern coastline of Africa or even over the southern African continent during austral winter months, bringing cold climatic conditions towards South Africa.

The interaction of warmer tropical air with these heavy cold air masses as they move eastwards mostly results in rising air, adiabatic cooling and rainfall spreading along the southern coastline of South Africa, as illustrated in Figure 2.1 (right). Since the eastward propagation of cold fronts is normally followed by anti-cyclonic flow from behind, a ridging high is often responsible for onshore flow of moist air bringing post-frontal rain that can extend from the southern coastline towards the coast of KwaZulu-Natal and Mpumalanga where topographic lift against the steep South African escarpment further contributes to cloud development and rainfall (Figure 2.1).

South African rainfall is therefore modulated by variable circulation forcing within a predominantly dry subtropics, and South Africa's annual rainfall ranges from less than 100mm in the north-west to almost 1200mm over the east (Figure 2.1 (left)) and on the southern margins, despite the country being located in this generally dry latitudinal zone. This leads to high rainfall variability which limits the current skill in forecasting weather and projecting climate, and makes the country, as far as rainfall is concerned, particularly vulnerable to conditions of climate change.

2.1.3 Near surface air temperatures

South Africa geographically location results in an annual seasonal temperature cycle that peaks in the austral summer during January, and reaches a minimum during July.

As shown in Figure 2.2 (left) averages of near surface daily maximum temperatures for January peak at over 30ºC in the north-western arid areas and Limpopo Province of the country, while milder maximum temperatures are recorded over the east, south-east and southern part of the country. Winter months are normally cold, with averages of near surface daily minimum temperatures for July of below -2ºC over Lesotho and extensive parts of the central Highveld. The coastal belt is somewhat warmer in winter (above 6ºC), with lower Karoo minimum temperatures ranging between 0ºC and 8ºC. It is important to note there are sometimes large fluctuations in intra-seasonal temperatures.

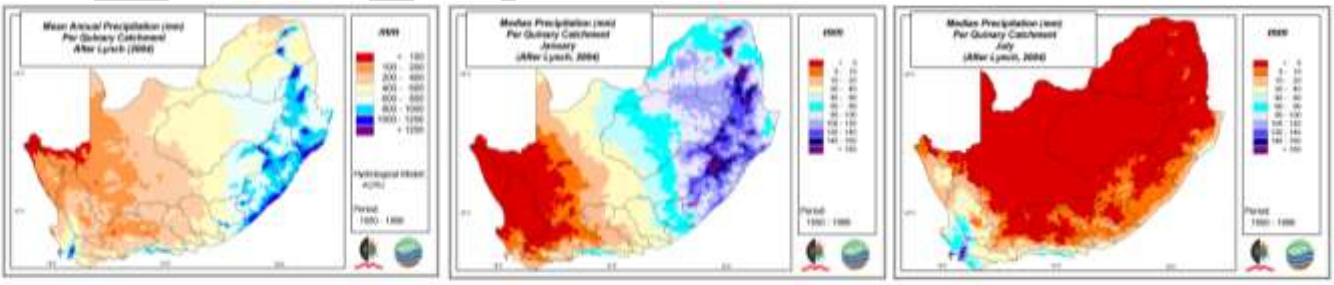


Figure 2.1: Mean annual precipitation in mm (left), and the associated median precipitation for January (middle) and July (right) as calculated over the period 1950 - 1999. From Schulze (2010).

2.2 Understanding change information

Conventionally, climate is often described as the mean or median values of temperature and rainfall. However, in terms of societal impacts and relevance to different sectors and natural systems, regional variations are important. This implies that the communication of climate information becomes more nuanced and includes a range of concepts that are central to correct interpretation of data and information.

2.2.1 Detection versus attribution

The starting point in assessing regional climate change is to ask "what has already changed?" The automatic (but possibly incorrect) inference is that identified changes are attributable to anthropogenic climate change. Detection of change is a comparatively simple task, but attribution – that one can ascribe the cause of the detected change – is considerably more difficult. Detection of the change in global mean temperature has long been established, although attribution of much (but not all) of this change to human factors is only a recent development (see IPCC AR4, 2007).

On regional scales detection of change is likewise comparatively easy. However, attribution of identified regional change has yet to be robustly demonstrated. While plausible and persuasive arguments may be made for attribution of historical change, the formal attribution to differentiate this from natural variability is much more difficult. Typically such work involves modelling the climate system with and without greenhouse gas forcing to assess the degree to which regional change is attributable to human factors.

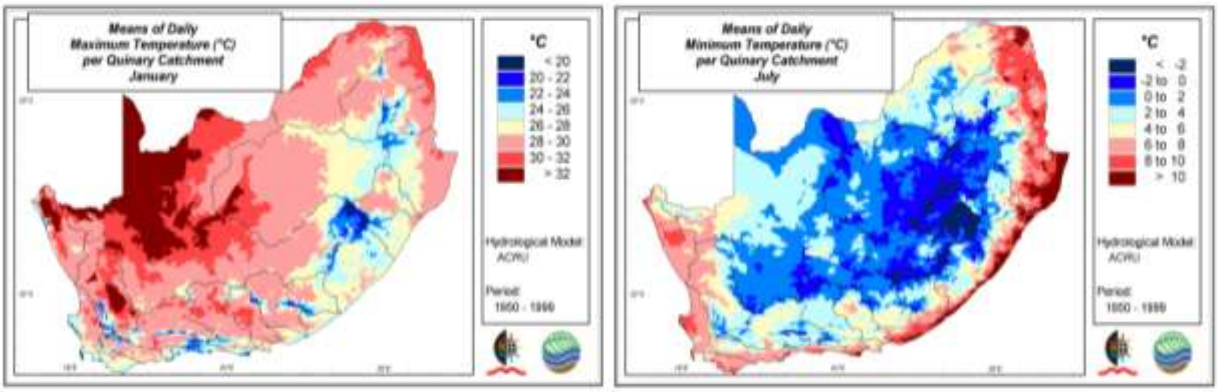


Figure 2.2:
Means of daily maximum temperature for January (left) and daily minimum temperature for July (right) in °C as calculated over the period 1950 - 1999. From Schulze (2010).

2.2.2 Principles of robust regional change messages

Developing a robust understanding of regional change on the time and space scales of relevance requires the integration of information from number of sources:

- *past trends in climate* - note that these are not a guarantee of future change;
- *changes in driving processes on synoptic to global scales* - assessing the physical basis of the climate system that gives rise to the regional climate;
- *model projections of change* - exploring the simulated regional response of the earth system to the anthropogenic forcing against a background of natural variability;
- *regional expressions of future global change* - these are usually derived through dynamical and/or statistical downscaling;
- *assessment of uncertainty* - all information is limited by a wide range of uncertainty sources that do not preclude deriving value information, but which does cloud the issue to differing degrees.

By drawing on the understanding of these complementary aspects it is possible to develop a more robust understanding of the climate system variability and change on regional scales. Ignoring one or other source of information leads to a risk that key element of the information will be missed. Moreover, the research on each of these aspects is not equally mature, and is continuously evolving. Thus it requires responsible recognition that numbers (data) are not information, that information is not knowledge, and that deriving robust messages requires critical assessment in the context of the intended application, and revisiting the subject as the science evolves.

2.2.3 Envelopes and thresholds

There is one past, but many possible futures. In mapping future projections one needs to explore the envelope of possibilities. As such, projections of future climate implicitly must take cognizance of the range of projections subject to factors such as, alternate greenhouse emission scenarios, different model responses, and that all projections are likely only a subset of the true envelope of possibilities.

Secondly, the interpretation of climate information is necessarily tied to thresholds. A shift in mean climate is largely of minimal value in terms of impacts, vulnerability, and adaptation. Systems (biophysical or societal) operate within limits, and it is through exceeding these thresholds that the impact of change is most commonly found. As thresholds are specific to the sector under analysis it is difficult to generalize regional climate change impact messages.

There are four levels of value in climate change messages, each progressively more difficult to attain:

- Whether or not it is possibility to generating useful information for a given location / variable (it is not always possible to generate a useful message on regional change);
- The likely direction of change (positive or negative, or equally importantly, no change if significance);
- The attributes of indicated change (changes in the mean, the extremes, derivative parameters, etc.);
- The absolute magnitudes of change, or at least the probable range of magnitudes.

2.2.4 Uncertainty

The question of uncertainty is arguably the single largest issue currently faced when dealing with climate change. Importantly, uncertainty does not mean that there is no information, but merely that the information is not definitive. There are many possible sources of uncertainty, and include issues of emission scenarios, the choice of climate models, quality of historical data, methods to downscale global data, amongst others. An often ignored attribute of uncertainty, yet one particularly relevant to South Africa, is what may be termed "boundary uncertainty". This refers to the situation where a geographic region of concern lies on the boundary of two regions showing strong, but opposite direction of change. In this case the change in the region is highly sensitive to the spatial position of that boundary.

2.3 Observed historical change

In assessing historical change it should be borne in mind that historical trends are strongly dependent on the time period being assessed, choice of start and end date, positioning of outlier events within the time series, and missing data.

Within the subcontinent the most comprehensive analysis (albeit with few locations) is the outcome (New *et al.* 2006) of the 2004 workshop by the World Meteorological Organization/Climate Variability and Predictability Expert Team on Climate Change Detection, Monitoring and Indices. A leading indication from this study was the cohesive spatial agreement in change across the sub-continent for a broad range of parameters. Subsequently, numerous studies have assessed different attributes (e.g. Fauchereau *et al.* 2003; Hulme *et al.* 2001; Kruger and Shongwe, 2004). The common message emerging from these and other studies is that the region displays clear detectable signals of change, especially in terms of warming.

These changes are not amenable to simple generalizations as there can be marked differences within a sub-region between stations even in close proximity, or as a function of season or proximity to topography and other physiographic factors.

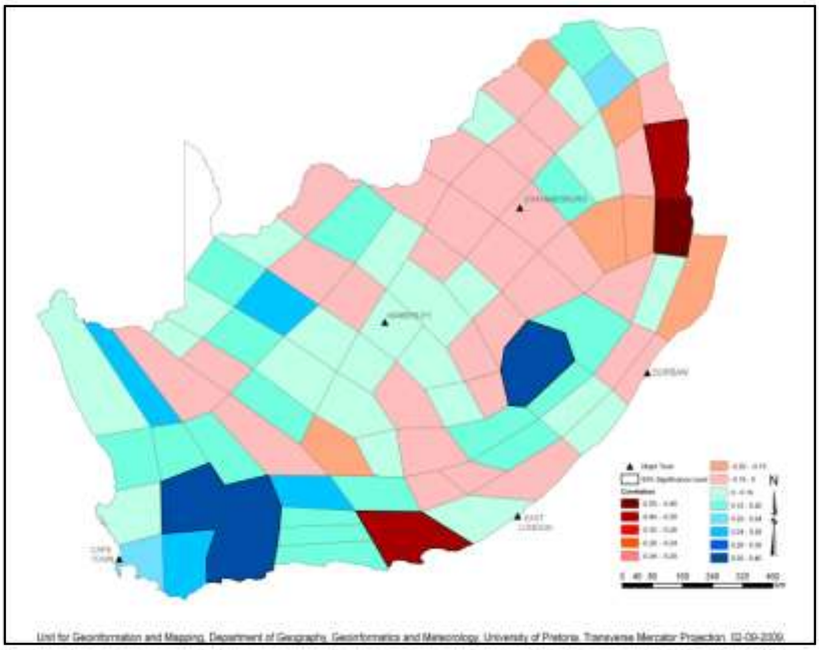
2.3.1 Trends in annual and monthly rainfall

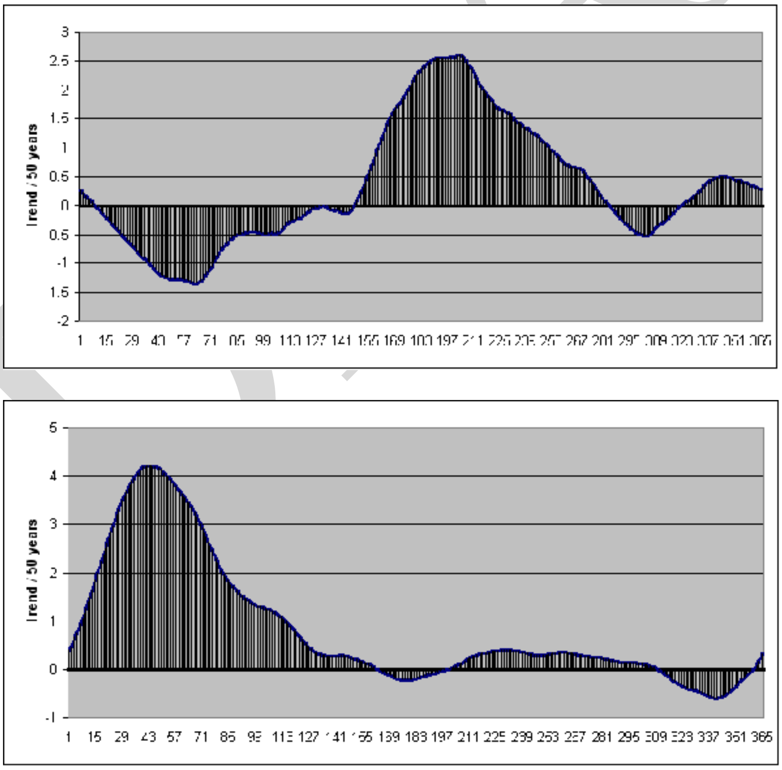
In most published studies no clear evidence of statistically significant spatially coherent rainfall trends could be identified in annual rainfall totals, although non-significant patterns are visible. These have been explored in preliminary analyses that are not yet published (Rautenbach, *pers. comm.*).

Figure 2.3, for example, illustrates consistent linear trends in annual district rainfall totals over a period of 50-years (1959 to 2008). Statistically significant changes point towards predominantly positive trends over the south-west (winter rainfall region) and negative trends over the north-east (summer rainfall region) of South Africa. Over the south-western and north-eastern districts these trends are spatially coherent with the surrounding non-significant trends. Most obvious in monthly trends are the negative trends for the month of April, which compares well with positive trends found in monthly averaged temperature.

Other ongoing work (Hewitson, *pers. comm.*) explores trends through assessing the trend robustness as a factor of time period and missing data (Figure 2.4). This approach and explores trends in a wide range of derivative attributes such as frost days, rain day frequency and dry spell duration, and provides an estimate of uncertainty. This analysis indicates that the heterogeneity of trends is predominantly a function of sub-annual period, and that there can be spatial variations, even within a local region.

Figure 2.3: Consistent linear trends of annual district rainfall totals (mm) as calculated for the period 1959 to 2008 (50-years). Districts with positive (blue) and negative (red) trends of above the 95% confidence level have thicker border lines. District rainfall data were obtained from the South African Weather Service (SAWS). Note that district rainfall averages across low-laying and mountainous regions, and should not be taken as representative for all locations in the district.





Trend in frequency of days with rain > 10mm

Trend in duration of average dry spell

Figure 2.4: Median trends between 1951 and 2000 (Stellenbosch, Western Cape), for a 60-day window centered on each day of the year, illustrating the sub-annual complexity that can exist, and which limits generalized statements of historical change. Trend is the median of all trends over the 50 year period, considering different start and end times for the calculation of the trend.

In many recent studies there is a strong agreement that there has been an historical increase in rainfall intensities and an increase in dry spell duration and drought (e.g. Zhang *et al*. 2007, Dai *et al*.2004) These changes are both consistent with physical understanding of anthropogenic forcing on the driving atmospheric processes.

Ongoing work indicates that strong trends do occur in South Africa at local and sub-seasonal scales, but significant work needs to be done to understand the complexities of spatial and temporal historical change. While large scale general assessments indicate some clear trends, these hide important regionally specific trends that can be significant.

2.3.2 Trends in near surface temperatures

The most complete recent study on South African temperature trends is that of Kruger and Shongwe (2004). Temporal and spatial linear trends were derived for annual, seasonal, monthly and diurnal temperatures from a 44-year record (1960 to 2003), and for a total of 26 stations that are distributed all over the country.

Annual temperatures: Kruger and Shongwe (2004) detected a general pre-dominating positive annual average temperature trend at 24 out of a total of 26 stations, with 18 stations having significant trends (Figure 2.5). Spatially, positive trends are more obvious over the western interior, the Cape, and KwaZulu-Natal Province. These results are consistent with previous findings. A high percentage of 88% of the stations recorded positive annual mean maximum temperature trends, with trends higher at coastal stations compared to continental stations over the eastern interior. Over the western interior maximum temperature trends were higher than at the coastal. A percentage of 81% of the stations had positive mean minimum temperature trends, with smaller trends over the interior compared to coastal stations. Urban stations showed lower trends than did non-urban stations, indicating that these average trends are not the result of the urban heat island effect. Kruger & Shongwe suggest that most of this warming occurred during the early 1980's.

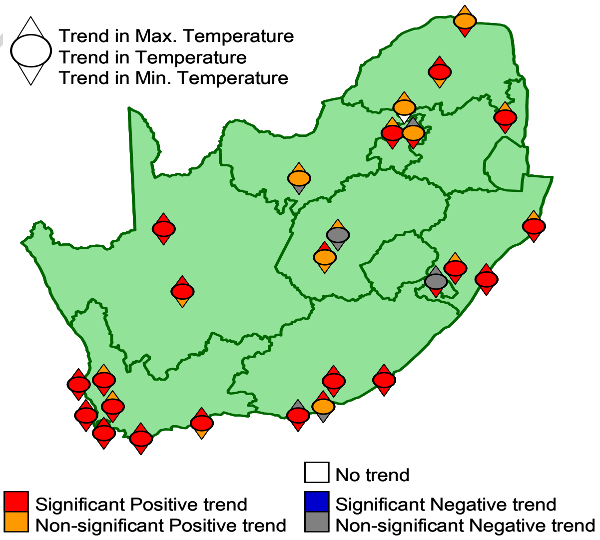


Figure 2.5: Trends in mean annual maximum, minimum and average temperatures as obtained from a record of 44-years (1960 to 2003). Adapted from Kruger and Shongwe (2004)

2.3.2.1 Seasonal and monthly temperatures:

In the seasonal mean temperature trends analysis by Kruger and Shongwe (2004) it was found that temperature trends are not consistent between seasons (Seasons defined as summer: December to February, autumn: March to May, winter: June to August, spring: September to November). The average trend for all 26 stations examined were found to be +0.21ºC, +0.13ºC, +0.12ºC and +0.08ºC per decade for autumn, winter, summer and spring, respectively (Figure 2.6). Autumn was identified as the season with the highest increase in temperature per decade.

On a sub-seasonal time scale of months, large temporal differences were found to appear in temperature trends for individual stations, although some temporal similarities with respect to differences in trends from month to month were found to exist. A significant number of stations spread over the central and eastern parts of the country (15 out of 26) had experienced the largest positive trends in mean temperature during April. The April temperature trend is also noticed in spring temperature trends (Figure 2.6). The months of largest minimum trend appears to fall in the late spring and early summer (September to December). Poor spatial coherence in monthly maximum and minimum trends appear over the Western Cape, but several stations in this region show significant mean monthly maximum and minimum temperature increases in the last three decades of 1°C, and even more in some cases, for several months (Midgley *et al*. 2005).

Diurnal temperature range: Findings usually indicate that observed minimum temperature trends generally appear to be higher than maximum temperature trends. Trends in the diurnal temperature range are therefore often found to be negative. Trends in the annual mean diurnal range are rather evenly distributed in South Africa, with a mixture of positive and negative values. Mixed trend signals occurred at coastal stations, while a significantly high positive trend occurred at stations in the southern Free State, Northern Cape and North West Provinces, mostly due to high trends in annual mean maximum temperatures.

Extreme temperatures: In the records of maximum temperatures (Tx) days with warmer temperatures have appear to have increased in frequency over the past 44-years, while days with cooler temperatures have decreased (Kruger and Shongwe, 2004). Hot (30ºC ≤ Tx < 35ºC) and very hot (Tx ≥ 35ºC) days were generally rare, but more common in the interior, especially at Upington and Vanwyksvlei, where very hot days have increased, and Polokwane, Skukuza and Durban where hot days have increased. Cool days (Tx ≤ 15ºC) are generally on the decline, confirming again that temperatures have generally risen over South Africa. The records of minimum temperatures (Tn) revealed that most warmer night have decreased while cooler nights have decreased, with cold (0ºC < Tn ≤ 5ºC) and very-cold (Tn ≤ 0ºC) nights were rare and less common along the coast. Hot nights (Tn ≥ 20ºC) have increased significantly at East London, Durban and Cape St Lucia (east coast), as well as at Skukuza. An increase in warm (15ºC ≤ Tn < 20ºC) nights was recorded in the Western Cape and parts of the Eastern Cape, and scattered over the rest of the coast and interior.

Along with the New *et al.*(2006) study for southern Africa, the key messages are that clear large scale changes exists, and especially a pattern of increased hot days with, to a lesser degree, decreased extremely cold days.

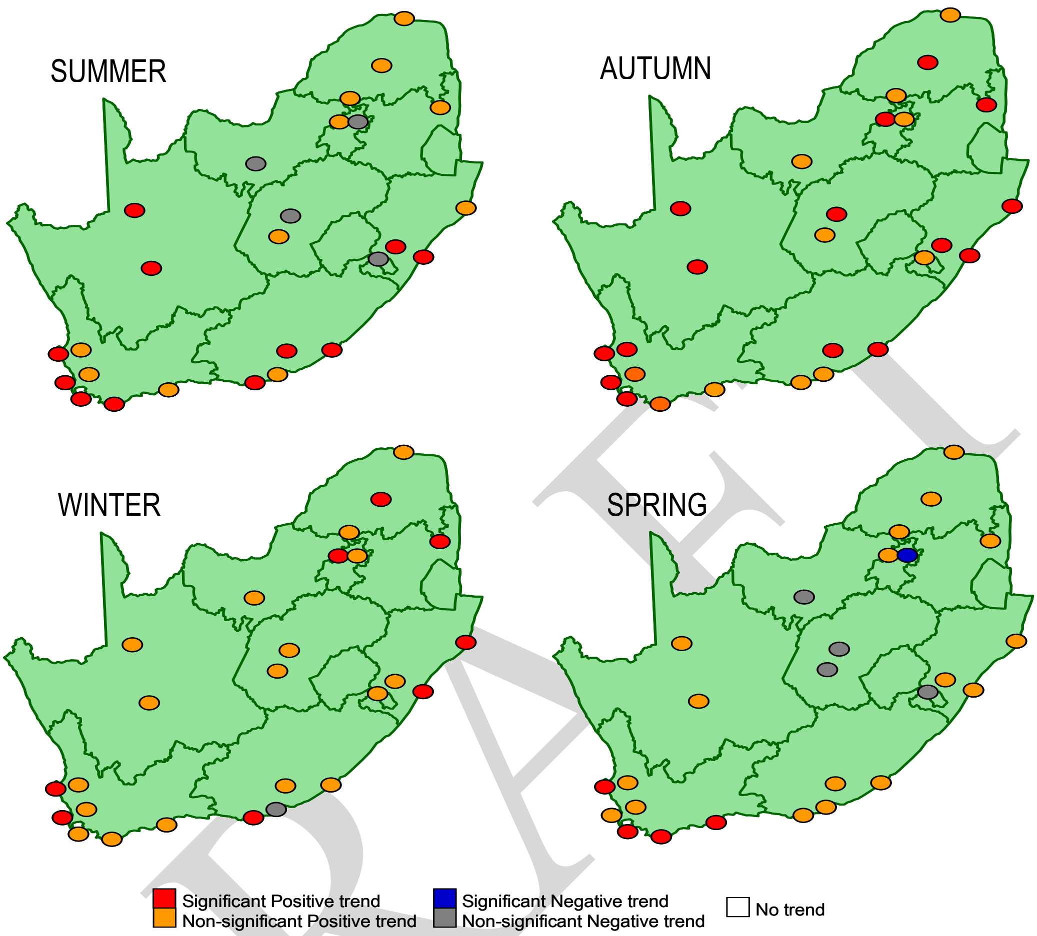


Figure 2.6: Trends in mean seasonal average temperatures as obtained from a record of 44-years (1960 to 2003). Most warming occurred in autumn, followed by winter, summer and spring. Adapted from Kruger and Shongwe (2004)

2.3.3 Trends in relation to planetary scale drivers

Natural cycles and events, such as solar energy cycles and unpredictable events such as volcanic eruptions, have important impacts on global and regional climate. South Africa is not excluded from these. One of the most important is the El Nino southern oscillation (ENSO) cycle, and it's well known impacts that originate in the eastern tropical Pacific, and appear to trigger many regional climate impacts, including dry conditions in much of southern Africa. The distinction between natural and anthropogenic impacts on regional and global surface temperature is best described by Lean and Rind (2008) who performed a robust multivariate analysis with the observed surface temperature record from 1889 to 2006. Results show that natural influences produce as much as a 0.2ºC warming during major El Niño events, near 0.3ºC cooling following large volcanic eruptions and 0.1ºC warming associated with peaks of recent solar cycles. However, none of these natural processes could account for the overall warming trend in global surface temperatures, and in the 100 years from 1905 to 2005, the temperature trends produce by all three natural influences are at least an order of magnitude smaller than the observed surface temperature trend reported by IPCC (2007).

2.3.4 Trends in the global oceans

Over the last 15-years much has been learned about how the oceans influence the global climate, and their possible effects on the rainfall of Southern Africa on different time scales. It is noteworthy that the most severe droughts in South Africa appear to occur during so-called "mature phases" of the El Niño (Rouault & Richard; 2003, 2005). Conversely, wet spells in South Africa are more likely to happen during La Niña events, which involve eastern Pacific ocean/atmosphere conditions that are roughly the opposite of conditions during El Nino. Despite this apparent pattern, it is important to note that there is no evidence of any linear relation between the El Niño Southern Oscillation and southern African rainfall, and ENSO is thus not a perfect predictor of rainfall variability in South Africa.

The warming of the global oceans since the 1950s (Figure 2.7), and in particular the Indian Ocean, appears to have increased the spatial extent and intensity of droughts in southern Africa since the mid-seventies (Richard *et al.* 2001, Rouault & Richard, 2003, 2005). This recent warming has also been shown to be responsible for a closer association between inter-annual variability of rainfall and the ENSO phenomenon (Richard *et al*. 2000).

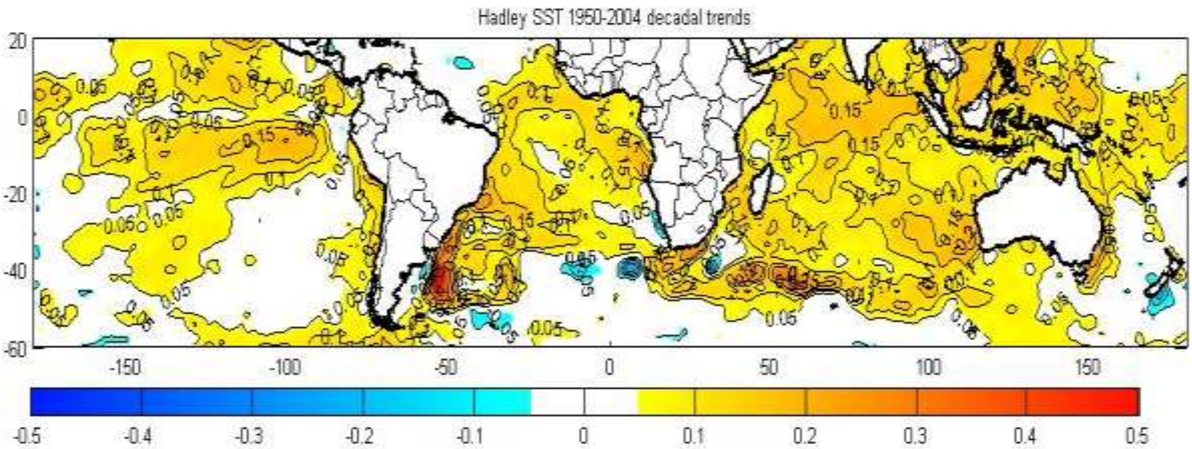


Figure 2.7: Linear trend in global sea surface temperatures over the period 1950 to 2004

It has fairly recently been learned that a low frequency changes in sea-surface temperatures in the Pacific Ocean (the Pacific Decadal Oscillation, Mantua *et al.* 1997), could also have substantially affected global climate, including rainfall variability over southern Africa (McCabe & Plucky 2005). Reason and Rouault (2005) have also found links between rainfall regimes in South Africa and fluctuations in a third low frequency cycle, the Antarctic Oscillation, as described by Thompson and Wallace (2000).

The modulation of the subtropical anticyclonic belt is another key element, and some evidence of synchronized variability in summer within the ocean-atmosphere system formed by both ocean basins (Fauchereau *et al.* 2003).

2.3.5 Trends in the Agulhas system

The Agulhas Current flows along the east coast of South Africa before moving offshore near 34oS and subsequently retroflecting back into the mid-latitude south-west Indian Ocean. This current has an impact both on the coastal climate of South Africa, and also on the global climate, because of its role in the circulation of water between ocean basins in the southern and northern hemispheres (the global thermohaline circulation). Measurements in the Agulhas Current have shown substantial transfers of water vapour in the marine boundary layer, a deepening of the marine boundary layer due to intense mixing and unstable atmospheric conditions created by the advection of colder and drier air above the current. The intensity of mixing in the local boundary layer is such that cloud lines can often be observed above the current. Rouault *et al*. (2002), for example, have provided evidence of the influence of the Agulhas Current on the evolution of a severe convective storm over the southern parts of South Africa.

Figure 2.8 illustrates linear trends in sea surface temperatures between 1985 and 2007. Over this period the Agulhas Current system has warmed significantly (+1.5 °C). Rouault *et al*. (2009) have shown that this warming was due to an intensification of the Agulhas Current system in response to an increase in trade winds and a poleward shift in the westerly wind belt in the south Indian Ocean. This also led to a substantial increase in evaporation rate (up to 1 mm per day per decade) and a 50 % increase in the transfer of warm Agulhas Current water into the colder south Atlantic Ocean. Other smaller-scale temperature trends are the cooling of 0.5°C per decade along the West Coast due to a poleward shift in westerly winds during winter (Rouault *et al.* 2009), and a cooling in the dynamic upwelling cell of Port Alfred and Port Elizabeth.

These cooling trends in the west and south coast surface waters is apparently due to the positive linear trend in surface wind speed in the region from 1982 to 2007 (Rouault *et al.* 2009). Surface wind speed increased in the subtropics of the southern Atlantic and Indian Oceans, which strengthened the wind stress curl in the south Indian Ocean at the origin of the intensification of the Agulhas Current system (Rouault *et al.* 2009). Observed changes in sea level pressure and wind speed is consistent with a suggested poleward shift of the westerly jet in the Southern Hemisphere and an increase of the south Atlantic Ocean and south Indian Ocean high pressure systems due to the intensification of the Hadley circulation, as well as trend towards a positive phase of the Antarctic Oscillation.

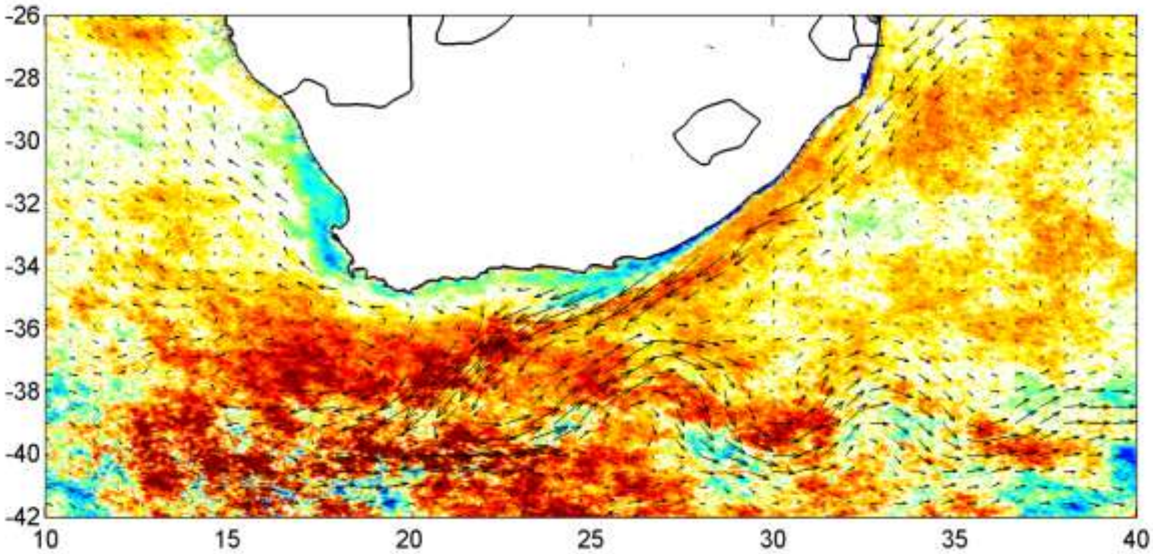


Figure 2.8: Linear trend in the Agulhas system between 1985 and 2007. Mean 1993-2007 absolute geostrophic velocity vectors derived from combined altimeter is superimposed.

2.4 Future projections

Projections of future climate are not forecasts of a specific outcome, but a projection of plausible and likely future conditions based on current knowledge and assumptions of changes in human activities that result in greenhouse gas emissions. The skill of projections is strongly dependent on how far into the future projections are done and which greenhouse gas emissions pathway is considered, and other factors including the temporal and spatial scales in question, which variables are considered, and which models are used. As discussed above, deriving the key regional messages of future potential change requires assessing multiple lines of evidence.

All regional change is ultimately driven by changes in the circulation of the atmosphere, coupled as it is to the complex inter-linkages of regional and global forcing and feedbacks. Substantial and valuable information can be drawn from understanding how such large scale processes are projected to change. These large scale attributes are the primary strength of Global Climate Models (GCMs) which are most skillful with respect to circulation and large area averages of surface variables.

Notably, GCMs are least skillful at their native (coarse) grid cell resolution – typically around 250km x 250km for a single grid cell – and especially so for grid cell rainfall. Thus, while map representations of GCM projections suggest detailed regional information, such maps encourage an artificial fine spatial interpretation which is not defensible.

It is very important that climate projections be assessed from as many models as possible; one model alone is a dangerous basis for developing regional change messages. Thus the regional projections need to be assessed in terms of the envelope and spread of indicated changes across available models. There is no best model across all relevant measures for South Africa. One approach sometimes considered is to weight models by the skill in simulating the observed climate during the 20th century. However, such skill does not imply the model is necessarily skillful at capturing the projected **change** factor for the future. Likewise, agreement between models on the sign of the projected change (an approach such as is used in the IPCC AR4, Chapter 11) also does not necessarily imply correctness. The GCM data used here are drawn from the World Climate Research Programme's (WCRP's) Coupled Model

Intercomparison Project phase 3 (CMIP3) multi-model dataset which form the foundation of the 2007 IPCC AR4.

The World Climate Modelling Summit in 2008 noted that to use GCMs directly for regional studies " … *means making their simulations good enough to guide hard decisions, … the adaptations required to meet changing rainfall and extreme weather events on regional and local scales. Today's modelling efforts, though, are not up to that job.*" (Editorial in Nature, 15 March 2008). Thus, to complement GCMs, the large scale changes are typically downscaled – whereby the large scale features simulated by the GCMs is translated to the local scale. Downscaling may be accomplished through statistical downscaling, by using Regional Climate Models (RCMs), or by using high resolution and variable resolution global models. All three approaches use the GCM large scale forcing, and are thus dependent on the GCM's. Downscaling is in effect a scale translation technique to add spatial information consistent with the large scale changes in the GCMs. The different downscaling approaches have relative merits and shortcomings, but are, in principle, considered to be of comparable skill (See Chapter 11, IPCC AR4).

At present comprehensive multi-model dynamical downscaling for southern Africa is still a work in progress within the Coordinated Regional Downscaling Experiment (see http://copes.ipsl.jussieu.fr/RCD_Projects/CORDEX/CORDEX.html). Thus the information reported here is primarily based on statistical downscaling based on the method of Hewitson and Crane (2006). This approach uses nine GCMs which are downscaled to a 25km grid resolution and to station locations over South Africa. Due to constraints in the available GCM data from the CMIP3 archive, it is only possible to downscale the last 30 years of the 20th century and two periods of twenty years each for the 21st century – 2046-2064 and 2080-2099. Downscaling is especially important for South Africa as the GCMs fail to adequately capture the detailed spatial gradients and strong topographical forcing that is so important to South Africa's climate.

2.4.1 Role of emission scenarios

The GCM simulations are forced by emission scenarios that describe the possible anthropogenic changes in future greenhouse gas concentrations. The model simulations data in the CMIP3 GCM archive is based on a range of emission scenarios from the IPCC Special Report on Emissions Scenarios (SRES), but the difference in projected climate change up to mid-21st century is small, and the impact of the emission scenario is only fully apparent in the latter half of the 21st century. Moreover the differences due to the choice of emission scenario are largely of magnitude and not substantial change in the pattern of response. Within the scope of this chapter the SRES A2 is used, which is close to the real world evolving emissions. The SRES A2 scenario is a moderately high emission scenario characterized by a heterogeneous world with increasing global population and regionally oriented economic growth. The focus in this chapter is on the changes by the middle of the 21st century, where the choice of emissions scenario seems to have limited impact.

2.4.2 Global circulation model projections: regional circulation changes

Figures 2.9 and 2.10 show three aspects of the projected change in regional circulation, respectively the sea level pressure, wind velocity, and wind direction. In each case the anomalies are shown, that is, the difference between the projected future for 2046-2065 and the present. From the multi-model set of GCMs the lower 25th percentile, the median, and the upper 75th percentile are calculated to indicate the primary spread of the indicated change from the different models. In addition the figures show the changes by 3-month seasons.

The primary large scale circulation changes indicated are:

- An increase in the intensity of the continental surface low pressure trough associated with an increased surface warming
- An extension of the Hadley circulation expressed as an increased surface pressure pole-ward of the continent, and increases in the southern margin of the oceanic high pressure systems associated with the Hadley cell expansion.
- A regional strengthening of wind velocity, primarily along the west coast and especially in summer
- A decrease in the strength of the prevailing westerly winds south of the continent
- A moderate increase in air flow transport onto the continent from the east, of key relevance in that is enhances the moisture transport into the region of air that is also becoming more moisture laden as the world warms.

These circulation changes suggest a number of consequences for the regional climate response, which include:

- Likely strengthening of upper air subsidence over the continent, with implication for stronger elevated inversions that can inhibit weak convective events.
- Shifts in the spatial west-east positioning of the summer rainfall gradient
- Stronger long-shore winds on the west coast with implications for coastal upwelling
- Increased moisture content over the continent (absolute, not relative humidity), which would translate to potentially more intense precipitation when it rained, as well as a likely increase in orographic cloud cover and topographically induced rainfall.
- Weaker frontal systems to the south, which would translate to weaker penetration of fronts onto the continent, drier conditions in the western cape (possibly compensated for in the mountains by an increased orographic rainfall), and an as yet indeterminate impact on the occurrence of tropical temperate troughs.

Across the range from the 25th to 75th percentile of the model range the message interpretation is not substantively altered, and the differences are mostly in terms of intensity. Likewise, the projections for the end of the 21st century are effectively a further intensification of the mid-century changes. These results reflect a robust first-order response of the regional circulation to the global scale changes.

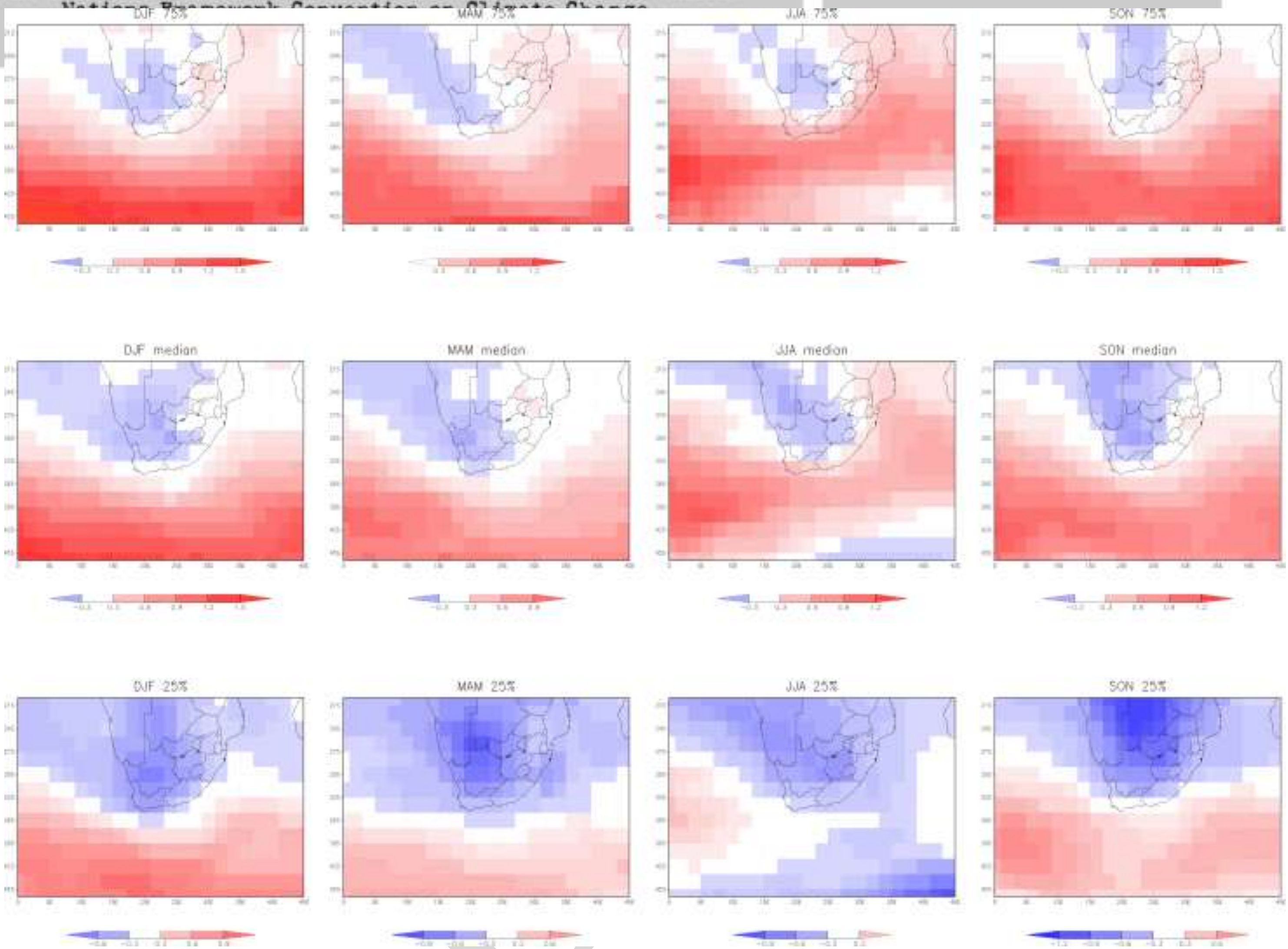


Figure 2.9: Projected change in average anomaly sea level pressure (hPa) from 10 GCMs of the CMIP-3 archive. Anomalies are the difference between 2046-2065 and 1961-2000, based on the SRES A2 emissions scenario. The columns are for each 3 month season of the year (DJF, MAM, JJA, SON). The upper row shows the 75th percentile of the model range, the middle row is the median, and the lower row the 25th percentile.

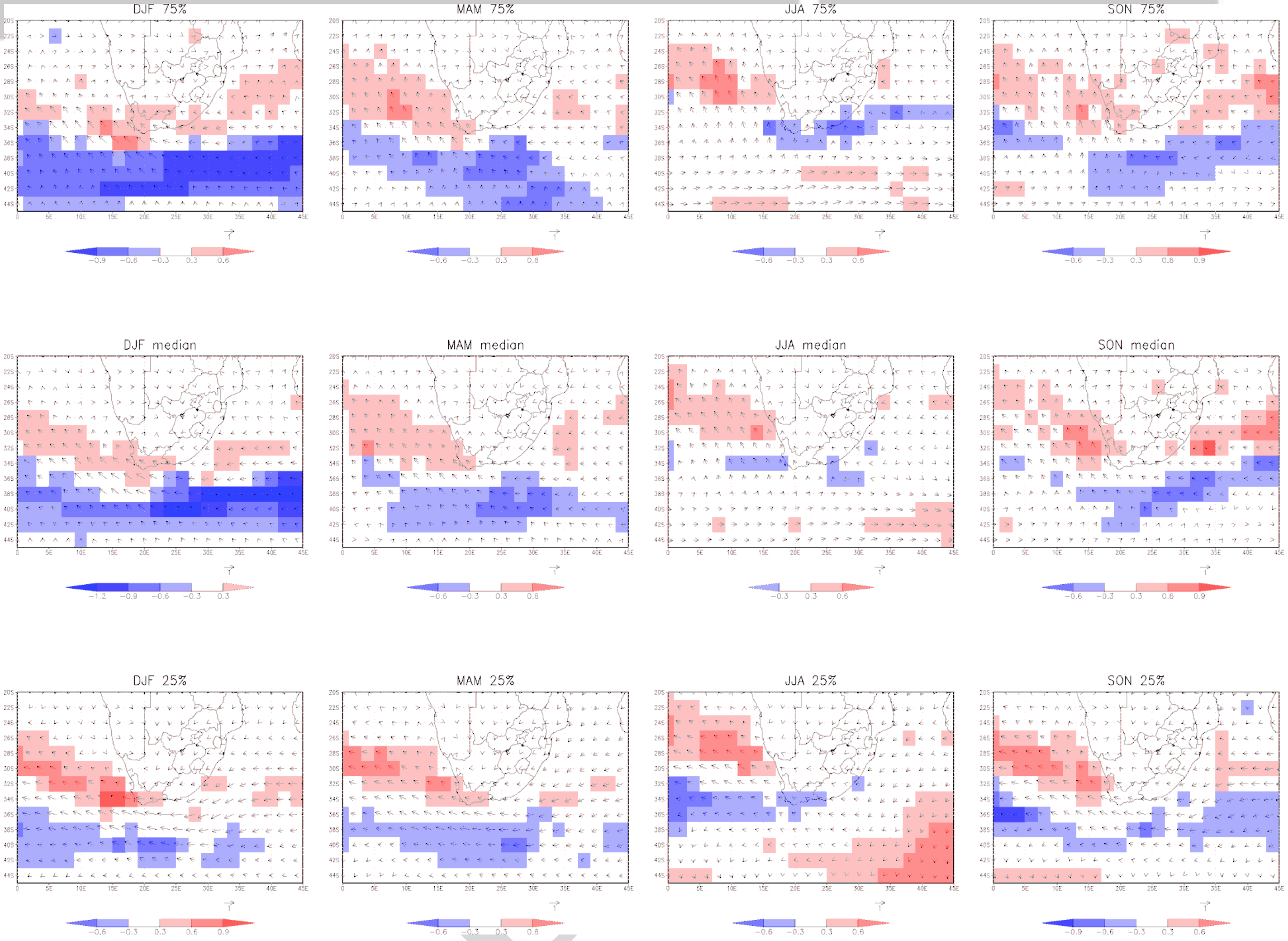


Figure 2.10: Projected change in average anomaly wind direction and in shaded colour the anomaly wind speed (m/s) from 10 GCMs of the CMIP-3 archive. Anomalies are the difference between 2046-2065 and 1961-2000, based on the SRES A2 emissions scenario. The columns are for each 3 month season of the year (DJF, MAM, JJA, SON). The upper row shows the 75th percentile of the model range, the middle row is the median, and the lower row the 25th percentile.

2.4.3 Global circulation model projections: surface variables

It is critical to understand that GCMs poorly represent the escarpment and coastal mountains, and hence key surface responses that are strongly modulated by the topography are likely to be inadequately represented in the GCM grid cell values for these regions. Chief among the variables of concern in this regard is precipitation, which should be viewed with special caution at single grid cells on the native GCM grid. These figures should also not be interpreted at a point or single grid cell as the model values are not robust at that scale; rather the focus should be on the pattern of change. For this reason the maps are plotted with actual grid cell sizes shown; the models vary in grid resolution but are all nominally similar, and the data here have been interpolated to a common indicative grid of 2º latitude by 2º longitude.

The surface variables from the GCMs (Figures 2.11 and 2.12) are shown as anomalies. When viewed in terms of the sub-continental pattern response, the results are physically consistent with the indicated large scale process changes described in the previous section – this increases the confidence in the pattern of indicated change. The magnitude of change across the range from 25th to 75th percentile is, however, quite large, to the point that in some regions for precipitation the sign of the change can be reversed. Nonetheless the relative pattern remains largely stable.

For precipitation, the changes indicate drying to the north-west, contrasted in the east of the country with increased summer rainfall (or smaller decreases). Winter rainfall over the south west is projected to decrease. Beyond this it is difficult to substantiate any stronger messages about precipitation when based only from the GCM grid cell data. Most problematic is the difficulty in determining the position of the spatial boundary between major regions with projected increases and decreases in rainfall, and this remains a key uncertainty.

Surface air temperature, a more spatially continuous parameter, shows warming everywhere, but most strongly in the interior. Coastal warming is of the order of 1ºC increasing to around 3ºC in the northern interior by the middle of the 21st century. By the end of the 21st century (not shown) the warming is greater still, but at that time scale the degree of warming is strongly dependent on the greenhouse gas emissions scenario.

Jointly, the raw GCM rainfall and temperature changes suggest a potential for decreased soil moisture as a result of the increased temperatures and the drying tendency for much of the region. However, these should be viewed in light of downscaled projections (following section) as well as the large scale circulation change.

2.4.4 Global circulation models downscaled projections

The downscaled data are generated as daily time series for precipitation, minimum and maximum temperature. From these a suite of derivative attributes is also derived, including: dry spell duration, rain day frequency, extreme values, frost day frequency, etc. In this chapter only mean seasonal totals are shown.

Since the downscaled data are derived from the GCM atmospheric fields, validation of the downscaling is warranted. Assessment of downscaling is usually accomplished by applying the downscaling to historical atmospheric circulation and comparing the results with actual observed high resolution observations. Space precludes detailed presentation here (see Hewitson & Crane (2006) for details). Validation shows that the observed accumulated precipitation downscaled from the National Centre for Environmental Prediction reanalysis atmospheric data (Kalnay *et al*.1996) are markedly similar to actual observed values, and indicate the robustness of the technique in downscaling from atmospheric fields.

Figure 2.13 shows the precipitation change downscaled from the same GCM climate change simulations shown in earlier figures. The direct comparison for the raw GCM data is Figure 2.12. In this case the downscaling represents the precipitation response at a high spatial resolution (0.25º) that is dynamically consistent with the large scale circulation and atmosphere state of the GCMs, and including the finer scale topographical forcing that is not captured well in the raw GCM response. The results are presented in the same form as the raw GCM data for the four season's upper and lower percentile and median. At first glance the results appear different from the raw GCM grid cells. However, two factors need to be recognized in interpreting this; firstly that the downscaling explicitly accounts for local scale topographical forcing and processes that are sub-resolution for the GCM grid, and secondly, are directly coupled to the larger scale circulation of the GCM – that is, the skillful scale attributes of the GCM.

The downscaled results support projections of increased rainfall along the east , but extend the region of increased rainfall further into the interior of the country. Similarly, the drying over the south western winter rainfall region is consistent with the raw GCM data, but is modulated by the mountains in the region and does not show the strong drying seen in the GCM raw data.

The GCMs are not able to represent the strong role played by the steep topographical gradients, especially on the south and east coasts where they are central to the formation of orographic triggered rainfall. Coupled with increased moisture content in the atmosphere as well as greater onshore flow (see Figure 2.10), it is reasonable to anticipate an increased precipitation response in these regions.

The derivative attributes of the downscaled rainfall – intensity, dry-spell duration, and rainday frequency (all not shown here) are physically consistent with the findings above. Leading messages among these are an increase in frequency and intensity of rainfall concentrated mostly in the early summer (September-October-November), and a less robust message of increase in dry spell duration in the western regions of the country.

2.4.5 Drawing conclusions and managing uncertainty

By linking the GCM grid cell response, downscaling results, and the indications of large scale circulation change, and considering the relevant strengths and weaknesses of each data form, some consistent messages can be identified.

- The west-east pattern response seems stable, physically consistent with the circulation changes, yet with uncertainty in the magnitude of the response
- There are clear indications that all regions are very likely to be warmer in the future.
- There is lack of clarity on the west-east spatial position of the boundary between regions that dry in the future, and the east coast wetting.
- The role of topography is critically important, especially as pertains to potentially enhancing the east coast increase in precipitation.
- The drying in the extreme southwest appears as a consistent message, although with a notable spread across the model solutions.

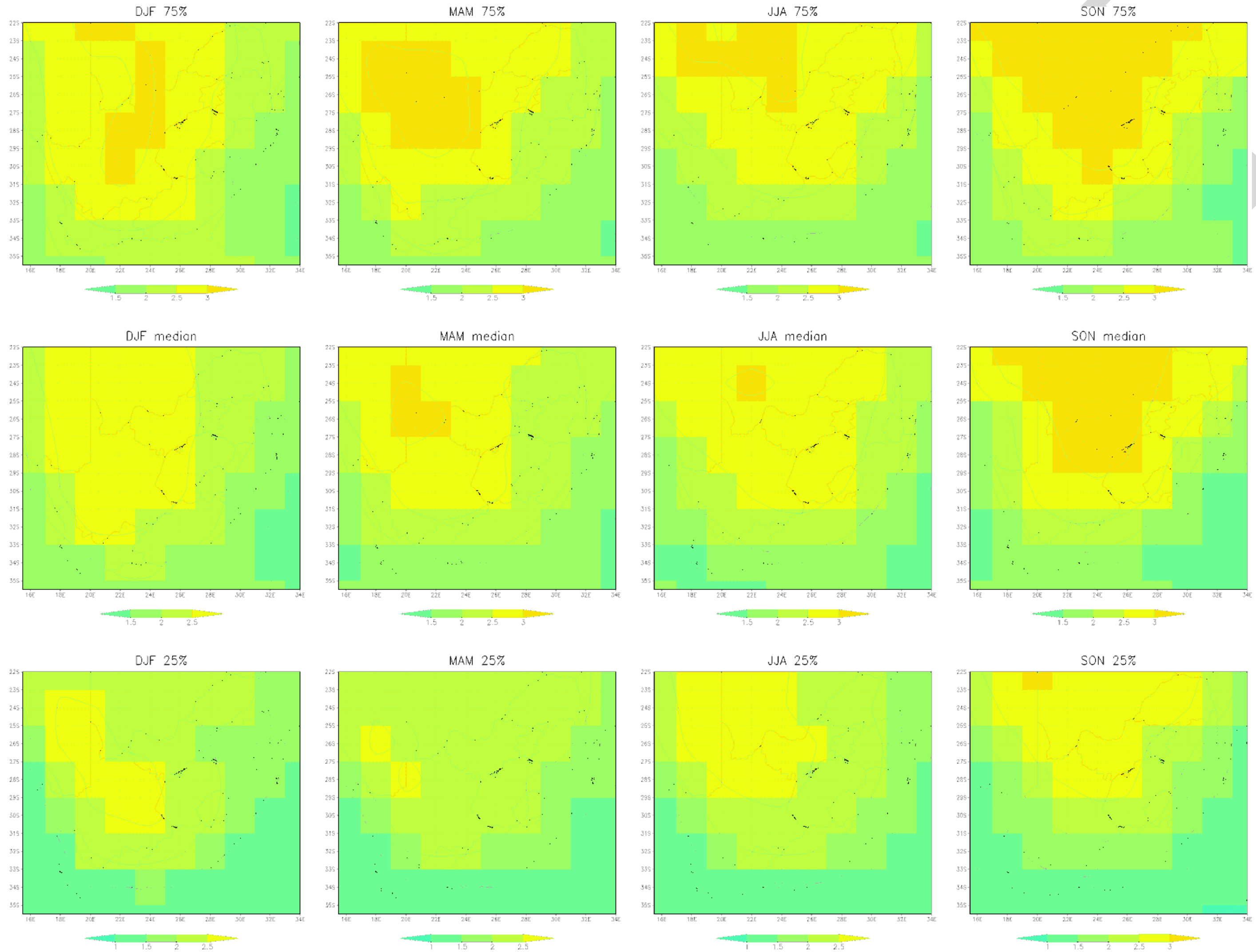


Figure 2.11: Projected change in average surface air temperature (ºC) from 10 GCMs of the CMIP-3 archive. Anomalies are the difference between 2046-2065 and 1961-2000, based on the SRES A2 emissions scenario. The columns are for each 3 month season of the year (DJF, MAM, JJA, SON). The upper row shows the 75th percentile of the model range, the middle row is the median, and the lower row the 25th percentile.

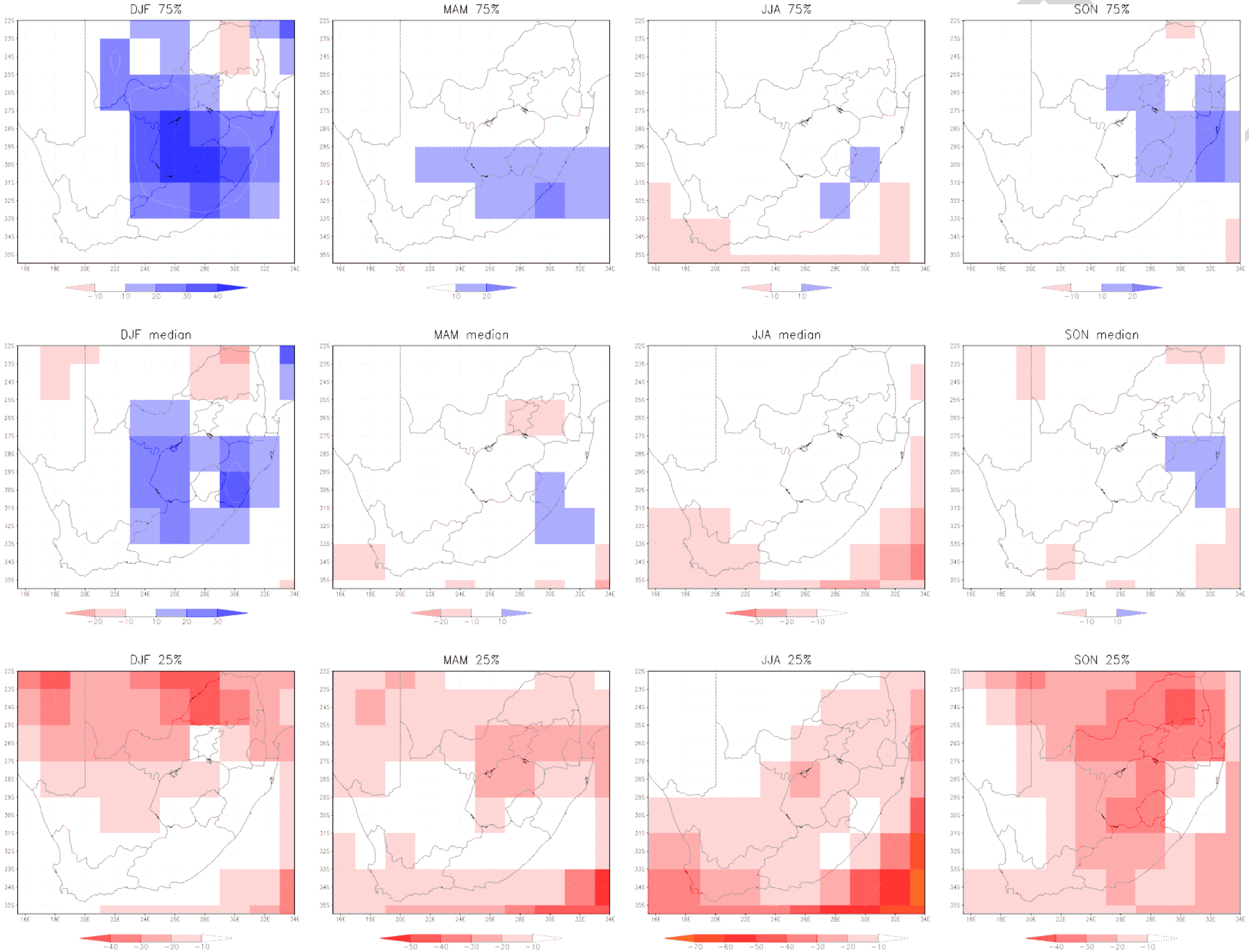


Figure 2.12: Projected change in average precipitation (mm/season) from 10 GCMs of the CMIP-3 archive. Anomalies are the difference between 2046-2065 and 1961-2000, based on the SRES A2 emissions scenario. The columns are for each 3 month season of the year (DJF, MAM, JJA, SON). The upper row shows the 75th percentile of the model range, the middle row is the median, and the lower row the 25th percentile.

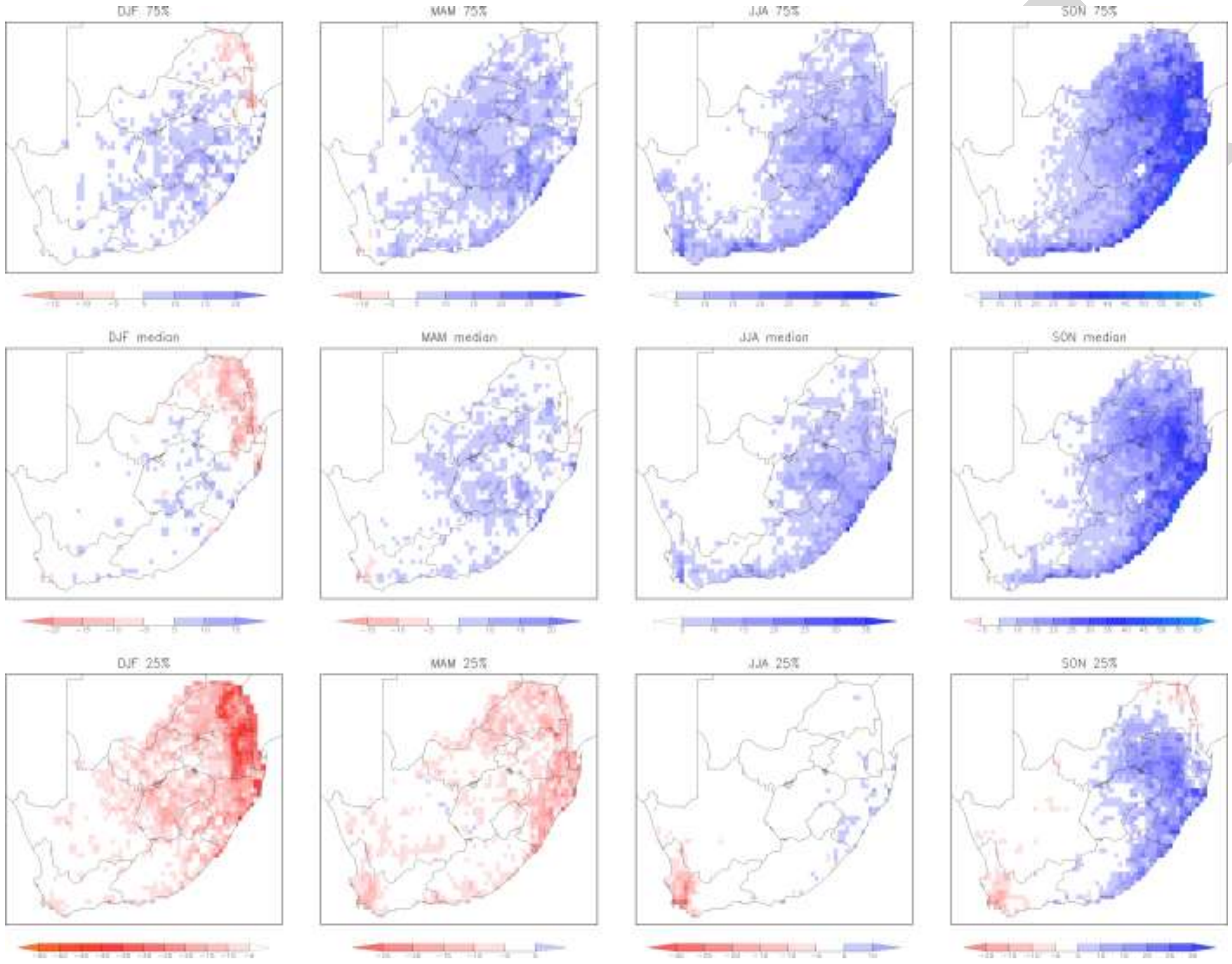


Figure 2.13: Downscaled projections of change in average precipitation (mm/season) from 10 GCMs of the CMIP-3 archive. Anomalies are the difference between 2046-2065 and 1961-2000, based on the SRES A2 emissions scenario. The columns are for each 3 month season of the year (DJF, MAM, JJA, SON). The upper row shows the 75th percentile of the model range, the middle row is the median, and the lower row the 25th percentile.

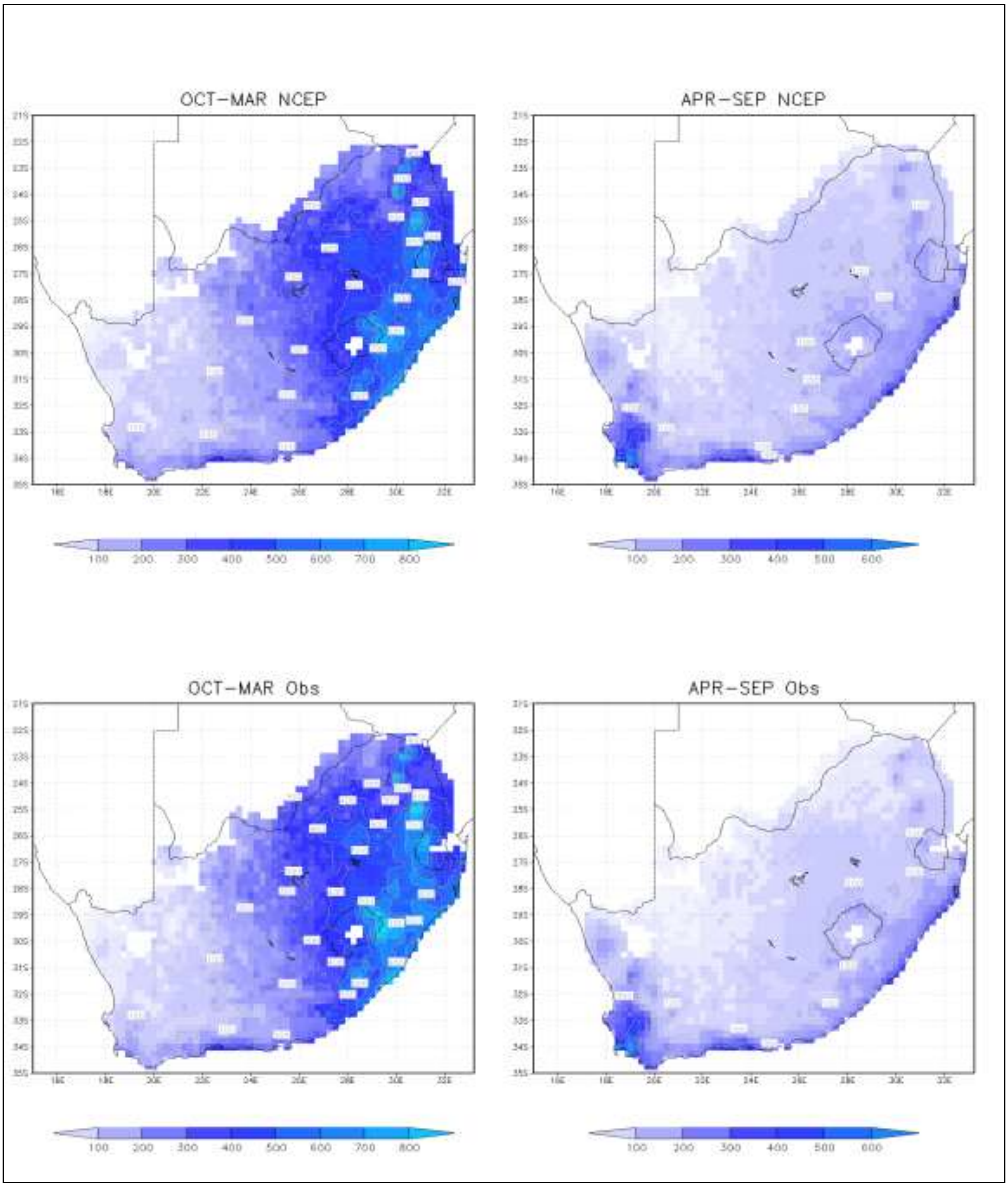


Figure 2.14: Observed accumulated rainfall (mm) for the period 1979-2000 (lower row), and downscaled precipitation (top row) for the same period from the NCEP reanalysis atmospheric circulation data (analogous to a GCM). The left column is for the summer 6 month period, and the right column for the winter 6 month period. The figure is to indicate the skill of downscaling from atmospheric circulation fields of a GCM.

2.5 Synthesis

The current understanding of regional climate change for South Africa is based on an assessment of past changes in surface temperature and rainfall, changes in large scale processes, and downscaled projections of regional change. The scientific understanding on regional climate change is continually evolving, and the scope of this chapter constrains the amount of detail that can be presented in this overview. The South African Risk and Vulnerability Atlas (http://www.rvatlas.org/) provides a gateway to further details, and will evolve as new results become available.

Past and projected climate changes are consistent with the physical understanding of global anthropogenic forcing. There is evidence of changes in synoptic scale processes that match the understanding of an intensified Hadley circulation, and the regional details are consistent with these changes. The broad messages of increased historical temperatures across the country and those projected for the future are likewise physically in agreement with scientific understanding, and provide a robust message of warmer temperatures and extreme hot days. Rainfall changes for recent decades are ambiguous, but with an indication of increased intensity. However, rainfall trends are complicated by low frequency drivers such as ENSO, and the lead/lag timing of response to anthropogenic forcing between the driving circulation, atmospheric humidity, and temperature.

As anthropogenic forcing becomes more dominant in relation to natural variability over the coming decades, the changes will become more apparent. Current projections of rainfall changes are physically consistent with the understanding of the climate process responses. Rainfall is likely to increase over the eastern portion of the country. Drying is indicated for the Limpopo province in summer and for the Western Cape in winter. The Western Cape regional details are complicated in the mountain regions where the drying signal will likely be delayed.

Overall, this level of understanding is a significant advance on the initial National Communication, and notable advances have been made even recently. New work currently underway, especially that of the WCRP CORDEX project in which South Africa is playing a leading role, is likely to bring continued advances in understanding, especially as to regional details of change. The parallel growth in communication avenues between science and society will likewise enable a greater effectiveness in science informing societal responses.

Contents

Chapter 3:

Measures to Facilitate Adequate Adaptation to Climate Change

3.1 Water resources

3.1.1 Current vulnerability

South Africa is, overall, a dry country with the mean annual rainfall of about 490 mm compared with the global average of about 876 mm. Less than 9% of the rainfall ends up in rivers, and about 5% recharges groundwater in aquifers (Midgley *et al.* 1994; DWAF GRA2 2005; Schulze 2005). Rainfall, and thus river flow, is unevenly distributed across the country with 12% of the land area generating 50% of streamflows. Rainfall is also variable, with the coefficient of variation of annual rainfall ranging from around 15% in areas with more than 1000 mm/yr to more than 40% in areas with < 250 mm/yr (Schulze 2008). There are also marked multi-year persistencies in rainfall, resulting in extended drought and wet periods across the country (Tyson 1971; Tyson *et al.* 1997).

Climate change is one of several drivers currently influencing water resources in South Africa. Most critically, surface water resources are almost fully allocated and by the 2000, five of 19 Water Management Areas (WMAs) were already over-allocated and experiencing water stress (Figure 3.1.1). Demand is expected to increase with economic growth, increased urbanisation, higher standards of living and population growth. Surface and groundwater are also exposed to contamination and pollution from diffuse urban, industrial and agricultural sources and point sources at water treatment works, land-fills and mines. All of these changes will have significant impacts on the future availability of water resources.

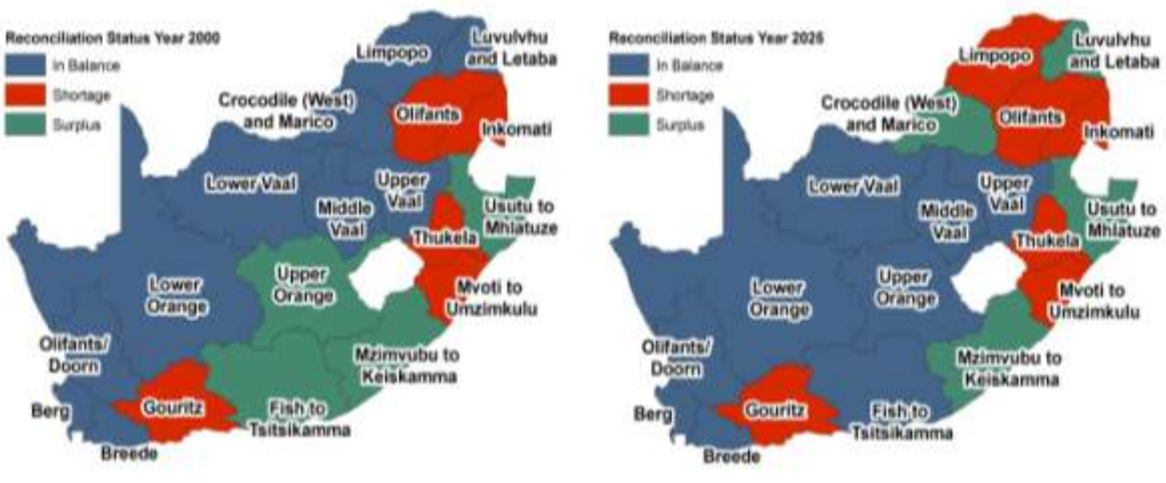


Figure 3.1.1: The reconciliation status of water resources in South African Water Management Areas in 2000 (left) and projected future water status by 2025 if current trends of use continue. Future reconciliation does not account for climate change.

The volumes of river flows are driven by rainfall and are amplified by climate variability by factor of 2 - 5 times (Schulze 2005). The greater inter-annual variability in flows is also evident during prolonged droughts, during which decreases in river flows may be more than twice those of rainfall. Rainfall is also strongly seasonal, which means that infiltration into soils abstract much of the early season rainfalls and river flows thus respond relatively slowly and later.

The high variability in surface runoff reduces the usable yield, i.e. the amount of stored water than can be reliably supplied on a sustained basis (e.g. with a 98% assurance of supply), to about 22% of the mean annual runoff of 49 000 million m^3 (DWAF 2004). More than 95% of the stored water yield has been allocated for domestic, industrial and agricultural use, the ecological reserve (i.e. that fraction of water required for the ecological functioning of rivers), and to meet international obligations. Currently surface water accounts for 77% of water used, return flows 14% and groundwater only 9% . Within-country water demand is projected to increase by 32% (17 000 million m^3) by 2030 due to population growth and ongoing industrial development, including electricity generation (van Rooyen & Versfeld 2009). This will increase stress, particularly in the north in the Limpopo WMA. This projected constraint does not incorporate the potential impacts of climate change on water availability.

Surface water quality in South Africa is variable, with pollution from mining, industry, urbanisation, agriculture and power generation evident in many areas. Many of the country's reservoirs and dams are downstream of urban areas and most of these have become progressively contaminated over many decades (Oberholster & Ashton 2008). Phosphorous pollution is a problem particularly due to inadequate treatment of effluent at municipal sewage works. South African freshwater resources are considered to be enriched and moderately to highly eutrophic, with average orthophosphate levels at 0.73 mg/l, and this has resulted in potentially toxic cyanobacterial blooms occurring at some time in most river and reservoir systems (Nationamaster.com 2003; Du Preez & Van Baalen 2006; Oberholster & Ashton 2008). This presents a risk to unserviced households who use untreated water.

Major aquifer systems include the dolomites (North West province), the Table Mountain Group aquifer in the Cape Fold Belt, the Kalahari in the Northern Cape province and the coastal sands aquifers in KwaZulu-Natal. The Karoo region (Upper and Lower Orange WMAs) also forms an extensive, complex aquifer system in the central interior. Total groundwater use in South Africa is estimated to be only 30% of mean annual recharge. However, some areas within the Breede, Gouritz, Fish to Tsitsikamma, Upper Orange, Crocodile (West)/Marico and Limpopo WMAs are known to be stressed with respect to groundwater (DWAF 2005; Figure 3.1.2).

Groundwater quality is variable across the country with incidences of contamination most often caused by on-site sanitation, industrial and mining effluent. Arid and semi-arid areas of South Africa, in common with Botswana and Namibia, often have naturally high nitrate levels which are unsafe to drink without treatment. 27% of abstracted groundwater sources have nitrate levels which exceed the World Health Organization's safe limit of 10 mg/l $N\text{-}NO_3$ and extremely high levels over 500 mg/l have been reported (Tredoux & Talma 2006). This can cause problems for livestock and bottle-fed infants who can develop methaemoglobinaemia, commonly known as blue-baby syndrome (WHO 1993), although there are only a handful of reported incidences (Colvin & Genthe 1999).

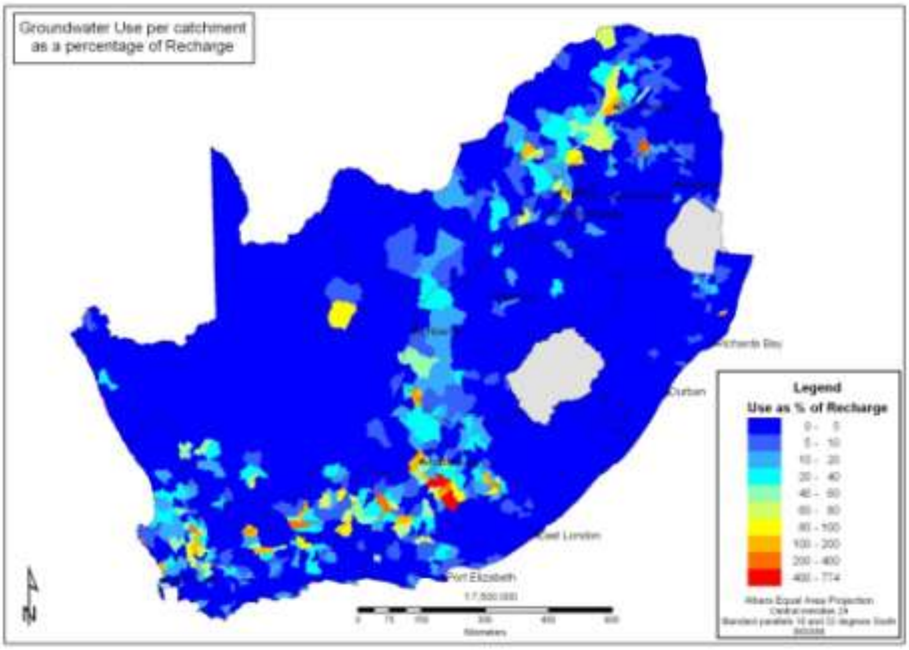


Figure 3.1.2: Groundwater use as a percentage of mean annual recharge in South Africa per Quaternary Catchment (DWAF, GRA2 2005).

3.1.2 Observed trends

Near-surface air temperatures have significant impacts on the hydrological cycle and therefore on water resources, with warming of the atmosphere potentially changing the hydrological cycle over South Africa by increasing atmospheric water vapour content, changing the frequency of occurrence, distribution and intensity of convective rainfall, changing the frequency of occurrence of extreme precipitation events, increasing evapotranspiration and consequently impacting on soil moisture, irrigation demand and runoff. Between 1906 and 2005, parts of the central interior of South Africa warmed at about twice the global rate (Kruger & Shongwe 2004). However, evidence across South Africa of changes occurring within the hydrological cycle over the past century is ambiguous. It is likely that trends in the hydrological cycle are currently masked by natural variability.

Observed precipitation change during the past century includes both drying and wetting trends depending the region and season, and with marked spatial and sub-annual complexity to the signal, which is not always statistically significant and which does not make a generalized statement possible (Hulme *et al.* 2001; Warburton & Schulze 2005; Kruger 2006; Hewitson *et al.* 2009). Significant increases in precipitation since the 1950's are observed in the south-west of the country and significant decreases in the north-east, especially in dry years (Warburton & Schulze 2005). In certain sub-regions in South Africa climate station data display spatially coherent and in some cases statistically significant drying trends (Kruger 2006), and these areas include some of the key upland watersheds for the major river systems.

3.1.3 Projections of impacts on water resources

There is high confidence that changes in hydrological processes such as increased evaporation are linearly related to increasing temperature. Projection of precipitation change and consequent runoff changes are less certain. It is well established in South Africa that surface and groundwater resources will amplify any changes in rainfall (Schulze 2005), as will any intensification or extensification of land uses complex interactions between vegetation, soil moisture, evapotranspiration and water resources (Schulze 2003).

In a recent assessment of climate change impacts on water resources, values of daily rainfall and temperature from downscaled climate models of the Intergovernmental Panel on Climate Change's 4th assessment report (IPCC AR4) have been used as inputs into the daily time-step ACRU hydrological model (Schulze 1995 and updates) to project their impacts on water resources in South Africa at Quinary catchment scale (Schulze & Horan 2010). Quinaries are nested subdivisions of Primary, Secondary, Tertiary and Quaternary catchments, with Quinaries delineated as relatively homogeneous hydrological response areas for purposes of water resource planning.

3.1.4 Rainfall

Predicted rainfall changes for the 21st century indicate a wetter east coast in summer, with drier conditions over the western parts of the country (e.g. Hewitson & Crane 2006; Tadross *et al.* 2006; Engelbrecht *et al.* 2009; Hewitson *et al.* 2009). There is a robust message from both Global Circulation Models (GCMs) and regional climate models for the south-western Cape to receive less winter rainfall in future (e.g. Christensen *et al.* 2007; Engelbrecht *et al.* 2009; Hewitson *et al.* 2009).

The rainfall signal over South Africa during the 21st century is projected to change in terms of the average annual rainfall, shifts in rainfall seasonality and patterns of extreme rainfall events, with indications that rainfall intensity is likely to increase over the summer rainfall region (e.g. Tadross *et al.* 2006; Engelbrecht *et al.* 2009; Schulze 2010). All these changes are hydrologically significant, but require more climate modelling guidance on the effects of anthropogenic forcing on rainfall attributes (Christensen *et al.* 2007), especially those with hydrological relevance.

3.1.5 Quantity of water resources

The projected increase in temperature will partially offset any increase in rainfall, due to an increase in potential evaporation of about 5% per 1^{o}C (Schulze 2010). Combined temperature and precipitation changes will have significant impacts on accumulated streamflows, which is reflected in the projected relative changes in median annual streamflows (by our current understanding, broadly increases in the east and decreases in the west) and similar patterns of changes in the year-to-year variability of streamflows derived for the intermediate future (2046-65) and more distant future (2081-2100) from multiple GCMs (Schulze 2010; Figure 3.1.3).

Some of the increases in river flows projected for the more arid areas are, however, so small in absolute quantities (because they come off a low base) that the effect for water resources management is minimal.

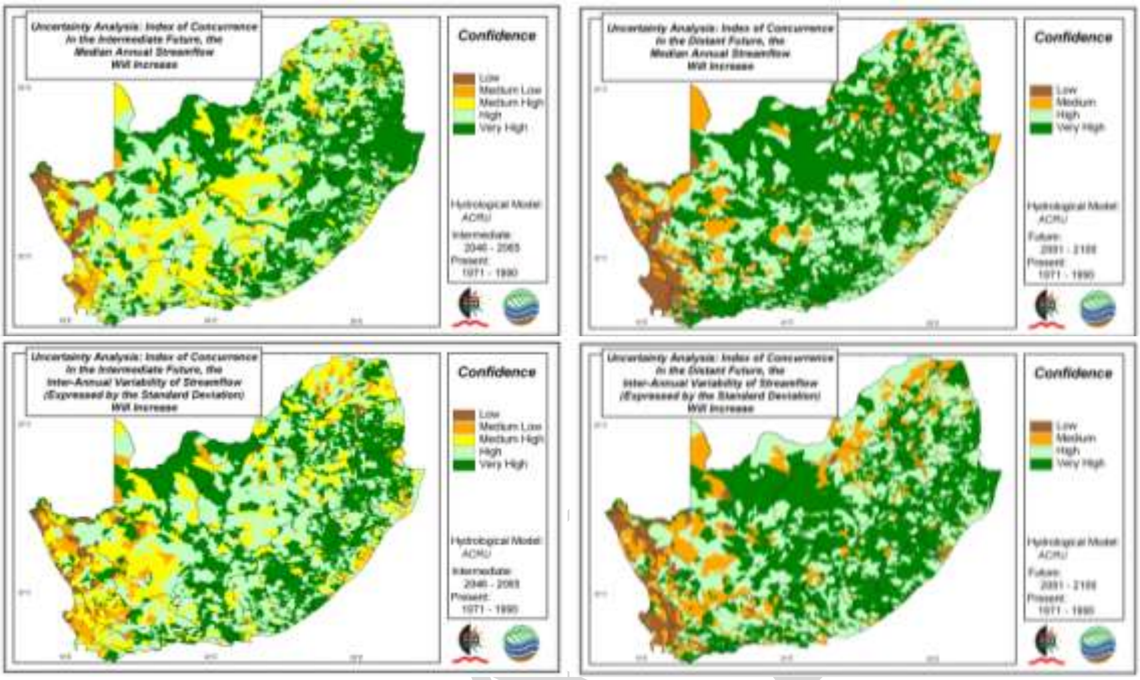


Figure 3.1.3. Output from multiple Global Circulation Models implying that median annual streamflows are projected (top left) to increase in the east and decrease in the west by the intermediate future (2046-2065), with (top right) this trend amplifying into the more distant future (2081-2100), while (bottom left and right) the inter-annual variability of streamflows shows similar spatial patterns (Schulze 2010).

The present state of knowledge indicates that by mid-century both the 1 in 10 year low flows and the 1 in 10 year high flows are projected to increase in much of the Eastern Cape and Kwa-Zulu Natal (Figure 3.1.4). This implies that there could also be more sustained flows in the dry season in those regions, but there is also a higher risk of floods in the wet season, which has negative impacts on water quality (see below) as well as on disaster risk management. On the other hand, the Western Cape, and particularly some of the catchments that supply Cape Town's water, show marked decreases in years of both high and low flows (Figure 3.1.4), as do parts of Limpopo. Such changes could lead to severe water management challenges, with potential socio-economic repercussions.

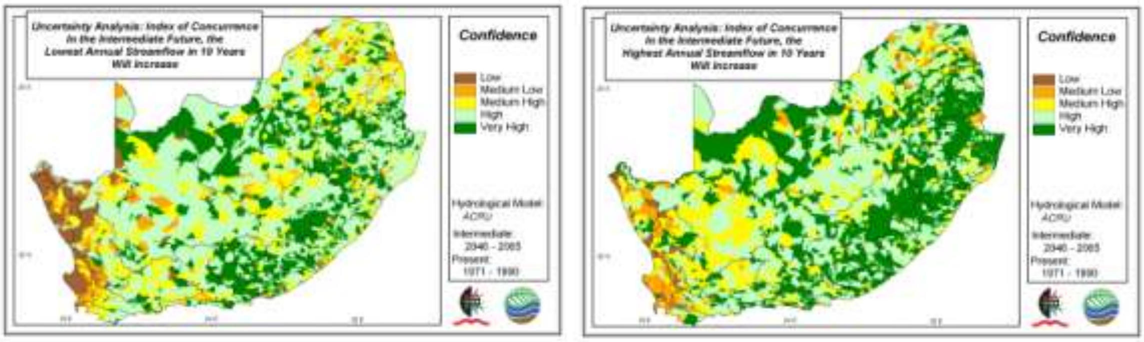


Figure 3.1.4. Output from multiple Global Circulation Models implying that both years of low annual streamflows (left) and high annual streamflows (right) are projected to increase in the east and decrease in the west by the intermediate future around mid-century (Schulze 2010).

Reduced rainfall in the Western Cape, Northern Cape, central interior and parts of Limpopo may also result in reduced recharge to groundwater and falling water levels in boreholes.   Studies have shown a non-linear relationship between mean annual rainfall and groundwater recharge in semi-arid areas, with a more rapid decline when annual rainfall drops below 500 mm (Figure 3.1.5). By implication, in the northern, central and south-western areas of the country where rainfall is currently around 500 mm p.a., a slight shift towards less rain, would be amplified by a steep decline in recharge. These vulnerable areas coincide with areas of over-abstraction of groundwater shown in Figure 3.1.2.

Less recharge will result in declining groundwater levels. Groundwater-fed baseflow to rivers would decrease (in duration and volume), impacting low flows in the dry season. Most of the smaller river systems in the interior do not flow continuously all year, but weakly perennial rivers in the Western Cape may become seasonal. Springs and wetlands that rely on groundwater discharging from 'full' aquifers, may dry up in areas where recharge is reduced and water levels decline.

Groundwater dependent ecosystems, such as riparian zones adjacent to dry river beds, are often keystone (critical) ecosystems, maintaining animal populations from rain-fed grasslands around them. They could become increasingly important as refuge habitats if the frequency of droughts increases in semi-arid areas.

Groundwater recharge to deeper aquifers (e.g. in the Karoo and Kalahari) is often controlled by extreme rainfall events rather than mean annual rainfall. Therefore it is difficult to predict the net effect of climate change on groundwater levels, because even in areas where total rainfall declines, if extreme storms become more frequent then a greater proportion of the annual rainfall may recharge aquifers. The impact of a reduction in total rainfall on groundwater may well be offset by the increase in rainfall per rainstorm because most of the recharge takes place after large rain storms. However, current projections indicate that there is high confidence in increases in heavy rainfall events (in excess of 25 mm/day) in the eastern part of the country and less so for the more arid western areas (Figure 3.1.6).

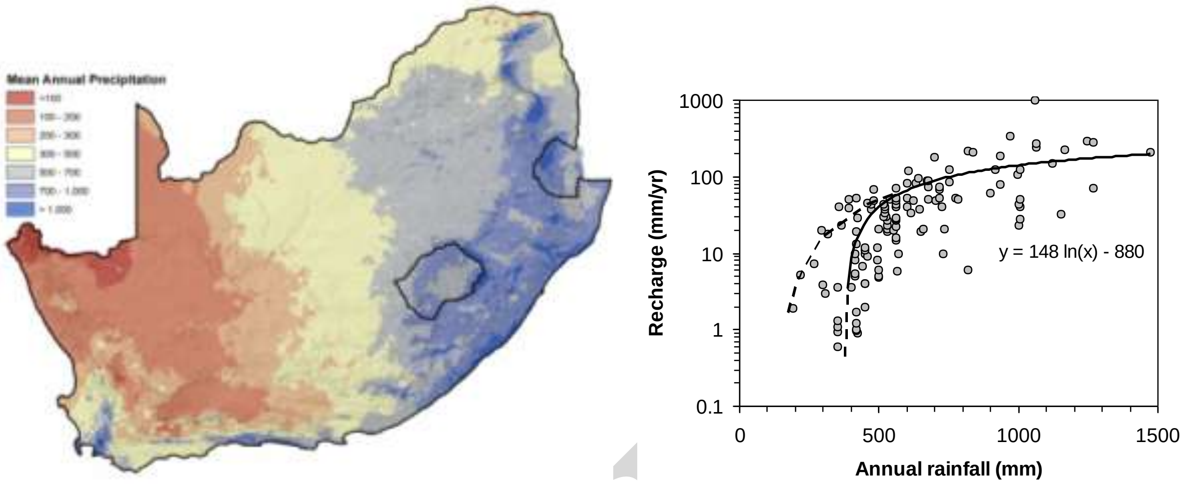


Figure 3.1.5: Non-linear relationship of annual groundwater recharge to rainfall in semi-arid areas, with the tipping point at less than 500 mm per annum rainfall (Beekman et al. 2003; with the map of mean annual precipitation from Lynch 2004).

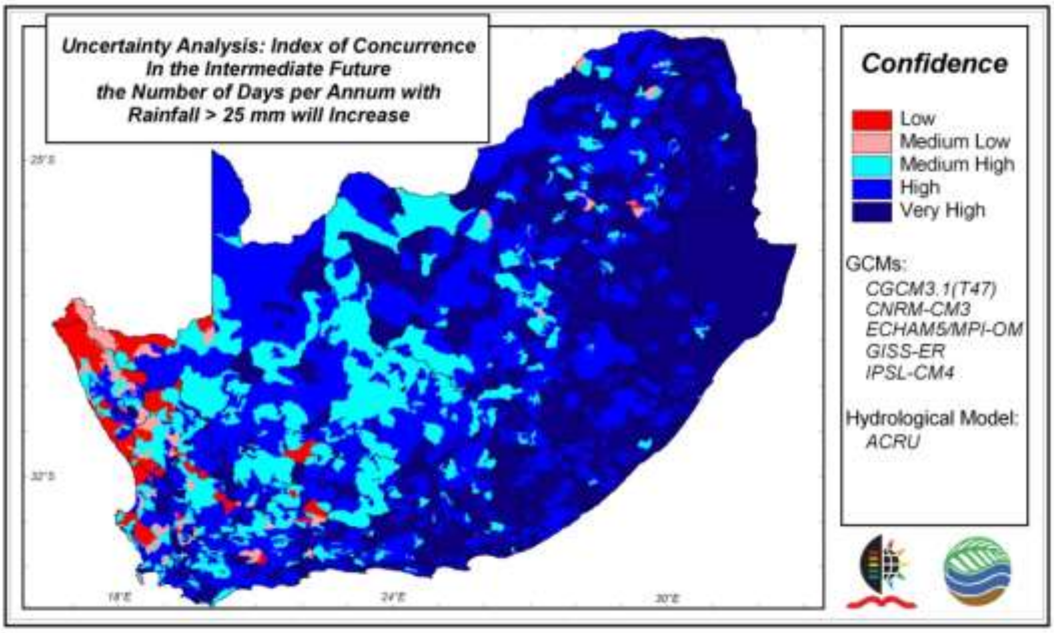


Figure 3.1.6. Concurrence between multiple Global Circulation Models showing higher confidence in projected increases in the frequency of days with heavy rainfall in the east of South Africa, with areas of low confidence in the west implying fewer heavy rainfall days (Schulze 2010).

3.1.6 Quality of water resources

One of the direct consequences of changing rainfall patterns, both increased and decreased rainfall, as well as changes in rainfall intensity, will be altered erosion patterns. This is expected to lead to increased sediment loads and increased turbidity and release of suspended pollutants in rivers and dams. Figure 3.1.7 illustrates current efforts of projected impacts of climate change on sediment yield, with output from multiple GCMs using the A2 emission scenarios implying projected increases in mean annual sediment yield in the east and reductions in the north-west of South Africa by mid-century (Schulze 2010). Increased turbidity will alter the albedo (reflectance) characteristics of rivers and reservoirs, and exacerbate the impact of higher temperatures. Changes in the water temperature regime will alter the conditions that promote or retard algal (phytoplankton) growth. Reduced light penetration will alter the suitability of conditions for many types of phytoplankton. Suspended sediments 'attract' a number of ionic species, for example, metal ions and ammonium ions, altering their bio-availability. Many of South Africa's rivers and water storage reservoirs are already turbid, and thus increased turbidity might not change their setting too dramatically. Reservoirs and rivers with low turbidity will change in unanticipated directions. All of these have important implications for water treatment processes and, ultimately sludge disposal systems.

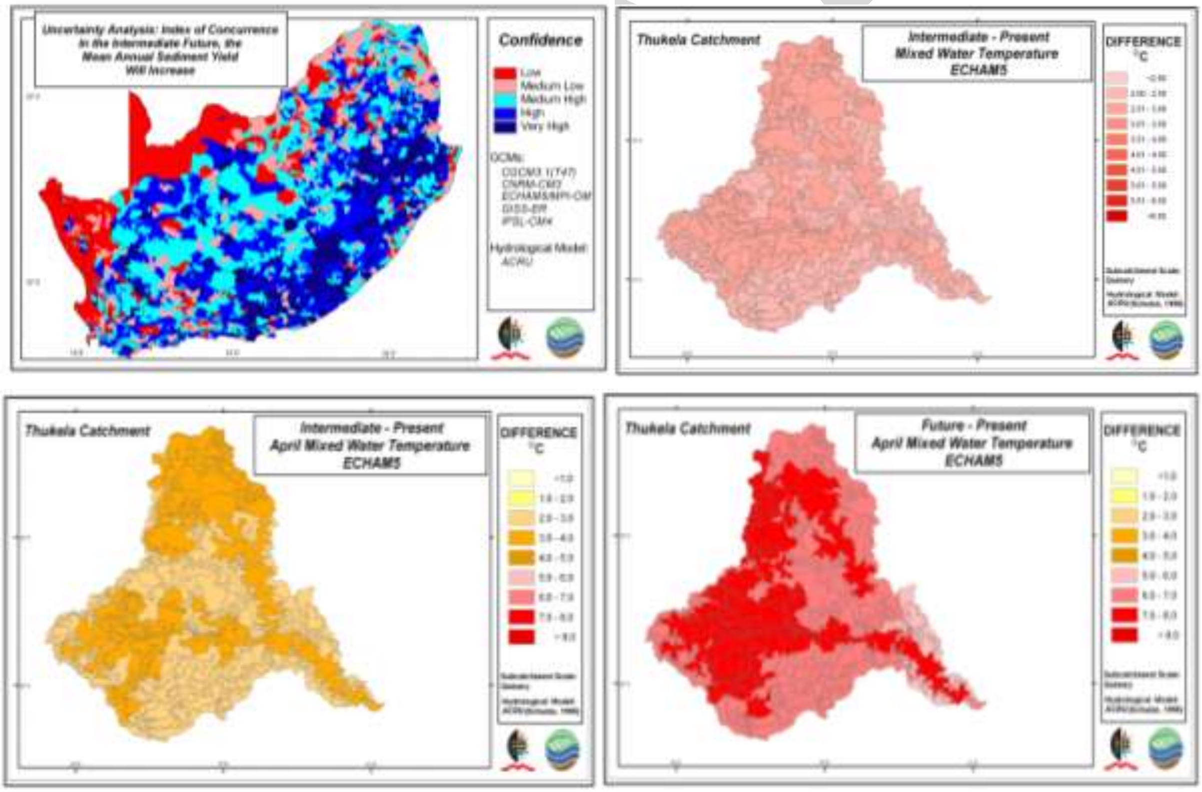


Figure 3.1.7: Potential impacts of climate change on water quality indicators, with (top left) output from multiple Global Circulation Models (GCM) implying projected increases in mean annual sediment yield in the east and reductions in the north-west of South Africa by mid-century (Schulze 2010a) and (top right) projected increases in annual water temperature by mid-century in the Thukela catchment computed from the European Centre Hamburg's Global Circulation Model (ECHAM5/MPI-OM), while the bottom maps illustrate April water temperature changes by the middle and end of the century (Barichievy et al. 2010).

An increase in water temperature renders conditions optimal for blue-green algae (cyanobacteria), which will likely become dominant for longer periods if sufficient nutrients are available. Given the problems experienced across the country with wastewater treatment works, this is already happening, and could worsen significantly. If the phytoplankton become dominated by toxic forms of cyanobacteria - for longer periods of the year - this poses additional (costly) implications for potable water treatment works because tertiary treatment with activated carbon will become necessary to remove the toxins present in the raw drinking water supplies. In Figure 3.1.7 (top right) increases in annual water temperature by mid-century in the Thukela catchment, computed from the European Centre Hamburg's ECHAM5/MPI-OM GCM (A2 emission scenario), are projected to be of the order of 2 - 3 °C, The lower panels of Figure 3.1.7 illustrate April water temperature increases by the middle of the century to be 2 - 4 °C, but with increases up to double that by the end of the century according to climate output from the particular GCM used in a water temperature model (Barichievy *et al.* 2010).

Denser phytoplankton blooms will also lead to serious increases in concentrations of dissolved organic carbon (DOC) and changes in concentrations of dissolved oxygen. Low concentrations of dissolved oxygen plus available DOC will promote denitrification, resulting in loss of nitrogen to the atmosphere. This will, in turn, promote the growth of nitrogen-fixing cyanobacteria some of which are also toxic (e.g. *Anabaena*).

Algal blooms occur at the base of the food-chain and will markedly affect aquatic ecosystems, particularly in dams and lakes. It will be difficult to distinguish between the effects on fish of low DOC concentrations, changes in food availability (due to altered phytoplankton composition) and toxic effects caused by increased solubility of metal ions (caused by low DOC and low redox conditions). It will be particularly difficult to "quantify" these effects, even if the different causes can be distinguished.

Altered rainfall patterns may also result in changes in the chemistry of water which recharges groundwater. Arid and semi-arid regions have much higher evaporation rates than recharge rates. This evaporation results in a concentration of salts (sodium, chloride, sulphate, magnesium, calcium, nitrate, fluoride,) in the soil profile. When rainfall events in these areas are intense, the accumulated salts are leached from the soil and unsaturated zone to the water table. This, combined with the fact that the interior of the subcontinent contains soils poor in organic matter, exacerbates the occurrence of high nitrate in groundwater in these areas (Tredoux & Talma 2006). The effects of climate change will impact these arid and semi arid areas if recharge events become more episodic and extreme. It could lead to leaching or stripping the soil of its nutrients and minerals that are important for plant or crop growth. Untreated groundwater may become unfit for drinking due to flushing elevated concentrations of salts into the aquifer.

3.1.7 Vegetation responses to climate change and impacts on water resources

The direct effects of climate change on hydrological processes are the ones that are most commonly discussed, particularly the changes in rainfall regimes (amount, intensity, duration) and temperature (influence on potential evaporation). There are, however, some more indirect effects which need to be considered as they have important implications for the future availability of water resources.

Changes in the interactions between woody plants and grasses may be driven by increased CO_2 concentrations and wildfire regime (Bond *et al.* 2003). Atmospheric CO_2 increase may enhance the competitiveness of woody plants and may already account for much of the observed increase in woody plant densities recorded in South Africa during the 20th century (Wigley *et al.* 2006). Much of the bush encroachment observed in South Africa is ascribed to overgrazing and reductions in fire intensity and frequency which favour woody plant proliferation, but increased CO_2 would exacerbate this process (Scheiter & Higgins 2009). Woody plants typically have deeper roots than grasses and herbs, so a shift to woody plants means more deep soil moisture and groundwater are lost by transpiration. The net impacts are speculative, but increased tree cover driven by rising CO_2 and climatic changes in currently grassland-dominated catchments of the Drakensberg (Scheiter & Higgins 2009) could have adverse impacts on surface water flows in a major source region for South Africa's water supply, while appropriate control of tree establishment through fire management could offset this change.

Increased air temperatures will alter vegetation growing seasons and growth patterns, as has been shown by Schulze and Perks (2000). Frequent and severe frosts are characteristic of the elevated interior plateau of South Africa (Schulze 2008). The frost period exceeds 60 days on most of the Highveld and 120 days on upper slopes of the Drakensberg-Maloti Mountains which are the source of most of South Africa's water. Frost kill of grass cover significantly reduces transpiration during the winter months. A reduction in the onset and intensity of frosts could extend the growing season and thus also reduce runoff from these key catchment areas which currently yield more than 20% of the rainfall as runoff, compared to the national mean of about 9% for South Africa.

Rising atmospheric CO_2 might also lead to a reduction in soil moisture depletion due to its effect of reducing water loss from vegetation (e.g. Drake *et al.*1997). This could increase the amount of surface water generated from the South Africa's catchment areas. A global study found that surface runoff may increase by as much as 6% as a result of increasing CO_2 concentrations in future (Betts *et al.* 2007). While an evaluation for southern Africa suggests that the effects would be small and offset by the effects of temperature rises on evaporation (Scholes & Biggs 2004), simulations by Schulze and Perks (2000) with the ACRU model, which facilitates modelling of the CO_2 transpiration feedback, show that for an effective doubling of atmospheric CO_2 concentrations over South Africa mean annual runoff generally increases by around 2%, but by up to 8% in the mountainous areas of the south-western Cape and the northern Drakensberg – both important water-generating areas.

It is thus difficult to project the net effect of changes in atmospheric CO_2 and climate on catchment water yield due to a complex interplay between vegetation and physical driving factors. What is clear is that catchment management options are available to control at least some of these changes.

3.1.8 Vulnerability and future risks

Decreasing water availability, flooding, droughts, eutrophication and contamination will impact all sectors of the South African economy. However, the most vulnerable groups are those with least resilience to changes in the natural environment and limited 'buffering' capacity.

Provision of basic services (water, sanitation, electricity and waste management) is the main responsibility of municipalities. However, due to a lack of resources and poverty, especially in rural areas, some communities have no access to these services. One in ten South Africans does not have access to basic water supply and three in ten do not have adequate sanitation. In many rural areas, lack of managed services means that people rely on unmanaged local resources such as springs and rivers. These are vulnerable to pollution and drought. Poor communities who are dependent on natural water resources (Figure 3.1.8) do not control the quality of their water or bulk storage for water supplies. Rural communities with the highest dependence on natural water sources are in KwaZulu-Natal, the Eastern Cape and Limpopo (Figure 3.1.8). The former two are expected to be exposed to more flooding and contamination, whilst Limpopo may be exposed to flooding, contamination and drought. These are also areas with some of the poorest communities and under resourced municipalities with limited capacity and skills to adapt to changing water conditions.

Unpredictable and poor quality water provision results in poor health, morbidity and mortality and maintains poverty traps in poor communities. Low levels of assurance of supply also inhibit economic investment in development, agriculture and industry.

Agriculture is currently allocated 62% of available water resources. This sector could be adversely affected by increased flooding and erosion, and decreases in water availability, particularly in the Northern and Western Cape and the Free State. Changes in suspended sediment loads, nutrient and TDS concentrations in rivers and reservoirs could progressively degrade the quality of water used in irrigation. This may occur through physical blockage of micro-jet sprayers (used to conserve water) and also through enhanced growth of cyanobacterial and fungal bio-films in pipelines. The presence of algal toxins in water could prevent its use for irrigation of table crops (eg, salad vegetables) as the uptake of these toxins will contaminate crops.

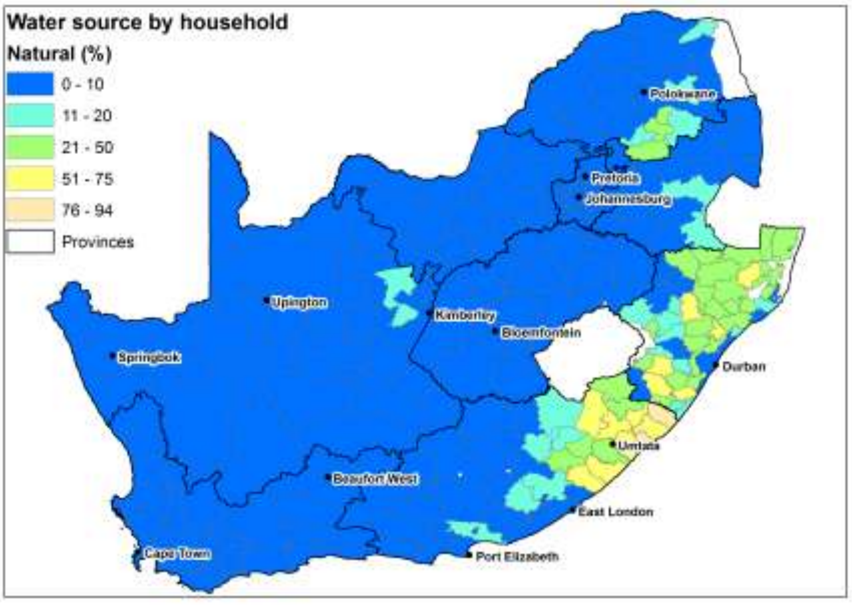


Figure 3.1.8: Percentage of households reliant on natural water sources – springs, rivers, wetlands (Statistics South Africa 2007).

3.1.9 Adaptation measures

South Africa's water resources are a key constraint to the country's continued economic development and the sustainable livelihoods of its people, and are already subjected to high hydro-climatic variability both over space and over time. Strategies and plans of action to adapt to climate change through an integrated approach to land and water management are urgently needed to establish effective resilience to the projected impacts of climate change. There are many reasons for this:

- Water is arguably the primary medium through which early (and subsequent) climate change impacts will be felt by people, ecosystems and economies.
- A large proportion of South Africa's population is impoverished (thus rendering them particularly vulnerable to impacts of climate change), and many ecosystems (both terrestrial and aquatic) are implicitly or explicitly water dependent.
- Water-related infrastructure (dams, irrigation projects, inter-basin transfers, and storm-water drains) are a long-term investment with a design life of 50 - 100 years, very expensive, essentially irreversible once constructed, and designed to cope with currently (but not necessarily future) expected extremes of floods and droughts.
- Any changes in rainfall, be they up or down, are amplified in changes to hydrological responses (in the case of year-to-year variability the amplification from rainfall to runoff can be 2-5 fold).
- Climate change is not going to be experienced evenly throughout the country, with some areas "winners", other areas "losers" and others still are likely to become real "hotspots of concern".
- Climate change does not occur on a "clean sheet" of virgin catchments not yet impacted upon by human interventions on the land and in the channel, but will rather be superimposed onto already water stressed catchments with complex land uses, water engineered systems and a strong socio-political as well as economic historical footprint.

Therefore, accounting for, and adapting to, potential effects of climate change in South Africa's water sector are imperatives - indeed, non-consideration of potential effects of climate change and adaptation on the country's water sector should be viewed as an act of omission.

South Africa has the potential to lead the continent in adapting to climate change, with its strong policies and laws to protect water resources and ensure their efficient and equitable use (e.g. Water Service Act 1997; National Water Act 1998; National Water Resource Strategy 2004). However, the water sector is characterized by capacity constraints, inadequate funding, a reliance on ageing bulk infrastructure and erratic water quality in smaller municipalities and rural areas (WISA 2008; SAICE 2006; Stuart-Hill & Schulze 2010). Climate change adds one more layer of uncertainty to the already challenged water sector. Whilst scientists' ability to project long term changes remains imperfect, in many areas we know enough to prioritize risks and put adaptation measures in place. In Table 3.1.1 some of the adaptation strategies that should be implemented to adapt to climate change are summarised.

With both drying and wetting projected over South Africa, an important primary measure to conserve the country's water resources is water demand management (WDM) – to use most efficiently and productively the limited water there is. WDM may be summarised as: 'A management approach for the water sector and user stressing the efficient use of existing supplies, through policy as well as ethical, educational, economic as well as technical means instead of developing new water resources' (van der Merwe 1999). In several municipalities WDM is no longer considered a possible option, but it is rather seen as a necessity that must be implemented with immediate effect. In line with this the Department of Water Affairs has put WDM high up on their agenda and they regard municipalities as the key implementers of WDM and water conservation programmes (van Vuuren 2008).

Table 3.1.1. Adaptation recommendations for water managers (Kabat et al. 2003; Schulze 2005)

ENHANCE ADAPTIVE CAPACITY TECHNOLOGICAL AND STRUCTURAL	IMPACTED SECTOR(S) (see footnote for key to abbreviations)	COPING WITH / ADAPTING TO? (see footnote for key to abbreviations)
- Storage and Reticulation		
- Surface water		
- Large Reservoirs	- BWS; IAG; NWP; RWP; AGI; MUN; DMT; HEP	- FLF; FLR; DRH; WSS; STS
- Small Reservoirs	- AGI; AGC; AGP; RWP; IHH; PRC; AOF	- FLF; DRA; DRH; WSS
- Groundwater		
- Artificial Recharge	- MUN; BWS; RWP; AQE; DMT; AGI - PRC; RWP; IHH; AGP	- DRH; WSG
- Borehole Drilling	- MUN; BWS; RWP; AQE	- DRH; DRA; WSG
- Sand Dams		- FLF; DRH; WSS; WSG
- System Maintenance	- MUN; BWS	
- Supply Leakage Control	- AGI	- DRH; WSS; WQU
- Irrigation. Equipment Maintenance	- AGI	- DRA
- Irrigation Canal Leakage	- PRC;IHH	- DRA
- Rainwater Harvesting	- MUN;PRC	- DRH; DRA; WSS; WSG
- Water Re-use/Recycling	- MUN;BWS	- DRH; DRA; WSS
- Desalination		- DRH; WSS
- Flood/Storm Surge Control	- RWP; MUN; TSP; DMT; AGC; AQE	
- Structures (i.e. Levees, Sand Bags, Wave Breaks, Planting)	- MUN; DMT; IHH	- FLF; FLR; SLR; STS
- Early Warning Systems	- MUN; AGI; AGC; AGP; IHH; DMT	
- Near Real-Time (Hours to Days)	- MUN; AGI; AGC; AGP; IHH; DMT	- FLF; FLR
- Short-Term (Days to Weeks)	- MUN; RWP; IHH; DMT; AQE; HEP	- FLR; DRH; DRA
- Medium-Term (Month to Season)	- MUN; IHH; AGI; AGC; AGP; BWS	- DRH; DRA; WSS; WSG
- Long-Term (Years to Decades)	- MUN; AGI; DMT; BWS; HEP	- DRH; WSS; WSG
- Communicate Forecasts to End Users	- MUN; BWS; DMT	- FLF; FLR; DRH; DRA; SLR; STS
- Operations/System Improvements		
- Reservoir Operations Rules	- AGI; AGC	- FLF; FLR; DRH
- Retrofitting Existing Structures	- MUN; IHH; RWP; NWP; BWS	- FLF; FLR; SLR; STS; WSS; WSG - DRA
- Irrigation Scheduling	- PRC	- DRA; DRH; SLR; WSS; WSG;

- Water Demand Management	- AGI; AGC; AGP; AQE; DMT	WQU
		- FLF; FLR; DRH; SLR; STS; WSS
- Indigenous Coping Strategies		- DRA
- Precipitation Enhancement		
KNOWLEDGE/SKILLS/PARTICIPATION	**IMPACTED SECTOR(S)**	**COPING WITH / ADAPTING TO?**
- Research and Development		
- Efficient Technologies	- ALL	- ALL
- Upgrade Climate Modelling	- ALL	- ALL
- Downscaling/RCMs	- ALL	- ALL
- Improve Forecast Skill / Dissemin-ation	- BWS; RWP; NWP; AGI; AGC; AGP; MUN; IHH	- ALL
- Drought Resistant Crops	- AGI; AGC; AGP	- DRA
- Development of Risk Maps/Floodlines	- INS; NWP; DMT; TSP	- FLR; DRH; SLR; STS
- Communication, Training and Dissemination	- ALL	- ALL
	- ALL	- ALL
- Participatory Approach in Decision-Making		
POLICY INSTRUMENTS	**IMPACTED SECTOR(S)**	**COPING WITH / ADAPTING TO?**
- International Conventions	- NWP	- ALL
- International Water Agreements	- NWP; RWP; TSP; DMT	- ALL
- International Trade	- NWP; MUN; AGI; AGC; DMT	- DRA
- National Water Master Plans	- NWP; RWP; DMT	- ALL
- Disaster Management Policies/Plans	- NWP; RWP; MUN; IHH; DMT	- ALL
RISK SHARING/SPREADING	**IMPACTED SECTOR(S)**	**COPING WITH / ADAPTING TO?**
- Private Sector Strategies		
- Insurance		
- Primary Insurers	- IHH; AGI; DMT; TSP	- DRA; DRH; FLR; FLF
- Re-Insurance	- MUN; DMT; TSP	- FLR; FLF
- Micro-Insurance	- AGI; AGC; AGP; DMT; IHH; PRC	- FLF; FLR; DRA
- Banks		
- Development	- NWP; DMT	- ALL
- Private	- IHH; DMT	- DRA; FLR; FLF
- Micro-Lenders	- AGI; AGC; AGP; IHH; DMT; PRC	- DRA; FLF; FLR
CHANGE OF USE / ACTIVITY / LOCATION	**IMPACTED SECTOR(S)**	**COPING WITH / ADAPTING TO?**
- Land Use Measures		
- Conservation Structures	- MUN; AGI; AGC; AQE	- FLF; FLR; SLR; STS; DRA
- Adaptive Spatial Planning	- MUN; RWP; AGI; AGC; AGP; TSP; DMT	- FLF; FLR; SLR; STS
- Tillage Practices	- AGI; AGC	- DRA
- Crop Change	- AGI; AGC	- DRA
- Resettlement	- IHH; PRC	- FLR; DRH; SLR; WQU

Key to abbreviations:

Impacted Sectors: *Coping with/adapting to:*

NATIONAL WATER PLANNERS (DWA)	NWP	FLOODS: FLASH	FLF
REGIONAL WATER PLANNERS (CMAs)	RWP	FLOODS: REGIONAL	FLR
MUNICIPALITIES	MUN	DROUGHT: AGRICULTURAL	DRA
BULK WATER SUPPLIERS (e.g. Rand Water)	BWS	DROUGHT: HYDROLOGICAL	DRH
INDIVIDUAL HOUSEHOLDS	IHH	WATER SUPPLY: SURFACE	WSS
POOR RURAL COMMUNITIES	PRC	WATER SUPPLY: GROUNDWATER	WSG
AGRICULTURE: IRRIGATED	AGI	WATER QUALITY	WQU
AGRICULTURE: CROPPING	AGC	STORM SURGES	STS
AGRICULTURE: PASTORAL	AGP	SEA LEVEL RISE	SLR
DISASTER MANAGEMENT	DMT		
HYDRO-ELECTRIC POWER	HEP		
THERMAL ELECTRIC POWER (Eskom)	TEP		
TRANSPORT	TSP		
INSURANCE	INS		

In western and central South Africa water service providers are likely to need greater water storage to buffer the projected higher extremes of future rainfall regimes. Currently South Africa has fairly low levels of per capita storage and it has typically relied on large and medium sized dams supplied by surface runoff. About 32,412 million m^3 is stored in major dams and on average 49,040 million m^3 of natural river runoff is generated per annum (DWAF 2004). Dams will likely become more vulnerable to losses from evaporation, siltation and contamination from algal blooms, and water suppliers will benefit from diversifying water storage strategies. Most water stored naturally in catchments is stored in aquifers underground, therefore groundwater can provide an important buffer against more uncertain rainfall in the future. It is estimated that mean annual recharge to groundwater is two thirds that of river runoff at 30 000 million m^3 (DWAF 2005). However, there is more than 7 times the volume of groundwater in stored in aquifers
(~ 235, 000 million m^3) than surface water stored in major dams (DWAF 2005). DWA is already developing a National Groundwater Strategy and plans to enable water service providers to 'diversify the water mix' by using more groundwater.

Groundwater plays a critical role in rural development as a robust resource with buffered storage and distributed occurrence. It allows local control and uses a range of off-grid energy (solar, wind, hand pumps etc) and has been identified for increased use by DWA. The storage of groundwater can be enhanced using managed aquifer recharge. The CSIR has pioneered artificial recharge to groundwater in southern Africa in Cape Town, the West Coast and Windhoek. Excess storm water from the winter rainy season is captured, treated and infiltrated or injected into the aquifer. The Department of Water Affairs is now encouraging municipalities to set up managed recharge schemes as part of their long term integrated water resource planning.

Water-sensitive urban design has been pioneered in some semi-arid cities (e.g. Perth, Australia) as a means of capturing water within the urban landscape and minimising pollution, erosion and disturbance resources. This ensures that storm water is treated as a valuable water resource and not simply discharged to rivers or the sea. The City of Cape Town has already put a policy in place to enable water-sensitive urban design.

Land use zoning in the future may need to take greater account of water resource impacts.

Buffer zones around rivers could be required to mitigate increased erosion and runoff and protect water quality in rivers and wetlands. Groundwater protection zones may be required in areas where groundwater recharge is vulnerable to the impacts of development of on-site sanitation, land-fills or petrol tanks. Agricultural best practice to reduce contamination and soil erosion will need to be implemented in areas increasing vulnerable to floods. Industrial and mining environmental management of potential contaminants will need to become a priority.

Municipal wastewater treatment plants will require stricter enforcement of effluent standards and significant investment in aging infrastructure. This process has begun with the roll-out of DWA's 'Green Drop' campaign which supports improved effluence compliance.

Finally, catchment management approaches, including the appropriate use of fire, are likely to be critical in the long term. Appropriate management interventions are likely to be necessary to ensure that upland catchments, in particular, continue to yield water in the face of possible changes in vegetation driven by climate and atmospheric changes.

3.2 Agriculture, rangelands and forestry

3.2.1 Current vulnerabilities

Crop and livestock agriculture: The South African agricultural sector has a range of vulnerabilities to climate change, due both to diverse agricultural natural capital that supports a dualistic, two-tiered agricultural system (commercial/emerging vs small-scale/homestead), and also to the wide variety and high variability of climatic conditions across the country (especially of rainfall). Roughly 90% of the country is sub-arid, semi-arid or sub-humid, while about 10% is considered hyper-arid (Middleton & Thomas 1997). Only 14% of the country is potentially arable, with one fifth of this land having high agricultural potential (http://www.info.gov.za/aboutsa/agricland.htm).

Overall vulnerability of the South African agricultural sector to climate change can be usefully viewed within a southern African context, which represents both risk and opportunity. Regional risks relate to potential declines in regional food security through the adverse impacts of climate change, socio-political conditions and population growth, while opportunities include those related to regional trade and technology sharing.

Climatic factors are important, to a large extent, in determining potential agricultural activities and suitability across the country, especially in small-holder and homestead settings. However, rainfall constraints are largely overcome through irrigation and conservation tillage practices, notably in the commercial agricultural sector, and to a lesser extent by water harvesting techniques used often by disadvantaged farmers to supplement rainfall in small-scale rural agriculture and urban settings. Rainfall variability introduces an inherently high risk to climate change at many time scales, especially in transitional zones of widely differing seasonality and amount of rainfall. These transitional zones seem particularly sensitive and vulnerable to geographical shifts in climate (Schulze 2007).

Agricultural production practices can be broadly differentiated between a commercially-oriented sector that services national food requirements and export earnings, and a small-scale and homestead farming sector constituting a high proportion of the farming population, mainly subsistence, and relying largely on traditional agriculture methods. Commercial agricultural activities in South Africa range from the intensive production of vegetables, ornamentals and other niche products to large scale production of annual cereals (e.g. wheat and maize), oil seeds and perennial herbaceous crops (e.g. sugarcane) and tropical, subtropical and temperate fruit crops. Livestock production is a major contributor to national and household food security and to GDP, with significant intensive production of cattle, pigs and poultry. In addition, livestock has a socio-cultural besides a monetary value.

Small-scale and homestead food production are practiced in rural areas on both high potential and marginal agricultural land, with roughly 1.3 million small-scale farm units. Seventy percent of the country's poorest households live in these areas and few of these households are food self-reliant throughout the year. Overall, about 35% of the population is estimated to be vulnerable to food insecurity and a quarter of the children under the age of 6 are stunted by malnutrition. However, this is primarily a function of total household income and much less a function of what the individual household produces for own consumption or agriculture per se (De Klerk *et al.* 2004). Small-scale and homestead food production is particularly vulnerable to climate variability, relying mostly on dryland food production, with limited capital to invest in soil fertilization, seed, and weed, pest and disease control. Programs are underway to reduce this vulnerability and enhance local food security by encouraging conservation agriculture practices and water harvesting by means of participatory, on-farm demonstration and experimentation.

Dependence on water represents a significant current vulnerability for almost all agricultural activities, with irrigation-based agriculture the largest single surface water user by far, consuming 60% of total available water, and with all agriculture-related activities consuming 65% (Blignaut *et al*. 2009). Irrigated crop production is practised on 1.35 million ha contributing almost 30% of the gross value of agricultural production, with water availability precluding further major expansion (De Villiers *et al*. 2005; Mpandeli *et al*. 2008). Surface water used in irrigation has increased by 4%, from 7630 million m^3 in 1995 to 7921 million m^3 in 2000, and representing 160% of the total water surplus remaining at the end of 2000. The total increase in water consumption for all sectors from 1995 to 2000 was 348 million m^3, and thus that the share of the increase due to irrigated agriculture was 84%.

Dryland production (without irrigation) is vulnerable to drought and other climate-related stress. Groundwater is of particular importance, notably for rural water supplies, but in the predominantly hard rock of South Africa's geology, only some 20% of groundwater occurs in major aquifer systems that can be used on a large scale (van der Merwe 2007). Water scarcity and a decline in water quality are therefore increasingly constraining South Africa's sustainable agriculture and rural development (Beukes *et al*. 2003; van der Merwe 2007).

The vulnerability of agriculture is exacerbated by soil properties and topographical constraints that limit intensive crop production (Barnard *et al*. 2000). South Africa's soil mantle is complex, diverse, often thin and susceptible to degradation. Soil organic matter is vulnerable to increasing temperatures (Benhin & Hassan 2006; Schulze 2006; 2007), adversely affecting soil biological, chemical and physical properties, resulting in more acid soils, soil nutrient depletion, a decline in microbiological diversity, a weakened soil structure, a lower water-holding capacity, increased runoff and soil degradation. Climatic characteristics cause agriculturally unproductive water losses by runoff, high soil water evaporation rates and deep drainage (Beukes 2003), potentially adversely affecting topsoil via nutrient depletion and land degradation.

Some evidence suggests that increasing population pressure, unsustainable land use, increasing competition for agricultural land resulting in land use change and poor economic decisions are leading to land degradation, aggravated by bush encroachment and invasive alien plants (Department of Agriculture 2007).

Food security: Food security encompasses components of food availability (production, distribution and exchange), food access (affordability, allocation and preference) and food utilisation (nutritional value, social value and food safety) (De Klerk *et al*. 2004; FAO 2005). Food security is achieved when food systems operate such that all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life.

Despite a status of being food-secure as a country (De Klerk *et al*. 2004), 50% of South Africans experience hunger and 9 % of children experience under-nutrition (Goldman 2010). There are comparatively few individuals or households in the case of homestead or subsistence farmers who are totally self-reliant for food throughout the year (De Klerk *et al*. 2004; Gregory *et al*. 1999). In a southern African context, the additional number of people at risk of hunger due to climate change in southern Africa has been estimated at 80 million (Bharwani *et al*. 2005), while by 2080 under-nourished people in sub-Saharan Africa could increase by as many as 50 million to 240 million (Pan African Climate Justice Alliance 2009).

South Africa's concern about food security, including climate change-related risk of increased hunger and the environment, is underpinned by Government's sustainable agrarian reform framework. Agrarian reform focuses on vibrant, equitable, sustainable rural communities contributing towards food security for all; protection and enhancement of our environmental assets and natural resources; and faster, sustainable and inclusive economic growth (Goldman 2010).

Rangelands: South African rangelands (untransformed ecosystems) include a diverse group of ecosystems comprising savanna, grasslands, Nama- and succulent karoo biomes, which extend across low rainfall areas, including arid and semi-arid, and some seasonally high rainfall areas. In the short-term, their composition and productivity are influenced primarily by rainfall, grazing and fire, while over longer periods changes in temperature and atmospheric CO_2 play a greater role (Hoffman & Vogel 2008). South African rangelands support a range of economic activities including conservation and tourism, commercial livestock production, and smallholder livestock systems (Thornton *et al*. 2006). South African rangelands are often considered to be environmentally and economically marginal, particularly where there is a high dependence of people on natural resources, livestock and agriculture. Overgrazing, desertification, natural climate variability, and bush encroachment are among the most serious problems facing rangelands. External stressors such as climate change, economic change, shifts in agricultural production and land use may further negatively impact the productivity of these regions and deepen pre-existing vulnerability (Nel & Hill 2008).

The link between rainfall, land use and degradation is important, since climate change can modify both the magnitude of, and frequency with which, thresholds are exceeded that may initiate desertification processes. For example, a higher frequency of drier spells or a lower rainfall can affect vegetation cover, with implications for both erosion and livestock production. In an area under pressure from overgrazing or inappropriate water use, and thus vulnerable, climate change can amplify desertification (Archer & Tadross 2009). Climate change impacts are likely to be an important consideration in the efforts of land reform beneficiaries and/or the emerging agriculture sector in rangelands. Strategies and policies supporting this sector could usefully be informed by such considerations.

Plantation forestry: Should rainfall remain stable, or increase in afforested areas of South Africa, it is unlikely that planted areas will decrease in extent. However, forestry plantations use more water than native vegetation, and depending on the extent of afforestation can significantly reduce the flow in rivers, and this makes them vulnerable as a competitor for scarce water resources. In highly-afforested catchments (Mpumalanga and the southern Cape) mean annual runoff and low flows are reduced by between 9-14%, and 12-22% respectively, when assessed at a primary catchment level (Scott *et al*. 1998). Groundwater recharge is also reduced by plantations where roots are able to tap into the groundwater table (Le Maitre *et al*. 1999). Forest plantations have been shown to significantly depress low flows of afforested streams, regardless of rainfall. Current vulnerability to fire may also increase if fires become more frequent, as they are predicted to do in some areas. Vulnerability is strongly dependent on the degree by which pro-active fuel load reduction strategies are implemented.

3.2.2 Observed trends

There are relatively few analyses of trends in agricultural production in relation to climate trends over the past few decades, though some recent studies have begun to address this gap. Significant relationships have been found between grain crop production and rainfall in all provinces that contribute 20% or more to national production. These include maize in the Free State (40%) and Mpumalanga (21%) and wheat in the Western Cape (35%) and Free State (37%) (Blignaut *et al*. 2009). A decline of 1.16% decline in maize production and 0.5% in wheat production for every 1% reduction in rainfall was projected from these trends. In the winter-rainfall region, export quality apple production seems to have already been adversely affected by warming trends, owing to its sensitivity to positive chill units which have decreased significantly in recent decades (DEAT 2007b). Rural rooibos tea farmers have been adversely affected by recent drought impacts (Oettle 2006).

Non-climatic land-use trends such as urbanization to accommodate increasing population and competition from other sectors (e.g. mining) appear to be impinging on limited agricultural land (van der Merwe *et al*. 1999a; 1999b).

Commercial forest productivity has to date remained unaffected despite significantly wetter and hotter trends having been recorded in the southwestern Cape and a drier, and a warmer trend in the northeast over the last 50 years, with the possible exception of an apparent increase in wildfire risk and greater frequency of damaging fires in recent years.

3.2.3 Climate projections and agricultural responses

The Initial National Communication interpolated projections for 2050 which indicated a decrease in rainfall by ~15% in the summer rainfall area and by ~25% in the winter rainfall area; temperature increases of between 2.5 and 3ºC; elevated evaporation rates in the interior and moister north-western regions; an increased frequency and intensity of drought, water stress and more frequent floods; and seasonality shifts such as earlier winter frontal systems in south-western regions (Department of Agriculture 2007). Major climate change impacts on and implications for agriculture projected included that: Western maize production areas to become unsuitable for maize production because of reduced water availability, but with possible crop yield increases in some eastern production areas mainly due to projected growth enhancement by higher atmospheric CO_2 levels; marginal land to become prone to reduced yields and crop failure because of diminished soil productivity and land degradation; Changes in plant and animal disease and insect distribution, adversely affecting both crop and livestock production (in the absence of any adaptive responses); and that animal health may be at risk as the distribution and abundance of vectors and ectoparasites change.

More recent studies largely support but significantly extend these predicted effects, and indicate in more depth where the specific vulnerabilities might lie (Oettle 2006; Benhin & Hassan 2006; Schulze 2006; Molope 2006; Schulze 2010 for South Africa; and Nelson *et al*. 2009 for sub-Saharan Africa). Some regional studies (e.g. Pan African Climate Alliance (2009)) project significant future economic costs of climate change in many regions of Africa, including a drop in crop revenues by ~90% in sub-Saharan Africa and a resulting significant increase in undernourishment in sub-Saharan Africa's population. It is difficult to reconcile these severely adverse impacts with projections for South African agriculture, but they may serve as a potential warning of regional impacts under worst case scenarios.

Projections of impacts on agriculture in South Africa have used different emissions scenarios, different climate models, and different downscaling techniques, in addition to simple sensitivity analyses using step changes in rainfall and temperature. There has been a trend to focus on SRES A2 and B1 scenarios, representing CO_2 equivalent levels of above 500 ppm by 2050. No projections have used levels of 450 ppm or less. Thus published projections represent the impacts of unmitigated climate change. A useful approach was used by Nelson *et al*. (2009), whose climate projections are driven by the A2 emissions scenarios, and based on CSIRO and NCAR climate models. These respectively represent drier and wetter future conditions, which align with interpolation between future projections (drier) and with statistically downscaled results (wetter) projections. The approach adopted by Schulze (2010) was to use daily statistically downscaled values from five IPCC AR4 global circulation models (GCMs) for present (1971-90), intermediate future (2046-65) and more distant future (2081-2100) time slices and from output of these multiple GCMs into crop yield models to assign median changes and confidence limits to projected agricultural yields and changes in climatically optimum production regions. Even relatively small mean temperature and rainfall changes may be amplified by specific crop sensitivities. For example, as little as a 2°C increase in daily temperature will lead to a 10-35% annual increase in biologically important heat units, a 40-60% reduction in positive chill units, and a 5-13% increase in potential evapotranspiration (DEAT 2007b; Schulze 2010).

3.2.4 Risks to key summer rainfall crops

Maize: Local consumption of maize amounts to about 8 million t and surplus is exported with a gross value of ZAR 21 billion. As South Africa's staple food crop, maize has been under the spotlight since the late 1990s, first in vulnerability research (Du Toit *et al*. 1999; 2002), later in regard to productivity (Schulze *et al*. 1995) and subsequently from a sustainability perspective (Walker & Schulze 2006; 2008), while an inter-continental comparative study focusing on South Africa was produced by Jones & Thornton (2003). Yields are likely to be sensitive to both climate and CO_2 fertilization, with doubled CO_2 offsetting much of the reduced profitability associated with a 2°C temperature rise or a 10% reduction in rainfall, especially in core areas of maize production (Walker & Schulze 2006). However, no field studies on CO_2 sensitivity of maize have been carried out in South Africa, and this thus remains a modelled result. Maize cultivars locally developed include drought-tolerant and stalk borer-resistant strains requiring less input cost (Department of Agriculture 2007).

Sugarcane: South Africa is the world's 13th largest sugar producer. Sugarcane is grown in the northern parts of the Eastern Cape through KwaZulu-Natal to the Mpumalanga lowveld. An estimated 2.5 million t of sugar is produced per season. Some 50% is marketed in southern Africa with the rest exported. Analysis indicates positive dryland sugarcane yield increments of ~ 5.0 to 5.5% per degree rise in temperature. When a temperature increase of 2°C is associated with simultaneous changes in rainfall, yields were modelled to decrease by ~ 7% for a 10% reduction in rainfall and to increase by a similar percentage for a 10% enhancement of rainfall (Schulze 2010).

Horticultural crops: Heat-tolerant, drought-resistant and water use-efficient crops have been locally developed for certain field and vegetable crops. Climate change could have serious implications for the sustainable agricultural production of these crops, but to date these effects have not been studied.

3.2.5 Risks to key winter rainfall crops

Winter rainfall agriculture is limited largely to the Western Cape, and has been identified as a key priority sector by the Western Cape Provincial Development Council, (2005). The winter rainfall region has a very small subsistence agriculture component, although there is key developing farmer participation, such in the Honeybush and Rooibos tea industry.

The most vulnerable commodities and regions in the winter rainfall region over the period to 2050 were identified in the Long Term Mitigation Scenarios (LTMS) (DEAT 2007b) as:

- those reliant on rainfall (small grains, rooibos tea, stock on western arid rangelands),
- those which require significant chill units (e.g. apples, pears),
- irrigated agricultural crops, especially during drought periods, and
- in geographic terms, the north-west and Swartland, the Cape Town Metropolitan region, and to a lesser degree Boland and Overberg regions (i.e. the Berg River catchment).

Commodities and regions which could benefit during this time frame are heat-tolerant fruit species, e.g. grapes, stone fruit, citrus in cool to warm regions, and indigenous horticultural species, e.g. fynbos, cut flowers.

Apples: South Africa currently ranks 15th in global apple production and in 2006 produced 1.25% of the global supply (Deciduous Fruit Producers' Trust (DFPT) 2007). However, South Africa ranks in the top 6 apple exporters. Total production in 2005/2006 was 780 000 tons, of which 32% was sold locally, 42% was exported, 26% was processed and 0.2% was dried (DFPT 2007). The industry currently provides permanent equivalent on-farm jobs for 25 900 people and 103 500 dependents (DFPT 2006). Five times the on-farm jobs are generated in related industries and service companies.

Projected temperature increases are projected to cause a 28% restriction of the area suitable for apple production by as early as 2020, with suitable apple producing climates thereafter limited only to the high-lying areas of the Koue Bokkeveld and Ceres by 2050 (Cartwright 2002). This projection is consistent with observed trends of reduced export apple volumes partly ascribed to adverse climatic conditions (Midgley *et al*. 2006).

Pears: Pears have similar climate requirements to apples, but with less stringent chilling requirements and lower sensitivity to heat stress. The total area under pears was 11 800 ha in 2006 (DFPT 2007), mostly under irrigation. Pears account for 15% of deciduous fruit production. Overall, the risks associated with producing export-quality pears is related to cultivar-specific sensitivities, with some cultivars at more risk than others. It is very likely that, over the next 30 years, most commercial pear producers should be able to make the necessary adjustments needed to remain profitable.

Viticulture: South Africa is the 9th largest wine producer in the world, with 90% of the country's production (2.8% of global production) from the Western Cape. Total producer income from wine and wine-related products in 2006 was R2.6 billion (SAWIS 2007), and the state's income through excise duty and VAT was R3.1 billion. However, the total value of production is about R13 billion. The industry generated R3.5 billion in wine tourism during 2003. The total area under grapevines was 102 000 ha in 2006, producing 1.3 million tons which was processed into 1.013 billion litres of wine and wine related products (SAWIS 2007).

The market is likely to dictate impacts and adaptations (DEAT 2007b). Global trends in supply and demand and resulting price volatility are by far the most important factors in determining future profitability. Impacts and vulnerabilities will differ depending on the scale (industry-wide vs. farm level). The industry as a whole may shrink, but successful producers in core areas could capitalize on opportunities such as changing market demand due to adverse climate impacts on international competitors. Water for irrigation or rainfall in non-irrigated vineyards will be a much greater issue than temperature. Marginal non-irrigated vineyards could become uneconomical and total production area could decrease by up to 30% under projected changes by 2050, but increasing yields are possible in irrigated well-managed vineyards in good areas. Shifting the industry to other regions would be difficult and expensive, not so much the planting of vineyards as the re-development of infrastructure (such as cellars). The mountainous regions of the eastern Overberg offers new opportunities on old lands provided there is sufficient water. The industry could usefully re-evaluate its cultivar mix and possibly make more use of early-season cultivars to avoid damaging effects of heat waves in mid-summer. Even within cultivars the style of wine will likely change. There are new opportunities to acquire cultivars (or breed locally) with pest/disease resistance without forfeiting high quality and yield. It takes ca. 10 years to source, quarantine, register and certify a new cultivar for release.

Wheat and Barley: The two main wheat- and barley-growing areas stretch from Grabouw to Heidelberg (21% of gross farming income for wheat, 94% for barley), and the areas around Malmesbury, Vredenburg and Piketberg (68% for wheat, 4% for barley). Together these two areas account for 89% of gross income from wheat in the Western Cape, which represents a contribution to GRP of 0.5%. Dry spells occur naturally during winter, and a decrease in winter rainfall would potentially accentuate this natural effect. In cases where areas are already close to threshold values for maximum temperature, a further increase can have devastating effects on production potential (DEAT 2007b). Preliminary analysis demonstrates that both timing and amount of rainfall is a good predictor for yields, and that potential future decreases in total rainfall in early winter months will have a negative impact of between 5 and 70% on yields, depending on area and eventual climate change scenario.

Rooibos tea: Rooibos tea production is vulnerable to reduced rainfall and lack of rainfall at critical times, with yields projected to decrease 40% during a drought year (Oettle 2006). Numerous adaptation strategies are, however, used or known by the farmers, including changes in ground preparation and tea harvesting times, wind erosion prevention measures, and water conservation measures. Not all measures are implemented, often due to lack of financial resources.

3.2.6 Impacts on pest species

Stages in the development, or durations of entire life cycles, of agricultural pests and diseases are closely related to temperature thresholds, and are thus affected by global warming. Two pests of sugarcane (the codling moth C*hilo sacchariphagus*, and the oriental fruit moth *Eldana saccharina*) may be able to increase their reproductive output under projected future climates (Schulze 2010). In the case of horticultural crop-associated coddling moth *Cyclia pomonella*, the number of life cycles per annum may increase by > 30 % of the present over the central areas of South Africa. The oriental fruit moth *Grapholita molesta* (which affects apples) has also been shown to increase under projected future climates.

3.2.7 Risks to livestock production

Livestock and livestock products contribute an estimated 51% of the agricultural income, mainly from the intensive livestock sector. Relevant climate impacts include high temperatures in conjunction with humidity conditions and insufficient water that cause heat stress in animals. This negatively affects animal production as feed intake and reproduction are lowered, mortality rates increase, and growth is slowed (Brown-Brandl *et al*. 2005).

To estimate the effects of climate change on the livestock sector, several approaches and simulations have been used in South Africa to develop heat stress (maximum ITH) and humidity (THI) indices for livestock (Brown-Brandl *et al*. 2005; Chase 2006; Christensen *et al*. 2007). Lower and upper critical temperatures determine the thermally comfortable zone per livestock type to ensure optimum development and productivity. Experimental results from simulation models suggest:

Pigs: Increased heat stress was found to result in a small reduction in growth rate because of reduced food intake, with piglets taking one day longer to reach target weight. Solutions to counteracting heat stress include a reduction in stocking rates per housing unit so that the level of gross stress is reduced significantly, or to improve ventilation, which would require capital investment and elevated running cost.

Broilers: Research has shown that, with a heat stress increase of 10%, despite a 10% increase in energy consumption for additional ventilation, each crop of broilers took a day longer to reach the target weight. Considering an expected 2.5-3ºC rise in temperature, substantial mortality can be expected. Options to be considered by farmers would be a reduction of stocking density by 12%, reducing the frequency of heat stress to baseline levels, or improving ventilation, which implies a capital investment.

Feedlot cattle: Feedlot cattle are adversely affected by high temperature, relative humidity, solar radiation and low wind speeds. Tolerance thresholds have been reached in the North West, Northern Cape and Free State during the summer months of 1980-1999. It is projected, using climate scenarios, that thresholds can be expected to be exceeded in these provinces towards the end of the century.

Dairy cattle: The present climate scenario (1980-1999) indicates that the north-eastern parts of the Northern Cape Province are experiencing moderate to severe heat stress, while this was less severe in Mpumalanga, north Free State and much of KwaZulu-Natal. Projected scenarios indicate that stress levels could increase to mild stress levels with a minimal effect on milk production. To counter-balance harmful effects without jeopardizing milk production, high milk-producing exotic breeds have been cross-bred with heat-tolerant indigenous breeds.

3.2.8 Plantation forestry

A number of studies have attempted to model the potential future impacts of climate change on the extent and productivity of plantation forestry in South Africa (Schulze *et al*. 1995; Fairbanks & Scholes 1999; Warburton & Schulze 2008). Most of these studies use rainfall and temperature to map areas that are potentially suitable for afforestation with a particular species. These studies have concluded that, in the medium and longer term, the total area of potential afforested land is projected to increase due to the wetting trend over the eastern seaboard and adjacent areas. For specific species, it is projected that *Acacia mearnsii* potential growing area will move towards the interior from the current near-coastal distribution, while the two other major species (*Eucalyptus grandis* and *Pinus patula)* will lose some of their current growing areas, but gain overall in climatically suitable area and in productivity. In the southwest the drying trend coupled by an increase in temperature of between 1.5 and 2.5°C will culminate in an increase in soil moisture stress in the distant future, which in turn will lead to a reduction in viability of commercial plantations.

3.2.9 Rangelands

Climate change (including increased atmospheric carbon) may complicate the existing problems of bush encroachment and invasive alien species in rangelands. Rising atmospheric CO_2 levels may be increasing the cover of shrubs and trees in grassland and savanna, with mixed effects on biodiversity, and possible positive implications for carbon sequestration. Increased temperatures are likely to provide a more conducive niche for a variety of pests and pathogens critical to agricultural and livestock activities, including those undertaken in rangelands. Increased temperatures and increased evaporation may increase the incidence of heat stress and the incidence of heat stress and increased livestock water requirements in the extensive livestock production that takes place in rangelands.

3.2.10 Agricultural yield and commodity prices

Crop net revenues in South Africa could fall by as much as 90% by 2100 due to climate change, with small-scale farmers most severely affected (Benhin 2006). However, with appropriate adaptation responses these losses could be reduced. Increased temperatures were projected to be harmful in summer but generally beneficial in winter. The effects of changes in both temperature and precipitation may be different for the different farming systems. For 2050, crop net revenues are expected to fall by between 2% to 5% for the whole of South Africa, by between 1% to 4% for irrigated farms, 26% to 28% for dryland farms, or 6% to 14% for large-scale farms, and 10% to 21% for small-scale farms. For the climate scenarios assumed, the negative effects are expected to increase by 2100, with a fall in crop net revenues ranging from 9% to as high as 90%, with small-scale farms most affected. This compares well with Pan African Climate Change Justice (2009) as arid and semi-arid areas are expected to expand by 5-8% by 2100 resulting in agricultural production losses of 0.4-7% of GDP in northern, western, central and southern Africa. Over 60% of Africans depend directly on agriculture for their livelihoods.

Nelson *et al*. (2009) concluded that in sub-Saharan Africa, maize production could decline by between 15% (rainfed) to 40% (under irrigation), soybean by up to 40%, and wheat by between 30 and 40%. Price increases are projected even without climate change effects, maize by 63%, soybeans by 72%, and wheat by 39%. Climate change was projected to increase prices further, by 52 to 55% for maize, 94 to 111% for wheat, and 11 to 14% for soybeans. CO_2 fertilization would reduce these price increases by 2050 by 10%. The effects of higher feed prices caused by climate change are projected to increase livestock prices, resulting in higher meat prices (e.g. beef prices 33% higher by 2050 with no climate change, and 60% higher with climate change impacts). Calorie availability in sub-Saharan Africa was projected to decline from ~2300 kcal/day to ~1,900 kcal/day by 2050. By 2050, the worldwide declines in calorie availability were projected to increase child malnutrition by 20% relative to a world with no climate change. Climate change could therefore eliminate much of the improvement in child malnourishment levels that would occur with no climate change. They concluded that increased investment of 3 billion US$ (2000 equivalent) would be needed annually in sub-Saharan Africa to counteract these negative trends, with about 2 billion US$ needed for road development, 300 million US$ for agricultural research, 500 million US$ for irrigation expansion, and 200 million for irrigation efficiency. A major constraint to irrigation expansion is soil suitability for irrigation and water availability (De Villiers *et al*. 2005).

3.2.11 Adaptation

3.2.11.1Broad categories of adaptation responses:

Adapting to projected climate change in South Africa's agriculture sector will be about large-scale commercial farmers staying ahead and being progressive by optimizing climatic conditions in order to maximize output in a sustainable manner and maintaining a competitive edge. At the rural livelihood scale, on the other hand, adaptation needs to focus on the most vulnerable groups and areas, so that livelihoods are not eroded by climate events, but rather that the affected communities become more resilient to the expected changes in climate. For both sets of farmers, adaptation will require an integrated approach that addresses multiple stressors, and will have to combine the indigenous knowledge/experiences of vulnerable groups together with latest specialist insights from the scientific community. Most agricultural programs and information are initiated at high levels in government for regional implementation and are not always adapted to local conditions. However, all agricultural programs and planning strategies in regard to climate change will need to focus on local conditions, as climate change will have very local repercussions (Schulze 2010). Given below is a summary of findings on adaptation options for the South African agriculture sector, with full details available in Schulze (2010).

- **Climate-related:** Farmers will need to adapt to the following, which are likely to vary from region to region within South Africa: The *lack of predictability of rains*, including changes to the start to the rainy season, rainfall at critical crop phenological stages or increases in rainfall variability; *changes to the beginning and end of the frost season*, with knock-on effects on climatic suitability of crops, plant dates or pest/disease incidence; *reduced chill units* with global warming and associated changes in deciduous fruit types grown; or changes in *wind erosion* resulting from more frequent drying of soils.
- **Water-related** adaptation options relate to *dams and dam operations* such as the construction of more large and/or farm dams for irrigation (conditional upon more impoundments not being a mal-adaptive practice in regard to environmental flows and downstream riparian water users), or making infrastructure modifications to dams in respect of dam safety to deal with future climate conditions; *water conservation practices* with a focus on water productivity, i.e. the so-called 'more crop per drop' by promoting water use efficiency related technologies, as well as conservation tillage and water harvesting; *wetlands conservation* in as much as they perform vital ecosystems functions and provide a wide range of agricultural goods and services in supporting livelihoods in many rural communities; c*ompetition for water* from other sectors; *flood and drought management* such as changing allocation rules during droughts and protecting agricultural lands from flooding; *sustainable groundwater use* by considering altered recharge rates under climate change; or the *reduction of high salinity levels* by more judicious management of soil and water by agriculture in future climates.
- **Natural resource base-related** adaptation includes undertaking s*oil suitability studies* prior to future land use decisions; *adopting a soil protection ethos* to underpin land use decisions in the future; and *local area specific soil husbandry.*

- **Dryland crop-related** adaptation embraces the *overall promotion of best management practices* based on the principles of the least possible soil disturbance, permanent soil cover, multi-cropping and integrated crop and livestock production in order to optimize yields, as well as sequestering carbon and minimizing methane and nitrous oxide emissions. BMPs include recognition of shifts in optimum growing areas of crops, eliminating farming on climatically marginal land more prone to future reduced yields/failures, procuring climate-specific farms for specific crops, growing indigenous species suitable for local conditions, altering plant times on consideration of seasonal climate forecasts, altering harvest times, diversifying crops, harvesting less often in drier regions to prevent nutrient depletion, or practicing no-till as a soil conservation measure; as well as *consolidation of small plots of land*.
- **Irrigation farmer-related** adaptation measures include *increasing the area under irrigation*, but only subject to water and suitable soils being available, the irrigation practices being efficient and expansion not leading to negative repercussions downstream; *integrated water use planning; conversion to drip irrigation; conversion to drip irrigation* (from overhead or flood methods) because of its high water use efficiency, application of *local and crop specific irrigation scheduling* to avoid excessive water and fertilizer losses from irrigated lands; or *use of mulching/crop residue* as a water saving mechanism.
- **Livestock-related** options include *adapting livestock (and game) densities* to changing grassveld carrying capacities, *minimizing overgrazing* to curb increased erosion through enhanced surface runoff, keeping *alien invasive grass species* to a minimum as they are likely to become a major threat to indigenous species, *minimizing weed infestations in grasslands* because weed infestations, being mostly pioneer species, tend to degrade ecosystems and adapt more rapid to environmental changes; practising *fodder storage* for livestock; *shifting of livestock to land with higher carrying capacity; and factoring in animal health* resulting from changes in rainfall and temperature which impact on the distribution, competence and abundance of vectors and parasites.
- **Subsistence farmer-specific** adaptation practices include *overcoming farmers' constraints* such as poor commercialization, poor infrastructure, and low farm productivity, which largely implies *eliminating the poverty trap* subsistence farmers find themselves in.
- **Hazard-related adaptation** will have to deal with consequences of projected *increased convectivity* (higher intensity thunderstorms) and enhanced surface runoff, erosion and mudslides by closer contour spacing; coping with *more frequent/hotter fires* and resultant loss of grazing and of other crops/plantations by making firebreaks and burning at the times dictated by law; improving *pest control* to anticipated increases in pest and disease infestations, including promotion of already tested natural

remedies of pest control and advice on new pesticides; and adapting to increased *water borne diseases* which can cause more outbreaks of insects as a result of warmer water.

- **Alien invasion-related** adaptation, resulting from better conditions for alien species to invade with climate change, will need to include revisiting policies on clearance, subsidies and benefit/cost analyses of alien clearing for farmers.
- **Policy-related** adaptation will need to focus on areas where *agriculture is the primary producer; on the importance of integrated planning* in with agriculture, mining and municipalities needs to be planned conjunctively in regard to water quantity and quality; streamlining *complex or cumbersome legislation* to make adaptation to the additional stressor of climate change easier; increasing *policy awareness; expanding extension services* to expedite adaptation to added uncertainties of climate change; finding means to *finance* and to use *current and new technology and practices*; considering climate change implications in *land reform and land redistribution* policy and practice; and preventing the *urban sprawl* from using up valuable high potential agricultural land which can never be recovered.
- **Science-related** adaptation includes *promoting the skill in, use of, and trust in, climate forecasts; reducing uncertainties about climate change* by continually improving answers for South African farmers on the when, where, how much, what impact, and how to adapt of climate change, especially reducing uncertainties on enhanced rainfall variability and its impacts, on multiple year droughts and long cycle crops (e.g. commercial timber species or deciduous fruit trees), on persistence of raindays, or the onset and duration of the rainy season; better *understanding the CO_2 fertilization effect* with its anticipated enhanced growth through increased photosynthesis and what any acclimation effects may accrue for annual vs. perennial crops;
  improving our understanding of South African grassland dynamics, including changing population dynamics of grazing lands, C_3 / C_4 grassland dynamics, grassland / woody species dynamics, alien invasive grass species, weed infestations in grasslands, and C_3 / C_4 grasslands and fire dynamics; assessing impacts on livestock health, where changes in rainfall and temperature will impact on animal health as the distribution, competence and abundance of vectors and ectoparasites change; evaluating potential changes in pest/disease distributions since more pest attacks are likely, distributions of plant and animal diseases and insects projected to change, the dynamics of insect pests and disease complexes likely to be perturbed, new pests emerging and currently effective biological control agents/predators losing their efficacy; better understanding weed control, including weeds as hosts and changing costs of weed control; undertake plant breeding programmes, with a need for geneticists to breed more drought/heat resistant varieties now, because response times for certain crops (e.g. deciduous fruit species) is long; re-assess plant needs, for example, in regard to water requirements, pH or fertilizer requirements; or revising sizing and safety of dams which may not necessarily be able to cope with future extreme events.

- **External and finance-related** adaptation would embrace *financing new technologies*, targeted especially towards South Africa's small scale farmers, *diversification within the agricultural sector*, including finding new locations which are climatically suitable for specific crops and growing indigenous species; and *diversification outside the agriculture sector* by seeking alternative/additional sources of income.
- **Water pricing-related** adaptations include *water curtailments to irrigators* in times of drought, in light of food security and conditional upon irrigators using water efficiently; *water price increase trade-offs* weighed up against national food security and export value/foreign earnings potential of the crops.
- **Labour-related** adaptations revolve, among other things, around the additional stresses resulting from HIV/AIDS on both skilled and unskilled labour.
- **Market Related** issues include maintaining a *competitive edge* with export crops against South Africa's competitors (e.g. Australia and South America) in light of global warming; as well as the *need for market projections into the future*; the potential repercussions which changing climate might have on government re-looking *forms of subsidisation* of key agricultural commodities; and *changing markets* within South Africa (e.g. from dairy farming to sugarcane).
- **Culture and tradition-related** issues on adaptation would include re-looking *communal land ownership* as well as land distribution/sub-delineation policies with resultant small fields that are generally unprofitable; and the *culture of many indigenous communities' maintaining large numbers of cattle*, both in light of additional challenges which might arise from climate change.
- Communications-related adaptation will require a clear *communication strategy* in regard to climate issues; also for *scientists to communicate* clearly on potential climate change impacts *now*, and to get the message of the *latest available agriculturally relevant science* across to government, agri-business, extension services and farmers; for improved *authorities to farmer communication and trust building; and for inter-farmer communications* through organized and operational networks of communication on climate change and information sharing with one another.

Specific options – crop and livestock agriculture: Conservation agriculture (CA) is an integrated approach addressing multiple sectors, including in-field rainwater harvesting; roof and road runoff water collection to supplement irrigation; and organic farming and precision farming. The benefits of conservation agriculture are well established at small scales, and are currently being quantified at commercial farm level and compared to conventional production methods. Quantification includes measuring greenhouse gas emissions. Adoption of CA practices by the commercial and household food security sectors are comparatively low (Smith *et al*. 2010), as the adoption process is intricate and as on-farm experimentation and demonstrations are limited. However, those who have adopted and expanded these practices are reporting benefits such as crop yield even during periods of drought; productive soils; minimum of input costs and thus a larger profit margin; less soil degradation; better soil water holding capacity; and all-year-round household food security. The CA adoption rate needs to be increased significantly by concerted and joint awareness campaigns and on-farm application by all agricultural stakeholders as it is quite impossible for the limited number of extension officers to reach all food producer levels. It is true, unfortunately, that CA is not a quick fix as it takes time to restore natural biological processes conducive to CA benefits. This affects the adoption rate.

Water and nutrient conservation technologies (Beukes *et al*. 2003), as an adaptation measure for sustainable dryland agriculture is well-documented for sub-Saharan Africa and forms part of CA application in South Africa. Other water conservation practices (e.g. Schulze 2006; 2007; van der Merwe 2007) include water use efficiency especially in irrigated systems; a reduction in reticulation losses; socially acceptable water recycling; ground water management systems; the artificial recharge of aquifers and rainwater harvesting; Farming operations adaptation such as changes in the planting dates of some crops, selecting crops with a shorter growing period, and high technology intensive solutions such as the increased use of modern machinery to take advantage of the shorter planting period.

Wetland conservation can be practiced to ensure general environmental health and in providing food and water security, notably to the rural poor (Grundling 2008; Kotze & Silima 2003; Mondi 2009; Swanepoel 2006).

Early warning systems, such as seasonal and shorter-term forecasts of climate, and in particular extreme events, can be effective in enabling land managers to take appropriate action to minimize the adverse impacts of negative events, and benefit from positive events. Climate information on a day-to-day basis is vital for farm operational procedures such as irrigation scheduling, timing of fertilizer applications, in-field traffic control, cultivar and variety selection and timing of planting and response farming. A major concern is timely early warnings of adverse weather and the possibility of related pest and disease occurrence. Timely information is of particular importance to the most vulnerable in remote areas, often without access to electronic media used to issue early warnings. Both the South African Weather Service and the Agricultural Research Council maintaining the agricultural weather stations network are providing such warnings by means of cell phones. Many food producers in remote areas, farming on marginal land, are prone to reduced yields and the impacts of climate change such as crop failure due the increased frequency of drought, floods and flash floods, diminishing soil productivity and land degradation, will add an additional stress layer.

Progress has been made with the development of genetically modified crops in view of notably heat resistance, drought tolerance and water use efficiency. These include potatoes, sweet potatoes, soybeans, indigenous vegetables, maize and wheat. Other notable developments include those to minimize crop failure under harsh climate conditions; low-cost alternatives to chemicals for organic production; a reduction in water consumption by vegetables; the production of indigenous and other vegetables crops under low input-cost conditions; and hydroponics.

A number of adaptation strategies can be implemented to protect intensive livestock production. Major infrastructure investment (for example to minimize the effects of heat stress and enhance water provision) could add substantially to the already-high input cost of intensive animal production systems and further affect the profitability margin of these farmers already burdened by high input cost. Best management technologies should be promoted by estimating the vulnerability of smallholder livestock farmers in marginal areas, and facilitating early adaptation to the effects of climate change. Programs could be established to breed heat-tolerant animals.

Awareness and knowledge of the impacts of climate change are essential to make the agricultural production sector less vulnerable; to adapt to climate change and most importantly, to adopt a soil protection ethos and conservation agriculture practices conducive to soil and water conservation; minimum greenhouse gas emissions and carbon sequestration. Many within the farming community are either not aware of climate change and its impacts or regard climate change as normal climate variability.

Specific options – plantation forestry: Current initiatives to limit wildfire damage in forests include government support (the Working on Fire Programme) as well as an integrated fire management approach by several industrial forestry companies. This involves the combination of pro-active fuel reduction strategies at strategically created buffer strips in the landscape, combined with reactive fire fighting at these locations, which has great potential to counter (to some extent) the potential increases in fire risk and severity. Intensively managed forest landscapes may thus play a significant role in landscape fire regimes in future. However, the necessary higher investments in fire management will surely impact economically on commercial forestry.

Commercial forestry in South Africa could benefit from preparation for both extreme events and changes in the current average resource availabilities to ameliorate the predicted impacts of climate change (higher incidences of drought, hail, fire and diseases). In light of this, forest management paradigms may require revision.

Tree selection and breeding could be beneficial in adapting commercial species to climatic changes. Tree species and provenances differ in climatic adaptability and vulnerability to hazards (e.g. Dvorak *et al*. 1993, Vasquez & Dvorak 1996, Swain & Gardner 2004, Cost & Silva 2007), and hybridisation and clonal selection provides the potential to adapt to environmental changes (Vasquez & Dvorak 1996, Kanzler 2002, McKeand *et al*. 2006). Despite the predicted increase of precipitation, the criteria for the selection of species, hybrids, and clones will have to focus more on water efficiency, drought and fire tolerance, and disease resistance as precipitation may be more erratic.

Enhanced efforts to optimize site-species matching are likely to provide benefits. Empirical and mechanistic modelling techniques have to be applied to predict site suitability on a national scale and match it with available species, hybrids or clones. First approaches in South Africa are promising (Fairbanks & Scholes 1999, Louw & Scholes 2006, Warburton & Schulze 2008), but still lack many important criteria to me*et al*l the challenges of climate change. An integrated multi-criteria decision support system could be developed to adapt site-species matching iteratively to the latest updates of climate predictions.

Specific options – rangelands: Adaptation interventions in rangeland systems would benefit from an integrated approach which incorporates both the ecological and socio-economic dimensions of rangeland use. A purely sectoral approach, whether targeting climate change, desertification, or amply addressing both phenomena, is likely to be limited in its ability to address the resilience of key processes and their related socio-economic benefits (for example, the protection and restoration of ecosystem services such net primary production).

Past policy shifts relating to advised and legislated stocking rates (as informed by estimated carrying capacity) have proven effective in reversing degradation trends in certain climatic and socio-economic settings. These mechanisms could benefit from science-based insights (i.e. ongoing observations and projections) relating to current and future carrying capacities as they may be influenced by climate change and variability, and from efforts to understand the factors that determine observance of such advice and legislation.

3.3 Terrestrial biodiversity

3.3.1 Current vulnerabilities

South Africa is noted for exceptionally high levels of terrestrial biodiversity, both in terms of its species richness (numbers of indigenous species) and endemic species numbers (indigenous species found only in South Africa), emerging as well above global averages (Cowling *et al*. 1996, Myers *et al*. 2000). Furthermore, many of southern and South Africa's ecosystems retain relatively intact communities of animals and plants (Scholes & Biggs 2005), despite significant land cover transformation associated with land use change. The country's protected areas network contributes both to biodiversity targets and nature-based tourism (Brooks *et al*. 2001, Rodrigues *et al*. 2004). While 6.5% of South Africa's land surface area is in formal protected areas, this does not cover all of South Africa's species and ecosystems, with relative under-representation in several ecosystem types (DEAT 2005).

Biodiversity is affected by a number of factors, including climate change and changes in land use, atmospheric composition CO_2, nitrogen deposition, climate, and the spread of invasive alien species (Hassan *et al*. 2005, Scholes and Biggs 2004). The potential impacts of climate change on ecosystems and biodiversity therefore need to be assessed in relation to and in conjunction with a range of current and future anthropogenic stresses. Loss of natural habitat has had a disproportionate effect on some vegetation types, with more than 80% of several endemic vegetation types transformed for agricultural and other uses (Mucina & Rutherford 2006). Pressures on biodiversity are increasing due to local and regional development and direct extractive resource use (Scholes & Biggs 2004), but may be decreasing in some rangelands due to de-stocking and improved land-use management practices. Alien plant invasive species are recognized as a significant threat in several ecosystems (Le Maitre *et al*. 2004). Air pollution impacts are most significant in the Highveld region of Gauteng Province due to unfavourable circulation patterns and a high concentration of industries, but pollution impacts also extend to areas of Mpumalanga and the Northwest Province, and the vicinity of urban centers nationally (van Tienhoven & Scholes 2006).

The distribution of biomes is thought to be controlled to a large extent both by climate and natural disturbance by wildfire (Bond *et al*. 2003b). Wildfire is itself partly a function of climate, but also of vegetation type, and so there is potential for climate change to alter the nature of South Africa's vegetation structure and its associated faunal diversity in complex ways, with relevance for the management and sustainable use of these ecosystems. Anthropogenic climate change has been projected to have predominantly adverse effects on South Africa and its biodiversity, with both ecological and socio-economic implications (IPCC 2007). However, most if not all of the impact assessments have used a limited set of future climate scenarios from a small set of general circulation models, have generally not accounted for locally downscaled scenarios (Hewitson & Crane 2006), and have tended to ignore ancillary stresses. Also, because of the important historical

and ongoing role of other stressors on biodiversity, species and ecosystems, together with a high degree of internal climate variability in the region, it is often difficult to attribute an observed change to a change in climate.

Several key impacts on the environment, biodiversity and ecosystem services were identified in South Africa's Initial National Communication (INC) on climate change, but assessments used modelled climate projections (Perks *et al*. 2000) driven by the IS92a greenhouse gas emissions scenarios used in the IPCC's second assessment report, and using older generation GCMs, such as HadCM2. These projections can be considered as presenting drier projections than the median case for the most recent IPCC report, especially for the summer rainfall region, and in the context of current understanding could be considered as tending towards worst case scenarios for mid-century.

Key findings of the terrestrial plant and animal studies were that:

- The bioclimate of the country is projected to change such that the area that is currently optimal for the country's biomes will be reduced to between 38 and 55% of their current combined area by 2050 due to drying and warming trends.
- The largest losses of biome-optimal bioclimates were projected in the western, central and northern parts of the country, including the almost complete displacement of bioclimatic conditions currently associated with the existing Succulent Karoo Biome along the west coast and interior coastal plain, an extensive eastward shift of the Nama-karoo Biome bioclimate across the interior plateau, and contraction of the Savanna Biome bioclimate on the northern borders of the country, and its expansion into the Grassland Biome bioclimate. The species-rich Fynbos Biome bioclimate was projected to lose many species.
- Analyses of plant species range shifts concurred generally with these biome-level patterns, with the majority of 44 plant species selected from across South Africa projected to show reduced geographic range sizes. The plant species-level analysis projected that species composition is likely to change in all biomes, but that areas projected to fall outside of an optimal biome bioclimate could continue to support indigenous and even some endemic species, but are likely to show a reduction in species richness.
- Plant species compositional change could lead to major vegetation structural changes in some biomes, notably in the Grassland Biome where virtually the entire existing biome could become susceptible to a potentially large number of invading savanna tree species.
- Analyses of animal species range shifts showed that of the 179 species modelled, 25% expanded their ranges, while 72% displayed range contractions varying of up to 98%. Only 3% of the species showed no response.
- A larger proportion of red-data and vulnerable species (58%) were susceptible to range change (decline and displacement) compared to other species investigated (43%).
- Due to predominantly eastward shifts in animal species distribution, and richness decline in the west, species rich areas contracted onto the eastern highlands, and with a decline of total country-level richness.
- The majority of the 16 centers of endemism studied also showed significant change of bioclimate according to the model projections, with more than half predicted to experience bioclimatic conditions completely unlike those of today.
- Protected areas of the arid west and central parts of the country are projected to experience a significant

alteration of bioclimate, while those of the eastern and highland regions show less significant changes. However, animal species loss even in the Kruger National Park, in the north-east, was projected to be high, with more than two thirds of species (including 97% of bird species) projected to experience <50% probability of occurrence.

Seven possible conservation adaptation strategies were proposed, namely, the establishment of a ***biodiversity monitoring network***, the integration of relevant biodiversity information and impacts projections into ***land-use planning and management outside of protected areas***, the application of ***sound vegetation management policies***, the possible ***expansion of the protected area networks***, focused attempts at ***ex-situ conservation***, future possible ***species translocation*** action, and ***tolerating loss***, a "triage" mechanism for assessing the value of biodiversity elements to assess their relative importance in the event of unavoidable sacrifices.

3.3.2 Observed trends

Focused monitoring of biological change over time provides important ancillary information to confirm the impacts of measured climatic shifts and to gauge the sensitivity of species and ecosystems to their impacts. Monitoring trends in biological systems also provides data needed for testing and refining modelled projections of change. Observation of biological and ecological changes, and their attribution to climate change as distinct from other drivers is in its infancy in South Africa, and Africa as a whole. The IPCC Working Group 2 (IPCC 2007) showed clearly that there was only a handful of such studies on the African continent (and only a few in the southern Hemisphere) relative to tens of thousands of long term records in Europe and North America.

Furthermore, the secular trends in temperature-related impacts on key life stages observed in organisms at high latitudes are not likely to be as obvious in the subtropics. This is because disturbance and water availability are relatively more important in driving ecological processes in the subtropics, and directional changes may be obscured by climate variability on a range of temporal scales (Tyson & Preston-Whyte 2000), driven most notably by El Nino cycles (Diaz *et al*. 2001, Glantz 2001). Fire regime is an important determinant of ecosystem structure and function in this region (Bond & Keeley 2005, Bond *et al*. 2003b, Bond & van Wilgen 1996), introducing further stochasticity and associated species population-level responses that are not clearly linked to climatic conditions. All of these characteristics are likely to obscure clear and unambiguous detection of systematic species responses to climate trends.

Very few observational studies have yet been done to track the related ecological impacts of climatic shifts, such as warming trends noted in the southern African sub-region (Hulme 1996, Hulme *et al*. 2001) and in south western and central regions of South Africa (Warburton *et al*. 2005). One important emerging shift attributable to a climatic change is an increase in fire frequency in the Fynbos Biome (Wilson *et al*.2010), which threatens plant species with long juvenile periods, but can also increase the rate of invasion by alien plants, and have potential adverse effects on forestry activities and built infrastructure. Only one study has purposely investigated the response of a species, and concluded that populations of the Succulent Karoo plant Aloe dichotoma (quiver tree) are contracting at its warmest and driest boundaries, and increasing in size at its cooler southern boundaries (Foden *et al*. 2007).

Preliminary analysis of key bird species using the South African Bird Atlas Project dataset (SABAP1 in the early 1990's and SABAP2 currently ongoing) indicates changes in phenology (timing of seasonal activities such as migration) and geographic ranges. Phenological responses of Barn Swallows suggest that arrival and departure dates in spring and autumn are responsive to climatic variability. Falling population sizes of some South African coastal and seabirds indicate a decline in food resources possible partly related to climate change associated warming of the Agulhas Current (Rouault *et al*. 2009).

Several studies have investigated the increase in woody plants (bush encroachment) in southern Africa, but only recently has it been considered possible that this trend is at least partly due to CO_2 fertilization of trees and shrubs, providing them a competitive advantage in relation to grasses.

Sub-Antarctic Islands have been shown to be warming and drying (Smith *et al.*1990). Key biological trends noted on sub-Antarctic Islands tend to indicate greater success of invasive alien species as climate warms and dries. Certain seabird species on Marion Island show population declines driven especially by changes in frontal tracks and storm intensity.

3.3.3 Projections and future risks

Many modelling analyses of hundreds of animal and plant species (in comparison to the 44 plant species and 179 animal species reported on in the INC) have generally supported the initial predictions laid out in the INC, and further support the suggestion that projected climatic and atmospheric change may induce significant spatial shifts in optimal bioclimatic conditions for southern African species (Erasmus *et al*. 2002, Rutherford *et al*. 2000, Broennimann *et al*. 2006), and may alter controls on ecosystem structure and function (Bond & Midgley 2000, Bond *et al*. 2003a, Hulme *et al*. 2001, Thuiller *et al*. 2006, Woodward & Lomas 2004) which may themselves affect species.

Plants species: Much of the recent work in southern Africa has focused on the Cape Floristic and Succulent Karoo biodiversity hotspots (sensu Myers *et al*. 2000). These mainly winter rainfall regions represent a unique climate in the region and occupy only a small proportion of its land surface, yet may be important indicators of climate change due to incipient shifts in regional weather patterns such as the latitudinal position of rain-bearing westerly frontal systems. However, uncertainties remain at many levels, including those relating to climate projections, and species, habitat and ecosystem responses (Midgley & Thuiller 2005; Neilson *et al*. 2005).

Post-INC impact assessments on South African plant species have used updated climate simulations from the GCM HadCM3 (Nakicenovic *et al*. 2000), and have also employed more sophisticated statistical methods (Guisan & Zimmermann 2000; Guisan & Thuiller 2005). In the Cape, iconic groups such as the Proteas have been used to infer potential climate change impacts on plant biodiversity as a whole (Midgley *et al*. 2003), and even to trial the design of conservation responses (Hannah *et al*. 2005, Williams *et al*. 2005) and early-warning systems using monitoring (Midgley *et al*. 2002). A comparison of biome- and species-level modelling approaches to estimate species extinction risk (using HadCM2 scenarios for CO_2 doubling) found that only 10% of endemic Proteaceae species had ranges restricted to the large portion (51-65%) of the biome where projected future climate would be outside of current envelopes, while range contractions and dislocations (no overlap between current and future modelled range) in up to one third of species were spread throughout the biome (Midgley *et al*. 2002). Species range changes were also projected to be sufficient to detect climate change impacts within decades (Midgley *et al*. 2002), thus allowing falsification of model projections and rapid improvements in understanding.

Climate change has been projected to be potentially more important in increasing the risk status of endemic Protea species than projected habitat loss through land use change over a short a time as two decades (Bomhard *et al*. 2005). Impacts of climate change (HadCM2 scenarios for CO_2 doubling) and habitat loss on species in regions of high risk of changing bioclimatic conditions (Midgley *et al*. 2003) used 28 Proteaceae species to show that most species experienced potential range contractions (17 of 28), of which five showed range elimination, but several species (11 of 28) showed potential range expansions. For species whose ranges contracted, current land transformation had less impact on future potential ranges than did climate change, because ranges tended to shift to higher altitudes with less land transformation pressure. These studies identify a need for migration to allow the persistence of species, and efforts to address this by designing effective links between protected areas might be achievable (Williams *et al*. 2005), though highly dependent on climate scenario and thus currently risky for conservation implementation.

Modelling of 975 endemic plant species of a range of life forms over a far broader region of southern Africa using HadCM3 scenarios (Broennimann *et al*. 2006), showed that the endemic flora of southern Africa on average could be reduced by about 40% in endemic species richness even under the most optimistic SRES scenario (B1). Species and life-form vulnerability to climate change could be partly explained by species' geographical distribution along climatic and biogeographic gradients, niche breadth, or proximity to physical barriers preventing migration, and suggested promises for estimating species vulnerability. A continent-wide study at rather coarse resolution using HadCM3 scenarios of potential geographic shifts of 5197 African plant species (McClean *et al*. 2005) predict substantial shifts by most species, and widespread changes in species composition. Range size reductions or shifts were projected for 81%–97% of the species modelled, with 25%–42% projected to lose all suitable range by 2085.

Studies such as those discussed above might lead to overestimates of the impacts of climate change on species persistence and community change as a result of assumptions implicit in bioclimatic (niche-based) modelling. This shortcoming requires that experimental and ongoing monitoring programs are designed to test the evolution of the early impacts of climate change to allow confirmation of this threat, and to improve the modelling approaches.

Based on experimental and observational studies, succulent species that dominate the species-rich, arid Succulent Karoo show a sensitivity to extended drought that contrasts with high drought tolerance of desert scherophylls (Midgley & van der Heyden 1999), and succulents also appear susceptible to daytime warming-induced mortality (Musil *et al*. 2005), as indicated also by the observational field study on the Quiver tree Aloe dichotoma, (Foden *et al*. 2007).

Animals species: Predictions of faunal responses to climate must be tempered by the finding that vegetation structure may be an important explanatory variable for animal species distributions (Andrews & O'Brien 2000); and therefore a better estimate of climate change effects will require the development of more inclusive explanatory models (including the climate, disturbance, human use and vegetation drivers).

Early work (1996) suggested a prevalence of range size decreases over range increases by 2050 for 44 African ungulates, with negative effects concentrated in the high altitude grasslands and interior savannas of South Africa. Projections for South African fauna based on HadCM2 climate scenarios for CO_2

doubling showed a strong contraction of the ranges of animal species including mammals, birds and reptiles, onto higher altitude grasslands and toward more humid and cooler regions of South Africa (eastward shift) in response to regional warming (Erasmus *et al*. 2002), and the potential local extinction of many species in lower-lying regions. More recent modelling of bird species ranges using HadCM3 scenarios has also suggested range contraction in endemic species of South Africa (Simmons *et al*. 2004), though this appears less significant in an arid-system generalist species.

Substantial shifts in the geographic range of 227 mammal species throughout Africa, have been projected using HadCM3 climate scenarios, (Thuiller *et al*. 2006), with a westward shift of species in the tropics, and an eastward shift in the temperate zone, probably in response to aridification, in congruence with the findings of the INC. A large fraction of species was also projected to become "critically endangered" or "extinct" by 2080, but that this was strongly contingent on the ability of species to shift their geographic range, with up to 40% critically endangered with null migration, and up to 20% with full migration.

A comprehensive study of census records (1977-96) for 11 ungulate species in the Kruger National Park showed severe population declines in seven species that could not be explained by ENSO forcing and its effects on annual rainfall (Ogutu & Owen-Smith 2003) but were correlated with an extreme reduction in dry season rainfall, interpreted as a possible fingerprint of regional climate change. This study noted that boundary fencing restricts potential range shifts by large mammals such as these in response to climatic variation and future climate change – and is a concern as model projections suggested local near-extirpation of three ungulate species under recurring dry summer conditions (Ogutu & Owen-Smith 2003)

Studies on insect species are rare, but insects may serve as sensitive indicators of climate change, as shown by Botes (2006), who found that ant assemblage structure in the Cape Floristic Kingdom responded to site temperature characteristics which, together with area and vegetation variables, contributed significantly to species mix in major vegetation types and biomes on a bioclimatic gradient. Ant community change in response to climate change might also cause vegetation change, especially due to their importance in seed dispersal and regeneration of local plant species endemics.

Overall, modelling studies support the initial projections of eastward range shifts in animal species suggested in the INC, and declines in plant and animal species richness in the west. The ability to shift geographic range via intrinsic species mobility traits and a landscape that support such shifts is an important determinant of future retention of biodiversity. However, findings such as these based on species range modelling is limited in that it fails to account for changes in vegetation structure, disturbance regime and ecosystem functions that might affect species. A comprehensive, focused national monitoring approach and an expanded set of modelling tools are both critical for further testing these projections and updating knowledge.

Biomes: Changes to major vegetation types have been modelled using correlative techniques and mechanistic techniques in South Africa. The latter approach has until very recently been relatively poorly developed in South Africa especially because of the inadequate representation of plant life forms. However, a recent series of advances (Bond *et al*. 2005, Higgins *et al*. 2000, Scheiter & Higgins 2009), has allowed far more useful and credible projections to be made. By contrast, correlative bioclimatic-niche based approaches are limited in that they do not account for the effects of CO_2 fertilization on productivity, and fail to account for changes in disturbance that are climate-sensitive, particularly fire regime.

Projected impacts on southern African biomes to update INC projections were reported in a South African study on long-term mitigation scenarios (DEAT 2007b). This modelling indicates less extreme and more delayed impacts of climate change, relative to the INC projections, on Succulent Karoo, Fynbos and Grassland Biomes by 2050 (SRES A2 scenarios; though predicted impacts in 2080 remain severe), and suggests an expansion of the Nama-Karoo Biome in contrast to the contraction and eastward range shift projected in the INC. The latter finding may simply reflect the inclusion in the models of more arid Nama-Karoo vegetation types of Botswana and Namibia which were not included by the work supporting the INC. This may imply the invasion of adjacent biomes (Savanna, Succulent Karoo and Grassland) by more arid-adapted Nama-Karoo elements.

This approach is therefore largely confirmatory of the INC and later species-based modelling approaches, in projecting that endemic species-rich winter-rainfall biomes, especially the Succulent Karoo, could show significant reduction in range (Midgley, submitted). Nonetheless, the spatial extent of persisting bioclimatic conditions in summer-rainfall biomes is revised upward relative to the INC.

Mechanistic modelling approaches provide critical alternative and complementary information about the possible range of biome-, landscape- and habitat-level responses that may occur under climate and atmospheric change drivers. Mechanistic approaches are based on physiological, carbon allocation and disturbance algorithms. These convert projected changes in primary productivity through changes in the performance of relatively few plant functional types (PFTs) to projections of process and structural changes. While the match between the PFTs modelled and those that dominate South African ecosystems is incomplete, these approaches provide increasingly useful insights.

Recent theoretical advances (Bond & Midgley 2000, Bond *et al*. 2003a, Bond *et al*. 2003b, Scheiter & Higgins 2009) have concluded that both rising atmospheric CO_2 and wildfire are important co-determinants of vegetation structure, in conjunction with climate drivers, especially in savannas where trees and grasses exist in a dynamic equilibrium. Maximum woody plant cover is strongly rainfall-controlled below ~500 mm mean annual rainfall (MAR), somewhat affected by disturbance regime within MAR limits of 650 +/- 134 mm MAR, and strongly disturbance-determined above ~ 800 mm (MAR) (Sankaran *et al*. 2005). However, with projected CO_2 rise, tree cover dominance may increase both under lower rainfall and currently fire-prone conditions (Bond *et al*. 2003a). Projecting climate change impacts in this region therefore requires an understanding of climate-disturbance-CO_2 interactions and their implications for assemblages of species (such as mammal browsers or grazers) that may be dependent on both climate and vegetation structure (habitat).

Even under drying scenarios, it is suggested that woody plant cover will increase across arid and semi-arid southern Africa (Scheiter & Higgins 2009), a finding that supports IPCC AR4 projections of "desert amelioration" (referring to an increase in vegetation cover and net primary productivity) in parts of southern Africa (Fischlin *et al*. 2007). This CO_2 fertilization effect may have the impact of more than doubling carbon stored in tree biomass above ground in South Africa's woodland, savanna and grassland ecosystems (Scheiter & Higgins 2009), and this increase may be at least somewhat enhanced by fire suppression (Bond *et al*. 2005). This increase in desert plant cover apparently contradicts projections of correlative modelling for species richness reduction. Although the implications are significant for South and southern Africa, and may have adverse impacts on species adapted to open environments, there is not a single field experiment to test this idea in Africa.

Forest systems: Because of the small spatial extent of the Forest Biome (<1% of South Africa), which limits the bioclimatic modelling application, little spatial modelling work has been done on its vulnerability to climate change. One bioclimatic niche based study based suggests shifts in altitudinal and latitudinal range that will be constrained by current fragmentation of natural habitats (Eeley *et al*. 1999). However, it is much more relevant that the forest ecosystem is vulnerable to increases in fire frequency or intensity (Bond 1997), and thus that increasing fire frequency and intensity in bordering vegetation types (Fynbos, Grassland and Savanna) could have direct adverse impacts on this Biome.

Desert Dune systems: Biophysical approaches applied to modelling dune field stability show a substantial risk of increasing dune mobility in the currently vegetated dunes of the Kalahari (Botswana and northern South Africa) by between 2050 and 2070 (Thomas & Leason 2005), with negative implications for subsistence livelihoods and biodiversity in this semi-arid region that hosts important protected areas.

Wetland ecosystems: Many river catchments in South Africa are already severely transformed through utilization and thus subject to water stress. Projected shifts in climate have significant implications for the persistence of these systems, and the key ability to deliver valuable ecosystem services. A recent impact assessment (Dallas & Rivers-Moore 2009) concluded that climate change is an additional, amplifying driver of system variability, and should not be viewed in isolation from other drivers. The report pointed out that the impacts of climate change on water are not only direct, but also from increased water demand (e.g. crop irrigation demand) and that many climate change policy responses could affect water use demand. There is thus a thus there is a need to keep wetlands intact wherever possible, because of the vital role they play in contributing to consistency of water availability and water quality..

CO_2 fertilization: Rising CO_2 concentrations potentially increase the rate of photosynthesis of the majority of plants, which use a form of photosynthesis that is CO_2 limited under current ambient CO_2 levels. However, South Africa contains a significant proportion of plants that use evolutionarily more derived forms of photosynthesis (many succulent species and grasses), for which much less information on potential CO_2 responsiveness is available, especially for tropical species. Experimental work on this issue is very limited, with a handful of studies carried out in the 1990's, and even fewer since 2000.

Hulme (1996) explored the impact of three climate scenarios for 2050 (core, dry and wet) based on IPCC First Assessment Report methods (Carter *et al*. 1994). This study found that the impacts of climate changes alone (excluding the effects of CO_2 fertilization and associated gains in vegetation water-use efficiency) caused an expansion of arid vegetation types (mainly Thorn-Scrub Savanna) by up to 30%, at the expense of the Grassland type. However, with CO_2 fertilization effects included, more mesic and tree-dominated Seasonal Forest vegetation more than doubled their extent at the expense of arid vegetation types.

More recent studies using HadCM3 climate projections for 2050 (Thuiller *et al*. 2006) also found a strong sensitivity of vegetation structure and function to CO_2 enrichment, with NPP reductions due to climate change almost negated by CO_2 fertilization, and a strong increase in the success of C_3 forms at the expense of C_4 grasses.

Further theoretical exploration of this topic has led to a new perspective that stresses the role of carbon allocation rather than carbon uptake rate as an important control of plant response to rising CO_2. According to this theory, rising CO_2 should tend to favour woody plants relative to herbaceous species (Bond & Midgley 2000, Bond *et al*. 2003a, Bond *et al*. 2003b). This issue is therefore most relevant to mixed tree/grass ecosystems, such as Savanna, where the role of atmospheric CO_2 enrichment could be amplified by the mechanisms that maintain the current balance between grasses and woody plants. A recent modelling study that incorporates this mechanism projects substantive increases in woody cover in South Africa as CO_2 rises, in conjunction with warming and rainfall changes (Scheiter & Higgins 2009).

One mechanism is mediated by grass fires that incinerate the stems of tree saplings, which are then forced to re-sprout using below-ground carbon stores. The accumulation of carbon storage is limited under low CO_2 conditions – but increase as CO_2 continues to rise (Bond & Midgley 2000, Bond *et al*. 2003a). A preliminary greenhouse-based study has found a strong sensitivity of carbon accumulation below-ground and above ground growth to atmospheric CO_2 level (Kgope *et al*., in press). C_4 grassland species responses to elevated CO_2 show increased water-use efficiency but no increase in growth (Wand *et al*. 2000, Wand *et al*. 2002), concurring with a global review of reported responses (Wand *et al*. 1999). Greenhouse and field-based studies have confirmed positive CO_2 impacts on grassland water-use efficiency (Motete *et al*. 2005, Wand *et al*. 2000, Wand *et al*. 2002, Stock *et al*. 2005). These may scale up to impact on grassland water balance under field conditions (Stock *et al*. 2005) that may even further favour the growth of trees. However, despite this apparent critical CO_2 sensitivity of southern African ecosystems, its regional and possibly global importance, and the associated uncertainties associated, no empirical field experiment exists in southern Africa to confirm or refute it.

Fire: Fire is a key determinant of vegetation structure and function in African ecosystems (Bond *et al*. 2005, van Wilgen & Scholes 1997), and thus also important in determining biodiversity. Three of South Africa's six biomes are not only fire-prone, but also fire-dependent, in the sense that fire exclusion leads to their structural transformation and major biodiversity change (Bond *et al*. 2003b, Bond *et al*. 2005). Fire is also important in determining standing biomass and thus carbon stock and carbon sequestration potential – it was estimated that fire suppression might contribute ~3-4% to South Africa's mitigation potential through increasing the size and permanence of the terrestrial sink (Long-Term Mitigation Scenarios (LTMS) (ERC 2007; RSA 2007; SBT 2007; Winkler 2007). Wildfire regimes also play a role in the emissions of greenhouse gases other than CO_2, in altering vegetation water balance and albedo, and in the emissions of aerosols that can have impacts on regional climate and air quality (Tyson & Gatebe 2001).

Wildfire occurrence is a function of vegetation (fuel availability), climate ("fire weather" conditions, with key critical limits of dry spell duration, air humidity, wind speed and air temperature), and ignitions (lightning or human and other sources). Analysis of fire frequency in the Kruger National Park by (van Wilgen *et al*. 2004), illustrates the close relationship between size of the area burned in a particular year and rainfall in the previous two years. Higher rainfall increases grass fuel loads and therefore increases fuel available to sustain the fire spread. Fire weather has been shown in Fynbos to be a key driver of large fires, which are responsible for the vast majority of area burned annually in this biome (Southey 2009b). The frequency of large fires has doubled across the Fynbos Biome, and this is associated with a shift in climatic conditions conducive to large fires which may be a result of a regional change in climate (Southey 2009a). A separate analysis has shown that, overall, fire intervals in Fynbos have shortened by about 5 years over the past 30 yrs on an original average of roughly 20 years (Wilson *et al.* 2010).

3.3.4 Adaptation

Adaptation responses underway: Several initial studies have considered potential adaptation responses mainly through biodiversity planning, and based on a broad consideration of future potential risks to species, biomes and ecosystem processes (e.g. CAPE (Cowling *et al.*2003), and the National Spatial Biodiversity Assessment (Driver *et al.*2005)). The more recently published National Protected Areas Expansion Strategy has made most use of strategies to minimize potential impacts of projections of climate change on biodiversity (Government of South Africa 2010). At this time, these general approaches have been implemented in the most appropriate ways, namely through attempting to grow the conservation estate through land acquisition or engagement of stakeholders, in ways that are aligned with maximizing opportunities for connecting landscapes along altitudinal, latitudinal or major drainage corridors. Some exploratory attempts at fine-scale approaches to planning for climate change induced species range shifts have been undertaken, but these are focused on learning and technique development rather than aimed at guidance for specific implementation.

Adaptation options: Most focus on adaptation in the biodiversity sector has been on conservation strategies to minimize the adverse impacts of climate change on biodiversity itself. More recently, the value of biodiversity in supporting adaptation actions of benefit to human society (termed ecosystem-based adaptation) has been recognized and explored, but this is not considered here due to a lack of local information (as highlighted in the previous section).

Adaptation planning for biodiversity recognizes four fundamental responses by individual species – they may tolerate change *in situ* by changing their behaviour (through phenological or physiological plasticity), they may undergo selection for tolerance of novel conditions (genetic adaptation), they may shift their geographic range, or they may decline and potentially face local and finally global extinction. Ecosystems possess the ability to adapt naturally to climate change through individual species response capacity and underlying species and genetic variation (biodiversity). Thus, management of adaptation in wild species may begin productively by attempting to enhance and facilitate these natural processes and biodiversity resources. However, disturbance regimes (e.g. wildfire and grazing/browsing) are emergent processes that are a function of species composition and relative dominance, and climate drivers. Therefore, managers of ecosystems may be able to control certain aspects of the disturbance regime as an adaptation response, such as the frequency and season of wildfire, or even intervene in more focused ways in the ecology or spatial distribution of specific species (e.g. the introduction of natural predators for biological control of invasive alien species). All of these adaptation strategies would be well-supported by research to anticipate the likely location and timing of key impacts, and systematic monitoring of wild species and ecosystem responses.

Conservation adaptation responses can usefully be divided into either passive responses that are informed by spatially-explicit impacts assessments and suggest land allocation to conservation protection of a range of levels both within and outside of formal protected areas, or active responses, involving management interventions on the ground (Table 3.3.1).

Table 3.3.1. Conservation strategies for adaptation to climate change and their estimated cost effectiveness

Conservation Strategy/Action	Estimated cost-effectiveness
Passive – Monitoring of biodiversity and ecosystem process indicators	High – provides key information required for national assessment of policy effectiveness and risk; scalable both in terms of numbers of indicators monitored and spatial extent; requires better co-ordination of actors and institutions
Passive - Protected Areas Expansion (including through contract agreements with land managers outside of state-owned protected areas, and incorporating climate change resilience)	Low to high – depends on region in question and likelihood of species/ecosystem process benefiting from greater extent of protected area
Passive - Corridor design (linking protected areas)	Low to high – depends on region in question and likelihood of species/ecosystem process benefiting from mobility and migration options provided
Passive - Develop management policies	High – provides co-ordinated context for national and sub-national responses; requires better co-ordination of actors and institutions
Active - Reduce ancillary stresses through management interventions (e.g. invasive alien removal)	Medium to high – Responses often make sense even in the absence of climate change (no-regrets); Align well with sustainable development and socio-economic objectives (e.g. poverty-relief programs for clearing invasive alien plants)
Active - Effective adaptive management action	Medium to high – depends on local expert knowledge and management experience; Could become less effective as climate changes far beyond current limits
Active – Restoration	Low to high – depends on spatial scale of intervention, can be very effective at small spatial scales, requires careful cost-benefit analysis
Active – Translocation	Low to high – Much experience for mammals suggests potential risks, potential for risk of invasiveness for plant translocation; requires investment in understanding risks of genetic mixing of local populations, a possible strategy of last resort
Active - *Ex situ* conservation (gene/seed banking; plant species cultivation in gardens; animal species breeding in zoos)	Low to high – ineffective under mild climate scenarios except for highly threatened species; potential gains in effectiveness as climate change exceeds current limits and leads to local and global extinctions

For effective response, managers require an understanding of the nature of the climatic and ecological changes that are likely to occur in their region, and the range of potential adaptive responses available. Monitoring environmental change including climate, and how ecosystems respond is important so that adjustments in management strategies can be made (e.g. Adger *et al*. 2003, Moldan *et al*. 2005). Biodiversity planners and ecosystem managers would benefit from improved information both about trends in climate, and about the potential consequences of climate change, which will allow local monitoring and adaptation strategies to be developed. Biodiversity planners in South Africa are at the forefront of integrating climate change resilience into the identification of biodiversity priority areas, and climate change is generally accepted as an important aspect of biodiversity plans across the country. Although, many adaptation options are available to wildlife managers, uncertainty about the magnitude and timing of climate change may discourage some from adopting new management practices. However, management based on 'no regrets' or the 'precautionary principle' would be prudent, including a policy of adaptive management (i.e. using management as experimental manipulation with careful monitoring of response).

Natural resource management techniques should explore ways that increase the resilience of ecosystems. There are many opportunities to achieve this (Tompkins & Adger 2003, Cropp & Gabrica 2002). Actions to reduce the impact of ancillary pressures are likely to enhance resilience to climate change (e.g. Opdam & Wascher 2004). Such pro-active approaches represent biodiversity planning that is both relevant today and in the future. Techniques that allow the management of conservation resources in response to climate variability and build climate change resilience into the identification of priority areas for protected area expansion provide key preparation for anticipated climatic shifts and possible increases in occurrence of extreme events.

Strategies to cope with climate change will increasingly become an important component of conservation management plans, but this is currently rarely the case (Chopra *et al.* 2005). Several options exist to enhance adaptation to climate change by management intervention in intensively managed ecosystems, but this is not the case in less-intensively managed ecosystems. In such systems, decisions about acceptable species compositional changes and changes in ecosystem processes may best be informed by considering the implications for the supply of ecosystem services, and the related socio-economic implications. This emerging field of applied science therefore requires development specifically aimed at addressing climate change concerns.

Protected area networks have been the traditional conservation response to increasing human pressure, but because they are fixed in space, they face an adaptation challenge (Hannah & Lovejoy 2003, Hannah *et al*. 2002). The development, expansion and linking of elements of protected area systems, however, can reduce their vulnerability to climate change (McNeely & Schutyser 2003). Protected area planners can usefully consider potential long-term shifts in plant and animal distributions. Such considerations have been applied in South Africa and preliminary work at the national scale has identified some key regions for prioritizing reserve expansion and linking (DEAT & SANBI 2008).

A primary adaptation strategy to climate change is to reduce and manage the other stresses on species and ecosystems (Duraiappah *et al*. 2005). This may lead to an increase in the resilience of habitats and species to both climate change and climate variability. In addition to removing other stressors it is necessary to maintain healthy, connected and genetically diverse populations. Isolated, small populations are often more prone to local extirpations than larger, more widespread populations (e.g. Gitay *et al*. 2002, Lovejoy & Hannah 2005). Connected populations also facilitate the movement of species between them. Although connectivity, genetic diversity and population size are goals managers already strive to accomplish, climate change increases the importance of doing so.

Reducing stress on ecosystems is difficult, especially in densely populated regions in Africa, Asia and Europe. Recent studies in southern Africa have signalled the need for policy to focus on managing areas outside protected areas such as subsistence rangelands (Von Maltitz *et al*. 2007). This can, in part, be achieved through the devolution of resource ownership and management to communities, securing community tenure rights and incentives for resource utilization. This argument is based on the observation that greater species diversity occurs outside protected areas that are more extensive (Scholes *et al*. 2004). Many species will need to track suitable habitats in response to climate change. Species migration will be difficult to achieve in protected areas without interventions such as the establishment of corridors. This contrasts with communal or private land use systems where migration may be encouraged by strategic policies.

Changes in vegetation structure due to climate change (and other global change drivers such as invasive alien species) can lead to significant changes in the frequency and intensity of fires, and changes in fire weather due to climate change have now been shown to increase fire frequency and potentially cause changes in vegetation structure directly. Management response to wildfire has focused on reducing ignitions or fuel availability to reduce fire risk. Fire management represents both a climate change mitigation and adaptation opportunity. Savanna fires are the largest source of pyrogenic emissions in southern Africa releasing considerable volumes of both carbon based (CO_2, CO, CH_4) and non carbon based (NOx, N_2O) greenhouse gases (Tyson & Gatebe 2001). A review of woody cover in African woodlands and savanna systems (Sankaran *et al*. 2005) illustrates that in the majority of Africa ecosystems, the amount of accumulated biomass is generally below the 'climatic potential' of the system – that which could be supported under prevailing rainfall and temperature regimes. Reducing the frequency and intensity of fires therefore presents a potential mitigation opportunity.

There has been a large amount of work on managing fire risk in South African Biomes. In general, it has been shown that fire suppression and control has a relatively low effectiveness in both fynbos and savanna ecosystems (van Wilgen 2008), but managers continue to believe that they can potentially use prescribed fires and other techniques to reduce fuel load and the potential for catastrophic fires (van Wilgen 2009 & van Wilgen *et al*. 2010). Adaptive responses may include the planned burning of savanna ecosystems in regions where rainfall is increasing, or there is evidence of thicket encroachment. This activity will require temporary restrictions on grazing to encourage accumulation of grass-based fuel loads necessary for hotter and more spatially-continuous fires.

Climate change is likely to increase opportunities for invasive species because of their adaptability to disturbance (Lake & Leishman 2004). Captive breeding for reintroduction and translocation is likely to be less successful if climate change is more rapid. Such change could result in large-scale modifications of environmental conditions, including the loss or significant alteration of existing habitat over some or all of a species' range. Captive breeding and translocation should therefore not be perceived as panaceas for the loss of biological diversity that might accompany large changes in the climate. Populations of many species are already perilously small and further loss of habitat and stress associated with severe climate change may push many taxa to extinction.

A costly adaptation option would be the restoration of habitats currently under serious threat in areas where natural colonization is unlikely to occur. Meshing existing species with new species in a given habitat would, however, be difficult and expensive. In many cases the knowledge of ecosystem interactions and species requirements may be lacking. Engineering habitats to facilitate species movements may require the development of an entirely new field of study. As a last resort, the banking of seed and genetic material may be a useful stopgap to ensure the persistence of genetic diversity, but this option does not allow the species to persist in the wild without re-introduction programs of uncertain effectiveness.

Ultimately, managers may need to enhance or replace diminished or lost ecosystem services. This could mean manual seed dispersal or reintroducing pollinators for some plant species. In the case of pest outbreaks, the use of pesticides may be necessary. Enhancing or replacing other services, such as contributions to nutrient cycling, ecosystem stability, and biodiversity may be much more difficult. The loss or reduced capacity of ecosystem services may be one of the major sources of surprise from climate change and variability.

There is minimal published information on comparative cost-effectiveness of climate change adaptation options in ecosystems, and we thus refer to a manuscript in preparation (Letsoaloa *et al*., in preparation), developed under the GEF-funded AIACC program (Assessment of Impacts and Adaptation to Climate Change). This makes a comprehensive assessment of the avoided damages (i.e. benefits) and costs very preliminary. This study estimates that gene and seed banking strategies are potentially inexpensive approaches that will provide a form of safety-net for current and future generations, as long as the approach is not dependent on establishing the fundamental scientific facilities and staff *de novo*. Extending the current reserve network is the next most expensive strategy, and while the costs associated are 100 times greater, the benefits far outweigh those obtained through seed and gene banking alone, and costs can be reduced through contract agreements with land owners.

3.4 Invasive aliens

3.4.1 Current vulnerabilities

South Africa includes a section focused on alien invasive species because of the significant current and projected impact of this environmental change on the ecosystems and biodiversity of the country, and likely interactions between the invasiveness of introduced species and climate change. Numerous studies have explored the potential effects of climate change on South African indigenous biodiversity (e.g. Erasmus *et al*. 2002; Midgley *et al*. 2003; Bomhard *et al*. 2005; Coetzee *et al*. 2009b), or the ecology and impact of alien species separately (e.g. Pimentel *et al*. 2001; Branch & Steffani 2004; van Wilgen *et al*. 2008). However, few studies have examined the ways in which alien and invasive species will respond to climate change in the region (see Richardson *et al*. 2000). Climate change is expected to have direct as well as compound, interacting indirect effects on alien species. The most direct effect of a changing climate on alien species will be in the form of changes in distributions, phenology and physiology as a consequence of responses to changes in precipitation patterns and increases in temperature, as well as an increase in the frequency of extreme events (Hobbs & Mooney 2005). Habitat changes affected by the latter will also be significant.

The geographic ranges of both alien and indigenous species are likely to be affected by projected changes in climate, with potential shifts in an easterly direction following precipitation patterns, and to higher latitudes (or altitudes) following temperature changes (Richardson *et al*. 2000; Erasmus *et al*. 2002; Rouget *et al*. 2004). The movement of species is expected to be consistent with natural dispersal, with leading edge range shifts, but also jump dispersal and movement via corridors (Tolley *et al*. 2008; Wilson *et al*. 2010) playing a role. However, human-mediated dispersal of most alien species is almost certain to be more important than such 'natural dispersal'. Thus, a direct result of climate change will be a shift in distributional ranges of alien species as well as a change in abundance in existing ranges (Hobbs & Mooney 2005; Walther *et al*. 2009). It can thus be expected that more alien species will appear in the eastern parts of the country (i.e. tropical species) compared with the western, arid parts of the country (Rouget *et al*. 2004).

Climate change is likely cause some alien species to become drivers in ecosystem conversion by enhancing their competitiveness, while others will become passengers, because climate will become unfavourable for indigenous species and disturb ecosystems from their current state (Didham *et al*. 2005). Assessments of the effects of climate change on alien and indigenous biota must also consider changes in ecosystem composition and functioning that will alter elements of invasibility. Changes in the frequency and intensity of extreme events such as storms, droughts and floods have the potential to alter the susceptibility of ecosystems to invasion (Hobbs & Mooney 2005).

Changing rainfall regimes will change the representation of C_3 and C_4 plants, which will drive crucial changes in fire regimes that could induce non-linear threshold effects (Richardson *et al*. 2000). Increases in carbon dioxide concentration [CO_2] are likely to have major effects on tree-grass dynamics in grasslands and savannas because of the different photosynthetic pathways used by the different growth forms. Subsequently these life forms will respond differently to increased [CO_2]. Generally, C_3 plants show increased photosynthetic efficiency with carbon fertilization and increase in biomass more than do C_4 plants under doubling of CO_2 (Wolfe & Erickson 1993; but see Stock *et al*. 2005). Increased CO_2 has also been found to increase water use efficiency of plants (Bazzaz 1990). These effects have been suggested as some of the main reasons for the expansion and densification of indigenous trees in South African grasslands (Bond & Midgley 2000; Wigley *et al*. 2010).

Climate change is likely to have indirect effects on invasive alien species by influencing the nature and intensity of human activities. Biological invasions are closely linked to human activities and the associated disturbance of natural ecosystems (Le Maitre *et al*. 2004; Richardson *et al*. 2005; Thuiller *et al*. 2007; King & Tschinkel 2008). Humans have deliberately dispersed alien species for purposes such as recreation (hunting - Spear & Chown 2009; fishing - Shelton *et al*. 2008), the pet trade (van Wilgen *et al*. 2010) and agriculture (forestry - Richardson 1998; agriculture and horticulture - Le Maitre *et al*. 2004). Other species have been introduced unintentionally in ballast water or as hull fouling organisms (Robinson *et al*. 2005), escapees from aquaculture (de Moor 2002) or mariculture (Carlton 2000) and by accidental contamination of a commodities or stowaways (Hulme *et al*. 2008). With climate change, the donor and recipient regions of pathways, as well as the intensity with which these are used, will change as humans adapt to novel climatic conditions (Galil *et al*. 2007). Globalization together with climate change will add new trade paths and alter existing ones, across the oceans as well as across land, which will increase propagule pressure (Galil *et al*. 2007; Bradley *et al*. 2010). Although the number of vessels arriving at South African harbours has declined over the last six years, the gross tonnage in cargo delivered has increased substantially (www.transnetnationalportsauthority.net). This cargo is then dispersed across land routes, contributing to increases in road and rail traffic. Furthermore, with increased urbanization, economic growth and infrastructure development, human disturbance of natural ecosystems will increase and result in the opening of new dispersal corridors (in the form of e.g. roadside verges) increasing the propagule pressure of aliens (Kalwij *et al*. 2008). Land is continuously being transformed, but with changing climate some of the already transformed land will not be utilized any longer and new natural habitats in climatically more suitable areas will be transformed (Biggs *et al*. 2008). Another consequence of altered land use is the nutrient enrichment of soil and water through the deposition of nitrogen and phosphate, increasing the vulnerability to invasion due to nutrient rich systems being favoured by alien species (Richardson *et al*. 2000; Coetzee *et al*. 2009a).

Trends in land use are closely linked to population growth (Chown *et al*. 2003). Human population density in South Africa is positively correlated with species richness of birds and frogs, implying that humans compete with indigenous biota for space (Evans *et al*. 2006). The size of newly proclaimed protected areas is also shrinking over time (on average) and human population density immediately adjacent to conservation areas is higher than expected for other regions (Chown *et al*. 2003), and is increasing. The positive correlation between human activity and alien species occurrence as well as altered disturbance regimes in close proximity to protected areas is resulting in increasing edge effects that negatively affect the indigenous biota of some protected areas. In many cases, human settlements adjacent to protected areas serve as sources of propagules of alien species as well as drivers of disturbance that render protected areas more susceptible to invasion (Alston & Richardson 2006). The change in human activities due to changing climate will mean that most aliens are 'change passengers' because natural ecosystems will be disturbed from their current state. The indirect effects of climate change outlined above are likely to play an even more significant role in driving invasions in South Africa than will the direct effects of climate change.

3.4.2 Observed trends

The impacts of invasive species on South African ecosystem services, biodiversity and the economy are multifaceted, and few attempts have been made to quantify these in a comprehensive way. Nonetheless, some work has been undertaken (van Wilgen *et al*. 2001; Pimentel 2002; van Wilgen & Richardson 2009). Plant invaders pose a significant threat to South African biodiversity: they have already caused the extinction of at least 58 plant species in the Cape Floral Kingdom and threaten thousands more (Macdonald *et al*. 2003; Gaertner *et al*. 2009). The potential economic impact on this region due to further invasion could amount to over US$ 11.75 billion if left unmanaged (Pimentel 2002). Invasive plants are also negatively affecting birds (Allan *et al*. 1997; Dean *et al*. 2002) and several invertebrate groups (grasshoppers - Samways & Moore 1991; ground-living invertebrate assemblages - Samways *et al*. 1996; dung beetles - Steenkamp & Chown 1996; spiders - van der Merwe *et al*. 1996; dragonflies and damselflies - Samways & Taylor 2004; Samways *et al*. 2005; Samways & Sharratt 2010). Plant invasions have a significant impact on South Africa's water resources. Currently an estimated 7% of mean annual runoff is taken up by invasive plants, with a single species (*Acacia mearnsii*) accounting for an estimated cost of US$ 1.4 billion due to streamflow reduction (de Wit *et al*. 2001). Invasive plants currently reduce the grazing potential by c. 74 500 large livestock units, equal to 1% of grazing potential. This could potentially rise to 71% if invasive species continue to spread and degrade grasslands (van Wilgen *et al*. 2008). The cost of clearing invasive plant species across the country was estimated at approximately US$ 1.2 billion (Pimentel 2002). Currently, the Working for Water programme and a provincial programme in KwaZulu-Natal spend c. US$ 80 million per annum on clearing and management of alien species. An estimated 42% of South Africa's arthropod agricultural pests are alien species, resulting in crop losses of approximately US$ 1 billion per annum, with alien weeds and pathogens adding a further US$ 3.3 billion in crop losses annually (Pimentel 2002). The marine invasive ascidian, *Ciona intestinalis*, has a significant economic impact on the cultured mussel industry (Robinson *et al*. 2005). The extent to which climate change will exacerbate these problems has not yet been determined.

An increase in atmospheric CO_2 has been shown to enhance the growth of indigenous woody species (Wigley *et al*. 2010), supporting the idea that higher [CO_2] promotes bush encroachment in grasslands and savannas (Bond & Midgley 2000). Not only indigenous woody species will benefit from increased [CO_2], but also invasive alien species, possibly resulting in the increased spread of these species. The unexplored role of increasing CO_2 during the past century on the accelerating spread of alien nitrogen fixing Acacia species in the nutrient-poor soils of the Cape is a case in point.

3.4.3 Projections and future risks

Terrestrial: Changes in temperature and rainfall regimes together with changes in atmospheric composition are likely to restructure the composition of indigenous and non-indigenous biota of South Africa (Richardson *et al*. 2000; Erasmus *et al*. 2002; Foden *et al*. 2007).

Biogeoclimatic modelling of several alien plant species has indicated that some areas currently occupied by alien species could become unsuitable and thus result in range contraction, particularly in the western, drier parts of the country. The eastern parts of the country, however, are projected to become wetter and thus climatically more suitable for some species, resulting in range expansion. Thus a geographic shift in invaded area is likely to occur for numerous alien and invasive species (Richardson *et al*. 2000), depending on each individual species tolerances to temperature and precipitation changes as well as their capabilities of spreading. As a consequence of the eastern parts of the country becoming more tropical, more tropical species could establish in the eastern parts of the country (Rouget *et al*. 2004; Henderson 2006). Woody plants, alien and indigenous, will benefit from CO_2 enrichment (Bond & Midgley 2000). The subsequent increased growth rate of woody species is likely to facilitate invasion of grasslands, as is being observed for *Prosopis* in North America (Polley *et al*. 2002). Through such increased growth the carbon:nitrogen ratio in the leaves may be modified, where nitrogen will become limiting for insect herbivores. This plant-herbivore interaction could result in increased leaf herbivory and decreased insect growth, but this remains poorly documented (Coviella & Trumble 1999). Nonetheless, it may have significant consequences for the herbivorous insects that constitute a large element of the current set of species utilized for biological control of invasive alien plants in the country (e.g. Anonymous 1999; Zimmerman *et al*. 2004). Plant-pollinator interactions may also be decoupled by phenological changes if each partner in the interaction responds to different cues (Hughes 2000). In the arid parts of South Africa, increased water use efficiency resulting from increased atmospheric CO_2 could open up niches for alien species that require more water (Smith *et al*. 2000; Betts *et al*. 2006; but see Piao *et al*. 2007), further exacerbating the effects of climate change.

With increased urbanization and economic development large natural habitats are being transformed to meet the growing human population's needs. Increased environmental disturbance, in the form of land transformation, land use practices and overexploitation enhances the establishment and success of alien species. In response to changing climatic conditions, spatial patterns of human activities will significantly affect propagule pressure (Lockwood *et al*. 2005). In the absence of effective policy implementation, increasing demands for goods and services will therefore lead to increasing pressure from invasive alien species (Hulme *et al*. 2008). Furthermore, with increased urbanization, economic growth and infrastructure development, an increase of goods being imported and transported along land routes will result in increased roadside invasion, thus further enhancing extant dispersal corridors (Kalwij *et al*. 2008).

South Africa has imported over 86 species of biological control agents for already established invasive alien plant species. Over 63 of these biocontrol agents have established with some of these being very successful in managing the invasion of its target species (Zimmermann *et al*. 2004). However, with climate change, it is uncertain how these agents will respond. Some biocontrol agents might become more successful in controlling their hosts, if climate becomes favourable for the agent. The beetle (*Gratiana spadicea*) controlling *Solanum sisymbriifolium* was found to be limited by low humidity in its release site in the Highveld (Byrne *et al*. 2002), a factor which could prove to be less limiting with climate change. Alternatively, increases in temperature could prove limiting for the gall wasp, *Trichilogaster acaciaelongifoliae,* controlling the long leaved wattle (*Acacia longifolia*) (Dennill & Gordon 1990). The response of other biocontrol agents to climate change and their effectiveness in managing their hosts remains unknown and poorly documented, an uncertainty posing a major risk for future management and control.

Changing climates are also likely to promote changes in the horticultural, agricultural and aquaculture species used as humans adapt to different climates. In consequence, species that were perhaps considered less likely to be utilized may gain increasing attention and vice versa. As a result, the pattern of accidental introductions or escapes of species already in the country could change substantially. The uncertainty associated with these kinds of responses is large, emphasizing the need for stringent risk assessment and for effective early detection and rapid response programmes.

Freshwater: Climate change will undoubtedly affect South Africa's aquatic ecosystems through increased temperatures and evaporation as well as changes in rainfall patterns. In response to the changing climate, land use is very likely to change simultaneously. Urbanisation, human population growth and economic development are increasing the pressure on South Africa's water supplies in much of the country. This will boost dam construction and interbasin transfers will consequently assisting the transfer of species between regions and increasing the spread of indigenous as well as alien invaders (Kolar & Lodge 2000; Johnson *et al*. 2008). Changes in land use as well as the increased conversion of natural environments for agriculture will place increasing pressure on aquatic systems by increasing the runoff of agricultural effluent into rivers and dams, which will reduce the quality of the water (Magadza 1994). The eutrophication of freshwater systems often makes the environment less suitable for indigenous species and more suitable for alien species. Furthermore, the temperature of the water is altered by increased/decreased shading due to agriculture and alien invasive trees (Kolar & Lodge 2000) and this may directly alter habitat quality for freshwater species such as dragonflies and damsel-flies (Samways & Taylor 2004). However, increased evaporation as well as increased aridity in the western parts of the country will decrease annual runoff and river flow (Magadza 1994). Increases in frequency and severity of floods and droughts are predicted across the country, heavily affecting freshwater systems (Knoesen *et al*. 2009).

Large physiological tolerance ranges of the four alien crayfish species that have been introduced to South Africa (de Moor 2002) indicate that these species can spread across large areas and will not be negatively impacted by climate change. This could prove problematic, as freshwater molluscs and crayfish act as intermediate hosts for parasites, such as lung fluke and bilharzias, affecting human health (de Kock & Wolmarans 1998; de Moor 2002). The effects of climate change on other aquatic invaders remain tentative and extensive research is required to understand the possible outcomes.

Marine: The effects of climate change on the marine environment are predicted to be complex and cascading (Carlton 2000). Changes in sea temperature, sea level, acidity and storm events (e.g. Clark 2006; Smith *et al*. 2007; Rouault *et al*. 2009), either individually or in combination, will all influence indigenous as well as non-indigenous biodiversity.

Changes in precipitation patterns across the country will influence annual runoff in complex ways, with a range of increases and decreases in runoff expected along the coast line (Clark *et al*. 2000). These changes in runoff will significantly affect the marine and estuarine environment (Clark 2006). The greatest effect on South Africa's marine biota due to climate change will be changes in pressure fields. These are expected to manipulate large-scale oceanographic processes, particularly the upwelling associated with the Benguela region (Clark 2006). All these climatic changes will almost certainly disturb marine environments, making them more susceptible to invasion. Invasive species from lower latitudes are likely to arrive in South African oceanic systems and warmer water species are likely to become more abundant (Carlton 2000; Drinkwater *et al*. 2010). Thus an overall decline in cold water indigenous species can be expected.

The response of alien marine organisms to climate change has not been investigated for South African species. Predictions can be made by looking at range maps and then modelling the likely change based on inferred environmental responses, or by looking at the physiological tolerances of the given species. For example, a marine invader with a preference for cool, temperate waters, *Balanus glandula*, is expected to have a detrimental effect on intertidal communities of cool, temperate waters (Laird & Griffiths 2008). Currently this barnacle species occurs mainly along the west coast, and its distribution along the southern coast is limited by the warmer waters of the Agulhas region. This alien species could become less abundant with an increase in ocean temperatures due to the low temperature range (below 17°C) required by this species (Laird & Griffiths 2008). However, studies elsewhere have indicated that this species can tolerate a wide range of temperature and salinity as well as exposed sites (Kado & Nanba 2003). The invasion of the European Green Crab (*Carcinus maenas*) is currently limited to intertidal sites with low wave exposure (Griffiths *et al*. 2009). Changes in storm frequency and severity could negatively affect this species by increasing wave action and severe storms could potentially induce local extinction of this species. The Mediterranean mussel (*Mytilus galloprovincialis*) negatively affects local mussel diversity by displacing indigenous species on the west coast of South Africa. It seems to prefer cool, temperate conditions and is limited by subtropical environments (Branch & Steffani 2004), but it is capable of surviving high sea temperatures (Rajagopal *et al*. 2005). Furthermore, the temperature range for spawning and larval survival is relatively broad and thus unlikely to be a limiting factor (Chícharo & Chicharo 2000). Wave action has been shown to cause higher mortality in *M. galloprovincialis* than the indigenous mussel (*Perna perna*) and thus its invasive potential could decline with increasing average wave action as a result of climate change (Zardi *et al*. 2008).

Disturbance events: Climate change is predicted to increase the severity and frequency of disturbance events such as extreme temperatures, droughts, flooding, and storms, as well as to alter fire regimes. These events will disturb natural habitats, making them more vulnerable to invasion (Thuiller *et al*. 2007). Extreme conditions could enhance the dispersal of alien species into regions that previously received few propagules (Walther *et al*. 2009).

Increased precipitation, floods and storms in agricultural areas will sporadically result in eutrophication of coastal zones and freshwater systems through increased runoff, as seen elsewhere (Carlton 2000; Zhang *et al*. 2009). These areas will become temporarily more nutrient rich, allowing alien species to establish, even if only in the short term, especially organisms that require high nutrient waters. Extreme events could also promote phytoplankton invasions, leading to toxic blooms (Carlton 2000). Furthermore, floods assist the spread of aquatic species by breaching barriers and enabling riparian zone invasion via the removal of indigenous vegetation along these zones (Walther *et al*. 2009). Floods assist the expansions of invasive plant species in arid areas, as demonstrated by the rapid increase in area invaded by *Prosopis* species in the North Cape associated with much higher than average rainfall between 1961 and 1976 (Harding & Bate 1991). The increased intensity and frequency of storms along the coast of KwaZulu-Natal has resulted in coastal erosion (Smith *et al*. 2007) partially attributed to the replacement of indigenous dune vegetation by alien plants.

During droughts, the introduction of supplementary fodder for livestock feeding is a source of alien seeds (Zimmermann & Moran 1991). Increased frequency or severity of droughts may weaken ecosystems, making the habitat susceptible to invasion by drought-tolerant species.

Fire regimes are changing as a result of climate change, human activities and the presence of alien plants, particularly woody species (Brooks *et al*. 2004). Increased atmospheric CO_2 is expected to increase plant biomass through accelerated growth rates. This consequently adds to fuel loads, increasing the frequency of fires and subsequently enhancing the disturbance of natural systems, enabling invaders to establish (Bond 2008; van Wilgen 2009). Altered fire regimes will negatively affect indigenous flora, favour alien invasions and change the tree:grass balance in savannas.

Emerging invaders: Thousands of alien species have already been introduced to South Africa, many of which are well known invasive species in other parts of the world. Species that show tendencies to become invasive either within the region or which are invasive in similar environments elsewhere, are known as emerging invaders (Nel *et al*. 2004). The identification of emerging invaders is not straightforward, but a recent study aimed at identifying some emerging plant invaders highlighted 85 species as having such potential (Net *et al*. 2004). Some of these species were introduced only fairly recently, and are still in their lag phase or have only recently started the phase of rapid population growth (Mgidi *et al*. 2007). Furthermore, new species continue to arrive and establish (van Wilgen & Richardson 2009). Due to the lack of knowledge on the interaction between climate change and alien species in South Africa, it is difficult to predict which species will become invasive in future. With changing climate some emerging invaders can be expected to increase in abundance due to conditions becoming more favourable than previously (van Wilgen & Richardson 2009). Some species might become invasive as a result of range shifts while for other species the lag phases could be shortened or ended by climate change (Mack 1996; Walther *et al*. 2009). Changing trade paths due to climate change will increase the propagule pressure of some species allowing them to become invasive (Carlton 2000). Some of the alien species already present in South Africa are grown or kept in large numbers for horticulture, forestry or food. Australian species are particularly invasive in South Africa, with 45% of alien species becoming invasive. Thus, other Australian alien species should be monitored carefully (Richardson *et al*. 1997). There is no doubt that many alien species that are already in South Africa, some of them widespread for example as horticultural subjects, will be become invasive in the future.

In response to climate change and the economics and availability of fossil fuels, interest in biofuels is growing. Although these may have economic benefits, the environmental cost could be substantial, as some species used for biofuels have traits which are also routinely documented for invasive species (Raghu *et al*. 2006). Similarly, invasions can be expected where plants are cultivated as carbon sinks (de Wit *et al*. 2001).

Indigenous species as problems: Species that are indigenous to South Africa may also become invasive in parts of the country outside their natural range, as a result of ongoing human-mediated translocation (Spear & Chown 2009). Many indigenous species are likely to respond to climate change by shifting their ranges unassisted by humans, but these should not be considered 'invasive' (Pyšek *et al*. 2004). Numerous freshwater fish have already spread through interbasin transfers threatening indigenous biota of these aquatic systems (Macdonald *et al*. 2003). Approximately 18 indigenous bird species have expanded their range into the Cape Peninsula since the 1940s, mainly due to anthropogenic landscape changes (Hockey & Midgley ,2009). The Painted Reed Frog (*Hyperolius marmoratus* - Tolley *et al*. 2008) has been translocated accidentally and is now considered alien in some parts of the country. However, distinguishing between natural range expansion and human assisted translocation is not always straightforward (Tolley *et al*. 2008), and is likely to become more complicated in future. In the face of climate change, it has been suggested that indigenous species may have to be translocated for conservation purposes (Mueller & Hellmann 2008; Richardson *et al*. 2009). However, a more comprehensive approach may be to factor climate change into conservation planning by combining a focus on the matrix within which reserves are embedded, appropriate corridors, areas of evolutionary significance, transfrontier approaches, and managed relocation.

3.4.4 Adaptation

Adaptation options: Effort could usefully be directed towards implementing policies and legislation to prevent the introduction of new alien species and the spread of those already in the country. In the absence of effective policy implementation, increasing demands for goods and services (Hulme *et al*. 2008), and the processes associated with species expansion, likely in a variety of instances to be exacerbated by climate change, will lead to increasing pressure from invasive alien species.

The identification of new and emerging invaders depends on an informed and aware public, a significant component of adaptation strategies. The availability of a global list of invasive species could be of significant use as an early-detection system for emerging invaders. Cataloguing of all new species coming into South Africa, including those used for agriculture, forestry, horticulture and other purposes would provide a sound base for the early detection of possible new invaders. Pro-active early detection and eradication can substantially reduce the costs of control and damage caused by these species (van Wilgen & Richardson 2009). An important component of mitigation is the effective regulation of introduction and movement of species.

Adaptation actions: To conserve biodiversity in a changing world, processes of systematic conservation planning are being refined (Pressey *et al*. 2007). However, consideration must be given to minimizing the further spread of established aliens and prevent the introduction of novel invaders (Mueller & Hellmann 2008; Richardson *et al*. 2009). The prevention and management of invasive alien species forms an integral part of South African policy, legislation, and government action aimed at protecting the region's biodiversity. Most legislation of direct relevance to the management of biological invasions is incorporated within the Conservation of Agricultural Resources Act (No. 43 of 1983), the National Environmental Management: Biodiversity Act (No. 10 of 2004), and the National Environmental Management: Protected Areas Act (No. 57 of 2003), although many other legal instruments have clauses that can be invoked in this regard (Richardson *et al*. 2003). Management interventions have been implemented both nationally (Working for Water at US$ 66 million per year), provincially (KwaZulu-Natal Invasive Alien Species Programme at US$ 13 million per year), and regionally (e.g. the Invasive Alien Species Strategy for the Greater Cape Floristic Region). Capacity building initiatives include the government-supported Centre for Invasion Biology (http://academic.sun.ac.za/cib/), a partnership between government and the tertiary education sector. Effective implementation of the legislation, sufficient capacity to undertake the extension and identification work required to prevent new invasions, and research capacity to keep pace with changing circumstances are all required for an effective strategy to reduce the rates and impacts of biological invasions in the future.

3.5 Coastal and Marine environment

3.5.1 Natural variability and the physical marine environment

Southern Africa experiences strong ocean influences on its weather and climate patterns. In particular, South Africa is situated near the meeting place of three oceans, the South Indian Ocean on the east coast, the South Atlantic Ocean on the west coast and the Southern Ocean to the south. These three oceans play a vital role in determining southern Africa's climate and weather patterns as well as strongly influencing the global climate, as discussed in Section 2.

3.5.2 Observed physical trends

Change in climate incorporates change in temperature, precipitation and evaporation rates, sea level rise and increased storminess, ocean circulation, winds and CO_2 concentrations all of which will have profound consequences for marine and coastal ecosystems (Roessig *et al*. 2004).

In South Africa, analysis of sea surface temperatures (SST) from satellite data gives slightly contrasting results. Roualt (2007) using optimally interpolated SST data recorded a rise in SST in the coastal and offshore areas of the west coast of, on average, approximately 1°C between 1920 and 1990, which was accompanied by an increasing trend in southerly winds Figure 3.5.1). High resolution SST records from 1982 indicate an increase of 0.13°C for the South Atlantic as a whole; an increase of 0.8-1.0°C in the northern Benguela in the vicinity of the Angola-Benguela Front across the boundary of the upwelling system (near the Angola-Namibia geopolitical border) and a corresponding increase of approximately 1.0°C in the Agulhas Retroflection area just south of the Agulhas Bank together with a SST decrease of 0.2-0.3°C near the coast along the west and south coast. Rouault *et al*. (2009) found that since the 1980s the SST of the Agulhas Current (measured from AVHRR satellite SST data) has increased significantly (up to 0.7°C per decade). Their analysis produced similar results for the west and south coasts, they indicated that along the west coast near-shore SST is cooling between -0.2 to -0.5^{0}C per decade, with isolated small scale pockets of cooling in the region between Cape Agulhas and Cape St Francis (South Coast) of about -0.2^{0}C per decade. In contrast a larger region of cooling, ranging from -0.2^{0}C to -0.7^{0}C was identified between East London and Port Elizabeth centered in the Port Alfred dynamic upwelling cell. In the sub-tropical province a very thin strip of near-shore water cooling at a rate of -0.6 to -0.8^{0}C per decade was identified as far as Port St. Johns.

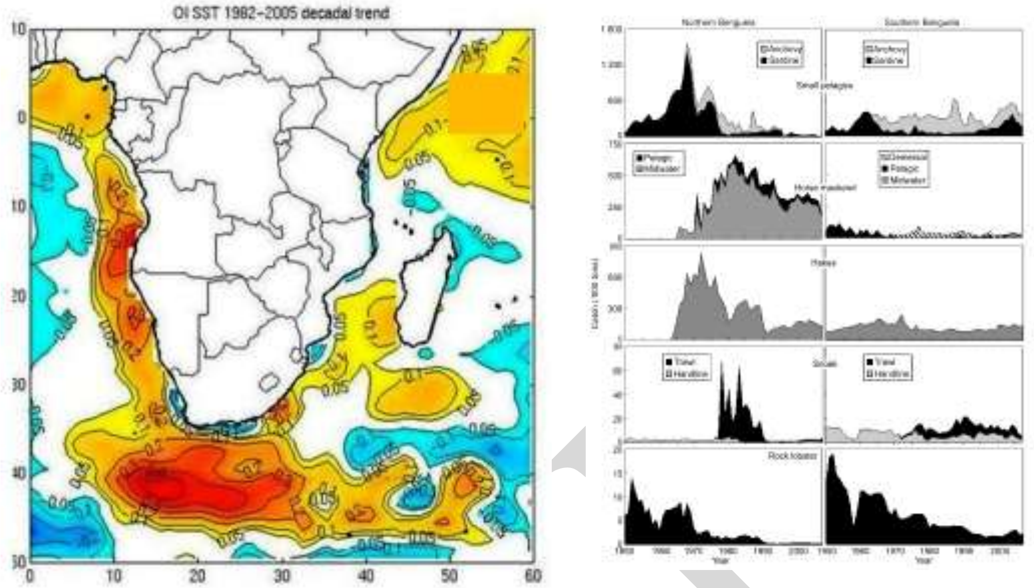


Figure 3.5.1: Decadal sea surface temperature trends (Rouault 2007) and changes in catches of major fish resources since 1950 (van der Lingen et al. 2006).

In contrast, sea surface temperatures measured over a 25 year period in situ off Port Elizabeth on the south-east coast of South Africa have been increasing by ± 0.25ºC per decade for the past four decades (Schumann *et al*. 1995). Similarly, despite considerable variation between years there has been a positive increase ($r^2 = 0.19$; $P > 0.05$) in mean annual SST measured in situ at the mouth of the Kowie Estuary at Port Alfred between 1996 and 2006 (James *et al*. 2008).

Bakun (1990) hypothesized that intensified alongshore winds, due to warming land masses would lead to more frequent, intense seasonal upwelling events. An increasing trend in upwelling intensity has been reported for the Benguela system over the last four decades (Scavia *et al*. 2002, Shannon *et al*. 1991). Recently, significant changes to Southerly and Westerly wind regimes have been reported in South Africa (Reason & Rouault 2005; Rouault *et al*. 2009) and an intensification of the Atlantic and Indian high pressure system (Rouault *et al*. 2009). Shifts in Westerly wind patterns are a well know feature of global climate change (Trenberth *et al*. 2007).

Sea-level is rising around the South African coast (Mather *et al*. 2009), in agreement with current global trends, but there are regional differences. The west coast is rising by +1.87 $mm.yr^{-1}$, the south coast by +1.47 $mm.yr^{-1}$ and the east coast by +2.74 $mm.yr^{-1}$. The eustatic level rise is lower along the west coast (+0.42 $mm.yr^{-1}$) but higher along the south (+1.57 $mm.yr^{-1}$) and (+3.55 $mm.yr^{-1}$) east coasts. These differences are attributed to regional differences in vertical crust movements and large scale oceanographic processes off the east and west coasts (including the Agulhas and Benguela Currents).

The intensity and frequency of extreme storms in South Africa seems to be increasing (Guestella & Rossouw 2009), in alignment with projections (IPCC 2007). The natural environment's vulnerability to sea level rise and increased storm intensity varies between systems. Hard shores and cliffs are relatively stable and not subject to catastrophic erosion, but mixed coastlines of rock and sand, especially pocket beaches, are likely to be severely impacted. Ancient primary dunes could experience slips along the steep seaward facing slope (e.g. The Bluff at Durban). Mildly sloping sandy shores could be subject to the greatest landward migration of the shoreline due to sea level rise (Brown & McLachlan 2002). Small increases in sea level rise could result in significant regression of the high water mark (e.g. on the Cape flats). Sandy beaches will erode with rises in sea level, reducing their surface area, while increasing storm intensity will require more coastal defence systems. Changes in the sand budget will affect estuary mouth dynamics, resulting in changes in the open/closed mouth status of estuaries.

Precipitation and runoff into South African rivers is expected to change. This change will impact on the functioning of estuaries and the nearshore coastal environment. The reduction in pH that accompanies elevated **CO_2** concentrations may have profound implications for coastal ecosystems (Harley *et al*. 2006). It is estimated that the **pH** of surface waters will decrease by 0.3 - 0.4 units by 2100 as atmospheric CO_2 levels continue to increase (Caldeira & Wickett 2003). In South African waters, long-term changes in pH have yet to be measured.

3.5.3 Observed biological and biophysical trends

Rocky intertidal zone and kelp beds: There is currently only one study which specifically examines climate change impacts on the rocky intertidal zone (Mead PhD in prep, University of Cape Town), despite the fact that South Africa has a long history of research on rocky intertidal and kelp bed ecosystems. Mead's study has shown that there have been shifts in population abundance and changes in the proportions of cold water and warm water affinity species within the community. This implies potentially significant changes in community functioning and dynamics, probably linked to cooling of near-shore SSTs in the cool-temperate region and adjacent transition zone and shifts in circulatory and upwelling patterns (Mead PhD in prep). There have been no specific observations for kelp bed communities due to a lack of climate change specific research on this community.

Estuaries: The degradation of many of South Africa's estuaries due to global change drivers such as eutrophication, fishing and harvesting, freshwater abstraction, sedimentation and mouth manipulation has been well documented. Documented changes that can be attributed to climate change are, however, far more limited and generally linked to range extensions of certain taxa due to changes in SST e.g. estuarine fish in the East Kleinemonde and Mngazana Estuaries.

Long term monitoring of the fishes in the warm-temperate East Kleinemonde Estuary just outside Port Alfred (33°32´42″S, 27°03´05″E) has occurred since December 1995 with six new species of tropical fishes being recorded in the catches from 1999 onwards. Mean annual SSTs recorded *in situ* along the adjacent coast have increased at a rate of 0.09□C per year over the past decade and may have facilitated the southward extension of tropical marine fishes into the warm-temperate biogeographic zone (James *et al*. 2008). Similarly, the diversity and dominance of tropical species in the Mngazana Estuary (31°41'29"S; 29°25'24"E) have increased when compared with a similar study conducted 25 years earlier (Mbande *et al*. 2005).

Sandy shores: Research on the effect of climate change on sandy shores in South Africa is limited to the possible impact of sea level rise and severe storms (Mather 2009; Harris 2008). A National overview of sandy beach ecosystems is currently being undertaken and should be available in late 2010. Early indications are that sea level rise in Kwa-Zulu Natal could result in the loss of backshore beach and upper intertidal areas due to "coastal squeeze".

Coral reefs: A long-term monitoring programme was initiated in 1993 (Schleyer *et al*. 2008), entailing temperature logging and image analysis of high resolution photographs of fixed quadrats on representative reef. Sea temperatures rose by 0.15°C p.a. at the site up to 2000 but have subsequently been decreasing by 0.07°C p.a. Insignificant bleaching was encountered in the region during the 1998 El Nino Southern Oscillation (ENSO) event, unlike elsewhere in East Africa, but quantifiable bleaching occurred during an extended period of warming in 2000. Peak temperatures on the South African reefs thus appear to have attained the coral bleaching threshold. While this has resulted in relatively little bleaching thus far, the increased temperatures appear to have had a deleterious effect on coral recruitment success as other anthropogenic influences on the reefs are minimal. Recruitment success diminished remarkably up to 2004 but appears again to be improving. Throughout, the corals have also manifested changes in community structure, involving an increase in hard coral cover and reduction in that of soft corals, resulting in a 5.5% drop in overall coral cover. These "silent" effects of temperature increase do not appear to have been reported in the literature.

The greater Agulhas current: Observations of the Greater Agulhas region are very limited. Peeters *et al*. (2004) have shown, using sediment cores, that there was a peak in Agulhas leakage at the end of each of the last five glacial periods. Other studies (e.g. Rau *et al*. 2002) have indicated that although the Agulhas leakage has undergone significant changes over the past 450 thousand years, it has never ceased completely. Over geologic time, increases in salt fluxes via Agulhas leakage have coincided with increases in the intensity of the meridional overturning circulation in the Atlantic Ocean (Martínez-Méndez *et al*. submitted) which suggests a mechanistic linking between the two. Other studies (Bard & Rickaby 2009; Zahn 2009) have in turn indicated that with a change in the latitude of the zero wind stress curl in the South Indian and South Atlantic Ocean, the equator-ward shift in the Subtropical Convergence will close off the inter-ocean leakage south of Africa. The Agulhas Current has a marked influence on the local atmosphere (e.g. Lee-Thorp *et al*. 1998), which can at times make a major difference to terrestrial synoptic systems (Rouault *et al*. 2002), enhancing their intensity. Apart from these very local and coastal effects, the Agulhas Current system and sea-surface temperatures in the South-West Indian Ocean have been shown to influence regional atmospheric circulation patterns and attendant rainfall patterns (e.g. Reason & Godfred-Spenning 1998, Reason and Mulenga 1999, Reason 2001).

The Benguela system and fisheries: One of the strongest trends (~50 years length) has been a warming at the northern and southern boundaries of the Benguela system, with potential consequences for increased hypoxia on the Namibian shelf. There has also been a long-term increase in southerly winds, which induce upwelling in the southern Benguela, with modulation over decadal time scales.

Zooplankton has increased (~10-fold), caused by changes in productivity and upwelling–favourable winds. Pelagic fish stocks have been decimated, resulting in the collapse of sardines in the 1960's. This could be attributed to fishing pressure, warming trends, competition with the increased horsemackerel stocks, or suppression by predators. By contrast, southern pelagic stocks have increased, accompanied by an eastward (perhaps cyclic) shift in sardine and anchovy. Horsemackerel stocks in Namibia have recently begun to decline, while deepwater hake appear to have expanded northwards. Rock lobsters have declined in the central

Benguela and shifted southwards and eastwards. Top predators have responded to the changes in fish availability in different parts of the ecosystem; seals have expanded northwards while seabirds and penguin have declined considerably in the north.

3.5.4 Projected vulnerabilities

Rocky intertidal zone and kelp beds: Climate change projections made for both systems within the South African region are still at a conceptual stage with observed trends from modern surveys and historic quantitative studies (Mead PhD in prep). Changes in ecosystem stressors (e.g. changes in air temperatures, sea surface temperatures, storm intensity, sea level rise and upwelling) associated with climate change make rocky intertidal and kelp bed communities vulnerable to climate change (Southward 1958, Chapman *et al*. 1995, Edwards 2004). Climate change driven species shifts in rocky intertidal ecosystems have been detected in Europe, America, the Arctic, Australia and New Zealand. Species which are close to their thermal limits are being lost from or introduced into community assemblages and this is strongly linked to warming sea and air temperatures at a range of temporal scales. Within-range-shifts have resulted in the creation of 'hotspots', 'coldspots' and pocket extinctions for rocky intertidal species. Increasing sea temperatures have also negatively impacted carrying capacity, densities and size of dominant cold water kelp species. Besides changes in the horizontal distribution of species, vertical squeezing of the upper distribution limit in rocky intertidal species due to increasing air temperatures has also been recorded. Increasing wave force has been predicted to create additional physical stress on low shore communities and within kelp bed ecosystems (Helmuth *et al*. 2006; Meiszokowska 2009). There is also a concern that rising sea levels and increased frequencies of storm events may transport significant amounts of sediment up and down coastlines (Drinkwater *et al*. 2010). Larval supply, which can influence the distribution and abundance of intertidal organisms, is impacted by offshore currents, upwelling and wave action, all of which are affected by temperature regime shifts.
In South Africa, climate change impacts on rocky intertidal and kelp bed communities will differ spatially as well as temporally, due to the existence of distinct biogeographic provinces and the transition zones between them.

Estuaries: National or regional scale models looking at the interaction between the various potential climate change drivers on the functioning of South African estuaries have not been developed. Basic conceptual models of the impacts of climate change on estuaries are available internationally and could be developed within a South African context. Mass balance ecosystem models such as ECOPATH have been used on individual estuarine systems in South Africa (e.g. East Kleinemonde Estuary) and can be further expanded to include a climate change emphasis. Decision-support systems are available within the Department of Water Affairs' Reserve process to examine the impact of abstractive changes in freshwater flow on individual estuarine systems. These reserve protocols, which have been extensively developed, could be readily adapted to include climate change scenarios.

Climatic envelope models that model shifts in fish species distribution with temperature changes associated with climate change are at an early stage of development. Preliminary models show contractions in the ranges of certain endemic estuarine fish species. Climate change is likely to produce profound modifications to the structure and functioning of estuaries (Kennedy 1990), and may have a range of implications for estuarine biota. Estuaries are shallow systems and are strongly influenced by rainfall (freshwater input), wind, wave action, sediment input and water and air temperatures. Climate change is predicted to alter precipitation patterns which will affect the quality, rate, magnitude and timing of freshwater delivery to estuaries and will potentially exacerbate existing human modifications of these flows (Alber 2002). Estuarine functioning is strongly influenced by the magnitude and timing of freshwater runoff reaching them (Turpie *et al*. 2002). Reductions in the amount of freshwater entering estuaries in South Africa, particularly in the Western Cape, would lead to an increase in the frequency and duration of estuary mouth closure and changes in nutrient levels, suspended particulate matter, temperature, conductivity, dissolved oxygen and turbidity (Clark 2006). The reduction in pH that accompanies elevated CO_2 concentrations may have profound implications for a wide range of estuarine organisms including coralline algae, echinoderms, crustaceans and mollusks (USEPA 2009). Estuarine acidification will also influence water quality (USEPA 2009). Sea-level rise and the increased intensity of storm events, both of which are already occurring, are seen as a threat to mangrove and salt marsh ecosystems in estuaries. Migration of coastal wetlands under current and projected levels of sea level rise may be prevented by artificial embankments and development which will cause a loss of coastal wetlands through "coastal squeeze" (coastal squeeze refers to situations where coastal development is located close to estuaries and beaches, preventing the systems from migrating landward in response to sea level rise).

Increased storminess, together with sea level rise, may result in a loss of estuarine habitat which ultimately affects estuarine fish communities and will have fisheries repercussions. One of the most obvious changes associated with changing SSTs will be shifts in the distributional patterns of estuarine species and changes in the composition of species assemblages. Changes in the distribution patterns of estuarine species are already being recorded both locally and globally, but are difficult to predict as different species respond differently to changes in temperature.

Sandy shores: In terms of climate change, South Africa's sandy shores are primarily vulnerable to sea-level rise and the increased frequency of high-intensity coastal storms in those areas where the beaches are constrained by hard structures such as sea walls, coastal infrastructure or buildings. In these developed regions of South Africa some sandy beach ecosystems are at risk of being lost through inundation and erosion as a result of "coastal squeeze". Other consequences of sea-level rise for sandy beaches in South Africa may include: increased erosion, dune blowout formation; intensified flooding; and increased saline intrusion into coastal aquifers.

Storms are important in shaping beaches because they move large quantities of sand from the upper shore and deposit it in the surf zone. This sand is moved back slowly to the beach and dunes during calmer conditions (Brown & McLachlan 2002, Costas *et al*. 2005, Anfuso *et al*. 2007). Increased storm frequency will have a serious effect on beaches as insufficient time (between storms) will be available for recovery from a preceding storm event. In South Africa the increased intensity and frequency of storms, coupled with sea level rise will present a synergistic erosive force that could remove large quantities of sand off the beach face. This will exacerbate the retreat of beaches in South Africa's unconstrained areas, and impact on the availability of sandy shore habitat, in the developed areas as well as increasing the risk of damage to coastal infrastructure.

Other possible impacts of climate change on beaches include: alteration of rainfall patterns that could have an effect on interactions such as groundwater flow and estuarine discharge. Changes in wind fields could also have a bearing on local wave climates and ocean currents, with implications for longshore drift of sediment and connectivity of populations that are connected by pelagic larvae. It is unlikely that temperature will have an effect on sandy beaches, with elevated temperatures possibly only having an indirect effect.

Coral reefs: Range shifts and extensions could occur in coral reef communities with climate change. These have been observed in fish communities, with the gradual appearance of more tropical species on southern reefs; a similar pattern will probably emerge amongst the benthos. Extreme weather events are associated with climate change and, in this case, appear to be generating more frequent and larger waves (Schleyer & Benayahu 2009) that will result in increased turbulence and sediment movement. The latter have a profound influence on coral distribution and survival (Schleyer 2000, Schleyer & Celliers 2003, Schleyer in press). Simple qualitative conceptual models are available to predict possible impacts of climate change, but significantly more investment is required if quantitative models, which incorporate regional driver projections, spatial parameters, community composition and species range extensions are to be developed.

Coral bleaching associated with climate change currently constitutes the greatest threat to coral reefs, the causes and consequences of which are reviewed by Hoegh-Guldberg (1999) and Wilkinson (1999). Yet there is cause for hope in the ultimate survival of corals through resilience to bleaching (Hughes *et al*. 2003). While one might expect global warming to result in a pole-ward expansion in the distribution of tropical corals, Scavia *et al*. (2002) suggest that this will not occur due to a reduction in aragonite saturation caused by the greater solubility of CO_2 in cooler waters. These are the factors one might expect to be at play on the high-latitude coral reefs in South Africa.

Coral reefs occur in northern KwaZulu-Natal, and have been subjected to extensive mapping for their biodiversity conservation and sustainable use (Schleyer & Celliers 2005; Ramsay *et al.*. 2006; Celliers & Schleyer 2008). They are small but provide a model for the study of many of the stresses to which these valuable ecosystems are being subjected globally (Schleyer & Celliers 2003). The value of the South African reefs in this regard is partially attributable to their marginal nature, as their coral communities constitute the southernmost distribution of this fauna on the African coast. Their marginality is thus attributable to latitudinal and climatic parameters, making them vulnerable to climate change.

The greater Agulhas current: A number of different scenarios have been presented. Van Sebille *et al*. (2009) have proposed that a weakening in the Agulhas Current leads to more inter-ocean leakage. By contrast Rouault *et al*. (2009) have indicated that a strengthening of the wind stress curl in the South Indian Ocean has led to an increase in intensity of the Agulhas Current and also an increase in inter-ocean exchange. This may also be due to a poleward shift of the westerlies over the South Indian Ocean (Biastoch *et al*. submitted). However, there is a decided complication, in that it is the mesoscale perturbations in the Agulhas system that control the inter-ocean exchanges south of Africa (Biastoch *et al*. 2008). This means that modelling the possible changes in this process due to global climate change will be very complex.

Potential changes in the Agulhas current could have a significant impact on coastal rainfall patterns and the functioning of important coastal oceanographic features such as the Port Alfred upwelling cell. For example, changes in the timing and intensity of upwelling events, or river runoff, into the nutrient-poor east coast environment could have significant ecological ramifications for both pelagic and coastal ecosystems. Changing factors such as nutrient availability can have a knock-on effect up the food web with impacts moving from phytoplankton to zooplankton and ultimately to fisheries and bird populations. The Agulhas Current is driven by the wind stress curl over the South Indian Ocean, but is strongly influenced by perturbations. Most of our current understanding of the system is based on numerical models and remotely-sensed data. Research suggests that it is changes in the large-scale wind fields that will have a major impact on the Agulhas Current. Of great importance is how such changes will impact the Agulhas leakage into the South Atlantic and its role in the global thermohaline circulation.

The Benguela system and fisheries: Over 50 years of catch records and research in the Benguela system have indicated a high degree of variability at a range of temporal and spatial scales. Ongoing research is needed to unpack the various connections between scale, ecosystem drivers, ecosystem responses and socio-economic impacts before a full understanding of the system can be gained and issues such as climate change, global warming, fishery impacts and natural long term variability can be fully assessed. A key to achieving this will be integrated ecosystem level biogeochemical modelling that takes into consideration terrestrial, oceanic and atmospheric forcings.

The Benguela ecosystem and associated fisheries are therefore vulnerable to changes in the frequency of harmful algal blooms, distribution of fishery resources, fishery landing points, stock levels and recruitment. These factors are likely to be influenced by climate change drivers such as changes in SST, currents, wind regimes etc. The Benguela is one of the major eastern boundary upwelling systems of the world, and may be described in terms of four components (Hutchings *et al*. in press): a northern subtropical region off Angola and a cool temperate upwelling region in the south, separated by the powerful Luderitz upwelling cell at 26oS, and a warm temperate zone on the Agulhas Bank. Many organisms migrate between the cool upwelling areas and the warm temperate boundary regions, and are influenced by their dynamics. Research has shown that the system is highly productive, complex and variable, and it is extremely difficult to attribute trends to climate change as opposed to other drivers.

Sea level rise: The sea level is predicted to rise (see Figure 3.5.2), and the frequency and intensity of storms and wave heights to increase (see Figure 3.5.3), on the South African coastline (Hughes *et al*. 1991), resulting in increased exposure to these events; increased saltwater intrusion and raised groundwater tables; greater tidal influence; increased flooding, with greater extent and frequency and increased coastal erosion. Areas vulnerable to sea-level rise and extreme storm events include: Greater Cape Town, including northern False Bay, Table Bay and the Saldana Bay area (Hughes *et al*., 1991; Hughes *et al*. 1993; Midgley *et al*. 2005, Brundrit 2008; Cartwright 2008); The south Cape coast centred on Mossel Bay, from Witsand to Plettenberg Bay (Hughes & Brundrit 1992); Port Elizabeth (Klages 2008); and KwaZulu-Natal coast from Port Edward to Richards Bay (Smith *et al*. 2007; Mather 2008a, b; Phelp *et al*. 2008).

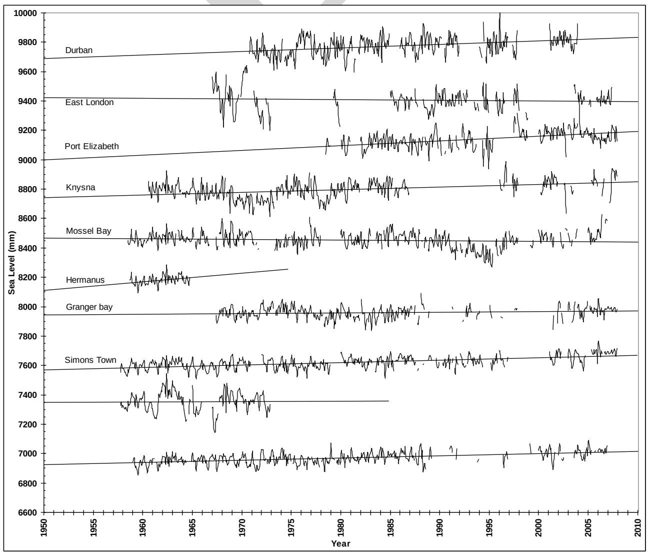


Figure 3.5.2 South African tide gauge time series from the PSMSL (Permanent Service for Mean Sea Level) database, 1959-2006 (Mather et al. 2009).

Numerical models, indices, decision-support tools and GIS models have been used in a number of regions in South Africa to assess possible sea level rise impacts. Examples include the production of sea level rise models and the incorporation of their projections into a risk assessment for the City of Cape Town (Brundrit 2008; Cartwright 2008); models of various sea level scenarios and their possible impacts for Durban (Mather 2007, 2008a, 2008b, 2009a, 2009b); a climate change study at a provincial scale for the Western Cape (Midgley *et al.*2005) which included an assessment of the areas most vulnerable to sea level rise; and a national-level analysis of potential coastal zone climate change impacts and possible response options in the southern African region (Theron 2007).

3.5.5 Adaptation

Biodiversity & fisheries: South African adaptation strategies to protect marine and coastal biodiversity from climate change will need to be centred on sound integrated ecosystem management practices. Key to this will be to ensure that existing non-climate stressors (habitat destruction, fisheries, pollution etc.) are managed as best possible as a reduction in their impact will increase resilience in the environment to cope with climate change. In terms of fisheries fishers are generally opportunistic and individualistic and they continually adapt to changing environmental conditions, using a combination of skill, experience and increasingly sophisticated electronic and mechanical technology. They are therefore "pre-conditioned" to adaptation to climate change. A number of relatively recent innovations in fisheries management have occurred, designed to mitigate some of the deleterious effects of fishing.

Figure 3.5.3: The effects of high sea-level and large waves on Tinley Manor, KwaZulu-Natal North Coast, during the March 2007 storm.

These include the Ecosystem Approach to Fisheries, the Code of Conduct for Responsible Fisheries and individual quota rights. These measures are in addition to classic measures such as Total Allowable Catch or global quota, fishing effort and gear limitations and closed seasons. In essence these measures are designed to introduce sustainability in yields and resilience in both fishing companies and fish stocks to inter-annual and long-term variations in environmental conditions. Decadal or large-scale shifts in climate can alter yields and distribution of fish over prolonged periods and may improve or decrease fishing success. Climate change is therefore implicit in adaptive management of resources, where fishing rights are granted for prolonged periods but interannual yields may vary with prevailing environmental conditions.

Sea level rise: In general, South Africa has very little adaptive capacity in developed coastal areas, other than relatively expensive upgrades or replacements to existing coastal infrastructures. The undeveloped areas have more adaptive capacity; for South Africa the best policy in the long-term in these areas appears to be to allow coastal processes to progress naturally. If left undisturbed, the natural ecosystem is expected to have good adaptive capacity in many instances. South Africa's ability to halt the coastal impacts of climate change on a large scale is virtually non-existent, and may well lead to other detrimental impacts if the problem is misunderstood or underestimated by authorities. Tol (2004) predicts that adaptation would reduce impacts by a factor of 10 to 100 (globally) and that adaptation would come at a minor cost compared to the damage done without adaptation. This strongly emphasizes the need for South Africa to set and implement measures before the damage becomes too costly to repair. 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. 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.

Midgley *et al*. (2005), Theron (2007) and Theron and Rossouw (2008) suggest that for South Africa the best approach appears to lie in planning and research-related activities, such as:

- Instigate and maintain a measurement program utilizing high resolution aerial photographic/satellite mapping, accompanied by a study of hydraulic conditions and surveys of coastal erosion/evolution and sediment transports/budgets. The purpose of the measurements is also to confirm the predicted sea-level rise and increased storminess and to quantify the many impacts.
- Identify important thresholds of dangerous change and include sensitivity analyses.
- Development of a GIS based operational system that highlights the vulnerable areas and places of potential impacts, and identification of hotspots and hazardous areas of change.
- Determine coastal erosion and development setback lines, allowing for at least a Bruun-type erosional response (Brunn 1983, 1988), as well as expanded profile envelopes.

- Draw up Shoreline Management Plans which could advocate responses of the type: “Do nothing”, “Hold the existing line”, and “Advance the existing line” or “Retreat”. In terms of developments and infrastructure, this will provide the strategic framework in which all coastal structures and sea defences are evaluated. Specialist studies and monitoring of the shoreline is an essential component of ongoing Shoreline Management Plans (Midgley *et al*. 2005).
- Design coastal protection /developments /structures specifically to compensate for effects of climate change.

3.6 Human livelihoods and social aspects

3.6.1 Current vulnerabilities

The social dimensions of climate change were not strongly profiled in South Africa's Initial National Communication on climate change (INC, DEAT 2004). The potential impacts of climate change on livelihoods were subsequently explored at a national level in the Long Term Mitigation Scenarios (Ziervogel & Cilliers in Winkler 2007), and the account that follows is paraphrased from that review. Assessing vulnerabilities in terms of livelihoods recognizes that people survive and thrive within society by doing many different things, and that their assets and activities cannot be adequately described using a sectoral approach. The approach of considering human livelihoods thus gives a more holistic picture of the complexities of low-income communities in South Africa than does a sectoral approach, in which, for example, the effects of climate change would be considered relative to single outcomes, such as health, income, or access to resources. A livelihoods approach considers the impacts of climate change on a person's "diverse portfolio of activities" (Ellis 2000).

Livelihoods consist collectively of different types of assets, abilities and activities that enable a person or a household to survive and thrive. 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.

Climate can affect livelihoods as either a shock or a stress (Ziervogel & Calder 2003). Shocks include events that are significantly different from average conditions, such as tropical cyclones, tsunamis, floods or drought. More gradual changes in the climate, such as long-term climate variability or a few months of above- or below-normal rainfall, are classed as stresses. These shocks and stresses fluctuate over space and time and contribute to patterns of household vulnerability (Francis 2002). 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).

In an ideal world, livelihood resilience could be increased if climatic shocks and stresses could be predicted and prepared for. 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.

If a climate extreme is imposed on an already vulnerable livelihood, the individuals might be unable to resist the shock. It is therefore critical to understand the environment in which the livelihood of interest is situated and to realize 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 people's vulnerability to climate to be assessed in a holistic sense, and which are often ignored when a sectoral approach is used. If climate change results in an increase in extreme weather events such as floods and uncertain weather patterns, the capacity for adaptation by vulnerable groups may be diminished along with the ability to sustain a livelihood.

In the context of livelihoods, assets or livelihood 'capital' can be broken down into five categories (listed below), each of which interacts with the others to contribute to the overall resilience of livelihoods. These are:

- *Economic or financial assets* include savings and credit, as well as inflows of money other than earned income – for example pensions and remittances. Increased or decreased precipitation can lead to decreased agricultural yields and may prompt the liquidation of wealth resources (Ziervogel & Calder 2003). Disrupted rainfall patterns can also have negative effects on these assets if employment is linked to agriculture or if the sale of crops or livestock is reduced. For vulnerable groups, with limited access to land, credit and other financial assets, these effects can be significant. More sudden events such as floods and droughts can cause loss of regular employment and result in financial constraints (Archer 2006 & Khandlela & May 2006). At the same time, change in precipitation or temperature might have positive impacts on production and assets if certain crops flourish in changed conditions. These impacts have not yet been documented in South Africa.

- *Human capital* includes people's skills, knowledge, health and ability to work. Changes in climate can put pressure on human capital in a number of ways. Significant changes in rainfall can put pressure on food supplies and may cause hunger, sickness or fatigue (Working Group 2005; Ziervogel & Calder 2003). Increased rainfall may lead to disease epidemics – for example, cholera – or structural damage, preventing the normal functioning of institutions such as schools or clinics. Drought or floods will exacerbate these impacts. Furthermore, changing weather patterns leave people unable to utilize their existing knowledge and experience – especially in the case of agricultural activities (Archer 2006; Ziervogel & Calder 2003). Persistent droughts may encourage labour migration (Ziervogel & Calder 2003).

- *Natural resource stocks* include people's access to and use of soils, biodiversity, crops and rangelands. These are often the first form of capital to be affected by climate change. Typically, increased or decreased rainfall will lead to a loss of crops, change in rangeland conditions and soil productivity, and may even encourage pests to proliferate. Decreased rainfall may prevent seeds from germinating, and reduce the amount of fodder and water available for livestock (Working Group 2005). Disrupted rainfall patterns may affect the crop maturing periods and lead to lower yields, while also reducing the amount of resources available for crafts such as thatching and weaving. In some instances, people may turn to the gathering of wild foods for sustenance, though these are also impacted by climate variability (Ziervogel & Calder 2003). Again, drought and floods will exacerbate these impacts, while also increasing affected communities' levels of vulnerability in the future (Khandlela & May 2006). Yet gradual change can also cause problems if not properly adapted to. Trends that are slow to emerge may promote disregard for resilience components (both social and ecological) until it is too late – for example, the steady depletion of fish stocks leads to their increased vulnerability to shocks (Adger *et al.* 2005).

- *Social resources* include kinship and support networks, and the ability and willingness to engage in knowledge-sharing. People draw on a plethora of social resources in pursuit of their livelihood objectives, especially in times of hardship. Knowledge sharing can help to identify gaps and changes and develop adaptation options, even when planning is difficult due to uncertain weather patterns (Archer, in press; Taylor 2006). While kinship networks are important during extreme events, relocation may be the only option, which will eventually weaken these safety nets (Khandlela & May 2006 and Ziervogel & Calder 2003). On the other hand, persistent drought may encourage community mobilisation, for example to reduce soil degradation (Archer, in press).

- *Physical capital* includes buildings, roads, water distribution networks and so on. When climate change results in decreased financial resources, it may make transport unaffordable (Working Group 2005). Furthermore, drought can affect the structure of the roads, complicating transport (Archer 2006). Perhaps most significantly, flooding will have a direct impact on dwellings, roads and other infrastructure. Dwellings can be lost completely, and surviving structures may become overcrowded as people seek shelter. Meanwhile rebuilding can be a temporary measure that results in further vulnerability in the future (Khandlela & May 2006; ActionAid International 2006).

Livelihood activities include: production and income; consumption; and processing and exchange. The first of these, production and income, is thought to be considerably vulnerable to climate change in the following ways:

- Increased or decreased rainfall can impact on rangelands and cattle health which can lead to the selling of livestock (Working Group 2005);
- High variability in rainfall and a change in rainfall patterns make it hard to manage irrigation and plan for market demands which impacts profit (Ziervogel *et al.* 2006);
- Drought and the inability to farm as normal may prompt households to find other sources of income, either through migrating for work (eg from rural to urban areas) or through other projects such as making bricks, sewing, selling firewood, etc (Working Group 2005; Ziervogel & Calder 2003).
- Increased rainfall can require improved shelter for livestock and fodder store in a dry place (Working Group 2005).
- Decreased rainfall can lead to diversification of agricultural practices, including: increasing the amount of irrigated land or finding new locations, sometimes on more marginal land; growing indigenous species; cutting plants to higher stem level; harvesting less often to prevent nutrient depletion; using local

techniques to decrease wind erosion (eg mulch strips for shelter belts of natural vegetation); and planting drought-resistant yellow maize, late-maturing fruit trees and winter crops (*ibid* 2005; Taylor 2006).

- Decreased rainfall will also increase the need to store fodder for livestock or use alternatives (eg maize stalks) (Working Group 2005) and require increased food storage for human consumption.
- More frequent droughts will encourage water conservation, altered ground preparation and harvesting times, wind erosion prevention measures, supplemental feed and water provision to livestock and the shifting of livestock to land with higher carrying capacity (Taylor 2006).

Much of the above discussion has focused on rural livelihoods, but in South Africa the impacts on urban livelihoods also require consideration, due to trends towards urbanization, particularly by the poor. Climate change is likely to affect resources relevant to the poor in urban settings such as water infrastructure through storm damage and heat stress, services such as sewage and refuse, health, through air pollution and diseases such as malaria and cholera and disasters such as fires and flood recovery (Midgley *et al*.2005).

Some risks are particularly specific to their location. The Cape Flats area, for example, is dominated by households with low socio-economic status, and has a high incidence of "shack fires" (Figure 3.6.1). Households in these areas have limited capacity to respond to fire, in terms of access to services and in terms of capacity to rebuild livelihoods after the devastation. Fires are often due to negligence, or even arson (MacGregor *et al*. 2005), and hot summer temperatures and high winds appear to have increased severity of fires (Dudzai 2005; Disaster Mitigation for Sustainable Development Programme (DiMP) 2004). Given that the link between weather, climate and fires is strong, it is important to consider how a change in climate and weather might impact urban areas, particularly when the biggest impact is often in informal areas.

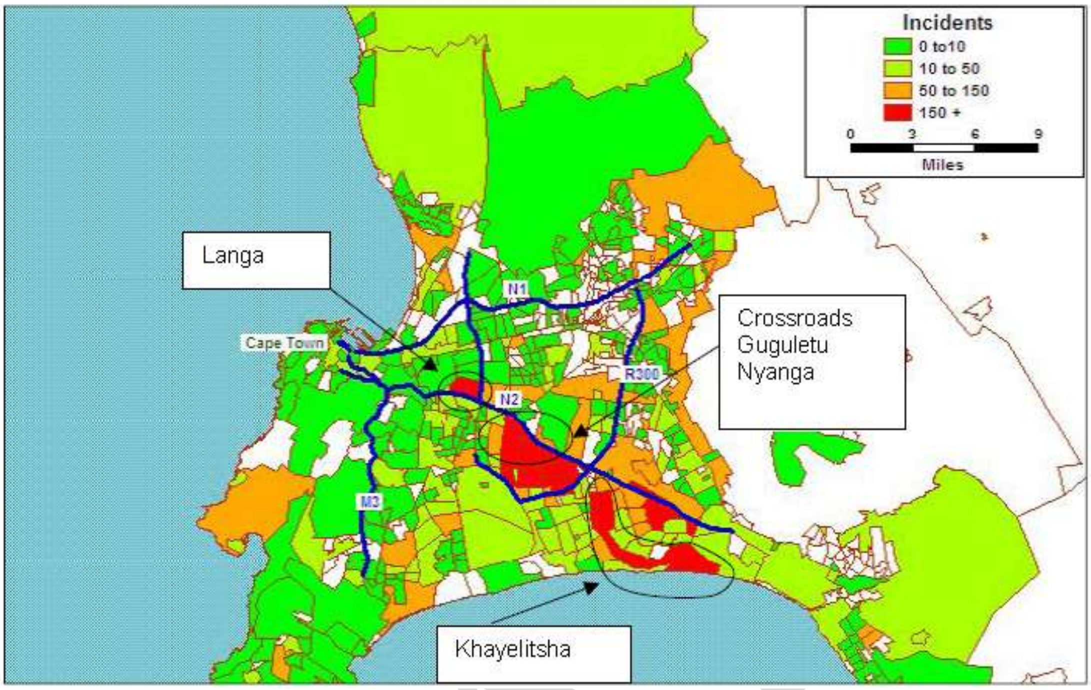


Figure 3.6.1: The total number of informal dwellings affected by fire in the City of Cape Town (1990 to 2004) (Source: Pelling 2007)

Current vulnerabilities to floods and fires in informal settlements are exacerbated by a location in flood- and ponding-prone areas, the use of inferior building materials, structures built on sand dunes, and inadequate road access for emergency vehicles (e.g. Holloway & Roomaney 2008). The convergence of intensifying weather events with rapidly expanding informal settlements has generated new challenges for development planning, disaster risk management and climate change adaptation. New flood risk configurations that are not easily studied with conventional flood hydrology methods have recently been identified in informal settlements (Holloway & Roomaney 2008; Benjamin 2008). These include distinct forms of localised flood exposure - ponding, overland surface run-off, upwelling (seepage or ‘rising flood’), riverine/stream flooding, wetland flooding, overtopping of stormwater channels and rain leakage into houses. The costs of flooding often exceed households’ average monthly income, which exacerbates the impacts. While those living in informal dwellings reported an average monthly income of approximately R 1 000, for instance, their average expenditure was almost R 900, leaving little spare money for replacing or repairing damaged property (DiMP 2007). This is made worse by the fact that many households have experienced repeated losses from multiple extreme weather events since 2003. For these households, losses of even a few hundred rand can progressively increase their vulnerability to the effects of flooding and other hazards.

3.6.2 Observed trends, projections and future risks

There has been a dearth of research that addresses the links between social trends and climate change, if any, and as a result very little is known about this topic. There is limited evidence that there may be a gender and age bias in those affected by severe weather events, with households headed by women the worst affected. Interviews and field observations suggest that women over the age of 50, particularly those with young children or grandchildren, tend to be the most vulnerable. These households reported very low household incomes, and could only afford the cheapest building materials and building sites. The number of such households is rising throughout South Africa, largely as a result of HIV/AIDS, suggesting gender and age will become increasingly important in assessing and responding to risk in South Africa.

There has been remarkably little comprehensive and integrated modelling of future projections and risks for human livelihoods in urban and rural settlements. A significant effort will be required to expand the application of modelled projections of future risk from simple impacts analysis in the three major urban centers that have addressed this issue (at varying levels of complexity), as well as better understanding of the current configuration of risks to derive an integrated view of the implications for human livelihoods.

3.6.3 Adaptation options and actions underway

Possible adaptations that can reduce the risks posed by climate change to people's livelihoods are emerging in South Africa. Planning that will incorporate potential climate change has been initiated in major cities, using the learning from recent climate-related disasters and building on existing legislative and administrative frameworks. At the same time, moves are afoot to establish disaster management centres and to improve forecasting and early warning systems. Some of these initiatives are outlined briefly here.

Some municipalities have begun to make the critical links between climate risks, climate change adaptation and planning. Efforts to better prepare coastal cities for climate change are also being undertaken, assisted by advances in research on storm surges and other developments in marine science. A number of climate change adaptation plans and strategies are in the process of being developed or in the early phases of implementation (Box 1). In many cases, however, current climate change-related planning activities are largely focused on mitigation-type actions that do not expressly consider potential adaptation benefits (e.g. energy efficient light bulbs, solar hot water geyser installations).

Box 1: Examples of local and provincial scale adaptation planning to climate change

In the *City of Cape Town,* an overarching framework and adaptation plan for climate change, that outlines a theoretical municipal-level approach to adapting to climate impacts and prioritizing intervention, has been outlined (Mukheibir & Ziervogel 2007; Department of Environmental Affairs & Development Planning 2008). This has been followed up by other initiatives including a Climate Change Think Tank addressing both adaptation and mitigation issues. Over the last few years, detailed disaster loss inventories have been compiled and supported by a better understanding of climate risks, particularly for informal settlements.

For *Durban (eThekwini)*, a comprehensive climate change adaptation planning effort has been undertaken (Roberts 2008), and a 'climate future' for Durban has been outlined (CSIR Environmentek 2006). Adaptation options per sector have been identified, including the need for public education, community response programmes, increased water efficiency, promotion of integrated water catchment management, recycling sewage improving urban drainage systems, and road and other infrastructural planning (CSIR Environmentek 2006). A Municipal Climate Protection Programme has been developed, and it includes capacity-building at the local level and the execution of some activities across sectors, particularly where these may impact on strategic planning. The City's Open Space System Plan is, for example, being remapped to include a climate-proofing element. New departmental structures(e.g. a branch in the Environmental Management Department) have also been created to deal with climate change.

The *City of Johannesburg* has recently called for a vulnerability assessment and an adaptation strategy (WSP 2009). Recent adaptation planning assessments for the City of Johannesburg show that local climate is likely to become both significantly hotter and more humid in future. There is also a risk that rainfall may be characterized by a higher frequency of storm events and a longer rainy season (these assessments were based on seven General Circulation Models; WSP 2009). Overall a moderate but significant increase in precipitation by the near-future (mid-century), with a possible lengthening of the rainy season and a possible increase in storm events is noted (WSP 2009). The impacts on various sectors including local communities, bulk infrastructure etc. are also outlined.

The *Western Cape Climate Change Response Strategy and Action Plan* of 2008 (http:www.capegateway.gov.za/eng/your_gov/406/pubs/public_info/W/162981) describes four key areas for cross-sectoral action in response to climate change, three of which are related to adaptation and one to mitigation responses.

Assigning responsibility and resources for implementing adaptation efforts remains a challenge. In Durban, for example, it was initially noted that "little internal institutional momentum and knowledge" is being built around climate change (Roberts 2008). Subsequently, efforts made to purposively build a meaningful appreciation of climate change science has meant greater uptake of the need to mainstream climate change and adaptation into planning including a range of users (e.g. Roberts 2008; Stuart-Hill & Schulze 2010).

Various existing planning frameworks and legislation can be used to enhance adaptation to climate change without creating new and additional activities. Integrated Environmental Management and Environmental Management Frameworks, Corporate Social Responsibility, Integrated Water Resource Management (IWRM), and Disaster Risk Reduction can all provide frameworks within which adaptation options can be evaluated (Schulze 2008; Vogel *et al*. 2010; Holloway *et al*. 2010). Numerous insights on adaptation to increasing climate variability can be usefully derived from the disaster risk reduction domain. For example, detailed studies of the effects of severe storms and associated flood events provide valuable insights on critical risk factors, and their associated causal pathways, that generate loss.

Similarly, they can also highlight useful potential adaptive strategies, including infrastructural and technological adaptation, that are centrally relevant to the management of climate variability and broader climate risks. One such area is in Early Warning Systems and planning (e.g. Klopper *et al*. 2005; Vogel & O'Brien 2006, DiMP 2003, 2005, 2007, and 2010; Holloway *et al*. 2010). Since the promulgation of the Disaster Management Act (2002), several Disaster Management Plans have been completed. For example, an Agricultural Drought Management Plan draws attention to various risk-reduction activities (van Zyl 2008). These are reflected especially in the finalization and implementation of the National Disaster Management Framework (Republic of South Africa 2005) and priority guidelines, both of which placed explicit emphasis on developmental risk reduction.

By 2008, institutional progress was specifically reflected in the establishment of fully functional provincial disaster management centres in five provinces – the Eastern and Western Cape, the Free State, Gauteng and Limpopo (Department of Provincial and Local Government (DPLG) 2008). In addition to these, some detailed studies on disaster loss costing and inventories have been undertaken, but much remains to be learnt.

A variety of efforts to improve early warning systems is underway. The development of the South African Risk and Vulnerability Atlas (SARVA) may generate useful data and tools for municipalities and rural settlements to become more active in adaptation planning.

A National Forecasting Centre, based in Pretoria is responsible for guidance on potential hazardous weather of a general and maritime nature, seven days in advance. The National Forecasting Centre also interacts closely with the National Disaster Management Centre in Pretoria and the flood forecasting room of the Department of Water Affairs. The Aviation Weather Centre operates on a 24-hr basis, and Regional Forecasting Offices liaise directly with the Provincial and Municipal Disaster Management Centre's Innovation and Research Division, which provides research and enhancement of early warning systems. Longer-term (seasonal) climate forecast outlooks are also being developed.

As part of the requirements of the Disaster Management Act, the South African Weather Service has completed a Disaster Risk Management Plan (South African Weather Service 2006). The institutional structure for weather and climate-related early warning systems has already been planned and includes a network of forecasting offices. The process of implementing a fully-fledged Severe Weather Warning System (an 'end-to-end' system; see Poolman *et al*. 2008) is also underway. The Weather Service's Severe Weather System, covers weather events that are experienced regularly in the country and if not managed in a timely manner can result in severe impacts.

Warning or advice from the Weather Service are being offered in various formats, including an *advisory* (providing early warning of hazardous weather in a >3 *days period*; an advisory and *watch* – weather likely to deteriorate to hazardous levels (2-3 *days period*) and finally a *warning* to take action when a hazardous event linked to weather changes is likely to occur in the *next 24 hours*. Various products are being designed, including web-based maps of warning and easily accessible information (e.g. colour-coded warnings; Poolman *et al*. 2008; Poolman 2010). Such systems are key elements of an overarching climate change adaptation system.

3.7 Human health

3.7.1 Current vulnerabilities

Climate variability and human health: Climatic perturbations are injurious to humans either directly (eg. through heat stress) or indirectly (by affecting floods, fires, and ecosystem services), leading to changes in the epidemiology or emergence of infectious diseases and famines, and ultimately to displacement and conflict (Butler & Harley 2010; Burke *et al.*2009; Smith *et al.*2009). A significant proportion of South Africans already have serious and complex health challenges which are compounded in dense informal settlements. These constitute a unique disease complex comprised of the highest global prevalence of Human Immunodeficiency Virus (HIV) and Tuberculosis (TB), complicated by waterborne and chronic respiratory disease, with children being particularly prone (Bradshaw, *et al*. 2003). Underpinning these conditions are the common denominators of malnutrition, poor indoor air quality and lack of social amenities. Acquired Immune Deficiency Syndrome (AIDS) caused by HIV and TB now account for about 75% of premature-deaths in South Africa (Harrison 2009). In particular sections of the country the threat of expanding vector-borne diseases like Malaria, Rift Valley Fever and Schistosomiasis are an ever-present reality, requiring concerted public health initiatives. Any new compounding factor such as unpredictable weather patterns and climate aberrations will have significant impact on this vulnerable sector of society, further aggravating the depth of poverty, food insecurity and demographic imbalances (Gommes *et al.*2004). It is most likely that the emerging infectious diseases that plague the region have already resulted from decades of changing weather patterns and delinquency with regard to good environmental practices. It is not generally recognised that under-nutrition and socio-economic stress are important contributors to poor human resilience and the creation of the perfect milieu for the emergence and propagation of disease (McMichael *et al.* 2008a).

Nutrition: Protein Energy Malnutrition (PEM) lowers immunity and predisposes people to infection. Evidence now clearly demonstrates that any person with an infection has a significantly higher protein and calorie requirement. Populations with a high prevalence of PEM (as in Southern Africa) are likely to be more prone to be infected by the multiplicity of tropical infectious diseases in the environment (de Waal & Whitehead 2003), due to an inability to mount an immune response to the invading organism (Chatraw *et al.*2008). Furthermore, infection in this setting of PEM, compounds the situation and causes further deterioration of the existing nutritional status, ushering in a vicious cycle of progressive malnutrition, fading immune status and super infections or even death (Macallan 2009). The combined effect of malnutrition and infection are profoundly synergistic and lead to metabolic effects that cannot be rectified by antimicrobial treatment alone and must incorporate nutrient replacement strategies (Fawzi *et al.*2005). Increased oxidative stress and micronutrient mineral deficiency have been implicated in this process and should receive equal attention. Children are particularly prone to the effects of PEM because it causes the thymus gland to become involuted in early development. Furthermore, infection in childhood requires higher supplementation with protein and calories (Keusch 2003). These trends demonstrate the profound relationship between environment, food security and the infection profile of a community and region. The evidence is that sub Saharan Africa, which has the world's highest burden of infectious disease, is the only region showing a growing proportion of undernourished populations predisposed to infection and death (Ambrus & Ambrus 2004). This can be attributed to many socio-political factors, but certainly abnormal weather patterns as far back as the 1970s have been responsible for declining food security in the whole region. In the context of a worsening AIDS epidemic, it becomes easy to see how under-nutrition facilitates the acquisition and spread of infection and at the same time the resulting chronic ill health, leading to further threats to food output and security. This complex is referred to as the new variant famine in Southern Africa (de Waal & Whitehead 2003). In some locations like South Africa where food is not technically in short production, adequate nutrition is not be accessible to the populations most vulnerable to PEM, who depend on rain fed agricultural traditional systems for subsistence. Macro-economic reasons amongst other factors associated with a heterogeneously diverse economic landscape are responsible for this dichotomy (SADB 2008; de Waal & Whitehead 2003; McMichael *et al.*2008a).

HIV/AIDS: HIV is now the largest health burden confronting South Africans. With national average prevalence rates of 10 to 15%, it threatens to wipe out the economic, social and developmental gains achieved in the last century (Harrison 2009, UNAIDS 2008 country reports). It is now consuming a large proportion of the health budget in South Africa, with attempts to implement Anti Retroviral Therapy (ARV) and support to the estimated 5.7 million people living with HIV/AIDS. The HIV epidemic has reduced life expectancy from 52 years in 1997 to 43 years in 2007.

South-Africa is home to the world's largest population of AIDS sufferers and just over a quarter of a million are under the age of 15. AIDS has to-date resulted in the deaths of at least 2.6 million South-Africans, mostly children under the age of five and young-adults (Harrison 2009; Avert 2010). Over 250,000 South-Africans died of AIDS in 2008 (Statistics South-Africa 2009). HIV/AIDS is projected to account for about 75% of premature deaths in South Africa in 2010, up from 39% a decade ago (Bradshaw *et al.*2008). There are 1.4 million AIDS-orphans in South-Africa (UNAIDS 2008). Almost one third of women aged 25-29 and over a quarter of men aged 30-34 are living with HIV (Harrison 2009).

Tuberculosis: Between 6 and 10 millions South-Africans are infected with *Myobacterium tuberculosis* – a bacterium that causes tuberculosis (TB). As a result of HIV and living conditions, TB is going through an unprecedented resurgence in South Africa (Harrison 2009). TB is spread from infected persons to vulnerable persons in close proximity by airborne TB laden droplets produced by aerosols that are generated by coughing. TB spread is facilitated by poor ventilation such as occurs in congested living conditions in shanty towns and houses, and by underlying lung injury. It is estimated that the small vaporized droplets of less than 2 microns produced by coughing can remain suspended for up to 4 hours in a confined unventilated area. When breathed in by uninfected persons, these droplets are capable of penetrating to the smallest unit of the lungs where they multiply, creating the highest chance of causing active disease transmission in human beings and particularly if factors in the community promote reduced immunity. Thus hot, overcrowded and confined living conditions with indoor pollution in the setting of malnutrition and HIV are the perfect scenario for continued spread and new infections (Gommes *et al.*2004; McMichael *et al.*2008a). Six percent of re-treated TB cases and 1% of new cases are multi-drug-resistant (DoH 2008), which translates to over 9,000 cases in 2008/2009. National estimates for the prevalence of multi-drug-resistant TB are between 2 and 6% and present in all nine provinces (Coetzee & Koornhof 2006; Gandhi *et al.*2006; DoH 2008; Andrews *et al.* 2005).

Direct physical temperature stress: Temperature-related adverse effects are associated both with high and cold temperatures. These effects exhibit spatial and temporal variability across regions. The elderly, children, and those with pre-existing ill health such as respiratory, cardiovascular and mental illness, as well as those with a poor

socioeconomic profile are especially vulnerable (Bambrick *et al.* 2008). Most human beings function comfortably at environmental temperatures between 17°C and 31°C (McMichael *et al*. 2008b). Hyperthermia in healthy human beings, as a result of abnormal climatic conditions, is restricted to a combination of ambient temperatures (Ta) exceeding 34°C and 100% relative humidity. In the absence of corrective measures, dehydration and multi-organ instability will ensue with profound risk of exhaustion, ill health and death within a short time under such conditions. Data from South Africa over 4 decades indicate that the number of hotter days and nights are increasing, especially in the interior, while cooler days and nights are decreasing, suggesting that warming may result in increased casualties from heat stress.
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Water and wind-induced weather-related events: The health impacts of catastrophic and extreme weather events (storms, flooding and cyclones) are well known. These high-impact, low-frequency weather patterns are estimated to have a twenty-fold higher impact in under-resourced countries, because they lack the preparedness and resources to cope, compared to developed nations. Disaster occurs when a climate hazard converges with a vulnerable population, and severe structural damage and social disruption can ensue which can result in profound psychological impact and behavioural changes when trying to cope. Some of the main factors driving or shaping vulnerabilities are population growth and concentration in high risk areas or informal settlements, poverty and environmental degradation. These events lead to immediate traumatic injury, death, pain and suffering. There is great risk of environmental pollution, social dislocation and infectious epidemics during such catastrophic events (DEAT 2007b)

Waterborne diseases: Waterborne infectious diseases are any illness caused by the consumption or usage of water, either contaminated with human and animal faeces, or water from sources where pathogens can survive and grow independent of a human host. These conditions have a close association with aberrant weather patterns and disaster situations which can have long-term socio-dynamic consequences (McMichael *et al.*2008a). Typical waterborne infectious disease pathogens include bacteria, viruses and protozoans. Cholera characterised by profound diarrhoea and vomiting is caused by a bacterium (*Vibrio cholerae*) and dysentery (i.e. intense diarrhoea with bloody mucous faeces) is most commonly caused by one of two different organisms, i.e. either a bacterium (Shigella) or an amoeba. Waterborne infectious diseases pose an acute problem in areas where populations are expanding and the water supply and sanitation infrastructure is either rudimentary or non-existent (eThekwini CC Study 2008).

On average about 4 billion cases of diarrhoea are reported globally every year (UNICEF 2005). Currently diarrhoeal diseases, including cholera, are the leading cause of morbidity and the second most common cause of death among children under 5 years of age in the world (UNICEF/WHO 2009). The most common waterborne infectious diseases in South Africa include cholera, dysentery, typhoid and other rotavirus infections. There is medium to high confidence that climate change directly or indirectly affects factors that influence outbreaks of these waterborne diseases in the long term, and can shift the timing and duration of such on an inter- and intra-annual basis.

The links between weather and diseases are well established, as many diseases are seasonal or occur during or after un-seasonal extreme events such as floods or droughts (Patz 2002). Studies in China also showed a strong association for example between the transmission dynamics of dysentery diseases and weather variability (Huang *et al.* 2008). It is however difficult to establish a link between long-term climate change and environmental related diseases, because of the lack of sufficiently long and well-documented health data, recorded at appropriate spatial and temporal scales. Strong confounding factors such as human migration and travel patterns, erratic intervention strategies, emerging drug resistance, demographic changes in the human population, development of immunity in the human population (to name a few) also contribute to the complexity of disentangling climate-related drivers from other drivers or confounding factors (Patz 2002; Koelle & Pascual 2004; Koelle *et al.* 2005). There is some quantitative evidence for an increased role of inter-annual climate variability on the temporal dynamics of cholera (Rodo *et al.* 2002). This study provided the first quantitative evidence for the link between the El Niño/Southern Oscillation (ENSO), regarded as the strongest naturally occurring source of climate variability around the globe with the exception of seasonal variability, and cholera outbreaks. The study was based on one of the longest available health data sets (from Bangladesh for 1893-2001). A strong and consistent ENSO signature for the period 1980-2001 explained 70% of the variance in the disease data.

Exploitable water supplies in South Africa are confined to rivers, artificial impoundments, and groundwater. The total capacity of impoundments amounts to more than 50 per cent of South Africa's total average annual river runoff (Oberholster *et al.*2005, Wilson *et al.*2005). Urban complexes and farmland run off in South Africa generate large amounts of sewage and effluents that are high in salts, phosphates and nitrates stimulating growth of algae including cyanobacteria, leading to accelerated eutrophication. Toxic cyanobacteria blooms (*Microcystis aeruginosa* is the most common in South Africa) produce more than 65 biotoxins as a protection mechanism against fresh water herbivory by filter feeders and pose a significant health threat to the food chain.

Air quality: Human-generated emissions affect air quality and subsequently human health. Exposure to air pollutants, such as particulate matter, sulphur dioxide, ozone and nitrogen dioxide, is associated with a depressed immune system and cardio-respiratory morbidity and mortality (Pope *et al.*2002; Brook 2004). A significant air-related health effect of pollution is in relation to the ozone, particulate matter (PM) and brown haze content of the tropospheric or near-surface level, especially in urban areas, all resulting from fossil fuels. Ozone, even at relatively low levels, when inhaled has been associated with pulmonary damage and asthma attacks (Mittal *et al.* 2007). The size of the particulate matter (PM) in air suspension, determines its capacity aerodynamically to be inhaled and to penetrate the lungs, either causing local damage to the lungs or being able to penetrate into the circulation. These sizes range from the largest at PM10 (10 µm) to the smallest ultrafine particles (UFPs) (0.1 µm) in diameter, which result mainly from combustion processes. UFPs demonstrate very high capacity to penetrate and deposit deep in human lungs and alveoli, potentially leading to enhanced biological toxicity. UFPs may even be able to pass directly through the lung lining into the blood, which could allow them to be disseminated systemically with profound systemic effect (Brook, 2004). All these pollutants http://circ.ahajournals.org/cgi/content/full/109/21/2655?ijkey=ac7b96b37346ed091be531cb5c34ea3c237874d1 - R29-148593#R29-148593http://circ.ahajournals.org/cgi/content/full/109/21/2655?ijkey=ac7b96b37346ed091be531cb5c34ea3c237874d1 - R30-148593#R30-148593 are dependant on, amongst others factors, meteorology and the relationship and dynamics of the planetary boundary layers. Therefore, changes in meteorology will lead to potential changes in the particulate matter concentrations. In particular, precipitation acts as the main sink for particulate matter (Jacob and Winner 2009). Stagnant air episodes occur primarily in winter, when inversion conditions occur, trapping pollutants and increasing their concentrations. The air pollution only disappears when the inversion is broken up by wind, rain or the warming effect of the sun. Climate change projections may possibly impact on the number and intensity of air pollution events (Midgley *et al*. 2005, CSAG).

Malaria: The malaria parasite, principally *falciparum* is transmitted by the *Anopheles* mosquito, which breeds in stagnant pools of water in warm and humid environments. It is believed that malaria causes over 500 million infections a year world wide, resulting in about a million deaths. Of these 91% are in Africa and 85% are children under the age of 5 years (WHO 2008, AR4, SACSCC Malaria report). While models and some observations in key locations support a potential risk for malaria resurgence, observation and data suggest that this has not been manifest in the last decade (Thompson *et al*. 2005; Rogers 2002; Ledford 2010). Malaria transmission rates can be classified as follows:

- Perennially endemic: Conditions suitable for transmission all year round.
- Seasonally endemic: Transmission occurs yearly but on a seasonal basis.
- Epidemic: Transmission occurs from time to time based of prevailing factors but not every year.
- Malaria free: Conditions unsuitable for transmission at any time.

In perennially and seasonally endemic zones, residents will have high levels of immunity within the community, while in the other zones, communal immunity will be weak or absent, and these populations will be susceptible to increased mortality from lack of immunity, public knowledge, slow response times and lack of preparedness by medical services, resulting in serious complications should unexpected epidemics of malaria occur. These regions of potential malaria epidemics are a predominant concern (SACSCC Malaria report). Human transmission is a complex interplay between vector and parasite densities, vector behaviour, land use, public health activities, human immunological status and drug use policies (Small *et al.* 2003, WHO EPR). A retrospective study of the trends over the last 90 years showed that most of Africa has had a relatively stable transmission index, but about 5% of the continent showed increased transmission, driven mainly by increased precipitation, and not temperature. Mozambique bordering with South Africa was mainly affected (Thompson *et al.* 2006, Small *et al.* 2003), but a concerted cross-border prevention program has offset the trend.

Malaria-HIV interactions: Malaria and HIV have considerable geographic overlap in Africa (WHO 2004). Persons with HIV suffer increased frequency and severity of malaria attacks, and during such episodes elevated HIV viral load levels increases the risk of sexual transmission of HIV (Whitworth *et al*. 2000, Whitworth & Hewitt 2005, Abu-Raddad, *et al.* 2006, Froebel *et al*. 2004). Therefore Malaria not only increases the morbidity and mortality in people living with HIV, but also the transmissibility, accelerating progress of HIV in a community (Menan *et al. 2*001). Modelling has suggested that the 4 million population at risk of dual infection with HIV and Malaria in the Limpopo area, (Sharp *et al.* 2007), could have resulted in > 170,000 HIV infections attributable to co-infection with malaria since the 1980s and about 2 million excess cases of malaria per year. Recent significant decline in malaria cases in the Limpopo area due to adaptive measures may have mitigated this scenario (Abu-Raddad, *et al. 2*006).

3.7.2 Trends and projections

HIV/AIDS: The HIV prevalence among people older than 2 has stabilised at about 11%, and is likely to remain there for at least five years (Scott & Harrison 2009). Women show a sustained rise from 5% in the late teens reaching a peak of above 30% by 29 years of age and subsequently reverting to about 5% in 55-59 year olds. In men the prevalence starts later at 5% in 20-24 year olds reaching peak levels of 25% in 30-34 year olds. The prevalence of HIV has now peaked in South-Africa (reviewed by Harrison 2009 and Avert 2010). There are indications of significant declines among young people. Child mortality has probably also peaked and should decline further with increasing availability of treatment. The decline in prevalence in younger age groups is linked to better access to prevention of mother- to- child transmission, and much higher self- reported condom-use. The number of people living with HIV who now need to be recruited into the expanded antiretroviral program is estimated at 2.25 million, increasing to 2.75 million by 2012 (Walensky *et al*. 2008). People living in informal-settlements have the highest rates of HIV infection (~ 20% in the urban-informal compared to ~ 10% in rural-formal, informal and urban-formal settings). Fragmentation of urban-transition, rural/urban and regional migration patterns for economic or climatic reasons creates the conditions and vulnerabilities that fuel the spread of HIV. Some coping mechanisms identified during environmental stresses like drought and floods are environmental desecration, migration, prostitution and dispatching children away to relatives in distant locations. Large populations in crowded high density and informal settlements with poor amenities will drive social interaction epidemics such as HIV and TB to new levels, while also contributing to crime and drug abuse in the setting of poverty and unemployment. Lack of organized infrastructure in these localities will result in increasing indoor and outdoor air, water and environmental pollution further aggravating those produced by motorization and industry (Gommes *et al*. 2004; McMichael *et al*.2008a).

Tuberculosis: The incidence of smear-positive tuberculosis has increased by between 200 and 300 new cases per 100,000 population annually in the presence of HIV. This does not take into account the numerous smear-negative patients that form a significant number of HIV positive co-infected cases. It is in this setting that drug resistant TB is set to become a major health issue.

Waterborne diseases: The first confirmed case of cholera in South Africa was reported in 1973 (Mugero & Hoque 2001), and the first major outbreak started in 1980, peaked in1982/1983 and ended in 1988, during which > 25 200 cases were reported (Küstner & Du Plessis 1991). A few cases were reported for some years during the 1990's until a devastating outbreak started in South Africa in 2000, in which nearly 146,000 cholera cases were reported between 2000 and 2005 (WHO, Weekly Epidemiological Reports on cholera: 2001, 2002, 2003, 2004, 2005 and 2006). No cases were reported for 2006 and 2007 until the most recent outbreak in November 2008. The introduction of the bacteria into South African water sources by people who contracted the disease somewhere else seems very likely. Favourable environmental conditions in the areas can support the bacteria's ability to persist in the water bodies for at least a couple of months after introduction.

Cholera: Africa had 94% (179 323) of global cholera cases in 2008, (WHO 2009), 12 752 of which were in South Africa (OCHA 2009). It is however not clear whether the bacteria responsible for the outbreaks are endemic in water bodies in South Africa (Keddy *et al*. 2007). The 'theoretical' cost of the outbreak in 2008/2009 in South Africa ranges between 40 and 67 million rands (Kirigia *et al*. 2009). A similar outbreak to that of 2000 to 2004 could be financially devastating.

South Africa is at risk of further cholera outbreaks due to 1) its history of cholera outbreaks, 2) its proximity to areas where the bacteria are known to be endemic, 3) the movement of people between these areas and South Africa, 4) the number of poor people dependent on natural water, and 5) environmental conditions conducive to the survival and growth of the bacteria, including hot rainy summers, droughts, estuaries and port cities (i.e. the bacterium can be imported from infected areas by means of ballast water). Communities in areas with no or limited access to safe water supplies and sanitation, poor or limited health infrastructure and medical and health personnel coupled with other existing endemic disease burdens, unfavourable socio-economic and environmental conditions will always be at risk of cholera outbreaks. Overcrowding plays an important role in the rate of spread of the disease (Collins 1996; Lucas *et al*. 2005; Soto 2009).

Air Quality: Based on the IPCC A2 emission scenario projections for the 1990 base year, South Africa falls within the 60 parts per billion (ppb) global ozone in summer. By 2030, projections indicate growth in the spatial extent of ozone coverage and increases in concentrations greater than 60 ppb, particularly in Europe and North America. The 2100 projection also suggests that most of the highly populated areas in the Southern Hemisphere will be within the 60 ppb contour (Anderson *et al*. 2001). In addition, places prone to bushfires, which are common in South Africa (Carter *et al*. 2008), are also set to experience increases in ground-level ozone (Liao *et al*. 2006) and particulate matter concentrations (Maenhaut *et al*. 1996). Bushfires are projected to increase in both intensity and occurrence in parts of South Africa, with the potential for increased particulate matter and ozone precursor gases.

Malaria: Several predictive models incorporating climate change scenarios have been developed, but none take the complex relationship between people, environment, vector and parasite into account (SACSCC malaria report). Predictions suggested an increase in the range of the malaria zone along South Africa's northeast borders, affecting the most vulnerable non-immune population. The predicted four-fold increase in populations susceptible to malaria in South Africa would translate to a cost burden of R1 billion rand per year by 2010 if no adaptive strategies were adopted (SACSCC). These predictions had not materialised by 2008, with the Department of Health (DoH) citing increasing success in the fight against malaria, with 60% decrease in case load reports compared to pervious years (DoH 2007 Malaria day reports; Ledford, 2010). However, the observed drying but warming tendency over the last 50 years needs to be taken into account.

3.7.3 Adaptation

HIV/AIDS: Despite a national policy for initiating antiretroviral (ARV) treatment at a CD4 count of 200/µl (the CD4 blood count measures the damage to the immune system, and is used to trigger various treatment strategies), most HIV sufferers are starting ARV therapy at counts which are less than 100/µl (Avert 2010). Furthermore, the ARV program currently only reaches 30% of sufferers. This reflects inadequate identification of sufferers and poor follow-up and recruitment, which may be related to issues of stigma and lack of information. The consequence of this late commencement of ARV is poor regeneration of the immune systems, leading later to major morbidity and mortality, and eroding the initial benefits of ARVs (Abayomi 2010). There are clear immediate and long term clinical benefits to starting ARVs at a minimum CD4 count of 200/µl (Kaufmann *et al.*2005; Badri *et al.*2006) and there needs to be greater efforts to achieve the goals set by the national policies. The initiation of ARVs at a threshold of 350/microl in pregnant women has been shown to virtually eliminate vertical-transmission and is likely to be highly cost-effective (Mofenson 2009). Similarly, earlier initiation of ARV in sufferers co-infected with TB is likely to lead to significant savings (Lawn & Wood 2007). For these reasons, policy was changed on the 1st of December 2009 to expand the ARV program to pregnant women with CD4 counts ≤ 350/µl (Harrison 2009). However, for the rest of the population, all efforts should be made to commence ARVs as close to a CD4 count of 200/µl as possible. Greater efforts need to be focused on the manufacturing the ARVs in South Africa and finding more-cost effective indigenous platforms to carry out HIV testing and laboratory monitoring, as these currently account for 80% of costs of ARV programs (Cleary 2009, Kevany *et al.*2009). Government has also initiated an ambitious programme to identify all persons living with HIV, which should provide a much-needed basis for ARV programs.

Tuberculosis: TB can usually be cured by a six months regimen of treatment. However, multi-drug resistant TB requires more sophisticated and costly treatment. The emergence of this phenomenon represents a major public-health-threat in South Africa, not just to the community but also to health care providers (Lawn & Churchyard 2009). Managing TB, especially multi-drug resistant TB, requires a heightened response with a focus on earlier detection, improved patient compliance and adequate drug sensitivity profiling. Health care environments must have suitable safety features to protect both carers and other patients (Fletcher). Particular attention must be placed on minimising interruption and defaulter rates with good monitoring of smear positive conversion rates after 2 months of TB treatment as a first benchmark of good response (DoH 2009). The ability to distinguish latent quiescent infection from Active TB, particularly in HIV patients, is critical. Ground-breaking work in identifying blood tests that can rapidly make these distinctions is being carried out by South African scientists (Chegou *et al.*2009; Siyawa *et al.*2009).

Waterborne Diseases: Intervention strategies to mitigate the effect of cholera outbreaks involve short-, medium- and long-term strategies. In the short term, governments provide affected communities with safe water and medical care. The South African government focuses on the reliable supply of safe water for human consumption and sanitation facilities, and is already supplying more than 85% of people with safe water (DWEA 2009). However, the absolute number of poor people with no access to safe water is close to 1.4 million. Most of these people live in the provinces affected by cholera outbreaks, which places them at high risk. Cholera outbreaks will continue to occur especially in Africa for reasons such as endemicity, favourable climatic and environmental conditions, movement of people and socio-economic conditions, and it is impossible to eradicate the bacteria fully. According to the AR4 report, cholera outbreaks in sub-Saharan Africa are associated with floods and the increase in faecal contamination of water supplies. South Africa is and will also be at risk not only during floods but also droughts. Ideally, a reliable early warning system is needed to identify possible outbreaks, so that decision-makers and communities have adequate time to respond appropriately. In the case of freshwater algal blooms caused by *Cynobacteria*, new molecular assays, applied directly to environmental samples, provide a useful indicator that the analyzed strains have the genetic potential to produce microcystin. Detection of toxic *Microcystis aeruginosa* strains through molecular markers for biotoxins may have great use-potential in routine analysis of aquatic ecosystems. Thus, it may make water monitoring more feasible and allow the early application of corrective action before cyanobacteria blooms start to die or disintegrate. It would be of value to be able to detect early stage blooms of cyanobacteria, especially if it is on a sufficiently timely basis to implement a response plan (Oberholster *et a*l. 2009)

Air Quality: Efforts to reduce levels of some air pollutants and greenhouse gases are being made through application of more stringent emission standards and pollution control. The newly-developed South African Air Quality Information System (www.saaqis.org.za) provides all information relevant to air quality and climate change initiatives and legislation. The new National Environmental Management: Air Quality Act (Act No.39 of 2004, the AQA) addresses the air pollution issues facing the country. The AQA adopts a receiving environment approach which considers all sources of air pollution and promotes the adoption of control measures that will improve the overall ambient air quality. The National Framework on Air Quality Management (2007) provides the medium to long-term plan to improve air quality and thus meet the objectives of the AQA. The AQA requires management plans at a national, provincial and local level, and numerous cities have already developed plans. They are based on reducing air pollutants such as sulphur dioxide, particulate matter, nitrogen oxides and volatile organic compounds. Whilst the AQA and the National Framework state that air quality measures should take cognisance of climate change, there is no directive or guidance on how this can be achieved (Manahan 2004; Mitchell & Johns 1997; Leiman 2007).

Malaria: The number of malaria cases in South Africa decreased by 65%, and deaths by 73%, between 2006 and 2007 (Malaria statistics for SA 2007). A collaboration between South Africa, Mozambique and Swaziland (the Lubombo Spatial Development Initiative, LSDI) annexes populations in South Africa with the highest malaria endemicity, and covers a cross-border area of ~125,000 km^2 inhabited by about 4 million people (Sharp *et al.* 2007). LSDI was launched in October 1999 to control vectors by indoor residual spraying using DDT or Pyrethroids; to control parasite control using Artemisin-Based Combination Therapy; and to intensify surveillance, training and community advocacy. Vector density of the most incriminating species that carries the malaria parasite decreased by about 5 fold since its inception (Figure 3.7.1).

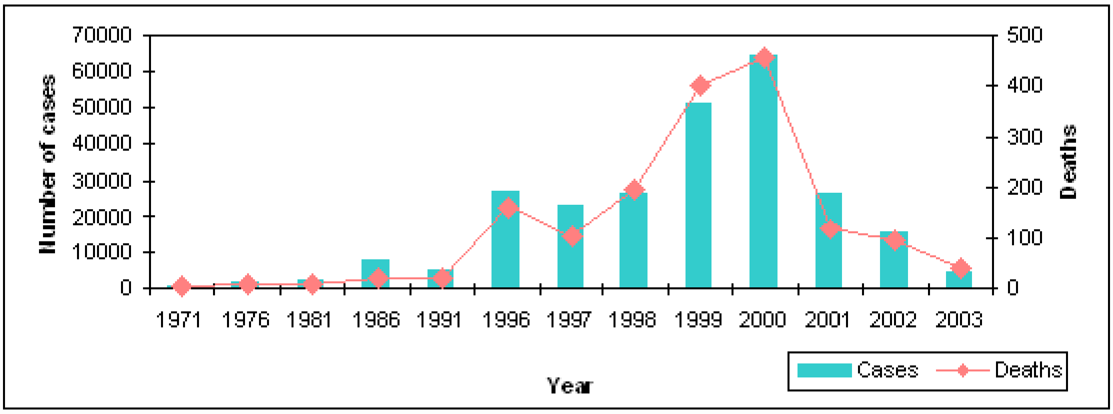

Figure 3.7.1 Annual malaria notifications, South Africa 1971-2003

These results show the significant health benefit of active control programs in these endemic zones, which may have offset the earlier predictions attributable to environmental changes (Ledford 2010).

Impact of organophosphate pesticide: The impact of DDT on human and environmental health is a major concern, but difficult to quantify. DDT is particularly feared because it is a Persisting Organic Pollutant (POP). POPs have a very long half-life and are able to accumulate in the environment, animal and human tissue for extensive periods, with serious consequences. As a result, over 140 countries have endorsed a 2001 treaty to banish a dozen of these substances from the environment. This treaty became legally binding in 2004 through a global multilateral agreement whose ultimate aim is to ban production of these chemicals (UNEP 1995; Bouwman 2004). South Africa is among a small group of countries applying for exemption from this ban because it is the most effective agent in the fight against the vector that carries the malaria parasite. The successful campaign against malaria described above is partly due to the continued use of DDT for Indoor Residual Spraying and potentially exposes up to 4 million inhabitants to sustained increased levels of this chemical. DDT levels have been shown to be significantly higher in the blood and tissues of residents whose homes were subject to spraying with DDT. Furthermore a significant association was found between DDT levels in men and quantity and quality of sperm (Aneck-Hahn *et al.*2007). There is therefore enough evidence to be highly concerned about the sustained exposure of humans and the environment to DDT (Jager *et al.*2006). The short-term gains from the use of DDT have to be appreciated in the light of long term damage and toxicity of DDT to the environment. This evidence calls into question the bio safety of the current malaria control strategy.

Nutrition and Health infrastructure: At the heart of all the health adaptation strategies lie sound nutritional policies, health care infrastructure and education. If a population's nutritional status is robust with attention to the correct balance between proteins, energy, lipid and micronutrients, then individuals will have greater resilience. More attention needs to be paid to children's nutritional status and particularly girls who will become key determinants of their future family nutritional profiles (DoH 2008). The interaction between malnutrition and infection requires focused attention to effectively combat prevailing and potentially emerging infectious epidemics (de Waal & Whitehead, 2003; Keusch 2003; Macallan 2009). Health care capacity is a key component of developmental growth and stability and central to all adaptation strategies.

Poor infrastructure and inadequate human resource is a barrier to any governmental plans for rural and urban welfare and alleviation of poverty goals. Issues of spatial location of health facilities, retention of skilled human resources, incentives to attract these resources to rural communities are all key issues that need urgent attention. At the same time regional trends to redistribute budgetary allocations mainly to primary and secondary health care service delivery should not be made at the expense of tertiary training, where indigenous research and development are the custodians of our future policies.

3.8 Preliminary cost estimates of extreme weather-related events

3.8.1 Introduction

Extreme weather-related events and associated disasters – such as storms, floods, drought and fires – may impose significant costs to South Africa annually. The impacts that result, range from infrastructure damage and death (primary affects) to logistical inefficiencies, health issues and even trauma (secondary and tertiary affects) and loss of livelihoods. Moreover, these impacts appear to be on an increasing trend (DiMP 2005) with "disaster risk and economic impact being highly concentrated in middle- and low-income countries and is felt most acutely by people living in poor rural areas and slums" (Ban Ki-moon in UNISDR 2009). A precise assessment of the national extent of these impacts and their trends is not currently possible due to a lack of robust data, and therefore this account is preliminary and indicative only. It is based on the period 2000-2009, and all estimated costs are expressed in 2008 currency terms.

The primary source of data was the Emergency Events Database (EM-DAT, http://www.emdat.be). Other data were sourced from international observatories or monitoring centers of extreme events, South Africa's National Disaster Management Center data, academic research units, such as the Disaster Mitigation for Sustainable Livelihoods Programme, Urban Geography, University of Cape Town (DiMP) and trade associations. Only those data reporting direct damage cost estimates was included in this assessment, with effort being made to ensure methodological consistency across data sources.

Although only direct (infrastructure damage) costs are included in the database and analysis, indirect (logistical and health as well as non-market impacts) effects and/or costs are estimated in accordance with conservative assumptions, and are included in the final estimate. Example case studies on wildfire damage costs and disaster costs in the Western Cape Province are included to provide further insight.

3.8.2 South African disasters and associated costs

An extreme weather-related disaster can be defined as a progressive 'slow onset' or sudden, widespread or localized, *weather related occurrence*, which causes or threatens to cause death, injury or disease, damage to property, infrastructure or the environment, disruption of the life of a community, and is of such a magnitude that it exceeds the ability of those affected by the disaster to recover using only their own resources. Below are the broadly defined types of extreme weather events that occur in South Africa.

Droughts: Traditionally defined in South Africa as a season's rainfall of 70% less than normal (Bruwer 1990), are considered progressive or 'creeping' (slow onset) disasters (DiMP 2004), as they are a temporary feature of a region felt over a period of time. In this way they are usually more widespread than localised, occurring over very large tracts of land. Over the period of investigation droughts have resulted in R1149.1 million in damage costs (Table 3.8.1; Figure 3.8.1).

Table 3.8.1. Cost estimates and mortality data for selected climate-related disasters between 2000 and 2009, for which estimates were available. WC = Western Cape, MP = Mpumalanga Province, KZN = KwaZulu/Natal, NW = Northwest, GT = Gauteng, EC = Eastern Cape, LP = Limpopo, NC = Northern Cape, FS = Free State. Data sourced from the EM-DAT database (www.emdat.be), unless indicated otherwise by footnotes.

Date	Location	Disaster Type	Estimated Direct Damage (millions of rands)	Direct Deaths
Jan-00	Cape Town, WC	Fire (Scrub)	110.4	0
Feb-00	MP, LP, KZN	Flood	1766.4	83
Nov-00	KZN	Flood	-	3
Dec-00	KZN, MP	Flood	-	7
Jul-01	Cape Town, WC	Flood[1]	468.4	0
Sep-01	NW	Fire (Scrub)	-	20
Sep-01	KZN	Fire (Scrub)	-	11
Sep-01	East and Mid Rand, GT	Storm	-	0
Dec-01	LP, MP	Flood	-	5
Feb-02	Newcastle, KZN	Storm	-	1
Apr-02	EC	Storm	0.6	0
Jul-02	WC	Fire (Scrub)	-	3
Jul-02	EC, KZN	Storm[2]	160.9	22
Aug-02	East London, EC	Flood	-	16
Sep-02	MP	Fire (Forest)[3]	-	0
Sep-02	Mapela, LP	Storm	131.1	0
Mar-03	Montagu, WC	Flood[4]	277.85	1
Jul-03	EC	Storm[5]	4.56	-
Aug-03	Cape Town, WC	Storm	-	-
Oct-03	LP, EC, FS, NC WC	Drought[3]	143	-
Feb-04	All provinces	Drought[3]	379.8	-
Aug-04	NC	Storm[3]	3.9	-
Dec-04	WC, EC	Storm[6]	72.9	-
Feb-05	All provinces	Drought[3]	626.3	-
Feb-06	NC	Flood	29.9	-
Mar-06	Taung, NW	Flood	574.7	-
Aug-06	WC, EC	Flood[7]	608.1	6
Feb-07	EC	Storm[3]	3.3	-
Jul-07	KZN, MP, EC, WC	Fires (Forest)[8]	1560.8	-
Jul-07	KZN	Flood	9.9	11
Jul-07	FS	Fire (Bush)[3]	80.6	
Aug-07	WC	Flood[3]	735.8	-
Nov-07	EC	Flood[3]	206.2	2
Apr-08	MP	Storm	18	-
Nov-08	Cape Winelands, WC	Flood	-	-
Nov-08	Durban, KZN	Storm	-	5
		TOTAL	7973.41	230

Footnotes:

1. Dartmouth Flood Observatory - http://www.dartmouth.edu/~floods/Archives/2001sum.htm
2. National Disaster Management Center data
3. Global Fire Monitoring Center - http://www.fire.uni-freiburg.de/current/archive/za/2000/01/za_01212000.htm
4. DiMP 2003. Montagu Floods Cut-off Low 2003: Consolidated Report. Available online at: www.riskreductionafrica.org.
5. DiMP 2004. Pilot Study on the socio-economic impact of disasters: 1994-2004. University of Cape Town.
6. DiMP 2004. December 2004 Cut-off Low: Consolidated Report. Available online at: www.riskreductionafrica.org.
7. DiMP 2007. Severe Weather Compound Disaster, August 2006 cut-off lows and their consequences in the Southern Cape, South Africa. Available online at: www.riskreductionafrica.org.
8. Forestry Southern Africa - www.forestry.co.za/forest/forest/Fire%20Damage%202007.ppt

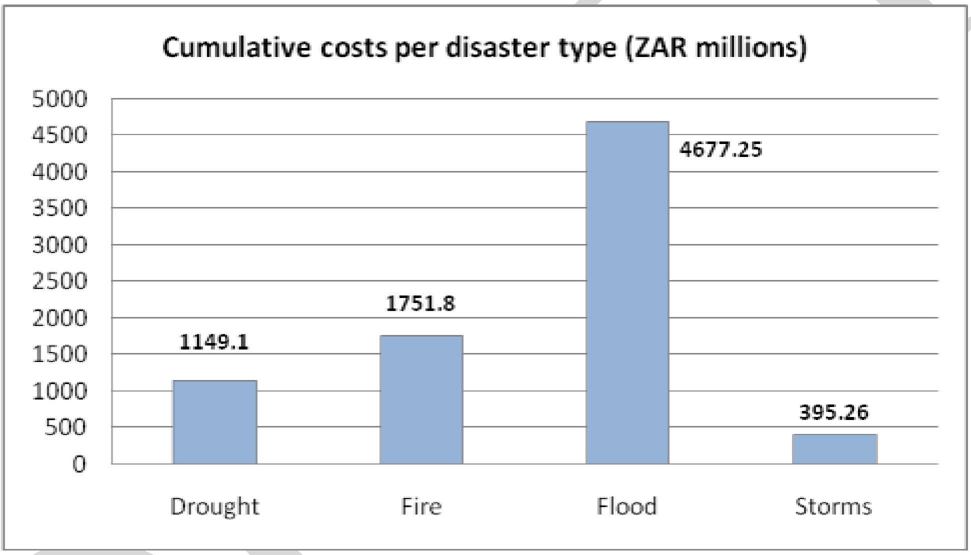

Figure 3.8.1: Total costs of the damage of selected disasters between 2000 and 2008 in South Africa, for which data were available, subdivided into four climate-related disaster types

Floods: Floods are more sudden disasters, yet can occur on both a localised and widespread scale depending on meteorological, topographical and hydrological characteristics of a given area. Flooding can occur in a number of different ways – such as flash floods, storm surge related, and rising floods. Floods have caused Rm4677.25 of damage, the greatest damage cost of all disasters that occurred in South Africa during the period of investigation, according to the available data (Table 3.8.1; Figure 3.8.1).

Fires: Fires are relatively sudden events that very rarely last more than a few days and affect a fairly localised area. Not all fires do damage, and natural wildfires are often necessary for the maintenance of healthy ecosystems, and are included as a land management strategy. "Harmful wildfires", those fires that damage infrastructure, crops and plantations, and that threaten livestock and humans, can occur over almost half of South Africa's surface, and resulted in damage costs of Rm1751.8 million over the period of investigation, the second most damaging disaster type (Table 3.8.1; Figure 3.8.1).

Storms or severe or extreme weather events: These usually consist of heavy precipitation, high winds and flash floods, often with coastal and landslide damage (Easterling *et al*. 2000). Each component has the ability to cause extensive damage and thus when aggregated often meets the definition of a disaster. Difficult to dissociate from floods, they are most often considered sudden events and occur over varying spatial areas although usually affecting an entire district or a number of municipalities. Storms can come in a number of forms, but those that most commonly affect South Africa as disasters are severe thunderstorms and cut-off lows (severe cold fronts). Such events have cost South Africa Rm395.26 over the period of investigation (Table 3.8.1; Figure 3.8.1).

3.8.3 Costs per disaster type and basic descriptive statistics

The total damage costs of the reported studies summarized here amounted to almost R8 billion (Table 3.8.1). These damage cost figures are almost certainly a skewed underestimate of the broader costs to local communities and to the nation of these events. This is due in part to a bias towards estimates of damage to infrastructure, which do not include the direct and indirect costs to urban and rural livelihoods, for example, where household losses are not covered by insurance, as well as costs to insurance companies where they are. The likelihood of an underestimate is also due to a lack of data on indirect and non-market costs, as well as under-reporting of most costs to the private sector (Environmental Resources Management 2005; Benson and Clay 2004, Carstens, *pers. comm*. 2009). Only those disasters that have been adequately recorded or using consistent methodology across sources have been included in the estimates. Hence it is likely that there are a number that are not represented here – i.e. less costly, more recent and poorly or inconsistently reported events. Finally, cost estimates are very often dependent on temporal dimension as with increased bands of time

over which an investigation is carried out the costs will generally rise. In this assessment the temporal dimension is restricted to the period of time over which the disaster occurred physically or climatologically, as is usually associated with direct cost reporting. Based on these and previous points, it must be cautioned that these figures should only be viewed as indicative preliminary estimates that are likely to be lower than the full national-level damage costs.

Two case studies are reviewed briefly below.

Wildfires

Vegetation fires occur regularly in South Africa, as many indigenous vegetation types are fire-dependent and flammable. However wildfire losses have been and continue to be reported especially poorly and are thus very uncertain (Forsyth *et al*. 2006; Kruger *et al*.2006; DiMP 2004). While loss data recorded on an event basis is listed in Table 3.8.1 for illustrative purposes, the total cost of wildfire damage in South Africa has been estimated by Forsyth *et al*. (2006). This study employed two approaches to arrive at a final figure. The first approach entailed estimating economic cost as the product of Total value at risk, the Proportion of value affected by fire, and the Probability of occurrence of a destructive wildfire", while the second approach estimated related indirect costs.

Using these methods the authors estimate annual losses of Rm743 (2006 value, Table 3.8.2). When aggregated, this amounts to a more realistic estimate of Rm7983 from 2000-2009, which is four times greater than the estimate of R1751.8 million given in Table 3.8.1. This also illustrates the likelihood that the total direct cost figure in Table 3.8.1 is a very conservative estimate.

Table 3.8.2. Summary of estimated annual costs associated with harmful wildfires in South Africa (from Forsyth et al. 2006).

Source of cost	Estimated annual cost (R millions in 2006)
Timber from plantations	63
Downstream timber processing	252
Livestock and grazing	155
Harvested products from savannas	61
Harvested products from grasslands	69
Harvested products from fynbos	5
Disruptions to power supply	36
Houses and structures	2
Smoke hazards	unknown
Alien plant control	100
Total	743

Western Cape flood disasters

An analysis flood events experienced in the last seven years in the Western Cape provides estimates of the level of costs for individual events. A cost analyses (based on available data) was conducted on three such extreme events, and they provide an indication of indirect costs which could be extrapolated across South Africa. Three flood events were analyzed: the Montagu Floods of 2003, the Cut off Low of 2004 and the Compound Disaster experienced in August 2006. Table 3.8.1 provides more detail on each of these events.

Collectively, these three events incurred direct damage costs of R1.33 billion. However, when including the indirect costs associated with these disasters, this estimate increased by between 15-30% (Mechler 2004). These indirect costs include some or all of the following:

- Rain and flood-affected households either temporarily evacuated or occupants relocated, resulting in productivity losses on the part of the occupant.
- Health costs, particularly in the months following the events, with significant increases in child illness recorded in health facilities in the areas affected. For example, the Montagu Floods correlated with a 42% increase in curative consultations and an 85% increase in lower respiratory infections.
- Agricultural productivity, inefficiencies in the supply and value chain experienced from crop, farm infrastructure and road damage with resulting lost contracts, logistical hold ups and wastage, higher prices and even hunger from shortages. The importance of environmental goods and services was evidenced in the August 2006 Compound disaster which resulted in soil losses of R27.6 million (25.25% of direct costs). Indirect costs include costs related to loss of soil quality, affecting yield for a number of seasons as the most nutrient rich top soil is usually removed in these types of events.
- Road damage revealed more obvious indirect effects with impassable roads not able to be used for transport, an essential component of trade, logistics, and tourism. Fuel costs increased with detours and time delays slowed supply and value chains with visitors unable to access and inject money into favoured tourist locations. Furthermore, safety is compromised on damaged roads not yet closed, leading to even more indirect costs.
- Another important service impacted by extreme events, is power supply, correlating with indirect costs associated with not having access to energy services such as lighting, cooking and heating, as well as industrial processes, all of which, in turn lead to further costs associated with having to find a way to accommodate or adapt to these changes or the costs of simply forging the service.

3.8.4 Conclusions

While no formal modelling allows the estimate of total cost for any of the disasters discussed above, or the national database compiled here, it would be conservative to assume 15% (ratios vary widely) of direct costs as the indirect and non-market costs as result of a disaster (Mechler 2004). Using this assumption to reach a conservative estimate for total cost for the period 2000 - 2009, yields an estimate Rm9170 (in 2008 values). This would equate to Rm1018 million per annum if averaged over the period, which equates to 0.04% of current GDP or R21 per capita.

South Africa is thus currently vulnerable to disaster risk. In addition, the nation has a 'backlog in development' and is the 7th most income unequal nation in the world (*ibid.*, UNDP 2008). In terms of disaster recovery capacity, a high Gini Coefficient can be taken to mean that there is a large percentage of the population that is very poor and thus would face great hardship in the recovery process due to a lack of personal financial resources. (The Gini Coefficient measures dispersion of wealth, and ranges between zero and 1; the closer to one the more unequal the distribution of wealth). This has negative socio-economic effects and in combination with investment in recovery required, and losses in productivity, slows the development process.

Although likely to be a significant underestimate of the national costs of current extreme weather related events, the above total cost figure serves as a preliminary approximation of baseline costs in relation to those that may occur in future (Van Niekerk *et al.* 2009). It is likely that this figure will rise significantly in the face of climate change, especially if further development does not account for current and future weather-related risks.

To better manage extreme weather impacts and losses South Africa could usefully adopt a risk based approach to the management of current infrastructure and to future development and development planning. In conjunction with sound disaster management and disaster risk reduction implementation, better management of the information regarding disaster impacts and recovery costs in South Africa is urgently needed to support such strategic risk assessment and disaster related planning.

Contents

Chapter 4:

Measures to Mitigate Climate Change, including Greenhouse Gas Inventory

4.1 National Greenhouse Gas Inventory

4.1.1 Introduction

South Africa's national inventory greenhouse gas (GHG) inventory has been developed for the year 2000 using the 2006 IPCC Guidelines. The 2000 GHG inventory is the third to be prepared in South Africa. The first was prepared in 1998 using 1990 activity data and the second was published in 2004 using 1994 activity data. The 1990 and 1994 inventories were developed using the 1996 IPCC Guidelines for National GHG Inventories (IPCC 1996) and were summarised in South Africa's Initial National Communication to the UNFCCC (DEAT 2000). One of the most significant changes in the 2006 IPCC Guidelines, relative to the 1996 IPCC Guidelines, was the restructuring of inventory sectors, in particular the combining of agriculture, forestry, and land use change, into one sector. GHG emissions have been classified into four categories:

Energy: Emissions from the combustion of fuel and fugitive fuel emissions from stationary and mobile energy activities, including public electricity and heat production; petroleum refining; manufacture of solid fuels; other energy industries; manufacturing industries and construction; transport; commercial; residential; agriculture; forestry; fishing; and fugitive emissions from coal mining, coal-to-liquid, oil and natural gas activities.

Industrial Processes and Product Use (IPPU): Emissions from by-products or fugitive emissions of GHGs from industrial processes. Emissions from the combustion of fuel in industry are reported under Energy. Emissions from the mineral, metal and chemical sectors have been reported in the 2000 GHG Inventory.

Waste: Emissions from waste management including disposal of solid waste on land and wastewater treatment.

Agriculture, Forestry and other Land Use (AFOLU): All anthropogenic emissions from agricultural activities except for fuel combustion (reported under Energy) and sewage emissions (reported under Waste). Activities include enteric fermentation, manure management, agricultural soils, prescribed burning of savannas and field burning of agricultural residues. This sector also includes total emissions from and removals by forest and land use change activities including changes in forest and other woody biomass stocks, forest and grassland conversion, and emissions from and removals by soil.

Data availability has been a key challenge in developing the 2000 GHG Inventory with most of the data only being available at an aggregated national level rather than point source level. This has made it difficult to undertake a detailed and informative review of data sources as it was often not possible to disaggregate data (particularly in the energy sector), and thus lower tier (tier 1) calculation methods had to be used. In a number of cases no information was available which has lead to the omission of some sources (e.g. the electronics industry, health sector and some industrial activities).

4.1.2 Total emissions

South Africa's total emissions in 2000 are estimated to be 461,178.5 Gg CO_2 equivalents (461 million tonnes CO_2e). 83% of emissions were associated with energy supply and consumption (380,988 Gg CO_2e) with 7% from industrial processes (32,081 Gg CO_2e), 8% from agriculture (38,716 Gg CO_2e) and 2% from waste (9,393 Gg CO_2e) (Figure 4.1.1). These figures exclude emissions or sinks from land use, land use change and forestry (LULUCF) activities within the AFOLU sector. These AFOLU activities contribute 2,057 Gg CO_2e as a source but also provide a sink of 20,751 Gg CO_2e to provide a net sink of emissions of 18,694 Gg CO_2e. Total emissions with LULUCF for the 2000 inventory total were 442,284.5 Gg CO_2e or 442 Mt CO_2e. When the Agriculture and LULUCF sectors are combined on the basis of 2006 IPCC guidelines, total net emissions from AFOLU are 20,022 Gg CO_2e or 20.0 Mt CO_2e (Figure 4.1.2).

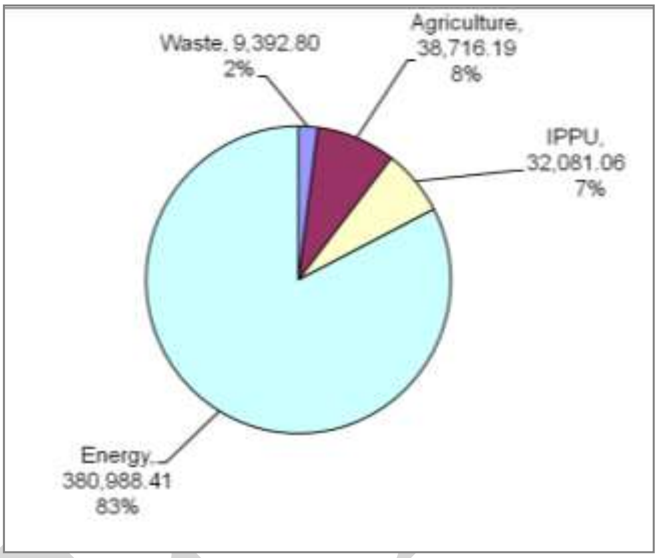

Figure 4.1.1: Total greenhouse gas emissions by sector in South Africa, without land use, land use change and forestry (GgCO_2 equivalents)

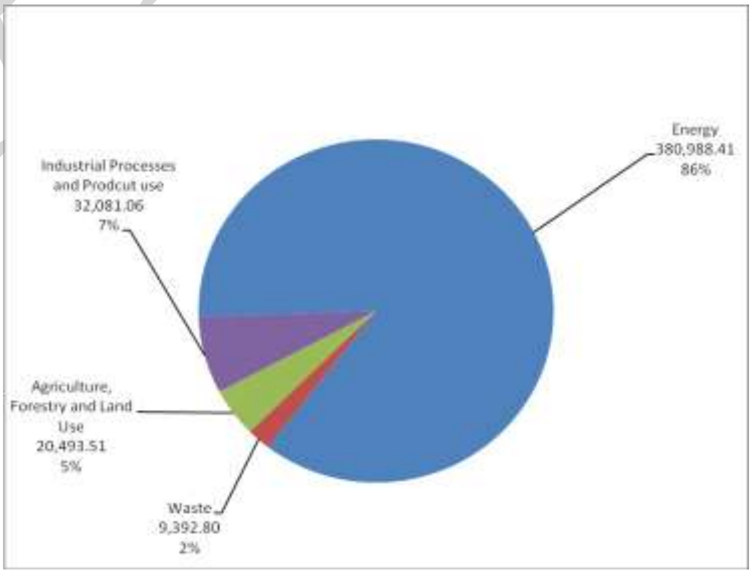

Figure 4.1.2: Total greenhouse gas emissions by sector in South Africa, including land use, land use change and forestry (GgCO_2 equivalents)

South Africa is using 1990 as the base year, and therefore emission trends to year 2000 refer to this baseline. It is important to note that different calculation methods have been used in the 1990 GHG Inventory (1996 IPCC Guidelines) and the 2000 GHG Inventory (2006 IPCC Guidelines) and the trend analysis needs to be treated with caution as changes could be due to the change in allocation of source categories rather than a significant change in activity data.

Greenhouse gas emissions either increased or decreases between 1990 and 2000, depending on the sector (Table 4.1.1 and 4.1.2). Energy sector emissions showed a consistently increasing trend from 1990 to 2000. Between 1994 and 2000 energy sector emissions increased by 28%, and between 1990 and 2000 there is an increase of 46%. Industrial Processes and Other Product Use emissions showed an increase of 6% between 1994 and 2000, and an increase of 4%between 1990 and 2000. Agriculture showed an increase of 9% between 1994 and 2000, but a decrease of 4% between 1990 and 2000. The Waste sector showed a decrease of 43% between 1994 and 2000, and a decrease of 38% between 1990 and 2000. It is acknowledged that some of these changes are attributable to more sources and better quality data, as well as changes in emission calculation methods and allocation of source categories, and not necessarily increased level in the sector activities. The use of 2006 IPCC Guidelines for the 2000 inventory may make trend emission comparison difficult for some sectors, particularly emissions or sinks from forestry, land use and land use change.

Carbon dioxide (CO_2) is the main GHG contributing 79% of total emissions with methane (CH_4) contributing 16%, nitrous oxide (N_2O) 5 % and Perfluorocarbons (PFCs) from aluminium production less than 1%. Lack of data prevented emissions from Hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6) and PFCs from other activities being estimated. Estimation of these gases (F-gases) will require an in-depth research study. The GHG emission trend from 1990 shows uniform increase in emissions for carbon dioxide (CO_2) and methane (CH_4). CO_2 emissions increased by 15% between 1994 and 2000, and show a general increase of 29% between 1990 and 2000. Methane emissions shows the highest percentage increase of all gases, recording an increase of 74% between 1994 and 2000, and an overall 74% increase between 1990 and 2000. Nitrous oxide showed an increase of 6% between 1994 and 2000, but a general decrease of 6% between 1990 and 2000. Table 4.1.3 summarises total in South Africa by sector and GHG for 2000.

Table 4.1.1. Greenhouse Gas Emissions by Sector in South Africa, without land use, land use change and forestry.

Sector	**Gg CO_2 equivalents in 2000**	**% of total**	**% change from 1994**	**% change from 1990**
Energy	380,988	83	28	46
Industrial Processes and Product Use	32,081	7	6	4
Agriculture	38,716	8	9	-4
Waste	9,393	2	-43	-38
Total	**461,178**	**-**	**21%**	**33%**

Table 4.1.2. Greenhouse Gas Emissions by Gas in South Africa, without land use, land use change and forestry

Greenhouse gas	Gg CO_2 equivalents in 2000	% of total	% change from 1994	% change from 1990
CO_2	362,071	79	15	29
CH_4	75,062	16	74	74
N_2O	21,827	5	6	-6
CF_4	1,971	0.4	-	-
C_2F_6	248	0.05	-	-
Total	**461,178**	-	**21**	**33**

Table 4.1.3. Total greenhouse gas emissions (Gg CO_2 equivalent) in South Africa in 2000. NA = not applicable; NO = not occurring; HFCs = Hydrofluorocarbons; PFCs = Perfluorocarbons

GHG source and sink category	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	Total
Total (Net Emissions)	**341,319.88**	**76,324.97**	**22,620.65**	**0.00**	**2,219.05**	**0.00**	**442,484.54**
1. Energy	**333,429.43**	**45,408.75**	**2,150.23**				**380,988.41**
A. Fuel Combustion (Sectoral Approach)	307,132.06	529.05	2,123.23				309,811.34
Energy Industries	218,314.02	79.45	1,070.09				219,490.57
Manufacturing Industries and Construction	38,879.34	65.61	145.87				39,090.83
Transport	38,623.88	258.19	629.23				39,511.31
Commercial/ institutional	1,901.59	0.43	9.28				1,911.30
Residential	5,547.25	122.25	258.89				5,928.40
Agriculture/ forestry/ fishing	3,705.54	3.06	9.74				3,718.34
Other	160.42	0.06	0.11				160.60
B. Fugitive Emissions from Fuels	26,273.04	44,879.70	NA,NO				71,177.07
Solid Fuels	24.33	40,366.25	NA,NO				40,390.58
Oil and Natural Gas	26,273.04	4,513.46	NO				30,786.49
2. Industrial Processes and Product Use	**28,641.12**	**3.38**	**1,217.52**	**NA,NO**	**2,219.05**	**NA,NO**	**32,081.06**
A. Mineral Products	6,025.41	NA,NO	NA,NO				6,025.41
B. Chemical Industry	656.31	0.08	1,217.52	NO	NO	NO	1,873.91
C. Metal Production	21,959.40	3.30	0.00	NA	2,219.05	NA,NO	24,181.75
3. Agriculture, Forestry and Land Use	**-20,750.67**	**22,136.94**	**18,636.00**				**20,022.27**
A. Enteric fermentation		18,969.09					18,969.09

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Table 4.13 (continued)…

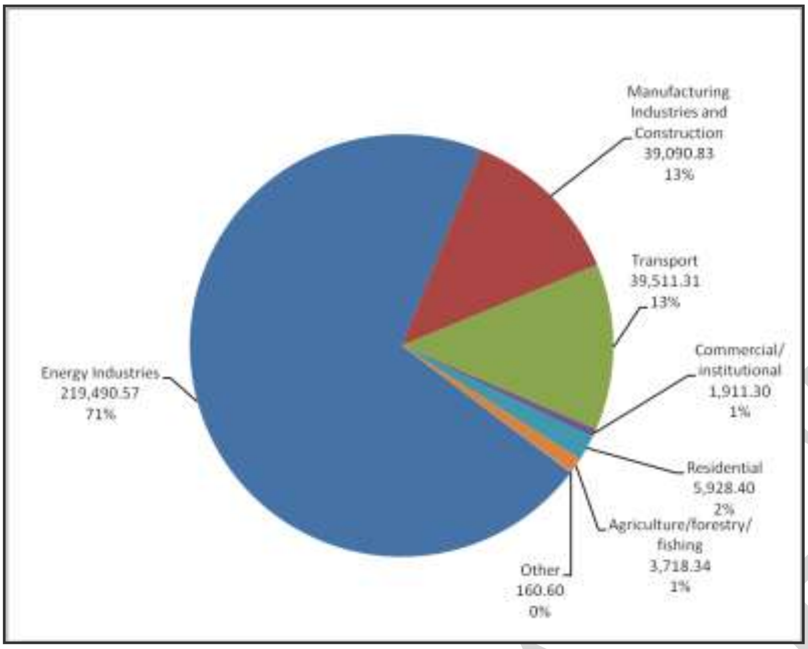
B. Manure management		1,904.70	415.40				2,320.10
C. Forest land	-13,020.52	NA,NO					-13,020.52
D. Cropland	-7,730.15						-7,730.15
F. Wetlands		190.89					190.89
I. GHG Emissions from biomass burning	IE	1,072.26	793.6				1,865.86
M. Indirect N_2O emissions from managed soils			1,7427				17,427.00
4. Waste	**0.00**	**8,775.90**	**616.90**				**9,392.80**
A. Solid waste disposal on land		8,085.00					8,085.00
B. Waste-water handling		690.90	616.90				1,307.80
Memo Items:							
International bunkers	11,645.83	17.11	95.56				11,758.50
Aviation	2,906.25	0.43	25.20				2,931.87
Marine	8,739.59	16.68	70.36				8,826.62
CO_2 Emissions from biomass	5,171.24						5,171.24
Total CO_2 Equivalent Emissions without Land Use, Land-Use Change and Forestry							**463,235.22**
Total CO_2 Equivalent Emissions with Land Use, Land-Use Change and Forestry							**442,484.54**

4.1.3 Emissions by sector

Energy: The Energy Sector is the largest sector in the South Africa and was responsible for 83% of emissions (380,988Gg CO_2e) in 2000 (Table 4.1.4). Fuel Combustion produced 81% of the energy emissions with Fugitive Emissions from Fuel contributing the remaining 19%.

Table 4.1.4. Energy Sector emissions (Gg CO_2 equivalent) of greenhouse gasses in South Africa in 2000

Sector	Subsector	CO_2	CH_4	N_2O	Total
Fuel Combustion	All	307,132	529	2,150	380,988
	Energy Industries	218314	79	1,097	219,491
	Manufacturing Industries & Construction	38,879	66	146	39,091
	Transport	38,624	258	629	39,511
	Commercial/Institutional	1,902	0.4	9	1,911
	Residential	5,547	122	259	5,928
	Agriculture/Forestry/Fishing	3,706	3	10	3,718
	Other	160	0.06	0.1	161
Fugitive Emissions from Fuels	All	26,297	44,880	NA,NO	71,177
	Solid Fuels	24	40,366	NA,NO	40,391
	Oil and Natural Gas	26,273	4,513	NO	30,786
TOTAL		**333,429**	**45,409**	**2,150**	**380,988**



Emissions from the combustion of fuel are divided into six subsectors. Energy industries emit 71% of the combustion emissions and 58% of the energy sector emissions; manufacturing industries and construction contribute 13% of the combustion emissions, and 10% of the energy sector emissions; transport contributes 13% of the combustion emissions and 10% of the energy sector emissions; and all other combustion subsectors the remaining 3% of the combustion emissions as illustrated in Figure 4.1.3.

Figure 4.1.3 Energy sector emissions (Gg CO_2 equivalents) from fuel combustion in South Africa in 2000

Emissions in the energy sector have increased by 46% since 1990. In the combustion emissions, energy industry subsector (predominantly public electricity production and refineries) has seen the largest increase in emissions of 37% between 1990 and 2000, followed by the transport sector which shows an increase of 25%. The highest emission decrease is recorded in the commercial emissions, a decrease of 62% between 1990 and 2000. Emissions from manufacturing industries and construction show a decrease of 17% between 1990 and 2000. Residential energy emissions show a decrease of 14% between 1990 and 2000. The 2000 GHG Inventory shows that about 82% of emissions from the Energy Industry subsector were from electricity production, 18% from refinery fuels and less than 1% from 'Other energy industry'.

Fugitive emissions from fuels (mainly coal mining and synthetic fuels) increased by 947% in comparison to the 1990 baseline. This substantial increase is attributed to more accurate fugitive emission quantification and reporting in the 2000 GHG Inventory, as well as fugitive emission factors used for the 2000 GHG inventory (from 2006 IPCC Guidelines), which were comparatively higher than in previous inventories. Further, the inclusion of emission from coal to liquid processes significantly increased the amount of fugitive emissions in 2000.

Looking at the transport sector emission trend, one observes an increase of 25% between 1990 and 1994, and a decrease of 9% between 1994 and 2000. In 2000 transport emissions contributed 10% of the Energy sector emissions and 9% of the total emissions. The decrease in transport emissions between 1994 and 2000 contradicts an increase in diesel and gasoline consumption between the same time period, 1994 and 2000. It can therefore be said that the recorded decrease in transport emissions between 1994 and 2000 is attributed to the change in reporting methodology, whereby in previous inventories non-transport fuel consumption emissions, such as those attributed to the manufacturing industry, were reported under the transport sector. This approach would incorrectly inflate emission estimates in the transport sector. While this difference complicates sub-sector analysis, it does not affect the grand total.

Industrial processes and product use: Emissions from the Industrial Process and Other Product Use (IPPU) sector amounted to 32,0816Gg CO_2e 7% of total GHG emissions in the 2000 GHG Inventory. Since 1990, IPPU sector emissions have increased by 4%. The IPPU sector is the third largest source of emissions in 2000 (Table 4.1.5). Lack of data prevented disaggregation of emissions within sub sectors and a more detailed analysis of profiles is not possible at present. Within the IPPU sector, 75% of the emissions were from metal production, followed by 19% from the mineral products and 6% from chemical industry (Figure 4.1.4).

Table 4. 1.5. Industrial Processes and Product Use emissions (Gg CO_2 equivalent) in South Africa in 2000. NA = Not Applicable; NE = Not Estimated; NO = Not Occurring

	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	Total
Mineral Products	6,025.41	NA,NO	NA,NO	NA	NA	NA	6,025.41
Chemical Industry	656.31	0.08	1,217.52	NO	NO	NO	1,873.91
Metal Production	21,959.40	3.30	0.00	NA	2, 219.05	NA,NO	24,181.75
Other Production	NO	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE	NO,NE
Production of Halocarbons and SF_6	NA	NA	NA	NA,NO	NA,NO	NA,NO	NA,NO
Consumption of Halocarbons and SF_6	NA	NA	NA	NA,NE	NA,NE	NA,NE	NA,NE
Other Product Manufacture and Use	NA,NE	NA,NE	NA,NE	NA,NE	NA,NE	NA,NE	NA,NE
Total	**28,641.12**	**3.38**	**1,217.52**	**NA,NO**	**2,219.05**	**NA,NO**	**32,081.06**

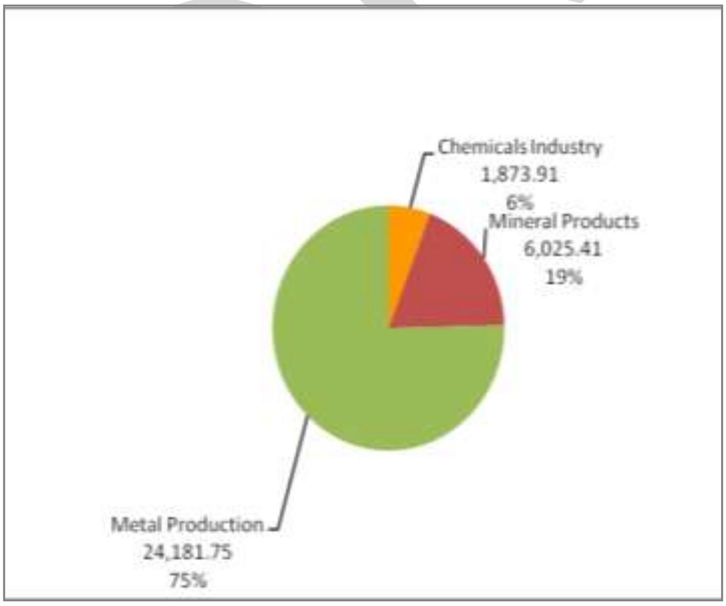


Figure 4.1.4 Industrial Processes and Product Use emissions (Gg CO_2 equivalent) in South Africa in 2000.

The overall GHG emissions from IPPU increased from 1990 to 2000. However, at subsector level there are both increasing and decreasing trends. The highest increase between 1990 and 2000 is from metal production, recording an increase of 11%. Between 1994 and 2000 metal production emission increase was 16%. Between 1994 and 2000 mineral products emissions shows a decrease of 13%, and a general increase of 10% between 1990 and 2000. The only decrease in emissions within the sector is in chemical industry emissions, recording a decrease of 56% between 1994 and 2000 and a general decrease of 47% between 1990 and 2000.

Table 4.1.6. Trends in the emission of Industrial Processes and Product Use emissions in South Africa between 1990 and 2000.

Industrial Processes or Product	2000 CO_2 equivalent (Gg)	% Total	% change from 1994	% change from 1990
Mineral products	6,025.41	19	13	10
Chemical industry	1,873.91	6	-56	-47
Metal production	24,181.75	75	16	11
TOTAL	**32,081.06**		**6**	**4**

Agriculture, forestry and other land use : In the 2000 GHG Inventory, activities in the Agriculture, Forestry and Land Use (AFOLU) sectors contributed a net emission of 20,022.27 Gg CO_2e, which comprised an emission of 40,772.94 Gg CO_2e and a sink of 20,750.67 GgCO_2e. Agricultural Soils and Enteric Fermentation were the major sources of emissions in AFOLU sector in 2000, contributing 42.7% and 46.5% respectively of the sector emissions. CH_4 is the dominant GHG in AFOLU, contributing 54.3% and N_2O contributing the remaining 45.7%. Sinks came from Forest land and Crop land respectively at 62.7% and 27.3% of the total CO_2 sequestration.

Separating AFOLU categories on the basis of 1996IPCC Guidelines, emissions from Agriculture are 38,716.19Gg CO_2e, where as LULUCF is a net sink of 18,693.25Gg CO_2. On this basis, Agriculture emissions decreased by 4% between 1990 and 2000, whereas LULUCF sinks increased by 11.8%, from 16,982.37 GgCO_2.

The subsector "Lands were divided in six classes namely Forestry, Croplands, Settlements, Wetlands, Grasslands and Other Lands according to the IPCC 2006 guidelines. The Forestry class includes Forest Lands, Forest Land Remaining Forest Land and Other Land Converted to Forest Land. Emissions from croplands were not estimated as required data was not publicly available. Data from 1990 and 1994 show agricultural soils as a CO_2 sink but more recent calculations show this may also be a source and hence it is critical to update the data for this sub-sector. Information on the emission factors for Settlements is currently very limited. The settlements category is not a key category and areas under settlements are relatively small compared to the total land area (less than 2%).

Wetlands emissions were reported for the first time. Three types were considered – Wetlands, Waterbodies and Peatlands. The Grassland biome is one of the most threatened biomes in South Africa, with 40% irreversibly transformed and only 2.8% formally conserved. It is estimated that 22.7% of the Grassland biome is currently under cultivation with virtually the entire remainder used as rangeland. The Other Lands sub-class includes bare soil, rock, ice, and all land areas that do not fall into any of the other classes. Although this class was included, more clarity is required to incorporate the results of the recent research in the next inventory.

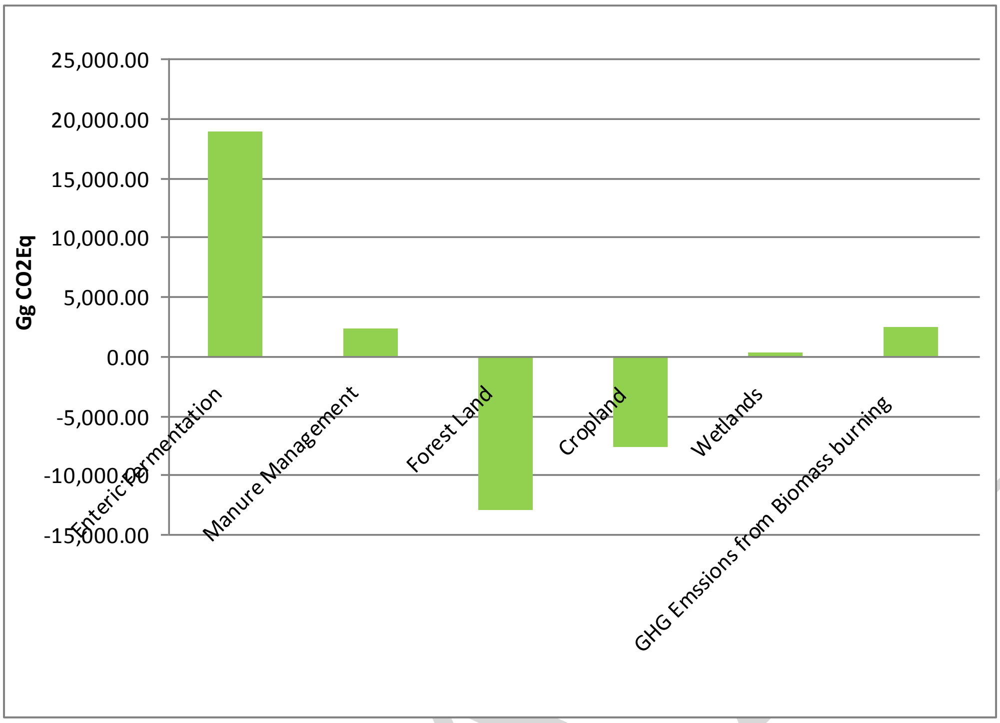


Figure 4.1.5. Greenhouse gas emissions from the Agriculture, Forestry and Land Use sector in South Africa in 2000.

The Department of Agriculture, Forestry and Fisheries (DAFF) has initiated development of an AFOLU sector inventory based on the IPCC 2006 Guidelines which is expected to be completed in early 2010. Hence the 2000 NIR states that the current estimations will serve to provide interim information until the DAFF AFOLU sector inventory is completed. However it should be noted that the DAFF inventory is for 2004 rather than 2000 and the data will not therefore be directly comparable.

Waste: The disposal of solid waste contributed less than 2% of total greenhouse gas (GHG) emissions in South Africa mainly through emissions of methane (CH_4) from urban landfills. Emissions from this sector have decreased by 43% between 1994 and 2000, and by 38% between 1990 and 2000. This decrease is likely due to the change in calculation methodology.

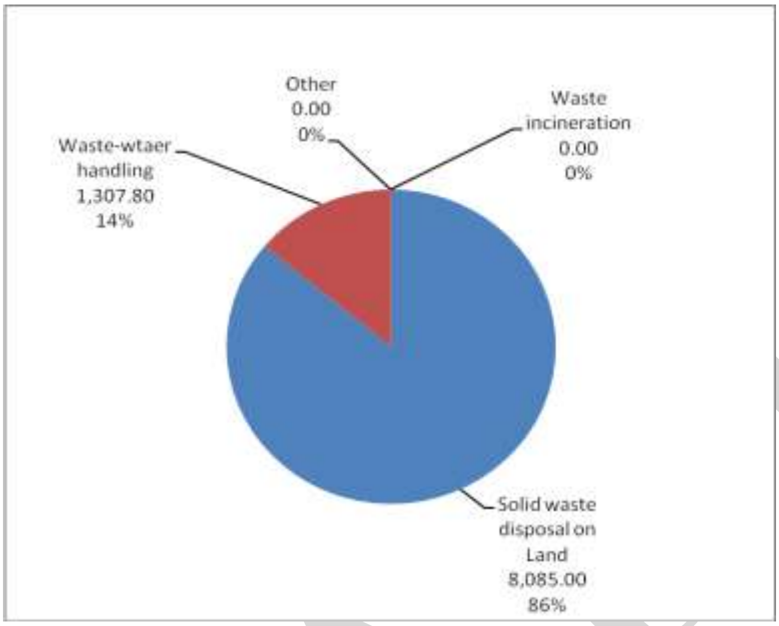


Figure 4.1.5 Emissions from waste activities (Gg CO_2 equivalent) in South Africa in 2000.

Only GHG's generated from managed disposal landfills in South Africa have been determined for 2000 because data on waste dumped in unmanaged and uncategorised disposal sites is not available, and most of the unmanaged and uncategorised disposal sites are scattered throughout rural and semi-urban areas across South Africa, and are generally shallow (i.e. less than 5m in depth). In such shallow sites, a large fraction of the organic waste decomposes aerobically, which means methane emissions are insignificant compared those from managed landfill sites.

Waste streams deposited into managed landfills in South Africa comprise waste from households, commercial businesses, institutions, and industry, as well as from the clearing of gardens and parks. It is estimated that waste from households, commercial enterprises, institutions and the manufacturing sector was approximately 13.5 to 15 million tonnes annually (DEAT 2007b). In addition, industrial wastes, generally handled and disposed of onsite, were estimated to be about 22 million tonnes annually.

For the 2000 GHG Inventory report, only the organic fraction of the waste in solid waste disposal sites in South Africa was considered for estimations of GHG emissions. Other waste stream components like metals, ash, plastics, rubble and soil, were excluded because they generate insignificant quantities of methane from landfills.

Based on the activity data and other variables, a total of 385 Gg methane (or 8.09 Mt CO_2 equivalent) was estimated as being generated from landfills for the year 2000 (see Table 4.1.7). This estimate was based on the assumption that the urban population of the country had good access to well managed solid waste dumping sites.

Table 4.1.7. Methane emissions from solid waste disposal in South Africa between 1990 and 2000.

Year	CH_4 (Gg)	CH_4 (Tg CO_2 equivalent)
1990	**225**	**4.73**
1991	234	4.91
1992	245	5.14
1993	257	5.39
1994	**257**	**5.67**
1995	270	5.99
1996	285	6.34
1997	302	6.72
1998	340	7.14
1999	362	7.6
2000	**385**	**8.09**

In South Africa, most of the wastewater generated from domestic and commercial sources is treated through Municipal Wastewater Treatment Systems. Data on industrial categories with high organic content are very limited. Some data exist on wastewater in sectors such as vegetables, fruits and juices, and the wine industry, but these are available only for a specific year, making it impossible to extrapolate such statistics accurately over any period. Therefore in the 2000 GHG inventory, only CH_4 emissions from domestic sources are presented. However wastewater from commercial and industrial sources discharged into sewers are accounted for, so the term "domestic wastewater" refers to the total wastewater discharged into sewers from all sources.

Table 4.1.8 presents GHG emissions from waste-water handling.

Table 4.1.8. Emissions from waste water handling in South Africa between 1990 and 2000.

Year	CH_4 (Gg)	CH_4 (Tg CO_2 equivalent)	N_2O (Gg)	N_2O (Tg CO_2 equivalent)	Total CO_2 Equivalents (Tg)
1990	**26**	**0.546**	**1.57**	**0.488**	**1.034**
1991	26.7	0.561	1.59	0.494	1.055
1992	27.5	0.577	1.64	0.507	1.084
1993	28.3	0.594	1.68	0.52	1.114
1994	**29**	**0.608**	**1.72**	**0.533**	**1.141**
1995	29.8	0.625	1.76	0.546	1.171
1996	30.4	0.638	1.8	0.556	1.194
1997	31	0.652	1.83	0.567	1.219
1998	31	0.66	1.85	0.572	1.232
1999	32.4	0.68	1.89	0.587	1.267
2000	**32.9**	**0.691**	**1.99**	**0.618**	**1.309**

4.1.4 Emissions by major Greenhouse Gas

Carbon dioxide: CO_2 is the main GHG contributing 79% of total emissions (362,071 Gg CO_2, without LULUCF). Trend for CO_2 emission shows a uniform increases in emissions with no decreases from 1990 (see Table 4.1.2). Within Fuel Combustion the greatest emissions by a significant margin are from Energy Industries (219, 491 CO_2e; 65% of sector CO_2 emissions and 60% of total CO_2 emissions) followed by Manufacturing and Transport (both approximately 39,000 Gg CO_2; 12% of sector CO_2 emissions and 11% of total CO_2 emissions each). IPPU produces approximately 28,641 Gg CO_2 (8% of total CO_2 emissions) with the Metal production contributing approximately 21,959 Gg CO_2 (6% of total CO2 emissions and 77% of sector CO_2 emissions). IPPU Mineral products contribution to CO_2 emissions was 6,025 GgCO2, which was 2% of total CO_2 emissions and 21% of CO_2 emissions in IPPU. AFOLU produces a sink of approximately 21,000 Gg CO_2, and a net emission of 20,000Gg CO_2.

Methane: Methane (CH_4) contributes 16% of total emissions to the 2000 GHG inventory (75,062 GgCO_2e, without LULUCF). The trend for Methane emissions shows a continuous increase from 1990 to 2000, with a slight increase of 0.2 % between 1990 and 1994 (see Table 4.1.2). CH_4 shows the highest increase of more than 74% between 1990 and 2000. The greatest CH_4 emissions are produced by the Energy sector, particularly the Fugitive Emissions from Fuels subsector (44,880 Gg CO_2e; 60% of total CH_4 emissions and 99% of Energy sector CH_4 emissions). Within Fugitive Emissions from Fuels the greatest emissions by a significant margin are produced from Fugitive Emissions from Solid Fuels (40,366 Gg CO_2e; 90% of fugitive CH_4 emissions) which result mainly from coal mining activities.

The Agriculture sector provides CH_4 emissions of 20,874 Gg CO_2e (29%of total CH_4 emissions, without LULUCF) with most emissions coming from Enteric Fermentation (approximately 19,000 Gg CO_2e; 25% of total CH_4 emissions, without LULUCF. The Waste sector produced CH_4 emissions of 8,776 Gg CO_2e (12%of total CH_4 emissions, without LULUCF).

Emissions of CH_4 from LULUCF activities were a total of 1,263 Gg CO_2e, which was 2% of the total CH_4 emissions and 0.3% of net GHG emissions.

Nitrous oxide: N_2O contributes about 5% of total emissions to the 2000 GHG inventory (21,827 Gg CO_2e, without LULUCF). The trend for N_2O emissions shows a decrease of 11% between 1990 and 1994, and an increase of 11% between 1994 and 2000 (see Table 4.1.2). There is an overall decrease of 6% between 1990 and 2000. The greatest N_2O emissions are produced from the Agriculture sector (17,842 Gg CO_2e; 82% of total N_2O emissions, without LULUCF), whereby 98% of these emissions come from Indirect N_2O Emissions from Managed Soils (approximately 17,400 Gg CO_2e). The IPPU sector produces N_2O emissions of approximately 1,218 Gg CO_2e (6% of total N_2O emissions, without LULUCF) with all these emissions coming from the Chemical Industry.

Other: Gases that fall under this category include HFCs, PFCs and SF_6 and contribute less than 1% of total emissions. Emissions from HFCs and SF_6 have not been estimated. Emissions from PFCs have only been estimated from aluminium production (Metal Production) which falls under the IPPU Sector and amount to 2,219.05 Gg CO_2e. An in-depth study of F-gases is required in order to come up with an accurate estimation of all F-gases (HFCs, PFCs, and SF_6).

4.2 Means of Mitigation

4.2.1 Introduction

Given that 79% of the South Afirca's greenhouse gas (GHG) emissions are attributable to energy supply and use, the focus of the tension between national development objectives and climate change mitigation objectives is therefore the energy system, and this is the point at which this tension can be resolved through innovative policies and measures. The major objectives of government policy for the energy sector were spelled out in the 1998 White Paper on Energy Policy (DME 1998), namely increasing access to affordable energy services; improving energy governance; stimulating economic development; managing energy-related environmental impacts; and securing supply through diversity. Mitigation is primarily part of the fourth objective, although it also has implications for all the other objectives. Making South Africa's development path more sustainable would be a major contribution to reducing its emissions relative to a business-as-usual development path. This chapter draws on all climate change mitigation developments in South Africa, with specific focus on long-term national mitigation plans.

4.2.2 Programmes and measures prior to 2006

Major steps have been taken by South Africa to formulate and publish national measures to mitigating climate change, especially in the energy sector. Developments in two areas of energy policy are particularly significant: measures to promote renewable energy and promotion of energy efficiency:

1. The 2003 White Paper on Renewable Energy sets a target of 10 000GWh contribution from new renewable energy in 2013, while the 2007 National Industrial Biofuels Strategy which sets a target of 2% (of the national liquid fuels supply) penetration of biofuels in 2013 (DME 1998; DME 2003; DME 2007).
2. In 2005, government published an Energy Efficiency Strategy which sets a goal of achieving savings of 12% by 2015 relative to a baseline, with disaggregated targets for each sector. Also the state electricity utility Eskom has undertaken a series of Demand-Side Management projects since 2004 (DME 2009).

From 2006 government also undertook two significant studies to address climate change in South Africa: the Long-Term Mitigation Scenarios (LTMS) (ERC 2007; RSA 2007; Scenario Building Team (SBT) 2007; Winkler 2007) and a Technology Needs Assessment (TNA) (DST 2007). Cabinet considered the LTMS outcomes in 2008 and agreed on a strategic direction – the country's GHG emissions must peak, at the latest by 2020-2025, stabilize for up to ten years and then decline in absolute terms. The LTMS is currently the key document on which national climate policy and strategies are based.

A significant number of Clean Development Mechanism (CDM) projects have been submitted to the South African Designated National Authority since its establishment in 2004. In 2009, 125 projects had been submitted –15 registered and four issued with Certified Emission Reductions (CERs).

4.2.3 Methodological approach

The LTMS was initiated with a mandate from Cabinet in March 2006, and concluded with outcomes agreed by a Cabinet meeting in July 2008. The LTMS methodology comprised research and process, and what made it unique was that research fed into a facilitated stakeholder process, producing evidence-based scenarios. Central to the process was the Scenario Building Team, bringing together strategic thinkers from key sectors across government, business and civil society (see the LTMS Process Report for a fuller description of the process (Raubenheimer 2007)).

Several research tools were combined for the analysis of nationally appropriate mitigation actions by South Africa. The MARKAL (acronym for MARKet ALlocation) model, an optimising energy system model developed by the International Energy Agency, was used to analyze actions in the energy demand and supply (Hughes, Haw *et al*. 2007). For emissions and mitigation options in non-energy sectors, a variety of spreadsheet models were used, as described in more detail in reports on waste, agriculture and forestry sectors (Taviv & van der Merwe *et al*. 2007) and for industrial process emissions (Kornelius *et al*. 2007).

The methodology for calculating the costs of nationally appropriate mitigation actions was based on the approach developed for the South African Country Study (Clark and Spalding-Fecher 1999). The approach drew on international best practice as described more fully in the LTMS Technical Report (Winkler 2007).

For the broader socio-economic implications, in particular the impact on economic growth, job creation and income distribution, economy-wide modelling methodologies were used, initially using a comparative static computable general equilibrium (CGE) model (Pauw 2007) and subsequently a dynamic CGE model (Kearney 2008).

4.2.4 Baseline

The baseline development path as defined by the LTMS is called the "Growth without constraints" scenario and it runs from 2003 to 2050. The baseline scenario represents a scenario where there is no change from the country's current trends, i.e. where not even existing policy is implemented.

Key drivers and assumptions: In the baseline scenario, it is assumed that there is no damage to the economy resulting from the adverse impacts of climate change, no significant oil supply constraint and that choices to supply energy to the economy are made purely on least-cost grounds, without internalizing external costs (SBT 2007).

Based on the historical growth trend of South Africa's gross domestic product (GDP) and comparing it to trends in other countries, a time-dependent GDP projection was developed for the baseline scenario. This series starts at a growth rate of 3% in 1993 and increases to about 6% before it starts to flatten out around 3% in the long-term. This trend is consistent with the growth targets of the accelerated strategy for growth in South Africa (AsgiSA 2006).

The population was projected to grow by no more than 15% of the 2001 population level by 2050 because of the high rate of HIV infection in the country. The rand-dollar exchange rate was projected to increase steadily from R7.50 to R19.02 in 2050. Future oil prices were projected to increase from $30 per barrel in the base year (2003) to $97 /bbl in nominal terms in 2030, while gas prices were assumed to rise from R28 per GJ in 2003 to R140 per GJ in 2030. These price increase trends were assumed to continue beyond 2030 for both oil and gas. For coal, the prices were assumed to rise from R3 per GJ in 2003 to R6 per GJ in 2030, after which they increase further (Winkler 2007).

Other drivers that were considered in the modelling process include discount rates, technology learning, future exchange rates and future energy prices (Winkler 2007).

Description of the baseline and emissions profiles: South Africa's emissions in the 2003 base year are at 446Mt CO_2-equivalent, increasing about four-fold by 2050 to 1637 Mt CO_2-equivalent (Figure 4.2.1). This trend is consistent with the country's latest GHG inventory which reports South Africa's emissions at 435Mt CO_2-equivalent in 2000 (DEAT 2009).

Most of the emissions in the baseline continue to come from fuel combustion for energy supply and use, with non-energy emissions (industrial processes, waste, agriculture and land use, land use change, and forestry) contributing roughly a fifth throughout the entire period. Overall fuel consumption grows more than five-fold, from 2,365 PJ in 2003 to 11,915 PJ in 2050, with the largest growth observed in the industry and transport sectors (Winkler 2007).

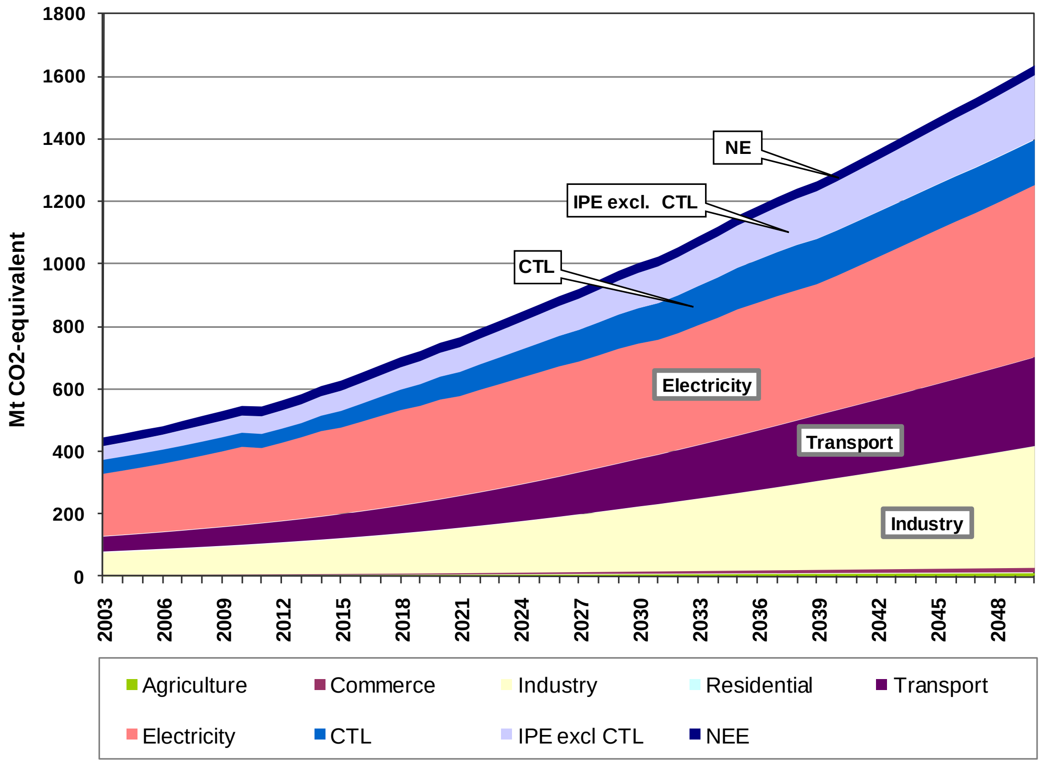


Figure 4.2.1: Emissions in the "growth without constraint" scenario – the baseline scenario. CTL, IPE and NEE refer to coal-to-liquids, industrial process emissions and non-energy emissions respectively

Source: (SBT 2007)

Electricity generation continues to be predominantly from coal in the baseline scenario, with all new coal-fired plants using either supercritical steam technology, which comes into the generation mix from 2016, or integrated gasification combined cycle (IGCC), which comes into the generation mix from 2020. Nine new conventional nuclear plants and 12 modules of the Pebble bed modular reactors are also built for electricity generation during this period. Renewable energy technologies for electricity generation remain limited, ranging from 2.18% of installed capacity in 2003 to 0.74% in 2050, and comprising only of existing hydro and biomass capacity, and a minute landfill gas capacity (Hughes *et al*. 2007).

Liquid fuel production is dominated by crude oil refining and synfuels in the baseline scenario, with five new crude oil refineries and five new low-temperature Fischer-Tropsch coal-to-liquids plants built within the period. None of the plants built in this scenario are equipped with carbon capture and storage (Hughes *et al*. 2007).

Growth in emissions also occurs in the demand sectors, with the two largest – transport and industry – contributing 17.4% and 45.1% respectively in 2050. The latter value includes emissions from direct use of fossil fuels in industry, which are accounted for separately from electricity and industrial process emissions.

4.2.5 Assessment of mitigation options

Long-term mitigation options: description, reduction potentials and costs: Mitigation actions in the LTMS were considered in three categories – energy supply, energy use and non-energy emissions.

Table 4.2.1 below presents a description of the mitigation actions that were modelled in the LTMS process, together with their respective mitigation capacities, mitigation costs and investment requirements, arranged in order of mitigation capacity from the largest GHG emission reduction to the smallest. While the mitigation cost depicts the cost of mitigating one ton of CO_2-equivalent emissions, the investment cost requirement highlights the undiscounted incremental cost of investment from the baseline scenario.

In the assessments of confidence levels in Table 4.2.1, “high” indicates much evidence and high consensus; whereas “low” indicates little evidence and little consensus. This methodology was applied using expert judgment.

Description of mitigation scenarios: In contrast to the baseline scenario, the LTMS defined a scenario that conforms to IPCC (2007) estimates of mitigation actions required to have an even chqance of keeping global temperature rise below 2°C, and termed the *Required by science* scenario. This scenario is driven by a climate target for South Africa to reduce its emissions by 30% to 40% from 2003 levels by 2050.

Three modelled strategic options: To explore how to bring South Africa’s emissions closer to what is required by science, three strategic options were modelled in the LTMS. Each option was arrived at by strategically combining various mitigation actions such that the final package of actions is large enough to reveal a distinct emission reduction pathway (SBT 2007). These options are described below while their properties are summarized in Table 4.2.2 below.

Start now: The first option, called *Start now*, is composed of all those mitigation actions in Table 4.2.1 that are not labelled as extended, excluding the CO_2 tax and subsidies which are modelled as part of the *Use the market* scenario below. All mitigation actions that have upfront costs, but where the savings over time more than outweigh the initial costs – also known as net-negative cost mitigation actions – are part of this strategic option.

Table 4.2.2 shows that this option saves money over time. The mitigation actions which have the biggest impact in *Start now* – in terms of emission reductions – are industrial efficiency, more renewable and nuclear sources for electricity generation, passenger modal shift and improved vehicle efficiency. Effectively the *Start now* scenario reduces the gap between the baseline and required by science scenarios by 43% in 2050 (SBT 2007).

Scale Up: The second strategic option is called the Scale up scenario, and it is an extension of the *Start now* package. Basically all the extendable mitigation actions in *Start now* are replaced in Scale up by their extended counterparts as shown in Table 4.2.1.

In terms of mitigation, the biggest actions in this scenario are energy efficiency, extended renewables, extended nuclear, synfuels with Carbon Capture and Storage and electric vehicles. Emissions follow the *Start now* profile fairly closely at first, and continue to rise; but in the last decade they level out (plateau). Under Scale up, the gap is closed by two-thirds (64%) in 2050 (SBT 2007).

Use the market: The last modelled strategic option is termed the *Use the market* scenario. This option focuses on the use of economic instruments, and it includes an escalating CO_2 tax on the whole energy sector, which generates revenue that could be used to provide incentives for renewable electricity, solar water heating and biofuels (SBT 2007).

The tax causes electricity supply to move away from coal to nuclear and renewables. Overall, *Use the market* reduces emissions by 17 500 Mt CO_2-eq between 2003 and 2050. In 2050 the emissions are at 620 Mt CO_2-eq, closing the gap between baseline and required-by-science scenarios by over three-quarters (76%).

Table 4.2.1. Summary of modelled mitigation actions, GHG emission reduction potentials and costs , [1,2]
Source: (Winkler 2007) [3] and additional analysis based on LTMS results

Mitigation action	Model description and parameters	GHG emission reduction, Mt CO_2-eq, 2003-2050	Confidence level: GHG reduction potential	Mitigation cost (R / t CO_2-eq)[4]	Rank costs – lowest cost is no.1	Total Incremental investment required (billion US$) 2010-2050	Annual incremental average investment (billion US$) 2010-2020	Confidence level: cost figures
Escalating CO_2 tax	An escalating CO_2 tax is imposed on all energy-related CO_2 emissions, including process emissions from Sasol plants.	12 287	High	42	20	115.77	1.76	High
Nuclear and renewable electricity, extended	Combines the extended renewables and nuclear scenarios below. At 50% each, this is a zero-carbon electricity case	8 297	High	52	23	348.47	3.06	High
Electric vehicles with nuclear, renewables	Electric vehicles are allowed to take up 10% of passenger kilometre demand between 2008 and 2015 increasing to 60% of demand in 2030 and remains at 60% to 2050	6 255	High	102	28	513.42	5.85	Low
Nuclear and renewables	Combines the individual nuclear and renewables cases. i.e. no electricity from fossil fuels by 2050	5 559	High	64	24	166.35	3.06	High
Industrial efficiency	Improved boiler efficiency, HVAC, refrigeration, water heating, lighting & air compressors, motors, compressed air management, building shell design optimising process control, energy management systems & introducing variable-speed drives	4 572	High	-34	8	27.30	-0.36	High

[1] N/A in the investment requirements columns means that the cost value is not available
[2] Values in 2008 US$
[3] Negative value of investment cost implies an investment saving compared to the baseline
[4] Average of incremental costs of mitigation action vs. Base case, at 10% discount rate

Table 4.2.1. Cont.

Mitigation action	Model description and parameters	GHG emission reduction, Mt CO_2-eq, 2003-2050	Confidence level: GHG reduction potential	Mitigation cost (R / t CO_2-eq)[5]	Rank costs – lowest cost is no.1	Total Incremental investment required (billion US$) 2010-2050	Annual incremental average investment (billion US$) 2010-2020	Confidence level: cost figures
Renewables with learning, extended	Same as renewables extended (50%), but assuming that the unit costs of renewable energy technologies decline, as global installed capacity increases	3 990	High	3	13	46.99	0.76	High
Subsidy for renewables	-106 R/GJ, on electricity from power tower, trough, PV, wind, hydro, bagasse, LFG	3 887	Medium	125	30	228.48	3.99	High
Nuclear, extended	The bound on investment in new capacity for both PBMR and PWR were increased to 2050	3 467	High	20	17	43.69	0.47	High
Renewable electricity, extended	In an extended mitigation action, the bound on commissioning of new parabolic trough and solar power tower plant is increased to 2.5GW/year by 2050	3 285	High	92	27	260.54	2.10	High
Renewables with learning	Same as renewables (27%), but assuming that the unit costs of renewable energy technologies decline, as global installed capacity increases	2 757	High	-143	7	30.59	0.72	High
Renewable energy for electricity generation	15% of electricity dispatched from domestic renewable resources by 2020, and 27% by 2030, from local hydro, wind, solar thermal, landfill gas, PV, bagasse / pulp & paper.	2 010	High	52	22	51.66	1.25	High
Nuclear electricity	27% of electricity dispatched by 2030 is from nuclear, either PBMRs or conventional nuclear PWRs – model optimised for cost etc.	1 660	High	18	16	17.09	0.47	High
Synfuels Carbon capture and storage 23 Mt	Carbon capture and storage on coal-to-liquid plant, with maximum storage of 23 Mt CO_2 per year, equivalent to concentrated emissions of existing plant	851	Medium	105	29	4.92	0.45	High

[5] Average of incremental costs of mitigation action vs. Base case, at 10% discount rate

Table 4.2.1. Cont.

Mitigation action	Model description and parameters	GHG emission reduction, Mt CO_2-eq, 2003-2050	Confidence level: GHG reduction potential	Mitigation cost (R / t CO_2-eq)[6]	Rank costs – lowest cost is no.1	Total Incremental investment required (billion US$) 2010-2050	Annual incremental average investment (billion US$) 2010-2020	Confidence level: cost figures
Improved vehicle efficiency	Improve energy efficiency of private cars and light commercial vehicles by 0.9%-1.2% per year (0.5% in base case).	758	High	-269	3	-17.89	-0.01	Medium
Biofuel subsidy	A subsidy of R1.06 per litre on biofuels applied as an incentive for biofuel take-up	573	Medium	697	35	-0.11	0.13	Low
Passenger modal shift	Passengers shift from private car to public transport and from domestic air to intercity rail/bus.–moving from 51.8% of passenger kms in 2003 to 75% by 2050	469	High	-1 131	2	-298.17	-0.62	Low
Land use: fire control and savannah thickening	50% reduction in fire episodes in savannah from 2004	455	High	-15	10	N/A	N/A	N/A
Electric vehicles in baseline grid	Electric up to 60% of the private passenger car market, operating in an unchanged grid, i.e. largely coal-fired	450	High	607	34	344.65	2.92	Low
Carbon capture and storage on power stations, 20 Mt	A cap on Carbon capture and storage use is increased annually starting with 1 Mt in 2015, and reaching a peak of 20 Mt in 2024.	449	Medium	72	26	5.58	0.24	High
Waste management	Waste Minimisation and composting	432	High	14	15	N/A	N/A	N/A
Residential efficiency	Penetration of SWHs, passive solar design, efficient lighting, appliance labelling & STDs, geyser insulation, LPG for cooking, 'Basa Njengo Magogo' coal fire-lighting method	430	High	-198	6	-9.66	-0.28	High

[6] Average of incremental costs of mitigation action vs. Base case, at 10% discount rate

Table 4.2.1. Cont.

Mitigation action	Model description and parameters	GHG emission reduction, Mt CO_2-eq, 2003-2050	Confidence level: GHG reduction potential	Mitigation cost (R / t CO_2-eq)[7]	Rank costs – lowest cost is no.1	Total Incremental investment required (billion US$) 2010-2050	Annual incremental average investment (billion US$) 2010-2020	Confidence level: cost figures
Commercial efficiency	In new buildings: SWH, efficient water heating, efficient HVAC, efficient lighting, variable speed drives, efficient motors, efficient refrigeration, building energy management systems, and efficient building shell design. In existing buildings, retrofit equipment and energy management systems	381	High	-203	5	-4.95	-0.11	High
Hybrids	20% of private cars are hybrids by 2030 (ramped up from 0% in 2001 to 7% in 2015).	381	High	1 987	36	487.60	3.89	Low
Agriculture: enteric fermentation	Cattle herd reduced by 30% between 2006 and 2011; 45% of free-range herd transferred to feedlots from 2006; high-protein, high digestibility feed supplementation	313	High	50	21	N/A	N/A	N/A
SWH subsidy	The cost of SWHs in the residential sector was reduced. The cost after subsidy in 2001 is R534.7 mil /PJ/a, which reduces further to R336.77 mil /PJ/a in 2050	307	Medium	-208	4	-6.02	-0.20	High
Carbon Capture and Storage 2 Mt	A cap is placed on the amount of CO_2 which can be stored annually by Carbon Capture and Storage to 2Mt.	306	High	67	25	7.71	0.39	High
Land use: afforestation	Rate of commercial afforestation will increase between 2008 to 2030 so that an additional 760 000 ha of commercial forests are planted by 2030	202	High	39	19	N/A	N/A	N/A
Cleaner coal for electricity generation	27% of electricity dispatched by supercritical coal and /or IGCC coal technologies by 2030; first plant could be commissioned by 2015.	167	High	-4.8	11	1.99	0	High

[7] Average of incremental costs of mitigation action vs. Base case, at 10% discount rate

Table 4.2.1. Cont.

Mitigation action	Model description and parameters	GHG emission reduction, Mt CO_2-eq, 2003-2050	Confidence level: GHG reduction potential	Mitigation cost (R / t CO_2-eq)[8]	Rank costs – lowest cost is no.1	Total Incremental investment required (billion US$) 2010-2050	Annual incremental average investment (billion US$) 2010-2020	Confidence level: cost figures
Biofuels	Biofuel blends increased to 8% ethanol with petrol and 2% biodiesel with diesel in 2013. Thereafter the percentage of ethanol in petrol is taken up to an assumed maximum of 20% and biodiesel to a maximum of 5% in 2030.	154	High	524	33	0.93	0.12	Low
Synfuels methane capture	Capture CH_4 emissions from existing coal-to-liquid plants from 2010	146	High	8	14	0.02	0	High
Agriculture: reduced tillage	Reduced tillage is adopted from 2007 on either 30% or 80% (more costly) of cropland	100	High	24	18	N/A	N/A	N/A
Synfuels Carbon Capture and Storage 2 Mt	Carbon capture and storage on coal-to-liquid plant, with maximum storage of 23 Mt CO_2 per year, equivalent to the largest planned storage at the time.	78	High	476	32	1.96	0.18	High
Coal mine methane reduction (50%)	Capture 25% or 50% (at higher cost) of methane emissions from coal mines, starting in 2020, and reaching goal by 2030	61	High	346	31	3.30	0.14	Medium
Agriculture: manure management	Percentage of feedlot manure from beef, poultry and pigs which is scraped and dried (does not undergo anaerobic decompositions) raised to 80% by 2010	47	High	-19	9	N/A	N/A	N/A
Aluminium: PFC capture[9]	Capture of PFCs from existing aluminium plant, starting in 2011, and reaching 100% by 2020	29	High	0.2	12	0	0	High
Limit on less efficient vehicles	SUVs limited to 2% of private passenger kms by 2030	18	High	-4 404	1	-43.39	-0.25	Medium

[8] Average of incremental costs of mitigation action vs. Base case, at 10% discount rate
[9] Investment for aluminium is only required once in 2006.

Table 4.2.2: Mitigation costs and emission reduction potentials of combined strategic actions

Mitigation action	Mitigation cost (R / t CO2-eq)	GHG emission reduction, Mt CO_2-eq, 2003-2050	Mitigation costs as share of GDP
	Average of incremental costs of mitigation action vs. base case, at 10% discount rate	Positive numbers are reductions of emissions by sources or removals of emissions by sinks	%, negative numbers mean negative costs
Start now	-R13	11 079	-0.5%
Scale up	R39	13 761	0.8%
Use the market	R10	17 434	0.1%

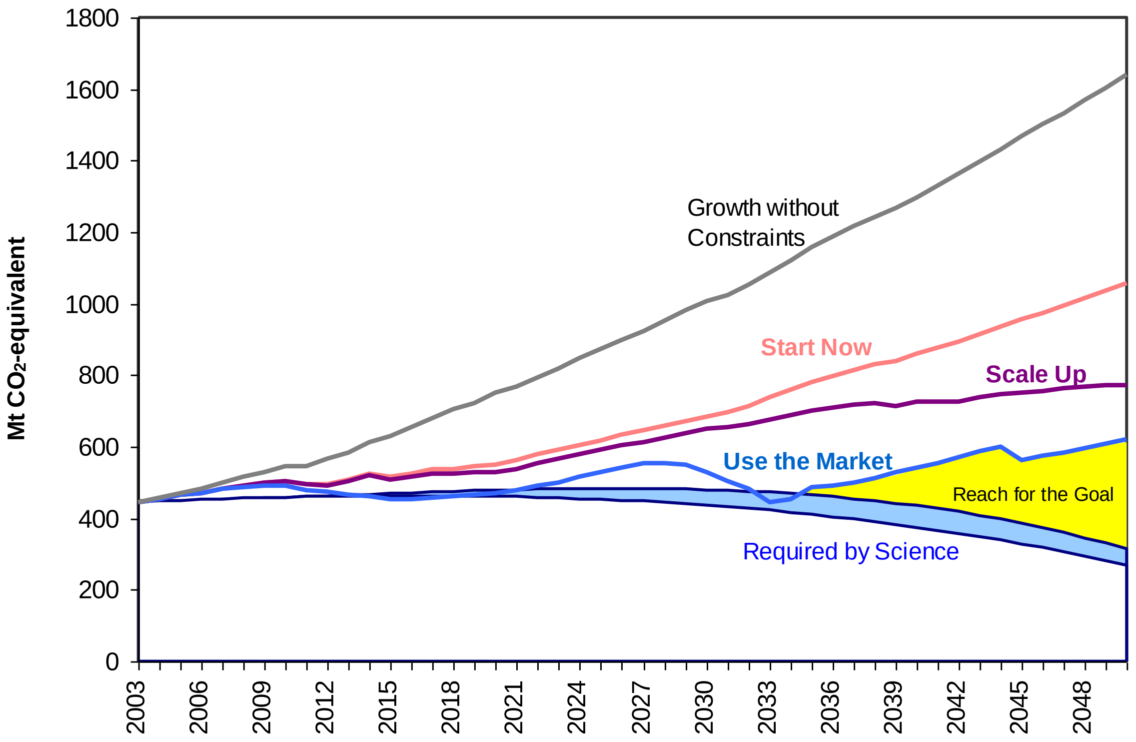


Figure 4.2.2: Emission pathways of various scenarios used to estimate emissions in South Africa

Reaching for the Goal: Strategic options beyond the modelled: Figure 4.2.2 shows emission pathways of all the modelled scenarios, and illustrates how far each strategic option closes the gap between the baseline and required-by-science scenarios.

There remains a 'triangle' of emissions between 2035 and 2050 that cannot be mitigated by either of the above strategic options (Figure 4.2.2). This implies that a new set of options would have to be ready for implementation by this time. What might these technologies look like? Awareness of climate change may induce significant changes in people's patterns of consumption and behaviour – but to what extent? The fourth strategic option, *Reaching for the goal*, lays a basis for elaborating these unknowns.

While it is acknowledged that the components of the *Reaching for the goal* strategic option cannot be modelled with any accuracy as was done with the other options, it can be imagined what some of its salient characteristics might have to be, by 2050. In the LTMS four actions, all requiring further study, were suggested (SBT 2007). New Technology – investigating technologies for the future; 2) Resource identification – searching for lower carbon resources; 3) People-orientated measure – incentivised behaviour; and 4) Transition to a low-carbon economy - redefining SA's competitive advantage.

Prioritisation of options: Four major areas with the largest mitigation potential were identified in the LTMS: energy efficiency, electricity generation, transport and carbon capture and storage. These deserve particular attention in terms of South Africa's technology needs.

4.2.6 Mitigation actions implemented and planned after the Long Term Mitigation Scenario process

Apart from mitigation projects aimed at obtaining Clean Development Mechanism (CDM) credits, many other mitigation initiatives have been undertaken in South Africa by both the private and the public sectors. In June 2009 a total of 56 mitigation projects were captured in the Department of Environmental Affairs' National Climate Change Response Database, with a total emission reduction potential of 25 million tonnes of CO_2-equivalent between 2000 and 2050 (DEAT 2009).

The Department of Minerals and Energy established a Renewable Energy Finance and Subsidy Office (REFSO) to manage renewable energy subsidies and to offer advice to developers and other stakeholders on renewable energy finance and subsidies. By 2010, six projects with a total installed capacity of 23.9 MW, had been supported by this office (DME 2009).

In 2009, the National Energy Regulator of South Africa announced South Africa's first Renewable Electricity Feed-In Tariff (REFIT) which designates Eskom as the single buyer from independent power producers. The key aim of REFIT is to facilitate the meeting of the 2013 renewable energy target. The technologies included in the REFIT program and respective tariffs are: Wind, Concentrated solar power, Small hydro (<10MW), Landfill gas, Large scale grid-connected PV (>1MW), Solid biomass, Biogas. Given the low price of electricity in South Africa, the impact of the REFIT on the viability of renewables projects is expected to be significant (NERSA 2009). By May 2010, however, no power purchasing agreements had been made with power producers.

In 2009, the Department of Energy acquired financing from the Global Environmental Facility towards the cost of Renewable Energy Market Transformation in the country. The aim of the project is to help South Africa eliminate barriers to renewable energy development through support for policy, regulation, legislation, financing mechanisms, institutional capacity building and grant finance for selected project development. The project comprises of two main areas of focus: strengthening local capacity to engage in renewable energy power generation and large-scale rollout of solar water heaters (DBSA 2010).

4.2.7 Barriers to and opportunities for mitigation

Level of financial support required for implementation: Both South Africa's Technical Needs Assessment (DST 2007) and the Long-Term Mitigation Scenario studies stressed that a number of technologies are required for South Africa to adequately contribute to climate change mitigation. In electricity generation, the technology choice is fairly clear: there are two key domestic alternatives to coal – nuclear and renewables. Both of these technologies have barriers, the primary one being cost (Table 4.2.1). Overall, the size of the price gap in the costs to South Africa of new technologies (compared to new coal) depends very much on technology learning, and hence on the investments made in these technologies by industrialized countries.

CDM as a financial mechanism presents an opportunity for individuals and private institutions to partake in various smaller mitigation projects, which have better socio-economic and sustainable development benefits. The total revenue projected over the entire crediting period from the 15 registered projects is about US$ 528 million (37 361 000 CERs). For consideration in international negotiations, other mechanisms such as programmatic CDM, and sectoral crediting have been proposed for the future.

Technology transfer: South Africa's position on technology transfer is that of balanced partnership arrangements. A notable barrier to mitigation technology transfer is that of obtaining global intellectual property rights to these and it is suggested in the TNA that an international code of compulsory licensing for mitigation technologies be established (DST 2007).

4.2.8 Conclusions

Without the establishment of new technology missions aligned to quality-of-life goals and economic and industrial strategies, South Africa will not be able to progress towards a knowledge-based economy (DST 2007). International support will be key in implementation, research and development (R&D). International cooperation on R&D could support South Africa in the following four areas identified by the LTMS (SBT 2007). Support for South Africa's efforts to make a just transition to a low-carbon economy; 2) Positive incentives for people-oriented measures; 3) Assistance in searching for lower-carbon resources; 4) New technology through joint development and transfer.

Contents

Chapter 5: General Steps to Implement the Convention, and other relevant information

5.1 South African National Climate Change Response Policy

5.1.1 Background

South Africa has made significant advances in climate policy since the publication of the Initial National communication. A far more comprehensive set of information on climate scenario development, impacts and adaptation assessment, and in mitigation (including an updated greenhouse gas inventory) is now available to inform national policy efforts. It is clear that policy development in South Africa is most advanced in the area of mitigation, as informed by the extensive Long-Term Mitigation Scenario (LTMS) process (see below), while national policy efforts in adaptation are relatively undeveloped. Given the apparent vulnerability in many sectors of South African economy and their associated livelihoods implications, this issue is now receiving far greater attention in the current development of sectoral adaptation policies, and in the development of a national climate policy process. The current policy imperatives have been informed by some key stakeholder engagements, and a maturing national awareness of the climate change issue. Key elements of this process and the evolution of the current situation are summarised in this section.

The 2005 "Climate Action Now" Conference: Although the National Climate Change Response Strategy for South Africa published in September 2004 was government's first formal provision of policy direction for national climate change responses, this strategy was developed in the context of the policies in place at the time and not within the context of a specific climate change policy.

The initiation of a dedicated climate change response policy development process took place at the National Climate Change Conference held in Midrand, Johannesburg, in October 2005 - the 2005 "Climate Action Now" Conference (DEAT 2005). From 17 to 20 October 2005, under the banner of "Climate Action Now", South Africans from all spheres of life came together to address the growing challenge of climate change and to prepare for its implications. Over 600 representatives from government, business, the scientific and academic communities, and civil society considered the science relating to climate change and key responses to the potential social and economic impacts associated with the compelling scientific evidence of climate change.

Most importantly, the conference unanimously agreed that climate change was a reality, sounding a death knell to the few denialist commentators that had confused and confounded the public debate up to this point.

Furthermore, the gathering was broadly considered a reflection of Government's commitment and determination to act on climate change and to shape policy informed by the best-available science.

In opening the Conference, the then Deputy President, Phumzile Mlambo-Ngcuka, affirmed that South Africa would accept its responsibility to address climate change and would mobilise different economic sectors to meet the challenge. She went on to note that this approach was to be carried out in line with government's strategy for accelerated and equitable growth and sustainable job creation and poverty alleviation.

The Conference gave a platform to eminent scientists and policy makers who outlined the present and likely impacts of climate change on South Africa. These predicted impacts included, among others, increases in the distribution and intensity of drought; reduced agricultural crop yields impacting on food security; potential species extinction; increased growth rates of invasive species; potentially catastrophic coral bleaching; and an increase in the areas affected by vector-borne diseases, including malaria. It was also clearly stated that, in all of these circumstances, it was the poor who would be worst affected.

The Conference agreed that climate change was one of the most significant threats to sustainable development across the globe and that human activity contributed to climate change. With this, the conference acknowledged the urgency of stabilising concentrations of greenhouse gas in the atmosphere - the ultimate objective of the UN Framework Convention on Climate Change – and called on all nations to join in support of the international effort to reduce greenhouse gas emissions, with developed countries taking stronger action.

The 2005 National Climate Change Conference branding

Furthermore, the conference also agreed that the time for countries like South Africa to take further action on the basis of differentiated responsibility had come and there was an expressed wish to see the emergence after 2012 of a strengthened Kyoto or Kyoto-plus regime that was more inclusive, flexible, cooperative and environmentally effective. In addition, the conference noted that the issue of adaptation needed to become a more prominent global priority in the climate regime.

Government's stated commitment to climate action was also voiced by Ministers whose portfolios included Environment, Minerals and Energy, Water and Forestry, Land and Agriculture, and Science and Technology. The Minister of Environmental Affairs and Tourism called for a world-wide climate change awareness campaign to demystify and mainstream climate change, urging the need to make the link, in the minds of ordinary people around the world, between their actions and climate change. The Minister of Agriculture and Land Affairs called for the promotion of food security in the face of the climate change threat. The Minister of Water Affairs and Forestry stressed the importance of water management for adapting to climate change impacts. The Minister of Science and Technology stressed the importance of a National Climate Change Research and Development Strategy as a key instrument to channel the nation's efforts. The Minister of Minerals and Energy launched the Designated National Authority which was hoped would realize the potential of the Clean Development Mechanism (CDM) and actively promote CDM projects in South Africa.

All conference participants agreed that South Africa must accelerate its national response as well as reinforce efforts in the international arena and affirmed that the nation's climate change response was located within a sustainable development paradigm.

From a science and technology perspective, the broadening and deepening of the knowledge base on climate change was considered to be core to an accelerated response. This included prediction, scenarios, early warning systems, disaster management, as well as adaptation and mitigation interventions for South Africa in particular and Africa in general. There was agreement to intensify efforts to use the best available science to address adaptive and mitigation actions in a coordinated manner and a commitment to grow a critical mass of climate scientists to develop a better understanding of the dynamics of climate change. Scientific institutions were urged to put measures in place to entice young scientists into this specialist field and emerging scientists were encouraged to exploit the opportunities presented to them through available programmes. It was affirmed that the nature of climate change and the issues associated with it lends itself to the need for a multi-disciplinary approach to research and development.

The conference resolved to take urgent action to meet the shared challenges in order to guarantee the nation's common future.

Importantly, the conference also compiled and published a number of "statements of intent" by the key constituencies present at the conference in an attempt to demonstrate the common resolve to action and the mainstreaming of climate change considerations in all their respective spheres of activity.

Government's Statement of Intent – the 2005 Midrand Plan of Action: The published undertakings by government describing a number of activities regarded as constituting the foundation of a Midrand Plan of Action was meant to lead the country's climate change programme into the future. These activities included:

- Ensuring the alignment, cohesion and coherence of government responses to climate change by coordinating and driving its climate change responses and interventions through the Inter-Ministerial Committee on Climate Change, its associated Inter-Departmental Committee and the multi-stakeholder National Committee on Climate Change;
- Continuing the review of the National Climate Change Response Strategy;
- Initiating a detailed scenario building process to map out how South Africa could meet its UNFCCC Article 2 commitment to greenhouse gas stabilisation whilst ensuring its focus on poverty alleviation and job creation;
- Initiating a participatory climate change policy development process;
- Using the Air Quality Act to regulate greenhouse gas emissions and encourage a move to cleaner production, including the setting of emission standards that encourage energy efficiency;
- Compiling sectoral action plans to implement the National Climate Change Response Strategy;
- Initiating a participatory national climate change research and development strategy development process that would coordinate and focus current research in a manner that delivers the critical mass of multi-disciplinary knowledge in focus areas while creating the opportunity to develop and retain human capital and research infrastructure;
- Driving increased research and innovation for the hydrogen economy

using the research chairs programme and providing early demonstration of technologies for 2010;
- Strengthening the South African Environmental Observation Network (SAEON) to facilitate long term climate research and establishing a coordinating mechanism for South Africa's investment in earth observation as well as providing an interface with the Global Earth Observation System of Systems (GEOSS);
- Establishing the South African National Energy Research Institute (SANERI);
- Developing a technology needs assessment to frame a programme of action for technology transfer;
- Facilitating the development of clean technologies for climate change mitigation;
- Actively supporting the strengthening of the CDM, particularly a streamlined methodology review process and mechanisms to reduce transactions costs for smaller, bundled projects, during the COP/MOP in Montreal in November 2005, without reopening the Marrakech Accords;
- Ensuring that renewable energy and energy efficiency are included as viable alternatives to conventional fossil fuels in government's integrated energy planning process;
- Exploring new funding sources and mechanisms to support the expansion and use of renewable energy;
- Establishing the National Energy Efficiency Agency to coordinate public and private investment in energy efficiency;
- Considering climate change impacts in its water conservation and demand management initiatives;
- Reviewing and reassessing the ways in which South Africa operates its dams and quantifies the Ecological Reserve to account for a changing climate;
- Reviewing the details of water-sharing agreements in the light of new physical realities;
- Examining the design and implementation of the water allocation reform process to ensure that climate change considerations are taken into account;
- Designing and implementing an outreach strategy to create awareness of the implications of climate change among stakeholders and customers in the water sector;
- Ensuring that climate change considerations are included in the evaluation of new agricultural research and development projects;
- Reviewing and revising agricultural policy to ensure climate change resilience; and
- Ensuring that climate change is fully considered and reflected in the four elements of agricultural early warning systems, including: prior risk knowledge; monitoring and warning services; dissemination of warnings/information; and response capacity.

5.1.2 The Long-Term Mitigation Scenario process

In response to the "initiating a detailed scenario building process…" and "initiating a participatory climate change policy development process" activities of the 2005 Midrand Plan of Action, in March 2006 Cabinet mandated a national process of building scenarios of possible greenhouse gas emission futures, informed by the best available research and information, to define not only South Africa's position on future commitments under international treaties, but also to shape the nation's climate change policy for the longer-term future. In line with the Cabinet mandate, the Long-Term Mitigation Scenario (LTMS) process was launched in mid-2006.

The focus of the LTMS process, as the name suggests, was mitigation (i.e. reducing emissions of greenhouse gases). The then Department of Environmental Affairs and Tourism (DEAT), as the focal point for climate change in South Africa, convened and managed the process, which was overseen by the Inter-Ministerial Committee on Climate Change. DEAT appointed the Energy Research Centre at the University of Cape Town to project manage the entire process and they, in turn, convened and contracted the process specialists and set up the personnel for four focussed Research Support Units. The LTMS Scenario Building Team was established in late 2006 to carry out the technical aspects of the process. The Scenario Building Team was made up of individual stakeholders from government, industry, labour, civil society, as well as other relevant players. The products of the LTMS were signed-off by the Scenario Building Team in November 2007.

The LTMS process and its products were well received by all stakeholders and are regarded as being robust and broadly supported. It was also clear that there was consensus that the results had been achieved through a sound technical methodology and extensive stakeholder involvement.

5.1.3 Government's 2008 Policy Directions

In July 2008, following a discussion around various developments in the climate change field, including the LTMS findings, Cabinet approved a climate change policy development process and associated development timeframes and also provided 6 broad policy themes to focus the development of the policy. In summary, the policy development plan required a high-profile launch of the process, the production and publication of a Green Paper by mid-2010 and a final draft policy to be submitted by the end of 2010. The six broad policy themes included:

Theme 1: Greenhouse gas emission reductions and limits – That climate change mitigation interventions should be informed by, and monitored and measured against a "peak, plateau and decline" emission trajectory where greenhouse gas (GHG) emissions stop growing (start of plateau) in 2020-25 and greenhouse gas emissions begin declining in absolute terms (end of plateau) in 2030-35.

Theme 2: Build on, strengthen and/or scale up current initiatives – That current energy efficiency and electricity demand-side management initiatives and interventions must be scaled-up and reinforced through available regulatory instruments and other appropriate mechanisms (made mandatory); that, based on the electricity-crisis response, government's energy efficiency policies and strategies must be continuously reviewed and amended to reflect more ambitious national targets aligned with the LTMS; and that Treasury will study a carbon tax in the range modelled by the LTMS, starting at low levels soon and escalating to higher levels by 2018/ 2020, with sensitivity to higher and lower tax levels, and report to Cabinet on its findings.

Theme 3: Implementing the "Business Unusual" Call for Action – That the renewable energy sector is identified as a key "business unusual" growth sector and policies and measures are put in place to meet a more ambitious national target for renewable energy; that in committing to national GHG emission limitation and reduction targets, government must promote the transition to a low-carbon economy and society and all policy and other decisions that may have an impact on South Africa's GHG emissions must take this commitment into regard; and that the transport sector is identified as another key "business unusual" growth sector and policies and measures are put in place to meet ambitious and mandatory national targets for the reduction of GHG emissions from this sector.

Theme 4: Preparing for the future – That there is increased support for the new and ambitious research and development targets that are being set, especially in the field of carbon-friendly technologies – with the focus on the renewable energy and transport sectors; and that formal and informal forms of education and outreach are used to encourage the behavioural changes required to support the efficient and effective implementation of the climate change response policy.

Theme 5: Vulnerability and Adaptation – That South Africa continues to identify and describe its vulnerabilities to climate change; that we describe and prioritise what adaptation interventions must be initiated, who should be driving these interventions and how implementation will be monitored; and that affected government departments will ensure that climate change adaptation interventions in their sectors are included as departmental key performance areas.

Theme 6: Alignment, Coordination and Cooperation – That the roles and responsibilities of all stakeholders, particularly the organs of state in all three spheres of government, will be clearly defined and articulated; that the structures required to ensure alignment, coordination and cooperation will be clearly defined and articulated; and that climate change response policies and measures are mainstreamed within existing alignment, coordination and cooperation structures.

5.1.4 The 2009 Climate Change Summit

In accordance with Cabinet's mandate, from 3-6 March 2009, South Africans from all spheres of life came together in Midrand to initiate a consultative process to develop the South African Climate Change Response Policy. The "Climate Change Summit 2009" involved 900 representatives from government, business, the scientific and academic communities, and civil society and over 150 "virtual participants" linked through the Internet.

The Climate Change Summit 2009 -

- considered the Intergovernmental Panel on Climate Change's 4th Assessment Report and more recent international and local science relating to climate change;
- discussed and debated the potential social and economic vulnerabilities and impacts associated with the compelling scientific evidence of climate change;
- discussed and debated the potential policy responses to these key vulnerabilities and impacts, in particular for the poor, women and youth;
- discussed and debated the urgency of reducing greenhouse gas emissions internationally and locally as well as the costs of both action and inaction;
- considered the outcomes of work done since the 2005 National Climate Change Conference, including the Long-Term Mitigation Scenarios (LTMS), the Climate Change R&D Strategy, the Technology Needs Assessment, the 2000 Greenhouse gas inventory and the initiation of the 2nd National Communication;
- discussed and debated the international implications of our response in line with the need for South Africa to shoulder its fair share of responsibility as part of an effective global response; and
- discussed and debated the process of developing an integrated, cohesive, coherent and effective National Climate Change Response Policy.

Following active and vigorous discussions and debates around South Africa's policy response to climate change, there was widespread consensus on:

- making a contribution to the goal of limiting global temperature increase to below 2°C above pre-industrial levels;
- the transition to a climate-resilient and low-carbon economy and society;

- placing the climate change response in the context of equity, sustainable development and poverty eradication;
- the maintenance of a strong science-policy interface;
- balancing our adaptation and mitigation responses and integrating adaptation into development planning;
- building climate resilience at a local level, including prioritisation of energy access for the poor;
- the scaling-up of renewable energies and energy efficiency;
- energy efficiency standards for industrial equipment and processes;
- the need for integrated energy planning;
- the need for enhanced government coordination and policy alignment;
- putting a price on carbon;
- massively up-scaled public education, awareness, media and information on climate change;
- advancing gender mainstreaming as a critical dimension of poverty eradication, sustainable development and adaptation to climate change; and
- mobilising the resources required, including the significant investment in research and development for new technologies.

Most participants also agreed on the need to fast-track the implementation of favourable tax treatment for carbon credits from Clean Development Mechanism projects.

The Summit also provided a space for the expression of differing views. In this regard, the following areas of divergence were identified as requiring further discussion during the policy development process –

- The nature of the country's energy mix, the meaning of 'cleaner energy', the transparency of integrated energy planning and optimal institutional arrangements. In particular, our approach to coal-based electricity, expanding the use of nuclear power and the feasibility of renewable energy technologies to address base load demand were hotly debated.
- Transparency in the decision-making process was stressed by most participants, with several calling for an independent review of the national electricity utility's expansion programme in the light of climate change considerations.
- On economic instruments, most participants felt that taxes, emissions trading, incentives and subsidies could play a role. Some felt that a double dividend (both GHG emission reductions and socio-economic benefits) could be achieved by recycling the revenues of a carbon tax or auctioning allowances for domestic GHG emissions trading, while others cautioned about the potential impacts of increased taxes in the current financial context, as well as concerns about ear-marking of revenues. Some participants proposed a pilot phase for domestic emissions trading, which could be voluntary initially and develop into a mandatory cap-and-trade system.

In taking the policy development process further, the Summit agreed that –

- The National Climate Change Response Policy will be developed through a participatory, multi-stakeholder, consultative and iterative process;
- Issues raised during the Climate Change Summit 2009 must be addressed in a transparent manner and fed into the policy development process;
- All key affected national departments must initiate and facilitate the development of the sector-specific components of the National Climate Change Response Policy that fall within their mandate, jurisdiction or sphere of influence;

- Local government, through the South African Local Government Association and associated provincial associations, must initiate and facilitate the development of the municipal components of the National Climate Change Response Policy that fall within their mandate, jurisdiction or sphere of influence, including undertaking vulnerability and risk assessments in their areas and the integration of climate adaptation and mitigation actions into Integrated Development Plans;
- Provincial government must initiate and facilitate the development of the provincial aspects of the National Climate Change Response Policy that fall within their mandate, jurisdiction or sphere of influence, in particular the integration of climate change issues into provincial spatial and strategic plans;
- The Department of Environmental Affairs will coordinate the policy development process using established inter-governmental and multi-stakeholder coordination forums and mechanisms and will ensure that all sector inputs are properly reflected in the evolving policy;
- Business will engage within its constituency to develop consensus inputs into the policy process and to work actively with Government and other stakeholders to contribute to a sound climate change response policy;
- Civil society, labour and the faith communities will continue to raise public awareness and motivate individuals, institutions and authorities to take actions to reduce greenhouse gas emissions and adapt to the adverse impacts of climate change, to critically evaluate and respond to the initiatives of government and the private sector, and to build the capacity of civil society to participate constructively in a consultative process to develop a national climate change response policy;
- The climate change science community will work together to improve projections of climate variability, climate change and their impacts, key vulnerabilities in affected sectors and communities, and exploration of appropriate mitigation and adaptation responses and their implementation.
- All Summit participants will engage with, and mobilise, their colleagues and/or constituencies to play an active role in the policy development process.

Finally, all Summit participants committed themselves to ensuring that the policy development time frames are adhered to with a view to the publication of a White Paper on the National Climate Change Response in December 2010.

5.1.5 The 2010 Climate Change Policy Round Table

Following a period of ongoing policy discussion after the 2009 Climate Change Summit, interrupted only by the UNFCCC COP 15 in Copenhagen, government hosted a Climate Change Policy Round Table on 17 May 2010 with the purpose of providing key climate change response stakeholders with an update on the National Climate Change Response Policy development process and to provide a platform for key climate change response stakeholders to respond to, and discuss, the most recent Climate Change Policy Discussion Document. During the round table discussions it was reconfirmed that a national Climate Change Response Green paper would be published for public comment in mid-2010 and that the final draft policy would be submitted to Cabinet by the end of the year.

5.1.6 *Current Policy Status*

From the above it is clear that South Africa has made every attempt to ensure that its climate change policy is informed by science and developed through a fully participatory process.

Although the policy is still under development and is unlikely to be completely finalized when this National Communication is submitted, it is clear that South Africa, taking into account the common but differentiated responsibilities and respective capabilities of all nations and the inter-generational commitment of the Environmental Right contained in the country's Constitution, has the climate change response objective of –

- making a reasonable contribution to the stabilisation of greenhouse gas concentrations in the atmosphere at a level that prevents dangerous anthropogenic interference with the climate system; and
- effectively adapting to unavoidable and potential climate change impacts through interventions that build and sustain South Africa's social, economic and environmental resilience and emergency response capacity.

It is also clear that, in respect of mitigation efforts and as a developing country, the scale and ambition of South Africa's contribution will also be dependant on the scale of international funding and technology transfers.

5.1.7 *Policy Coordination*

The development of the National Climate Change Response Policy, greenhouse gas mitigation and climate change adaptation are specifically included in the President's list of outputs that Cabinet Ministers must generate in the current term of office. With this, the policy development process is reported to Cabinet on, at least, a quarterly basis. Furthermore, the Presidency also requires the establishment of a technical cross-cutting "delivery forum" to coordinate and align the activities associated with these outputs.

Intergovernmental Committee on Climate Change (IGCCC): In order to operationalise cooperative governance in the area of climate change, the Intergovernmental Committee on Climate Change (IGCCC) was established in 2008 to foster the exchange of information, consultation, agreement, assistance and support among the spheres of government with respect to climate change and government's response to climate change and facilitate the policy development process and implementation thereof. Furthermore, the IGCCC is now regarded as the "delivery forum" in respect of the President's required climate change outputs.

The terms of reference for the IGCCC includes:

Dealing with International and Local Policy matters, including:

- Informing South Africa's climate change-related international negotiation positions and the make-up of South African negotiating teams and delegations;
- Facilitating and coordinating the alignment of all policies, strategies, action plans, legislation, regulations, systems, implementation projects, pilot projects, that may have an impact on government's climate change policies and programmes;

Dealing with implementation matters, including:

- Acting as the de-facto Government Steering Committee for climate change-related projects that impact on, or require the active involvement of, more than one of the IGCCC members (e.g. National Greenhouse Gas Inventory, Climate Change Policy development process, etc.);

- Providing a platform for all IGCCC members to share information on their various climate change-related projects and initiatives (including, but not limited to, policy, strategies, action plans, legislation, regulations, systems, implementation projects, and pilot projects);
- Facilitating and coordinating the efficient and effective implementation of various climate change-related projects and initiatives that impact on, or require the active involvement of, more than one of the IGCCC members;
- Monitoring and reporting progress on the implementation of various climate change-related projects and initiatives that impact on, or require the active involvement of, more than one of the IGCCC members;

Dealing with information management matters, including:

- Providing a platform for all IGCCC members to share information on forthcoming national, regional and international climate change-related events (e.g. conferences, seminars, workshops, training opportunities, etc.);
- Acting as a reference group to ensure consistent, integrated and coherent government messaging for climate change-related outreach and awareness-raising activities.

5.2 Technology transfer

5.2.1 Technology Needs Assessment

South Africa has conducted a Technology Needs Assessment in conformance with Article 4, paragraph 5 of the Convention, read with decision 4/CP7. The assessment began in November 2004, commissioned by the Department of Science and Technology (DST) and conducted by the CSIR. The process followed the guidelines laid out in UNDP (2003), Gross *et al.*(2004). The first document delivered was a background paper (CSIR 2005) reviewing the scope of the assessment and the indicative technologies under consideration. The second phase, beginning July 2006, included a process of consultation with stakeholders in government, industry, civil society and academia that generated a prioritised set of technologies. A report synthesising the outcome of the assessment (Taviv *et al.*2007) was presented to stakeholders in August 2007. The South African Technology Needs Assessment (TNA), based on this information, was published by the Department of Science and Technology in September of that year (DST 2007). The TNA was approved by Cabinet in November 2007 and has since been submitted to the UNFCCC. The Long Term Mitigation Scenarios (LTMS) project began after the TNA was underway, and ended after the completion of the TNA. Therefore the DST commissioned an addendum to the TNA that dealt with the technology needs as revealed by the LTMS (Winkler & Boyd 2009).

5.2.2 The Climate Change Technology Needs of South Africa

Technology Transfer is defined as a 'broad set of processes covering the flows of know-how, experience and equipment for mitigating or adapting to climate change amongst different stakeholders such as governments, private sector entities, financial institutions, NGOs and research/education institutions' (IPCC 2000). In other words, technology transfer includes both the 'hard issues' of accessing technology and the skills and capabilities necessary to use it, and the 'soft issues' that are associated with its adoption or non-adoption. These include, amongst others, issues such as the cost of the technology, market failures that impede its implementation, technology design issues such as poor adaptation to local conditions and consumer preferences.

'Technology transfer' is sometimes narrowly construed as the final step in the technology cycle. South Africa takes a holistic view of the technology acquisition process, placing it within the context of South Africa's National System of Innovation. The 'technology cycle' includes several overlapping phases: research; development, demonstration and transfer (in the narrow sense). Constraints to technology implementation can occur in any one or several of these phases, requiring targeted and specific interventions if the overall technology flow is to be unimpeded. Thus, for the purposes of this chapter 'Technology Transfer' is taken to refer to the entire process of identifying, researching, developing or adapting and implementation of technology.

The South African TNA process generated an initial list over a hundred specific technologies related to climate change mitigation and/or adaptation. The options were then scored in relation to eleven criteria (mitigation potential, vulnerability to climate change, alignment with national strategies and policies, environmental sustainability, competitive advantage, economic cost and benefit, potential scale of use, technology maturity, the availability of support systems including human capacity, cultural preferences of users, and relation to indigenous knowledge) by eight domain experts. The weightings associated with each criterion were determined by the broader stakeholder community, and the scores were summed to give a ranked priority list consisting of approximately the top quartile (Table 6.1.1).

The LTMS project focussed only on mitigation. It was also highly participatory, but prioritised its technologies on the basis of effectiveness and cost-benefit analyses. The

TNA and LTMS were in general agreement (with one exception, discussed below), but the LTMS provides more specific detail in some cases. It identified four broad areas with high mitigation potential, in the sense of achieving the greatest emission reductions in a cost-effective manner: energy efficiency; electricity generation; carbon capture and storage; and transport. These areas deserve particular attention in terms of South Africa's technology needs – however, a robust portfolio of mitigation options must necessarily include other components as well. Furthermore, in the context of South Africa's priorities for development and poverty alleviation, the portfolio of mitigation activities should also include smaller activities, some of which have better socio-economic or sustainable development benefits than the ambitious projects which could lead to a large reduction in greenhouse gas emissions.

Energy efficiency was the one area not prioritized by the TNA, but identified by the LTMS as integral to all strategic options. Energy efficiency in industry shows the greatest potential emission reductions, but energy efficiency has benefits in almost all sectors, including commercial and residential buildings and transport. Key technologies considered include, among others, solar water heating and a range of industrial equipment and processes. Improved energy efficiency can be implemented immediately, using incentives such as mandatory energy efficiency standards.

The broad prioritisation of "solar power", "clean coal technologies" and "wind power" in the TNA can be enhanced by detail from the LTMS analysis. "Clean coal" by itself shows relatively modest emission reductions, unless accompanied by Carbon Capture and Storage. Concentrating Solar Power (CSP), the parabolic trough and wind turbines are three specific renewable energy technologies highlighted by LTMS.

Wind power is currently more cost-competitive than CSP. There are some areas of medium-to-high wind power potential in South Africa. Key barriers to widespread adoption is the absence of a critical-mass wind power industry in South Africa, and the distance between the areas of high wind potential and the areas of electricity demand. Technology support could take the form of assistance with the capital cost of the initial 1000 MW of wind turbines needed to make the industry viable, and extension of the transmission grid to remote windy locations. Both wind and CSP are relatively labour intensive, which fits in with South Africa's priorities on poverty alleviation and reducing unemployment.

The LTMS identified Carbon Capture and Storage as a key element in making the 'clean coal' technologies such as coal gasification climate-friendly (Table 6.1.2). There are significant research needs relating to CCS, and challenges regarding implementation at large scale. The largest potential reduction of industrial process emission are from applying CCS to new coal-to-liquid synfuel plants, where approximately half the CO_2 emissions are already in more than 90% concentrated form. South Africa considers only geological carbon storage. Work is underway to produce an atlas of potential storage sites.

Both the TNA and the LTMS identified the transport sector as one with priority technology needs. Modest improvements in the efficiency of vehicles using conventional (internal combustion) technology would yield substantial emission reductions relative to the baseline, at a cost saving. Electric, hybrid internal combustion-electric and hydrogen-fueled vehicles all deserve consideration. A South African company is developing an electric vehicle, making this an area for joint technology development. According to the LTMS the potential for biofuels is limited. More potential exists in a modal shift in passenger and freight transport (eg, from road to rail).

Table 6.1.1. The prioritised technologies identified in the TNA, by response type (mitigation, adaptation or overarching) and sector. This list was selected, on the basis of multicriteria analysis, from over 110 options that were considered. Source: DST (2007)

Response	Sector	Subsector	Measure/technology Options	Total score (% of the maximum possible score)
Mitigation	Energy	Electrical energy generation	Solar power	85.6
			Clean coal technologies	75
			Wind power	75
		Industry/mining	Boiler improvement	78.8
		Waste management	Promote the source reduction, recycle and reuse	84.8
	Agriculture, Land Use and Forestry		Conservation agriculture	83.3
			Control of biomass burning on wildfires (including forests)	81.8
	Transport		Improvement of urban mass-transport systems	81.8
			Fuel-efficiency improvement	81.1
Adaptation	Human Health		Provision of water supply and sanitation	90.4
			Control of the spread of vector-born disease	87.1
	Agriculture, Land Use and Forestry		New crop species and cultivars	88.6
			Information technology	87.1
			Macro-economic diversification and livelihood diversification in rural areas	82.6
			Pest management	80.3
			Vulnerability research	80.1
	Water Resources		Technologies that promote water efficiency	81.8
	Built Environment and Infrastructure		Climate-sensitive building design	81.8

Overarching Issues	Measures/technology options	Total Score (% of the maximum possible score)
	Weighting factor	57
Cross Cutting	Improved data management, processing and integration	75.4
	Improved communication and response in Disaster management	74.6
	Networks for information sharing and data integration	72.8
Financial Mechanisms	Incentives for energy efficiency	88.6
	Incentives for renewable energy	75.4
	Disincentives for high fuel consumption vehicles	72.8

Table 6.1.2. Selected mitigation technologies identified by the LTMS as having high potential, either due to low mitigation costs or high mitigation quantities. Source: Extract from LTMS Technical Summary (ERC 2007: 7-8)

Mitigation option	Mitigation cost (R / t CO_2-eq)	GHG emission reduction, Mt CO_2-eq, 2003-2050
Passenger modal shift	-1,131	469
Improved vehicle efficiency	-269	758
SWH subsidy	-208	307
Commercial efficiency	-203	381
Residential efficiency	-198	430
Industrial efficiency	-34	4,572
Renewables with learning, extended	3	3,990
Waste management	14	432
Nuclear, extended	20	3,467
Agriculture: reduced tillage	24	100
Escalating CO_2 tax	42	12,287
CCS on power stations, 20 Mt per year	72	449
Synfuels CCS 23 Mt	105	851
Subsidy for renewables	125	3,887
Coal mine methane reduction (50%)	346	61
Electric vehicles in GWC grid	607	450
Hybrids	1,987	381

5.2.3 Enabling Environments for Technology Transfer

Successful technology assimilation requires a holistic supporting environment. All of the following factors need to be satisfied: sound policy; adequate human resources; and the affordable availability of the technologies themselves and the associated technologies and infrastructure necessary for their implementation and maintenance.

The list of potential barriers to the adoption of climate-beneficial technology is long (Table 6.1.3). In the South African experience, two stand out especially. They are project finance (not just the terms of payment, but the absolute scale of the required investment), and the uptake capacity, especially in terms of human resources.

Table 6.1.3. A comprehensive list of barriers to technology transfer identified by the TNA process, and the suggested solutions.

Barriers	**Suggestions for enabling environment**
Intellectual property issues payments required limit innovation in developing countries	International and bilateral negotiations, research partnerships, treating critical technologies as public goods
Technology contributes to the advancement of knowledge on climate change, but is too costly	Government support; International cooperation and knowledge transfer; international funding
New technology with promise for local application (or specific for Africa/developing countries), but too costly to develop	Government support; International cooperation and knowledge transfer; international funding
Technology has not yet been proven for local application	Pilot and case studies in cooperation with developers
Physical resource constraints	Examine possibility of applying in other Southern African Development Community countries
Lack of knowledge by potential users of technology and its benefits	Communication and education; development of a critical mass of human capital via appropriate policies; development of adequate support for the national education system, awareness and marketing (branding)
Lack of technical capacity to establish and maintain the technology	International cooperation and knowledge transfer; technology-related capacity building; development of a critical mass of human capital via appropriate policies; development of adequate support for the national education system
High cost of establishment of the technology	Re-evaluation taking full cost into account; R&D for local substitutes; removal of import tariffs, international funding or subsidies
High cost of operation and maintenance for the technology	Re-evaluation taking full cost into account; R&D for local substitutes; subsidies
Various market failures, including the lock-in of existing technologies due to large investment in them in the past	Strategic planning and interventions at appropriate level
Cultural preferences impeding uptake of technologies	Communication and education; culturally appropriate modification of the technology
Inadequate macro-economic policies	Changes in the macro-economic environment; improving financial and administrative efficiencies
Low perception of importance by economic actors	Necessity of an explicit national policy supporting technology development

Barriers	Suggestions for enabling environment
Low savings potential	Measure to improve productivity through streamlining of government functions
Lack of suitable small and medium sized firms for subcontracting	Provision of support to small and medium-sized firms for productive activities in the economy
Lack of appropriate financial systems	Cooperation with financial institutions, such as the Development Bank of Southern Africa
Unfair pricing system, no price signals and barriers to introduction of technologies, e.g. energy efficiency options	Change price policies
Monopolistic or oligopolistic market structure	Allow and encourage competition
Absence of feasible and appropriate standards based on local conditions	Establish appropriate standards
Institutional inertia and unwillingness to change	Restructuring and introducing corporate and personal accountability
Lack of adequate government support facilities	Government investments; international funding
Lack of access to global information (e.g. expensive technology for attending conferences)	Establishment of effective linkages with national education systems, web-based information dissemination, international cooperation and knowledge transfer
Lack of local data (e.g. on performance, banking and insurance) for design of good investment projects and for appraisal (monitoring, assessment and evaluation)	Develop and maintain integrated and accessible information systems
Lack of engineering procedures for testing, commissioning, and supporting equipment purchases (e.g. PV technology), leading to poor performance, maintenance and operation, and making the technology), appearing to be dysfunctional	Develop engineering procedures for testing and commissioning of equipment and system of support to users, international knowledge transfer
Non-transparent legal system	Legal system reform ensuring compliance, property rights and transparency
Relatively weak enforcement mechanisms for legislation relating to investments and companies	Legal system reform ensuring transparency of investment considering triple bottom line

One of the key barriers to technology diffusion is risk aversion by operational and commercial entities. Risk is high in new technologies, and especially when they are applied in new environments. A solution is risk sharing. The example below illustrates how it could work for the example of Concentrating Solar Power. A 100 MW CSP demonstration plant is estimated to cost between 3 and 6 billion rands, and could be completed within a few years. Risk sharing of 50% with the international community is likely to make it an attractive proposition. In the next phase, risk sharing could be reduced to a lower percentage (e.g. 25%) on a further 4 x 100 MW (R 5 billion, up to 2015). The next stage would be agreements on R&D collaboration (with appropriate sharing of intellectual property) and support to develop institutional capacity for the roll-out of large-scale CSP to 30 GW by 2030.

The TNA noted that focused mechanisms, such as disincentives, are needed to affect consumers' choices and behaviour. The largest single mitigation option identified by LTMS was an escalating CO_2 tax. The main impact of the tax is to reduce coal use; as a result, the projected electricity grid becomes dominated by nuclear and renewable energy. A carbon tax, while not a technology in itself, is highly relevant to technology adoption, since it is a means to remove relative cost barriers to climate-friendly technologies.

Support from the international community for ‘putting a price on carbon’ could take the form of technical assistance in consideration of carbon taxes, emissions trading, tradable certificates for energy efficiency and / or renewable energy, as well as other incentives.

Setting price on carbon that is sufficient to discourage emission-intensive technologies relative to low emission technologies is a key policy element of an enabling environment. Pricing carbon should take place in the context of a broader enabling environment, drawing on the elements outlined in Table 6.1.3 of the TNA. The macro-economic analysis conducted for the LTMS confirmed that recycling of revenues is critical to the impact of a carbon tax on the economy as a whole and poor households in particular.

5.2.4 Mechanisms for technology transfer

South Africa is a relatively technologically advanced developing country. Due to a range of circumstances, it has become adept at identifying the technologies it needs, and importing, adapting or developing them locally. The skills needed for mastering technology are broadly (but not comprehensively) spread through the private sector, state-owned enterprise, and government sectors. The legacy of past educational and economic inequities means that not all sectors of the population and economy are equally technology-ready. The challenges of technology transfer, in the broad sense, are therefore as much within the country as between the rest of the world and South Africa.

South Africa has a pivotal role as a partner in transferring technologies from the developed world into developing world situations, particularly in sub-Saharan Africa, and it has demonstrated this capability in many spheres, including electricity generation, transport, communications, mining and agriculture. It also has some technologies of its own that could be useful elsewhere.

Experience in South Africa demonstrates that technologies that are simply imposed, or even donated with good intent but little local buy-in, seldom take root. On the other hand, despite several outstanding examples of world-class locally-developed technology, a realistic review of inward-looking local technology development will also reveal many complete or partial failures (either technically or economically). South Africa recognises that it commands a small fraction of the global pool of technological expertise, and that the bulk of South African technological needs, now and in the future, will be sourced internationally. The global technologies that have been successfully and sustainably embedded in South Africa have had two attributes: a real and well-evaluated local demand; and a high degree of joint development and local adaptation.

South Africa recognises the validity and appropriateness of several different modes of technology transfer. For instance, in the climate change mitigation sector the main mode of technology transfer is likely to be market-based, with a willing buyer, and a willing seller. The main role of national and international interventions in this model is to prevent 'market failures', for instance by 1) ensuring that suitable controls exist to minimise anticompetitive practices such as price-fixing 2) to reduce information asymmetries by knowledge brokering and the setting of verifiable and relevant product standards.

In the adaptation sector, some technologies are amenable to market-based transfer mechanisms, but many are 'public goods', for which it is either unethical or impractical to charge a use fee. The key interventions involve information dissemination and training. In South Africa, as elsewhere, it is recognised that the movement of relevant information from researcher to user is a slow and uncertain process. To facilitate better communication of research results, the South African Global Change Grand Challenge has established a mechanism, called the South African Risk and Vulnerability Atlas, to make information on global change impacts easier to obtain and understand for users.

Even with a well-functioning technology market and the free flow of information, climate-beneficial technologies will not necessarily be adopted if they are more expensive than alternative less-beneficial technologies. Article 4.5 of the UNFCCC makes the case for the 'incremental cost' of adopting the more climate-friendly technology by a non-Annex 1 country, such as South Africa, to be fully or partially offset by contributions from Annex 1 countries. South Africa favours the establishment of a global climate technology fund, financed through levies on Annex 1 nations (with verified bilateral contributions offset against the assessment), for this purpose. Non-Annex 1 countries would have equitable access to this fund, according to their needs and circumstances, and in relation to a Technology Action Plan. The system would need to be governed by an Executive Board for Technology.

South Africa does not consider intellectual property rights to be a general constraint on technology transfer. However, there are potentially situations where the parties most affected by climate change are also those least able to pay for technology. It is thus not attractive for the technology owners and developers to deliver the product under standard market conditions. Furthermore, there is an ethical argument that additional cost of adaptation to climate change should not be borne by those who are only minimally responsible for the historical burden of climate change. In these circumstances there is a clear case for placing the intellectual property in the public domain, and subsidising the transfer of the technologies to the point where they are affordable by those that need them.

5.3 Systematic Observation, Monitoring and Research

5.3.1 Introduction

South Africa hosts some of the most extensive monitoring networks in Africa, and has launched its own Earth Observation Strategy (SAEOS) in 2007, as a contribution to earth observation of the integrated global system. Since the adoption of this strategy, awareness of the importance of a system of a geospatial infrastructure to coordinate the collection, assimilation and dissemination of earth observation data to support decision-making processes in South Africa has gained much momentum. This brief account provides some examples of the country's activities with respect to systematic observation, monitoring and research in the field of climate change.

As part of the country's strides to better coordinate and strengthen its research efforts, a 10 year research plan that provides a focussed framework for global change research has been developed. Systemic observation and monitoring forms one of the key knowledge generation focus areas within that framework. In 2009, the South African Risk and Vulnerability Atlas project was initiated. The intention of this project is to ensure that scientifically sound information regarding local risks and vulnerabilities across sectors is easily accessible to decision-makers, particularly at the local government level. It is envisaged that the project will be expanded into the region as efforts to build Africa's resilience to climate variability.

South Africa's efforts have to date have resulted in progress on:

- the scientific understanding of climate variability and change on seasonal, decadal and centennial time scales;
- the analysis and prediction of Earth's climate system variability and change; and
- establishing a dialogue between scientists, policy-makers and practitioners that facilitate the sharing of information for decision makers concerned with climate adaptation, mitigation and risk management.

5.3.2 Status of national programmes

As a progressive developing country, South Africa is committed to the imperatives of sustainable development. However, as in other countries, this is at times impeded by a lack of reliable long-term data at scales that are relevant to policy, and by the lack of integration between the various systems that provide information on the environmental, social and economic elements of sustainability.

To address this critical gap, the South African Environmental Observation Network (SAEON) was established in 2002. SAEON seeks to coordinate and support long-term in-situ environmental observation systems. SAEON is almost unique in the southern hemisphere and is the first such network in Africa. In addition, its innovative, integrated information management systems will strengthen scientific research and inform policy-making for many years to come. SAEON has played a crucial role in the formation of a network of environmental observatories for Southern Africa. The Environmental Long-Term Observatories of Southern Africa network, ELTOSA, launched in 2003, creates synergy among the observation networks of the southern African countries. It also has the effect of building sufficient critical mass in human and infrastructural capacity building for in situ earth observation in the region. The ELTOSA countries have since been collaborating to increase the effectiveness of regional earth observations and information.
In addition to SAEON, the Department of Water Affairs assembles, curates and monitors

data on climatic and hydrological variables from selected sites across South Africa. Similarly the Department of Environmental Affairs has put in place the South African Air Quality Information system as a tool to comply with national and international information management requirements and commitments. A record of climate change related projects are also maintained by this Department.

In general, observation, monitoring and research programmes are undertaken by a variety of science councils, universities and non governmental organizations, often in partnership with government departments and their agencies. Some of these are mentioned below.

Programmes at the science councils: The Agriculture Research Council (ARC), Council for Geo-sciences (CGS), Council for Scientific and Industrial Research (CSIR) and the South African Institute of Aquatic Biodiversity (SAIAB) are involved in observation, monitoring and research programmes that cover wetlands and inland water systems, the atmosphere, agricultural land and rangelands, the Southern and Indian Oceans, marine ecosystems, coastal and estuarine ecosystems, savanna, forests and woodlands, and arid and semi-arid regions. The work involves detection of climate change, and assessment of its impacts on these diverse ecosystems. It also extends to developing mitigation and adaptation strategies. Their main outputs have been publications in scientific journals, technical reports, collections and data banks.

Programmes at the agencies of government departments: The South African National Biodiversity Institute (SANBI), South African National Parks (SANParks), South African Weather Services (SAWS) and the Water Research Commission (WRC) are agencies of the Department of Water and Environmental Affairs (DWEA) that are engaged in climate change-related monitoring and/or research work.

SAWS conduct research on the meteorological fundamentals of climate change. They manage 20 fully equipped weather offices, including stations on the Gough and Marion islands, as well as at the Antarctic Base (the South African National Antarctic Expedition, SANAE). A number of "drifting buoy" weather stations are also deployed by the SAWS every year in the southern Atlantic Ocean. A comprehensively equipped and long-established station at Cape Point is the focal point for Global Atmosphere Watch activities in southern Africa, which include the monitoring and research of the ozone layer, solar radiation, as well as measurements of atmosphere trace gases. Since 1995, routine measurements have been made of ozone-depleting gases, as well as UV-A and UV-B radiation. A number of numerical weather prediction models are used to produce forecasts. The Weather Forecasting Research programme focuses on the consolidation of methods to evaluate weather forecast accuracy, including temperatures, rainfall and forecasts of severe weather.

The efforts of SANBI (nationally) and SANParks (within national parks) focus on the impact of climate change on biodiversity and habitats, whilst the WRC contracts institutions to carry out research on impacts of climate change on the hydrological cycle and water resources. The agencies are also involved in investigations of climate change mitigation and adaptation in their respective spheres of operation and influence. The outputs of the work carried out by SANBI and SANParks form the basis for developing and revising biodiversity and habitat management plans (such as the National Biodiversity Strategy and Action Plan), and the work commissioned by the WRC informs the development and revision of water catchment and water resource management plans.

Meteorological, Atmospheric and Oceanographic Programmes: Most recently the Applied Centre on Climate and Earth System Science (ACCESS) has been established as a South African Centre of Excellence. The research programme of ACCESS seeks, amongst other things, to assemble an integrated understanding of southern African earth systems over a wide range of timescales. It is designed to approach the coupled ocean- atmosphere- terrestrial system in the context of the entire regional segment of the earth's surface, regarding the Southern Ocean, the Agulhas and Benguela Currents, the tropical regions of influence and the intrusion of the southern African land mass as a whole. It seeks to both better understand the influence of global scale processes on the regional system, and the feedbacks that the region imposes on the global earth systems, by addressing what has driven and drives the climate cycle in palaeo-climatic terms, and what influences its variability and trajectory.

The institutions most actively involved in meteorological and atmospheric observation, monitoring and research programmes include:

- The South African Space Agency, particularly the Pathfinder Satellite Programme;
- South African National Antarctic Programme;
- The Climate and Environment Research and Monitoring Unit at South African Weather Services;
- The Climate Systems Analysis Research Group at the University of Cape Town;
- The Hydrology and Water Resources Section at the University of KwaZulu/Natal;
- The Climate Research Group at the University of Witwatersrand; and
- Department of Geography, Geo-informatics and Meteorology at the University of Pretoria.

Their main focus themes include determining historical climate change and climate variability; observing and monitoring long-term trends in atmospheric composition of green houses gases, ozone-depleting gases, optical and chemical properties of aerosols; investigating the origins of air masses; refining extant and/or developing new climate modelling and forecasting tools; and analysing and modelling of land surface feedbacks to changes in atmospheric properties, and climate process coupling.

The main programmes in oceanography include:

- The Ocean Dynamics and Climate Programme at the Council for Scientific and Industrial Research;
- South African Environmental Observation Network marine research programme at its Egagasini Marine offshore node; and
- The South African Institute for Aquatic Biodiversity, offshore and marine research programme.

These programmes observe and monitor temporal and spatial weather and climate dynamics across the Southern and Indian Oceans. Research includes investigation of the possible impacts of climatic change on water quality, tidal characteristics and patterns, conditions of coastal and estuarine ecosystems, and conditions and productivity of marine and coastal resources. Other research themes include limnology and oceanic biogeochemistry.

Adaptation and mitigation research programmes: In response to the South African Climate Change Response Strategy (2004), various national and provincial government departments have taken steps to develop adaptation and mitigation strategies and measures, particularly in the water and agricultural sectors. A number of municipalities have also incorporated adaptation and mitigation measures in their integrated development planning processes.

The South African National Energy Research Institute is the public entity entrusted with the coordination and undertaking of public interest mitigation (energy-related) research, development and demonstration.

Similarly, the South African National Biodiversity Institute plays a leading role in monitoring and reporting on the counties biodiversity as well as in developing a climate change and biodiversity strategy.

A variety of science councils, universities and non-governmental organizations, along with businesses, are increasingly initiating adaptation and mitigation projects across a range of sectors.

5.3.3 Participation in international programmes

South African climate change-related observation, monitoring and research programmes contribute to and leverage programmes established as part of the Inter-governmental Panel on Climate Change, the Earth System Science Partnership of the International Community of Scientific Unions, the Group on Earth Observations, the World Meteorological Organisation, and the Global Climate Observation System of Systems.

South Africa is a member and contributor to the Group on Earth Observations (GEO). The GEO brings governments together at a high level to work towards a future in which our decisions and actions, for the benefit of people, are informed by coordinated, comprehensive and sustained earth observations and information.

Through these activities and contributions, South Africa, in concert with other GEO members and participating organisations, aims to achieve the effective and sustained operation of the global climate observing system, as well as reliable delivery of adequate climate information for predicting, mitigating and adapting to climate variability and change, including for better understanding of the global carbon cycle.

South African technicians, researchers and research institutions, organisations, agencies and departments also participate in regional and international climate change-related observation, monitoring and research programmes including CarboAfrica (a European Union-funded monitoring and research programme); the African savanna monitoring programme of the Carnegie Airborne Observatory based at Stanford University; the Environmental Long Term Observatories of the southern Africa programme for observing and monitoring of drivers and responses of global change (including climate change); and the EnerKey Programme that investigates the mitigation of climate change in the energy sectors. Other international programmes include the German National Research Centre's (GKSS) programme on climate change in coastal areas; climate change research programme of the Indian-based International Crop Research Institute for the Semi-Arid Tropics; the air monitoring programme of the Norwegian Institute for Air Research; and the SADC Hydrological Cycle Observing System programme.

5.3.4 Challenges and needs

Globally there is a need for better-quality, integrated information to support decision-making related to global environmental challenges. These are needed to inform key political and policy decisions, and they require development of a thorough understanding of our geophysical environment. In South Africa a key challenge is the lack of permanent observation and monitoring sites, and the sub-optimal size of sites that are used. Furthermore, arid and semi-arid areas, forest and woodlands, mountains, agro-ecosystems, and rural areas are under-represented in the monitoring network, despite the fact that they are likely to be affected earliest and most by climate change. There is a clear need for an integrated system of adequately sized and equipped permanent observation and monitoring sites that cover all biomes and eco-regions throughout the country. This integration includes the need for multiple simultaneous observations such as combined in situ and remote sensing observation and monitoring systems. The data currently obtained are tend to be one-dimensional, or monitored at limited spatial scales, preventing the formulation of a complete picture. Some programmes lack laboratory infrastructure, and modern equipment. Furthermore, information management is weak in most programmes, and non-existent in some. The needs in terms of infrastructure include suites of in situ sampling, observation and monitoring systems, and remote sensing imagery and imaging devices. Other needs include state-of-the-art data processing and analysis hardware and software, relevant laboratory space and equipment, and robust and accessible information management systems.

Systematic observation and monitoring programmes also experience funding challenges. Whilst the government remains the principal source of funding, its investment in research broadly has remained at less than 1% of the gross national product. For this reason it is important that other funding sources are found.

Human capital capacity is yet another important challenge. The intake of research students in climate change-related fields in universities is still relatively low, and the graduation rate is even lower. The need for suitably-qualified personnel to collect data, operate the relevant instrumentations, process and analyse data, and communicate results cannot be over-emphasised.

5.4 Public awareness, training and capacity building

5.4.1 Key government initiatives

The South African government has introduced a number of initiatives that will, among other things, make significant contributions to education and awareness-raising around issues related to climate change. The Department of Science and Technology is developing a science plan and institutional architecture for responding to global change (including climate change) over the next ten years (DST 2010). This plan includes a focus on balancing research with the "science-policy-practice" interface, focusing on the practical applications of knowledge. The African Centre for Climate and Earth Systems Science (ACCESS), and the proposed Global Change and Sustainability Centres will consider mechanisms, processes and institutions (and combinations of all three) that translate the outputs of global change research into material that can support policy and decision-making. The recently-created Risk and Vulnerability Atlas (DST 2010), for example, is being distributed to local government throughout the country, and access to further information will be facilitated by the proposed Risk and Vulnerability Network/Assessment Units.

5.4.2 Key civil society initiatives

Many non-government organizations have the interest, the potential, and in some cases the capacity, to make meaningful contributions to awareness-raising and education in the field of climate change, although this potential is not yet fully realized (Knowles, Archer & Tadross 2009). Key locally-based examples include (but are not limited to) AWARD (Association for Water and Rural Development), the Environmental Monitoring Group (EMG), the Centre for Environment, Agriculture and Development at the University of Kwazulu-Natal (CEAD), Indigo Development and Change, Drynet and Food and Trees for Africa. A number of international NGOs have also campaigned in South Africa on climate and energy issues, among them BirdLife International, Greenpeace, Oxfam and the Worldwide Fund for Nature, playing a key role in informing the public about climate change and appropriate individual responses.

5.4.3 Media engagement

The current level of media reporting on climate change appears to be more frequent than it was prior to South Africa's initial national communication, although the magnitude of this increase has not been quantified. Interest appears to have grown as a result of the release of major publications such as the IPCC's Fourth Assessment Report (AR4) in 2007. Several South African IPCC authors have engaged actively in promoting public understanding of the 2007 IPCC AR4 through specific media releases and press conferences, and invited appearances on radio and television broadcasts and debates. A South African NGO - the Fynbos Foundation (http://fynbosmedia.co.za/foundation.html) - whose core mission is to develop art and science journalism in the country - held a conference on "Practising the craft: writing about climate change and global warming" in 2008 , which brought together climate-change scientists and journalists, in an attempt to bridge the gap between science and journalism. The conference highlighted the dwindling opportunities for science journalism training, and agreed on the need for building links between journalists and scientists, to ensure the accurate communication of information about climate change, and in particular its inherent risks and uncertainties. A recent example of efforts by journalists to better understand and translate scientific outputs, and to collaborate with scientists is the Science Journalists Network, comprising a community of shared expertise and experience around science journalism and communication. In SADC, the Climate Journalists Network (CJN) has been in existence for six years, with a particular focus on translating seasonal climate forecasts for media dissemination as part of a dialogue with meteorologists and climate professionals. CJN's effectiveness is, however, impeded by a lack of funds.

5.4.4 Key initiatives in education

School curriculum : South Africa's school curriculum does not explicitly cater for climate change education, although the curriculum is structured in such a way that opportunities exist in several areas for its inclusion. Natural Sciences and Social Sciences are two of eight Learning Areas presented in grades 0 to 9 in which climate change would logically be addressed. The principle of "Social justice, a healthy environment, human rights and inclusivity" is included in each Learning Area, and understanding the relationship between people and the environment is a clear Learning Outcome. Despite no explicit references to climate change, there are numerous openings where the subject may be taught. For instance, in the Natural Sciences, the Learning Outcome of "Science, Society and the Environment" is introduced in Grade 4 and requires that the scholar "understands the impact of science and technology". From Grade 7 scholars are expected to "understand sustainable use of the earth's resources". The Learning Area of Social Science includes an outcome that "the scholar will be able to make informed decisions about social and environmental issues and problems".

In Grades 10 to 12, scholars are able to choose from a range of approved subjects, including those that provide a natural home for the teaching of climate change. Teachers at individual schools are expected to develop Work Schedules for each grade, and what gets taught, and how it is taught, is determined by factors that include, most importantly, the capacity of teaching staff and the resources available to individual schools. In South Africa, inequalities exist between schools with regard to the capacity of teaching staff and resources available. Thus, while many of the better-funded schools are able to teach aspects of climate change, it is not the case in the majority of schools. Many teachers, if they teach climate change at all, teach within the old paradigm of "global warming" and "the greenhouse effect". Textbooks are also often outdated and inadequate.

Tertiary Education: South Africa's tertiary education institutions offer varying levels of training in climate change-related topics. These opportunities usually reside in Geography, Environmental or Physics departments, and are either early-level compulsory or higher-level options. The subject material of modules offered reflects the research interests of faculty members, and so their availability and focus tends to be varied between institutions. One important implication is that where climate change science and human dimensions interests and expertise exist, opportunities are available for both undergraduate teaching and postgraduate research supervision, contributing to the growth of specific "hubs" of knowledge and capacity. Examples of such hubs include the Climate Systems Analysis Group at the University of Cape Town (UCT), and the

Climatology Research Group, a unit that addresses the human dimensions of vulnerability, adaptation, mitigation and planning (REVAMP) in relation to global environmental change at the University of the Witwatersrand. These hubs may also draw from experienced professionals from outside of academia to add diversity to the material offered, such as the climate change module of the Conservation Biology Master's Course at UCT which includes co-ordination and lectures by professional scientists from the South African National Biodiversity Institute. At these hubs, and at many other universities, individuals are planning climate-specific degree courses at postgraduate level, so that in the near future South African universities will be offering climate change-led degrees, as well as addressing climate training needs through specific disciplines (for example, ACCESS have designed a proposed Masters in Climate Change; while an MSc in Climate and Development has been approved for inclusion at the University of the Witwatersrand).

The Global Change System for Analysis, Research and Training (known by its acronym START), is a non-governmental organization with headquarters in Washington D.C. START has a long and respected history in training and capacity-building in climate change, and has focused on training scientists in global change (with an emphasis on climate change) in developing countries in Africa, Asia and the Pacific region. Linked to its funding and support of research is a key emphasis on increasing the representation of young scientists in developing countries in processes such as those run by the IPCC. START's Africa Doctoral Fellowships, for example, have aided in increasing the quantity and quality of climate change PhD graduates on the continent. START also established an African Climate Change Fellowships Program (ACCFP) in 2009 offering scholarships and training support to African early-career scientists and graduate students. The Fellowship Program is particularly significant in the broader suite of climate change human capacity development initiatives due to its soliciting of peer review on its terms of reference early in the process, as well as its emphasis on teaching in addition to research support. Teaching support can include opportunities for expert sharing around curriculum development in climate change, a priority focus area. Since its inception START has supported almost 40 fellowships (supporting postgraduate study and early-career research) in South Africa.

Contents

Chapter 6:

Constraints and gaps, and related financial, technical and capacity needs

6.1 Introduction

This section draws directly from the Department of Science and Technology's (DST) global change research plan (DST 2010), which was drawn up with broad consultation with appropriate stakeholders. In common with most countries, South Africa faces several challenges in understanding, mitigating, and adapting to predicted climate change. These challenges arise from gaps in knowledge and understanding, and our ability to address them is constrained by a lack of capacity and research infrastructure, and of an ability to communicate understanding and to facilitate the implementation of solutions and action. In particular, there is a need to develop human capital, generate new and relevant knowledge, facilitate the establishment of research infrastructure, and bridge the divide between research results and socio-economic outcomes.

6.2 Key major knowledge challenges

The Department of Science and Technology has identified four "knowledge challenges" that will provide the framework for addressing gaps in technical understanding, and these underpin a proposed research plan for global change. The two knowledge challenges that have bearing on climate change are (1) Understanding a changing planet; and (2) Adapting the way we live. In the sections that follow, the themes associated with each knowledge challenge are briefly described, and the proposed high-level research focus areas are listed.

6.2.1 Understanding a changing planet

This key focus area seeks to build an understanding of how our ecosystems are changing, where that change is taking place, and how rapidly the change is happening. It also seeks to understand complex interactions that take place within ecosystems, and how changing certain aspects of any of them will affect other aspects. This is basic research that does not necessarily result in technologies or applications, but the understanding will be necessary to improve predictive capability and to plan appropriate adaptive responses. The focus area has identified 5 themes, discussed below.

Observation and monitoring: South Africa shares with the Group on Earth Observations (GEO) the objective of improving and coordinating Earth observation systems, providing easier and more open access to data and information, fostering the use of Earth observations for societal benefit and building the Earth observation capacity to facilitate its use. As a global citizen our priorities for observation, monitoring and research are on par with those of the Global Earth Observation System of Systems (GEOSS) and are dealt with broadly within the South African Earth Observation Strategy (SAEOS) and the South African Global Change Research Plan (DST 2010).

Fundamental research focus areas underlie the development and design of Earth observation networks. These include:

- Understanding the nature of change – What are critical thresholds that, if exceeded, will precipitate significant and possibly irreversible changes; what would the consequences of such change be; and what indicators can be used to detect them?
- Ensuring ongoing benefits   What earth observation network models are best suited for detecting critical thresholds and promoting appropriate knowledge dissemination and action?

Dynamics of the oceans around southern Africa: The regional ocean-basin scale processes around southern Africa regulate its climate variability and change. They also affect the global climate and long-term change. The main gaps in regional understanding centre on the natural variability of the climate in this part of the world. Strengthening the modelling capabilities of this "coupled" ocean–atmosphere-biosphere will improve weather and seasonal climate predictions, with benefits to ecosystem services affecting food and water security, protection from extreme events and, more broadly, human well-being.

There is also uncertainty about the regional effects of large-scale global climate change. While it is understood, for example, that the Earth will become warmer if concentrations of carbon dioxide and other greenhouse gases continue to rise at their present rates of 1 to 3% per annum, regional responses to such a rise remain unclear. There are strong links between local climate and the three oceans surrounding the southern African landmass, and this means that any seasonal and decade-scale forecasts are dependent on the changing nature of these links. This is a key knowledge gap.

The region's oceans are of importance in driving the global climate system, biogeochemically and physically. One of the most important services offered by the Southern Ocean is its ability to provide a "sink" for some 50% of all the natural and anthropogenic carbon dioxide taken up by the world's oceans. It is unclear how this ability will be affected by global warming. Also insufficiently understood is the role of the Southern Ocean in modulating albedo (that is, the ability of the Earth to reflect solar radiation). The ocean produces (emits) trace gases, which help to seed low clouds that increase reflectivity, but some of these gases also reduce stratospheric ozone, allowing more radiation to reach the Earth's surface.

Key research focus areas include:

- How will the large-scale Southern Ocean ocean-climate system such as the Antarctic Oscillation, frontal zones, overturning circulation and surface mixed layers respond to global warming?
- How will the Southern Ocean's capacity to take up anthropogenic and natural carbon dioxide and provide the required energy supply to its ecosystems change in response to climate change?
- How will the Southern Ocean respond to climate change through changes in ecosystem function and structure which modify food webs and climate feedbacks such as atmospheric albedo?

Linking the land, the air and the sea: Although many researchers tend to work within a single domain (for example, oceanographers who focus on marine ecosystems), it remains a fact that ecosystems are connected. In order to further understanding of the ways in which ecosystems are linked, and how changes in one system will affect others, studies that cross traditional boundaries are needed. Key research focus areas address the following gaps:

- What are the priority forms of change on the land that will directly or indirectly affect atmospherics, estuarine and marine dynamics?
- Can any thresholds be identified beyond which changes in one system will cause irreversible or sudden

change in another system? If so, how can reaching such thresholds best be avoided?

Improving model predictions at different scales: Current predictions of climate change rely on a number of models that simulate possible future changes in the real world. When they were first developed, these models were relatively rough, but they have improved steadily as new knowledge became available, and better understanding has resulted. In addition, several different models were initially developed in isolation of each other. With improved global collaboration, these models are starting to converge as global understanding develops. However, global models focus on broad-scale changes to the Earth's climate, and their predictions are often too coarse to be useful at a regional or local level. It is also true that, by adding understanding generated at a local level, it is possible to improve global models, their predictions, and therefore their usefulness.

The overarching research focus areas to be addressed in this theme are:

- What is the relative importance of southern Africa's biomes in terms of their influence on climate and on carbon storage?
- Which were the global climate changes that favoured the evolution of the impressive diversity of flora and fauna of southern Africa? More specifically, what were the climate changes over the past 5 million years that saw the rise of African homonids, fynbos and many other life-forms?
- What are the relationships between bushfires and greenhouse gases and carbon storage? Are fire regimes likely to change and, if so, how will the relationships change?
- To what degree do the land and the oceans around southern Africa act as sources and sinks for carbon and other important elements?
- How will changes in sea surface temperature and ocean currents affect rainfall patterns?

6.2.2 Adapting the way we live

The twin challenges of reducing people's impact by reducing their levels of consumption and waste generation, on the one hand, while still being able to raise the average standard of living to an acceptable level, on the other, will require us to make radical changes to the way we live. These changes will take two forms. The first involves altering the activities that are driving change, with the express aim of slowing or reversing the adverse consequences that are predicted. Actions in this sphere include, for example, reducing human levels of fossil-fuel consumption. The second involves making changes that will help us to avoid the negative consequences, and benefit from the opportunities offered by change that we cannot avoid; such measures are known as "adaptation". This key focus area outlines four themes designed to address these issues.

6.2.3 Preparing for rapid change and extreme events

The generation of greenhouse gases has initiated changes to the Earth's climate that cannot be reversed in the foreseeable future. In addition, it is likely that the activities that generate these gases will continue, even if at a reduced rate. Some changes are therefore unavoidable at this stage, and scientists need to predict where these changes will have negative effects, and how serious these are likely to be, so that plans can be made to avoid or tolerate them as far as possible. The kinds of change that can be expected include increases in the magnitude and frequency of both floods and droughts; changes to fire regimes that will place people and property at higher levels of risk; rises in sea level, and accompanying increases in the magnitude and frequency of storm damage along the coast, and changes to the dynamics of diseases affecting humans and livestock.

Key research focus areas include the following:

- What methods should be developed to better understand uncertainty and risk?
- Which areas are most at risk from rapidly-changing conditions?
- What can be done to avoid, or ameliorate, adverse effects of change?

- How can South Africa's biodiversity – especially threatened, rare, or otherwise important species – be protected from adverse change?

Planning for sustainable urban development: The great challenge of 21st-century urban development lies in finding ways for city planning and management to address not only the needs of urban dwellers in large, rapidly growing, and mainly poor cities, but to do so in a manner that acknowledges the interdependence of cities and the ecosystems of which they form part, including global regulating services such as climate regulation. Cities are particularly vulnerable to climate change because they are slow to adapt, they rely on an ever-increasing hinterland, and they have entrenched dependencies on specific delivery mechanisms for critical services. There is increasing recognition that the sustainability of urban social-ecological systems is a function of their functional integrity and resilience. The application of the concept of resilience (well developed in ecological studies) to urban social-ecological systems is still immature (both locally and internationally) and the opportunities it presents needs further definition.

Important research focus areas include:

- What are the factors that would determine urban resilience? The research would consider the ways in which ecosystem concepts such as diversity, redundancy, vulnerability and ecological variability apply to the urban social-ecological system, and would include biophysical factors as well as social factors such as regulations, values and aspirations.
- How does a city's physical form and infrastructure affect its resilience?
- How can cities, their infrastructure, and the control and management systems that regulate their functions be designed so to improve the resilience of the conurbation?
- What would be appropriate monitoring and assessment tools with which to evaluate a city's ongoing resilience?
- What are the implications of climate change risks and declining ecosystem services for decision making and policy development regarding resource allocation, settlement planning and design, development in rural areas and growth and management of major city-regions?

Water security : The first order effects of climate change (such as the amount of rainfall) are often the focus of discussion on mitigation measures and adaptation strategies. It is, however, very likely that secondary effects could be much more significant, and a lack of understanding in this regard is a key gap. This theme will focus on the following:

- Can we develop dynamic predictive models that will allow water planners to move away from a dependence on data from the past 50 years (which will not reflect future trends)?
- What are the important secondary effects of a changing climate on water security?
- What are the limits within which freshwater ecosystems can maintain their integrity, and where are these limits likely to be exceeded?
- What transboundary effects can be expected, considering that a number of South Africa's major river systems are shared with our neighbouring countries?

Food and fibre security: The effects of climate change on food security are difficult to predict at present, and research is needed to deepen our understanding of the issue. This theme focuses on the following:

- How and where will southern Africa's main crops and livestock be affected by climate change? Can the most vulnerable crops and livestock types be identified with a view to replacing them, or ensuring ongoing production?
- What new crop or livestock species, or production methods, can be developed to offset the effects of climate change?

- Can cropping systems be developed to derive multiple benefits from the same area (for example by using tree crops for food, fodder, energy and to enhance cash income)?
- Which wild plant and animal species are important sources of food? How will these be affected by climate change, and do alternative sources of food exist to replace such species?

6.3 Specific gaps identified in relation to climate change impacts and vulnerability

6.3.1 Financial constraints and needs

There is a lack of information on the potential cost of planned adaptation responses to climate change, especially in relation to uncertainty about a potentially wide range of needs for upgrading existing, or developing new infrastructure. Key exceptions are preliminary assessments conducted in some major urban municipalities. A comprehensive assessment of these needs and their potential costs and technical and capacity implications could draw usefully from information on the impacts and vulnerability information provided in this communication. An estimate of the average annual cost of climate-related events (storms, floods, droughts and fires) in South Africa cannot be made with any level of accuracy, due to a lack of reliable and comprehensive data.

6.3.2 Capacity constraints and needs

The shortage of climate change professionals in Africa trained at the PhD and postdoctoral level is a critical capacity gap (Archer 2008), and support is needed in this regard. One obstacle to this is the lack of employment opportunities available to PhD graduates, many of whom leave the research and education sector. Doctoral and postdoctoral-trained climate change scientists support the furthering of education, by contributing to the (currently small) pool of supervisors available for postgraduate study. Furthermore, these scientists can play a key role in ensuring dissemination of research findings through publication of scientific literature and teaching undergraduates, and can contribute to the leadership and management of climate change projects and programmes. Archer (2008) further observes that future funding to develop climate change capacity needs to complement existing initiatives, including activities planned by the Department of Science and Technology's Global Change Human Capital Development foci, and the planned activities envisaged by the National Research Foundation.

6.3.3 Research and monitoring constraints and needs

Climate and oceanography: There is need to further develop climate models that are specific for southern Africa, in order to represent peculiarities of the region's climate and its dynamics. Specifically, there is need to model the future climate change evolution; dynamics of the climate change system; interplay of terrestrial, atmospheric, and oceanic systems that give rise to natural variability; and impacts of climate change on agriculture, biodiversity and other sectors.

Current statistical forecasting schemes used in South Africa require improvement. These do not perform satisfactorily over the South Atlantic as a whole (Landman & Mason 2001), for reasons that can be addressed with further research and monitoring. In addition, responses of sea surface temperature off Angola to wind patterns (Florenchie *et al*. 2004) emphasizes the need for further work to understand the way that climate events are influenced by processes in the southeast Atlantic. Similar needs exist for the Indian and southern Oceans.

Water and hydrology: A more integrated understanding of water demand, storage and supply under climate change is needed, requiring both research and monitoring effort. Research could include better projections of urban vs irrigation agricultural demand, matched with a supply focus on processes in South Africa's runoff-producing areas. The latter are sensitive and vulnerable to climate change, but have inadequate hydro-climatic monitoring networks. Development and testing of integrated hydrological models that assess both surface water and below-ground water resource impacts of demand and supply changes are a key need. Because impacts remain uncertain, and the results of adaptation responses are medium to long-term, it is important to strengthen the relationship between management responses and information availability, especially with regard to infrastructure design needs and tolerances. Further key needs relate to understanding vulnerability of the poor in both urban areas (e.g. living on floodplains) and rural areas (e.g. availability of potable water), and in developing integrated catchment management approaches in particularly stressed catchments.

Marine and sea level: Research needs relating to ocean dynamics and associated marine impacts are well described in the Global Change Research Plan (DST 2010). Further research into the impact of, and adaptation to, sea-level rise on coastal infrastructure, and related monitoring of trends, is required. A key impact of sea level rise is on environmental quality in estuaries. Although there are a few established long-term monitoring programmes in estuaries, more need to be initiated to better assess the impacts of climate change on these systems. Coral reefs provide a model for the study of many of the stresses to which these valuable systems are being subjected globally. Work on these reefs needs to continue to fully elucidate climate change impacts.

Agriculture, rangelands and forestry: Key impact assessment work is needed in these sectors to update work carried out using previous-generation climate and impact models. These should be based on appropriately downscaled climate change scenarios of long and continuous time series (rather time slices) from multiple global climate models to facilitate better modelling of impacts and provide better confidence in projections. Very little is understood in these sectors with respect to multiple stress factors that occur simultaneously. The interaction of damaging insects and pathogens, especially, with changes in climate are not reliably predictable on the basis of current knowledge. A constant monitoring of pathogens on a national spatial level seems advisable.

Key improvements in agriculture needed include utilizing credible crop production models. Similarly in rangelands, reassessments of previous findings for vegetation cover and productivity changes are urgently needed. Higher resolution downscaling of results will also improve the ability of decision-makers in rangelands to understand impacts, and to use such information in adaptive planning. In forestry, the lack of a consistent forest inventory on a national scale in South Africa is a significant gap. Such an inventory would provide a benchmark against which to monitor changes in forest distribution, structure, growth, biomass, and carbon sequestration. It could be based on permanent sample plots and/or remote sensing technologies. A national inventory should be designed to cover natural forests, plantations and woodlands. The obtained information would be essential to a holistic management approach at the landscape level but also for enhancing national carbon balances and related mitigation issues.

The dynamics and vulnerability of natural forests to climatic changes is still not clear. By maintaining and extending the monitoring plots on natural forests (Geldenhuys 1997, 1998 2000), changes due to climate change could be detected. There is also insufficient knowledge about growth changes in plantation forests that may be triggered by climatic changes. Apparent knowledge gaps are the effects of climate change on the timber and pulp quality, and also the competition in the stand.

Finally, credible assessments of changing fire risk are necessary. Well-founded information on main ‘fire corridors’ predicted from prevailing wind directions at the landscape level could facilitate a more directed fire management and save money and prevent damage.

Human health: Priority should be given to research that will facilitate the unravelling of the complex relationships between governance, human footprint, environmental degradation and disease, with a view to the development of an early-warning, rapid-response system able to predict scenarios that place communities at risk in the short and long term (Gommes *et al*. 2004). The supply of safe water for human consumption and sanitation to all South Africans is a priority, regardless of cholera concerns. However, the potential effect of climate change and climate variability and extreme weather events on the spread and intensity of cholera outbreaks have not yet been considered. More research and the regular monitoring and surveillance of environmental conditions and patients are needed to address these issues.

Biodiversity: This sector suffers greatly from an inadequate and fragmented monitoring system, only now being partially addressed by the South African Environmental Observation Network (SAEON) programme. A significant input of funding for this program is needed to provide the long-term information needed to test projections and the impacts of policy responses, and this would benefit from an assessment of the success of monitoring programmes conducted so far. It will be important to link projections of biodiversity impacts with related impacts on ecosystem services and human livelihoods, to develop appropriate adaptation responses that benefit people.

Key work on the impacts of climate change on alien invasives is required, especially in relation to enhancing early-warning programmes. Furthermore, the number of species that are invasive, as well as the economic and environmental impacts of the invaders, remains poorly documented. Consequently, predictions regarding the response of these species to climate change remain largely speculative.

Analysis of the mitigation potential of natural ecosystems, especially in relation to possible efforts to manage fire regimes, will provide key information necessary for management decisions in this regard. Finally, the impacts of national and international mitigation responses, and changes in societal emphasis on food security and renewable fuel concerns are all likely to have an impact on land use change and biodiversity, and require analysis.

Socio economic aspects: More knowledge and understanding is required about existing and future vulnerabilities in a wide range of sectors relevant to rural and urban livelihoods, and relevant adjustments and adaptation to related adverse impacts. While some efforts have been made to understand the potential impacts of climate change on livelihoods, much remains to be done.

Few studies have explored the factors shaping adaptation and adaptive behaviours. The potential role of social capital and networks of various types is widely recognized for enhancing adaptive responses, but few studies have interrogated this dimension, and the measures that might prompt beneficial changes.

Implementation of climate change adaptation in municipal and rural settlement areas is currently facing very distinct development challenges, including but not limited to capacity. Possible options for action include stakeholder dialogue, social-learning and careful investigation of science-policy-practice interactions (Pahl-Wostl 2007, 2008; Vogel *et al*. 2007).

There is a need to clarify what is meant by adaptation responses in both the shorter and the longer term, and the local, provincial and national governance implications and responsibilities for such responses. This will require both the development of clearer adaptation concepts and the quantification of pragmatic responses that are relevant to stakeholders, and extensive interaction with and engagement of stakeholders and decision-makers through broader outreach and education efforts. Such efforts could usefully include wider civic society participation in discussions, debate and actions on adaptation at all levels, and allow the communication of the best science to inform discussions and potential responses. There is little quantitative information available to assess what limits to adaptation may exist for rural and urban environments in South Africa.

The inclusion of various forms of knowledge systems requires more attention. Indigenous knowledge, for example, can be essential in the effectiveness of early warning systems. Traditional communities and structures possess valuable knowledge, various sources of information as well as various indicators that have been used for many years to respond to changes in climate and weather. The links to using such knowledge together with other traditional knowledge sources (e.g. local medicines) may thus emerge as a useful avenue to explore in future adaptations to climate change in a number of sectors (e.g. water and the health sector).

A major limitation in adaptation to climate change is also finding effective ways to estimate economic trade-offs to adaptation responses, particularly of planned and/or purposive adaptation actions. Some good estimations of current disaster losses have been undertaken, which, together with adaptation planning scenarios and cost estimations would be a useful exercise to advance thinking in this area in South Africa.

Public awareness, training and capacity-building: An introduction to climate change needs to be integrated at school level, in primary and secondary curricula, with more advanced treatment at tertiary level. Within the tertiary sector, opportunities should exist for the education of climate change professionals who will remain in the field, as well as ensuring that all graduates have an appreciation of climate change. The training system is also not yet fully sustainable, so that at least some of those individuals with specialised climate change knowledge remain within the education system, facilitating capacity building of the next generation. This is arguably easier to maintain in the primary and secondary education sectors, where recent graduates and newly qualified teachers have the scope within the education policy frameworks to integrate their appreciation of the climate change issue and challenge into their teaching.

Climate change inputs into both education curricula and stand-alone training courses need to be horizontally and vertically integrated in tertiary education (Vogel 2008). Horizontal integration means that climate change courses must tie in with, and complement, course offerings from a variety of related disciplines, whilst vertical integration means that there must be adequate pathways for building on each course as a student progresses through their degree path. Climate change educationalists, or those educationalists in South African universities interested in integrating climate change into their curricula, would need to work closely with Academic Planning Offices or their equivalent, ensuring early institutional support for and coordination of such integration, as well as early advice on accreditation and cross-university or cross-country recognition (working, for example, within the South African Qualifications Authority standards). Vogel (2008) highlights the critical gap and key challenge within tertiary education as transforming short course material on climate change into longer courses within the general curriculum as part of a long term accreditation process that has some form of external quality control. Such models must be integrated into existing undergraduate and postgraduate courses with a focus on practical skills transfer, building on the co-learning process identified with the disaster risk professional community advocated above. Further support also needs to be provided, whether by government to other sources, to scientists to allow them to engage in constructive and iterative dialogue with the media. As mentioned above, whilst awareness of climate change among civil society has increased, it is a rapidly evolving field and thus gaps still remain. Key authors' recommendations include support for science training modules in journalism curricula and greater incentives for scientists to liaise with the media (albeit perhaps through boundary organizations, if this is more appropriate). Columbia University in New York, for example, have a dual Masters degree programme in Earth and Environmental Science Journalism (http://www.ldeo.columbia.edu/edu/eesj/), a partnership between the Graduate School of Journalism and the Department of Earth and Environmental Sciences. The curriculum includes a practical focus on science writing, where case studies in earth and environmental journalism are undertaken, including climate change options. A similar postgraduate degree course in science journalism in South Africa comprises one recommended option, while the integration of science journalism into existing undergraduate and postgraduate journalism curricula is touted as desirable but as yet largely unrealised. The Fynbos Foundation's 2008 conference on "Practising the craft: writing about climate change and global warming" observed that only the University of Stellenbosch is currently engaged in science journalism curriculum development; although discussions have been held at other universities.

Given the aforementioned challenges in climate change awareness and communication in South Africa, a focused strategy for climate change communication to a range of stakeholders would be beneficial, including local government, provincial government, the private sector (including incentives for increased climate change awareness in companies, and integration of climate change concerns into operations) and the media. For example, the South African Local Government Association has explicitly asked for climate change awareness raising and capacity building to be undertaken for municipalities in South Africa.

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